Massachusetts Grid Modernization Program Year 2020 Evaluation Report: Volt-VAR Optimization

Massachusetts Electric Distribution Companies

Submitted by:

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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) 2020. The focus of this evaluation is on VVO Infrastructure Metrics and Performance Metrics. VVO On/Off testing began on select substations in December for Eversource and National Grid, so the Performance Metrics analysis focuses on winter 2020/21 for those substations. The evaluation team will provide analysis of Performance Metrics associated with spring and summer 2021 VVO On/Off testing in December 2021.

Evaluation Process

The DPU requires a third-party evaluation for the EDCs' preauthorized grid modernization investments. Guidehouse (formerly Navigant Consulting, Inc.)[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 EDCs submitted the original Evaluation Plan developed by Navigant Consulting (now Guidehouse) to the DPU in a petition for approval on May 1, 2019. Modifications to this original Evaluation Plan were made 1) to 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] The EDCs submitted modifications to the original Evaluation Plan to the DPU in a petition for approval on December 1, 2020. Guidehouse used the modified Evaluation Plan to develop the analysis and evaluation provided in this document.

[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 illustrates the key Infrastructure Metrics and Performance Metrics relevant for the VVO evaluation by EDC.[4] Section 2.1 and Section 2.2 further detail surrounding Infrastructure Metrics (IMs) and Performance Metrics (PMs), respectively.

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.

[4] Unitil will be included in VVO Performance Metrics analysis in the 2021 report, as VVO On/Off testing for select feeders in will begin in Winter 2021/22.

Table 2. VVO Data Sources

Data Source	Description
2019 Grid Modernization Plan Annual Report[5, 6, 7]	Planned device deployment and cost information from each EDC's 2019 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. Planned device deployment information and estimated spend for PY2020 was provided at the most granular level.
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[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

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 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.

[5] Massachusetts Electric Company and Nantucket Electric Company d/b/a National Grid, Grid Modernization Plan Annual Report 2019. Submitted to Massachusetts DPU on April 1, 2020 as part of DPU 15-120

[6] NSTAR Electric Company d/b/a Eversource Energy, Grid Modernization Plan Annual Report 2019. Submitted to Massachusetts DPU on April 1, 2020 as part of DPU 15-122

[7] Fitchburg Gas and Electric Light Company d/b/a Unitil, Grid Modernization Plan Annual Report 2019. Submitted to Massachusetts DPU on April 1, 2020 as part of DPU 15-121

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

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 • Identify variance in the January 1 through June 30, 2019 data provided in 2020, and the work order-level data provided for PY2019 • Identify variance between the aggregated year-end total information and work order-level data (applicable to Eversource only) • Flag deviation between 2019 GMP Annual Report (filed April 1, 2020) and actual deployment and spend
Performance Metrics	• Confirm time series telemetry 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 interval data were provided for large distributed generation facilities • Verify interconnection information for distributed generation facilities connected to the VVO feeders were updated • 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

Table 4 includes the Infrastructure Metrics results through PY2020 for all EDCs. The following subsections provide further detail surrounding findings for each of the Infrastructure Metrics.

Table 4. 2020 Infrastructure Metrics for VVO Device Deployment Progress

Infrastructure Metrics		Eversource*	National Grid	Unitil
GMP Plan Total, 2018-2021	# Devices Commissioned	367	106	59
	Spend, $M	$17.35**	$8.50	$2.06
EDC Data Total, 2018-2021	# Devices Commissioned	1,201	249	77

Infrastructure Metrics			Eversource*	National Grid	Unitil
		Spend, $M	$18.93	$19.27	$5.12
IM-4	Number of Devices Deployed through PY2020	# Devices Deployed	577	111	3
		% Devices Deployed	157%	105%	5%
IM-5	Cost for Deployment through PY2020	Total Spend, $M	$12.93	$11.98	$1.85
		% Spend	105%	141%	90%
IM-6	Deviation Between Actual and Planned Deployment for PY 2020	% On Track (Devices)	800%	105%	5%
		% On Track (Spend)	114%	159%	90%
IM-7	Projected Deployment for the Remainder of the GMP Term	# Devices Remaining	624	138	74
		Spend Remaining, $M	$6.00	$7.29	$3.26

*Eversource spend and deployment includes spend and deployment for grid monitoring line sensors and microcapacitors.

**Includes the Eversource planned spend for PY2021, set forth the in the *GMP Extension and Funding Report*, filed on July 1, 2020 and approved on February 4, 2021.

Source: Guidehouse analysis of 2019 GMP Annual Reports, "GMP Extension and Funding Report," and 2020 EDC Data

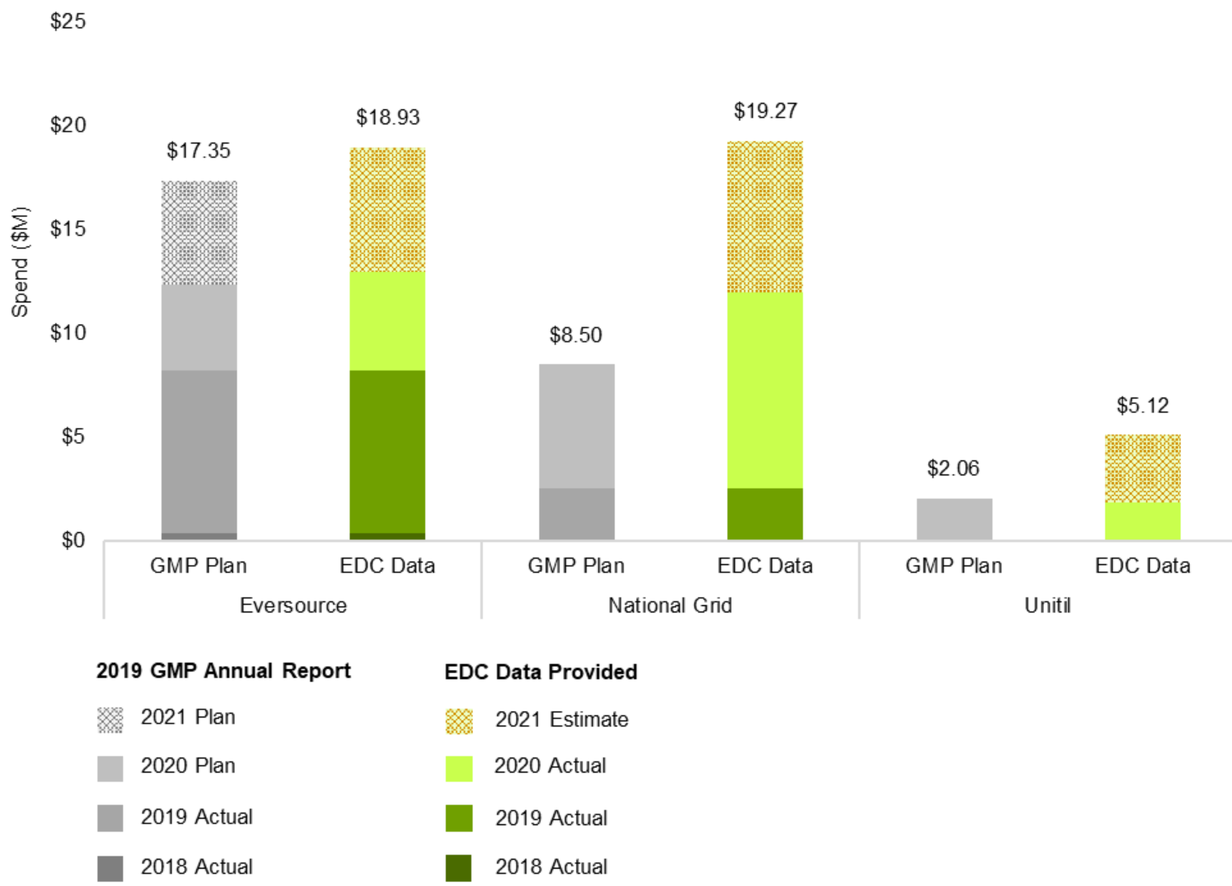
Table 5. 2020 Infrastructure Metrics for VVO Feeder Deployment Progress

IM	Parameter	Eversource	National Grid	Unitil
IM-4	# Feeders with VVO Enabled	26	6	0
	% Feeders with VVO Enabled	100%	38%	0%
IM-6	% On Track (Feeders with VVO Enabled)	100%	38%	0%
IM-7	# Feeders Remaining for VVO Enablement	26	33	11

Source: Guidehouse analysis of 2019 GMP Annual Report and 2020 EDC Data

Figure 1 differentiates between the original planned spend per the *2019 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)



Source: Guidehouse analysis of 2019 GMP Annual Reports and EDC Data

PY2020'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 follow:

Device Deployment:

- Eversource device deployment exceeded initially planned devices in line sensors, while device deployment fell short of original plans on all other pre-approved device types.[9] In addition, Eversource commissioned two new device types: microcapacitors and grid monitoring line sensors. These devices will supplement the overall long-term VVO investment and allow Eversource to gather additional data integral to the distribution management system (DMS).

[9] Deployment fell short of plans across all other pre-approved device types after full engineering analysis was conducted by Eversource, reducing the number of pre-approved devices required to accommodate VVO operation.

- National Grid device deployment also exceeded initially planned devices, primarily due to National Grid's decision to install midline regulators on VVO substations and additional load tap changers (LTC) controls to allow for four additional Maplewood feeders to receive VVO.
- Unitil device deployment fell short of plan due to delays in Field Area Network (FAN) implementation. Despite completing construction work on regulators and capacitor banks throughout 2020, since advanced distribution management system (ADMS) is planned to be a control system for VVO, delays in FAN implementation interfered with deployment of the devices before the close of the year.

VVO Enablement:

- Eversource completed deployment of VVO for the original 2018–2020 plan feeders, with all feeders having VVO enabled on December 2, 2020. VVO enablement was behind Eversource's schedule laid out in the PY2019 Evaluation Report due to ongoing commissioning troubleshooting prior to enabling VVO. However, all four substations had the VVO system enabled by the end of 2020. Eversource has been conducting VVO On/Off testing on the Agawam, Piper, and Silver substations since December 2, 2020 and on the Podick substation since March 4, 2021.
- National Grid had not enabled VVO for all of the original 2018–2020 plan feeders by the end of 2020 as anticipated in the PY2019 Evaluation Report. This is because National Grid had not completed deployment of VVO for the East Methuen and Maplewood substations by the end of the year. National Grid experienced delays in deployment of VVO throughout 2020 due to the addition of midline regulators and additional LTC controls, as well as delays and complexities associated with IT work during the COVID-19 pandemic. However, National Grid enabled VVO and began VVO On/Off testing at its Stoughton substation on December 1, 2020.
- Unitil VVO enablement fell short of its schedule laid out in the PY2019 Evaluation Report, as Unitil has not completed deployment of VVO at the original 2018–2020 plan feeders due to delays in FAN implementation.

Total Spend:

- Eversource costs for deployment of pre-approved devices exceeded Eversource's plans due to regulator design changes and unplanned commissioning and startup costs incurred prior to enabling VVO. Spend on IT work was lower than planned. Eversource also deployed microcapacitors and grid monitoring line sensors.
- National Grid costs for deployment exceeded plan due to increased spending on regulators, LTC controls, and IT work. Spend on regulators exceeded plans due to the introduction of midline regulators to maximize VVO benefits, which increased capital and labor costs. In addition, spend on LTC controls exceeded plan due to the installation of additional controls and retrofitting of LTCs to receive necessary data. Lastly, spend on IT work exceeded plan due to increased complexities introduced during the COVID-19 pandemic and cybersecurity concerns requiring software patches and retesting.
- Unitil's investment pace has been slower than anticipated. As a result, Unitil spending during PY2020 was lower than anticipated. Spending was lower than anticipated for LTC controls and line sensors, although spending was on plan for regulators and capacitor

banks primarily due to the large amount of construction work conducted throughout 2020 even during the COVID-19 pandemic.

The EDCs are slated to continue to deploy VVO investments throughout 2021. In particular:

- Eversource plans to continue VVO On/Off testing throughout the year at all four original 2018–2020 plan substations (Agawam, Piper, Podick, Silver) until sufficient winter, summer, and shoulder season data are collected for Performance Metrics analysis. Eversource also plans to deploy additional VVO investments throughout 2021 at other substations.
- National Grid is slated to continue VVO On/Off testing at its Stoughton and East Methuen substations throughout the year and expects to begin VVO On/Off testing at its Maplewood substation by summer 2021. In addition, National Grid plans to deploy VVO investments on additional feeders connected to the East Bridgewater, East Dracut, and West Salem substations. Engineering and design and construction work has begun on devices to be installed at these substations, and VVO On/Off testing is expected to begin in summer 2021.
- Unitil is expected to complete the VVO deployment for its original 2018–2020 plan substations throughout 2021. This work will include assembly of communications equipment to facilitate ADMS control of VVO. VVO On/Off testing is expected to begin in winter 2021-2022 at the Townsend and Lunenburg substations and in summer 2022 at the Summer Street substation. In addition, Unitil expects to deploy VVO investments at the West Townsend substation, which is currently expected to begin VVO On/Off testing in fall 2022.

Findings for VVO Performance Metrics

Table 6 includes the Performance Metrics results for the winter 2020/21 measurement and verification (M&V) period for Eversource and National Grid.

Table 6. Performance Metrics Results for the Winter 2020/21 M&V Period

Performance Metrics		Eversource	National Grid
Feeders Enabled for Evaluation		19	6
PM-1	Winter 2020/21 Baseline	113,470 MWh	32,442 MWh
PM-2	Winter 2020/21 Energy Savings*	853 ± 124 MWh	170 ± 59 MWh
		0.75 ± 0.11%	0.52 ± 0.18%
PM-3	Peak Load Impact**	N/A	N/A
PM-4	Distribution Losses†	N/A	N/A
PM-5	Power Factor‡	N/A	N/A
PM-6	GHG Reductions (CO_2)	422 ± 61 tons	84 ± 29 tons
PM-7	Voltage Complaints	No Increase / Decrease Observed	No Increase / Decrease Observed

* Calculated energy savings assumes VVO was enabled for the entirety of winter 2020/21.
** Guidehouse does not provide an estimate of peak load impacts for the winter 2020/21 M&V period, as Guidehouse will estimate peak load impacts for the summer on-peak period, defined as 1:00–5:00 pm for June 1–August 31 on non-holiday weekdays per ISO-NE.

† Guidehouse will provide an estimate of the impact of VVO on distribution losses once a full winter, full summer, and one shoulder season have been covered by M&V testing.
‡Per the Stage 3 Plan filed December 1, 2020, Guidehouse will provide an estimate of the impact of VVO on the power factor for hours with power >75% of each feeder's peak annual demand. Given the M&V period being examined within this evaluation corresponds with winter 2020/21, very few hours had power >75% of each feeder's peak annual demand.

