KEEGAN WERLIN LLP

ATTORNEYS AT LAW
99 HIGH STREET, SUITE 2900
BOSTON, MASSACHUSETTS 02110
———
(617) 951-1400

TELECOPIER:
(617) 951-1354

July 1, 2022

Mark D. Marini, Secretary
Department of Public Utilities
One South Station, 5th Floor
Boston, MA 02110

Re: Petition(s) of Massachusetts Electric Company and Nantucket Electric Company, d/b/a National Grid (D.P.U. 15-120), Fitchburg Gas and Electric Light Company d/b/a Unitil (D.P.U. 15-121), and NSTAR Electric Company d/b/a Eversource Energy (D.P.U. 15-122) for Approval by the Department of Public Utilities of its Grid Modernization Plan(s)

Dear Secretary Marini:

On behalf of Massachusetts Electric Company and Nantucket Electric Company, d/b/a National Grid, Fitchburg Gas and Electric Light Company d/b/a Unitil, and NSTAR Electric Company d/b/a Eversource Energy (collectively, the "EDCs"), enclosed please find the 2021 Evaluation Reports for Advanced Distribution Automation, Advanced Distribution Management System/Advanced Load Flow, Communications, Monitoring and Control, and Volt-Var Optimization prepared by Guidehouse Inc., the Grid Modernization evaluation consultant, on behalf of the EDCs in the above-referenced proceedings.

Thank you for your attention to this matter. Please contact me with any questions.

Sincerely,

Kerri A. Mahoney, Esq.

Enclosures

cc: Tina Chin, Hearing Officer
Kerri Phillips, Hearing Officer
Susan Geiser, Hearing Officer
D.P.U. 15-120, 15-121, and 15-122 Service Lists
D.P.U. 21-40, 22-41, 22-42 Service Lists

Massachusetts Grid Modernization Program Year 2021 Evaluation Report: Advanced Distribution Automation (ADA)

Massachusetts Electric Distribution Companies

Submitted by:

Guidehouse Inc.
77 South Bedford Street, Suite 400
Burlington, MA 01803
Telephone (781) 270-8300
Guidehouse.com

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Executive Summary

Introduction

As a part of the Grid Modernization Plan (GMP), the Massachusetts electric distribution companies (EDCs) are investing to enable Advanced Distribution Automation (ADA) on selected circuits across their distribution networks. These investments enable greater automation and are intended to enhance reliability, facilitate integration of DERs, and provide other grid and customer benefits.

This evaluation focuses on the progress and effectiveness of the Massachusetts Department of Public Utilities (DPU) preauthorized ADA investments for each EDC toward meeting the DPU's grid modernization objectives for Program Year (PY) 2021.

Evaluation Process

The DPU requires a formal evaluation process, including an evaluation plan and evaluation studies, for the EDCs' preauthorized GMP investments. Guidehouse[1] is completing the evaluation to help ensure a uniform statewide approach and to facilitate coordination and comparability of evaluation results. The evaluation's objective is to measure the progress made toward the achievement of the DPU's grid modernization objectives. The evaluation uses the DPU-established Infrastructure Metrics and Performance Metrics along with a set of Case Studies to understand if the GMP investments are meeting the DPU's objectives.

The original Evaluation Plan was submitted to the DPU by the EDCs in a petition for approval on May 1, 2019. Modifications to this original Evaluation Plan were made to 1) request changes to the reporting schedule to accommodate Performance Metrics data availability timing, as discussed in response to DPU EP-1-1 submitted on February 6, 2020[2], and 2) to extend the Grid Modernization term period from the original 3 year term to a 4 year term as ordered by the DPU in its May 12, 2020 Order.[3] Modifications to the original Evaluation Plan were submitted to the DPU by the EDCs in a petition for approval on December 1, 2020. The modified Evaluation Plan has been used to develop the analysis and evaluation provided below in this document.

Table 1 illustrates the key Infrastructure Metrics, Performance Metrics, and Case Studies (shown as Other metrics in the table) relevant for the ADA evaluation by EDC.

[1] Guidehouse LLP completed its acquisition of Navigant Consulting, Inc, in October of 2019. The two brands are now combined as one Guidehouse.

[2] Submitted to Massachusetts DPU 15-120, 15-121, 15-122

[3] Order (1) Extending Current Three-Year Grid Modernization Plan Investment Term; and (2) Establishing Revised Filing Date for Subsequent Grid Modernization Plans; DPU 15-120-D/DPU 15-121-D/DPU 15-122-D; May 12, 2020.

Table 1. ADA Evaluation Metrics

Metric Type	ADA Evaluation Metrics	ES	NG
IM	System Automation Saturation*	✓	✓
IM	Number of Devices or Other Technologies Deployed	✓	✓
IM	Cost for Deployment	✓	✓
IM	Deviation between Actual and Planned Deployment for the Plan Year	✓	✓
IM	Projected Deployment for the Remainder of the 3-Year Term	✓	✓
PM	Numbers of Customers that Benefit from GMP-Funded Distribution Automation Devices	✓	✓
PM	Grid Modernization Investments’ Effect on Outage Durations	✓	✓
PM	Grid Modernization Investments’ Effect on Outage Frequency	✓	✓
PM	Eversource Customer Outage Metric	✓	
PM	National Grid Specific Metric: Impact of ADA Investments on Customer Minutes of Interruption (CMI) for Main-Line Interruptions		✓
Other	Case Studies	✓	✓

*The EDCs are responsible for these metric calculations and the calculations are not addressed in this evaluation

IM = Infrastructure Metric, PM = Performance Metric, ES = Eversource, NG = National Grid

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020

The EDCs shared the data supporting the Infrastructure Metrics, Performance Metrics and Case Studies with the evaluation team. Guidehouse presents results from analysis of Infrastructure Metrics data in Section 3.2 and the Performance Metrics Data in Section 4.2.

Data Management

Guidehouse worked with the EDCs to collect data to complete the ADA evaluation for the assessment of Infrastructure Metrics, Performance Metrics and Case Studies. A consistent methodology was used across investment areas and EDCs for evaluating and illustrating EDC progress toward the GMP metrics.

Table 2 summarizes data sources used throughout the evaluation of ADA in PY2021. Section 3.1.1 provides further details each of the data sources.

Table 2. ADA Data Sources

Data Source	Description
2020 Grid Modernization Plan Annual Report[4,5,6]	Planned device deployment and cost information from each EDC's appendix to the 2020 GMP Annual Report (filed April 1, 2021). Data is used as the reference to track progress against the GMP targets and is referred to as the GMP Plan in summary tables and figures throughout the report.
2021 Grid Modernization Plan Annual Report[7,8,9]	All PM-related data are from these 2021 GMP Annual Report Appendices. In addition, data collected as part of EDC Data Template (below) was compared to the data submitted by the EDCs to the DPU in the 2021 Grid Modernization Plan Annual Reports and associated Appendix 1 filings. The evaluation team confirmed the consistency of the data from the various sources and reconciled any differences
EDC Device Deployment Data Template	Captures planned and actual device deployment and spend data. Actual device deployment and cumulative spend information were provided by work order ID and specified at the feeder- or substation-level as appropriate. Carryover device deployment information and estimated carryover spend for 2022 were provided as well.
Eversource's 2021 DPU-Filed Plan[10]	Eversource's GMP Extension request, which was approved by the DPU on February 4, 2021. Includes budgets for PY2021 deployment at the Investment Area level. This data source is included in the "EDC Plan" for Eversource planned spend at the Investment Area level.

Source: Guidehouse analysis

Guidehouse reviewed all data provided upon receipt and conducted a detailed QA/QC of data inputs used in analysis of Infrastructure Metrics and Performance Metrics. These QA/QC steps include checks to confirm each of the required data inputs are accounted for and can be incorporated into analysis. Additional information about the QA/QC process is covered in Section 4.1.2.

Findings and Recommendations

Table 3 summarizes the Infrastructure Metrics results for each EDC's ADA investment area through PY 2021. Based on reported data, Eversource made significant progress in ADA device deployment in 2021. It met deployment target for underground oil switch replacement. It met

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4 Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30

5 NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30.

6 Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU. 21-30.

7 Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-41.

8 NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-40.

9 Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU. 22-42

10 Grid Modernization Program Extension and Funding Report. Submitted to Massachusetts DPU on July 1, 2020 as part of DPU 15-122.

91% of overhead recloser deployment target, with remaining 9 under way and slated for 2022 commissioning. Eversource worked to trouble-shoot challenges with its 4kV underground loop scheme but could not make sufficient progress within an acceptable timeframe and therefore made the decision to discontinue the investment in 2022.

National Grid commissioned 14 FLISR schemes in PY2021 (52 devices) and put another 27 devices in-service (fully installed, pending commissioning in 2022). COVID-19-related resource constraints and supply chain delays contributed to National Grid carrying over some 2021 planned work to 2022.

Table 3. ADA Infrastructure Metrics Summary

Infrastructure Metrics			Eversource	National Grid
GMP Plan Total, PY2018-2021		Devices	602	101
		Spend, $M	$60.89	$8.71
IM-4	Number of devices or other technologies deployed PY2018-2021*	# Devices Deployed	577	73
		% Devices Deployed	96%	72%
IM-5	Cost for Deployment PY2018-2021*	Total Spend, $M	$60.46	$9.28
		% Spend	99%	106%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	83%	65%
		% On Track (Spend)	97%	112%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	9	59
		Spend Remaining, $M	$0.45	$3.16

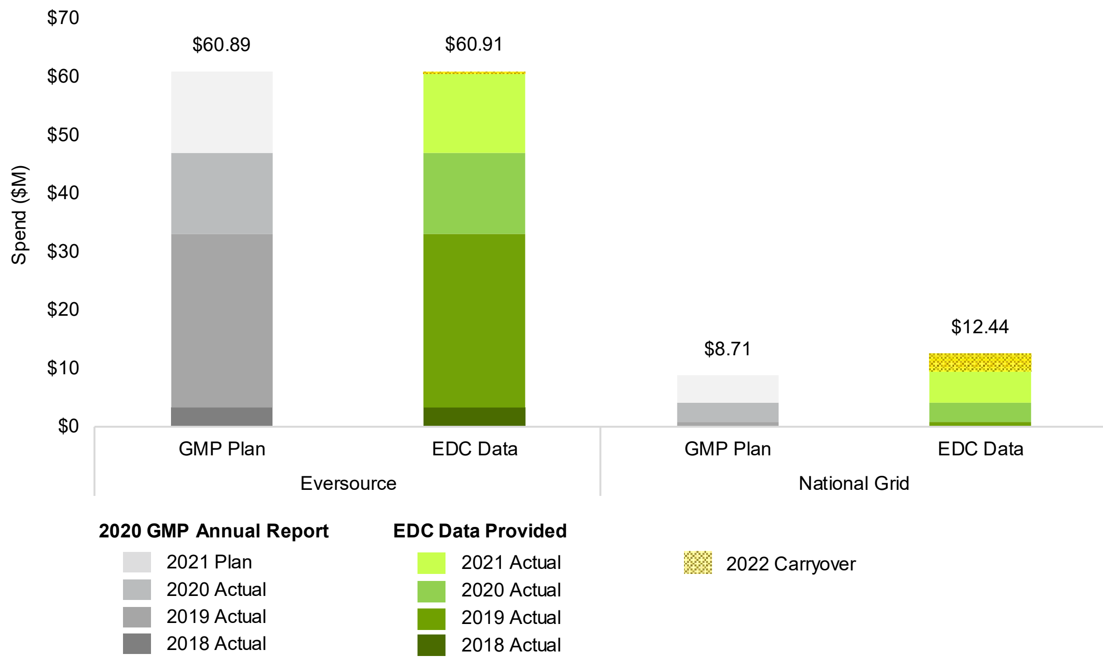
Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

*The metric names have been slightly changed here to clarify the time span used in analysis.

**This metric has been interpreted here as the “carryover” spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs’ 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

Figure 1 highlights planned versus actual spend in ADA for each of the EDCs. The sections that follow include detailed differences between planned and actual spend.

Figure 1. ADA Spend Comparison (2018-2021, $M)



Note: Includes the Eversource planned spend for PY2021, set forth the in the GMP Extension and Funding Report, filed on July 1, 2020.

Source: Guidehouse analysis of 2020 GMP Annual Reports, GMP Extension and Funding Report, and 2021 EDC Data

Table 4 summarizes key findings related to Guidehouse's ADA evaluation for each EDC.

Table 4. Summary of Infrastructure Metrics Findings for ADA Investment Area

EDC	Summary of Findings
Eversource	• Eversource's ADA circuit selection criteria included minimizing customer zone sizes, targeting poor reliability areas, and minimizing cost. • Eversource performed significant pre-planning and built organizational capacity to deploy GMP devices on schedule and on budget relative to the Plan filed on April 1, 2020. • Eversource managed well the unforeseen disruption of the Covid-19 pandemic. In PY 2020, Eversource exceeded 3-year deployment targets over the original 2018-2020 GMP term for three out of four ADA investments. • In PY 2021, Eversource met underground oil switch replacement target. It also met 91% of overhead recloser deployment target. Eversource pivoted to a different area work center for resources mid-year to attempt to meet the overhead recloser target but fell slightly under target. In hindsight, Eversource suggests it could have pivoted earlier or employed a contracting strategy. The remaining 9 reclosers are slated for 2022 commissioning. • The underground auto-restoration loop scheme was discontinued. This was first-of-a-kind technology for Eversource. Eversource SCADA-commissioned 18 devices but encountered software and communication issues in getting the devices to operate as a loop scheme. After performing engineering and troubleshooting in 2020 and 2021, Eversource discontinued the investment. Lessons learned include the need to fully understand the communications requirements (latency, bandwidth, capacity) of a major new technology. Eversource surmises that with continued dedication of time and resources the challenges could be overcome, but determined this was not the best path forward. Alternative approaches will be explored as part of the ADMS investment. • Eversource managed its spending closely to original pre-authorized budget. This meant continually re-evaluating the portfolio of investments and re-adjusting. As a result, Eversource's four-year ADA spending from 2018-2021 ($60.9 million) came close to DPU pre-authorized budget of $58 million. • Eversource has deployed distribution automation on portions of its system for several years. The ADA investment has been some of the newest distribution automation, but overall Eversource has a higher level of saturation for this type of technology than, say, National Grid. In some cases, Eversource installed ADA devices on circuits that already had pre-existing ADA devices on other locations on the circuit. Eversource ADA investments have focused, among other benefits, on reducing zone size to 500 customers.

EDC	Summary of Findings
National Grid	• National Grid targeted feeders with poor reliability performance for ADA investments. • National Grid's PY2019 ADA deployment targets were pushed to PY2020. In late 2020, National Grid commissioned two FLISR schemes. In PY2021, commissioned 14 FLISR schemes (52 devices) and began work on six more schemes which will be commissioned in 2022. 27 devices are in-service as of year-end 2021 which means they are installed and operational but not Grid Mod-commissioned. • National Grid installed some of its ADA devices at strategic tie points between circuits. Tie reclosers are expected to have enhanced reliability and redundancy benefits for customers. However, reconductoring and pole upgrades are sometimes needed to ensure that load can be shifted safely between circuits, adding to the project costs. • National Grid adapted its work practices to meet the challenge of the COVID-19 pandemic. National Grid carried over some of PY2021 planned work to 2022 due to COVID-19-related equipment delays, resource constraints, and a policy to minimize planned outages when people are working from home. • National Grid plans to operate GMP ADA devices using a public cellular network to keep projects moving forward. National Grid is evaluating a 700MHz private radio communications network and if found to be acceptable will use a combination of a public cellular and private communications for new GMP ADA devices. • National Grid's cost to deploy the investment is greater than originally forecasted. Based on the historical cost to install the equipment, is it estimated that the total cost to complete the work will be 145% of the original forecasted budget • National Grid is beginning its effort to deploy the ADA investment and has limited ADA on its system. As such the saturation of ADA devices is low on a system-wide perspective. This should provide an opportunity to improve reliability as saturation increases and National Grid continues to leverage this investment.

Source: Guidehouse analysis

Table 5, Table 6, and Table 7 summarize the Performance Metric Results for the ADA Investment Area in PY2021. Table 5 shows the results for the Performance Metric that analyzes the Effect on Outage Duration (CKAIDI) and Table 6 shows the results for the Effect on Outage Frequency (CKAIFI). In both tables, the baseline and PY2021 results are summarized for both system-wide circuits and ADA circuits. Table 7 presents the results for the ADA-specific Performance Metrics: Numbers of Customers that Benefit from GMP Funded Distribution Automation Devices, Average Zone Size (Eversource-specific metric), and Average Main-Line Customer Minutes of Interruption (National Grid-specific metric).

Table 5. ADA Performance Metrics Summary: CKAIDI

Eversource ADA	2015-2017 Avg. CKAIDI (Baseline)				2021 CKAIDI (Program Year)			
	System-wide		ADA Circuits		System-wide		ADA Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIDI Statistics								
Total Circuits	2,071	2,071	234	234	2,071	2,071	234	234
Total Circuits with Non-zero Customers	1,658	1,658	233	233	1,572	1,572	224	224
% Zero CKAIDI	22%	22%	1%	1%	29%	35%	5%	8%
Average CKAIDI	133	105	152	133	643	66	667	74
Change from Baseline (Baseline - Plan Year)					-510	39	-515	59
% Change from Baseline					-383%	37%	-338%	44%
Std. Dev.	154	117	154	139	1,289	82	1,339	89
National Grid ADA	**2015-2017 Avg. CKAIDI (Baseline)**				**2021 CKAIDI (Program Year)**			
	System-wide		ADA Circuits		System-wide		ADA Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIDI Statistics								
Total Circuits	1,076	1,076	30	30	1,076	1,076	30	30
Total Circuits with Non-zero Customers	1,073	1,073	30	30	1,042	1,042	30	30
% Zero CKAIDI	3%	4%	0%	0%	19%	20%	0%	0%
Average CKAIDI	222	118	279	131	366	113	275	76
Change from Baseline (Baseline - Plan Year)					-145	5	4	55
% Change from Baseline					-65%	4%	2%	42%
Std. Dev.	258	162	290	95	672	122	373	81

Note: EME = Excludable Major Events. CKAIDI of zero indicates circuit did not experience any outages.

Source: *Guidehouse analysis of 2021 GMP Annual Reports Appendix 1*

Table 6. ADA Performance Metrics Summary: CKAIFI

Eversource ADA	2015-2017 Avg. CKAIFI (Baseline)				2021 CKAIFI (Program Year)			
	System-wide		ADA Circuits		System-wide		ADA Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIFI Statistics								
Total Circuits	2,071	2,071	234	234	2,071	2,071	234	234
Total Circuits with Non-zero Customers	1,658	1,658	233	233	1,572	1,572	224	224
% Zero CKAIFI	22%	22%	1%	1%	29%	36%	5%	8%
Average CKAIFI	1.0	0.9	1.2	1.1	1.3	0.7	1.3	0.8
Change from Baseline (Baseline - Plan Year)					-0.3	0.2	-0.2	0.3
% Change from Baseline					-31%	22%	-13%	29%
Std. Dev.	0.8	0.7	0.8	0.7	1.4	0.8	1.4	0.8
National Grid ADA	**2015-2017 Avg. CKAIFI (Baseline)**				**2021 CKAIFI (Program Year)**			
	System-wide		ADA Circuits		System-wide		ADA Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIFI Statistics								
Total Circuits	1,076	1,076	30	30	1,076	1,076	30	30
Total Circuits with Non-zero Customers	1,073	1,073	30	30	1,042	1,042	30	30
% Zero CKAIFI	3%	4%	0%	0%	19%	20%	0%	0%
Average CKAIFI	1.0	0.9	1.0	1.0	1.1	0.9	0.9	0.7
Change from Baseline (Baseline - Plan Year)					-0.1	0.0	0.1	0.2
% Change from Baseline					-9%	0%	10%	24%
Std. Dev.	0.6	0.6	0.6	0.6	1.0	0.8	0.5	0.5

Note: EME = Excludable Major Events. CKAIFI of zero indicates circuit did not experience any outages

Source: *Guidehouse analysis of 2021 GMP Annual Reports Appendix 1*

Table 7. ADA Performance Metrics Summary: ADA-Specific Metrics

	Eversource	National Grid
Numbers of Customers that Benefit from DA Devices	249,316	75,970
Average Change in Zone Size: ADA Circuits	254	N/A
Average Change in Main-Line Customer Minutes of Interruption	N/A	43,858

Source: Guidehouse analysis of 2021 GMP Annual Reports Appendix 1

Table 8 summarizes key findings related to Guidehouse's ADA Performance Metrics evaluation for each EDC.

Table 8. Summary of Performance Metrics Findings for ADA Investment Area

PM	Eversource	National Grid
PM-12: Grid Modernization investments' effect on outage durations	Outage duration for ADA circuits in PY2021 improved by 58 minutes from baseline on non-EME days. *	Outage duration for ADA circuits in PY2021 improved by 55 minutes from baseline on non-EME days. ADA circuits performed better in PY2021 than system-wide circuits on average. *
PM-13: Grid Modernization investments' effect on outage frequency	Outage frequency for ADA circuits in PY2021 was 29% better than Baseline on non-EME days. *	Outage frequency for ADA circuits in PY2021 was 24% better than baseline for non-EME days and 10% better for EME days. ADA circuits performed better than system-wide circuits on average in PY2021. *
PM-11: Numbers of Customers that benefit from GMP funded Distribution Automation Devices	Almost 250,000 (18%) Eversource customers benefitted from ADA devices.	Almost 76,000 (6%) National Grid customers benefitted from ADA devices.
PM-ES2: Protective Zone: Average Zone Size per Circuit	The average zone size on circuits with ADA devices decreased by 254 customers in PY2021 from 2018.	N/A – Eversource specific metric
PM-NG1: Main Line Customer Minutes of Interruption Saved	N/A – National Grid specific metric	Main-line CMI for circuits with ADA decreased (improved) 29% in PY2021 from baseline. *
Case studies	Case studies showed improvements in reliability from ADA devices evaluated.	Case studies showed improvements in reliability from ADA devices evaluated.

** Note: This metric is not able to readily discern whether change in this metric was due to ADA investment or other factors. Source: Guidehouse Analysis*

Guidehouse has developed the following recommendations and submits them for EDC consideration:

1) The CKAIDI and CKAIFI reliability related Performance Metrics as defined have deficiencies in measuring the effectiveness of Grid Modernization Investments. Many factors unrelated to the Grid Modernization investments will affect these metrics in any given year, and it is not possible to distinguish among these factors using the metrics. For example, the variation in storm activity between years can cause significant changes in these metrics, as apparently happened in PY2020 and PY2021. This observation has been made previously, and these recommendations were made last year, but bear repeating.

a. Recommendation: Continue to track these Performance Metrics, but establish other methods of isolating the specific impacts of Grid Modernization investments.[11]
b. Recommendation: Additional Performance Metrics should be explored to determine if it is possible to capture the actual reliability performance attributable to the investments. Exploration could include:
    i. Exploring the pros and cons of making the reliability metrics baseline a rolling average of, perhaps, the most recent 3 years, as opposed to the fixed years of 2015 through 2017. The fixed baseline has the issue, as pointed out in the report, that individual circuits are reconfigured over time, go out of service, and new circuits are created, making circuit-wise comparisons over time more challenging.
    ii. Exploring the pros and cons of understanding the timing and sequencing of reliability events more closely in the first several minutes of the event. This timing would lend insight whether an event was resolved within a 1 minute versus a 5 minute threshold, which would impact CKAIFI metrics. As the network becomes more complex (e.g., increased DER penetration, additional switching to reconfigure for changing loads), the processing logic to perform proper load and device status before automation controls are used will become more complex and tend to take longer. So, understanding these dynamics will grow in importance.
    iii. Reviewing the data and techniques necessary to understand the relationship between circuit reliability and weather conditions, vegetation management cycles and other reliability drivers that are independent of the grid modernization investments.
    iv. Expanding the use of case studies to cover a greater proportion of the investments—more outage cases examined on more circuits (see Recommendation 4a below).
    v. Leveraging new processes and data collection to perform outage case studies more efficiently, and perhaps extrapolate these results to a broader set of circuits to understand investment performance with more certainty.
    vi. Comparing number of customers out and customer minutes of interruption (CMI) that occurred, with the number of customers out and CMI that would have occurred without Grid Modernization investments.
    vii. Developing a way to expand the use of counter-factual analysis on a broader basis than what is currently being done in the Case Studies could help develop a better understanding of overall system impacts from the ADA investments.

[11] Note: the EDCs do have additional reliability metrics that are being tracked: National Grid has the *Mainline Customer Minutes of Interruption Saved* metric (PM-NG1), and Eversource has the *Protective Zone Average Zone Size per Circuit* metric (PM-ES2), which provide additional information about reliability performance. However, neither of these metrics directly isolates and measures the investments' performance impact on customer reliability vis a vis other factors that may impact reliability.

2) The use of currently defined CKAIDI and CKAIFI reliability related Performance Metrics—which are circuit level metrics—has increasing challenges over time as circuits get re-configured or retired and new circuits are created. The comparability of each circuit in the program year to its baseline depends on that circuit not having been reconfigured or significantly changed (e.g., a normally open switch between circuit segments is changed to operate as normally closed, changing the customer counts and outage measurements on that circuit). The number of circuits that are comparable between baseline and program year is reduced year after year as more circuits change due to ongoing operation of the system. This observation has been made previously, and this recommendation was made last year, but bears repeating.
    a. Recommendation: Explore metrics that are robust to these operating changes to help ensure that Grid Mod investment assessment based on these metrics are not misleading, and are able to better capture the impact of the investment.

3) Current metrics do not provide an understanding of how M&C and ADA investments facilitate easier interconnection, or more capacity, of DER added to the system. This observation has been made previously, and this recommendation was made last year, but bears repeating.
    a. Recommendation: Consider developing additional metrics and/or performing pilot projects that utilize the installation of ADA and M&C investments at DER locations to understand the value or benefits that are provided. This would provide actual data on the effectiveness of these investments to support DER integration.

4) Case studies show detailed functioning and impact of GMP devices, and they are proving to be a useful tool in understanding the effectiveness of the Grid Modernization investments. Based on case studies performed, the ADA investment is yielding reliability and service delivery benefits to customers for each of the EDCs. This observation has been made previously, and these recommendations were made last year, but bear repeating.
    a. Recommendation: Continue to perform case studies in future evaluations, and increase the use of case studies where practicable, to analyze the mitigation of customer outages and help determine the effectiveness of Grid Modernization investments in improving reliability and service delivery.

5) The evaluation team found that the EDC definition for the term “deployed” devices reported to the DPU was not consistent across EDCs. “Deployed” was used to indicate different stages of device implementation, including *in-service* (installed, used and useful) and *commissioned* (GMP functionalities and remote communication are enabled). This evaluation report considers only fully commissioned devices to be “deployed”.
    a. Recommendation: The Department should recommend the establishment of a consistent state-wide definition of “deployed” for future program tracking and reporting.

6) The 4 kV underground loop scheme was first-of-a-kind technology for Eversource. It encountered communication and software issues in commissioning the scheme in 2020.

After performing engineering and troubleshooting in 2020 and 2021, Eversource discontinued the investment.

   a. Recommendation: Eversource should perform a more rigorous assessment of the communication requirements (latency, bandwidth and capacity) of major new technologies in the future.

7) For Eversource, ADA deployment has reduced the zone size of many circuits to under 500 customers.
   a. Recommendation for Eversource: On blue-sky days, analyze outages affecting greater than 500 customers in a case-study manner to determine:
      i. Was the zone size reduced to 500 or is additional ADA deployment warranted?
      ii. Did FLISR operate correctly or are equipment or software changes required?

8) For Eversource, the evaluation team validated the performance of ADA to automatically operate to restore power to customers. Case Study 5.6 demonstrated that while automatic restoration was achieved, two of the field devices appear to have automatically operated "slower" than other automated devices on the same circuit. This slower than expected operation was not noted during the review of other case studies.
   a. Recommendation: Eversource should verify the automatic settings in field devices 27A7-90T and 20A33-71S to assure they have proper settings.
   b. Recommendation: If improper settings are found, Eversource should determine if other devices may also have settings that need to correction.

9) For Eversource, the evaluation team validated the performance of modern VFI switches that replaced legacy oil switches in underground 4kV circuits. The new VFI switches have SCADA capability and automatic fault isolating capability during a main line fault. Based on Case Study 5.7 a main line fault, with the modern gird modernization investments, will reduce the number of customers affected between 25 to 75% while also reducing outage duration time. While this is a significant improvement in reliability, if VFI tripping can be made selective (i.e., VFI closest to the fault location opened), it would even further reduce the number of customers affected.
   a. Recommendation: Eversource should perform a study to determine if the VFIs can be programmed so that only the VFI closest to the fault would open during a main line fault. As an alternative, Eversource should evaluate installing fault indicators (remote fault locating devices) which could provide operating personnel real-time information on the location of the fault. This would further minimize the number of customers affected.

10) Case Studies demonstrated that National Grid's initial FLISR schemes are operating properly and restoring power quickly to customers.
   a. Recommendation: National Grid should continue to evaluate circuits for ADA deployment.
   b. Recommendation: Since National Grid has limited ADA deployment at this time, it is recommended that each main-line outage on ADA circuits be analyzed for proper automation. This would determine early in the deployment process if:

i. Main-line customer outage impact was reduced, and if so, how many customers avoided a sustained outage;
ii. The FLISR scheme operated correctly and, if not, whether equipment/software changes are required;
iii. Lessons learned from early deployment can be used to inform additional deployment of ADA.
iv. This can also help determine if zone size between ADA devices is optimal or should be further reduced.

1. Introduction to Massachusetts Grid Modernization

This section includes a brief background to the Grid Modernization Evaluation process and an overview of the Advanced Distribution Automation (ADA) investment area and specific ADA evaluation objectives. Subsequent sections address the evaluation processes and findings, for which these objectives provide context.

1.1 Massachusetts Grid Modernization Plan Background

On May 10, 2018, the Massachusetts Department of Public Utilities (DPU) issued its Order[12] regarding the individual Grid Modernization Plans (GMPs) filed by the three Massachusetts electric distribution companies (EDCs): Eversource, National Grid, and Unitil.[13,14] In the Order, the DPU preauthorized grid-facing investments over 3 years (2018-2020) for each EDC and adopted a 3-year (2018-2020) regulatory review construct for preauthorization of grid modernization investments. On May 12, 2020, the DPU issued an Order[15] extending the 3-year GMP investment term to a 4-year term, including 2018-2021. The company-specific GMP budget caps did not change with the term extension. On July 1, 2020 Eversource filed a request for an extension of the budget authorization associated with grid modernization investments. The budget extension was approved by the DPU on February 4, 2021.

The preauthorized GMP investments should advance the achievement of DPU's grid modernization objectives:

- Optimize system performance by attaining optimal levels of grid visibility command and control, and self-healing
- Optimize system demand by facilitating consumer price responsiveness
- Interconnect and integrate distributed energy resources (DER)

As part of the GMPs, the DPU determined the need for a formal evaluation process for the preauthorized GMP investments (including an evaluation plan and studies) to help ensure that the benefits are capitalized on and achieved with greater certainty.

The grid modernization investments were organized into six investment areas to facilitate understanding, consistency across EDCs, and analysis.

- Monitoring and Control (M&C)
- Advanced Distribution Automation (ADA)
- Volt/VAR Optimization (VVO)
- Advanced Distribution Management Systems/Advanced Load Flow (ADMS and ALF)

[12] Massachusetts DPU 15-120/DPU 15-121/DPU 15-122 (Grid Modernization) Order issued May 10, 2018 (DPU Order).

[13] On August 19, 2015, National Grid, Unitil, and Eversource each filed a grid modernization plan with the DPU. The DPU docketed these plans as DPU 15-120, DPU 15-121, and DPU 15-122, respectively.

[14] On June16, 2016, Eversource and National Grid each filed updates to their respective grid modernization plans

[15] Massachusetts DPU 15-120-D/ DPU 15-121-D/ DPU 15-122-D (Grid Modernization) Order (1) Extending Current Three-Year Grid Modernization Plan Investment Term; and (2) Establishing Revised Filing Date for Subsequent Grid Modernization Plans (issued May 12, 2020)

- Communications/IoT (Comms)
- Workforce Management (WFM)

This report focuses on the ADA Investment Area. Guidehouse developed similarly structured evaluation reports for each of the other Investment Areas.

1.1.1 Investment Areas

Table 9 summarizes the preauthorized GMP investments.

Table 9. Overview of Investment Areas

Investment Area	Description	Objective
Monitoring and Control (M&C)	Remote monitoring and control of devices in the substation for feeder monitoring or online devices for enhanced visibility outside the substation	Enhancing grid visibility and control capabilities, reliability increase
Advanced Distribution Automation (ADA)	Isolation of outage events with automated restoration of unaffected circuit segments	Reduces the impact of outages
Volt/VAR Optimization (VVO)	Control of line and substation equipment to optimize voltage, reduce energy consumption, and increase hosting capacity	Optimization of distribution voltage to reduce energy consumption and demand
Advanced Distribution Management Systems/Advanced Load Flow (ADMS and ALF)[16]	New capabilities in real-time system control with investments in developing accurate system models and enhancing Supervisory control and data acquisition (SCADA) and outage management systems to control devices for system optimization and provide support for distribution automation and VVO with high penetration of DER	Enables high penetration of DER by supporting the ability to control devices for system optimization, ADA, and VVO
Communications/IoT	Fiber middle mile and field area communications systems	Enables the full benefits of grid modernization devices to be realized
Workforce Management (WFM)	Investments to improve workforce and asset usage related to outage management and storm response	Improves the ability to identify damage after storms

Source: Grid Mod RFP – SOW (Final 8-8-18).pdf; Guidehouse

The Massachusetts DPU preauthorized budget for grid modernization varies by Investment Area and EDC. Eversource originally had the largest preauthorized budget at $133 million, with ADA and M&C representing the largest share ($44 million and $41 million, respectively). National Grid's preauthorized budget was $82.2 million, with ADMS representing over 50% ($48.4 million). Unitil's preauthorized budget was $4.4 million and VVO makes up 50% ($2.2 million).

[16] Note that ALF is an Eversource-only investment, and is not being pursued by the other EDCs, whereas ADMS investment is being pursued by all three EDCs.

On July 1, 2020, Eversource filed a request for an extension of the budget authorization associated with grid modernization investments.[17] The budget extension, approved by the DPU on February 4, 2021,[18] includes $14 million for ADA, $16 million for ADMS/ALF, $5 million for Communications, $15 million for M&C, and $5 million for VVO. These values are included in the Eversource total budget by Investment Area in Table 10.

Table 10. 2018-2021 GMP Preauthorized Budget, $M

Investment Areas	Eversource	National Grid	Unitil	Total
ADA	$58.00	$13.40	N/A	**$71.40**
ADMS/ALF	$33.00	$48.40	$0.70	**$79.10**
Comms	$23.00	$1.80	$0.84	**$25.60**
M&C	$56.00	$8.00	$0.35	**$64.75**
VVO	$18.00	$10.60	$2.22	**$30.80**
WFM	-	$0.00	$0.30	**$1.00**
2018-2021 Total	**$188.00**	**$82.20**	**$4.41**	**$272.65**

Source: DPU Order, May 10, 2018, and Eversource filing GMP Extension and Funding Report, July 1, 2020

The DPU added flexibility to these budgets based on changing technologies and circumstances. For example, EDCs can shift funds across the different preauthorized investments if they supply a reasonable explanation for these shifts. The following subsections discuss these evaluation goals, objectives, and the metrics to be used.

1.1.2 Evaluation Goals and Objectives

The DPU requires a formal evaluation process (including an evaluation plan and evaluation studies) for the EDCs' preauthorized GMP investments. Guidehouse is completing the evaluation to ensure a uniform statewide approach and to facilitate coordination and comparability. The evaluation's objective is to measure the progress made toward the achievement of DPU's grid modernization objectives. The evaluation uses the DPU-established Infrastructure Metrics, Performance Metrics, and Case Studies that illustrate the performance of specific technology installations to determine if the investments meet the DPU's GMP objectives.

1.1.3 Metrics for Evaluation

The DPU-required evaluation involves Infrastructure Metrics and Performance Metrics for each investment area. In addition, Guidehouse added selected case studies for some Investment Areas (e.g., ADA) as part of the evaluation to show how the technology has performed in specific instances (e.g., in remediating the effects of a line outage).

[17] Grid Modernization Program Extension and Funding Report. Submitted to Massachusetts DPU on July 1, 2020 as part of DPU 15-122

[18] Massachusetts DPU 20-74 Order issued on February 4, 2021.

1.1.3.1 Infrastructure Metrics

The Infrastructure Metrics assess the deployment of the GMP investments. Table 11 summarizes the Infrastructure Metrics.

Table 11. Infrastructure Metrics Overview

Metric		Description	Applicable IAs	Metric Responsibility
IM-1	**Grid Connected Distribution Generation Facilities**	Tracks the number and type of distributed generation facilities in service and connected to the distribution system.	ADMS/ALF	EDC
IM-2	**System Automation Saturation**	Measures the quantity of customers served by fully or partially automated devices.	M&C, ADA	EDC
IM-3	**Number and Percent of Circuits with Installed Sensors**	Measures the total number of circuits with installed sensors which will provide information useful for proactive planning and intervention.	M&C	EDC
IM-4	**Number of Devices Deployed and In Service**	Measures how the EDC is progressing with its GMP from an equipment and/or device standpoint.	All IAs	Evaluator
IM-5	**Cost for Deployment**	Measures the associated costs for the number of devices or technologies installed; designed to measure how the EDC is progressing under its GMP.	All IAs	Evaluator
IM-6	**Deviation Between Actual and Planned Deployment for the Plan Year**	Measures how the EDC is progressing relative to its GMP on a year-by-year basis.	All IAs	Evaluator
IM-7	**Projected Deployment for the Remainder of the Four-Year Term**	Compares the revised projected deployment with the original target deployment as the EDC implements its GMP.	All IAs	Evaluator

IM = Infrastructure Metric, IA = Investment Area
Source: Guidehouse review of Infrastructure Metric filings

1.1.3.2 Performance Metrics

The Performance Metrics assess the performance of all the GMP investments. Table 12 summarizes the Performance Metrics used for the various Investment Areas. This report discusses Performance Metrics that pertain specifically to the ADA Investment Area.

Table 12. Performance Metrics Overview

Metric		Description	Applicable IAs	Metric Responsibility
PM-1	**VVO Baseline**	Establishes a baseline impact factor for each VVO-enabled circuit which will be used to quantify the peak load, energy savings, and greenhouse gas (GHG) impact measures.	VVO	All
PM-2	**VVO Energy Savings**	Quantifies the energy savings achieved by VVO using the baseline established for the circuit against the annual circuit load with the intent of optimizing system performance.	VVO	All
PM-3	**VVO Peak Load Impact**	Quantifies the peak demand impact VVO/CVR has on the system with the intent of optimizing system demand.	VVO	All
PM-4	**VVO Distribution Losses without Advanced Metering Functionality (AMF) (Baseline)**	Presents the difference between circuit load measured at the substation via the SCADA system and the metered load measured through advanced metering infrastructure.	VVO	All
PM-5	**VVO Power Factor**	Quantifies the improvement that VVO/CVR is providing toward maintaining circuit power factors near unity.	VVO	All
PM-6	**VVO – GHG Emissions**	Quantifies the overall GHG impact VVO/CVR has on the system.	VVO	All
PM-7	**Voltage Complaints**	Quantifies the prevalence of voltage-related complaints before and after deployment of VVO investments to assess customer experience, voltage stability under VVO.	VVO	All
PM-8	**Increase in Substations with DMS Power Flow and Control Capabilities**	Examines the deployment and data cleanup associated with deployment of ADMS/ALF, primarily by counting and tracking the number of circuits and substations per year.	ADMS/ ALF	All
PM-9	**Control Functions Implemented by Circuit**	Examines the control functions of DMS power flow and control capabilities, focused on the control capabilities including VVO-CVR and FLISR.	ADMS/ ALF	All

Metric		Description	Applicable IAs	Metric Responsibility
PM-11	**Numbers of Customers that Benefit from GMP-Funded Distribution Automation Devices**	Shows the progress of ADA investments by tracking the number of customers that have benefitted from the installation of ADA devices.	ADA	ES, NG
PM-12	**Grid Modernization Investments' Effect on Outage Durations**	Provides insight into how M&C investments can reduce outage durations (CKAIDI). Compares the experience of customers on GMP M&C-enabled circuits as compared to the previous three-year average for the same circuit.	M&C, ADA	All
PM-13	**Grid Modernization Investments' Effect on Outage Frequency**	Provides insight into how M&C investments can reduce outage frequencies (CKAIFI). Compares the experience of customers on M&C-enabled circuits as compared to the prior three-year average for the same circuit.	M&C, ADA	All
PM-ES1	**Advanced Load Flow – Percent Milestone Completion**	Examines the fully developed ALF capability across Eversource's circuit population.	ADMS/ ALF	ES
PM-ES2	**Protective Zone: Average Zone Size per Circuit**	Measures Eversource's progress in sectionalizing circuits into protective zones designed to limit outages to customers located within the zone.	ADA	ES
PM-UTL1	**Customer Minutes of Outage Saved per Circuit**	Tracks time savings from faster AMI outage notification than customer outage call, leading to faster outage response and reduced customer minutes of interruption.	M&C	UTL
PM-NG1	**Main Line Customer Minutes of Interruption Saved**	Measures the impact of ADA investments on the customer minutes of interruption (CMI) for main line interruptions. Compares the CMI of GMP ADA-enabled circuits to the previous three-year average for the same circuit.	ADA	NG

PM = Performance Metric, IA = Investment Area, ES = Eversource, NG = National Grid, UTL = Unitil

Source: Stamp Approved Performance Metrics, July 25, 2019.

This report discusses Performance Metrics that pertain specifically to the ADA Investment Area.

1.1.3.3 Case Studies

The evaluation team developed a Case Study approach to provide more insight into the actual operation of the GMP devices and to illustrate how these investments provide customer reliability and operational benefits. The impacts of GMP devices on system reliability metrics can be difficult to discern due to the range of factors that affect these metrics. Storm conditions, vehicle accidents and other factors drive reliability from year to year. This is especially likely if the device has less than several years of operation to affect the metric. The case studies illustrate the benefits provided by GMP devices during outage events. This approach investigates outage events on specific circuits where the utility used GMP equipment to address the outage. The approach also allows for comparison between what did occur due to the presence of the GMP device and what would have likely happened had the GMP investment not been made.

1.2 ADA Investment Area Overview

Eversource and National Grid are investing in ADA. Unitil does not have preauthorized ADA investments in its GMP. ADA investments will enable a greater level of distribution grid automation and are expected to result in improved electric system reliability. As identified in the 2020 Grid Modernization Annual Reports, filed by the EDCs on April 1, 2021, and the PY2021 EDC Data Request, received by the EDCs in early 2022, the ADA investments totaled to $69.40 million from 2018 to 2021:

- $60.46 million by Eversource
- $8.95 million by National Grid

There is an additional total of $3.61 million across all EDCs for ADA investments that were begun in 2021 but are planned to be carried over and completed in 2022. This includes carryover of $0.45 million for Eversource and $3.16 million for National Grid.

The following subsection discusses EDC-specific approaches to ADA.

1.2.1 EDC Approach to ADA

ADA investments all serve to increase visibility of the distribution grid, add more control and restoration options, reduce the customer zone size for fault isolation, and reduce the impact and extent of outages when they occur.

Eversource’s investments include new overhead recloser installations, underground oil switch replacements, and a pilot to develop underground auto-reclosing loops. Some of the reclosers are at tie locations between circuits.

National Grid’s ADA investments include new installations of overhead reclosers and upgrades to existing reclosers with SCADA. Some of these reclosers are at tie locations between circuits. In 2020, National Grid added feeder monitors to its ADA investments for enhanced fault location.

Table 13 summarizes these GMP ADA devices and technologies.

Table 13. Devices and Technologies Deployed Under ADA Investment

EDC	Device/Investment Type	Description
Eversource	New Overhead Recloser Locations	New SCADA-enabled overhead recloser installations at new locations to increase auto-sectionalizing capability and reduce customer zone size.
	New Recloser Locations with Ties	New SCADA-enabled overhead recloser installations at new locations with ties to adjacent feeders, to add power supply redundancy and increase switching options.
	Underground Oil Switch Replacement	New SCADA-enabled switches that replace century-old oil-filled underground switches in Boston and Cambridge, to reduce manual operation and increase auto-sectionalizing capability.
	4 kV Auto-Reclosing Loops	This investment was previously called 4 kV Vacuum Fault Interrupters (VFI) Retrofit Program. Eversource commissioned 18 devices but could not expand this investment to loop several circuits with multiple tie points.
National Grid	New Overhead Recloser Locations	SCADA-enabled overhead recloser installations at new locations to increase auto-sectionalizing capability and reduce customer zone size.
	New Overhead Recloser Locations with Ties	New SCADA-enabled overhead recloser installations at new locations with ties to adjacent feeders, to add power supply redundancy and increase switching options.
	Feeder Monitors	Installation of interval power monitoring devices on feeders to aid in fault location where National Grid does not have distribution information.

Source: Guidehouse

1.3 ADA Evaluation Objectives

This evaluation focuses on the progress and effectiveness of the DPU preauthorized ADA investments for each EDC toward meeting the DPU's grid modernization objectives. Table 14 illustrates the key Infrastructure Metrics and Performance Metrics relevant for the ADA evaluation.

Table 14. ADA Evaluation Metrics

Metric Type	ADA Evaluation Metrics	ES	NG
IM	System Automation Saturation	✓	✓
IM	Number of Devices or Other Technologies Deployed	✓	✓
IM	Cost for Deployment	✓	✓
IM	Deviation between Actual and Planned Deployment for the Plan Year	✓	✓
IM	Projected Deployment for the Remainder of the 3-Year Term	✓	✓
PM	Numbers of Customers that Benefit from GMP-Funded Distribution Automation Devices	✓	✓
PM	Grid Modernization Investments' Effect on Outage Durations	✓	✓
PM	Grid Modernization Investments' Effect on Outage Frequency	✓	✓
PM	Protective Zone: Average Zone Size per Circuit	✓	
PM	Main Line Customer Minutes of Interruption Saved		✓
Other	Case Studies**	✓	✓

IM = Infrastructure Metric, PM = Performance Metric, ES = Eversource, NG = National Grid, UTL = Unitil

* Denotes that generating the metrics is EDC responsibility

** In addition to the IMs and PMs listed, Case Studies were added to the evaluation to help explain the operation and value of the selected ADA investments.

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020

The EDCs provided the data supporting the Infrastructure Metrics and Performance Metrics as well as for case studies to the evaluation team. The results from the analysis of Infrastructure Metrics, Performance Metrics, and Case Study data are presented in Sections 3.2, 4.2, and 5, respectively. The Infrastructure Metrics analysis measures whether the investments are taking place on the projected schedule and budget. The Performance Metrics analyses provide insight into the reliability impacts due to grid modernization investments. The Case Studies facilitate understanding of the reliability improvement mechanisms and performance at select feeder locations.

Table 15 summarizes the ADA evaluation objectives and associated research questions. The scope of the ADA evaluation includes tracking the ADA infrastructure deployment against the plan and evaluating the impact on system reliability.

Table 15. ADA M&V Research Questions

ADA M&V Research Questions
1. Are the EDCs progressing in deployment of their ADA investments according to their GMPs?
2. What factors, if any, are affecting the deployment schedule of ADA equipment?
3. What is the cost of deploying various types of ADA equipment?
4. What is the effect of ADA investments on key reliability metrics, such as SAIDI and SAIFI?
5. Is the FLISR automation for the overhead and underground equipment operating as designed?

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020

2. ADA Evaluation Process

This section presents a high-level overview of Guidehouse's methodologies for the evaluation of Infrastructure and Performance Metrics, as well as Case Studies. Figure 2 highlights the filing background and timeline of the GMP order and the evaluation process.

Figure 2. ADA Evaluation Timeline

Source: Guidehouse review of the DPU orders and GMP process

2.1 Infrastructure Metrics Analysis

Guidehouse annually assesses the progress of each EDC toward deploying ADA devices and technologies. Table 16 highlights the Infrastructure Metrics that were evaluated and their associated calculation parameters.

Table 16. Infrastructure Metrics Overview

Infrastructure Metrics			Calculation
IM-4	Number of devices or other technologies deployed thru. PY2021	# Devices Deployed	$\sum_{PY=2018}^{2021}(Devices\ Commissioned)_{PY}$
		% Devices Deployed	$\frac{\sum_{PY=2018}^{2021}(Devices\ Commissioned)_{PY}}{\sum_{PY=2018}^{2020}(Devices\ Commissioned)_{PY}+(Planned\ Devices)_{PY2021}}$
IM-5	Cost through PY2021	Total Spend, $M	$\sum_{PY=2018}^{2021}(Actual\ Spend)_{PY}$
		% Spend	$\frac{\sum_{PY=2018}^{2021}(Actual\ Spend)_{PY}}{\sum_{PY=2018}^{2020}(Actual\ Spend)_{PY}+(Planned\ Spend)_{PY2021}}$
IM-6	Deviation Between Actual and Planned Deployment for PY2021	% On Track (Devices)	$\frac{(Devices\ Commissioned)_{PY2021}}{(Planned\ Devices)_{PY2021}}$
		% On Track (Spend)	$\frac{(Actual\ Spend)_{PY2021}}{(Planned\ Spend)_{PY2021}}$
IM-7	Projected Deployment	# Devices Remaining	$(Devices\ Planned)_{CY2022}$

for the remainder of the GMP Term*	Spend Remaining, $M	$(Planned\ Spend)_{CY2022}$

** This metric has been interpreted here (i.e., within the context of the 2021 Program Year Evaluation) as the "carryover" units and "carryover" spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent plan totals were included in each EDC's Grid Modernization Plan Annual Report 2020 (filed on April 1, 2021), which listed the planned units and spending to be completed in PY2021..*

Source: Guidehouse

Section 3.2 provides the results from the evaluation of Infrastructure Metrics. To evaluate Infrastructure Metrics, Guidehouse:

- Reviewed the data provided by the EDCs to their progress through PY2021 (see Section 3.1.2, "Data QA/QC Process")
- Interviewed representatives from each EDC to understand the status of the ADA investments, including:
  - Updates to their planned ADA investments
  - Reasons for deviation between actual and planned deployment and spend

2.2 Performance Metrics Analysis

Performance Metrics were evaluated for each EDC, focusing on the reliability metrics (CKAIDI and CKAIFI) at the circuit level. Table 17 describes the Performance Metrics used in the PY2021 evaluation.

Table 17. ADA Performance Metrics Overview

Performance Metrics		EDC	Description
PM-11	Number of Customers that Benefit from GMP-Funded Distribution Automation Devices	All	Provides insight into how many customers have benefitted from the installation of ADA devices. Compares the automated zone size on GMP ADA-enabled circuits as compared to the previous 3-year average for the same circuit.
PM-12	Grid Modernization Investments' Effect on Outage Durations	All	Provides insight into how ADA devices reduce the duration of outages (CKAIDI). Compares the experience of customers on GMP ADA-enabled circuits as compared to the previous 3-year average for the same circuit.
PM-13	Grid Modernization Investments' Effect on Outage Frequency	All	Provides insight into how ADA investments can reduce outage frequency (CKAIFI). Compares the experience of customers on GMP ADA-enabled circuits as compared to the previous 3-year average for the same circuit.

PM-ES2	Protective Zone: Average Zone Size per Circuit	ES	Measures Eversource's progress in sectionalizing circuits into protective zones designed to limit outages to customers located within the zone.
PM-NG1	Main Line Customer Minutes of Interruption Saved	NG	Measures the impact of ADA investments on the CMI for main line interruptions. Compares the CMI of GMP ADA-enabled circuits to the previous 3-year average for the same circuit.

Source: Stamp Approved Performance Metrics, July 25, 2019.

2.3 Case Study Analysis

The evaluation team developed a case study approach to provide more insight into the actual operation of the GMP devices and to illustrate how these investments provide customer reliability and operational benefits. The impacts of GMP devices on system reliability metrics can be difficult to discern due to the range of factors that affect these metrics. Storm conditions, vehicle accidents and other factors drive reliability from year to year. This is especially likely if the device has less than several full years of operation to affect the metric. The case studies illustrate the benefits provided by GMP devices during outage events. This approach investigates outage events on specific circuits where the GMP equipment operated to address the outage. It also allows for comparison between what did occur due to the presence of the GMP device and what would have likely happened had the GMP investment not been made.

For the ADA evaluation, Guidehouse conducted six Case Studies: three for Eversource and three for National Grid. Section 5 details the analysis and the results.

3. ADA Infrastructure Metrics

Assessment of the Infrastructure Metrics includes Infrastructure Metric data collection and QA/QC, assessment of ADA deployment progress for each EDC, and conclusions drawn from the analysis.

3.1 Data Management

Guidehouse worked with the EDCs to collect data to complete the ADA evaluation and the assessment of Infrastructure Metrics. The following subsections highlight the data sources and data QA/QC processes used by the team to complete the evaluation and calculate the Infrastructure Metrics.

3.1.1 Data Sources

Guidehouse used a consistent methodology (across investment areas and EDCs) for evaluating the data and illustrating EDC progress indicated by the GMP metrics. The following sections summarize the data sources.

3.1.1.1 2020 Grid Modernization Plan Annual Report

Guidehouse used the planned device deployment and cost information from each EDCs' *2020 GMP Annual Reports*, which were filed on April 1, 2021. These filings served as the sources for planning data in this report and are referred collectively as the GMP Plan for each EDC in summary tables and figures throughout this report.

Table 18 provides a legend of the different planned and actual quantities reviewed and specifies the color/shade used to represent these quantities in graphics throughout the rest of the report.

Table 18. Deployment Categories Used for the EDC Plan

Representative Color	Data	Description
(crosshatched light gray)	2021 Plan	Projected 2021 unit deployment and spend
(light gray)	2020 Actual	Actual reported unit deployment and spend in 2020
(medium gray)	2019 Actual	Actual reported unit deployment and spend in 2019
(dark gray)	2018 Actual	Actual reported unit deployment and spend in 2018

Source: Plan and actual data is sourced from the EDCs' 2020 GMP Annual Report Appendix 1 filed April 1, 2021.

3.1.1.2 EDC PY2021 Device Deployment Data Template

Guidehouse collected device deployment data using standardized data collection templates (e.g., the All Device Deployment workbook) for all EDCs during January and February 2022. The data collected provides an update of planned and actual deployment, in dollars and device units, through the end of PY2021. Data from this source are referred to as EDC Data in summary tables and figures throughout the report. Table 19 summarizes the date of file version receipt used for the evaluation. The collected data was compared to the data submitted by the EDCs to the DPU in the 2021 Grid Modernization Plan Annual Reports and associated

Appendix 1 filings.[19,20,21] The evaluation team confirmed the consistency of the data from the various sources and reconciled any differences.

Table 19. All Device Deployment Data File Versions for Analysis

EDC	File Version
Eversource	Received 2/2/2022
National Grid	Received 2/4/2022

Source: Guidehouse

The EDC device deployment data (collected primarily in the All Device Deployment workbook) captured planned and actual device deployment and spend data. Actual device deployment and cumulative spend information were provided by work order ID and specified at the feeder- or substation-level, as appropriate.

The team also collected current implementation stage of the work order (commissioned, in-service, construction, or design/engineering), the commissioned date (if applicable), and all cumulative costs associated with the work order. Planned device deployment information and estimated spend for PY2021 was provided at the most granular level (circuit or substation) available. Table 20 summarizes the categories used for the planned and actual deployment and spend from the EDC Data; it also specifies the color and pattern used in bar graphs to represent each in the remainder of the report.

Table 20. EDC Device Deployment and Spending Data Legend

Representative Color	Data	Description
Device Deployment Data		
	2022 Estimate	Remaining units planned for 2022 where work will begin in 2022
	2021 Design/ Engineering	Detailed design and engineering are in progress but the device is not yet in construction
	2021 Construction	Field construction is in progress but the device is not yet in-service
	2021 In-Service	Device is installed and is used and useful but not yet commissioned to enable all grid modernization functionalities
	2021 Commissioned	Device is fully operational with all grid modernization functionalities, and thus is considered deployed in PY2020
	2020 Actual	Actual devices commissioned in 2020
	2019 Actual	Actual devices commissioned in 2019
	2018 Actual	Actual devices commissioned in 2018

[19] Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-41.
[20] NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-40.
[21] Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-42.

Representative Color	Data	Description
Spend Data		
	2022 Carryover	Projected 2022 spend
	2021 Actual	Actual 2021 spend
	2020 Actual	Actual 2020 spend
	2019 Actual	Actual 2019 spend
	2018 Actual	Actual 2018 spend

Source: Guidehouse analysis

3.1.2 Data QA/QC Process

To ensure accuracy, Guidehouse conducted a high-level QA/QC of all device deployment data received. This review involved following up with the EDCs for explanations regarding the following:

- Potential errors in how the forms were filled out (e.g., circuit information provided in the wrong field)
- Missing or incomplete information
- Large variation in the unit cost of commissioned devices
- Variance between the aggregated year-end total information and work order-level data
- Variance between the actual unit costs and planned unit costs

Guidehouse reviewed all data provided for Infrastructure Metrics analysis upon receipt of requested data. The following sections detail the data QA/QC process.

3.2 Deployment Progress and Findings

Guidehouse presents findings from the Infrastructure Metrics analysis for the ADA investment area in the following subsections.

3.2.1 Statewide Comparison

This section discusses the scope of ADA investments relative to the number of feeders and customers within the EDCs in Massachusetts, and it summarizes the deployment progress and findings across all three EDCs.

3.2.1.1 Impact on Massachusetts

Across the three EDCs in Massachusetts, ADA investments have impacted about 19% of total EDC customers and 7% of feeders. Table 21 summarizes the number of feeders and customers covered by GMP ADA investments spanning 2018 through 2021.

Table 21. Number of Massachusetts Feeders and Customers Covered by ADA Investment

ADA Impact	Eversource		National Grid		Total	
	Feeders	Customers	Feeders	Customers	Feeders	Customers
Systemwide Total	2,377	1,400,554	1,121	1,342,182	3,498	2,739,138
2018-2021 Commissioned	293	450,155	33	82,131	251	532,286
% System Total	12%	32%	3%	6%	7%	19%

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

3.2.1.2 Infrastructure Metrics Results

Table 22 summarizes the Infrastructure Metrics results for each EDC's ADA investment area through PY2020. Sections 3.2.2 through 3.2.3 explain each EDC's progress and plans in greater detail.

Table 22. ADA Infrastructure Metrics Summary

Infrastructure Metrics			Eversource	National Grid
GMP Plan Total, PY2018-2021		Devices	602	101
		Spend, $M	$60.89	$8.71
IM-4	Number of devices or other technologies deployed PY2018-2021*	# Devices Deployed	577	73
		% Devices Deployed	96%	72%
IM-5	Cost for Deployment PY2018-2021*	Total Spend, $M	$60.46	$9.28
		% Spend	99%	106%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	83%	65%
		% On Track (Spend)	97%	112%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	9	59
		Spend Remaining, $M	$0.45	$3.16

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

*The metric names have been slightly changed here to clarify the time span used in analysis.

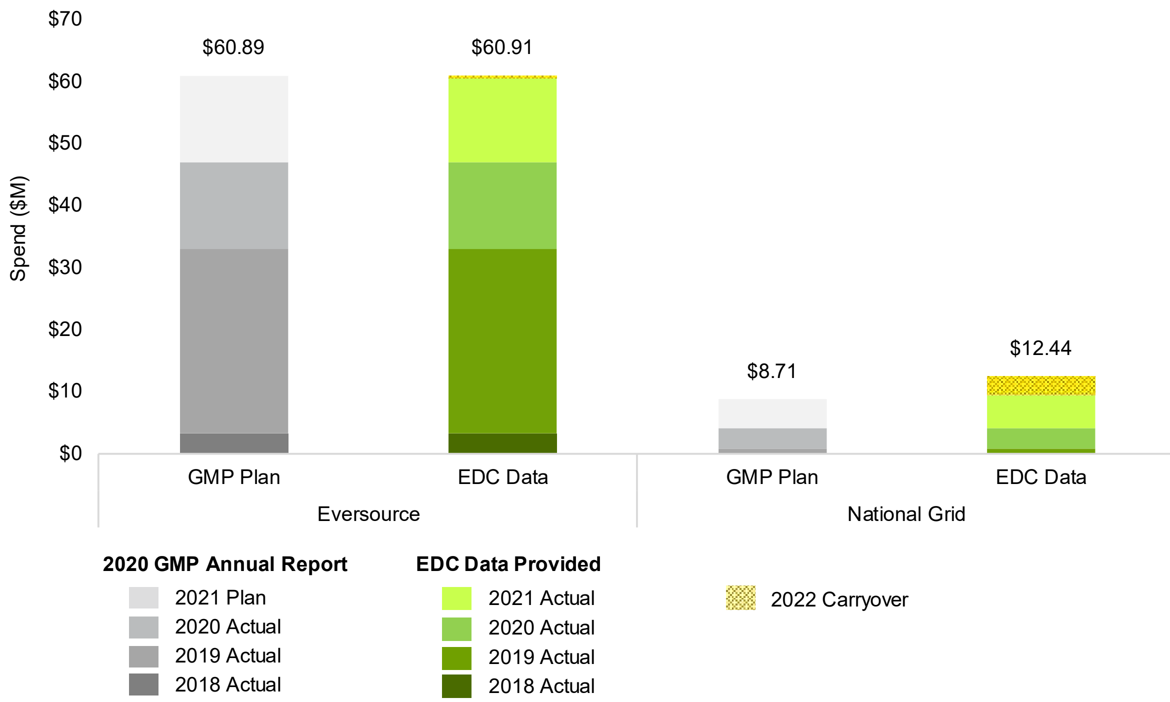
**This metric has been interpreted here as the "carryover" spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs' 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

Based on reported data, Eversource made significant progress in ADA device deployment in 2021. It met deployment target for underground oil switch replacement. It met 91% of overhead recloser deployment target, with remaining 9 under way and slated for 2022 commissioning. Eversource worked to trouble-shoot challenges with its 4kV underground loop scheme but could not make sufficient progress within an acceptable timeframe and therefore made the decision to discontinue the investment in 2022.

National Grid commissioned 14 FLISR schemes in PY2021 (52 devices) and put another 27 devices in-service (fully installed, pending commissioning in 2022). COVID-19-related resource constraints and supply chain delays contributed to National Grid carrying over some 2021 planned work to 2022.

Figure 3 highlights planned versus actual spend in ADA for each of the EDCs. The sections that follow include detailed differences between planned and actual spend.

Figure 3. ADA Spend Comparison (2018-2021, $M)



Note: Includes the Eversource planned spend for PY2021, set forth the in the GMP Extension and Funding Report, filed on July 1, 2020.

Source: Guidehouse analysis of 2020 GMP Annual Reports, GMP Extension and Funding Report, and 2021 EDC Data

In addition to the capital costs in Figure 3, Eversource incurred approximately $0.24 million in O&M costs toward the ADA investment area in PY2021 and approximately $0.50 million toward Administration and Regulatory costs across the GMP investments in PY2021. National Grid incurred approximately $0.12 million in O&M costs toward the ADA investment area in PY2021. National Grid also incurred approximately $0.92 million toward Administration and Regulatory costs across the GMP investments in PY2020.

3.2.2 Eversource

This section discusses Eversource's ADA investment progress through PY2021 and estimated PY2021 progress.

3.2.2.1 Overview of GMP Deployment Plan

Eversource's objective is to increase distribution grid visibility and control and provide additional automated switching to restore electric service. Its investments focus on the following:

- Replacing legacy underground 4kV oil switches with modern, automated switches
- Adding automated overhead reclosers at new locations along a feeder and at tie points that were previously manually operated
- Deploying a new technology to automate 4 kV underground circuits

These investments should help reduce the impact of outages by decreasing the number of customers in each zone between sectionalizing automated devices and tying circuits for added redundancy in power supply.

For its ADA program, Eversource prioritized circuits with customer zone sizes of >500 in Eversource West and >1,000 in Eversource East. (A zone is the length of a feeder between two sectionalizing switches.) In prioritizing circuits, Eversource also took reliability scores into consideration. In the case of outages during major events (e.g., storms), these distribution automation investments will reduce the duration and extent of outage events and will benefit customers. From a system planning perspective, having real-time information increases the flexibility to shift load based on prevailing conditions with the potential to defer capital upgrades. As part of Eversource's longer term planning, the new ADA devices will be incorporated into the ADMS platform when it is available.

Table 23. Eversource GMP ADA Technologies

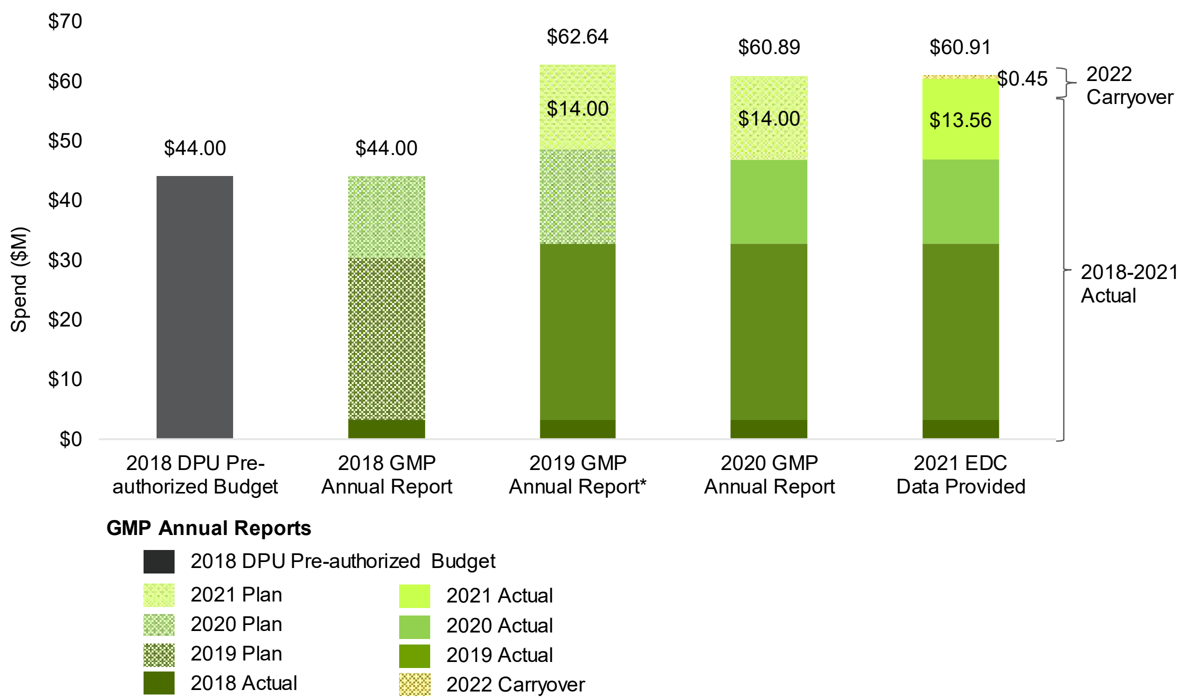
Overhead ADA	Underground ADA
(1) New Recloser Locations	**(3) 4kV Oil Switch Replacement**
New SCADA-enabled overhead recloser installations at new locations to increase auto-sectionalizing capability and reduce customer zone size.	New SCADA-enabled switches that replace obsolete, oil-filled underground switches in Boston and Cambridge, to reduce manual operation and increase auto-sectionalizing capability.
(2) New Recloser Locations with Ties	**(4) 4 kV Auto-Reclosing Loops**
New SCADA-enabled overhead recloser installations at locations with ties to adjacent feeders, to add power supply redundancy and increase switching options.	The original project involved retrofitting the 4 kV underground VFI switches to modern, SCADA-enabled switches. After GMP approval in 2018, Eversource enhanced the project to include a new technology to automate the restoration of underground switches. The deployment was a first-of-a-kind project for Eversource. After attempting to overcome the communication challenges in automating the first loop scheme, Eversource discontinued the project.

Source: Guidehouse analysis of GMP Annual Reports and EDC Data

3.2.2.2 ADA Deployment Plan Progression

Figure 4 shows the progression of Eversource's ADA deployment plans from DPU-preauthorization in 2018 through PY2021. Eversource largely met its 2018-2020 ADA plan in 2020. Eversource's 2021 ADA deployment exceeded the original 3-year ADA plan.

Figure 4. Eversource ADA Planned and Actual Spend Progression, $M



*Note that Eversource received pre-authorization from the Department for another $14 million in spending for its ADA investment area in late 2020.

Source: Guidehouse analysis of DPU Order (May 10, 2018), 2018-2020 GMP Annual Reports, Eversource GMP Extension and Funding Report filed on July 1, 2020, and *2021 EDC Data*

3.2.2.3 ADA Device Type Progress through PY2021

As the 2020 evaluation report notes, Eversource scaled up its base operations and mobilized to deploy GMP devices. This allowed Eversource to exceed its 2019 deployment targets for all four ADA technologies. In 2020, Eversource continued to exceed its 2020 deployment targets for three out of four ADA technologies. Figure 5 and Table 24 show Eversource's progress against targets by device type.

In 2021, Eversource met its oil switch replacement target, commissioning 35 devices as planned. This was a complex project involving manhole work in the dense downtown Boston/Cambridge area.

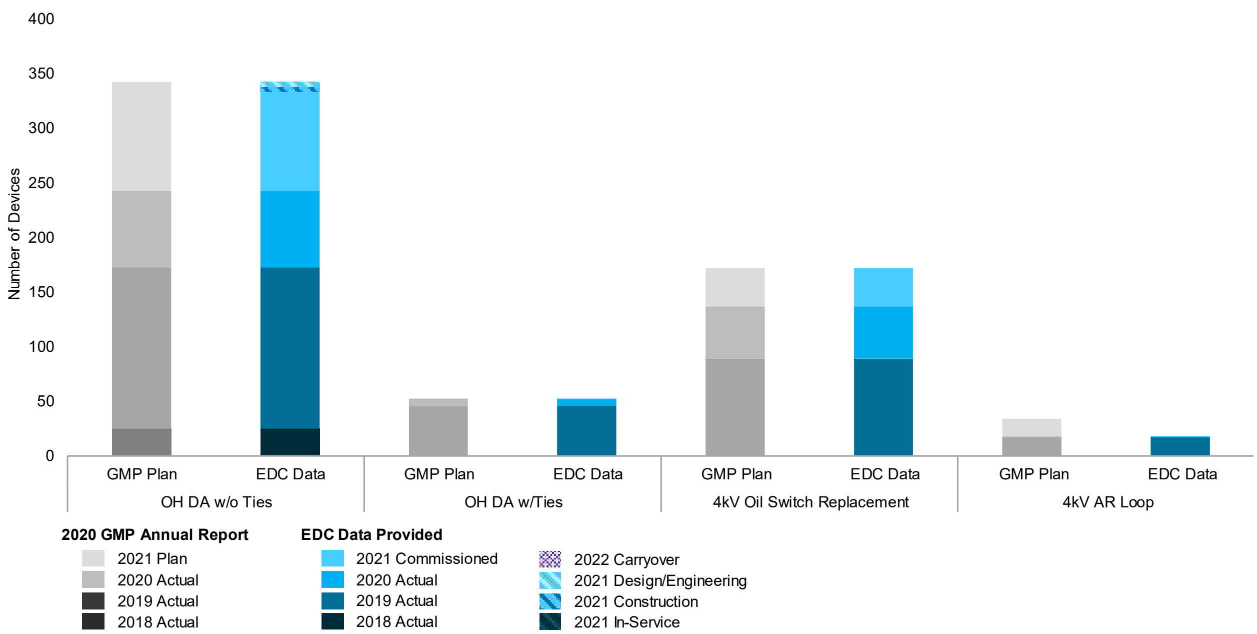
Eversource also commissioned 91 overhead reclosers in 2021 against a target of 100. The reason for the shortfall was resource constraints. The reclosers are located in the South-Eastern region of Eversource Massachusetts territory, where resources had competing priorities with the ongoing Provincetown Energy Storage project. The Company called on another local Area Work

Center (AWC) to provide resources and was able to commission all but 9 of the 100 reclosers on time. Work on the remaining 9 reclosers was started in 2021 and commissioning is planned for 2022.

Eversource discontinued its 4kV auto-reclosing loop investment. Earlier in 2019, Eversource had placed 18 4kV devices in service with the intention to automate them into an automatic loop scheme. These substation and related field devices are located in manholes and were installed, in service, and SCADA commissioned. However, a software limitation prevented the devices from operating together in an automated loop scheme configuration. Eversource paused construction on the second loop scheme while it worked to resolve the technical challenge with the first scheme. In 2020, Eversource conducted engineering and research to resolve the issue, but was unsuccessful. While the 18 devices are fully operational in SCADA, they are no longer undergoing loop scheme automation. The second scheme (comprising 16 devices) is no longer planned.

Figure 5 shows Eversource's planned versus actual device deployment progress over the 2018-2021 period. The EDC Data is presented in Figure 5 and the quantified numbers are shown in Table 24.

Figure 5. Eversource ADA Device Deployment Comparison (2018-2021)



Note that Carryover here would include all units not fully commissioned at the end of PY 2021.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 24. Eversource ADA Plan and Actual Device Deployment (2018-2021)

	OH DA w/o Ties	OH DA w/Ties	4kV Oil Switch Replacement	4kV AR Loop
2018-2021 Total	**334**	**53**	**172**	**18**
Engineering/Design during PY 2021*	4	0	0	0
Construction during PY 2021*	5	0	0	0
In-Service during PY 2021*	0	0	0	0
Commissioned in PY 2021	91	0	35	0
Commissioned in PY 2020	70	8	48	1
Commissioned in PY 2019	148	45	89	17
Commissioned in PY 2018	25	0	0	0

*Deployment of these devices began during PY 2021, but was not completed during the program year. Deployment (through commissioning) is planned as carryover in 2022.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Eversource ADA spending is tracking closely (99%) to plan (as filed in Eversource 2020 Annual Report). Actual spending from 2018-2021 ($60.9 million) also came close to DPU pre-authorized budget of $58 million. For PY 2021, actual spending was 97% of plan and device deployment was 83% of plan.

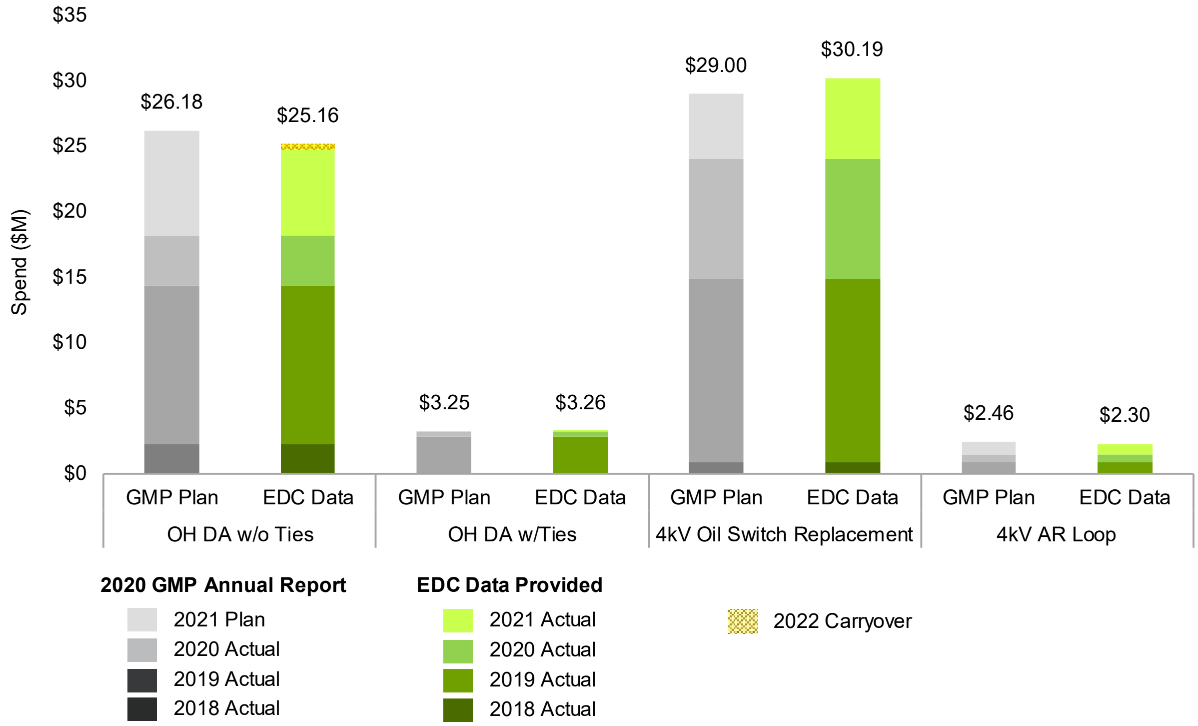
- For underground oil switch replacement, unit deployment targets were met but costs were exceeded. Unit costs for these 35 units were higher than historical average due to larger-than-expected area outages for customers in downtown Boston/Cambridge, requiring customer backup generation assets, manhole racking, additional conductor work, etc. Eversource learned that using historical average cost and standard deviation did not wholly account for individual variation in unit cost.

- For overhead reclosers, Eversource spent 81% of planned cost to commission 91% of planned devices. Cost includes work that was begun in 2021 on the remaining 9 devices slated for 2022 commissioning.

- For the 4 kV AR Loop investment, PY 2021 spending went towards engineering and reconfiguration to troubleshoot the first intended loop scheme.

Figure 6 shows Eversource's planned versus actual spend over the 2018-2021 Term period, broken out by device type. The EDC Data Figure 6 presents is also shown in Table 25.

Figure 6. Eversource ADA Spend Comparison (2018-2021, $M)



Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 25. Eversource ADA Plan and Actual Spend (2018-2021, $M)

	OH DA w/o Ties	OH DA w/Ties	4kV Oil Switch Replacement	4kV AR Loop
2018-2021 Total	**$24.71**	**$3.26**	**$30.19**	**$2.30**
2022 Carryover Estimate	$0.45	$0.00	$0.00	$0.00
PY 2021 Actual	$6.53	$0.00	$6.19	$0.84
PY 2020 Actual	$3.84	$0.46	$9.19	$0.57
PY 2019 Actual	$12.07	$2.80	$13.88	$0.89
PY 2018 Actual	$2.27	$0.00	$0.93	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Eversource has integrated incremental GMP deployment with its base capital spending. For example, GMP investments are on a coordinated schedule with base capital activities to achieve cost efficiencies. Nevertheless, Eversource continues to track incremental GMP spending separately from base activities using separate work orders.

The following sub-sections discuss the progress through PY2021 and actuals for PY2021 for each device type.

Replacement of Underground 4 kV Oil Switches

This investment is focused on modernizing legacy underground switches in Boston and Cambridge. Installed in 1920-1940, these switches represent some of the oldest assets in Eversource's distribution grid and are not suited to serving the densely populated hubs of Boston and Cambridge. These switches (Figure 7, left panel) cannot be automated or provide remote communication. They require a fault to be traced to one of many manholes, often inaccessible and requiring lengthy repairs. For these reasons, Eversource accelerated this program, replacing 89 switches in 2019 ahead of the planned 67. In 2020, Eversource replaced 48 oil switches, 3 times the plan. In 2021, Eversource replaced 35 oil switches, meeting its plan for the GMP term.

The new GMP devices, called vacuum fault interrupters (VFI), perform better than legacy devices in terms of improving customer reliability and ease of operation (Figure 7, right panel). The new switches are SCADA-enabled and capable of automatically isolating faults and restoring sections of the grid using SCADA control. Once the fault zone is isolated, Eversource crews can quickly access SCADA data to determine the fault location for repairs. The expected result is a reduction in the duration and extent of outages in Boston and Cambridge. Additionally, these devices will integrate with and allow for future automation.

Underground oil switch replacement is complex, in part due to high customer density and inaccessibility of small legacy manholes. Outages must be carefully planned along with the use of backup generators to minimize customer impact. For these reasons, budget was exceeded in PY 2021. Despite these challenges, Guidehouse determined that the Eversource deployment was completed on schedule.

Figure 7. Old Oil-Filled Switches (Left) and New VFI Switches (Right)

Source: Eversource

4 kV Underground Auto-Reclosing Loops

In its 2018 GMP annual report, Eversource proposed retrofitting its underground 4 kV VFI switches to enable remote control and automation. Eversource modified this program to include a new, leading-edge technology for creating auto-restoration loops. This program was proposed to enable existing field ties on underground circuits in an automated restoration switching scheme. Eversource used a Schweitzer (SEL) distribution automation controller with 4G/5G communications to bring in data from field devices at one 4 kV substation which would communicate information back to the SCADA system. The results of this project would inform future ADA deployments.

Eversource found underground auto-reclosing loops challenging to design and deploy. Eversource installed one scheme in 2019, placing 18 devices in service with SCADA capability. This met the original plan. In 2020, it encountered software and communications issues in commissioning auto-restoration loop functionality for this scheme. Eversource spent 2020 and 2021 conducting reconfiguration and engineering to resolve the issue, meanwhile placing the second planned scheme on hold. After two years of troubleshooting, Eversource discontinued the auto-reclosing project. Lessons learned include the need to prepare for integration of various manufactures of equipment and the challenges to communications with underground devices inherent in new technology deployments. The 18 devices continue to function in SCADA.

New Overhead Reclosers

Eversource is installing pole-top reclosers at new locations along its overhead distribution lines (Figure 8). Adding new recloser locations reduces zone sizes and increases sectionalizing capability with expected reliability benefits for customers within the new zone created.

Eversource exceeded its 2019 target for overhead recloser installations. In 2020 it overcame control and protection coordination issues in the southeast Massachusetts area and again exceeded 2020 deployment targets. In 2021, Eversource commissioned all but 9 of its planned 100 overhead reclosers. Work was started on the remaining 9 in 2021 and will be finished in 2022. The carryover was partly due to shared resources with the Provincetown battery project. It was also due to Eversource waiting until February 2022 to receive DPU authorization before it began work on 2021 GMP.

Figure 8. Eversource Overhead Recloser

Source: Eversource

New Overhead Reclosers with Feeder Ties

This investment was completed in 2020 and no overhead ties were planned in 2021. This is the same technology as overhead reclosers the previous section describes, except these are installed at strategic locations to tie feeders together. For the GMP, Eversource selected locations where feeders are already in close proximity and where ties can be created without adding new line extensions. This is a cost-effective way of adding redundancy to Eversource's distribution grid.

Eversource planned 38 overhead tie recloser devices in the original 3-year GMP term. It commissioned 45 in 2019, exceeding its 3-year target one year ahead of time. It commissioned an additional eight tie reclosers in 2020 (against plan of zero).

3.2.2.4 Infrastructure Metrics Results and Key Findings

Table 26 presents the Infrastructure Metrics results through PY2021 for each investment type related to Eversource's ADA investment area.

Table 26. Eversource ADA: Infrastructure Metrics Summary

Infrastructure Metrics			OH DA w/o Ties	OH DA w/Ties	4kV Oil Switch Replacement	4kV AR Loop
GMP Plan Total, PY2018-2021		Devices	343	53	172	34
		Spend, $M	$26.18	$3.25	$29.00	$2.46
IM-4	Number of devices or other technologies deployed PY2018-2021	# Devices Deployed	334	53	172	18
		% Devices Deployed	97%	100%	100%	53%
IM-5	Cost for Deployment PY2018-2021	Total Spend, $M	$24.71	$3.26	$30.19	$2.30
		% Spend	94%	100%	104%	93%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	91%	N/A	100%	0%
		% On Track (Spend)	82%	N/A	124%	84%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	9	0	0	0
		Spend Remaining, $M	$0.45	$0.00	$0.00	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the “carryover” units and spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs’ 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

A summary of Guidehouse’s evaluation findings for Eversource is below:

- Eversource’s ADA circuit selection criteria included minimizing customer zone sizes, targeting poor reliability areas, and minimizing cost.
- Eversource performed significant pre-planning and built organizational capacity to deploy GMP devices on schedule and on budget, relative to the Plan filed on April 1, 2020.
- Eversource managed well the unforeseen disruption of the Covid-19 pandemic. In PY 2020, Eversource exceeded 3-year deployment targets over the original 2018-2020 GMP term for three out of four ADA investments.
- In PY 2021, Eversource met underground oil switch replacement target. It also met 91% of overhead recloser deployment target. Eversource pivoted to a different area work center for resources mid-year to attempt to meet the overhead recloser target but fell slightly under target. In hindsight, Eversource suggests it could have pivoted earlier or employed a contracting strategy. The remaining 9 reclosers are slated for 2022 commissioning.

- The underground auto-restoration loop scheme was discontinued. This was first-of-a-kind technology for Eversource. Eversource SCADA-commissioned 18 devices but encountered software and communication issues in getting the devices to operate as a loop scheme. After performing engineering and troubleshooting in 2020 and 2021, Eversource discontinued the investment. Lessons learned include the need to fully understand the communications requirements (latency, bandwidth, capacity) of a major new technology. Eversource surmises that with continued dedication of time and resources the challenges could be overcome, but determined this was not the best path forward. Alternative approaches will be explored as part of the ADMS investment.
- Eversource managed its spending closely to original pre-authorized budget. This meant continually re-evaluating the portfolio of investments and re-adjusting. As a result, Eversource's four-year ADA spending from 2018-2021 ($60.9 million) came close to DPU pre-authorized budget of $58 million.
- Eversource has deployed distribution automation on portions of its system for several years. The ADA investment has been some of the newest distribution automation, but overall Eversource has a higher level of saturation for this type of technology than, say, National Grid. In some cases, Eversource installed ADA devices on circuits that already had pre-existing ADA devices on other locations on the circuit. Eversource ADA investments have focused, among other benefits, on reducing zone size to 500 customers.

3.2.3 National Grid

This section discusses National Grid's ADA investment progress through PY2021 and projected PY2021 estimates.

3.2.3.1 Overview of GMP Deployment Plan

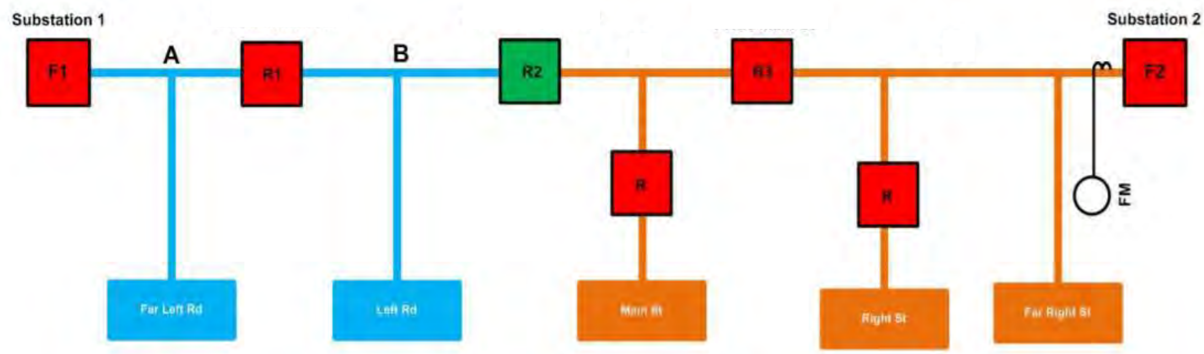
With its ADA investments, National Grid's objective is to improve grid reliability by adding automation and control capabilities at new and existing overhead feeder locations. In 2020, National Grid added Feeder Monitors to its ADA program for more granular fault location capabilities at strategic locations on its distribution feeders.

National Grid has status and control capabilities to 89% of the existing reclosers on the distribution system. With the GMP ADA investments, National Grid has been adding control and automation capability on existing reclosers and adding new recloser locations. The ADA program includes replacing manual tie points between adjacent feeders with remote-controlled automated switches.

National Grid's criteria for ADA feeder selection included but was not limited to: feeder metrics, poorly performing or worst-performing feeders, feeder length, and number of customers served. In the GMP timeframe, National Grid did not deploy ADA on circuits with moderate to high DER penetration, which would require detailed load-flow analysis.

Figure 9 illustrates the benefit of reliable ADA investments on National Grid's distribution grid. It depicts National Grid's distribution feeders, substations, and reclosers. If a fault occurs at point A, F1 (substation breaker) will lock out and R1 (a recloser switch) will automatically open. The entire blue zone will experience loss of power supply from substation 1. With ADA, R2 (a recloser switch that ties two feeders together) would sense loss of power and close automatically. This would restore power to customers in zone B, which would then be supplied from substation 2 instead of substation 1. This process isolates the effects of a fault to the smallest possible section of the grid, in this case, Far Left Road.

Figure 9. National Grid's Illustrative ADA Scheme



Source: National Grid

National Grid expects the benefits of ADA to include:

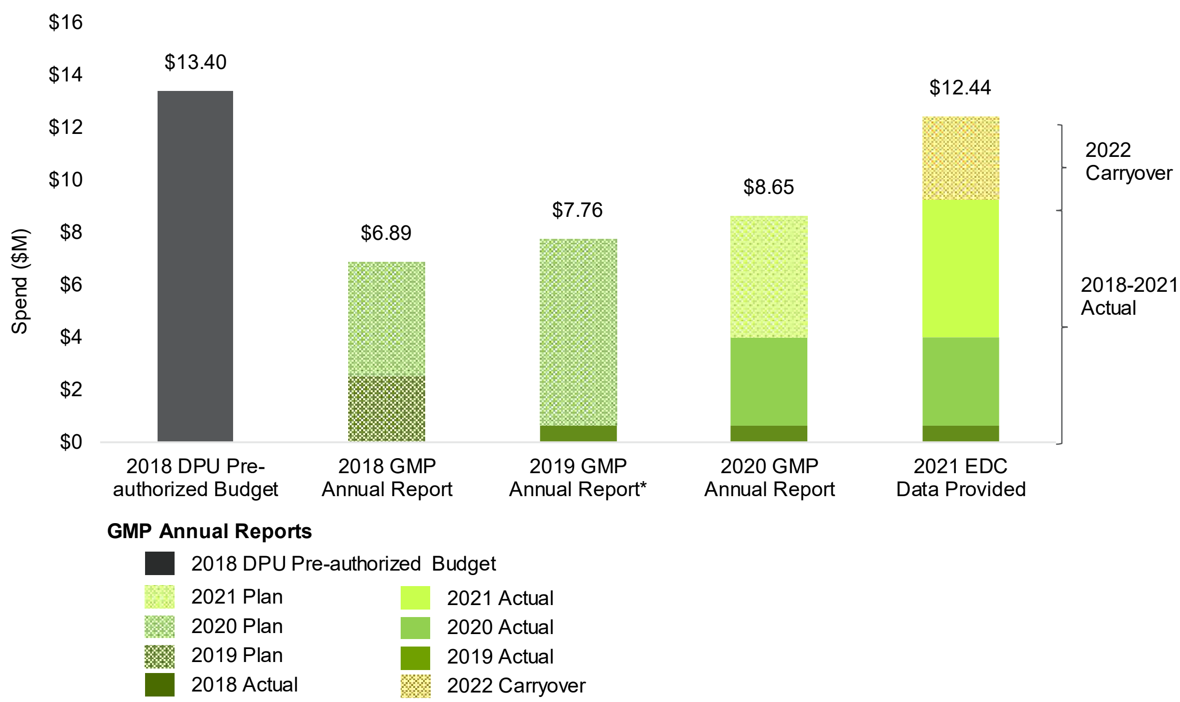
- **Optimizing system performance:** National Grid anticipates a 25% reduction in main-line customer minutes of interruption (CMI) on the individual feeders targeted for the ADA deployment.
- **Optimizing system demand:** The additional operational data collected by the automated switches will support the improved management of the distribution system, assisting in demand optimization.
- **Interconnecting and integrating DER:** The additional operational data collected by the automated switches will support the improved management of the distribution system, assisting in the interconnection of distributed generation and potential integration of distributed resources as a tool to operate the system.

National Grid is integrating lessons learned from the ADA demonstration pilot in its Worcester Smart Energy Solutions Pilot into the Massachusetts GMP ADA program. National Grid learned that the distributed, localized ADA operating model in Worcester was too difficult to operate and maintain. In the Worcester pilot, when the SCADA system (EMS) lost communications to the field device, devices would continue to operate without control room knowledge or interaction. Switches changing position without control knowledge was determined not to be the best approach going forward. After deliberating with several vendors, National Grid adopted a centralized ADA model instead. A centralized ADA model brings field device data back through the communications network, performs centralized decision-making and issues the commands to reclosers.

3.2.3.2 ADA Deployment Plan Progression

Figure 10 shows the progression of National Grid's ADA deployment plans from DPU-preauthorization in 2018 through PY2021. National Grid has spent $8.95 million through PY2021 out of DPU pre-authorized budget of $13.40. COVID-19-related supply chain delays and resource constraints have impacted both PY2020 and PY2021 deployment. National Grid plans to carry over some ADA budget to 2022.

Figure 10. National Grid ADA Planned and Actual Spend Progression, $M



Source: Guidehouse analysis of DPU Order (May 10, 2018), 2018-2020 GMP Annual Reports, and 2021 EDC Data

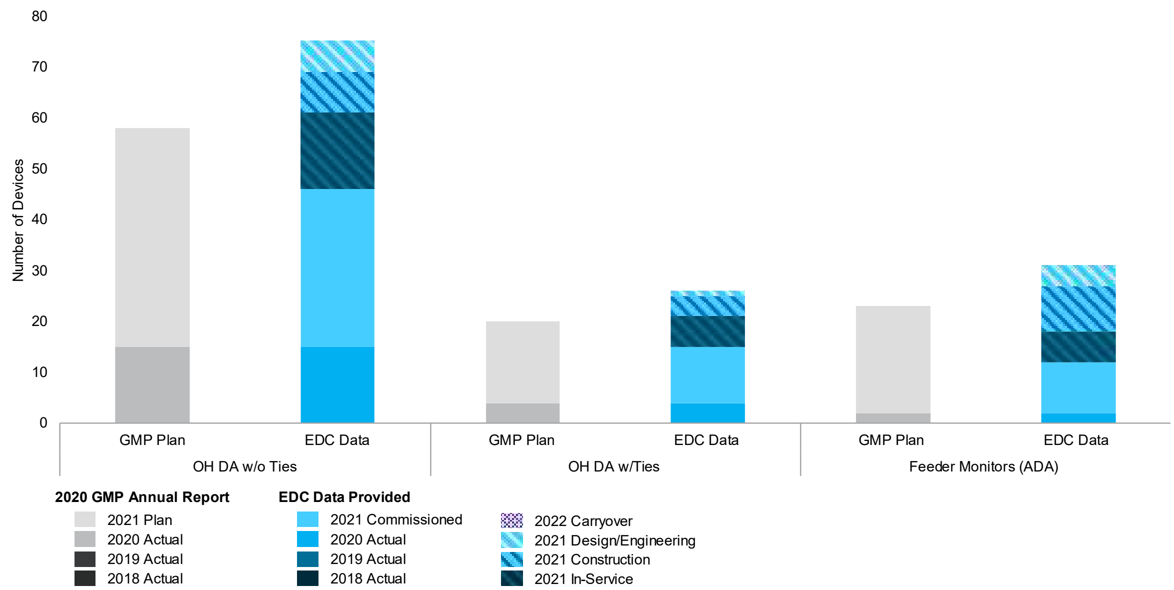
3.2.3.3 ADA Investment Progress through PY2021

Figure 11 below shows National Grid's planned versus actual device deployment progress over the 2018-2021 period. The EDC Data in Figure 11 is also shown in Table 27.

Figure 11 indicates rapid ADA deployment in National Grid's Massachusetts territory in PY2021. National Grid had commissioned two FLISR schemes in late PY2020. In PY2021, it picked up momentum and commissioned 14 schemes. Work is underway on another 6 schemes, pending commissioning in 2022. Note that "in-service" is the penultimate stage before final commissioning. In other words, the devices shown as in-service in the figure are close to complete as of year-end 2021. With the devices underway, National Grid is planning to deploy more ADA devices than plan while staying under the DPU pre-authorized budget.

Each National Grid FLISR scheme consists of overhead recloser devices that work together with pre-programmed logic to quickly isolate a fault to the smallest possible section of the grid. In addition, National Grid installed feeder monitors at strategic points for granular fault location and enhanced FLISR operation. It trained its control center workforce in using the FLISR automation functionality.

Figure 11. National Grid ADA Device Deployment Comparison (2018-2021)



Note that Carryover here would include all units not fully commissioned at the end of PY 2021.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 27. National Grid ADA Plan and Actual Device Deployment (2018-2021)

	OH DA w/o Ties	OH DA w/Ties	Feeder Monitors (ADA)
2018-2021 Total	**46**	**15**	**12**
Engineering/Design during PY 2021*	6	1	4
Construction during PY 2021*	8	4	9
In-Service during PY 2021*	15	6	6
Commissioned in PY 2021	31	11	10
Commissioned in PY 2020	15	4	2
Commissioned in PY 2019	0	0	0
Commissioned in PY 2018	0	0	0

*Deployment of these devices began during PY 2021, but was not completed during the program year. Deployment (through commissioning) is planned as carryover in 2022.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

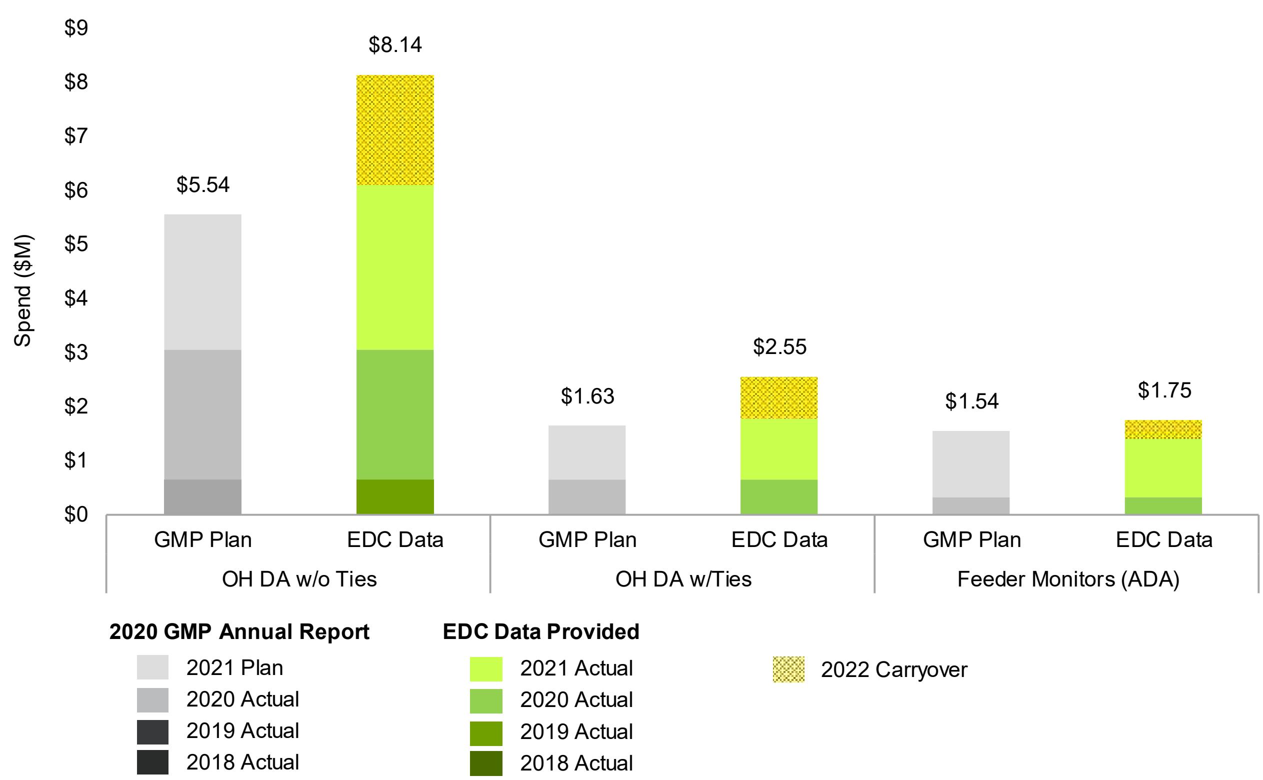
National Grid deployed 11 reclosers at tie points between circuits in PY2021. Installing reclosers at strategic locations that tie two feeders together increases the redundancy and reliability benefits of ADA investments. Tie reclosers allow customers to be supplied from alternate sources and allow for load to be shifted between circuits, increasing the number of possible FLISR switching operations. National Grid performed reconductoring or pole upgrades in some cases to ensure load shifting between feeders is possible without overloading.

In PY2021, National Grid's ADA progress continued to be impacted by the COVID-19 pandemic. Earlier in 2020, National Grid had adapted its work practices to social distancing protocols so that certain field reporting locations had 20%-25% reduction in crews. These resource limitations led to delays in ADA construction schedules that cascaded into 2021. Additionally, National Grid decided after the initial coronavirus outbreak to limit the use of planned outages, since many residential customers were working at home. Limited use of planned outages also delayed ADA construction schedules in PY2021, as did weather events.

National Grid's implementation schedule indicates that work orders ongoing at year-end PY2021 will be completed and commissioned in 2022.

Figure 12 shows National Grid's planned versus actual spend over the 2018-2021 period. The EDC Data in Figure 12 is also shown in Table 28. For overhead reclosers, actual spend was higher than plan but the spend includes devices where work was begun in PY2021 but will be commissioned in 2022. National Grid has begun work on more devices than its plan, explaining the over-spend. Another reason for cost overrun was incremental cost for project make ready (pole work) and reconducting of overhead lines which was required for transferring customers from one circuit to another.

Figure 12. National Grid ADA Spend Comparison (2018-2021, $M)



Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 28. National Grid ADA Plan and Actual Spend (2018-2021, $M)

	OH DA w/o Ties	OH DA w/Ties	Feeder Monitors (ADA)
2018-2021 Total	**$6.11**	**$1.78**	**$1.39**
2022 Carryover Estimate	$2.03	$0.77	$0.36
PY 2021 Actual	$3.07	$1.14	$1.07
PY 2020 Actual	$2.39	$0.64	$0.32
PY 2019 Actual	$0.65	$0.00	$0.00
PY 2018 Actual	$0.00	$0.00	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Figure 13 illustrates National Grid's pole-top reclosers and controls, which include G&W Viper Overhead Reclosers and SEL control cabinets. It plans to migrate to an ADMS in the coming years, at which point it may use a DMS FLISR application in place of its current NovaTech OrionLX substation automation platform. (See Guidehouse's *2021 ADMS Evaluation Report* for more detail.)

Figure 13. National Grid Pole-top Reclosers and Controls

Source: National Grid

National Grid plans to operate the ADA devices installed in 2021 using its public cellular network. National Grid recognized that cellular may not be the preferred technology to operate grid-controlling assets like reclosers, especially during major outage events. Cellular could be hampered by busy signals and will require telecommunication providers to maintain their backup electrical power. During 2021 began testing a private 700MHz radio system. As their 700Mhz radio system is acceptance tested and rolled out, National Grid proposes to deploy a combination of public cellular and private 700MHz radio network depending on coverage availability. (See Guidehouse's *2020 Communications Evaluation Report* for more detail.)

3.2.3.4 Infrastructure Metrics Results and Key Findings

Table 29 presents the Infrastructure Metrics results through PY2021 for each investment type related to National Grid's ADA investment area.

Table 29. National Grid ADA: Infrastructure Metrics Summary

Infrastructure Metrics			OH DA w/o Ties	OH DA w/Ties	Feeder Monitors (ADA)
GMP Plan Total, PY2018-2021		Devices	58	20	23
		Spend, $M	$5.54	$1.63	$1.54
IM-4	Number of devices or other technologies deployed PY 2018-2021*	# Devices Deployed***	46	15	12
		% Devices Deployed	79%	75%	52%
IM-5	Cost for Deployment PY2018-2021*	Total Spend, $M	$6.11	$1.78	$1.39
		% Spend	110%	109%	90%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	72%	69%	48%
		% On Track (Spend)	123%	114%	88%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	29	11	19
		Spend Remaining, $M	$2.03	$0.77	$0.36

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
**The metric names have been slightly changed here to clarify the time span used in analysis.*
*** This metric has been interpreted here as the "carryover" units and spending that National Grid is planning in 2022 or beyond to complete their most recent 4-year Term plan totals. These most recent totals were included in the National Grid's 2020 Grid Modernization Plan, which targeted the planned units and spending to be completed in PY2021.*
****Note that "Deployed" here refers to commissioned devices. In National Grid's Term Report (filed April 1, 2022), deployed refers to in-service and/or commissioned devices. In-service devices are fully installed and used and useful, but not yet commissioned with Grid Mod functionality (communication and remote visibility and/or control). For full definitions of commissioned and in-service, see Docket 20-46 Response to Information Request DPU-AR-4-11, September 3, 2020.*

Guidehouse's Infrastructure Metrics evaluation findings for National Grid as follows:

- National Grid targeted feeders with poor reliability performance for ADA investments.
- National Grid's PY2019 ADA deployment targets were pushed to PY2020. In late 2020, National Grid commissioned two FLISR schemes. In PY2021, commissioned 14 FLISR schemes (52 devices) and began work on six more schemes which will be commissioned in 2022. 27 devices are in-service as of year-end 2021 which means they are installed and operational but not Grid Mod-commissioned.
- National Grid installed some of its ADA devices at strategic tie points between circuits. Tie reclosers are expected to have enhanced reliability and redundancy benefits for customers. However, reconductoring and pole upgrades are sometimes needed to ensure that load can be shifted safely between circuits, adding to the project costs.
- National Grid adapted its work practices to meet the challenge of the COVID-19 pandemic. National Grid carried over some of PY2021 planned work to 2022 due to

COVID-19-related equipment delays, resource constraints, and a policy to minimize planned outages when people are working from home.

- National Grid plans to operate GMP ADA devices using a public cellular network to keep projects moving forward. National Grid is evaluating a 700MHz private radio communications network and if found to be acceptable will use a combination of a public cellular and private communications for new GMP ADA devices.
- National Grid's cost to deploy the investment is greater than originally forecasted. Based on the historical cost to install the equipment, is it estimated that the total cost to complete the work will be 145% of the original forecasted budget.
- National Grid is in early stages of its effort to deploy the ADA investment and has limited ADA on its system. As such the saturation of ADA devices is low on a system-wide perspective. This should provide an opportunity to improve reliability as saturation increases and National Grid continues to leverage this investment.

4. ADA Performance Metrics

Guidehouse's assessment of the Performance Metrics included Performance Metric data collection, data QA/QC, data analysis for each EDC, and determination of findings and conclusions from the analysis.

4.1 Data Management

This section discusses the data sources used for the Performance Metric evaluation and summarizes the Quality Assessment and Quality Control (QA/QC) steps, and selection of circuits used in the PY2021 analysis.

4.1.1 Data Sources

2021 Grid Modernization Plan Annual Report Appendix 1[22,23,24]: On April 1, 2022 each EDC submitted Appendix 1 along with its Annual Report. The Appendix 1 contains feeder-level data for all feeders within each EDC's territory. All PM-related data presented below are from these 2021 GMP Annual Report Appendices. These documents contain baseline and program year data for all circuits for each EDC. Key data from these Appendices that were utilized in this analysis include:

- Customer Counts
- Feeder Level SAIDI (CKAIDI) and SAIFI (CKAIFI) for the Plan Year and Baseline Years
- Number of Customers that Benefit from GMP Investments
- Average Protective Zone Size
- Main Line Customer Minutes of Interruption

Work Order Information: Circuit-level work order data was collected during the infrastructure metrics evaluation to understand the current status (e.g., Construction, Design, In-Service, Commissioned) of GMP investments. This work order data was used to determine when GMP investments were commissioned on each circuit with more granularity than is provided in the Appendix 1 data.

4.1.2 Data QA/QC Process

The evaluation team reviewed the Appendix 1 filings for completeness, accuracy, and alignment with the metrics set forward in the DPU Stamp Approved Metrics. The QA/QC process involved the following:

- Check that the change in CKAIDI/CKAIFI, average zone size, and customer minutes of interruption were properly calculated using the Stamp Approved Metric's definition. Note: DPU Stamp Approved Metric Guidance defines this as "BASELINE – PROGRAM YEAR"

[22] Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 22-41

[23] NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-40.

[24] Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-42

- Comparison of circuits with GMP investments in the Appendix 1 filing and the work order data collected during the Infrastructure Metric analysis.
- Comparison of PY2020 and PY2021 Appendix 1 filings to ensure baseline reliability data match.
- Comparison of circuit lists between Appendix 1 tabs to understand changes in circuit lists due to decommissioning and reconfigurations that occurred during the baseline and program years.

During this QA/QC process, the evaluation team identified issues in both the Eversource and National Grid Appendix 1 filings that required adjustments and updates:

Eversource: Formula errors for Eversource's reported change in SAIFI with and without EMEs lead to incorrect values being calculated. Additionally, there were discrepancies between Eversource's work order data and Appendix 1 device deployment data with regards to which circuits had received ADA investments. Eversource provided explanations for both of these findings and indicated that corrections would be made in the future.

National Grid: Due to differences in reporting timeframe and requirements, National Grid resubmitted its initial EDC Data Device Deployment workbook with updated device counts and spend to align with its Appendix 1 filing. Baseline reliability data for Nantucket circuits was noted to be different than in the PY2020 Appendix 1 but was subsequently corrected by National Grid. Furthermore, National Grid also corrected some discrepancies between its Appendix 1 device deployment tabs, as well as circuit IDs in the work order data to align with Appendix 1 stated deployment.

4.1.3 Circuit Selection

The key reliability metrics involving outage duration (CKAIDI) and frequency (CKAIFI) are annual metrics and impacts to these metrics from GMP investments would only be seen if the investments were installed for sufficient time on a particular circuit to impact outages that drive these annual metrics. The approach most likely to detect metric impacts from the investments would be to wait until the investment had been commissioned for several full years on the circuit before attempting to understand its impact on these metrics. However, the evaluation team determined that the use of the technology for at least one-half of the full program year could provide insight into the impacts of the GMP investments.[25]

The evaluation team reviewed the installation and commissioning timing for the various investments to understand when during the 2021 Program Year the devices were commissioned. For the CKAIDI/CKAIFI metrics (PM-12 and PM-13), circuits with *at least* a half year with the technology commissioned and in service were selected for inclusion in the analysis. This includes circuits with devices installed during 2018, 2019, 2020, as well as the

[25] Equipment installed in the first half of the program year has at least half a year to fully operate and provide measurable reliability benefits to customers on a particular circuit, and using the half-year cutoff for circuit analysis also allows—on average—half the devices deployed in the program year to be included in the analysis. The evaluation team determined that this was a reasonable rule to use for exploring reliability impacts of the installed grid modernization devices, being mindful that many other factors affect these metrics, including weather, car strikes, and animal/bird interference.

first half of 2021. All circuits receiving ADA investments were included in the remaining performance metrics.

The evaluation team also identified a number of circuits for each EDC which had been reconfigured, split, or decommissioned between the baseline and program year. As a result of these changes, a comparison of CKAIDI/CKAIFI metrics was either not possible or deemed to be potentially misleading and these circuits were excluded from the analysis. Similar measures were taken to ensure that other performance metrics were calculated using a consistent circuit list between the baseline and the program year.[26]

The subsections below detail which circuits were included in the analysis for each EDC.

4.1.3.1 Eversource Circuits

Eversource commissioned ADA devices throughout PY2018, PY2019, PY2020, and PY2021. Table 30 shows circuits with ADA devices commissioned through the first half of 2021. A number of circuits were excluded from the analysis due to being newly created, reconfigured, split or retired since the baseline period. A smaller percentage of ADA circuits were excluded for the same reasons. A total of 109,960 (8%) customers were associated with the 306 excluded circuits. The evaluation team explored ways to include these circuits by mapping them to circuits in the baseline period, but determined that the mapping was not one-to-one. The evaluation team determined it was not practical to include the circuits and including them would not significantly alter the performance metrics results.

Table 30. Eversource Circuits Included in Analysis

Eversource Circuits	System-Wide	ADA Commissioned Prior to H2 2021
Total Circuit Count	2,377	252
Circuits for CKAIDI/CKAIFI Analysis		
Circuits Included in Analysis	2,071	234
% of Total Circuits Included in Analysis	87%	93%
Circuits for Average Zone Size Analysis		
Circuits Included in Analysis	2,214	279
% of Total Circuits Included In Analysis	93%	91%

Source: Guidehouse analysis of GMP Annual Reports and EDC Data

4.1.3.2 National Grid Circuits

National Grid commissioned ADA devices throughout PY2020 and PY2021. Table 31 shows circuits with ADA devices commissioned through the first half of 2021. Again, some circuits were excluded from the analysis, largely due to the reconfiguration of circuits between the baseline and PY2021, as discussed above. A smaller number of ADA circuits were excluded from the analysis for the same reasons. A total of 50,171 (4%) customers were located on the 68 excluded circuits.

[26] A comparison of system wide baselines between this report and the PY 2020 PM Evaluation Report shows only minor differences in the baseline circuit list, which is expected given changing customer counts and changes in circuit configurations.

Table 31. National Grid Circuits Included in Analysis

National Grid Circuits	System-Wide	ADA Commissioned Prior to H2 2021
Total Circuit Count	1,144	32
Circuits for CKAIDI/CKAIFI Analysis		
Circuits Included in Analysis	1,076	30
% of Total Circuits Included In Analysis	94%	94%
Circuits for Mainline Customer Minutes of Interruption Saved		
Circuits Included in Analysis	1,076	30
% of Total Circuits Included In Analysis	94%	94%

Source: Guidehouse analysis of GMP Annual Reports and EDC Data

4.2 ADA Performance Metrics Analysis and Findings

Evaluation of the various performance metrics for each EDC is provided below. A summary of findings is presented first, followed by an overview of the analysis approach to facilitate understanding of the detailed results analysis. The analysis for each relevant metric is then provided, organized by EDC.

Results Summary: Table 32 **Error! Reference source not found.**provides a high-level summary of the results for each performance metric and EDC.

Table 32. Summary of Findings for ADA Investment Area

PM	Eversource	National Grid
PM-12: Grid Modernization investments' effect on outage durations	Outage duration for ADA circuits in PY2021 improved by 58 minutes from baseline on non-EME days. *	Outage duration for ADA circuits in PY2021 improved by 55 minutes from baseline on non-EME days. ADA circuits performed better in PY2021 than system-wide circuits on average. *
PM-13: Grid Modernization investments' effect on outage frequency	Outage frequency for ADA circuits in PY2021 was 29% better than Baseline on non-EME days. *	Outage frequency for ADA circuits in PY2021 was 24% better than baseline for non-EME days and 10% better for EME days. ADA circuits performed better than system-wide circuits on average in PY2021. *
PM-11: Numbers of Customers that benefit from GMP funded Distribution Automation Devices	Almost 250,000 (18%) Eversource customers benefitted from ADA devices.	Almost 76,000 (6%) National Grid customers benefitted from ADA devices.
PM-ES2: Protective Zone: Average Zone Size per Circuit	The average zone size on circuits with ADA devices decreased by 254 customers in PY2021 from 2018.	N/A – Eversource specific metric
PM-NG1: Main Line Customer Minutes of Interruption Saved	N/A – National Grid specific metric	Main-line CMI for circuits with ADA decreased (improved) 29% in PY2021 from baseline. *
Case studies	Case studies showed improvements in reliability from ADA devices evaluated.	Case studies showed improvements in reliability from ADA devices evaluated.

** Note: This metric is not able to readily discern whether change in this metric was due to ADA investment or other factors.*

Source: Guidehouse Analysis

PY 2021 Reliability: Evidence suggests that PY2021 was a bad storm year in Massachusetts, negatively impacting system-wide reliability performance – without specific consideration of GMP investment (including M&C and ADA investments). Customer-weighted average CKAIDI and CKAIFI metrics with EMEs for PY2021 were significantly worse than they were for the Baseline years (2015-2017), as shown in Table 33*Table 33*.

Table 33: Baseline vs PY2021 Reliability with EMEs

EDC	CKAIDI/CKAIFI Metric	Baseline	PY2021
Eversource	Weighted Average CKAIDI	133	643
	Weighted Average CKAIFI	1.0	1.3
National Grid	Weighted Average CKAIDI	222	366
	Weighted Average CKAIFI	1.0	1.1

Source: Guidehouse Analysis.

Analysis Approach: The following approach was developed to provide additional insight into the EDC Performance Metrics were published by the EDCs in their PY2021 Annual Report

Appendix 1. The circuit-level data provided by the EDCs was used to evaluate the metrics. The evaluation approach has three elements:

1. Baseline and Program Year System-wide and ADA circuit comparisons: The evaluation team compared the baseline and program year data across the entire system and for circuits receiving ADA investments (see Section 4.1.3 for details). Statistical averages for these circuit groupings were used to make simple comparisons, and standard deviations were calculated to provide insight into the variability compared with the average values. For PM-12 (change in CKAIDI) and PM-13 (change in CKAIFI), the system-wide metric baseline was compared against the program year metric. This facilitates a general understanding of where the ADA investments fit into the context of the overall system metric performance and to compare changes in metrics for ADA circuits to those of system-wide circuits.

2. Before and after comparison**:** For PM-12, PM-13, and PM-ES2 the program year performance was compared to the baseline performance for all circuits within the system. “Box-and-whisker” plots[27] are used to illustrate the distribution of data across the entire system and for circuits receiving ADA investments.[28]

3. Difference in differences: The difference in system-wide circuits change from baseline vs. ADA circuits change from baseline was calculated to understand if there is any discernable reliability improvement on the ADA circuits. This change is defined as “average metric for ADA circuits minus average metric for system-wide circuits.”

The sections below leverage the three steps listed above to provide additional insights into the impacts of ADA investments. In addition, ancillary metrics are used for informative purposes. For clarity, a subset of those metrics is defined below.

- Weighted Average refers to the customer weighted average, e.g., CKAIDI or CKAIFI weighted by average annual number of customers on the circuit and averaged over circuits for the year. The weighted average is computed using 2017 customer counts for the baseline, and 2021 customer counts for the Program Year.

- Standard Deviation of CKAIDI or CKAIFI values is computed to provide an indication of the variability in these metrics for the year(s) in question. A high value relative to the averages described above tends to indicate high variability and prevents us from drawing strong conclusions about changes in the average values. Standard deviation is also weighted by customer counts.