Source: Guidehouse analysis

Findings from Guidehouse's evaluation of VVO Performance Metrics indicate that VVO allowed Eversource and National Grid to realize energy savings and voltage reductions during the winter 2020/21 M&V period. More specifically:

- During the winter 2020/21 M&V period, Eversource's Agawam, Piper, and Silver substations realized 853 MWh (0.75%) energy savings and 1.24 V (1.01%) voltage reduction associated with VVO. The conservation voltage reduction (CVR) factor, which provides an estimate of energy savings possible with voltage reductions, was 0.82.
- During the same M&V period, National Grid's Stoughton substation realized 170 MWh (0.52%) energy savings and 0.12 V (0.88%) voltage reduction associated with VVO. The CVR factor was 0.60.
- Reductions in energy use were found to be greater during peak energy hours relative to off-peak energy hours for both Eversource and National Grid. In addition, Eversource experienced greater voltage reductions during off-peak energy hours, while National Grid experienced greater voltage reductions during peak energy hours.
- Eversource energy savings of 853 MWh yielded a 422 short ton reduction in CO_2 emissions, a 274 lb. reduction in NO_X emissions, and a 68 lb. reduction in SO_2 emissions. National Grid energy savings of 170 MWh yielded an 84 short ton reduction in CO_2 emissions, a 54 lb. reduction in NO_X emissions, and a 14 lb. reduction in SO_2 emissions.
- For Eversource, a total of 13 voltage complaints were received from customers connected to the Agawam, Piper, and Silver VVO feeders during the winter 2020/21 M&V period. For National Grid, a total of five voltage complaints were received from customers connected to the Stoughton VVO feeders during the period. Guidehouse did not identify a substantial increase or decrease in voltage complaints during the winter 2020/21 M&V period.

Recommendations

In 2021 and beyond, Guidehouse recommends that:

- EDCs explore voltage setpoints to determine whether further voltage reductions can be achieved when VVO is engaged.
- EDCs identify whether there is an impact of reverse power flow from distributed generation on VVO operation. The impact of reverse power flow on VVO operation may have a large impact on the evaluated performance of VVO for the upcoming spring and summer 2021 M&V periods.
- Guidehouse and the EDCs 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. To provide results for reporting of Performance Metrics later in 2021 and 2022, the EDCs should continue with this plan.

- If possible, Unitil should accelerate the VVO On/Off testing start date for the Summer Street substation to December 1, 2021 from June 1, 2022 to enable PM analysis of all three of the original 2018–2020 plan substations can be included in the 2021 Evaluation Report. If VVO On/Off testing begins by December 1, 2021 for all three substations, Guidehouse recommends continuing VVO On/Off testing for these three substations through at least August 31, 2022.
- EDCs should identify and take additional steps to balance load across feeders and phases before the deployment of VVO. This step can yield energy savings that could be attributed to VVO investment.
- EDCs and Guidehouse should work to update stamped-approved performance metrics after completing analysis of all VVO performance metrics, based upon methods included in this evaluation report.

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[10] regarding the individual Grid Modernization Plans (GMPs) filed by the three Massachusetts Electric Distribution Companies (EDCs): Eversource, National Grid, and Unitil.[11,12] 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[13] 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)

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

[11] 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.

[12] On June 16, 2016, Eversource and National Grid each filed updates to their respective grid modernization plans

[13] 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) 2020 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
Advanced Distribution Automation (ADA)	Isolation of outage events with automated backup for 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)	New capabilities in real-time system control with investments in developing accurate system models and enhancing SCADA and outage management systems to control devices for system optimization and provide support for distribution automation and VVO with high penetration of distributed energy resources (DER)	Enables high penetration of DER by supporting the ability to control devices for system optimization, ADA, and VVO
Communications/IoT (Comms)	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 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 and ALF 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.

On July 1, 2020, Eversource filed a request for an extension of the budget authorization associated with grid modernization investments.[14] The budget extension, approved by the DPU

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

on February 4, 2021,[15] 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.

[15] 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 under 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 EDC.	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.

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[16] (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.

[16] 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.[17] 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	✓	✓	✓

[17] 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. The Stage 3 Evaluation Plan filed December 1, 2020 includes additional details about approaches used in the evaluation of Infrastructure Metrics and Performance Metrics.

This VVO evaluation is focused on Infrastructure Metrics for PY2020 and Performance Metrics for winter 2020/21. VVO On/Off testing began in winter 2020/21 for Eversource and National Grid, and VVO investments and VVO commissioning are ongoing for Unitil. The evaluation of Performance Metrics will be provided for Eversource and National Grid using data collected during the course of VVO On/Off testing conducted in winter 2020/21.

2.1 Infrastructure Metrics Analysis

Guidehouse annually assesses the progress of each of the EDCs toward enabling 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. PY2020	# Devices Deployed	$\sum_{PY=2018}^{2020}(Devices\ Commissioned)_{PY}$
		% Devices Deployed	$\frac{\sum_{PY=2018}^{2020}(Devices\ Commissioned)_{PY}}{\sum_{PY=2018}^{2019}(Devices\ Commissioned)_{PY} + (Planned\ Devices)_{PY2020}}$
IM-5	Cost through PY2020	Total Spend, $M	$\sum_{PY=2018}^{2020}(Actual\ Spend)_{PY}$
		% Spend	$\frac{\sum_{PY=2018}^{2020}(Actual\ Spend)_{PY}}{\sum_{PY=2018}^{2019}(Actual\ Spend)_{PY} + (Planned\ Spend)_{PY2020}}$
IM-6	Deviation Between Actual and Planned Deployment for PY2020	% On Track (Devices)	$\frac{(Devices\ Commissioned)_{PY2020}}{(Planned\ Devices)_{PY2020}}$
		% On Track (Spend)	$\frac{(Actual\ Spend)_{PY2020}}{(Planned\ Spend)_{PY2020}}$
IM-7	Projected Deployment for 2021	# Devices Remaining	$(Devices\ Planned)_{PY2021}$
		Spend Remaining, $M	$(Planned\ Spend)_{PY2021}$

* Planned devices and spend are based on the *2019 GMP Annual Report* filing (filed on April 1, 2020).

** Remaining devices and spend are based on the data provided to Guidehouse by the EDCs between January and March 2021.

Source: Guidehouse

Table 17. Infrastructure Metrics Overview by Feeder

Infrastructure Metrics			Calculation
IM-4	Number of Devices or Other Technologies Deployed through PY2020	# Feeders with VVO Enabled	$\sum_{PY=2018}^{2020} (VVO\ Enabled\ Feeders)_{PY}$
		% Feeders with VVO Enabled	$\frac{\sum_{PY=2018}^{2020} (VVO\ Enabled\ Feeders)_{PY}}{\sum_{PY=2018}^{2019} (VVO\ Enabled\ Feeders)_{PY} + (Planned\ VVO\ Enabled\ Feeders)_{PY2020}}$
IM-6	Deviation Between Actual and Planned Deployment for PY2020	% On Track (VVO Enabled Feeders)	$\frac{(VVO\ Enabled\ Feeders)_{PY2020}}{(Planned\ VVO\ Enabled\ Feeders)_{PY2020}}$
IM-7	Projected Deployment for 2021	# VVO Enabled Feeders Remaining	$(Planned\ VVO\ Enabled\ Feeders)_{PY2021}$

* Planned devices and spend are based on the *2019 GMP Annual Report* filing (filed on April 1, 2020).

** Remaining devices and spend are based on the data provided to Guidehouse by the EDCs between January and March 2021.

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 their progress through PY2020 (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 PY2020.

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.

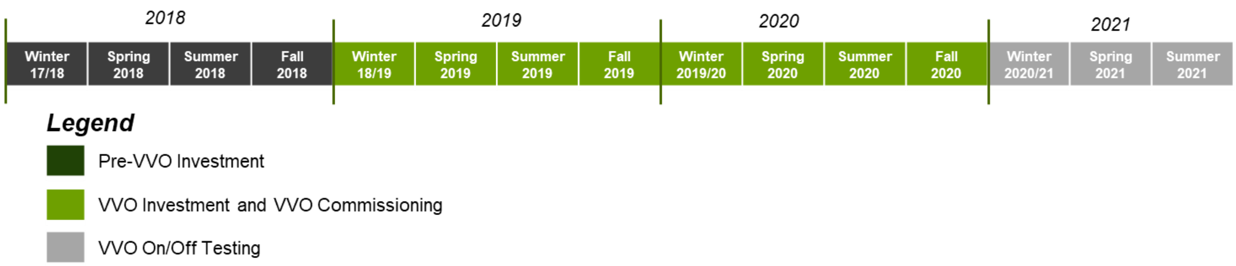
For changes associated with VVO being enabled to be quantified, Guidehouse and the EDCs have agreed to the plan for VVO On/Off testing to continue for at least 9 months, covering summer (June, July, and August), winter (December, January, and February), and one of the spring (March, April, and May) or fall (September, October, November) shoulder seasons.

2.2.1 Performance Metrics Timeline

Figure 2 highlights the timeline of events that will be covered by Performance Metrics analysis for Eversource and National Grid.[18] VVO On/Off testing began in December 2020 for a subset of Eversource and National Grid substations. VVO On/Off testing is expected to begin for additional Eversource and National Grid substations in early- to mid-2021. Eversource and National Grid plan for VVO On/Off testing to be in effect for one full winter, full summer, and a spring and/or fall shoulder season across all feeders. This will enable Guidehouse to complete a full evaluation and reporting on Performance Metrics for Eversource and National Grid in 2022.

[18] Unitil is excluded from this Performance Metrics timeline because, while investment for VVO has started, VVO On/Off testing with not start until 12/01/2021 at the earliest. A separate timeline for Unitil is provided within Section 0.

Figure 2. Performance Metrics Timeline*



*Note: Performance Metrics analysis timeline for Eversource and National Grid for VVO feeders identified in the May 1, 2019 filing. Unitil is not shown on this timeline as VVO On/Off Testing is not expected to begin until winter 2021-2022.

Source: Guidehouse analysis of EDC Data

Unitil is completing device deployment and expects to begin VVO On/Off testing by winter 2021-2022 on the Townsend and Lunenburg substations, with Summer Street to kick off VVO On/Off testing in 2022. In 2022 Guidehouse will evaluate Performance Metrics for Unitil for winter 2021-2022 for the Townsend and Lunenburg substations.

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 toward the GMP metrics. The subsections that follow summarize each of the data sources used to evaluate Infrastructure Metrics.

3.1.1.1 2019 Grid Modernization Plan Annual Report

Guidehouse used the planned device deployment and cost information from each EDCs' *2019 GMP Annual Reports*, which were filed on April 1, 2020. These filings served as the sources for planning data in this report[19] and are referred collectively as the EDC Plan for each EDC in summary tables and figures throughout this report. Table 19 summarizes the planned and actual deployment and spend data and specifies the color used to represent each in the remainder of the report.

Table 19. Data Used for the EDC Plan

Representative Color	Data	Description
	2021 Plan	Projected 2021 unit deployment and spend
	2020 Plan	Projected 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: 2021 Plan (Applicable to Eversource only): 2021 Grid Modernization Program Extension and Funding Report filed July 1, 2020; Other plan and actual data: EDCs' 2019 GMP Annual Report Appendix 1 filed April 1, 2020.

Guidehouse used the Feeder Status tab of the 2020 GMP Annual Report Appendix 1 to obtain feeder characteristics including system voltage, total feeder count, customer count, feeder length, and annual peak load.

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. These data sources are referred to as EDC Data in summary tables and figures throughout the report. Table 20 summarizes the file versions used for the evaluation. The collected data was

[19] See Section 5 for specific details regarding *2019 GMP Annual Report* data used for each EDC.

compared to the data submitted by the EDCs to the DPU in the 2020 Grid Modernization Plan Annual Reports and associated Appendix 1 filings.[20,21,22] 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[23]	
	All Device Deployment	VVO Supplemental
Eversource	Received 2/18/2021	Received 3/5/2021
National Grid	Received 2/24/2021	Received 3/8/2021
Unitil	Received 1/21/2021	Received 3/8/2021

Source: Guidehouse

3.1.1.3 EDC PY 2020 Device Deployment Data Template

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 device deployment information and estimated spend for PY2021 was provided at the most granular level (circuit or substation, where available).

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 Data

Representative Color	Data	Description
Device Deployment Data		
	2021 Plan	Remaining units planned for 2021 where work will begin in 2021
	2020 Design/ Engineering	Detailed design and engineering is in progress, but the device is not yet in construction
	2020 Construction	Field construction is in progress, but the device is not yet in-service
	2020 In-Service	Device is installed and used and useful, but not yet commissioned to enable all grid modernization functionalities

[20] 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

[21] 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

[22] 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

[23] Some minor additional updates to specific work orders were addressed after these dates via email.

Representative Color	Data	Description
	2020 Commissioned	Device is fully operational with all grid modernization functionalities, and so is considered deployed in PY2020
	2019 Actual	Actual devices commissioned in 2019
	2018 Actual	Actual devices commissioned in 2018
Spend Data		
	2021 Plan	Projected 2021 spend
	2020 Actual	Actual 2020 spend[24]
	2019 Actual	Actual 2019 Spend[25]
	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 and covers the baseline period through the VVO On/Off testing period.

[24] The 2020 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 **Error! Reference source not found.**.

[25] 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.[26]
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 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 VVO Investment Area in the following subsections.

3.2.1 Statewide Comparison

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

[26] IT work progress includes: planning, procurement, development, deployment, and go-live

3.2.1.1 Anticipated Impact on Massachusetts

As part of the 2018-2021 GMP, VVO deployment is anticipated to impact 76 feeders serving 148,968 customers (5.4% 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); the specific substations are TBD for the additional feeders to receive VVO in 2021
- **National Grid:** East Methuen, Maplewood, and Stoughton (original 2018–2020 plan feeders); East Dracut, East Bridgewater, 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	2,350	1,399,076	1,123	1,342,182	43	29,990	3,516	2,771,248
Original 2018-2020 Plan Feeders								
Count	26	38,130	20	52,905	9	8,829	55	99,864
% System Total	1.1%	2.7%	1.8%	3.9%	20.9%	29.4%	1.6%	3.6%
Additional Feeders[27]								
Count	N/A	N/A	19	45,822	2	3,282	21	49,104
% System Total	N/A	N/A	1.7%	3.4%	4.7%	10.9%	0.6%	1.8%
2018-2021 Projected Total								
Count	26	38,130	39	98,727	11	12,111	76	148,968
% System Total	1.1%	2.7%	3.5%	7.4%	25.6%	40.4%	2.2%	5.4%

Source: Guidehouse analysis of 2020 GMP Annual Report Appendix 1, filed April 1, 2021

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, the planned VVO On/Off testing period start date, and the number of VVO devices required as part

[27] Eversource is going to deploy VVO on additional feeders in 2021 but has not yet determined the specific substations that will be targeted.

of the VVO investment period for each EDC.[28] The following subsections include specifics related to each EDC's approach to VVO.

Table 24. VVO Investments and VVO On/Off Testing Start by EDC

Company	Substations (Feeder Count)	Plan VVO On/Off Testing Start	VVO Investments Required (3-Year Total)			
			Capacitor Banks	Line Sensors[29]	LTC Controls	Voltage Regulators
Original 2018-2020 Plan Feeders						
Eversource	Agawam (7)	Winter 2020/21	22	54	2	15
	Piper (6)	Winter 2020/21	13	36	2	15
	Podick (7)	Spring 2021	19	57	2	44
	Silver (6)	Winter 2020/21	20	42	2	22
National Grid	E. Methuen (6)	Spring 2021	19	6	2	12
	Maplewood (8)	Summer 2021	17	9	2	15
	Stoughton (6)	Winter 2020/21	19	6	1	3
Unitil	Townsend (3)	Winter 2021/22	4	12	1	6
	Lunenburg (2)	Winter 2021/22	4	23	0	21
	Summer St. (4)	Summer 2022	4	26	1	16
Additional Feeders[30]						
National Grid	E. Bridgewater (7)	Summer 2021	0	0	0	0
	East Dracut (6)	Summer 2021	0	0	0	0
	West Salem (6)	Summer 2021	0	0	0	0
Unitil	W. Townsend (2)	Fall 2022	6	14	1	11

Source: Guidehouse analysis of 2020 GMP Annual Reports

[28] For all the EDCs, VVO devices deployed prior to VVO enablement has been focused on the installation of equipment and commissioning of the VVO software. No load rebalancing has not been conducted during this process.

[29] Count represents 1-phase line sensors for Eversource and 3-phase line sensors for National Grid and Unitil

[30] Eversource is going to deploy VVO on additional feeders in 2021 but has not yet determined the specific substations that will be targeted.

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 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 2020/2021–Spring 2021 (complete)	Winter 2020/2021–Spring 2021 (in progress)	Summer 2021–Winter 2021/2022 (planned)
VVO On/Off Testing Period	Winter 2020/21–TBD (in progress)	Winter 2020/21–TBD (in progress)	Winter 2021/2022–TBD (planned)
Additional Feeders			
VVO Investment	CY2021[31] (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 analysis of 2020 GMP Annual Reports and EDC Data

VVO deployment and VVO commissioning have been completed by Eversource, and VVO On/Off testing is ongoing. Among its original 2018–2020 plan feeders, Eversource began VVO On/Off testing in winter 2020/21 at the Agawam, Piper, and Silver substations and in spring 2021 at the Podick substation. VVO On/Off testing is expected to continue until sufficient winter, summer, and shoulder season data have been collected for Performance Metrics analysis.

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 and in spring 2021 at the East Methuen substation. VVO commissioning is ongoing at the Maplewood substation, which is expected to begin On/Off testing by June 2021. For its additional feeders, National Grid estimates that it will complete VVO deployment throughout the first half of 2021 at all additional feeders connected to the East Bridgewater, East Dracut, and

[31] Eversource is going to deploy VVO on additional feeders in 2021 but has not yet determined the specific substations that will be targeted.

West Salem substations. National Grid estimates that it will begin VVO On/Off testing at these substations in summer 2021.

VVO deployment and VVO commissioning are ongoing for Unitil's original 2018–2020 plan feeders, and Unitil plans to begin VVO On/Off testing on its Townsend and Lunenburg substations by winter 2021-2022 and at its Summer Street substation by summer 2022. Unitil plans to deploy VVO investments at the West Townsend substation throughout 2021 and 2022 and estimates that the substation will be ready for VVO On/Off testing by fall 2022.

3.2.1.4 Infrastructure Metrics Results

Table 26 and Table 27 include the Infrastructure Metrics results through PY2020 for all EDCs. The following EDC-specific subsections provide further detail.

Table 26. 2020 Infrastructure Metrics for VVO Progress

Infrastructure Metrics			Eversource*	National Grid	Unitil
GMP Plan Total, 2018-2021		# Devices Commissioned	367	106	59
		Spend, $M	$17.35**	$8.50	$2.06
EDC Data Total, 2018-2021		# Devices Commissioned	1,201	249	77
		Spend, $M	$18.93	$19.27	$5.12
IM-4	Number of Devices Deployed through PY2020	# Devices Deployed	577	111	3
		% Devices Deployed	157%	105%	5%
IM-5	Cost for Deployment through PY2020	Total Spend, $M	$12.93	$11.98	$1.85
		% Spend	105%	141%	90%
IM-6	Deviation Between Actual and Planned Deployment for PY2020	% On Track (Devices)	800%	105%	5%
		% On Track (Spend)	114%	159%	90%
IM-7	Projected Deployment for the Remainder of the GMP Term	# Devices Remaining	624	138	74
		Spend Remaining, $M	$6.00	$7.29	$3.26

*Eversource spend and deployment includes spend and deployment for grid monitoring line sensors and microcapacitors.

**Includes the Eversource planned spend for PY2021, set forth the in the *GMP Extension and Funding Report*, filed on July 1, 2020 and approved on February 4, 2021.

Source: Guidehouse analysis of 2019 GMP Annual Reports, "GMP Extension and Funding Report," and 2020 EDC Data

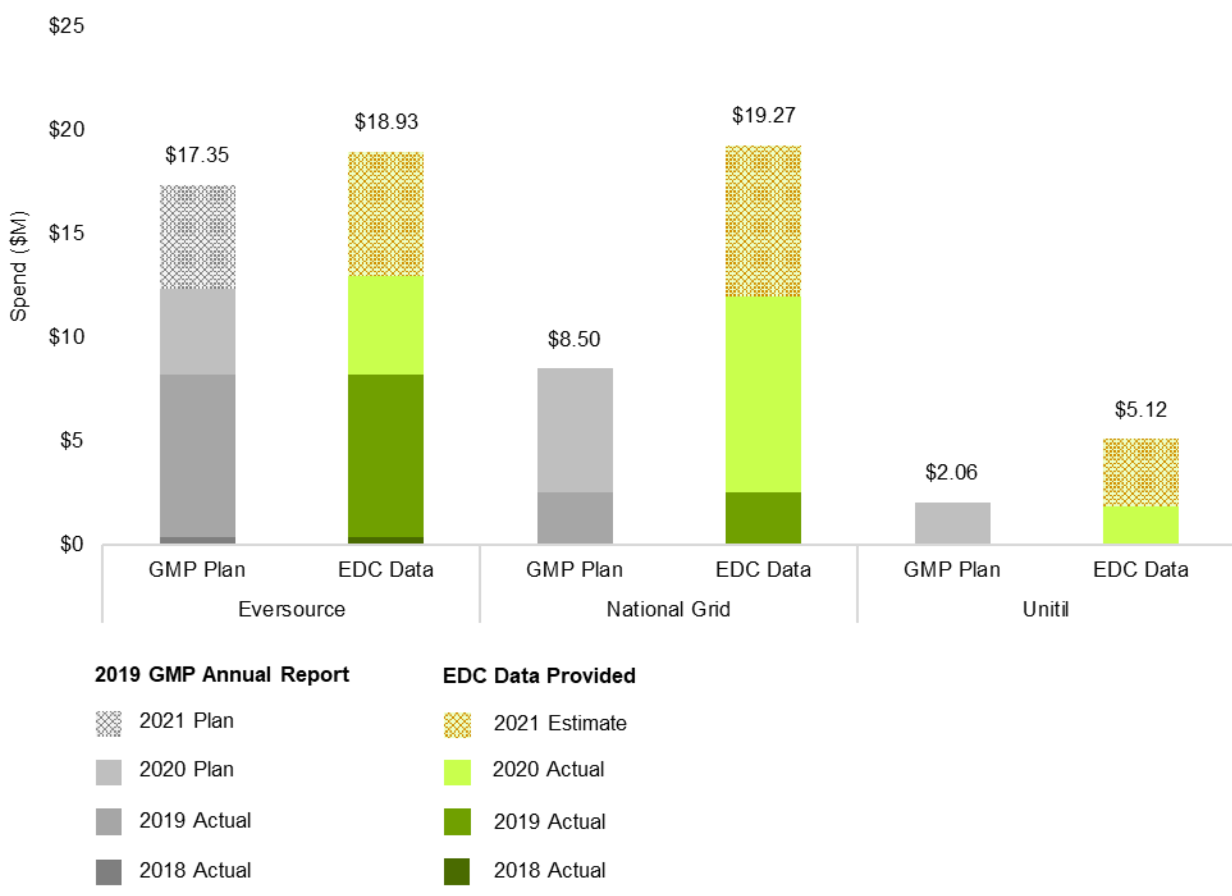
Table 27. 2020 Infrastructure Metrics for VVO Feeder Deployment Progress

IM	Parameter	Eversource	National Grid	Unitil
IM-4	# Feeders with VVO Enabled	26	6	0
	% Feeders with VVO Enabled	100%	15%	0%
IM-6	% On Track (Feeders with VVO Enabled)	100%	15%	0%
IM-7	# Feeders Remaining for VVO Enablement	0	39	11

Source: Guidehouse analysis of 2019 GMP Annual Report and 2020 EDC Data

Figure 3 highlights planned versus actual spend in 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 3. VVO Planned vs. Actual Spend (2018–2021, $M)



*Includes the Eversource planned spend for PY2021, set forth the in the *GMP Extension and Funding Report*, filed on July 1, 2020 and approved on February 4, 2021.

Source: Guidehouse analysis of 2019 GMP Annual Reports, "GMP Extension and Funding Report," and 2020 EDC Data

In addition to the capital costs Figure 3 shows, Eversource incurred $0.39 million in operations and maintenance (O&M) costs toward the VVO Investment Area in PY2020. Eversource also incurred approximately $0.54 million toward general O&M costs across the GMP investments in PY2020. National Grid incurred approximately $0.30 million in O&M costs toward the VVO Investment Area in PY2020. National Grid also incurred approximately $1.79 million toward general O&M costs across the GMP investments in PY2020. Unitil incurred approximately $9,000 in O&M costs toward the VVO Investment Area and approximately $12,000 toward general O&M costs across the GMP investments in PY2020.

PY2020'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 device deployment exceeded initially planned devices in line sensors, while device deployment fell short of original plans on all other pre-approved device types.[32] In addition, Eversource commissioned two new device types: microcapacitors and grid monitoring line sensors. These devices should supplement the overall VVO investment and allow Eversource to gather additional data integral to the distribution management system (DMS).
- National Grid device deployment also exceeded initially planned devices, primarily due to National Grid's decision to install midline regulators at VVO substations, as well as additional load tap changers (LTC) controls to allow for four additional Maplewood feeders to receive VVO.
- Unitil device deployment fell short of plans due to delays in Field Area Network (FAN) implementation. Despite completing construction work on regulators and capacitor banks throughout 2020, since ADMS is planned to be a control system for VVO, delays in FAN implementation interfered with deployment of the devices before the close of the year.

VVO Enablement:

- Eversource completed deployment of VVO for the original 2018 – 2020 plan feeders, with all feeders having VVO enabled on December 2, 2020. VVO enablement was behind Eversource's schedule laid out in the PY2019 Evaluation Report due to ongoing commissioning troubleshooting prior to enabling VVO. However, by the end of 2020 all four substations had the VVO system enabled. Eversource has been conducting VVO On/Off testing on the Agawam, Piper, and Silver substations since December 2, 2020 and on the Podick substation since March 4, 2021.
- National Grid had not enabled VVO for all of the original 2018 – 2020 plan feeders by the end of 2020 as anticipated in the PY2019 Evaluation Report. This is due to the fact that National Grid had not completed deployment of VVO at the East Methuen and Maplewood substations by the end of the year. National Grid experienced delays in deployment of VVO throughout 2020 due to the addition of midline regulators and additional LTC controls, as well as delays and complexities associated with IT work

[32] Deployment fell short of plans across all other pre-approved device types after full engineering analysis was conducted by Eversource, reducing the number of pre-approved devices required to accommodate VVO operation.

during the COVID-19 pandemic. However, National Grid enabled VVO and began VVO On/Off testing at its Stoughton substation on December 1, 2020.

- Unitil VVO enablement fell short of its schedule laid out in the PY2019 Evaluation Report, as Unitil has not completed deployment of VVO at the original 2018 – 2020 plan feeders due to delays in FAN implementation.

Total Spend:

- Eversource costs for deployment of pre-approved devices exceeded plans due to regulator design changes and unplanned commissioning and startup costs incurred prior to enabling VVO. Spend on IT work was lower than planned. Eversource also deployed microcapacitors and grid monitoring line sensors.
- National Grid costs for deployment exceeded plans due to increased spending on regulators, LTC controls, and IT work. Spend on regulators exceeded plans due to the introduction of midline regulators to maximize VVO benefits, which increased capital and labor costs. In addition, spend on LTC controls exceeded plans due to the installation of additional controls and retrofitting of LTCs to receive necessary data. Lastly, spend on IT work also exceeded plans due to increased complexities introduced during the COVID-19 pandemic and cybersecurity concerns requiring software patches and retesting.
- The pace of Unitil investment has been slower than anticipated. As a result, Unitil spending during PY2020 was lower than anticipated. Spending was lower than anticipated for LTC controls and line sensors, while spending was on plan for regulators and capacitor banks, primarily due to the large amount of construction work conducted throughout 2020 even during the COVID-19 pandemic.

The EDCs are slated to continue to deploy VVO investments throughout 2021. In particular:

- Eversource plans to continue VVO On/Off testing throughout the year at all four original 2018–2020 plan substations (Agawam, Piper, Podick, Silver) until sufficient winter, summer, and shoulder season data are collected for Performance Metrics analysis. Eversource also plans to deploy additional VVO investments throughout 2021 at other substations.
- National Grid is slated to continue VVO On/Off testing at its Stoughton and East Methuen substations throughout the year and expects to begin VVO On/Off testing at its Maplewood substation by summer 2021. In addition, National Grid plans to deploy VVO investments at additional feeders connected to the East Bridgewater, East Dracut, and West Salem substations. Engineering and design and construction work have already begun on devices to be installed at these substations, and VVO On/Off testing is expected to begin in summer 2021.
- Unitil is expected to complete the VVO deployment for its original 2018–2020 plan substations throughout 2021. This work will include assembly of communications equipment to facilitate ADMS control of VVO. VVO On/Off testing is expected to begin in winter 2021-2022 at the Townsend and Lunenburg substations and in summer 2022 at the Summer Street substation. In addition, Unitil expects to deploy VVO investments at the West Townsend substation, which is currently expected to begin VVO On/Off testing in fall 2022.

3.2.2 Eversource

This section discusses Eversource's VVO investment progress through PY2020 as compared to the *2019 GMP Annual Report* and their new 2021 estimated progress. 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 four substations, amounting to 26 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 as part of the original 2018–2020 plan. Eversource plans to deploy VVO on additional feeders in 2021 but has not yet determined the specific feeders that will receive these investments.

Table 28 and Table 29 summarize the planned deployment and spending on VVO from 2018 through 2021. The cost of VVO deployment is estimated to total to $17.9 million by the end of 2021.

Table 28. Eversource VVO Feeder Deployment Year-over-Year Comparison

Data	2018	2019	2020	2021	2018-2021
EDC Actual Progress	0	0	26	N/A	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	TBD[35]	26
% EDC Revised Plan/EDC Original Plan	100%	0%	100%	N/A	100%

Source: Guidehouse analysis of 2019 GMP Annual Reports and EDC Data

[33] The EDC original plan includes actuals reported for 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 – PY2020 and updated projections for PY2021.