- Total Circuits with Non-Zero Customers only counts circuits that serve customer loads under normal conditions. It excludes backup circuits, express circuits between

[27] The “box-and-whisker” plot divides the sample into quartiles. The boxes show the 2nd and 3rd quartile in the sample. The lower and upper “whiskers” indicate 1.5 times the interquartile range (IQR) (difference between the start of the 2nd and the end of the 3rd quartile) or the maximum/minimum value within the range if it falls within 1.5x the IQR. The “x” indicates the sample average. Data points that fall outside 1.5x the IQR are not shown on the graph.

[28] Note that the DPU Guidance defines the change as “Baseline – Program Year” which means that positive values of this metric indicate reliability improvement—the opposite of what you would expect for improvement in CKAIDI or CKAIFI metric (which fall with improvement).

substations, etc. The CKAIDI/CKAIFI analysis only considers circuits with non-zero customers.

- % Zero is the proportion of circuits with non-zero customers that had zero CKAIDI/CKAIFI in the 3 baseline years (for the baseline) or in 2021 (for the program year). This value for the baseline comprises circuits that have not experienced any outages in any of the 2015-2017 years, while this value for the program year comprises circuits that did not experience any outages in 2021.

4.2.1 PM-12: Effect on Outage Duration (CKAIDI)

Metric PM-12, Reliability-Focused Grid Modernization Investments' Effect on Outage Duration (CKAIDI), was developed to try to provide insight on how GMP devices impact outage duration and is intended to track performance improvements over time. Per the DPU Stamp Approved GMP Performance Metrics Guidance:

> *This metric will compare the experience of customers on GMP DA-enabled circuits as compared to the prior three-year average for the same circuit. This metric will provide insight into how DA can reduce the duration of outages (by tracking and reporting) the following:*
>
> - *Circuit level SAIDI for the program year*
> - *Three-year average SAIDI for 2015, 2016, and 2017*
> - *Comparison of the current year SAIDI with the three-year historic average: AVERAGE(CKAIDI 2015, CKAIDI 2016, CKAIDI 2017) – PY CKAIDI = if greater than 0, positive impact*

The EDCs provided the CKAIDI metric in their Appendix 1 filings. As discussed in Section 4.1.3, only circuits with ADA investments in the first half of 2021 and prior are included in the analysis. Analysis of this metric for each EDC is presented in the following subsections.

4.2.1.1 Eversource Analysis

In comparison to the baseline, ADA circuits in PY2021 had a 59-minute improvement in average CKAIDI without EMEs. System-wide circuits showed a 39-minute improvement in CKAIDI without EMEs in 2021 from the baseline. ADA circuits are included in the system-wide results. Eversource reports having deployed ADA on system-wide circuits from non-GMP funds (including oil switch replacement and overhead recloser deployment), which may have contributed to system-wide reliability improvement.

However, CKAIDI with EMEs significantly worsened for both ADA circuits and system-wide circuits from the baseline to PY2021. Eversource noted that the worsened EME performance in PY2021 is mainly driven by an excludable major event that occurred 10/26/21 through 11/1/21 and caused over 7,000 excludable event restorations across more than 700 circuits. The baseline CKAIDI with EMEs is a three-year average which “masks” individual major events – meaning a circuit would have to be hit by major events three years in a row for the baseline CKAIDI to be impacted.

The CKAIDI standard deviation with EMEs increased, while the CKAIDI standard deviation without EMEs decreased, highlighting the impact of EMEs on system reliability metrics. However, the standard deviation is on the same order of magnitude as the weighted average, providing some indication that the change in the weighted average is not simply statistical noise, but an actual improvement in non-EME performance during the program year.

System-wide and ADA circuit counts: Table 34 is structured with CKAIDI ranges, or "bins", to provide insight about the range of outage durations across circuits in the system, and to show where circuits selected for ADA investment fall within these bins. For the ADA circuits (green bars indicate number of circuits in bin), more circuits were in the "low CKAIDI" bins than in the baseline, for both non-EME and EME days.

Approximately 22% of system-wide and 1% of ADA circuits with customers experienced no outages at all within the baseline period. This difference indicates that Eversource targeted circuits that experienced outages in the baseline period for ADA investments. [29]

Table 34. Eversource Baseline and PY2021 CKAIDI Distribution

Eversource ADA	2015-2017 Avg. CKAIDI (Baseline)				2021 CKAIDI (Program Year)			
	System-wide		ADA Circuits		System-wide		ADA Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIDI Statistics								
Total Circuits	2,071	2,071	234	234	2,071	2,071	234	234
Total Circuits with Non-zero Customers	1,658	1,658	233	233	1,572	1,572	224	224
% Zero CKAIDI	22%	22%	1%	1%	29%	35%	5%	8%
Average CKAIDI	133	105	152	133	643	66	667	74
Change from Baseline (Baseline - Plan Year)					-510	39	-515	59
% Change from Baseline					-383%	37%	-338%	44%
Std. Dev.	154	117	154	139	1,289	82	1,339	89
CKAIDI Range	**No. of Circuits in Range**							
0	367	368	3	3	452	545	12	17
0 - 50	483	527	60	65	362	552	62	114
50 - 150	446	489	89	96	255	296	60	58
150 - 250	181	165	35	36	105	111	21	22
250 - 350	82	61	29	23	60	36	11	5
350 - 450	44	27	9	3	41	18	7	5
450 - 550	20	8	2	2	17	4	3	0
550 - 650	11	3	0	0	17	2	3	0
650 - 750	9	5	1	3	11	4	2	2
750 - 850	9	3	4	1	15	1	3	0
850 - 950	3	1	0	0	7	3	2	1
950 - 1050	1	1	1	1	11	0	1	0
1050 - 1300	1	0	0	0	18	0	2	0
1300 - 1550	1	0	0	0	21	0	5	0
1550 - 1800	0	0	0	0	18	0	2	0
1800 - 2050	0	0	0	0	13	0	2	0
2050 - 3050	0	0	0	0	51	0	8	0
> 3050	0	0	0	0	98	0	18	0

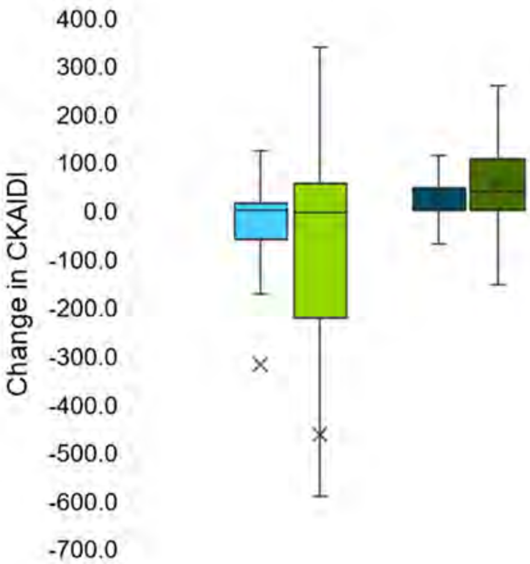
[29] Eversource's 2018 GMP Annual Report contains the following text about methodology of choosing circuits for GMP investments: *Circuit reliability based on historical SAIDI and SAIFI from 2015, 2016 and 2017 was also considered when selecting circuits for investment.*

Note: EME = Excludable Major Events. CKAIDI of zero indicates circuit did not experience any outages.

Source: *Guidehouse analysis of 2021 GMP Annual Report Appendix 1*

Before and after comparison: A simple graphical summary of the statistical change in CKAIDI is shown in Figure 14 below, which uses the "box-and-whisker" format.[30] This chart compares the difference in CKAIDI between baseline and Program Year 2021, for both the system-wide and ADA circuits.

Figure 14. Eversource Outage Duration Performance Metric Results



	Change in System-wide CKAIDI w/ EMEs	Change in ADA CKAIDI w/ EMEs
Count	2,071	234
% No Change	35%	0%
Average Change in CKAIDI	-318	-463
Standard Deviation	1008	1198
Median Change in CKAIDI	0	-3

	Change in System-wide CKAIDI w/o EMEs	Change in ADA CKAIDI w/o EMEs
Count	2,071	234
% No Change	36%	0%
Average Change in CKAIDI	22	56
Standard Deviation	115	154
Median Change in CKAIDI	0	39

Note: EME = Excludable Major Events. Change in CKAIDI is reported as minutes. Change in CKAIDI is calculated as defined by the DPU PM Guidance: 2015-2017 Avg. CKAIDI – 2021 CKAIDI = if greater than zero, positive impact.

Source: *Guidehouse analysis of 2021 GMP Annual Report Appendix 1*

CKAIDI without EMEs improved more for ADA circuits than for system-wide circuits, indicating an improved performance on the ADA circuits on average.[31] In particular, 50% of ADA circuits reflected at least a 39-minute improvement in outage duration, compared to the baseline which had a median change of 0 minutes.

The average system-wide CKAIDI with EMEs worsened in PY2021 over the baseline. For the selected ADA circuits, CKAIDI with EMEs increased more than for system-wide circuits,

[30] The "box-and-whisker" plot divides the sample into quartiles. The boxes show the 2nd and 3rd quartile in the sample. The lower and upper "whiskers" indicate 1.5 times the interquartile range (IQR) (difference between the start of the 2nd and the end of the 3rd quartile) or the maximum/minimum value within the range if it falls within 1.5x the IQR. The "x" indicates the sample average. Data points that fall outside 1.5x the IQR are not shown on the graph for visualization purposes.

[31] Note that the "whiskers" extend further for the circuits with ADA investments because there are fewer ADA circuits that experienced zero change in CKAIDI. As a result, the IQR for these circuits is larger than the IQR range of the whole system.

indicating a worsening performance on the ADA circuits on average.[32] In particular, the bottom quartile of change for the ADA circuits is larger than that for system-wide circuits, signifying that ADA circuits had a greater proportion of circuits with worse performance in 2021.

However, the standard deviation of the change in CKAIDI for each group is significantly larger—several times larger – than the average change in CKAIDI itself, providing an indication that the change in the average is of limited statistical significance, and not indicative of any clearly discernible trend in CKAIDI. As indicated above, there are many potential reasons for these changes and many factors impacting this metric. The impact of the ADA investment in operation is not discernable using the metric itself, as discussed previously.

Difference in differences: The differences in the change in CKAIDI (baseline to 2021) between the system-wide average and the average for circuits with ADA investments are shown in Table 35**Error! Reference source not found.**. The change in CKAIDI with EME for ADA circuits was greater than the system-wide circuits, while the reverse was true for CKAIDI without EME. Although the standard deviation for these samples is larger than the CKAIDI changes (as discussed above), 2021 without EMEs reflected improved reliability on both system-wide and ADA circuits. The reduced performance of ADA circuits during major excludable events can be partially explained by the fact that a small subset of ADA circuits had much larger outage durations than in the baseline, which led to a skewed average change metric.

Table 35. Eversource CKAIDI Difference in Differences

	System-Wide Circuits	ADA Circuits	Difference in Differences (ADA - System-Wide)
Change in CKAIDI w/ EMEs	-318	-463	-145
Change in CKAIDI w/o EMEs	22	56	44

Source: *Guidehouse analysis of 2021 GMP Annual Report Appendix 1*

Erosion of Baseline: As mentioned in section 4.1.3.1, 13% of Eversource system-wide circuits and 7% of Eversource ADA circuits had to be excluded from this metric, because circuits had been retired, reconfigured or split since 2017. The comparability of each circuit in the program year to its baseline, as defined in the DPU approved metric, depends on that circuit not having been reconfigured or significantly changed (e.g., a normally open switch between circuit segments is changed to operate as normally closed, changing the customer counts and outage measurements on that circuit). The number of circuits that are comparable between baseline and program year is reduced year over year as more circuits are reconfigured, leading to an erosion of metric baseline over time.

Major Events in the Baseline: A shortcoming of PM-12 is the methodology of averaging CKAIDI over 3 years, which masks the impact of single-year EMEs, as it is unlikely for the same circuit to be affected by an EME three years in a row. Thus, when comparing a single-year CKAIDI with EME to the baseline, the change in CKAIDI is more likely to indicate decreased reliability.

[32] Note that the "whiskers" extend further for the circuits with ADA investments because there are fewer ADA circuits that experienced zero change in CKAIDI. As a result, the IQR for these circuits is larger than the IQR range of the whole system.

4.2.1.2 National Grid Analysis

National Grid ADA circuits experienced a 55-minute improvement without EMEs on average in PY2021 from baseline. This is a 42% improvement from baseline in contrast to system-wide circuits, where CKAIDI showed no change from baseline without EMEs. Note that National Grid has minimal ADA on its system-wide circuits apart from GMP investments.

Average CKAIDI with EMEs significantly worsened system-wide from the baseline in PY2021, indicating a bad storm year. In contrast, average CKAIDI for ADA circuits with EMEs stayed the same as baseline. See the Case Studies for two examples of how National Grid's FLISR schemes reduced CKAIDI during an EME in 2021.

The CKAIDI standard deviation with EMEs increased, while the CKAIDI standard deviation without EMEs decreased, highlighting the impact of EMEs on system reliability metrics. However, the standard deviation is on the same order of magnitude as the weighted average, providing some indication that the change in the weighted average is not simply statistical noise, but an actual improvement in non-EME performance during the program year.

System-wide and ADA circuit counts: Table 36 is structured with CKAIDI ranges, or "bins", to provide insight about the range of outage durations across circuits in the system, and to show where circuits selected for ADA investment fall within these bins. For the ADA circuits (green bars indicate number of circuits in bin), more circuits were in the "low CKAIDI" bins than in the baseline, for both non-EME and EME days.

Table 36. National Grid Baseline and PY2021 CKAIDI Distribution

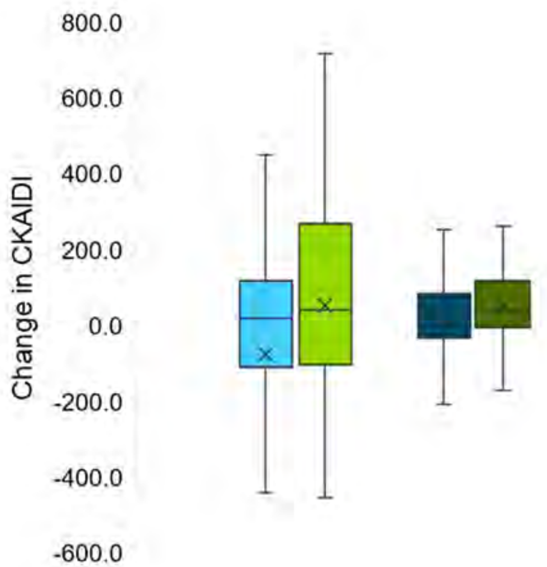
National Grid ADA	2015-2017 Avg. CKAIDI (Baseline)				2021 CKAIDI (Program Year)			
	System-wide		ADA Circuits		System-wide		ADA Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIDI Statistics								
Total Circuits	1,076	1,076	30	30	1,076	1,076	30	30
Total Circuits with Non-zero Customers	1,073	1,073	30	30	1,042	1,042	30	30
% Zero CKAIDI	3%	4%	0%	0%	19%	20%	0%	0%
Average CKAIDI	222	118	279	131	366	113	275	76
Change from Baseline (Baseline - Plan Year)					-145	5	4	55
% Change from Baseline					-65%	4%	2%	42%
Std. Dev.	258	162	290	95	672	122	373	81
CKAIDI Range	**No. of Circuits in Range**							
0	34	39	0	0	193	208	0	0
0 - 50	255	329	5	7	241	327	8	14
50 - 150	349	433	7	12	242	274	9	11
150 - 250	185	180	5	7	105	113	2	3
250 - 350	78	55	4	3	70	56	5	2
350 - 450	43	18	2	1	41	34	0	0
450 - 550	27	10	1	0	29	13	2	0
550 - 650	26	4	2	0	18	9	2	0
650 - 750	16	0	1	0	10	2	0	0
750 - 850	10	1	1	0	10	2	0	0
850 - 950	14	3	0	0	6	1	0	0
950 - 1050	7	0	0	0	7	1	0	0
1050 - 1300	23	0	2	0	12	2	1	0
1300 - 1550	4	0	0	0	13	0	1	0
1550 - 1800	0	0	0	0	5	0	0	0
1800 - 2050	1	0	0	0	8	0	0	0
2050 - 3050	1	0	0	0	18	0	0	0
> 3050	0	1	0	0	14	0	0	0

Note: EME = Excludable Major Events. CKAIDI of zero indicates circuit did not experience any outages.

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

Before and after comparison: A simple graphical summary of the statistical change in CKAIDI is shown in **Error! Reference source not found.** below, which uses the "box-and-whisker" format.[33] This chart compares the difference in CKAIDI between baseline and Program Year 2021, for both the system-wide and ADA circuits.

Figure 15. National Grid Outage Duration Performance Metric Results



	Change in System-wide CKAIDI w/ EMEs	Change in ADA CKAIDI w/ EMEs
Count	1,076	30
% No Change	3%	0%
Average Change in CKAIDI	-78	52
Standard Deviation	641	458
Median Change in CKAIDI	19	39

	Change in System-wide CKAIDI w/o EMEs	Change in ADA CKAIDI w/o EMEs
Count	1,076	30
% No Change	3%	0%
Average Change in CKAIDI	12	49
Standard Deviation	218	90
Median Change in CKAIDI	23	34

Note: EME = Excludable Major Events. Change in CKAIDI is reported as minutes. Change in CKAIDI is calculated as defined by the DPU PM Guidance: 2015-2017 Avg. CKAIDI – 2021 CKAIDI = if greater than zero, positive impact.

Source: *Guidehouse analysis of 2021 GMP Annual Report Appendix 1*

The average system CKAIDI with EMEs increased in Program Year 2021 over the baseline. For the selected ADA circuits, CKAIDI with EMEs decreased, indicating better performance on the ADA circuits on average.

The average change in CKAIDI for circuits with ADA on non-EME days was also better than the system-wide change for PY2021, which provides additional indication of improved performance on the ADA circuits on average. In particular, 50% of ADA circuits reflected at least a 34-minute improvement in outage reduction, compared to the baseline which had a median change of 23 minutes.

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[33] The "box-and-whisker" plot divides the sample into quartiles. The boxes show the 2nd and 3rd quartile in the sample. The lower and upper "whiskers" indicate 1.5 times the interquartile range (IQR) (difference between the start of the 2nd and the end of the 3rd quartile) or the maximum/minimum value within the range if it falls within 1.5x the IQR. The "x" indicates the sample average. Data points that fall outside 1.5x the IQR are not shown on the graph for visualization purposes.

However, the standard deviation of the change in CKAIDI for each group is significantly larger—several times larger – than the average change in CKAIDI itself, and thus the average may not indicate a clear directional trend in CKAIDI.

Difference in differences: The differences in the change in CKAIDI (baseline to 2021) between the system-wide average and the average for circuits with ADA investments are shown in Table 37. The change in CKAIDI for ADA circuits was greater than the change in system-wide circuits for both EME and non-EME days. Although the standard deviation for these samples is larger than the CKAIDI changes (as discussed above), 2021 without EMEs reflected improved reliability on both system-wide and ADA circuits. The improved performance of ADA circuits during major excludable events indicates that ADA investments may have had a positive effect on reliability in outage conditions.

Table 37. National Grid CKAIDI Difference in Differences

	System-Wide Circuits	ADA Circuits	Difference in Differences (ADA - System-Wide)
Change in CKAIDI w/ EMEs	-78	52	130
Change in CKAIDI w/o EMEs	12	49	37

Source: *Guidehouse analysis of 2021 GMP Annual Report Appendix 1*

Erosion of Baseline: As mentioned in section 4.1.3.1, 6% of National Grid system-wide circuits and 6% of National Grid ADA circuits had to be excluded from this metric, because circuits had been retired, reconfigured or split since 2015. The comparability of each circuit in the program year to its baseline, as defined in the DPU approved metric, depends on that circuit not having been reconfigured or significantly changed (e.g., a normally open switch between circuit segments is changed to operate as normally closed, changing the customer counts and outage measurements on that circuit). The number of circuits that are comparable between baseline and program year is reduced year over year as more circuits are reconfigured, leading to an erosion of metric baseline over time.

Major Events in the Baseline: A shortcoming of PM-12 is the methodology of averaging CKAIDI over 3 years, which masks the impact of single-year EMEs, as it is highly unlikely for the same circuit to be affected by an EME three years in a row. Thus, when comparing a single-year CKAIDI with EME to the baseline, the change in CKAIDI is much more likely to indicate decreased reliability.

4.2.2 PM-13: Effect on Outage Frequency (CKAIFI)

Metric PM-13, Reliability-Focused Grid Modernization Investments' Effect on Outage Frequency (CKAIFI), provides insight on how GMP devices impact outage duration and will track the improvements over time. Per the DPU Stamp Approved GMP Performance Metrics Guidance:

> *This metric will compare the experience of customers on GMP DA-enabled circuits as compared to the prior three-year average for the same circuit. This metric will provide insight into how DA can reduce the frequency of outages (by tracking and reporting) the following:*
>
> - *Circuit level SAIFI (CKAIFI) for the program year*

- *Three-year average SAIFI (CKAIFI) for 2015, 2016, and 2017*
- *Comparison of the current year SAIFI (CKAIFI) with the three-year historic average: AVERAGE(CKAIFI 2015, CKAIFI 2016, CKAIFI 2017) – PY CKAIFI = if greater than 0, positive impact*

The EDCs provided the CKAIFI metric in their Appendix 1 filings. As discussed in Section 4.1.3, only circuits with ADA investments commissioned in the first half of 2021 and prior are included in the analysis. Analysis of this metric for each EDC is presented in the following subsections and align closely with the previous metric (PM-12: Impact on Outage Duration).

4.2.2.1 Eversource Analysis

Compared to the baseline, ADA circuits had a 29% lower CKAIFI in 2021 on non-EME days, indicating an improved performance. CKAIFI with EME worsened slightly (13%) for ADA circuits in 2021 from baseline.

System-wide circuits (which include GMP circuits) showed a 22% improvement in CKAIFI without EMEs, and a 31% worsening of CKAIFI with EMEs in 2021 from baseline. Eversource reports having rolled out non-GMP automation on system-wide circuits (including oil switch replacement and overhead reclosers) which may have impacted the reliability metrics.

The system average CKAIFI with EMEs from the baseline to PY2021 increased, however the reverse is true for CKAIFI without EMEs. This indicates that EMEs had a substantial impact on system reliability in PY2021.

The percentage difference in CKAIFI with EMEs between the baseline and PY2021 is not as large as the percentage difference in CKAIDI, thus the average frequency of customer outages did not increase as much as the average duration did in 2021.

The CKAIFI standard deviation also increased, indicating increased variability in CKAIFI across system circuits. However, the standard deviation is on the same order of magnitude as the weighted average, providing some indication that the change in the weighted average is not simply statistical noise, but an actual improvement in non-EME performance during the program year.

System-wide and ADA circuit counts: Table 38**Table 37Error! Reference source not found.** is structured with CKAIFI ranges, or “bins,” to provide insight about the range of outage durations across the system, and to show where circuits selected for ADA investment fall within these bins. For the ADA circuits (green bars indicate percentage of circuits in the bin), more circuits were in the “low CKAIFI” bins than in the baseline, for both non-EME and EME days.

Similar to CKAIDI, the proportion of system-wide circuits with zero CKAIFI in the baseline is higher than that of ADA circuits. This provides some indication that these less reliable circuits were targeted more for ADA investment.[34]

[34] Eversource’s 2018 GMP Annual Report contains the following text about methodology of choosing circuits for GMP investments: *Circuit reliability based on historical SAIDI and SAIFI from 2015, 2016 and 2017 was also considered when selecting circuits for investment.*

Table 38. Eversource Baseline and PY2021 CKAIFI Distribution

Eversource ADA	2015-2017 Avg. CKAIFI (Baseline)				2021 CKAIFI (Program Year)			
	System-wide		ADA Circuits		System-wide		ADA Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIFI Statistics								
Total Circuits	2,071	2,071	234	234	2,071	2,071	234	234
Total Circuits with Non-zero Customers	1,658	1,658	233	233	1,572	1,572	224	224
% Zero CKAIFI	22%	22%	1%	1%	29%	36%	5%	8%
Average CKAIFI	1.0	0.9	1.2	1.1	1.3	0.7	1.3	0.8
Change from Baseline (Baseline - Plan Year)					-0.3	0.2	-0.2	0.3
% Change from Baseline					-31%	22%	-13%	29%
Std. Dev.	0.8	0.7	0.8	0.7	1.4	0.8	1.4	0.8
CKAIFI Range	**No. of Circuits in Range**							
0	371	372	3	3	461	566	12	18
0 - 0.25	203	209	26	29	241	348	34	63
0.25 - 0.75	513	529	69	68	191	209	54	65
0.75 - 1.25	265	272	56	57	235	231	36	38
1.25 - 1.75	153	159	30	36	117	85	27	13
1.75 - 2.25	88	68	28	22	103	80	16	11
2.25 - 2.75	35	27	12	10	67	25	14	9
2.75 - 3.25	17	14	4	5	38	14	4	3
3.25 - 3.75	9	7	4	2	35	7	8	2
3.75 - 4.25	3	1	1	1	30	4	6	1
4.25 - 4.75	0	0	0	0	14	3	3	1
4.75 - 5.25	0	0	0	0	8	0	2	0
5.25 - 5.75	0	0	0	0	6	0	1	0
5.75 - 6.25	0	0	0	0	8	0	2	0
6.25 - 6.75	0	0	0	0	4	0	0	0
6.75 - 7.25	0	0	0	0	6	0	2	0
7.25 - 7.75	0	0	0	0	1	0	1	0
> 7.75	1	0	0	0	7	0	2	0

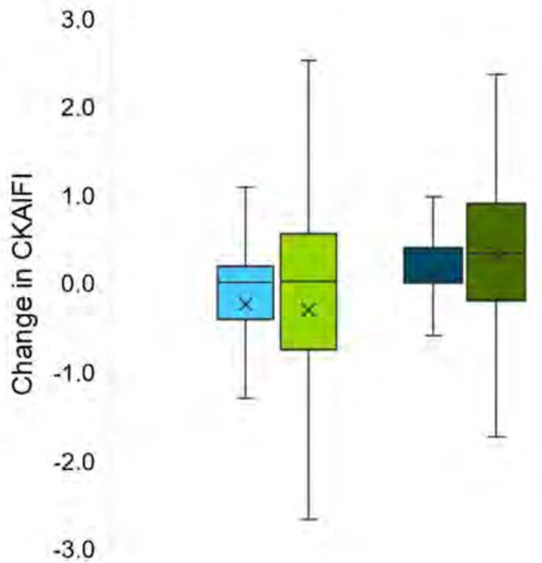
Note: EME = Excludable Major Events. CKAIFI of zero indicates circuit did not experience any outages

Source: *Guidehouse analysis of 2021 GMP Annual Report Appendix 1*

Before and after comparison: A simple graphical summary of the statistical change in CKAIFI is shown in Figure 16**Error! Reference source not found.** below, which uses the “box-and-whisker” format.[35] This chart compares the difference in CKAIFI between baseline and PY2021 for each circuit, for both the system-wide and the selected ADA circuits. The change shown below is calculated per the DPU Stamped Approved formula of Baseline CKAIFI – Program Year CKAIFI, so a positive change indicates improved performance in the Program Year.

[35] The “box-and-whisker” plot divides the sample into quartiles. The boxes show the 2nd and 3rd quartile in the sample. The lower and upper “whiskers” indicate 1.5 times the interquartile range (IQR) (difference between the start of the 2nd and the end of the 3rd quartile) or the maximum/minimum value within the range if it falls within 1.5x the IQR. The “x” indicates the sample average. Data points that fall outside 1.5x the IQR are not shown on the graph for visualization purposes.

Figure 16. Eversource Outage Frequency Performance Metric Results



	Change in System-wide CKAIFI w/ EMEs	Change in ADA CKAIFI w/ EMEs
Count	2,071	234
% No Change	35%	0%
Average Change in CKAIFI	-0.2	-0.3
Standard Deviation	1.1	1.5
Median Change in CKAIFI	0.0	0.0

	Change in System-wide CKAIFI w/o EMEs	Change in ADA CKAIFI w/o EMEs
Count	2,071	234
% No Change	36%	0%
Average Change in CKAIFI	0.1	0.3
Standard Deviation	0.7	1.0
Median Change in CKAIFI	0.0	0.3

Note: EME = Excludable Major Events. Change in CKAIFI is calculated as defined by the DPU PM Guidance: 2015-2017 Avg. CKAIFI – 2021 CKAIFI = if greater than zero, positive impact.

Source: *Guidehouse analysis of 2021 GMP Annual Report Appendix 1*

The average system-wide CKAIFI changed very little in PY2021 relative to the baseline period. Without EMEs, the average change in CKAIFI was better for ADA circuits than system-wide, which indicates that ADA circuits performed slightly better than system wide circuits. However, the standard deviation of the change in CKAIFI for each group is significantly larger—several times larger–than the average change in CKAIFI itself, providing an indication that the change in the average is of limited statistical significance, and not indicative of a clearly discernible trend in CKAIFI. There are many potential reasons for these changes and many factors impacting this metric. The impact of the ADA investment in operation is one of the factors but is not discernable using the metric itself.

Difference in differences: The differences in the change in CKAIFI (baseline to 2021) between the system-wide average and the average for circuits ADA investments are shown in Table 39**Error! Reference source not found.**. The change in CKAIFI with EMEs for circuits with ADA investments was almost the same as the system-wide circuits. However, the standard deviation for these samples is much larger that the CKAIFI changes indicating that the difference is likely not statistically significant and is more probably a factor of randomness in the metric data than any type of trend. It is difficult to conclude how much positive (or negative) impact the ADA investments had on this metric for Program Year 2021.

Table 39. Eversource CKAIFI Difference in Differences

	System-Wide Circuits	ADA Circuits	Difference in Differences (ADA - System-Wide)
Change in CKAIFI w/ EMEs	-0.2	-0.3	-0.1
Change in CKAIFI w/o EMEs	0.1	0.3	0.2

Note: Due to rounding, manual calculations of Difference in Differences will not precisely match calculated numbers provided in this table.

Source: *Guidehouse analysis of 2021 GMP Annual Report Appendix 1*

Erosion of Baseline: As mentioned in section 4.1.3.1, 13% of Eversource system-wide circuits and 7% of Eversource ADA circuits had to be excluded from this metric, because circuits had been retired, reconfigured or split since 2015. The comparability of each circuit in the program year to its baseline, as defined in the DPU approved metric, depends on that circuit not having been reconfigured or significantly changed (e.g., a normally open switch between circuit segments is changed to operate as normally closed, changing the customer counts and outage measurements on that circuit). The number of circuits that are comparable between baseline and program year is reduced year over year as more circuits are reconfigured, leading to an erosion of metric baseline over time.

Major Events in the Baseline: A shortcoming of PM-13 is the methodology of averaging CKAIFI over 3 years, which masks the impact of single-year EMEs, as it is highly unlikely for the same circuit to be affected by an EME three years in a row. Thus, when comparing a single-year CKAIFI with EME to the baseline, the change in CKAIFI is much more likely to indicate decreased reliability.

4.2.2.2 National Grid Analysis

For ADA circuits, CKAIFI improved in PY2021 over baseline. This was true both with EME (10% improvement) and without EME (24% improvement). In contrast, system-wide circuits show the same or worsening performance in 2021 from baseline.

The CKAIFI standard deviation increased, indicating increased variability in CKAIFI across system circuits. However, the standard deviation is smaller than the weighted average, providing some indication that the change in the weighted average is not simply statistical noise, but an actual improvement in non-EME performance during the program year.

System-wide and ADA circuit counts: Table 40 is structured with CKAIFI ranges, or "bins," to provide insight about the range of outage durations across the system, and to show where circuits selected for ADA investment fall within these bins. The number of ADA circuits with lower CKAIFI on non-EME days in PY2021 was similar to baseline, and same is true for EME days.

Similar to CKAIDI, the proportion of system-wide circuits with zero CKAIFI in the baseline is higher than that of ADA circuits. This provides some indication that these less reliable circuits were targeted more for ADA investment. For ADA circuits, CKAIFI slightly improved in PY2021 over baseline on both non-EME and EME days. On the other hand, for system-wide circuits, CKAIFI was either the same or worse.

Table 40. National Grid Baseline and PY2021 CKAIFI Distribution

National Grid ADA	2015-2017 Avg. CKAIFI (Baseline)				2021 CKAIFI (Program Year)			
	System-wide		ADA Circuits		System-wide		ADA Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIFI Statistics								
Total Circuits	1,076	1,076	30	30	1,076	1,076	30	30
Total Circuits with Non-zero Customers	1,073	1,073	30	30	1,042	1,042	30	30
% Zero CKAIFI	3%	4%	0%	0%	19%	20%	0%	0%
Average CKAIFI	1.0	0.9	1.0	1.0	1.1	0.9	0.9	0.7
Change from Baseline (Baseline - Plan Year)					-0.1	0.0	0.1	0.2
% Change from Baseline					-9%	0%	10%	24%
Std. Dev.	0.6	0.6	0.6	0.6	1.0	0.8	0.5	0.5
CKAIFI Range	**No. of Circuits in Range**							
0	34	40	0	0	194	209	0	0
0 - 0.25	121	144	2	2	236	273	4	9
0.25 - 0.75	373	401	8	12	138	142	10	6
0.75 - 1.25	299	282	12	8	191	197	7	7
1.25 - 1.75	153	132	3	5	94	75	8	7
1.75 - 2.25	60	52	3	2	89	76	0	1
2.25 - 2.75	22	15	2	1	46	34	1	0
2.75 - 3.25	8	5	0	0	24	20	0	0
3.25 - 3.75	2	1	0	0	14	6	0	0
3.75 - 4.25	0	0	0	0	9	6	0	0
4.25 - 4.75	0	0	0	0	5	3	0	0
4.75 - 5.25	0	0	0	0	1	1	0	0
5.25 - 5.75	0	1	0	0	1	0	0	0
5.75 - 6.25	0	0	0	0	0	0	0	0
6.25 - 6.75	0	0	0	0	0	0	0	0
6.75 - 7.25	0	0	0	0	0	0	0	0
7.25 - 7.75	0	0	0	0	0	0	0	0
> 7.75	1	0	0	0	0	0	0	0

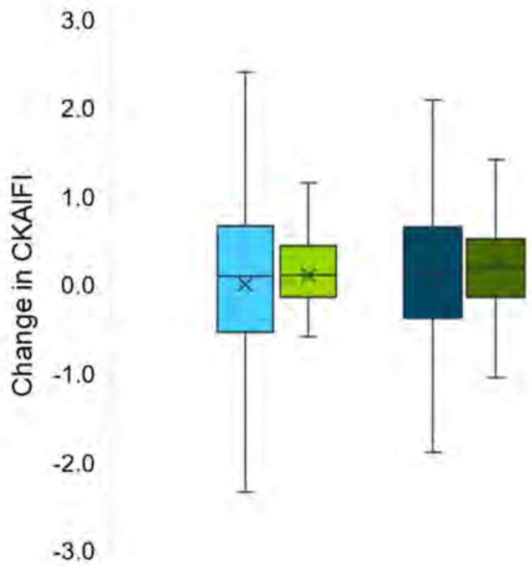
Note: EME = Excludable Major Events. CKAIFI of zero indicates circuit did not experience any outages

Source: *Guidehouse analysis of 2021 GMP Annual Report Appendix 1*

Before and after comparison: A simple graphical summary of the statistical change in CKAIFI is shown in Figure 17 below, which uses the "box-and-whisker" format.[36] This chart compares the difference in CKAIFI between baseline and Program Year 2021 for each circuit, for both the system-wide and the selected ADA circuits. The change shown below is calculated per the DPU Stamped Approved formula of Baseline CKAIFI – Program Year CKAIFI, so a positive change indicates improved performance in the Program Year.

[36] The "box-and-whisker" plot divides the sample into quartiles. The boxes show the 2nd and 3rd quartile in the sample. The lower and upper "whiskers" indicate 1.5 times the interquartile range (IQR) (difference between the start of the 2nd and the end of the 3rd quartile) or the maximum/minimum value within the range if it falls within 1.5x the IQR. The "x" indicates the sample average. Data points that fall outside 1.5x the IQR are not shown on the graph for visualization purposes.

Figure 17. National Grid Outage Frequency Performance Metric Results



	Change in System-wide CKAIFI w/ EMEs	Change in ADA CKAIFI w/ EMEs
Count	1,076	30
% No Change	3%	0%
Average Change in CKAIFI	0.0	0.1
Standard Deviation	1.0	0.6
Median Change in CKAIFI	0.1	0.1

	Change in System-wide CKAIFI w/o EMEs	Change in ADA CKAIFI w/o EMEs
Count	1,076	30
% No Change	3%	0%
Average Change in CKAIFI	0.1	0.2
Standard Deviation	0.9	0.7
Median Change in CKAIFI	0.1	0.2

Note: EME = Excludable Major Events. Change in CKAIFI is calculated as defined by the DPU PM Guidance: 2015-2017 Avg. CKAIFI – 2021 CKAIFI = if greater than zero, positive impact.

Source: *Guidehouse analysis of 2021 GMP Annual Report Appendix 1*

The average system-wide CKAIFI changed very little in PY2021 relative to the baseline period. For ADA circuits, the average change in CKAIFI was small but slightly better than system-wide, which indicates that ADA circuits performed better than system wide circuits. However, the standard deviation of the change in CKAIFI for each group is significantly larger—several times larger–than the average change in CKAIFI itself, providing an indication that the change in the average is of limited statistical significance, and not indicative of a clearly discernible trend in CKAIFI.

Difference in differences: The differences in the change in CKAIFI (baseline to 2021) between the system-wide average and the average for circuits ADA investments are shown in Table 41. Relative to system-wide circuits, ADA circuits reflected a slightly greater improvement in average CKAIFI with and without EME. Again, the standard deviation for these samples is much larger that the CKAIFI changes indicating that the difference is likely not statistically significant and is more probably a factor of randomness in the metric data than any type of trend. It is difficult to conclude how much positive (or negative) impact the ADA investments had on this metric for Program Year 2021.

Table 41. National Grid CKAIFI Difference in Differences

	System-Wide Circuits	ADA Circuits	Difference in Differences (ADA - System-Wide)
Change in CKAIFI w/ EMEs	0.0	0.1	0.1
Change in CKAIFI w/o EMEs	0.1	0.2	0.1

Note: Due to rounding, manual calculations of Difference in Differences will not precisely match calculated numbers provided in this table.

Source: *Guidehouse analysis of 2021 GMP Annual Report Appendix 1*

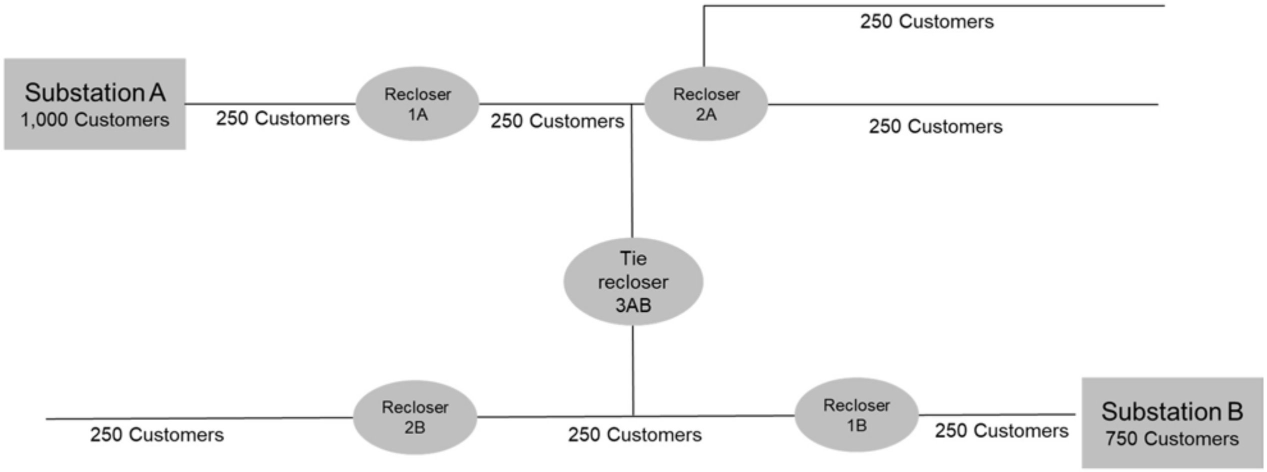
Erosion of Baseline: As mentioned in section 4.1.3.1, 6% of National Grid system-wide circuits and 6% of National Grid ADA circuits had to be excluded from this metric, because circuits had been retired, reconfigured or split since 2015. The comparability of each circuit in the program year to its baseline, as defined in the DPU approved metric, depends on that circuit not having been reconfigured or significantly changed (e.g., a normally open switch between circuit segments is changed to operate as normally closed, changing the customer counts and outage measurements on that circuit). The number of circuits that are comparable between baseline and program year is reduced year over year as more circuits are reconfigured, leading to an erosion of metric baseline over time.

Major Events in the Baseline: A shortcoming of PM-13 is the methodology of averaging CKAIFI over 3 years, which masks the impact of single-year EMEs, as it is highly unlikely for the same circuit to be affected by an EME three years in a row. Thus, when comparing a single-year CKAIFI with EME to the baseline, the change in CKAIDI is much more likely to indicate decreased reliability.

4.2.3 PM-11: Numbers of Customers that Benefit from GMP Funded Distribution Automation Devices

The goal of this metric is to track the number of customers that have benefitted from the installation of ADA devices. At a high-level, a customer is counted as benefitting from an ADA device when their zone size has been reduced. The evaluation team worked with the EDCs to determine a more detailed definition for this metric to provide clarify and consistency. A specific example and explanation are provided below:

Figure 18. Example One-Line Diagram of Grid Modernization Devices



Source: Guidehouse and EDCs

Broadly speaking, all customers within the zone in which a recloser is placed benefit from the device. In **Error! Reference source not found.**, if Recloser 1A was installed in 2021 as part of the GMP and all other devices previously existed, then 500 customers benefitted from the installation of this device. All customers between the new device and the next connective device benefit. In this case, that is 250 customers on each side of the device for a total of 500 customers.

The customers that benefit from tie reclosers are counted in the same way. In **Error! Reference source not found.**, if Tie Recloser 3AB was installed in 2021 as part of the GMP and all other devices previously existed, then 500 customers benefitted from the installation of this device. The 500 customers include the 250 customers between Recloser 1A and 2A and the 250 customers between Recloser 2B and 1B. This is a very conservative method of estimating the number of customers that benefit from a tie recloser, as in many cases the majority of customers on affected circuit may benefit from this addition.

The metric calculation was performed by the EDCs, as detailed data is required to calculate this metric for each circuit with ADA devices commissioned in Program Year 2021 or prior. Unlike the Performance Metrics for outage duration and frequency, the timing of the commissioning of the ADA device is not relevant for evaluation. Thus, all circuits with ADA devices installed any time in 2021 or prior are “eligible” to be included in the evaluation of this metric.

4.2.3.1 Eversource Analysis

The number of customers that benefit from ADA devices is reported in Appendix 1 of the Eversource’s Annual GMP Report. The number of customers that benefit is non-zero only for circuits that had sectionalizing devices installed. Through PY2021, these devices (OH Reclosers and Ties) were installed on 219 Eversource circuits. Table 42 shows the average and total number of customers that benefitted across all 219 circuits. As of the end of 2021, 249,316 customers (18% of total customers) benefitted from ADA devices.

Table 42. Number of Eversource Customers that Benefitted from GMP ADA Devices

Summary Statistics	
Total Circuits with DA Installed	219
Average Number of Customer Benefiting per circuit	1,138
Total Number of Customers Benefiting from DA Devices	249,316
Percent of Total Customers that Benefit from DA Devices	18%

Source: Guidehouse analysis of Eversource 2021 GMP Annual Report Appendix 1

4.2.3.2 National Grid Analysis

The number of customers that benefit from ADA devices is reported in Appendix 1 of the National Grid's Annual GMP Report. The number of customers that benefit is non-zero only for circuits that had sectionalizing devices installed. Through PY2021, these devices (OH Reclosers and Ties) were installed on 31 National Grid circuits. Table 43Table 42 shows the average number of customers that benefitted as well as the total across all 31 circuits. As of the end of PY2021, almost 75,970 National Grid customers (6% of total customers) benefitted from ADA devices. Note that National Grid only counted customers benefitting from ADA *schemes* when calculating this metric. In other words, National Grid did not count towards this metric customers benefitting from individual reclosers (that were not part of FLISR schemes).

Table 43. Number of National Grid Customers that Benefitted from GMP ADA Devices

Summary Statistics	
Total Circuits with DA Installed	31
Average Number of Customer Benefiting per circuit	2,451
Total Number of Customers Benefiting from DA Devices	75,970
Percent of Total Customers that Benefit from DA Devices	6%

Source: Guidehouse analysis of Eversource 2020 GMP Annual Report Appendix 1

4.2.4 PM-ES2: Eversource Customer Outage Metric: Average Zone Size

The goal of this Eversource-specific metric is to track the progress in sectionalizing circuits into protective zones via the deployment of ADA devices. A zone size is defined as the number of customers located between sectionalizing devices. The average zone size for the whole circuit is the average number of customers in each protective zone on that circuit. Over time with increased deployment of ADA devices, the average zone size should decrease, which increases the overall reliability of the circuit and the system.

Table 44 shows the baseline (2018) and Program Year 2021 average zone size of the system-wide and ADA circuits for Eversource. For this Performance Metric, the group of ADA circuits is defined as any circuit with an ADA device commissioned during PY2021 or prior. Table 44Table 44 is structured with zone size ranges, or "bins", to provide insight into the range of zone sizes across the system, and to show where circuits selected for ADA investment fall within these bins.

ADA circuits in the 2018 baseline had an average zone size more than double that of system-wide circuits. But ADA circuits' zone size decreased to a similar size as system wide circuits in PY2021. The standard deviation of zone size has also significantly decreased, indicating that there is less variability in the number of customers per zone. These combined observations suggest that ADA investments were targeted towards circuits with a larger zone sizes and succeeded in reducing it.

Table 44. Baseline and PY2021 Average Zone Size Customer Count

Eversource ADA	Average Protective Zone Size Baseline (2018)		Average Protective Zone Size 2021	
	System-Wide Circuit	ADA Circuit	System-Wide Circuit	ADA Circuit
Average Protective Zone Size Statistics				
Total Circuits	2,214	279	2,214	279
% Zero	25%	1%	25%	4%
Simple Average	271	590	214	326
Std. Dev.	348	367	285	210
Range				
0	550	3	551	12
0 - 100	496	13	552	20
100 - 200	185	17	231	39
200 - 300	196	29	247	73
300 - 400	172	34	182	46
400 - 500	155	41	146	40
500 - 600	97	21	93	23
600 - 700	94	29	62	15
700 - 800	69	22	42	7
800 - 900	61	15	36	1
900 - 1000	44	17	22	1
1000 - 1100	27	11	19	0
> 1100	68	27	31	2

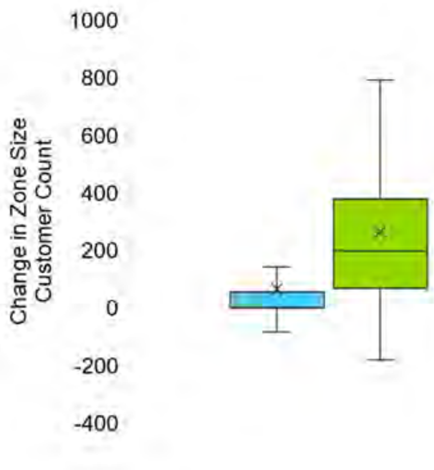
Source: Guidehouse Analysis of Eversource's 2021 GMP Annual Report Appendix 1

A simple graphical summary of the statistical change in average zone size customer count is shown in Figure 19**Error! Reference source not found.** below, which uses a "box-and-whisker" format.[37] This chart compares the difference in the average zone size customer count between baseline and Program Year 2021 for each circuit, for both the system-wide circuits and the selected ADA circuits.[38]

[37] The "box-and-whisker" plot shows divides the sample into quartiles. The lower and upper "whiskers" indicate the lowest and highest values in the range, and the boxes show the 2nd and 3rd quartile in the sample. The "x" indicates the sample average.

[38] Note that the DPU Guidance defines the change as "Baseline – Program Year" which means that positive values of this metric indicate reliability improvement—the opposite of what you would expect for improvement in Zone Size, which falls with improvement.

Figure 19. Eversource Change in Average Zone Size Customer Count



	Change in System-wide Circuits	Change in ADA Circuits
Count	2214	279
% No Change	25%	1%
Average Change in Zone Size	57	264
Standard Deviation	199	292
Median Change in Zone Size	0	195

Source: *Guidehouse analysis of 2021 GMP Annual Report Appendix 1*

The average zone size per circuit for ADA circuits decreased by 264 customers. This average change in zone size is much greater than the system-wide average change in zone size of 57 customers. The average zone size of ADA circuits was reduced by nearly 5 times the system-wide average, indicating that ADA investments had a major impact in decreasing the zone size customer counts.

4.2.5 PM-NG1: National Grid Reliability-Related Metric: Main Line Customer Minutes of Interruption Saved

Main Line Customer Minutes of Interruption Saved is a metric designed to measure the effectiveness of ADA investments. The DPU-defined calculation approach requires tracking of:

- Historical customer minutes of interruption for mainline interruptions
- Calendar year customer minutes of interruption for mainline interruptions

The evaluation of this National Grid-specific metric follows the same criteria for circuits included in the analysis as PM-12 and PM-13, i.e., a circuit where ADA was commissioned in first half of 2021 or prior was considered an "ADA circuit". The baseline is defined as the average of 2015, 2016 and 2017. Main-line CMI should decrease over time with increased deployment of ADA, indicating increase reliability.

Table 41 shows the baseline and Program Year 2021 main line customer minutes of interruptions (CMI) saved of the system-wide and ADA circuits for National Grid.

The standard deviation is on the same order of magnitude as the weighted average, providing some indication that the change in the weighted average is not simply statistical noise, but an actual improvement in performance during the program year.

Table 45Table 45 shows the baseline (2015-17) and PY2021 average main-line CMI for system-wide and ADA circuits for National Grid. ADA circuits show a 29% improvement in CMI in 2021 from the baseline, in contrast to system-wide circuits whose CMI slightly worsened in 2021 from baseline.

Moreover, standard deviation increased for system-wide circuits but decreased for ADA circuits. The standard deviation is the same order of magnitude as the average CMI, indicating that the change in CMI is not likely simply statistical noise but an actual improvement in reliability.

In baseline period, ADA circuits had more than double the average CMI compared to system-wide circuits, suggesting that ADA investments were targeted towards circuits with high CMI. In PY2021, ADA and system-wide circuits had more similar CMI, which further indicates that ADA investments reflected potential effectiveness in reducing CMI.

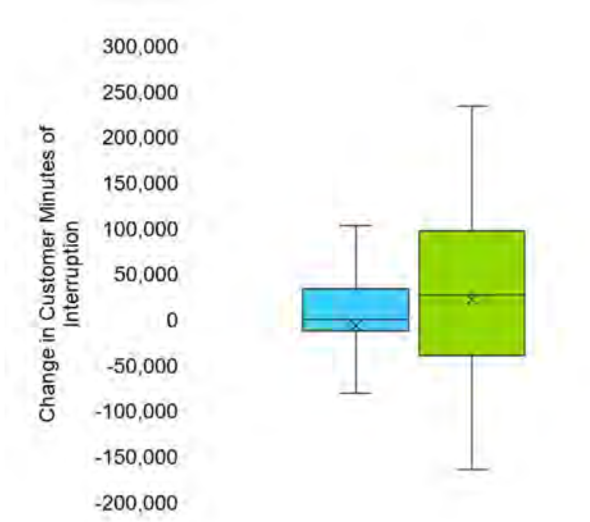
Table 45: Baseline and PY2021 Average Main-Line Customer Minutes of Interruption (CMI) for National Grid

National Grid ADA	Average Customer Minutes of Interruption (2015-2017)		Customer Minutes of Interruption 2021	
	System-Wide Circuit	ADA Circuit	System-Wide Circuit	ADA Circuit
Customer Minutes of Interruption Statistics				
Total Circuits	1,076	30	1,076	30
% Circuits with Zero CMI	26%	7%	51%	20%
Average CMI	71,790	153,391	77,537	109,533
Change from Baseline			-5,747	43,858
% Change from Baseline			-8%	29%
Std. Dev.	126,739	159,319	169,170	140,608

Before and after comparison: A simple graphical summary of the statistical change in main-line CMI is shown in Figure 20Figure 20 below, which uses the “box-and-whisker” format.[39] This chart compares the difference in CMI between baseline and PY2021 for each circuit, for both the system-wide and the selected ADA circuits. The change shown below is calculated per the DPU Stamped Approved formula of Baseline CMI – Program Year CMI, so a positive change indicates improved performance in the Program Year.

[39] The “box-and-whisker” plot divides the sample into quartiles. The boxes show the 2nd and 3rd quartile in the sample. The lower and upper “whiskers” indicate 1.5 times the interquartile range (IQR) (difference between the start of the 2nd and the end of the 3rd quartile) or the maximum/minimum value within the range if it falls within 1.5x the IQR. The “x” indicates the sample average. Data points that fall outside 1.5x the IQR are not shown on the graph for visualization purposes.

Figure 20: National Grid Statistical Change in National Grid Main-Line CMI from Baseline



	Change in System-wide Circuits	Change in ADA Circuits
Count	1076	30
% No Change	18%	0%
Average Change in CMI	-5747	43858
Standard Deviation	169935	169146
Median Change in CMI	79	42745

The average change in CMI for ADA circuits decreased by 43,858 minutes, which is significantly greater than the system-wide average change in CMI of -5,747 minutes. The average change in CMI of ADA circuits was reduced by nearly 9 times the system-wide average, indicating that ADA investments had an impact in decreasing the main line customer minutes of interruption.

The median change in ADA circuits was 42,745 minutes, compared to almost no change in the system-wide change.

5. ADA Case Studies

Six case studies were performed for the ADA investment area: three for Eversource and three for National Grid. The case studies illustrate the operation and impacts of the GMP devices installed through PY2021. The analyses were based on information from EDCs including OMS data, one-line diagrams, SCADA data, circuit maps and discussions with EDCs. However, Guidehouse made certain reasonable assumptions to reconstruct the precise details of an outage event in cases where not all information was available.

5.1 Data Management

Case studies were performed using data from the outage management system (OMS), switching orders, SCADA data, circuit maps and one-line diagrams. The outage data contains details of outage events, such as location, timing, and customers affected, that were integral to understanding the role of the GMP device in resolving the outage. The One-Line Diagrams helped support the analysis by using visualization to better understand the operation of the relevant devices during the outage event. Supplemental information was obtained from the EDCs to reconstruct the details of an event.

5.2 National Grid Case Study: ADA Reduces Nor'easter Impact on Quincy Customers

5.2.1 Background

On October 26, 2021, a nor'easter brought major damage to coastal New England. Wind speeds of 84 mph were recorded in the South Shore district and nearly half a million Massachusetts customers remained without power the next morning (October 27). National Grid had commissioned a FLISR scheme in the South Shore district (Field Street and West Quincy Substations) with Grid Modernization ADA funds. This FLISR scheme serves 3,135 customers in Quincy and surrounding areas, including the areas pictured in Figure 21Figure 21. During the nor'easter, the FLISR scheme operated as designed and kept power on for 2,055 customers, who otherwise would have experienced a nearly eight-hour outage.

Figure 21: Nor'easter Damage in Quincy, Massachusetts on October 26, 2021 (Craig Walker/Boston Globe via Getty Images).[40] Clockwise from Top: Whitwell Street, Atherton Street and Ellerton Road in Quincy, Massachusetts

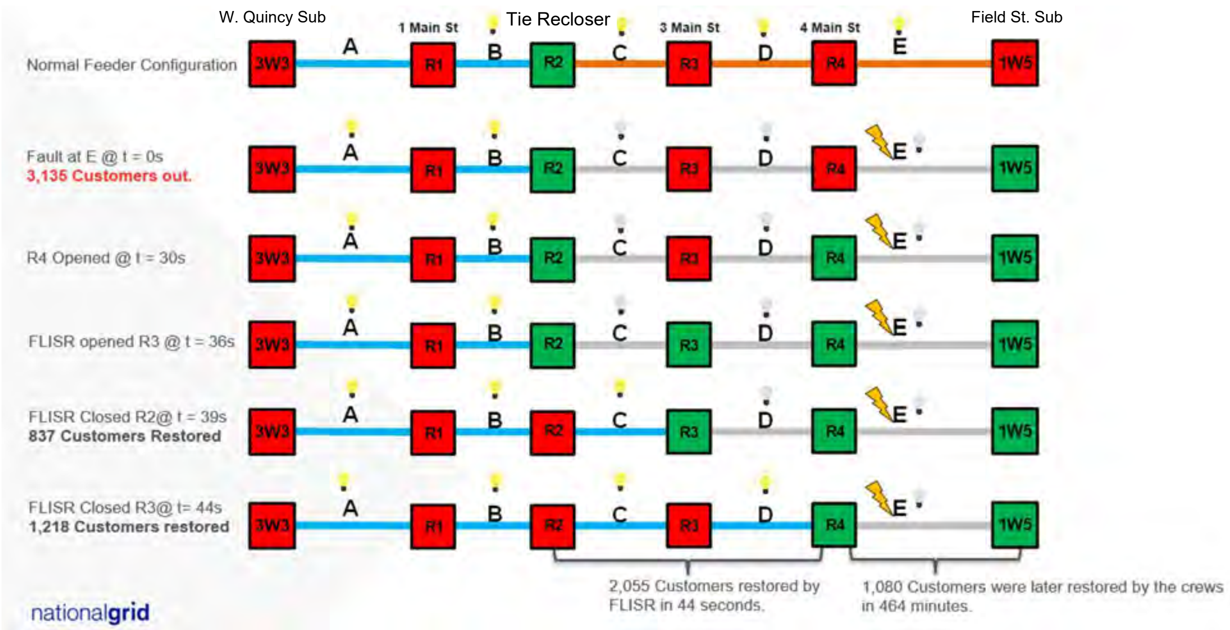
5.2.2 Event Description

On October 26, 2021 at 5:04 am, tree damage caused the circuit breaker for circuit 1W5 to lock out in the Field Street substation. This initiated National Grid's FLISR logic, which restored service to 2,055 customers by supplying them from the West Quincy substation (via circuit 3W3). The FLISR scheme operated as designed in 44 seconds, isolating the fault to the smallest zone. The remaining 1,080 customers experienced a 464-minute outage while repairs were performed.

Figure 22**Error! Reference source not found.** shows the step-by-step operation of the FLISR scheme, in which red color indicates a closed device (conducting current) and a green color indicates an open device, stopping power flow. When a fault occurred in zone E, initially 3,135 customers served by Field Street Substation lost power. The fault activated FLISR logic which isolated the fault by opening recloser R4. The scheme then closed a tie recloser (R2). The tie recloser, which connects two circuits together, allowed 2,055 of the affected customers to be served from the West Quincy substation.

[40] The Weather Channel, October 26, 2021. URL: https://weather.com/photos/news/2021-10-26-noreaster-northeast-storm-photos

Figure 22. One-Line Diagram Illustrating Sequence of Events. All reclosers ("R") are GMP-funded.

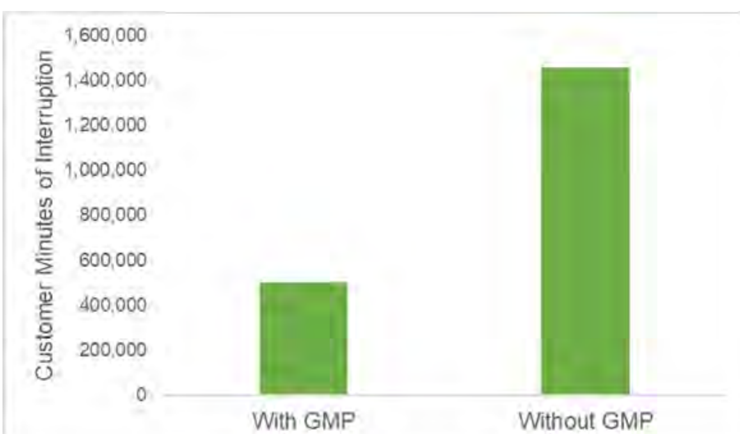


Source: National Grid

5.2.3 Benefit of Grid Modernization Investment

In this case, an ADA investment prevented a long-duration outage for 2,055 customers. The customers experienced a 44-second outage, whereas without ADA they would have experienced a 464-minute outage. The reliability savings (customer minutes of interruption) are illustrated in Figure 23Figure 23.

Figure 23. Reduction in Customer Minutes of Interruption with Grid Modernization in Quincy



Source: Guidehouse

5.3 National Grid Case Study: ADA Reduces Nor'easter Impact on Salem Customers

5.3.1 Background

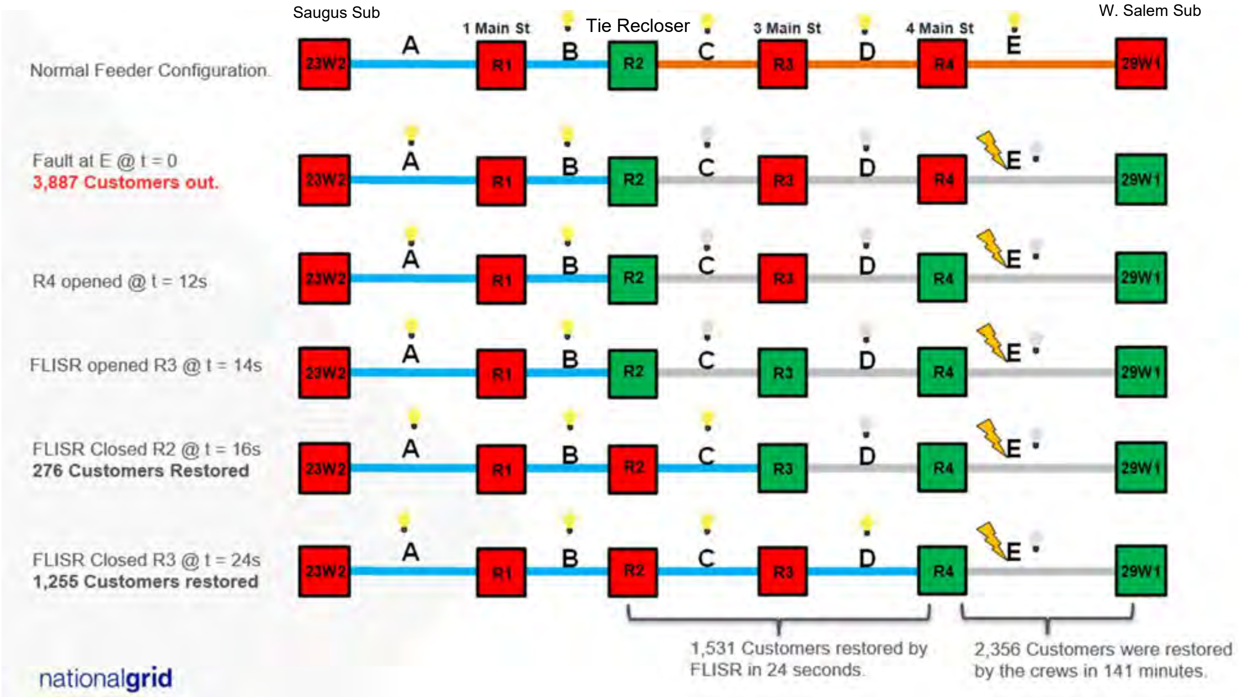
During the same nor'easter as in the prior case study (pictured in Figure 21), a National Grid FLISR scheme operated in Salem, Massachusetts to reduce outage impact on customers. National Grid had commissioned the FLISR scheme in the North Shore district (West Salem and Saugus Substations) with Grid Modernization ADA funds. During the nor'easter, the FLISR scheme operated as designed and kept power on for 1,531 customers who otherwise would have experienced a 141-minute outage.

5.3.2 Event Description

Shortly after midnight on October 27, 2021, tree limbs fell on an overhead main line on Euclid Avenue in West Salem, Massachusetts, causing the line to burn and break off the pole. This mainline fault initiated National Grid's FLISR logic which restored service to 1,531 customers by supplying them from another (Saugus) substation. The FLISR scheme operated in 16 seconds, isolating the fault to the smallest zone with 2,356 customers. These customers were restored in 141 minutes after repairs were completed.

Figure 24 shows the step-by-step operation of the FLISR scheme. When a fault occurred in zone E (between the West Salem substation and the first pole-top recloser), initially all 3,887 customers served by the West Salem Substation lost power. This fault activated the FLISR scheme which opened recloser R4 and closed a tie recloser (R2). The tie recloser, which connects two circuits together, allowed 1,531 of the affected customers to be served from the Saugus substation.

Figure 24. One-Line Diagram Illustrating Sequence of Events. All reclosers ("R") are GMP-funded.

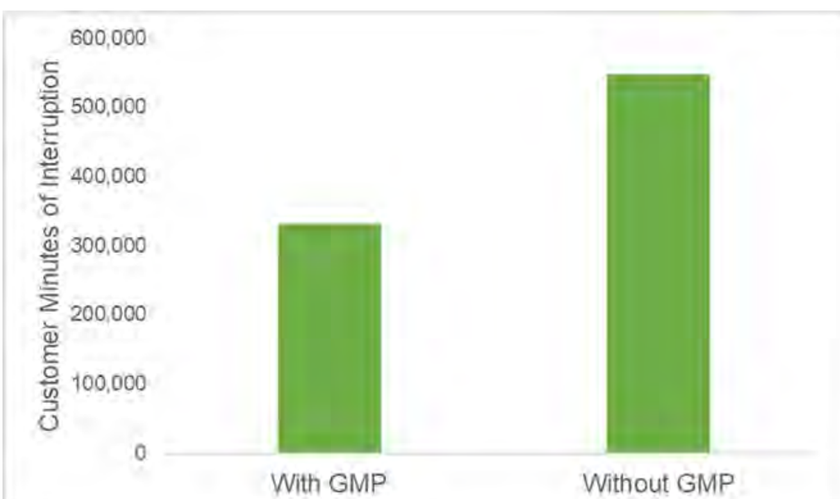


Source: National Grid

5.3.3 Benefit of Grid Modernization Investment

In this case, ADA investments prevented a long-duration outage for 1,531 customers who experienced a 16-second outage, whereas without ADA they would have experienced a 141-minute outage. The reliability savings (customer minutes of interruption) are shown in Figure 25Figure 25.

Figure 25. Benefit of Grid Modernization Devices in Reducing Customer Minutes of Interruption



Source: Guidehouse Analysis

5.4 National Grid Case Study: ADA Reduces Outage Duration for Stoughton Customers

5.4.1 Background

National Grid had commissioned a FLISR scheme in Stoughton, Massachusetts with Grid Modernization ADA funds. This FLISR scheme operated in November, 2021 and kept power on for 2,821 customers who otherwise would have experienced a 150-minute outage.

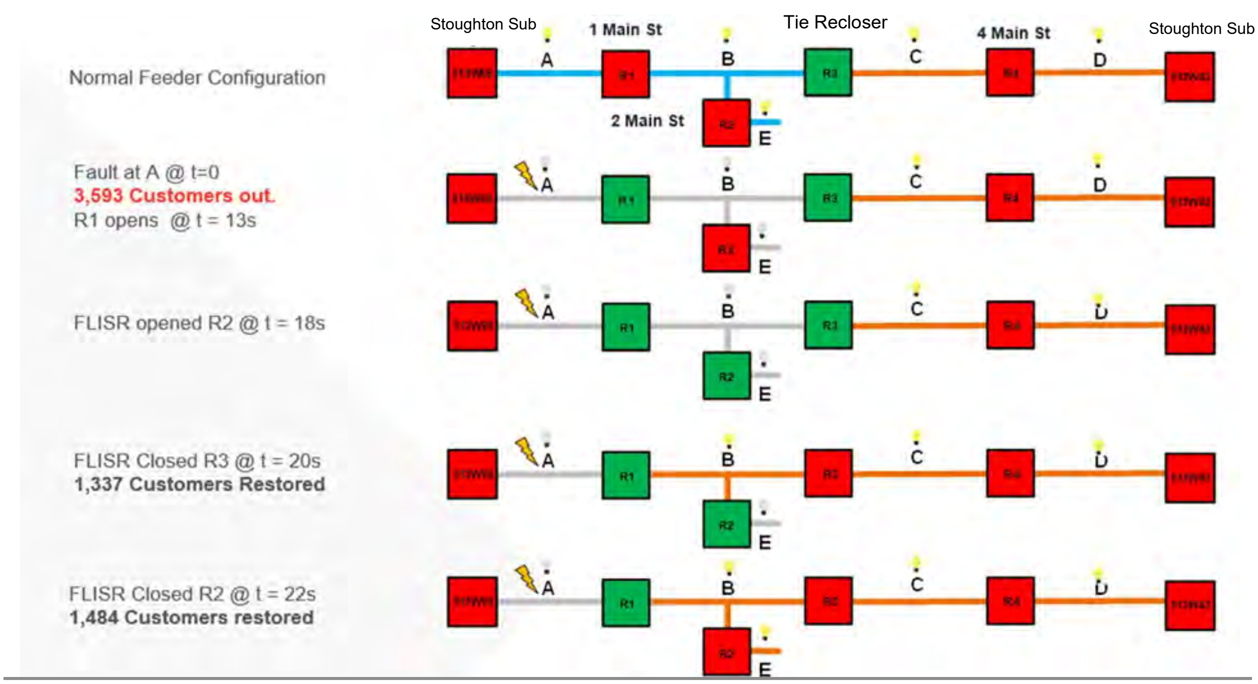
5.4.2 Event Description

On November 4, 2021 at 8:35 am, animal contact caused a spacer cable to get damaged and the circuit breaker to lock out in Stoughton, Massachusetts. This fault initiated National Grid's FLISR logic which restored service to 2,821 customers in 22 seconds, by supplying them from an alternate route. The remaining customers experiencing the outage were restored in 150 minutes after repairs were completed.

Figure 26Figure 26 shows the step-by-step operation of the FLISR scheme. When a fault occurred in zone A, initially 3,593 customers on circuit 913W69 lost power. The loss of power activated the FLISR logic which isolated the fault zone by opening recloser R1. It then closed a tie recloser R3 in 20 seconds, restoring power to 1,337 customers via a neighboring circuit. Two seconds later, it closed another tie recloser R2, restoring power to another 1,484 customers.

Forty-five minutes later, field crews manually operated a switch (non-Grid Mod device), restoring power to 376 customers and further isolating the fault to the smallest possible zone. They performed repairs and restored power to remaining 396 customers after a 150-minute outage.

Figure 26. One-Line Diagram Illustrating Sequence of Events. All reclosers ("R") are GMP-funded.



Source: National Grid

5.4.3 Benefit of Grid Modernization Investment

In this case, an ADA investment prevented a long-duration outage for 2,821 customers. They experienced a 22-second outage, whereas without ADA they would have experienced a 150-minute outage. The reliability savings (customer minutes of interruption) are illustrated in Figure 27.

Figure 27. Reduction in Customer Minutes of Interruption with Grid Modernization in Stoughton

5.5 Eversource Case Study: ADA Maintains Power to Customers in Springfield

5.5.1 Background

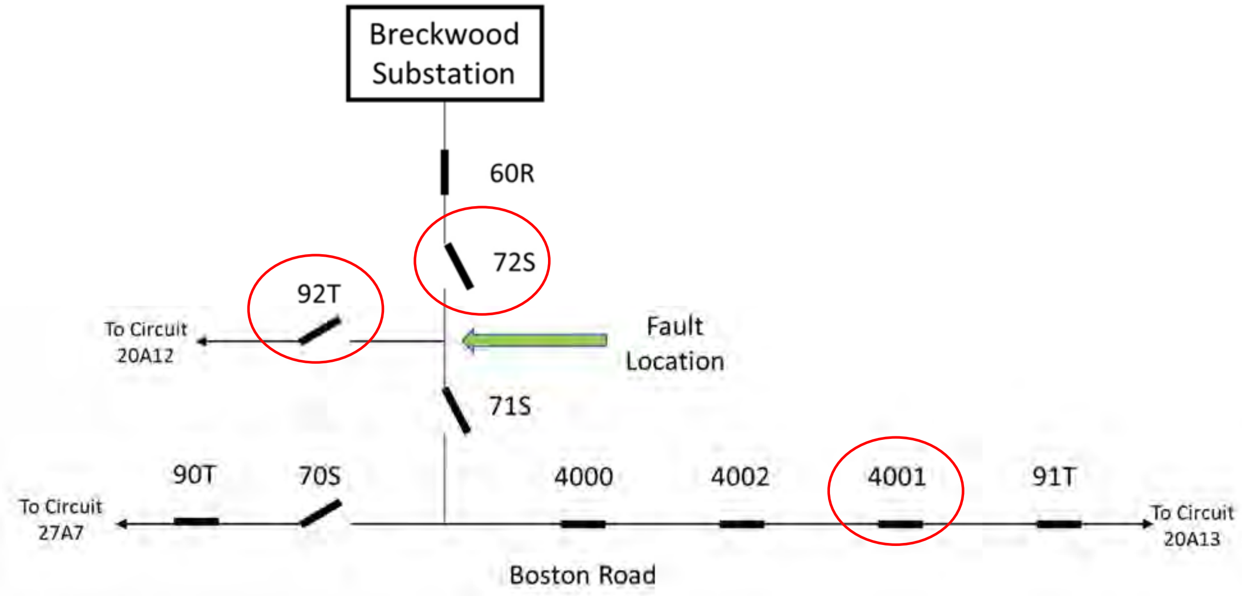
A GMP-funded ADA recloser helped reduce the number of customers affected by an outage when an overhead wire burned down in Springfield in Western Massachusetts. The circuit 20A33 (shown in Figure 28 below) serves 2,845 customers.

5.5.2 Event Description

At 8:57 pm on November 25, 2021, an overhead wire burned and broke off a pole on Grayson Drive in Springfield, Massachusetts. The recloser 72S sensed the fault and locked open, protecting 104 customers between 72S and the substation from an outage. Sensing this operation, recloser 71S opened to isolate the fault to the zone between 71S and 72S. Once 71S was opened, the ADA scheme closed 91T. As part of the FLISR scheme, 70S opened and 90T closed transferring a portion of circuit 20A33 to circuit 27A7. The automatic operation of the ADA operation restored customers along Boston Road using circuit 21N4 and 27A7, leaving only 495 customers without power. The automated operations above maintained service to 2,246 customers along Boston Road.

After the fault had been isolated to the zone between 71S and 72S, crews arrived to perform repairs to damaged equipment. Power was restored to 495 customers after a 126-minute interruption.

Figure 28: One-Line Diagram for Circuit 20A33 (Grid Mod Devices are circled).



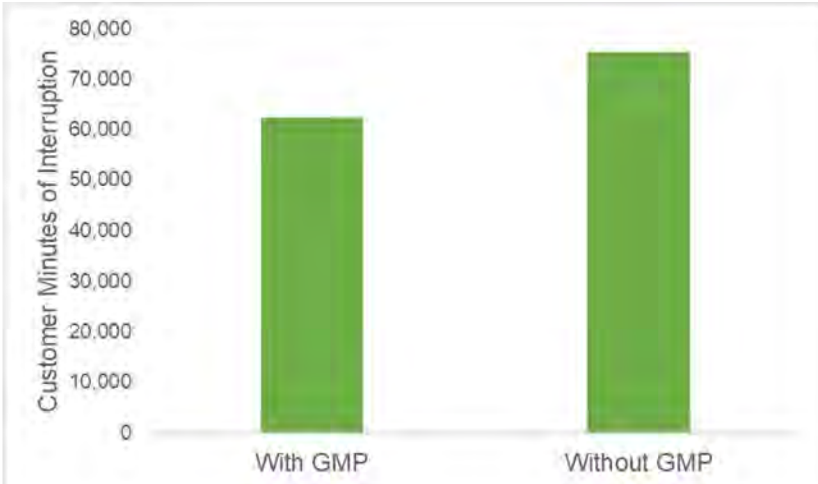
Source: Guidehouse analysis of Eversource One-Line Diagram

5.5.3 Benefit of Grid Modernization Investment

In this case, an ADA investment prevented a long-duration outage for customers. Without the GMP-funded recloser 72S, 104 customers (between 72S and 60R) would have experienced a 126-minute outage. The reliability savings (customer minutes of interruption) are illustrated in Figure 29.

In addition, without the tie reclosers 91T and 90T, 2,246 customers along Boston Road would have experienced a 126-minute outage. These tie reclosers, though not GMP-funded, are similar to GMP-funded tie reclosers (e.g., recloser 92T) and highlight the benefit of tie reclosers in general.

Figure 29: Savings in Customer Minutes of Interruption with GMP. 495 customers experienced an extended outage out of 2,845 customers on the circuit. Chart does not show benefit of non-GMP automation.



5.6 Eversource Case Study: ADA Reduces Outage Impact to Customers in Springfield

5.6.1 Background

This case study occurred on the same circuit as the Case Study 5.5 above, in Springfield, Massachusetts. The devices operated in a similar way to Case Study 5.5, highlighting that GMP investments can yield repeated value within the same year. Similar to Case Study 5.5, the GMP-funded ADA recloser opened to isolate the faulted zone and non-GMP tie-recloser closed to reduce the number of customers affected by an outage, this time due to a tree coming into contact with overhead wires. The circuit 20A33 serves 2,845 customers in western Massachusetts.

5.6.2 Event Description

At 12:24 am on September 2, 2021, in rainy weather, a tree came into contact with all three phases of overhead lines on Grayson Drive in Springfield, Massachusetts. The recloser 72S (refer to Figure 3 above) sensed the fault and all three phases locked open, protecting 104 customers between 72S and the substation from an outage.

Sensing the loss of voltage, the automation scheme, opened 70S and 90T automatically closed transferring a portion of circuit 20A33 to circuit 27A7. Also, automatically device 20A33-71S opened and 20A13-91T closed transferring the remaining portion of circuit 20A33 to 20A13.

The automatic operation of the ADA devices restored customers along Boston Road from using circuit 27A7 and 20A13, leaving only 495 customers without power. The automated operations above maintained service to 2,246 customers along Boston Road.

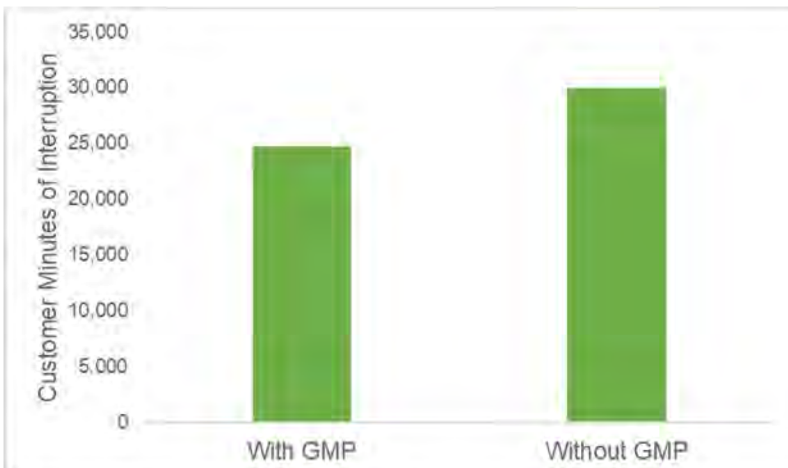
After the fault had been isolated to the zone between 71S and 72S, crews arrived to remove the tree and perform repairs. Power was restored to 495 customers after a 50-minute interruption.

5.6.3 Benefit of Grid Modernization Investment

In this case, an ADA investment protected customers from a long-duration outage. Without the GMP-funded recloser 72S, 104 customers (between 72S and 60R) would have experienced a 50-minute outage. The reliability savings (customer minutes of interruption) are illustrated in Figure 30.

In addition, 2,246 customers along Boston Road would have experienced a 50-minute outage without the tie-reclosers 90T and 91T. While these two reclosers are not GMP-funded, they are similar to GMP-funded tie reclosers (such as 92T) and illustrate the efficacy of tie reclosers.

Figure 30: Savings in Customer Minutes of Interruption Due to Grid Modernization. 495 customers experienced an extended outage out of 2,845 customers on the circuit. Chart does not show benefit of non-GMP automation.



5.7 Eversource Case Study: Underground ADA Maintains Power to Customers in Downtown Boston

5.7.1 Background

Eversource had modernized a 4kV underground circuit in downtown Boston serving 819 customers in the Tremont Street and Massachusetts Avenue area using GMP funding, replacing obsolete underground equipment with modern technology. Eversource replaced five legacy oil-filled underground switches with SCADA-controlled vacuum fault interrupters (VFI). These GMP ADA devices were used to restore an outage in the City of Boston, Massachusetts.

5.7.2 Event Description

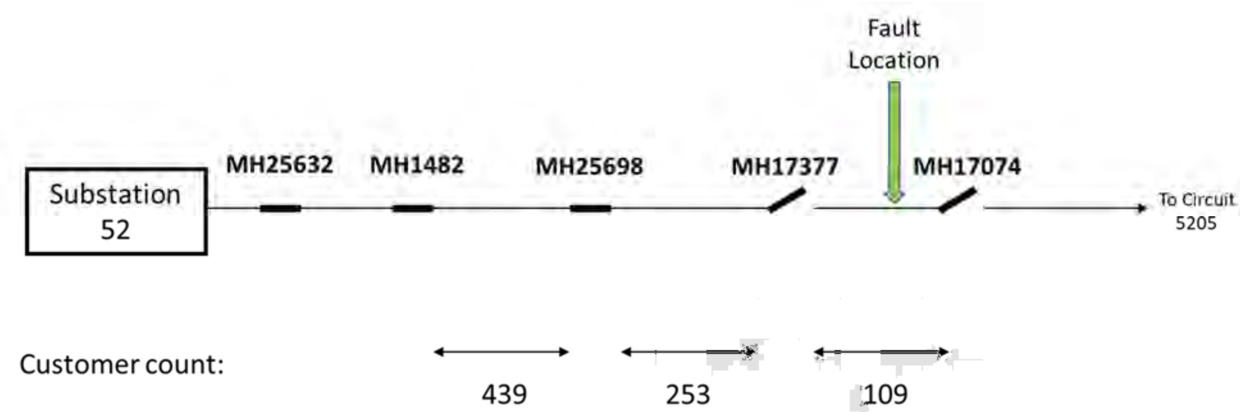
At 03:07 am on Sunday, November 21, 2021, Eversource operators in the control center received SCADA alarms from the newly installed Grid Modernization device in manhole (MH)

25698 in downtown Boston (see Figure 31). SCADA reported that the device had automatically opened and a loss of power had occurred in the area.

Underground field crews were dispatched to the area to determine the cause of the power outage and begin restoration of power to the affected customers. The field crews reported that the device in nearby MH1482 was also open. Based on the SCADA indication from the newly installed GMP device, the dispatch center determined the fault was located between MH 17074 and MH 17377. This enabled the dispatch center to open the device in MH17377 to isolate the fault zone. The operators then remotely closed the switch in MH 25698 using SCADA at 3:53 am, restoring 253 customers in 46 minutes. The dispatch center also closed, by SCADA control, the device in MH 1482 at 4:04 am, restoring 439 customers in 57 minutes.

The field crews determined the cause of the power outage was faulted cables in MH 17377. The field crews made temporary repairs and closed the newly installed grid modernization device in MH 25698 at 6:31 am, restoring power to the remaining 109 customers.

Figure 31: One-Line Diagram for Circuit 5207 (Grid Mod Devices in bold)



Source: Guidehouse analysis of Eversource One-Line Diagram

5.7.3 Benefit of Grid Modernization Investment

In this case, the replacement of legacy underground oil switches with modern VFIs reduced the outage duration for customers by an hour or more. The VFIs also communicated important information to operators in a timely manner, allowing them to quickly restore power. Legacy oil switches do not operate automatically. They can only be manually operated from inside the manhole. So with oil switches, the entire circuit would have lost power. Since none of the oil switches would have opened, there would be no way to know where the fault was. Crew would enter the first manhole from the left (MH25632), manually opened the switch, and tested for fault. Then they would have proceeded to the second manhole, MH1482, opened it and tested for a fault, and so on. In this way, crew would have to open five manholes before finding the fault. And then the repairs would have begun. Opening a manhole is a time consuming process and, in downtown Boston, often requires traffic to be diverted and water to be pumped out.

Guidehouse estimates that the outage duration would have been 1-2 hours longer for all customers without GMP investment. Figure 32Figure 32 shows the savings in customer minutes of interruption with ADA investment.

Figure 32: Savings in Customer Minutes of Interruption with Grid Modernization

6. Recommendations

Guidehouse has developed the following recommendations and submits them for EDC consideration:

11) The CKAIDI and CKAIFI reliability related Performance Metrics as defined have deficiencies in measuring the effectiveness of Grid Modernization Investments. Many factors unrelated to the Grid Modernization investments will affect these metrics in any given year, and it is not possible to distinguish among these factors using the metrics. For example, the variation in storm activity between years can cause significant changes in these metrics, as apparently happened in PY2020 and PY2021. This observation has been made previously, and these recommendations were made last year, but bear repeating.
    a. Recommendation: Continue to track these Performance Metrics, but establish other methods of isolating the specific impacts of Grid Modernization investments.[41]
    b. Recommendation: Additional Performance Metrics should be explored to determine if it is possible to capture the actual reliability performance attributable to the investments. Exploration could include:
        i. Exploring the pros and cons of making the reliability metrics baseline a rolling average of, perhaps, the most recent 3 years, as opposed to the fixed years of 2015 through 2017. The fixed baseline has the issue, as pointed out in the report, that individual circuits are reconfigured over time, go out of service, and new circuits are created, making circuit-wise comparisons over time more challenging.
        ii. Exploring the pros and cons of understanding the timing and sequencing of reliability events more closely in the first several minutes of the event. This timing would lend insight whether an event was resolved within a 1 minute versus a 5 minute threshold, which would impact CKAIFI metrics. As the network becomes more complex (e.g., increased DER penetration, additional switching to reconfigure for changing loads), the processing logic to perform proper load and device status before automation controls are used will become more complex and tend to take longer. So, understanding these dynamics will grow in importance.
        iii. Reviewing the data and techniques necessary to understand the relationship between circuit reliability and weather conditions, vegetation management cycles and other reliability drivers that are independent of the grid modernization investments.
        iv. Expanding the use of case studies to cover a greater proportion of the investments—more outage cases examined on more circuits (see Recommendation 4a below).

[41] Note: the EDCs do have additional reliability metrics that are being tracked: National Grid has the *Mainline Customer Minutes of Interruption Saved* metric (PM-NG1), and Eversource has the *Protective Zone Average Zone Size per Circuit* metric (PM-ES2), which provide additional information about reliability performance. However, neither of these metrics directly isolates and measures the investments' performance impact on customer reliability vis a vis other factors that may impact reliability.

v. Leveraging new processes and data collection to perform outage case studies more efficiently, and perhaps extrapolate these results to a broader set of circuits to understand investment performance with more certainty.
vi. Comparing number of customers out and customer minutes of interruption (CMI) that occurred, with the number of customers out and CMI that would have occurred without Grid Modernization investments.
vii. Developing a way to expand the use of counter-factual analysis on a broader basis than what is currently being done in the Case Studies could help develop a better understanding of overall system impacts from the ADA investments.

12) The use of currently defined CKAIDI and CKAIFI reliability related Performance Metrics—which are circuit level metrics—has increasing challenges over time as circuits get re-configured or retired and new circuits are created. The comparability of each circuit in the program year to its baseline depends on that circuit not having been reconfigured or significantly changed (e.g., a normally open switch between circuit segments is changed to operate as normally closed, changing the customer counts and outage measurements on that circuit). The number of circuits that are comparable between baseline and program year is reduced year after year as more circuits change due to ongoing operation of the system. This observation has been made previously, and this recommendation was made last year, but bears repeating.
    a. Recommendation: Explore metrics that are robust to these operating changes to help ensure that Grid Mod investment assessment based on these metrics are not misleading, and are able to better capture the impact of the investment.

13) Current metrics do not provide an understanding of how M&C and ADA investments facilitate easier interconnection, or more capacity, of DER added to the system. This observation has been made previously, and this recommendation was made last year, but bears repeating.
    a. Recommendation: Consider developing additional metrics and/or performing pilot projects that utilize the installation of ADA and M&C investments at DER locations to understand the value or benefits that are provided. This would provide actual data on the effectiveness of these investments to support DER integration.

14) Case studies show detailed functioning and impact of GMP devices, and they are proving to be a useful tool in understanding the effectiveness of the Grid Modernization investments. Based on case studies performed, the ADA investment is yielding reliability and service delivery benefits to customers for each of the EDCs. This observation has been made previously, and these recommendations were made last year, but bear repeating.
    a. Recommendation: Continue to perform case studies in future evaluations, and increase the use of case studies where practicable, to analyze the mitigation of customer outages and help determine the effectiveness of Grid Modernization investments in improving reliability and service delivery.

15) The evaluation team found that the EDC definition for the term “deployed” devices reported to the DPU was not consistent across EDCs. “Deployed” was used to indicate different stages of device implementation, including *in-service* (installed, used and useful) and *commissioned* (GMP functionalities and remote communication are enabled). This evaluation report considers only fully commissioned devices to be “deployed”.
    a. Recommendation: The Department should recommend the establishment of a consistent state-wide definition of “deployed” for future program tracking and reporting.

16) The 4 kV underground loop scheme was first-of-a-kind technology for Eversource. It encountered communication and software issues in commissioning the scheme in 2020. After performing engineering and troubleshooting in 2020 and 2021, Eversource discontinued the investment.
    a. Recommendation: Eversource should perform a more rigorous assessment of the communication requirements (latency, bandwidth and capacity) of major new technologies in the future.

17) For Eversource, ADA deployment has reduced the zone size of many circuits to under 500 customers.
    a. Recommendation for Eversource: On blue-sky days, analyze outages affecting greater than 500 customers in a case-study manner to determine:
        i. Was the zone size reduced to 500 or is additional ADA deployment warranted?
        ii. Did FLISR operate correctly or are equipment or software changes required?

18) For Eversource, the evaluation team validated the performance of ADA to automatically operate to restore power to customers. Case Study 5.6 demonstrated that while automatic restoration was achieved, two of the field devices appear to have automatically operated “slower” than other automated devices on the same circuit. This slower than expected operation was not noted during the review of other case studies.
    a. Recommendation: Eversource should verify the automatic settings in field devices 27A7-90T and 20A33-71S to assure they have proper settings.
    b. Recommendation: If improper settings are found, Eversource should determine if other devices may also have settings that need to correction.

19) For Eversource, the evaluation team validated the performance of modern VFI switches that replaced legacy oil switches in underground 4kV circuits. The new VFI switches have SCADA capability and automatic fault isolating capability during a main line fault. Based on Case Study 5.7 a main line fault, with the modern gird modernization investments, will reduce the number of customers affected between 25 to 75% while also reducing outage duration time. While this is a significant improvement in reliability, if VFI tripping can be made selective (i.e., VFI closest to the fault location opened), it would even further reduce the number of customers affected.

    a. Recommendation: Eversource should perform a study to determine if the VFIs can be programmed so that only the VFI closest to the fault would open during a main line fault. As an alternative, Eversource should evaluate installing fault indicators (remote fault locating devices) which could provide operating personnel real-time information on the location of the fault. This would further minimize the number of customers affected.

20) Case Studies demonstrated that National Grid's initial FLISR schemes are operating properly and restoring power quickly to customers.
    a. Recommendation: National Grid should continue to evaluate circuits for ADA deployment.
    b. Recommendation: Since National Grid has limited ADA deployment at this time, it is recommended that each main-line outage on ADA circuits be analyzed for proper automation. This would determine early in the deployment process if:
        i. Main-line customer outage impact was reduced, and if so, how many customers avoided a sustained outage;
        ii. The FLISR scheme operated correctly and, if not, whether equipment/software changes are required;
        iii. Lessons learned from early deployment can be used to inform additional deployment of ADA.
        iv. This can also help determine if zone size between ADA devices is optimal or should be further reduced.

Massachusetts Grid Modernization Program Year 2021 Evaluation Report: Advanced Distribution Management System/Advanced Load Flow (ADMS/ALF)

Massachusetts Electric Distribution Companies

Submitted by:

Guidehouse Inc.
77 South Bedford Street, Suite 400
Burlington, MA 01803
Telephone (781) 270-8300
Guidehouse.com

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Executive Summary

Introduction

As part of the Grid Modernization Plan (GMP), the Massachusetts Electric Distribution Companies (EDCs) are investing in advanced distribution management systems (ADMS) and advanced load flow (ALF). ADMS/ALF is a software platform investment fundamental to a modernized grid. ADMS consists of supervisory control and data acquisition (SCADA), outage management systems (OMSs), distribution management systems (DMSs), and advanced applications such as operational power flow, conservation voltage reduction (CVR), Volt/VAR optimization (VVO), fault location isolation and service restoration (FLISR), and distributed energy resource management systems (DERMS). An ADMS's capabilities are key to delivering on the Massachusetts Department of Public Utilities' (DPU's) grid modernization objectives. These objectives include the ability to control devices for system optimization, provide support for advanced distribution automation (ADA) and VVO, and serve as an enabling platform to support a high penetration of distributed energy resources (DER). ALF investments are tightly coupled with ADMS investments at Eversource, the only Electric Distribution Company (EDC) with a separate investment plan for ALF.

The evaluation focuses on the progress and effectiveness of the DPU's preauthorized ADMS/ALF investments for each EDC toward meeting the DPU's grid modernization objectives for Program Year (PY) 2021.

Table 1 summarizes the preauthorized ADMS/ALF investments for the EDCs in the Program Year (PY) PY2018 to PY2021 timeframe.

Table 1. ADMS/ALF Investments

EDCs	Description
Eversource	Implementation of ADMS supported by implementation of ALF
National Grid	Implementation of DMS integrated with SCADA
Unitil	Implementation of ADMS for VVO enablement

Source: Guidehouse review of 2020 GMP Annual Reports and EDC Data

Evaluation Process

The DPU requires a formal evaluation process (including an evaluation plan and evaluation studies) for the EDCs' preauthorized GMP investments. Guidehouse[1] is completing the evaluation to help ensure a uniform statewide approach and to facilitate coordination and comparability of evaluation results. The evaluation process assesses the progress and effectiveness of the DPU preauthorized ADMS and ALF investments for each EDC to help meet the DPU's grid modernization objectives.[2]

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[1] Guidehouse LLP completed its acquisition of Navigant Consulting, Inc, in October of 2019. The two brands are now combined as one Guidehouse. Document filings in the docket prior to this rebranding are filed under the name "Navigant Consulting."

[2] DPU 15-120/DPU 15-121/DPU 15-22, at 106 , May 10, 2018 (DPU Order).

The original Evaluation Plan was submitted to the DPU by the EDCs in a petition for approval on May 1, 2019. Modifications to this original Evaluation Plan were made to 1) request changes to the reporting schedule to accommodate Performance Metrics data availability timing, as discussed in response to DPU EP-1-1 submitted on February 6, 2020 [3], and 2) to extend the Grid Modernization term period from the original 3 year term to a 4 year term as ordered by the DPU in its May 12, 2020 Order.[4] Modifications to the original Evaluation Plan were submitted to the DPU by the EDCs in a petition for approval on December 1, 2020. The company specific GMP budget caps did not change with the term extension. The modified Evaluation Plan has been used to develop the analysis and evaluation provided below in this document.

The evaluation process guides the investments' contribution to meeting all three DPU objectives:

1) Optimize system performance by attaining optimal levels of grid visibility, command and control, and self-healing
2) Optimize system demand
3) Interconnect and integrate DER

ADMS is an enabling technology that has the potential to significantly enhance a utility's ability to meet DPU objectives. ALF enables ADMS and supports all three of the DPU's objectives, and enables improved modeling of the distribution system's current and future states. ALF is tightly coupled with the ADMS investment for Eversource—the geographic information system (GIS) and other system data cleanup components of ALF enable engineering load flow in Synergi and are necessary for operational load flow, and other ADMS functions in Eversource's future ADMS investment. GIS data cleanup is a component of each of the ADMS/ALF investments and is addressed differently at each EDC.

Guidehouse's evaluation of the ADMS/ALF investments consists of four tasks:

- **Task 1. Evaluation Plan:** Define overall study goals and identify metrics, including a round of plan refinement and coordination with the EDCs prior to finalization.
- **Task 2. Data Assimilation and Collection:** Distribute written data requests to each EDC semiannually, with each EDC providing the data specified and Guidehouse conducting follow-up data review meetings.
- **Task 3. Analysis and Presentation:** Analyze data following data collection tasks, producing a year-end draft presentation for each EDC to review. Outputs from Task 3 feed directly into preparation for Task 4.
- **Task 4. Reporting:** Provide interim draft reports following the yearly analysis review meetings with the EDCs and incorporate feedback into this final evaluation report. Evaluation reports are provided to the EDCs to incorporate into filings and reports to the DPU.

[3] Submitted to Massachusetts DPU 15-120, 15-121, 15-122.

[4] Order (1) Extending Current Three-Year Grid Modernization Plan Investment Term; and (2) Establishing Revised Filing Date for Subsequent Grid Modernization Plans; DPU 15-120-D/DPU 15-121-D/DPU 15-122-D; May 12, 2020.

Data Management

The objective of data management is to collect planning and cost information. Data management tracks enabled power flow and control capabilities at regular intervals with each EDC based on the approved evaluation plan. It includes defining details on the data to be collected, identifying the timing of data collection, and designating owners at each EDC for the ADMS data as well as owners at Eversource for ALF data.

The evaluation strategy for the implementation of ADMS components is followed by the progression of functional realization of each EDC's ADMS. This progression means that the data helps identify the progress each EDC has made to establish the functionality of its ADMS. This process starts with evaluating the foundational prerequisites, moves to basic ADMS software, and finishes with advanced application functionality. These steps include integrating OMS and distribution SCADA (DSCADA) components if needed, cleaning the data, and enabling functionality (including load flow on circuits and substations) and advanced functionality, potentially including VVO, FLISR, and DERMS.

For Eversource's ALF investment, the data helps identify Eversource's progress toward establishing the functionality of the ALF, starting with foundational prerequisites, basic Synergi software, integrating Synergi to GIS and other systems, and cleaning up data in GIS and other systems.

Table 2 summarizes data sources used throughout the ADMS/ALF evaluation in PY2021. Sections 3.1.1 and 4.1.1 detail each of the data sources.

Table 2. ADMS/ALF Data Sources

Data Source	Description
2020 Grid Modernization Plan Annual Report[5,6,7]	Planned device deployment and cost information from each EDC's 2020 GMP Annual Report Appendix 1 as the reference to track progress against the GMP targets. This data source is referred to as the *EDC Plan* in summary tables and graphs throughout the report.
EDC Device Deployment Data Template	Captures planned and actual device deployment and spend data. Actual device deployment and cumulative spend information were provided by work order ID and specified at the feeder- or substation-level as appropriate. *Carryover* device deployment information and estimated carryover spend for 2022 were provided as well.
ADMS/ALF Supplemental Data Template	Includes additional information unique to the ADMS/ALF Investment Area spanning inputs required for the Infrastructure Metrics and the Performance Metrics. Data covers actual versus planned ADMS/ALF implementation, data cleanup, schedule, and cost. Information was requested at the feeder- and substation-level where possible.
Eversource's 2021 DPU-Filed Plan[8]	Eversource's GMP extension request was approved by the DPU on February 4, 2021. It includes budgets for PY2021 deployment at the Investment Area level. This data source is included in the EDC Plan for Eversource planned spend at the Investment Area level.

Source: Guidehouse analysis

Guidehouse reviewed all data provided upon receipt. The team conducted detailed quality assurance/quality control (QA/QC) of data inputs used in the analysis of Infrastructure and Performance Metrics. These QA/QC steps included checks to confirm each of the required data inputs are accounted for and can be incorporated into analysis.

After receiving the data, Guidehouse provided status update memos that summarized the QA/QC to the EDCs, confirming receipt of the datasets and indicating quality. Additional follow-up based on standing questions was required to confirm all EDC-provided data could be used in analysis.

Findings and Recommendations

Table 3 presents the Infrastructure Metric results through PY2021 for all EDCs. Additional detail surrounding findings for each Infrastructure Metric are provided in Section 3.2. Although Infrastructure Metrics are the same across all Investment Areas, ADMS/ALF investments are

[5] Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30.

[6] NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30. Note that Eversource Energy filed an updated Appendix 1 filing in December of 2021; however that update did not affect any of the data or results in the evaluation.

[7] Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30.

[8] Grid Modernization Program Extension and Funding Report. Submitted to Massachusetts DPU on July 1, 2020 as part of DPU 15-122

not tracked by device. Instead, ADMS/ALF investments are tracked by technology or software implementation.[9]

Table 3. ADMS/ALF Infrastructure Metric Summary

Infrastructure Metrics			Eversource*	National Grid	Unitil
GMP Plan Total, 2018-2021		Devices	0	0	0
		Spend, $M	$28.16	$19.29	$0.60
IM-4	Number of devices or other technologies deployed PY2018-2021*	# Devices Deployed	N/A	N/A	N/A
		% Devices Deployed	N/A	N/A	N/A
IM-5	Cost for Deployment PY2018-2021*	Total Spend, $M	$22.61	$17.02	$0.33
		% Spend	80%	88%	56%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	N/A	N/A	N/A
		% On Track (Spend)	57%	75%	38%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	N/A	N/A	N/A
		Spend Remaining, $M	$10.87	$0.00	$0.15

IM = Infrastructure Metric
Note: For ADMS/ALF, '0 devices' means there is no hardware deployment. For Eversource, IM-6 denotes 'N/A' because there was no 2021 Plan Spend for ALF and GIS.
*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the "carryover" units and spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs' 2020 Grid Modernization Plans, which stated the planned units and spending to be completed through PY2021.
Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

The EDCs continue to realize that IT/operational technology (OT) applications, including ADMS/ALF, are different from device-centric investments and require a different approach to planning, budgeting, and monitoring. Infrastructure Metric findings for PY2021 (see IM-6 above) show that the EDCs are behind is spending on these investments relative to what they anticipated in their 2020 GMP Annual Reports. However, significant progress was made. Eversource completed Synergi Upgrades in PY2021 and enabled full ALF automation build. ADMS, Forecasting Tool, and PI Asset Framework had spending underruns in PY2021 due to delayed start accommodating February 2021 DPU Approval. National Grid ADMS deployment milestones and data prep are progressing as indicated in PM-1 below. Unitil is continuing its ADMS implementation by location, which is tied closely to their M&C and VVO investments.

[9] Throughout this report, the term *technology* or *software implementation* is used instead of device deployment.

Table 4 presents the progress of the Performance Metrics across the state's three EDCs.

Table 4. ADMS/ALF Performance Metrics Progress

Performance Metrics		Eversource		National Grid		Unitil	
		Circuits	Sub-stations	Circuits	Sub-stations	Circuits	Sub-stations
PM-8	Increase in Circuits and Substations with DMS Power Flow and Control Capabilities	0	0	271	89	3	0
PM-9	Control Functions Implemented by Circuit and Substation	0	0	0	0	14	1
PM-ES-1	ALF – Percent of Milestone Completion	100%	100%	N/A	N/A	N/A	N/A
Other	Distributed Generation (DG) Interconnection Queue Wait Time	N/A	N/A	N/A	N/A	N/A	N/A

PM = Performance Metric

Source: EDC data

Eversource

Eversource is progressing its ADMS/ALF program, but is somewhat behind its 2020 GMP Annual Report plan. There was a slight budget underrun of ADMS implementation in 2021. Synergi Upgrades were completed in 2021 and enabled full ALF automation build. There was a budget overrun for Synergi Upgrades due to the Infosys CED Graphical User Interface development work for Hosting Capacity Maps not being accounted for in the original PAF (Project Approval Form) estimate. ALF PY2021 costs are associated with some minor reallocation of budget after completion of the 2020 project. There was a budget underrun for ADMS, Forecasting Tool, and PI Asset Framework in PY2021 due to delayed start accommodating February 2021 DPU Approval. ADMS implementation is planned to continue in PY2022. Finally, although GIS survey spending is categorized as O&M spending, it is included as part of the ADMS/ALF Investment Area for Eversource because it makes up a significant portion of the ADMS/ALF budget.

National Grid

National Grid has moved forward with the ADMS investment in PY2021 but spent less than the 2020 GMP Annual Report plan, in which the *Monitor* and *Inform* phases were planned to be deployed in 2021. ADMS continues to be foundational towards enabling other technologies and managing the electric grid (e.g., Distribution Automation). Adequate data prep for analysis was completed on 271 out of 1042 potential feeders, 26%, across all regions, with a plan to make 320 feeders ADMS ready. The remainder of data prep is progressing as planned. Finally, National Grid continues to follow a multistep process for data prep by feeder. Preliminary data prep is largely complete, with remainder of data prep work planned for 2022.

Unitil

Unitil's ADMS progress is behind its 2020 GMP Annual Report plan, with 2022 carryover planned spend to continue this progress. This is due in part to the following: first, Unitil faced challenges in coordinating operational IT/OT systems between corporate and non-corporate networks due to cybersecurity concerns; second, a systemic problem was discovered with an underestimate of the level of effort required to prepare data and integrate unavailable data for use in ADMS (e.g., line rating, impedance, and customer usage data); finally, ADMS implementation for Unitil is tied closely with M&C and VVO rollout, constraining how quickly ADMS deployment can proceed.

Statewide Conclusions and Recommendations

The evaluation during the PY2021 and prior periods leads to the following conclusions and recommendations:

Conclusions:

- The implementation of ADMS / ALF continues to experience minor budget issues, delays, and technological hurdles. These types of delays are characteristic across the industry and may be due to the EDCs' lack of experience with implementation of large IT/OT programs. Rather than assuming that they can be identified and mitigated ahead of time, including some budget and schedule flexibility will enable the EDCs to be more successful in implementation.
- Data prep continues to be critical to success across the EDCs. As the ADMS/ALF systems progress to larger adoption, ensuring high data *hygiene* is likely to present itself as a challenge. The "Day 1"[10] problem of ensuring that data remains at an adequate threshold for continued operation of ADMS will persist, and should be addressed.
- ADMS, as an enabling investment, continues to be coupled to other enterprise investments, and this will continue as the EDCs modernize their grid and IT/OT systems.

Recommendations:

- EDCs must absorb the lessons and institutionalize the concept that ADMS will continue to be foundational towards other enabling technologies (e.g., Distribution Automation, M&C, and VVO) and plan for this dependency in future technology implementation.
- As the scope of ADMS implementations increases at the EDCs, continuing to capture, clean, and mature data is of paramount importance. The level of effort required to capture, clean, and mature data continues to be an impediment to successful ADMS implementation and managing this proactively is critical to success.

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[10] "Day 1" is a common parlance in the utility industry to indicate that once you 'go live' with data and systems on the first day, the data needs to be maintained and updated via deliberate processes and systems or else the data quality degrades over time as system changes happen and the data changes do not keep up.

1. Introduction to Massachusetts Grid Modernization

This section provides a brief background to the grid modernization evaluation process along with an overview of the ADMS/ALF Investment Area and specific ADMS/ALF evaluation objectives. These are provided for context when reviewing the subsequent sections that address the specific evaluation process and findings.

1.1 Massachusetts Grid Modernization Plan Background

On May 10, 2018, the Massachusetts Department of Public Utilities (DPU) issued its Order[11] regarding the individual Grid Modernization Plans (GMPs) filed by the three Massachusetts Electric Distribution Companies (EDCs): Eversource, National Grid, and Unitil.[12,13] In the Order, the DPU preauthorized grid-facing investments over 3 years (2018-2020) for each EDC and adopted a 3-year (2018-2020) regulatory review construct for preauthorization of grid modernization investments. On May 12, 2020, the DPU issued an Order[14] extending the 3-year GMP investment term to a 4-year term, including 2018-2021. The company specific GMP budget caps did not change with the term extension. On July 1, 2020, Eversource filed a request for an extension of the budget authorization associated with grid modernization investments.[15] The budget extension, approved by the DPU on February 4, 2021.

The preauthorized GMP investments should advance the achievement of the DPU's grid modernization objectives:

- Optimize system performance by attaining optimal levels of grid visibility, command and control, and self-healing
- Optimize system demand by facilitating consumer price responsiveness
- Interconnect and integrate distributed energy resources (DER)

As part of the GMPs, the DPU determined that a formal evaluation process for the preauthorized GMP investments, including an evaluation plan and studies, was necessary to help confirm the benefits are capitalized on and achieved with greater certainty.

The grid modernization investments were organized into six Investment Areas to facilitate understanding, consistency across EDCs, and analysis.

- Monitoring and Control (M&C)
- Advanced Distribution Automation (ADA)
- Volt/VAR Optimization (VVO)

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[11] DPU Order.

[12] On August 19, 2015, National Grid, Unitil, and Eversource each filed a grid modernization plan with the DPU. The DPU docketed these plans as DPU 15-120, DPU 15-121, and DPU 15-122, respectively.

[13] On June16, 2016, Eversource and National Grid each filed updates to their respective grid modernization plans

[14] Massachusetts DPU 15-120; DPU 15-121; DPU 15-122 (Grid Modernization) Order (1) Extending Current Three-Year Grid Modernization Plan Investment Term; and (2) Establishing Revised Filing Date for Subsequent Grid Modernization Plans (issued May 12, 2020).

[15] Grid Modernization Program Extension and Funding Report. Submitted to Massachusetts DPU on July 1, 2020 as part of DPU 15-122.

- Advanced Distribution Management Systems/Advanced Load Flow (ADMS and ALF)
- Communications/IoT (Comms)
- Workforce Management (WFM)

This report covers the Program Year (PY) 2021 evaluation of Infrastructure and Performance Metrics and focuses on the ADMS/ALF Investment Area. The following subsection discusses these Investment Areas in greater detail.

1.1.1 Investment Areas

Table 5 summarizes the preauthorized GMP investment.

Table 5. Overview of Investment Areas

Investment Area	Description	Goal/Objective
Monitoring and Control (M&C)	Remote monitoring and control of devices in the substation for feeder monitoring or online devices for enhanced visibility outside the substation.	Enhance grid visibility and control capabilities, reliability increase
Advanced Distribution Automation (ADA)	Isolation of outage events with automated backup for unaffected circuit segments.	Reduce the impact of outages
Volt/VAR Optimization (VVO)	Control of line and substation equipment to optimize voltage, reduce energy consumption, and increase hosting capacity.	Optimize distribution voltage to reduce energy consumption and demand
Advanced Distribution Management Systems/Advanced Load Flow (ADMS/ALF)	New capabilities in real-time system control with investments in developing accurate system models and enhancing Supervisory control and data acquisition (SCADA) and outage management systems to control devices for system optimization and provide support for distribution automation and VVO with high penetration of DER.	Enable high penetration of DER by supporting the ability to control devices for system optimization, ADA, and VVO
Communications/IoT	Fiber middle mile and field area communications systems.	Enable the full benefits of grid modernization devices to be realized
Workforce Management (WFM)	Investments to improve workforce and asset utilization related to outage management and storm response.	Improve the ability to identify damage after storms

Sources: Grid Mod RFP – SOW (Final 8-8-18).pdf; Guidehouse

The Massachusetts DPU preauthorized budget for grid modernization varies by Investment Area and EDC. Eversource originally had the largest preauthorized budget at $133 million, with ADA and M&C representing the largest share ($44 million and $41 million, respectively). National Grid's preauthorized budget was $82.2 million, with ADMS/ALF representing over 50% ($48.4 million). Unitil's preauthorized budget was $4.4 million and VVO makes up 50% ($2.2 million).

On July 1, 2020, Eversource filed a request for an extension of the budget authorization associated with grid modernization investments.[16] The budget extension, approved by the DPU on February 4, 2021,[17] includes $14 million for ADA, $16 million for ADMS/ALF, $5 million for Communications, $15 million for M&C, and $5 million for VVO. These values are included in the Eversource total budget by Investment Area in Table 6.

Table 6. 2018-2021 GMP Preauthorized Budget, $M

Investment Areas	Eversource	National Grid	Unitil	Total
ADA	$58.00	$13.40	N/A	**$71.40**
ADMS/ALF	$33.00	$48.40	$0.70	**$79.10**
Communications	$23.00	$1.80	$0.84	**$25.60**
M&C	$56.00	$8.00	$0.35	**$64.75**
VVO	$18.00	$10.60	$2.22	**$30.80**
WFM	$0.00	$0.00	$0.30	**$1.00**
2018-2021 Total	**$188.00**	**$82.20**	**$4.41**	**$272.65**

Sources: DPU Order, May 10, 2018, and Eversource filing GMP Extension and Funding Report, July 1, 2020

The DPU allowed flexibility in these budgets based on changing technologies and circumstances. For example, EDCs can shift funds across the different preauthorized investments if a reasonable explanation for these shifts is supplied. The following subsections discuss these evaluation goals, objectives, and the metrics to be used.

1.1.2 Evaluation Goal and Objectives

The DPU requires a formal evaluation process (including an evaluation plan and evaluation studies) for the EDCs' preauthorized GMP investments. Guidehouse is completing the evaluation to enable a uniform statewide approach and to facilitate coordination and comparability. The evaluation measures the progress made toward the achievement of DPU's grid modernization objectives. The evaluation uses the DPU-established Infrastructure Metrics and Performance Metrics, as well as Case Studies that illustrate the performance of specific technology installations, to help determine if the investments are meeting the DPU's GMP objectives.

1.1.3 Metrics for Evaluation

The DPU-required evaluation involves Infrastructure Metrics and Performance Metrics for each Investment Area. In addition, selected case studies have been added for some Investment Areas (e.g., M&C) as part of the evaluation to help facilitate understanding of how the technology performs in specific instances (e.g., in remediating the effects of a line outage).

[16] Grid Modernization Program Extension and Funding Report. Submitted to Massachusetts DPU on July 1, 2020 as part of DPU 15-122

[17] Massachusetts DPU 20-74 Order issued on February 4, 2021.

1.1.3.1 Infrastructure Metrics

Infrastructure Metrics were designed to evaluate the deployment of the GMP investments. Table 7 summarizes the Infrastructure Metrics.

Table 7. Infrastructure Metrics Overview

Metric		Description	Applicable IAs	Metric Responsibility
IM-1	**Grid-Connected Distribution Generation Facilities**	Tracks the number and type of distributed generation facilities in service and connected to the distribution system.	ADMS/ALF	EDC
IM-2	**System Automation Saturation**	Measures the quantity of customers served by fully or partially automated devices.	M&C, ADA	EDC
IM-3	**Number and Percentage of Circuits with Installed Sensors**	Measures the total number of circuits with installed sensors that will provide information useful for proactive planning and intervention.	M&C	EDC
IM-4	**Number of Devices Deployed and In Service**	Measures how the EDC is progressing with its GMP from an equipment or device standpoint.	All IAs	Evaluator
IM-5	**Cost for Deployment**	Measures the associated costs for the number of devices or technologies installed; designed to measure how the EDC is progressing under its GMP.	All IAs	Evaluator
IM-6	**Deviation Between Actual and Planned Deployment for the Plan Year**	Measures how the EDC is progressing under its GMP on a year-by-year basis.	All IAs	Evaluator
IM-7	**Projected Deployment for the Remainder of the 4-Year Term**	Compares the revised projected deployment with the original target deployment as the EDC implements its EDC.	All IAs	Evaluator

IM = Infrastructure Metric, IA = Investment Area

Source: Guidehouse review of Infrastructure Metric filings

1.1.3.2 Performance Metrics

Table 8 summarizes the Performance Metrics, which are used to evaluate the performance of the GMP investments.

Table 8. Performance Metrics Overview

Metric		Description	Applicable IAs	Metric Responsibility
PM-1	**VVO Baseline**	Establishes a baseline impact factor for each VVO-enabled circuit, which will be used to quantify the peak load, energy savings, and greenhouse gas (GHG) impact measures.	VVO	All
PM-2	**VVO Energy Savings**	Quantifies the energy savings achieved by VVO using the baseline established for the circuit against the annual circuit load with the intent of optimizing system performance.	VVO	All
PM-3	**VVO Peak Load Impact**	Quantifies the peak demand impact VVO/conservation voltage reduction (CVR) has on the system with the intent of optimizing system demand.	VVO	All
PM-4	**VVO Distribution Losses without Advanced Metering Functionality (AMF) (Baseline)**	Presents the difference between circuit load measured at the substation via the SCADA system and the metered load measured through advanced metering infrastructure (AMI).	VVO	All
PM-5	**VVO Power Factor**	Quantifies the improvement that VVO/CVR is providing toward maintaining circuit power factors near unity.	VVO	All
PM-6	**VVO – GHG Emissions**	Quantifies the overall GHG impact VVO/CVR has on the system.	VVO	All
PM-7	**Voltage Complaints**	Quantifies the prevalence of voltage-related complaints before and after deployment of VVO investments to assess customer experience, voltage stability under VVO.	VVO	All
PM-8	**Increase in Substations with Distribution Management System (DMS) Power Flow and Control Capabilities**	Examines the deployment and data cleanup associated with deployment of ADMS/ALF, primarily by counting and tracking the number of circuits and substations per year.	ADMS/ ALF	All

Metric		Description	Applicable IAs	Metric Responsibility
PM-9	**Control Functions Implemented by Circuit**	Examines the control functions of DMS power flow and control capabilities, focused on the control capabilities including VVO/CVR and fault location isolation and service restoration (FLISR).	ADMS/ ALF	All
PM-11	**Numbers of Customers that Benefit from GMP-Funded Distribution Automation Devices**	Shows the progress of ADA investments by tracking the number of customers that have benefitted from the installation of ADA devices.	ADA	ES, NG
PM-12	**Grid Modernization Investments' Effect on Outage Durations**	Provides insight into how M&C investments can reduce outage durations (CKAIDI). Compares the experience of customers on GMP M&C-enabled circuits as compared to the previous 3-year average for the same circuit.	M&C, ADA	All
PM-13	**Grid Modernization Investments' Effect on Outage Frequency**	Provides insight into how M&C investments can reduce outage frequencies (CKAIFI). Compares the experience of customers on M&C-enabled circuits as compared to the prior 3-year average for the same circuit.	M&C, ADA	All
PM-ES1	**Advanced Load Flow – Percent Milestone Completion**	Examines the fully developed ALF capability across Eversource's circuit population.	ADMS/ ALF	ES
PM-ES2	**Protective Zone: Average Zone Size per Circuit**	Measures Eversource's progress in sectionalizing circuits into protective zones designed to limit outages to customers located within the zone.	ADA	ES
PM-UTL1	**Customer Minutes of Outage Saved per Circuit**	Tracks time savings from faster AMI outage notification than customer outage call, leading to faster outage response and reduced customer minutes of interruption.	M&C	UTL
PM-NG1	**Main Line Customer Minutes of Interruption Saved**	Measures the impact of ADA investments on the customer minutes of interruption (CMI) for main line interruptions. Compares the CMI of GMP ADA-enabled circuits to the previous 3-year average for the same circuit.	ADA	NG

Metric		Description	Applicable IAs	Metric Responsibility
PM-Other*	**Distributed Generation (DG) Interconnection Queue Wait Time**	Estimates the difference in queue wait time between circuits with and without ALF based on publicly filed data.	ALF	ES

PM = Performance Metric, IA = Investment Area, ES = Eversource, NG = National Grid, UTL = Unitil
*This is not a DPU stamp-approved metric. This Performance Metric was added as an evaluation metric to help better understand the investment's ability to meet one of the three DPU grid modernization objectives: "Interconnect and integrate distributed energy resources (DER)." However, it is not one of the DPU Stamped Approved Metrics. As Eversource ALF was enabled in Q4 PY2020, DG Interconnection Queue Wait Time is evaluated in this report.
Source: Stamp Approved Performance Metrics, July 25, 2019

Performance Metrics that pertain specifically to the ADMS/ALF Investment Area are discussed in this report.