[35] Eversource is going to deploy VVO on additional feeders but has not yet determined the specific substations that will be targeted.

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	N/A	$12.9
EDC Original Plan[36]	$0.4	$7.8	$4.2	N/A	$12.4
% EDC Actual Progress/EDC Original Plan	100%	69%	114%	N/A	105%
EDC Revised Plan[37]	$0.4	$7.8	$4.7	$5.0	$18.9
% EDC Revised Plan/EDC Original Plan	100%	69%	114%	N/A	153%

*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 2019 GMP Annual Reports and EDC Data

Table 30 highlights the characteristics of substations selected to receive VVO investments between 2018 and 2020. The team's evaluation of Infrastructure Metrics spans spending and deployment under the VVO investment and VVO commissioning stages.

Table 30. Eversource VVO Feeder Characteristics

Substation	Feeder	Feeder Length (mi.)	Customer Count	Annual Peak Load (MVA)	Distributed Generation (MW)
Agawam (13.8 kV)	**16C11**	24	1,310	6.2	2.0
	16C12	6	76	4.6	2.0
	16C14	15	1,624	6.3	0.1
	16C15	11	1,275	4.1	0.1
	16C16	23	2,599	7.1	2.3
	16C17	29	2,367	7.4	1.0
	16C18	21	3,021	6.5	0.6
Piper (13.8 kV)	**21N4**	33	2,278	7.4	1.3
	21N5	15	830	10.4	0.2
	21N6	15	779	3.9	0.5
	21N7	5	2	4.7	0.0
	21N8	9	558	6.3	0.1
	21N9	24	2,394	6.7	0.8
Podick (13.8 kV)	**18G2**	4	10	0.3	0.0
	18G3	37	2,111	3.5	2.1
	18G4	34	2,320	7.4	5.5
	18G5	39	1,734	6.7	5.6
	18G6	37	1,271	4.8	3.5
	18G7	63	2,180	4.2	7.0
	18G8	45	1,065	6.7	8.5

[36] The EDC original plan includes actuals reported for 2018 and 2019, along with plans reported for 2020, contained in the EDC's 2019 GMP Annual Report, Appendix 1.

[37] Based on the EDC's actual progress in PY2018 – PY2020 and updated projections for PY2021.

Substation	Feeder	Feeder Length (mi.)	Customer Count	Annual Peak Load (MVA)	Distributed Generation (MW)
Silver (13.8 kV)	**30A1**	36	2,437	8.5	1.1
	30A2	12	2,259	9.7	0.3
	30A3	12	242	7.1	5.1
	30A4	11	792	2.3	0.2
	30A5	21	1,631	5.2	0.6
	30A6	19	965	5.1	2.1

Source: 2020 GMP Annual Report, Appendix 1 filed April 1, 2021. Distributed Generation data was provided by the EDCs to Guidehouse as of January 2021.

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 8.5 MW. Appendix 5.3A.1 contains additional information related to the VVO feeders

VVO Timeline

Table 31 summarizes substation-specific progress in each of the four VVO investment phases.

Table 31. Eversource VVO Deployment Completion Dates by Phase and Substation

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[38]	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[39]	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 EDC Data

Eversource enabled VVO on all substations and began VVO On/Off testing on three of four substations in December 2020. VVO On/Off testing is slated to continue on these substations through at least summer 2021 to allow for winter, summer, and spring shoulder season data collection. Note that Eversource began VVO On/Off testing at the Podick substation in December 2020, but the substation experienced multiple equipment issues, which required halting VVO On/Off testing until these issues were resolved. VVO On/Off testing began again on

[38] VVO Commissioning is the time at which VVO devices are controlled by and have data visible to each EDC.

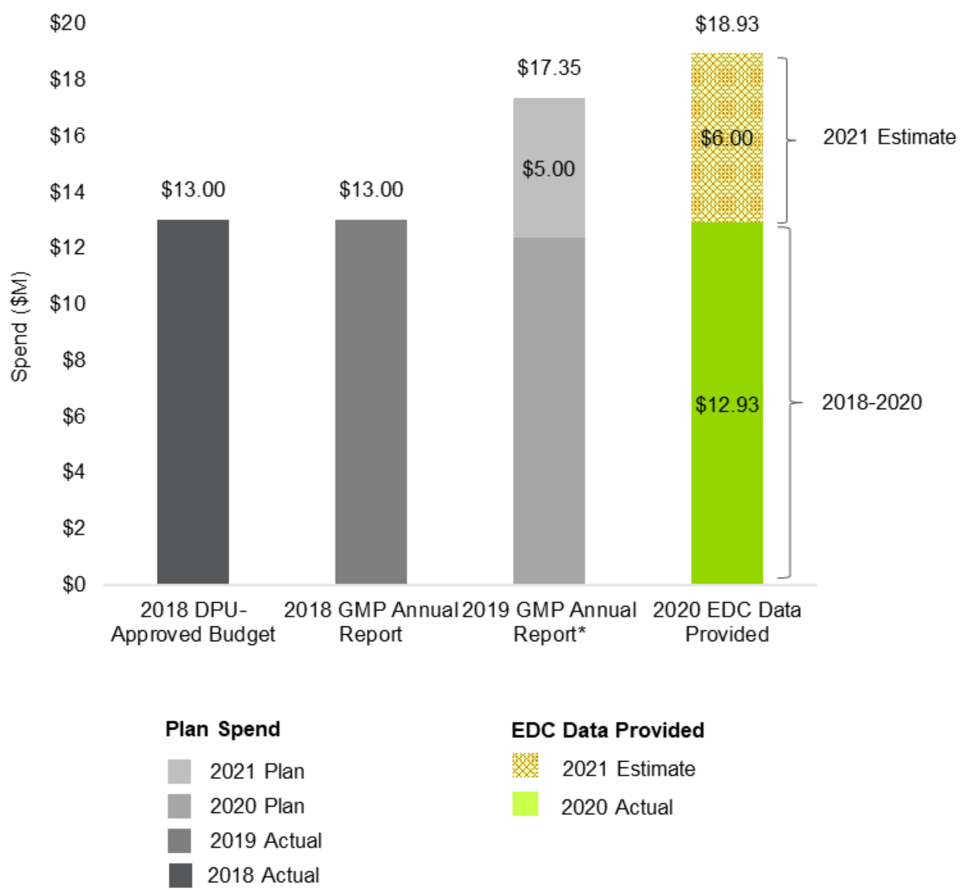
[39] VVO Enabled is the time at which the VVO system is commissioned and VVO is engaged.

March 4, 2021 and is planned to continue until data spanning a spring shoulder, full summer, and full winter are collected.

3.2.2.2 VVO Deployment Plan Progression

Figure 4 shows how Eversource's VVO deployment spend has progressed since the GMP was approved in 2018.

Figure 4. Eversource VVO Planned vs. Actual Spend (2018–2021, $M)



* Includes the Eversource plan for 2021, set forth the in the *GMP Extension and Budget Report*

Source: Guidehouse analysis of DPU Order (May 10, 2018), 2019 GMP Annual Reports, GMP Extension and Budget filing (July 1, 2020), and 2020 EDC Data

Eversource deployment and spend are on track, with deployment of VVO completed slightly below anticipated costs by the end of 2020. Costs for deployment of pre-approved devices exceeded plans due to regulator design changes and unplanned commissioning and startup costs incurred prior to enabling VVO for all device types. However, IT work costs were below plans, and Eversource adjusted plans to include two new device types: microcapacitors and grid monitoring line sensors. Microcapacitors enable additional voltage and power factor control on feeders. Grid monitoring line sensors allow Eversource to gather additional telemetry from VVO enabled feeders. In sum, despite adding two new device types and deployment costs exceeding plans for pre-approved devices, costs for deployment were slightly below anticipated costs by the end of 2020.

3.2.2.3 VVO Investment Progress through PY2020

Table 32 presents VVO enablement progress by substation, including anticipated and actual VVO enabled dates and notes on the current status of VVO deployment.

Table 32. Eversource VVO Enabled Progress by Substation

Substation	January 2020 Plan VVO Enabled Date	January 2021 Plan Actual/Planned VVO Enabled Date	Current Status[40]
Agawam	1/31/2020	12/2/2020 (actual)	VVO On/Off testing in progress
Piper	2/29/2020	12/2/2020 (actual)	VVO On/Off testing in progress
Podick	3/31/2020	12/2/2020 (actual)	VVO On/Off testing in progress
Silver	3/31/2020	12/2/2020 (actual)	VVO On/Off testing in progress

Source: Guidehouse analysis of EDC Data

As of December 2020, all four substations had the VVO system enabled. Agawam, Piper, and Silver substations have been conducting VVO On/Off testing since December 2, 2020. Podick began VVO On/Off testing on December 14 but experienced equipment failures at two locations, requiring VVO On/Off testing to be put on hold until equipment failures could be resolved. Eversource restarted VVO On/Off testing at the Podick substation on March 4, 2021 after equipment issues were resolved.

Figure 5 shows the actual device deployment for all device types compared to the projected deployment in the *2019 GMP Annual Report*, as well as 2021 EDC-estimated deployment. Table 33 highlights the status of VVO investments through PY2020 for each device/investment type per the EDC data provided.

[40] Status can be: planning, design, construction, device deployment complete, VVO commissioning in process, or VVO enabled.

Figure 5. Eversource Planned vs Actual Deployment (2018–2021, Unit Count)

Source: Guidehouse analysis of 2019 GMP Annual Report and EDC Data

Table 33. Eversource VVO Deployment Progress

Deployment Progress	VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors	Microcapacitors	Grid Monitoring Line Sensors
2018-2021 Planned Deployment	**144**	**106**	**12**	**229**	**299**	**411**
PY 2021 Estimate	48	32	4	40	200	300
Engineering/Design during PY2020	0	0	0	0	0	0
Construction during PY2020	0	0	0	0	0	0
In-Service during PY2020	0	0	0	0	0	0
Commissioned in PY2020	27	3	0	0	99	111
Commissioned in PY2019	69	71	4	189	0	0
Commissioned in PY2018	0	0	4	0	0	0

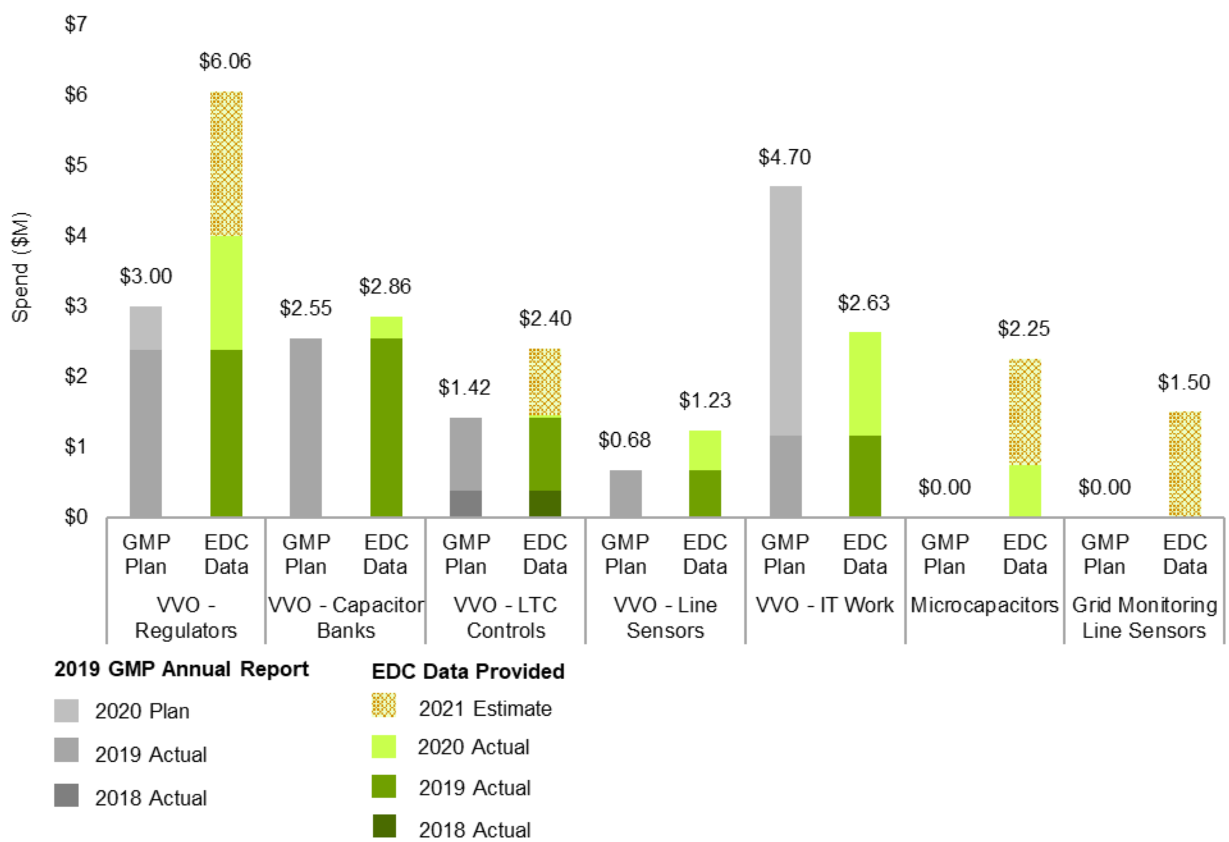
Source: Guidehouse analysis of EDC Data

Eversource completed deployment of VVO devices in 2020, commissioning remaining regulators and capacitor banks that were outstanding at the end of PY2019. Eversource met 100% of planned deployment of all pre-approved device types by the end of 2020. In addition, Eversource adjusted plans to include two new device types: microcapacitors and grid monitoring line sensors. Microcapacitors enable additional voltage and power factor control on feeders. Grid monitoring line sensors allow Eversource to gather additional telemetry from VVO enabled feeders.

Estimated deployment for 2021 spans deployment at new VVO substations in Western Massachusetts, which will receive all pre-approved device types. Microcapacitors and grid monitoring line sensors are also slated to be deployed. Microcapacitors will support system load, provide remote visibility and control, and prepare additional circuits for conversion to VVO in the future. Grid monitoring line sensors will gather data at strategic locations such as large side taps, step down transformers, and larger distributed generation sites that do not have SCADA reclosers.

Figure 6 presents planned versus actual spending on VVO devices, and Table 34 summarizes actual spending in PY2018 through PY2020, as well as EDC-estimated spending for 2021.

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



Note: The Eversource plan for 2021, set forth in the *GMP Extension and Budget Report*, provided planned spend by Investment Area but did not identify specific planned spend by device type within an Investment Area. The 2021 planned spend for VVO is $5.0 million.