1.2 ADMS/ALF Investment Area Overview

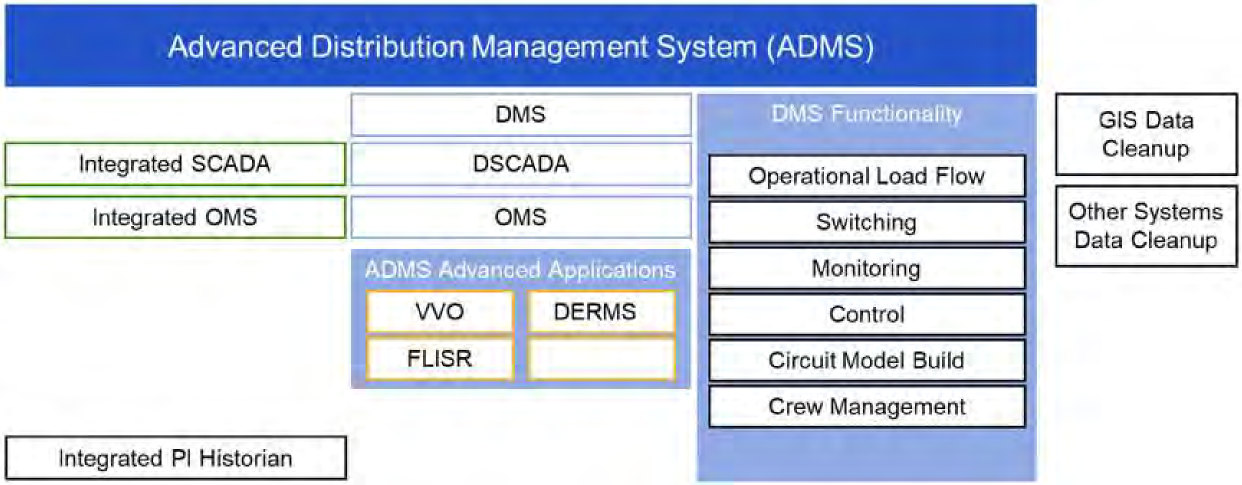
ADMS/ALF is a software platform investment fundamental to a modernized grid. ADMS consists of a combination of SCADA, outage management systems (OMSs), DMSs, and advanced applications such as operational power flow, VVO, FLISR, and DER management systems (DERMS). The capabilities of ADMS are key to delivering on all three of the DPU's grid modernization objectives. These objectives include the ability to control devices for system optimization, provide support for ADA and VVO, and serve as an enabling platform to support a high penetration of DER. As identified in the 2020 Grid Modernization Annual Reports, filed by the EDCs on April 1, 2021, and the PY2021 EDC Data Request, received by the EDCs in early 2022, the ADMS/ALF investments totaled to $40.28 million from 2018 to 2021:

- $22.93 million by Eversource
- $17.02 million by National Grid
- $0.33 million by Unitil

There is an additional total of $10.55 million across all EDCs for ADMS/ALF investments that began in 2021 but are planned to be carried over and completed in 2022. This includes carryover of $10.40 million for Eversource and $0.15 million for Unitil.

Figure 1 shows the typical components of an ADMS. This diagram shows the intrinsic and integrated components of an ADMS and a functionality stack related to the DMS component of the ADMS. The components and functionality are foundational to the industry status of ADMS and serve as the consistent picture for evaluating ADMSs at the EDC. Each of the EDCs are implementing solution components, integration, and functionality and are supporting data cleanup with different plans and timeframes in response to the Investment Area and their needs.

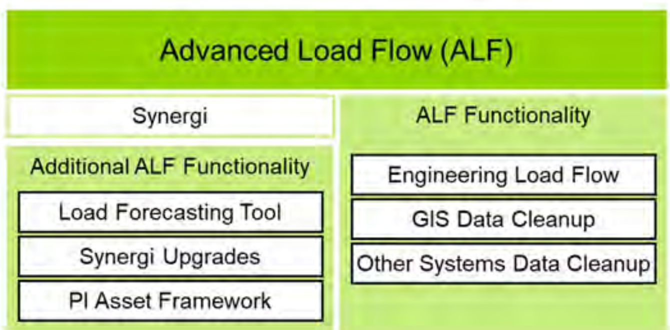
Figure 1. ADMS Evaluation Components and Functionality



Source: Guidehouse

The ALF context is shown in Figure 2. This diagram shows Synergi and a functionality stack related to the data cleanup component of ALF. The components and functionality shown in the figure are foundational to the industry definition of ALF and serve as the consistent picture for evaluating ALF at Eversource. Previously (in PY2020) Eversource added three components to its ALF investment plan: a load forecasting tool, Synergi upgrades, and a PI asset framework.

Figure 2. ALF Evaluation Components and Functionality



Source: Guidehouse

1.3 ADMS/ALF Evaluation Objectives

This evaluation focuses on the progress and effectiveness of the DPU preauthorized ADMS and ALF investments for each EDC toward meeting the DPU's grid modernization objectives.[18] Table 9 and Table 10 illustrate the key metrics on which the evaluation reports, including two Infrastructure Metrics and three Performance Metrics as well as several "other" metrics that can help provide understanding of progress.

[18] DPU Order, May 10, 2018, p.106.

Table 9. ADMS Evaluation Metrics

Metric Type	ADMS Evaluation Metrics	ES	NG	UTL
IM	Deviation between actual and planned deployment for the plan year	✓	✓	✓
IM	Projected deployment for the remainder of the 4-year term	✓	✓	✓
PM	Increase in circuits and substations with DMS power flow and control capabilities	✓	✓	✓
PM	Control functions implemented by circuit and substation	✓	✓	✓
Other*	DMS implementation (planning, procurement, development, deployment, go-live)	✓	✓	✓
Other	Distribution SCADA (DSCADA) implementation or integration (planning, procurement, development, deployment, go-live)	✓	✓	✓
Other	OMS implementation or integration (planning, procurement, development, deployment, go-live)	✓	✓	✓
Other	Cleanup of geographic information system (GIS) data by circuit, substation, and region		✓	
Other	Cleanup of other data by circuit, substation, and region		✓	

IM = Infrastructure Metric, PM = Performance Metric, ES = Eversource, NG = National Grid, UTL = Unitil
* The “Other” metric type applies to metrics not specifically outlined by the DPU but that will be measured to understand aspects of ADMS/ALF for a comprehensive evaluation. See Guidehouse Stage 3 Evaluation Plan filed December 1, 2020.

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020; Stamp Approved Performance Metrics, July 25, 2019

Table 10. ALF Evaluation Metrics

Metric Type	ALF Evaluation Metrics	ES	NG	UTL
IM	Deviation between actual and planned deployment for the plan year	✓		
IM	Projected deployment for the remainder of the 4-year term	✓		
PM	Advanced load flow – percent milestone completion	✓		
Other*	Data cleanup of GIS and other systems by circuit, substation, sub-region, and region	✓		
Other	Use of load flow tools for engineering (e.g., CYME, Synergi) by percentage of service territory	✓		
Other	Percentage of region and sub-region using automated scripting on a monthly basis	✓		
Other	Use of near-real-time system telemetry in load flow analysis	✓		
Other**	Percentage of DG interconnection requests that use advanced load flow investment	✓		
Other	Comparison of reduction in average DG interconnection request between ALF-enabled vs. non-ALF-enabled feeders	✓		

IM = Infrastructure Metric, PM = Performance Metric, ES = Eversource, NG = National Grid, UTL = Unitil
* The “Other” metric type applies to metrics not specifically outlined by the DPU but that will be measured to understand additional aspects of ADMS/ALF for a comprehensive evaluation. See Guidehouse Stage 3 Evaluation Plan filed December 1, 2020.
**This is not a DPU stamp-approved metric. This PM has been added as an evaluation metric to help better understand the investment’s ability to meet one of the 3 DPU grid modernization objectives: “Interconnect and integrate distributed energy resources (DER);” However, it is not one of the DPU Stamped Approved Metrics. Eversource ALF was enabled in Q4 PY2020, DG Interconnection Queue Wait Time is a potential future PM.

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020; Stamp Approved Performance Metrics, July 25, 2019

The EDCs provided the data supporting the Infrastructure Metrics to the evaluation team. The Infrastructure Metrics analysis measures whether the investments are taking place on the projected schedule and budget. The Performance Metrics are based on statistical analyses performed by the evaluation team using data provided by each EDC. The results from the analysis of Infrastructure Metrics and Performance Metrics are included in Sections 3.2 and 4.2, respectively.

The scope of the ADMS/ALF evaluation includes tracking the ADMS/ALF software implementation against plan, data cleanup progress, and cost. Table 11 presents the research questions associated with the ADMS/ALF evaluation objectives.

Table 11. ADMS/ALF Evaluation Objectives and Associated Research Questions

ADMS/ALF Evaluation Objective	Associated Research Questions
Software Implementation	• How do the ADMS and ALF investments align with optimizing system performance, optimizing system demand, and enabling interconnection and integration of DER? • What is each EDC's specific investment plan strategy for ADMS and ALF implementation (components and timeframes) during the preauthorized investment period, 2018-2021? • What does each EDC plan to leverage as a baseline ADMS and ALF application/component stack (GIS, PI Historian, DSCADA, OMS, Synergi, other systems, or other)? • What does each EDC plan to do related to ADMS functionality, including operational load flow, VVO, FLISR, and DERMS? • What does each EDC plan to do related to ALF functionality, including static analysis, semiautomated analysis, and fully automatic analysis? • What is the specific timing of ADMS implementation, integration with supporting systems, and data cleanup in GIS and other systems?
Data Cleanup	• What is the specific timing of ALF investment components including GIS data cleanup, other system data cleanup, and Synergi implementation?

Source: Guidehouse

2. ADMS/ALF Evaluation Process

This section summarizes Guidehouse's methodologies for evaluating Infrastructure Metrics and Performance Metrics, which were the focus of this PY2021 ADMS/ALF evaluation. ADMS/ALF data cleanup and planning are ongoing, and the use of ADMS/ALF functionality has begun. Figure 3 highlights the filing background and timeline of the GMP order and the evaluation process.

Figure 3. ADMS/ALF Evaluation Timeline

Source: Guidehouse review of the DPU orders and GMP process

2.1 Infrastructure Metrics Analysis

Guidehouse annually assesses the progress of each of the EDCs toward enabling ADMS/ALF on their feeders and substations. Table 12 highlights the Infrastructure Metrics that were evaluated. Although Infrastructure Metrics are the same across all Investment Areas, ADMS/ALF investments are not tracked by device. Instead, ADMS/ALF investments are tracked by technology or software implementation. Throughout this report, the term technology or software implementation is used instead of device deployment, which is more pertinent to some of the other Investment Areas.

Table 12. Infrastructure Metrics Overview

Infrastructure Metrics			Calculation
IM-4	Number of devices or other technologies deployed thru. PY2021	# Devices Deployed	$\sum_{PY=2018}^{2021} (Devices\ Commissioned)_{PY}$
		% Devices Deployed	$\frac{\sum_{PY=20}^{2021} (Devices\ Commissioned)_{PY}}{\sum_{PY=2018}^{2020} (Devices\ Commissioned)_{PY} + (Planned\ Devices)_{PY2021}}$
IM-5	Cost through PY2021	Total Spend, $M	$\sum_{PY=2018}^{2021} (Actual\ Spend)_{PY}$
		% Spend	$\frac{\sum_{PY=2018}^{2021} (Actual\ Spend)_{PY}}{\sum_{PY=2018}^{2020} (Actual\ Spend)_{PY} + (Planned\ Spend)_{PY2021}}$

IM-6	Deviation Between Actual and Planned Deployment for PY2021	% On Track (Devices)	$\frac{(Devices\ Commissioned)_{PY2021}}{(Planned\ Devices)_{PY2021}}$
		% On Track (Spend)	$\frac{(Actual\ Spend)_{PY2021}}{(Planned\ Spend)_{PY2021}}$
IM-7*	Projected Deployment for the remainder of the GMP Term*	# Devices Remaining	$(Devices\ Planned)_{CY2022}$
		Spend Remaining, $M	$(Planned\ Spend)_{CY2022}$

* This metric has been interpreted here (i.e. within the context of the ADMS/ALF 2021 Program Year Evaluation) as the "carryover" spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals (note that # devices is not applicable for ADMS/ALF investment). These most recent plan totals were included in each EDC's *Grid Modernization Plan Annual Report 2020* (filed on April 1, 2021), which listed the planned units and spending to be completed in PY2021.

Source: Guidehouse

Section 3 provides the results from the evaluation of Infrastructure Metrics. To evaluate Infrastructure Metrics, Guidehouse:

- Reviewed the EDC data provided to ensure the information provided accurately reflected progress through PY2021 (see Section 3.1.2).
- Interviewed representatives from each EDC to understand the status of the ADMS/ALF investments, including:
    - Updates to their planned ADMS/ALF investments.
    - Reasons for deviation between actual and planned deployment and spend.

2.2 Performance Metrics Analysis

Performance Metrics were evaluated for each of the three EDCs. The EDCs have proposed to score and then count the number of substations with fully implemented and successful ADMS power flow analysis and the number of circuits with the specified control functions implemented. For ALF, Eversource proposed a metric designed to demonstrate progress toward the final completion of a fully automated modeling tool. Table 13 describes the Performance Metrics evaluated for PY2021.

Table 13. Performance Metrics Overview

PM	Performance Metrics	Description
PM-8	**Increase in Circuits and Substations with DMS Power Flow and Control Capabilities**	• Increase in circuits and substations with DMS power flow and control capabilities. • Primary Performance Metric to examine the deployment and data cleanup associated with ADMS deployment (situational awareness, basic power flow, switching, restoration capabilities). • The assumption is that data must be ready and fully clean prior to ADMS deployment, allowing converging power flow on specific circuits and substations. Counting and tracking the number of circuits and substations per year is the primary component of this Performance Metric.
PM-9	**Control Functions Implemented by Circuit and Substation**	• Control functions implemented by circuit and substation. • Secondary Performance Metric to examine implementation of advanced applications (e.g., automated capabilities, VVO, CVR, FLISR)
PM-ES-1	**Advanced Load Flow – Percent Milestone Completion**	• Percent milestone completion of circuits (100% of planned circuits) with ALF capabilities. • Addresses Eversource narrowly and examines the fully developed ALF capability across its circuit population. This includes components of the hosting capacity maps that Eversource is now addressing.
PM-Other	**DG Interconnection Queue Wait Time**	• DG Interconnection Queue Wait Time is a proposed PM to be evaluated in the future when there is sufficient data to evaluate. • Comparison of reduction in average DG interconnection queue wait time between ALF-enabled vs. non-ALF-enabled feeders.* Reduction in average timing of DG interconnection requests for all EDCs across Massachusetts. • The work done on ALF and Synergi upgrades during the PY2018-2021 term is not expected to have any measurable impact on the interconnection study process.

PM = Performance Metric
Note: Potential metrics in the future would be to assess the implementation and functionality of ADMS-based advanced applications such as ADMS-based VVO and ADMS-based FLISR.
*Depending on availability of appropriate data.
Source: Stamp Approved Performance Metrics, July 25, 2019

3. ADMS/ALF Infrastructure Metrics

3.1 Data Management

Guidehouse worked with the EDCs to collect data to complete the ADMS/ALF evaluation for the assessment of Infrastructure Metrics and Performance Metrics. The following sections highlight the evaluation team's data sources and data quality assurance/quality control (QA/QC) processes used to evaluate the Infrastructure Metrics.

3.1.1 Data Sources

Guidehouse used a consistent methodology (across Investment Areas and EDCs) to evaluate the data and illustrate EDC progress toward the GMP metrics. The data sources are summarized as follows.

3.1.1.1 2020 Grid Modernization Plan Annual Report

Guidehouse used the planned cost information from each EDCs' *2020 GMP Annual Reports*, which were filed on April 1, 2021. These filings served as the sources for planning data in this report and are referred collectively as the *GMP Plan* for each EDC in summary tables and figures throughout this report.

Table 14 provides a legend of the different planned and actual quantities reviewed and specifies the color/shade used to represent each in the remainder of the report.

Table 14. Deployment Categories Used for the EDC Plan

Representative Color	Data	Description
	2021 Plan	Projected 2021 unit deployment and spend
	2020 Actual	Actual reported unit deployment and spend in 2020
	2019 Actual	Actual reported unit deployment and spend in 2019
	2018 Actual	Actual reported unit deployment and spend in 2018

Source: Plan and actual data is sourced from the EDCs' 2020 GMP Annual Report Appendix 1 filed April 1, 2021.

3.1.1.2 EDC Data Sources

Guidehouse collected device deployment data and ADMS/ALF implementation at the feeder- and substation-level using standardized data collection templates. Guidehouse developed these templates for all EDCs: the *GMP All Device Deployment data* and *ADMS_ALF_Supplemental* workbooks, respectively. These data sources are referred to as *EDC Data* in summary tables and figures throughout the report. Table 15 summarizes the file versions used for the evaluation. The collected data was compared to the data submitted by the EDCs to the DPU in the 2021 Grid Modernization Plan Annual Reports and associated Appendix 1 filings.[19,20,21] The evaluation team confirmed the consistency of the data from the various sources and reconciled any differences.

Table 15. All Device Deployment and Supplemental Data Files Versions for Analysis

Company	File Version Used for Analysis[22]	
	All Device Deployment	ADMS Supplemental
Eversource	Received 2/2/2022	Received 2/14/2022
National Grid	Received 2/4/2022	Received 3/7/2022
Unitil	Received 2/4/2022	Received 3/2/2022

Source: Guidehouse

The EDC device deployment data (collected in the *All Device Deployment* workbook) captured planned and actual device deployment and spend data. Actual device deployment and cumulative spend information were provided by work order ID and specified at the feeder- or substation-level, as appropriate.

The implementation stage of the work order (commissioned, in service, construction, or design/engineering), the commissioned date (if applicable), and all cumulative costs associated with the work order were also collected. Planned device deployment information and estimated spend for PY2021 was provided by the EDCs at the most granular level (circuit or substation) available. Table 16 summarizes the categories used for the revised planned and actual deployment and spend and specifies the color and pattern used in bar graphs to represent each in the remainder of the report.

[19] Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2022. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 22-41
[20] NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-40
[21] Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-42
[22] Some minor additional updates to specific work orders were addressed after these dates via email.

Table 16. EDC Device Deployment Data

Representative Color	Data	Description
	2022 Carryover	Projected 2022 spend
	2021 Actual	Actual 2021 spend
	2020 Actual	Actual 2020 spend
	2019 Actual	Actual 2019 spend
	2018 Actual	Actual 2018 spend

Source: Guidehouse analysis

3.1.2 Data QA/QC Process

To enable accuracy, Guidehouse conducted a high-level QA/QC of all device deployment data received. This review involved following up with the EDCs for explanations regarding the following:

- Potential errors in how the forms were filled out (e.g., circuit information provided in the wrong field)
- Missing or incomplete information
- Large variation in the unit cost of commissioned devices
- Variance between the aggregated totals by device/technology and work order-level data
- Variance between the actual unit costs and planned unit costs

3.2 Deployment Progress and Findings

Guidehouse presents findings from the Infrastructure Metrics analysis for the ADMS/ALF Investment Area in the following subsections.

3.2.1 Statewide Comparison

This section discusses statewide ADMS/ALF investment progress through PY2021 and projected PY2022 progress.

Table 17 presents the Infrastructure Metric results through PY2021 for all EDCs. Additional detail surrounding findings for each Infrastructure Metric are provided in the other subsections below. Although several Infrastructure Metrics track progress by *device* for the various Investment Areas, ADMS/ALF investments are not tracked by device. Instead, ADMS/ALF investments are tracked by technology or software implementation. Throughout the remainder of the report, the term *technology* or *software implementation* is used instead of device deployment.

Table 17. ADMS/ALF Infrastructure Metrics Summary

Infrastructure Metrics			Eversource*	National Grid	Unitil
GMP Plan Total, 2018-2021		Devices	0	0	0
		Spend, $M	$28.16	$19.29	$0.60
IM-4	Number of devices or other technologies deployed through PY2018-2021*	# Devices Deployed	N/A	N/A	N/A
		% Devices Deployed	N/A	N/A	N/A
IM-5	Cost for Deployment through PY2018-2021*	Total Spend, $M	$22.61	$17.02	$0.33
		% Spend	80%	88%	56%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	N/A	N/A	N/A
		% On Track (Spend)	57%	75%	38%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	N/A	N/A	N/A
		Spend Remaining, $M	$10.87	$0.00	$0.15

Note: For ADMS/ALF, ‘0 devices’ means there is no hardware deployment.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the “carryover” spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs’ 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

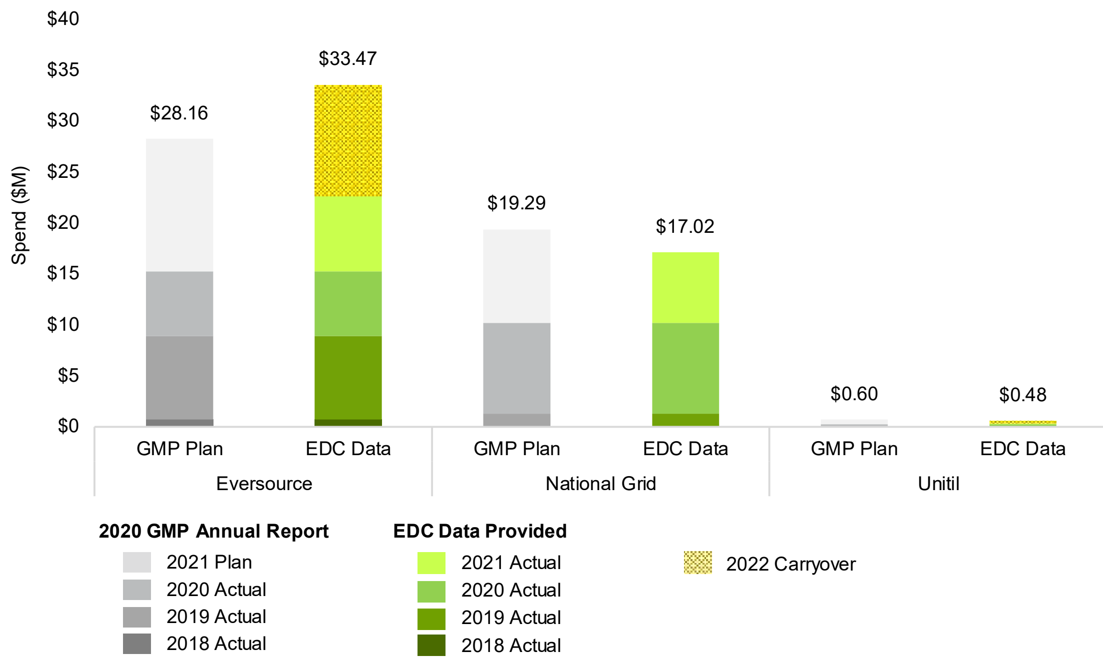
All three EDCs have operating territories that include Massachusetts and surrounding states. The ADMS/ALF programs include investments in Massachusetts as evaluated in this report.

Regions that contain feeders with planned ADMS/ALF investments include the following within the evaluation period:

- **Eversource:** All Massachusetts operating territory
- **National Grid:** All Massachusetts operating territory
- **Unitil:** Cities/towns of Fitchburg, Townsend, and Lunenburg

Error! Reference source not found. compares the GMP plans and EDC data totals and year-over-year spending for each EDC.

Figure 4. ADMS/ALF Spend Comparison (2018-2021, $M)



Note: Includes the Eversource planned spend for PY2021, set forth the in the GMP Extension and Funding Report, filed on July 1, 2020.

Source: Guidehouse analysis of 2020 GMP Annual Reports, "GMP Extension and Funding Report," and 2021 EDC Data

For Eversource and National Grid, O&M spending toward the GIS Survey[23] investment is included in the tables and figures. In addition to the PY2021 capital costs and GIS survey costs shown in **Error! Reference source not found.**, Eversource incurred approximately $0.51 million toward Administration and Regulatory costs across the GMP investments in PY2021. National Grid incurred approximately $1.74 million in O&M costs toward the ADMS/ALF Investment Area in PY2021. National Grid incurred approximately $900,000 toward Administration and Regulatory costs across the GMP investments in PY2021. Unitil incurred approximately $19,500 toward Administration and Regulatory costs across the GMP investments in PY2021.

3.2.1.1 Key Findings

Infrastructure Metric findings for PY2021 show that the EDCs are progressing their ADMS/ALF deployment but are behind in spending relative to where they anticipated in their 2020 GMP Annual Reports.

- Eversource completed Synergi Upgrades in PY2021 and enabled full ALF automation build. ADMS, Forecasting Tool, and PI Asset Framework had budget underruns in

[23] For Eversource, GIS Survey is also referred to as GIS Verification.

PY2021 due to delayed start accommodating February 2021 DPU Approval. The 2022 carryover is projected to go over the total budget by about $5M.

- National Grid ADMS deployment milestones are on track, data prep is progressing as planned. National Grid has a budget underrun by about $2.3M due to reduction in ADMS scope based on learnings obtained in the evaluation period.
- Unitil is continuing its ADMS implementation to a limited set of locations which are tied closely to their M&C and VVO investments.

3.2.2 Eversource

This section discusses Eversource's ADMS/ALF investment progress through PY2021 and its projected PY2022 progress as compared to the 2020 GMP Annual Report.

3.2.2.1 Overview of GMP Deployment Plan

Table 18 presents the GMP objectives that Eversource aims to achieve with its ADMS/ALF implementation.

Table 18. Eversource ADMS/ALF GMP Objective Summary

Company	GMP Objective	Software Implementation
Eversource	Implement ALF and ADMS throughout the region to: • Increase visibility • Enhance the grid for DER customers • Increase DER hosting capacity	ADMS • ADMS work in PY2021 was foundational, no specific circuits planned to be ADMS-enabled in 2021.
		ALF • Implemented enhanced semi-automatic ALF analysis on all planned circuits. • Deployed ALF on 2,242 circuits across 246 substations. • Synergi Upgrades completed in 2021 and enabled full ALF automation build.
		Load Forecasting Tool[24] • Improve capability for long-term load forecasting. • Add new capability for long-term DER forecasting.
		Synergi Upgrades[25] • Evolution and refinement of the ALF tool capability to build upon what has been implemented. • Initial step in producing a precise hosting capacity value on the Massachusetts distribution network.
		PI Asset Framework[26] • Data analytics tool to provide insight into the impact of DER on system operations and establish a more uniform data model for historical data.

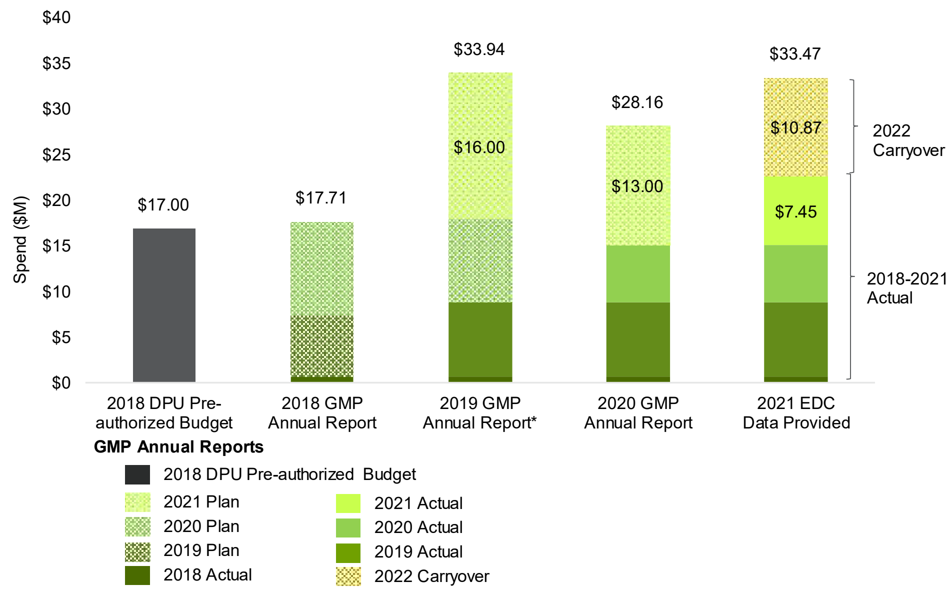
Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

3.2.2.2 ADMS/ALF Deployment Plan Progression

Figure 5 presents the costs, planned and actual, for Eversource's ADMS/ALF investment over the GMP term. Costs for Eversource's ADMS investment over this expanded 4-year GMP term are reflected in the figure.

[24] New device investment added in 2021: load forecasting tool.
[25] New device investment added in 2021. Synergi upgrades.
[26] New device investment added in 2021. PI asset framework.

Figure 5. Eversource ADMS/ALF Planned and Actual Spend Progression, $M



Notes: GIS survey is O&M spending, but is included in this figure as it makes up a significant portion of the total spending. Chart includes the Eversource plan for 2021, set forth in the *GMP Extension and Budget* filing on July 1, 2020.

Source: Guidehouse analysis of DPU Order (May 10, 2018), 2018-2020 GMP Annual Reports, GMP Extension and Funding Report filed on July 1, 2020, and *2021 EDC Data*

There was a budget underrun for ADMS/ALF for PY2021, including Forecasting Tool, and PI Asset Framework. However, Eversource plans carryover investment in 2022 that will bring the total spending to above previous plan, and very close to the pre-authorized budget after the term extension made by the Department in 2020. This carryover is primarily due to the pause taken prior to the February 2021 DPU Approval.

3.2.2.3 ADMS/ALF Progress through PY2021

Eversource's ADMS/ALF investment is on track with its revised plan once the carryover is included, with a slight budget underrun of ADMS implementation when viewing costs incurred during calendar year 2021. Eversource tracks ADMS/ALF costs in six different areas, including:

- **ALF.** ALF PY2021 costs are associated with some minor reallocation of budget after completion of the 2020 project.
- **GIS.** Although GIS survey spending is categorized as O&M spending, it is included as part of the ADMS/ALF Investment Area for Eversource because it makes up a significant portion of the ADMS/ALF budget.
- **ADMS.** There was a budget underrun for ADMS in PY2021 due to delayed start accommodating February 2021 DPU Approval. ADMS implementation is planned to continue in 2022.

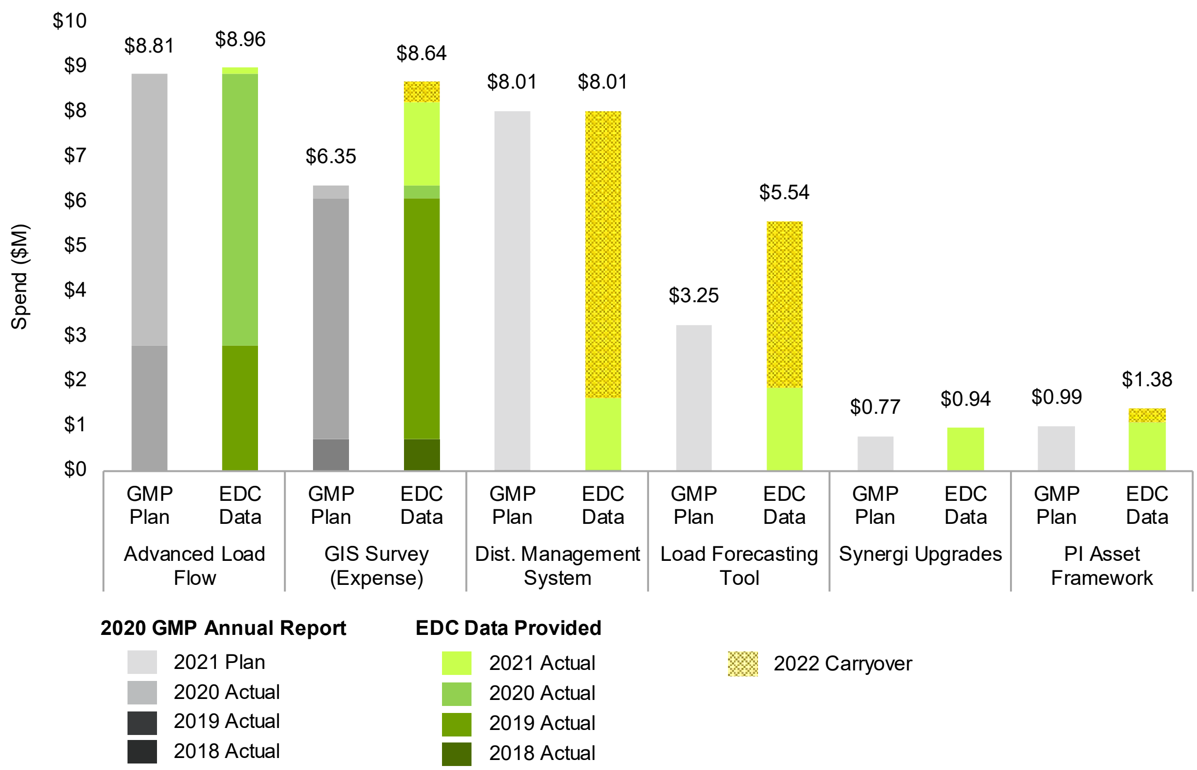
- **Load Forecasting.** There was a budget underrun for Forecasting Tool in PY2021 due to delayed start accommodating February 2021 DPU Approval.

- **Synergi Upgrades.** Synergi Upgrades were completed in 2021 and enabled full ALF automation build. There was a slight budget overrun for Synergi Upgrades due to the Infosys CED GUI development work for Hosting Capacity Maps not being accounted for in the original PAF (Project Approval Form) estimate.

- **PI Asset Framework.** There was a budget underrun for PI Asset Framework in PY2021 due to delayed start accommodating February 2021 DPU Approval.

Figure 6 summarizes the planned and actual technology implementation progress for Eversource's ADMS/ALF investment in each of these six areas.

Figure 6. Eversource ADMS/ALF Spend Comparison (2018-2021, $M)



Notes: GIS survey is O&M spending, but is included in this figure as it makes up a significant portion of the total spending.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Error! Reference source not found.19 presents additional detail for the totals shown in Figure 6: the of total planned and actual spend for Eversource's ALF/ADMS investment during the evaluation period.

Table 19. Eversource ADMS/ALF Plan and Actual Spend (2018-2021, $M)

	Advanced Load Flow	GIS Survey (Expense)	Dist. Management System	Load Forecasting Tool	Synergi Upgrades	PI Asset Framework
2018-2021 Total	$8.96	$8.18	$1.60	$1.84	$0.94	$1.08
PY 2022 Estimate	$0.00	$0.47	$6.40	$3.70	$0.00	$0.30
PY 2021 Actual	$0.15	$1.83	$1.60	$1.84	$0.94	$1.08
PY 2020 Actual	$6.03	$0.28	$0.01	$0.00	$0.00	$0.00
PY 2019 Actual	$2.78	$5.36	$0.00	$0.00	$0.00	$0.00
PY 2018 Actual	$0.00	$0.71	$0.00	$0.00	$0.00	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

3.2.2.4 Infrastructure Metrics Results and Key Findings

Error! Reference source not found.20 presents the Infrastructure Metrics results through PY2021 for Eversource.

Table 20. Eversource ADMS/ALF: Infrastructure Metrics Summary

Infrastructure Metrics			Advanced Load Flow	GIS Survey (Expense)	Dist. Management System	Load Forecasting Tool	Synergi Upgrades	PI Asset Framework
GMP Plan Total, PY2018-2021		Devices	0	0	0	0	0	0
		Spend, $M	$8.81	$6.35	$8.01	$3.25	$0.77	$0.99
IM-4	Number of devices or other technologies deployed through PY2018-2021*	# Devices Deployed	N/A	N/A	N/A	N/A	N/A	N/A
		% Devices Deployed	N/A	N/A	N/A	N/A	N/A	N/A
IM-5	Cost for Deployment through PY2018-2021*	Total Spend, $M	$8.96	$8.64	$1.60	$1.84	$0.94	$1.08
		% Spend	102%	129%	20%	57%	123%	109%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	N/A	N/A	N/A	N/A	N/A	N/A
		% On Track (Spend)	N/A	N/A	20%	57%	123%	109%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	N/A	N/A	N/A	N/A	N/A	N/A
		Spend Remaining, $M	$0.00	$0.47	$6.40	$3.70	$0.00	$0.30

Note: For ADMS/ALF, '0 devices' means there is no hardware deployment. For Eversource, IM-6 denotes 'N/A' because there was no 2021 Plan Spend for ALF and GIS.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the "carryover" spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs' 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

Key findings related to Eversource's progress include the following:

- Synergi Upgrades completed in 2021 and enabled full ALF automation build
- GIS verification in Western MA completion delayed due to contractor personnel availability (potentially Covid-related)
- Budget underrun for ADMS, Forecasting Tool, and PI Asset Framework in PY2021 due to delayed start but with a plan for catching up in 2022

Guidehouse's review of Eversource's ADMS/ALF progress confirmed that Eversource is in line with where it expected to be in its 2020 GMP Annual Report with some budget underrun, but with a plan for using carryover funding to complete the investment during 2022.

3.2.3 National Grid

This section discusses National Grid's ADMS investment progress through PY2021 and projected 2022 carryover progress as compared to the prior plan presented in the 2020 GMP Annual Report.

3.2.3.1 Overview of GMP Deployment Plan

Table 21 presents the GMP objectives that National Grid aims to achieve with its ADMS implementation overall. In 2021, the ADMS investment moved forward with data preparation and clean-up on planned circuits.

Table 21. National Grid Summary

Company	GMP Objective	Software Implementation
National Grid	Using ADMS to optimize: • Performance • Demand • DER integration ADMS also helps reach the overall reliability and customer experience objectives.	ADMS • 320 feeders planned to be ADMS ready, out of a total 1042 potential feeders. • Three-phase implementation approach: – Monitor and inform – Manage and control – Implement DERMS

Source: Guidehouse analysis of 2020 GMP Annual Reports and EDC Data

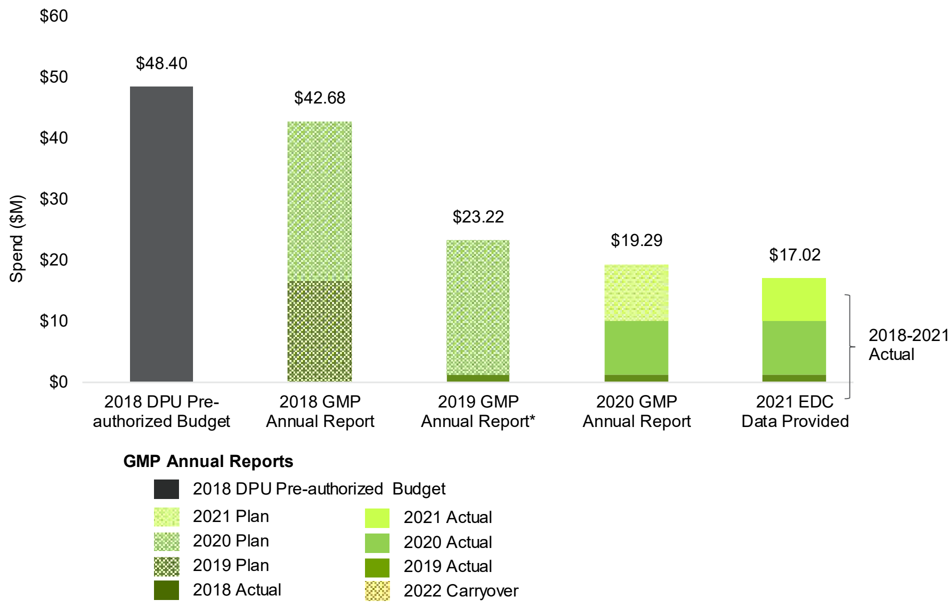
3.2.3.2 ADMS Deployment Plan Progression

Figure 7 presents the costs, planned and actual, for National Grid's ADMS investment over the GMP evaluation period. National Grid has spent less on their ADMS investment than its 2020 GMP Annual Report plan. National Grid has a budget underrun by about $2.3M due to reduction in ADMS scope based on learnings obtained in the evaluation period and additional drivers of reduced spending. Learnings included:

- organizational realignment to effectively manage related transformational programs (which included ADMS) to maximize operational benefits and reduce overlap
- addition of new roles that were identified during the design phase of the project.
- Successful business integration, adoption and benefits realization from systems/applications was ensured through resourcing of proper skill sets for business process analysis, use case alignment, change assessment, governance and controls.
- Resourcing challenges created a slower than expected ramp up for the project, due to a tight job market and niche skillsets required

- favorable vendor contracts for hardware and software led to reduced spending
- reduced travel by internal and external labor due to Covid-19 restrictions, and a delay of hardware receivables due to Covid-19 supply chain constraints

Figure 7. National Grid ADMS Planned and Actual Spend Progression, $M



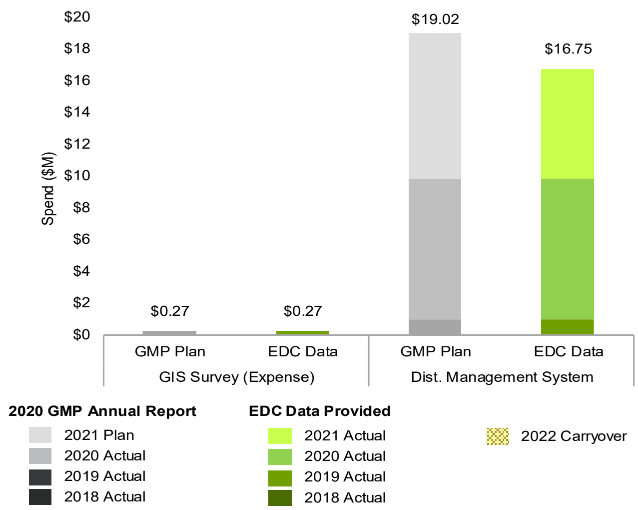
Notes: GIS survey is O&M spending, but is included in this figure as it makes up a significant portion of the total spending.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

3.2.3.3 ADMS Progress through PY2021

Figure 8 summarizes the total spend for National Grid's ADMS investment over the 3-year evaluation period. ADMS spending is estimated to be less than planned.

Figure 8. National Grid ADMS Spend Comparison (2018-2021, $M)



Notes: GIS survey is O&M spending, but is included in this figure as it makes up a significant portion of the total spending.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 22 presents the total planned and actual spend for National Grid's ADMS investment during the evaluation period.

Table 22. National Grid ADMS Plan and Actual Spend (2018-2021, $M)

	GIS Survey (Expense)	Dist. Management System
2018-2021 Total	$0.27	$16.75
PY 2021 Actual	$0.00	$6.92
PY 2020 Actual	$0.00	$8.88
PY 2019 Actual	$0.27	$0.95
PY 2018 Actual	$0.00	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

National Grid follows a multistep process for ADMS data cleanup. This process is designed to align with go-live activities within ADMS and is commonly used in the industry for ADMS implementation.

Process steps continue to be the following:

- Circuit retirement/renaming
- Initial data prep for circuits for base ADMS
- Final data prep for circuits for base ADMS
- Go-live of ADMS with circuits
- Additional circuit cleanup (post go-live)

This process reflects practical realities of ADMS implementation.

3.2.3.4 Infrastructure Metrics Results and Key Findings

Table 23 presents the Infrastructure Metrics results through PY2021 for National Grid.

Table 23. National Grid ADMS: Infrastructure Metrics Summary

Infrastructure Metrics			GIS Survey (Expense)	Dist. Management System
GMP Plan Total, 2018-2021		Devices	0	0
		Spend, $M	$0.27	$19.02
IM-4	Number of devices or other technologies deployed through PY2018-2021*	# Devices Deployed	N/A	N/A
		% Devices Deployed	N/A	N/A
IM-5	Cost for Deployment thru. PY2018-2021*	Total Spend, $M	$0.27	$16.75
		% Spend	100%	88%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	N/A	N/A
		% On Track (Spend)	N/A	75%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	N/A	N/A
		Spend Remaining, $M	$0.00	$0.00

Note: For ADMS/ALF, '0 devices' means there is no hardware deployment.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the "carryover" spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs' 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

Guidehouse's review of National Grid's ADMS progress confirmed that National Grid has moved forward with the ADMS investment in PY2021 but spent less than its latest plan filed in the PY2020 Annual Report. Key findings related to its progress include the following:

- ADMS is foundational towards enabling other technologies and managing the electric grid (e.g., Distribution Automation)
- The project completed adequate data prep for analysis on 271 out of 1042 potential feeders, 26%, across all regions. National Grid's plan is to make 320 feeders ADMS ready.
- Data prep is progressing as planned
- National Grid continues to follow a multistep process for data prep by feeder. Preliminary data prep is largely complete, with remainder of data prep work planned for 2022.
- National Grid has a budget underrun by about $2.3M due to reduction in ADMS scope based on learnings obtained in the evaluation period

3.2.4 Unitil

This section discusses Unitil's ADMS investment progress through PY2021 and projected carryover into 2022 compared to the prior plan presented in the 2020 GMP Annual Report.

3.2.4.1 Overview of GMP Deployment Plan

Table 24 presents the GMP objectives that Unitil aims to achieve with its ADMS implementation.

Table 24. Unitil Summary

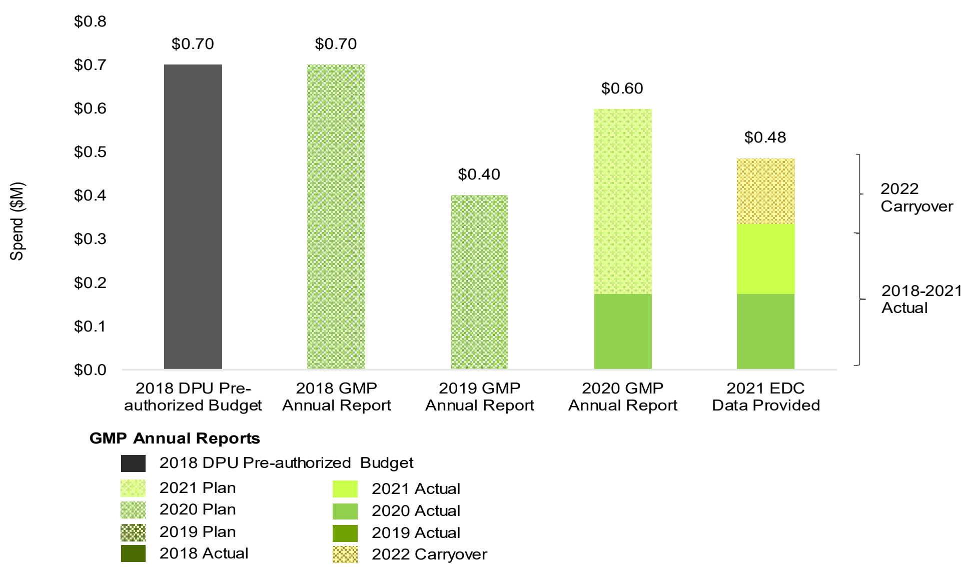
Company	GMP Objective	Software Implementation
Unitil	• Improve reliability • Use current SCADA system more effectively • Use ADMS as the platform for VVO, providing the most customer savings • *Future application*: DERMS, increasing M&C of DER on the system	ADMS • Accelerating the ADMS project to go hand in hand with other investments – Original plan was to have no ADMS spending in first 3 years – As VVO investment developed, ADMS was chosen as platform for VVO

Source: Guidehouse analysis of 2020 GMP Annual Reports and EDC Data

3.2.4.2 ADMS Deployment Plan Progression

Figure 9 presents the total cost, planned and actual, for Unitil's ADMS investment over the GMP term period. Unitil accelerated ADMS to support VVO in the prior plan,[27] but the ADMS project is overall under budget based on the that plan.

Figure 9. Unitil ADMS Planned and Actual Spend Progression, $M



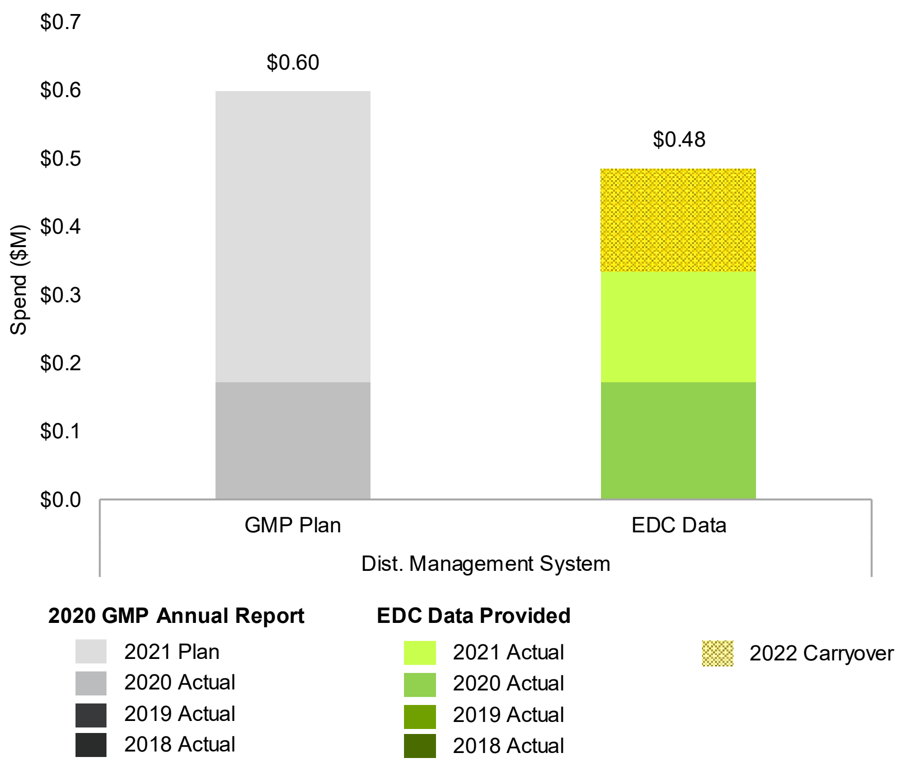
Source: Guidehouse analysis of DPU Order (May 10, 2018), 2018-2020 GMP Annual Reports, GMP Extension and Funding Report filed on July 1, 2020, and 2021 EDC Data

[27] For additional details on Unitil's VVO progress, see *Massachusetts Grid Modernization Program Year 2020 Evaluation Report: Volt-VAR Optimization* DPU 15-120 submitted July 1, 2021.

3.2.4.3 ADMS Progress through PY2021

Figure 10 summarizes the planned and actual spend for Unitil's ADMS investment. Actual spending on ADMS was under budget in PY2021. $0.60M total planned spending from 2020 GMP Annual Report, while actual spend was $0.48M. Unitil has spent a total of $0.48M by end of PY2021, with about $0.23M planned carryover spend in PY2022. This is slightly behind the prior plan, but with the carryover spend planned for 2022 to make up some of the shortfall.

Figure 10. Unitil ADMS Spend Comparison (2018-2021, $M)



Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 25 presents the total planned and actual spend for Unitil's ADMS investment during the evaluation period.

Table 25. Unitil ADMS Plan and Actual Spend (2018-2021, $M)

	Dist. Management System
2018-2021 Total	**$0.33**
2022 Carryover Estimate	$0.15
PY 2021 Actual	$0.16
PY 2020 Actual	$0.17
PY 2019 Actual	$0.00

PY 2018 Actual	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

3.2.4.4 Infrastructure Metrics Results and Key Findings

Table 26 presents the Infrastructure Metrics results through PY2021 for Unitil.

Table 26. Unitil ADMS: Infrastructure Metrics Summary

Infrastructure Metrics			Dist. Management System
GMP Plan Total, 2018-2021		Devices	0
		Spend, $M	$0.60
IM-4	Number of devices or other technologies deployed through PY2018-2021*	# Devices Deployed	N/A
		% Devices Deployed	N/A
IM-5	Cost for Deployment through PY2018-2021*	Total Spend, $M	$0.33
		% Spend	56%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	N/A
		% On Track (Spend)	38%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	N/A
		Spend Remaining, $M	$0.15

Note: For ADMS/ALF, ‘0 devices’ means there is no hardware deployment.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

*The metric names have been slightly changed here to clarify the time span used in analysis.

**This metric has been interpreted here as the “carryover” spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs’ 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

Key findings related to Unitil’s progress include the following:

- Unitil faced challenges in coordinating operational IT/OT systems between corporate and non-corporate networks, due to cybersecurity concerns
- Unitil underestimated level of effort required to prepare data and integrate unavailable data for use in ADMS (e.g., line rating, impedance, and customer usage data)
- ADMS implementation is tied closely with M&C and VVO rollout, constraining how quickly ADMS deployment can proceed

Guidehouse’s review of Unitil’s ADMS progress confirmed that Unitil is slightly behind the prior plan presented in its 2020 GMP Annual Report, with some 2022 carryover planned spend.

4. ADMS Performance Metrics

4.1 Data Management

Guidehouse worked with the EDCs to collect data to complete the ADMS/ALF evaluation for the assessment of Infrastructure Metrics and Performance Metrics. The following sections highlight Guidehouse's data sources and data QA/QC processes to evaluate the Performance Metrics.

4.1.1 Data Sources

Guidehouse used a consistent methodology (across Investment Areas and EDCs) to evaluate the data and illustrate EDC progress toward the GMP metrics. The data sources used for the Performance Metrics are summarized in the subsections below.

4.1.1.1 EDC PY2021 Device Deployment Data Template

Guidehouse collected ADMS/ALF-specific data at the feeder- and substation-level using standardized data collection templates—the *ADMS/ALF Supplemental Data Template*-- for all EDCs. This data source is referred to as *EDC Data* in summary tables and figures throughout the report. Table 27 summarizes the file versions used for the evaluation.

Table 27. EDC ADMS/ALF-Specific Data Received for Analysis

Company	ADMS/ALF Supplemental Data Template
Eversource	Received 2/14/2022
National Grid	Received 3/7/2022
Unitil	Received 3/2/2022

Source: Guidehouse

4.1.1.2 DG Interconnection Data

The PM is being explored to help understand any reduction in average DG interconnection time for EDCs across Massachusetts can be attributed to GMP investments. This prospective PM[28] is the comparison of reduction in average DG interconnection queue wait time between ALF-enabled vs. non-ALF-enabled feeders.

Guidehouse utilized a public data set of DG interconnection queue information[29] to determine the availability of data to compute this metric. However, on the current public data set, there are gaps in interconnection step start/end dates that may make establishing a baseline difficult once the EDCs do begin to see mature performance on ADMS/ALF.

[28] *This potential Performance Metric was added as an evaluation metric to help better understand the investment's ability to meet one of the Department's three grid modernization objectives: "Interconnect and integrate distributed energy resources (DER)." However, it is not one of the Stamped Approved Metrics and is not required by the Department.

[29] MassDGIC: Interconnection in Massachusetts, https://sites.google.com/site/massdgic/home/interconnection.

Eversource does not expect its currently completed ALF/Synergi upgrades to have a measurable impact on DG interconnection queue times, but notes that its updated hosting capacity maps allow applicants to better identify areas of available capacity and thus reduce the number of applications to locations without capacity.

4.1.2 Data QA/QC Process

To ensure accuracy, Guidehouse conducted high level QA/QC of all Performance Metric data received to confirm each of the required data inputs could be incorporated in the Performance Metrics analysis. This review involved following up with the EDCs for explanations regarding the following:

- Potential errors in how the forms were filled out (e.g., circuit information provided in the wrong field)
- Missing or incomplete information

4.2 Performance Metrics Analysis and Findings

4.2.1 Statewide Comparison

This section discusses statewide ADMS/ALF investment progress through PY2021. Table 28 presents the progress of the three Performance Metrics across the state's three EDCs.

Table 28. ADMS/ALF Performance Metrics Progress

Performance Metrics		Eversource		National Grid		Unitil	
		Circuits	Substations	Circuits	Substations	Circuits	Substations
PM-8	Increase in Circuits and Substations with DMS Power Flow and Control Capabilities	0	0	271	89	3	0
PM-9	Control Functions Implemented by Circuit and Substation	0	0	0	0	14	1
PM-ES-1	ALF – Percent of Milestone Completion	100%	100%	N/A	N/A	N/A	N/A
PM-Other	DG Interconnection Queue Wait Time	N/A	N/A	N/A	N/A	N/A	N/A

PM = Performance Metric, N/A = Not Applicable (i.e., not sufficient data yet for evaluation)

Source: EDC data

Additional explanation for the Performance Metrics progress is provided in the subsections below for each EDC.

4.2.2 Eversource

Eversource has implemented enhanced semi-automatic ALF analysis on all planned circuits. ADMS work in PY2021 was foundational, no specific circuits were planned to be ADMS-enabled in PY2021.

For Eversource, PM-1 (increase in circuits and substations with DMS power flow and control capabilities) is 0 for circuits and substations because its ADMS work in PY2021 was foundational, no specific circuits were planned to be ADMS-enabled in PY2021. In addition, PM-2 (control functions implemented by circuit and substation) is 0 and 0 for the same reason.

Eversource has implemented enhanced semi-automatic ALF analysis on all planned circuits; this is reflected in PM-3 with 100% complete on all planned circuits and substations. Synergi Upgrades completed in PY2021 and enabled full ALF automation build.

The work done on ALF and Synergi upgrades during the PY2018-2021 term is not expected to have any measurable impact on the interconnection study process. DG Interconnection Queue Wait Time is a future PM for when there is sufficient data to evaluate.

4.2.3 National Grid

National Grid has completed adequate data prep for analysis on 271 out of 1042 potential feeders, 26%, across all regions. National Grid's plan is to make 320 feeders ADMS ready. PM-1 (increase in circuits and substations with DMS power flow and control capabilities) is 271 for circuits and 89 for substations for National Grid. In addition, PM-2 (control functions implemented by circuit and substation) is 0 and 0; no capabilities or control functions yet implemented.

National Grid does not have an ALF investment, so PM-3 is not applicable (N/A).

DG Interconnection Queue Wait Time is a future prospective PM for when there is sufficient data to evaluate. This PM has been added as a proposed evaluation metric to help better understand the investment's ability to meet one of the 3 DPU grid modernization objectives: "Interconnect and integrate distributed energy resources (DER);" however, it is not one of the DPU Stamped Approved Metrics.

4.2.4 Unitil

Unitil has implemented VVO control function, and therefore ADMS, on three additional circuits in PY2021. PM-1 (increase in circuits and substations with DMS power flow and control capabilities) is 3 and 0 for circuits and substations. In addition, PM-2 (control functions implemented by circuit and substation) is 14 and 1 to reflect the VVO advanced application implemented within the ADMS.

Unitil does not have an ALF investment, so PM-3 is N/A.

DG Interconnection Queue Wait Time is a future prospective PM for when there is sufficient data to evaluate.

5. Conclusions and Recommendations

Guidehouse's conclusions and recommendations are listed as follows.

Conclusions:

- The implementation of ADMS / ALF continues to experience minor budget issues, delays, and technological hurdles. These types of delays are characteristic across the industry and instead of assuming that they can be identified and mitigated ahead of time, incorporating some budget and schedule flexibility will enable the EDCs to be more successful in implementation.
- Data prep continues to be critical to success across the EDCs. As the ADMS / ALF systems progress to larger adoption, ensuring high data *hygiene* is likely to present itself as a challenge. The "Day 1"[30] problem of ensuring that data remains at an adequate threshold for continued operation of ADMS will persist and should be addressed.
- ADMS, as an enabling investment, continues to be coupled to other enterprise investments, which can affect project timing and priorities, and this will continue as the EDCs modernize their grid and IT/OT systems.

Recommendations:

- EDCs must *internalize* that ADMS will continue to be foundational for other programs and technologies (e.g., Distribution Automation, M&C, and VVO) and plan for this dependency in future technology implementation.
- As the scope of ADMS implementations increases at the EDCs, continuing to capture, clean, and mature data is of paramount importance. The level of effort required to capture, clean, and mature data can become an impediment to successful ADMS implementation and managing this proactively is critical to success.

[30] "Day 1" is a common parlance in the utility industry to indicate that once you 'go live' with data and systems on the first day, the data needs to be maintained and updated via deliberate processes and systems or else the data quality degrades over time as system changes happen and the data changes do not keep up.

Massachusetts Grid Modernization Program Year 2021 Evaluation Report: Communications

Massachusetts Electric Distribution Companies

Submitted by:

Guidehouse Inc.
77 South Bedford Street, Suite 400
Burlington, MA 01803
Telephone (781) 270-8300
Guidehouse.com

Reference No.: 209941
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Executive Summary

Introduction

As a part of the Grid Modernization Plan (GMP), the Massachusetts Electric Distribution Companies (EDCs) are investing in communications infrastructure to enable and support the grid modernization investments. This evaluation focuses on the progress and effectiveness of the Massachusetts Department of Public Utilities' (DPU's) preauthorized communications investments for each EDC toward meeting the DPU's grid modernization objectives for Program Year (PY) 2021.

Evaluation Process

The DPU requires a formal evaluation process (including an evaluation plan and evaluation studies) for the EDCs' preauthorized GMP investments. Guidehouse (formerly Navigant Consulting, Inc.)[1] is completing the evaluation to help ensure a uniform statewide approach and to facilitate coordination and comparability of evaluation results. The evaluation's objective is to measure the progress made toward the achievement of the DPU's grid modernization objectives. The evaluation uses the DPU-established Infrastructure Metrics and Performance Metrics along with a set of Case Studies to understand if the GMP investments are meeting the DPU's objectives.[2]

The original Evaluation Plan developed by Navigant Consulting (now Guidehouse) was submitted to the DPU by the EDCs in a petition for approval on May 1, 2019. Modifications to this original Evaluation Plan were made to 1) request changes to the reporting schedule to accommodate Performance Metrics data availability timing, as discussed in response to DPU EP-1-1 submitted on February 6, 2020[3], and 2) to extend the Grid Modernization term period from the original 3 year term to a 4 year term as ordered by the DPU in its May 12, 2020 Order.[4] Modifications to the original Evaluation Plan were submitted to the DPU by the EDCs in a petition for approval on December 1, 2020. The modified Evaluation Plan has been used to develop the analysis and evaluation provided below in this document.

Table 1 illustrates the key Infrastructure Metrics relevant for the Communications evaluation by EDC. Section 2.1 details Infrastructure Metrics.

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[1] Guidehouse LLP completed its acquisition of Navigant Consulting, Inc, in October of 2019. The two brands are now combined as one Guidehouse.

[2] DPU 15-120/15-121/15-122, at 106 (May 10, 2018) (DPU Order).

[3] Submitted in Massachusetts DPU Dockets 15-120, 15-121, and 15-122.

[4] Order (1) Extending Current Three-Year Grid Modernization Plan Investment Term; and (2) Establishing Revised Filing Date for Subsequent Grid Modernization Plans; DPU 15-120-D/DPU 15-121-D/DPU 15-122-D (May 12, 2020).

Table 1. Communications Evaluation Metrics

Metric Type	Communications Evaluation Metrics	ES	NG	UTL
IM	Number of devices or other technologies deployed	✓	✓	✓
IM	Cost for deployment	✓	✓	✓
IM	Deviation between actual and planned deployment for the plan year	✓	✓	✓
IM	Projected deployment for the remainder of the GMP term*	✓	✓	✓

* This metric has been interpreted here (i.e., within the context of the PY2021 Evaluation) as the “carryover” units and “carryover” spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent plan totals were included in each EDC’s *Grid Modernization Plan Annual Report 2020* (filed on April 1, 2021), which listed the planned units and spending to be completed in PY2021.

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020

The EDCs provided data supporting the Infrastructure Metrics to the evaluation team. Guidehouse presents results from analysis of Infrastructure Metrics data in Section 4.

Data Management

Guidehouse worked with the EDCs to collect data to complete the communications evaluation for the assessment of Infrastructure Metrics. Guidehouse used a consistent methodology across Investment Areas and EDCs for evaluating and illustrating EDC progress toward the GMP metrics. Table 2 summarizes data sources used throughout the evaluation of communications in PY2021. Section 3.1 details each of the data sources.

Table 2. Communications Data Sources

Data Source	Description
2020 Grid Modernization Plan Annual Report[5,6,7]	Planned device deployment and cost information from each EDC's Supplement to the 2020 GMP Annual Report (filed April 1, 2021). Data was used as the reference to track progress against the GMP targets and are referred to as the GMP Plan in summary tables and figures throughout the report.
EDC Device Deployment Data Template	Captures planned and actual device deployment and spend data. Actual device deployment and cumulative spend information were provided by work order ID and specified at the feeder- or substation-level as appropriate. Carryover device deployment information and estimated carryover spend for 2022 were provided as well.
Eversource's 2021 DPU-Filed Plan[8]	Eversource's GMP extension request, which was approved by the DPU on February 4, 2021. Includes budgets for PY2021 deployment at the Investment Area level. This data source is included in the EDC Plan for Eversource planned spend at the Investment Area level.

Source: Guidehouse

Guidehouse reviewed all data provided upon receipt. The team conducted a detailed QA/QC of data inputs used in analysis of Infrastructure Metrics. These QA/QC steps included checks to confirm each of the required data inputs is accounted for and can be incorporated into analysis. Table 3 summarizes some of the QA/QC steps conducted for Infrastructure Metrics. See Section 2.1 for a thorough summary.

Table 3. Summary of QA/QC Steps Used for Evaluation

Communications Evaluation Area	QA/QC Steps
Infrastructure Metrics	Data was checked for: • Potential errors in how the forms were filled out (e.g., circuit information provided in the wrong field) • Missing or incomplete information • Large variation in the unit cost of commissioned devices • Variance between the aggregated year-end total information and work order-level data • Variance between the actual unit costs and planned unit costs

Source: Guidehouse

After data was received, Guidehouse provided status update memos that summarize the QA/QC to the EDCs, confirming receipt of the datasets and indicating quality. In some cases,

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[5] Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30.

[6] NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30. Note that Eversource Energy filed an updated Appendix 1 filing in December of 2021; however, that update did not affect any of the data or results in the evaluation.

[7] Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30.

[8] Grid Modernization Program Extension and Funding Report. Submitted to Massachusetts DPU on July 1, 2020 as part of DPU 15-122.

the team submitted additional follow-up questions to the EDC to confirm all EDC-provided data could be used in analysis.

Findings and Recommendations

A robust and high-performance communications network will maximize the benefits of other GMP investments (M&C, VVO, and ADA). The three EDCs continue to make progress in the deployment of their communications investment plans.

Eversource focused on building out its FAN master radio node sites to improve capacity, communication coverage and signal strength. To accomplish these improvements in communications, Eversource worked on eight master communications sites from which two sites were completed and commissioned in 2021. Of the eight master radio sites, four are located in Eversource's eastern region and four are located in their western region. See section 4.2.3 for a more complete breakdown and status of the master radio installations. In addition to the installation of the master radio sites, Eversource installed three fiber optics cables between substation 23 to a master radio, substation 318 to a master radio and the Bear Hill Master Radio Tower Site.

Unitil's third-party communication study, started in 2019 and completed in 2020, led to the selection of AT&T FirstNet as Unitil's communications path forward. In 2021, Unitil started the installation process to connect its communications backbone to the AT&T communications backbone. This required existing backhaul fiber optics to be connected and tested between AT&T and Unitil. To enable redundancy paths for the fiber optic communications, routers were installed at two separate locations. Bench testing was successfully completed for the integration of field radios and devices. The bench testing determined that the field radios would properly send information to AT&T FirstNet which would then be backhauled to Unitil. The rollout process was finalized and documented during the year. It was determined from a control, process and efficiency standpoint, that the field radios would follow the VVO investment roll out. When a VVO field device (sensor) required communications, the sensor would be integrated with the field radio, fully tested on the bench and then taken into the field for final acceptance testing.

National Grid's 2021 communications investment focused on: 1) performing a FAN strategy review which included equipment bench testing and some field test sites of a private 700MHz radio equipment, 2) Installing equipment on a public cellular network to support the other grid modernization investments, 3) Completing the Telecom Operations Management System (TOMS) installation and placing it in service, 4) Testing and evaluating an IP-based replacement for Nokia DMX to enhance FAN backhaul capability, and 5) Lease Line replacement for Verizon copper lines that cannot support the increased bandwidth needs. Each is described below:

1) **FAN Strategy Evaluation:** Evaluation of a 700MHz private radio system. Bench testing, field evaluation and coverage studies were performed.

2) **Radio Nodes:** While National Grid determines its longer-term FAN strategy (item 1 in this list), it is presently enabling the ADA and M&C investments using a public cellular network.

3) **Telecommunication Operations Management System (TOMS):** An integrated application to plan, design, engineer, deploy, commission, and maintain the operational

telecom network for end-to-end connectivity. This investment has been placed in service to improve the efficiency and accuracy of National Grid-US telecom network build-out and operations.

4) **Transition to packet-based MPLS solutions:** This investment will transition the existing WAN to Multi-Protocol Label Switching (MPLS), which is protocol-independent and highly scalable, to allow for any type of transport medium. MPLS will enable true network convergence by providing the capability of combining many older legacy platforms while establishing the foundation for future technology growth and connectivity of the communications WAN.

5) **Pursue options for bandwidth needs:** National Grid is evaluating options to cost effectively expand and deploy incremental infrastructure investments for additional bandwidth needs, such as fiber optics or high-speed radio networks.

All EDCs are positioned to continue 2021 communications work scope that is in progress but not completed or commissioned in 2022 as follows:

- Eversource plans on completing and commissioning the remaining seven master radio sites, started in 2021 but delayed in commissioning due to integration issues with the master radios. The vendor for the front-end processor “FEP” of the SCADA system is working with Eversource to correct programming deficiencies.

- Unitil’s decision to deploy field radios in conjunction with the VVO rollout has resulted in fewer radios being installed then scheduled. As the VVO investment moves forward, it will enable the communication project to ramp up.

- National Grid has made significant progress evaluating a private 700MHz radio system. In 2022 field testing is proposed on 700MHz private radio network which will be used in conjunction with a public cellular radio network. National Grid has detected some radio interference which it is evaluating how to resolve. It is expected that the two communication networks will provide improved communication to support the other Grid Modernization Investments.

Table 4 summarizes key findings related to Guidehouse’s Communications evaluation for each EDC.

Table 4. EDC-Specific Communications Findings

EDC	Summary of Findings
Eversource	• Eversource has improved its private radio networks' coverage and performance for the monitoring and operation of grid endpoints. The improvement is a result of installing both 450MHZ and 900MHz radios at key tower and substation locations. This investment will improve communications latency and enable better performance for ADA, M&C, and VVO deployments over their service areas. • Eversource is behind schedule in completing the acceptance testing of master radio sites due to manufacturer software bugs. Eversource planned to deploy eight sites in 2021 but commissioned two. Eversource is working closely with the manufacturer to resolve the issues. It expects that by the second quarter of 2022 the remaining masters installed with pass commissioning tests. • Eversource has determined that significant amounts of fiber optics cable are not required going forward. Selected, small lengths of fiber optics will be installed to connect the master radio towers into the existing WAN.
National Grid	• National Grid is transitioning to an MPLS packet-based solution to expand its capability of the communications WAN. Vendor selection and the Scope of Work for replacement has been developed. • National Grid has installed a Telecom Operations Management System (TOMS), an integrated application to plan, design, engineer, deploy, commission, and maintain the operational telecom network for end-to-end connectivity. This system will improve the efficiency and accuracy of National Grid-US telecom network build-out and operations. • National Grid is researching its FAN communication investment options, including public versus private networks. It is presently testing a private 700 MHz radio network system. Two sites have been deployed for evaluation. National Grid has detected some radio interference which they are evaluating how to resolve. • Fiber optics requirements and standards development has progressed. • National Grid will be using either a public cellular network or a private 700 MHz network for new GMP devices that are installed.
Unitil	• Unitil has completed its due diligence in determining its communications strategy. They have determined their communications path forward will be the AT&T FirstNet private system. • Unitil's FAN communications deployment was started in 2021, with 22 modems installed to support the other GMP investments.

Source: Guidehouse analysis

Guidehouse submits the following recommendations for EDC consideration.

1) National Grid provided a coverage study (coverage maps) showing the expected performance if they migrate to a public radio network. The coverage study was high-level and not specific to the equipment located on each of the distribution circuits. The study was not sufficient to validate actual performance.
    a. **Recommendation for National Grid:** Field signal strength measurements should be taken to validate that the public network would provide acceptable communications performance.

2) Eversource provided coverage studies (coverage maps) showing the communications performance before the investment and expected improved performance after the

investment is completed. These coverage studies were not available or performed for each of the communications investments performed.

Recommendations for Eversource:

a. To validate the performance and value of the investment, coverage studies should be performed prior to implementation of base station radios.
b. Field signal strength measurements should be taken to validate acceptable communications performance.
c. To improve speed of communications and restoration, a study should be performed to determine if ADA devices on each specific circuit should use a different communication medium. For example, the first device on the circuit uses 450 MHz RF, second device use 900 MHz RF, third device use 5G, etc. (multiple paths for each FLISR scheme).

3) Unitil has decided to install field radios in conjunction with VVO rollout to improve efficiency of radio deployment. While Guidehouse agrees with this approach, the risk could be a delay in VVO investment deployment if unforeseen communications issues arise.

   a. **Recommendation for Unitil:** At the locations where VVO equipment will be installed, field signal strength measurements should be taken to validate that the public network will provide acceptable communications performance.

1. Introduction to Massachusetts Grid Modernization

This section provides a brief background to the grid modernization evaluation process along with an overview of the Communications Investment Area and specific Communications evaluation objectives. These are provided for context when reviewing the subsequent sections that address the specific evaluation process and findings.

1.1 Massachusetts Grid Modernization Plan Background

On May 10, 2018, the Massachusetts Department of Public Utilities (DPU) issued its Order[9] regarding the individual Grid Modernization Plans (GMPs) filed by the three Massachusetts Electric Distribution Companies (EDCs): Eversource, National Grid, and Unitil.[10,11] In the Order, the DPU preauthorized grid-facing investments over 3 years (2018-2020) for each EDC and adopted a 3-year (2018-2020) regulatory review construct for preauthorization of grid modernization investments. On May 12, 2020, the DPU issued an Order[12] extending the 3-year GMP investment term to a 4-year term, including 2018-2021. The company-specific GMP budget caps did not change with the term extension. On July 1, 2020, Eversource filed a request for an extension of the budget authorization associated with grid modernization investments.[13] The budget extension, approved by the DPU on February 4, 2021, included $14 million for ADA, $16 million for ADMS/ALF, $5 million for Communications, $15 million for M&C, and $5 million for VVO.

The preauthorized GMP investments are expected to advance the achievement of DPU's grid modernization objectives:

- Optimize system performance by attaining optimal levels of grid visibility command and control, and self-healing
- Optimize system demand by facilitating consumer price responsiveness
- Interconnect and integrate distributed energy resources (DER)

As part of the GMPs, the DPU determined that a formal evaluation process for the preauthorized GMP investments, including an evaluation plan and studies, was necessary to help confirm that the benefits are capitalized on and achieved with greater certainty.

The grid modernization investments were organized into six Investment Areas to facilitate understanding, consistency across EDCs, and analysis:

- Monitoring and Control (M&C)

[9] DPU Order issued May 10, 2018.

[10] On August 19, 2015, National Grid, Unitil, and Eversource each filed a grid modernization plan with the DPU. The DPU docketed these plans as DPU 15-120, DPU 15-121, and DPU 15-122, respectively.

[11] On June16, 2016, Eversource and National Grid each filed updates to their respective grid modernization plans.

[12] Massachusetts DPU 15-120-D/DPU 15-121-D/DPU 15-122-D (Grid Modernization) Order (1) Extending Current Three-Year Grid Modernization Plan Investment Term; and (2) Establishing Revised Filing Date for Subsequent Grid Modernization Plans (issued May 12, 2020).)

[13] Grid Modernization Program Extension and Funding Report. Submitted to Massachusetts DPU on July 1, 2020 as part of DPU 15-122

- Advanced Distribution Automation (ADA)
- Volt/VAR Optimization (VVO)
- Advanced Distribution Management Systems/Advanced Load Flow (ADMS and ALF)
- Communications/IoT
- Workforce Management (WFM)

This report focuses on the Communications Investment Area. Similarly structured evaluation reports have been developed for each of the other Investment Areas.

1.1.1 Investment Areas

Table 5 summarizes the preauthorized GMP investments.

Table 5. Overview of Investment Areas

Investment Area	Description	Objective
Monitoring and Control (M&C)	Remote monitoring and control of devices in the substation for feeder monitoring or online devices for enhanced visibility outside the substation	Enhancing grid visibility and control capabilities, reliability increase
Advanced Distribution Automation (ADA)	Isolation of outage events with automated restoration of unaffected circuit segments	Reduces the impact of outages
Volt/VAR Optimization (VVO)	Control of line and substation equipment to optimize voltage, reduce energy consumption, and increase hosting capacity	Optimization of distribution voltage to reduce energy consumption and demand
Advanced Distribution Management Systems/Advanced Load Flow (ADMS and ALF[14])	New capabilities in real-time system control with investments in developing accurate system models and enhancing Supervisory control and Data Acquisition (SCADA) and outage management systems to control devices for system optimization and provide support for distribution automation and VVO with high penetration of DER.	Enables high penetration of DER by supporting the ability to control devices for system optimization, ADA, and VVO
Communications/IoT	Fiber middle mile and field area communications systems	Enables the full benefits of grid modernization devices to be realized
Workforce Management (WFM)	Investments to improve workforce and asset utilization related to outage management and storm response	Improves the ability to identify damage after storms

Source: Grid Mod RFP – SOW (Final 8-8-18).pdf; Guidehouse

The Massachusetts DPU preauthorized budget for grid modernization varies by Investment Area and EDC. Eversource originally had the largest preauthorized budget at $133 million, with

[14] Note that ALF is an Eversource-only investment, and is not being pursued by the other EDCs, whereas ADMS investment is being pursued by all three EDCs.

ADA and M&C representing the largest share ($44 million and $41 million, respectively). National Grid's preauthorized budget was $82.2 million, with ADMS representing over 50% ($48.4 million). Unitil's preauthorized budget was $4.4 million and VVO makes up 50% ($2.2 million).

On July 1, 2020 Eversource filed a request for an extension of the budget authorization associated with grid modernization investments. The budget extension, approved by the DPU on February 4, 2021, includes $14 million for ADA, $16 million for ADMS/ALF, $5 million for communications, $15 million for M&C, and $5 million for VVO. These values are included in the Eversource total budget by Investment Area in Table 6.

Table 6. 2018-2021 GMP Preauthorized Budget, $M

Investment Areas	Eversource	National Grid	Unitil	Total
ADA	$58.00	$13.40	N/A	**$71.40**
ADMS/ALF	$33.00	$48.40	$0.70	**$79.10**
Communications	$23.00	$1.80	$0.84	**$25.60**
M&C	$56.00	$8.00	$0.35	**$64.75**
VVO	$18.00	$10.60	$2.22	**$30.80**
WFM	-	-	$0.30	**$1.00**
2018-2021 Total	**$188.00**	**$82.20**	**$4.41**	**$272.65**

Source: DPU Order, May 10, 2018, and Eversource filing "GMP Extension and Funding Report," July 1, 2020

The DPU added flexibility to these budgets based on changing technologies and circumstances. For example, EDCs can shift funds across the different preauthorized investments if a reasonable explanation for these shifts is supplied. The following subsections discuss these evaluation goals, objectives, and the metrics to be used.

1.1.2 Evaluation Goal and Objectives

The DPU requires a formal evaluation process (including an evaluation plan and evaluation studies) for the EDCs' preauthorized GMP investments. Guidehouse is completing the evaluation to enable a uniform statewide approach and to facilitate coordination and comparability. The evaluation's objective is to measure the progress made toward the achievement of DPU's grid modernization objectives. The evaluation uses the DPU-established Infrastructure Metrics to help determine if the investments are meeting the DPU's GMP objectives.

1.1.3 Metrics for Evaluation

The DPU required evaluation involves Infrastructure Metrics and Performance Metrics. In addition, selected case studies have been added for some Investment Areas (e.g., M&C) as part of the evaluation to help facilitate understanding of how the technology performed in specific instances (e.g., in remediating the effects of a line outage). For Communications, only Infrastructure Metrics are required.

1.1.3.1 Infrastructure Metrics

Infrastructure Metrics were designed to evaluate the deployment of the GMP investments. Table 7 summarizes the Infrastructure Metrics.

Table 7. Infrastructure Metrics Overview

Metric		Description	Applicable IAs	Metric Responsibility
IM-1	**Grid Connected Distribution Generation Facilities**	Tracks the number and type of distributed generation facilities in service and connected to the distribution system.	ADMS/ALF	EDC
IM-2	**System Automation Saturation**	Measures the quantity of customers served by fully or partially automated devices.	M&C, ADA	EDC
IM-3	**Number and Percent of Circuits with Installed Sensors**	Measures the total number of circuits with installed sensors which will provide information useful for proactive planning and intervention.	M&C	EDC
IM-4	**Number of Devices Deployed and In Service**	Measures how the EDC is progressing with its GMP from an equipment or device standpoint.	All IAs	Evaluator
IM-5	**Cost for Deployment**	Measures the associated costs for the number of devices or technologies installed; designed to measure how the EDC is progressing under its GMP.	All IAs	Evaluator
IM-6	**Deviation Between Actual and Planned Deployment for the Plan Year**	Measures how the EDC is progressing relative to its GMP on a year-by-year basis.	All IAs	Evaluator
IM-7	**Projected Deployment for the Remainder of the Four-Year Term**	Compares the revised projected deployment with the original target deployment as the EDC implements its GMP.	All IAs	Evaluator

IM = Infrastructure Metric, IA = Investment Area
Source: Guidehouse review of Infrastructure Metric filings

1.1.3.2 Performance Metrics

Performance Metrics are used to evaluate the performance of all the GMP investments. Table 8 summarizes the Performance Metrics used for the various Investment Areas.

Table 8. Performance Metrics Overview

Metric	Metric	Description	Applicable IAs	Metric Responsibility
PM-1	**VVO Baseline**	Establishes a baseline impact factor for each VVO-enabled circuit which will be used to quantify the peak load, energy savings, and GHG impact measures.	VVO	All

Metric	Metric	Description	Applicable IAs	Metric Responsibility
PM-2	**VVO Energy Savings**	Quantifies the energy savings achieved by VVO using the baseline established for the circuit against the annual circuit load with the intent of optimizing system performance.	VVO	All
PM-3	**VVO Peak Load Impact**	Quantifies the peak demand impact VVO/CVR has on the system with the intent of optimizing system demand.	VVO	All
PM-4	**VVO Distribution Losses without Advanced Metering Functionality (AMF) (Baseline)**	Presents the difference between circuit load measured at the substation via the SCADA system and the metered load measured through advanced metering infrastructure.	VVO	All
PM-5	**VVO Power Factor**	Quantifies the improvement that VVO/CVR is providing toward maintaining circuit power factors near unity.	VVO	All
PM-6	**VVO – GHG Emissions**	Quantifies the overall GHG impact VVO/CVR has on the system.	VVO	All
PM-7	**Voltage Complaints**	Quantifies the prevalence of voltage-related complaints before and after deployment of VVO investments to assess customer experience, voltage stability under VVO.	VVO	All
PM-8	**Increase in Substations with DMS Power Flow and Control Capabilities**	Examines the deployment and data cleanup associated with deployment of ADMS/ALF, primarily by counting and tracking the number of circuits and substations per year.	ADMS/ ALF	All
PM-9	**Control Functions Implemented by Circuit**	Examines the control functions of DMS power flow and control capabilities, focused on the control capabilities including VVO-CVR and FLISR.	ADMS/ ALF	All
PM-11	**Numbers of Customers that benefit from GMP funded Distribution Automation Devices**	Shows the progress of ADA investments by tracking the number of customers that have benefitted from the installation of ADA devices.	ADA	ES, NG

Metric	Metric	Description	Applicable IAs	Metric Responsibility
PM-12	**Grid Modernization investments' effect on outage durations**	Provides insight into how M&C investments can reduce outage durations (CKAIDI). Compares the experience of customers on GMP M&C-enabled circuits as compared to the previous 3-year average for the same circuit.	M&C, ADA	All
PM-13	**Grid Modernization investments' effect on outage frequency**	Provides insight into how M&C investments can reduce outage frequencies (CKAIFI). Compares the experience of customers on M&C-enabled circuits as compared to the prior 3-year average for the same circuit.	M&C, ADA	All
PM-ES1	**Advanced Load Flow – Percent Milestone Completion**	Examines the fully developed ALF capability across Eversource's circuit population.	ADMS/ ALF	ES
PM-ES2	**Protective Zone: Average Zone Size per Circuit**	Measures Eversource's progress in sectionalizing circuits into protective zones designed to limit outages to customers located within the zone.	ADA	ES
PM-UTL1	**Customer Minutes of Outage Saved per Circuit**	Tracks time savings from faster AMI outage notification than customer outage call, leading to faster outage response and reduced customer minutes of interruption.	M&C	UTL
PM-NG1	**Main Line Customer Minutes of Interruption Saved**	Measures the impact of ADA investments on the customer minutes of interruption (CMI) for main line interruptions. Compares the CMI of GMP ADA-enabled circuits to the previous 3-year average for the same circuit.	ADA	NG

PM = Performance Metric, IA = Investment Area, ES = Eversource, NG = National Grid, UTL = Unitil

Source: Stamp Approved Performance Metrics, July 25, 2019.

Evaluation of Performance Metrics is not required for the Communications Investment Area and so the Performance Metrics sections are omitted from this report.

1.2 Communications Investment Area Overview

The Communications Investment Area is an enabling technology that will support most (if not all) preauthorized investments, including ADA, VVO, ADMS, and M&C.

Investments in a robust and effective communication network are required for the other preauthorized investments to "(1) optimize system performance (by attaining optimal levels of grid visibility, command and control and self-healing),” “(2) optimize system demand,” and “(3) interconnect and integrate distributed energy resources.” [15]

All EDCs recognize that the successful deployment of communications systems will maximize GMP benefits. If communications network deployment is delayed, it can potentially limit the performance of other GMP devices.

Table 9 describes the areas or classifications of communications investments each of the EDCs are performing. While overall EDC communications goals are similar, each EDC begins with a different set of capabilities and needs, and so is charting a unique course to communications deployment.

Table 9. Communications Investment Plans by EDC

Technology	Description	Four-Year Deployment Plan		
		Eversource	National Grid	Unitil
Wide Area Network (WAN)	Fiber optic and supporting electronics, used as backhaul to bring data from substations and radio master sites to IT control systems	Existing: Eversource East has redundant WAN at major substations. Eversource West has limited WAN Planned: New deployments at key locations	Existing: Limited fiber optic coverage to substations; Obsolete DMX MUX hardware Planned: Replacement of obsolete Nokia DMX system. Fiber standards development and deployment	No existing WAN Planned: No WAN required with selected FAN approach
Field Area Network (FAN)	Communications systems used to monitor and operate field end devices	Existing: Private network with public cellular filling coverage gaps Planned: Expanded coverage area with master radios using private network	Existing: Using public cellular network Planned: Evaluating FAN options	Existing public cellular network Planned: FAN deployment using AT&T FirstNet public network
Application Software	Applications use for the planning, designing, and deploying communication systems	Planned: No investments planned	Planned: Install Telecom Operations Management System (TOMS)	Planned: No investments planned

Source: Guidehouse analysis of 2019 GMP Annual Reports and 2020 EDC data

[15] DPU Order at p. 106

1.3 Communications Evaluation Objectives

This evaluation focuses on the progress and effectiveness of the DPU preauthorized Communications investments for each EDC toward meeting the DPU's grid modernization objectives.[16] Table 10 illustrates the key Infrastructure Metrics relevant for the Communications evaluation.

Table 10. Communications Evaluation Metrics

Metric Type	Communications Evaluation Metrics	ES	NG	UTL
IM	Number of devices or other technologies deployed	✓	✓	✓
IM	Cost for deployment	✓	✓	✓
IM	Deviation between actual and planned deployment for the plan year	✓	✓	✓
IM	Projected deployment for the remainder of the 4-year term	✓	✓	✓

IM = Infrastructure Metric, ES = Eversource, NG = National Grid, UTL = Unitil

Source: Guidehouse review of Infrastructure Metric filings

The EDCs provided the data supporting the Infrastructure Metrics to the evaluation team. Guidehouse presents results from analysis of Infrastructure Metrics data in Section 4.

Table 11 summarizes the communications M&V objectives and associated research questions addressed in this report.

Table 11. Communications Evaluation Objectives and Associated Research Questions

Associated Research Questions
Are the EDCs progressing in deployment of their communications networks according to their GMPs?
What factors, if any, are affecting the deployment schedule of communications equipment?
What is the cost of deploying various types of communications equipment, including the FAN devices (radio base stations) and WAN (miles of fiber optics cables)?
Are the communication investments (WAN and FAN) effective at supporting the other DPU approved investments?

Source: Guidehouse Evaluation Plan

[16] Massachusetts DPU 15-120; DPU 15-121; DPU 15-122 (Grid Modernization) Order issued May 10, 2018 at p. 106

2. Communications Evaluation Process

This section summarizes Guidehouse's methodologies for the evaluation of Infrastructure Metrics. The revised Stage 3 Evaluation Plan (filed December 1, 2020) includes additional details about approaches used in the evaluation. Figure 1 highlights the filing background and timeline of the GMP order and the evaluation process.

Figure 1. Communications Evaluation Timeline

Source: Guidehouse review of the DPU orders and GMP process

2.1 Infrastructure Metrics Analysis

Guidehouse annually assesses the progress of each EDC toward communications deployment. Table 12 highlights the Infrastructure Metrics that were evaluated and their associated calculation parameters.

Table 12. Infrastructure Metrics Overview

Infrastructure Metrics			Calculation
IM-4	Number of devices or other technologies deployed thru. PY2021	# Devices Deployed	$\sum_{PY=2018}^{2021}(Devices\ Commissioned)_{PY}$
		% Devices Deployed	$\frac{\sum_{PY=2018}^{2021}(Devices\ Commissioned)_{PY}}{\sum_{PY=2018}^{2020}(Devices\ Commissioned)_{PY}+(Planned\ Devices)_{PY2021}}$
IM-5	Cost through PY2021	Total Spend, $M	$\sum_{PY=2018}^{2021}(Actual\ Spend)_{PY}$
		% Spend	$\frac{\sum_{PY=2018}^{2021}(Actual\ Spend)_{PY}}{\sum_{PY=2018}^{2020}(Actual\ Spend)_{PY}+(Planned\ Spend)_{PY2021}}$
IM-6	Deviation Between Actual and Planned Deployment for PY2021	% On Track (Devices)	$\frac{(Devices\ Commissioned)_{PY2021}}{(Planned\ Devices)_{PY2021}}$
		% On Track (Spend)	$\frac{(Actual\ Spend)_{PY2021}}{(Planned\ Spend)_{PY2021}}$
IM-7	Projected Deployment for the remainder of the GMP Term*	# Devices Remaining	$(Devices\ Planned)_{CY2022}$
		Spend Remaining, $M	$(Planned\ Spend)_{CY2022}$

* This metric has been interpreted here (i.e., within the context of the 2021 Program Year Evaluation) as the "carryover" units and "carryover" spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent plan totals were included in each EDC's *Grid Modernization Plan Annual Report 2020* (filed on April 1, 2021), which listed the planned units and spending to be completed in PY2021.

Source: Guidehouse

Section 2.1 provides the results from the evaluation of the Infrastructure Metrics. To evaluate Infrastructure Metrics, Guidehouse:

- Reviewed the data provided by the EDCs to confirm their progress through PY2021 (see Section 3.2, "Data QA/QC Process")
- Interviewed representatives from each EDC to understand the status of the Communications investments, including:
    - Updates to their planned Communications investments
    - Reasons for deviation between actual and planned deployment and spend

3. Data Management

Assessment of the Infrastructure Metrics includes Infrastructure Metrics data collection and QA/QC, assessment of Communications deployment progress for each of the three EDCs, and determination of conclusions from the analysis. Guidehouse worked with the EDCs to collect data to complete the Communications evaluation and the assessment of Infrastructure Metrics. The following subsections highlight data sources and the data QA/QC processes followed to complete the evaluation and calculate the Infrastructure Metrics.

3.1 Data Sources

Guidehouse used a consistent methodology (across Investment Areas and EDCs) for evaluating the data and illustrating EDC progress indicated by the GMP metrics. The data sources are summarized below.

3.1.1 2019 Grid Modernization Plan Annual Report

Guidehouse used the planned device deployment and cost information from each EDCs' *2020 GMP Annual Reports*, which were filed on April 1, 2021. These filings served as the sources for planning data in this report and are referred collectively as the *GMP Plan* for each EDC in summary tables and figures throughout this report.

Table 13 provides a legend of the different planned and actual quantities reviewed and specifies the color/shade used to represent these quantities in graphics throughout the rest of the report.

Table 13. Deployment Categories Used for the EDC Plan

Representative Color	Data	Description
	2021 Plan	Projected 2021 unit deployment and spend
	2020 Actual	Actual reported unit deployment and spend in 2020
	2019 Actual	Actual reported unit deployment and spend in 2019
	2018 Actual	Actual reported unit deployment and spend in 2018

Source: Plan and actual data is sourced from the EDCs' 2020 GMP Annual Report Appendix 1 filed April 1, 2021.

3.1.2 EDC PY2021 Device Deployment Data Template

Guidehouse collected device deployment data using standardized data collection templates (e.g., the All Device Deployment workbook file) for all EDCs during January and February 2022. The data collected provides an update of planned and actual deployment, in dollars and device units, through the end of PY2021. Data from this source are referred to as EDC Data in summary tables and figures throughout the report. Table 14 summarizes the date of file version receipt used for the evaluation. The collected data was compared to the data submitted by the EDCs to the DPU in the 2021 Grid Modernization Plan Annual Reports and associated

Appendix 1 filings.[17,18,19] The evaluation team confirmed the consistency of the data from the various sources and reconciled any differences.

Table 14. All Device Deployment Data File Versions for Analysis

EDC	File Version
Eversource	Received 2/2/2022
National Grid	Received 2/4/2022
Unitil	Received 2/4/2022

Source: Guidehouse

The EDC device deployment data (collected primarily in the All Device Deployment workbook) captured planned and actual device deployment and spend data. Actual device deployment and cumulative spend information were provided by work order ID and specified at the feeder- or substation-level, as appropriate.

The evaluation team collected the implementation stage of the work order (commissioned, in service, construction, or design/engineering), the commissioned date (if applicable), and all cumulative costs associated with the work order. Planned device deployment information and estimated spend for PY2021 was provided by the EDCs at the most granular level (circuit or substation) available. Table 15 summarizes the categories used for the planned and actual deployment and spend from the EDC Data and specifies the color and pattern used in bar graphs to represent each in the remainder of the report.

[17] Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-41

[18] NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-40

[19] Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-42

Table 15. EDC Device Deployment Data

Representative Color	Data	Description
Device Deployment Data		
Purple crosshatch	2022 Estimate	Remaining units planned for 2022 where work will begin in 2022
Light blue diagonal stripes	2021 Design/Engineering	Detailed design and engineering are in progress but the device is not yet in construction
Blue diagonal stripes	2021 Construction	Field construction is in progress but the device is not yet in-service
Dark blue diagonal stripes	2021 In-Service	Device is installed and “used and useful” but not yet commissioned to enable all Grid Modernization functionalities
Light blue	2021 Commissioned	Device is fully operational with all Grid Mod functionalities, and thus is considered “deployed” in PY2021
Blue	2020 Actual	Actual devices commissioned in 2020
Medium dark blue	2019 Actual	Actual devices commissioned in 2019
Dark navy	2018 Actual	Actual devices commissioned in 2018
Spend Data		
Orange crosshatch	2022 Carryover	Projected 2022 spend
Light yellow-green	2021 Actual	Actual 2021 spend
Light green	2020 Actual	Actual 2020 spend
Green	2019 Actual	Actual 2019 spend
Dark green	2018 Actual	Actual 2018 spend

Source: Guidehouse analysis

3.2 Data QA/QC Process

Guidehouse reviewed all data provided for Infrastructure Metrics analysis upon receipt of requested data. The following sections detail the data QA/QC processes adopted for the two analysis areas.

3.2.1 Data QA/QC

To enable accuracy, Guidehouse conducted a high-level QA/QC of all device deployment data received. This review involved following up with the EDCs for explanations regarding the following:

- Potential errors in how the forms were filled out (e.g., circuit information provided in the wrong field)
- Missing or incomplete information
- Large variation in the unit cost of commissioned devices
- Variance between the aggregated year-end total information and work order-level data
- Variance between the actual unit costs and planned unit costs

4. Communications Deployment Progress and Findings

Guidehouse presents findings from the Infrastructure Metrics analysis for communications in Section 4.1 through Section 4.4. Tables and figures highlighting statewide findings, with detailed findings presented thereafter.

4.1 Statewide Comparison

Eversource focused on building out its FAN master radio node sites to improve capacity, communication coverage and signal strength. To accomplish these improvements in communications, Eversource worked on eight master communications sites from which two sites were completed and commissioned in 2021. Of the eight master radio sites, four are located in Eversource's eastern region and four are located in their western region. See section 4.2.3 for a more complete breakdown and status of the master radio installations. In addition to the installation of the master radio sites, Eversource installed three fiber optics cables between substation 23 to a master radio, substation 318 to a master radio and the Bear Hill Master Radio Tower Site.

Unitil's third-party communication study, started in 2019 and completed in 2020, led to the selection of AT&T FirstNet as Unitil's communications path forward. In 2021, Unitil started the installation process to connect its communications backbone to the AT&T communications backbone. This required existing backhaul fiber optics to be connected and tested between AT&T and Unitil. To enable redundancy paths for the fiber optic communications, routers were installed at two separate locations. Bench testing was successfully completed for the integration of field radios and devices. The bench testing determined that the field radios would properly send information to AT&T FirstNet which would then be backhauled to Unitil. The rollout process was finalized and documented during the year. It was determined from a control, process and efficiency standpoint, that the field radios would follow the VVO investment roll out. When a VVO field device (sensor) required communications, the sensor would be integrated with the field radio, fully tested on the bench and then taken into the field for final acceptance testing.

National Grid's 2021 communications investment focused on: 1) performing a FAN strategy review which included equipment bench testing and some field test sites of a private 700MHz radio equipment, 2) Installing equipment on a public cellular network to support the other grid modernization investments, 3) Completing the Telecom Operations Management System (TOMS) installation and placing it in service, 4) Testing and evaluating an IP-based replacement for Nokia DMX to enhance FAN backhaul capability, and 5) Lease Line replacement for Verizon copper lines that cannot support the increased bandwidth needs . Each is described below:

6) **FAN Strategy Evaluation:** Evaluation of a 700MHz private radio system. Bench testing, field evaluation and coverage studies were performed.

7) **Radio Nodes:** While National Grid determines its longer-term FAN strategy (item 1 in this list), it is presently enabling the ADA and M&C investments using a public cellular network.

8) **Telecommunication Operations Management System (TOMS):** An integrated application to plan, design, engineer, deploy, commission, and maintain the operational telecom network for end-to-end connectivity. This investment has been placed in

service to improve the efficiency and accuracy of National Grid-US telecom network build-out and operations.

9) **Transition to packet-based MPLS solutions:** This investment will transition the existing WAN to Multi-Protocol Label Switching (MPLS), which is protocol-independent and highly scalable, to allow for any type of transport medium. MPLS will enable true network convergence by providing the capability of combining many older legacy platforms while establishing the foundation for future technology growth and connectivity of the communications WAN.

10) **Pursue options for bandwidth needs:** National Grid is evaluating options to cost effectively expand and deploy incremental infrastructure investments for additional bandwidth needs, such as fiber optics or high speed radio networks.

All EDCs are positioned to continue 2021 communications work scope that is in progress but not completed or commissioned in 2022 as follows:

- Eversource plans on completing and commissioning the remaining seven master radio sites, started in 2021 but delayed in commissioning due to integration issues with the master radios. The vendor for the front-end processor “FEP” of the SCADA system is working with Eversource to correct programming deficiencies.
- Unitil’s decision to deploy field radios in conjunction with the VVO rollout has resulted in fewer radios being installed then scheduled. As the VVO investment moves forward, it will enable the communication project to ramp up.
- National Grid has made significant progress evaluating a private 700MHz radio system. In 2022 field testing is proposed on 700MHz private radio network which will be used in conjunction with a public cellular radio network. National Grid has detected some radio interference which it is evaluating how to resolve. It is expected that the two communication networks will provide improved communication to support the other Grid Modernization Investments.

When commissioned, these communications investments will enable or support the M&C, ADA, and VVO equipment. Table 16 presents an overview of Infrastructure Metrics results for each EDC.

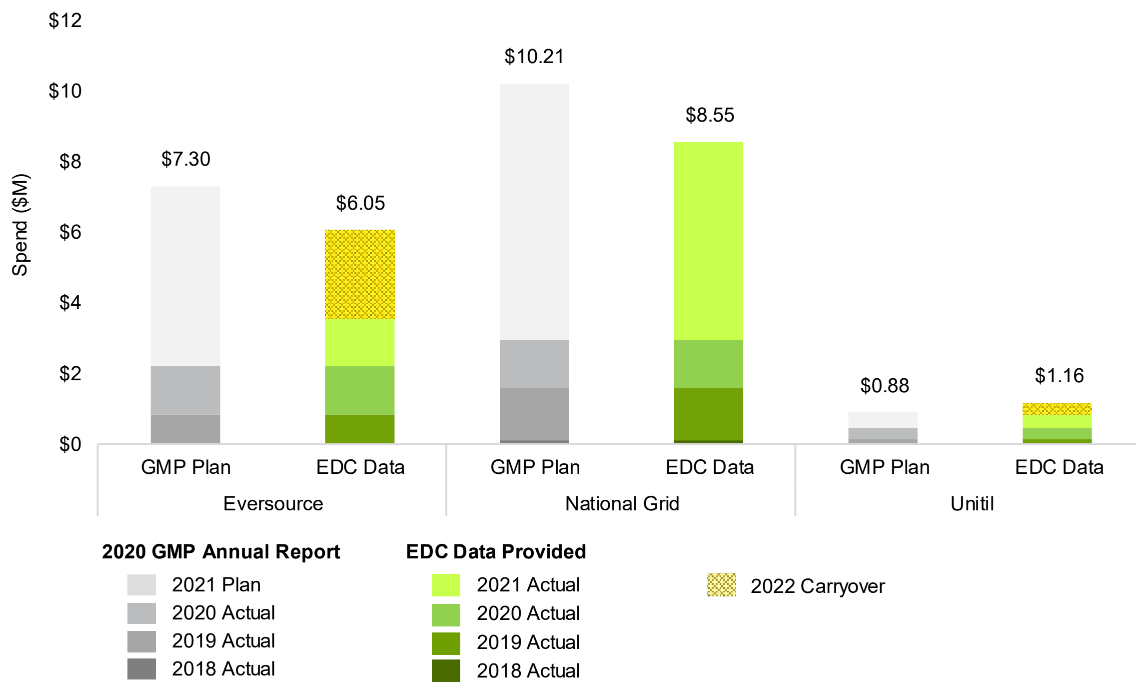
Table 16. Communications Infrastructure Metrics Summary

Infrastructure Metrics			Eversource	National Grid	Unitil
GMP Plan Total, PY2018-2021		Devices	14	348	121
		Spend, $M	$7.30	$10.21	$0.88
IM-4	Number of devices or other technologies deployed through PY2018-2021	# Devices Deployed	12	391	23
		% Devices Deployed	86%	112%	19%
IM-5	Cost for Deployment PY2018-2021	Total Spend, $M	$3.55	$8.55	$0.83
		% Spend	49%	84%	94%
IM-6	Deviation Between Actual and Planned Deployment for PY2021	% On Track (Devices)	67%	N/A	18%
		% On Track (Spend)	27%	77%	88%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	6	330	100
		Spend Remaining, $M	$2.50	$0.00***	$0.33

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the “carryover” units and spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs’ 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.
***"Spend for Communications is 0, because the costs associated with the nodes are embedded in VVO, M&C, and ADA device spend

Figure 2 highlights planned versus actual spend in communications for each of the three EDCs. Detailed differences between planned and actual spend are provided in each specific EDC’s results section.

Figure 2. Communications Spend Comparison (2018-2021, $M)



Note: Includes the Eversource planned spend for PY2021, set forth the in the GMP Extension and Funding Report, filed on July 1, 2020.

Source: Guidehouse analysis of 2020 GMP Annual Reports, GMP Extension and Funding Report, and 2021 EDC Data

In addition to the PY2021 capital costs Figure 2 shows, Eversource incurred approximately $0.51 million toward Administration and Regulatory costs across the GMP investments in PY2020. Eversource incurred $40 in O&M costs specific to the Communications Investment Area in PY2021. National Grid incurred approximately $1.11 million in O&M costs toward the Communications Investment Area in PY2020. National Grid incurred approximately $0.92 million toward Administration and Regulatory costs across the GMP investments in PY2020. Unitil incurred approximately $19,500 toward Administration and Regulatory costs across the GMP investments in PY2020.

4.2 Eversource

4.2.1 Overview of GMP Deployment Plan

Eversource's GMP deployment plan, as articulated in its *2020 GMP Annual Report*, included a $5.1 million investment in a high-bandwidth communications network to enable near real-time data flows between the field devices and control systems. Eversource proposed enhanced bandwidth and data speeds for both fiber and radio networks across the service territory. These upgraded communications capabilities will support the company's suite of grid modernization investments, in addition to existing infrastructure. This network investment is designed to enable and support ADA, M&C, and VVO functionalities.

Eversource's FAN coverage enhancement strategy is to install additional master radios (base stations) at new and existing locations. Our high-level evaluation, performed by reviewing a sample of communications coverage maps, determined that the greater number of master radio sites will improve the latency and overall performance of the communications network.

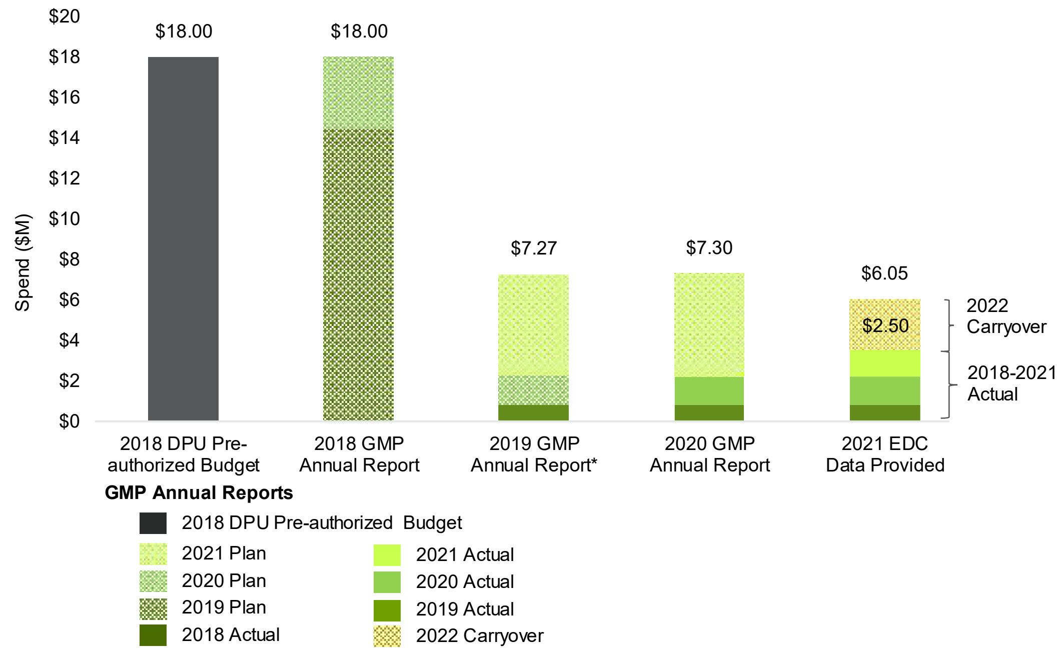
The radio nodes investment is focused on installing additional radio master nodes at existing radio tower sites, with different frequencies, or installing master radio at new base stations to expand coverage and reduce latency. Eversource is utilizing several licensed and unlicensed frequencies. These include a licensed private 900 MHz frequency, an unlicensed 900 spread spectrum frequency and a licensed 450 MHz frequency. ADA and M&C investment data is transmitted from the local device to the radio base station, then backhauled via the WAN fiber network to the GE distribution automation concentrators or the new front-end processors ("FEP") of the electrical energy control system ("eECS"), and then displayed on SCADA screens for operator control.

4.2.2 Communications Deployment Plan Progression

Figure 3 shows the progression of Eversource's Communication deployment plans from DPU-preauthorization in 2018 through PY2021. In 2021 a total of nine master radio sites were scheduled for completion with two commissioned and placed into service. Several software issues (bugs) were found during acceptance testing of the 450MHz system, which prohibited the proper communications between the field radio, master radio, data concentrator and SCADA system. The concentrator vendor worked closely with Eversource to resolve the software bugs. While a few bugs remained in 2021, based on progress made by the manufacturer, it is expected that the remaining seven master radio sites will be completed and pass acceptance testing in the 2nd quarter of 2022.

The 2021 workplan included the installation of three fiber optic cables. These fiber installations were between substation 23 to a master radio, substation 318 to a master radio and the Bear Hill Master Radio Tower Site. These fiber optic cables were approximately than 2.0 miles in length. Connecting the Master Radios to the Eversource Wide Area Network, using fiber optics, will improve overall radio performance when compared to other backhauls such as point to point radios.

Figure 3. Eversource Communications Planned and Actual Spend Progression, $M



Source: Guidehouse analysis of DPU Order (May 10, 2018), 2018-2020 GMP Annual Reports, GMP Extension and Funding Report filed on July 1, 2020, and *2021 EDC Data*

As indicated above, Eversource owns private radio networks that required improvement in specific areas to its coverage, bandwidth, and speed. Eversource is focusing its GMP communications investments on improving its radio network in those areas.

In 2019, Eversource performed an analysis reaching the conclusion that a significant amount of fiber optics cable will not be required to support the buildout of WAN along with the actual design and installation costs for the FAN deployment. Eversource revised its communications investment from $18 million to $7.27 million over the 4 years in GMP term. Guidehouse's evaluation determined this is not a concern, as Eversource's existing communications system (WAN and FAN) is robust in most locations to support GMP deployment and is being upgraded in other locations. Eversource is expected to continue expanding coverage to areas where coverage is poor, in coordination with other GMP investments. This evaluation report used the revised $7.3 million communications plan as the benchmark for assessing progress in 2021.

4.2.3 Communications Investment Progress through PY2021

Eversource commissioned ten communication nodes from 2018 through 2021. These nodes consisted of nine master radio sites and the upgrading of data concentrators (GE D-200) at two service centers. Eversource considered the GE-D200s at two service centers, combined as one node. Eversource also deployed at three locations and placed into service approximately 2 miles of fiber optic cable.

In 2021, Eversource commissioned two master radio communication sites and continued construction at six other locations. These sites were:

Commissioned and In-Service

1) Mt. Tom: Commissioned a 900 MHz master radio which communicates to GMP field equipment

2) Pelham: Commissioned a 450 MHz master radio which communicates to GMP field equipment.

Construction to be Completed in 2022

3) Nobsott: Installation underway for a 450 MHz master radio which will communicate to GMP field equipment.

4) Shoot Flying Hill: Installation underway for a 450 MHz master radio which will communicate to GMP field equipment.

5) Southborough Service Center: Installation underway for a 450 MHz master radio which will communicate to GMP field equipment.

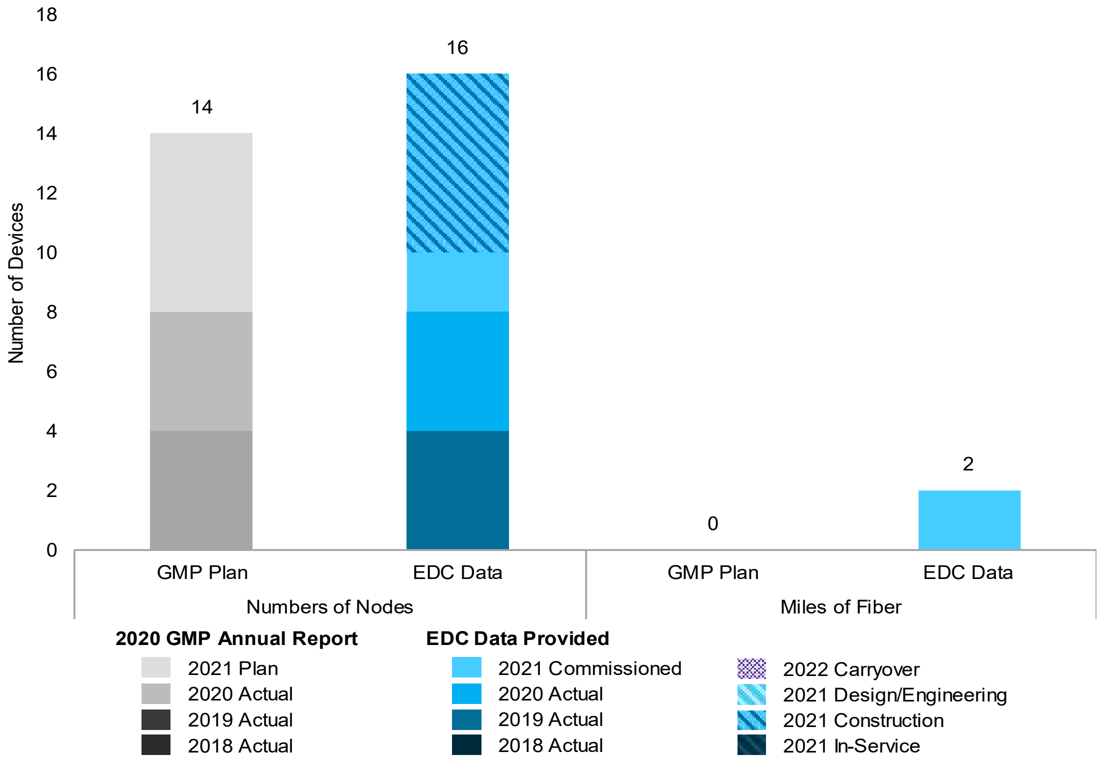
6) Prudential Center: Installation underway for a 450 MHz master radio which will communicate to GMP field equipment.

7) East Springfield: Installation underway for a 900 MHz master radio which will communicate to GMP field equipment.

8) East Springfield Service Center: Installation underway for a 450 MHz master radio which will communicate to GMP field equipment.

Figure 4 shows Eversource's planned versus actual communications device deployment progress over the 2018-2021 period. The EDC Data in Figure 4 is also shown in Table 17.

Figure 4. Eversource Communications Device Deployment Comparison (2018-2021)



Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 17. Eversource Communications Plan and Actual Device Deployment (2018-2021)

	Numbers of Nodes	Miles of Fiber
2018-2021 Total	**10**	**2**
Engineering/Design during PY 2021*	0	0
Construction during PY 2021*	6	0
In-Service during PY 2021*	0	0
Commissioned in PY 2021	2	2
Commissioned in PY 2020	4	0
Commissioned in PY 2019	4	0
Commissioned in PY 2018	0	0

**Deployment of these devices began during PY 2021, but was not completed during the program year. Deployment (through commissioning) is planned as carryover in 2022.*

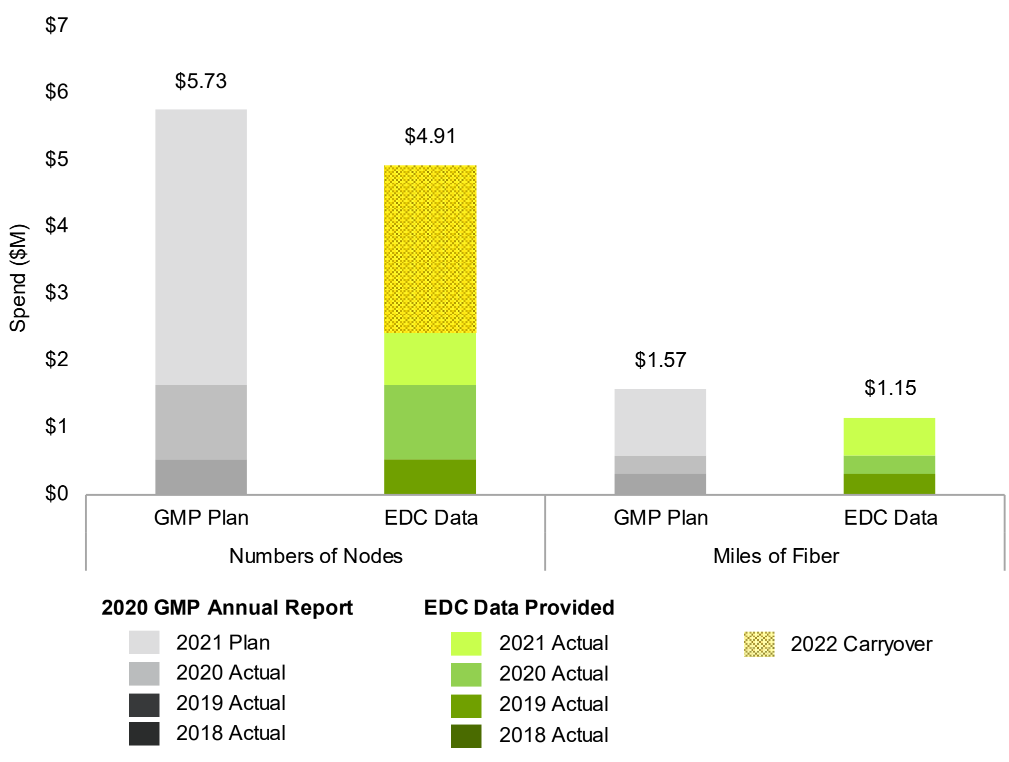
Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

In 2019, Eversource commissioned three radios and one front end processor (fiber optics mux equipment). In 2020, Eversource deployed four master radio locations. In 2021, Eversource planned to commission eight master radio sites but only two were commissioned with six delayed and are now planned to be carried over into 2022. The delay was due to vendor software problems with the front-end processor, which hindered integration with the newer eECS (SCADA) equipment. Eversource is working closely with the manufacturer and expects to have the programming issues addressed during the first half of 2022.