Source: Guidehouse analysis of 2019 GMP Annual Report and EDC Data

Table 34. Eversource Total Spend Comparison (2018–2021, $M)

Deployment Spend	VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors	VVO - IT Work	Microcapacitors	Grid Monitoring Line Sensors
2018-2021 Planned Spend	**$6.06**	**$2.86**	**$2.40**	**$1.23**	**$2.63**	**$2.25**	**$1.50**
PY2021 Estimate	$2.05	$0.00	$0.94	$0.00	$0.00	$1.50	$1.50
PY2020 Actual	$1.63	$0.31	$0.03	$0.56	$1.47	$0.75	$0.00
PY2019 Actual	$2.38	$2.55	$1.04	$0.68	$1.16	$0.00	$0.00
PY2018 Actual	$0.00	$0.00	$0.38	$0.00	$0.00	$0.00	$0.00

Source: Guidehouse analysis of 2019 GMP Annual Report and EDC Data

The cost through PY2020 and the overall 3-year estimated cost are greater than anticipated in the *2019 GMP Annual Report* across all pre-approved device types except for IT work. Spend on regulators was higher than planned, as design and implementation of a new installation standard was required after stability issues were identified at Eversource's largest regulator installation. This required uninstallation and reinstallation of some other installed regulators as well. Spend on capacitor banks, LTC controls, and line sensors was higher than planned, primarily due to commissioning troubleshooting prior to enabling VVO. Spend on IT work was lower than planned, as it had been originally overbudgeted due to anticipated vendor costs that were not necessary. Eversource adjusted plans to include microcapacitors and grid monitoring line sensors, introducing spend on these two new device types.

As Table 33 describes, estimated spend for 2021 spans deployment at new VVO substations, which will receive all pre-approved devices. Microcapacitors and grid monitoring line sensors are also slated to be deployed. Microcapacitors will support system load, provide remote visibility and control, and prepare additional circuits for conversion to VVO in the future. Grid monitoring line sensors will gather data at strategic locations such as large side taps, step down transformers, and larger distributed generation sites that do not have SCADA reclosers.

3.2.2.4 Infrastructure Metrics Results and Key Findings

Table 35 and Table 36 present the Infrastructure Metrics results through PY2020 for Eversource.

Table 35. 2020 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, 2018-2020*		Devices	96	74	8	189	0	0	0
		Spend, $M	$3.00	$2.55	$1.42	$0.68	$4.70	$0.00	$0.00
EDC Data 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 through PY2020	# Devices Deployed	96	74	8	189	N/A	99	111
		% Devices Deployed	100%	100%	100%	100%	N/A	N/A	N/A
IM-5	Cost for Deployment through PY2020	Total Spend, $M	$4.01	$2.86	$1.45	$1.23	$2.63	$0.75	$0.00
		% Spend	134%	112%	102%	182%	56%	N/A	N/A
IM-6	Deviation Between Actual and Planned Deployment for PY2020	% On Track (Devices)	100%	100%	N/A	N/A	N/A	N/A	N/A
		% On Track (Spend)	263%	N/A	N/A	N/A	41%	N/A	N/A
IM-7	Projected Deployment for the Remainder of the GMP Term	# Devices Remaining	48	32	4	40	N/A	200	300
		Spend Remaining, $M	$2.05	$0.00	$0.94	$0.00	$0.00	$1.50	$1.50

* The Eversource plan for 2021, set forth in the *GMP Extension and Budget Report*, provided planned spend by Investment Area but did not identify specific planned spend by device type within an Investment Area. The 2021 planned spend for VVO is $5.0 million.

Source: Guidehouse analysis of 2019 GMP Annual Report and 2020 EDC Data

Table 36. 2020 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

Source: Guidehouse analysis of EDC Data

Guidehouse's review of Eversource's VVO progress revealed that Eversource exceeded planned spend and deployment outlined in their *2019 GMP Annual Report*. Key findings related to Eversource's progress include:

- Eversource completed deployment of VVO devices in 2020, meeting 100% of planned deployment of all pre-approved device types by the end of 2020. In addition, Eversource commissioned two new device types: microcapacitors and grid monitoring line sensors. These devices should supplement the overall VVO process and allow Eversource to gather additional data integral to the DMS system.
- Costs for deployment of pre-approved devices exceeded plans due to regulator design changes and unplanned commissioning and startup costs incurred prior to enabling VVO. Spend on IT work was lower than planned, as it had been originally overbudgeted due to anticipated vendor costs that were not necessary. Eversource redeployed the additional funds and allocated some of these funds toward the deployment of microcapacitors and grid monitoring line sensors.
- Eversource completed deployment of VVO at the original 2018 – 2020 plan feeders, with all feeders having VVO enabled on December 2nd. VVO enablement was behind Eversource's schedule laid out in the PY2019 Evaluation Report due to ongoing commissioning troubleshooting prior to enabling VVO. However, by the end of 2020 all four substations had the VVO system enabled. Eversource has been conducting VVO On/Off testing on the Agawam, Piper, and Silver substations since December 2, 2020 and on the Podick substation since March 4, 2021.
- Eversource plans to deploy additional VVO investments throughout 2021. Eversource plans to deploy pre-approved devices at new substations. Microcapacitors and grid monitoring line sensors are also slated to be deployed.

3.2.3 National Grid

This section discusses National Grid's VVO investment progress through PY2020 as compared to the *2019 GMP Annual Report* and their 2021 estimated deployment.

3.2.3.1 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 19 feeders connected to the East

Bridgewater, East Dracut, and West Salem substations. The team selected substations selected to receive VVO primarily based on whether they yielded the greatest customer savings. Other considerations in the selection process included the expected total energy savings, the future or ongoing planned work scopes, the resourcing availability, and a load flow and power quality analysis.

Table 37 and Table 38 summarize the planned deployment and spending on VVO from 2018 through 2021. National Grid plans to conduct VVO On/Off testing across 20 feeders connected to the East Methuen, Stoughton, and Maplewood substations. In addition, National Grid plans to deploy VVO on 19 feeders connected to East Bridgewater, East Dracut, and West Salem substations. Deployment is estimated to come in at a total cumulative cost of $13.5 million by the end of 2021.

Table 37. National Grid VVO Feeder Deployment Year-over-Year Comparison

Data	2018	2019	2020	2021	2018-2021
EDC Actual Progress	0	0	6	N/A	6
EDC Original Plan[41]	0	0	16	N/A	16
% EDC Actual Progress/EDC Original Plan	100%	0%	38%	N/A	38%
EDC Revised Plan[42]	0	0	6	33	39
% EDC Revised Plan/EDC Original Plan	100%	100%	100%	N/A	244%

Source: Guidehouse analysis of 2019 GMP Annual Reports and EDC Data

Table 38. National Grid VVO Investment Year-over-Year Comparison ($M)*

Data	2018	2019	2020	2021	2018-2021
EDC Actual Progress	$0	$2.6	$9.4	N/A	$12.0
EDC Original Plan[43]	$0	$2.6	$5.9	N/A	$8.5
% EDC Actual Progress/EDC Original Plan	N/A	100%	159%	N/A	141%
EDC Revised Plan[44]	N/A	$2.6	$9.4	$7.29	$19.3
% EDC Revised Plan/EDC Original Plan	N/A	100%	115%	N/A	227%

*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 2019 GMP Annual Reports and EDC Data

Table 39 highlights National Grid VVO feeder characteristics from 2018 through 2020. Similar to Eversource, feeder lengths and customer counts vary considerably. Selected substations also present a mix of distributed generation capacity across feeders, with distributed generation capacity ranging from 0.2 MW to 7.9 MW. Appendix A.2 contains additional information related to the VVO feeders.

[41] The EDC original plan includes actuals reported for 2018 and 2019, along with plans reported for 2020, contained in the EDC's 2019 GMP Annual Report, Appendix 1.

[42] Based on the EDC's actual progress in PY2018 – PY2020 and updated projections for PY2021.

[43] The EDC original plan includes actuals reported for 2018 and 2019, along with plans reported for 2020, contained in the EDC's 2019 GMP Annual Report, Appendix 1.

[44] Based on the EDC's actual progress in PY2018 – PY2020 and updated projections for PY2021.

Table 39. 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	3,097	10.7	5.4
	74L2	17	1,573	6.6	7.9
	74L3	20	3,346	7.8	1.4
	74L4	9	1,622	6.8	1.0
	74L5	54	3,079	9.9	1.0
	74L6	8	1,770	5.4	0.5
Stoughton (13.8 kV)	913W17	14	1,364	5.2	1.5
	913W18	12	1,560	4.1	0.4
	913W43	32	2,148	7.7	1.1
	913W47	16	1,804	5.9	0.4
	913W67	13	753	3.2	0.6
	913W69	32	3,746	10.1	1.4
Maplewood (13.8 kV)	16W1	17	3,613	9.1	0.9
	16W2*	11	4,608	8.3	0.7
	16W3	13	2,953	7.4	0.5
	16W4	8	1,115	6.2	0.8
	16W5	7	1,646	5.1	0.9
	16W6*	25	5,779	13.5	1.5
	16W7*	14	3,914	10.1	1.4
	16W8*	16	3,415	9.2	1.5
Additional Feeders					
East Bridgewater (13.8 kV)	797W1	35	2,775	9.2	4.2
	797W19	38	2,570	8.8	2.2
	797W20	31	1,708	10.2	0.4
	797W23	41	2,718	9.8	1.5
	797W24	54	2,601	10.7	1.1
	797W29	37	2,363	8.7	1.1
	797W42	22	1,257	4.8	2.7
East Dracut (13.2 kV)	75L1	16	3,078	7.8	0.7
	75L2	39	2,500	9.9	0.8
	75L3	49	2,300	8.7	1.8
	75L4	9	402	4.0	0.2
	75L5	20	3,619	7.5	0.8
	75L6	25	1,490	10.6	0.7
West Salem (13.8)	29W1	23	3,774	10.1	1.6
	29W2	15	1,485	5.8	3.0
	29W3	15	4,234	9.3	0.8
	29W4	18	2,715	8.5	1.5
	29W5	12	2,891	6.9	0.9
	29W6	17	1,342	7.3	1.2

* Additional feeders that were not included in the original set of 16 reported for 2018–2020 VVO investment.

Source: 2020 GMP Annual Report, Appendix 1 filed April 1, 2021. EDCs provided distributed generation data.

VVO Timeline

Table 40 and Table 41 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 40. 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[45]	7/27/2020-1/22/2021 (complete)	7/15/2020-TBD (in progress)	5/1/2020-7/23/2020 (complete)
VVO Enabled Date[46]	2/8/2021 (complete)	5/1/2021 (planned)	7/24/2020 (complete)
VVO On/Off Testing Period	3/1/2020-TBD (in progress)	6/1/2021-TBD (planned)	12/1/2020-TBD (in progress)

Source: Guidehouse analysis of EDC Data

Table 41. National Grid Additional Feeders Deployment Completion Dates

Phase	E. Bridgewater	E. Dracut	W. Salem
VVO Investment	5/15/2020-3/31/2021 (planned)	2/1/2021-5/31/2021 (planned)	2/1/2021-5/31/2021 (planned)
VVO Commissioning	4/1/2021-4/30/2021 (planned)	6/1/2021-6/15/2021 (planned)	6/1/2021-6/15/2021 (planned)
VVO Enabled Date	5/1/2021 (planned)	6/16/2021 (planned)	6/16/2021 (planned)
VVO On/Off Testing Period	6/1/2021-TBD (planned)	6/16/2021-TBD (planned)	6/16/2021-TBD (planned)

Source: Guidehouse analysis of EDC Data

National Grid completed the deployment of VVO investments on all feeders connected to the East Methuen, Maplewood, and Stoughton substations by the end of 2020. The utility completed VVO commissioning on all feeders connected to the Stoughton substation in July 2020, and completed commissioning at the East Methuen substation in January 2021. Commissioning is ongoing at the Maplewood substation. VVO On/Off testing began on December 1, 2020 for the Stoughton substation and on March 1, 2021 for the East Methuen substation. VVO On/Off testing is slated to begin by June 1, 2021 for the Maplewood substation once VVO commissioning is complete.

[45] VVO Commissioning is the time at which VVO devices are controlled by and have data visible to each EDC.

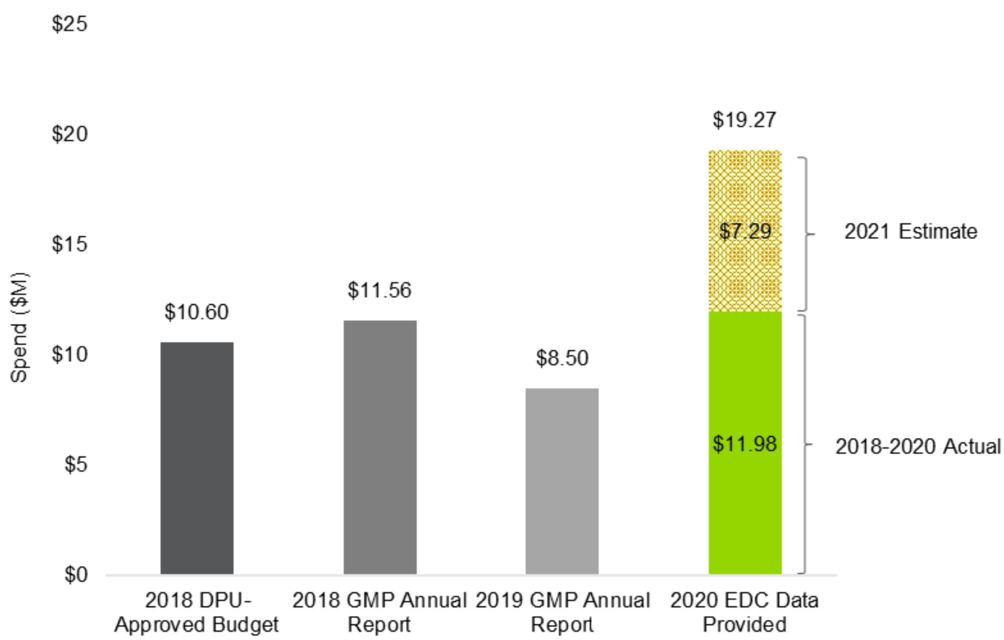
[46] VVO Enabled is the time at which the VVO system is commissioned and VVO is engaged.

In addition to the original 2018–2020 plan feeders, National Grid estimates that it will complete deployment of VVO investments by June 2021 at the East Bridgewater, East Dracut, and West Salem substations. VVO commissioning is expected to be complete by mid-June 2021, allowing National Grid to begin VVO On/Off testing in June 2021 at all three substations.

3.2.3.2 VVO Deployment Plan Progression

Figure 7 shows how National Grid's VVO deployment spend has progressed since the GMP was approved in 2018.

Figure 7. National Grid's VVO Planned and Actual Spend Progression, $M



Source: Guidehouse analysis of DPU Order (May 10, 2018), 2019 GMP Annual Reports, GMP Extension and Budget filing (July 1, 2020), and 2021-provided EDC Data

National Grid deployment and spend through 2020 exceeded plans. National Grid increased its planned deployment from covering 16 feeders to covering 20 feeders, which increased the number of pre-approved devices for its VVO investment. Spend on regulators, LTC controls, and IT work was greater than initially planned, while spend on capacitor banks and line sensors was lower than initially planned. Lastly, a large amount of design and engineering and construction work was conducted on feeders receiving VVO investments throughout 2021. Estimated spend for 2021 will be on pre-approved devices and concentrated on remaining carryover work at the Maplewood substation, as well as deployment of VVO at the East Bridgewater, East Dracut, and West Salem substations.