In addition, Eversource installed fiber optics between the Zion Hill Tower and Bear Hill Tower to connect these radio nodes to existing WAN. Eversource learned that there are two major challenges with fiber deployment: 1) Whether or not sufficient, existing ducts are in place to install new fiber conductors; and 2) permitting (when required) through the larger cities can be time-consuming. COVID exacerbated this latter challenge and caused a backlog, particularly for Boston. To mitigate these challenges, Eversource recommends having a good record of existing duct and manhole system. The company also learned it is beneficial to apply early for permits and obtain schedules for local city road replacement, since new fiber ducts require digging in the streets.

Error! Reference source not found. shows Eversource's planned versus actual spend over the 2018-2021 period. The EDC Data in **Error! Reference source not found.** is also shown in Table 18. Eversource's 2021 spend on RF nodes was significantly below plan as the manufacturer worked to troubleshoot software issues. Eversource expects to overcome these issues and carryover the spend to 2022.

Figure 5. Eversource Communications Spend Comparison (2018-2021, $M)



Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 18. Eversource Communications Plan and Actual Spend (2018-2021, $M)

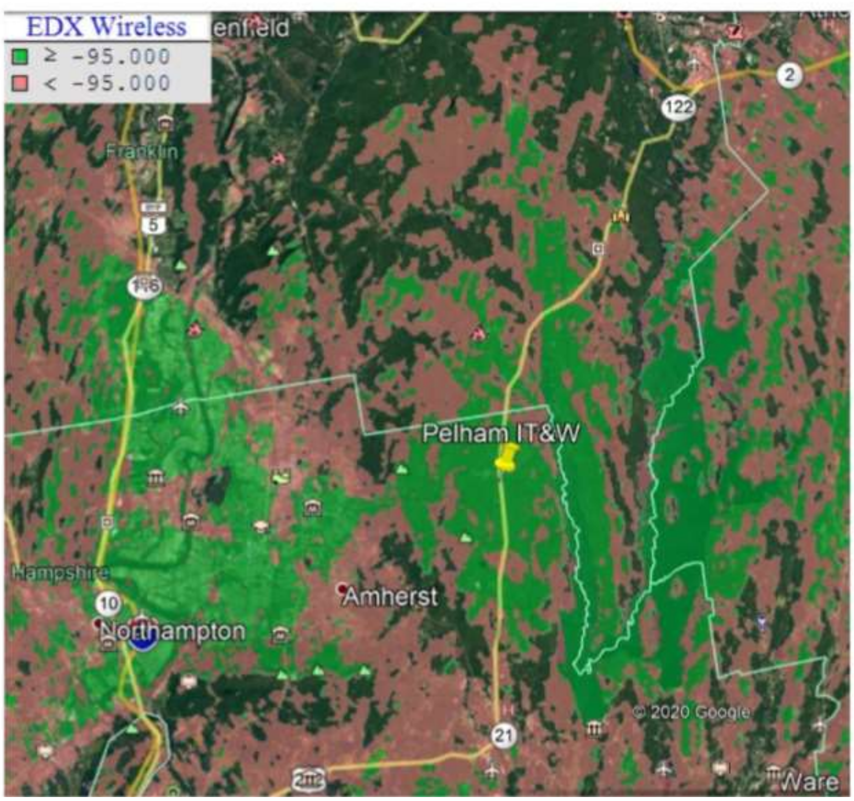
	Numbers of Nodes	Miles of Fiber
2018-2021 Total	**$2.41**	**$1.15**
2022 Carryover Estimate	$2.50	$0.00
PY 2021 Actual	$0.78	$0.58
PY 2020 Actual	$1.11	$0.26
PY 2019 Actual	$0.52	$0.31
PY 2018 Actual	$0.00	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

4.2.3.1 Progress Highlights

Eversource continues to make improvements in the radio coverage required to provide improved performance of its ADA and M&C field devices. Under the GMP, between 2018 and 2021, Eversource installed 9 new master radio base stations. In 2021, the Mt. Toms 900 MHz and Pelham 450 MHz master radio sites were commissioned. As indicated in the coverage study (Figure 6), the installed 450 MHz equipment at Pelham would provide good coverage to field devices.

Figure 6. Map of Pelham Western MA 450 MHz Master Radio Coverage



Source: Eversource

4.2.4 Infrastructure Metrics Results and Key Findings

Table 19 presents the Infrastructure Metrics results through PY2021 for each investment type related to Eversource's Communications Investment Area. Eversource is improving its private radio networks' coverage and performance for the monitoring and operation of grid endpoints. This investment will improve communications latency and enable better performance for ADA, M&C, and VVO deployments in these areas.

Table 19. Eversource Communications: Infrastructure Metrics Summary

Infrastructure Metrics			Numbers of Nodes	Miles of Fiber
GMP Plan Total, PY2018-2021		Devices	14	0
		Spend, $M	$5.73	$1.57
IM-4	Number of devices or other technologies deployed through PY2018-2021*	# Devices Deployed	10	2
		% Devices Deployed	71%	N/A
IM-5	Cost for Deployment through PY2018-2021	Total Spend, $M	$2.41	$1.15
		% Spend	42%	73%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	33%	N/A
		% On Track (Spend)	19%	58%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	6	0
		Spend Remaining, $M	$2.50	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the "carryover" units and spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs' 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

4.3 National Grid

4.3.1 Overview of GMP Deployment Plan

National Grid's legacy communications system consists of a fiber optics network for a limited number of its substations, and a public cellular network to monitor and operate field devices. Recognizing that advanced GMP functions require a modern, reliable communications network, National Grid proposed to modernize its communications network as part of its GMP investments. National Grid's GMP communications proposal included backhaul (WAN) networks from substation using fiber optics or other communication means, transition to Multi-Protocol Label Switching (MPLS) which is protocol-independent and highly scalable multiplexing equipment, determining the requirements of a field-based (FAN) wireless communication network, and software to support the planning, development, and monitoring of its communication infrastructure.

As stated in National Grid's *2018 GMP Annual Report*, the main objectives for the telecommunications (telecom) network plan are to:

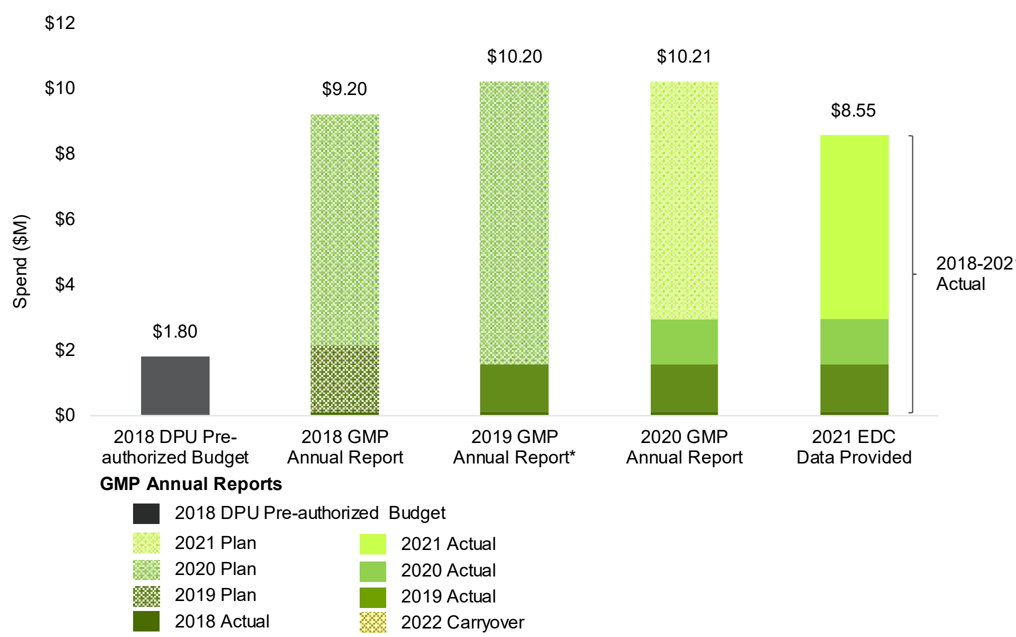
- Provide a reliable, cost-effective, two-way communications capability to end devices including grid automation controls, field sensors, and substations.
- Confirm the network meets all technical requirements for the devices and systems deployed. These requirements include availability, latency, bandwidth, security, and other factors.
- Provide operations groups the capability to manage, maintain, and troubleshoot the communications network.
- Enable new grid technologies as they become available and future-proof the network as much as possible.

In its GMP, National Grid proposed building both a FAN and WAN. The FAN would provide last mile communications to the end devices. The WAN would provide the backbone and tie the end devices to major field communications nodes and ultimately the ADMS and backend data systems. Substations and other facilities make up the major nodes (locations) of the WAN.

4.3.2 Communications Deployment Plan Progression

Figure 7 shows the progression of National Grid's communication deployment plans from DPU-approval in 2018 through PY2021.

Figure 7. National Grid Communications Planned and Actual Spend Progression, $M



Source: Guidehouse analysis of DPU Order (May 10, 2018), 2018-2020 GMP Annual Reports, and *2021 EDC Data*

In 2017, National Grid hired a third-party communications firm to perform a study to assess its communications requirements. Based on this study and National Grid's internal assessment, National Grid is moving forward with fiber to support a WAN and will be evaluating a private 700 MHz FAN to operate and monitor the grid. Meanwhile, to accelerate other GMP investments, National Grid is using a public cellular network as the FAN.

4.3.3 Communications Investment Progress through PY2021

National Grid is modernizing its Wide Area Network (WAN) to a packet-based MPLS solution. National Grid is continuing to evaluate the use of fiber optics between substations to backhaul communications. They are also evaluating the use of point-to-multipoint (PMP) along with point-to-point (PTP) radio communications.

National Grid has determined that a private radio network along with the use of public cellular will be the preferred communications method going forward for the Field Area Network (FAN). These two communications technologies would be used to operate and monitor grid-controlling assets. The evaluation of the 700 MHz private radio equipment was started in 2021. Until the new 700 MHz network evaluation is completed and then built, other GMP devices—ADA, M&C, and VVO—are being connected to the public cellular network to keep projects moving forward.

National Grid has purchased and implemented a Telecom Operations Management System (TOMS) software. TOMS is a software tool that will enable the planning, designing, engineering, deploying, commissioning, and maintaining of telecom networks.

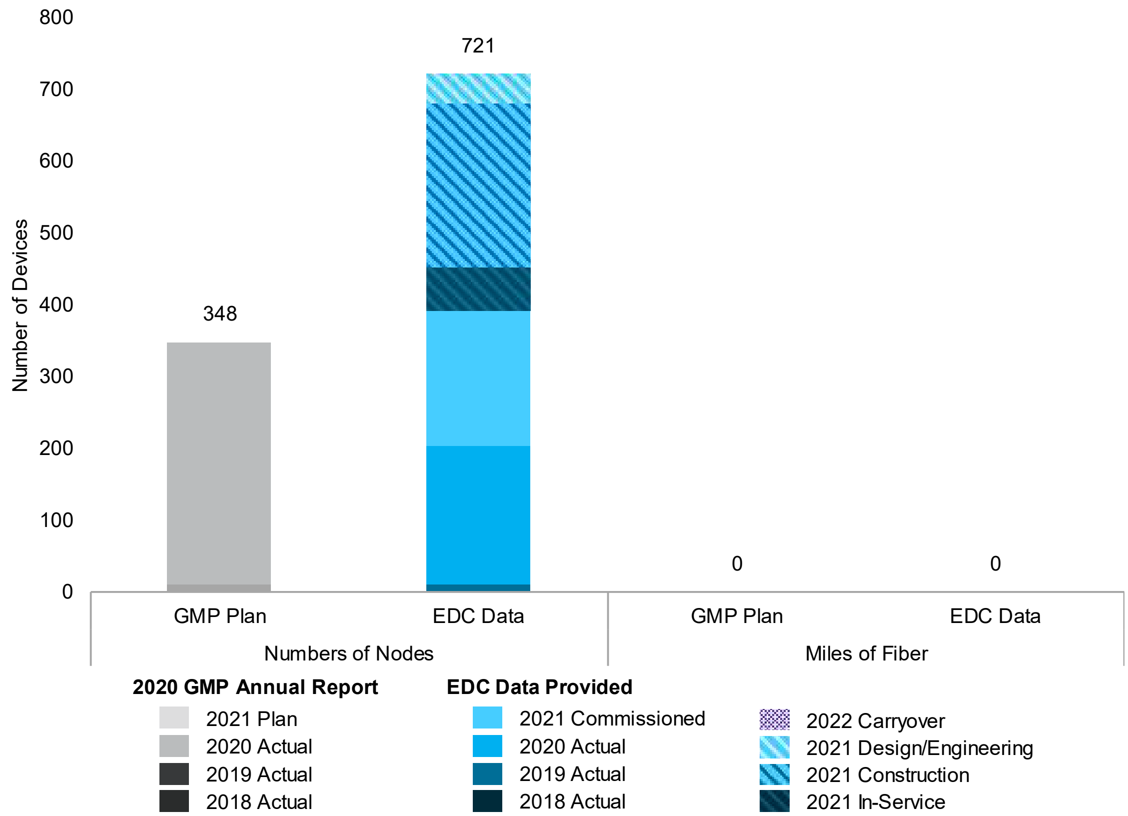
In 2021, National Grid performed the final selection of a vendor to replace its legacy Nokia DMX SONET system with an MPLS solution. Vendor selection included RFP development, terms negotiations, Statement of Work (SOW) development, and various pre-design workshops. The new MPLS system will be used to expand the WAN and support the other grid modernization devices. MPLS will enable true network convergence by providing the capability of combining many older legacy platforms while establishing the foundation for future technology growth and connectivity.

Error! Reference source not found. shows National Grid's planned versus actual device deployment progress over the 2018-2021 period. The EDC Data presented in Figure 8. is also shown in Note that Carryover here would include all units not fully commissioned at the end of PY 2021.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 20. The radio nodes shown in the figure and table are part of the M&C, ADA, and VVO devices, not standalone radios. The costs of these nodes are counted in the M&C, ADA and VVO Investment Areas, respectively.

Figure 8. National Grid Communications Device Deployment Comparison (2018-2021)



Note that Carryover here would include all units not fully commissioned at the end of PY 2021.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 20. National Grid Communications Plan and Actual Device Deployment (2018-2021)

	Numbers of Nodes	Miles of Fiber
2018-2021 Total	**391**	**0**
Engineering/Design during PY 2021*	41	0
Construction during PY 2021*	228	0
In-Service during PY 2021*	61	0
Commissioned in PY 2021	188	0
Commissioned in PY 2020	192	0
Commissioned in PY 2019	11	0
Commissioned in PY 2018	0	0

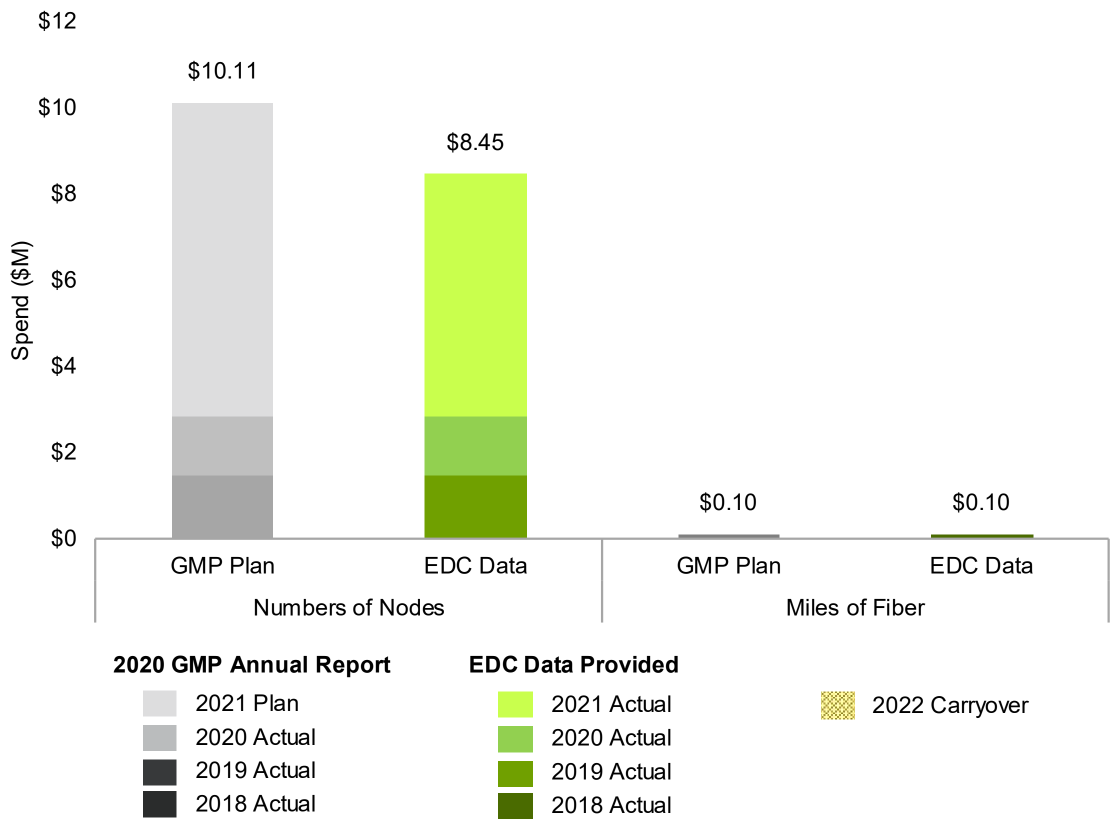
*Deployment of these devices began during PY 2021, but was not completed during the program year. Deployment (through fully commissioning) is planned as carryover in 2022.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Figure 9Figure 9 shows National Grid's planned versus actual spend over the 2018-2021 period. The EDC Data is presented in Figure 9 and is also shown in Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 21. The 2021 actual spend shown is O&M costs incurred toward pre-planning, design, engineering, standards development, and current communications operation.

Figure 9. National Grid Communications Spend Comparison (2018-2021, $M)



Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 21. National Grid Communications Plan and Actual Spend (2018-2021, $M)

	Numbers of Nodes	Miles of Fiber
2018-2021 Total	**$8.45**	**$0.10**
PY 2021 Actual	$5.60	$0.00
PY 2020 Actual	$1.38	$0.00
PY 2019 Actual	$1.47	$0.00
PY 2018 Actual	$0.00	$0.10

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

4.3.4 Infrastructure Metrics Results and Key Findings

Table 22 presents the Infrastructure Metrics results through PY2021 for each investment type related to National Grid's Communications Investment Area.

Table 22. National Grid Communications: Infrastructure Metrics Summary

Infrastructure Metrics			Numbers of Nodes	Miles of Fiber
GMP Plan Total, PY2018-2021		Devices	348	0
		Spend, $M	$10.11	$0.10
IM-4	Number of devices or other technologies deployed through PY2018-2021*	# Devices Deployed	391	0
		% Devices Deployed	112%	N/A
IM-5	Cost for Deployment through PY2018-2021	Total Spend, $M	$8.45	$0.10
		% Spend	84%	100%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	N/A	N/A
		% On Track (Spend)	77%	N/A
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	330	0
		Spend Remaining, $M	$0.00***	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the "carryover" units and spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs' 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.
***Spend for Communications is 0, because the costs associated with the nodes are embedded in VVO, M&C, and ADA device spend

National Grid's communications investment includes the following components:

- **FAN Strategy Evaluation Status:** Evaluation of a 700MHz private radio system. Bench testing, field evaluation and coverage studies were being performed. National Grid has detected some radio interference which they are evaluating how to resolve. While National Grid executes its longer-term FAN strategy, it is currently enabling the ADA and M&C investments using a public cellular radio network.
- **Radio Nodes:** While National Grid executes its longer-term FAN strategy (item 1 in this list), it is presently enabling the ADA and M&C investments using a public cellular network.
- **Telecommunication Operations Management System (TOMS):** An integrated application to plan, design, engineer, deploy, commission, and maintain the operational telecom network for end-to-end connectivity. This investment has been placed in service to improve the efficiency and accuracy of National Grid-US telecom network build-out and operations.
- **Transition to packet-based MPLS solutions:** This investment transitions the existing WAN to Multi-Protocol Label Switching (MPLS), which is protocol-independent and

highly scalable, allowing for any type of transport medium. MPLS will enable true network convergence by providing the capability of combining many older legacy platforms while establishing the foundation for future technology growth and connectivity of the communications WAN.

- **Pursue options for band-width needs:** National Grid is evaluating options to cost effectively expand and deploy incremental infrastructure investments for additional band-width needs, such as fiber optics or high speed radio networks.

4.4 Unitil

4.4.1 Overview of GMP Deployment Plan

Unitil's legacy communications network consists of a combination of public cellular and land-line telecommunications services, and power-line carrier (PLC) technology for its AMI endpoints. This existing communications network is inadequate to support GMP functions including M&C and VVO. In its GMP, Unitil proposed to build a FAN for communications between collectors and endpoint devices, and a WAN for the backhaul of communications from substations to the central office.

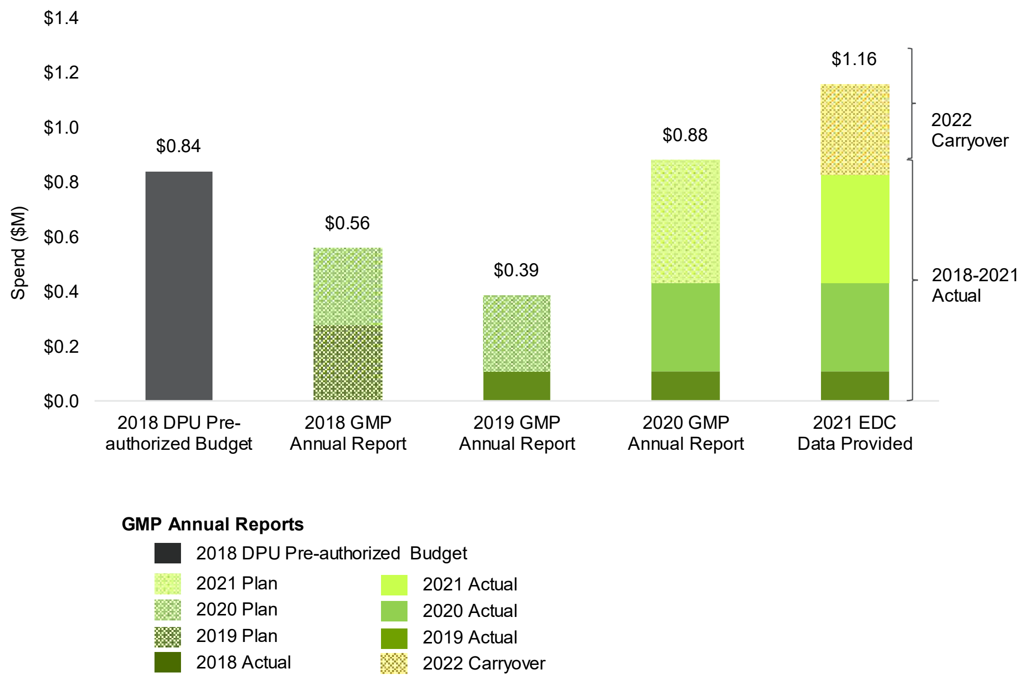
In 2019, Unitil engaged a third-party firm to evaluate technology options that would satisfy its communications requirements. Unitil determined that a private network offered by AT&T, called FirstNet, would be its path forward for its FAN. With this approach the construction of a WAN is no longer required since the backhaul is provided within the AT&T network. During 2020, Unitil entered into contract with AT&T for the FAN, and with installation providers for the backhaul connections and routers between AT&T and Unitil.

In 2021, Unitil set up the backhaul fiber optics connections to AT&T, the cellular provider. This work required the installation of routers and fiber optic connections to existing fiber optics cables at Exeter and Hampton locations in New Hampshire.

To assure proper operations, Unitil performed "bench testing" of the radio equipment integrated with devices that will be installed in the field. A rollout process was validated and documented. In the 2nd quarter of 2021 Unitil deployed the FirstNet field radios. The communications rollout plan is in sequence and timing to support the VVO GMP investment. The field deployments to support the VVO project were on the Townsend circuits. This enabled 22 field devices to send data to the AT&T FirstNet communications and then to the ADMS.

Figure 10 shows the progression of Unitil's Communication deployment plan from DPU-approval in 2018 through PY2021.

Figure 10. Unitil Communications Planned and Actual Spend Progression, $M



Source: Guidehouse analysis of DPU Order (May 10, 2018), 2018-2020 GMP Annual Reports, and *2021 EDC Data*

Unitil's original 2018 plan included funds for a communications study and the deployment of communications equipment. Consistent with the original plan, the spending from 2018 through 2020 included consultant fees to determine communication options, followed by an RFP for design and project management services. The 2021 spend was for equipment procurement, installation of fiber optics / router, testing, and commissioning of communications equipment.

4.4.2 Communications Investment Progress through PY2021

In 2019, Unitil hired a third-party communications firm to complete a study determining the bandwidth, speed, latency, reliability, and availability required for the deployment of grid modernization devices. The study also evaluated various types of ownership for the communications network, design considerations, applications, and nonfunctional requirements. The third-party communications firm evaluated the following technologies for considered deployment: WiMAX, 220 MHz microwave, unlicensed P2MP, fiber, PLC, cellular, and WAN carrier circuits.

Unitil determined that the AT&T FirstNet Cellular approach was the best path forward for its FAN. Although fiber routing of communication from the FAN to the AT&T network would be required, a WAN was no longer needed since the backhaul is handled within the AT&T network.

Following the selection of AT&T FirstNet Cellular, Unitil developed an RFP for a turnkey communication deployment to support the GMP investment. The RFP addressed the FAN between collectors and endpoints and the fiber and routing equipment to connect the FAN to the AT&T connection points. This RFP was issued in February 2020 and the vendor was selected in the fourth quarter of 2020.

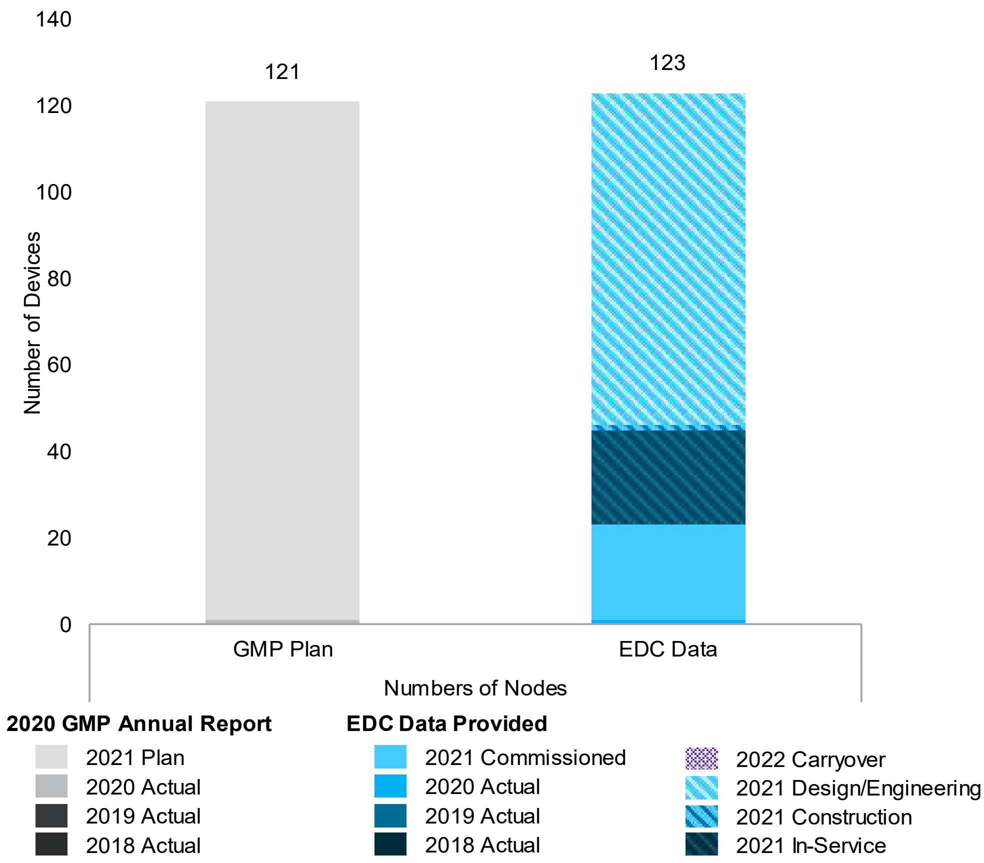
During 2021 work was completed to connect Unitil's communications to the AT&T FirstNet System. This included the integration with ADMS, firewall rules establishment and testing. As of Q2 2021, all contracts and FAN design have been finalized. Equipment deployment was underway.

Figure 11Figure 11 shows Unitil's planned versus actual device deployment progress over the 2018-2021 period. Unitil had not completed a detailed communications study prior to the initial GMP. Therefore, the number of devices was not known at that time of the initial GMP filing. The EDC Data presented in Figure 11 is also shown in Note that *Carryover here would include all units not fully commissioned at the end of PY 2021.*

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 23.

Figure 11. Unitil Communications Device Deployment Comparison (2018-2021)



Note that Carryover here would include all units not fully commissioned at the end of PY 2021.
Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 23. Unitil Communications Plan and Actual Device Deployment (2018-2021)

	Numbers of Nodes
2018-2021 Total	**23**
Engineering/Design during PY 2021*	77
Construction during PY 2021*	1
In-Service during PY 2021*	22
Commissioned in PY 2021	22
Commissioned in PY 2020	1
Commissioned in PY 2019	0
Commissioned in PY 2018	0

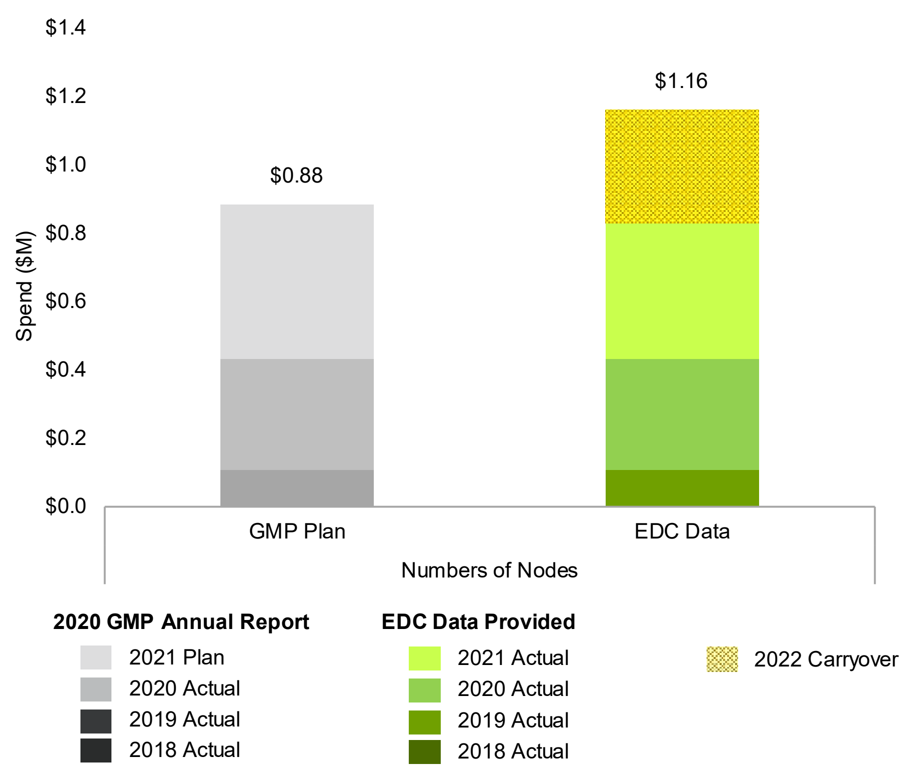
*Deployment of these devices began during PY 2021, but was not completed during the program year. Deployment (through commissioning) is planned as carryover in 2022.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Unitil's overall deployment schedule slipped several months as RFP responses evaluation took longer than planned. In 2019, Unitil indicated the first circuit, Townsend, would have a FAN completed in the fourth quarter of 2020 to support their VVO investment. The first circuit, Townsend, had communications equipment installed in the 2nd quarter of 2021. Unitil's FAN installation schedule is focused on supporting the VVO installation schedule with 22 devices installed during 2021.

Figure 12 shows Unitil's planned versus actual spend over the 2018-2021 period. The EDC Data presented in Figure 12 is also shown in Table 24.

Figure 12. Unitil Communications Spend Comparison (2018-2021, $M)



Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 24. Unitil Communications Plan and Actual Spend (2018-2021, $M)

	Numbers of Nodes
2018-2021 Total	**$0.83**
2022 Carryover Estimate	$0.33
PY 2021 Actual	$0.40
PY 2020 Actual	$0.32
PY 2019 Actual	$0.11
PY 2018 Actual	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Unitil's spending from 2018 through 2021 is behind planned spend when compared to the most recent plan filed in April, 2021. In 2019 Unitil's spend was primarily for consulting fees to complete their communication study and develop an RFP to move forward. The 2020 spend was on RFP evaluation and vendor selection. 2021 spending supported fiber integration with AT&T, purchase of routers, FAN equipment and field installations. When the 2022 carry-over estimated spend is included in overall communications spending Unitil will be back on track with their plan.

In 2021, after the selection of AT&T FirstNet private cellular wireless for FAN communications, Unitil coordinated with AT&T to bring in private ethernet to the primary and backup ADMS systems located in the substations at Exeter, New Hampshire and Hampton, New Hampshire. This ethernet connection eliminated the need for a WAN since the backhaul of communications is handled within the AT&T network. Both sites are FAN connections to AT&T for communications reliability. Cisco routers were installed to provide a fail-over from a primary to secondary communication path. The FAN cellular modems were received, and 23 field installations have been deployed. Unitil has engineered the mounting and connections to the field devices (e.g., capacitor bank controls, voltage regulator controls and line sensors) that are used to support the VVO investments. Bench testing of the field devices, using the cellular modems, and AT&T FirstNet private cellular modems, has been completed.

4.4.3 Infrastructure Metrics Results and Key Findings

Table 25 presents the Infrastructure Metrics results through PY2021 for Unitil's Communications Investment Area.

Table 25. Unitil Communications: Infrastructure Metrics Summary

Infrastructure Metrics			Numbers of Nodes
GMP Plan Total, PY2018-2021		Devices	121
		Spend, $M	$0.88
IM-4	Number of devices or other technologies deployed thru. PY2018-2021*	# Devices Deployed	23
		% Devices Deployed	19%
IM-5	Cost for Deployment through PY2018-2021	Total Spend, $M	$0.83
		% Spend	94%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	18%
		% On Track (Spend)	88%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	100
		Spend Remaining, $M	$0.33

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the "carryover" units and spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs' 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

A summary of Infrastructure Metrics evaluation findings follows:

- Unitil selected AT&T FirstNet as the path forward for its FAN deployment. FirstNet is a private cellular provider of communications.
- A third-party company was selected to provide the FAN design and project management for the FAN deployment.
- Unitil is deploying their FAN communications modems on the same integrated schedule as other GMP investments (i.e., VVO), by substation. This approach ensures GMP devices are commissioned with the new communications network.
- Deployment of the FAN modems began in 2021 on the Townsend circuits. A total of 20 sites were completed in 2021 and the remaining planned sites are in progress.

- For the reliability of communications, Cisco routers were installed at the Exeter, New Hampshire and Hampton, New Hampshire substations to provide a primary and secondary communication path.

5. Conclusions and Recommendations

A robust and high-performance communications network will maximize the benefits of other GMP investments (M&C, VVO, and ADA). The DPU Order emphasized that communications be deployed in tandem with the GMP suite of investments to enable timely benefit realization. Table 26 summarizes Guidehouse's conclusions from evaluating the progress of the three EDCs toward GMP communications plans.

Table 26. EDC-Specific Communications Findings and Recommendations

EDC	Summary of Findings
Eversource	• Eversource has improved its private radio networks' coverage and performance for the monitoring and operation of grid endpoints. The improvement is a result of installing both 450MHZ and 900MHz radios at key tower and substation locations. This investment will improve communications latency and enable better performance for ADA, M&C, and VVO deployments over their service areas. • Eversource is behind schedule in completing the acceptance testing of master radio sites due to manufacturer software bugs. Eversource planned to deploy eight sites in 2021 but commissioned two. Eversource is working closely with the manufacturer to resolve the issues. It expects that by the second quarter of 2022 the remaining masters installed with pass commissioning tests. • Eversource has determined that significant amounts of fiber optics cable are not required going forward. Selected, small lengths of fiber optics will be installed to connect the master radio towers into the existing WAN.
National Grid	• National Grid is transitioning to an MPLS packet-based solution to expand its capability of the communications WAN. Vendor selection and the Scope of Work for replacement has been developed. • National Grid has installed a Telecom Operations Management System (TOMS), an integrated application to plan, design, engineer, deploy, commission, and maintain the operational telecom network for end-to-end connectivity. This system will improve the efficiency and accuracy of National Grid-US telecom network build-out and operations. • National Grid is researching its FAN communication investment options, including public versus private networks. It is presently testing a private 700 MHz radio network system. Two sites have been deployed for evaluation. National Grid has detected some radio interference which they are evaluating how to resolve. • Fiber optics requirements and standards development has progressed. • National Grid will be using either a public cellular network or a private 700 MHz network for new GMP devices that are installed.
Unitil	• Unitil has completed its due diligence in determining its communications strategy. They have determined their communications path forward will be the AT&T FirstNet private system. • Unitil's FAN communications deployment was started in 2021, with 22 modems installed to support the other GMP investments.

Guidehouse submits the following recommendations for EDC consideration.

4) National Grid provided a coverage study (coverage maps) showing the expected performance if they migrate to a public radio network. The coverage study was high-level and not specific to the equipment located on each of the distribution circuits. The study was not sufficient to validate actual performance.

   a. **Recommendation for National Grid:** Field signal strength measurements should be taken to validate that the public network would provide acceptable communications performance.

5) Eversource provided coverage studies (coverage maps) showing the communications performance before the investment and expected improved performance after the investment is completed. These coverage studies were not available or performed for each of the communications investments performed.
   Recommendations for Eversource:
   a. To validate the performance and value of the investment, coverage studies should be performed prior to implementation of base station radios.
   b. Field signal strength measurements should be taken to validate acceptable communications performance.
   c. To improve speed of communications and restoration, a study should be performed to determine if ADA devices on each specific circuit should use a different communication medium. For example, the first device on the circuit uses 450 MHz RF, second device use 900 MHz RF, third device use 5G, etc. (multiple paths for each FLISR scheme).

6) Unitil has decided to install field radios in conjunction with VVO rollout to improve efficiency of radio deployment. While Guidehouse agrees with this approach, the risk could be a delay in VVO investment deployment if unforeseen communications issues arise.
   a. **Recommendation for Unitil:** At the locations where VVO equipment will be installed, field signal strength measurements should be taken to validate that the public network will provide acceptable communications performance.

Guidehouse

Massachusetts Grid Modernization Program Year 2021 Evaluation Report: Monitoring and Control (M&C)

Massachusetts Electric Distribution Companies

Submitted by:

Guidehouse Inc.
77 South Bedford Street, Suite 400
Burlington, MA 01803
Telephone (781) 270-8300
Guidehouse.com

Reference No.: 209941
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Executive Summary

Introduction

As a part of the Grid Modernization Plan (GMP), the Massachusetts Electric Distribution Companies (EDCs) are investing to enable Monitoring and Control (M&C) on selected circuits across their distribution networks. These investments should enhance grid visibility and control capabilities to increase reliability, facilitate integration of DERs, and provide other grid and customer benefits.

This evaluation focuses on the progress and effectiveness of the Department of Public Utilities (DPU) preauthorized M&C investments for each EDC toward meeting the DPU's grid modernization objectives for Program Year (PY) 2021.

Evaluation Process

The DPU requires a formal evaluation process, including an evaluation plan and evaluation studies, for the EDCs' preauthorized grid modernization plan investments. Guidehouse (formerly Navigant Consulting, Inc.)[1] is completing the evaluation to establish a uniform statewide approach and to facilitate coordination and comparability. The evaluation is to measure and assess progress toward achieving the DPU's grid modernization objectives. The evaluation uses the DPU-established Infrastructure Metrics and Performance Metrics along with a set of Case Studies to understand if the GMP investments are meeting the DPU's objectives.

The original Evaluation Plan developed by Navigant Consulting (now Guidehouse) was submitted to the DPU by the EDCs in a petition for approval on May 1, 2019. Modifications to this original Evaluation Plan were made to 1) request changes to the reporting schedule to accommodate Performance Metrics data availability timing, as discussed in response to DPU EP-1-1 submitted on February 6, 2020[2], and 2) to extend the Grid Modernization term period from the original 3 year term to a 4 year term as ordered by the DPU in its May 12, 2020 Order.[3] Modifications to the original Evaluation Plan were submitted to the DPU by the EDCs in a petition for approval on December 1, 2020. The modified Evaluation Plan has been used to develop the analysis and evaluation provided below in this document.

Table 1 illustrates the key Infrastructure Metrics, Performance Metrics, and Case Studies (shown as Other metrics in the table) relevant for the M&C evaluation by EDC.

[1] Guidehouse LLP completed its acquisition of Navigant Consulting, Inc, in October of 2019. The two brands are now combined as one, under the name "Guidehouse."

[2] Submitted to Massachusetts DPU 15-120, 15-121, 15-122.

[3] Order (1) Extending Current Three-Year Grid Modernization Plan Investment Term; and (2) Establishing Revised Filing Date for Subsequent Grid Modernization Plans; DPU 15-120-D/DPU 15-121-D/DPU 15-122; May 12, 2020.

Table 1. M&C Evaluation Metrics

Type	M&C Evaluation Metrics	ES	NG	UTL
IM	System Automation Saturation*	✓	✓	✓
IM	Number and Percent of Circuits with Installed Sensors*	✓	✓	✓
IM	Number of Devices or Other Technologies Deployed and In Service	✓	✓	✓
IM	Cost for Deployment	✓	✓	✓
IM	Deviation Between Actual and Planned Deployment for the Plan Year	✓	✓	✓
IM	Projected Deployment for the Remainder of the 3-Year Term	✓	✓	✓
PM	Grid Modernization Investments' Effect on Outage Durations	✓	✓	✓
PM	Grid Modernization Investments' Effect on Outage Frequency	✓	✓	✓
PM	Protective Zone: Average Zone Size per Circuit**	✓		
PM	Customer Minutes of Outage Saved per Circuit			✓
PM	Main Line Customer Minutes of Interruption Saved**		✓	
Other	Case Studies	✓	✓	✓

IM = Infrastructure Metric, PM = Performance Metric, ES = Eversource, NG = National Grid, UTL = Unitil

* The EDCs are responsible for these metric calculations and the calculations are not addressed in this evaluation

** Metrics apply to ADA

Source: Stamp Approved Performance Metrics, July 25, 2019

Data Management

Guidehouse worked with the EDCs to collect data to complete the M&C evaluation for the assessment of Infrastructure Metrics, Performance Metrics and Case Studies. A consistent methodology was used across investment areas and EDCs for evaluating and illustrating EDC progress toward the GMP metrics.

Table 2 summarizes data sources used throughout the M&C evaluation for PY2021. Section 3.1.1 details each of the data sources.

Table 2. M&C Data Sources

Data Source	Description
2020 Grid Modernization Plan Annual Report[4,5,6]	Planned device deployment and cost information from each EDC's appendix to the *2020 GMP Annual Report* (filed April 1, 2021). Data was used as the reference to track progress against the GMP targets and are referred to as the GMP Plan in summary tables and figures throughout the report.
2021 Grid Modernization Plan Annual Report[7,8,9]	All PM-related data are from these 2021 GMP Annual Report Appendices. In addition, data collected as part of EDC Data Template (below) was compared to the data submitted by the EDCs to the DPU in the 2021 Grid Modernization Plan Annual Reports and associated Appendix 1 filings. The evaluation team confirmed the consistency of the data from the various sources and reconciled any differences
EDC Device Deployment Data Template	Captures planned and actual device deployment and spend data. Actual device deployment and cumulative spend information were provided by work order ID and specified at the feeder- or substation-level as appropriate. Carryover device deployment information and estimated carryover spend for 2022 were provided as well.
Eversource's 2021 DPU-Filed Plan[10]	Eversource's GMP extension request was approved by the DPU on February 4, 2021. It includes budgets for PY2021 deployment at the Investment Area level. This data source is included in the EDC Plan for Eversource planned spend at the Investment Area level.

Source: Guidehouse analysis

Findings and Recommendations

Table 3 summarizes the Infrastructure Metrics results for each EDC's M&C Investment Area through PY2021.

[4] Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30.
[5] NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30. Note that Eversource Energy filed an updated Appendix 1 filing in December of 2021; however that update did not affect any of the data or results in the evaluation.
[6] Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30.
[7] Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-41.
[8] NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-40.
[9] Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-42.
[10] Grid Modernization Program Extension and Funding Report. Submitted to Massachusetts DPU on July 1, 2020 as part of DPU 15-122.

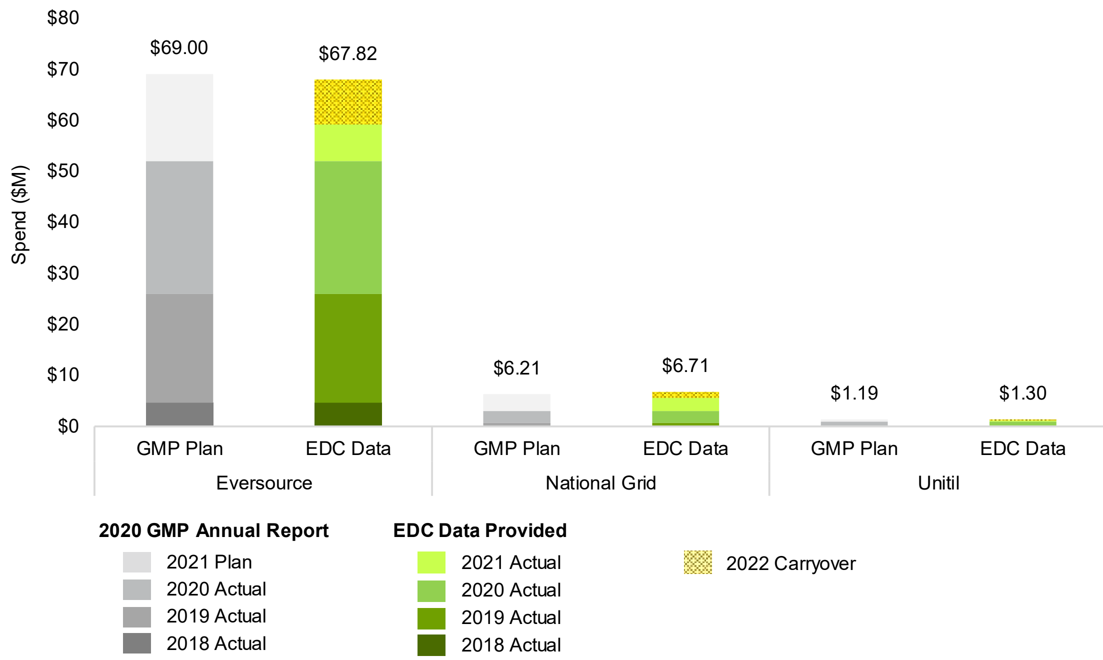
Table 3. M&C Infrastructure Metrics Summary

Infrastructure Metrics			Eversource	National Grid	Unitil
GMP Plan Total, PY2018-2021		Devices	560	202	14
		Spend, $M	$69.00	$6.21	$1.19
IM-4	Number of devices or other technologies deployed PY2018-2021*	# Devices Deployed***	504	155	11
		% Devices Deployed	90%	77%	79%
IM-5	Cost for Deployment PY2018-2021*	Total Spend, $M	$59.16	$5.52	$0.98
		% Spend	86%	89%	82%
IM-6	Deviation Between Actual and Planned Deployment for PY2021	% On Track (Devices)	55%	64%	0%
		% On Track (Spend)	42%	78%	26%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	56	53	3
		Spend Remaining, $M	$8.66	$1.19	$0.32

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the "carryover" units and spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs' 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.
****Note that "Deployed" here refers to commissioned devices. In National Grid's Term Report (filed April 1, 2022), deployed refers to in-service and/or commissioned devices. In-service devices are fully installed and used and useful, but not yet commissioned with Grid Mod functionality (communication and remote visibility and/or control). For full definitions of commissioned and in-service, see Docket 20-46 Response to Information Request DPU-AR-4-11, September 3, 2020.*

Figure 1 compares the GMP Plans and EDC Data totals and year-over-year spending for each EDC.

Figure 1. M&C Spend Comparison (2018-2021, $M)



Note: Includes the Eversource planned spend for PY2021, set forth the in the GMP Extension and Funding Report, filed on July 1, 2020.

Source: Guidehouse analysis of 2020 GMP Annual Reports, GMP Extension and Funding Report, and 2021 EDC Data

Table 4 summarizes key findings related Guidehouse's M&C deployment evaluation for each EDC.

Table 4. Summary of Infrastructure Metrics Findings for M&C Investment Area

EDC	Summary of Findings
Eversource	• Actual device deployment and spending in PY2021 were lower than planned for Eversource, largely due to a pause in deployment of some device types while ensuring approval to proceed with proposed plan. • The Power Quality Monitors and Network Protector SCADA programs were completed in PY2021, with Microprocessor Relays and 4kV Circuit Breaker SCADA carried over into 2022.
National Grid	• National Grid deployed fewer devices than planned, but at a higher per-unit cost, thus slightly exceeding the budget planned in PY2021 due to supply chain issues and underestimating some of the field deployment complexities.
Unitil	• Unitil had delays in device deployment and corresponding spend (see IM-6 in Table 21) due to internal resource constraints and identification of additional complexities discovered as the engineering work proceeded but on track to complete deployment of these units in 2022.

Source: Guidehouse analysis of 2020 GMP Annual Reports and EDC Data

Table 5 and Table 6 summarize the Performance Metric Results for each EDC's M&C Investment Area in PY2021. Table 5 shows the results for the Performance Metric that analyzes the Effect on Outage Duration (CKAIDI) and Table 6 shows the results for the Effect on Outage Frequency (CKAIFI). In both tables, the baseline and PY2021 results are summarized for both system-wide circuits and M&C circuits. The Unitil-specific metric of Customer Minutes Saved per Outage was not analyzed as the AMI-OMS integration has not been completed.

Table 5. M&C Performance Metrics Summary: CKAIDI

Eversource M&C	2015-2017 Avg. CKAIDI (Baseline)				2021 CKAIDI (Program Year)			
	System-wide		M&C Circuits		System-wide		M&C Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIDI Statistics								
Total Circuits	2,071	2,071	288	288	2,071	2,071	288	288
Total Circuits with Non-zero Customers	1,658	1,658	230	230	1,572	1,572	230	230
% Zero CKAIDI	22%	22%	15%	15%	29%	35%	27%	32%
Average CKAIDI	133	105	96	89	643	66	185	77
Change from Baseline (Baseline - Plan Year)					-510	39	-90	12
% Change from Baseline					-383%	37%	-93%	14%
Std. Dev.	154	117	101	86	1,289	82	590	89
National Grid M&C	**2015-2017 Avg. CKAIDI (Baseline)**				**2021 CKAIDI (Program Year)**			
	System-wide		M&C Circuits		System-wide		M&C Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIDI Statistics								
Total Circuits	1,076	1,076	91	91	1,076	1,076	91	91
Total Circuits with Non-zero Customers	1,073	1,073	91	91	1,042	1,042	91	91
% Zero CKAIDI	3%	4%	0%	0%	19%	20%	3%	4%
Average CKAIDI	222	118	196	114	366	113	682	143
Change from Baseline (Baseline - Plan Year)					-145	5	-486	-28
% Change from Baseline					-65%	4%	-247%	-25%
Std. Dev.	258	162	177	69	672	122	940	120
Unitil M&C	**2015-2017 Avg. CKAIDI (Baseline)**				**2021 CKAIDI (Program Year)**			
	System-wide		M&C Circuits		System-wide		M&C Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIDI Statistics								
Total Circuits	31	31	9	9	31	31	9	9
Total Circuits with Non-zero Customers	31	31	9	9	31	31	9	9
% Zero CKAIDI	0%	3%	0%	11%	6%	13%	0%	11%
Average CKAIDI	175	66	204	75	218	117	212	115
Change from Baseline (Baseline - Plan Year)					-43	-51	-8	-41
% Change from Baseline					-25%	-77%	-4%	-55%
Std. Dev.	85	34	43	31	128	107	75	72

Source: Guidehouse analysis of 2021 GMP Annual Reports Appendix 1

Table 6. M&C Performance Metrics Summary: CKAIFI

Eversource M&C	2015-2017 Avg. CKAIFI (Baseline)				2021 CKAIFI (Program Year)			
	System-wide		M&C Circuits		System-wide		M&C Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIFI Statistics								
Total Circuits	2,071	2,071	288	288	2,071	2,071	288	288
Total Circuits with Non-zero Customers	1,658	1,658	230	230	1,572	1,572	230	230
% Zero CKAIFI	22%	22%	15%	15%	29%	36%	28%	33%
Average CKAIFI	1.0	0.9	0.8	0.8	1.3	0.7	0.9	0.7
Change from Baseline (Baseline - Plan Year)					-0.3	0.2	-0.1	0.1
% Change from Baseline					-31%	22%	-8%	16%
Std. Dev.	0.8	0.7	0.6	0.6	1.4	0.8	1.0	0.7
National Grid M&C	**2015-2017 Avg. CKAIFI (Baseline)**				**2021 CKAIFI (Program Year)**			
	System-wide		M&C Circuits		System-wide		M&C Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIFI Statistics								
Total Circuits	1,076	1,076	91	91	1,076	1,076	91	91
Total Circuits with Non-zero Customers	1,073	1,073	91	91	1,042	1,042	91	91
% Zero CKAIFI	3%	4%	0%	0%	19%	20%	3%	4%
Average CKAIFI	1.0	0.9	1.0	0.9	1.1	0.9	1.5	1.3
Change from Baseline (Baseline - Plan Year)					-0.1	0.0	-0.5	-0.3
% Change from Baseline					-9%	0%	-47%	-35%
Std. Dev.	0.6	0.6	0.5	0.5	1.0	0.8	1.0	0.9
Unitil M&C	**2015-2017 Avg. CKAIFI (Baseline)**				**2021 CKAIFI (Program Year)**			
	System-wide		M&C Circuits		System-wide		M&C Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIFI Statistics								
Total Circuits	31	31	9	9	31	31	9	9
Total Circuits with Non-zero Customers	31	31	9	9	31	31	9	9
% Zero CKAIFI	0%	3%	0%	11%	6%	13%	0%	11%
Average CKAIFI	2.0	1.1	2.4	1.3	2.8	1.4	2.8	1.7
Change from Baseline (Baseline - Plan Year)					-0.8	-0.3	-0.4	-0.5
% Change from Baseline					-41%	-32%	-18%	-36%
Std. Dev.	0.7	0.5	0.4	0.4	1.5	1.2	1.6	1.6

Source: Guidehouse analysis of 2021 GMP Annual Reports Appendix 1

Table 7 summarizes key findings related to Guidehouse's M&C Performance Metrics evaluation for each EDC.

Table 7. Summary of Performance Metrics Findings for M&C Investment Area

PM	Eversource	National Grid	Unitil
PM-12: Grid Modernization investments' effect on outage durations	Outage duration for M&C circuits for PY2021 slightly decreased, compared to baseline. *	Outage duration for M&C circuits for PY2021 was significantly longer than baseline. *	Relative to the baseline, outage duration for both system-wide and M&C circuits increased. However, there is an insufficient number of devices installed to draw conclusions. *
PM-13: Grid Modernization investments' effect on outage frequency	Outage frequency for M&C circuits for PY2021 was slightly lower than baseline. *	Outage frequency for M&C circuits for PY2021 was higher than baseline. *	Outage frequency was slightly increased for both M&C and system-wide circuits, but there is an insufficient number of devices installed to draw conclusions. *
PM-UTL1: Customer Minutes of Outage Saved per Circuit	N/A – Unitil specific metric	N/A – Unitil specific metric	The OMS/AMI Integration is not complete; this metric cannot yet be evaluated.

** Note: This metric is not able to readily discern whether change in this metric was due to M&C investment or other factors.*

Source: Guidehouse Analysis

Guidehouse submits the following recommendations for EDC consideration in PY2021:

1) The CKAIDI and CKAIFI reliability related Performance Metrics as defined have deficiencies in measuring the effectiveness of standalone M&C Grid Modernization Investments. Many factors unrelated to the Grid Modernization investments will affect these metrics in any given year, and it is not possible to distinguish among these factors using the metrics. For example, the variation in storm activity between years can cause significant changes in these metrics, as apparently happened in PY2020 and PY2021. This observation has been made previously, and some of these recommendations were made last year, but bear repeating.
    a. Recommendation: Continue to track these Performance Metrics but establish other methods of isolating the specific impacts of M&C investments.
    b. Recommendation: Additional Performance Metrics should be explored to determine if it is possible to capture the actual reliability performance attributable to the M&C investments. Exploration could include:
        i. Exploring the pros and cons of making the reliability metrics baseline a rolling average of, perhaps, the most recent 3 years, as opposed to the fixed years of 2015 through 2017. The fixed baseline has the issue, as pointed out in the report, that individual circuits are reconfigured over time, go out of service, and new circuits are created, making circuit-wise comparisons over time more challenging.
        ii. Exploring the pros and cons of understanding the timing and sequencing of reliability events more during the initial stages of the event. This timing

would lend insight whether and when an event was visible within the control room or for automated decision making, and then how long before action was taken. As the network becomes more complex (e.g., increased DER penetration, will become more complex and may tend to take longer. So, understanding these dynamics will grow in importance.

iii. Reviewing the data and techniques available to expand the understanding of the relationship between circuit reliability and weather conditions, vegetation management cycles and other reliability drivers that are independent of the grid modernization investments.

iv. Expanding the use of case studies to provide greater understanding of the situational awareness and improved visibility and data provided by these investments (see Recommendation 4a below).

v. Recognizing the role of M&C data within outage case studies, and perhaps extrapolate these results to a broader set of circuits to understand investment performance with more certainty.

vi. Developing a way to expand the use of counter-factual analysis on a broader basis than what is currently being done in the Case Studies could help develop a better understanding of overall system impacts from the ADA investments.

2) Use of currently defined CKAIDI and CKAIFI reliability related Performance Metrics—which are circuit level metrics—has increasing challenges over time as circuits get re-configured or retired and new circuits are created. The comparability of each circuit in the program year to its baseline depends on that circuit not having been reconfigured or significantly changed (e.g., a normally open switch between circuit segments is changed to operate as normally closed, changing the customer counts and outage measurements on that circuit). The number of circuits that are comparable between baseline and program year is reduced year after year as more circuits change due to ongoing operation of the system. This observation has been made previously, and this recommendation was made last year, but bears repeating.

   a. Recommendation: Explore metrics and baselines that are robust to these operating changes to help ensure that Grid Mod investment assessment based on these metrics is not misleading, and is able to better capture the impact of the investment.

3) Current metrics do not provide an understanding of how M&C and ADA investments facilitate easier interconnection or more capacity for DER added to the system. This observation has been made previously, and this recommendation was made last year, but bears repeating.

   a. Recommendation: Consider developing additional metrics and/or performing pilot projects that utilize the installation of ADA and M&C investments at DER locations to understand the value or benefits that are provided. This would provide actual data on the effectiveness of these investments to support DER integration.

4) Case studies show detailed functioning and impact of GMP devices, and they are proving to be a useful tool in understanding the effectiveness of the Grid Modernization

investments. Based on case studies performed, the M&C investment is yielding reliability and service delivery benefits to customers for each of the EDCs. This observation has been made previously, and these recommendations were made last year, but bear repeating.

a. Recommendation: Continue to perform case studies in future evaluations, and increase the use of case studies where practicable, to analyze the mitigation of customer outages and help determine the effectiveness of Grid Modernization investments in improving reliability and service delivery.
b. Recommendation: Continue the deployment of M&C technologies as part of the Grid Modernization Program and continue to monitor progress (including through amended or additional metrics to be determined by the Department).

5) For National Grid, the evaluation process validated that the feeder monitor sensor investment improves situational awareness, but at this time the impact on reducing outage duration or number of customers affected during an outage is not clear.

   a. Recommendation for National Grid: Develop programs to use the feeder monitor sensors to identify and review momentary outages to predict causes which could mitigate future outage causes. For instance:
      i. Momentary Outage Reduction: Use existing sensors to detect momentary outages (breaker trip and reclose). Using the sensors with data analytics, determine location, potential causes and corrective actions.
      ii. Outage Duration Reduction: Incorporate M&C monitors into future ADA investments to support the outage restoration process. Sensors will enable additional situational awareness and information for field crews to locate the faulted area of the circuit more quickly.
      iii. Battery Backup: Evaluate the costs and benefits of installing batteries to enable the ability of the sensors to support outage management.

1. Introduction to Massachusetts Grid Modernization

This section provides a brief background to the grid modernization evaluation process along with an overview of the Monitoring and Control (M&C) Investment Area and specific M&C evaluation objectives. These are provided for context when reviewing the subsequent sections that address the specific evaluation process and findings.

1.1 Massachusetts Grid Modernization Plan Background

On May 10, 2018, the Massachusetts Department of Public Utilities (DPU) issued its Order[11] regarding the individual Grid Modernization Plans (GMPs) filed by the three Massachusetts Electric Distribution Companies (EDCs): Eversource, National Grid, and Unitil.[12,13] In the Order, the DPU preauthorized grid-facing investments over 3 years (2018-2020) for each EDC and adopted a 3-year (2018-2020) regulatory review construct for preauthorization of grid modernization investments. On May 12, 2020, the DPU issued an Order[14] extending the 3-year grid modernization plan investment term to a 4-year term, which now includes the 2021 program year. The company-specific GMP budget caps did not change with the term extension. On July 1, 2020, Eversource filed a request for an extension of the budget authorization associated with grid modernization investments.[15] The budget extension, approved by the DPU on February 4, 2021, included $14 million for ADA, $16 million for ADMS/ALF, $5 million for Communications, $15 million for M&C, and $5 million for VVO.

The preauthorized GMP investments are expected to advance the achievement of DPU's grid modernization objectives:

- Optimize system performance by attaining optimal levels of grid visibility command and control, and self-healing
- Optimize system demand by facilitating consumer price responsiveness
- Interconnect and integrate distributed energy resources (DER)

As part of the GMPs, the DPU determined that a formal evaluation process for the preauthorized GMP investments, including an evaluation plan and studies, was necessary to understand progress and help ensure that the objectives were achieved with greater certainty.

The grid modernization investments were organized into six Investment Areas to facilitate understanding, consistency across EDCs, and analysis.

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[11] Massachusetts DPU 15-120/DPU 15-121/DPU 15-122 (Grid Modernization) Order issued May 10, 2018 (DPU Order).

[12] On August 19, 2015, National Grid, Unitil, and Eversource each filed a grid modernization plan with the DPU. The DPU docketed these plans as DPU 15-120, DPU 15-121, and DPU 15-122, respectively.

[13] On June16, 2016, Eversource and National Grid each filed updates to their respective grid modernization plans

[14] Massachusetts DPU 15-120; DPU 15-121; DPU 15-122 (Grid Modernization) Order (1) Extending Current Three-Year Grid Modernization Plan Investment Term; and (2) Establishing Revised Filing Date for Subsequent Grid Modernization Plans (issued May 12, 2020).

[15] Grid Modernization Program Extension and Funding Report. Submitted to Massachusetts DPU on July 1, 2020 as part of DPU 15-122.

- Monitoring and Control (M&C)
- Advanced Distribution Automation (ADA)
- Volt/VAR Optimization (VVO)
- Advanced Distribution Management Systems/Advanced Load Flow (ADMS and ALF)
- Communications/IoT (Comms)
- Workforce Management (WFM)

This report focuses on the M&C Investment Area. Similarly structured evaluation reports have been developed for each of the other Investment Areas.

1.1.1 Investment Areas

Table 8 summarizes the preauthorized GMP investments.

Table 8. Overview of Investment Areas

Investment Area	Description	Objective
Monitoring and Control (M&C)	Remote monitoring and control of devices in the substation for feeder monitoring or online devices for enhanced visibility outside the substation	Enhancing grid visibility and control capabilities, reliability increase
Advanced Distribution Automation (ADA)	Isolation of outage events with automated restoration of unaffected circuit segments	Reduces the impact of outages
Volt/VAR Optimization (VVO)	Control of line and substation equipment to optimize voltage, reduce energy consumption, and increase hosting capacity	Optimization of distribution voltage to reduce energy consumption and demand
Advanced Distribution Management Systems/Advanced Load Flow (ADMS and ALF[16])	New capabilities in real-time system control with investments in developing accurate system models and enhancing Supervisory control and data acquisition (SCADA) and outage management systems to control devices for system optimization and provide support for distribution automation and VVO with high penetration of DER	Enables high penetration of DER by supporting the ability to control devices for system optimization, ADA, and VVO
Communications/IoT	Fiber middle mile and field area communications systems	Enables the full benefits of grid modernization devices to be realized
Workforce Management (WFM)	Investments to improve workforce and asset utilization related to outage management and storm response	Improves the ability to identify damage after storms

[16] Note that ALF is an Eversource-only investment, and is not being pursued by the other EDCs, whereas ADMS investment is being pursued by all three EDCs.

Source: Grid Mod RFP – SOW (Final 8-8-18).pdf; Guidehouse

The Massachusetts DPU preauthorized budget for grid modernization varies by Investment Area and EDC. Eversource originally had the largest preauthorized budget at $133 million, with ADA and M&C representing the largest share ($44 million and $41 million, respectively). National Grid's preauthorized budget was $82.2 million, with ADMS representing over 50% ($48.4 million). Unitil's preauthorized budget was $4.4 million and VVO makes up 50% ($2.2 million).

On July 1, 2020, Eversource filed a request for an extension of the budget authorization associated with grid modernization investments.[17] The budget extension, approved by the DPU on February 4, 2021,[18] includes $14 million for ADA, $16 million for ADMS/ALF, $5 million for Communications, $15 million for M&C, and $5 million for VVO. These values are included in the Eversource total budget by Investment Area in Table 6.

Table 9. 2018-2021 GMP Preauthorized Budget, $M

Investment Areas	Eversource	National Grid	Unitil	Total
ADA	$58.00	$13.40	N/A	**$71.40**
ADMS/ALF	$33.00	$48.40	$0.70	**$79.10**
Comms	$23.00	$1.80	$0.84	**$25.60**
M&C	$56.00	$8.00	$0.35	**$64.75**
VVO	$18.00	$10.60	$2.22	**$30.80**
WFM	-	-	$0.30	**$1.00**
2018-2021 Total	**$188.00**	**$82.20**	**$4.41**	**$272.65**

Source: DPU Order, May 10, 2018, and Eversource filing "GMP Extension and Funding Report," July 1, 2020

The DPU allowed flexibility to these budgets to accommodate changing technologies and circumstances. For example, EDCs can shift funds across the different preauthorized investments if a reasonable explanation for these shifts is supplied. The following subsections discuss these evaluation goals, objectives, and the metrics to be used.

1.1.2 Evaluation Goal and Objectives

The DPU requires a formal evaluation process (including an evaluation plan and evaluation studies) for the EDCs' preauthorized GMP investments. Guidehouse is completing the evaluation to enable a uniform statewide approach and to facilitate coordination and comparability. The evaluation measures the progress made toward the achievement of DPU's grid modernization objectives. The evaluation uses the DPU-established Infrastructure Metrics and Performance Metrics, as well as Case Studies that illustrate the performance of specific technology installations, to help determine if the investments are meeting the DPU's GMP objectives.

[17] Grid Modernization Program Extension and Funding Report. Submitted to Massachusetts DPU on July 1, 2020 as part of DPU 15-122

[18] Massachusetts DPU 20-74 Order issued on February 4, 2021.

1.1.3 Metrics for Evaluation

The DPU-required evaluation involves Infrastructure Metrics and Performance Metrics for each Investment Area. In addition, selected case studies have been added for some Investment Areas (e.g., M&C) as part of the evaluation to help facilitate understanding of how the technology performs in specific instances (e.g., in remediating the effects of a line outage).

1.1.3.1 Infrastructure Metrics

The Infrastructure Metrics assess the deployment of the GMP investments. Table 10 summarizes the Infrastructure Metrics.

Table 10. Infrastructure Metrics Overview

Metric		Description	Applicable IAs	Metric Responsibility
IM-1	**Grid Connected Distribution Generation Facilities**	Tracks the number and type of distributed generation facilities in service and connected to the distribution system	ADMS/ALF	EDC
IM-2	**System Automation Saturation**	Measures the quantity of customers served by fully or partially automated devices.	M&C, ADA	EDC
IM-3	**Number and Percent of Circuits with Installed Sensors**	Measures the total number of circuits with installed sensors which will provide information useful for proactive planning and intervention.	M&C	EDC
IM-4	**Number of Devices Deployed and In Service**	Measures how the EDC is progressing with its GMP from an equipment or device standpoint.	All IAs	Evaluator
IM-5	**Cost for Deployment**	Measures the associated costs for the number of devices or technologies installed; designed to measure how the EDC is progressing under its GMP.	All IAs	Evaluator
IM-6	**Deviation Between Actual and Planned Deployment for the Plan Year**	Measures how the EDC is progressing relative to its GMP on a year-by-year basis.	All IAs	Evaluator
IM-7	**Projected Deployment for the Remainder of the Four - Year Term**	Compares the revised projected deployment with the original target deployment as the EDC implements its GMP.	All IAs	Evaluator

IM = Infrastructure Metric, IA = Investment Area

Source: Guidehouse review of Infrastructure Metric filings

1.1.3.2 Performance Metrics

The Performance Metrics assess the performance of all the GMP investments. Table 11 summarizes the Performance Metrics used for the various Investment Areas.

Table 11. Performance Metrics Overview

Metric		Description	Applicable IAs	Metric Responsibility
PM-1	**VVO Baseline**	Establishes a baseline impact factor for each VVO-enabled circuit which will be used to quantify the peak load, energy savings, and greenhouse gas (GHG) impact measures.	VVO	All
PM-2	**VVO Energy Savings**	Quantifies the energy savings achieved by VVO using the baseline established for the circuit against the annual circuit load with the intent of optimizing system performance.	VVO	All
PM-3	**VVO Peak Load Impact**	Quantifies the peak demand impact VVO/CVR has on the system with the intent of optimizing system demand.	VVO	All
PM-4	**VVO Distribution Losses without Advanced Metering Functionality (AMF) (Baseline)**	Presents the difference between circuit load measured at the substation via the SCADA system and the metered load measured through advanced metering infrastructure.	VVO	All
PM-5	**VVO Power Factor**	Quantifies the improvement that VVO/CVR is providing toward maintaining circuit power factors near unity.	VVO	All
PM-6	**VVO – GHG Emissions**	Quantifies the overall GHG impact VVO/CVR has on the system.	VVO	All
PM-7	**Voltage Complaints**	Quantifies the prevalence of voltage-related complaints before and after deployment of VVO investments to assess customer experience, voltage stability under VVO.	VVO	All
PM-8	**Increase in Substations with DMS Power Flow and Control Capabilities**	Examines the deployment and data cleanup associated with deployment of ADMS, primarily by counting and tracking the number of circuits and substations per year.	ADMS/ ALF	All
PM-9	**Control Functions Implemented by Circuit**	Examines the control functions of DMS power flow and control capabilities, focused on the control capabilities including VVO-CVR and FLISR.	ADMS/ ALF	All

Metric		Description	Applicable IAs	Metric Responsibility
PM-11	**Numbers of Customers that benefit from GMP funded Distribution Automation Devices**	Shows the progress of ADA investments by tracking the number of customers that have benefitted from the installation of ADA devices.	ADA	ES, NG
PM-12	**Grid Modernization investments' effect on outage durations**	Provides insight into how ADA and M&C investments can reduce outage durations (CKAIDI). Compares the experience of customers on GMP M&C-enabled circuits as compared to the previous 3-year average for the same circuit.	M&C, ADA	All
PM-13	**Grid Modernization investments' effect on outage frequency**	Provides insight into how ADA and M&C investments can reduce outage frequencies (CKAIFI). Compares the experience of customers on M&C-enabled circuits as compared to the prior 3-year average for the same circuit.	M&C, ADA	All
PM-ES1	**Advanced Load Flow – Percent Milestone Completion**	Examines the fully developed ALF capability across Eversource's circuit population.	ADMS/ ALF	ES
PM-ES2	**Protective Zone: Average Zone Size per Circuit**	Measures Eversource's progress in sectionalizing circuits into protective zones designed to limit outages to customers located within the zone.	ADA	ES
PM-UTL1	**Customer Minutes of Outage Saved per Circuit**	Tracks time savings from faster AMI outage notification than customer outage call, leading to faster outage response and reduced customer minutes of interruption.	M&C	UTL
PM-NG1	**Main Line Customer Minutes of Interruption Saved**	Measures the impact of ADA investments on the customer minutes of interruption (CMI) for main line interruptions. Compares the CMI of GMP ADA-enabled circuits to the previous 3-year average for the same circuit.	ADA	NG

PM = Performance Metric, IA = Investment Area, ES = Eversource, NG = National Grid, UTL = Unitil

Source: Stamp Approved Performance Metrics, July 25, 2019.

This report discusses Performance Metrics that pertain specifically to the M&C Investment Area.

1.1.3.3 Case Studies

A case study approach was developed to provide more insight into the actual operation of the GMP devices and to illustrate how these investments provide customer reliability and operational benefits. The impacts of GMP devices on system reliability metrics can be difficult to discern due to the range of factors that affect these metrics. Storm conditions, vehicle accidents and other factors drive reliability from year to year. This is especially likely if the device has less than several full years of operation to affect the metric. The case studies help to illustrate the benefits provided by GMP devices during outages and other events. This approach investigates outage events on specific circuits where the GMP equipment was used to address the outage. The approach also allows for comparison between what did occur due to the presence of the GMP device and what would have likely happened had the GMP investment not been made.

1.2 M&C Investment Area Overview

As a part of the grid modernization efforts, the EDCs are making investments to advance their M&C capabilities and enhance network visibility. These M&C investments contribute to optimized system performance, higher reliability, and DER integration. As identified in the *2020 Grid Modernization Annual Reports*, filed by the EDCs on April 1, 2021, and the PY2021 EDC Data Request, received by the EDCs in early 2022, the M&C investments totaled to $66.56 million from 2018 to 2021:

- $59.16 million by Eversource
- $6.50 million by National Grid
- $0.90 million by Unitil

There is an additional total of $10.18 million across all EDCs for M&C investments that began in 2021 but are planned to be carried over and completed in 2022. This includes carryover of $8.66 million for Eversource, $1.19 million for National Grid, and $0.32 million for Unitil.

The following subsection discusses EDC-specific approaches to M&C.

1.2.1 EDC Approach to M&C

Each EDC has a unique approach to their M&C Investment Area. Eversource and Unitil are focused on expanding SCADA on substations and distribution networks, while National Grid is focused on deploying feeder monitors on its distribution network. Unitil has an additional investment focused on integrating its advance metering infrastructure (AMI) data with its outage management system (OMS).

Table 12 defines the devices and technologies that each EDC has deployed as part of M&C investment. Sections 3 (Infrastructure Metrics), 4 (Performance Metrics), and 5 (Case Studies) discuss specifics related to each EDCs' goals and objectives in the M&C Investment Area.

Table 12. Devices and Technologies Deployed Under M&C Investment

EDC	Device/ Investment Type	Description
Eversource	Microprocessor relays	Includes advanced overcurrent protection, pushbutton controls for the breakers, safety hot line tagging, reclosing, breaker failure, and under-frequency load-shedding schemes.
	4 kV Circuit Breaker SCADA	Provides real-time visibility to loading conditions on the 4 kV circuits that are among the most heavily loaded on Eversource’s distribution system.
	Recloser SCADA	Addition of communications capability so the device can be centrally monitored and controlled from the dispatch center.
	Padmount Switch SCADA	Addition of a radio package to enable communications and central monitoring.
	Network Protector SCADA	Provides real-time network load data and additional telemetric information.
	Power Quality Monitors	Provides remote access and storage of power quality meter data for Eversource system planning, protection, and controls engineering to evaluate disturbance events and share information with customers.
National Grid	Feeder Monitors	Installation of interval power monitoring devices on feeders where National Grid does not have distribution information.
Unitil	Substation SCADA	The installation and interconnection of a SCADA terminal unit at the site, the establishment of communications between the terminal unit and the remotely located SCADA master system, and the associated programming to implement desired functions.
	AMI-OMS Integration	The deployment of software that analyzes AMI status changes and relevant data points, detects suspect outages, and reports them as such to the OMS.

Source: Guidehouse

1.3 M&C Evaluation Objectives

This evaluation focuses on the progress and effectiveness of the DPU preauthorized M&C investments for each EDC toward meeting the DPU’s grid modernization objectives. Table 13 illustrates the key Infrastructure Metrics and Performance Metrics relevant for the M&C evaluation.

Table 13. M&C Evaluation Metrics

Type	M&C Evaluation Metrics	ES	NG	UTL
IM	System Automation Saturation*	✓	✓	✓
IM	Number and Percent of Circuits with Installed Sensors*	✓	✓	✓
IM	Number of Devices or Other Technologies Deployed and In Service	✓	✓	✓
IM	Cost for Deployment	✓	✓	✓
IM	Deviation Between Actual and Planned Deployment for the Plan Year	✓	✓	✓
IM	Projected Deployment for the Remainder of the 4-Year** Term	✓	✓	✓
PM	Grid Modernization Investments' Effect on Outage Durations	✓	✓	✓
PM	Grid Modernization Investments' Effect on Outage Frequency	✓	✓	✓
Other	Case Studies***	✓	✓	✓

IM = Infrastructure Metric, PM = Performance Metric, ES = Eversource, NG = National Grid, UTL = Unitil

* Denotes that generating the metric is EDC responsibility

** Note that the original 3-year term was extended to a 4-year term by the Department in 2020.

*** In addition to the IMs and PMs listed, Case Studies were added to the evaluation to help explain the operation and value of the selected M&C investments.

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020

The EDCs provided the data supporting the Infrastructure Metrics and Performance Metrics to the evaluation team. Sections 3.2, 4.2, and 5, present the results from the analysis of Infrastructure Metrics, Performance Metrics, and case study data respectively. The Infrastructure Metrics analysis measures whether the investments are taking place on the projected schedule and budget. The Performance Metrics analysis provides insight into the reliability impacts due to grid modernization investments. The Case Studies facilitate understanding of the reliability improvement mechanisms and performance at select feeder locations.

Table 14 summarizes the M&C evaluation objectives and associated research questions. The scope of the M&C evaluation includes tracking the M&C infrastructure deployment against the plan and evaluating the impact on system reliability.

Table 14. M&C Evaluation Objectives and Associated Research Questions

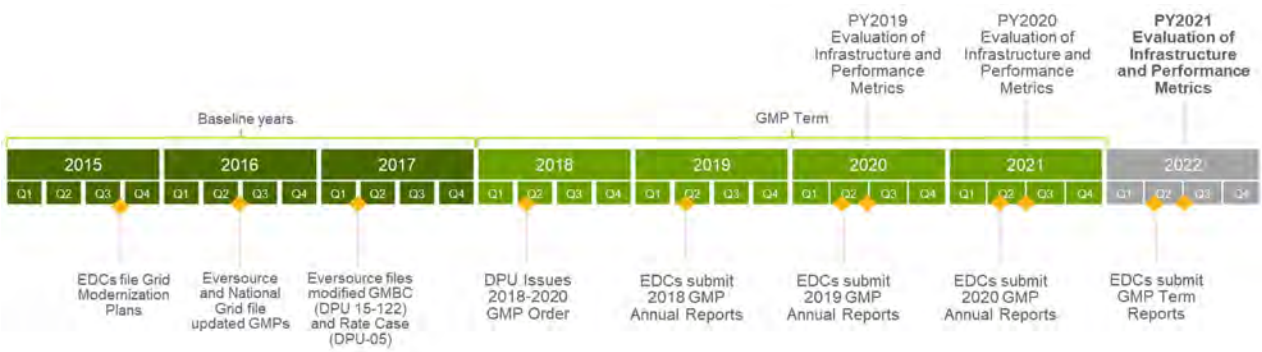
Associated Research Questions	IM	PM
1) Are the EDCs progressing in deployment of their M&C investments according to their GMPs?	✓	
2) What factors, if any, are affecting the deployment schedule of M&C equipment?	✓	
3) What is the cost of deploying various types of M&C equipment, including SCADA retrofits and microprocessor relays?	✓	
4) What is the effect of M&C investments on key reliability metrics, such as SAIDI and SAIFI?		✓

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020

2. M&C Evaluation Process

This section presents a high-level overview of the Guidehouse methodologies for the evaluation of Infrastructure and Performance Metrics as well as Case Studies. Figure 2 highlights the filing background and timeline of the GMP Order and the evaluation process.

Figure 2. M&C Evaluation Timeline



Source: Guidehouse review of the DPU orders and GMP process

2.1 Infrastructure Metrics Analysis

Guidehouse annually assesses the progress of each EDC toward deploying M&C devices and technologies on their feeders. Table 15 highlights the evaluated Infrastructure Metrics and their associated calculation parameters.

Table 15. Infrastructure Metrics Overview

Infrastructure Metrics			Calculation
IM-4	Number of devices or other technologies deployed thru. PY2021	# Devices Deployed	$\sum_{PY=2018}^{2021} (Devices\ Commissioned)_{PY}$
		% Devices Deployed	$\frac{\sum_{PY=20}^{2021} (Devices\ Commissioned)_{PY}}{\sum_{PY=2018}^{2020} (Devices\ Commissioned)_{PY} + (Planned\ Devices)_{PY2021}}$
IM-5	Cost through PY2021	Total Spend, $M	$\sum_{PY=2018}^{2021} (Actual\ Spend)_{PY}$
		% Spend	$\frac{\sum_{PY=2018}^{2021} (Actual\ Spend)_{PY}}{\sum_{PY=2018}^{2020} (Actual\ Spend)_{PY} + (Planned\ Spend)_{PY2021}}$
IM-6	Deviation Between Actual and Planned Deployment for PY2021	% On Track (Devices)	$\frac{(Devices\ Commissioned)_{PY2021}}{(Planned\ Devices)_{PY2021}}$
		% On Track (Spend)	$\frac{(Actual\ Spend)_{PY2021}}{(Planned\ Spend)_{PY2021}}$

IM-7	Projected Deployment for the remainder of the GMP Term*	# Devices Remaining	$(Devices\ Planned)_{CY2022+}$
		Spend Remaining, $M	$(Planned\ Spend)_{CY2022+}$

* This metric has been interpreted here (i.e. within the context of the 2021 Program Year Evaluation) as the "carryover" units and "carryover" spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent plan totals were included in each EDC's *Grid Modernization Plan Annual Report 2020* (filed on April 1, 2021), which listed the planned units and spending to be completed in PY2021.

Source: Guidehouse

Section 3.2 provides the results from the evaluation of Infrastructure Metrics. To evaluate Infrastructure Metrics, Guidehouse:

- Reviewed the data provided by the EDCs to confirm their progress through PY2021 (see Section 3.1.2, "Data QA/QC Process")
- Interviewed representatives from each EDC to understand the status of the M&C investments, including:
  - Updates to their planned M&C investments
  - Reasons for deviation between actual and planned deployment and spend

2.2 Performance Metrics Analysis

Performance Metrics were evaluated for each EDC, focusing on the reliability metrics (CKAIDI and CKAIFI) at the circuit level. Table 16 describes the Performance Metrics included in the PY2021 evaluation.

Table 16. M&C Performance Metrics Overview

Performance Metric		EDC	Description
PM-12	Grid Modernization Investments' Effect on Outage Durations	All	Provides insight into how M&C investments can reduce outage durations (CKAIDI). Compares the experience of customers on GMP M&C-enabled circuits as compared to the previous three-year average for the same circuit.
PM-13	Grid Modernization Investments' Effect on Outage Frequency	All	Provides insight into how M&C investments can reduce outage frequencies (CKAIFI). Compares the experience of customers on M&C-enabled circuits with the prior three-year average for the same circuit.
PM-UTL1	Customer Minutes of Outage Saved per Circuit	UTL	Tracks time savings from faster AMI outage notification than customer outage call, leading to faster outage response and reduced customer minutes of interruption.

Source: Stamp Approved Performance Metrics, July 25, 2019.

2.3 Case Study Analysis

The evaluation team developed a case study approach to provide more insight into the actual operation of the GMP devices and to illustrate how these investments provide customer reliability and operational benefits. The impacts of GMP devices on system reliability metrics can be difficult to discern due to the range of factors that affect these metrics. Storm conditions, vehicle accidents and other factors drive reliability from year to year. This is especially likely if the device has less than several full years of operation to affect the metric. The case studies help to illustrate the benefits provided by GMP devices during outage events. This approach investigates outage events on specific circuits where the GMP equipment operated to address the outage. The approach also allows for comparison between what did occur due to the presence of the GMP device and what would have likely happened had the GMP investment not been made.

The team performed five case studies for the M&C evaluation: two for Eversource, one for National Grid and two for Unitil. Section 5 examines the details of the analysis and the results.

3. M&C Infrastructure Metrics

Assessment of the Infrastructure Metrics included Infrastructure Metric data collection and QA/QC, assessment of M&C deployment progress for each EDC, and determination of conclusions from the analysis.

3.1 Data Management

Guidehouse worked with the EDCs to collect data to complete the M&C evaluation and the assessment of Infrastructure Metrics. The following subsections highlight data sources and the data QA/QC processes followed to complete the evaluation and calculate the Infrastructure Metrics.

3.1.1 Data Sources

Guidehouse used a consistent methodology (across Investment Areas and EDCs) for evaluating the data and illustrating EDC progress indicated by the GMP metrics. The following subsections summarize data sources.

3.1.1.1 2020 Grid Modernization Plan Annual Report

Guidehouse used the planned device deployment and cost information from each EDCs' *2020 GMP Annual Reports*, which were filed on April 1, 2021. These filings served as the sources for planning data in this report and are referred collectively as the *GMP Plan* for each EDC in summary tables and figures throughout this report.

Table 17 provides a legend of the different planned and actual quantities reviewed and specifies the color/shade used to represent these quantities in graphics throughout the rest of the report.

Table 17. Deployment Categories Used for the EDC Plan

Representative Color	Data	Description
	2021 Plan	Projected 2021 unit deployment and spend
	2020 Actual	Actual reported unit deployment and spend in 2020
	2019 Actual	Actual reported unit deployment and spend in 2019
	2018 Actual	Actual reported unit deployment and spend in 2018

Source: Plan and actual data is sourced from the EDCs' 2020 GMP Annual Report Appendix 1 filed April 1, 2021.

3.1.1.2 EDC PY2021 Device Deployment Data Template

Guidehouse collected device deployment data using standardized data collection templates (e.g., the All Device Deployment workbook file) for all EDCs during January and February 2022. The data collected provides an update of planned and actual deployment, in dollars and device units, through the end of PY2021. Data from this source are referred to as *EDC Data* in summary tables and figures throughout the report. Table 18 summarizes the date of file version receipt used for the evaluation. The collected data was compared to the data submitted by the EDCs to the DPU in the 2021 Grid Modernization Plan Annual Reports and associated

Appendix 1 filings.[19,20,21] The evaluation team confirmed the consistency of the data from the various sources and reconciled any differences.

Table 18. All Device Deployment Data File Versions for Analysis

EDC	File Version
Eversource	Received 2/2/2022
National Grid	Received 2/4/2022
Unitil	Received 2/4/2022

Source: Guidehouse

The EDC device deployment data (collected primarily in the All Device Deployment workbook) captured planned and actual device deployment and spend data. Actual device deployment and cumulative spend information were provided by work order ID and specified at the feeder- or substation-level, as appropriate.

The implementation stage of the work order (commissioned, in service, construction, or design/engineering), the commissioned date (if applicable), and all cumulative costs associated with the work order were also collected. Planned device deployment information and estimated spend for PY2021 was provided by the EDCs at the most granular level (circuit or substation) available. Table 19 summarizes the categories used for the planned and actual deployment and spend from the EDC Data and specifies the color and pattern used in bar graphs to represent each in the remainder of the report.

[19] Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2022. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 22-41

[20] NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-40

[21] Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-42

Table 19. EDC Device Deployment and Spending Data Legend

Representative Color	Data	Description
Device Deployment Data		
(purple crosshatch)	2022 Plan	Remaining units planned for 2022 where work will begin in 2022
(light blue hatch)	2021 Design/Engineering	Detailed design and engineering is in progress but the device is not yet in construction
(blue hatch)	2021 Construction	Field construction is in progress but the device is not yet in-service
(dark blue hatch)	2021 In-Service	Device is installed and “used and useful” but not yet commissioned to enable all Grid Modernization functionalities
(light blue)	2021 Commissioned	Device is fully operational with all Grid Mod functionalities, and thus is considered “deployed” in PY2021
(blue)	2020 Actual	Actual devices commissioned in 2020
(medium blue)	2019 Actual	Actual devices commissioned in 2019
(dark navy)	2018 Actual	Actual devices commissioned in 2018
Spend Data		
(orange crosshatch)	2022 Carryover	Projected 2022 spend
(light green)	2021 Actual	Actual 2021 spend
(green)	2020 Actual	Actual 2020 spend
(medium green)	2019 Actual	Actual 2019 spend
(dark green)	2018 Actual	Actual 2018 spend

Source: Guidehouse analysis

3.1.2 Data QA/QC Process

To enable accuracy, Guidehouse conducted a high-level QA/QC of all device deployment data received. This review involved following up with the EDCs for explanations regarding the following:

- Potential errors in how the forms were filled out (e.g., circuit information provided in the wrong field)
- Missing or incomplete information
- Large variation in the unit cost of commissioned devices
- Variance between the aggregated year-end total information and work order-level data
- Variance between the actual unit costs and planned unit costs

3.2 Deployment Progress and Findings

Guidehouse presents findings from the Infrastructure Metrics analysis for the M&C Investment Area in the following subsections.

3.2.1 Statewide Comparison

This section discusses the anticipated scope of M&C investments relative to the number of feeders and customers within the EDCs in Massachusetts, and it summarizes the deployment progress and findings across all three EDCs.

3.2.1.1 Impact on Massachusetts

Across the three EDCs in Massachusetts, M&C investments have impacted about 17% of total EDC customers and 11% of feeders. Table 20 summarizes the number of feeders and customers covered by GMP M&C investments spanning 2018 through 2021.

Table 20. Number of Feeders and Customers Impacted by M&C Investments

M&C Impact	Eversource		National Grid		Unitil		Total	
	Feeders	Customers	Feeders	Customers	Feeders	Customers	Feeders	Customers
Systemwide Total	2,377	1,400,554	1,121	1,318,825	38	30,355	3,536	2,749,734
2018-2021 Deployed	326	239,481	133	218,576	11	10,191	373	468,248
% System Total	14%	17%	12%	17%	29%	34%	11%	17%

Source: Guidehouse analysis of 2021 GMP Annual Reports Appendix 1

3.2.1.2 Infrastructure Metrics Results

Table 21 summarizes the Infrastructure Metrics results for each EDC's M&C Investment Area through PY2021. Sections 3.2.2 through 3.2.4 explain each EDC's progress and plans in greater detail.

Table 21. M&C Infrastructure Metrics Summary

Infrastructure Metrics			Eversource	National Grid	Unitil
GMP Plan Total, PY2018-2021		Devices	560	202	14
		Spend, $M	$69.00	$6.21	$1.19
IM-4	Number of devices or other technologies deployed PY2018-2021*	# Devices Deployed***	504	155	11
		% Devices Deployed	90%	77%	79%
IM-5	Cost for Deployment PY2018-2021*	Total Spend, $M	$59.16	$5.52	$0.98
		% Spend	86%	89%	82%
IM-6	Deviation Between Actual and Planned Deployment for PY2021	% On Track (Devices)	55%	64%	0%
		% On Track (Spend)	42%	78%	26%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	56	53	3
		Spend Remaining, $M	$8.66	$1.19	$0.32

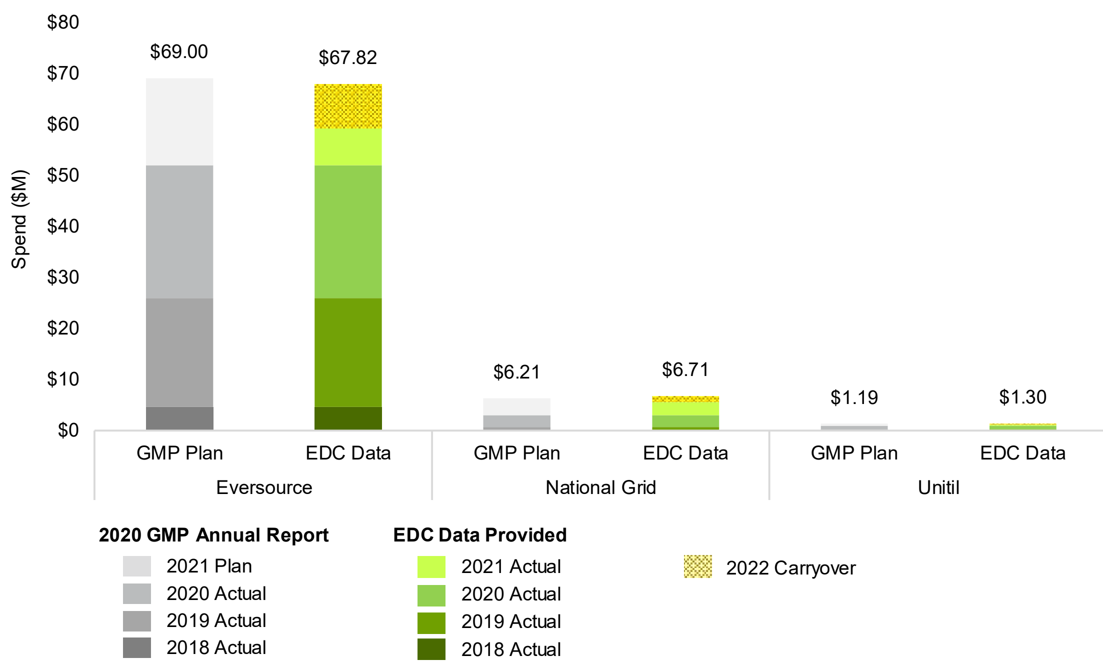
Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the "carryover" units and spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs' 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.
****Note that "Deployed" here refers to commissioned devices. In National Grid's Term Report (filed April 1, 2022), deployed refers to in-service and/or commissioned devices. In-service devices are fully installed and used and useful, but not yet commissioned with Grid Mod functionality (communication and remote visibility and/or control). For full definitions of commissioned and in-service, see Docket 20-46 Response to Information Request DPU-AR-4-11, September 3, 2020.*

Actual device deployment and spending in PY2021 were lower than planned for Eversource, largely due to a pause in deployment of some device types while ensuring approval to proceed with proposed plan. National Grid deployed fewer devices than planned, but at a higher per-unit cost, thus slightly exceeding the budget planned in PY2021 due to supply chain issues and underestimating some of the field deployment complexities. Unitil had delays in device deployment and corresponding spend (see IM-6 in Table 21) due to internal resource constraints and identification of additional complexities discovered as the engineering work proceeded but is on track to complete deployment of these units in 2022.

The total estimated units deployment for the 4-year Term is slightly below previous plan with Eversource deploying most of planned units and National Grid and Unitil deploying approximately three quarters of planned units. Both Eversource and Unitil spent less over the 4-year Term than indicated in the previous plan, whereas National Grid spent slightly more (see IM-4 and IM-5 in Table 21).

Figure 3 compares the GMP plans and EDC data totals and year-over-year spending for each EDC.

Figure 3. M&C Spend Comparison (2018-2021, $M)



Note: Includes the Eversource planned spend for PY2021, set forth the in the GMP Extension and Funding Report, filed on July 1, 2020.

Source: Guidehouse analysis of 2020 GMP Annual Reports, GMP Extension and Funding Report, and 2021 EDC Data

In addition to the capital costs shown in Figure 3, Eversource incurred approximately $5,000 in O&M costs towards the M&C Investment Area and $0.51 million toward Administration and Regulatory costs across the GMP investments in PY2021. National Grid incurred approximately $0.17 million in O&M costs toward the M&C Investment Area in PY2021. National Grid also incurred approximately $0.92 million Administration and Regulatory costs across the GMP investments in PY2021. Unitil incurred approximately $19,500 toward Administration and Regulatory costs across the GMP investments in PY2021.

3.2.2 Eversource

This section discusses Eversource's M&C investment progress through PY2021 and planned 2022 carryover deployment.

3.2.2.1 Overview of GMP Deployment Plan

Eversource's M&C Investment Area goals and objectives include:

- Increasing the amount of data that is collected by the existing SCADA system for enhanced analytical capabilities (e.g., load flow analysis)
- Increasing reliability by enabling crew dispatch to remotely isolate faulted cable sections, restoring power to customers

To achieve these goals, Eversource is deploying a range of M&C devices on its distribution network. Table 22 details the technologies and devices that are being implemented as part of Eversource's M&C Investment Area.

Table 22. Eversource M&C Devices and Technologies

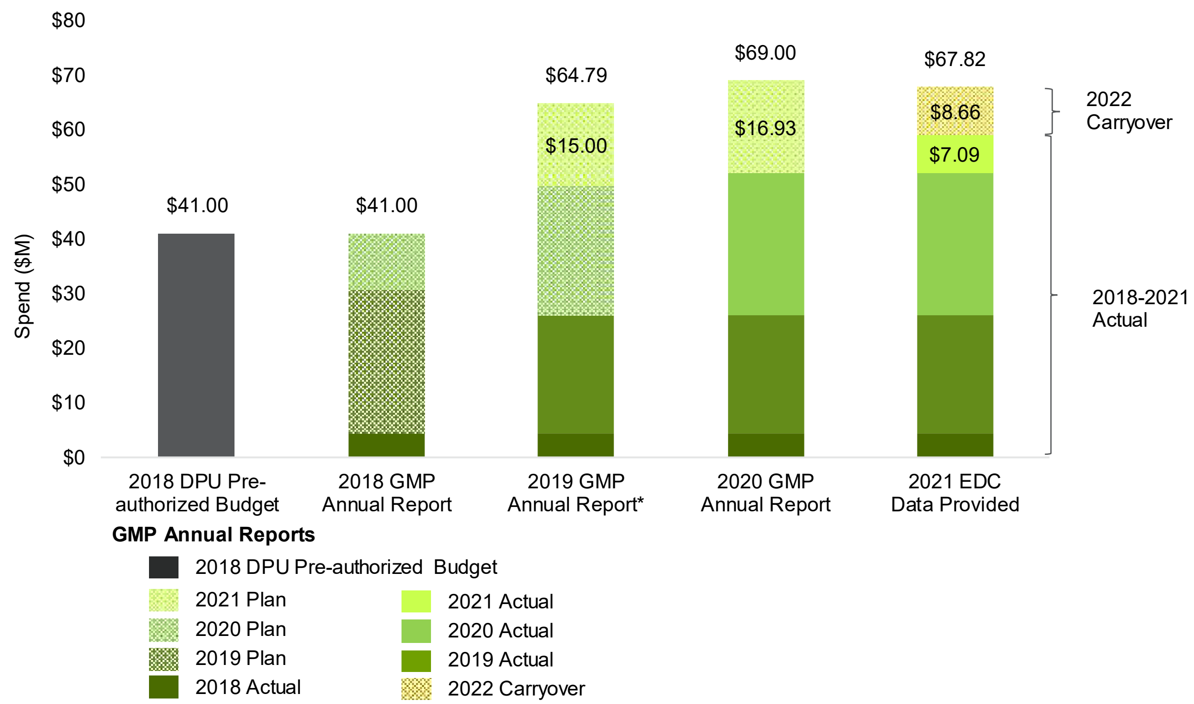
Device/Investment Type	Description
Microprocessor Relays	Includes advanced primary overcurrent protection, pushbutton controls for the breakers, safety hot line tag, reclosing, breaker failure, and under-frequency load-shedding schemes.
4 kV Circuit Breaker SCADA	Provides real-time visibility of loading conditions on the 4 kV circuits that are among the most heavily loaded on Eversource's distribution system.
Recloser SCADA	Addition of communications capability so the device can be centrally monitored and controlled from the dispatch center.
Padmount Switch SCADA	Addition of a radio package to enable communications and central monitoring.
Network Protector SCADA	Provides real-time network load data and remote control capability to underground network.
Power Quality Monitors	Provide remote access and storage of power quality meter data for the Eversource system planning, protection, and controls engineering to evaluate disturbance events and share information with customers.

Source: Guidehouse analysis of GMP Annual Reports and EDC Data

3.2.2.2 M&C Deployment Plan Progression

Figure 4 shows the progression of Eversource's M&C deployment plans from DPU-approval in 2018 through PY2021, as well as planned carryover deployment into 2022.

Figure 4. Eversource M&C Planned and Actual Spend Progression, $M



*Note that Eversource received pre-authorization from the Department for another $15 million in spending for its M&C investment area in late 2020.

Source: Guidehouse analysis of DPU Order (May 10, 2018), 2018-2020 GMP Annual Reports, Eversource GMP Extension and Funding Report filed on July 1, 2020, and *2021 EDC Data*

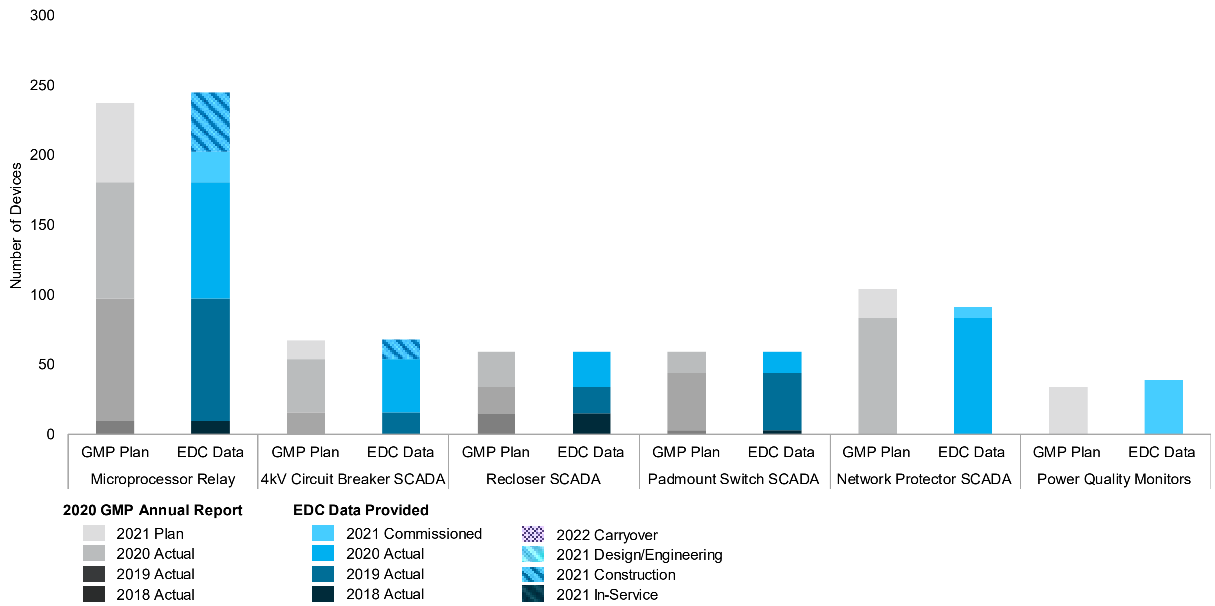
During PY2021, Eversource spent slightly less than half of the PY2021 planned spend, with most of the remaining amount being carried over into 2022. Microprocessor relays and 4 kV Circuit Breaker SCADA account for the remaining $8.66 million carryover investment into 2022. Overall 4-year actual spending was slightly under the 4-year planned spending indicated in the 2020 GMP Annual Report. Microprocessor relays and 4kV Circuit Breakers account for the remaining $8.66 million carryover investment into 2022.

3.2.2.3 M&C Device Type Progress through PY2021

Overall, the number of Eversource's M&C devices deployed fell below plans for PY2021. Figure 5 shows the progress and details of each device type for the 2018-2021 period. The Power Quality Monitors and Network Protector SCADA programs were completed in PY2021, with only Microprocessor Relays and 4kV Circuit Breaker SCADA carried over into 2022.

Deployment for Microprocessor Relays and 4kV Circuit Breaker deployment was paused while waiting for program approval. From past experience these device types require a 12-18 month planning to implementation cycle, and thus made a decision to prioritize deployment of other device types during PY2021, while engineering and design activities for these devices proceeded.

Figure 5. Eversource M&C Device Deployment Comparison (2018-2021)



Note that Carryover here would include all units not fully commissioned at the end of PY 2021.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

The Recloser SCADA and Padmount Switch SCADA programs were completed in PY2020, and the Network Protector SCADA and Power Quality Monitors were completed in PY2021. Eversource plans to complete remaining deployments for Microprocessor Relay and 4kV Circuit Breaker SCADA in 2022.

The EDC Data presented in Figure 5 is also shown in tabular form in Table 23 to provide the specific deployment units in each category.

Table 23. Eversource M&C Plan & Actual Device Deployment (2018 - 2021)

	Microprocessor Relay	4kV Circuit Breaker SCADA	Recloser SCADA	Padmount Switch SCADA	Network Protector SCADA	Power Quality Monitors
2018-2021 Total	**202**	**54**	**59**	**59**	**91**	**39**
Engineering/Design during PY 2021*	0	0	0	0	0	0
Construction during PY 2021*	42	14	0	0	0	0
In-Service during PY 2021*	0	0	0	0	0	0

Commissioned in PY 2021	22	0	0	0	8	39
Commissioned in PY 2020	83	38	25	15	83	0
Commissioned in PY 2019	87	16	19	41	0	0
Commissioned in PY 2018	10	0	15	3	0	0

**Deployment of these devices began during PY 2021, but was not completed during the program year. Deployment (through commissioning) is planned as carryover in 2022.*

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Eversource completed deployment of 39 Power Quality Monitors, a total of 39 devices or 5 over the original plan of 34. Despite the additional devices, spending was less than estimated due to conservative cost estimates initially used as well as to efficient planning and execution. The Network Protector SCADA program was ended with fewer devices deployed than planned due to an unrelated substation failure causing unacceptable project delays. Thus, spending and devices were below plan.

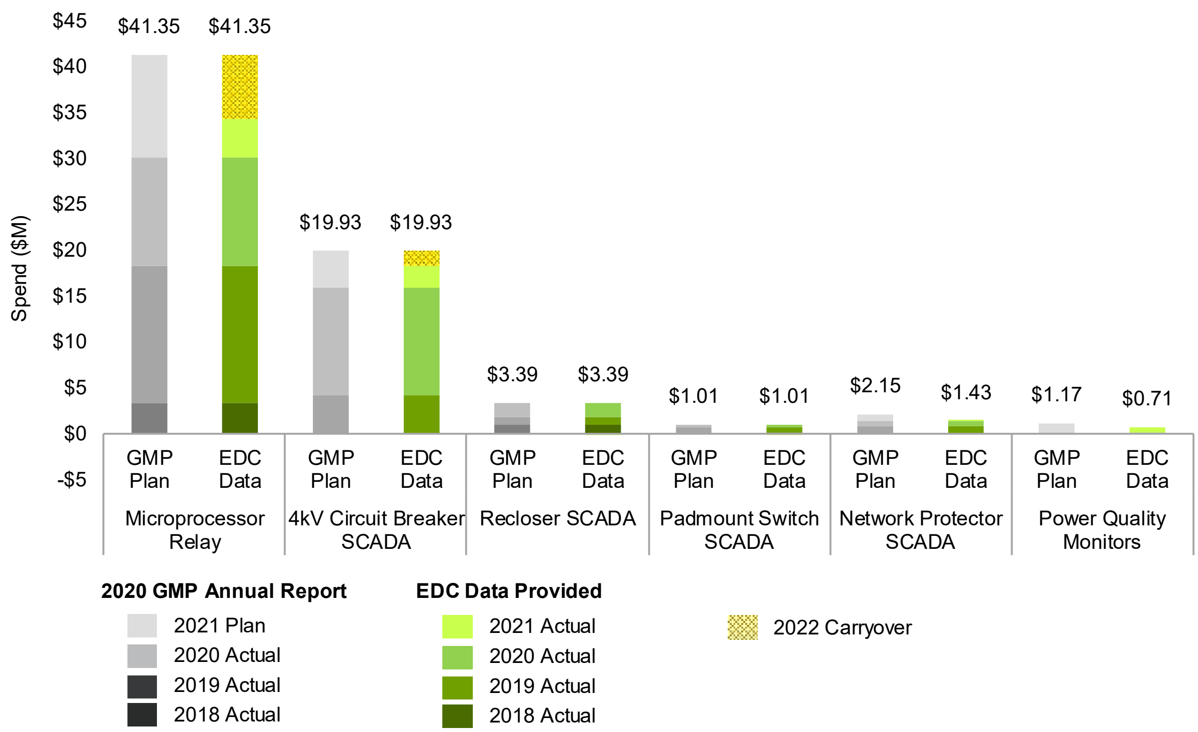
Eversource plans on deploying 7 additional microprocessor relays over its prior plan, and expects to complete the remaining 42 Microprocessor Relays and 14 4kV Circuit Breakers in 2022.

Figure 6 shows Eversource's corresponding planned versus actual spend over the 2018-2021 Term period, broken out by device type.

Spending in PY2021 generally followed similar trends to device deployment. Actual spending on Microprocessor Relays was slightly under half of the initial plan, which tracks the delayed deployment in PY2021 (with 42 MPRs in construction and 22 commissioned). Overall 4-year spend with 2022 carryover on Microprocessor Relays is still expected to meet plan, despite the 7 additional devices. 4kV Circuit Breaker spend in PY2021 is about 60% of planned spend with all 14 devices in-construction and none commissioned. Eversource expects to meet the original planned spend for this device type.

PY2021 Device deployment for Power Quality Monitors was above plan, despite spending being only 61% of planned spend. Per unit spending for Power Quality Monitors was significantly below plan, and the project is considered to be completed. Network Protector SCADA spending also fell below plan, but fewer devices than planned were deployed due to the un-related substation failure mentioned above.

Figure 6. Eversource M&C Spend Plan vs. Actual (2018-2021, $M)



Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

The EDC Data presented in Figure 6 is also shown in Table 24 to provide the specific dollar spend in each category.

Table 24. Eversource M&C Plan and Actual Spend (2018-2021, $M)

	Microprocessor Relay	4kV Circuit Breaker SCADA	Recloser SCADA	Padmount Switch SCADA	Network Protector SCADA	Power Quality Monitors
2018-2021 Total	**$34.36**	**$18.26**	**$3.39**	**$1.01**	**$1.43**	**$0.71**
2022 Carryover Estimate	$6.99	$1.67	$0.00	$0.00	$0.00	$0.00
PY 2021 Actual	$4.27	$2.33	$0.00	$0.00	$0.00	$0.50
PY 2020 Actual	$11.74	$11.76	$1.53	$0.29	$0.56	$0.21
PY 2019 Actual	$14.99	$4.09	$0.89	$0.62	$0.87	$0.00
PY 2018 Actual	$3.36	$0.08	$0.96	$0.11	$0.00	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

The following sub-sections discuss the term progress through PY2021 and actuals for PY2021 for each device type.

Microprocessor Relays

Eversource used much of PY2021 planning microprocessor relay and 4kV SCADA projects after DPU approval was obtained, and is now proceeding with construction for the remaining projects.

Thus, microprocessor relay actual deployment and spend for PY2021 were lower than projected, but total term spending, including the carryover into 2022, is on track to meet the previous plan. Eversource was able to complete work and commission a total of 22 microprocessor relays in PY2021, with 42 additional devices in-construction. Overall deployment totals are 7 devices higher than the 2020 GMP Plan, while total spending is expected to remain the same.

4 kV Circuit Breaker SCADA

For the same reason as was the case for microprocessor relays, Eversource determined it was not feasible to reasonably accelerate deployment of 4 kV circuit breaker SCADA units. Thus, actual deployment and spend of 4 kV circuit breaker SCADA units for PY2021 was lower than projected, but total Term spending, including carryover into 2022, is on track to meet the prior plan. Eversource was not able to complete work and commission any 4 kV circuit breaker SCADA units in PY2021, however 14 devices are in-construction. Despite the challenges, overall deployment totals are 1 device higher than the 2020 GMP Plan, with total spending expected to remain the same.

Recloser SCADA

Recloser SCADA was completed in PY2020, therefore Eversource did not have deployment and spend in PY2021.

Padmount Switch SCADA

Padmount switch SCADA was completed in PY2020, therefore Eversource did not have deployment and spend in PY2021.

Network Protector SCADA

Eversource had intended to implement the network protector SCADA program at Greenfield substation, which subsequently had an emergent repair. The repair resulted in a reconfiguration of the substation, which no longer made the implementation of the GMP network protectors a viable investment. Eversource determined that this opportunity could not reasonably be pursued, and therefore determined that the program is completed. Consequently, network protector SCADA actual deployment and spend in PY2021 were lower than projected, with total Term deployment and spend falling below prior plan. A total of 8 devices were commissioned in 2021.

Power Quality Monitors

The project was executed efficiently, and original budgets were underrun due to adjustments to the execution plan. As a result, even though PY2021 actual capital spend was significantly lower than projected, device deployment was higher than anticipated. Overall deployment totals are 5 devices higher than the prior plan, while total term spending is lower than anticipated.

3.2.2.4 Infrastructure Metrics Results and Key Findings

Error! Reference source not found. presents the Infrastructure Metrics results through PY2021 for each device type related to Eversource's M&C Investment Area.

Table 25. Eversource M&C: Infrastructure Metrics Summary

Infrastructure Metrics			Micro-processor Relay	4kV Circuit Breaker SCADA	Recloser SCADA	Padmount Switch SCADA	Network Protector SCADA	Power Quality Monitors
GMP Plan Total, 2018-2021		Devices	237	67	59	59	104	34
		Spend, $M	$41.35	$19.93	$3.39	$1.01	$2.15	$1.17
IM-4	Number of devices or other technologies deployed PY2018-2021*	# Devices Deployed	202	54	59	59	91	39
		% Devices Deployed	85%	81%	100%	100%	88%	115%
IM-5	Cost for Deployment. PY2018-2021*	Total Spend, $M	$34.36	$18.26	$3.39	$1.01	$1.43	$0.71
		% Spend	83%	92%	100%	100%	67%	61%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	39%	0%	N/A	N/A	38%	115%
		% On Track (Spend)	38%	58%	N/A	N/A	0%	52%
IM-7	Projected Deployment for the Remainder of the GMP Term **	# Devices Remaining	42	14	0	0	0	0
		Spend Remaining, $M	$6.99	$1.67	$0.00	$0.00	$0.00	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the "carryover" units and spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs' 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

Eversource's device deployment through PY2021 (Table 25, IM-4) tracked within 20% of 2020 GMP Plan across all device categories. Microprocessor Relays, 4KV Circuit Breaker SCADA and Network Protector SCADA tracking below prior plan, Power Quality Monitors tracking above prior plan. Recloser and Padmount Switch SCADA were both completed in PY2020, as described above, and therefore did not have deployment and spend in PY2021.

Costs were generally commensurate with these unit deployment numbers, with Microprocessor Relays less than 20% under prior plan spending and 4KV Circuit Breaker SCADA less than 10% under prior plan spending. Network Protector SCADA and Power Quality Monitors tracked 30 to 40% below prior plan spending. Recloser and Padmount Switch SCADA were both completed in PY2020, as described above, and therefore did not have deployment and spend in PY2021.

3.2.3 National Grid

This section discusses National Grid's planned and actual M&C investment progress through PY2021.

3.2.3.1 Overview of GMP Deployment Plan

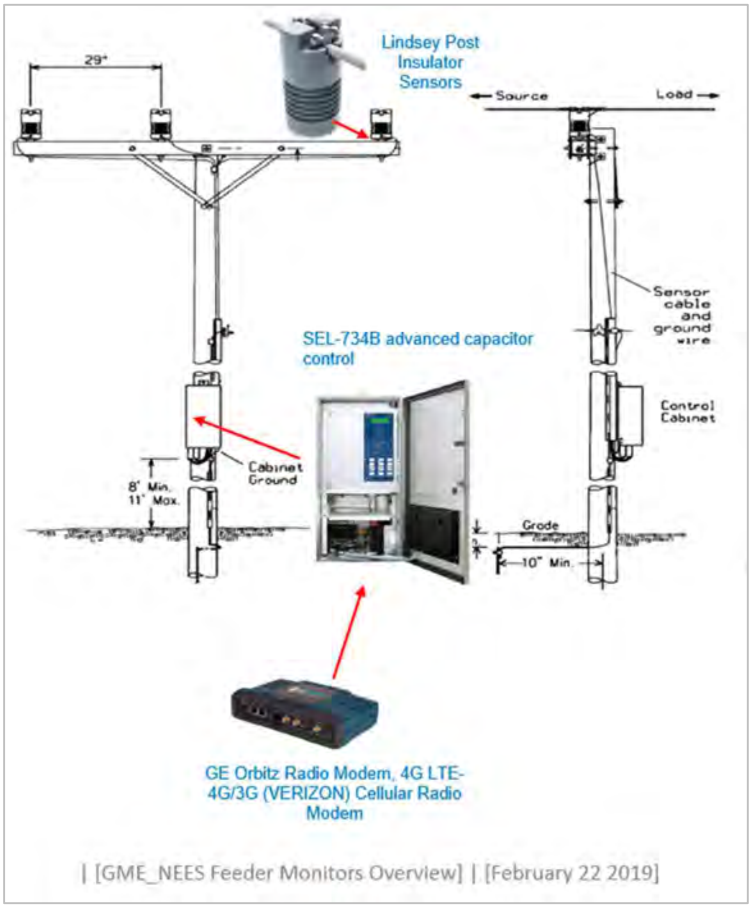
National Grid's M&C Investment Area goals and objectives include:

- Provide critical data for operations and distribution designer by providing near real-time voltage, current, and power monitoring information to the operations control center
- Focus on overhead feeders within the distribution system and substations with minimal to no existing SCADA

The achieve these goals, National Grid is installing interval power monitoring devices—feeder monitors—on overhead feeders within its distribution system. National Grid's selected technology will be installed outside of the substation fence for increased visibility. Information is transmitted cellularly every 5 minutes. Figure 7 shows a detailed schematic of how the EDC will implement the technology. Each circuit location includes three sensors (one per phase) and one control box with a communications package.[22]

[22] For GMP accounting purposes, National Grid is counting this configuration as a single device deployed on a circuit. Guidehouse adopted this definition in the evaluation for consistency.

Figure 7. Feeder Monitor Schematic

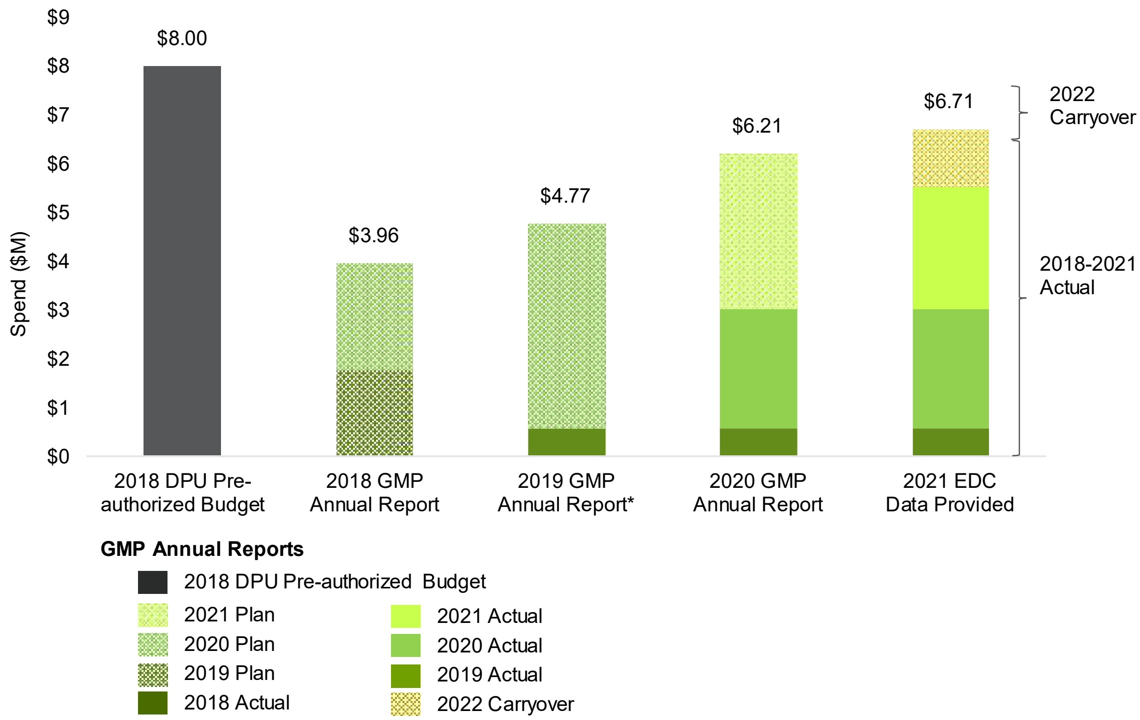


Source: National Grid

3.2.3.2 M&C Deployment Plan Progression

Figure 8 shows the progression of National Grid's M&C deployment plans from DPU pre-authorization in 2018 through PY2021.

Figure 8. National Grid M&C Planned and Actual Spend Progression, $M



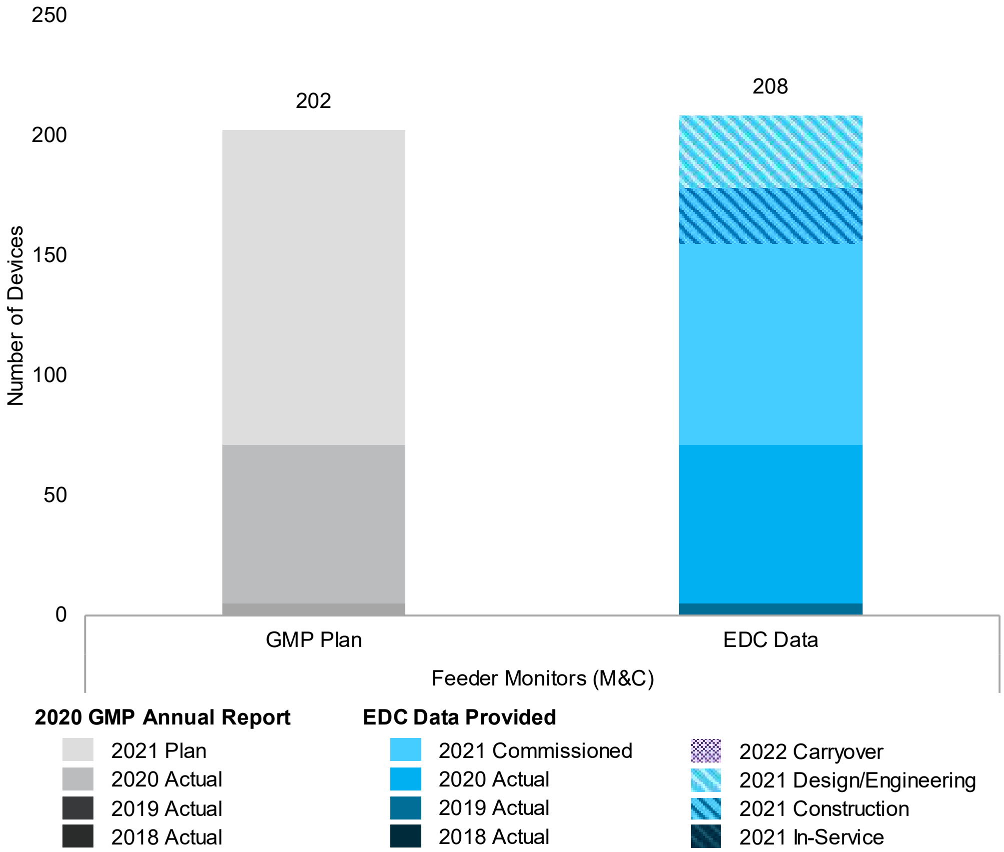
Source: Guidehouse analysis of DPU Order (May 10, 2018), 2018-2020 GMP Annual Reports, and *2021 EDC Data*

During PY2021, National Grid's spending was slightly greater than the planned PY2021 budget. However, overall 4-year actual spending was less than the original DPU Pre-authorized budget, even including the planned carryover into 2022. Actual spending in PY2021 was slightly higher than expected due to COVID constraints, as well as an increase in the complexity of the installs. Feeder monitors account for $1.2 million carryover investment into 2022.

3.2.3.3 M&C Investment Progress through PY2021

National Grid's M&C investment consists of a single device type, feeder monitors. Unit deployment of feeder monitors fell below plan for PY2021 due to COVID-related constraints, supply chain issues, and an overall increase in the complexity of installs. In PY2021, National Grid continued to deploy Lindsey sensors while also adding new QNA sensors. The new QNA sensors clamp directly onto distribution lines and are better suited to monitoring lower (4kV) voltages than the Lindsey sensors that are being deployed. Figure 9 shows National Grid's planned versus actual device deployment progress over the 2018-2021 period.

Figure 9. National Grid M&C Device Deployment Comparison (2018-2021)



Note that Carryover here would include all units not fully commissioned at the end of PY 2021.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Some devices that were planned for deployment in PY2021 were still in the engineering/design and construction phase at the end of the year. National Grid plans on spending additional funds in 2022 to complete these deployments to help meet previously planned device deployment goals. The EDC Data presented in Figure 9 is also shown in Table 26.

Table 26. National Grid M&C Plan and Actual Device Deployment (2018-2021)

	Feeder Monitors (M&C)
2018-2021 Total	***155***
Engineering/Design during PY 2021*	*30*
Construction during PY 2021*	*23*
In-Service during PY 2021*	*0*
Commissioned in PY 2021	*84*
Commissioned in PY 2020	*66*
Commissioned in PY 2019	*5*
Commissioned in PY 2018	*0*

* EDC Data indicates these devices will be commissioned in 2022, for a total of 208.

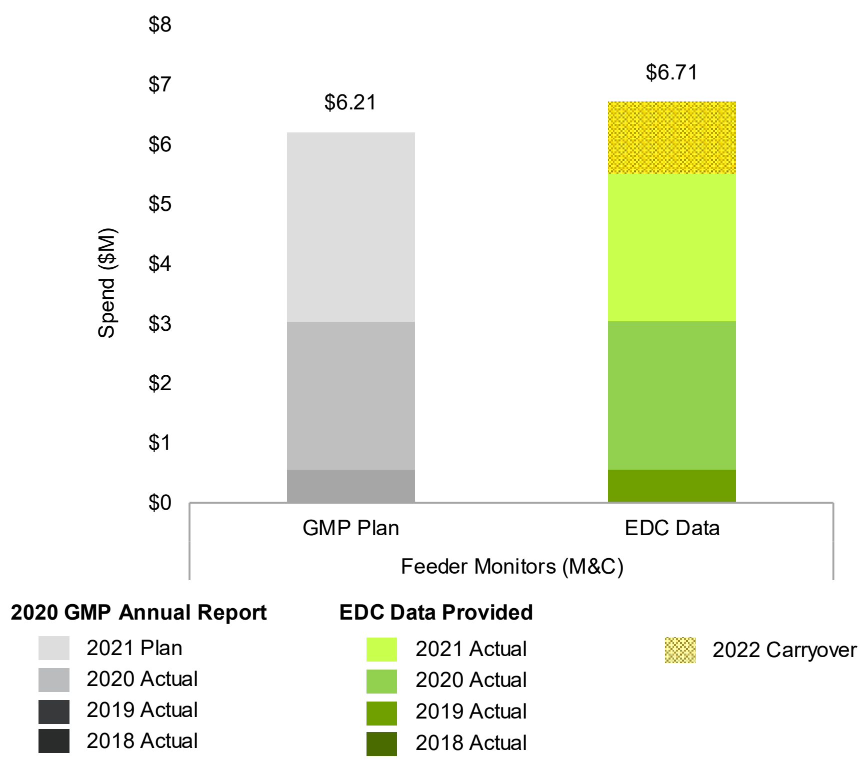
Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

National Grid completed deployment of 84 devices in PY2021, which is slightly more than half of the previous plan of 131. Despite the increase in spending, device deployment was less than estimated due to the previously mentioned production delays.

National Grid plans on deploying 6 feeder monitors more than its prior plan and expects to complete the remaining 53 feeder monitors in 2022. Feeder monitor spending PY2021 was about 9% over planned spend with 30 devices in engineering and 23 in construction, out of the remaining 53.

Figure 10 shows National Grid's planned versus actual spend over the 2018-2021 period. The EDC Data presented in Figure 10 is also shown in Table 27.

Figure 10. National Grid M&C Spend Plan vs. Actual (2018-2021, $M)



Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 27. National Grid M&C Plan and Actual Spend (2018-2021, $M)

	Feeder Monitors (M&C)
2018-2021 Total	**$5.52**
2022 Carryover Estimate	$1.19
PY 2021 Actual	$2.49
PY 2020 Actual	$2.46
PY 2019 Actual	$0.57
PY 2018 Actual	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Spending in PY2021 slightly outpaced plan. Overall, 4-year spending on feeder monitors, including 2022 carryover estimate, is expected to be about 24% higher than previous plan. Per unit spending for feeder monitors was slightly higher than prior plan.

The primary cause of deployment delays and shortfalls was supply chain issues, which lead to an increase in vendor lead time and an inability to deliver equipment on schedule. Furthermore, a semi-conductor shortage caused subsequent production delays for QNA line sensors. This delayed deployment of feeder monitors and pushed portions of work into 2022.

By the end of PY2021, National Grid appears to have gained momentum on the construction and commissioning of the feeder monitors and plans to carry this work into 2022. This will result in deployment of over 200 feeder monitors since the beginning of the 4-year term.

3.2.3.4 Infrastructure Metrics Results and Key Findings

Table 28 presents the Infrastructure Metrics results through PY2021 for National Grid's feeder monitor deployment.

Table 28. National Grid M&C: Infrastructure Metrics Summary

Infrastructure Metrics			Feeder Monitors (M&C)
GMP Plan Total, PY2018-2021		Devices	202
		Spend, $M	$6.21
IM-4	Number of devices or other technologies deployed PY2018-2021*	# Devices Deployed***	155
		% Devices Deployed	77%
IM-5	Cost for Deployment PY2018-2021*	Total Spend, $M	$5.52
		% Spend	89%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	64%
		% On Track (Spend)	78%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	53
		Spend Remaining, $M	$1.19

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
*The metric names have been slightly changed here to clarify the time span used in analysis.
*** This metric has been interpreted here as the "carryover" units and spending that National Grid is planning in 2022 or beyond to complete their most recent 4-year Term plan totals. These most recent totals were included in the National Grid's 2020 Grid Modernization Plan, which targeted the planned units and spending to be completed in PY2021.*
****Note that "Deployed" here refers to commissioned devices. In National Grid's Term Report (filed April 1, 2022), deployed refers to in-service and/or commissioned devices. In-service devices are fully installed and used and useful, but not yet commissioned with Grid Mod functionality (communication and remote visibility and/or control). For full definitions of commissioned and in-service, see Docket 20-46 Response to Information Request DPU-AR-4-11, September 3, 2020.*

Overall, National Grid's M&C progress is behind what was planned for PY2021. The shortfall was largely due to supply chain issues which limited and delayed construction timelines. National Grid plans on spending additional funds in 2022 to meet previously planned device deployment goals. While the costs significantly outpaced the units deployed in PY2021, reflecting a higher unit cost, the 4-year costs were just slightly above prior plan.

3.2.4 Unitil

This section discusses Unitil's planned and actual M&C investment progress through PY2021.

3.2.4.1 Overview of GMP Deployment Plan

Unitil's M&C Investment Area goals and objectives include:

- Provide remote monitoring of conditions on the electric system (e.g., voltage, current)
- Provide remote control of equipment and functions (e.g., circuit breakers/reclosers, transformer load tap changers, capacitor banks)

- Enable technologies required for other GMP projects (e.g., ADMS/ALF, VVO)
- Improve integration of outage information from meters into the OMS outage prediction engine to enhance outage prediction process, reduce false positives, and enhance outage location detection

To achieve these goals, Unitil is implementing substation SCADA and integrating the AMI data with their OMS. Table 29 describes these technologies in greater detail.

Table 29. Unitil M&C Devices and Technologies

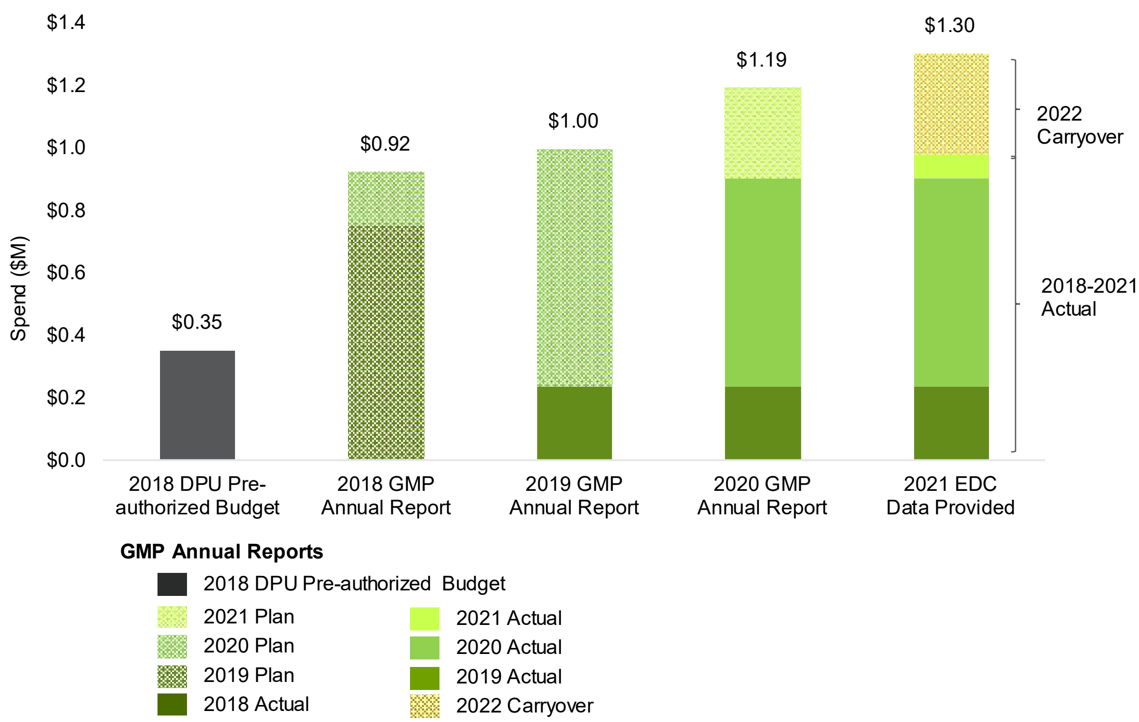
Investment Type	Description
Substation SCADA	The installation and interconnection of a SCADA terminal unit at the site, the establishment of communications between the terminal unit and the remotely located SCADA master system, and the associated programming to implement desired functions.
AMI-OMS Integration	The deployment of software that analyzes AMI status changes and relevant data points, detects suspect outages, and reports them as such to the OMS.

Source: Guidehouse

3.2.4.2 M&C Deployment Plan Progression

Figure 11 shows the progression of Unitil's M&C deployment plans from DPU pre-authorization in 2018 through PY2021.

Figure 11. Unitil M&C Planned and Actual Spend Progression, $M



Source: Guidehouse analysis of DPU Order (May 10, 2018), 2018-2020 GMP Annual Reports, and *2021 EDC Data*

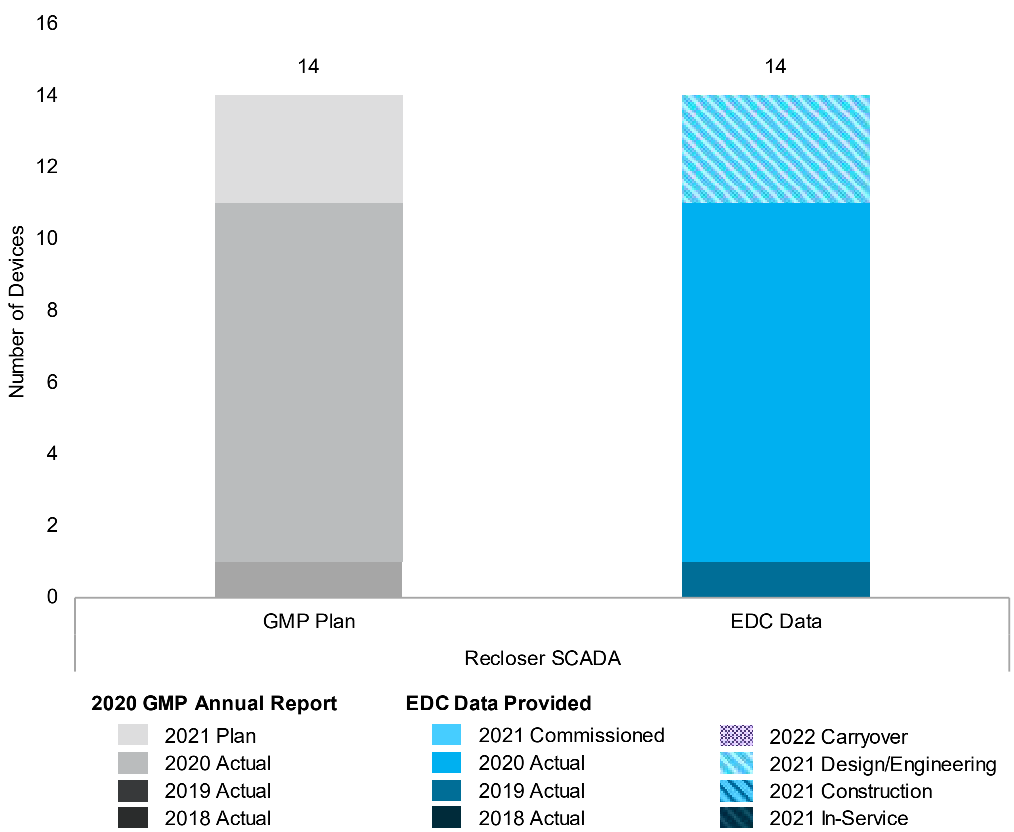
Unitil decided to defer its entire planned M&C spending for PY2021 to prioritize implementation of ADMS.

3.2.4.3 M&C Investment Progress through PY2021

In PY2021, Unitil's progress toward substation SCADA retrofitting[23] and OMS/AMI integration was lower than planned, due to the decision to pause deployment.

Figure 12 shows Unitil's planned versus actual device deployment progress for PY2018-2021. The EDC Data in Figure 12 is also shown in Table 30. The OMS/AMI integration plan is not quantified on a unit basis and so does not appear in the device deployment figures or tables. This investment is further discussed qualitatively below.

Figure 12. Unitil M&C Device Deployment Comparison (2018-2021)



Note that Carryover here would include all units not fully commissioned at the end of PY 2021.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

[23] Note the investment referred to as "Substation SCADA Retrofit" is labeled as "Recloser SCADA" in all figures and tables to align with the nomenclature of the DPU-approved device/technology types.

Table 30. Unitil M&C Plan and Actual Device Deployment (2018-2021)

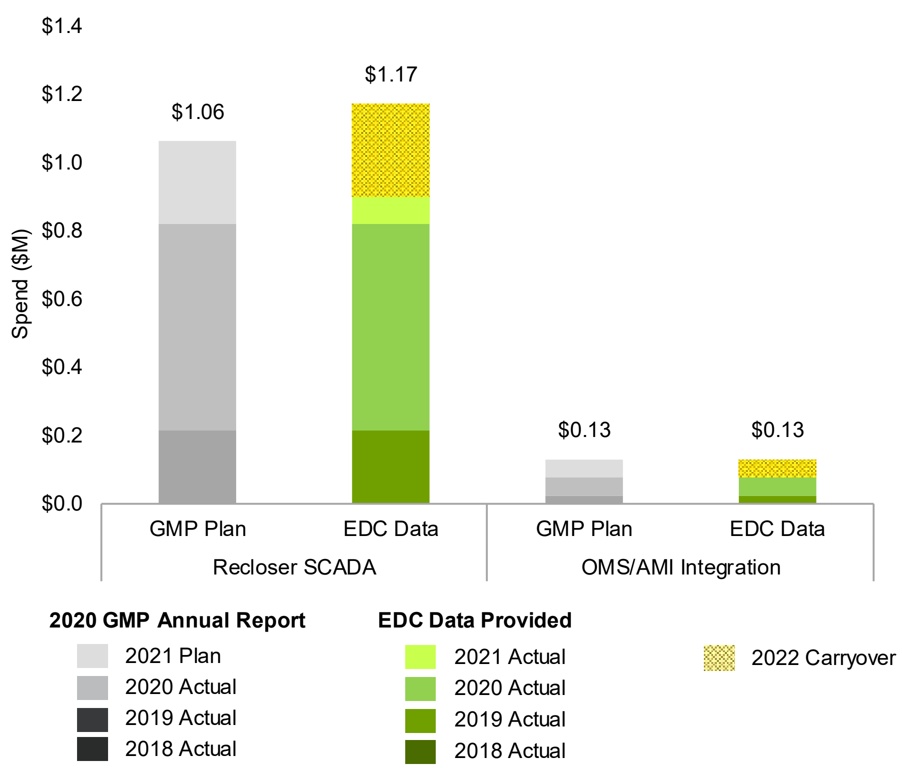
	Recloser SCADA
2018-2021 Total	**11**
Engineering/Design during PY 2021*	3
Construction during PY 2021*	0
In-Service during PY 2021*	0
Commissioned in PY 2021	0
Commissioned in PY 2020	10
Commissioned in PY 2019	1
Commissioned in PY 2018	0

* EDC Data indicates these devices will be commissioned in 2022.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

The PY2021 spend for both SCADA and OMS/AMI integration was deferred, primarily due to reallocation of resources to other priorities, as well as the lower urgency for the M&C functionality required to support VVO. Unitil plans on spending additional funds in 2022 to meet previously planned device deployment goals and account for increases in cost estimates. Figure 13 shows Unitil's planned versus actual spend over the 2018-2021 period. The EDC Data presented in Figure 13 is also shown in Table 31.

Figure 13. Unitil M&C Spend Plan vs. Actual (2018-2021, $M)



Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 31. Unitil M&C Plan and Actual Spend (2018-2021, $M)

	Recloser SCADA	OMS/AMI Integration
2018-2021 Total	**$0.90**	**$0.08**
2022 Carryover Estimate	$0.27	$0.05
PY 2021 Actual	$0.08	$0.00
PY 2020 Actual	$0.61	$0.06
PY 2019 Actual	$0.22	$0.02
PY 2018 Actual	$0.00	$0.00

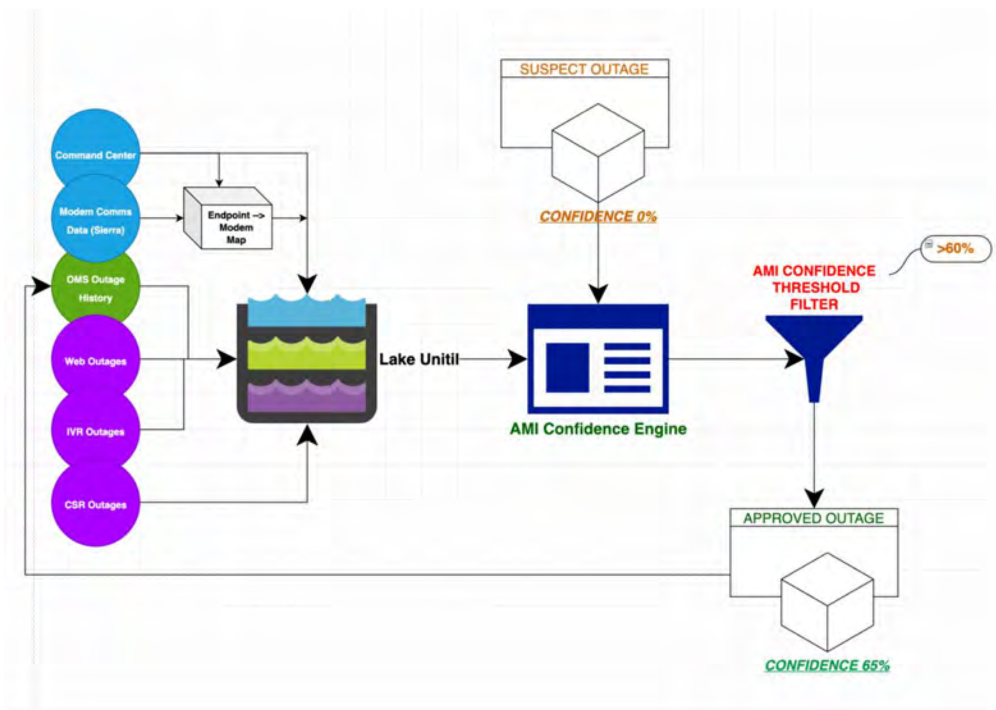
Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

The following sections discuss each technology in greater detail.

OMS/AMI Integration

Unitil spent the majority of PY2021 prioritizing the implementation of ADMS. Once the new ADMS environment is established enough for consistent data access, Unitil will use 2022 to continue progress towards building out the OMS/AMI integration.

Figure 14. OMS/AMI Integration: Confidence Engine and Filter Schematic



Source: Unitil

The plan to build out the engine leverages three types of data:

- Confirmed outage data from OMS, including past outage history
- Low level signal to noise data from collectors
- Weather and temperature data

In addition to incorporating the signal to noise and weather and temperature data, the next steps include further building out the database, finalizing an initial version of the confidence engine, and developing the user interface.

Actual spend on this effort for PY2021 was deferred, but total term spending, if carryover into 2022 in included, is on track to meet the prior plan. Total spending estimate is not expected to change.

Substation SCADA Retrofit

The substation SCADA retrofit initiative aims to upgrade existing SCADA or add new SCADA to distribution substations. Prior to initiating this work through the GMP, most substations had little to no SCADA. Where SCADA did exist, it was not capable of getting the analog quantities needed due to the lack of power quantities of voltage measurements.

This initiative supports the VVO deployment, which determined the timeline and workplan for the first few years of the GMP term. Work on the first substation began in PY2019, and the remaining work (completion of two additional substations) was completed during PY2020.

In PY2021, Unitil expected to continue the substation SCADA work ahead of the VVO and ADMS deployment schedule. However, a lower urgency for VVO support was determined and resources were reallocated to other priorities, specifically the implementation of ADMS. Consequently, for the same reason as was the case for OMS/AMI Integration, Unitil determined it was not feasible to continue the substation SCADA retrofit in PY2021.

Thus, actual deployment and spend for PY2021 was deferred, but total Term spending, if expected carryover into 2022 is included, is on track to slightly exceed prior plan. This is primarily due to an increase in cost estimates. Unitil was not able to complete work on any substation SCADA retrofits, however 3 substations are in-engineering/design and are planned to be completed in 2022.

Beyond 2021, Unitil expects to continue deploying substation SCADA at a rate of about one substation each year through around 2025. The work is largely prioritized by the impact, which includes metrics of substation size, load, and number of customers. The substation for PY2021, for example, was prioritized because it has three distribution circuits, while other remaining substations have only one or two circuits.

3.2.4.4 Infrastructure Metrics Results and Key Findings

Table 32 presents the Infrastructure Metrics results through PY2021 for the two technologies included in Unitil's M&C Investment Area.

Table 32. Unitil M&C: Infrastructure Metrics Summary

Infrastructure Metrics			Recloser SCADA	OMS/AMI Integration
GMP Plan Total, PY2018-2021		Devices	14	0
		Spend, $M	$1.06	$0.13
IM-4	Number of devices or other technologies deployed PY2018-2021*	# Devices Deployed	11	0
		% Devices Deployed	79%	N/A
IM-5	Cost for Deployment PY2018-2021*	Total Spend, $M	$0.90	$0.08
		% Spend	85%	62%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	0%	N/A
		% On Track (Spend)	32%	0%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	3	0
		Spend Remaining, $M	$0.27	$0.05

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data
**The metric names have been slightly changed here to clarify the time span used in analysis.*
**This metric has been interpreted here as the "carryover" units and spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs' 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

Unitil's progress in PY2021 was paused and total spend during PY2021 was lower than anticipated, as a result of the deferment. However, Unitil plans to deploy these funds in 2022 to continue work on both substation SCADA retrofit and OMS/AMI integration.

4. M&C Performance Metrics

Guidehouse's assessment of the Performance Metrics included Performance Metric data collection, data QA/QC, data analysis for each of the three EDCs, and determination of findings and conclusions from the analysis.

4.1 Data Management

This section discusses the data sources used for the Performance Metric evaluation and summarizes the Quality Assessment and Quality Control (QA/QC) steps, and selection of circuits used in the PY2021 analysis.

4.1.1 Data Sources

2021 Grid Modernization Plan Annual Report Appendix 1[24,25,26]: On April 1, 2022 each EDC submitted Appendix 1 along with its Annual Report. The Appendix 1 contains feeder-level data for all feeders within each EDC's territory. All PM-related data presented below are from these 2021 GMP Annual Report Appendices. These documents contain baseline and program year data for all circuits for each EDC. Key data from these Appendices that were utilized in this analysis include:

- Customer Counts
- Feeder Level SAIDI (CKAIDI) and SAIFI (CKAIFI) for the Plan Year and Baseline Years
- Number of Customers that Benefit from GMP Investments
- Average Protective Zone Size
- Main Line Customer Minutes of Interruption

Work Order Information: Circuit-level work order data was collected during the infrastructure metrics evaluation to understand the current status (e.g., Construction, Design, In-Service, Commissioned) of GMP investments. This work order data was used to determine when GMP investments were commissioned on each circuit with more granularity than is provided in the Appendix 1 data.

4.1.2 Data QA/QC Process

The evaluation team reviewed the Appendix 1 filings for completeness, accuracy, and alignment with the metrics set forward in the DPU Stamp Approved Metrics. The QA/QC process involved the following:

[24] Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-41.

[25] NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-40.

[26] Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-42.

- Check that the change in CKAIDI/CKAIFI and average zone sizes were properly calculated using the Stamp Approved Metric's definition. Note: DPU Stamp Approved Metric Guidance defines this as "BASELINE – PROGRAM YEAR"

- Comparison of circuits with GMP investments in the Appendix 1 filing and the work order data collected during the Infrastructure Metric analysis.

- Comparison of PY2020 and PY2021 Appendix 1 filings to ensure baseline reliability data match.

- Comparison of circuit lists between Appendix 1 tabs to understand changes in circuit lists due to decommissioning and reconfigurations that occurred during the baseline and program years.

During this QA/QC process, the evaluation team identified issues in both the Eversource and National Grid Appendix 1 filings that required adjustments and updates:

Eversource: Formula errors for Eversource's reported change in SAIFI with and without EMEs lead to incorrect values being calculated. Additionally, there were discrepancies between Eversource's work order data and Appendix 1 device deployment data with regards to which circuits had received M&C investments. Eversource provided explanations for both of these findings and indicated that corrections would be made in the future.

National Grid: Due to differences in reporting timeframe and requirements, National Grid resubmitted its initial EDC Data Device Deployment workbook with updated device counts and spend to align with its Appendix 1 filing. Baseline reliability data for Nantucket circuits was noted to be different than in the PY2020 Appendix 1 but was subsequently corrected by National Grid. Furthermore, National Grid also corrected some discrepancies between its Appendix 1 device deployment tabs, as well as circuit IDs in the work order data to align with Appendix 1 stated deployment.

4.1.3 Circuit Selection

The key reliability metrics involving outage duration (CKAIDI) and frequency (CKAIFI) are annual metrics, and impacts to these metrics from GMP investments would only be seen if the investments were installed for sufficient time on a particular circuit to impact outages that drive these annual metrics. The approach most likely to detect metric impacts from the investments would be to wait until the investment had been commissioned for several full years on the circuit before attempting to understand its impact on these metrics. However, the evaluation team determined that the use of the technology for at least one-half of the full program year could provide insight into the impacts of the GMP investments.[27]

[27] Equipment installed in the first half of the program year has at least half a year to fully operate and provide measurable reliability benefits to customers on a particular circuit, and using the half-year cutoff for circuit analysis also allows—on average—half the devices deployed in the program year to be included in the analysis. The evaluation team determined that this was a reasonable rule to use for exploring reliability impacts of the installed grid modernization devices, being mindful that many other factors affect these metrics, including weather, car strikes, and animal/bird interference.

The evaluation team reviewed the installation and commissioning timing for the various investments to understand when during PY2021 the devices were installed. For the CKAIDI/CKAIFI metrics (PM-12 and PM-13), circuits with *at least* a half year with the technology commissioned and in service were selected for inclusion in the analysis. This includes circuits with devices installed during 2018, 2019, 2020 as well as the first half of 2021. All circuits receiving M&C investments were included in the remaining performance metrics.

The evaluation team also identified a number of circuits for each EDC which had been reconfigured, split, or decommissioned between the baseline and program year. As a result of these changes, a comparison of CKAIDI/CKAIFI metrics was either not possible or deemed to be potentially misleading and these circuits were excluded from the analysis. Similar measures were taken to ensure that other performance metrics were calculated using a consistent circuit list between the baseline and the program year.[28]

The subsections below detail which circuits were included in the analysis for each EDC.

4.1.3.1 Eversource Circuits

Eversource commissioned M&C devices throughout PY2018, PY2019, PY2020, and PY2021. Table 33 shows circuits with M&C devices commissioned through the first half of 2021. It also shows number of circuits not included in the analysis largely due to the reconfiguration of circuits between the baseline and PY2021, as discussed above. A similar percentage of M&C circuits were not included in the analysis for the same reasons. A total of 109,960 (8%) customers were associated with the 306 excluded circuits. The evaluation team explored ways to include these circuits by mapping them to circuits in the baseline period, but determined that the mapping was not one-to-one. The evaluation team determined it was not practical to include the circuits and including them would not significantly alter the performance metrics results.

Table 33. Eversource Circuits Included in Analysis

Eversource Circuits	System-Wide	M&C Commissioned Prior to H2 2021
Total Circuit Count	2,377	326
Circuits Included in Analysis	2,071	288
% of Total Circuits Included In Analysis	87%	88%

Source: Guidehouse analysis of GMP Annual Reports and EDC Data

4.1.3.2 National Grid Circuits

National Grid commissioned M&C Feeder Monitor devices throughout PY2019, PY2020, and PY2021. Table 34 shows circuits with M&C devices commissioned through the first half of 2021. A majority of system-wide circuits and M&C circuits were included in the analysis. A total of 50,171 (4%) customers were located on the 68 excluded circuits.

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[28] A comparison of system wide baselines between this report and the PY 2020 PM Evaluation Report shows only minor differences in the baseline circuit list, which is expected given changing customer counts and changes in circuit configurations.

Table 34. National Grid Circuits Included in Analysis

National Grid Circuits	System-Wide	M&C Commissioned Prior to H2 2021
Total Circuit Count	1,144	92
Circuits Included in Analysis	1,076	91
% of Total Circuits Included In Analysis	94%	99%

Source: Guidehouse analysis of GMP Annual Reports and EDC Data

4.1.3.3 Unitil Circuits

Unitil did not commission any M&C investments on circuits in PY2021, considering the program was paused for the full program year. As shown in Table 35, approximately 30% of system-wide Unitil circuits were not included in the analysis either because they were network circuits, serving zero customers, or lacked CKAIFI/CKAIDI data in the plan year or the baseline. This includes 2 of the 11 M&C circuits, resulting in 9 M&C circuits included in the analysis.

Table 35. Unitil Circuits Included in Analysis

Unitil Circuits	System-Wide	M&C Commissioned Prior to H2 2021
Total Circuit Count	44	11
Circuits Included in Analysis	31	9
% of Total Circuits Included In Analysis	70%	82%

Source: Guidehouse analysis of GMP Annual Reports and EDC Data

4.2 M&C Performance Metrics Analysis and Findings

Evaluation of the relevant performance metrics for each EDC is provided below. A summary of findings is presented first, followed by an overview of the analysis approach to facilitate understanding of the detailed results analysis. The analysis for each relevant metric is then provided, organized by EDC.

Results Summary:

Table 36 provides a high-level summary of the results for each performance metric and EDC.

Table 36. Summary of Findings for M&C Investment Area

PM	Eversource	National Grid	Unitil
PM-12: Grid Modernization investments' effect on outage durations	Outage duration for M&C circuits for PY2021 slightly decreased, compared to baseline. *	Outage duration for M&C circuits for PY2021 was significantly longer than baseline. *	Relative to the baseline, outage duration for both system-wide and M&C circuits increased. However, there is an insufficient number of devices installed to draw conclusions. *
PM-13: Grid Modernization investments' effect on outage frequency	Outage frequency for M&C circuits for PY2021 was slightly lower than baseline. *	Outage frequency for M&C circuits for PY2021 was higher than baseline. *	Outage frequency was slightly increased for both M&C and system-wide circuits, but there is an insufficient number of devices installed to draw conclusions. *
PM-UTL1: Customer Minutes of Outage Saved per Circuit	N/A – Unitil specific metric	N/A – Unitil specific metric	The OMS/AMI Integration is not complete; this metric cannot yet be evaluated.

* *Note: This metric is not able to readily discern whether change in this metric was due to M&C investment or other factors.*

Source: Guidehouse Analysis

PY 2021 Reliability: Evidence suggests that PY2021 was a bad storm year in Massachusetts, negatively impacting system-wide reliability performance – without specific consideration of GMP investment (including M&C and ADA investments). Customer-weighted average CKAIDI and CKAIFI metrics with EMEs for PY2021 were significantly worse than they were for the Baseline years (2015-2017), as shown in Table 37.

Table 37: Baseline vs PY2021 Reliability with EMEs

EDC	CKAIDI/CKAIFI Metric	Baseline	PY2021
Eversource	Weighted Average CKAIDI	133	643
	Weighted Average CKAIFI	1.0	1.3
National Grid	Weighted Average CKAIDI	222	366
	Weighted Average CKAIFI	1.0	1.1
Unitil	Weighted Average CKAIDI	175	218
	Weighted Average CKAIFI	2.0	2.8

Source: Guidehouse Analysis.

Analysis Approach: The following approach was developed to provide additional insight into the EDC Performance Metrics that were published by the EDCs in their PY2021 Annual Reports, Appendix 1. The circuit-level data provided by the EDCs was used to evaluate the metrics. The evaluation approach has three elements:

1. Baseline and Program Year System-wide and M&C circuit comparisons: The evaluation team compared the baseline and program year data across the entire system and for circuits receiving M&C investments (see Section 4.1.3 for details). Statistical averages for these circuit groupings were used to make simple comparisons, and standard deviations were calculated to provide insight into the variability compared with the average values. For PM-12 (change in CKAIDI) and PM-13 (change in CKAIFI), the system-wide metric baseline was compared against the program year metric using reliability bins. This facilitates a general understanding of where the M&C investments fit into the context of the overall system metric performance and to compare changes in metrics for M&C circuits to those of system-wide circuits.

2. Before and after comparison**:** For PM-12 and PM-13, the program year performance was compared to the baseline performance for all circuits within the system. “Box-and-whisker” plots[29] are used to illustrate the distribution of data across the entire system and for circuits receiving M&C investments.[30]

3. Difference in differences: The difference in system-wide circuits change from baseline vs. M&C circuits change from baseline was calculated to understand if there is any discernable reliability improvement on the M&C circuits. This change is defined as “average metric for M&C circuits minus average metric for system-wide circuits.”

The sections below leverage the three steps listed above to provide additional insights into the impacts of M&C investments. In addition, ancillary metrics are used for informative purposes. For clarity, a subset of those metrics are defined below.

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[29] The “box-and-whisker” plot divides the sample into quartiles. The boxes show the 2nd and 3rd quartile in the sample. The lower and upper “whiskers” indicate 1.5 times the interquartile range (IQR) (difference between the start of the 2nd and the end of the 3rd quartile) or the maximum/minimum value within the range if it falls within 1.5x the IQR. The “x” indicates the sample average. Data points that fall outside 1.5x the IQR are not shown on the graph.

[30] Note that the DPU Guidance defines the change as “Baseline – Program Year” which means that positive values of this metric indicate reliability improvement—which may be counter intuitive as CKAIDI or CKAIFI metrics fall with improvement.

- Weighted Average refers to the customer weighted average, e.g., CKAIDI or CKAIFI weighted by average annual number of customers on the circuit and averaged over circuits for the year. This is used alongside the Simple Average, e.g., simply averaging CKAIDI or CKAIFI values for the circuits for the year, to compare the extent to which higher customer count circuits were impacted by outages. A Weighted Average greater than a simple average indicates that circuits with higher customer counts were more impacted by outages. The weighted average is computed using 2017 customer counts for the baseline, and 2020 customer count for the Program Year.
- Standard Deviation of CKAIDI or CKAIFI values is computed to provide an indication of the variability in these metrics for the year(s) in question. A high value relative to the averages described above tends to indicate high variability and prevents us from drawing strong conclusions about changes in the average values.
- Total Circuits with Non-Zero Customers only counts circuits that serve customer loads under normal conditions., i.e., it excludes backup circuits, and express circuits between substations, etc. The CKAIDI/CKAIFI analysis only considers circuits with non-zero customers.
- % Zero is the proportion of circuits that had zero CKAIDI/CKAIFI in the 3 baseline years (for the baseline) or in 2021 (for the program year). This value for the baseline comprises circuits that have not experienced any outages in any of the 2015-2017 years, while this value for the program year comprises circuits that did not experience any outages in 2021.

4.2.1 PM-12: Effect on Outage Duration (CKAIDI)

Metric PM-12, Reliability-Focused Grid Modernization Investments' Effect on Outage Duration (CKAIDI), was developed to try to provide insight on how GMP devices impact outage duration and is intended to track performance improvements over time. Per the DPU Stamp Approved GMP Performance Metrics Guidance:

> *This metric will compare the experience of customers on GMP DA-enabled circuits as compared to the prior three-year average for the same circuit. This metric will provide insight into how DA can reduce the duration of outages (by tracking and reporting) the following:*
>
> - *Circuit level SAIDI for the program year*
> - *Three-year average SAIDI for 2015, 2016, and 2017*
> - *Comparison of the current year SAIDI with the three-year historic average: AVERAGE(CKAIDI 2015, CKAIDI 2016, CKAIDI 2017) – PY CKAIDI = if greater than 0, positive impact*

The EDCs provided the circuit-level CKAIDI metric in their Appendix 1 filings. As discussed in Section 4.1.3, only circuits with M&C investments in the first half of 2021 and prior are included in the analysis. Analysis of this metric for each EDC is presented in the following subsections.

4.2.1.1 Eversource Analysis

The analysis of the CKAIDI metric for Eversource is presented in the subsection below.

System-wide and M&C circuit counts: Table 38 is structured with CKAIDI ranges, or "bins", to provide insight about the range of outage durations across circuits in the system, and to show where circuits selected for M&C investment fall within these bins. Approximately 22% of system wide and 15% of M&C circuits experienced no outages at all within the baseline period; this number increased across the board in PY2021.

In comparison to the baseline, M&C circuits in PY2021 had a 12-minute improvement in average CKAIDI without EMEs. System-wide circuits showed a slightly greater improvement of 39 minutes in CKAIDI without EMEs in 2021 from the baseline. M&C circuits are included in the system-wide results.

However, CKAIDI with EMEs significantly worsened for both M&C circuits and system-wide circuits from the baseline to PY2021. Eversource noted that the worsened EME performance in PY2021 is mainly driven by an excludable major event that occurred 10/26/21 through 11/1/21 and caused over 7,000 excludable event restorations across more than 700 circuits. The baseline CKAIDI with EMEs is a three-year average which "masks" individual major events – meaning a circuit would have to be hit by major events three years in a row for the baseline CKAIDI to be impacted.

The CKAIDI standard deviation also increased significantly, indicating increased variability in CKAIDI across circuits in the system. The standard deviation reflects extremely large values, thus signifying that the results are of limited statistical significance.

Table 38. Eversource Baseline and PY2021 CKAIDI Distribution

Eversource M&C	2015-2017 Avg. CKAIDI (Baseline)				2021 CKAIDI (Program Year)			
	System-wide		M&C Circuits		System-wide		M&C Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIDI Statistics								
Total Circuits	2,071	2,071	288	288	2,071	2,071	288	288
Total Circuits with Non-zero Customers	1,658	1,658	230	230	1,572	1,572	230	230
% Zero CKAIDI	22%	22%	15%	15%	29%	35%	27%	32%
Average CKAIDI	133	105	96	89	643	66	185	77
Change from Baseline (Baseline - Plan Year)					-510	39	-90	12
% Change from Baseline					-383%	37%	-93%	14%
Std. Dev.	154	117	101	86	1,289	82	590	89
CKAIDI Range	**No. of Circuits in Range**							
0	367	368	35	35	452	545	62	74
0 - 50	483	527	74	74	362	552	72	77
50 - 150	446	489	87	90	255	296	54	56
150 - 250	181	165	19	18	105	111	16	16
250 - 350	82	61	7	7	60	36	9	3
350 - 450	44	27	5	4	41	18	3	2
450 - 550	20	8	1	2	17	4	2	0
550 - 650	11	3	1	0	17	2	1	0
650 - 750	9	5	0	0	11	4	2	1
750 - 850	9	3	1	0	15	1	1	0
850 - 950	3	1	0	0	7	3	1	1
950 - 1050	1	1	0	0	11	0	0	0
1050 - 1300	1	0	0	0	18	0	1	0
1300 - 1550	1	0	0	0	21	0	2	0
1550 - 1800	0	0	0	0	18	0	1	0
1800 - 2050	0	0	0	0	13	0	0	0
2050 - 3050	0	0	0	0	51	0	0	0
> 3050	0	0	0	0	98	0	3	0

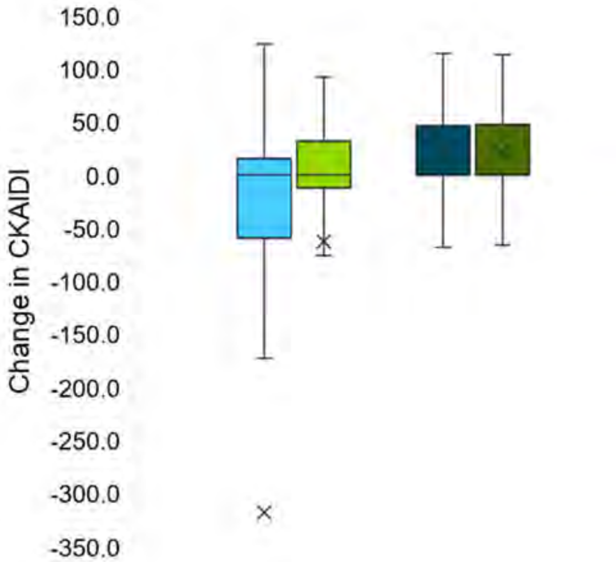
Note: EME = Excludable Major Events. CKAIDI of zero indicates circuit did not experience any outages.

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

Before and after comparison: A simple graphical summary of the statistical change in CKAIDI is shown in Figure 15 below, which uses the “box-and-whisker” format. This chart compares the difference in CKAIDI between baseline and PY 2020, for both the system-wide and the selected M&C circuits. The change shown below is calculated per the DPU Stamped Approved formula of Baseline CKAIDI – Program Year CKAIDI, so a positive change indicates improved performance in the Program Year. Figure 15 uses the “box-and-whisker” format.[31]

Figure 15. Eversource Outage Duration Performance Metric Results

[31] The “box-and-whisker” plot divides the sample into quartiles. The boxes show the 2nd and 3rd quartile in the sample. The lower and upper “whiskers” indicate 1.5 times the interquartile range (IQR) (difference between the start of the 2nd and the end of the 3rd quartile) or the maximum/minimum value within the range if it falls within 1.5x the IQR. The “x” indicates the sample average. Data points that fall outside 1.5x the IQR are not shown on the graph.



	Change in System-wide CKAIDI w/ EMEs	Change in M&C CKAIDI w/ EMEs
Count	2,071	288
% No Change	35%	30%
Average Change in CKAIDI	-318	-63
Standard Deviation	1008	507
Median Change in CKAIDI	0	0

	Change in System-wide CKAIDI w/o EMEs	Change in M&C CKAIDI w/o EMEs
Count	2,071	288
% No Change	36%	30%
Average Change in CKAIDI	22	21
Standard Deviation	115	109
Median Change in CKAIDI	0	0

Note: EME = Excludable Major Events. Change in CKAIDI is reported as minutes and is calculated as defined by the DPU PM Guidance: 2015-2017 Avg. CKAIDI – 2021 CKAIDI = if greater than zero, positive impact.

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

Both average system-wide and M&C CKAIDI with EMEs increased (worsened) in Program Year 2021 over the baseline. For the system-wide circuits, CKAIDI increased significantly more than for M&C circuits, indicating a relatively better performance on the M&C circuits on average for EME days. For non-EME days, both average system-wide and M&C improved (decreased) similarly over the baseline.

However, the standard deviation of the change in CKAIDI for each group is significantly larger—several times larger–than the average change in CKAIDI itself, indicating that the change in the average is of limited statistical significance, and not indicative of a clearly discernible trend in CKAIDI. As indicated above, there are many potential reasons for these changes and many factors impacting this metric. The impact of the M&C investment in operation is one of the factors but is not discernable using the metric itself.

Difference in differences: The differences in the change in CKAIDI (baseline to 2021) between the system-wide average and the average for circuits with M&C investments are shown in Table 39. The change in CKAIDI for system-wide circuits was substantially greater than the circuits with M&C investments for EME days. Although the standard deviation for these samples is larger than changes in CKAIDI with EME (as discussed above), it is difficult to discern how much positive impact the M&C investments had on this metric for PY2021.

Table 39. Eversource CKAIDI Difference in Differences

	System-Wide Circuits	M&C Circuits	Difference in Differences (M&C - System-Wide)
Change in CKAIDI w/ EMEs	-318	-63	256
Change in CKAIDI w/o EMEs	22	21	-1

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

Erosion of Baseline: As mentioned in section 4.1.3.1, 13% of Eversource system-wide circuits and 12% of Eversource M&C circuits had to be excluded from this metric, because circuits had been retired, reconfigured or split since 2017. The comparability of each circuit in the program year to its baseline, as defined in the DPU approved metric, depends on that circuit not having been reconfigured or significantly changed (e.g., a normally open switch between circuit segments is changed to operate as normally closed, changing the customer counts and outage measurements on that circuit). The number of circuits that are comparable between baseline and program year is reduced year over year as more circuits are reconfigured, leading to an erosion of metric baseline over time.

Major Events in the Baseline: A shortcoming of PM-12 is the methodology of averaging CKAIDI over 3 years, which masks the impact of single-year EMEs, as it is highly unlikely for the same circuit to be affected by an EME three years in a row. Thus, when comparing a single-year CKAIDI with EME to the baseline, the change in CKAIDI is much more likely to indicate decreased reliability.

4.2.1.2 National Grid Analysis

The analysis of the CKAIDI metric for National Grid is presented in the subsection below. Feeder monitors provide visibility of real-time current and voltage, which are valuable to operators and planners. However, the feeder monitors are currently not used for fault identification and fault location. As the next step, National Grid plans to use feeder monitor data to reduce momentary interruptions and locating faults. For these reasons, National Grid's M&C investments, at this time, are not used to reduce outage duration or reduce the number of customers affected by an outage. The results presented below are consistent with this observation.

System-wide and M&C circuit counts: Table 40 is structured with CKAIDI ranges, or "bins," to provide insight about the range of outage durations across circuits in the system, and to show where circuits selected for M&C investment fall within these bins. For the M&C circuits (green bars indicate number of circuits in bin), more circuits were in the "low CKAIDI" bins in PY2021 than in the baseline, for both non-EME and EME days. There were many more circuits with CKAIDI greater than 1,000 during EME days in PY2021 than in baseline; this is true for both system-wide and M&C.

Relative to the baseline, an increase in average CKAIDI for M&C circuits on both EME and non-EME days indicates decreased reliability in PY2021. Moreover, the M&C average CKAIDI with EMEs is more than three times larger than that of the baseline.

The 91 M&C circuits had higher average CKAIDI values than the system-wide CKAIDI values in PY2021, indicating that these circuits performed comparatively worse. However, there was a high standard deviation, particularly for EME days, therefore indicating wide differences across circuits in PY2021.

Table 40. National Grid Baseline and PY2021 CKAIDI Distribution

National Grid M&C	2015-2017 Avg. CKAIDI (Baseline)				2021 CKAIDI (Program Year)			
	System-wide		M&C Circuits		System-wide		M&C Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIDI Statistics								
Total Circuits	1,076	1,076	91	91	1,076	1,076	91	91
Total Circuits with Non-zero Customers	1,073	1,073	91	91	1,042	1,042	91	91
% Zero CKAIDI	3%	4%	0%	0%	19%	20%	3%	4%
Average CKAIDI	222	118	196	114	366	113	682	143
Change from Baseline (Baseline - Plan Year)					-145	5	-486	-28
% Change from Baseline					-65%	4%	-247%	-25%
Std. Dev.	258	162	177	69	672	122	940	120
CKAIDI Range	**No. of Circuits in Range**							
0	34	39	0	0	193	208	3	4
0 - 50	255	329	19	23	241	327	6	19
50 - 150	349	433	29	44	242	274	17	32
150 - 250	185	180	23	20	105	113	15	19
250 - 350	78	55	9	3	70	56	9	5
350 - 450	43	18	2	1	41	34	9	8
450 - 550	27	10	3	0	29	13	1	0
550 - 650	26	4	2	0	18	9	5	4
650 - 750	16	0	1	0	10	2	2	0
750 - 850	10	1	0	0	10	2	2	0
850 - 950	14	3	0	0	6	1	2	0
950 - 1050	7	0	0	0	7	1	3	0
1050 - 1300	23	0	3	0	12	2	2	0
1300 - 1550	4	0	0	0	13	0	3	0
1550 - 1800	0	0	0	0	5	0	0	0
1800 - 2050	1	0	0	0	8	0	0	0
2050 - 3050	1	0	0	0	18	0	7	0
> 3050	0	1	0	0	14	0	5	0

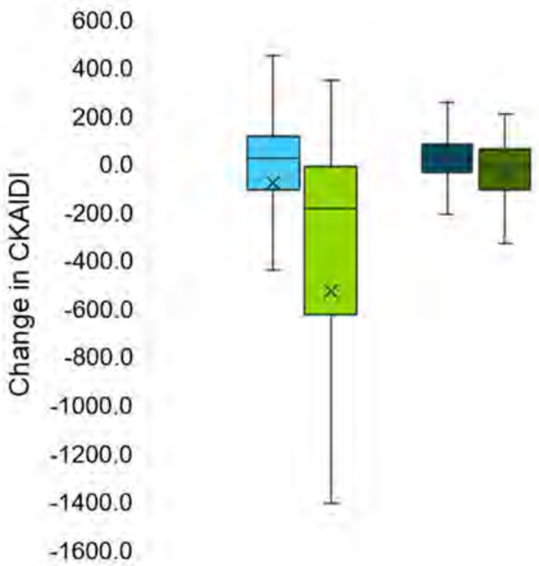
Note: EME = Excludable Major Events. CKAIDI of zero indicates circuit did not experience any outages.

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

Before and after comparison: A simple graphical summary of the statistical change in CKAIDI is shown in Figure 16 below, which uses the "box-and-whisker" format.[32] This chart compares the difference in CKAIDI between baseline and PY 2021, for both the system-wide and the selected M&C circuits. The change shown below is calculated per the DPU Stamped Approved formula of Baseline CKAIDI – Program Year CKAIDI, so a positive change indicates improved performance in the Program Year.

[32] The "box-and-whisker" plot divides the sample into quartiles. The boxes show the 2nd and 3rd quartile in the sample. The lower and upper "whiskers" indicate 1.5 times the interquartile range (IQR) (difference between the start of the 2nd and the end of the 3rd quartile) or the maximum/minimum value within the range if it falls within 1.5x the IQR. The "x" indicates the sample average. Data points that fall outside 1.5x the IQR are not shown on the graph.

Figure 16. National Grid Outage Duration Performance Metric Results



	Change in System-wide CKAIDI w/ EMEs	Change in M&C CKAIDI w/ EMEs
Count	1,076	91
% No Change	3%	0%
Average Change in CKAIDI	-78	-529
Standard Deviation	641	1016
Median Change in CKAIDI	19	-188

	Change in System-wide CKAIDI w/o EMEs	Change in M&C CKAIDI w/o EMEs
Count	1,076	91
% No Change	3%	0%
Average Change in CKAIDI	12	-48
Standard Deviation	218	149
Median Change in CKAIDI	23	-14

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

On average, the M&C circuits experienced a much higher increase in CKAIDI from the baseline to 2021 on EME days, reflecting worsening performance overall. Except for M&C CKAIDI with EMEs, the close to 0 median change value across all other categorizations indicates that half of all system wide and M&C circuits showed either improved, no difference, or slightly decreased performance in 2021 over the baseline. For M&C circuits, the average change in CKAIDI was worse than system average on both EME and non-EME days.

However, the standard deviation of the change in CKAIDI for each group is significantly larger than the average change in CKAIDI itself, providing an indication that the change in the average is of limited statistical significance, and not indicative of any clearly discernible trend in CKAIDI.

Difference in differences: The differences in the change in CKAIDI between the system-wide average and the average for circuits with M&C investments are shown in Table 41. The change in CKAIDI for circuits with M&C investments was significantly greater than the system wide circuits. As discussed above, this illustrates that the M&C circuits performed worse than the system average, for both EME and non-EME outages: although they fared significantly worse when EMEs were included. Again, this data does not provide any clear indication of how the M&C investments themselves performed, as it is not possible to isolate the outage duration impacts using this metric.

Table 41. National Grid CKAIDI Difference in Differences

	System-Wide Circuits	M&C Circuits	Difference in Differences (M&C - System-Wide)
Change in CKAIDI w/ EMEs	-78	-529	-451
Change in CKAIDI w/o EMEs	12	-48	-60

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

Major Events in the Baseline: A shortcoming of PM-12 is the methodology of averaging CKAIDI over 3 years, which masks the impact of single-year EMEs, as it is highly unlikely for the same circuit to be affected by an EME three years in a row. Thus, when comparing a single-year CKAIDI with EME to the baseline, the change in CKAIDI is much more likely to indicate decreased reliability.

4.2.1.3 Unitil Analysis

The analysis of the CKAIDI metric for Unitil is presented in the subsection below. Unitil's M&C investment consists of SCADA visibility and control in the substation. Substation SCADA enables Unitil to remotely monitor and manage distribution and transmission-level operations and outages. During PY2021, Unitil did not experience a main line circuit outage or transmission event on the 9 qualifying circuits meeting the M&C selection criteria.

Table 42 provides an overview of circuit performance during the baseline period and PY2021.

Table 42. Unitil Baseline and PY2021 CKAIDI Distribution

Unitil M&C	2015-2017 Avg. CKAIDI (Baseline)				2021 CKAIDI (Program Year)			
	System-wide		M&C Circuits		System-wide		M&C Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIDI Statistics								
Total Circuits	31	31	9	9	31	31	9	9
Total Circuits with Non-zero Customers	31	31	9	9	31	31	9	9
% Zero CKAIDI	0%	3%	0%	11%	6%	13%	0%	11%
Average CKAIDI	175	66	204	75	218	117	212	115
Change from Baseline (Baseline - Plan Year)					-43	-51	-8	-41
% Change from Baseline					-25%	-77%	-4%	-55%
Std. Dev.	85	34	43	31	128	107	75	72
CKAIDI Range	**No. of Circuits in Range**							
0	0	1	0	1	2	4	0	1
0 - 50	6	13	0	3	3	8	0	1
50 - 150	11	17	1	5	6	15	2	6
150 - 250	12	0	7	0	15	1	5	0
250 - 350	1	0	1	0	2	2	1	1
350 - 450	1	0	0	0	2	1	1	0
450 - 550	0	0	0	0	0	0	0	0
550 - 650	0	0	0	0	1	0	0	0
650 - 750	0	0	0	0	0	0	0	0
750 - 850	0	0	0	0	0	0	0	0
850 - 950	0	0	0	0	0	0	0	0
950 - 1050	0	0	0	0	0	0	0	0
1050 - 1300	0	0	0	0	0	0	0	0
1300 - 1550	0	0	0	0	0	0	0	0
1550 - 1800	0	0	0	0	0	0	0	0
1800 - 2050	0	0	0	0	0	0	0	0
2050 - 3050	0	0	0	0	0	0	0	0
> 3050	0	0	0	0	0	0	0	0

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

Average CKAIDI was worse than baseline CKAIDI for both system-wide and M&C circuits. As with other EDCs, the circuit performance in 2021 decreased compared to the baseline. However, M&C circuits reflect relatively better performance than system-wide circuits. Circuits with M&C investments on EME days had an 8-minute increase in average CKAIDI, while system-wide circuits had a 43-minute increase. The high standard deviation coupled with the low number of circuits with M&C investments result in this metric not fully capturing the specific effect of M&C investment on the CKAIDI metric.

Major Events in the Baseline: A shortcoming of PM-12 is the methodology of averaging CKAIDI over 3 years, which masks the impact of single-year EMEs, as it is highly unlikely for the same circuit to be affected by an EME three years in a row. Thus, when comparing a single-year CKAIDI with EME to the baseline, the change in CKAIDI is much more likely to indicate decreased reliability.

4.2.2 PM-13: Effect on Outage Frequency (CKAIFI)

Metric PM-13, Reliability-Focused Grid Modernization Investments' Effect on Outage Frequency (CKAIFI), provides insight on how GMP devices impact outage frequency and will track the improvements over time. Per the DPU Stamp Approved GMP Performance Metrics Guidance:

> *This metric will compare the experience of customers on GMP DA-enabled circuits as compared to the prior three-year average for the same circuit. This metric will provide insight into how DA can reduce the frequency of outages (by tracking and reporting) the following:*
>
> - *Circuit level SAIFI (CKAIFI) for the program year*
> - *Three-year average SAIFI (CKAIFI) for 2015, 2016, and 2017*
> - *Comparison of the current year SAIFI (CKAIFI) with the three-year historic average: AVERAGE(CKAIFI 2015, CKAIFI 2016, CKAIFI 2017) – PY CKAIFI = if greater than 0, positive impact*

The EDCs have provided the CKAIFI metric in their Appendix 1 filings. As discussed in Section 4.1.3, only circuits with M&C investments in the first half of 2021 and prior are included in the analysis. Analysis of this metric for each EDC is presented in the following subsections and the presentation structure aligns closely with that used with the previous metric (PM-12: Impact on Outage Duration).

4.2.2.1 Eversource Analysis

The analysis of the CKAIFI metric for Eversource is presented in the subsection below.

System-wide and M&C circuit counts: Table 43 is structured with CKAIFI ranges, or "bins", to provide insight about the range of outage durations across circuits in the system, and to show where circuits selected for M&C investment fall within these bins. Approximately 22% of system wide and 15% of M&C circuits experienced no outages at all within the baseline period; this number increased in PY2021.

Relative to the baseline, both system-wide and M&C circuit average CKAIFI increased on EME days. On the other hand, both decreased on non-EME days. This indicates the impact of EMEs on reliability performance.

The CKAIFI standard deviation increased for both system-wide and M&C circuits, indicating increased variability in CKAIFI across all circuits. However, the standard deviation is on the same order of magnitude as the weighted average, providing some indication that the change in the weighted average is not simply statistical noise, but an actual degradation in performance on EME days during the program year.

Table 43. Eversource Baseline and PY2021 CKAIFI Distribution

Eversource M&C	2015-2017 Avg. CKAIFI (Baseline)				2021 CKAIFI (Program Year)			
	System-wide		M&C Circuits		System-wide		M&C Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIFI Statistics								
Total Circuits	2,071	2,071	288	288	2,071	2,071	288	288
Total Circuits with Non-zero Customers	1,658	1,658	230	230	1,572	1,572	230	230
% Zero CKAIFI	22%	22%	15%	15%	29%	36%	28%	33%
Average CKAIFI	1.0	0.9	0.8	0.8	1.3	0.7	0.9	0.7
Change from Baseline (Baseline - Plan Year)					-0.3	0.2	-0.1	0.1
% Change from Baseline					-31%	22%	-8%	16%
Std. Dev.	0.8	0.7	0.6	0.6	1.4	0.8	1.0	0.7
CKAIFI Range	**No. of Circuits in Range**							
0	371	372	35	35	461	566	64	77
0 - 0.25	203	209	28	28	241	348	35	44
0.25 - 0.75	513	529	81	82	191	209	44	45
0.75 - 1.25	265	272	49	49	235	231	41	35
1.25 - 1.75	153	159	22	22	117	85	17	13
1.75 - 2.25	88	68	11	10	103	80	9	10
2.25 - 2.75	35	27	2	3	67	25	10	5
2.75 - 3.25	17	14	2	1	38	14	3	0
3.25 - 3.75	9	7	0	0	35	7	1	1
3.75 - 4.25	3	1	0	0	30	4	2	0
4.25 - 4.75	0	0	0	0	14	3	0	0
4.75 - 5.25	0	0	0	0	8	0	0	0
5.25 - 5.75	0	0	0	0	6	0	0	0
5.75 - 6.25	0	0	0	0	8	0	2	0
6.25 - 6.75	0	0	0	0	4	0	0	0
6.75 - 7.25	0	0	0	0	6	0	0	0
7.25 - 7.75	0	0	0	0	1	0	1	0
> 7.75	1	0	0	0	7	0	1	0

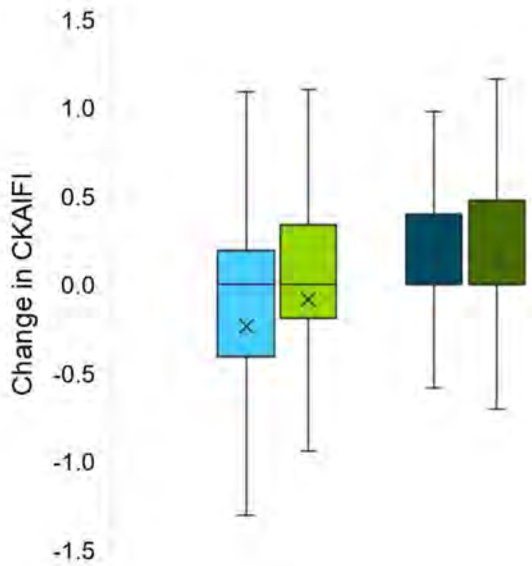
Note: EME = Excludable Major Events. CKAIFI of zero indicates circuit did not experience any outages.

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

Before and after comparison: A simple graphical summary of the statistical change in CKAIFI is shown in Figure 17 below, which uses a "box-and-whisker" format.[33] This chart compares the difference in CKAIFI between baseline and Program Year 2021 for each circuit, for both the system-wide and the selected M&C circuits. The change shown below is calculated per the DPU Stamped Approved formula of Baseline CKAIFI – Program Year CKAIFI, so a positive change indicates improved performance in the Program Year.

[33] The "box-and-whisker" plot divides the sample into quartiles. The boxes show the 2nd and 3rd quartile in the sample. The lower and upper "whiskers" indicate 1.5 times the interquartile range (IQR) (difference between the start of the 2nd and the end of the 3rd quartile) or the maximum/minimum value within the range if it falls within 1.5x the IQR. The "x" indicates the sample average. Data points that fall outside 1.5x the IQR are not shown on the graph for visualization purposes.

Figure 17. Eversource Outage Frequency Performance Metric Results



	Change in System-wide CKAIFI w/ EMEs	Change in M&C CKAIFI w/ EMEs
Count	2,071	288
% No Change	35%	30%
Average Change in CKAIFI	-0.2	-0.1
Standard Deviation	1.1	1.1
Median Change in CKAIFI	0.0	0.0

	Change in System-wide CKAIFI w/o EMEs	Change in M&C CKAIFI w/o EMEs
Count	2,071	288
% No Change	36%	30%
Average Change in CKAIFI	0.1	0.1
Standard Deviation	0.7	0.7
Median Change in CKAIFI	0.0	0.0

Note: EME = Excludable Major Events. Change in CKAIFI is calculated as defined by the DPU PM Guidance: 2015-2017 Avg. CKAIFI – 2021 CKAIFI = if greater than zero, positive impact.

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

The average system-wide CKAIFI changed very little in PY2021 relative to the baseline period. For the selected M&C circuits, CKAIFI increased slightly less than for system-wide circuits indicating a slight improvement of performance on the M&C circuits on average. However, the standard deviation of the change in CKAIFI for each group is significantly larger—several times larger–than the average change in CKAIFI itself, providing an indication that the change in the average is of limited statistical significance, and not indicative of a clearly discernible trend in CKAIFI. There are many potential reasons for these changes and many factors impacting this metric. The impact of the M&C investment in operation is one of the factors but is not discernable using the metric itself.

Difference in differences: The differences in the change in CKAIFI (baseline to 2021) between the system-wide average and the average for circuits with M&C investments are shown in Table 44. The change in CKAIFI for system-wide circuits was slightly greater than the system-wide circuits for both w/ EME and w/o EME data. However, the standard deviation for these samples is much larger that the CKAIFI changes indicating that the difference is likely not statistically significant and is more probably a factor of randomness in the metric data than any type of trend. It is difficult to conclude how much positive (or negative) impact the M&C investments had on this metric for Program Year 2021.

Table 44. Eversource CKAIFI Difference in Differences

	System-Wide Circuits	M&C Circuits	Difference in Differences (M&C - System-Wide)
Change in CKAIFI w/ EMEs	-0.2	-0.1	0.1
Change in CKAIFI w/o EMEs	0.1	0.1	0.0

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

While Eversource M&C investments provide useful information about outages and help to reduce outage durations, M&C investments, by themselves, are not expected to *prevent* an outage from occurring. M&C investments when coupled with devices such as reclosers, padmount switchgear, network protectors, etc. will reduce overall outage times. As such, Eversource's M&C investments are expected to have little impact on CKAIFI which measures the frequency (number) of outages.

Erosion of Baseline: As mentioned in section 4.1.3.1, 13% of Eversource system-wide circuits and 12% of Eversource M&C circuits had to be excluded from this metric, because circuits had been retired, reconfigured or split since 2017. The comparability of each circuit in the program year to its baseline, as defined in the DPU approved metric, depends on that circuit not having been reconfigured or significantly changed (e.g., a normally open switch between circuit segments is changed to operate as normally closed, changing the customer counts and outage measurements on that circuit). The number of circuits that are comparable between baseline and program year is reduced year over year as more circuits are reconfigured, leading to an erosion of metric baseline over time.

Major Events in the Baseline: A shortcoming of PM-13 is the methodology of averaging CKAIFI over 3 years, which masks the impact of single-year EMEs, as it is highly unlikely for the same circuit to be affected by an EME three years in a row. Thus, when comparing a single-year CKAIFI with EME to the baseline, the change in CKAIFI is much more likely to indicate decreased reliability.

4.2.2.2 National Grid Analysis

The analysis of the CKAIFI metric for National Grid is presented in the subsection below.

System-wide and M&C circuit counts: Table 45 is structured with CKAIFI ranges, or "bins", to provide insight about the range of outage durations across circuits in the system, and to show where circuits selected for M&C investment fall within these bins.

Average CKAIFI increased from baseline in PY2021 for circuits with M&C investments on both EME and non-EME days. Compared to the baseline, CKAIFI on M&C circuits was 47% worse than baseline on EME days and 35% worse than baseline on non-EME days. Average system-wide performance was similar to the baseline, but showed higher variability in CKAIFI, as can be seen by the increased standard deviation. For example, about 20% of system-wide circuits experienced no outages in PY2021, despite the increased EME activity. This aligns with the observation that there was greater variability in customers' outages for 2021, with some customers experiencing no outages while others noticeably more.

The 91 M&C circuits had a greater increase in average CKAIFI values than the system-wide CKAIFI values in PY2021, indicating that these circuits performed comparatively worse. The CKAIFI standard deviation also increased significantly, indicating increased variability in CKAIFI across the system. The standard deviation is smaller than the weighted average, providing some indication that the change in the weighted average is not simply statistical noise, but an actual degradation in performance during the program year.

Table 45. National Grid Baseline and PY2021 CKAIFI Distribution

National Grid M&C	2015-2017 Avg. CKAIFI (Baseline)				2021 CKAIFI (Program Year)			
	System-wide		M&C Circuits		System-wide		M&C Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIFI Statistics								
Total Circuits	1,076	1,076	91	91	1,076	1,076	91	91
Total Circuits with Non-zero Customers	1,073	1,073	91	91	1,042	1,042	91	91
% Zero CKAIFI	3%	4%	0%	0%	19%	20%	3%	4%
Average CKAIFI	1.0	0.9	1.0	0.9	1.1	0.9	1.5	1.3
Change from Baseline (Baseline - Plan Year)					-0.1	0.0	-0.5	-0.3
% Change from Baseline					-9%	0%	-47%	-35%
Std. Dev.	0.6	0.6	0.5	0.5	1.0	0.8	1.0	0.9
CKAIFI Range	**No. of Circuits in Range**							
0	34	40	0	0	194	209	3	4
0 - 0.25	121	144	8	8	236	273	5	9
0.25 - 0.75	373	401	26	35	138	142	12	13
0.75 - 1.25	299	282	32	28	191	197	21	29
1.25 - 1.75	153	132	18	14	94	75	12	9
1.75 - 2.25	60	52	6	6	89	76	15	11
2.25 - 2.75	22	15	1	0	46	34	9	7
2.75 - 3.25	8	5	0	0	24	20	4	4
3.25 - 3.75	2	1	0	0	14	6	7	3
3.75 - 4.25	0	0	0	0	9	6	1	1
4.25 - 4.75	0	0	0	0	5	3	1	1
4.75 - 5.25	0	0	0	0	1	1	0	0
5.25 - 5.75	0	1	0	0	1	0	1	0
5.75 - 6.25	0	0	0	0	0	0	0	0
6.25 - 6.75	0	0	0	0	0	0	0	0
6.75 - 7.25	0	0	0	0	0	0	0	0
7.25 - 7.75	0	0	0	0	0	0	0	0
> 7.75	1	0	0	0	0	0	0	0

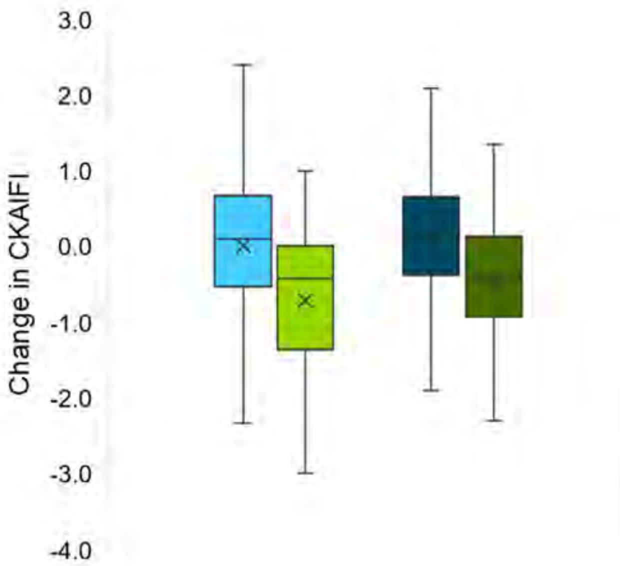
Note: EME = Excludable Major Events. CKAIFI of zero indicates no outages occurred.

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

Before and after comparison: A simple graphical summary of the statistical change in CKAIFI is shown in Figure 18 below, which uses a "box-and-whisker" format.[34] This chart compares the difference in CKAIFI between baseline and Program Year 2021 for each circuit, for both the system-wide and the selected M&C circuits. The change shown below is calculated per the DPU Stamped Approved formula of Baseline CKAIFI – Program Year CKAIFI, so a positive change indicates improved performance in the Program Year.

[34] The "box-and-whisker" plot divides the sample into quartiles. The boxes show the 2nd and 3rd quartile in the sample. The lower and upper "whiskers" indicate 1.5 times the interquartile range (IQR) (difference between the start of the 2nd and the end of the 3rd quartile) or the maximum/minimum value within the range if it falls within 1.5x the IQR. The "x" indicates the sample average. Data points that fall outside 1.5x the IQR are not shown on the graph for visualization purposes.

Figure 18. National Grid Outage Frequency Performance Metric Results



	Change in System-wide CKAIFI w/ EMEs	Change in M&C CKAIFI w/ EMEs
Count	1,076	91
% No Change	3%	0%
Average Change in CKAIFI	0.0	-0.7
Standard Deviation	1.0	1.1
Median Change in CKAIFI	0.1	-0.4

	Change in System-wide CKAIFI w/o EMEs	Change in M&C CKAIFI w/o EMEs
Count	1,076	91
% No Change	3%	0%
Average Change in CKAIFI	0.1	-0.5
Standard Deviation	0.9	1.0
Median Change in CKAIFI	0.1	-0.4

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

The system-wide CKAIFI changed only slightly from the baseline to PY2021. The magnitude of the difference in baseline and PY2021 CKAIFI was greater for M&C circuits, indicating a worsening performance on the M&C circuits on average. The below-median average change value for M&C circuits signifies that the overall decreased performance is driven by a smaller subset of circuits with significantly higher CKAIFI in 2021.

Difference in differences: The differences in the change in CKAIFI between the system-wide average and the average for circuits with M&C investments are shown in Table 46. The change in CKAIFI for circuits with M&C investments was worse than the circuits without M&C investments. Again, due to the high change in CKAIFI standard deviation, the result is likely not statistically significant and is more probably a factor of randomness in the metric data than any type of trend. It is difficult to conclude how much positive (or negative) impact the M&C investments had on this metric for PY2021.

Table 46. National Grid CKAIFI Difference in Differences

	System-Wide Circuits	M&C Circuits	Difference in Differences (M&C - System-Wide)
Change in CKAIFI w/ EMEs	0	-0.7	-0.7
Change in CKAIFI w/o EMEs	0.1	-0.5	-0.6

Note: Due to rounding error, manual calculations of Difference in Differences will not precisely match calculated numbers provided in this table.

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

Major Events in the Baseline: A shortcoming of PM-13 is the methodology of averaging CKAIFI over 3 years, which masks the impact of single-year EMEs, as it is highly unlikely for the same circuit to be affected by an EME three years in a row. Thus, when comparing a single-year CKAIFI with EME to the baseline, the change in CKAIFI is much more likely to indicate decreased reliability.

4.2.2.3 Unitil Analysis

The analysis of the CKAIFI metric for Unitil is presented in the subsection below.

Unitil had 9 qualifying M&C circuits meeting the criteria. Table 47 provides an overview of circuit performance during the baseline period and Program Year 2021. As noted above, during PY2021, Unitil did not experience a main line circuit outage or transmission event on M&C circuits.

Table 47. Unitil Baseline and PY2021 CKAIFI Distribution

Unitil M&C	2015-2017 Avg. CKAIFI (Baseline)				2021 CKAIFI (Program Year)			
	System-wide		M&C Circuits		System-wide		M&C Circuits	
	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs	w/ EMEs	w/o EMEs
CKAIFI Statistics								
Total Circuits	31	31	9	9	31	31	9	9
Total Circuits with Non-zero Customers	31	31	9	9	31	31	9	9
% Zero CKAIFI	0%	3%	0%	11%	6%	13%	0%	11%
Average CKAIFI	2.0	1.1	2.4	1.3	2.8	1.4	2.8	1.7
Change from Baseline (Baseline - Plan Year)					-0.8	-0.3	-0.4	-0.5
% Change from Baseline					-41%	-32%	-18%	-36%
Std. Dev.	0.7	0.5	0.4	0.4	1.5	1.2	1.6	1.6
CKAIFI Range	**No. of Circuits in Range**							
0	0	1	0	1	2	4	0	1
0 - 0.25	1	3	0	0	0	1	0	0
0.25 - 0.75	5	9	0	3	2	5	0	1
0.75 - 1.25	6	10	1	1	5	9	1	5
1.25 - 1.75	5	6	2	3	3	7	1	0
1.75 - 2.25	6	2	2	1	4	0	4	0
2.25 - 2.75	5	0	3	0	1	2	1	0
2.75 - 3.25	3	0	1	0	3	1	0	0
3.25 - 3.75	0	0	0	0	5	0	0	0
3.75 - 4.25	0	0	0	0	1	0	0	0
4.25 - 4.75	0	0	0	0	2	1	0	1
4.75 - 5.25	0	0	0	0	1	1	0	1
5.25 - 5.75	0	0	0	0	1	0	1	0
5.75 - 6.25	0	0	0	0	0	0	0	0
6.25 - 6.75	0	0	0	0	1	0	1	0
6.75 - 7.25	0	0	0	0	0	0	0	0
7.25 - 7.75	0	0	0	0	0	0	0	0
> 7.75	0	0	0	0	0	0	0	0

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1

The M&C circuits have slightly higher CKAIFI values than the system wide circuits in the baseline. This continued to be true in PY2021, where circuits with M&C investments reflect slightly higher or same CKAIFI values than system-wide circuits. Compared to the baseline, average CKAIFI for both system-wide and M&C circuits slightly worsened, with M&C reflecting a greater increase than system-wide. However, due to the small sample size, limited conclusions can be drawn about any trends or impacts of M&C based on this metric.

Major Events in the Baseline: A shortcoming of PM-13 is the methodology of averaging CKAIFI over 3 years, which masks the impact of single-year EMEs, as it is highly unlikely for the same circuit to be affected by an EME three years in a row. Thus, when comparing a single-year CKAIFI with EME to the baseline, the change in CKAIFI is much more likely to indicate decreased reliability.

4.2.3 PM-UTL1: Unitil Reliability-Related Metric: Customer Minutes Saved per Outage

This metric tracks the time savings realized from faster AMI outage notification compared customer outage call. The metric seeks to quantify the impacts of Unitil's OMS/AMI integration through the reduced customer of minutes of interruption. The OMS/AMI integration has not been completed, and so this metric cannot yet be analyzed.

5. M&C Case Studies

Five case studies were performed for the M&C investment area: two for Eversource, one for National Grid and two for Unitil. The case studies illustrate the operation and impacts of the GMP devices deployed through PY 2021. The analyses were based on information from EDCs including OMS data, one-line diagrams, SCADA data, switching orders and discussions with EDCs. However, Guidehouse made certain reasonable assumptions to reconstruct the precise details of events in cases where not all information was available.

5.1 Data Management

Case studies were performed using data from the outage management system (OMS), switching orders, SCADA data, circuit topology maps, one-line diagrams, and interviews with the EDCs. The outage data contains details of outage events, such as location, timing, and customers affected, that were integral to understanding the role of the GMP device in resolving the outage. The One-Line Diagrams helped support the analysis by using visualization to better understand the operation of the relevant devices during the outage event. Supplemental information was obtained from the EDCs in some cases to reconstruct the details of an event.

5.2 Case Study 1: Eversource Uses M&C Recloser to Reduce Outage Duration for Pittsfield Customers

5.2.1 Background

A GMP-funded SCADA investment provided Eversource with situational awareness of an outage in Pittsfield, Massachusetts. Eversource had added SCADA capability (M&C investment) to an existing overhead recloser on circuit 30B3. This circuit serves 2,585 customers including critical customers like the Berkshire County airport and the Pittsfield wastewater treatment plant.

On March 29, 2021, western Massachusetts experienced unusually strong winds with gusts up to 60 miles per hour, prompting the National Weather Service to issue a high wind warning (Figure 19). Pittsfield in Berkshire County is a heavily wooded and hilly area where the risk of tree damage to overhead lines is high.

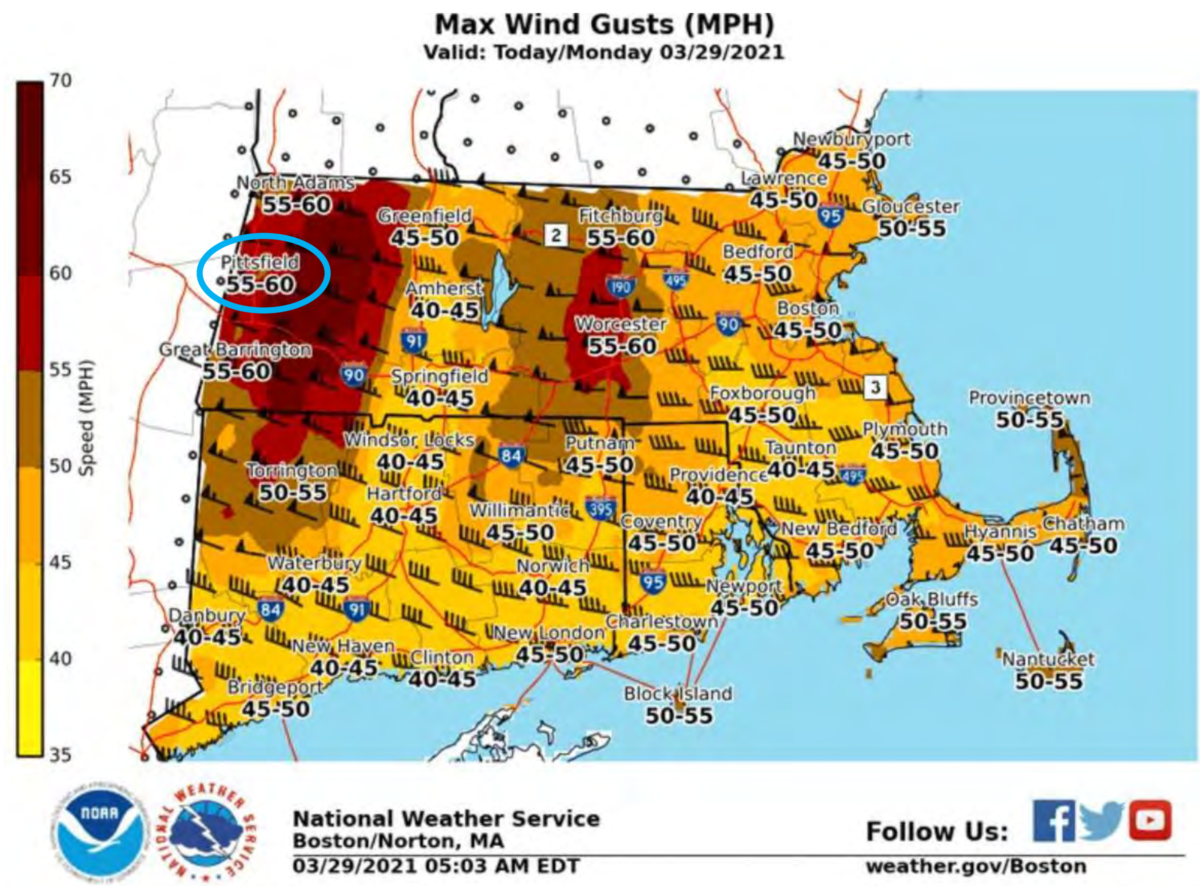


Figure 19: National Weather Service High Wind Advisory for Western Massachusetts, Issued March 29, 2021[35]

5.2.2 Event Description

At 10:18 am on Monday, March 29, 2021, Eversource operators in the control center received a SCADA alarm that the recloser 64R (**bolded** in one-line diagram in Figure 20 below) on Tamarack Road in Pittsfield had locked open, causing an outage to 272 customers. The recloser operation allowed the Berkshire County Airport and 774 other customers to remain in power.

Eversource had added SCADA capability to the recloser 64R with Grid Modernization funds. The SCADA alarm allowed operators to direct crews to the recloser location. Crews found a nearby fault indicator flashing, confirming the proper open operation of the recloser 64R to isolate the fault and minimize the outage. Crews patrolled the suspected fault zone in the right-of-way (ROW) downstream of the indicator. Crews restored power after a 104-minute outage.

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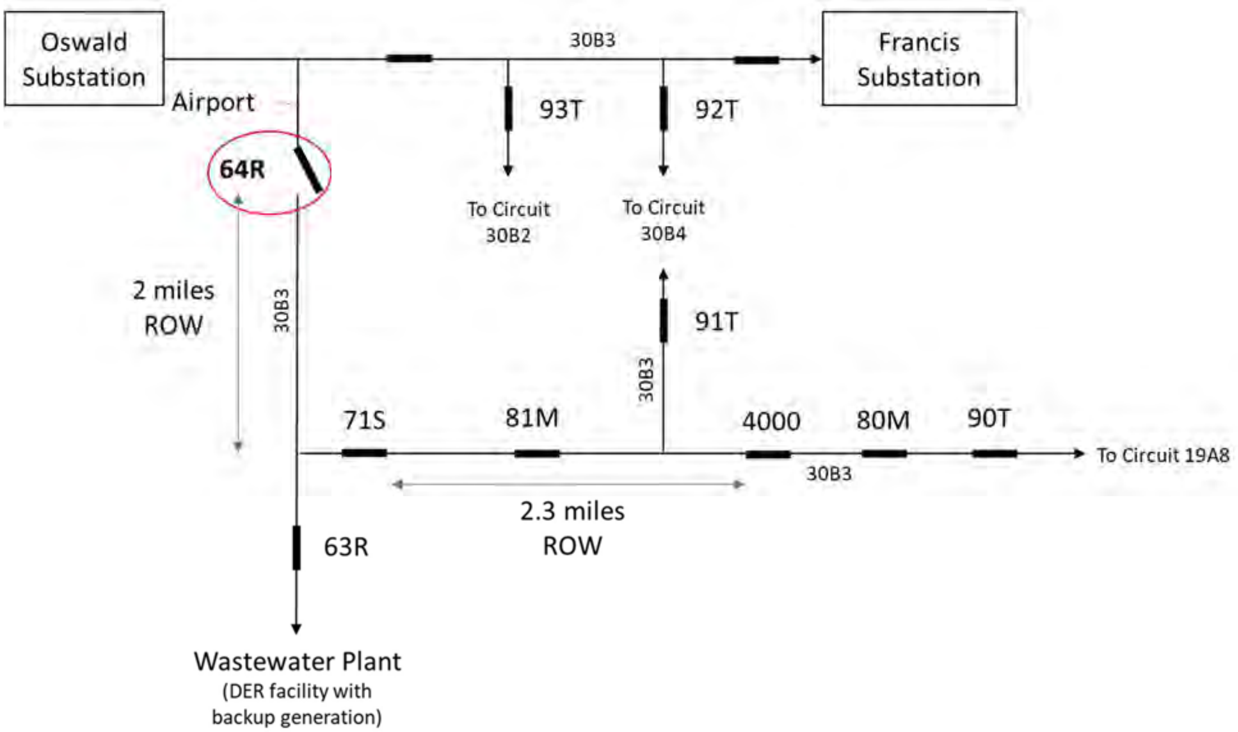
[35] Masslive.com, March 29, 2021 URL: https://www.masslive.com/weather/2021/03/wind-gusts-up-to-60-mph-forecast-high-wind-warning-issued-ahead-of-potential-power-outages.html

Figure 20. One-Line Diagram for Circuit 30B3 (Grid Modernization Devices in bold)



Source: Guidehouse analysis of Eversource One-Line Diagram

5.2.3 Benefit of Grid Modernization Investment

In this case, monitoring and control investment helped to reduce outage duration for customers. Operators received a SCADA alarm promptly after the outage event and directed crews to device location. Without SCADA, Eversource would have had to wait for customer calls to locate the fault zone, and then crews would have had to patrol a longer distance before restoring service. Without SCADA, Guidehouse estimates that customers would have conservatively experienced an additional 15 minutes of outage duration. The resulting reliability savings are illustrated in Figure 21.

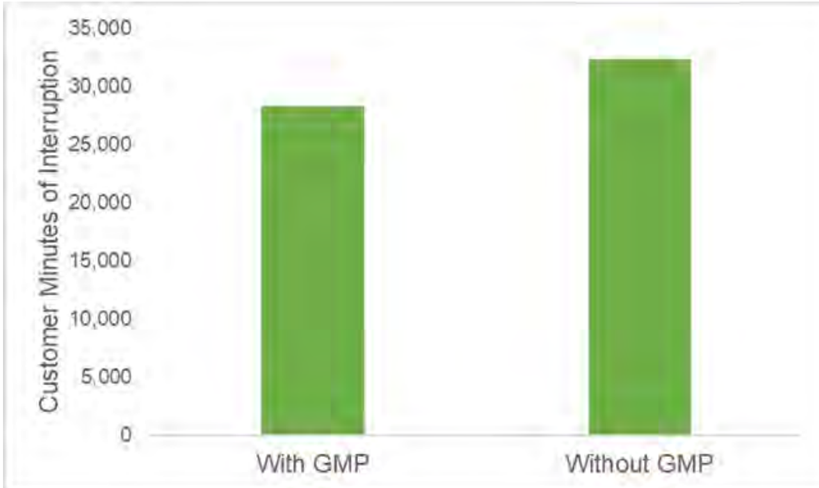


Figure 21: Savings in Customer Minutes of Interruption with GMP

5.3 Case Study 2: National Grid Uses Feeder Monitors to Support DER Integration

5.3.1 Background

National Grid's substations in Warren (Little Rest Road) and Ware, Massachusetts have 27 MW and 8 MW of connected solar and other distributed generation (DG) capacity, respectively. During the day, DG output serves some of the load so that the "net" load visible at the substation "masks" the true load on the feeder. For DG to be maximally beneficial, and to prevent adverse effects such as reverse flow of power to the substation, the utility must monitor current and voltage on the circuit. Before feeder monitors, National Grid would manually collect substation data a few times a month (by visiting the substation) to monitor how DG is affecting loads and voltage on those circuits.

In 2020, National Grid commissioned feeder monitors just outside both substations (on circuits 09-501L1, 09-501L2, 09-516L2 and 09-516L3) using GMP M&C funds. With feeder monitors, National Grid now receives near-real time current and voltage data via SCADA in the control center.

5.3.2 DG Study Description

In 2021, National Grid used the feeder monitor data to create "unmasked" load profiles for the circuits. It programmed the feeder monitors to read and delineate between load and DG output. It then developed timeseries models of both quantities for each circuit. This was a new capability for National Grid and a step to ensuring safe and beneficial integration of DERs into the grid.

National Grid used the unmasked load profiles in a DG Study which explored two important questions:

1. Whether the local grid has sufficient capacity to serve load on a "cloudy" day when DG output is low.
2. Determine how much more DG can be accommodated on the circuits without infrastructure upgrades.

5.3.3 Benefit of Grid Modernization Investment

Before the installation of feeder monitors, National Grid had limited knowledge of the impact of DG on circuit conditions. With feeder monitors, National Grid was able to determine how much load is being served by DG and how much additional DG can be incorporated without adverse effects on the grid. This study will be useful in promoting further DG integration on the grid.

5.4 Case Study 3: Eversource Circuit Breaker SCADA Reduces Outage Duration for Roxbury Customers

5.4.1 Background

A GMP-funded SCADA investment provided Eversource with situational awareness of an outage in Roxbury, Massachusetts. The SCADA data helped to expedite outage restoration. Eversource had added SCADA capability (M&C investment) to an existing 4kV circuit breaker on circuit 5205 serving 420 customers in Roxbury.

5.4.2 Event Description

Amid rain showers at 7:52 pm on Saturday, July 3, 2021, Eversource operators in the control center received a SCADA alarm that a circuit breaker had locked open on Tremont Street, causing an outage to 420 customers near Downtown Boston. Eversource had added SCADA capability to the 4 kV circuit breaker (circled in Figure 22) in the substation with Grid Modernization M&C funds.

Operators monitored SCADA data from the substation and found no fault current or other indication that a fault had occurred on the circuit. Operators responded to the alarm by directing crews to the substation where the breaker was located. Crews inspected the relay and suspected a relay issue. They removed the substation relay and circuit breaker for maintenance. Operators then closed a tie switch (underground VFI located in MH 4799) remotely via SCADA to supply all 420 customers from an adjacent circuit (5201), restoring power.

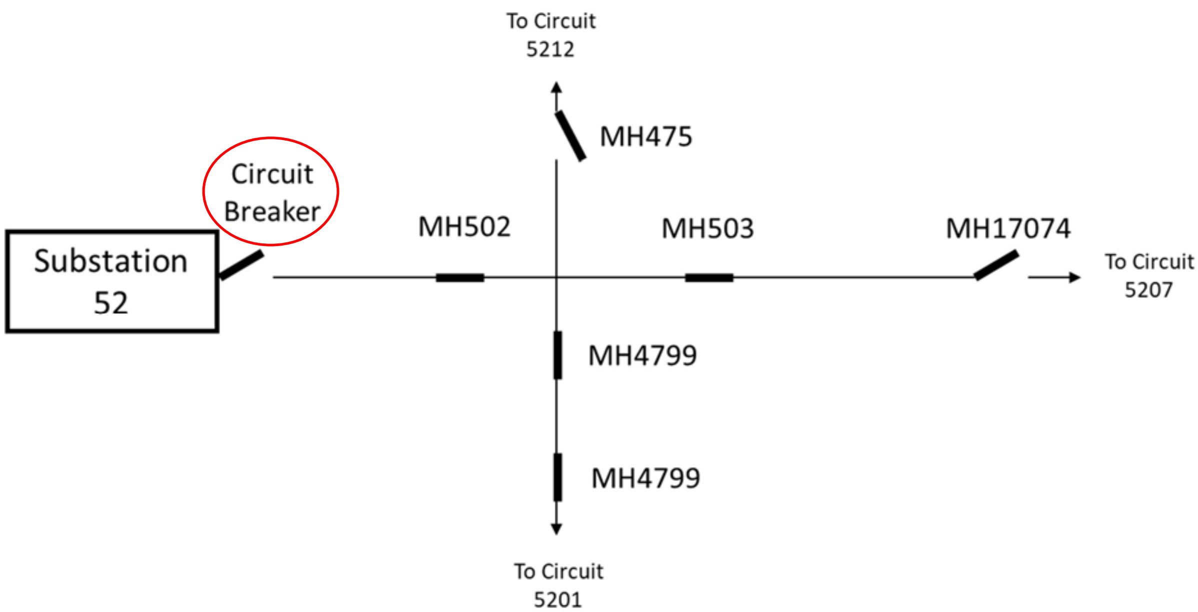


Figure 22: One-Line Diagram for Circuit 5205 (Grid Mod device is circled)

Source: Guidehouse analysis of Eversource One-Line Diagram

5.4.3 Benefit of Grid Modernization Investment

In this case, the addition of SCADA M&C capability to an existing substation (circuit breaker) helped reduced outage duration by about an hour. SCADA capability saved time in at least two ways:

1. The operators received a SCADA alarm immediately after the outage event. Without SCADA, operators would have had to wait for customer calls.
2. Operators reviewed SCADA data from the substation and learned that there was no fault on the circuit. Without substation SCADA, operators would have assumed a fault must have occurred somewhere on the circuit. They would have performed troubleshooting steps to try to find the fault zone. For example, operators would have opened MH502 remotely, found no fault downstream of MH502, and assumed that the fault was between the substation and MH502. Crews would then enter manholes between the substation and MH502 to find the fault, a time-consuming process. The customers in this zone would have experienced an hour or more of additional interruption duration without SCADA.

5.5 Case Study 4: Unitil Uses Townsend Substation SCADA for Remote Switching

5.5.1 Background

As part of GMP M&C investment, Unitil added SCADA capability to the Townsend substation. This allows remote communication with substation equipment from the control center, including monitoring of current/voltage conditions as well as remote control of devices. The Townsend substation serves over 2,000 customers including schools and municipal emergency response facilities.

5.5.2 Event Description

On January 3, 2022, Unitil needed to complete a project at the Summer Street substation which required de-energizing equipment at the substation. To avoid an outage while Summer Street was de-energized, Unitil had to perform switching at the Townsend substation, so that customers who are normally supplied by Summer Street could temporarily be supplied from Townsend.

Unitil operators performed remote switching at the Townsend substation using SCADA. The Summer Street substation work lasted about an hour. After it was complete, operators again used SCADA to remotely operate Townsend substation equipment, returning power flow to normal conditions. Customers did not experience an outage.

5.5.3 Benefit of Grid Modernization Investment

SCADA M&C capability saved crew time and resources. Without SCADA, crews would have traveled to Townsend substation to perform the switching. Townsend substation is 17 miles from Summer Street and can take 30 minutes one way in a bucket truck. Since work lasted just over an hour, the approach would have been to have crew stand by at the Townsend substation. Crews would have returned the equipment to normal positions and then traveled back.

Unitil estimates that remote operation at Townsend using SCADA M&C capability saved 3 hours of crew time and $1,279 in utility costs relative to what this operation would have cost without the M&C investment. This type of maintenance operation is common, and so this specific type of savings (one of several potential use cases that can be performed by the new capability) can be expected to occur many times over from the M&C investment being made.

5.6 Case Study 5: Unitil Uses Townsend Substation SCADA for DER Monitoring and Energy Storage Optimization

5.6.1 Background

As part of GMP M&C investment, Unitil installed SCADA capability at the Townsend substation. The Townsend substation serves two distribution circuits with 245 interconnected Distributed Energy Resources (DER) facilities totaling 2.1 MW of generation capacity. Also located at the substation is a Unitil-owned 2MW/4MWh energy storage system (ESS, pictured in Figure 23). The SCADA M&C investment provides better situational awareness, including better monitoring of (DER) installations, to improve system operation and planning.

Figure 23: Energy Storage System at the Townsend Substation (Source: Unitil)

5.6.2 Situational Awareness Improvement with SCADA

The Townsend substation was built with legacy technology available at the time. It had very limited remote reporting capability to support system planning and DER operation. The substation required personnel to periodically (i.e., monthly) go to the substation to obtain information which was then passed on to operations and planning personnel for their system operation and upgrade decisions.

With the widespread adoption of Distribution Energy Resource's (DERs) such as solar inverters and energy storage devices, it became critical that employees working in operation, engineering and planning receive accurate, near-real time data on system performance. For DER to provide maximum benefits, while avoiding negative effects, Planners and Engineers must monitor voltage and current readings on the circuit to maintain voltage at an acceptable level and assure that DER current does not flow backwards into the substation causing "unintentional islanding".

With SCADA monitoring, Unitil created hourly profiles to better understand the circuit loads at different times of the day and throughout the year (summer, winter, spring/fall). Hourly profiles helped Unitil better understand what time of day the substation transformer is more heavily loaded, and then program the charge and discharge times of the ESS to match the times of heavy load and help prevent reverse power at the substation.

5.6.3 Benefit of Grid Modernization Investment

The SCADA installation gives Unitil near real-time measurements of the effects of DER on circuit load and voltage. The SCADA data enables planners to determine the level of DER that can be installed on the Townsend circuits without system upgrades, or determine the type of system upgrades that may be required for DER interconnections. Before the SCADA measurements, only monthly peak reads for the substation circuits were available to determine needed capacity for the circuits or substation devices. The data provided by SCADA can also be used to address DER or customer system performance concerns.

In addition, hourly SCADA reads are also allowing Unitil to program the ESS to charge and discharge at the optimal times of the day and throughout the year to yield maximum system benefit. Without hourly load profiles, it was not possible for Unitil to tailor ESS schedules to changing system conditions.

6. Recommendations

Several recommendations are provided below based on the analysis and summaries made during the PY 2021 Evaluation process.

1) The CKAIDI and CKAIFI reliability related Performance Metrics as defined have deficiencies in measuring the effectiveness of standalone M&C Grid Modernization Investments. Many factors unrelated to the Grid Modernization investments will affect these metrics in any given year, and it is not possible to distinguish among these factors using the metrics. For example, the variation in storm activity between years can cause significant changes in these metrics, as apparently happened in PY2020 and PY2021. This observation has been made previously, and some of these recommendations were made last year, but bear repeating.
    a. Recommendation: Continue to track these Performance Metrics, but establish other methods of isolating the specific impacts of M&C investments.
    b. Recommendation: Additional Performance Metrics should be explored to determine if it is possible to capture the actual reliability performance attributable to the M&C investments. Exploration could include:
        i. Exploring the pros and cons of making the reliability metrics baseline a rolling average of, perhaps, the most recent 3 years, as opposed to the fixed years of 2015 through 2017. The fixed baseline has the issue, as pointed out in the report, that individual circuits are reconfigured over time, go out of service, and new circuits are created, making circuit-wise comparisons over time more challenging.
        ii. Exploring the pros and cons of understanding the timing and sequencing of reliability events more during the initial stages of the event. This timing would lend insight whether and when an event was visible within the control room or for automated decision making, and then how long before action was taken. As the network becomes more complex (e.g., increased DER penetration, will become more complex and may tend to take longer. So, understanding these dynamics will grow in importance.
        iii. Reviewing the data and techniques available to expand the understanding of the relationship between circuit reliability and weather conditions, vegetation management cycles and other reliability drivers that are independent of the grid modernization investments.
        iv. Expanding the use of case studies to provide greater understanding of the situational awareness and improved visibility and data provided by these investments (see Recommendation 4a below).
        v. Recognizing the role of M&C data within outage case studies, and perhaps extrapolate these results to a broader set of circuits to understand investment performance with more certainty.
        vi. Developing a way to expand the use of counter-factual analysis on a broader basis than what is currently being done in the Case Studies could help develop a better understanding of overall system impacts from the ADA investments.
2) Use of currently defined CKAIDI and CKAIFI reliability related Performance Metrics—which are circuit level metrics—has increasing challenges over time as circuits get re-

configured or retired and new circuits are created. The comparability of each circuit in the program year to its baseline depends on that circuit not having been reconfigured or significantly changed (e.g., a normally open switch between circuit segments is changed to operate as normally closed, changing the customer counts and outage measurements on that circuit). The number of circuits that are comparable between baseline and program year is reduced year after year as more circuits change due to ongoing operation of the system. This observation has been made previously, and this recommendation was made last year, but bears repeating.

   a. Recommendation: Explore metrics and baselines that are robust to these operating changes to help ensure that Grid Mod investment assessment based on these metrics is not misleading, and is able to better capture the impact of the investment.

3) Current metrics do not provide an understanding of how M&C and ADA investments facilitate easier interconnection or more capacity for DER added to the system. This observation has been made previously, and this recommendation was made last year, but bears repeating.
   a. Recommendation: Consider developing additional metrics and/or performing pilot projects that utilize the installation of ADA and M&C investments at DER locations to understand the value or benefits that are provided. This would provide actual data on the effectiveness of these investments to support DER integration.

4) Case studies show detailed functioning and impact of GMP devices, and they are proving to be a useful tool in understanding the effectiveness of the Grid Modernization investments. Based on case studies performed, the M&C investment is yielding reliability and service delivery benefits to customers for each of the EDCs. This observation has been made previously, and these recommendations were made last year, but bear repeating.

   a. Recommendation: Continue to perform case studies in future evaluations, and increase the use of case studies where practicable, to analyze the mitigation of customer outages and help determine the effectiveness of Grid Modernization investments in improving reliability and service delivery.
   b. Recommendation: Continue the deployment of M&C technologies as part of the Grid Modernization Program and continue to monitor progress (including through amended or additional metrics to be determined by the Department).

5) For National Grid, the evaluation process validated that the feeder monitor sensor investment improves situational awareness, but at this time the impact on reducing outage duration or number of customers affected during an outage is not clear.
   a. Recommendation for National Grid: Develop programs to use the feeder monitor sensors to identify and review momentary outages to predict causes which could mitigate future outage causes. For instance:

i. Momentary Outage Reduction: Use existing sensors to detect momentary outages (breaker trip and reclose). Using the sensors with data analytics, determine location, potential causes and corrective actions.
ii. Outage Duration Reduction: Incorporate M&C monitors into future ADA investments to support the outage restoration process. Sensors will enable additional situational awareness and information for field crews to locate the faulted area of the circuit more quickly.
iii. Battery Backup: Evaluate the costs and benefits of installing batteries to enable the ability of the sensors to support outage management.

i.

Massachusetts Grid Modernization Program Year 2021 Evaluation Report: Volt-VAR Optimization

Massachusetts Electric Distribution Companies

Submitted by:

Guidehouse Inc.
77 South Bedford Street, Suite 400
Burlington, MA 01803
Telephone (781) 270-8300
Guidehouse.com

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Executive Summary

Introduction

As a part of their Grid Modernization Plans (GMPs), the Massachusetts Electric Distribution Companies (EDCs) are investing to enable Volt/VAR Optimization (VVO) on selected feeders across their distribution networks. VVO optimizes distribution voltage to reduce energy consumption and demand without the need for customer interaction or participation. The principle behind VVO is that power demand is reduced at voltages in the lower end of their allowable range for many end-use loads.

This evaluation focuses on the progress and effectiveness of the Massachusetts Department of Public Utilities (DPU) preauthorized VVO investments for each EDC toward meeting the DPU's grid modernization objectives for Program Year (PY) 2021.

Evaluation Process

The DPU requires a third-party evaluation for the EDCs' preauthorized grid modernization investments. Guidehouse[1] is completing the evaluation to enable a uniform statewide approach and to facilitate coordination and comparability. The evaluation's objective is to measure the progress toward achieving DPU's grid modernization objectives. The evaluation uses the established Infrastructure Metrics and Performance Metrics (discussed in Section 1.1.3) to meet the evaluation objectives.

The original Evaluation Plan was submitted to the DPU by the EDCs in a petition for approval on May 1, 2019. Modifications to this original Evaluation Plan were made to 1) request changes to the reporting schedule to accommodate Performance Metrics data availability timing, as discussed in response to DPU EP-1-1 submitted on February 6, 2020[2], and 2) to extend the Grid Modernization term period from the original 3 year term to a 4 year term as ordered by the DPU in its May 12, 2020 Order.[3] Modifications to the original Evaluation Plan were submitted to the DPU by the EDCs in a petition for approval on December 1, 2020. The modified Evaluation Plan has been used to develop the analysis and evaluation provided below in this document. Table 1 illustrates the key Infrastructure Metrics and Performance Metrics relevant for the VVO evaluation by EDC. Section 2.1 and Section 2.2 further detail surrounding Infrastructure Metrics (IMs) and Performance Metrics (PMs), respectively.

[1] Guidehouse LLP completed its acquisition of Navigant Consulting, Inc, in October of 2019. The two brands are now combined as one Guidehouse.

[2] Submitted to Massachusetts DPU 15-120, 15-121, 15-122.

[3] Order (1) Extending Current Three-Year Grid Modernization Plan Investment Term; and (2) Establishing Revised Filing Date for Subsequent Grid Modernization Plans; DPU 15-120, DPU 15-121, DPU 15-122; May 12, 2020.

Table 1. VVO Evaluation Metrics

Type	VVO Evaluation Metrics	ES	NG	UTL
IM	Number of Devices or Other Technologies Deployed	✓	✓	✓
IM	Cost for Deployment	✓	✓	✓
IM	Deviation between Actual and Planned Deployment for the Plan Year	✓	✓	✓
IM	Projected Deployment for the Remainder of the 3-Year Term	✓	✓	✓
PM	VVO Baseline	✓	✓	
PM	VVO Energy Savings	✓	✓	
PM	VVO Peak Load Impact	✓	✓	
PM	VVO Distribution Losses without Advanced Metering Functionality (AMF) (Baseline)	✓	✓	
PM	VVO Power Factor	✓	✓	
PM	VVO – GHG Emissions	✓	✓	
PM	Voltage Complaints	✓	✓	

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020

The EDCs provided the data supporting the Infrastructure Metrics and Performance Metrics to the evaluation team. Guidehouse presents results from analysis of Infrastructure Metrics data in Section 3. The Performance Metrics are based on statistical analyses the evaluation team performed using telemetry and other data from each EDC.

Data Management

Guidehouse worked with the EDCs to collect data to complete the VVO evaluation for the assessment of Infrastructure Metrics and Performance Metrics. Guidehouse used a consistent methodology across Investment Areas and EDCs for evaluating and illustrating EDC progress toward the GMP metrics.

Table 2 summarizes data sources used throughout the VVO evaluation. Table 2 details each of the data sources.

Table 2. VVO Data Sources

Data Source	Description
2020 Grid Modernization Plan Annual Report[4, 5, 6]	Planned device deployment and cost information from each EDC's 2020 GMP Annual Report Appendix 1 as the reference to track progress against the GMP targets. This data source is referred to as the EDC Plan in summary tables and graphs throughout the report.
2021 Grid Modernization Plan Annual Report[7,8,9]	All PM-related data are from these 2021 GMP Annual Report Appendices. In addition, data collected as part of EDC Data Template (below) was compared to the data submitted by the EDCs to the DPU in the 2021 Grid Modernization Plan Annual Reports and associated Appendix 1 filings. The evaluation team confirmed the consistency of the data from the various sources and reconciled any differences.
EDC Device Deployment Data Template	Captures planned and actual device deployment and spend data. Actual device deployment and cumulative spend information were provided by work order ID and specified at the feeder- or substation-level as appropriate. Carryover device deployment information and estimated carryover spend for 2022 were provided as well.
VVO Supplemental Data Template	Includes additional information unique to the VVO Investment Area spanning inputs required for the Infrastructure Metrics and the Performance Metrics. Data covers actual versus planned VVO schedule, IT work schedule, customer demand response events, system events, distributed generation information, and voltage complaints. Information was requested at the feeder-level where possible.
Additional VVO Data Required for Performance Metrics	Includes data on feeder characteristics, time series data measuring feeder voltage, real power, and reactive power, time series energy data for large, distributed generation facilities, VVO system information including VVO state changes between on and off states and any other VVO modes, and hourly weather data from selected weather stations.
Eversource's 2021 DPU-Filed Plan[10]	Eversource's GMP extension request was approved by the DPU on February 4, 2021. It includes budgets for PY2021 deployment at the Investment Area level. This data source is included in the EDC Plan for Eversource planned spend at the Investment Area level.

Source: Guidehouse

Guidehouse reviewed all data provided upon receipt of the requested data. Guidehouse conducted a detailed QA/QC of data inputs used in analysis of Infrastructure Metrics and

4 Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30.

5 NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30. Note that Eversource Energy filed an updated Appendix 1 filing in December of 2021; however that update did not affect any of the data or results in the evaluation.

6 Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2020. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 21-30.

7 Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-41

8 NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-40.

9 Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU. 22-42.

10 Grid Modernization Program Extension and Funding Report. Submitted to Massachusetts DPU on July 1, 2020 as part of DPU 15-122.

Performance Metrics. These QA/QC steps include checks to confirm each of the required data inputs are accounted for and can be incorporated into analysis. Table 3 includes some of the QA/QC steps conducted for Infrastructure Metrics and Performance Metrics. Table 3 thoroughly summarizes these metrics.