3.2.3.3 VVO Investment Progress Through PY2020

Table 42 presents VVO enablement progress by substation, including anticipated and actual VVO enabled dates and notes on the current status of VVO deployment.

Table 42. National Grid VVO Enabled Progress by Substation

Substation	January 2020 Plan VVO Enabled Date	January 2021 Plan Actual/Planned VVO Enabled Date	Current Status[47]
Original 2018–2020 Plan Feeders			
E. Methuen	5/30/2020	2/8/2021 (actual)	VVO On/Off testing in progress
Maplewood	5/30/2020	6/1/2021 (planned)	VVO commissioning in progress
Stoughton	5/1/2020	7/24/2020 (actual)	VVO On/Off testing in progress
Additional Feeders			
E. Bridgewater	N/A	5/1/2021 (planned)	Construction
E. Dracut	N/A	6/16/2021 (planned)	Construction
W. Salem	N/A	6/16/2021 (planned)	Construction

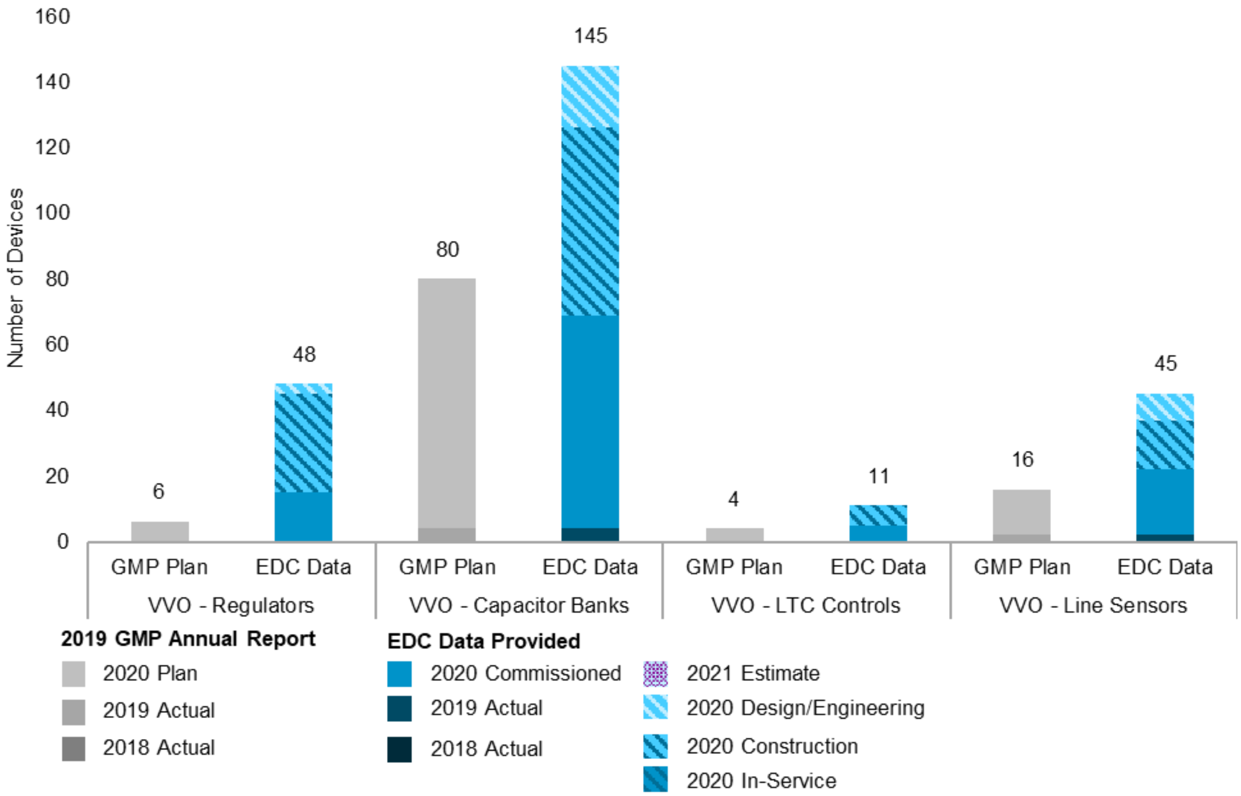
Source: Guidehouse analysis of EDC Data

VVO On/Off testing began on December 1, 2020 for the Stoughton substation and on March 1, 2021 for the East Methuen substation. VVO is expected to be enabled by May 1, 2021 and VVO On/Off testing is slated to begin by June 1, 2021 for the Maplewood substation. In addition to the original 2018–2020 planned feeders, National Grid estimates that it will begin VVO On/Off testing on in June 2021 at the East Bridgewater, East Dracut, and West Salem substations.

Figure 8 and Table 43 illustrate the actual device deployment for all device types compared to the projected deployment in the *2019 GMP Annual Report*, as well as 2021 EDC-estimated deployment.

[47] Status can be: planning, design, construction, device deployment complete, VVO commissioning in process, or VVO enabled.

Figure 8. National Grid Planned vs. Actual Deployment (2018–2021, Unit Count)



Source: Guidehouse analysis of 2019 GMP Annual Report and EDC Data

Table 43. National Grid VVO Planned and Actual Device Deployment

	VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors
2018-2021 Total	**48**	**145**	**11**	**45**
PY 2021 Estimate[48]	0	0	0	0
Engineering/Design during PY2020	3	19	0	8
Construction during PY2020	30	57	6	15
In-Service during PY2020	0	0	0	0
Commissioned in PY2020	15	65	5	20
Commissioned in PY2019	0	4	0	2
Commissioned in PY2018	0	0	0	0

Source: Guidehouse analysis of EDC Data

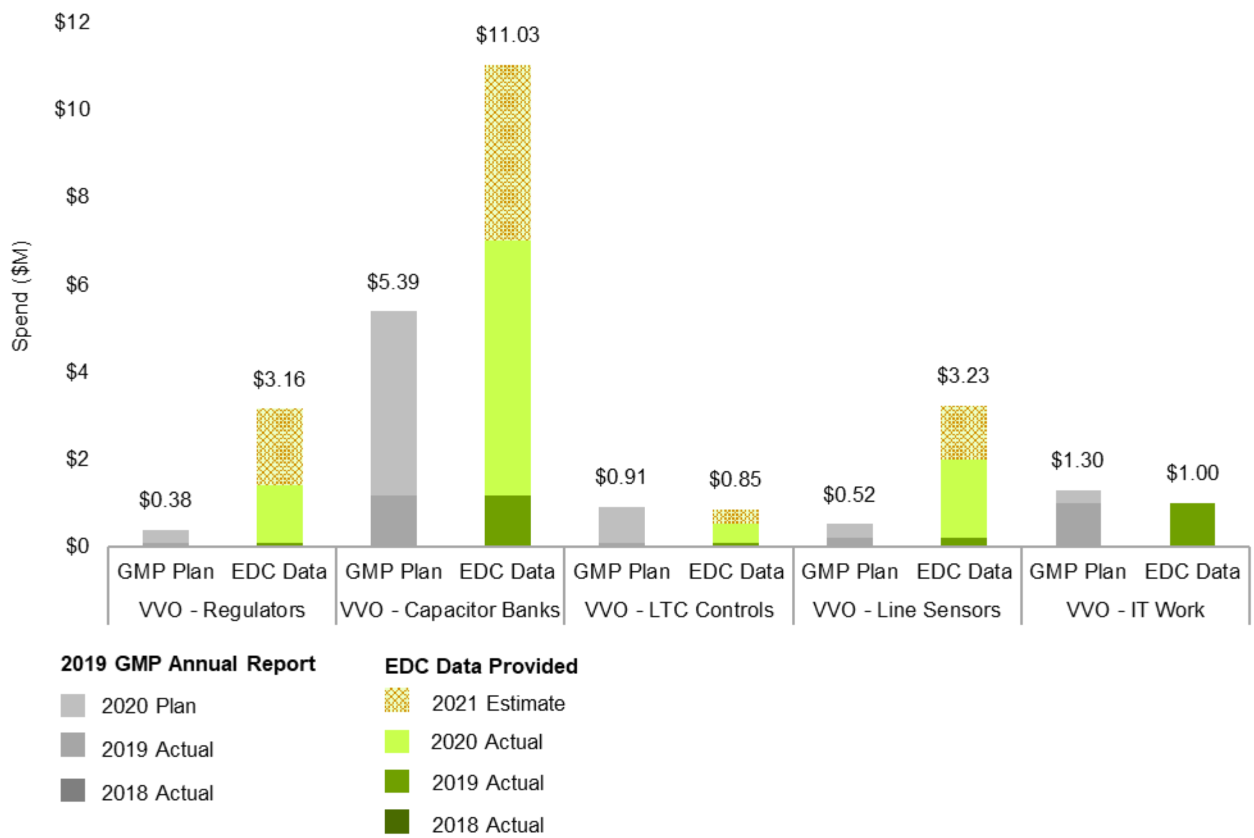
Numerous devices were commissioned in PY2020, with Stoughton beginning VVO On/Off testing in December 2020 and East Methuen and Maplewood completing deployment of almost

[48] This includes the devices planned for 2021 that are not yet in Engineering/Design, Construction, or In-Service phases as of the end of PY2020.

all devices by the end of 2020. Remaining devices to be deployed include devices at the Maplewood substation, which is slated to be completed during winter 2020/21, as well as devices at the East Dracut, East Bridgewater, and West Salem substations. Construction and engineering and design work has already begun on both the Maplewood carryover work and on devices to be installed at the new 2021 substations.

Figure 9 and Table 44 summarize planned and actual spending on VVO devices.

Figure 9. National Grid Planned vs. Actual Device Spend (2018–2021, $M)



Source: Guidehouse analysis of 2019 GMP Annual Report and EDC Data

Table 44. 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	**$3.16**	**$11.03**	**$0.85**	**$3.23**	**$1.00**
PY2021 Estimate	$1.74	$4.01	$0.32	$1.22	$0.00
PY2020 Actual	$1.34	$5.83	$0.45	$1.79	$0.00
PY2019 Actual	$0.08	$1.19	$0.08	$0.22	$1.00
PY2018 Actual	$0.00	$0.00	$0.00	$0.00	$0.00

Source: Guidehouse analysis of 2018 GMP Annual Report and EDC Data

Spend on regulators, LTC controls, and IT work was greater than initially planned. Spend on regulators exceeded plans due to the introduction of midline regulators to maximize VVO benefits. Midline regulators were not originally planned due to the short length of feeders and closeness of the substation to all devices. With the addition of these regulators, National Grid implemented design changes to the installation standards and brought in subject matter experts to advise on their installation.

Spend on LTC controls also exceeded plans, as National Grid installed additional controls to allow for four additional Maplewood feeders to receive VVO. In addition, National Grid retrofitted LTCs to receive necessary data and upgraded substation RTUs to accommodate additional data and communications cards. Spend on IT work also exceeded plans, as COVID-19-related impacts required shutdown of key facilities, restrictions on visitor numbers, increased time spent and use of workaround methods to complete necessary work. In addition, a PEN test revealed vulnerabilities in the IT space and required additional software patches and retesting.

Spend on capacitor banks and line sensors was lower than planned. Capacitor banks are intended to provide reactive power control. Combined with the introduction of midline regulators, National Grid decided to install fewer capacitor banks than originally planned. Spend on line sensors was also lower than planned, despite installing a greater number of line sensors than originally intended. Along with combining line sensor installations with capacitor bank installations, the process of installation and commissioning was refined, resulting in gained proficiencies and lowering the reported spending for line sensors.

National Grid estimates additional deployment and spend in 2021. Spend on pre-approved devices will be concentrated on remaining carryover commissioning work at the Maplewood substation, as well as deployment of VVO devices at the East Bridgewater, East Dracut, and West Salem substations.

3.2.3.4 Infrastructure Metrics Results and Key Findings

Table 45 and Table 46 summarize the Infrastructure Metrics results through PY2020 for each investment type related to National Grid's VVO Investment Area.

Table 45. National Grid Infrastructure Metrics Findings

Infrastructure Metrics			VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors	VVO - IT Work
GMP Plan Total, 2018-2020		Devices	6	80	4	16	0
		Spend, $M	$0.38	$5.39	$0.91	$0.52	$1.30
EDC Data Total, 2018-2021		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 through PY2020	# Devices Deployed	15	69	5	22	0
		% Devices Deployed	250%	86%	125%	138%	N/A

Infrastructure Metrics			VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors	VVO - IT Work
IM-5	Cost for Deployment through PY2020	Total Spend, $M	$1.42	$7.02	$0.53	$2.01	$1.00
		% Spend	374%	130%	58%	387%	77%
IM-6	Deviation Between Actual and Planned Deployment for PY2020	% On Track (Devices)	250%	86%	125%	143%	N/A
		% On Track (Spend)	447%	139%	54%	597%	0%
IM-7	Projected Deployment for the Remainder of the GMP Term	# Devices Remaining	33	76	6	23	0
		Spend Remaining , $M	$1.74	$4.01	$0.32	$1.22	$0.00

Source: Guidehouse analysis of 2019 GMP Annual Report and EDC Data

Table 46. 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	6
		% Feeders with VVO Enabled	15%
IM-6	Deviation Between Actual and Planned Deployment	% On Track (Feeders with VVO Enabled)	15%
IM-7	Projected Deployment for the Remainder of the GMP Term	# Feeders Remaining for VVO Enablement	39

Source: Guidehouse analysis of 2019 GMP Annual Report and EDC Data

Guidehouse's review of National Grid's VVO progress revealed that National Grid exceeded planned spend and deployment outlined in their *2019 GMP Annual Report*. Key findings related to National Grid's progress include:

- National Grid deployed numerous devices throughout PY2020, with Stoughton beginning VVO On/Off testing in December 2020 and East Methuen and Maplewood completing deployment of almost all devices by the end of 2020. In addition, engineering and design and construction work began on devices to be installed at the East Bridgewater, East Dracut, and West Salem substations. National Grid device deployment exceeded initially planned devices, primarily due to National Grid's decision to install midline regulators at VVO substations, as well as additional LTC controls to allow for four additional Maplewood feeders to receive VVO.

- National Grid had not enabled VVO on all of the original 2018 – 2020 plan feeders by the end of 2020 as anticipated in the PY2019 Evaluation Report. This is due to the fact that National Grid had not completed deployment of VVO for the East Methuen and Maplewood substations by the end of the year. National Grid experienced delays in deployment of VVO throughout 2020 due to the addition of midline regulators and additional LTC controls, as well as delays and complexities associated with IT work due to the COVID-19 pandemic.