Table 3. Summary of QA/QC Steps Used for Evaluation

VVO Evaluation Area	QA/QC Steps
Infrastructure Metrics	• Check for potential errors in how Guidehouse forms were filled out (e.g., circuit information provided in the wrong field) • Flag missing or incomplete information • Detect large variation in the unit cost of commissioned devices • Check for variance between the aggregated totals by device/technology and work order-level data • Detect variance between the actual unit costs and planned unit costs
Performance Metrics	• Confirm time series data cover each feeder receiving VVO investments and include variables needed to facilitate analysis of Performance Metrics, including voltage, real power, and reactive or apparent power • Confirm time series telemetry are complete in time and extent of devices and identify periods to remove (e.g., interpolated values, feeder outages, and outliers) • Verify voltage complaints data were received for each feeder receiving VVO investments and are at an adequate level of detail for analysis

Source: Guidehouse

After data is received, Guidehouse provides status update memos that summarize the QA/QC to the EDCs, confirming receipt of the datasets and indicating quality. Additional follow-up based on standing questions may be required to confirm all EDC-provided data can be used in the analysis.

Findings and Recommendations

Findings for VVO Infrastructure Metrics

Error! Reference source not found. and **Error! Reference source not found.** includes the Infrastructure Metrics results through PY2021 for all EDCs. The following subsections provide further detail surrounding findings for each of the Infrastructure Metrics.

Table 4. 2021 Infrastructure Metrics for VVO Progress

Infrastructure Metrics			Eversource	National Grid	Unitil
GMP Plan Total, PY-2018-2021		Devices	1,201	249	77
		Spend, $M	$18.93	$19.27	$5.12
IM-4	Number of devices or other technologies deployed. PY 2018-2021*	# Devices Deployed***	800	163	26
		% Devices Deployed	67%	66%	34%
IM-5	Cost for Deployment PY 2018-2021*	Total Spend, $M	$14.83	$17.04	$2.58
		% Spend	78%	88%	50%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	36%	39%	31%
		% On Track (Spend)	32%	69%	22%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	342	219	151
		Spend Remaining, $M	$2.26	$7.67	$2.42

*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the “carryover” units and spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs’ 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

***Note that “Deployed” here refers to commissioned devices. In National Grid’s Term Report (filed April 1, 2022), deployed refers to in-service and/or commissioned devices. In-service devices are fully installed and used and useful, but not yet commissioned with Grid Mod functionality (communication and remote visibility and/or control). For full definitions of commissioned and in-service, see Docket 20-46 Response to Information Request DPU-AR-4-11, September 3, 2020.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 5. 2021 Infrastructure Metrics for VVO Feeder Deployment Progress

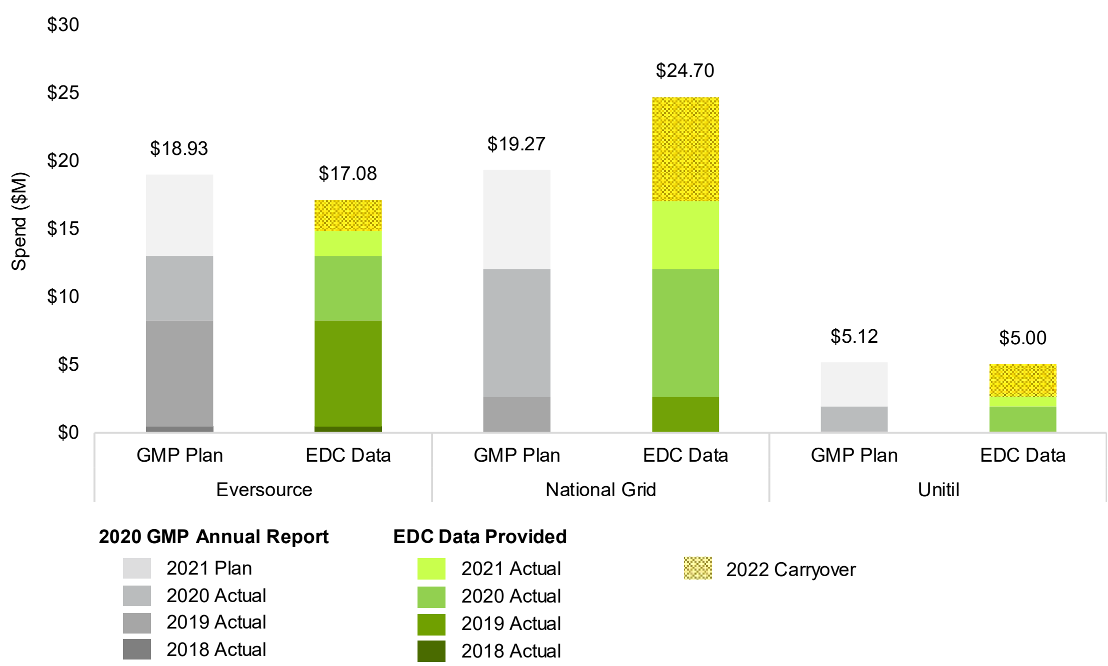
IM	Parameter	Eversource	National Grid	Unitil
IM-4	# Feeders with VVO Enabled	26	20	3
	% Feeders with VVO Enabled	100%	100%	27%
IM-6	% On Track (Feeders with VVO Enabled)	100%	100%	27%
IM-7	# Feeders Remaining for VVO Enablement*	0	0	8

* Does not include additional feeders that were not laid out in the original 3-Year Grid Modernization Plans.

Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Figure 1 differentiates between the original planned spend per the *2020 GMP Annual Report* and the actual/updated projected spend based on the EDC data provided.

Figure 1. VVO Planned vs. Actual Spend (2018–2021, $M)



* Note: Includes the Eversource planned spend for PY2021, set forth the in the GMP Extension and Funding Report, filed on July 1, 2020.

Source: Guidehouse analysis of 2020 GMP Annual Reports, "GMP Extension and Funding Report," and 2021 EDC Data

PY2021's VVO Infrastructure Metrics findings show that the EDCs are at varying stages in VVO deployment. Details pertaining to device deployment progress, VVO enablement progress, and total spend are shown below:

Device Deployment:

- Eversource overall deployment was below plans for 2021, however this varied by device type. Overall deployment was below plans due to several factors. Eversource scaled down deployment plans for its Gunn and Oswald substations, as the substations required fewer regulators and capacitor banks for VVO and did not require LTC control devices or new feeder head sensors, as these devices were already deployed in prior capital projects. In addition, delayed engineering and design work, long vendor lead times, and crew resource constraints combined to delay Eversource's ability to meet revised deployment goals set out for 2021.
- National Grid deployment through 2021 was lower than initially planned, with all device types having fewer fully commissioned devices than planned. One large factor at play in 2021 was competing priorities of crew resources. National Grid had adapted its work practices to COVID-19 protocols so that certain field reporting locations had a reduction in crews. These resource limitations led to delays in construction schedules and backlogs of customer work were prioritized. Despite lower deployment than planned,

National Grid continued construction and design/engineering work across all device types throughout 2021.

- Unitil deployment of VVO devices was below plans in 2021. Unitil did not fully deploy and commission devices at the Lunenburg and Summer Street substations as planned, as Unitil revised its VVO deployment timeline partway through 2021. Despite the shift in timeline, Unitil continued construction work throughout 2021 for Summer Street, Lunenburg, and West Townsend, as well as engineering/design work for the Princeton Road substation.

VVO Enablement:

- Eversource conducted VVO On/Off testing at all of its original 2018-2020 plan substations throughout 2021, conducting VVO On/Off testing at the Agawam, Piper, and Silver substations all year, and at the Podick substation beginning in March 2021. In tandem with VVO On/Off testing at the original 2018-2020 plan substations, Eversource conducted deployment of VVO devices across the Gunn and Oswald substations. VVO On/Off testing is expected to begin at these substations in May and June 2022, respectively.
- National Grid has completed deployment of VVO on all original 2018-2020 plan feeders and conducted VVO On/Off testing on these feeders throughout 2021. On its additional feeders, National Grid completed VVO deployment at the East Bridgewater substation and has been conducting VVO On/Off testing since July 2021. VVO On/Off testing is expected to begin for the East Dracut and West Salem substations in June 2022, and is expected to begin for the Easton, Melrose, and Westboro substations in December 2022.
- Unitil VVO enablement fell short of its schedule laid out in the PY2020 Evaluation Report. Unitil completed VVO deployment at the Townsend substation in 2021, enabling VVO in December. VVO On/Off testing is expected to begin at the Townsend substation in April 2022. For the Summer Street, Lunenburg, and West Townsend substations, VVO On/Off testing is expected to begin in December 2022, December 2023, and December 2024, respectively.

Total Spend:

- Eversource spend in 2021 was lower than plans for all device types. Eversource scaled down plans for the Oswald and Gunn substations, reducing spend on capacitor banks and regulators. In addition, vendor lead times and crew resources required for deployment of VVO devices were committed to other Eversource objectives, contributing to Eversource's delay in meeting deployment goals set out for 2021. Lastly, Gunn and Oswald substations did not require LTC control devices, as these devices had been completed historically, reducing spend on LTC controls. These factors combined to keep spend lower than plans on all device types.
- National Grid spend in 2021 was lower than plans for all device types except for LTC controls. Spend on LTC controls exceeded plans due to significant engineering required for VVO to be operational and due to initial cost estimates being too conservative. Despite higher-than-expected spending on LTC controls, spending across all VVO devices was lower than planned. The largest factors for lower spend was increased vendor lead times, leading to delays in fully commissioning devices, as well as increased

efficiencies in VVO device pre-testing and field commissioning because of prior lessons learned during deployment of VVO devices in 2018-2020.

- Unitil spending on VVO devices was below plans in 2021. Spend during 2021 covered fully commissioning VVO devices at the Townsend substation. However, given Unitil shifted its deployment timeline, spend that would have been conducted on commissioning VVO devices at Summer Street, Lunenburg, and West Townsend has been deferred. Spending at these substations was instead focused on construction work.

The EDCs are slated to complete carryover deployment of VVO investments throughout 2022. In particular:

- Eversource carryover deployment and spending for 2022 spans completing deployment of regulators, capacitor banks, and line sensors on the Gunn and Oswald circuits. Additionally, carryover deployment and spending will cover deployment of grid monitoring line sensors across numerous circuits in Eastern and Western Massachusetts. Total spend through 2022 is expected to end up below plans.
- National Grid carryover deployment and spending for 2022 covers carryover work that was initially planned for 2021 across five of six new substations, which will include work to bring devices from the construction and in-service phases to commissioned. VVO is then expected to conduct VVO On/Off testing starting in June 2022 for 2 substations and starting in December 2022 for 3 substations. Total spend and deployment through 2022 is expected end up above plans.
- Unitil carryover deployment and spending for 2022 spans deployment VVO devices at substations identified in recent 4-year Term plan totals. Remaining carryover deployment spans commissioning the remaining VVO devices at the Summer Street, Lunenburg, and West Townsend substations in 2022 through 2024. In addition, deployment and spend spans continuing design/engineering and construction work across additional substations slated to receive VVO between 2022 and 2028.

Findings for VVO Performance Metrics

Error! Reference source not found. includes the Performance Metrics results for the spring 2021 through winter 2021/22 measurement and verification (M&V) period for Eversource and National Grid. It can be difficult to compare the results from Performance Metrics analysis between Eversource and National Grid. For example, there are differences in the granularity of telemetry (e.g., 15-minute versus 1 hour), data quality at different times of the year (e.g., sustained pauses in VVO On / Off testing during Spring 2021 for one EDC, repeated data during Summer 2021 for another EDC). As such, data cleaning can cause certain portions of the M&V period to be represented more for one EDC than the other. Additionally, there are numerous differences in DG penetration, customer types, and geographic areas served by Eversource and National Grid feeders that limit the ability to directly compare Eversource and National Grid VVO outcomes.

Table 6. Performance Metrics Results for the Spring 2021 – Winter 2021/22 M&V Period

Performance Metrics		Eversource		National Grid	
Feeders Included in Evaluation		19*		20	
PM-1	Spring 2021 – Winter 2021/22 Baseline	441,252 MWh		352,663 MWh	
PM-2	Energy Savings – All Hours VVO On†	1,681± 346 MWh	0.38 ± 0.08%	4,273 ± 715 MWh	0.77 ± 0.13%
	Energy Savings – Actual VVO On Hours‡	484 ± 88 MWh	0.38 ± 0.08%	948 ± 171 MWh	0.77 ± 0.13%
-	Voltage Reduction	1.14 ± <0.01 V	0.93 ± <0.01%	0.05 ± <0.01 kV	0.37 ± 0.01%
-	CVRf^	0.70		0.54	
PM-3^^	Peak Load Reduction	-892 ± 324 kW	-1.19 ± 0.48%	-437 ± 518 kW	-0.91 ± 1.16%
PM-4	Reduction in Distribution Losses	0.18%		-0.88%	
PM-5	Change in Power Factor	0.0009 ± 0.005	0.09 ± 0.06%	-0.03 ± 0.01	-0.43 ± 0.13%
PM-6	GHG Reductions (CO_2) All Hours VVO On†	831 ± 171 tons		2,110 ± 354 tons	
	GHG Actual VVO-On Hours‡	239 ± 43 tons		468 ± 84 tons	
PM-7	Voltage Complaints	67 (12% increase from 2015 – 2017 average)		74 (1% decrease from 2016 – 2017 average)	

* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period. As such, the number of feeders included in the analysis includes 19 of 26 VVO engaged feeders.

† Calculation assumes VVO was enabled for all hours between March 1, 2021 and February 28, 2022.

‡ Calculation uses actual number of VVO On hours spanning the analysis period. Actual VVO On Hours are the number of hours VVO was engaged in the clean analysis data between March 1, 2021 and February 28, 2022.

^The CVR factor provided for each EDC is the load-weighted average of CVR factors estimated for each feeder.

^^Guidehouse evaluated the impact of VVO during peak load periods, defined by ISO-NE as 1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays.

§ National Grid did not start tracking voltage complaints until 2016.

Source: Guidehouse analysis

Findings from the evaluation of Performance Metrics indicate that VVO allowed Eversource and National Grid to realize energy savings and voltage reductions during the Spring 2021 – Winter 2021/22 M&V period.[11] More specifically:

- During the Spring 2021 – Winter 2021/22 M&V period, Eversource's Agawam, Piper, and Silver substations realized 484 MWh (0.38%) energy savings and 1.14 V (0.93%) voltage reduction associated with VVO. The CVR Factor, which provides an estimate of

[11] It can be difficult to compare the results from Performance Metrics analysis between Eversource and National Grid. For example, there are differences in the granularity of telemetry (e.g., 15-minute versus 1 hour), data quality at different times of the year (e.g., sustained pauses in VVO On / Off testing during Spring 2021 for one EDC, repeated data during Summer 2021 for another EDC). As such, data cleaning can cause certain portions of the M&V period to be represented more for one EDC than the other. Additionally, there are numerous differences in DG penetration, customer types, and geographic areas served by Eversource and National Grid feeders that limit the ability to directly compare Eversource and National Grid VVO outcomes.

energy savings possible with voltage reductions, was 0.70. During the same M&V period, National Grid's East Methuen, Maplewood, and Stoughton substations realized 948 MWh (0.77%) energy savings and 0.05 kV (0.37%) voltage reduction associated with VVO. National Grid's CVR factor was 0.54.

- Eversource Energy savings of 484 MWh yielded a 239 short ton reduction of CO_2 emissions, a 0.077 short ton reduction of NO_x emissions, and a 0.019 short ton reduction of SO_2 emissions. National Grid energy savings of 948 MWh yielded a 468 short ton reduction in CO_2 emissions, a 0.15 short ton reduction in NO_x emissions, and a 0.04 short ton reduction in SO_2 emissions.

- Eversource and National Grid VVO feeders experienced a minimal benefit associated with peak load, power factor, and line losses. Eversource VVO feeders experienced a statistically significant increase (1.19%) in peak load, a statistically insignificant increase (0.08%) in power factor, and a minimal decrease in line losses when VVO was engaged. National Grid VVO feeders experienced no statistically significant change in peak load, a small decrease (0.43%) in power factor, and a minimal increase in line losses when VVO was engaged.
- For Eversource, a total of 67 voltage complaints were received from customers connected to the Agawam, Piper, and Silver VVO feeders during the Spring 2021 – Winter 2021/22 M&V period. This is a 12% increase relative to the average voltage complaints per year received between 2015 – 2017. For National Grid, a total of 74 voltage complaints were received from customers connected to the East Methuen, Maplewood, and Stoughton VVO feeders during the period. This is a 1% decrease relative to the average voltage complaints per year received between 2016 – 2017. For both EDCs, there is not sufficient evidence to support changes in voltage complaints being attributed to VVO.

Recommendations

In 2022 and beyond, Guidehouse recommends that:

- EDCs ensure that VVO On / Off testing is running according to plan, with limited pauses to the VVO On / Off testing schedule. A large number of data points across substations and feeders were removed due to extended pauses in VVO On / Off testing. Sustained VVO On / Off testing will increase the amount of usable data in the evaluation and improve the precision and accuracy of impact estimates.
- EDCs consider investigating how to improve outcomes across VVO feeders. The voltage reductions varied across the substations and feeders. Some feeders underwent no material change in voltage, indicating potential VVO malfunctions, while other feeders exhibited sustained reductions in voltage when VVO was engaged. Both Eversource and National Grid should investigate how to better maintain sustained voltage reductions when VVO is engaged across all substations and feeders.

1. Introduction to Massachusetts Grid Modernization

This section provides a brief background to the Grid Modernization Evaluation process and an overview of the Volt/VAR Optimization (VVO) Investment Area and specific VVO evaluation objectives. These are provided for context when reviewing the subsequent sections that address the specific evaluation process and findings.

1.1 Massachusetts Grid Modernization Plan Background

On May 10, 2018, the Massachusetts Department of Public Utilities (DPU) issued its Order[12] regarding the individual Grid Modernization Plans (GMPs) filed by the three Massachusetts Electric Distribution Companies (EDCs): Eversource, National Grid, and Unitil.[13,14] In the DPU Order, the DPU preauthorized grid-facing investments over 3 years (2018-2020) for each EDC and adopted a 3-year (2018-2020) regulatory review construct for preauthorization of grid modernization investments. On May 12, 2020, the DPU issued an Order[15] extending the 3-year grid modernization plan investment term to a 4-year term, including 2018-2021. The company-specific GMP budget caps did not change with the term extension.

The preauthorized GMP investments will advance the achievement of DPU's grid modernization objectives:

- Optimize system performance by attaining optimal levels of grid visibility command and control, and self-healing
- Optimize system demand by facilitating consumer price responsiveness
- Interconnect and integrate distributed energy resources (DER)

As part of the GMPs, the DPU determined that a formal evaluation process for the preauthorized GMP investments, including an evaluation plan and studies, was necessary to help ensure that the benefits are maximized and achieved with greater certainty.

In addition, the grid modernization investments were organized into six Investment Areas to facilitate understanding, consistency across EDCs, and analysis.

- Monitoring and Control (M&C)
- Advanced Distribution Automation (ADA)
- Volt/VAR Optimization (VVO)
- Advanced Distribution Management Systems/Advanced Load Flow (ADMS and ALF)
- Communications/IoT (Comms)

[12] Massachusetts DPU 15-120; DPU 15-121; DPU 15-122 (Grid Modernization) Order issued May 10, 2018 (DPU Order).

[13] On August 19, 2015, National Grid, Unitil, and Eversource each filed a grid modernization plan with the DPU. The Department docketed these plans as DPU 15-120, DPU 15-121, and DPU 15-122, respectively.

[14] On June 16, 2016, Eversource and National Grid each filed updates to their respective grid modernization plans.

[15] Massachusetts DPU 15-120; DPU 15-121; DPU 15-122 (Grid Modernization) Order (1) Extending Current Three-Year Grid Modernization Plan Investment Term; and (2) Establishing Revised Filing Date for Subsequent Grid Modernization Plans (issued May 12, 2020).

- Workforce Management (WFM)

This report covers the Program Year (PY) 2021 evaluation of Infrastructure Metrics and focuses on the VVO Investment Area. The following subsection discusses these Investment Areas in greater detail.

1.1.1 Investment Areas

Table 7 summarizes the preauthorized GMP investment.

Table 7. Overview of Investment Areas

Investment Area	Description	Goal/Objective
Monitoring and Control (M&C)	Remote monitoring and control of devices in the substation for feeder monitoring or online devices for enhanced visibility outside the substation	Enhancing grid visibility and control capabilities, reliability increase
Advanced Distribution Automation (ADA)	Isolation of outage events with automated restoration of unaffected circuit segments	Reduces the impact of outages
Volt/VAR Optimization (VVO)	Control of line and substation equipment to optimize voltage, reduce energy consumption, and increase hosting capacity	Optimization of distribution voltage to reduce energy consumption and demand
Advanced Distribution Management Systems/Advanced Load Flow (ADMS and ALF)[16]	New capabilities in real-time system control with investments in developing accurate system models and enhancing Supervisory control and data acquisition (SCADA) and outage management systems to control devices for system optimization and provide support for distribution automation and VVO with high penetration of DER	Enables high penetration of DER by supporting the ability to control devices for system optimization, ADA, and VVO
Communications/IoT	Fiber middle mile and field area communications systems	Enables the full benefits of grid modernization devices to be realized
Workforce Management (WFM)	Investments to improve workforce and asset usage related to outage management and storm response	Improves the ability to identify damage after storms

Source: Grid Mod RFP – SOW (Final 8-8-18).pdf; Guidehouse

The Massachusetts preauthorized budget for grid modernization varies by Investment Area and EDC. Eversource has the largest preauthorized budget at $133 million, with ADA and M&C representing the largest share ($44 million and $41 million, respectively). National Grid's preauthorized budget is $82.2 million, with ADMS representing almost 60% ($48.447 million). Unitil's preauthorized budget is $4.4 million and VVO makes up 50% ($2.2 million). Table 8 shows the budget for each Investment Area by EDC.

[16] Note that ALF is an Eversource-only investment, and is not being pursued by the other EDCs, whereas ADMS investment is being pursued by all three EDCs.

On July 1, 2020, Eversource filed a request for an extension of the budget authorization associated with grid modernization investments.[17] The budget extension, approved by the DPU on February 4, 2021,[18] includes $14 million for ADA, $16 million for ADMS, $5 million for Comms, $15 million for M&C, and $5 million for VVO. These values are included in the Eversource total budget by Investment Area in Table 8.

DPU added flexibility to these budgets based on changing technologies and circumstances. For example, EDCs can shift funds across the different preauthorized investments if a reasonable explanation for these shifts is supplied.

Table 8. 2018–2021 GMP Preauthorized Budget, $M

Investment Areas	Eversource	National Grid	Unitil	Total
ADA	$58.00	$13.40	N/A	**$71.40**
ADMS/ALF	$33.00	$48.40	$0.70	**$79.10**
Comms	$23.00	$1.80	$0.84	**$25.60**
M&C	$56.00	$8.00	$0.35	**$64.75**
VVO	$18.00	$10.60	$2.22	**$30.80**
WFM	-	$0.00	$0.30	**$1.00**
2018-2021 Total	**$188.00**	**$82.20**	**$4.41**	**$272.65**

Source: DPU Order, May 10, 2018, and Eversource filing “GMP Extension and Funding Report,” July 1, 2020

1.1.2 Evaluation Goal and Objectives

As part of the GMPs, the DPU requires a formal evaluation process (including an evaluation plan and evaluation studies) for the EDCs’ preauthorized GMP investments. Guidehouse is completing the evaluation to ensure a uniform statewide approach and to facilitate coordination and comparability. The evaluations’ objective is to measure the progress made toward the achievement of DPU’s grid modernization objectives. The evaluation uses the DPU-established Infrastructure Metrics and Performance Metrics (discussed in Section 1.1.3) to meet the DPU’s evaluation objectives.

1.1.3 Metrics for Evaluation

The DPU-required evaluation involves Infrastructure Metrics and Performance Metrics for each Investment Area. In addition, selected case studies have been added for some Investment Areas (e.g., M&C) as part of the evaluation to help facilitate understanding of how the technology has performed in specific instances (e.g., in remediating the effects of a line outage).

1.1.3.1 Infrastructure Metrics

The Infrastructure Metrics assess the deployment of the GMP investments. Table 9 summarizes the Infrastructure Metrics.

[17] Grid Modernization Program Extension and Funding Report. Submitted to Massachusetts DPU on July 1, 2020 as part of DPU 15-122

[18] Massachusetts DPU 20-74 Order issued on February 4, 2021.

Table 9. Infrastructure Metrics Overview

Metric		Description	Applicable IAs	Metric Responsibility
IM-1	**Grid Connected Distribution Generation Facilities**	Tracks the number and type of distributed generation facilities in service and connected to the distribution system.	ADMS/ALF	EDC
IM-2	**System Automation Saturation**	Measures the quantity of customers served by fully or partially automated devices.	M&C, ADA	EDC
IM-3	**Number and Percent of Circuits with Installed Sensors**	Measures the total number of circuits with installed sensors which will provide information useful for proactive planning and intervention.	M&C	EDC
IM-4	**Number of Devices Deployed and In Service**	Measures how the EDC is progressing with its GMP from an equipment and/or device standpoint.	All IAs	Evaluator
IM-5	**Cost for Deployment**	Measures the associated costs for the number of devices or technologies installed; designed to measure how the EDC is progressing under its GMP.	All IAs	Evaluator
IM-6	**Deviation Between Actual and Planned Deployment for the Plan Year**	Measures how the EDC is progressing relative to its GMP on a year-by-year basis.	All IAs	Evaluator
IM-7	**Projected Deployment for the Remainder of the Three-Year Term**	Compares the revised projected deployment with the original target deployment as the EDC implements its GMP.	All IAs	Evaluator

IM = Infrastructure Metric, IA = Investment Area
Source: Guidehouse review of Infrastructure Metric filings

1.1.3.2 Performance Metrics

Table 10 summarizes the Performance Metrics, which are used to evaluate the performance of the GMP investments.

Table 10. Performance Metrics Overview

Metric	Metric	Description	Applicable IAs	Metric Responsibility
PM-1	**VVO Baseline**	Establishes a baseline impact factor for each VVO enabled circuit which will be used to quantify the peak load, energy savings, and greenhouse gas (GHG) impact measures.	VVO	All

Metric	Metric	Description	Applicable IAs	Metric Responsibility
PM-2	**VVO Energy Savings**	Quantifies the energy savings achieved by VVO using the baseline established for the circuit against the annual circuit load with the intent of optimizing system performance.	VVO	All
PM-3	**VVO Peak Load Impact**	Quantifies the peak demand impact VVO/Conservation Voltage Reduction (CVR) has on the system with the intent of optimizing system demand.	VVO	All
PM-4	**VVO Distribution Losses without AMF (Baseline)**	Presents the difference between circuit load measured at the substation via the SCADA system and the metered load measured through advanced metering infrastructure.	VVO	All
PM-5	**VVO Power Factor**	Quantifies the improvement that VVO/CVR is providing toward maintaining circuit power factors near unity.	VVO	All
PM-6	**VVO – GHG Emissions**	Quantifies the overall GHG impact VVO/CVR has on the system.	VVO	All
PM-7	**Voltage Complaints**	Quantifies the prevalence of voltage-related complaints before and after deployment of VVO investments to assess customer experience, voltage stability under VVO.	VVO	All
PM-8	**Increase in Substations with DMS Power Flow and Control Capabilities**	Examines the deployment and data cleanup associated with deployment of ADMS/ALF, primarily by counting and tracking the number of circuits and substations per year.	ADMS/ ALF	All
PM-9	**Control Functions Implemented by Circuit**	Examines the control functions of DMS power flow and control capabilities, focused on the control capabilities including VVO-CVR and FLISR.	ADMS/ ALF	All
PM-11	**Numbers of Customers that benefit from GMP funded Distribution Automation Devices**	Shows the progress of ADA investments by tracking the number of customers that have benefitted from the installation of ADA devices.	ADA	ES, NG
PM-12	**Grid Modernization investments' effect on outage durations**	Provides insight into how M&C investments can reduce outage durations (CKAIDI). Compares the experience of customers on GMP M&C-enabled circuits as compared to the previous 3-year average for the same circuit.	M&C, ADA	All

Metric	Metric	Description	Applicable IAs	Metric Responsibility
PM-13	**Grid Modernization investments' effect on outage frequency**	Provides insight into how M&C investments can reduce outage frequencies (CKAIFI). Compares the experience of customers on M&C-enabled circuits as compared to the prior 3-year average for the same circuit.	M&C, ADA	All
PM-ES1	**Advanced Load Flow – Percent Milestone Completion**	Examines the fully developed ALF capability across Eversource's circuit population.	ADMS/ ALF	ES
PM-ES2	**Protective Zone: Average Zone Size per Circuit**	Measures Eversource's progress in sectionalizing circuits into protective zones designed to limit outages to customers located within the zone.	ADA	ES
PM-UTL1	**Customer Minutes of Outage Saved per Circuit**	Tracks time savings from faster advanced metering infrastructure outage notification than customer outage call, leading to faster outage response and reduced customer minutes of interruption.	M&C	UTL
PM-NG1	**Main Line Customer Minutes of Interruption Saved**	Measures the impact of ADA investments on the customer minutes of interruption (CMI) for main line interruptions. Compares the CMI of GMP ADA-enabled circuits to the previous 3-year average for the same circuit.	ADA	NG

PM = Performance Metric, IA = Investment Area, ES = Eversource, NG = National Grid, UTL = Unitil

Source: Stamp Approved Performance Metrics, July 25, 2019.

1.2 VVO Investment Area Overview

As a part of grid modernization, the Massachusetts EDCs are investing to enable VVO on selected feeders across their distribution networks. VVO optimizes distribution voltage to reduce energy consumption and demand without the need for customer interaction or participation. The principle behind VVO is that power demand is reduced at voltages in the lower end of their allowable range for many end-use loads.

VVO reduces circuit demand and energy consumption by flattening and lowering the voltage profile on the circuit while maintaining customer service voltage standards. In addition, VVO systems allow for more gradual and responsive control of reactive power control devices, such as capacitors, which can improve the overall system power factor and reduce system losses. VVO allows customers to realize lower consumption without experiencing a reduction in their level of service.

The VVO investment will first be used to condition feeders, install equipment, and commission software. Once the software commissioning is complete, and as feeders complete their conditioning and equipment installation, they will become VVO enabled.

As identified in the 2020 Grid Modernization Annual Reports, filed by the EDCs on April 1, 2021, and the PY2021 EDC Data Request, received by the EDCs in early 2022, the VVO investments totaled to $33.22 million from 2018 to 2021:

- $14.83 million by Eversource
- $15.80 million by National Grid
- $2.59 million by Unitil

There is an additional total of $13.62 million across all EDCs for VVO investments that began in 2021 but are planned to be carried over and completed in 2022. This includes carryover of $2.26 million for Eversource, $8.95 million for National Grid, and $2.42 million for Unitil.

1.2.1 VVO Timeline

The VVO investment process for each of the EDCs involves four core phases: VVO investment, VVO commissioning, VVO enablement, and VVO On/Off testing. Table 11 provides the four phases and a brief description of each.

Table 11. VVO Deployment Phases

Phase	Description
VVO Investment	Deployment and installation of VVO devices, including but not limited to capacitor banks, load tap changer (LTC) controls, and voltage regulators. Load rebalancing may occur during this time.
VVO Commissioning	Process of preparing VVO investments installed on conditioned feeders to begin VVO control.
VVO Enablement	Date at which the VVO system is enabled and managing voltage and reactive power.
VVO On/Off Testing Period	Dates over which the VVO system is cycled between the on and off states using a predetermined cycling schedule.

Source: Guidehouse

The four core VVO deployment phases are at varying levels of completion by EDC. Table 12 shows the status of each deployment phase, detailed by EDC. Section 3 includes additional information on all EDCs.

Table 12. VVO Deployment Timeline by Phase, All EDCs

Phase	3-Year GMP Estimated Timeframe		
	Eversource	National Grid	Unitil
Original 2018–2020 Plan Feeders			
VVO Investment	Winter 2019/2020 (complete)	Summer 2020 (complete)	Spring 2021 (in progress)
VVO Commissioning	Winter 2019/2020 (complete)	Spring 2021 (in progress)	Summer–Fall 2021 (planned)
VVO Enabled Date	Winter 2020/21–Spring 2021 (complete)	Winter 2020/2021–Spring 2021 (in progress)	Summer 2021–Winter 2021/2022 (planned)
VVO On/Off Testing Period	Winter 2020/2021–TBD (in progress)	Winter 2020/2021–TBD (in progress)	Winter 2021/2022–TBD (planned)
Additional Feeders			
VVO Investment	CY2021[19] (in progress)	Spring 2021 (in progress)	Winter 2021/2022 (planned)
VVO Commissioning	TBD (planned)	Summer 2021 (planned)	Spring 2022 (planned)
VVO Enabled Date	TBD (planned)	Summer 2021 (planned)	Summer 2022 (planned)
VVO On/Off Testing Period	TBD (planned)	Summer 2021–TBD (planned)	Fall 2022–Summer 2023 (planned)

Source: Guidehouse review of EDC data

1.2.2 VVO Investment Devices

One of the main focuses of this report are the devices deployed as part of the VVO investment phase. Table 13 defines these assets.

[19] Eversource is going to deploy VVO on additional feeders in 2021 but has not yet determined the specific substations that will be targeted.

Table 13. Description of Devices Deployed Under VVO Investment

Device	Description
Capacitor Bank Controls	Reactive compensation devices, equipment combined with two-way communications infrastructure, and remote-control capability to regulate reactive power (VAR) flows throughout the distribution network.
Line Sensors	Voltage sensors, which relay verified field measurements to allow VVO algorithm to regulate voltage and reactive power appropriately.
Load Tap Changer (LTC) Controls	Transformer load tap changers, which automatically adjust feeder voltage based on local measurement. First of the two devices required to regulate voltage on a distribution circuit.
Voltage Regulators	Optimized for VVO and equipped with communications equipment to enable remote-control and monitoring of voltage; required to regulate voltage on a distribution circuit.
Microcapacitors*	Installed at strategic locations in order to support system load, provide remote visibility and control of the devices, and prepare the circuit for conversion to VVO in the future. While not commissioned into the VVO system, microcapacitors enable additional voltage and power factor control on feeders.
Grid Monitoring Line Sensors*	Deployed at strategic locations like large side taps, step down transformers, and larger distributed generation sites that do not have SCADA reclosers. Grid monitoring line sensors also allow Eversource to gather additional telemetry from VVO enabled feeders.

* Devices are applicable to Eversource only

Source: Guidehouse

1.2.3 VVO Evaluation Objectives

This evaluation focuses on the progress and effectiveness of the DPU preauthorized VVO investments for each EDC toward meeting the DPU's grid modernization objectives.[20] Table 14 illustrates the key Infrastructure Metrics and Performance Metrics relevant for the VVO evaluation.

Table 14. VVO Evaluation Metrics

Metric Type	VVO Evaluation Metrics	ES	NG	UTL
IM	Number of devices or other technologies deployed	✓	✓	✓
IM	Cost for deployment	✓	✓	✓
IM	Deviation between actual and planned deployment for the plan year	✓	✓	✓
IM	Projected deployment for the remainder of the 3-year term	✓	✓	✓
PM	VVO Baseline	✓	✓	
PM	VVO Energy Savings	✓	✓	
PM	VVO Peak Load Impact	✓	✓	
PM	VVO Distribution Losses w/o AMF (Baseline)	✓	✓	
PM	VVO Power Factor	✓	✓	
PM	VVO GHG Emissions	✓	✓	
PM	Voltage Complaints	✓	✓	

[20] DPU Order, May 10, 2018, p.106.

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020

The EDCs provided data supporting the Infrastructure Metrics to the evaluation team. Guidehouse presents results from analysis of Infrastructure Metrics data in Section 3. The Performance Metrics will be based on statistical analyses performed by the evaluation team using data provided by each EDC.

Table 15 summarizes the VVO evaluation objectives and associated research questions that will be addressed in the report. The scope of the VVO measurement and verification (M&V) includes tracking the VVO infrastructure deployment against the plan (Infrastructure Metrics) and measuring the energy, peak demand, greenhouse gas (GHG), and voltage complaint impacts of installing the VVO investments and operating VVO (Performance Metrics).

Table 15. VVO M&V Objectives and Associated Research Questions

VVO M&V Objective	Associated Research Questions
Infrastructure Deployment	• What is the extent, type, and cost of VVO investments? • How well does each EDC's deployment track the planned deployment?
Energy and Peak Savings by Feeder (Device Deployment)	• How many energy savings were realized from device deployment on VVO enabled feeders? • What is the impact on peak load from VVO investments operating on VVO enabled feeders? • How much GHG emissions reduction has been enabled from device deployment on VVO enabled feeders?
Energy and Peak Savings by Feeder (VVO-Operation)	• How many energy savings were realized from VVO operating on VVO enabled feeders? • What is the impact on peak load from VVO operating on VVO enabled feeders? • What is the impact on loss reductions and feeder-level power factor associated from VVO operating on VVO enabled feeders? • How much GHG emissions reduction was enabled from VVO operating on VVO enabled feeders?
Voltage Complaints	• What is the impact of VVO-related investments on the number of voltage complaints?

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020

2. VVO Evaluation Process

This section presents a high-level overview of the Guidehouse methodologies for the evaluation of Infrastructure Metrics and Performance Metrics. Figure 2 highlights the filing background and timeline of the GMP Order and the evaluation process.

2.1 Infrastructure Metrics Analysis

Guidehouse annually assesses the progress of each of the EDCs toward deploying VVO on their feeders. Table 16 highlights the Infrastructure Metrics that were evaluated.

Table 16. Infrastructure Metrics Overview

Infrastructure Metrics			Calculation
IM-4	Number of devices or other technologies deployed thru. PY2021	# Devices Deployed	$\sum_{PY=2018}^{2021} (Devices\ Commissioned)_{PY}$
		% Devices Deployed	$\frac{\sum_{PY=2018}^{2021} (Devices\ Commissioned)_{PY}}{\sum_{PY=2018}^{2020} (Devices\ Commissioned)_{PY} + (Planned\ Devices)_{PY2021}}$
IM-5	Cost through PY2021	Total Spend, $M	$\sum_{PY=2018}^{2021} (Actual\ Spend)_{PY}$
		% Spend	$\frac{\sum_{PY=2018}^{2021} (Actual\ Spend)_{PY}}{\sum_{PY=2018}^{2020} (Actual\ Spend)_{PY} + (Planned\ Spend)_{PY2021}}$
IM-6	Deviation Between Actual and Planned Deployment for PY2021	% On Track (Devices)	$\frac{(Devices\ Commissioned)_{PY2021}}{(Planned\ Devices)_{PY2021}}$
		% On Track (Spend)	$\frac{(Actual\ Spend)_{PY2021}}{(Planned\ Spend)_{PY2021}}$
IM-7	Projected Deployment for the remainder of the GMP Term*	# Devices Remaining	$(Devices\ Planned)_{PY2022}$
		Spend Remaining, $M	$(Planned\ Spend)_{CY2022}$

* This metric has been interpreted here (i.e. within the context of the 2021 Program Year Evaluation) as the "carryover" units and "carryover" spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent plan totals were included in each EDC's *Grid Modernization Plan Annual Report 2020* (filed on April 1, 2021), which listed the planned units and spending to be completed in PY2021.

Source: Guidehouse

Table 17. Infrastructure Metrics Overview by Feeder

Infrastructure Metrics			Calculation
IM-4	Number of Devices or Other Technologies Deployed through PY2021	# Feeders with VVO Enabled	$\sum_{PY=2018}^{2021}(VVO\ Enabled\ Feeders)_{PY}$
		% Feeders with VVO Enabled	$\frac{\sum_{PY=2018}^{2021}(VVO\ Enabled\ Feeders)_{PY}}{\sum_{PY=2018}^{2020}(VVO\ Enabled\ Feeders)_{PY} + (Planned\ VVO\ Enabled\ Feeders)_{PY2021}}$
IM-6	Deviation Between Actual and Planned Deployment for PY2021	% On Track (VVO Enabled Feeders)	$\frac{(VVO\ Enabled\ Feeders)_{PY2021}}{(Planned\ VVO\ Enabled\ Feeders)_{PY2021}}$
IM-7	Projected Deployment for the remainder of the GMP Term*	# VVO Enabled Feeders Remaining	$(Planned\ VVO\ Enabled\ Feeders)_{CY2022}$

* This metric has been interpreted here (i.e. within the context of the 2021 Program Year Evaluation) as the "carryover" units and "carryover" spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent plan totals were included in each EDC's *Grid Modernization Plan Annual Report 2020* (filed on April 1, 2021), which listed the planned units and spending to be completed in PY2021.

Source: Guidehouse

Figure 2 highlights the infrastructure metrics evaluation timeline. The period currently being evaluated is highlighted in light green, corresponding with PY2021.

Figure 2. Infrastructure Metrics Evaluation Timeline

Source: Guidehouse review of the DPU orders and GMP process

Section 3.2 provides the results from the evaluation of Infrastructure Metrics. To evaluate Infrastructure Metrics, Guidehouse:

- Reviewed the data provided by the EDCs to confirm their progress through PY2021 (see Section 3.1.2, "Data QA/QC Process")

- Interviewed representatives from each EDC to understand the status of the VVO investments, including:
  - Updates to their planned VVO investments
  - Reasons for deviation between actual and planned deployment and spend

2.2 Performance Metrics Analysis

Guidehouse evaluated Performance Metrics for each of the three EDCs, focusing on the utility and customer experience with VVO. Table 18 describes the Performance Metrics evaluated in PY2021.

Table 18. Performance Metrics Overview

PM	Performance Metrics	Description
PM-1	VVO – Baseline	Establishes a baseline impact factor for each VVO enabled circuit which will be used to quantify the peak load, energy savings, and GHG impact measures
PM-2	VVO – Energy Savings	Quantifies the energy savings achieved by VVO using the baseline established for the circuit against the annual circuit load with the intent of optimizing system performance
PM-3	VVO – Peak Load Impact	Quantifies the peak demand impact VVO/CVR has on the system with the intent of optimizing system demand
PM-4	VVO – Distribution Losses without AMF (Baseline)	Presents the difference between circuit load measured at the substation via the SCADA system and the metered load measured through advanced metering infrastructure
PM-5	VVO – Power Factor	Quantifies the improvement that VVO/CVR is providing toward maintaining circuit power factors near unity
PM-6	VVO – GHG Emissions	Quantifies the overall GHG impact VVO/CVR has on the system
PM-7	Voltage Complaints	Quantifies the prevalence of voltage-related complaints before and after deployment of VVO investments to assess customer experience, voltage stability under VVO

Source: Stamp Approved Performance Metrics, July 25, 2019.

The metrics in Table 18 are based on a M&V process, which uses statistical analysis to quantify the impacts the VVO system has on the customers it serves. Quantifying VVO Performance Metrics requires interval measurements of feeder-level voltage and power demand while the voltage and reactive power controls are operated in both baseline (non-VVO) and VVO modes.

For changes associated with VVO being enabled to be quantified, Guidehouse and the EDCs have agreed to the plan for VVO On/Off testing to continue for at least 9 months, covering summer (June, July, and August), winter (December, January, and February), and one of the spring (March, April, and May) or fall (September, October, November) shoulder seasons.

2.2.1 Performance Metrics Timeline

Figure 3 highlights the key Performance Metrics analysis periods. The Performance Metrics analysis provided for this report will be focused on results from VVO On/Off testing conducted during Spring 2021 – Winter 2021/22.

Figure 3. Performance Metrics Timeline

3. VVO Infrastructure Metrics

3.1 Data Management

Guidehouse worked with the EDCs to collect data to complete the evaluation for the assessment of VVO Infrastructure Metrics and Performance Metrics. The sections that follow highlight Guidehouse's data sources and data QA/QC processes used in the evaluation of Infrastructure Metrics.

3.1.1 Data Sources

Guidehouse used a consistent methodology (across Investment Areas and EDCs) for evaluating and illustrating EDC progress indicated by the GMP metrics. The subsections that follow summarize each of the data sources used to evaluate Infrastructure Metrics.

3.1.1.1 2020 Grid Modernization Plan Annual Report

Guidehouse used the planned device deployment and cost information from each EDCs' *2020 GMP Annual Reports*, which were filed on April 1, 2021. These filings served as the sources for planning data in this report[21] and are referred collectively as the EDC Plan for each EDC in summary tables and figures throughout this report.

Table 19 provides a legend of the different planned and actual quantities reviewed and specifies the color/shade used to represent these quantities in the graphics throughout the rest of the report.

Table 19. Deployment Categories Used for the EDC Plan

Representative Color	Data	Description
	2021 Plan	Projected 2021 unit deployment and spend
	2020 Actual	Actual 2020 unit deployment and spend
	2019 Actual	Actual reported unit deployment and spend in 2018
	2018 Actual	Actual reported unit deployment and spend in 2018

Source: Plan and actual data is sourced from the EDCs' 2020 GMP Annual Report Appendix 1 filed April 1, 2021.

Guidehouse used the Feeder Status tab of the 2021 GMP Annual Report Appendix 1[22,23,24] to obtain feeder characteristics including system voltage, total feeder count, customer count, feeder length, and annual peak load.

[21] See Section 5 for specific details regarding *2019 GMP Annual Report* data used for each EDC.

[22] Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2022. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 22-41

[23] NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-40

[24] Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-42

3.1.1.2 EDC Data Sources

Guidehouse collected device deployment data and VVO schedule information at the feeder-level using standardized data collection templates. Guidehouse developed these templates for all EDCs: the All Device Deployment data and VVO Supplemental workbooks, respectively.

Table 20 summarizes the file versions used for the evaluation, and the following subsections provide additional detail surrounding requested inputs in each workbook. The collected data was compared to the data submitted by the EDCs to the DPU in the 2020 Grid Modernization Plan Annual Reports and associated Appendix 1 filings.[25,26,27] The evaluation team confirmed the consistency of the data from the various sources and reconciled any differences.

Table 20. EDC Data Received for Analysis

Company	File Version Used for Analysis[28]	
	All Device Deployment	VVO Supplemental
Eversource	Received 2/2/2022	Received 3/4/2022
National Grid	Received 2/4/2022	Received 3/9/2022
Unitil	Received 2/4/2022	Received 2/4/2022

Source: Guidehouse

3.1.1.3 All Device Deployment Workbook

Guidehouse collected device deployment data using standardized data collection templates (e.g., the All Device Deployment workbook file) for all EDCs in January–February 2022. The data collected provides an update of planned and actual deployment, in dollars and device units, through the end of PY2021. Data from these sources are referred to as EDC Data in summary tables and figures throughout the report.

The EDC device deployment data (collected in the All Device Deployment workbook) captured planned and actual device deployment and spend data. Actual device deployment and cumulative spend information were provided by work order ID and specified at the feeder- or substation-level, as appropriate.

The evaluation team also collected the current implementation stage of the work order (commissioned, construction, or design), the commissioned date (if applicable), and all cumulative costs associated with the work order. Planned carryover device deployment information and estimated carryover spend for PY2022 was provided at the most granular level (circuit or substation) available.

[25] Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2022. Submitted to Massachusetts DPU on April 1, 2021 as part of DPU 22-41
[26] NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-40
[27] Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2021. Submitted to Massachusetts DPU on April 1, 2022 as part of DPU 22-42
[28] Some minor additional updates to specific work orders were addressed after these dates via email.

Table 21 summarizes the categories used for the revised planned and actual deployment and spend and specifies the color and pattern used in bar graphs to represent each in the remainder of the report.

Table 21. EDC Device Deployment and Spending Data Legend

Representative Color	Data	Description
Device Deployment Data		
	2022 Estimate	Remaining units planned for 2022 where work will begin in 2022
	2021 Design/ Engineering	Detailed design and engineering is in progress, but the device is not yet in construction
	2021 Construction	Field construction is in progress, but the device is not yet in-service
	2021 In-Service	Device is installed and used and useful, but not yet commissioned to enable all grid modernization functionalities
	2021 Commissioned	Device is fully operational with all grid modernization functionalities, and so is considered deployed in PY2021
	2020 Actual	Actual devices commissioned in 2020
	2019 Actual	Actual devices commissioned in 2019
	2018 Actual	Actual devices commissioned in 2018
Spend Data		
	2022 Carryover	Projected 2022 spend
	2021 Actual	Actual 2021 spend[29]
	2020 Actual	Actual 2020 spend
	2019 Actual	Actual 2019 Spend[30]
	2018 Actual	Actual 2018 Spend

Source: Guidehouse analysis

3.1.1.4 VVO Supplemental Data Template

The VVO supplemental data collection template includes additional information unique to the VVO Investment Area. Table 22 summarizes the information requested. Data was provided in the data collection template or submitted in a separate file. Information was requested at the feeder-level where possible (except for IT work). The VVO schedule information and the IT work information are the only data within this template that are applicable to the Infrastructure Metrics. All additional information is applicable to the Performance Metrics.

[29] The 2021 actual costs shown in the tables and figures include only capital spending and do not include operations and maintenance (O&M) spending. This has been done to maintain consistency and comparability with the EDC's 2020 Annual GMP Filings (Appendix 1 required format). O&M spending information is included separately in Section 3.2.1.4

[30] The 2019 and 2018 spending reported by the EDCs in the Annual Reports (and in the Appendix 1) included the associated O&M costs as well as Capital costs. The O&M costs are small relative to the capital costs for VVO so were not removed from the analysis.

Table 22. VVO Supplemental Data

Information	Description
Actual/Planned VVO Schedule	Actual and updated planned VVO deployment start/end dates by feeder, including feeder conditioning, load rebalancing, phase balancing, VVO commissioning, VVO enabled, and On/Off testing.
IT Work	Actual and updated planned IT work progress start/end dates and cost information.[31]
Customer Demand Response (DR) Events	Demand response events (time-stamped log of any systemwide demand response (or similar), for example: ISO-NE DR, EDC direct load control programs, EDC behavioral demand response programs).
System Events	Operational changes, a time-stamped log of changes to substation and feeders away from normal operating state (temporary or permanent), and power outages.
DG Log	Log of distributed generation facilities connected to VVO feeders (e.g., type, size, installation date, feeder).
Voltage Complaints	Voltage-related complaints based on voltage perturbation (e.g., high voltage, low voltage, flicker), duration (e.g., multiple days, sporadic).

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020

3.1.2 Data QA/QC Process

Guidehouse reviewed all data provided for Infrastructure Metrics analysis upon receipt of requested data. To ensure accuracy, Guidehouse conducted a QA/QC of all device deployment data received. This review involved following up with the EDCs for explanations regarding the following:

- Potential errors in how the forms were filled out (e.g., circuit information provided in the wrong field)
- Missing or incomplete information
- Large variation in the unit cost of commissioned devices
- Variance between the aggregated totals by device/technology and work order-level data
- Variance between the actual unit costs and planned unit costs

3.2 Deployment Progress and Findings

Guidehouse presents findings from the Infrastructure Metrics analysis for the VVO Investment Area in the following subsections. Throughout this section, Guidehouse will reference “Original 2018-2020 Plan Feeders” and “Additional Feeders”. Original 2018-2020 Plan Feeders are the feeders identified by each of the EDCs in their original 3-Year Grid Modernization Plans as being planned to receive VVO investments in 2018 through 2020. Additional Feeders are feeders identified by each of the EDCs in 2020 and onwards as being planned to receive VVO investments within the pre-authorized budget limits for VVO. The number of original 2018-2020 plan feeders for Eversource, National Grid, and Unitil total to 26, 20, and 9, respectively. As of

[31] IT work progress includes: planning, procurement, development, deployment, and go-live

the end of 2021, the number of additional feeders for Eversource, National Grid, and Unitil total to 6, 34, and 2, respectively.

3.2.1 Statewide Comparison

This section discusses the current scope of VVO investments relative to the number of feeders and customers within the EDCs in Massachusetts and it summarizes the deployment progress and findings across all three EDCs.

3.2.1.1 Anticipated Impact on Massachusetts

As part of the 2018-2021 GMP, VVO deployment is anticipated to impact 97 feeders serving 206,889 customers (7.5% of all EDC customers) throughout Massachusetts. Table 23 highlights the anticipated impact by EDC. VVO investments are being rolled out at the following substations:

- **Eversource:** Agawam, Piper, Podick, and Silver (original 2018–2020 plan feeders); Gunn and Oswald (additional feeders)
- **National Grid:** East Methuen, Maplewood, and Stoughton (original 2018–2020 plan feeders); East Dracut, East Bridgewater, Easton, Melrose, Westboro, and West Salem (additional feeders)
- **Unitil:** Lunenburg, Summer Street, and Townsend (original 2018–2020 plan feeders); West Townsend (Additional Feeders)

Table 23. Number of Feeders and Customers Covered by VVO

VVO Impact	Eversource		National Grid		Unitil		Total	
	Feeders	Customers	Feeders	Customers	Feeders	Customers	Feeders	Customers
Systemwide Total	2,262	1,391,745	1,144	1,338,584	44	31,498	3,450	2,761,827
Original 2018-2020 Plan Feeders								
Count	26	34,692	20	55,911	9	10,693	55	101,296
% System Total	1.1%	2.5%	1.7%	4.2%	20.5%	33.9%	1.6%	3.7%
Additional Feeders								
Count	6	28,340	34	73,952	2	3,301	42	105,593
% System Total	0.3%	2.0%	3.0%	5.5%	4.5%	10.5%	1.2%	3.8%
2018-2021 Projected Total								
Count	32	63,032	54	129,863	11	13,994	97	206,889
% System Total	1.4%	4.5%	4.7%	9.7%	25.0%	44.4%	2.8%	7.5%

Source: Guidehouse analysis of 2021 GMP Annual Report Appendix 1, filed April 1, 2022

3.2.1.2 Approach to VVO

Each EDC has a unique approach to selecting feeders for VVO, deploying VVO devices, and implementing VVO control. Table 24 highlights the substations covered by VVO investment and the planned VVO On/Off testing period start date for each EDC. The following subsections include specifics related to each EDC's approach to VVO.

Table 24. VVO Substations and VVO On/Off Testing Start by EDC

Company	Substations (Feeder Count)	VVO On/Off Testing Start
Original 2018-2020 Plan Feeders		
Eversource	Agawam (7)	Winter 2020/21
	Piper (6)	Winter 2020/21
	Podick (7)	Spring 2021
	Silver (6)	Winter 2020/21
National Grid	E. Methuen (6)	Spring 2021
	Maplewood (8)	Winter 2021/22
	Stoughton (6)	Winter 2020/21
Unitil	Townsend (3)	Spring 2022
	Lunenburg (2)	Winter 2023/24
	Summer St. (4)	Winter 2022/23
Additional Feeders		
Eversource	Gunn (4)	Spring 2022
	Oswald (2)	Summer 2022
National Grid	E. Bridgewater (7)	Summer 2021
	East Dracut (6)	Summer 2022
	Easton (5)	Winter 2022/23
	Melrose (5)	Winter 2022/23
	Westboro (5)	Winter 2022/23
	West Salem (6)	Summer 2022
Unitil	W. Townsend (2)	Winter 2024/25

Source: Guidehouse analysis of data submissions

3.2.1.3 VVO Timeline

Table 25 summarizes the expected timelines for completion of each of the four VVO investment phases for each EDC. Further detail surrounding these timelines follows.

Table 25. VVO Deployment Completion Dates by Phase and EDC

Phase	3-Year GMP Estimated Timeframe		
	Eversource	National Grid	Unitil
Original 2018 – 2020 Plan Feeders			
VVO Investment	Winter 2018/19–Winter 2019/20 (complete)	Fall 2019–Summer 2020 (complete)	Winter 2018/19–Summer 2023 (in progress)
VVO Commissioning	Winter 2019/20 (complete)	Winter 2021/22 (complete)	Summer 2021 – Fall 2023 (in progress)
VVO Enabled Date	Winter 2020/21–Spring 2021 (complete)	Winter 2020/21–Winter 2021/22 (complete)	Winter 2021/22–Fall 2023 (in progress)
VVO On/Off Testing Period	Winter 2020/21–TBD (in progress)	Winter 2020/21–TBD (in progress)	Spring 2022–TBD (planned)
Additional Feeders			
VVO Investment	Winter 2020/21 – Winter 2022/23 (in progress)	Spring 2020–Fall 2022 (in progress)	Winter 2020/21–Summer 2024 (planned)
VVO Commissioning	Spring 2022 (planned)	Summer 2021–Fall 2022 (in progress)	Spring 2024–Fall 2024 (planned)
VVO Enabled Date	Spring 2022 (planned)	Summer 2021–Winter 2022/23 (in progress)	Fall 2024 (planned)
VVO On/Off Testing Period	Spring 2022–TBD (planned)	Summer 2021–TBD (in progress)	Winter 2024/25–TBD (planned)

Source: Guidehouse analysis of 2020 GMP Annual Reports and EDC Data

Among its original 2018–2020 plan feeders, VVO deployment and VVO commissioning have been completed by Eversource and VVO On/Off testing is ongoing. Eversource began VVO On/Off testing at these feeders in winter 2020/21 for the Agawam, Piper, and Silver substations and in spring 2021 for the Podick substation. For its additional feeders, Eversource is deploying VVO investments and is expected to begin VVO On/Off testing at the Gunn and Oswald substations in spring 2022 and summer 2022, respectively.[32]

VVO deployment and VVO On/Off testing are ongoing for National Grid. Of National Grid's original 2018–2020 plan feeders, VVO On/Off testing began in winter 2020/21 at the Stoughton substation, in spring 2021 at the East Methuen substation, and in winter 2021/22 at the Maplewood substation. For its additional feeders, National Grid is completing VVO deployment

[32] Some minor additional updates to specific work

on a staggered basis. VVO On/Off testing began at the East Bridgewater substation in summer 2021, and VVO On/Off testing is expected to begin across five additional substations between summer 2022 and winter 2022/23.

VVO deployment and VVO commissioning are ongoing for Unitil's original 2018–2020 plan feeders, and VVO was enabled in winter 2021/22 at the Townsend substation. Unitil plans to deploy and commission VVO equipment throughout the period spanning spring 2022 through winter 2024/25. During this time, Unitil plans to begin VVO On/Off testing on its Lunenburg and Summer Street substations by winter 2022/23 and winter 2023/24, respectively. Then Unitil plans to begin VVO On/Off testing at the West Townsend substation by winter 2024/25.

3.2.1.4 Infrastructure Metrics Results

Table 26 and Table 27 include the Infrastructure Metrics results through PY2021 for all EDCs. The following EDC-specific subsections provide further detail.

Table 26. 2021 Infrastructure Metrics for VVO Progress

Infrastructure Metrics			Eversource	National Grid	Unitil
GMP Plan Total, PY-2018-2021		Devices	1,201	249	77
		Spend, $M	$18.93	$19.27	$5.12
IM-4	Number of devices or other technologies deployed. PY 2018-2021*	# Devices Deployed***	800	163	26
		% Devices Deployed	67%	66%	34%
IM-5	Cost for Deployment PY 2018-2021*	Total Spend, $M	$14.83	$17.04	$2.58
		% Spend	78%	88%	50%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	36%	39%	31%
		% On Track (Spend)	32%	69%	22%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	342	219	151
		Spend Remaining, $M	$2.26	$7.67	$2.42

*The metric names have been slightly changed here to clarify the time span used in analysis.
**This metric has been interpreted here as the "carryover" units and spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs' 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

***Note that "Deployed" here refers to commissioned devices. In National Grid's Term Report (filed April 1, 2022), deployed refers to in-service and/or commissioned devices. In-service devices are fully installed and used and useful, but not yet commissioned with Grid Mod functionality (communication and remote visibility and/or control). For full definitions of commissioned and in-service, see Docket 20-46 Response to Information Request DPU-AR-4-11, September 3, 2020.

Source: Guidehouse analysis of 2020 GMP Annual Reports and 2021 EDC Data

Table 27. 2021 Infrastructure Metrics for VVO Feeder Deployment Progress

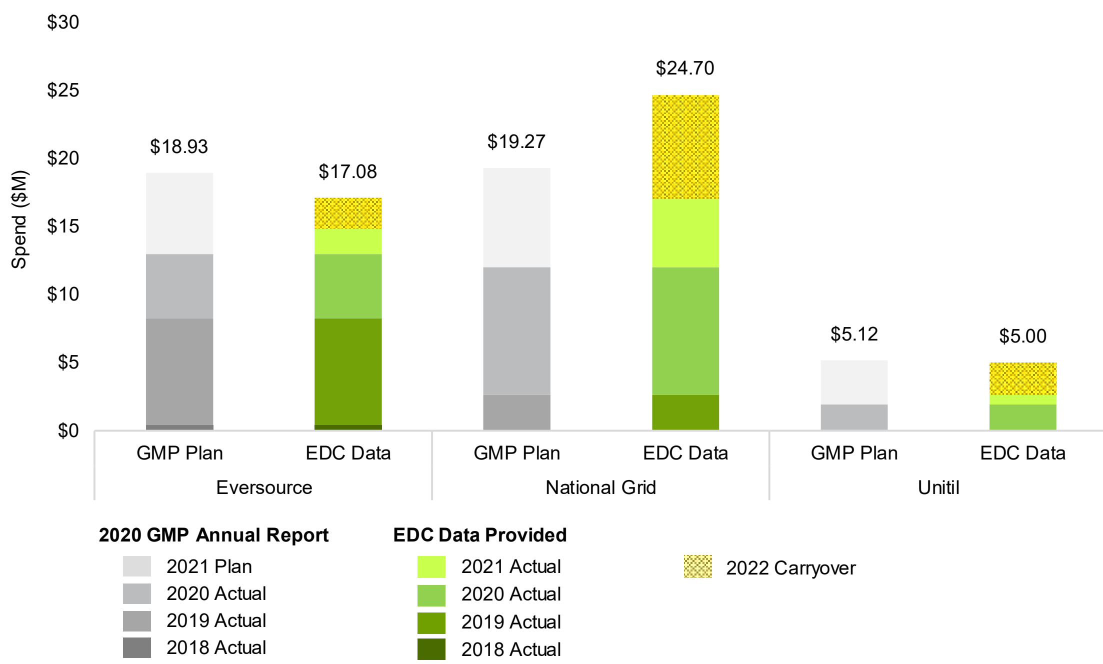
IM	Parameter	Eversource	National Grid	Unitil
IM-4	# Feeders with VVO Enabled	26	20	3
	% Feeders with VVO Enabled	100%	100%	27%
IM-6	% On Track (Feeders with VVO Enabled)	100%	100%	27%
IM-7	# Feeders Remaining for VVO Enablement*	0	0	8

* Does not include additional feeders that were not laid out in the original 3-Year Grid Modernization Plans.

Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Figure 4 highlights planned versus actual spend on VVO for each of the three EDCs. Further details on the differences between planned and actual spend are provided in each specific EDC's results sections.

Figure 4. VVO Spend Comparison (2018–2021, $M)



** Note: Includes the Eversource planned spend for PY2021, set forth the in the GMP Extension and Funding Report, filed on July 1, 2020.Source: Guidehouse analysis of 2020 GMP Annual Reports, "GMP Extension and Funding Report," and 2021 EDC Data*

In addition to the capital costs Figure 4 shows, Eversource incurred approximately $42,000 in operations and maintenance (O&M) costs toward the VVO Investment Area in PY2021. Eversource also incurred approximately $0.51 million toward admin and regulatory O&M costs across the GMP investments in PY2021. National Grid incurred approximately $0.25 million in O&M costs toward the VVO Investment Area in PY2020. National Grid also incurred approximately $0.92 million toward admin and regulatory costs across the GMP investments in PY2021. Unitil incurred approximately $4,700 in O&M costs toward the VVO Investment Area and approximately $19,500 toward admin and regulatory O&M costs across the GMP investments in PY2021.

PY2021's VVO Infrastructure Metrics findings show that the EDCs are at varying stages in VVO deployment. Details pertaining to device deployment progress, VVO enablement progress, and total spend are shown below:

Device Deployment:

- Eversource overall deployment was below plans for 2021, however this varied by device type. Overall deployment was below plans due to several factors. Eversource scaled down deployment plans for its Gunn and Oswald substations, as the substations required fewer regulators and capacitor banks for VVO and did not require LTC control devices or new feeder head sensors, as these devices were already deployed in prior capital projects. In addition, delayed engineering and design work, long vendor lead times, and crew resource constraints combined to delay Eversource's ability to meet revised deployment goals set out for 2021.
- National Grid deployment through 2021 was lower than initially planned, with all device types having fewer fully commissioned devices than planned. One large factor at play in 2021 was competing priorities of crew resources. National Grid had adapted its work practices to COVID-19 protocols so that certain field reporting locations had a reduction in crews. These resource limitations led to delays in construction schedules and backlogs of customer work were prioritized. Despite lower deployment than planned, National Grid continued construction and design/engineering work across all device types throughout 2021.
- Unitil deployment of VVO devices was below plans in 2021. Unitil did not fully deploy and commission devices at the Lunenburg and Summer Street substations as planned, as Unitil revised its VVO deployment timeline partway through 2021. Despite the shift in timeline, Unitil continued construction work throughout 2021 for Summer Street, Lunenburg, and West Townsend, as well as engineering/design work for the Princeton Road substation.

VVO Enablement:

- Eversource conducted VVO On/Off testing at all of its original 2018-2020 plan substations throughout 2021, conducting VVO On/Off testing at the Agawam, Piper, and Silver substations all year, and at the Podick substation beginning in March 2021. In tandem with VVO On/Off testing at the original 2018-2020 plan substations, Eversource conducted deployment of VVO devices across the Gunn and Oswald substations. VVO On/Off testing is expected to begin at these substations in May and June 2022, respectively.
- National Grid has completed deployment of VVO on all original 2018-2020 plan feeders and conducted VVO On/Off testing on these feeders throughout 2021. On its additional feeders, National Grid completed VVO deployment at the East Bridgewater substation and has been conducting VVO On/Off testing since July 2021. VVO On/Off testing is expected to begin for the East Dracut and West Salem substations in June 2022, and is expected to begin for the Easton, Melrose, and Westboro substations in December 2022.

- Unitil VVO enablement fell short of its schedule laid out in the PY2020 Evaluation Report. Unitil completed VVO deployment at the Townsend substation in 2021, enabling VVO in December. VVO On/Off testing is expected to begin at the Townsend substation in April 2022. For the Summer Street, Lunenburg, and West Townsend substations, VVO On/Off testing is expected to begin in December 2022, December 2023, and December 2024, respectively.

Total Spend:

- Eversource spend in 2021 was lower than plans for all device types. Eversource scaled down plans for the Oswald and Gunn substations, reducing spend on capacitor banks and regulators. In addition, vendor lead times and crew resources required for deployment of VVO devices were committed to other Eversource objectives, contributing to Eversource's delay in meeting deployment goals set out for 2021. Lastly, Gunn and Oswald substations did not require LTC control devices, as these devices had been completed historically, reducing spend on LTC controls. These factors combined to keep spend lower than plans on all device types.
- National Grid spend in 2021 was lower than plans for all device types except for LTC controls. Spend on LTC controls exceeded plans due to significant engineering required for VVO to be operational and due to initial cost estimates being too conservative. Despite higher-than-expected spending on LTC controls, spending across all VVO devices was lower than planned. The largest factors for lower spend was increased vendor lead times, leading to delays in fully commissioning devices, as well as increased efficiencies in VVO device pre-testing and field commissioning because of prior lessons learned during deployment of VVO devices in 2018-2020.
- Unitil spending on VVO devices was below plans in 2021. Spend during 2021 covered fully commissioning VVO devices at the Townsend substation. However, given Unitil shifted its deployment timeline, spend that would have been conducted on commissioning VVO devices at Summer Street, Lunenburg, and West Townsend has been deferred. Spending at these substations was instead focused on construction work.

The EDCs are slated to complete carryover deployment of VVO investments throughout 2022. In particular:

- Eversource carryover deployment and spending for 2022 spans completing deployment of regulators, capacitor banks, and line sensors on the Gunn and Oswald circuits. Additionally, carryover deployment and spending will cover deployment of grid monitoring line sensors across numerous substations in Eastern and Western Massachusetts. Total spend through 2022 is expected to end up below plans.
- National Grid carryover deployment and spending for 2022 covers carryover work that was initially planned for 2021 across five of six new substations, which will include work to bring devices from the construction and in-service phases to commissioned. VVO is then expected to conduct VVO On/Off testing starting in June 2022 for 2 substations and starting in December 2022 for 3 substations. Total spend and deployment through 2022 is expected end up above plans.
- Unitil carryover deployment and spending for 2022 spans deployment VVO devices at substations identified in recent 4-year Term plan totals. Remaining carryover deployment spans commissioning the remaining VVO devices at the Summer Street, Lunenburg,

and West Townsend substations in 2022 through 2024. In addition, deployment and spend spans continuing design/engineering and construction work across additional substations slated to receive VVO between 2022 and 2028.

3.2.2 Eversource

This section discusses Eversource's VVO investment progress through PY2021 as compared to the *2020 GMP Annual Report*. Eversource spend and deployment referenced throughout this section includes spend and deployment for grid monitoring line sensors and microcapacitors.

3.2.2.1 Overview of GMP Deployment Plan

Approach to VVO
Eversource is making VVO investments across six substations, amounting to 32 feeders. In deployment planning, the substations and feeders were selected based on whether they could be controlled from a single control room, cover a mix of residential, commercial, and industrial customers, and cover a range of distributed generation capacities. Substation selections were based on engineering analysis and coordination with grid modernization teams. This resulted in the selection of Agawam, Piper, Podick, and Silver substations, spanning 26 feeders, as part of the original 2018–2020 plan. Eversource is currently deploying VVO across an additional 6 feeders at the Gunn and Oswald substations.

Table 28 and Table 29 summarize the planned and actual deployment and spending on VVO from 2018 through 2021. Eversource is currently conducting VVO On/Off testing across 26 feeders connected to the original 2018 – 2020 plan Agawam, Piper, Podick, and Silver substations. Throughout PY2021, Eversource conducted work to deploy VVO on feeders connected to the Gunn and Oswald substations.

Table 28. Eversource VVO Feeder Deployment Year-over-Year Comparison

Data	2018	2019	2020	2021	2018-2021
EDC Actual Progress	0	0	26	26	26
EDC Original Plan[33]	0	5	26	N/A	26
% EDC Actual Progress/EDC Original Plan	N/A	0%	100%	N/A	100%
EDC Revised Plan[34]	0	0	26	32	32
% EDC Revised Plan/EDC Original Plan	100%	0%	100%	N/A	123%

Source: Guidehouse analysis of 2021 GMP Annual Reports and 2021 EDC Data

orders were addressed after these dates via email.

or 2018 and 2019, along with plans reported for 2020, contained in the EDC's 2019 GMP Annual Report, Appendix 1.

[34] Based on the EDC's actual progress in PY2018 – PY2021 and updated projections for PY2022.

Table 29. Eversource VVO Investment Year-over-Year Comparison ($M)**

Data	2018	2019	2020	2021	2018-2021
EDC Actual Progress	$0.4	$7.8	$4.7	$1.9	$14.8
EDC Original Plan[35]	$0.4	$7.8	$4.7	$6.0	$18.9
% EDC Actual Progress/EDC Original Plan	100%	100%	100%	32%	78%
EDC Revised Plan[36]	$0.4	$7.8	$4.7	$1.9	$14.8
% EDC Revised Plan/EDC Original Plan	100%	100%	100%	32%	78%

*Note: Due to rounding error, manual calculations of % EDC Actual Progress / EDC Original Plan and % EDC Revised Plan / EDC Original Plan will not precisely match calculated numbers provided in this table.

Source: Guidehouse analysis of 2021 GMP Annual Reports and 2021 EDC Data

Table 30 highlights Eversource feeder characteristics as of the end of 2021. Feeder lengths and customer counts vary considerably across VVO feeders. Selected substations also present a mix of distributed generation capacity across feeders, with distributed generation capacity ranging from 0.0 MW to 14.0 MW. Appendix A.2 contains additional information related to the VVO feeders.

Table 30. 2021 Eversource VVO Feeder Characteristics

Substation	Feeder	Feeder Length (mi.)	Customer Count	Annual Peak Load (MVA)	Distributed Generation (MW)
Original 2018–2020 Plan Feeders					
Agawam (13.8 kV)	**16C11**	24	1,321	6.5	2.1
	16C12	6	79	5.1	2.0
	16C14	16	1,640	6.6	0.1
	16C15	11	1,271	4.4	0.1
	16C16	23	2,606	7.7	2.4
	16C17	29	2,379	7.4	1.1
	16C18	21	3,047	6.7	0.7
Piper (13.8 kV)	**21N4**	33	2,303	7.4	1.5
	21N5	15	829	8.9	0.2
	21N6	15	787	4.3	0.5
	21N7	5	2	5.0	0.0
	21N8	9	558	7.0	0.1
	21N9	24	2,412	6.6	0.9
Podick (13.8 kV)	**18G2**	5	10	0.6	0.0
	18G3	37	2,122	4.0	2.1
	18G4	35	2,334	4.8	5.6
	18G5	40	1,761	5.9	5.7
	18G6	38	1,277	5.1	3.5
	18G7	64	2,208	4.5	11.0

[35] The EDC original plan includes actuals reported for 2018,2019, and 2020, along with plans reported for 2021, contained in the EDC’s 2020 GMP Annual Report, Appendix 1.

[36] Based on the EDC’s actual progress in PY2018 – PY2021.

Substation	Feeder	Feeder Length (mi.)	Customer Count	Annual Peak Load (MVA)	Distributed Generation (MW)
	18G8	46	1,079	7.5	8.6
Silver (13.8 kV)	**30A1**	36	2,454	8.5	1.3
	30A2	12	986	9.8	0.3
	30A3	12	242	6.3	5.1
	30A4	11	794	6.6	0.3
	30A5	21	1,648	4.7	0.7
	30A6	20	997	5.3	2.2
Additional Feeders					
Gunn (23 kV)	**15A1**	78	3,108	8.5	5.2
	15A2	22	2,107	9.6	4.0
	15A3	96	3,737	8.6	4.8
	15A5	31	3,404	7.1	1.9
Oswald (23 kV)	**30B5**	34	2,442	4.5	4.8
	30B7	85	1,943	7.4	14.0

Source: 2021 GMP Annual Report, Appendix 1 filed April 1, 2022.

Feeder lengths and customer counts vary considerably across Eversource feeders selected for VVO. Consistent with the substation selection process adopted by Eversource, VVO substations present a mix of distributed generation capacity across feeders, with distributed generation capacity ranging from 0 MW to 11 MW. Appendix 5.3A.1 contains additional information related to the VVO feeders

VVO Timeline

Table 31 and Table 32 summarize substation-specific progress in each of the four VVO investment phases.

Table 31. Eversource Original 2018–2020 Plan Feeders Deployment Completion Dates

Phase	Agawam	Piper	Podick	Silver
VVO Investment	1/14/2019-12/31/2019 (complete)	1/14/2019-12/31/2019 (complete)	3/29/2019-12/31/2019 (complete)	1/14/2019-12/31/2019 (complete)
VVO Commissioning[37]	11/1/2019-12/31/2019 (complete)	11/1/2019-12/31/2019 (complete)	11/1/2019-12/31/2019 (complete)	11/1/2019-12/31/2019 (complete)
VVO Enabled[38]	12/2/2020 (complete)	12/2/2020 (complete)	12/2/2020 (complete)	12/2/2020 (complete)
VVO On/Off Testing	12/2/2020-TBD (in progress)	12/2/2020-TBD (in progress)	3/4/2021-TBD (in progress)	12/2/2020-TBD (in progress)

Source: Guidehouse analysis of 2021 EDC Data

Table 32. Eversource Additional Feeders Deployment Completion Dates

Phase	Gunn	Oswald
VVO Investment[39]	1/1/2021-2/28/2023 (in progress)	1/1/2021-2/28/2023 (in progress)
VVO Commissioning[40]	2/1/2022-4/1/2022 (planned)	3/1/2022-5/1/2022 (planned)
VVO Enabled[41]	4/15/2022 (planned)	5/15/2022 (planned)
VVO On/Off Testing	5/1/2022-TBD (planned)	6/1/2022-TBD (planned)

Source: Guidehouse analysis of 2021 EDC Data

Eversource conducted VVO On/Off testing at all of its original 2018-2020 plan substations throughout 2021, conducting VVO On/Off testing at the Agawam, Piper, and Silver substations all year, and at the Podick substation beginning in March 2021. In tandem with VVO On/Off testing at the original 2018-2020 plan substations, Eversource conducted deployment of VVO

37 VVO Commissioning is the time at which VVO devices are controlled by and have data visible to each EDC.

38 VVO Enabled is the time at which the VVO system is commissioned and VVO is engaged.

39 Due to long vendor lead times, Eversource plans to commission VVO regulators after VVO On/Off testing has started at the Gunn and Oswald substations. regulators Eversource plans to modify voltage setpoints manually during the course of VVO On/Off testing prior to commissioning of VVO.

40 VVO Commissioning is the time at which VVO devices are controlled by and have data visible to each EDC.

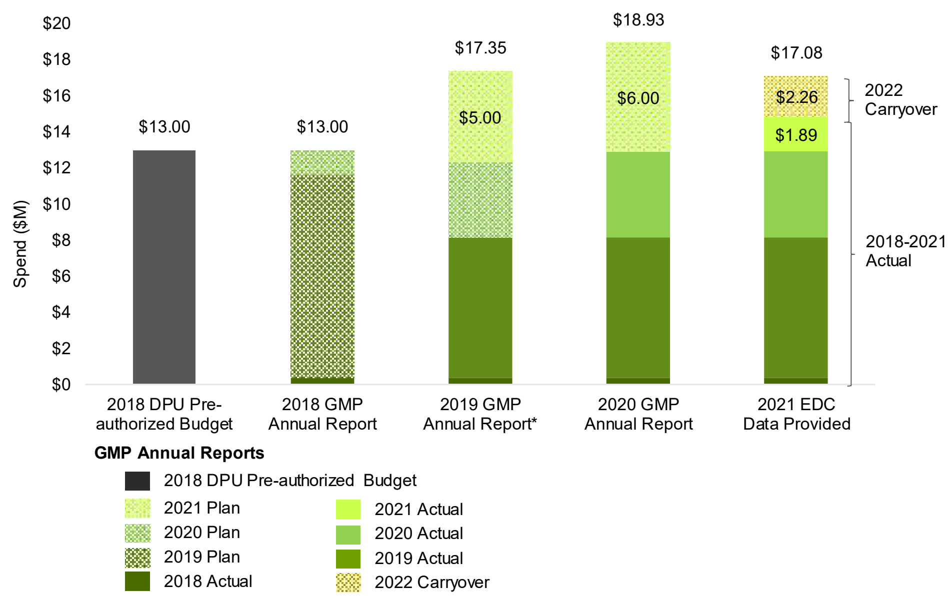
41 VVO Enabled is the time at which the VVO system is commissioned and VVO is engaged.

devices across the Gunn and Oswald substations. VVO On/Off testing is expected to begin at these substations in May and June 2022, respectively.

3.2.2.2 VVO Deployment Plan Progression

Figure 5 shows how Eversource's VVO deployment spend has progressed since the GMP was approved in 2018.

Figure 5. Eversource VVO Planned vs. Actual Spend (2018–2021, $M)



*Note that Eversource received pre-authorization from the Department for another $5 million in spending for its VVO investment area in late 2020.

Source: Guidehouse analysis of DPU Order (May 10, 2018), 2018-2020 GMP Annual Reports, Eversource GMP Extension and Funding Report filed on July 1, 2020Eversource extension filing, and 2021 EDC Data

Eversource deployment and spend in 2021 were below plans. Spend and deployment fell short of plans due to several factors. First, engineering and design work was delayed until the GMP Extension and Budget filing was pre-authorized in February 2021. In addition, Eversource faced procurement challenges throughout 2021, with vendor lead times well above what is usually observed.[42] Resource challenges were also prevalent, with full-crew resources required for deployment of VVO devices committed to other Eversource objectives, delaying Eversource's ability to meet deployment goals set out for 2021.

Eversource also scaled down spend and deployment for its Gunn and Oswald substations. Estimated spend and deployment for the two substations were based on a deployment footprint and equipment quantities roughly proportional to the VVO deployment on the original 2018-2020 feeders. Eversource proceeded with the Gunn substation as planned, but scaled down plans for the Oswald substation, which have fewer feeders per station bus than the 2018-2020

[42] Eversource has observed lead times double across some equipment types, with lead times for VVO regulators increasing from 52 weeks to over 100 weeks.

deployment.[43] In addition, the substations did not require LTC control devices or feeder head-end sensors, as these devices had been completed historically. Lastly, there were challenges and lessons learned from the initial deployment of VVO related to regulator deployment, including permitting difficulties and installation limitations. The count of regulators planned for Gunn and Oswald circuits was therefore reduced in consideration of those challenges, while still ensuring an effective VVO system is deployed.

3.2.2.3 VVO Device Type Progress through PY2021

Table 33 presents VVO enablement progress by substation, including actual and planned VVO enabled dates and notes on the status of VVO deployment.

Table 33. Eversource VVO Enabled Progress by Substation

Substation	January 2021 Planned/Actual VVO Enabled Date	January 2022 Planned/Actual VVO Enabled Date	Current Status[44]
Original 2018–2020 Plan Feeders			
Agawam	12/2/2020 (actual)	12/2/2020 (actual)	VVO On/Off testing in progress
Piper	12/2/2020 (actual)	12/2/2020 (actual)	VVO On/Off testing in progress
Podick	12/2/2020 (actual)	12/2/2020 (actual)	VVO On/Off testing in progress
Silver	12/2/2020 (actual)	12/2/2020 (actual)	VVO On/Off testing in progress
Additional Feeders			
Gunn	N/A	4/15/2022 (planned)	VVO Investment in progress
Oswald	N/A	5/15/2022 (planned)	VVO Investment in progress

Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

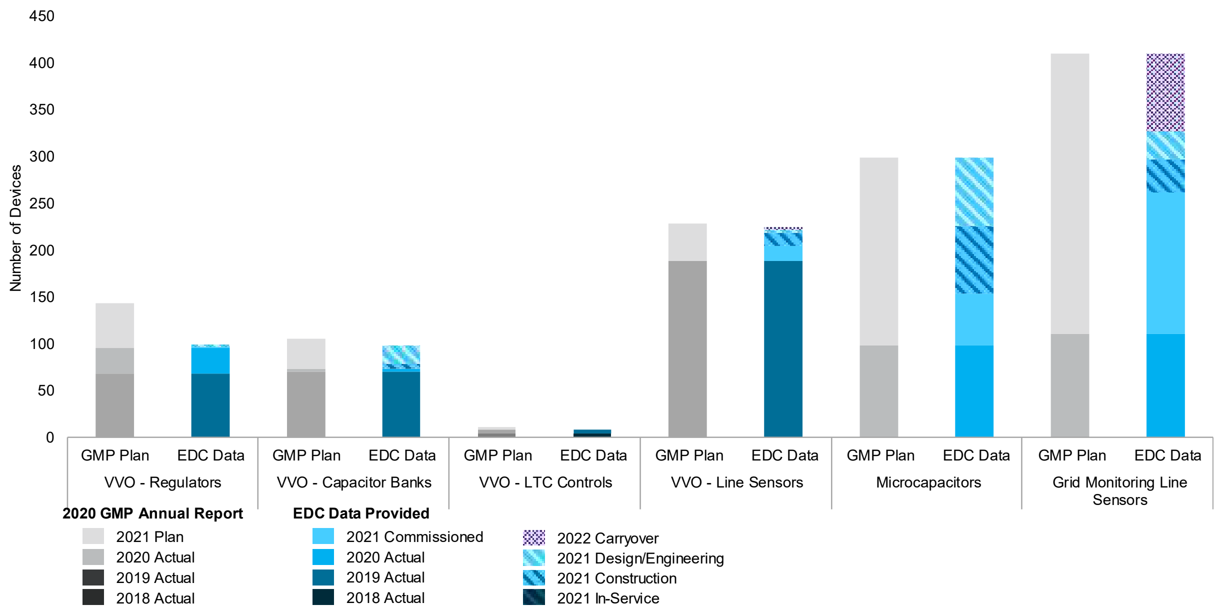
All original 2018-2020 plan feeders were VVO enabled as of December 2020. Additionally, Eversource conducted VVO On/Off testing at all of its original 2018-2020 plan substations throughout 2021, conducting VVO On/Off testing at the Agawam, Piper, and Silver substations all year, and at the Podick substation beginning in March 2021. In tandem with VVO On/Off testing at the original 2018-2020 plan substations, Eversource has conducted deployment of VVO devices across the Gunn and Oswald substations. VVO is expected to be enabled on April 15, 2022 and May 15, 2022, respectively, with VVO On/Off testing then expected to begin on May 1, 2022 and June 1, 2022.

Figure 6 shows the actual device deployment for all device types compared to the projected deployment in the *2020 GMP Annual Report*, as well as EDC-estimated deployment for 2022. Table 34 highlights the status of VVO investments through PY2021 for each device/investment type per the EDC data provided.

[43] Since part of the Oswald substation feeds underground network load that was not suitable for VVO, a lower-than-planned number of capacitor banks and regulators were required for VVO deployment at this substation.

[44] Status can be: planning, design, construction, device deployment complete, VVO commissioning in process, or VVO enabled.

Figure 6. Eversource Planned vs Actual Deployment (2018–2021, Unit Count)



Note that Carryover here would include all units not fully commissioned at the end of PY 2021.
Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Table 34. Eversource VVO Deployment Progress

	VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors	VVO - IT Work	Microcapacitors	Grid Monitoring Line Sensors
2018-2021 Total	**97**	**74**	**8**	**205**	**0**	**254**	**262**
2022 Carryover Estimate	0	0	0	3	0	0	84
Engineering/Design during PY 2021*	3	20	0	3	0	73	30
Construction during PY 2021*	0	5	0	14	0	72	35
In-Service during PY 2021*	0	0	0	0	0	0	0
Commissioned in PY 2021	1	0	0	16	0	55	151
Commissioned in PY 2020	27	3	0	0	0	99	111
Commissioned in PY 2019	69	71	4	189	0	0	0
Commissioned in PY 2018	0	0	4	0	0	0	0

**Deployment of these devices began during PY 2021, but was not completed during the program year. Deployment (through commissioning) is planned as carryover in 2022.*

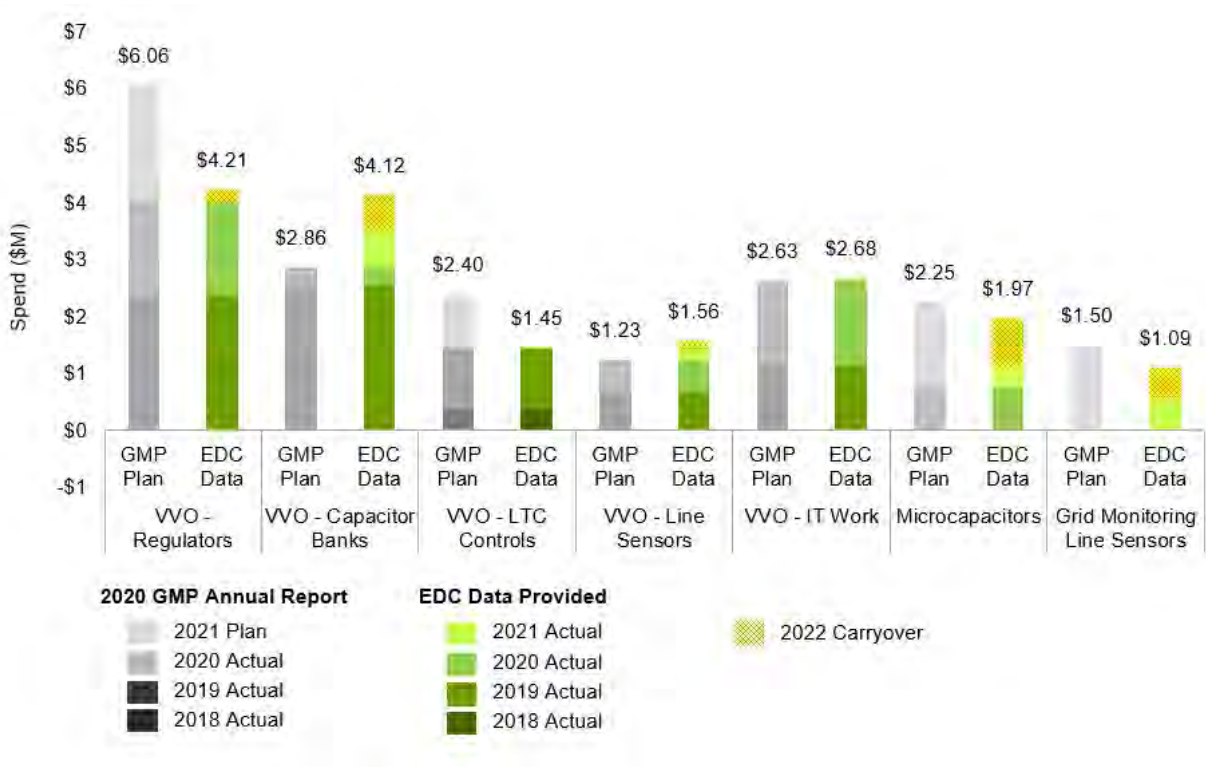
Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

On its original 2018–2020 plan feeders, Eversource completed deployment of VVO devices in 2020 and conducted VVO On/Off testing throughout 2021. On the additional feeders at the

Gunn and Oswald substations, Eversource commissioned a regulator and line sensors, and conducted construction and engineering/design work across regulators, capacitor banks, and line sensors. Since the Gunn and Oswald substations previously received LTC control device installation, Eversource did not deploy and does not plan to deploy additional LTC controls at the two substations. Lastly, Eversource conducted engineering/design, construction, and commissioning of microcapacitors and grid monitoring line sensors across numerous circuits in Eastern and Western Massachusetts. Carryover deployment for 2022 spans line sensors at Gunn and Oswald substations as well as grid monitoring line sensors across numerous substations in Eastern and Western Massachusetts.

Figure 7 presents planned versus actual spending on VVO devices, and Table 35 summarizes actual spending in PY2018 through PY2021, as well as EDC-estimated spending for 2022.

Figure 7. Eversource VVO Spend Plan vs. Actual (2018-2021, $M)



Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Table 35. Eversource Total Spend Comparison (2018–2021, $M)

	VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors	VVO - IT Work	Microcapacitors	Grid Monitoring Line Sensors
2018-2021 Total	**$3.99**	**$3.57**	**$1.45**	**$1.43**	**$2.68**	**$1.12**	**$0.59**
PY 2022 Estimate	$0.23	$0.55	$0.00	$0.13	$0.00	$0.85	$0.50
PY 2021 Actual	-$0.02	$0.71	$0.00	$0.20	$0.05	$0.36	$0.59
PY 2020 Actual	$1.63	$0.31	$0.03	$0.56	$1.47	$0.75	$0.00
PY 2019 Actual	$2.38	$2.55	$1.04	$0.68	$1.16	$0.00	$0.00
PY 2018 Actual	$0.00	$0.00	$0.38	$0.00	$0.00	$0.00	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Eversource spend in 2021 was lower than plans for all device types, while Eversource spend relative to plans for 2018 through 2021 varied based on VVO device type. For 2021 spend, Eversource scaled down plans for the Oswald substation, which have fewer feeders per station bus than the 2018-2020 deployment, reducing spend on capacitor banks and regulators.[45] In addition, vendor lead times and crew resources required for deployment of VVO devices were committed to other Eversource objectives, delaying Eversource's ability to meet deployment goals set out for 2021. Lastly, Gunn and Oswald substations did not require LTC control devices, as these devices had been completed historically, reducing spend on LTC controls. These factors combined to keep 2021 spend lower than plans on all device types.

For spend relative to plans spanning 2018 through 2021, regulators, microcapacitors, and grid monitoring line sensors costs including 2022 carryover are expected to be lower than initially planned. Costs are lower than planned for regulators, as the planned number of regulators for VVO was reduced to avoid permitting issues and to reduce installation and operational limitations while still deploying an effective VVO system. Costs for microcapacitors and grid monitoring line sensors are lower than planned, as deployment costs are lower than initially expected.

Carryover spending for 2022 spans deployment of regulators, capacitor banks, and line sensors at the Gunn and Oswald substations. In addition, carryover spending for 2022 spans deployment of grid monitoring line sensors across numerous substations in Eastern and Western Massachusetts.

3.2.2.4 Infrastructure Metrics Results and Key Findings

Table 36 and Table 37 present the Infrastructure Metrics results through PY2021 for Eversource.

[45] Since part of the Oswald substation feeds underground network load that was not suitable for VVO, a lower-than-planned number of capacitor banks and regulators were required for VVO deployment.

Table 36. 2021 Eversource Infrastructure Metrics for VVO Devices

Infrastructure Metrics			VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors	VVO - IT Work	Microcapacitors	Grid Monitoring Line Sensors
GMP Plan Total, 2018-2021		Devices	144	106	12	229	0	299	411
		Spend, $M	$6.06	$2.86	$2.40	$1.23	$2.63	$2.25	$1.50
IM-4	Number of devices or other technologies deployed PY2018-2021*	# Devices Deployed	97	74	8	205	0	154	262
		% Devices Deployed	67%	70%	67%	90%	N/A	52%	64%
IM-5	Cost for Deployment PY2018-2021*	Total Spend, $M	$3.99	$3.57	$1.45	$1.43	$2.68	$1.12	$0.59
		% Spend	66%	125%	61%	116%	102%	50%	39%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	2%	0%	0%	40%	N/A	28%	50%
		% On Track (Spend)	-1%	N/A	0%	N/A	N/A	24%	39%
IM-7	Projected Deployment for the Remainder of the GMP Term**	# Devices Remaining	3	25	0	20	0	145	149
		Spend Remaining, $M	$0.23	$0.55	$0.00	$0.13	$0.00	$0.85	$0.50

*The metric names have been slightly changed here to clarify the time span used in analysis.

** This metric has been interpreted here as the "carryover" units and spending that Eversource is planning in 2022 or beyond to complete their most recent 4-year Term plan totals. These most recent plan totals were included in the Eversource's 2020 Grid Modernization Plan, and included planned units and spending to be completed in PY2021.

Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Table 37. 2021 Eversource Infrastructure Metrics for VVO Feeders

IM	Metric	Parameter	Number of Feeders
IM-4	Number of Devices/Technologies Deployed	# Feeders with VVO Enabled	26
		% Feeders with VVO Enabled	100%
IM-6	Deviation Between Actual and Planned Deployment	% On Track (Feeders with VVO Enabled)	100%
IM-7	Projected Deployment for the Remainder of the GMP Term*	# Feeders Remaining for VVO Enablement	0

* Does not include 6 additional feeders that were not laid out in the original 3-Year Grid Modernization Plans.

Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Guidehouse's review of Eversource's VVO progress revealed that Eversource were below planned spend and deployment outlined in their *2020 GMP Annual Report*. Key findings related to Eversource's progress include:

- Eversource overall deployment and spend were below plans for 2021 and for 2018-2021, however this varied by device type.[46] Overall spend and deployment are below plans due to several factors, including delayed engineering and design work, long vendor lead times, and crew resource constraints, delaying Eversource's ability to meet deployment goals set out for 2021. Additionally, Eversource scaled down deployment plans for its Gunn and Oswald substations, as the substations required fewer regulators and capacitor banks for VVO and did not require LTC control devices or new feeder head sensors, as these devices were already deployed in prior capital projects.
- On its original 2018 – 2020 plan feeders, Eversource completed deployment of VVO devices in 2020 and conducted VVO On/Off testing throughout 2021. Eversource conducted VVO On/Off testing at the Agawam, Piper, and Silver substations all year, and at the Podick substation beginning in March 2021. VVO is expected to be enabled in April 2022 at the Gunn substation and May 2022 at the Oswald substation, with VVO On/Off testing then expected to begin in May 2022 and June 2022.
- On the additional feeders at the Gunn and Oswald substations, Eversource conducted construction and engineering/design work across regulators, capacitor banks, and line sensors. In addition, Eversource commissioned a regulator and line sensors. Since the Gunn and Oswald substations previously received LTC control device installation, Eversource did not deploy and does not plan to deploy additional LTC controls at the two substations. Across numerous substations in Eastern and Western Massachusetts, Eversource conducted engineering/design, construction, and commissioning of microcapacitors and grid monitoring line sensors.
- Carryover deployment and spending for 2022 spans completing deployment of regulators, capacitor banks, and line sensors at the Gunn and Oswald substations. In addition, carryover deployment and spending for 2022 spans completing deployment of grid monitoring line sensors across numerous substations in Eastern and Western Massachusetts.

3.2.3 National Grid

This section discusses National Grid's planned and actual VVO investment progress through PY2021. Overview of GMP Deployment Plan

Approach to VVO
National Grid is deploying VVO investments across the East Methuen, Stoughton, and Maplewood substations, contained within the 2018–2020 GMP, amounting to 20 feeders. In addition, National Grid is deploying VVO investments across 34 feeders connected to the East Bridgewater, East Dracut, Easton, Melrose, Westboro, and West Salem substations. National Grid selected substations for VVO primarily based on whether they yielded the greatest customer savings. Other considerations in the selection process included the future or ongoing planned work scopes, resourcing availability, and a load flow and power quality analysis.

Table 38 and Table 39 summarize the planned and actual deployment and spending on VVO from 2018 through 2021. National Grid is conducting VVO On/Off testing across 20 feeders connected to the original 2018 – 2020 plan East Methuen, Stoughton, and Maplewood substations. During the time of the previous evaluation, for PY2021 National Grid planned to

[46] For more information on spending and deployment by device type, please refer to Section 3.2.2.3.

deploy VVO on 19 feeders connected to East Bridgewater, East Dracut, and West Salem substations. Throughout PY2021, National Grid conducted work to deploy VVO on feeders connected to the Easton, Melrose, and Westboro substations.

Table 38. National Grid VVO Feeder Deployment Year-over-Year Comparison

Data	2018	2019	2020	2021	2018-2021
EDC Actual Progress	0	0	6	27	27
EDC Original Plan[47]	0	0	16	N/A	16
% EDC Actual Progress/EDC Original Plan	100%	0%	38%	N/A	169%
EDC Revised Plan[48]	0	0	6	33	39
% EDC Revised Plan/EDC Original Plan	100%	100%	100%	N/A	244%

Source: Guidehouse analysis of 2021 GMP Annual Reports and 2021 EDC Data

Table 39. National Grid VVO Investment Year-over-Year Comparison ($M)*

Data	2018	2019	2020	2021	2018-2021
EDC Actual Progress	$0	$2.6	$9.4	$5.1	$17.1
EDC Original Plan[49]	$0	$2.6	$9.4	$7.3	$19.3
% EDC Actual Progress/EDC Original Plan	N/A	100%	100%	70%	89%
EDC Revised Plan[50]	N/A	$2.6	$9.4	$5.1	$17.1
% EDC Revised Plan/EDC Original Plan	N/A	100%	100%	70%	89%

*Note: Due to a rounding error, manual calculations of % EDC Actual Progress / EDC Original Plan and % EDC Revised Plan / EDC Original Plan will not precisely match calculated numbers provided in this table.

Source: Guidehouse analysis of 2021 GMP Annual Reports and 2021 EDC Data

Table 40 highlights National Grid VVO feeder characteristics as of the end of 2021. Feeder lengths and customer counts vary considerably across VVO feeders. Selected substations also present a mix of distributed generation capacity across feeders, with distributed generation capacity ranging from 0.2 MW to 7.5 MW. Appendix A.2 contains additional information related to the VVO feeders.

[47] The EDC original plan includes actuals reported for 2018,2019, and 2020, along with plans reported for 2021, contained in the EDC's 2020 GMP Annual Report, Appendix 1.

[48] Based on the EDC's actual progress in PY2018 – PY2021.

[49] The EDC original plan includes actuals reported for 2018,2019, and 2020, along with plans reported for 2021, contained in the EDC's 2020 GMP Annual Report, Appendix 1

[50] Based on the EDC's actual progress in PY2018 – PY2021.

Table 40. 2021 National Grid VVO Feeder Characteristics

Substation	Feeder	Feeder Length (mi.)	Customer Count	Annual Peak Load (MVA)	Distributed Generation (MW)
Original 2018–2020 Plan Feeders					
East Methuen (13.2 kV)	74L1	39	3,081	11.1	5.7
	74L2	17	1,578	6.6	0.5
	74L3	20	3,283	7.1	1.8
	74L4	9	1,611	6.6	1.1
	74L5	54	3,108	9.9	1.2
	74L6	8	1,788	4.6	0.6
Stoughton (13.8 kV)	913W17	14	1,354	5.3	1.7
	913W18	12	1,530	4.8	0.6
	913W43	32	2,119	7.7	1.2
	913W47	16	1,813	6.1	0.5
	913W67	13	738	3.1	0.8
	913W69	32	3,607	10.2	1.5
Maplewood (13.8 kV)	16W1	17	3,597	4.5	1.1
	16W2*	11	4,619	9.8	0.9
	16W3	13	3,018	7.8	0.6
	16W4	8	1,111	5.1	0.8
	16W5	7	1,650	11.0	1.0
	16W6*	25	5,696	12.2	1.7
	16W7*	14	3,857	9.8	1.6
	16W8*	16	3,371	7.0	1.6
Additional Feeders					
East Bridgewater (13.8 kV)	797W1	35	2,762	9.9	1.4
	797W19	38	2,549	8.7	2.4
	797W20	31	1,709	10.0	0.6
	797W23	41	2,707	10.3	1.5
	797W24	54	2,560	10.1	1.3
	797W29	37	2,335	8.4	1.9
	797W42	22	1,248	4.6	1.9
East Dracut (13.2 kV)	75L1	16	3,022	7.4	0.8
	75L2	39	2,546	8.1	0.9
	75L3	49	2,291	9.6	2.0
	75L4	9	385	2.8	0.2
	75L5	19	3,593	7.6	0.9
	75L6	25	1,518	8.0	0.8
Easton (13.8 kV)	92W43	28	1,964	7.7	1.1
	92W44	26	1,764	8.3	1.2
	92W54	34	2,282	6.5	7.5
	92W78	38	1,961	11.2	0.8
	92W79	24	1,617	6.1	5.3
	25W1	19	1,586	11.4	2.3

Substation	Feeder	Feeder Length (mi.)	Customer Count	Annual Peak Load (MVA)	Distributed Generation (MW)
Melrose (13.8 kV)	**25W2**	17	1,242	6.4	0.8
	25W3	9	732	11.0	0.3
	25W4	20	4,543	6.6	1.0
	25W5	20	3,823	9.7	1.3
Westboro (13.8 kV)	**312W1**	31	2,249	10.4	1.9
	312W2	9	186	5.3	3.0
	312W3	21	1,351	8.0	0.9
	312W4	55	2,650	9.7	4.8
	312W5	14	423	10.2	0.9
West Salem (13.8 kV)	**29W1**	23	3,782	10.3	1.9
	29W2	15	1,477	6.0	0.9
	29W3	15	4,228	9.8	1.2
	29W4	18	2,671	8.8	1.8
	29W5	12	2,839	7.0	1.1
	29W6	17	1,353	6.7	1.2

* Additional feeders that were not included in the original set of 16 reported for 2018–2020 VVO investment.
Source: 2021 GMP Annual Report, Appendix 1 filed April 1, 2022. EDCs provided distributed generation data.

VVO Timeline

Table 41, Table 42, and Table 43 summarize substation-specific progress in each of the four VVO investment phases. The evaluation of Infrastructure Metrics spans spending and deployment under the VVO investment and VVO commissioning stages.

Table 41. National Grid Original 2018–2020 Plan Feeders Deployment Completion Dates

Phase	E. Methuen	Maplewood	Stoughton
VVO Investment	2/1/2020-8/31/2020 (complete)	1/15/2020-7/15/2020 (complete)	11/15/2019-3/31/2020 (complete)
VVO Commissioning[51]	7/27/2020-1/22/2021 (complete)	7/15/2020-12/15/2021 (complete)	5/1/2020-7/23/2020 (complete)
VVO Enabled Date[52]	2/8/2021 (complete)	12/16/2021 (complete)	7/24/2020 (complete)
VVO On/Off Testing Period	3/1/2020-TBD (in progress)	12/16/2021-TBD (in progress)	*12/1/2020*- 9/1.2021 (complete)

Source: Guidehouse analysis of 2021 EDC Data

[51] VVO Commissioning is the time at which VVO devices are controlled by and have data visible to each EDC.
[52] VVO Enabled is the time at which the VVO system is commissioned and VVO is engaged.

Table 42. National Grid Additional Feeders Deployment Completion Dates

Phase	E. Bridgewater	E. Dracut	Easton
VVO Investment	5/15/2020-6/1/2021 (complete)	1/1/2021-5/1/2022 (in progress)	1/1/2021-10/14/2022 (*in progress*)
VVO Commissioning	6/1/2021-7/29/2021 (complete)	5/1/2022-5/31/2022 (planned)	10/15/2022-11/14/2022 (*planned*)
VVO Enabled Date	7/29/2021 (complete)	6/1/2022 (planned)	11/15/2022 (*planned*)
VVO On/Off Testing Period	7/30/2021-TBD (in progress)	6/15/2022-3/15/2023 (planned)	12/2/2022-9/15/2023 (*planned*)

Source: Guidehouse analysis of 2021 EDC Data

Table 43. National Grid Additional Feeders Deployment Completion Dates Continued

Phase	Melrose	Westboro	W. Salem
VVO Investment	1/1/2021-10/14/2022 (in progress)	1/1/2021-10/14/2022 (in progress)	1/1/2021-3/31/2022 (in progress)
VVO Commissioning	10/15/2022-11/14/2022 (planned)	10/15/2022-11/14/2022 (planned)	4/1/2022-5/31/2022 (planned)
VVO Enabled Date	11/15/2022 (planned)	11/15/2022 (planned)	6/1/2022 (planned)
VVO On/Off Testing Period	12/2/2022-9/15/2023 (planned)	12/2/2022-9/15/2023 (planned)	6/15/2022-3/15/2023 (planned)

Source: Guidehouse analysis of 2021 EDC Data

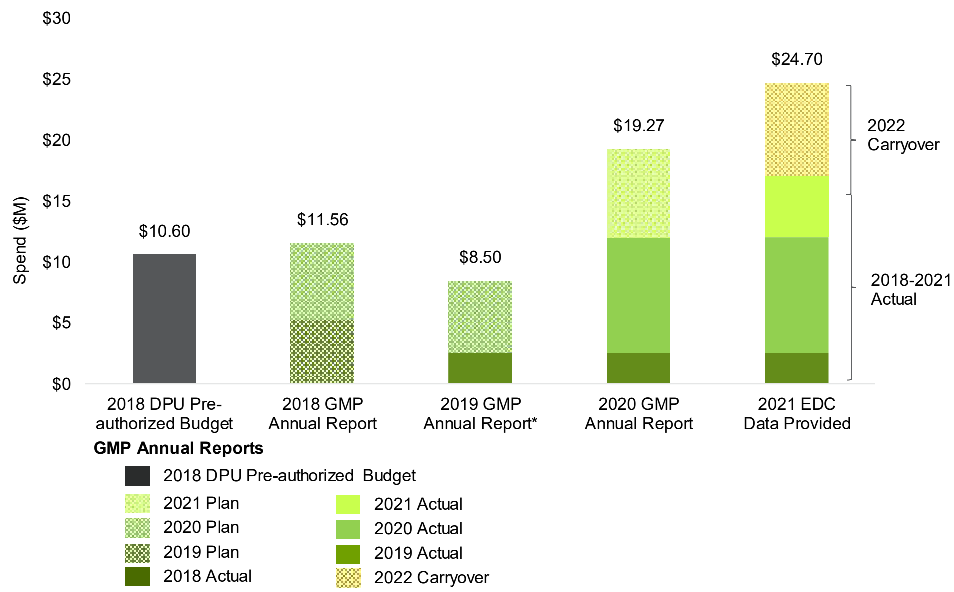
National Grid has completed deployment of VVO on all original 2018-2020 plan feeders and conducted VVO On/Off testing on these feeders throughout 2021. Stoughton feeders have been undergoing VVO On/Off testing since December 2020, whereas East Methuen and Maplewood feeders have been undergoing VVO On/Off testing since March 2021 and December 2021, respectively.

On its additional feeders, National Grid completed VVO deployment at the East Bridgewater substation and began VVO On/Off testing in July 2021. VVO On/Off testing is expected to begin for the East Dracut and West Salem substations in June 2022, and is expected to begin for the Easton, Melrose, and Westboro substations in December 2022.

3.2.3.1 VVO Deployment Plan Progression

Figure 8 shows how National Grid's VVO deployment spend has progressed since the GMP was approved in 2018.

Figure 8. National Grid's VVO Planned and Actual Spend Progression, $M



Source: Guidehouse analysis of DPU Order (May 10, 2018), 2018-2020 GMP Annual Reports, and 2021 EDC Data

National Grid deployment and spend in 2021 were lower than initially planned. Crew resources became limited due to COVID-19 quarantine policies and sick leave causing work both on VVO and customer related projects to be postponed. As COVID-19 restriction policies eased, previously delayed customer work became the priority. This has led to actual deployment in 2021 being lower than initially planned. In addition, spending on regulators, capacitor banks, and line sensors were lower than plans, as overhead line operations gained efficiency from prior lessons learned, reducing spend devoted to installation and testing of VVO devices during pre-testing and field commissioning. In the meantime, spending on LTC controls exceeded plans due to significant engineering required to implement all necessary features for VVO to function properly.

National Grid is expected to have both deployment and spend end up above original plans when considering 2022 carryover. Spend in 2022 includes carryover work that was initially planned for 2021 across five of the six new substations, which will include work to bring devices from the construction and in-service phases to commissioned. VVO is then expected to be engaged and VVO On/Off testing started by June 2022 for 2 substations and by December 2022 for 3 substations.

3.2.3.2 VVO Investment Progress through PY2021

Table 44 presents VVO enablement progress by substation, including anticipated and actual VVO enabled dates and notes on the current status of VVO deployment.

Table 44. National Grid VVO Enabled Progress by Substation

Substation	January 2021 Planned/Actual VVO Enabled Date	January 2022 Planned/Actual VVO Enabled Date	Current Status[53]
Original 2018–2020 Plan Feeders			
E. Methuen	2/8/2021 (actual)	2/8/2021 (actual)	VVO On/Off testing in progress
Maplewood	6/1/2021 (planned)	12/16/2021 (actual)	VVO On/Off testing in progress
Stoughton	7/24/2020 (actual)	7/24/2020 (actual)	VVO On/Off testing in progress
Additional Feeders			
E. Bridgewater	5/1/2021 (planned)	7/29/2021 (actual)	VVO On/Off testing in progress
E. Dracut	6/16/2021 (planned)	6/1/2022 (planned)	Construction
Easton	N/A	11/15/2022 (planned)	Construction
Melrose	N/A	11/15/2022 (planned)	Construction
Westboro	N/A	11/15/2022 (planned)	Construction
W. Salem	6/16/2021 (planned)	6/1/2022 (planned)	Construction

Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

All original 2018-2020 plan feeders are currently undergoing VVO On/Off testing. VVO On/Off testing began in December 2020 for the Stoughton substation and in March 2021 for the East Methuen substation. For the Maplewood substation, VVO was expected to be enabled in May 2021 and VVO On/Off testing was slated to begin in June 2021. However, due to delays in device commissioning, National Grid began VVO On/Off testing in December 2021 for the Maplewood substation.

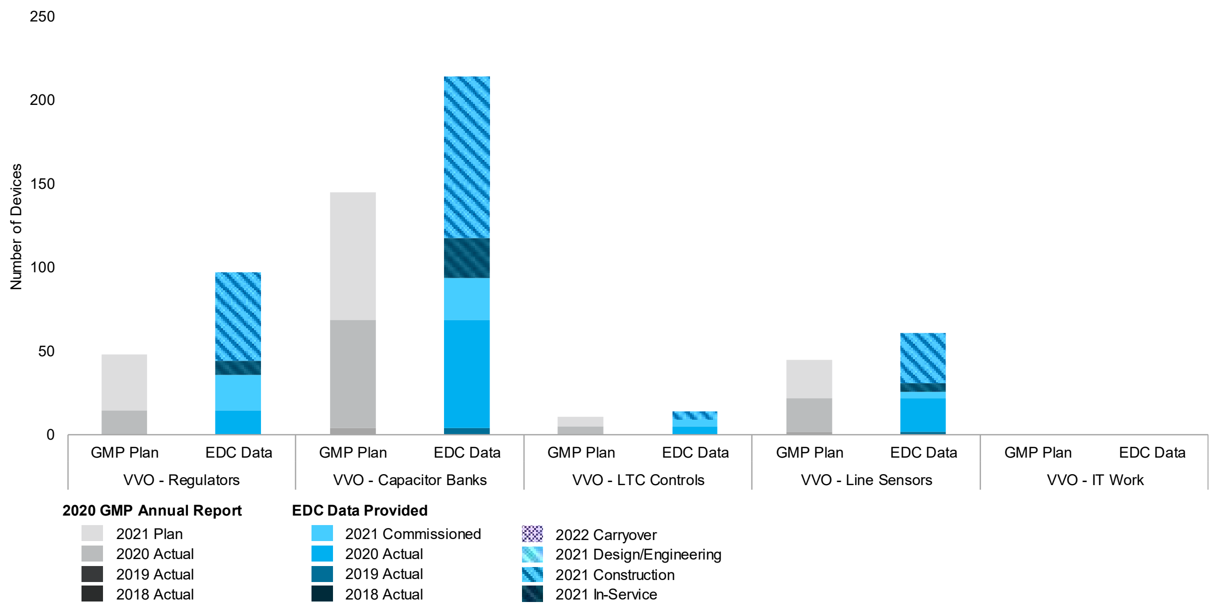
For National Grid's additional feeders receiving VVO, National Grid anticipated beginning VVO On/Off testing on in June 2021 at the East Bridgewater, East Dracut, and West Salem substations. However, due to deployment delays, this timeline has slipped, and East Bridgewater was the sole substation amongst the list of additional substations receiving VVO that began VVO On/Off testing in July 2021. East Dracut and West Salem substations are expected to undergo VVO On/Off testing beginning in June 2022.

National Grid added three additional substations to its VVO investment area since adding East Bridgewater, East Dracut, and West Salem to its plans in 2020. Therefore, the Easton, Melrose, and Westboro substations do not have a planned VVO enabled date listed for the January 2021 plan column in Table 44. As of January 2022, National Grid expects to complete VVO deployment and enable VVO in November 2022 across the three new substations, then expects to begin VVO On/Off testing in December 2022.

Figure 9 and Table 45 illustrate the actual device deployment for all device types compared to the projected deployment in the *2020 GMP Annual Report*, as well as 2022 EDC-estimated deployment.

[53] Status can be: planning, design, construction, device deployment complete, VVO commissioning in process, or VVO enabled.

Figure 9. National Grid VVO Device Deployment (2018–2021)



Note that Carryover here would include all units not fully commissioned at the end of PY 2021.
Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Table 45. National Grid VVO Planned and Actual Device Deployment (2018-2021)

	VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors	VVO - IT Work
2018-2021 Total	**39**	**94**	**9**	**24**	**0**
Engineering/Design during PY 2021*	0	0	0	0	0
Construction during PY 2021*	53	96	5	30	0
In-Service during PY 2021*	6	24	0	5	0
Commissioned in PY 2021	21	25	4	4	0
Commissioned in PY 2020	18	65	5	18	0
Commissioned in PY 2019	0	4	0	2	0
Commissioned in PY 2018	0	0	0	0	0

**Deployment of these devices began during PY 2021, but was not completed during the program year. Deployment (through commissioning) is planned as carryover in 2022.*

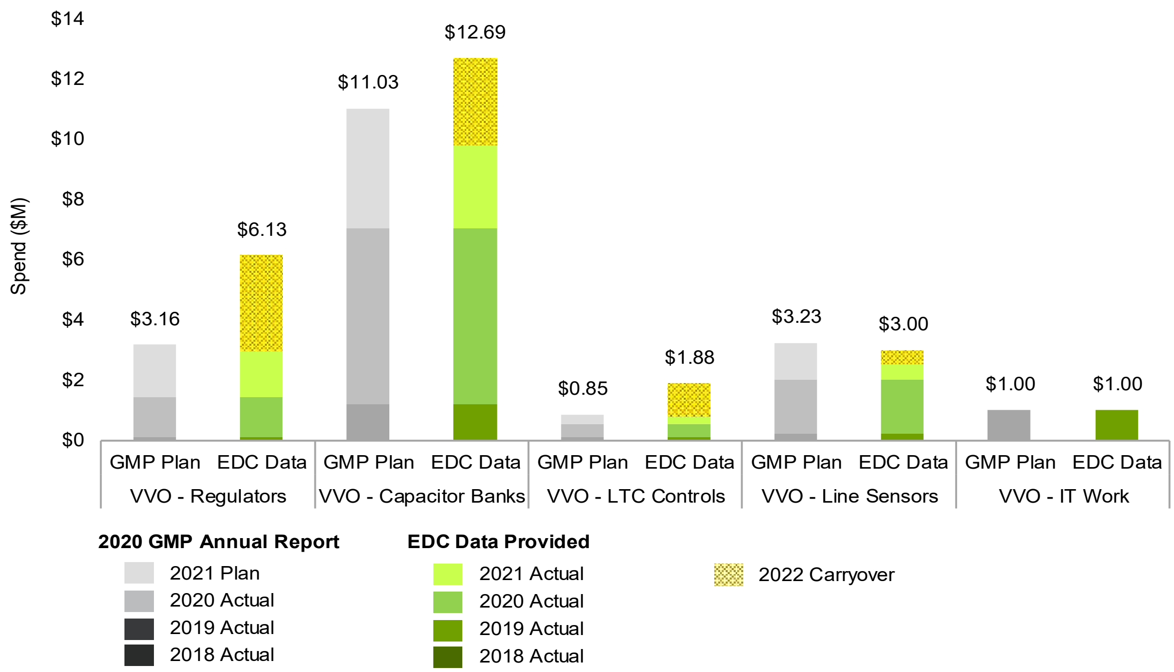
Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

National Grid deployment in 2018 through 2021 was lower than initially planned, with all devices having fewer fully commissioned devices that expected in the PY2020 Annual Report. However, when considering carryover deployment in 2022, all device types are expected to exceed planned deployment. One large factor at play in 2021 leading to lower than expected deployment was competing priorities of crew resources, leading to delays in fully commissioning devices. Despite lower deployment than planned, National Grid continued construction across all device types for six additional substations and numerous devices were placed in-service, awaiting full commissioning with the VVO system. These six additional substations are the East

Bridgewater, East Dracut, Easton, Melrose, Westboro, and West Salem substations, expected to be VVO engaged and begin VVO On/Off testing in 2022. Carryover deployment in 2022 is planned to cover completing commissioning of devices current in the construction and in-service phases in order to support full VVO operation by the end of 2022.