- Spend on the VVO Investment Area was greater than planned due to increased spending on regulators, LTC controls, and IT work. Spend on regulators exceeded plans due to the introduction of midline regulators to maximize VVO benefits, which increased capital and labor costs. Spend on LTC controls also exceeded plans, due to the installation of additional controls and retrofitting of LTCs to receive necessary data. Spend on IT work also exceeded plans due to increased complexities introduced by the COVID-19 pandemic and cybersecurity concerns requiring software patches and retesting.
- National Grid estimates additional deployment and spend in 2021 concentrated on remaining carryover work at the Maplewood substation, as well as deployment and commissioning of VVO at the East Bridgewater, East Dracut, and West Salem substations.
- VVO On/Off testing began on December 1, 2020 for the Stoughton substation and on March 1, 2021 for the East Methuen substation. VVO On/Off testing is slated to begin in June 2021 for the Maplewood, East Bridgewater, East Dracut, and West Salem substations.

3.2.4 Unitil

This section discusses Unitil's VVO investment progress through PY2020 and projected PY2020 progress compared to the *2019 GMP Annual Report*.

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 pushed out due to complexities associated with tying VVO to the ADMS Investment Area. This delay necessitated an extensive review of vendors during the VVO investment process to ensure regulators and capacitors could accommodate both Investment Areas. Deployment of VVO also relies on the SCADA system being in place, tying the VVO deployment to the M&C Investment Area. As such, SCADA deployment has been accelerated beyond installing at one substation per year. The VVO project is also tied with the FAN deployment plan which will allow communication from the ADMS to the field devices.

Table 47 and Table 48 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 plans 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.[49]

[49] Unitil has not yet been asked to provide estimated deployment for PY2022.

Table 47. Unitil VVO Feeder Deployment Year-over-Year Comparison

Data	2018	2019	2020	2021	2022	2018-2022
EDC Actual Progress	0	0	0	N/A	N/A	0
EDC Original Plan[50]	0	0	5	4	2	11
% EDC Actual Progress/EDC Original Plan	N/A	0%	0%	N/A	N/A	0%
EDC Revised Plan[51]	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 2019 GMP Annual Reports and EDC Data

Table 48. Unitil VVO Investment Year-over-Year Comparison ($M)*

Data	2018	2019	2020	2021	2022	2018-2022
EDC Actual Progress	$0	$0	$1.8	N/A	N/A	$1.8
EDC Original Plan[52]	$0	$0	$2.0	N/A[53]	N/A	$2.0
% EDC Actual Progress/EDC Original Plan	100%	100%	90%	N/A	N/A	91%
EDC Revised Plan[54]	N/A	N/A	$1.8	$3.3	TBD[55]	$5.1
% EDC Revised Plan/EDC Original Plan	N/A	N/A	90%	N/A	N/A	248%

*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 2019 GMP Annual Reports and EDC Data

Table 49 highlights Unitil feeder characteristics for feeders to receive VVO investments between 2018 and 2022. Similar to Eversource and National Grid, feeder lengths and customer counts vary considerably. Selected substations also present a mix of distributed generation capacity, with distributed generation capacity ranging from 0 MW to 3.8 MW. Appendix A.3 contains additional information related to the VVO feeders.

Table 49. 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	4.0	0.0
	15W16	42	1,514	5.2	1.5
	15W17	11	573	1.6	0.4

50 The EDC original plan includes actuals reported for 2018 and 2019, along with plans reported for 2020, contained in the EDC's 2019 GMP Annual Report, Appendix 1.

51 Based on the EDC's updated projections for PY2021.

52 The EDC original plan includes actuals reported for 2018 and 2019, along with plans reported for 2020, contained in the EDC's 2019 GMP Annual Report, Appendix 1.

53 While Unitil did provide planned feeder deployment for 2021 and 2022 in 2019 GMP Annual Report Appendix 1, no planned spend was provided.

54 Based on the EDC's actual progress in PY2018 – PY2020 and updated projections for PY2021.

55 Unitil has not yet been asked to provide estimated spending for PY2022.

Substation	Feeder	Feeder Length (mi.)	Customer Count	Annual Peak Load (MVA)	Distributed Generation (MW)
Lunenburg (13.8 kV)	**30W30**	46	1,347	5.2	1.4
	30W31	45	1,658	4.0	3.8
Summer Street (13.8 kV)	**40W38**	1	4	0.3	1.8
	40W39	8	428	3.4	1.0
	40W40	18	1,579	8.1	1.4
	40W42	13	1,725	3.4	0.4
Additional Feeders					
West Townsend (13.8 kV)	**39W18**	52	1,966	4.2	2.0
	39W19	62	1,316	2.8	3.3

Source: 2020 GMP Annual Report, Appendix 1 filed April 1, 2021. Distributed Generation data was provided by the EDCs.

VVO Timeline

Table 50 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 50. Unitil VVO Deployment Completion Dates by Phase and Substation

Phase	Townsend	Lunenburg	Summer St.	W. Townsend[56]
VVO Investment	1/1/2019-5/31/2021 (in progress)	1/1/2020-7/1/2021 (in progress)	1/1/2019-10/1/2021 (in progress)	12/1/2020-12/1/2021 (in progress)
VVO Commissioning[57]	6/1/2021-7/1/2021 (planned)	7/1/2021-8/1/2021 (planned)	10/1/2021-11/1/2021 (planned)	12/1/2021-5/1/2022 (planned)
VVO Enabled Date[58]	8/1/2021 (planned)	9/1/2021 (planned)	12/1/2021 (planned)	7/1/2022 (planned)
VVO On/Off Testing Period	12/1/2021-8/31/2022 (planned)	12/1/2021-8/31/2022 (planned)	6/1/2022-3/31/2023 (planned)	9/1/2022-8/31/2023 (planned)

Source: Guidehouse analysis of EDC Data

For Unitil, the Townsend and Lunenburg substations are expected to be ready for VVO On/Off testing beginning in winter 2021-2022. Summer Street and West Townsend substations will then undergo VVO On/Off testing beginning in summer 2022 and fall 2022, respectively.

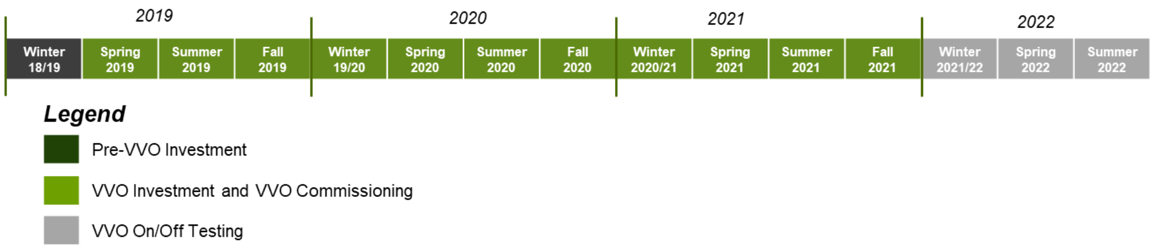
[56] West Townsend is an additional feeder not contained within the original 2018 – 2020 plan feeders that were slated to receive VVO.

[57] VVO Commissioning is the time at which VVO devices are controlled by and have data visible to each EDC.

[58] VVO Enabled is the time at which the VVO system is commissioned and VVO is engaged.

Figure 10 highlights the key timeline for the Townsend and Lunenburg substations during the evaluation period. Performance Metrics analysis is not provided for Unitil in this report as VVO On/Off testing has not yet begun. In the *2021 Evaluation Report*, Performance Metrics analysis will be provided for winter 2021-2022 for the Townsend and Lunenburg substations.

Figure 10. Unitil Performance Metrics Analysis Timeline*



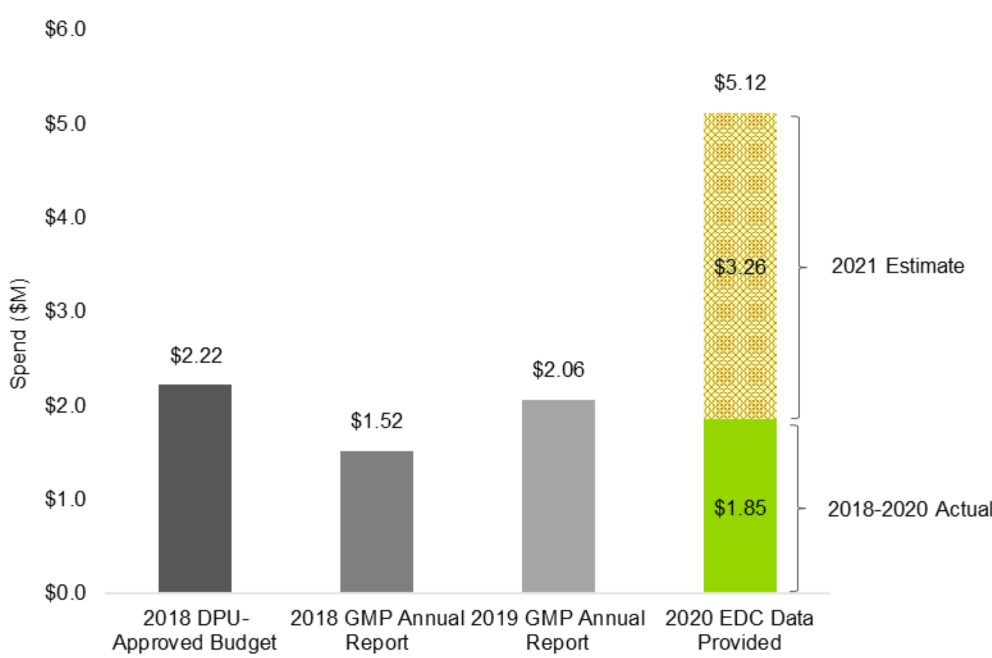
*Note: Unitil Performance Metrics analysis timeline only applicable for Townsend and Lunenburg substations, whose VVO investment, commissioning, and On/Off testing fall within the Guidehouse reporting period.

Source: Guidehouse analysis of 2019 GMP Annual Reports and EDC Data

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.

Figure 11. Unitil's VVO Planned and Actual Spend Progression, $M



Source: Guidehouse analysis of DPU Order (May 10, 2018), 2019 GMP Annual Reports, and EDC Data

Deployment and spending on VVO fell short of plans in PY2020. Unitil completed construction work on primary equipment for capacitor banks and regulators for the Townsend, Lunenburg, and Summer Street substations by the end of 2020. However, due to delays in FAN implementation, VVO deployment was delayed and could not be completed by the end of 2020. Since VVO will be under ADMS control, device deployment will not be complete until secondary work coupling FAN equipment with capacitor bank and regulator control boxes is completed.

During PY2020, Unitil determined how to link FAN equipment with control boxes. Unitil coupled FAN equipment with control boxes and has begun receiving FAN equipment. Spending and deployment are planned throughout 2021 to finalize this secondary work on VVO devices and commission these devices. Estimated spending for 2021 is also planned to cover deployment of new VVO devices at the West Townsend substation.

3.2.4.3 VVO Investment Progress Through PY2020

Table 51 shows Unitil's enablement progress by substation, including anticipated and actual VVO enabled dates and notes on the current status of VVO deployment.

Table 51. Unitil VVO Enabled Progress by Substation

Substation	January 2020 Plan VVO Enabled Date	January 2021 Plan Actual/Planned VVO Enabled Date	Current Status[59]
Original 2018–2020 Plan Feeders			
Townsend	12/31/2020	8/1/2021 (planned)	Construction
Lunenburg	3/31/2021	9/1/2021 (planned)	Construction
Summer St.	6/30/2021	12/1/2021 (planned)	Construction
Additional Feeders			
W. Townsend	N/A	7/1/2022 (planned)	Construction

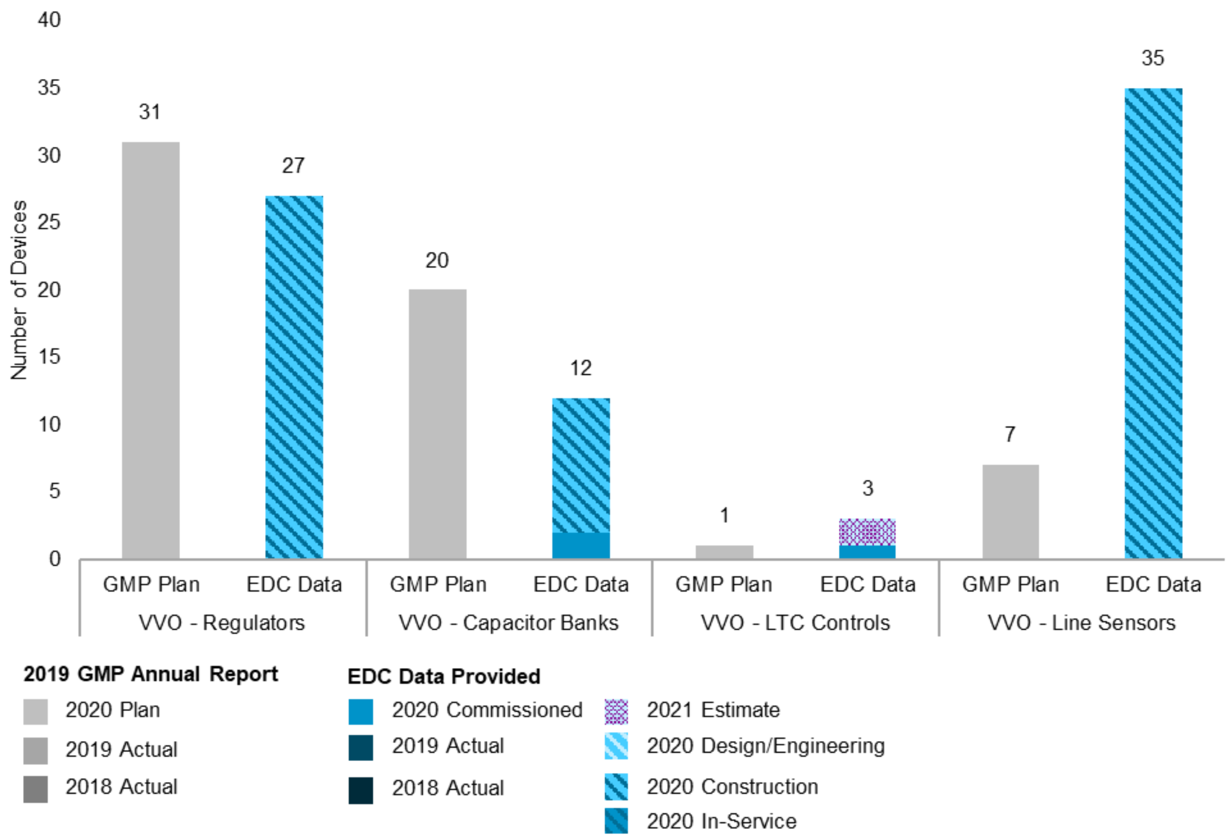
Source: Guidehouse analysis of EDC Data

Unitil will complete deployment of VVO in phases over the next 10 years, with one to two new substations per year to be VVO enabled during this time period. Among the original 2018–2020 plan feeders, the Townsend substation is expected to be VVO enabled on August 1, 2021, with Lunenburg and Summer Street to follow. Once VVO is enabled at those substations, Unitil estimates that it will enable VVO at the West Townsend substation during summer 2022.

Figure 12 and Table 52 compare the actual device deployment to the projected deployment in the *2019 GMP Annual Report*.

[59] Status can be: planning, design, construction, device deployment complete, VVO commissioning in process, or VVO enabled.