Figure 10 and Table 46 summarize planned and actual spending on VVO devices.

Figure 10. National Grid VVO Plan vs. Actual (2018–2021, $M)



Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Table 46. National Grid Total Spend Comparison (2018–2021, $M)

	VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors	VVO - IT Work
2018-2021 Total	**$2.95**	**$9.81**	**$0.76**	**$2.52**	**$1.00**
2022 Carryover Estimate	$3.18	$2.88	$1.13	$0.48	$0.00
PY 2021 Actual	$1.53	$2.79	$0.23	$0.51	$0.00
PY 2020 Actual	$1.34	$5.83	$0.45	$1.79	$0.00
PY 2019 Actual	$0.08	$1.19	$0.08	$0.22	$1.00
PY 2018 Actual	$0.00	$0.00	$0.00	$0.00	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Spend through the end of PY 2021 on regulators, capacitor banks, and line sensors were less than initially planned. National Grid gained efficiencies in VVO device pre-testing and field commissioning because of prior lessons learned during deployment of VVO devices in 2018-2020. As such, these efficiencies ultimately led to fewer person hours required to deploy VVO regulators, capacitor banks, and line sensors during PY 2021, resulting in lower spend than expected in 2021.

Spend on LTC controls exceeded plans for PY 2021. One such reason for greater-than-expected spend in 2021 was the significant engineering required for LTC controls, as each substation LTC control and associated mechanics are unique, so significant engineering is required to implement all the features and requirements of the VVO system.[54] Additionally, National Grid estimated the costs to be lower than required. During initial VVO deployment, cost estimates skewed too low due to conservative civil construction scopes that underestimated the overall schedule, labor, resources, and material needed. National Grid expects that subsequent years have better estimation based on these lessons learned.

National Grid is expected to spend above the original planned spend when considering 2022 carryover for regulators, capacitor banks, and LTC controls. Spend in 2022 includes carryover work that was initially planned for 2021 across five of the six new substations, which will include work to bring devices from the construction and in-service phases to commissioned. VVO is then expected to be engaged and VVO On/Off testing started by June 2022 for 2 substations and by December 2022 for 3 substations.

3.2.3.3 Infrastructure Metrics Results and Key Findings

Table 47 and Table 48 summarize the Infrastructure Metrics results through PY2021 for each investment type related to National Grid's VVO Investment Area.

[54] One such area is tap positions for LTC controls, since LTC controls do not have a digital signal for the tap position and require a mechanical solution that needs to be custom designed and fabricated for each LTC control to enable digital capabilities.

Table 47. National Grid Infrastructure Metrics Findings

Infrastructure Metrics			VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors	VVO - IT Work
GMP Plan Total, PY2018-2021		Devices	48	145	11	45	0
		Spend, $M	$3.16	$11.03	$0.85	$3.23	$1.00
IM-4	Number of devices or other technologies deployed PY2018-2021*	# Devices Deployed***	36	94	9	24	0
		% Devices Deployed	75%	65%	82%	53%	N/A
IM-5	Cost for Deployment PY2018-2021*	Total Spend, $M	$2.95	$9.81	$0.76	$2.52	$1.00
		% Spend	94%	89%	89%	78%	100%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	64%	33%	67%	17%	N/A
		% On Track (Spend)	88%	69%	71%	42%	N/A
IM-7	Projected Deployment for the Remainder of the GMP Term	# Devices Remaining	59	120	5	35	0
		Spend Remaining, $M	$3.18	$2.88	$1.13	$0.48	$0.00

*The metric names have been slightly changed here to clarify the time span used in analysis.

** This metric has been interpreted here as the "carryover" units and spending that National Grid is planning in 2022 or beyond to complete their most recent 4-year Term plan totals. These most recent totals were included in the National Grid's 2020 Grid Modernization Plan, which targeted the planned units and spending to be completed in PY2021.

***Note that "Deployed" here refers to commissioned devices. In National Grid's Term Report (filed April 1, 2022), deployed refers to in-service and/or commissioned devices. In-service devices are fully installed and used and useful, but not yet commissioned with Grid Mod functionality (communication and remote visibility and/or control). For full definitions of commissioned and in-service, see Docket 20-46 Response to Information Request DPU-AR-4-11, September 3, 2020.

Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Table 48. 2020 National Grid Infrastructure Metrics for VVO Feeders

IM	Metric	Parameter	Number of Feeders
IM-4	Number of Devices/Technologies Deployed	# Feeders with VVO Enabled	20
		% Feeders with VVO Enabled	100%
IM-6	Deviation Between Actual and Planned Deployment	% On Track (Feeders with VVO Enabled)	100%
IM-7	Projected Deployment for the Remainder of the GMP Term*	# Feeders Remaining for VVO Enablement	0

* Does not include 34 additional feeders that were not laid out in the original 3-Year Grid Modernization Plans.

Source: Guidehouse analysis of EDC Data

Guidehouse's review of National Grid's VVO progress revealed that National Grid spend and deployment were lower than plans outlined in their *2020 GMP Annual Report*. Key findings related to National Grid's progress include:

- National Grid deployment through 2021 is lower than initially planned, with all devices having fewer fully commissioned devices than planned. However, when considering carryover deployment in 2022, all device types are expected to exceed planned deployment. One large factor at play in 2021, leading to lower than expected deployment, competing priorities of crew resources, leading to delays in fully commissioning devices. Despite lower deployment than planned, National Grid continued construction and design/engineering work across all device types throughout 2021.

- Spend on regulators, capacitor banks, and line sensors in 2021 was less than initially planned, while spend on LTC controls exceeded plans in 2021. Spend on regulators, capacitor banks, and line sensors was lower than planned due to efficiencies in VVO device pre-testing and field commissioning because of prior lessons learned during deployment of VVO devices in 2018-2020. Spend on LTC controls exceeded plans due to significant engineering required for VVO to be operational and due to initial cost estimates being too conservative. Despite higher-than-expected spending on LTC controls, spending across all VVO devices was lower than planned.

- National Grid is expected to have both deployment and spend end up above original plans when considering 2022 carryover. Spend in 2022 includes carryover work that was initially planned for 2021 across five of six new substations, which will include work to bring devices from the construction and in-service phases to commissioned. VVO is then expected to be engaged and VVO On/Off testing started by June 2022 for 2 substations and by December 2022 for 3 substations.

- All original 2018-2020 plan feeders are currently undergoing VVO On/Off testing. VVO On/Off testing began in December 2020 for the Stoughton substation and in March 2021 for the East Methuen substation. For the Maplewood substation, VVO was expected to be enabled in May 2021 and VVO On/Off testing was slated to begin in June 2021. However, due to delays in equipment commissioning, National Grid began VVO On/Off testing in December 2021 for the Maplewood substation.

3.2.4 Unitil

This section discusses Unitil's planned and actual VVO investment progress through PY2021.

3.2.4.1 Overview of GMP Deployment Plan

Approach to VVO

Unitil's approach to VVO investment is unique. Unitil initially planned to enable VVO for the Townsend substation in 2019, the Lunenburg substation in 2020, and the Summer Street substation in 2021. This timeline was revised to allow Unitil to complete all grid modernization activities at a single substation before moving to another, as VVO is tied to the ADMS and M&C Investment Areas. For instance, deployment of VVO relies on the SCADA system being in place, tying the VVO deployment to the M&C Investment Area. The VVO project is also tied with the FAN deployment plan which will allow communication from the ADMS to the field devices. Unitil completed VVO deployment at Townsend substation in 2021 and plans to transition deployment activities to the Summer Street substation in 2022.

Table 49 and Table 50 summarize the planned deployment and spending on VVO from 2018 through 2022. Unitil plans to deploy VVO across all substations within its territory over a 10-year period. As of March 2021, Unitil planned to deploy VVO investments across 11 feeders connected to the Lunenburg, Summer Street, Townsend, and West Townsend substations at a cost of $4.0 million by the end of 2022. As of March 2022, this timeline has been revised due to equipment delays experienced throughout 2021. Deployment at the Townsend substation was completed in 2021, and deployment at the Summer Street, Lunenburg, and Townsend substations is expected to be complete in 2022, 2023, and 2024, respectively.

Table 49. Unitil VVO Feeder Deployment Year-over-Year Comparison

Data	2018	2019	2020	2021	2022	2018-2022
EDC Actual Progress	0	0	0	3	N/A	3
EDC Original Plan[55]	0	0	5	4	2	11
% EDC Actual Progress/EDC Original Plan	N/A	0%	0%	75%	N/A	27%
EDC Revised Plan[56]	N/A	N/A	0	5	6	11
% EDC Revised Plan/EDC Original Plan	N/A	N/A	0%	125%	300%	100%

Source: Guidehouse analysis of 2021 GMP Annual Reports and 2021 EDC Data

Table 50. Unitil VVO Investment Year-over-Year Comparison ($M)*

Data	2018	2019	2020	2021	2018-2021
EDC Actual Progress	$0	$0	$1.8	$0.7	$2.5
EDC Original Plan[57]	$0	$0	$1.8	$3.3	$5.1
% EDC Actual Progress/EDC Original Plan	100%	100%	100%	22%	49%
EDC Revised Plan[58]	N/A	N/A	$1.8	$0.7	$2.5
% EDC Revised Plan/EDC Original Plan	N/A	N/A	100%	22%	49%

*Note: Due to rounding error, manual calculations of % EDC Actual Progress / EDC Original Plan and % EDC Revised Plan / EDC Original Plan will not precisely match calculated numbers provided in this table.

Source: Guidehouse analysis of 2021 GMP Annual Reports and 2021 EDC Data

Table 51 highlights Unitil feeder characteristics for feeders to receive VVO investments between 2018 and 2022. Feeder lengths and customer counts vary considerably. Selected substations also present a mix of distributed generation capacity, with distributed generation capacity

[55] The EDC original plan includes actuals reported for 2018,2019, and 2020, along with plans reported for 2021, contained in the EDC's 2020 GMP Annual Report, Appendix 1.

[56] Based on the EDC's updated projections for PY2021.

[57] The EDC original plan includes actuals reported for 2018,2019, and 2020, along with plans reported for 2021, contained in the EDC's 2020 GMP Annual Report, Appendix 1.

[58] Based on the EDC's actual progress in PY2018 – PY2021.

ranging from 0 MW to 3.9 MW. Appendix 0 contains additional information related to the VVO feeders.

Table 51. 2021 Unitil VVO Feeder Characteristics

Substation	Feeder	Feeder Length (mi.)	Customer Count	Annual Peak Load (MVA)	Distributed Generation (MW)
Original 2018 – 2020 Plan Feeders					
Townsend (13.8 kV)	**15W15**	1	1	4.2	0.0
	15W16	41	1,523	5.4	1.6
	15W17	11	577	1.5	0.5
Lunenburg (13.8 kV)	**30W30**	46	1,363	5.3	1.5
	30W31	46	1,677	4.1	3.9
Summer Street (13.8 kV)	**40W38**	1	3	0.3	0.0
	40W39	8	430	5.0	1.0
	40W40	18	1,574	7.9	1.5
	40W42	13	1,785	3.7	0.5
Additional Feeders					
West Townsend (13.8 kV)	**39W18**	51	1,970	4.2	2.9
	39W19	62	1,331	3.1	3.4

Source: 2021 GMP Annual Report, Appendix 1 filed April 1, 2022. Distributed Generation data was provided by the EDCs.

VVO Timeline

Table 52 summarizes substation-specific progress in each of the four VVO investment phases. The evaluation of Infrastructure Metrics spans spending and deployment under the VVO investment and VVO commissioning phases.

Table 52. Unitil VVO Deployment Completion Dates by Phase and Substation

Phase	Lunenburg	Summer St.	Townsend	W. Townsend[59]
VVO Investment	1/1/2019-6/1/2023 (in progress)	1/1/2020-6/1/2022 (in progress)	1/1/2019-6/1/2021 (complete)	12/1/2020-6/1/2024 (in progress)
VVO Commissioning[60]	3/1/2023-10/1/2023 (planned)	3/1/2022-10/1/2022 (planned)	6/1/2021-12/1/2021 (complete)	3/1/2024-10/1/2024 (planned)
VVO Enabled Date[61]	11/1/2023 (planned)	11/1/2022 (planned)	12/1/2021 (complete)	11/1/2024 (planned)
VVO On/Off Testing Period	12/1/2023-9/1/2024 (planned)	12/1/2022-9/1/2023 (planned)	4/1/2022-TBD (planned)	12/1/2024-9/1/2025 (planned)

Source: Guidehouse analysis of 2021 EDC Data

Unitil completed VVO deployment at the Townsend substation in 2021, enabling VVO on December 1, 2021. VVO On/Off testing is expected to begin at the Townsend substation in April 2022 once Unitil fully integrates VVO with ADMS to ensure On/Off testing is conducted properly.[62] For the Summer Street, Lunenburg, and West Townsend substations, VVO On/Off testing is expected to begin in December 2022, December 2023, and December 2024, respectively.

3.2.4.2 VVO Deployment Plan Progression

Figure 11 shows how Unitil's VVO deployment spend has progressed since the GMP was approved in 2018.

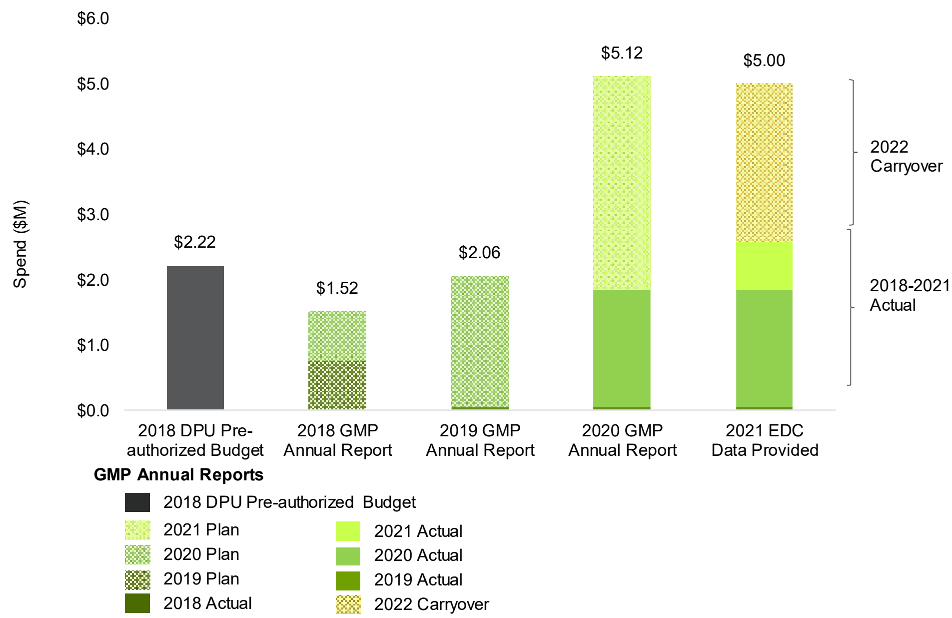
[59] West Townsend is an additional feeder not contained within the original 2018 – 2020 plan feeders that were slated to receive VVO.

[60] VVO Commissioning is the time at which VVO devices are controlled by and have data visible to each EDC.

[61] VVO Enabled is the time at which the VVO system is commissioned and VVO is engaged.

[62] Unitil has integrated VVO with ADMS and M&C investment areas. Unitil is currently conducting modeling using ADMS to ensure issues related to unbalanced load flow are resolved prior to beginning VVO On/Off testing.

Figure 11. Unitil's VVO Planned and Actual Spend Progression, $M



Source: Guidehouse analysis of DPU Order (May 10, 2018), 2018-2020 GMP Annual Reports, and 2021 EDC Data

Deployment and spending on VVO were below plans in PY2021. Early in the VVO deployment process, Unitil determined that it was more practical to complete all grid modernization activities at a single substation before moving to another. Additionally, VVO is closely tied to the ADMS, M&C, and Communications investment areas. For instance, deployment of VVO relies on the SCADA system being in place, tying the VVO deployment to the M&C Investment Area. The VVO project is also tied with the FAN deployment plan which will allow communication from the ADMS to the field devices. Therefore, delays in VVO equipment, or equipment tied to any of the other investment area, can cascade into the VVO investment area and Unitil's ability to fully deploy VVO equipment and enable VVO at planned substations.

Due to delays in receiving equipment across the other investment areas, particularly communications equipment, there were delays in deploying VVO devices. Unitil had planned to enable VVO at the Townsend, Lunenburg, and Summer Street substations in 2021. Unitil was able to commission all VVO devices and enable VVO at the Townsend substation. However, VVO was not enabled at the Lunenburg and Summer Street substations.

Given observed delays in equipment throughout 2021, Unitil has revised its deployment timeline to ensure delays do not compound across future years. Therefore, Summer Street, Lunenburg, and West Townsend substations are expected to be VVO enabled by the end of 2022, 2023, and 2024 respectively. By 2025, Unitil believes it will be back on track with the original ten-year plan.

3.2.4.3 VVO Investment Progress through PY2021

Table 53 shows Unitil's enablement progress by substation, including anticipated and actual VVO enabled dates and notes on the current status of VVO deployment.

Table 53. Unitil VVO Enabled Progress by Substation

Substation	January 2021 Actual/Planned VVO Enabled Date	January 2022 Actual/Planned VVO Enabled Date	Current Status[63]
Original 2018–2020 Plan Feeders			
Townsend	8/1/2021 (planned)	12/1/2021 (actual)	VVO Enabled
Lunenburg	9/1/2021 (planned)	11/1/2023 (planned)	Construction
Summer St.	12/1/2021 (planned)	11/1/2022 (planned)	Construction
Additional Feeders			
W. Townsend	7/1/2022 (planned)	11/1/2024 (planned)	Construction

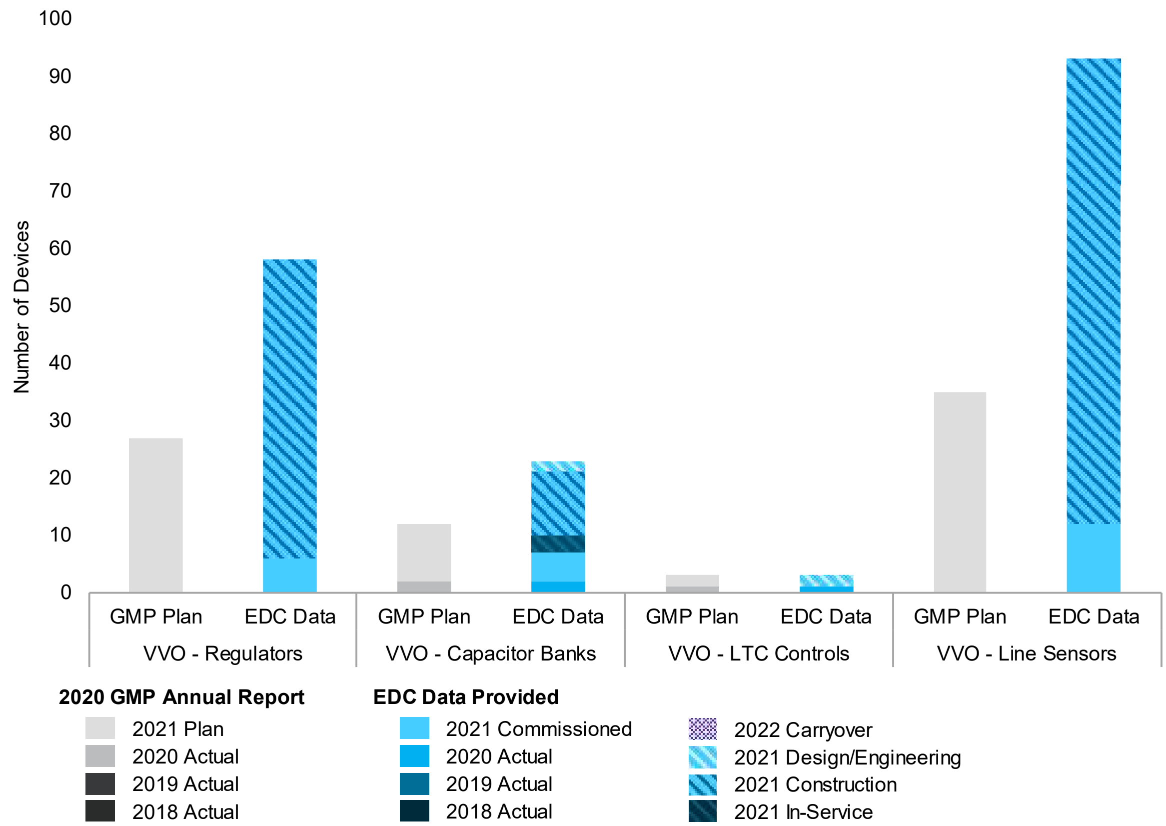
Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Unitil had planned to enable VVO at all original 2018–2020 plan feeders by the end of 2021. Given delays in equipment throughout 2021, Unitil was ultimately able to deploy VVO devices and enable VVO at the Townsend substation in December 2021. Unitil has revised its deployment timeline to ensure that delays do not compound across future years, with Summer Street, Lunenburg, and West Townsend substations are expected to be VVO enabled by the end of 2022, 2023, and 2024 respectively.

Figure 12 and Table 54 compare the actual device deployment to the projected deployment in the *2020 GMP Annual Report*.

[63] Status can be: planning, design, construction, device deployment complete, VVO commissioning in process, or VVO enabled.

Figure 12. Unitil VVO Device Deployment Comparison (2018–2021)



Note that Carryover here would include all units not fully commissioned at the end of PY 2021.

Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Table 54. Unitil VVO Deployment Progress

	VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors
2018-2021 Total	**6**	**7**	**1**	**12**
Engineering/Design during PY 2021*	0	2	2	0
Construction during PY 2021*	52	11	0	81
In-Service during PY 2021*	0	3	0	0
Commissioned in PY 2021	6	5	0	12
Commissioned in PY 2020	0	2	1	0
Commissioned in PY 2019	0	0	0	0
Commissioned in PY 2018	0	0	0	0

**Deployment of these devices began during PY 2021, but was not completed during the program year. Deployment (through commissioning) is planned as carryover in 2022.*

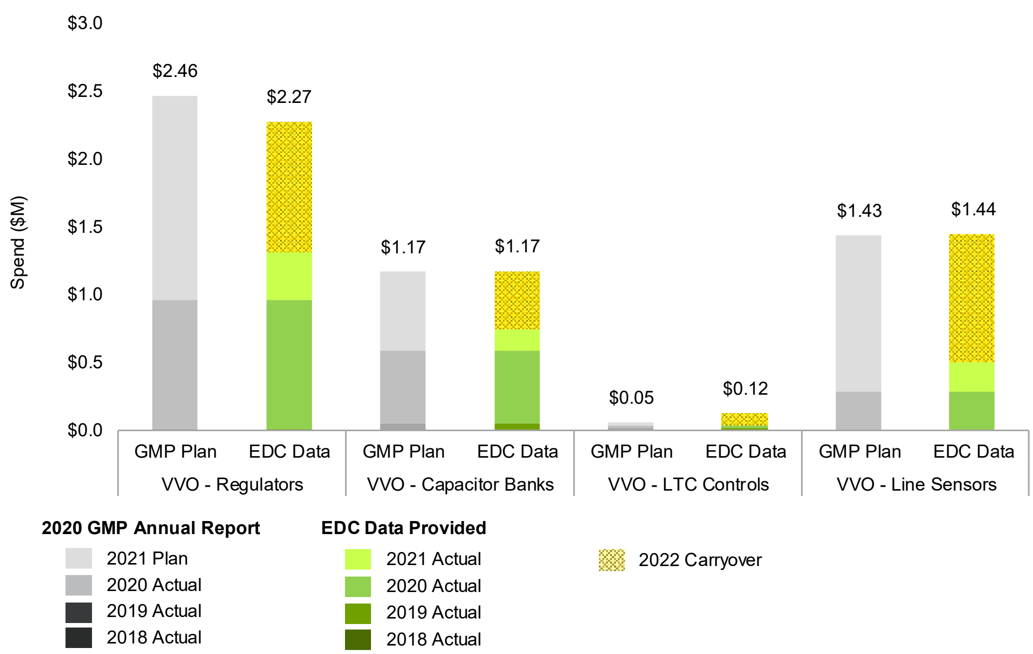
Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Unitil deployment of VVO devices was below plans in 2021. Throughout 2021, Unitil commissioned regulators, capacitor banks, and line sensors at the Townsend substation, then enabled VVO in December 2021. Unitil did not fully deploy and commission devices at the Lunenburg and Summer Street substations as planned, as Unitil revised its VVO deployment timeline partway through 2021, pushing full VVO deployment to 2022 for Summer Street and to 2023 for Lunenburg. Unitil continued construction work on regulators, capacitor banks, and line sensors through 2021 for these substations. Unitil also conducted construction work on regulators, capacitor banks, and line sensors for the West Townsend substation, as well as engineering/design work on LTC controls and capacitor banks for the Princeton Road substation.

Deployment presented as 2022 carryover spans deployment of carryover units that Unitil is planning in 2022 through 2024 to complete their most recent 4-year Term plan totals. In this case, Unitil's remaining carryover deployment spans commissioning the remaining VVO devices at the Summer Street, Lunenburg, and West Townsend substations in 2022 through 2024. In addition, deployment spans continuing design/engineering and construction work across additional substations slated to receive VVO between 2018 and 2028.

Figure 13 and Table 55 compare actual spending and projected spending laid out in the 2020 GMP Annual Report.

Figure 13. Unitil VVO Plan vs. Actual (2018–2021, $M)



Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Table 55. Unitil Total Spend Comparison (2018–2021, $M)

	VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors
2018-2021 Total	**$1.31**	**$0.74**	**$0.03**	**$0.50**
2022 Carryover Estimate	$0.96	$0.43	$0.09	$0.94
PY 2021 Actual	$0.36	$0.16	$0.00	$0.22
PY 2020 Actual	$0.95	$0.53	$0.02	$0.28
PY 2019 Actual	$0.00	$0.05	$0.01	$0.00
PY 2018 Actual	$0.00	$0.00	$0.00	$0.00

Source: Guidehouse analysis of 2020 GMP Annual Report and 2021 EDC Data

Spending on VVO devices was below plans in 2021. Spend during 2021 covered fully commissioning VVO devices at the Townsend substation. However, given Unitil shifted its timeline for the Lunenburg and Summer Street substations, spend that would have been conducted on commissioning VVO devices at these substations has been deferred until 2022 and 2023. Unitil also shifted its deployment timeline for West Townsend, which is expected to be VVO enabled in 2024, further reducing spend from initial plans for 2021.

Spend presented as 2022 carryover spans deployment of carryover units and spending that Unitil is planning in 2022 through 2024 to complete their most recent 4-year Term plan totals. In this case, Unitil's remaining carryover spending spans completing deployment of VVO devices at the Summer Street, Lunenburg, and West Townsend substations in 2022 through 2024. In addition, spending spans continuing design/engineering and construction work across additional substations slated to receive VVO between 2018 and 2028.

3.2.4.4 Infrastructure Metrics Results and Key Findings

Table 56 and Table 57 summarize the Infrastructure Metrics results through PY2021 for each investment type related to Unitil's VVO Investment Area.

Table 56. 2021 Unitil Infrastructure Metrics Findings

Infrastructure Metrics			VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors
GMP Plan Total, PY2018-2021		Devices	27	12	3	35
		Spend, $M	$2.46	$1.17	$0.05	$1.43
IM-4	Number of devices or other technologies deployed PY2018-2021*	# Devices Deployed	6	7	1	12
		% Devices Deployed	22%	58%	33%	34%
IM-5	Cost for Deployment PY2018-2021*	Total Spend, $M	$1.31	$0.74	$0.03	$0.50
		% Spend	53%	63%	62%	35%
IM-6	Deviation Between Actual and Planned Deployment for PY 2021	% On Track (Devices)	22%	50%	0%	34%
		% On Track (Spend)	24%	27%	0%	19%
IM-7	Projected Deployment for the Remainder of the GMP Term	# Devices Remaining	52	16	2	81
		Spend Remaining, $M	$0.96	$0.43	$0.09	$0.94

*The metric names have been slightly changed here to clarify the time span used in analysis.

**This metric has been interpreted here as the "carryover" units and spending that the EDC is planning in 2022 or beyond to complete their most recent 4-year term plan totals. These most recent totals were included in the EDCs' 2020 Grid Modernization Plans, which targeted the planned units and spending to be completed through PY2021.

Source: Guidehouse analysis of 2020 GMP Annual Report and EDC Data

Table 57. 2021 Unitil Infrastructure Metrics for VVO Feeders

IM	Metric	Parameter	Number of Feeders
IM-4	Number of Devices/Technologies Deployed	# Feeders with VVO Enabled	3
		% Feeders with VVO Enabled	27%
IM-6	Deviation Between Actual and Planned Deployment	% On Track (Feeders with VVO Enabled)	27%
IM-7	Projected Deployment for the Remainder of the 3-Year Term	# Feeders Remaining for VVO Enablement	8

Source: Guidehouse analysis of 2020 GMP Annual Report and EDC Data

Guidehouse's review of Unitil's VVO progress revealed that Unitil is behind where it had anticipated in its *2020 GMP Annual Report*. Key findings related to Unitil's progress include:

- Unitil had planned to enable VVO at all original 2018–2020 plan feeders by the end of 2021. Given delays in equipment throughout 2021, Unitil was ultimately able to deploy VVO devices and enable VVO at the Townsend substation in December 2021. Unitil has revised its deployment timeline to ensure that delays do not compound across future years and affect additional VVO substations. Under the revised timeline, Unitil expects for VVO to be fully deployed and enabled at the Summer Street, Lunenburg, and West Townsend substations by the end of 2022, 2023, and 2024, respectively.

- Unitil deployment of VVO devices was below plans in 2021. Unitil did not fully deploy and commission devices at the Lunenburg and Summer Street substations as planned, as Unitil revised its VVO deployment timeline partway through 2021. Despite the shift in timeline, Unitil continued construction work throughout 2021 for Summer Street, Lunenburg, and West Townsend, as well as engineering/design work for the Princeton Road substation.

- Spending on VVO devices was below plans in 2021. Spend during 2021 covered fully commissioning VVO devices at the Townsend substation. However, given Unitil shifted its deployment timeline, spend that would have been conducted on commissioning VVO devices at Summer Street, Lunenburg, and West Townsend has been deferred.

- Deployment and spend presented as 2022 carryover spans deployment of carryover units that Unitil is planning in 2022 through 2024 to complete their most recent 4-year Term plan totals. Remaining carryover deployment spans commissioning the remaining VVO devices at the Summer Street, Lunenburg, and West Townsend substations in 2022 through 2024. In addition, deployment and spend spans continuing design/engineering and construction work across additional substations slated to receive VVO between 2018 and 2028.

4. VVO Performance Metrics

4.1 Data Management

Guidehouse worked with the EDCs to collect data to complete the evaluation for the assessment of VVO Infrastructure Metrics and Performance Metrics. The sections that follow highlight Guidehouse's data sources and data QA/QC processes used in the evaluation of Performance Metrics.

4.1.1 Data Sources

Guidehouse used numerous datasets to evaluate Performance Metrics. The subsections that follow summarize the data sources used to evaluate Performance Metrics.

4.1.1.1 VVO Supplemental Data Template

The VVO supplemental data collection template includes additional information unique to the VVO Investment Area. Table 58 summarizes the information requested and included in the analysis. The EDCs provided data to the team in the data collection template or submitted it in a separate file. Guidehouse requested information at the feeder level where possible.

Table 58. VVO Supplemental Data

Information	Description
Actual/Planned VVO Schedule	Actual and updated planned VVO deployment start/end dates by feeder, including feeder conditioning, load rebalancing, phase balancing, VVO commissioning, VVO enabled, and On/Off testing.
Customer DR Events	DR events (time-stamped log of any systemwide DR (or similar), for example: ISO-NE DR, EDC direct load control programs, EDC behavioral DR programs).
Voltage Complaints	Voltage-related complaints based on voltage perturbation (e.g., high voltage, low voltage, flicker) and duration (e.g., multiple days, sporadic).

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020

4.1.1.2 Additional VVO Data Required for Performance Metrics Evaluation

Table 59 summarizes the additional data inputs required for Performance Metrics analysis. Except for the weather data, the team obtained all fields from the EDCs.

Table 59. Additional Data Required for Evaluation of Performance Metrics

Data Type	Description
EDC system information	• Feeder characteristics (e.g., rated primary voltage, rated capacity, feeder length, number of customers [residential, commercial, industrial, etc.]), load factor (ratio of average load to peak load), ZIP code or town, number of capacitors, number of regulators
Time series data (hourly)	• Feeder head end data (voltage, real power, current, apparent power or reactive power, power factor) • VVO status flags (e.g., VVO On/Off)
VVO system information	• Time-stamped log of VVO state changes between on and off states and any other VVO modes
Weather data	• Hourly temperature data from selected weather stations and collected by the National Oceanic and Atmospheric Administration (NOAA)

Source: Guidehouse Stage 3 Evaluation Plan filed December 1, 2020

4.1.2 Data QA/QC Process

Guidehouse reviewed all data provided for Performance Metrics analysis upon receipt of requested data. The QA/QC of Performance Metrics data included checks to confirm each of the required data inputs could be incorporated within the Performance Metrics analysis. Examples of the QA/QC include the following criteria:

- Time series data cover each feeder receiving VVO investments and include variables needed to facilitate analysis of Performance Metrics, including voltage, real power, and reactive or apparent power
- Time series data are complete in time and extent of devices and do not include erroneous data (e.g., interpolated values and outliers)
- Voltage complaints data have been received for each feeder receiving VVO investments and are at an adequate level of detail for analysis

After Performance Metrics data are received at the end of every season, Guidehouse provides status update memos that summarize the QA/QC to the EDCs, confirming receipt of the datasets and indicating quality. Any additional follow-up based on standing questions is required to confirm all EDC-provided data can be applied to Performance Metrics analysis.

4.2 VVO Performance Metrics Analysis and Findings

Guidehouse presents findings from the Performance Metrics analysis for the VVO Investment Area in the following subsections.

4.2.1 Statewide Comparison

This section summarizes the Performance Metrics analysis results and key findings for Eversource and National Grid. Results and key findings are provided for the Spring 2021 – Winter 2021/22 M&V period. It can be difficult to compare the results from Performance Metrics analysis between Eversource and National Grid. For example, there are differences in the granularity of telemetry (e.g., 15-minute versus 1 hour), data quality at different times of the year (e.g., sustained pauses in VVO On / Off testing during Spring 2021 for one EDC, repeated data during Summer 2021 for another EDC). As such, data cleaning can cause certain portions of the M&V period to be represented more for one EDC than the other. Additionally, there are numerous differences in DG penetration, customer types, and geographic areas served by Eversource and National Grid feeders that limit the ability to directly compare Eversource and National Grid VVO outcomes.

4.2.1.1 Performance Metrics Analysis Results

Table 60 includes the Performance Metrics results for Spring 2021 – Winter 2021/22 for Eversource and National Grid. The following EDC-specific subsections provide further detail.

Table 60. Performance Metrics Results for the Spring 2021 – Winter 2021/22 M&V Period

Performance Metrics		Eversource		National Grid	
Feeders Included in Evaluation		19*		20	
PM-1	Spring 2021 – Winter 2021/22 Baseline	441,252 MWh		352,663 MWh	
PM-2	Energy Savings – All Hours VVO On†	1,681± 346 MWh	0.38 ± 0.08%	4,273 ± 715 MWh	0.77 ± 0.13%
	Energy Savings – Actual VVO On Hours‡	484 ± 88 MWh	0.38 ± 0.08%	948 ± 171 MWh	0.77 ± 0.13%
-	Voltage Reduction	1.14 ± <0.01 V	0.93 ± <0.01%	0.05 ± <0.01 kV	0.37 ± 0.01%
-	CVRf^	0.70		0.54	
PM-3^^	Peak Load Reduction	-892 ± 324 kW	-1.19 ± 0.48%	-437 ± 518 kW	-0.91 ± 1.16%
PM-4	Reduction in Distribution Losses	0.18%		-0.88%	
PM-5	Change in Power Factor	0.0009 ± 0.005	0.09 ± 0.06%	-0.03 ± 0.01	-0.43 ± 0.13%
PM-6	GHG Reductions (CO_2) All Hours VVO On†	831 ± 171 tons		2,110 ± 354 tons	
	GHG Actual VVO-On Hours‡	239 ± 43 tons		468 ± 84 tons	
PM-7	Voltage Complaints	67 (12% increase from 2015 – 2017 average)		74 (1% decrease from 2016 – 2017 average)§	

* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period. As such, the number of feeders included in the analysis includes 19 of 26 VVO engaged feeders.

† Calculation assumes VVO was enabled for all hours between March 1, 2021 and February 28, 2022.

‡ Calculation uses actual number of VVO On hours spanning the analysis period. Actual VVO On Hours are the number of hours VVO was engaged in the clean analysis data between March 1, 2021 and February 28, 2022.

^The CVR factor provided for each EDC is the load-weighted average of CVR factors estimated for each feeder.

^^Guidehouse evaluated the impact of VVO during peak load periods, defined by ISO-NE as 1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays.

§ National Grid did not start tracking voltage complaints until 2016.

Source: Guidehouse analysis

4.2.1.2 Key Findings and Recommendations

Findings from the evaluation of Performance Metrics indicate that VVO allowed Eversource and National Grid to realize energy savings and voltage reductions during the Spring 2021 – Winter 2021/22 M&V period.[64] More specifically:

- During the Spring 2021 – Winter 2021/22 M&V period, Eversource's Agawam, Piper, and Silver substations realized 484 MWh (0.38%) energy savings and 1.14 V (0.93%) voltage reduction associated with VVO. The CVR Factor, which provides an estimate of energy savings possible with voltage reductions, was 0.70. During the same M&V period, National Grid's East Methuen, Maplewood, and Stoughton substations realized 948 MWh (0.77%) energy savings and 0.05 kV (0.37%) voltage reduction associated with VVO. National Grid's CVR factor was 0.54.

- Eversource energy savings of 484 MWh yielded a 239 short ton reduction of CO_2 emissions, a 0.077 short ton reduction of NO_x emissions, and a 0.019 short ton reduction of SO_2 emissions. National Grid energy savings of 948 MWh yielded a 468 short ton reduction in CO_2 emissions, a 0.15 short ton reduction in NO_x emissions, and a 0.04 short ton reduction in SO_2 emissions.

- Eversource and National Grid VVO feeders experienced a minimal benefit associated with peak load, power factor, and line losses. Eversource VVO feeders experienced a statistically significant increase (1.19%) in peak load, a statistically insignificant increase (0.08%) in power factor, and a minimal decrease in line losses when VVO was engaged. National Grid VVO feeders experienced no statistically significant change in peak load, a small decrease (0.43%) in power factor, and a minimal increase in line losses when VVO was engaged.
- For Eversource, a total of 67 voltage complaints were received from customers connected to the Agawam, Piper, and Silver VVO feeders during the Spring 2021 – Winter 2021/22 M&V period. This is a 12% increase relative to the average voltage complaints per year received between 2015 – 2017. For National Grid, a total of 74 voltage complaints were received from customers connected to the East Methuen, Maplewood, and Stoughton VVO feeders during the period. This is a 1% decrease relative to the average voltage complaints per year received between 2016 – 2017. For both EDCs, there is not sufficient evidence to support changes in voltage complaints being attributed to VVO.

In 2021 and beyond, Guidehouse recommends that Eversource and National Grid:

- Ensure that VVO On / Off testing is running according to plan, with limited pauses to the VVO On / Off testing schedule. A large number of data points across substations and feeders were removed due to extended pauses in VVO On / Off testing. Sustained VVO

[64] It can be difficult to compare the results from Performance Metrics analysis between Eversource and National Grid. For example, there are differences in the granularity of telemetry (e.g., 15-minute versus 1 hour), data quality at different times of the year (e.g., sustained pauses in VVO On / Off testing during Spring 2021 for one EDC, repeated data during Summer 2021 for another EDC). As such, data cleaning can cause certain portions of the M&V period to be represented more for one EDC than the other. Additionally, there are numerous differences in DG penetration, customer types, and geographic areas served by Eversource and National Grid feeders that limit the ability to directly compare Eversource and National Grid VVO outcomes.

On / Off testing will increase the amount of usable data in the evaluation, and improve the precision and accuracy of impact estimates.

- Consider investigating how to improve outcomes across VVO feeders. The voltage reductions varied across the substations and feeders. Some feeders underwent no material change in voltage, indicating potential VVO malfunctions, while other feeders exhibited sustained reductions in voltage when VVO was engaged. Both Eversource and National Grid should investigate how to better maintain sustained voltage reductions when VVO is engaged across all substations and feeders.

4.2.2 Eversource

This section discusses Eversource's VVO Performance Metrics results following the Spring 2021 – Winter 2021/22 VVO M&V period.

4.2.2.1 Performance Metrics Analysis Timeline

Figure 14 highlights the key Performance Metrics analysis periods for Eversource. The Performance Metrics analysis provided for this report will be focused on results from VVO On/Off testing conducted during Spring 2021 – Winter 2021/22.

Figure 14. Eversource Performance Metrics Analysis Timeline*

*Note: Eversource Performance Metrics analysis timeline for VVO feeders identified in the May 1, 2019 filing.
Source: Guidehouse analysis

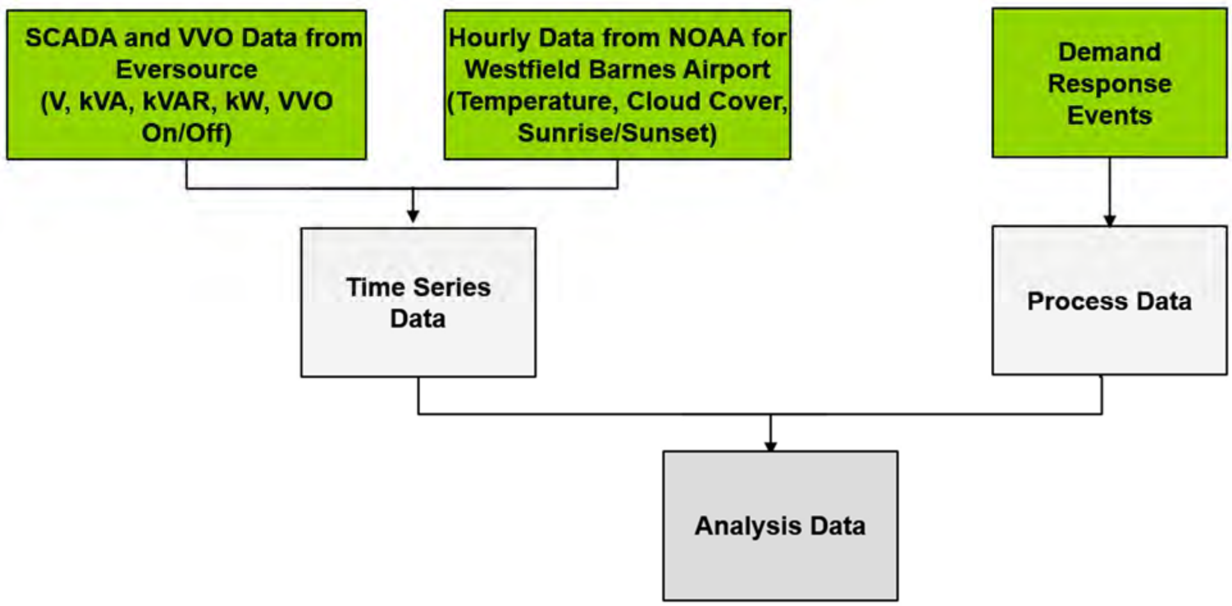
4.2.2.2 Evaluation Methodology

Guidehouse worked with Eversource to collect data necessary to complete the evaluation of VVO Performance Metrics. The sections that follow highlight the analysis data construction, analysis data cleaning, and the analysis approach.

Analysis Data Construction

To assess Performance Metrics, Guidehouse constructed an analysis dataset. This dataset was used in regression modeling to assess changes in multiple outcome variables, such as energy and peak load. Figure 15 summarizes the data integration process used to construct the analysis dataset for the Eversource Performance Metrics analysis.

Figure 15. Eversource Analysis Data Construction Flowchart



Source: Guidehouse

Guidehouse constructed time series and process data to arrive at a final analysis dataset for Eversource's Performance Metrics analysis. To construct time series data, the evaluation team first integrated SCADA interval data from Eversource that contained 15-minute measurements of voltage, real power, apparent power, and reactive power. Time-stamped logs of VVO state changes between VVO On (engaged) and Off (disengaged) states were also contained within the SCADA data provided by Eversource. To complete the construction of time series data, hourly dry bulb temperature and hourly cloud cover data from NOAA for Westfield Barnes Municipal Airport were then joined to SCADA interval data.[65]

To construct the process data, Guidehouse collected a log of demand response events during the evaluation period. The team joined resulting process data to time series data to construct a final analysis dataset.

Analysis Data Cleaning

After constructing the analysis dataset, the team conducted data cleaning steps to remove interval data that may bias the estimates of VVO impacts. Table 61 summarizes data observations made by the evaluation team and the resulting data cleaning steps that were executed.

[65] Westfield Barnes Municipal Airport was selected due to it having a quality controlled local climatological dataset and due to its being near the Agawam, Piper, Podick, and Silver substations. Documentation on the NOAA dataset used in this analysis can be found here: https://data.noaa.gov/dataset/dataset/quality-controlled-local-climatological-data-qclcd-publication

Table 61. Data Cleaning Conducted for Eversource Analysis

Data Observation	Data Cleaning Step
Guidehouse identified a handful of periods of repeated, interpolated, and outlier values in the interval data received, as well as periods missing VVO-status data.	Guidehouse removed observations where anomalous data readings were flagged.
Guidehouse identified numerous periods where VVO events were shorter or longer than 24 hours during the evaluation period.	To reduce the risk of VVO estimates detecting effects tied to events being cut short or running long, Guidehouse removed all VVO events shorter than 16 hours and longer than 72 hours.
For the entirety of the analysis period, the Podick substation did not experience any voltage reductions when VVO was engaged.	Guidehouse removed the Podick substation from the analysis data, as there was evidence that VVO was non-functional for the entirety of the analysis period.

Source: Guidehouse

Table 62 indicates the number of 15-minute intervals contained in the analysis dataset for the Agawam substation. After data cleaning, there were around 7,700 VVO On and 9,300 VVO Off quarter-hours remaining for each feeder to use in the analysis. Much of the data removed during data cleaning was due to extended periods over which VVO was engaged or disengaged. Detailed data attrition information is included in Appendix B.6.

Table 62. Count of VVO On, VVO Off, and Removed Quarter-Hours for Agawam

Number of Quarter-Hours	16C11	16C12	16C14	16C15	16C16	16C17	16C18
VVO On	7,676	8,841	7,453	7,450	7,445	7,451	7,432
VVO Off	9,719	10,421	9,032	9,047	9,018	9,040	9,031
Removed by Data Cleaning	17,645	15,778	18,855	18,543	18,577	18,549	18,577
Spring 2021 – Winter 2022 Total	35,040	35,040	35,040	35,040	35,040	35,040	35,040

Source: Guidehouse analysis

Table 63 indicates the number of 15-minute intervals contained in the analysis dataset for the Piper substation. After data cleaning, there were around 11,000 VVO On and 12,700 VVO Off quarter-hours remaining for each feeder to use in the analysis. Much of the data removed during data cleaning was removed due to extended periods over which VVO was engaged or disengaged. Detailed data attrition information is included in Appendix B.6.

Table 63. Count of VVO On, VVO Off, and Removed Quarter-Hours for Piper

Number of Quarter-Hours	21N4	21N5	21N6	21N7	21N8	21N9
VVO On	11,327	11,119	10,894	11,038	11,008	11,032
VVO Off	12,851	12,753	12,622	12,593	12,587	12,612
Removed by Data Cleaning	10,862	11,168	11,524	11,409	11,445	11,396
Spring 2021 – Winter 2021/22 Total	35,040	35,040	35,040	35,040	35,040	35,040

Source: Guidehouse analysis

Table 64 indicates the number of 15-minute intervals contained in the analysis dataset for the Silver substation. After data cleaning, there were around 10,900 VVO On and 11,500 VVO off quarter-hours remaining for feeders 30A2, 30A4, and 30A6 to use in the analysis. There were around 6,200 VVO On and 6,500 VVO Off quarter-hours remaining in the analysis data for feeders 30A1, 30A3, and 30A5. For all Silver feeders, much of the data removed from data cleaning was removed due to extended periods over which VVO was engaged or disengaged and due to numerous interpolated or repeated values being present. This was especially pronounced for feeders 30A1, 30A3, and 30A5. Detailed data attrition information is included in Appendix B.6.

Table 64. Count of VVO On, VVO Off, and Removed Quarter-Hours for Silver

Number of Quarter-Hours	30A1	30A2	30A3	30A4	30A5	30A6
VVO On	6,295	10,995	5,943	10,892	6,322	10,848
VVO Off	6,595	11,505	6,222	11,541	6,729	11,525
Removed by Data Cleaning	22,150	12,540	22,875	12,607	21,989	12,667
Spring 2021 – Winter 2021/22 Total	35,040	35,040	35,040	35,040	35,040	35,040

Source: Guidehouse analysis

Analysis Approach

After the analysis data was constructed and cleaned, Guidehouse conducted regression modeling to assess the impacts of VVO on measured feeder-level energy and voltage. Equation B-2 in the Appendix summarizes the regression model used to estimate energy and voltage as a function of VVO.

To inform the regression model construction for estimation of energy and voltage, Guidehouse inspected the data to control for exogenous patterns. Table 65 summarizes observations made during this inspection and the implemented data analysis steps.

Table 65. Data Analysis Summary for Eversource

Data Observation	Data Analysis Step
Numerous feeders had a large nominal capacity of connected solar facilities.	Cloud cover and daylight hour data from NOAA were integrated and included in regression analysis to control for hourly generation observed under an array of solar conditions.
Large differences in energy and voltage were observed between most months/weeks in the analysis period	Weekly fixed effects were incorporated into regression modeling to capture energy and voltage differences observed across each week.
Numerous feeders were identified with non-residential customers making up a large portion of load, with drops in measured load during holidays and non-business hours.	Day of week and hour of day fixed effects were incorporated into regression models to capture typical load shapes by day of week and control for large drops in demand observed during non-business hours.
Numerous holidays coincided with the Spring 2021 – Winter 2021/22 M&V test period.	Holiday flags were included in regression models to control for typical holiday energy and voltage.
Numerous demand response events were called during the Spring 2021 – Winter 2021/22 M&V test period.	Intervals that occurred during demand response events were flagged and included in the regression analysis to control for changes in energy and voltage associated with demand response events.

Source: Guidehouse

4.2.2.3 Performance Metrics Results

This section summarizes the Performance Metrics results for Eversource. Each of the subsections separately summarizes the evaluation results for each performance metric.

PM-1: Baseline

As detailed in the Stage 3 Plan filed December 1, 2020, Guidehouse provides a baseline using data collected when VVO was disabled during the evaluation period, which spans Spring 2021 – Winter 2021/22. Table 66 shows the energy baseline calculated using VVO Off data collected during Spring 2021 – Winter 2021/22 from the Agawam, Piper, and Silver substations.

Table 66. Eversource VVO Energy Baseline

Metric	Baseline Total Energy Use*
Baseline Energy	441,252 MWh

* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

Source: Guidehouse analysis

To calculate total baseline energy use, Guidehouse used regression models to estimate energy savings for what energy usage would have been in each hour of Spring 2021 – Winter 2021/22 for each VVO feeder if VVO had been disabled for the entirety of the evaluation period. Guidehouse then summed this calculated energy usage across all hours and feeders to calculate a baseline total energy use for the Spring 2021 – Winter 2021/22 evaluation period. Baseline energy use is provided by VVO feeder in Appendix B.7.

PM-2: Energy Savings

Table 67 provides Eversource's evaluated energy savings for summer peak energy hours, summer off-peak energy hours, winter peak energy hours, winter off-peak energy hours, and Spring 2021 – Winter 2021/22 overall. The ± figure indicates 90% confidence bounds associated with the energy savings estimates.

Table 67. Eversource VVO Net Energy Reduction during Actual VVO On Hours

Energy Period	Net Energy Reduction*	
	MWh†	%‡
Summer peak energy hours	-32 ± 38 MWh	-0.06 ± 0.14%
Summer off-peak energy hours	48 ± 40 MWh	0.20 ± 0.17%
Winter peak energy hours	276 ± 47 MWh	0.95 ± 0.15%
Winter off-peak energy hours	184 ± 47 MWh	0.41 ± 0.17%
Spring 2021 – Winter 2021/22 Total	484 ± 88 MWh	0.38 ± 0.08%

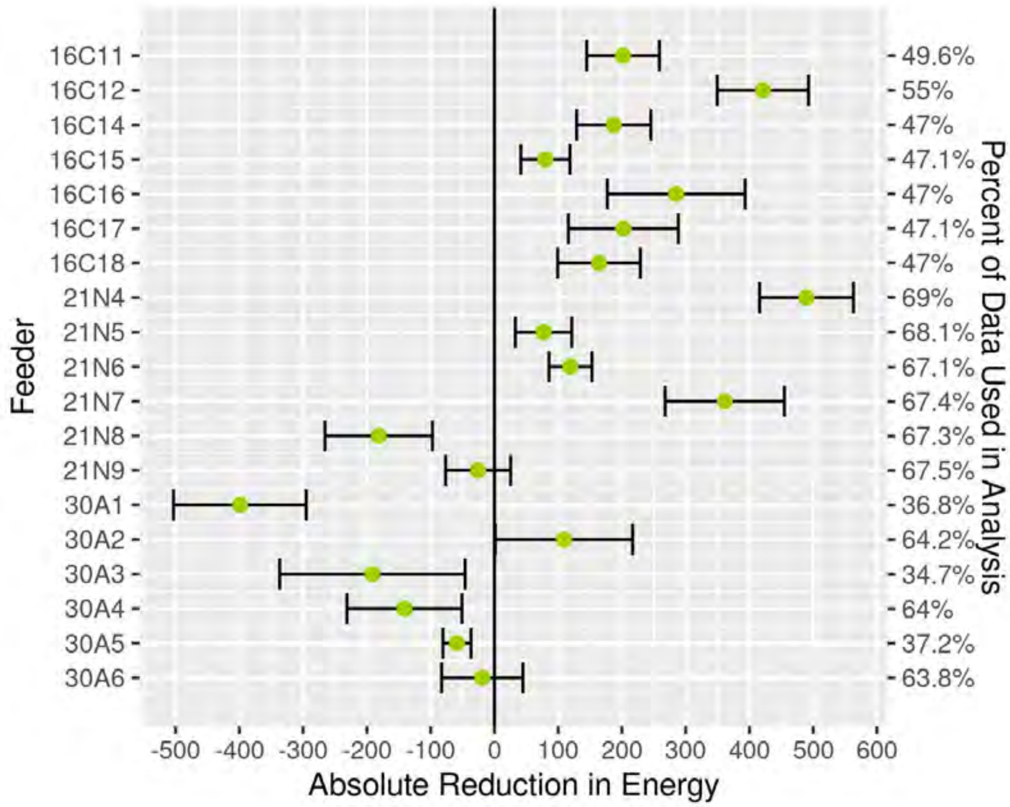
* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.
† Total energy savings provided for each period is the sum of each feeder's energy savings within that period. Due to model noise, a manual sum of savings across periods may not equal the amount provided in the Total row.
‡ Percentage energy savings provided for each period is the load-weighted average of percentage savings estimated for each feeder.
Source: Guidehouse analysis

Regression estimates indicate a statistically significant reduction in energy use associated with VVO, with 484 MWh (0.38%) in energy savings realized during the Spring 2021 – Winter 2021/22 M&V period.[66] Regression estimates indicate that there were statistically significant reductions in energy use for all peak and off-peak energy hours except for summer peak energy hours. The winter off-peak period saw the largest reduction in energy, with a value of 276 MWh, and the summer peak period saw the smallest reduction in energy, with a value statistically indistinguishable from 0 MWh.

Error! Reference source not found. indicates the net energy reductions for each Eversource feeder in absolute terms (MWh), with green points indicating each feeder's MWh savings. The associated 90% confidence intervals are provided by the whiskers overlaid on each feeder's MWh savings estimate. Of the 19 feeders included in the Spring 2021 – Winter 2021/22 M&V period, 12 experienced statistically significant reductions in energy. Of these 12 feeders, feeders 16C12, 21N4, and 21N7 realized the greatest energy savings.

66 Calculation uses actual number of VVO On hours spanning the analysis period. Actual VVO On Hours are the number of hours VVO was engaged in the clean analysis data between March 1, 2021 and February 28, 2022.

Figure 16. Net Energy Reduction (MWh) for Eversource VVO Feeders*

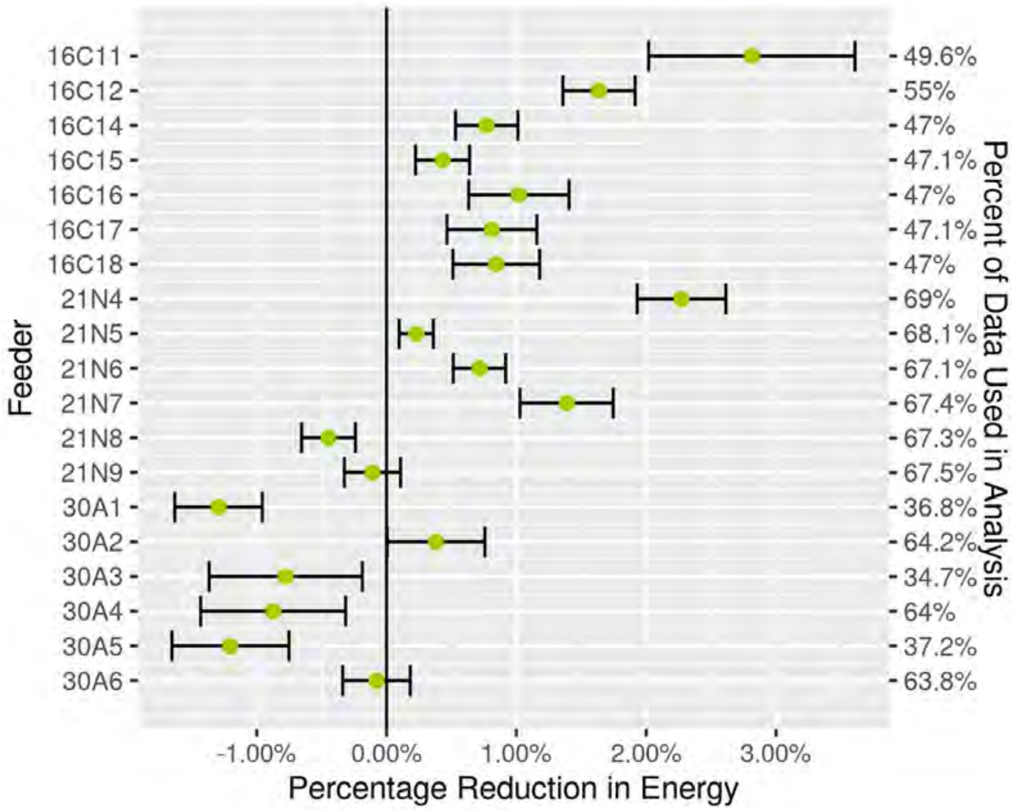


* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

Source: Guidehouse analysis

Figure 17 indicates the net energy reductions for each Eversource feeder in percentage terms, with green points indicating each feeder's percentage MWh savings. The whiskers overlaid on each feeder's percentage MWh savings estimate provide the associated 90% confidence levels.

Figure 17. Net Energy Reduction (%) for Eversource VVO Feeders*



* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

Source: Guidehouse analysis

To further understand VVO impacts, Guidehouse estimated changes in voltage associated with VVO. **Error! Reference source not found.** provides the evaluated voltage reductions for Eversource, with 90% confidence bounds associated with voltage reductions estimates indicated by the ± figure. Regression estimates indicate a statistically significant reduction in voltage associated with VVO, with a 1.14 V (0.93%) voltage reduction realized during the Spring 2021 – Winter 2021/22 M&V period.

Table 68. Eversource VVO Average Hourly Voltage Reduction*

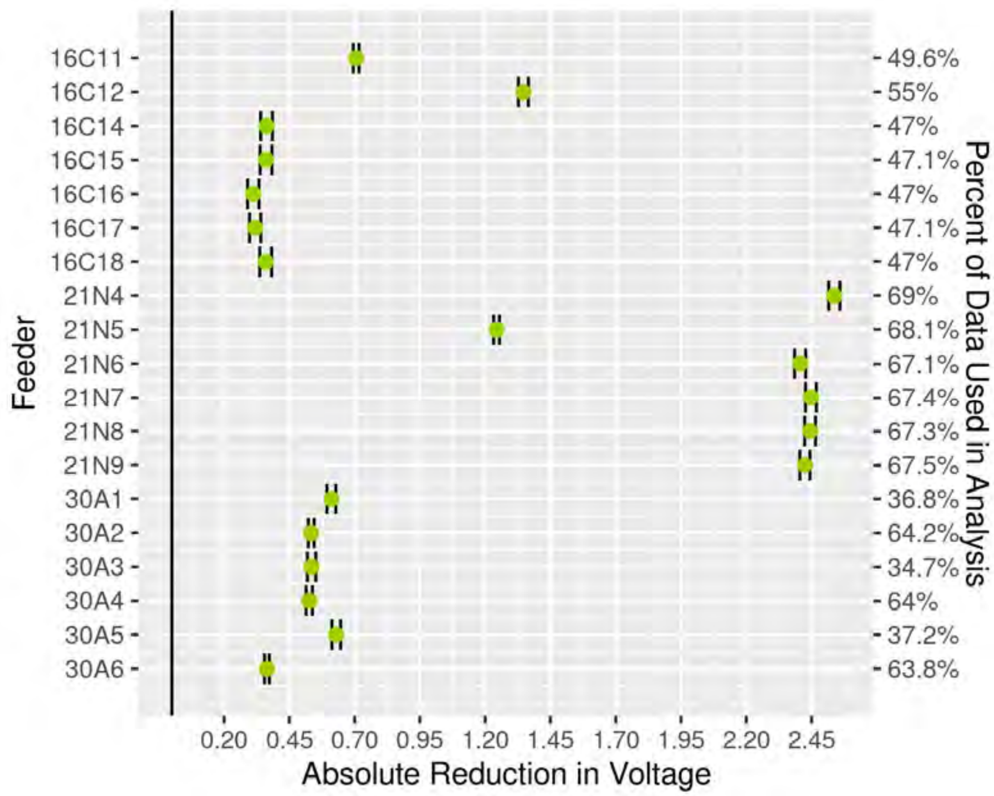
Average Hourly Reduction (V)	Average Hourly Reduction (%)
1.14 ± 0.004 Volts	0.93 ± 0.004%

* Absolute and percentage voltage reductions provided for each period is the load-weighted average of absolute and percentage voltage reductions estimated for each feeder.

Source: Guidehouse analysis

Figure 18 indicates the average hourly voltage reductions for each Eversource feeder, with green points indicating each feeder's voltage reduction. The whiskers overlaid on each feeder's voltage reduction estimate provide the associated 90% confidence intervals. All 19 feeders experienced statistically significant reductions in voltage when VVO was engaged.

Figure 18. Average Hourly Voltage Reduction (V) for Eversource VVO Feeders*

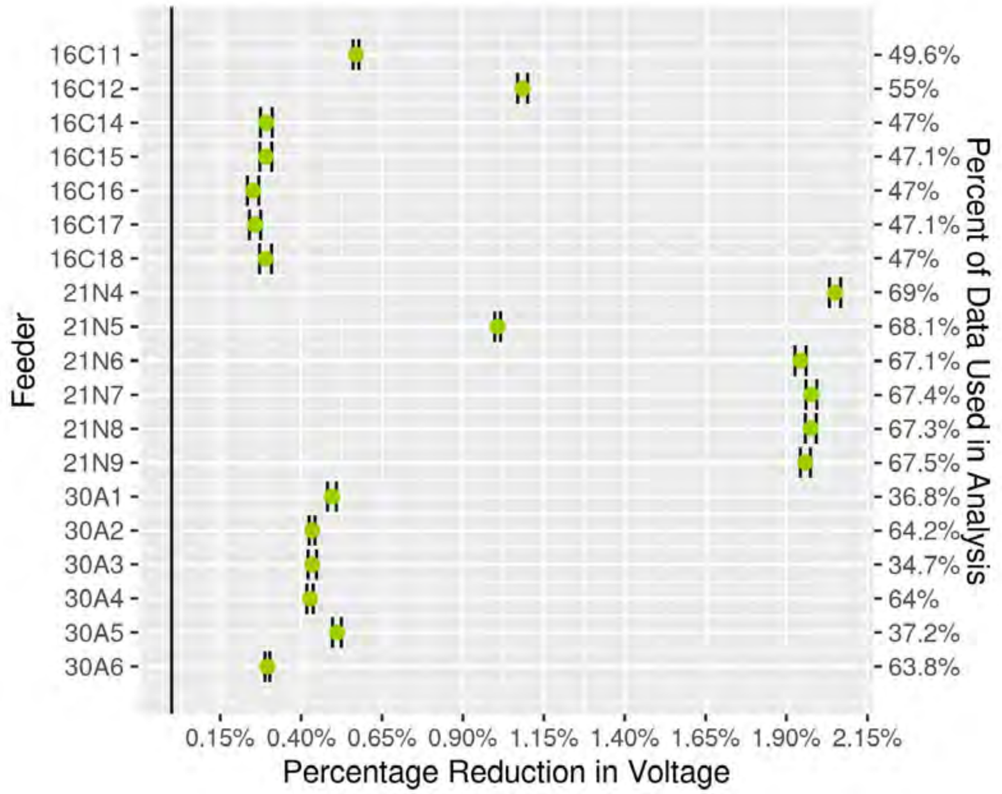


* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

Source: Guidehouse analysis

Figure 19 indicates the net voltage reductions for each Eversource feeder in percentage terms, with green points indicating each feeder's percentage voltage reduction. The whiskers overlaid on each feeder's percentage voltage reduction estimate provide the associated 90% confidence intervals.

Figure 19. Average Hourly Voltage Reduction (%) for Eversource VVO Feeders*



* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

Source: Guidehouse analysis

Following an estimation of percentage energy savings and percentage voltage reductions attributed to VVO, Guidehouse calculated the associated CVR factors for each feeder. The CVR factor, which is the ratio of percentage energy savings to percentage voltage reductions, can provide an estimate of the percentage energy savings possible with each percent voltage reduction. Equation B-1 in the Appendix highlights how the CVR factor is calculated using an estimated percentage change in energy and in voltage. **Error! Reference source not found.** provides the CVR factor for Eversource.

Table 69. Eversource VVO CVR Factor*

CVR Factor†
0.70

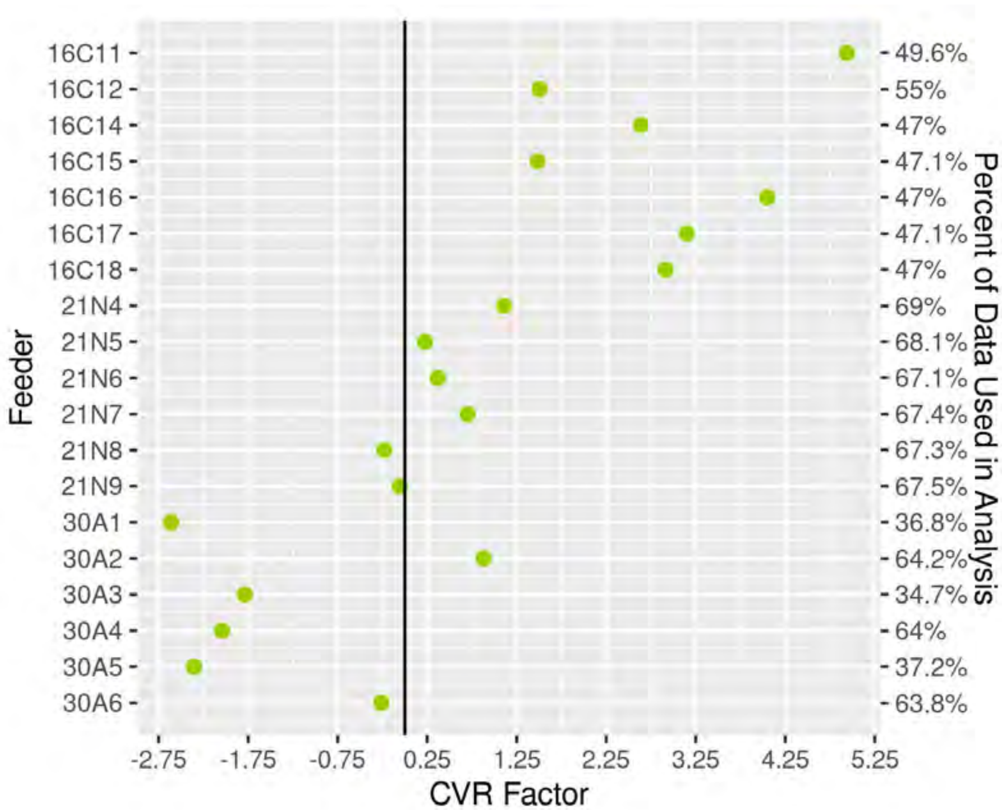
* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

† The CVR factor provided for each period is the load-weighted average of CVR factors estimated for each feeder.

Source: Guidehouse analysis

From prior experience evaluating VVO, Guidehouse expects a CVR factor about 0.80 from a year of VVO M&V testing. Based on evaluation findings, the CVR factor for the Spring 2021 – Winter 2021/22 time period was 0.70. Figure 20 provides the CVR factors for the Spring 2021 – Winter 2021/22 M&V period for each feeder.

Figure 20. Eversource VVO CVR Factors*



* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

Source: Guidehouse analysis

PM-3: Peak Load Impact

Guidehouse evaluated the impact of VVO during peak load periods, defined by ISO-NE as 1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays. Table 70 details the evaluated peak load impact across all feeders in absolute and percentage terms.

Table 70. Eversource VVO Average Reduction in Peak Load*

Peak Load Reduction (kW) †	Peak Load Reduction (%)†
-892 ± 324 kW	-1.19 ± 0.48%

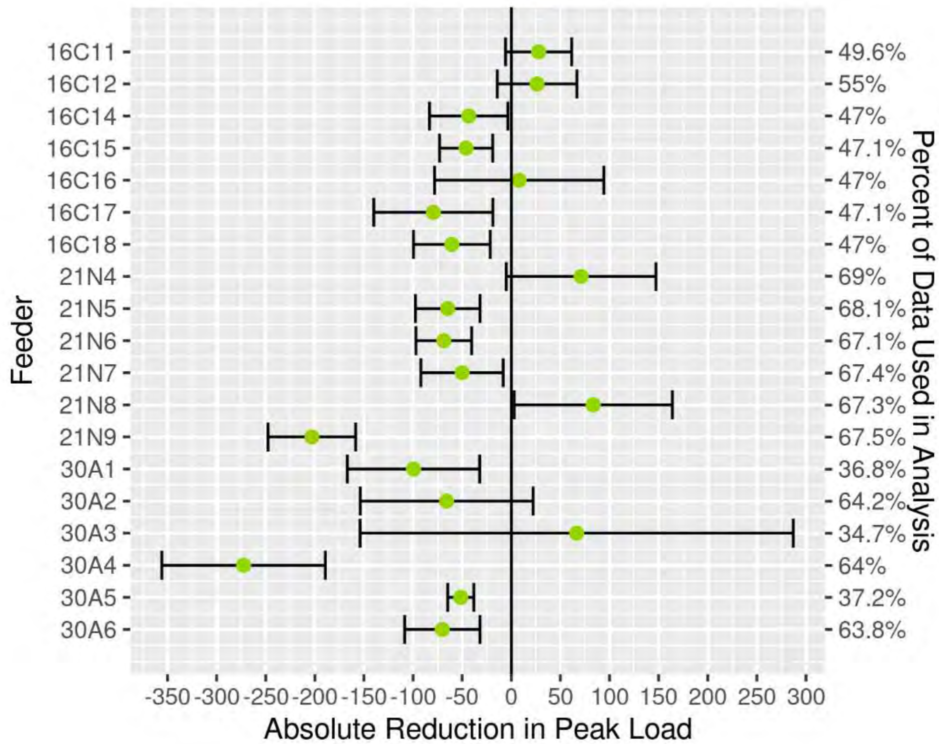
* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

† Peak load change presented in this table is the load-weighted average of peak load changes estimated for each feeder

Source: Guidehouse analysis

Figure 21 indicates the load reductions measured in kW realized during the peak load period, defined by ISO-NE as 1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays. The whiskers overlaid on each feeder's absolute load reduction estimate provide the associated 90% confidence intervals. Of the feeders on the Agawam, Piper, and Silver substations, only feeder 21N8 experienced a statistically significant reduction in peak load.

Figure 21. Eversource Reduction in Peak Load (kW)*

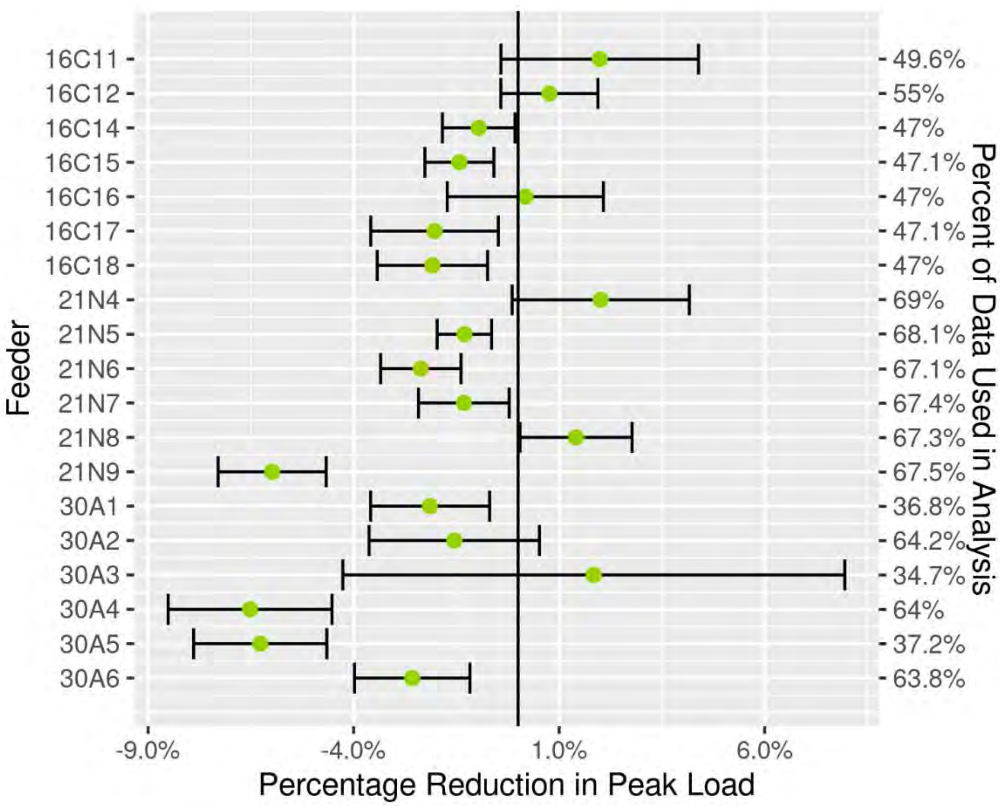


* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

Source: Guidehouse analysis

Figure 22 indicates the percentage load reductions realized during the peak load period, defined by ISO-NE as 1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays. The whiskers overlaid on each feeder's percentage load reduction estimate provide the associated 90% confidence intervals.

Figure 22. Eversource Reduction in Peak Load (%)*



* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

Source: Guidehouse analysis

PM-4: Distribution Losses

Guidehouse evaluated reduction in distribution losses as a function of VVO during the Spring 2021 – Winter 2021/22 M&V period. There were some feeders with very little data where kW was greater than 75% of annual peak load for kVA. Given that power factor is an input for the distribution losses equation, these feeders were ultimately removed from the distribution losses calculation, as they had fewer than 100 hours available for use in the regression modeling. The methodology for calculating the percent reduction in distribution losses is shown in Appendix B.3.

Table 71 details the evaluated percentage change in distribution losses for each Eversource feeder with sufficient data quality.

Table 71. Eversource VVO Distribution Losses*

Reduction in Distribution Losses (%)†
0.18%

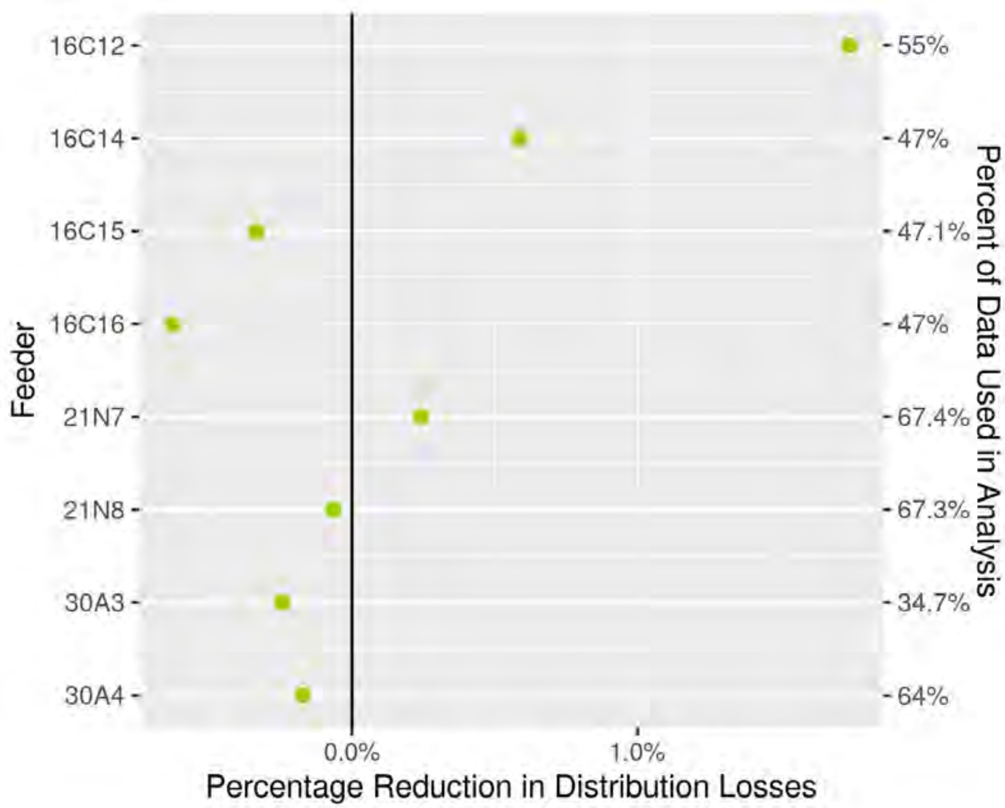
* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

† The change in line losses presented in this table is the load-weighted average of change in line losses estimated for each feeder

Source: Guidehouse analysis

Figure 23 indicates the percentage change in distribution losses.

Figure 23. Eversource Reduction in Distribution Losses*



* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

Source: Guidehouse analysis

PM-5: Power Factor

Guidehouse evaluated the impact on power factor associated with VVO during the Spring 2021 – Winter 2021/22 M&V period. Changes in power factor were analyzed during periods where power was greater than 75% of feeder-specific annual demand. Table 72 details the evaluated change in power factor for each Eversource feeder where clean data existed in sufficient quantity.[67]

Table 72. Eversource VVO Average Hourly Power Factor Change*

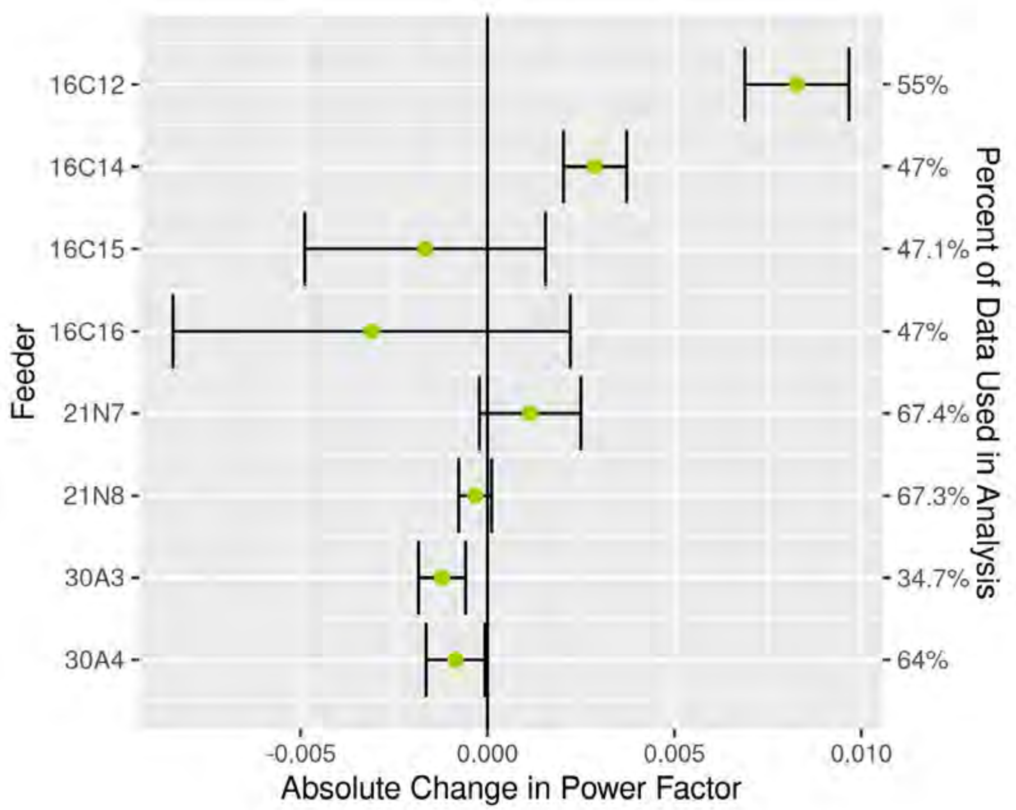
Change in Power Factor†	Change in Power Factor (%)†
0.0009 ± 0.005	0.09 ± 0.06%

* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

† Power factor change presented in this table is the load-weighted average of power factor changes estimated for each feeder
Source: Guidehouse analysis

Figure 24 indicates the change in power factor for each Eversource feeder in absolute terms, with green points indicating each feeder's absolute power factor change. The whiskers overlaid on each feeder's absolute power factor change estimate provide the associated 90% confidence intervals.

Figure 24. Eversource Absolute Change in Power Factor*



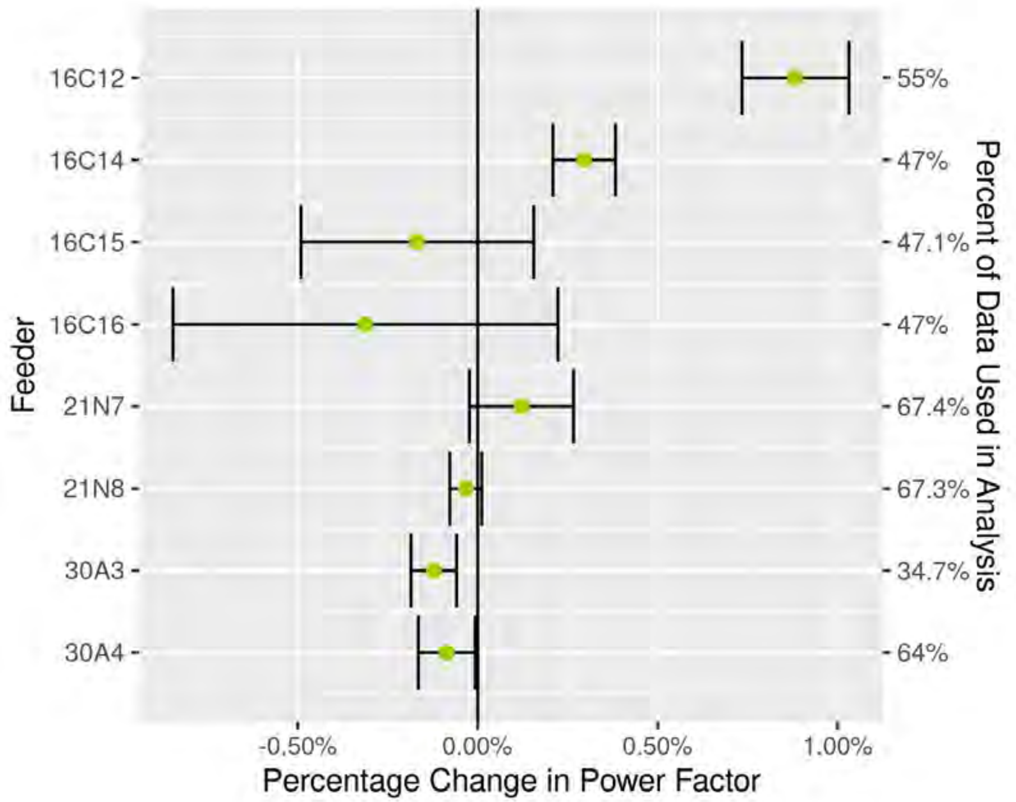
* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

[67] There were some feeders with very little data where kW was greater than 75% of annual peak load for kVA. These feeders were ultimately removed from the power factor models, as they had fewer than 100 hours available for use in regression modeling.

Source: Guidehouse analysis

Figure 25 indicates the change in power factor for each Eversource feeder in percentage terms, with green points indicating each feeder's percentage power factor change. The whiskers overlaid on each feeder's percentage power factor change estimate provide the associated 90% confidence intervals.

Figure 25. Eversource Percentage Change in Power Factor



* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

Source: Guidehouse analysis

PM-6: GHG Reduction

After evaluating energy savings attributed to VVO, Guidehouse calculated the resulting emissions reductions. Emissions reductions were determined by calculating the product of energy savings and emissions reduction factors provided in the Massachusetts Joint Statewide Electric and Gas Three Year Energy Efficiency Plans for 2019–2021.[68]

[68] Emissions factors can be found on page 201 of Massachusetts Joint Statewide Electric and Gas Three Year Energy Efficiency Plans for 2019 – 2021 https://ma-eeac.org/wp-content/uploads/Exh.-1-Final-Plan-10-31-18-With-Appendices-no-bulk.pdf

Table 73 provides emissions reductions associated with VVO, with 90% confidence bounds indicated by the ± figure.

Table 73. Eversource VVO Emissions Reductions*

Metric	NO_X	SO_2	CO_2
Spring 2021 – Winter 2021/22 Emissions Reduction	0.077 ± 0.01 tons	0.019 ± 0.004 tons	239 ± 43 tons

* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.

Source: Guidehouse analysis

PM-7: Voltage Complaints

Guidehouse received voltage complaint logs from Eversource to facilitate Performance Metrics analysis. Guidehouse tabulated voltage complaints received by VVO feeder between 2015 and Q1 2022, as well as the Spring 2021 – Winter 2021/22 M&V period. Discussion below highlights key observations for voltage complaints, comparing the count of voltage complaints received during Spring 2021 – Winter 2021/22 to the average number of voltage complaints from the 2015–2017 baseline period.[69]

Table 74 summarizes voltage complaints for the Agawam substation. Relative to the average number of voltage complaints per year received prior to when VVO investments were deployed on these feeders (2015 – 2018), the Spring 2021 – Winter 2021/22 M&V period saw a 25% decrease in voltage complaints at the Agawam substation.

Table 74. Count of Voltage Complaints for Agawam Substation

Number of Voltage Complaints	16C11	16C12	16C14	16C15	16C16	16C17	16C18	Total
Customers*	1,321	79	1,640	1,271	2,606	2,379	3,047	12,343
2015	0	0	2	2	4	2	0	10
2016	0	0	2	0	7	3	2	14
2017	1	0	2	3	7	3	5	21
2018	0	0	2	0	3	8	1	14
2019	4	0	1	0	5	5	4	19
2020	5	3	0	3	6	4	2	23
2021	1	0	1	2	7	2	2	15
2022†	1	0	0	0	0	0	0	1
Spring 2021 – Winter 2021/22	2	0	0	2	5	1	1	11

* Count of customers served by each feeder was extracted from 2021 GMP Annual Report, Appendix 1.

[69] Guidehouse presents a comparison of complaints between the 2015–2017 period and winter 2020/21 M&V period. For new VVO feeders that begin receiving VVO investments beginning in 2021, Guidehouse recommends that a 3-year moving average (i.e., 2019–2021) be used instead of an average for the time period spanning 2015 through 2017, as conditions in 2015 through 2017 may not accurately reflect baseline conditions immediately preceding deployment of VVO investments.

† Only includes the first quarter of voltage complaints for 2022.
Source: Guidehouse analysis

Voltage complaints vary considerably across years and VVO feeders, ranging from 10 complaints received in 2015 to 23 complaints received in 2020. Looking at 2015–2017 baseline period, there were 45 voltage complaints received, amounting to 15 voltage complaints per year. Based on voltage complaints data received, a total of 11 voltage complaints were reported along the Agawam feeders during Spring 2021 – Winter 2021/22, which is slightly below the baseline period average number of complaints per year.

Table 75 summarizes the count of voltage complaints for the Piper substation. Voltage complaints vary considerably across years and VVO feeders, ranging from 4 complaints received in 2018 to 11 complaints received in 2019 and 2020. Looking at 2015–2017 baseline period, there were 21 voltage complaints received, amounting to 7 voltage complaints per year. Based on voltage complaints data received, a total of 13 voltage complaints were reported along the Piper feeders during Spring 2021 – Winter 2021/22 M&V period, most of which were complaints received from customers connected to feeders 21N4 and 21N9. The voltage complaints recorded during the most recent M&V period are higher than the baseline period of 2015 – 2017, but are consistent with the average number of complaints recorded between 2019 and 2021, which was approximately 12. Relative to the average number of voltage complaints per year received prior to when VVO investments were deployed on these feeders (2015 – 2018), the Spring 2021 – Winter 2021/22 M&V period saw a 108% increase in voltage complaints at the Piper substation.

Table 75. Count of Voltage Complaints for Piper Substation

Number of Voltage Complaints	21N4	21N5	21N6	21N7	21N8	21N9	Total
Customers*	2,303	829	787	2	558	2,412	6,891
2015	1	1	2	0	0	2	6
2016	2	1	0	0	0	3	6
2017	4	2	1	0	0	2	9
2018	1	0	0	0	0	3	4
2019	2	1	0	0	3	5	11
2020	6	3	1	0	0	1	11
2021	5	1	0	0	0	8	14
2022†	0	0	0	0	0	1	1
Spring 2021 – Winter 2021/22	5	1	0	0	0	7	13

* Count of customers served by each feeder was extracted from 2021 GMP Annual Report, Appendix 1.
† Only includes the first quarter of voltage complaints for 2022.
Source: Guidehouse analysis

Table 76 summarizes the count of voltage complaints for the Podick substation. Voltage complaints vary considerably across years and VVO feeders, ranging from 13 complaints received in 2015 to 39 complaints received in 2021. Looking at 2015–2017 baseline period, there were 69 voltage complaints received, amounting to 23 voltage complaints per year. Based on voltage complaints data received, a total of 28 voltage complaints were reported along the

Podick feeders during Spring 2021 – Winter 2021/22, which is slightly above the baseline period average number of complaints per year. Relative to the average number of voltage complaints per year received prior to when VVO investments were deployed on these feeders (2015 – 2018), the Spring 2021 – Winter 2021/22 M&V period saw a 7% decrease in voltage complaints at the Podick substation.

Table 76 Count of Voltage Complaints for Podick Substation

Number of Voltage Complaints	18G2	18G3	18G4	18G5	18G6	18G7	18G8	Total
Customers*	10	2,122	2,334	1,761	1,277	2,208	1,079	10,791
2015	0	3	1	2	1	3	3	13
2016	1	1	4	1	2	11	13	33
2017	0	0	5	4	3	6	5	23
2018	0	1	4	6	3	8	14	36
2019	0	6	5	8	1	4	3	27
2020	0	1	4	11	9	8	6	39
2021	0	3	6	7	3	7	5	31
2022†	0	0	0	0	1	0	0	1
Spring 2021 – Winter 2021/22	0	3	4	7	4	6	4	28

* Count of customers served by each feeder was extracted from 2021 GMP Annual Report, Appendix 1.
† Only includes the first quarter of voltage complaints for 2022.
Source: Guidehouse analysis

Error! Reference source not found. summarizes the count of voltage complaints for the Silver substation. Voltage complaints vary considerably across years and VVO feeders, ranging from 7 complaints received in 2015 to 20 complaints received in 2017. Looking at 2015–2017 baseline period, there were 45 voltage complaints received, amounting to 15 voltage complaints per year. Based on voltage complaints data received, a total of 12 voltage complaints were reported along the Silver feeders during the Spring 2021 – Winter 2021/22 M&V period, slightly below the baseline period average number of complaints per year. The majority of these 15 complaints were from customers connected to feeder 30A1 and in line with the baseline period average number of complaints per year. Relative to the average number of voltage complaints per year received prior to when VVO investments were deployed on these feeders (2015 – 2018), the Spring 2021 – Winter 2021/22 M&V period saw a 9% decrease in voltage complaints at the Silver substation.

Table 77. Count of Voltage Complaints for Silver Substation

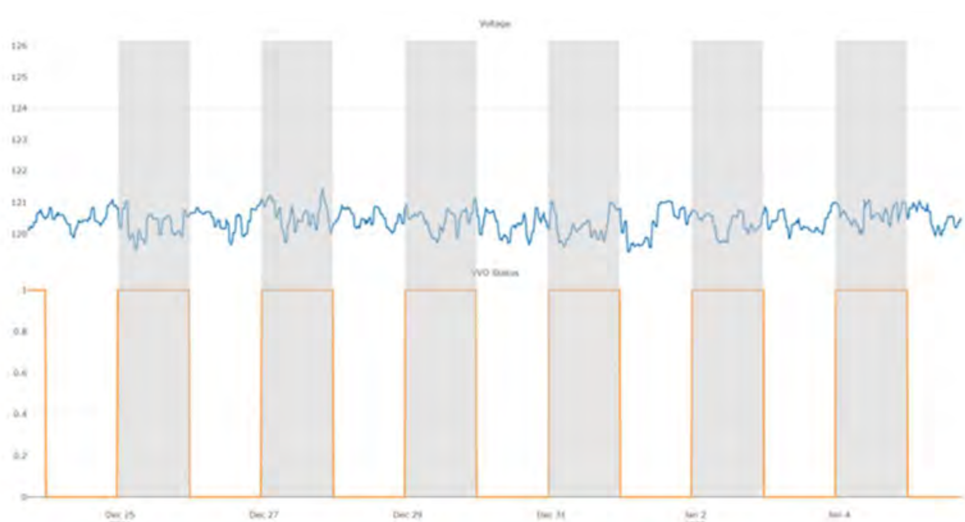
Number of Voltage Complaints	30A1	30A2	30A3	30A4	30A5	30A6	Total
Customers*	2,454	986	242	794	1,648	997	7,121
2015	2	1	0	1	1	2	7
2016	4	5	1	1	2	5	18
2017	3	8	2	1	3	3	20
2018	4	2	0	2	0	2	10
2019	6	5	1	0	2	3	17
2020	5	1	2	4	1	4	17
2021	8	3	0	0	1	5	17
2022†	1	0	0	1	0	0	2
Spring 2021 – Winter 2021/22	8	1	0	1	1	4	15

* Count of customers served by each feeder was extracted from 2021 GMP Annual Report, Appendix 1.
† Only includes the first quarter of voltage complaints.
Source: Guidehouse analysis

4.2.2.4 Additional Investigation of Podick Substation

Guidehouse removed the Podick substation from results for PM-1 through PM-6, as there was evidence that VVO was not engaged at the substation for the entirety of the analysis period. The issue was first discovered during seasonal QA/QC of interval data from Eversource, where Guidehouse observed that voltage was not cycling with changes in VVO On / Off statuses. Figure 26 below highlights voltage (in blue) and VVO On / Off status (in orange) observed between December 24, 2021 and January 6, 2022, with VVO On days highlighted in grey.

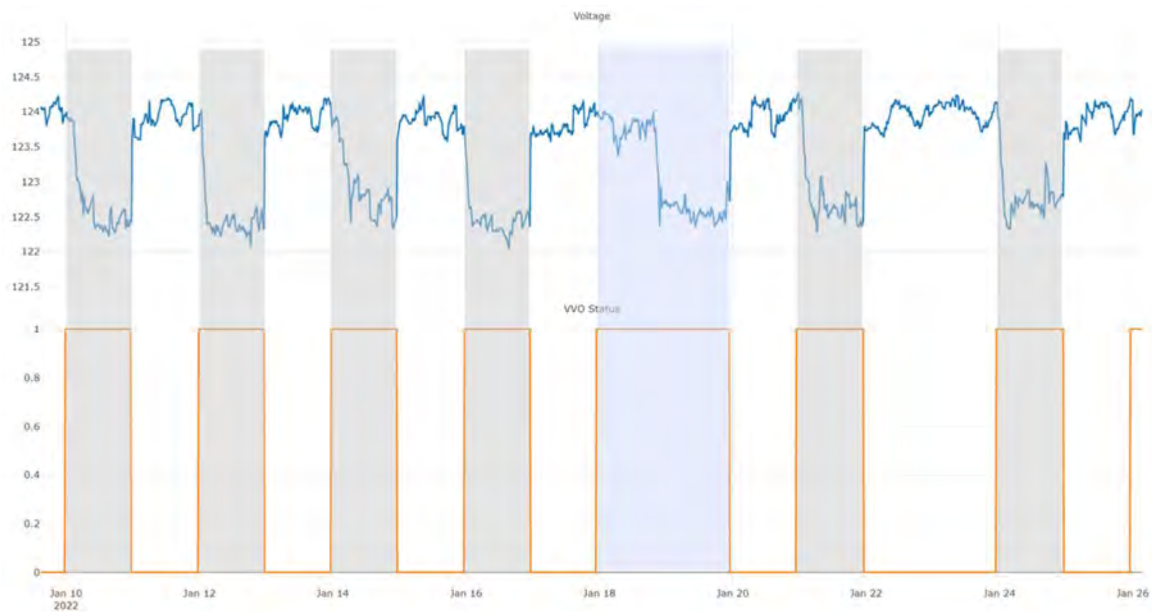
Figure 26. VVO On / Off Testing at Podick Substation



Source: Guidehouse analysis

Figure 26 illustrates that voltage maintained a steady level around 120 Volts throughout the period spanning December 24, 2021 through January 6, 2022. However, when feeders are undergoing VVO On / Off testing, Guidehouse usually expects to see head-end voltage levels cycling with VVO On / Off status, with voltage levels remaining somewhat higher when VVO is disengaged (e.g., 124 Volts) and remaining somewhat lower when VVO is engaged (e.g., 122 Volts). An example of the expected voltage response to VVO is shown in Figure 27 below for the Agawam substation from January 10, 2022 through January 25, 2022.

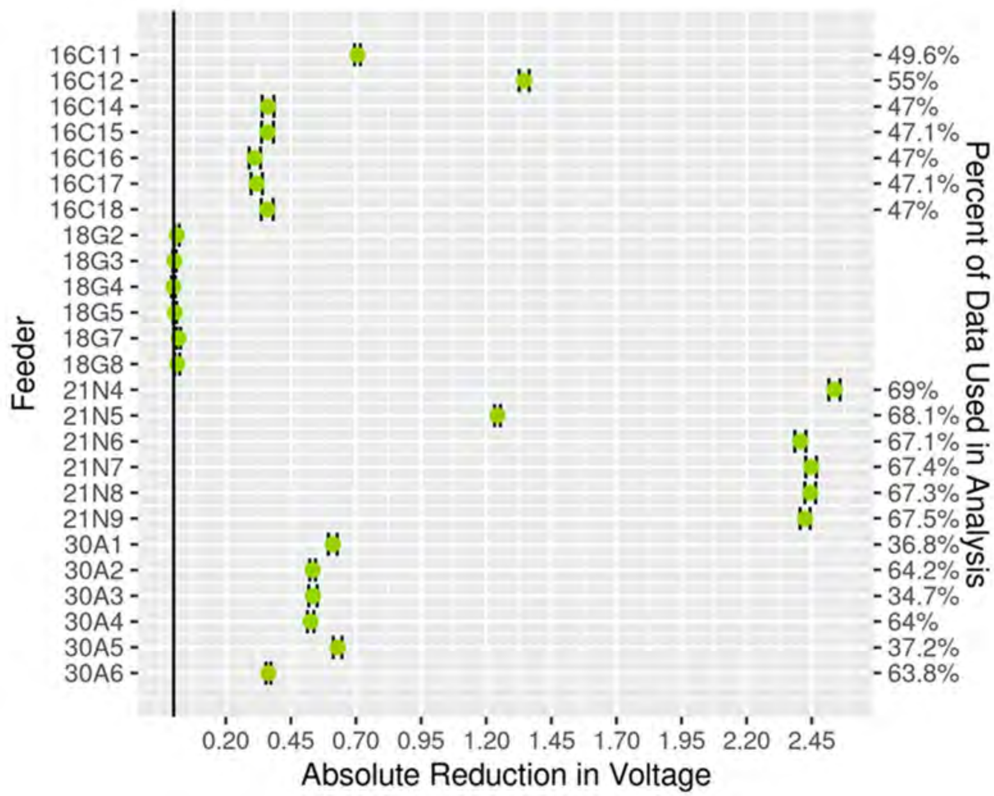
Figure 27. VVO On / Off Testing at Agawam Substation



Source: Guidehouse analysis

Figure 28 illustrates hourly voltage reductions measured in Volts including the Podick substation. Consistent with trends identified during seasonal QA/QC and illustrated in Figure 26, Guidehouse did not detect a voltage reduction for feeders connected to the Agawam substation. As such, Guidehouse recommends that Eversource examine factors, such as DG penetration, that may have led to VVO failing to result in reductions in voltage at the Podick substation.

Figure 28. Hourly Voltage Reductions (V) including Podick Substation

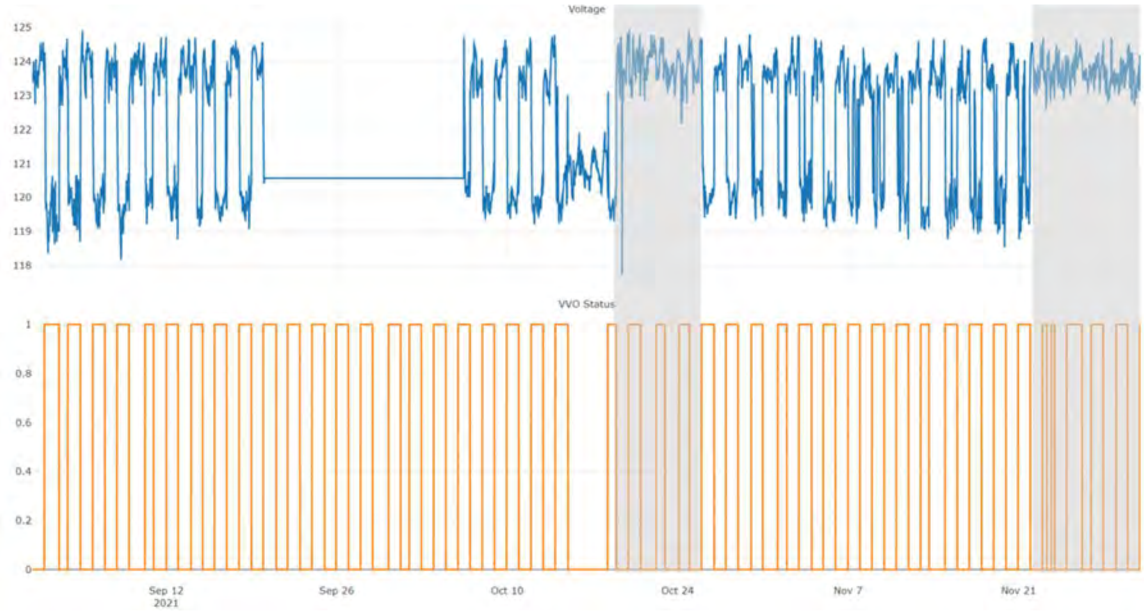


Source: Guidehouse analysis

4.2.2.5 Additional Investigation of Eversource VVO Signals

Guidehouse typically expects voltage to cycle with VVO On / Off statuses, as illustrated in Figure 27 above. However, Guidehouse has identified additional cases outside of the Podick substation where VVO signals did not correspond with reductions in voltage. One such case is presented in Figure 29 for the Piper substation, where voltage (in blue) and VVO On / Off status (in orange) are plotted together for the period spanning September 1 through November 30, 2021.

Figure 29. VVO On / Off Testing at Piper Substation



Source: Guidehouse analysis

The figure illustrates a few key findings. First, using VVO signals received (plotted in orange), it appears that VVO On / Off testing was followed throughout the season, switching between VVO On (VVO Status = 1) and VVO Off (VVO Status = 0) with a few periodic pauses in VVO On / Off testing in October and November. Further, there appears to have been a three-week voltage data outage between mid-September and mid-October, as seen via the straight line in voltage spanning this period.

While VVO On / Off testing appeared to be functioning as expected, with voltage maintaining a higher level during VVO Off days and a lower level during VVO On days, there were two prolonged periods highlighted in grey in which VVO signals do not coincide with voltage increases or decreases. One of these periods was in late October, and another in late November. These periods ultimately informed regression models and reduced assessed impacts of VVO across numerous feeders, as VVO was marked as engaged but was not yielding clear voltage benefits. Guidehouse recommends that Eversource investigate what may be driving these voltage patterns and what, if any, changes to VVO need to occur to ensure that VVO is correctly regulating voltage when VVO is engaged.

4.2.2.6 Key Findings and Recommendations

Guidehouse's VVO evaluation findings indicate that VVO allowed Eversource to realize some benefits during the Spring 2021 – Winter 2021/22 M&V period. More specifically:

- Eversource VVO feeders realized 0.38% energy savings and 0.93% voltage reductions when VVO was engaged. Podick feeders realized the least voltage benefits, with no change in voltage when VVO was engaged, which may indicate VVO malfunctions occurred. Additionally, Agawam 16C11 and Piper 21N4 realized the greatest energy savings, with 2.25% to 3.0% energy savings when VVO was engaged. Lastly, Silver

30A1, 30A3, 30A4, and 30A5 realized the least energy benefits, with a 1.0% increase in energy associated with VVO.

- Eversource VVO feeders experienced a minimal benefit associated with peak load, power factor, and line losses. VVO feeders experienced a statistically significant increase (1.19%) in peak load when VVO was engaged. Additionally, Eversource VVO feeders experienced a statistically insignificant increase (0.08%) in power factor when VVO was engaged, which resulted in a minimal decrease in line losses.

In 2021 and beyond, Guidehouse recommends that Eversource:

- Ensure VVO on / off testing is running according to plan, with limited pauses to the VVO on / off testing schedule. Across the VVO feeders, one-quarter to one-half of data points were removed due to extended pauses in VVO on / off testing. Sustained on / off testing will increase the amount of usable data in the evaluation, thereby improving precision and accuracy of impact estimates.
- Consider investigating how to improve outcomes across VVO feeders. Podick feeders underwent no material change in voltage, indicating potential VVO malfunctions. Further, there were several periods at other substations in which VVO appeared to cycle between the engaged and disengaged states with no corresponding change in voltage occurring, indicating further VVO malfunctions may have occurred.

4.2.3 National Grid

This section discusses National Grid's VVO Performance Metrics results following the Spring 2021 – Winter 2021/22 VVO M&V period.

4.2.3.1 Performance Metrics Analysis Timeline

Figure 30 highlights the key Performance Metrics analysis periods for National Grid. The Performance Metrics analysis provided for this report will be focused on results from VVO On/Off testing conducted during Spring 2021 – Winter 2021/22.

Figure 30. National Grid Performance Metrics Analysis Timeline

* Note: National Grid Performance Metrics analysis timeline for VVO feeders identified in the May 1, 2019 filing.
Source: Guidehouse analysis

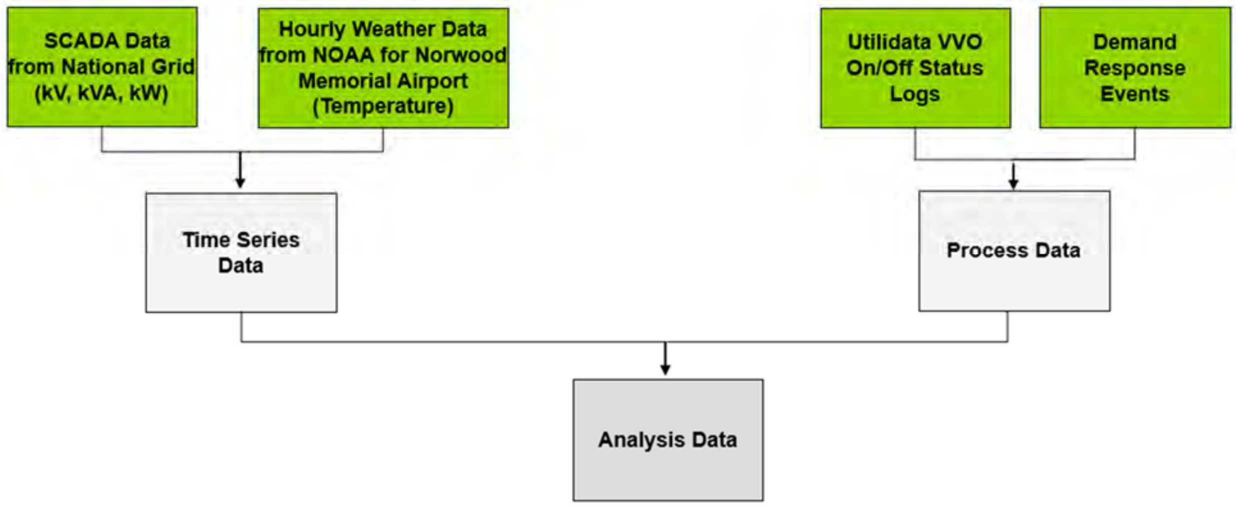
4.2.3.2 Evaluation Methodology

Guidehouse worked with National Grid to collect data necessary to complete the evaluation of VVO Performance Metrics. The sections that follow highlight the analysis data construction, analysis data cleaning, and the analysis approach.

Analysis Data Construction

To assess Performance Metrics, Guidehouse constructed an analysis dataset. This dataset was used in regression modeling to assess changes in multiple outcome variables, such as energy and peak load. Figure 31 summarizes the data integration process used to construct the analysis dataset for the National Grid Performance Metrics analysis.

Figure 31. National Grid Analysis Data Construction Flowchart



Source: Guidehouse

Guidehouse constructed time series and process data to arrive at a final analysis dataset for National Grid Performance Metrics analysis. To construct time series data, the evaluation team first integrated SCADA interval data from National Grid that contained hourly measurements of voltage, real power, and apparent power. The team then integrated hourly dry bulb temperature and hourly cloud cover data from NOAA for Norwood Memorial Airport to arrive at a final time series dataset.[70]

To construct the process data, Guidehouse integrated other VVO system information. Other system information included time-stamped logs of VVO state changes between VVO On (engaged) and Off (disengaged) states from Utilidata, and demand response events during the evaluation period. The time series and process data were then joined to construct a final analysis dataset.

Analysis Data Cleaning

After constructing the analysis dataset, the team conducted data cleaning steps to remove interval data that may bias the estimates of VVO impacts. Table 78 summarizes data observations made by the evaluation team and the resulting data cleaning steps that were executed.

[70] Norwood Memorial Airport was selected due to it having a quality controlled local climatological dataset and due to its being in close proximity to the East Methuen, Maplewood, and Stoughton substations. Documentation on the NOAA dataset used in this analysis can be found here: https://data.noaa.gov/dataset/dataset/quality-controlled-local-climatological-data-qclcd-publication

Table 78. Data Cleaning Conducted for National Grid Analysis

Data Observation	Data Cleaning Step
Guidehouse identified a handful of periods of repeated, interpolated, and outlier values in kV, kW, and kVA data, as well as periods missing VVO-status data.	Guidehouse removed hours where anomalous data readings were flagged.
Guidehouse identified numerous VVO events that were shorter or longer than 24 hours.	To reduce the risk of VVO estimates detecting impacts from incidents that may have led to events being cut short or running long, Guidehouse removed all VVO events shorter than 16 hours and longer than 72 hours.

Source: Guidehouse

Table 79 indicates the number of hours contained in the analysis dataset for the East Methuen substation. After data cleaning, there were between 2,700 and 3,700 hours remaining (both VVO On and VVO Off) for each feeder to use in the analysis. Much of the data removed during data cleaning was due to extended periods over which VVO was engaged or disengaged. Detailed data attrition information is included in Appendix B.6.

Table 79. Count of VVO On, VVO Off, and Removed Hours for East Methuen

Number of Hours	74L1	74L2	74L3	74L4	74L5	74L6
VVO On	3,624	3,704	2,755	3,688	2,751	3,699
VVO Off	2,748	4,150	3,619	4,145	3,619	4,139
Removed by Data Cleaning	2,388	906	2,386	927	2,390	822
Spring 2021 – Winter 2021/22 Total	8,760	8,760	8,760	8,760	8,760	8,760

Source: Guidehouse analysis

Table 80 indicates the number of hours contained in the analysis dataset for the Maplewood substation. After data cleaning, there were around 620 VVO On hours and 810 VVO Off hours remaining for each feeder to use in the analysis.[71] Much of the data removed during data cleaning was due to extended periods over which VVO was engaged or disengaged. Detailed data attrition information is included in Appendix B.6.

Table 80. Count of VVO On, VVO Off, and Removed Hours for Maplewood

Number of Hours	16W1	16W2	16W3	16W4	16W5	16W6	16W7	16W8
VVO On	641	596	641	594	639	594	641	596
VVO Off	950	676	952	676	951	676	952	675
Removed by Data Cleaning	569	888	567	890	570	890	567	889

[71] The Maplewood substation went through VVO On / Off testing during 12/01/2021 through 02/28/2022, whereas the East Methuen and Stoughton substations began VVO On / Off testing prior to 03/01/2021.

Number of Hours	16W1	16W2	16W3	16W4	16W5	16W6	16W7	16W8
Spring 2021 – Winter 2021/22 Total	2,160	2,160	2,160	2,160	2,160	2,160	2,160	2,160

Source: Guidehouse analysis

Table 81 indicates the number of hours contained in the analysis dataset for the Stoughton substation. After data cleaning, there were around 3,390 VVO On and 3,800 VVO Off hours remaining for feeders to use in the analysis. Much of the data removed during data cleaning was due to extended periods over which VVO was engaged or disengaged. Detailed data attrition information is included in Appendix B.6.

Table 81. Count of VVO On, VVO Off, and Removed Hours for Stoughton

Number of Hours	913W17	913W18	913W43	913W47	913W67	913W69
VVO On	3,386	3,392	3,388	3,391	3,390	3,392
VVO Off	3,808	3,818	3,812	3,809	3,812	3,816
Removed by Data Cleaning	1,566	1,550	1,560	1,560	1,558	1,552
Spring 2021 – Winter 2021/22 Total	8,760	8,760	8,760	8,760	8,760	8,760

Source: Guidehouse analysis

Analysis Approach

After the analysis data was constructed and cleaned, Guidehouse conducted regression modeling to assess the impacts of VVO on measured feeder-level energy and voltage. Equation B-2 in the Appendix summarizes the regression model used to estimate energy and voltage as a function of VVO.

To inform the regression model specification for estimation of energy and voltage as a function of VVO, Guidehouse conducted further inspection of the data to control for exogenous patterns. Table 82 summarizes observations made during this inspection and the resulting data analysis steps that were implemented.

Table 82. Data Analysis Summary for National Grid

Data Observation	Data Analysis Step
Numerous feeders had a large nominal capacity of connected solar facilities.	Cloud cover and daylight hour data from NOAA were integrated and included in regression analysis to control for hourly generation observed under an array of solar conditions.
Large differences in energy and voltage were observed between most months/weeks in the analysis period	Weekly fixed effects were incorporated into regression modeling to capture energy and voltage differences observed across each week.
Some feeders were identified as having nonresidential customers make up a large portion of load, with drops in measured load during holidays and non-business hours.	Day of week and hour of day fixed effects were incorporated into regression models to capture typical load shapes by day of week and control for large drops in demand observed during non-business hours.

Data Observation	Data Analysis Step
Numerous holidays coincided with the Spring 2021 – Winter 2021/22 M&V test period.	Holiday flags were included in regression models to control for typical holiday energy and voltage.
Numerous demand response events were called during the Spring 2021 – Winter 2021/22 M&V test period.	Intervals that occurred during demand response events were flagged and included in the regression analysis to control for changes in energy and voltage associated with demand response events.

Source: Guidehouse

4.2.3.3 Performance Metrics Results

This section summarizes the Performance Metrics results for National Grid. Each of the subsections separately summarize the evaluation results for each performance metric.

PM-1: Baseline

As detailed in the Stage 3 Plan filed December 1, 2020, Guidehouse provides a baseline using data collected when VVO was disabled during the evaluation period, which spans Spring 2021 – Winter 2021/22. Table 83 provides the energy baseline calculated using VVO Off data collected during Spring 2021 – Winter 2021/22.

Table 83. National Grid VVO Energy Baseline

Metric	Baseline Total Energy Use
Baseline Energy	352,663 MWh

Source: Guidehouse analysis

To calculate total baseline energy use, Guidehouse used regression models to estimate energy savings for what energy usage would have been in each hour of Spring 2021 – Winter 2021/22 for each VVO feeder if VVO had been disabled for the entirety of the evaluation period. Guidehouse then summed this calculated energy usage across all hours and feeders to calculate a baseline total energy use for the Spring 2021 – Winter 2021/22 evaluation period. Baseline energy use is provided by VVO feeder in Appendix 5.3B.7.

PM-2: Energy Savings

Table 84 provides the evaluated energy savings for National Grid for summer peak energy hours, summer off-peak energy hours, winter peak energy hours, winter off-peak energy hours, and Spring 2021 – Winter 2021/22 overall. The ± figure indicate 90% confidence bounds associated with energy savings estimates.

Table 84. National Grid VVO Net Energy Reduction During Actual VVO On Hours

Energy Period	Net Energy Reduction	
	MWh *	% †
Summer peak energy hours	235 ± 61 MWh	1.22 ± 0.36%
Summer off-peak energy hours	282 ± 65 MWh	2.01 ± 0.41%
Winter peak energy hours	329 ± 96 MWh	0.85 ± 0.20%
Winter off-peak Energy Hours	85 ± 107 MWh	0.33 ± 0.20%
Spring 2021 – Winter 2021/22 Total†	948 ± 171 MWh	0.77 ± 0.13%

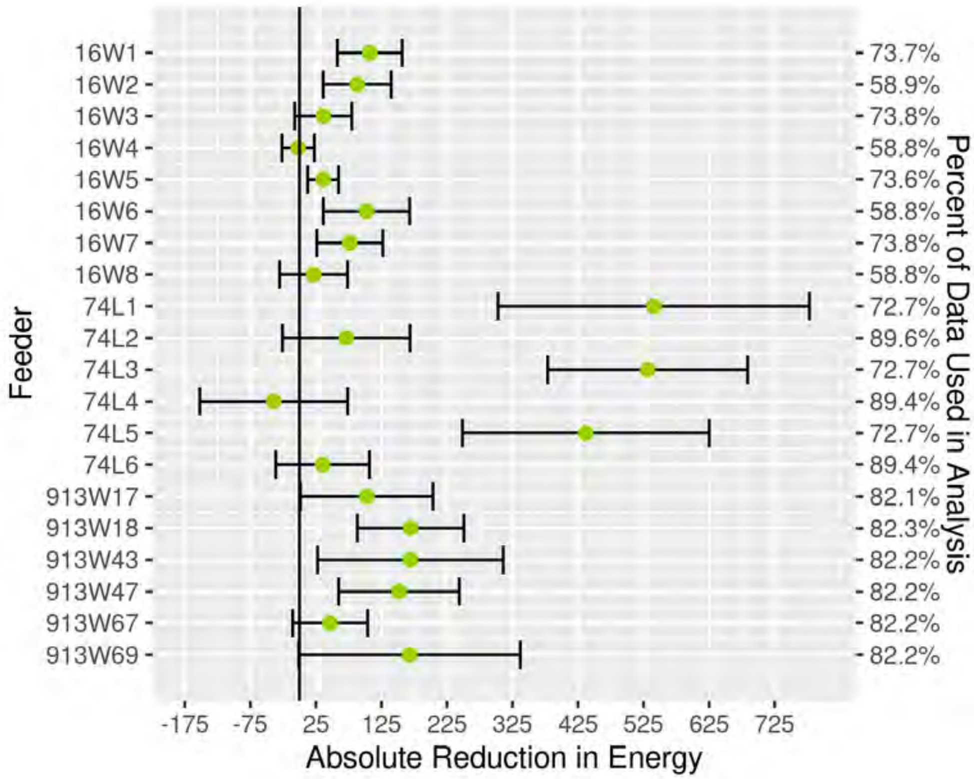
* Total energy savings provided for each period is the sum of each feeder's energy savings within that period. Due to model noise, a manual sum of savings across periods may not equal the amount provided in the Total row.
† Percentage energy savings provided for each period is the load-weighted average of percentage savings estimated for each feeder.
Source: Guidehouse analysis

Regression estimates indicate a statistically significant change in energy use associated with VVO, with 948 MWh (0.77%) energy savings realized during the Spring 2021 – Winter 2021/22 M&V period.[72] Regression estimates indicate that there were statistically significant reductions in energy use during all peak and off-peak energy hours except winter off-peak. The winter peak energy period saw the largest reduction in energy, with a value of 329 MWh, and the winter off-peak period saw the smallest reduction in energy, with a value statistically indistinguishable from zero.

Figure 32 indicates the net energy reductions for each National Grid feeder in absolute terms (MWh), with green points indicating each feeder's MWh savings. The whiskers overlaid on each feeder's MWh savings estimate provide the associated 90% confidence intervals. Of the 20 feeders that were included in the Spring 2021 – Winter 2021/22 M&V period, 13 experienced statistically significant reductions in energy.

72 Total energy savings were determined by multiplying the average hourly energy savings by the total number of hours from 12:00 AM December 1, 2020 through 11:59 PM February 28, 2021 (2,160 hours total).

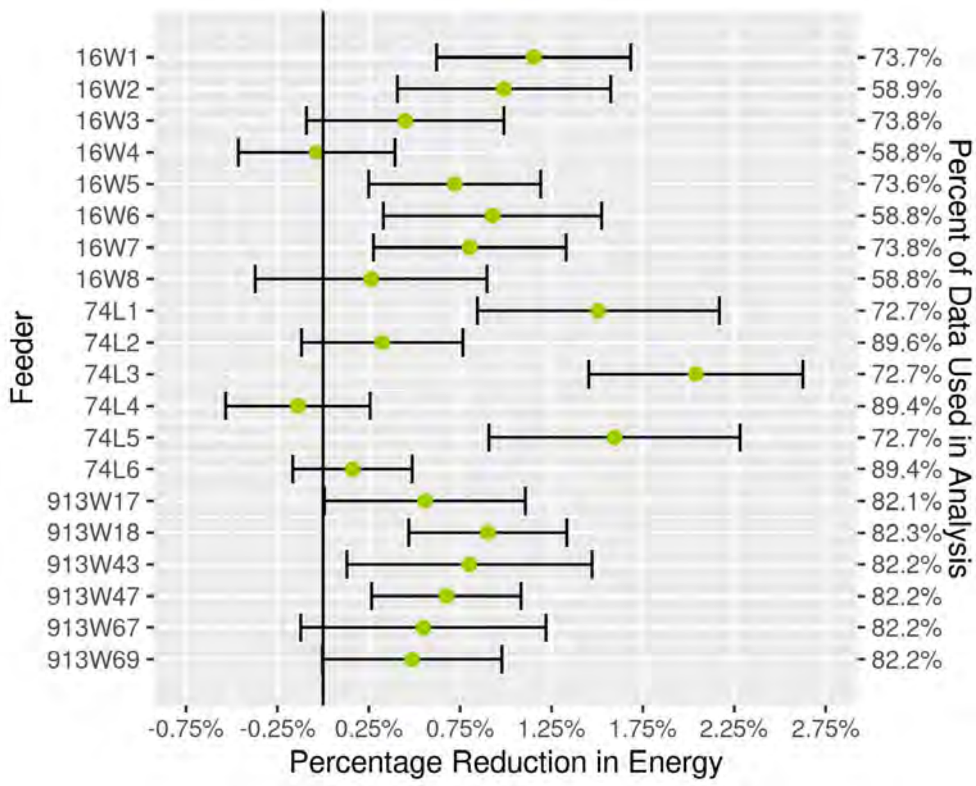
Figure 32. Net Energy Reduction (MWh) for National Grid VVO Feeders



Source: Guidehouse analysis

Figure 33 indicates the net energy reductions for each National Grid feeder in percentage terms, with green points indicating each feeder's percentage MWh savings. The whiskers overlaid on each feeder's percentage MWh savings estimate provide the associated 90% confidence intervals.

Figure 33. Net Energy Reduction (%) for National Grid VVO Feeders



Source: Guidehouse analysis

To further understand impacts, Guidehouse estimated changes in voltage associated with VVO. Table 85 provides the evaluated voltage reductions for National Grid, with 90% confidence bounds associated with voltage reductions estimates indicated by the ± figure. Regression estimates indicate a statistically significant reduction in voltage associated with VVO, with a 0.05 kV (0.37%) voltage reduction realized during the Spring 2021 – Winter 2021/22 M&V period.

Table 85. National Grid VVO Average Hourly Voltage Reduction*

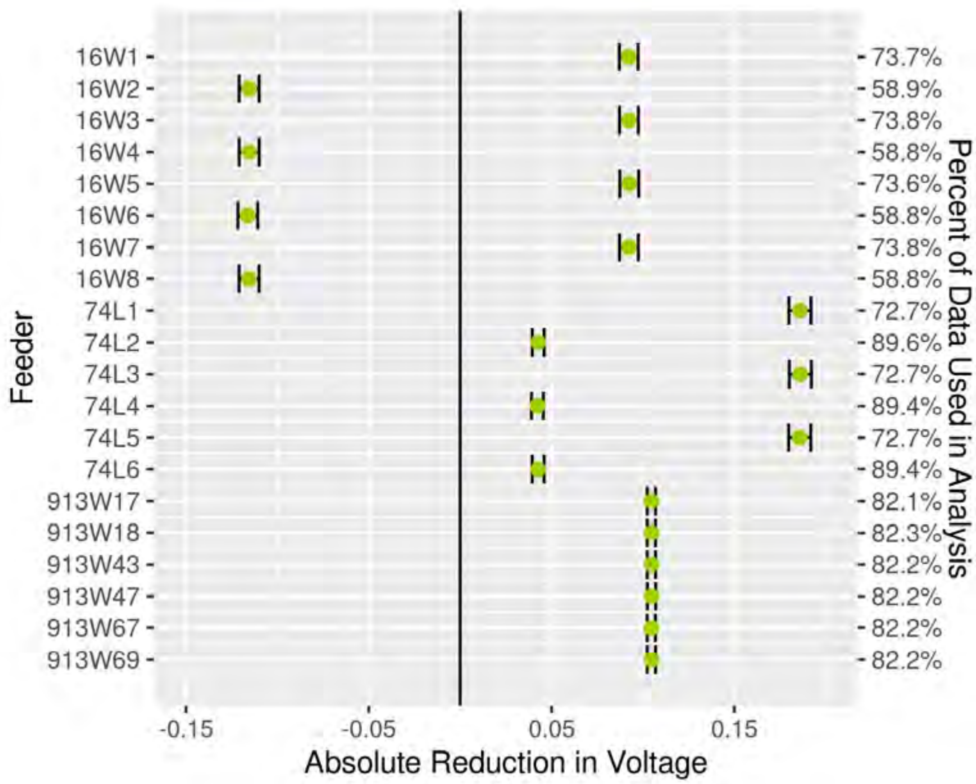
Average Hourly Reduction (kV)	Average Hourly Reduction (%)
0.05 ± <0.01 kV	0.37 ± 0.01%

* Absolute and percentage voltage reductions provided for each period is the load-weighted average of absolute and percentage voltage reductions estimated for each feeder.
Source: Guidehouse analysis

Figure 34 indicates the average hourly voltage reductions for each National Grid feeder, with green points indicating each feeder's voltage reduction. The whiskers overlaid on each feeder's voltage reduction estimate provide the associated 90% confidence intervals, and the dashed line denotes the weighted average voltage reduction. All feeders except 16W2, 16W4, 16W6, and 16W8, which are all connected to the same station bank, experienced a statistically significant average hourly voltage reduction when VVO was engaged.

A potential explanation for the evaluated increase in voltage associated with a VVO-on state for Maplewood feeders 16W2, 16W4, 16W6, and 16W8 is that when VVO was disengaged, customers were receiving lower optimal voltage (e.g., 112 to 114 volts), and when the VVO system was engaged it provided voltage closer to 118 for customers on the feeder. This phenomenon was identified in a similar evaluation of other VVO-enabled substations in New York where AMI data was available.[73] Unfortunately, AMI data was not available for the substations in this analysis, so Guidehouse could not perform a similar analysis with these feeders to confirm this hypothesis.

Figure 34. Average Hourly Voltage Reduction (kV) for National Grid VVO Feeders

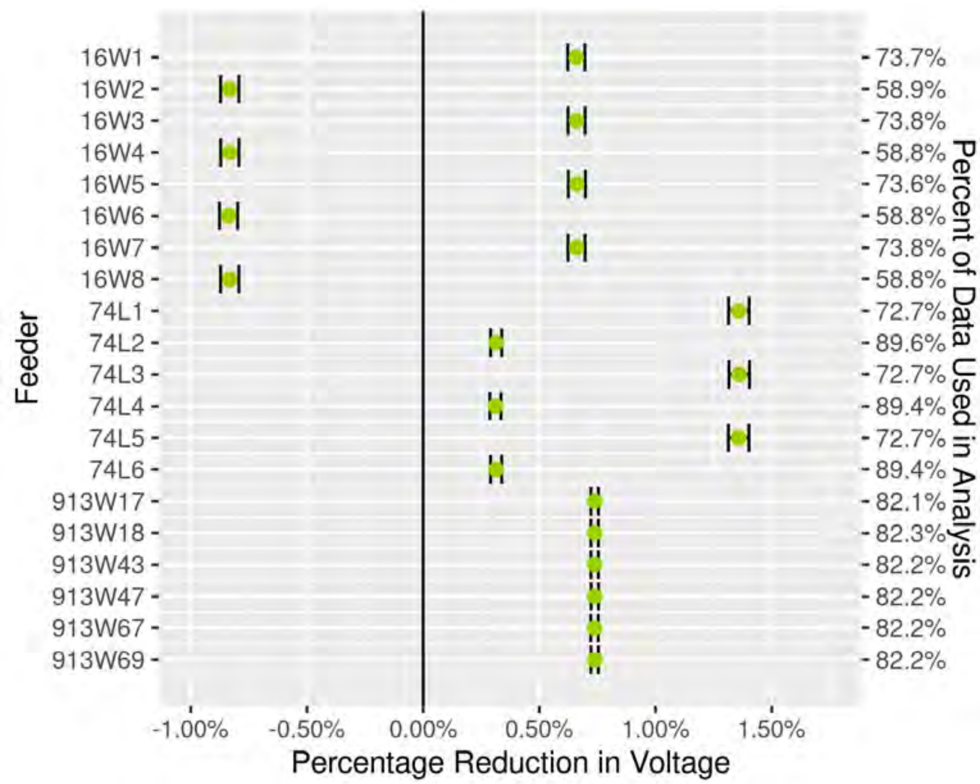


Source: Guidehouse analysis

Figure 35 indicates the net voltage reductions for each National Grid feeder in percentage terms, with green points indicating each feeder's percentage voltage reduction. The whiskers overlaid on each feeder's percentage voltage reduction estimate provide the 90% confidence intervals. Similar to absolute voltage impacts, all feeders except 16W2, 16W4, 16W6, and 16W8 experienced a statistically significant increase in voltage when VVO was enabled.

[73] Guidehouse, on behalf of National Grid, *Clifton Park Volt/VAR Optimization Evaluation Report*, April 2021.

Figure 35. Average Hourly Voltage Reduction (%) for National Grid VVO Feeders



Source: Guidehouse analysis

Following an estimation of percentage energy savings and percentage voltage reductions attributed to VVO, Guidehouse calculated the associated CVR factors for each feeder. The CVR factor, which is the ratio of percentage energy savings to percentage voltage reductions, can provide an estimate of the percentage energy savings possible with each percent voltage reduction. Equation B1 in the Appendix highlights how the CVR factor is calculated using an estimated percentage change in energy and in voltage. Table 86 provides the CVR factor for National Grid.

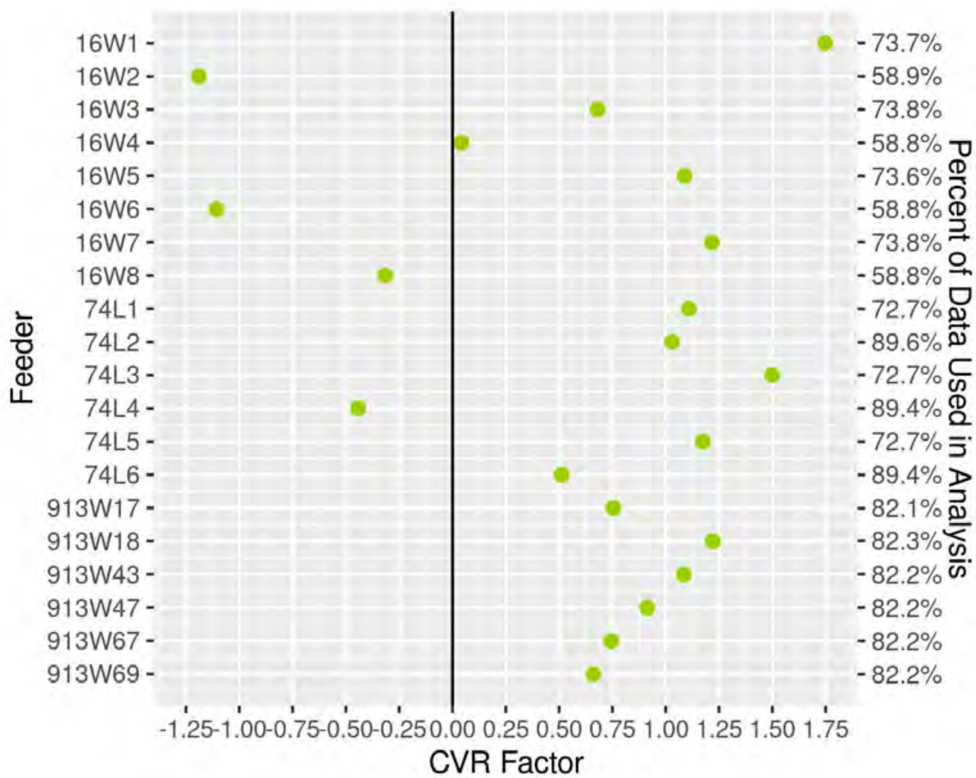
Table 86. National Grid VVO CVR Factor

CVR Factor*
0.54

** The CVR factor provided for each period is the load-weighted average of CVR factors estimated for each feeder.*
Source: Guidehouse analysis

From prior experience evaluating VVO, Guidehouse expects a CVR factor in the neighborhood of 0.80 from a year of VVO M&V testing. Based on evaluation findings, the CVR factor for the Spring 2021 – Winter 2021/22 time period was 0.54, which is on the lower end of what may be expected from a year of VVO M&V testing. Figure 36 provides the CVR factors for the Spring 2021 – Winter 2021/22 M&V period for each feeder.

Figure 36. National Grid VVO CVR Factors



Source: Guidehouse analysis

PM-3: Peak Load Impact

Guidehouse evaluated the impact of VVO during peak load, defined by ISO-NE as 1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays. For all peak load tables and figures in this section, Maplewood feeders are not included in the results because VVO On / Off testing did not occur for these feeders during the peak load period.[74] Table 87 details the evaluated peak load impact across all feeders in absolute and percentage terms.

Table 87. National Grid Average Reduction in Peak Load*

Peak Load Reduction (kW)	Peak Load Reduction (%)
-437 ± 518 kW	-0.91 ± 1.16%

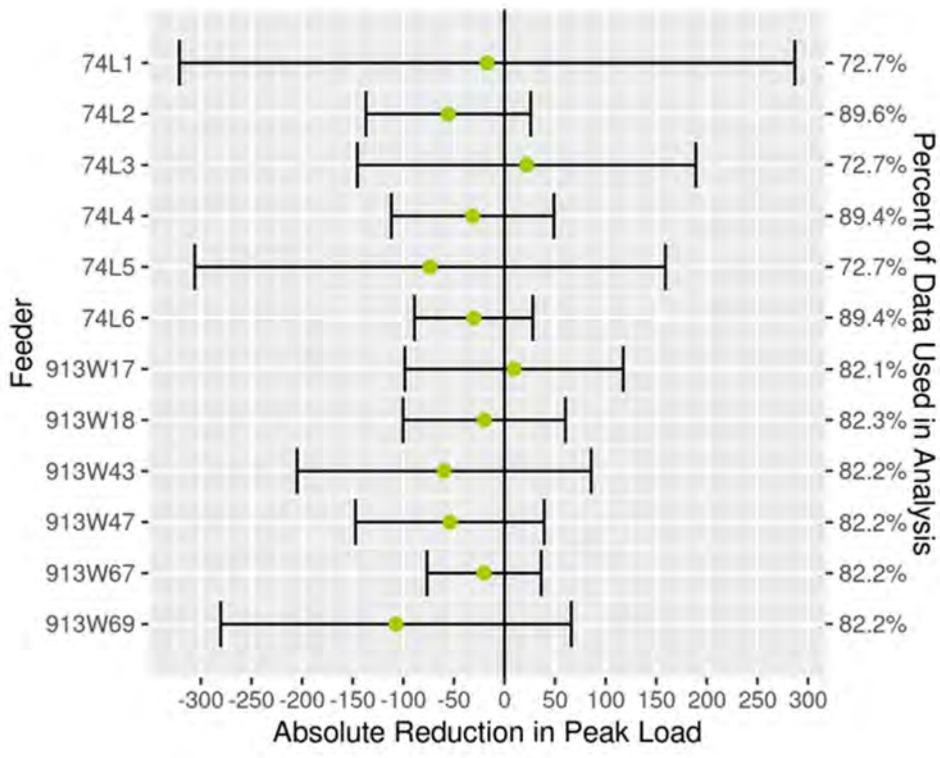
* Peak load change presented in this table is the load-weighted average of peak load changes estimated for each feeder.
Source: Guidehouse analysis

Figure 37 indicates the load reductions measured in kW realized during the peak load period, defined by ISO-NE as 1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays. The whiskers overlaid on each feeder's absolute load reduction estimate provide the

[74] Maplewood feeders began VVO On / Off testing 12/01/2021.

associated 90% confidence intervals. None of the feeders included in the analysis experienced a statistically significant reduction in peak load.

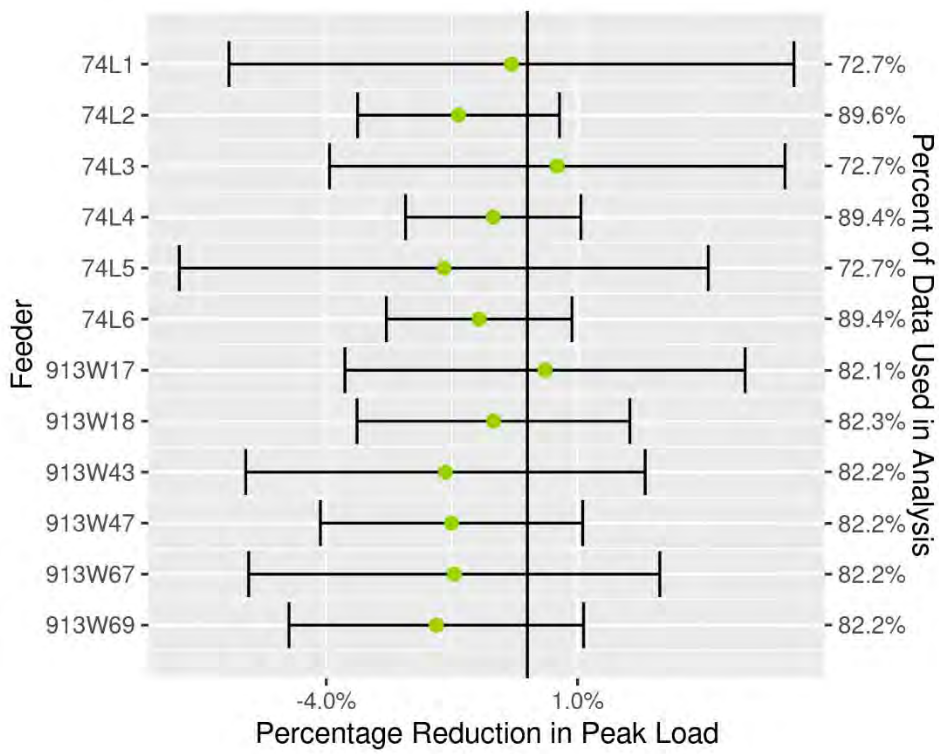
Figure 37. National Grid Reduction in Peak Load (kW)



Source: Guidehouse analysis

Figure 38 indicates the percentage load reductions realized during the peak load period, defined by ISO-NE as 1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays. The whiskers overlaid on each feeder's percent load reduction estimate provide the associated 90% confidence intervals.

Figure 38. National Grid Reduction in Peak Load (%)



Source: Guidehouse analysis

PM-4: Distribution Losses

Guidehouse evaluated reduction in distribution losses as a function of VVO during the Spring 2021 – Winter 2021/22 M&V period. There were some feeders with very little data where kW was greater than 75% of annual peak load for kVA. Given that power factor is an input for the distribution losses equation, these feeders were ultimately removed from the distribution losses calculation, as they had fewer than 100 hours available for use in the regression modeling. The methodology for calculating the percent reduction in distribution losses is shown in Appendix B.3. Table 88 details the evaluated percentage reduction in distribution losses for each National Grid feeder with sufficient data quality.

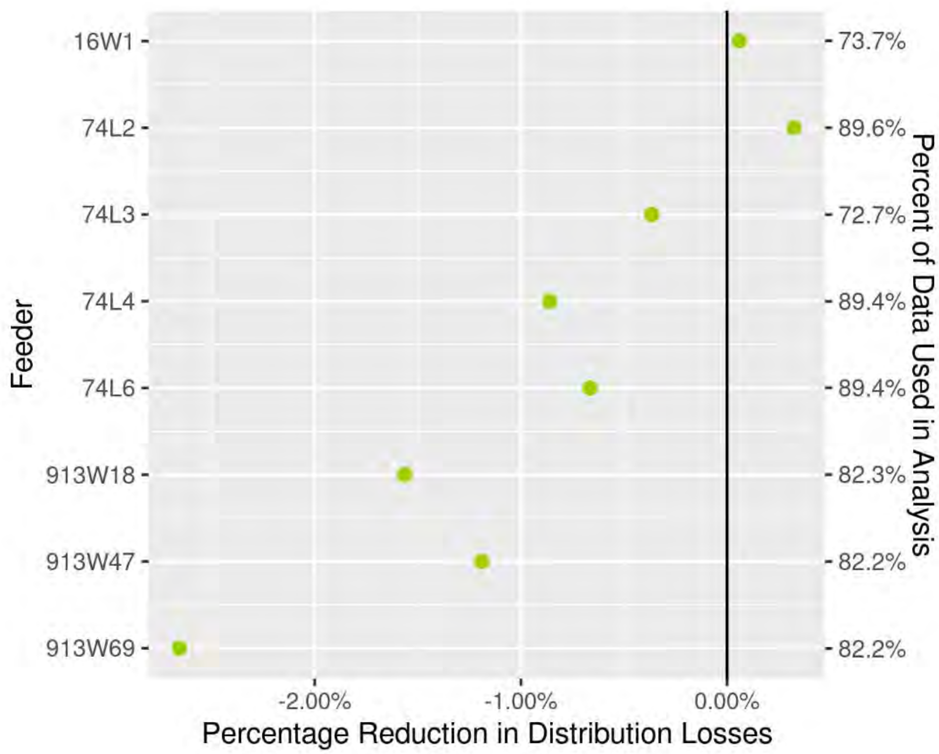
Table 88. National Grid Reduction in Distribution Losses

Reduction in Distribution Losses (%)*
-0.88%

* The change in line losses presented in this table is the load-weighted average of reduction in line losses estimated for each feeder.
Source: Guidehouse analysis

Figure 39 indicates the percentage reduction in distribution losses.

Figure 39. National Grid Reduction In Distribution Losses (%)



Source: Guidehouse analysis

PM-5: Power Factor

Guidehouse evaluated the impact on power factor associated with VVO during the Spring 2021 – Winter 2021/22 M&V period. Changes in power factor were analyzed during periods where power was greater than 75% of feeder-specific annual demand. Table 89 details the evaluated change in power factor for each National Grid feeder with sufficient data quality[75].

Table 89. National Grid VVO Average Hourly Power Factor Change*

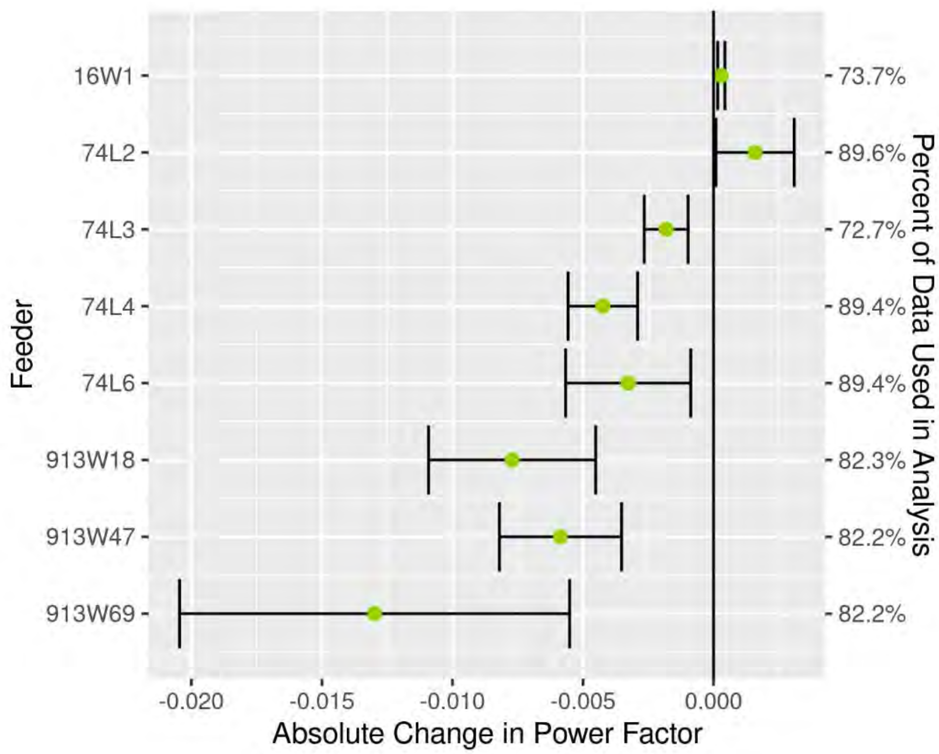
Change in Power Factor	Change in Power Factor (%)
-0.03 ± 0.01	-0.43 ± 0.13%

* Power factor change presented in this table is the load-weighted average of power factor changes estimated for each feeder.
Source: Guidehouse analysis

Figure 40 indicates the change in power factor for each National Grid feeder in absolute terms, with green points indicating each feeder's absolute power factor change. The whiskers overlaid on each feeder's absolute power factor change estimate provide the associated 90% confidence intervals.

[75] There were some feeders with very little data where kW was greater than 75% of annual peak load for kVA. These feeders were ultimately removed from the power factor models, as they had fewer than 100 hours available for use in regression modeling.

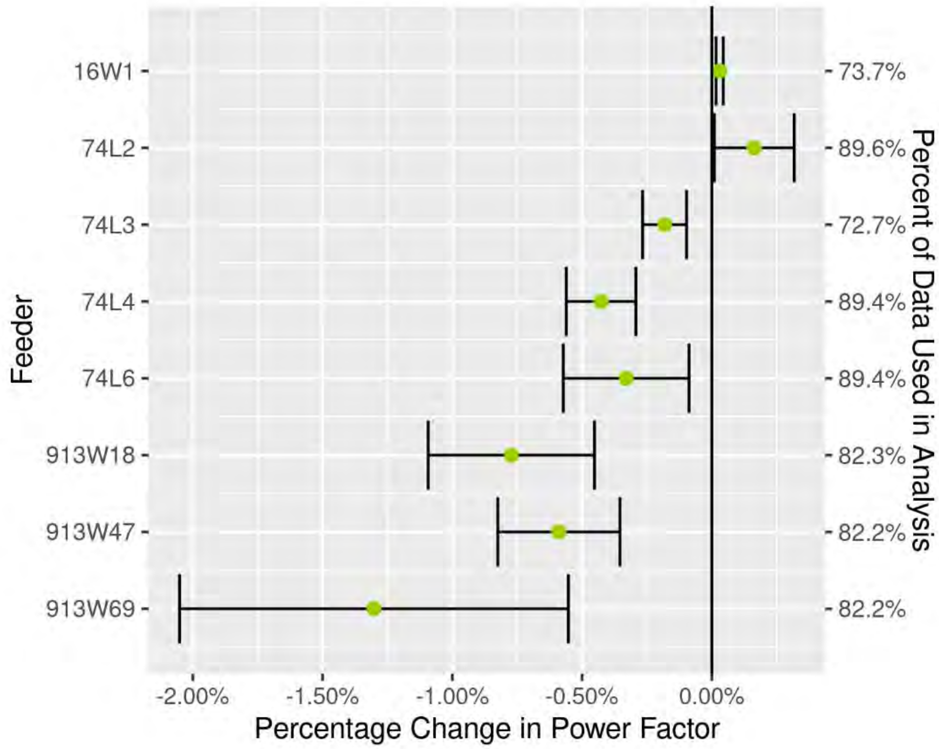
Figure 40. National Grid Absolute Change in Power Factor



Source: Guidehouse analysis

Figure 41 indicates the change in power factor for each National Grid feeder in percentage terms, with green points indicating each feeder's percentage power factor change. The whiskers overlaid on each feeder's percentage power factor change estimate provide the associated 90% confidence intervals.

Figure 41. National Grid Percentage Change in Power Factor



Source: Guidehouse analysis

PM-6: GHG Emissions

After evaluating energy savings attributed to VVO, Guidehouse calculated the resulting emissions reductions. Emissions reductions were determined by calculating the product of energy savings and emissions reduction factors provided in the Massachusetts Joint Statewide Electric and Gas Three Year Energy Efficiency Plans for 2019–2021.[76]

Table 90 provides emissions reductions associated with VVO, with 90% confidence bounds indicated by the ± figure.

Table 90. National Grid VVO Emissions Reductions During Actual VVO On Hours

Metric	NO_X	SO_2	CO_2
Spring 2021 – Winter 2021/22 Emissions Reduction	0.15 ± 0.03 tons	0.04 ± 0.007 tons	468 ± 84 tons

Source: Guidehouse analysis

PM-7: Voltage Complaints

Guidehouse received voltage complaint logs from National Grid to facilitate Performance Metrics analysis. Guidehouse tabulated voltage complaints received by VVO feeder between

[76] Emissions factors can be found on page 201 of Massachusetts Joint Statewide Electric and Gas Three Year Energy Efficiency Plans for 2019 – 2021 https://ma-eeac.org/wp-content/uploads/Exh.-1-Final-Plan-10-31-18-With-Appendices-no-bulk.pdf

2016 and Q1 2022, as well as the Spring 2021 – Winter 2021/22 M&V period.[77] Discussion below highlights key observations for voltage complaints, comparing the count of voltage complaints received during Spring 2021 – Winter 2021/22 to the average number of voltage complaints from the 2016–2017 baseline period. Table 91 summarizes voltage complaints for the East Methuen substation.

Table 91. Count of Voltage Complaints for East Methuen Substation

Number of Voltage Complaints	74L1	74L2	74L3	74L4	74L5	74L6	Total
Customers	3,081	1,578	3,283	1,611	3,108	1,788	14,449
2016	2	5	10	7	9	2	35
2017	8	1	5	2	6	2	24
2018	3	0	2	3	5	3	16
2019	5	0	2	2	3	2	14
2020	1	1	7	3	2	2	16
2021	7	1	5	1	5	3	22
2022	2	0	5	0	1	0	8
Spring 2021 – Winter 2021/22	8	1	10	0	6	2	27

Source: Guidehouse analysis

Voltage complaints vary considerably across years and VVO feeders, ranging from 14 complaints in 2019 to 35 complaints in 2016. Looking at 2016–2017 baseline period,[78] there were 59 voltage complaints received, amounting to about 30 voltage complaints per year. Based on voltage complaints data received, a total of 27 voltage complaints were reported along the East Methuen feeders during Spring 2021 – Winter 2021/22 M&V period, slightly below the baseline period average number of complaints per year.

Table 92 summarizes voltage complaints for the Maplewood substation. Voltage complaints vary considerably across years and VVO feeders, ranging from 20 complaints in 2016 to 50 complaints in 2019. Looking at 2016–2017 baseline period, there were 51 voltage complaints received, amounting to about 26 voltage complaints per year. Based on voltage complaints data received, a total of 35 voltage complaints were reported along the Maplewood feeders during the Spring 2021 – Winter 2021/22 M&V period, slightly above the baseline period average number of complaints per year.

[77] Since 2016 is the earliest date at which voltage complaints data are available, Guidehouse limited its summary of voltage complaints to January 1, 2016 through February 28, 2022.

[78] Guidehouse presents a comparison of complaints between the 2016–2017 period and winter 2020/21 M&V period. For new VVO feeders that begin receiving VVO investments beginning in 2021, Guidehouse recommends that a 3-year moving average (i.e. 2019–2021) be used instead of an average for the time period spanning 2016 through 2017, as conditions in 2016 through 2017 may not accurately reflect baseline conditions immediately preceding deployment of VVO investments.

Table 92. Count of Voltage Complaints for Maplewood Substation

Number of Voltage Complaints	16W1	16W2	16W3	16W4	16W5	16W6	16W7	16W8	Total
Customers	3,597	4,619	3,018	1,111	1,650	5,696	3,857	3,371	26,919
2016	4	3	0	2	3	4	2	2	20
2017	6	3	2	0	5	6	4	5	31
2018	6	3	1	4	1	6	6	7	24
2019	7	10	5	3	1	8	6	10	50
2020	6	7	4	4	3	10	6	8	48
2021	4	11	0	1	2	11	4	6	39
2022	0	2	0	0	0	0	1	2	5
Spring 2021 – Winter 2021/22	4	9	0	0	1	9	5	7	35

Source: Guidehouse analysis

Table 93 summarizes voltage complaints for the Stoughton substation. Voltage complaints vary considerably across years and VVO feeders, ranging from 14 complaints in 2019 to 32 complaints in 2016. Looking at 2016–2017 baseline period, there were 52 voltage complaints received, amounting to 26 voltage complaints per year. Based on voltage complaints data received, a total of 11 voltage complaints were reported along the Stoughton feeders during Spring 2021 – Winter 2021/22, moderately below the baseline period average number of complaints per year.

Table 93. Count of Voltage Complaints for Stoughton Substation

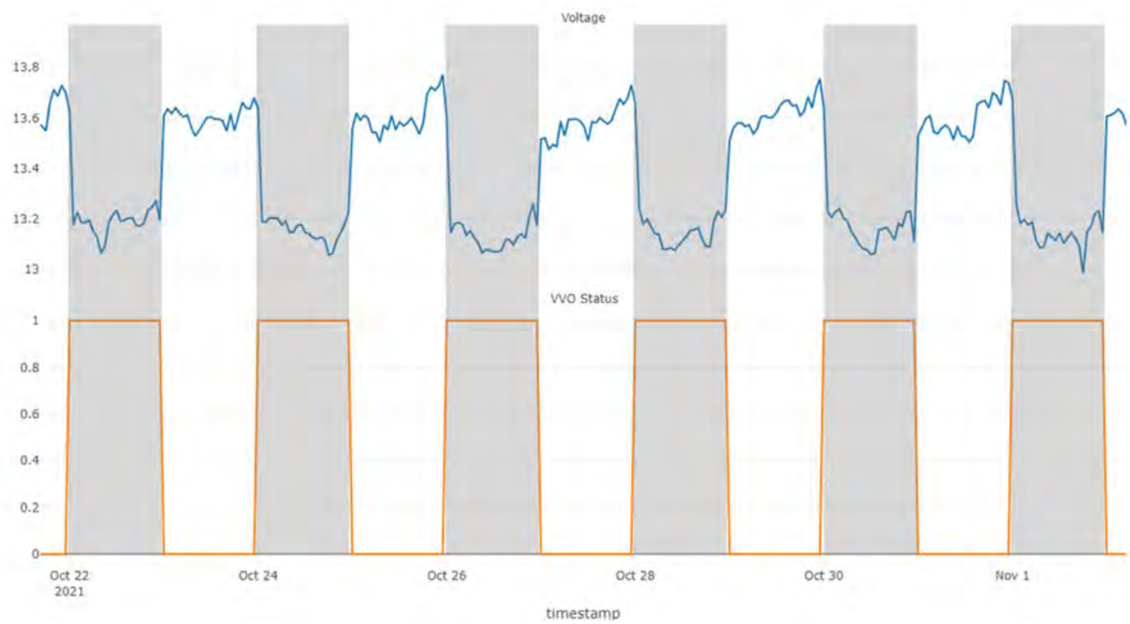
Number of Voltage Complaints	913W17	913W18	913W43	913W47	913W67	913W69	Total
Customers	1,354	1,530	2,119	1,813	738	3,607	11,161
2016	2	7	5	5	2	11	32
2017	1	8	5	1	1	4	20
2018	8	1	6	0	1	7	23
2019	4	3	4	2	0	1	14
2020	3	3	3	6	6	3	24
2021	2	3	1	4	0	5	15
2022	0	0	1	0	0	0	1
Spring 2021 – Winter 2021/22	1	2	2	3	0	4	12

* Count of customers served by each feeder was extracted from 2020 GMP Annual Report, Appendix 1.
Source: Guidehouse analysis

4.2.3.4 Additional Investigation of National Grid VVO Signals

Guidehouse identified patterns in voltage and VVO On / Off statuses that may be informative to National Grid moving forward. When a utility is conducting VVO On / Off testing, Guidehouse expects to observe noticeable increases and decreases in voltage as VVO alternates between engaged and disengaged states. Figure 42 illustrates head-end voltage (in blue) and VVO On / Off status (in orange) between October 22, 2021 and November 2, 2021 for a transformer at the East Methuen substation, where days where VVO was engaged highlighted in grey. The figure represents an expected voltage response to VVO, where head-end voltage maintained a lower steady state when VVO was engaged (VVO Status = 1) and a higher steady state when VVO was disengaged (VVO Status = 0).

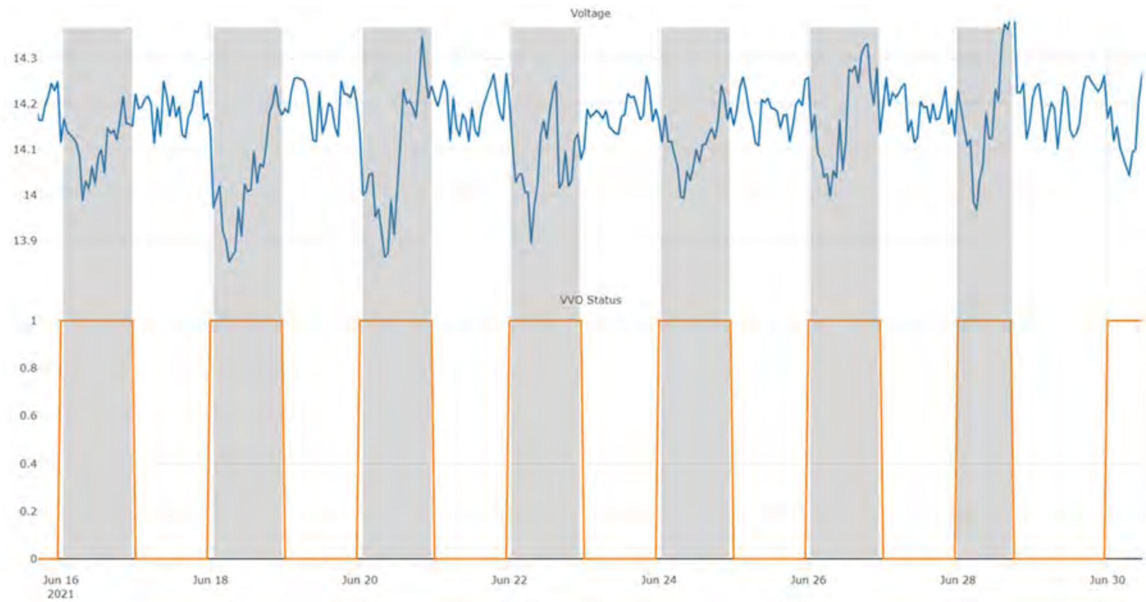
Figure 42. VVO On / Off Testing at East Methuen Substation



Source: Guidehouse analysis

During the process of data inspection, Guidehouse identified numerous cases where the expected voltage response was not observed. Figure 43 illustrates head-end voltage (in blue) and VVO On / Off status (in orange) between June 16, 2021 and June 30, 2021 for the Stoughton substation, where days where VVO was engaged highlighted in grey. From this figure, it is apparent that voltage did not maintain a lower steady state when VVO was engaged. Instead, voltage appears to have dropped when VVO switched from the disengaged state to the engaged state, but then began to rise around midday on the VVO engaged day. This was particularly notable on June 20, June 26, and Jun 28, 2021, where Stoughton head-end voltage rose above levels that were observed on neighboring days where VVO was disengaged.

Figure 43. VVO On / Off Testing at Stoughton Substation



Source: Guidehouse analysis

Guidehouse recommends that National Grid explore ways to improve voltage responses across substations with VVO investments. In particular, National Grid should look to determine whether there are conditions that cause midday increases in voltage on days where VVO is engaged. Once identified, National Grid should consider working with its VVO vendor to determine a way to improve voltage responses under these conditions.

4.2.3.5 Key Findings and Recommendations

Guidehouse's VVO evaluation findings indicate that VVO allowed National Grid to realize energy savings and voltage reductions during the Spring 2021 – Winter 2021/22 M&V period. More specifically:

- National Grid VVO feeders realized 0.77% energy savings and 0.37% voltage reductions when VVO was engaged. East Methuen 74L1, 74L3, and 74L5 feeders realized greatest energy and voltage benefits, with 1.5 to 2.0% energy savings and around 1.5% voltage reduction when VVO was engaged. Maplewood 16W2, 16W4, 16W6, and 16W8 feeders realized least energy and voltage benefits, with a 0.75% increase in voltage when VVO was engaged.
- National Grid VVO feeders experienced limited changes in peak load, power factor, and line losses. VVO feeders experienced no statistically significant change in peak load when VVO was engaged. In addition, VVO feeders experienced a small decrease (0.43%) in power factor when VVO was engaged. This resulted in a minimal increase in line losses.

In 2021 and beyond, Guidehouse recommends that National Grid:

- Ensure VVO On / Off testing runs according to plan, with limited pauses to the VVO On / Off testing schedule. A large number of data points removed due to extended pauses in

VVO On / Off testing. Sustained VVO On / Off testing will increase amount of usable data in evaluation, improve precision and accuracy of impact estimates.

- Investigate how to improve voltage outcomes across VVO feeders. East Methuen 74L1, 74L3, and 74L5 feeders exhibited sustained reductions in voltage when VVO was engaged. Other feeders exhibited a rebound in voltage when VVO was engaged, particularly during the summer months. Given higher energy and voltage reductions for the East Methuen 74L1, 74L3, and 74L5 feeders, National Grid should investigate how to better maintain sustained voltage reductions when VVO is engaged.

5. Key Findings and Recommendations

The subsections that follow present key findings for VVO Infrastructure Metrics, VVO Performance Metrics, and recommendations for the VVO investment area for each of the EDCs.

5.1 Key Findings for VVO Infrastructure Metrics

PY2021's VVO Infrastructure Metrics findings show that the EDCs are at varying stages in VVO deployment. Details pertaining to device deployment progress, VVO enablement progress, and total spend are shown below:

Device Deployment:

- Eversource overall deployment was below plans for 2021, however this varied by device type. Overall deployment was below plans due to several factors. Eversource scaled down deployment plans for its Gunn and Oswald substations, as the substations required fewer regulators and capacitor banks for VVO and did not require LTC control devices or new feeder head sensors, as these devices were already deployed in prior capital projects. In addition, delayed engineering and design work, long vendor lead times, and crew resource constraints combined to delay Eversource's ability to meet revised deployment goals set out for 2021.
- National Grid deployment through 2021 was lower than initially planned, with all device types having fewer fully commissioned devices than planned. One large factor at play in 2021 was competing priorities of crew resources. National Grid had adapted its work practices to COVID-19 protocols so that certain field reporting locations had a reduction in crews. These resource limitations led to delays in construction schedules and backlogs of customer work were prioritized. Despite lower deployment than planned, National Grid continued construction and design/engineering work across all device types throughout 2021.
- Unitil deployment of VVO devices was below plans in 2021. Unitil did not fully deploy and commission devices at the Lunenburg and Summer Street substations as planned, as Unitil revised its VVO deployment timeline partway through 2021. Despite the shift in timeline, Unitil continued construction work throughout 2021 for Summer Street, Lunenburg, and West Townsend, as well as engineering/design work for the Princeton Road substation.

VVO Enablement:

- Eversource conducted VVO On/Off testing at all of its original 2018-2020 plan substations throughout 2021, conducting VVO On/Off testing at the Agawam, Piper, and Silver substations all year, and at the Podick substation beginning in March 2021. In tandem with VVO On/Off testing at the original 2018-2020 plan substations, Eversource conducted deployment of VVO devices across the Gunn and Oswald substations. VVO On/Off testing is expected to begin at these substations in May and June 2022, respectively.
- National Grid has completed deployment of VVO on all original 2018-2020 plan feeders and conducted VVO On/Off testing on these feeders throughout 2021. On its additional feeders, National Grid completed VVO deployment at the East Bridgewater substation

and has been conducting VVO On/Off testing since July 2021. VVO On/Off testing is expected to begin for the East Dracut and West Salem substations in June 2022, and is expected to begin for the Easton, Melrose, and Westboro substations in December 2022.

- Unitil VVO enablement fell short of its schedule laid out in the PY2020 Evaluation Report. Unitil completed VVO deployment at the Townsend substation in 2021, enabling VVO in December. VVO On/Off testing is expected to begin at the Townsend substation in April 2022. For the Summer Street, Lunenburg, and West Townsend substations, VVO On/Off testing is expected to begin in December 2022, December 2023, and December 2024, respectively.

Total Spend:

- Eversource spend in 2021 was lower than plans for all device types. Eversource scaled down plans for the Oswald and Gunn substations, reducing spend on capacitor banks and regulators. In addition, vendor lead times and crew resources required for deployment of VVO devices were committed to other Eversource objectives, contributing to Eversource's delay in meeting deployment goals set out for 2021. Lastly, Gunn and Oswald substations did not require LTC control devices, as these devices had been completed historically, reducing spend on LTC controls. These factors combined to keep spend lower than plans on all device types.
- National Grid spend in 2021 was lower than plans for all device types except for LTC controls. Spend on LTC controls exceeded plans due to significant engineering required for VVO to be operational and due to initial cost estimates being too conservative. Despite higher-than-expected spending on LTC controls, spending across all VVO devices was lower than planned. The largest factors for lower spend was increased vendor lead times, leading to delays in fully commissioning devices, as well as increased efficiencies in VVO device pre-testing and field commissioning because of prior lessons learned during deployment of VVO devices in 2018-2020.
- Unitil spending on VVO devices was below plans in 2021. Spend during 2021 covered fully commissioning VVO devices at the Townsend substation. However, given Unitil shifted its deployment timeline, spend that would have been conducted on commissioning VVO devices at Summer Street, Lunenburg, and West Townsend has been deferred. Spending at these substations was instead focused on construction work.

The EDCs are slated to complete carryover deployment of VVO investments throughout 2022. In particular:

- Eversource carryover deployment and spending for 2022 spans completing deployment of regulators, capacitor banks, and line sensors on the Gunn and Oswald circuits. Additionally, carryover deployment and spending will cover deployment of grid monitoring line sensors across numerous substations in Eastern and Western Massachusetts. Total spend through 2022 is expected to end up below plans.
- National Grid carryover deployment and spending for 2022 covers carryover work that was initially planned for 2021 across five of six new substations, which will include work to bring devices from the construction and in-service phases to commissioned. VVO is then expected to conduct VVO On/Off testing starting in June 2022 for 2 substations and

starting in December 2022 for 3 substations. Total spend and deployment through 2022 is expected end up above plans.

- Unitil carryover deployment and spending for 2022 spans deployment VVO devices at substations identified in recent 4-year Term plan totals. Remaining carryover deployment spans commissioning the remaining VVO devices at the Summer Street, Lunenburg, and West Townsend substations in 2022 through 2024. In addition, deployment and spend spans continuing design/engineering and construction work across additional substations slated to receive VVO between 2022 and 2028.

5.2 Key Findings for VVO Performance Metrics

Findings from the evaluation of Performance Metrics indicate that VVO allowed Eversource and National Grid to realize energy savings and voltage reductions during the Spring 2021 – Winter 2021/22 M&V period. It can be difficult to compare the results from Performance Metrics analysis between Eversource and National Grid. For example, there are differences in the granularity of telemetry (e.g., 15-minute versus 1 hour), data quality at different times of the year (e.g., sustained pauses in VVO On / Off testing during Spring 2021 for one EDC, repeated data during Summer 2021 for another EDC). As such, data cleaning can cause certain portions of the M&V period to be represented more for one EDC than the other. Additionally, there are numerous differences in DG penetration, customer types, and geographic areas served by Eversource and National Grid feeders that limit the ability to directly compare Eversource and National Grid VVO outcomes. Key Findings from the evaluation of Performance Metrics are as follows:

- During the Spring 2021 – Winter 2021/22 M&V period, Eversource's Agawam, Piper, and Silver substations realized 484 MWh (0.38%) energy savings and 1.14 V (0.93%) voltage reduction associated with VVO. The CVR Factor, which provides an estimate of energy savings possible with voltage reductions, was 0.70. During the same M&V period, National Grid's East Methuen, Maplewood, and Stoughton substations realized 948 MWh (0.77%) energy savings and 0.05 kV (0.37%) voltage reduction associated with VVO. National Grid's CVR factor was 0.54.

- Eversource energy savings of 484 MWh yielded a 239 short ton reduction of CO_2 emissions, a 0.077 short ton reduction of NO_x emissions, and a 0.019 short ton reduction of SO_2 emissions. National Grid energy savings of 948 MWh yielded a 468 short ton reduction in CO_2 emissions, a 0.15 short ton reduction in NO_x emissions, and a 0.04 short ton reduction in SO_2 emissions.

- Eversource and National Grid VVO feeders experienced a minimal benefit associated with peak load, power factor, and line losses. Eversource VVO feeders experienced a statistically significant increase (1.19%) in peak load, a statistically insignificant increase (0.08%) in power factor, and a minimal decrease in line losses when VVO was engaged. National Grid VVO feeders experienced no statistically significant change in peak load, a small decrease (0.43%) in power factor, and a minimal increase in line losses when VVO was engaged.

- For Eversource, a total of 67 voltage complaints were received from customers connected to the Agawam, Piper, and Silver VVO feeders during the Spring 2021 – Winter 2021/22 M&V period. This is a 12% increase relative to the average voltage complaints per year received between 2015 – 2017. For National Grid, a total of 74 voltage complaints were received from customers connected to the East Methuen, Maplewood, and Stoughton VVO feeders during the period. This is a 1% decrease relative to the average voltage complaints per year received between 2016 – 2017. For both EDCs, there is not sufficient evidence to support changes in voltage complaints being attributed to VVO.

5.3 Recommendations

In 2021 and beyond, Guidehouse recommends that Eversource and National Grid:

- Ensure that VVO On / Off testing is running according to plan, with limited pauses to the VVO On / Off testing schedule. A large number of data points across substations and feeders were removed due to extended pauses in VVO On / Off testing. Sustained VVO On / Off testing will increase the amount of usable data in the evaluation, and improve the precision and accuracy of impact estimates.
- Consider investigating how to improve outcomes across VVO feeders. The voltage reductions varied across the substations and feeders. Some feeders underwent no material change in voltage, indicating potential VVO malfunctions, while other feeders exhibited sustained reductions in voltage when VVO was engaged. Both Eversource and National Grid should investigate how to better maintain sustained voltage reductions when VVO is engaged across all substations and feeders.

Appendix A. Additional Feeder Characteristics by EDC

A.1 Eversource Additional Feeder Characteristics

Table A-1. Additional Eversource Feeder Characteristics

Substation	Feeder	Avg Customer Loading (kVA/customer)	Customer Density (customer/mi.)	Load Density (MVA/mi.)	DG Penetration (DG MW/MVA)
Original 2018–2020 Plan Feeders					
Agawam (13.8 kV)	16C11	7.24	55	0.40	0.32
	16C12	148.25	12	1.82	0.37
	16C14	7.14	106	0.75	0.03
	16C15	9.48	112	1.06	0.02
	16C16	4.49	116	0.52	0.31
	16C17	4.02	81	0.32	0.15
	16C18	3.37	145	0.49	0.12
Piper (13.8 kV)	21N4	3.91	69	0.27	0.20
	21N5	14.56	56	0.82	0.02
	21N6	14.88	53	0.79	0.12
	21N7	6,991	0	2.90	0.00
	21N8	16.06	65	1.04	0.01
	21N9	5.30	102	0.54	0.14
Podick (13.8 kV)	18G2	1,434	2	3.04	0.00
	18G3	6.03	57	0.34	0.53
	18G4	4.71	67	0.31	1.17
	18G5	5.84	44	0.26	0.97
	18G6	7.88	34	0.27	0.69
	18G7	4.65	35	0.16	2.42
	18G8	11.52	23	0.27	1.15
Silver (13.8 kV)	30A1	5.84	68	0.39	0.15
	30A2	12.97	82	1.06	0.03
	30A3	48.40	21	1.01	0.81
	30A4	13.85	74	1.02	0.05
	30A5	7.11	77	0.55	0.15
	30A6	8.15	51	0.41	0.42
Additional Feeders					
Gunn (23 kV)	15A1	5.90	141	0.23	0.28
	15A2	8.70	22	0.83	0.22
	15A3	4.49	120	0.17	0.28
	15A5	5.38	59	0.59	0.10
Oswald (23 kV)	30B5	6.22	71	0.44	0.32
	30B7	8.41	23	0.19	0.86

Source: Guidehouse analysis of 2021 GMP Annual Report, Appendix 1 filed April 1, 2022. EDCs provided distributed generation data.

A.2 National Grid Additional Feeder Characteristics

Table A-2. Additional National Grid Feeder Characteristics

Substation	Feeder	Avg Customer Loading (kVA/customer)	Customer Density (customer/mi.)	Load Density (MVA/mi.)	DG Penetration (DG MW/MVA)
Original 2018–2020 Plan Feeders					
East Methuen (13.2 kV)	74L1	6.06	80	0.48	0.20
	74L2	6.16	94	0.58	0.08
	74L3	3.46	168	0.58	0.15
	74L4	5.93	186	1.10	0.12
	74L5	3.53	57	0.20	0.11
	74L6	6.78	212	1.43	0.05
Stoughton (13.8 kV)	913W17	9.36	96	0.90	0.12
	913W18	6.64	129	0.86	0.06
	913W43	6.34	66	0.42	0.09
	913W47	8.00	113	0.90	0.03
	913W67	18.20	59	1.07	0.06
	913W69	3.72	115	0.43	0.11
Maplewood (13.8 kV)	16W1	3.36	208	0.70	0.09
	16W2	2.11	426	0.90	0.07
	16W3	4.20	225	0.94	0.05
	16W4	11.40	143	1.63	0.08
	16W5	7.46	247	1.84	0.09
	16W6	2.16	228	0.49	0.11
	16W7	3.28	270	0.89	1.11
	16W8	3.76	213	0.80	0.11
Additional Feeders					
Easton (13.8 kV)	92W43	5.17	71	0.36	0.10
	92W44	7.62	67	0.51	0.09
	92W54	4.45	68	0.30	0.74
	92W78	6.34	52	0.33	0.06
	92W79	7.69	67	0.51	0.43
East Bridgewater (13.8 kV)	797W1	5.30	78	0.41	0.09
	797W19	5.69	68	0.39	0.17
	797W20	8.25	55	0.46	0.04
	797W23	5.36	66	0.35	0.11
	797W24	5.67	48	0.27	0.09
	797W29	6.21	63	0.39	0.13
	797W42	11.30	57	0.59	0.13
East Dracut (13.8 kV)	75L1	3.22	185	0.28	0.08
	75L2	4.32	65	0.24	0.08
	75L3	5.29	46	1.27	0.16
	75L4	28.80	44	0.51	0.02
	75L5	2.70	188	0.46	0.10

Substation	Feeder	Avg Customer Loading (kVA/customer)	Customer Density (customer/mi.)	Load Density (MVA/mi.)	DG Penetration (DG MW/MVA)
	75L6	7.76	60	0.59	0.07
Melrose (13.8 kV)	25W1	7.76	85	0.66	0.18
	25W2	10.20	73	0.75	0.06
	25W3	15.35	85	1.30	0.02
	25W4	2.71	224	0.61	0.08
	25W5	3.24	192	0.62	0.10
West Salem (13.8 kV)	29W1	3.32	162	0.54	0.16
	29W2	7.61	96	0.73	0.08
	29W3	2.94	277	0.81	0.09
	29W4	4.21	150	0.63	0.16
	29W5	3.62	240	0.87	0.10
	29W6	9.36	80	0.75	0.10
Westboro (13.8 kV)	312W1	5.63	73	0.41	0.15
	312W2	67.59	22	1.46	0.24
	312W3	7.52	65	0.49	0.09
	312W4	4.74	48	0.23	0.38
	312W5	29.95	31	0.93	0.07

Source: Guidehouse analysis of 2021 GMP Annual Report, Appendix 1 filed April 1, 2022. EDCs provided distributed generation data.

A.3 Unitil Additional Feeder Characteristics

Table A-3. Additional Unitil Feeder Characteristics

Substation	Feeder	Avg Customer Loading (kVA/customer)	Customer Density (customer/mi.)	Load Density (MVA/mi.)	DG Penetration (DG MW/MVA)
Original 2018–2020 Plan Feeders					
Townsend (13.8 kV)	15W15	8,844	16	137.23	0.00
	15W16	5.81	37	0.21	0.18
	15W17	15.33	51	0.77	0.05
Lunenburg (13.8 kV)	30W30	6.75	29	0.20	0.16
	30W31	6.08	36	0.22	0.38
Summer Street (13.8 kV)	40W38	2,558	5	12.65	0.00
	40W39	21.39	54	1.16	0.11
	40W40	6.07	85	0.52	0.16
	40W42	5.36	139	0.74	0.05
Additional Feeders					
West Townsend (13.8 kV)	39W18	6.44	38	0.25	0.23
	39W19	5.74	21	0.12	0.45

Source: Guidehouse analysis of 2021 GMP Annual Report, Appendix 1 filed April 1, 2022. EDCs provided distributed generation data.

Appendix B. Detailed Information for Performance Metrics Analysis

B.1 Conservation Voltage Reduction Factor

One informative metric associated with VVO is the conservation voltage reduction (CVR) factor, which reveals the percentage of energy savings that can be expected for each percentage of voltage reduction. Equation B-1 highlights how the CVR factor is calculated using an estimated percentage change in energy and percentage change in voltage.

Equation B-1. CVR Factor Calculation

$$CVRf = \frac{\%\Delta\, Energy}{\%\Delta\, Voltage}$$

B.2 Regression Methodology for Energy and Voltage

Guidehouse conducted regression modeling to assess the impacts of VVO on measured feeder-level real power and voltage. To estimate the impact of VVO on feeder-level real power and voltage observed during the Spring 2021 – Winter 2021/22 M&V period, Guidehouse estimated a regression model of real power and a regression model of voltage for each individual feeder. Equation B-2 summarizes the regression model specification used to estimate real power and voltage as a function of VVO.

Equation B-2. Regression Model of Energy and Voltage

$$\begin{aligned}\{kW_{it}, V_{it}\} = {} & \beta_1 Summer\ Peak_{it} + \beta_2 Summer\ OffPeak_{it} + \beta_3 Winter\ Peak_{it} + \beta_4 Winter\ OffPeak_{it} \\ & + \beta_5 VVO_{it} * Summer\ Peak_{it} + \beta_6 VVO_{it} * Summer\ OffPeak_{it} + \beta_7 VVO_{it} * Winter\ Peak_{it} \\ & + \beta_8 VVO_{it} * Winter\ OffPeak_{it} + \beta_9 Holiday_{it} + \beta_{10} Daylight_{it} + \sum_{d=1}^{7} \beta_{11} * \tau_d \\ & + \sum_{w=1}^{52} \beta_{12} * \tau_w + \sum_{d,h=1}^{168} \beta_{13\ ,h} * \tau_{d,h} + \sum_{h=1}^{24} \beta_{14h} * \tau_h * Cloud_{it} * Daylight_{it} + \beta_{15} HDH_{it} \\ & + \beta_{16} HDH_{it}^2 + \beta_{17} CDH_{it} + \beta_{18} CDH_{it}^2 + \beta_{19} DR\ Flag_t + \epsilon_{it}\end{aligned}$$

Where:

$i, t, h, d,$ and w	index feeder, time-interval, each of the 24 hours of the day, day of week, and week of year respectively.
kW_{it}	is real power (kW) measured at feeder i at time t.
V_{it}	is voltage (V) measured at feeder i at time t.
$Summer\ Peak_{it}$	is an indicator equal to 1 when feeder i at time t falls within 7:00 AM to 11:00 PM during a non-holiday weekday, June to September. The

corresponding coefficient β_1 captures the average real power and voltage observed during peak energy hours.

$Summer\ OffPeak_{it}$ is an indicator equal to 1 when feeder i at time t falls within a weekend, a holiday, or within 11:00 PM to 7:00 AM during a non-holiday weekday, June to September. The corresponding coefficient β_2 captures the average real power and voltage observed during off peak energy hours.

$Winter\ Peak_{it}$ is an indicator equal to 1 when feeder i at time t falls within 7:00 AM to 11:00 PM during a non-holiday weekday, October to May. The corresponding coefficient β_3 captures the average real power and voltage observed during peak energy hours.

$Winter\ OffPeak_{it}$ is an indicator equal to 1 when feeder i at time t falls within a weekend, a holiday, or within 11:00 PM to 7:00 PM during a non-holiday weekday, October to May. The corresponding coefficient β_4 captures the average real power and voltage observed during off peak energy hours.

VVO_{it} is an indicator equal to 1 when VVO is engaged for feeder i at time t. The coefficient β_5 captures the average hourly impact of VVO on real power or voltage during the summer peak energy period; the coefficient β_6 captures the average hourly impact of VVO on real power or voltage during the summer off-peak energy period; the coefficient β_7.captures the average hourly impact of VVO on real power or voltage during the winter peak energy period; and the coefficient β_8 captures the average hourly impact of VVO on real power or voltage during the winter of-peak energy period. A combination of $\beta_5, \beta_6, \beta_7, \text{and } \beta_8$ captures the average hourly impact of VVO on real power or voltage during the entire analysis period.

$Holiday_{it}$ is an indicator equal to 1 when feeder i at time t falls within a holiday. The coefficient β_9 captures the average real power or voltage observed on holidays during the Spring 2021 – Winter 2021/22 analysis period.

$Daylight_{it}$ is an indicator equal to 1 when feeder i at time t falls within a daylight hour. The coefficient β_{10} captures the average real power or voltage

	observed during daylight hours when distributed solar facilities are producing electricity.
τ_d	are fixed effects for each day of the week d. The corresponding β_{11d} coefficients capture the average daily real power or voltage for each day of the week.
τ_w	are fixed effects for each week w. The corresponding β_{12w} coefficients capture the average weekly real power or voltage for each week of the Spring 2021 – Winter 2021/22 analysis period.
$\tau_{d,h}$	are hourly fixed effects for each hour of day h and each day of week d. The corresponding $\beta_{13\ \ ,h}$ coefficients capture the average hourly real power or voltage for each day of the week.
τ_h	are hourly fixed effects for each hour of day h. The corresponding β_{14h} coefficients capture the average hourly real power or voltage for each hour across the Spring 2021 – Winter 2021/22 analysis period.
$Cloud_{it}$	is a categorical variable denoting hourly cloud cover conditions recorded by NOAA, intended to control for distributed solar generation connected to VVO feeders. Cloud cover multiplied by $Daylight_{it}$ and τ_h forces the regression model to provide an estimate of real power or voltage associated with distributed solar during each daylight hour. The coefficient β_{14h} captures this average real power or voltage observed during daylight hours when distributed solar facilities are producing electricity.
HDH_{it} and HDH_{it}^2	are heating degree-hours (HDH), base 65°F, and its square for feeder i at time t to capture the (potentially nonlinear) impacts of temperature on heating load. The corresponding coefficients β_{15} and β_{16} capture the impact of HDH and its square on real power or voltage.
CDH_{it} and CDH_{it}^2	are cooling degree-hours (CDH), base 65°F, and its square for feeder i at time t to capture the (potentially nonlinear) impacts of temperature on cooling load. The corresponding coefficients β_{17} and β_{18} capture the impact of CDH and its square on real power or voltage.
$DR\ Flag_t$	is an indicator equal to 1 when a demand response event occurred at time t. The coefficient β_{19} captures the average hourly impact of VVO on real power or voltage during the demand response events.
ϵ_{it}	is an error term for feeder i at time t and captures unexplained variation in real power or voltage.

B.3 Regression Methodology for Peak Load

Equation B-3 summarizes the regression model specification used to estimate peak load as a function of VVO.

Equation B-3. Regression Model of Peak Load

$$Peak_{it} = \beta_1 VVO_{it} + \sum_{d=1}^{7} \beta_{2d} * \tau_d + \sum_{d,h=1}^{168} \beta_{3d,h} * \tau_{d,h} + \sum_{h=1}^{24} \beta_{4h} * \tau_h * Cloud_{it} + \beta_5 CDH_{it} + \beta_6 CDH_{it}^2 + \epsilon_{it}$$

Where:

i, t, h, d	index feeder, time-interval, each of the 24 hours of the day, and day of week respectively.
$Peak\ kW_{it}$	is peak load (kW) measured at feeder i at time t.
VVO_{it}	is an indicator equal to 1 when VVO is engaged for feeder i at time t. The coefficient β_1 captures the average hourly impact of VVO on peak load during the entire analysis period.
τ_d	are fixed effects for each day of the week d. The corresponding β_{2d} coefficients capture the average daily peak load for each day of the week.
$\tau_{d,h}$	are hourly fixed effects for each hour h and each day of week d. The corresponding $\beta_{3d,h}$ coefficients capture the average hourly peak load for each day of the week.
τ_h	are hourly fixed effects for each hour h. The corresponding β_{4h} coefficients capture the average hourly peak load across the Spring 2021 – Winter 2021/22 analysis period.
$Cloud_{it}$	is a categorical variable denoting hourly cloud cover conditions recorded by NOAA, intended to control for distributed solar generation connected to VVO feeders. Cloud cover multiplied by τ_h forces the regression model to provide an estimate of peak load associated with distributed solar during each peak load hour of the day. The coefficient β_{4h} captures this average peak load observed during daylight hours when distributed solar facilities are producing electricity.
CDH_{it} and CDH_{it}^2	are cooling degree-hours (CDH), base 65°F, and its square for feeder i at time t to capture the (potentially nonlinear) impacts of temperature on cooling load. The corresponding coefficients β_5 and β_6 capture the impact of CDH and its square on peak load.
ϵ_{it}	is an error term for feeder i at time t and captures unexplained variation in peak load.

B.4 Regression Methodology for Power Factor

Equation B-4 summarizes the regression model specification used to estimate power factor as a function of VVO.

Equation B-4 Regression Model of Power Factor

$$PF_{it} = \beta_1 VVO_{it} + \beta_2 Holiday_{it} + \beta_3 Daylight_{it} + \sum_{d=1}^{7} \beta_{4d} * \tau_d + \sum_{d,h=1}^{168} \beta_{5d,h} * \tau_{d,h} + \sum_{h=1}^{24} \beta_{6h} * \tau_h * Cloud_{it} * Daylight_{it} + \beta_7 HDH_{it} + \beta_8 HDH_{it}^2 + \beta_9 CDH_{it} + \beta_{10} CDH_{it}^2 + \beta_{11} DR\ Flag_t + \epsilon_{it}$$

Where:

i, t, h, d	index feeder, time-interval, each of the 24 hours of the day, and day of week respectively.
PF_{it}	is power factor measured at feeder i at time t.
VVO_{it}	is an indicator equal to 1 when VVO is engaged for feeder i at time t. The coefficient β_1 captures the average hourly impact of VVO on power factor during the entire analysis period.
$Holiday_{it}$	is an indicator equal to 1 when feeder i at time t falls within a holiday. The coefficient β_2 captures the average power factor observed on holidays during the Spring 2021 – Winter 2021/22 analysis period.
$Daylight_{it}$	is an indicator equal to 1 when feeder i at time t falls within a daylight hour. The coefficient β_3 captures the average power factor observed during daylight hours when distributed solar facilities are producing electricity.
τ_d	are fixed effects for each day of the week d. The corresponding β_{4d} coefficients capture the average daily power factor for each day of the week.
$\tau_{d,h}$	are hourly fixed effects for each hour h and each day of week d. The corresponding $\beta_{5d,h}$ coefficients capture the average hourly power factor for each day of the week.
τ_h	are hourly fixed effects for each hour h. The corresponding β_{6h} coefficients capture the average hourly power factor across the Spring 2021 – Winter 2021/22 analysis period.
$Cloud_{it}$	is a categorical variable denoting hourly cloud cover conditions recorded by NOAA, intended to control for distributed solar generation connected to VVO feeders. Cloud cover multiplied by $Daylight_{it}$ and τ_h forces the regression model to provide an estimate of power factor associated with distributed solar during each daylight hour. The

	coefficient β_{6h} captures this average power factor observed during daylight hours when distributed solar facilities are producing electricity.
HDH_{it} and HDH_{it}^2	are heating degree-hours (HDH), base 65°F, and its square for feeder i at time t to capture the (potentially nonlinear) impacts of temperature on heating load. The corresponding coefficients β_7 and β_8 capture the impact of HDH and its square on power factor.
CDH_{it} and CDH_{it}^2	are cooling degree-hours (CDH), base 65°F, and its square for feeder i at time t to capture the (potentially nonlinear) impacts of temperature on cooling load. The corresponding coefficients β_9 and β_{10} capture the impact of CDH and its square on power factor.
$DR\ Flag_t$	is an indicator equal to 1 when a demand response event occurred at time t. The coefficient β_{11} captures the average hourly impact of VVO on power factor during the demand response events.
ϵ_{it}	is an error term for feeder i at time t and captures unexplained variation in power factor.

B.5 Distribution Line Losses Methodology

Guidehouse evaluated change in distribution losses as a function of VVO during the Spring 2021 – Winter 2021/22 M&V period. To estimate the impact of VVO on feeder-level distribution losses, Guidehouse used a distribution losses equation for each individual feeder.[79] Equation B-5 summarizes the equation used to estimate the change in distribution losses as a function of VVO.

Equation B-5. Distribution Line Losses Equation

$$\%\ Loss\ Reduction = 100 - 100\left(\frac{PF_{VVO\ Off}}{PF_{VVO\ On}}\right)^2$$

Where:

$PF_{VVO\ Off}$	Power factor when VVO is in the disengaged state.
$PF_{VVO\ On}$	Power factor when VVO is in the engaged state.

B.6 Overall Data Attrition from Data Cleaning

The tables in this section provide a detailed summary of data attrition from cleaning steps applied to analysis datasets. Detailed data attrition results are provided separately by EDC and substation.

B.6.1 Eversource

79 https://www.nepsi.com/resources/calculators/loss-reduction-with-power-factor-correction.htm

Table B-1. Count of Quarter-Hours Remaining by Data Cleaning Step for Agawam

Data Cleaning Step	16C11	16C12	16C14	16C15	16C16	16C17	16C18
Initial Dataset (Spring 2021 – Winter 2021/22)	35,040	35,040	35,040	35,040	35,040	35,040	35,040
1. Remove Missing VVO Status	35	35	32	32	32	32	32
2. Remove Long and Short Events	15,308	15,308	16,926	16,926	16,926	16,926	16,926
3. Remove Interpolated	902	230	1,551	1,540	1,550	1,550	1,557
4. Remove Repeated	431	6	5	4	2	2	4
5. Remove Outliers	969	199	41	41	67	67	58
Final Dataset	17,395	19,262	16,485	16,497	16,463	16,491	16,463
Observations Removed	17,645	15,778	18,855	18,543	18,577	18,549	18,577

Source: Guidehouse analysis

Table B-2. Count of VVO On, VVO Off, and Removed Quarter-Hours for Agawam

Number of Quarter-Hours	16C11	16C12	16C14	16C15	16C16	16C17	16C18
VVO On *Weekday*	5,549	6,467	5,270	5,270	5,269	5,273	5,254
VVO On *Weekend*	2,127	2,374	2,183	2,180	2,176	2,178	2,178
VVO Off *Weekday*	6,767	7,279	6,529	6,545	6,515	6,539	6,529
VVO Off *Weekend*	2,952	3,142	2,503	2,502	2,503	2,501	2,502
Removed	17,645	15,778	18,855	18,543	18,577	18,549	18,577
Spring 2021 – Winter 2021/22 Total	35,040	35,040	35,040	35,040	35,040	35,040	35,040

Source: Guidehouse analysis

Table B-3. Count of Quarter-Hours Remaining by Data Cleaning Step for Piper

Data Cleaning Step	21N4	21N5	21N6	21N7	21N8	21N9
Initial Dataset (Spring 2021 – Winter 2021/22)	35,040	35,040	35,040	35,040	35,040	35,040
1. Remove Missing VVO Status	32	32	32	32	32	32
2. Remove Long and Short Events	8,993	8,993	9,569	9,569	9,569	9,569
3. Remove Interpolated	1,750	2,084	1,708	1,725	1,716	1,708
4. Remove Repeated	23	43	25	13	11	8
5. Remove Outliers	64	16	190	70	117	79
Final Dataset	24,178	23,872	23,516	23,631	23,595	23,644
Observations Removed	10,862	11,168	11,524	11,409	11,445	11,396

Source: Guidehouse analysis

Table B-4. Count of VVO On, VVO Off, and Removed Quarter-Hours for Piper

Number of Quarter-Hours	21N4	21N5	21N6	21N7	21N8	21N9
VVO On *Weekday*	8,188	8,022	7,900	7,998	7,982	7,988
VVO On *Weekend*	3,139	3,097	2,994	3,040	3,026	3,044
VVO Off *Weekday*	9,183	9,062	8,998	8,992	8,961	8,986
VVO Off *Weekend*	3,668	3,691	3,624	3,601	3,626	3,626
Removed	10,862	11,168	11,524	11,409	11,445	11,396
Spring 2021 – Winter 2021/22 Total	35,040	35,040	35,040	35,040	35,040	35,040

Source: Guidehouse analysis

Table B-5. Count of Quarter-Hours Remaining by Data Cleaning Step for Silver

Data Cleaning Step	30A1	30A2	30A3	30A4	30A5	30A6
Initial Dataset (Spring 2021 – Winter 2021/22)	35,040	35,040	35,040	35,040	35,040	35,040
1. Remove Missing VVO Status	20	36	20	32	16	32
2. Remove Long and Short Events	21,549	12,037	21,549	12,037	21,549	12,037
3. Remove Interpolated	158	237	920	192	25	297
4. Remove Repeated	324	166	307	211	277	152
5. Remove Outliers	99	64	79	135	122	149
Final Dataset	12,890	22,500	12,165	22,433	13,051	22,373
Observations Removed	22,191	12,284	22,567	12,607	21,989	12,667

Source: Guidehouse analysis

Table B-6. Count of VVO On, VVO Off, and Removed Quarter-Hours for Silver

Number of Quarter-Hours	30A1	30A2	30A3	30A4	30A5	30A6
VVO On *Weekday*	4,554	4,554	4,554	4,554	4,554	4,554
VVO On *Weekend*	1,621	1,621	1,621	1,621	1,621	1,621
VVO Off *Weekday*	4,901	4,901	4,901	4,901	4,901	4,901
VVO Off *Weekend*	1,773	1,773	1,773	1,773	1,773	1,773
Removed	22,191	12,284	22,567	12,607	21,989	12,667
Spring 2021 – Winter 2021/22 Total	35,040	35,040	35,040	35,040	35,040	35,040

Source: Guidehouse analysis

B.6.2 National Grid

Table B-7. Count of Hours Remaining by Data Cleaning Step for East Methuen

Data Cleaning Step	74L1	74L2	74L3	74L4	74L5	74L6
Initial Dataset (Spring 2021 – Winter 2021/22)	8,760	8,760	8,760	8,760	8,760	8,760
1. Remove Missing VVO Status	34	34	34	34	34	34
2. Remove Long and Short Events	2,273	746	2,273	746	2,273	746
3. Remove Interpolated	67	114	69	118	69	125
4. Remove Repeated	4	9	5	14	6	14
5. Remove Outliers	13	6	8	18	11	6
Final Dataset	6,369	7,851	6,371	7,830	6,367	7,835
Observations Removed	2,388	906	2,386	927	2,390	822

Source: Guidehouse analysis

Table B-8. Count of VVO On, VVO Off, and Removed Hours for East Methuen

Number of Hours	74L1	74L2	74L3	74L4	74L5	74L6
VVO On *Weekday*	1,896	2,673	1,902	2,657	1,898	2,668
VVO On *Weekend*	850	1,029	851	1,029	851	1,029
VVO Off *Weekday*	2,638	3,037	2,633	3,031	2,639	3,028
VVO Off *Weekend*	985	1,112	985	1,113	979	1,110
Removed	2,388	906	2,386	927	2,390	822
Spring 2021 – Winter 2021/22 Total	8,760	8,760	8,760	8,760	8,760	8,760

Source: Guidehouse analysis

Table B-9. Count of Hours Remaining by Data Cleaning Step for Maplewood

Data Cleaning Step	16W1	16W2	16W3	16W4	16W5	16W6	16W7	16W8
Initial Dataset (Spring 2021 – Winter 2021/22)	2,160	2,160	2,160	2,160	2,160	2,160	2,160	2,160
1. Remove Missing VVO Status	0	0	0	0	0	0	0	0
2. Remove Long and Short Events	562	883	562	883	562	883	562	883
3. Remove Interpolated	1	0	1	2	1	2	1	0
4. Remove Repeated	0	0	0	0	2	0	0	0
5. Remove Outliers	6	5	4	5	5	5	4	6
Final Dataset	1,591	1,272	1,593	1,270	1,590	1,270	1,593	1,271
Observations Removed	569	888	567	890	570	890	567	889

Source: Guidehouse analysis

Table B-10. Count of VVO On, VVO Off, and Removed Hours for Maplewood

Number of Hours	16W1	16W2	16W3	16W4	16W5	16W6	16W7	16W8
VVO On *Weekday*	408	453	408	451	407	451	408	453
VVO On *Weekend*	233	143	233	143	232	143	233	143
VVO Off *Weekday*	662	442	664	442	664	442	664	441
VVO Off *Weekend*	288	234	288	234	287	234	288	234
Removed	569	888	567	890	570	890	567	889
Spring 2021 – Winter 2021/22 Total	2,160	2,160	2,160	2,160	2,160	2,160	2,160	2,160

Source: Guidehouse analysis

Table B-11. Count of Hours Remaining by Data Cleaning Step for Stoughton

Data Cleaning Step	913W17	913W18	913W43	913W47	913W67	913W69
Initial Dataset (Spring 2021 – Winter 2021/22)	8,760	8,760	8,760	8,760	8,760	8,760
1. Remove Missing VVO Status	34	34	34	34	34	34
2. Remove Long and Short Events	1,415	1,415	1,415	1,415	1,415	1,415
3. Remove Interpolated	73	72	71	77	79	75
4. Remove Repeated	4	4	3	3	4	3
5. Remove Outliers	43	28	40	34	29	28
Final Dataset	7,191	7,207	7,197	7,197	7,199	7,205
Observations Removed	1,566	1,550	1,560	1,560	1,558	1,552

Source: Guidehouse analysis

Table B-12. Count of VVO On, VVO Off, and Removed Hours for Stoughton

Number of Hours	913W17	913W18	913W43	913W47	913W67	913W69
VVO On *Weekday*	2,337	2,344	2,340	2,342	2,343	2,343
VVO On *Weekend*	1,047	1,046	1,046	1,047	1,045	1,047
VVO Off *Weekday*	2,765	2,772	2,766	2,765	2,767	2,769
VVO Off *Weekend*	1,042	1,045	1,045	1,043	1,044	1,046
Removed	1,566	1,550	1,560	1,560	1,558	1,552
Spring 2021 – Winter 2021/22 Total	8,760	8,760	8,760	8,760	8,760	8,760

Source: Guidehouse analysis

B.7 Detailed Performance Metrics Results

This section details feeder-specific performance metrics estimates for the Spring 2021 – Winter 2021/22 period by VVO circuit. Results are provided separately by EDC.

B.7.1 Eversource

Table B-13. Eversource Performance Metrics Results by Feeder

Feeder	Energy Baseline (MWh)	Net Energy Reduction (MWh)* †	Voltage Reduction (V)	CVRf	Peak Load Reduction (kW)	Distribution Loss Reduction (%)	Power Factor Change	GHG Reductions (CO2) †
16C11	7,246	44 ± 12	0.71 ± 0.01	4.9	28 ± 34	NA	NA	22 ± 6
16C12	25,682	106 ± 18	1.35 ± 0.02	1.5	26 ± 41	1.74	<0.01 ± <0.01	52 ± 9
16C14	24,270	40 ± 12	0.36 ± 0.02	2.6	-43 ± 40	0.59	<0.01 ± <0.01	20 ± 6
16C15	18,502	17 ± 8	0.36 ± 0.02	1.5	-46 ± 27	-0.34	<-0.01 ± <0.01	8 ± 4
16C16	28,156	61 ± 23	0.31 ± 0.02	4	8 ± 86	-0.63	<-0.01 ± <0.01	30 ± 11
16C17	24,992	43 ± 18	0.32 ± 0.02	3.2	-79 ± 61	NA	NA	21 ± 9
16C18	19,396	35 ± 14	0.36 ± 0.02	2.9	-61 ± 39	NA	NA	17 ± 7
21N4	21,647	158 ± 24	2.54 ± 0.02	1.1	71 ± 76	NA	NA	78 ± 12
21N5	33,756	24 ± 14	1.24 ± 0.01	0.2	-65 ± 33	NA	NA	12 ± 7
21N6	16,664	37 ± 10	2.41 ± 0.02	0.4	-69 ± 28	NA	NA	18 ± 5
21N7	26,063	114 ± 29	2.45 ± 0.02	0.7	-50 ± 42	0.24	<0.01 ± <0.01	56 ± 15
21N8	40,611	-57 ± 26	2.44 ± 0.02	-0.2	83 ± 80	-0.07	<0.01 ± <0.01	-28 ± 13
21N9	23,592	-8 ± 16	2.42 ± 0.02	-0.1	-203 ± 44	NA	NA	-4 ± 8
30A1	31,054	-72 ± 19	0.61 ± 0.02	-2.6	-100 ± 67	NA	NA	-35 ± 9
30A2	28,998	34 ± 34	0.53 ± 0.01	0.9	-66 ± 88	NA	NA	17 ± 17
30A3	24,836	-32 ± 25	0.53 ± 0.02	-1.8	67 ± 220	-0.25	<-0.01 ± <0.01	-16 ± 12
30A4	16,248	-44 ± 28	0.53 ± 0.01	-2	-273 ± 83	-0.17	<-0.01 ± <0.01	-22 ± 14

Feeder	Energy Baseline (MWh)	Net Energy Reduction (MWh)* †	Voltage Reduction (V)	CVRf	Peak Load Reduction (kW)	Distribution Loss Reduction (%)	Power Factor Change	GHG Reductions (CO2) †
30A5	4,922	-11 ± 4	0.63 ± 0.02	-2.4	-51 ± 13	NA	NA	-5 ± 2
30A6	24,618	-6 ± 20	0.36 ± 0.01	-0.3	-70 ± 38	NA	NA	-3 ± 10
Overall*	441,252	484 ± 88	1.14 ± <0.01	0.70	-892 ± 324	0.18%	<0.01± <0.01	239 ± 43

* Overall energy savings is the sum of each feeder's energy savings, and due to model noise, a manual sum of savings across periods may not equal the amount provided in the Total row. Overall voltage reductions and CVR factors provided are load-weighted averages of these estimates provided for each feeder.
† Calculation uses actual number of VVO On hours spanning the analysis period. Actual VVO On Hours are the number of hours VVO was engaged in the clean analysis data between March 1, 2021 and February 28, 2022.

Source: Guidehouse analysis

B.7.2 National Grid

Table B-14. National Grid Performance Metrics Results by Feeder

Feeder	Energy Baseline (MWh)	Net Energy Reduction (MWh)* †	Voltage Reduction (kV)	CVRf	Peak Load Reduction (kW)	Distribution Loss Reduction (%)	Power Factor Change	GHG Reductions (CO2) †
74L1	36,138	169 ± 74	0.19 ± 0.01	0.7	-17 ± 302	NA	NA	84 ± 37
74L2	22,031	30 ± 41	0.04 ± <0.01	0.0	-55 ± 81	0.33	<0.01 ± <0.01	15 ± 20
74L3	26,065	167 ± 48	0.19 ± 0.01	1.1	22 ± 166	-0.36	<-0.01 ± <0.01	82 ± 24
74L4	28,584	-17 ± 47	0.04 ± <0.01	-1.1	-31 ± 80	-0.86	<-0.01 ± <0.01	-8 ± 23
74L5	27,408	137 ± 59	0.19 ± 0.01	1.2	-74 ± 231	NA	NA	68 ± 29
74L6	21,862	15 ± 30	0.04 ± <0.01	-0.3	-30 ± 58	-0.66	<-0.01 ± <0.01	7 ± 15
913W17	18,487	40 ± 39	0.11 ± <0.01	0.8	10 ± 107	NA	NA	20 ± 19
913W18	18,852	66 ± 31	0.11 ± <0.01	1.2	-20 ± 80	-1.56	<-0.01 ± <0.01	32 ± 16
913W43	21,207	65 ± 55	0.11 ± <0.01	1.1	-60 ± 145	NA	NA	32 ± 27
913W47	22,534	59 ± 36	0.11 ± <0.01	0.9	-54 ± 93	-1.19	<-0.01 ± <0.01	29 ± 18
913W67	8,567	18 ± 22	0.11 ± <0.01	0.7	-20 ± 56	NA	NA	9 ± 11
913W69	34,542	65 ± 65	0.11 ± <0.01	0.7	-107 ± 172	-2.66	<-0.01 ± <0.01	32 ± 32
16W1	9,453	32 ± 15	0.09 ± 0.01	1.1	NA	0.06	<0.01 ± <0.01	16 ± 7
16W2	8,929	24 ± 14	-0.12 ± 0.01	1.0	NA	NA	NA	12 ± 7
16W3	8,101	11 ± 13	0.09 ± 0.01	1.5	NA	NA	NA	5 ± 6
16W4	5,806	-1 ± 7	-0.12 ± 0.01	-0.4	NA	NA	NA	0 ± 3
16W5	5,064	11 ± 7	0.09 ± 0.01	1.2	NA	NA	NA	5 ± 3
16W6	11,107	28 ± 18	-0.12 ± 0.01	0.5	NA	NA	NA	14 ± 9
16W7	9,681	23 ± 15	0.09 ± 0.01	1.7	NA	NA	NA	11 ± 7
16W8	8,245	6 ± 14	-0.12 ± 0.01	-1.2	NA	NA	NA	3 ± 7
Overall*	352,633	948 ± 171	0.05 ± <0.01 kV	0.54	-437 ± 518	0.88%	-0.03 ± 0.01	468 ± 84

* Overall energy savings is the sum of each feeder's energy savings, and due to model noise, a manual sum of savings across periods may not equal the amount provided in the Total row. Overall voltage reductions and CVR factors provided are load-weighted averages of these estimates provided for each feeder.
† Calculation uses actual number of VVO On hours spanning the analysis period. Actual VVO On Hours are the number of hours VVO was engaged in the clean analysis data between March 1, 2021 and February 28, 2022.

Source: Guidehouse analysis

B.8 Feeder MW Percent of Peak MVA

This section details feeder-specific comparisons of feeder demand in the clean analysis data and feeder annual peak MVA. Each table details each feeder's average demand during the entire analysis period, average demand during the summer peak period,[80] and annual peak MVA.[81] The average feeder demand during the entire analysis period and during the summer peak period are then compared to annual peak MVA by taking the ratio of these values to annual peak MVA. Results are provided separately by EDC.

B.8.1 Eversource

Table B-15. Eversource Feeder MW Percent of Peak MVA by Feeder

Circuit*	Average MW (Spring 2021 – Winter 2021/22†)	Average MW (Summer Peak‡)	Annual Peak MVA¶	Average MW Percent of Peak MVA (Spring 2021 – Winter 2021/22)	Average MW Percent of Peak MVA (Summer Peak)
16C11	0.8	1.4	6.5	12.5%	21.8%
16C12	2.9	3.4	5.1	57.1%	67.4%
16C14	2.8	4.6	6.6	41.8%	70.1%
16C15	2.1	3.3	4.4	47.9%	75.0%
16C16	3.2	4.7	7.7	41.5%	60.5%
16C17	2.8	4.1	7.4	38.4%	54.9%
16C18	2.2	3.0	6.7	32.9%	44.6%
21N4	2.4	3.7	7.4	33.0%	49.6%
21N5	3.8	5.1	8.9	43.3%	56.9%
21N6	1.9	3.0	4.3	44.1%	69.9%
21N7	3.0	3.9	5.0	59.1%	78.4%
21N8	4.6	5.9	7.0	66.4%	84.4%
21N9	2.7	3.6	6.6	40.8%	53.9%

80 Summer peak is defined by ISO-NE as 1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays.
81 Annual peak MVA was drawn from 2021 GMP Annual Report Appendix 1, filed April 1, 2022

Circuit*	Average MW (Spring 2021 – Winter 2021/22†)	Average MW (Summer Peak‡)	Annual Peak MVA¶	Average MW Percent of Peak MVA (Spring 2021 – Winter 2021/22)	Average MW Percent of Peak MVA (Summer Peak)
30A1	3.6	4.8	8.5	42.0%	56.3%
30A2	3.3	4.5	9.8	33.7%	45.8%
30A3	2.8	3.5	6.3	45.0%	55.4%
30A4	1.9	4.4	6.6	28.2%	67.1%
30A5	0.6	0.9	4.7	12.0%	18.5%
30A6	2.8	2.8	5.3	53.0%	52.6%

* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.
† Calculations are based off of clean analysis data.
‡ Summer peak is defined by ISO-NE as 1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays.
¶ Annual peak MVA was drawn from 2021 GMP Annual Report Appendix 1, filed April 1, 2022
Source: Guidehouse analysis

B.8.2 National Grid

Table B-16. National Grid Feeder MW Percent of Peak MVA by Feeder

Circuit	Average MW (Spring 2021 – Winter 2021/22*)	Average MW (Summer Peak†)	Annual Peak MVA‡	Average MW Percent of Peak MVA (Spring 2021 – Winter 2021/22)	Average MW Percent of Peak MVA (Summer Peak)
74L1	4.1	5.5	11.2	36.7%	49.0%
74L2	2.5	4.1	6.6	38.3%	62.1%
74L3	3.0	3.7	7.1	41.8%	52.8%
74L4	3.3	4.6	6.6	49.4%	69.9%
74L5	3.1	4.5	9.9	31.5%	45.8%
74L6	2.5	3.2	4.6	53.8%	68.3%

Circuit	Average MW (Spring 2021 – Winter 2021/22*)	Average MW (Summer Peak†)	Annual Peak MVA‡	Average MW Percent of Peak MVA (Spring 2021 – Winter 2021/22)	Average MW Percent of Peak MVA (Summer Peak)
913W17	2.1	2.8	5.3	39.9%	53.1%
913W18	2.1	3.1	4.8	44.4%	63.2%
913W43	2.4	3.8	7.7	31.5%	50.2%
913W47	2.6	3.7	6.1	42.3%	60.9%
913W67	1.0	1.4	3.1	31.7%	46.8%
913W69	3.9	6.1	10.2	38.7%	60.4%
16W1	4.4	NA	4.5	96.2%	NA
16W2	4.1	NA	9.8	41.9%	NA
16W3	3.7	NA	7.8	47.8%	NA
16W4	2.7	NA	5.1	52.5%	NA
16W5	2.3	NA	11.0	21.4%	NA
16W6	5.1	NA	12.2	41.9%	NA
16W7	4.5	NA	9.8	45.5%	NA
16W8	3.8	NA	7.0	54.2%	NA

* Calculations are based off of clean analysis data.
† Summer peak is defined by ISO-NE as 1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays.
‡ Annual peak MVA was drawn from 2021 GMP Annual Report Appendix 1, filed April 1, 2022
Source: Guidehouse analysis

B.9 VVO Energy Savings and Voltage Reductions by Season

At the request of Eversource, in this section Guidehouse provides energy savings and voltage reductions attributed to VVO for each season from Spring 2021 through Winter 2021/22. Each table provides the energy savings and voltage reductions, and the associated 90 percent confidence bounds. A value of "-" for any one season has been provided for feeders without sufficient data in that specific season. Estimates are provided by feeder for Eversource and National Grid separately.

B.9.1 Eversource

Table B-17. Eversource Energy Savings by Feeder and Season

Feeder*	Spring 2021		Summer 2021		Fall 2021		Winter 2021/22	
	MWh†‡	%¶	MWh†‡	%¶	MWh†‡	%¶	MWh†‡	%¶
16C11	1.3 ± 5.1	0.7 ± 2.6	27.8 ± 7.2	4.3 ± 1.1	7.6 ± 3.3	7.0 ± 3.1	4.0 ± 8.4	0.6 ± 1.4
16C12	10.7 ± 7.5	1.0 ± 0.7	0.4 ± 10.1	0.0 ± 0.5	40.4 ± 4.7	9.6 ± 1.1	52.4 ± 12.2	1.8 ± 0.4
16C14	20.0 ± 5.7	2.1 ± 0.6	-0.8 ± 7.7	-0.0 ± 0.4	16.4 ± 7.9	0.9 ± 0.4	3.2 ± 2.8	2.6 ± 2.3
16C15	13.8 ± 3.7	1.9 ± 0.5	-7.4 ± 5.0	-0.5 ± 0.3	9.3 ± 5.1	0.6 ± 0.4	1.6 ± 1.8	1.7 ± 1.9
16C16	-2.4 ± 10.2	-0.3 ± 1.1	7.2 ± 13.9	0.3 ± 0.5	61.8 ± 14.3	2.8 ± 0.7	2.0 ± 5.0	1.3 ± 3.2
16C17	10.2 ± 8.1	1.1 ± 0.9	3.8 ± 11.0	0.2 ± 0.5	30.9 ± 11.4	1.7 ± 0.6	3.0 ± 4.0	2.2 ± 2.9
16C18	16.5 ± 6.1	2.2 ± 0.8	5.6 ± 8.2	0.3 ± 0.5	14.7 ± 8.5	1.0 ± 0.6	1.2 ± 2.9	1.1 ± 2.8
21N4	9.5 ± 9.0	1.2 ± 1.1	104.4 ± 11.8	4.9 ± 0.6	35.7 ± 12.0	2.2 ± 0.7	21.1 ± 14.2	0.9 ± 0.6
21N5	13.7 ± 5.5	0.9 ± 0.4	-20.6 ± 7.2	-0.7 ± 0.3	25.6 ± 7.0	1.0 ± 0.3	2.6 ± 8.7	0.1 ± 0.2
21N6	8.4 ± 3.9	1.2 ± 0.6	-3.6 ± 5.1	-0.3 ± 0.4	32.6 ± 5.5	2.5 ± 0.4	10.9 ± 6.6	0.6 ± 0.3
21N7	25.2 ± 11.2	2.5 ± 1.1	-0.7 ± 13.7	-0.0 ± 0.7	56.8 ± 14.8	2.5 ± 0.6	38.0 ± 17.6	1.4 ± 0.6
21N8	15.2 ± 10.1	0.8 ± 0.5	-7.7 ± 12.5	-0.3 ± 0.4	-63.8 ± 13.4	-2.2 ± 0.5	3.0 ± 15.9	0.1 ± 0.3
21N9	7.7 ± 6.1	0.8 ± 0.7	-69.4 ± 7.5	-3.7 ± 0.4	32.9 ± 8.1	1.8 ± 05	21.0 ± 9.7	0.8 ± 0.4
30A1	3.0 ± 4.0	1.0 ± 1.4	-70.4 ± 11.4	-2.9 ± 0.5	-1.7 ± 14.0	-0.1 ± 0.5	-	-
30A2	-21.0 ± 3.7	-13.2 ± 2.3	24.1 ± 16.3	0.8 ± 0.6	31.1 ± 19.4	1.12 ± 0.7	23.0 ± 20.2	0.7 ± 0.6
30A3	-0.1 ± 5.5	-0.1 ± 3.3	-12.5 ± 14.8	-0.7 ± 0.8	-9.6 ± 19.2	-0.4 ± 0.8	-	-
30A4	3.2 ± 2.7	5.3 ± 4.4	-51.9 ± 14.2	-2.7 ± 0.7	17.3 ± 16.7	1.2 ± 1.1	-13.7 ± 17.4	-0.9 ± 1.1
30A5	0.8 ± 0.9	1.8 ± 2.0	-12.7 ± 2.4	-3.0 ± 0.6	2.2 ± 3.0	0.5 ± 0.7	-	-
30A6	5.3 ± 1.4	8.8 ± 2.4	-1.7 ± 9.8	-0.1 ± 0.5	9.8 ± 11.7	0.4 ± 0.5	-15.2 ± 12.0	-0.5 ± 0.4
Overall*	141.1 ± 28.2	0.8 ± 0.4	-86.2 ± 46.4	-0.3 ± 0.1	350.1 ± 50.9	1.5 ± 0.2	157.8 ± 46.0	0.9 ± 0.4

* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.
† Total energy savings provided for each period is the sum of each feeder's energy savings within that period. Due to model noise, a manual sum of savings across periods may not equal the amount provided in the Total row.

‡ Calculation uses actual number of VVO On hours spanning the analysis period. Actual VVO On Hours are the number of hours VVO was engaged in the clean analysis data between March 1, 2021 and February 28, 2022.
¶ Percentage energy savings provided for each period is the load-weighted average of percentage savings estimated for each feeder.
Source: Guidehouse analysis

Table B-18. Eversource Voltage Reductions by Feeder and Season

Feeder*	Spring 2021		Summer 2021		Fall 2021		Winter 2021/22	
	V†	%	V†	%	V†	%	V†	%
16C11	1.00 ± 0.03	0.81 ± 0.02	0.28 ± 0.02	0.23 ± 0.02	1.03 ± 0.04	0.83 ± 0.03	0.83 ± 0.02	0.67 ± 0.01
16C12	1.27 ± 0.04	1.03 ± 0.04	0.65 ± 0.03	0.53 ± 0.03	2.17 ± 0.07	1.75 ± 0.06	1.72 ± 0.03	1.39 ± 0.02
16C14	0.86 ± 0.04	0.69 ± 0.04	1.08 ± 0.03	0.87 ± 0.03	-0.49 ± 0.03	-0.39 ± 0.03	-0.93 ± 0.19	-0.75 ± 0.15
16C15	0.87 ± 0.04	0.70 ± 0.04	1.08 ± 0.03	0.88 ± 0.03	-0.50 ± 0.03	-0.40 ± 0.03	-0.97 ± 0.19	-0.78 ± 0.15
16C16	0.65 ± 0.04	0.53 ± 0.03	1.09 ± 0.03	0.88 ± 0.03	-0.50 ± 0.03	-0.41 ± 0.03	-0.95 ± 0.18	-0.77 ± 0.15
16C17	0.87 ± 0.04	0.70 ± 0.03	0.97 ± 0.03	0.78 ± 0.03	-0.50 ± 0.03	-0.40 ± 0.03	-0.98 ± 0.18	-0.80 ± 0.14
16C18	0.87 ± 0.04	0.70 ± 0.04	1.09 ± 0.03	0.88 ± 0.03	-0.51 ± 0.03	-0.41 ± 0.03	-0.97 ± 0.19	-0.78 ± 0.15
21N4	1.50 ± 0.05	1.21 ± 0.04	2.94 ± 0.04	2.37 ± 0.04	2.72 ± 0.04	2.20 ± 0.02	2.60 ± 0.03	2.10 ± 0.03
21N5	1.40 ± 0.03	1.13 ± 0.02	1.87 ± 0.02	1.51 ± 0.02	1.10 ± 0.02	0.89 ± 0.03	0.87 ± 0.02	0.70 ± 0.02
21N6	0.41 ± 0.05	0.33 ± 0.04	2.67 ± 0.04	2.16 ± 0.03	3.12 ± 0.04	2.52 ± 0.03	2.53 ± 0.03	2.04 ± 0.03
21N7	0.76 ± 0.05	0.62 ± 0.04	2.68 ± 0.04	2.17 ± 0.03	3.12 ± 0.04	2.52 ± 0.03	2.52 ± 0.03	2.03 ± 0.03
21N8	0.82 ± 0.05	0.67 ± 0.04	2.66 ± 0.04	2.15 ± 0.03	3.12 ± 0.04	2.52 ± 0.03	2.51 ± 0.03	2.02 ± 0.03
21N9	1.24 ± 0.05	1.00 ± 0.04	2.67 ± 0.04	2.16 ± 0.03	3.09 ± 0.03	2.49 ± 0.03	2.29 ± 0.03	1.84 ± 0.02
30A1	1.01 ± 0.07	0.82 ± 0.06	0.39 ± 0.03	0.31 ± 0.02	0.72 ± 0.02	0.59 ± 0.02	-	-
30A2	1.27 ± 0.07	1.03 ± 0.05	0.77 ± 0.02	0.63 ± 0.02	0.80 ± 0.02	0.65 ± 0.01	0.08 ± 0.02	0.07 ± 0.01
30A3	0.66 ± 0.07	0.54 ± 0.06	0.41 ± 0.03	0.33 ± 0.02	0.60 ± 0.02	0.49 ± 0.02	-	-
30A4	1.07 ± 0.08	0.87 ± 0.06	0.74 ± 0.02	0.61 ± 0.02	0.80 ± 0.02	0.65 ± 0.02	0.11 ± 0.02	0.09 ± 0.02
30A5	1.06 ± 0.07	0.86 ± 0.05	0.39 ± 0.03	0.32 ± 0.02	0.74 ± 0.02	0.60 ± 0.02	-	-
30A6	0.96 ± 0.07	0.78 ± 0.06	0.50 ± 0.02	0.41 ± 0.01	0.52 ± 0.01	0.42 ± 0.01	0.11 ± 0.01	0.09 ± 0.01
Overall*	0.98 ± 0.01	0.79 ± 0.01	1.41 ± 0.01	1.14 ± 0.01	1.19 ± 0.01	0.96 ± 0.01	0.78 ± 0.03	0.63 ± 0.02

* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.
† Voltage and percent voltage savings provided for each period is the load-weighted average of kV and percent savings estimated for each feeder.
Source: Guidehouse analysis

B.9.2 National Grid

Table B-19. National Grid Energy Savings by Feeder and Season

Feeder	Spring 2021		Summer 2021		Fall 2021		Winter 2021/22	
	MWh*†	%	MWh*†	%	MWh*†	%	MWh*†	%
74L1	26.3 ± 42.6	0.9 ± 1.4	72.9 ± 34.7	2.3 ± 1.1	29.6 ± 31.9	1.6 ± 1.7	43.7 ± 38.6	1.4 ± 1.2
74L2	-18.9 ± 21.1	-0.9 ± 1.0	18.9 ± 20.1	0.7 ± 0.8	7.9 ± 21.0	0.4 ± 0.9	21.4 ± 20.1	0.9 ± 0.9
74L3	17.8 ± 27.5	0.8 ± 1.2	69.0 ± 22.4	3.3 ± 1.1	40.4 ± 20.6	2.9 ± 1.5	39.2 ± 24.9	1.7 ± 1.1
74L4	-4.8 ± 23.0	-0.2 ± 0.8	6.2 ± 22.1	0.2 ± 0.6	2.2 ± 23.0	0.1 ± 0.1	-22.4 ± 21.9	-0.8 ± 0.8
74L5	17.5 ± 33.8	0.6 ± 1.2	71.9 ± 27.6	3.1 ± 1.2	19.3 ± 25.4	1.5 ± 2.0	29.9 ± 30.7	1.3 ± 1.4
74L6	-14.5 ± 15.4	-0.7 ± 0.7	10.0 ± 14.7	0.4 ± 0.6	9.5 ± 15.4	0.4 ± 0.7	13.5 ± 14.7	0.6 ± 0.7
913W17	-20.3 ± 20.0	-1.3 ± 1.3	40.2 ± 19.7	1.9 ± 0.9	15.2 ± 19.6	1.0 ± 1.3	3.1 ± 18.6	0.2 ± 1.0
913W18	-2.9 ± 16.1	-0.2 ± 1.0	50.7 ± 15.9	2.4 ± 0.7	12.8 ± 15.8	0.8 ± 1.0	4.5 ± 14.9	0.2 ± 0.8
913W43	-31.3 ± 28.0	-1.8 ± 1.6	64.8 ± 27.6	2.4 ± 1.0	25.1 ± 27.5	1.5 ± 1.6	8.9 ± 25.9	0.4 ± 1.3
913W47	-23.1 ± 18.2	-1.2 ± 0.9	52.5 ± 17.9	2.0 ± 0.7	20.3 ± 17.8	1.0 ± 0.9	10.3 ± 16.9	0.5 ± 0.8
913W67	-13.0 ± 11.3	-1.9 ± 1.6	21.4 ± 11.2	2.0 ± 1.0	10.8 ± 11.1	1.5 ± 1.6	0.0 ± 10.5	0.0 ± 1.3
913W69	-32.9 ± 33.4	-1.1 ± 1.1	60.8 ± 32.9	1.5 ± 0.8	27.2 ± 32.8	0.9 ± 1.1	8.7 ± 31.0	0.3 ± 1.0
16W1	VVO On / Off Testing Not Yet Begun						31.9 ± 14.7	1.2 ± 0.5
16W2							26.2 ± 14.3	1.1 ± 0.6
16W3							10.8 ± 12.9	0.5 ± 0.5
16W4							1.3 ± 6.9	0.1 ± 0.4
16W5							10.7 ± 7.1	0.7 ± 0.5
16W6							29.2 ± 18.0	1.0 ± 0.6
16W7							22.8 ± 15.0	0.8 ± 0.5
16W8							6.9 ± 14.3	0.3 ± 0.6
Overall*	-99.9 ± 89.1	-0.4 ± 0.4	539.3 ± 80.6	1.8 ± 0.3	220.2 ± 78.7	1.1 ± 0.4	300.4 ± 90.4	0.7 ± 0.2

* Total energy savings provided for each period is the sum of each feeder's energy savings within that period. Due to model noise, a manual sum of savings across periods may not equal the amount provided in the Total row.

† Calculation uses actual number of VVO On hours spanning the analysis period. Actual VVO On Hours are the number of hours VVO was engaged in the clean analysis data between March 1, 2021 and February 28, 2022.

Source: Guidehouse analysis

Table B-20. National Grid Voltage Reductions by Feeder and Season

Feeder	Spring 2021		Summer 2021		Fall 2021		Winter 2021/22	
	kV	%	kV	%	kV	%	kV	%
74L1	-0.07 ± 0.01	-0.50 ± 0.04	0.03 ± 0.01	0.23 ± 0.05	0.45 ± 0.01	3.32 ± 0.06	0.47 ± 0.01	3.41 ± 0.05
74L2	-0.11 ± 0.00	-0.78 ± 0.03	-0.04 ± 0.00	-0.32 ± 0.03	0.15 ± 0.00	1.13 ± 0.03	0.17 ± 0.00	1.29 ± 0.03
74L3	-0.07 ± 0.01	-0.50 ± 0.04	0.03 ± 0.01	0.24 ± 0.05	0.45 ± 0.01	3.32 ± 0.06	0.47 ± 0.01	3.41 ± 0.05
74L4	-0.11 ± 0.00	-0.78 ± 0.03	-0.04 ± 0.00	-0.32 ± 0.03	0.15 ± 0.00	1.13 ± 0.03	0.17 ± 0.00	1.28 ± 0.03
74L5	-0.07 ± 0.01	-0.50 ± 0.04	0.03 ± 0.01	0.23 ± 0.05	0.45 ± 0.01	3.32 ± 0.06	0.47 ± 0.01	3.41 ± 0.05
74L6	-0.11 ± 0.00	-0.78 ± 0.03	-0.04 ± 0.00	-0.32 ± 0.03	0.15 ± 0.00	1.13 ± 0.03	0.17 ± 0.00	1.28 ± 0.03
913W17	0.11 ± 0.00	0.81 ± 0.03	0.08 ± 0.00	0.53 ± 0.03	0.11 ± 0.00	0.79 ± 0.03	0.12 ± 0.00	0.86 ± 0.03
913W18	0.11 ± 0.00	0.81 ± 0.03	0.08 ± 0.00	0.53 ± 0.03	0.11 ± 0.00	0.79 ± 0.03	0.12 ± 0.00	0.86 ± 0.03
913W43	0.11 ± 0.00	0.81 ± 0.03	0.08 ± 0.00	0.53 ± 0.03	0.11 ± 0.00	0.79 ± 0.03	0.12 ± 0.00	0.86 ± 0.03
913W47	0.11 ± 0.00	0.81 ± 0.03	0.08 ± 0.00	0.53 ± 0.03	0.11 ± 0.00	0.79 ± 0.03	0.12 ± 0.00	0.86 ± 0.03
913W67	0.11 ± 0.00	0.81 ± 0.03	0.07 ± 0.00	0.53 ± 0.03	0.11 ± 0.00	0.79 ± 0.03	0.12 ± 0.00	0.86 ± 0.03
913W69	0.11 ± 0.00	0.81 ± 0.03	0.08 ± 0.00	0.53 ± 0.03	0.11 ± 0.00	0.79 ± 0.03	0.12 ± 0.00	0.86 ± 0.03
16W1	VVO On / Off Testing Not Yet Begun						0.09 ± 0.01	0.66 ± 0.04
16W2							-0.12 ± 0.01	-0.83 ± 0.04
16W3							0.09 ± 0.01	0.66 ± 0.04
16W4							-0.12 ± 0.01	-0.83 ± 0.04
16W5							0.09 ± 0.01	0.66 ± 0.04
16W6							-0.12 ± 0.01	-0.83 ± 0.04
16W7							0.09 ± 0.01	0.66 ± 0.04
16W8							-0.12 ± 0.01	-0.83 ± 0.04
Overall*	0.00 ± 0.00	0.00 ± 0.01	0.03 ± 0.00	0.22 ± 0.01	0.23 ± 0.00	1.67 ± 0.01	0.12 ± 0.00	0.86 ± 0.01

* kV and percent voltage savings provided for each period is the load-weighted average of kV and percent savings estimated for each feeder.
Source: Guidehouse analysis

B.10 Seasonal Data Attrition from Data Cleaning

This section details data attrition from data cleaning for each season from Spring 2021 through Winter 2021/22. Tables provide the number of observations received, then the observations remaining after data cleaning by season and by feeder. Tables are provided separately by EDC.

B.10.1 Eversource

Table B-21. Eversource Data Attrition by Feeder and Season

	Spring 2021		Summer 2021		Fall 2021		Winter 2021/22	
Feeder	Observations Received	Observations Remaining	Observations Received	Observations Remaining	Observations Received	Observations Remaining	Observations Received	Observations Remaining
16C11	8,828	3,195	8,832	5,283	8,736	1,219	8,609	7,698
16C12	8,828	3,819	8,832	5,770	8,736	1,290	8,609	8,383
16C14	8,828	3,832	8,832	5,831	8,736	6,545	8,612	277
16C15	8,828	3,836	8,832	5,836	8,736	6,547	8,612	278
16C16	8,828	3,821	8,832	5,829	8,736	6,536	8,612	277
16C17	8,828	3,835	8,832	5,838	8,736	6,540	8,612	278
16C18	8,828	3,824	8,832	5,828	8,736	6,535	8,612	276
21N4	8,828	3,933	8,832	5,487	8,736	6,465	8,612	8,293
21N5	8,828	3,930	8,832	5,584	8,736	6,059	8,612	8,299
21N6	8,828	3,788	8,832	4,972	8,736	6,463	8,612	8,293
21N7	8,828	3,896	8,832	5,002	8,736	6,462	8,612	8,271
21N8	8,828	3,903	8,832	4,998	8,736	6,429	8,612	8,265
21N9	8,828	3,925	8,832	4,998	8,736	6,435	8,612	8,286
30A1	8,828	789	8,832	4,963	8,740	7,138	8,628	0
30A2	8,828	661	8,832	5,576	8,740	7,832	8,612	8,431
30A3	8,828	757	8,832	4,313	8,740	7,095	8,628	0
30A4	8,828	726	8,832	5,524	8,736	7,765	8,612	8,418
30A5	8,828	966	8,832	4,963	8,736	7,122	8,628	0
30A6	8,828	602	8,832	5,597	8,736	7,808	8,612	8,366

* Podick substation is removed from all results, as there was evidence of VVO not functioning for the entirety of the analysis period.
Source: Guidehouse analysis

B.10.2 National Grid

Table B-22. National Grid Data Attrition by Feeder and Season

	Spring 2021		Summer 2021		Fall 2021		Winter 2021/22	
Feeder	Observations Received	Observations Remaining	Observations Received	Observations Remaining	Observations Received	Observations Remaining	Observations Received	Observations Remaining
74L1	2,174	2,054	2,208	1,419	2,184	1,249	2,160	1,647
74L2	2,174	2,014	2,208	1,921	2,184	2,115	2,160	1,801
74L3	2,174	2,057	2,208	1,418	2,184	1,247	2,160	1,649
74L4	2,174	2,015	2,208	1,918	2,184	2,110	2,160	1,787
74L5	2,174	2,059	2,208	1,420	2,184	1,246	2,160	1,642
74L6	2,174	2,011	2,208	1,918	2,184	2,108	2,160	1,798
913W17	2,174	1,825	2,208	1,980	2,184	1,644	2,160	1,742
913W18	2,174	1,826	2,208	1,986	2,184	1,649	2,160	1,746
913W43	2,174	1,826	2,208	1,981	2,184	1,644	2,160	1,746
913W47	2,174	1,827	2,208	1,979	2,184	1,648	2,160	1,743
913W67	2,174	1,823	2,208	1,986	2,184	1,647	2,160	1,743
913W69	2,174	1,827	2,208	1,984	2,184	1,649	2,160	1,745
16W1	VVO On / Off Testing Not Yet Begun						2,160	1,591
16W2							2,160	1,272
16W3							2,160	1,593
16W4							2,160	1,270
16W5							2,160	1,590
16W6							2,160	1,270
16W7							2,160	1,593
16W8							2,160	1,271

Source: Guidehouse analysis