Figure 12. Unitil Planned vs Actual Deployment (2018–2021, Unit Count)



Source: Guidehouse analysis of 2019 GMP Annual Report and EDC Data

Table 52. Unitil VVO Deployment Progress

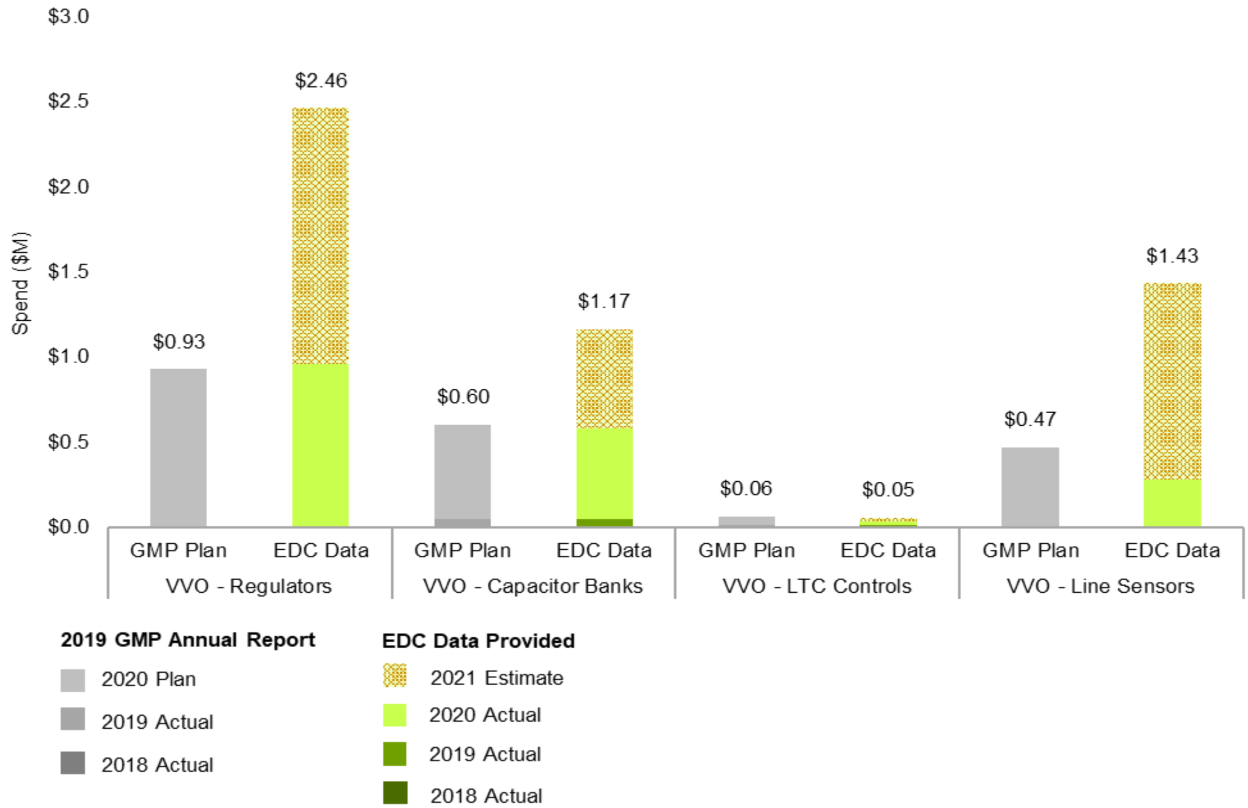
	VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors
2018-2021 Total	**27**	**12**	**3**	**35**
PY 2021 Estimate	0	0	2	0
Engineering/Design during PY2020	0	0	0	0
Construction during PY2020	27	10	0	35
In-Service during PY2020	0	0	0	0
Commissioned in PY2020	0	2	1	0
Commissioned in PY2019	0	0	0	0
Commissioned in PY2018	0	0	0	0

Source: Guidehouse analysis of EDC Data

Unitil's deployment of pre-approved devices fell short of plans. Throughout 2020, Unitil completed construction work on regulators and capacitor banks. However, due to delays in receiving FAN equipment, Unitil could not complete deployment of the devices before the close of the year. Deployment is estimated to occur throughout 2021 and spans completion of secondary work on VVO devices to facilitate ADMS control of VVO, along with planned work to begin deploying VVO devices at the West Townsend substation. As of February 2021, Unitil received numerous communications modems and was expected to begin assembly of secondary controls in the coming weeks.

Figure 13 and Table 53 compare actual spending and projected spending laid out in the 2019 GMP Annual Report.

Figure 13. Unitil Planned vs. Actual Spend (2018–2021, $M)



Source: Guidehouse analysis of 2019 GMP Annual Report and EDC Data

Table 53. Unitil Total Spend Comparison (2018–2021, $M)

	VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors
2018-2021 Total	**$2.46**	**$1.17**	**$0.05**	**$1.43**
PY2021 Estimate	$1.51	$0.59	$0.02	$1.15
PY2020 Actual	$0.95	$0.53	$0.02	$0.28
PY2019 Actual	$0.00	$0.05	$0.01	$0.00
PY2018 Actual	$0.00	$0.00	$0.00	$0.00

Source: Guidehouse analysis of 2019 GMP Annual Report and EDC Data

Spending during PY2020 fell short of plans, with Unitil reaching approximately 90% of planned spend. Actual spending was 103% of planned spend on regulators and 96% of planned spend on capacitor banks, primarily due to the large amount of construction work conducted throughout 2020. Actual spending was lower than planned for LTC controls and line sensors, with control work conducted on both equipment types throughout 2020. Remaining spending estimated to occur throughout 2020 spans carryover assembly of communications equipment to facilitate ADMS control of VVO and planned work to deploy VVO at the West Townsend substation. Deployment is expected to be complete at the Townsend, Lunenburg, and Summer Street substations by the end of 2021, with VVO On/Off testing slated to begin on December 1, 2021 on the Townsend and Lunenburg substations.

3.2.4.4 Infrastructure Metrics Results and Key Findings

Table 54 and Table 55 summarize the Infrastructure Metrics results through PY2020 for each investment type related to Unitil's VVO Investment Area.

Table 54. 2020 Unitil Infrastructure Metrics Findings

Infrastructure Metrics			VVO - Regulators	VVO - Capacitor Banks	VVO - LTC Controls	VVO - Line Sensors
GMP Plan Total, 2018-2020		Devices	31	20	1	7
		Spend, $M	$0.93	$0.60	$0.06	$0.47
EDC Data Total, 2018-2021		Devices	27	12	3	35
		Spend, $M	$2.46	$1.17	$0.05	$1.43
IM-4	Number of Devices or Other Technologies Deployed through PY2020	# Devices Deployed	0	2	1	0
		% Devices Deployed	0%	10%	100%	0%
IM-5	Cost for Deployment through PY2020	Total Spend, $M	$0.96	$0.58	$0.03	$0.28
		% Spend	103%	96%	55%	60%
IM-6	Deviation Between Actual and Planned Deployment for PY2020	% On Track (Devices)	0%	10%	100%	0%
		% On Track (Spend)	103%	96%	45%	60%
IM-7	Projected Deployment for the Remainder of the GMP Term	# Devices Remaining	27	10	2	35
		Spend Remaining, $M	$1.51	$0.59	$0.02	$1.15

Source: Guidehouse analysis of 2019 GMP Annual Report and EDC Data

Table 55. 2020 Unitil Infrastructure Metrics for VVO Feeders

IM	Metric	Parameter	Number of Feeders
IM-4	Number of Devices/Technologies Deployed	# Feeders with VVO Enabled	0
		% Feeders with VVO Enabled	0%
IM-6	Deviation Between Actual and Planned Deployment	% On Track (Feeders with VVO Enabled)	0%
IM-7	Projected Deployment for the Remainder of the 3-Year Term	# Feeders Remaining for VVO Enablement	11

Source: Guidehouse analysis of 2019 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 *2019 GMP Annual Report*. Key findings related to Unitil's progress include:

- Despite completing construction work on regulators and capacitor banks throughout 2020, deployment of pre-approved devices fell short of plans. Since ADMS is planned to be a control system for VVO, delays in FAN implementation interfered with deployment of the devices before the close of the year.
- The pace of Unitil investment has been slower than anticipated. As a result, Unitil spending during PY2020 was lower than anticipated. Spending was lower than anticipated for LTC controls and line sensors, while spending was on plan for regulators and capacitor banks, primarily due to the large amount of construction work conducted throughout 2020 even during the COVID-19 pandemic.
- Unitil VVO enablement fell short of its schedule laid out in the PY2019 Evaluation Report, as Unitil has not completed deployment of VVO on the original 2018 – 2020 plan feeders due to delays in FAN implementation.
- Remaining deployment and spending is estimated to occur for original 2018–2020 plan feeders and spans assembly of communications equipment to facilitate ADMS control of VVO. Deployment is expected to be complete at the Townsend, Lunenburg, and Summer Street substations by the end of 2021.
- VVO On/Off testing is planned to begin on December 1, 2021 for the Townsend and Lunenburg substations and on June 1, 2022 for the Summer Street substation.
- Unitil is continuing with planned work to begin deploying VVO devices at the West Townsend substation. Deployment is expected to be completed along with West Townsend substation by the end of 2021, with VVO On/Off testing to begin by September 1, 2022.

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 56 summarizes the information requested. 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. IT work information was the only data within this template that was not applicable to the Performance Metrics analysis.

Table 56. 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.[60]
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).
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 DG 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

4.1.1.2 Additional VVO Data Required for Performance Metrics Evaluation

Table 57 summarizes the additional data inputs required for Performance Metrics analysis. Except for the weather data, the team obtained all fields from the EDCs.

[60] IT work progress includes: planning, procurement, development, deployment, and go-live

Table 57. 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) • Distributed generation (gross generation) energy data for large facilities (e.g., >100 kW)
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)
- Interval data have been provided for large distributed generation facilities
- 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 winter 2020/21 M&V period.

4.2.1.1 Performance Metrics Analysis Results

Table 58 includes the Performance Metrics results for winter 2020/21 for Eversource and National Grid. The following EDC-specific subsections provide further detail.

Table 58. Performance Metrics Results for the Winter 2020/21 M&V Period

Performance Metrics		Eversource	National Grid
Feeders Enabled for Evaluation		19	6
PM-1	Winter 2020/21 Baseline	113,470 MWh	32,442 MWh
PM-2	Winter 2020/21 Energy Savings*	853 ± 124 MWh	170 ± 59 MWh
		0.75 ± 0.11%	0.52 ± 0.18%
PM-3	Peak Load Impact**	N/A	N/A
PM-4	Distribution Losses†	N/A	N/A
PM-5	Power Factor‡	N/A	N/A
PM-6	GHG Reductions (CO_2)	422 ± 61 tons	84 ± 29 tons
PM-7	Voltage Complaints	No Increase / Decrease Observed	No Increase / Decrease Observed

* Calculated energy savings assumes VVO was enabled for the entirety of winter 2020/21.
** Guidehouse does not provide an estimate of peak load impacts for the winter 2020/21 M&V period, as Guidehouse will estimate peak load impacts for the summer on-peak period, defined as 1:00–5:00 pm for June 1–August 31 on non-holiday weekdays per ISO-NE.
† Guidehouse will provide an estimate of the impact of VVO on distribution losses once a full winter, full summer, and one shoulder season have been covered by M&V testing.
‡Per the Stage 3 Plan filed December 1, 2020, Guidehouse will provide an estimate of the impact of VVO on the power factor for hours with power > 75% of each feeder's peak annual demand. Given the M&V period being examined within this evaluation corresponds with winter 2020/21, very few hours had power >75% of each feeder's peak annual demand.
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 winter 2020/21 M&V period. More specifically:

- During the winter 2020/21 M&V period, Eversource's Agawam, Piper, and Silver substations realized 853 MWh (0.75%) energy savings and 1.24 V (1.01%) voltage reduction associated with VVO. The CVR factor, which provides an estimate of energy savings possible with voltage reductions, was 0.82. During the same M&V period, National Grid's Stoughton substation realized 170 MWh (0.52%) energy savings and 0.12 V (0.88%) voltage reduction associated with VVO. National Grid's CVR factor was 0.60.

- Reductions in energy use were greater during peak energy hours relative to off-peak energy hours for both Eversource and National Grid. In addition, Eversource experienced greater voltage reductions during off-peak energy hours, while National Grid experienced greater voltage reductions during peak energy hours.

- Eversource energy savings of 853 MWh yielded a 422 short ton reduction in CO_2 emissions, a 274 lb. reduction in NO_X emissions, and a 68 lb. reduction in SO_2 emissions. National Grid energy savings of 170 MWh yielded an 84 short ton reduction in CO_2 emissions, a 54 lb. reduction in NO_X emissions, and a 14 lb. reduction in SO_2 emissions.

- For Eversource, a total of 13 voltage complaints were received from customers connected to the Agawam, Piper, and Silver VVO feeders during the winter 2020/21 M&V period. For National Grid, a total of five voltage complaints were received from customers connected to the Stoughton VVO feeders during the period. Guidehouse did not identify a substantial increase or decrease in voltage complaints during the winter 2020/21 M&V period.

In 2021 and beyond, Guidehouse recommends that Eversource and National Grid:

- Explore voltage setpoints to determine whether further voltage reductions can be achieved when VVO is engaged.
- Identify whether there is an impact of reverse power flow from distributed generation on VVO operation. The impact of reverse power flow on VVO operation may have a large impact on the evaluated performance of VVO for the upcoming spring and summer 2021 M&V periods.

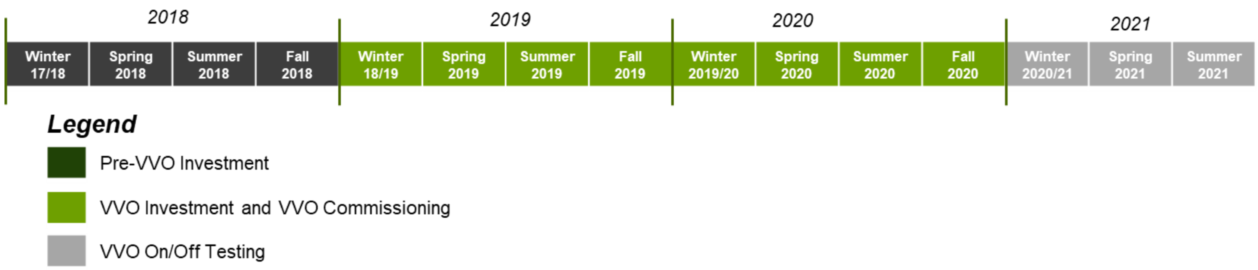
4.2.2 Eversource

This section discusses Eversource's VVO Performance Metrics results following the winter 2020/21 VVO M&V period.

4.2.2.1 Performance Metrics Analysis Timeline

Figure 14 highlights the key Performance Metric analysis periods for Eversource. The Performance Metrics analysis provided for this report will be focused on results from VVO On/Off testing conducted during winter 2020/21, with analysis of spring and summer 2021 to be provided in an addendum report in late 2021.

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

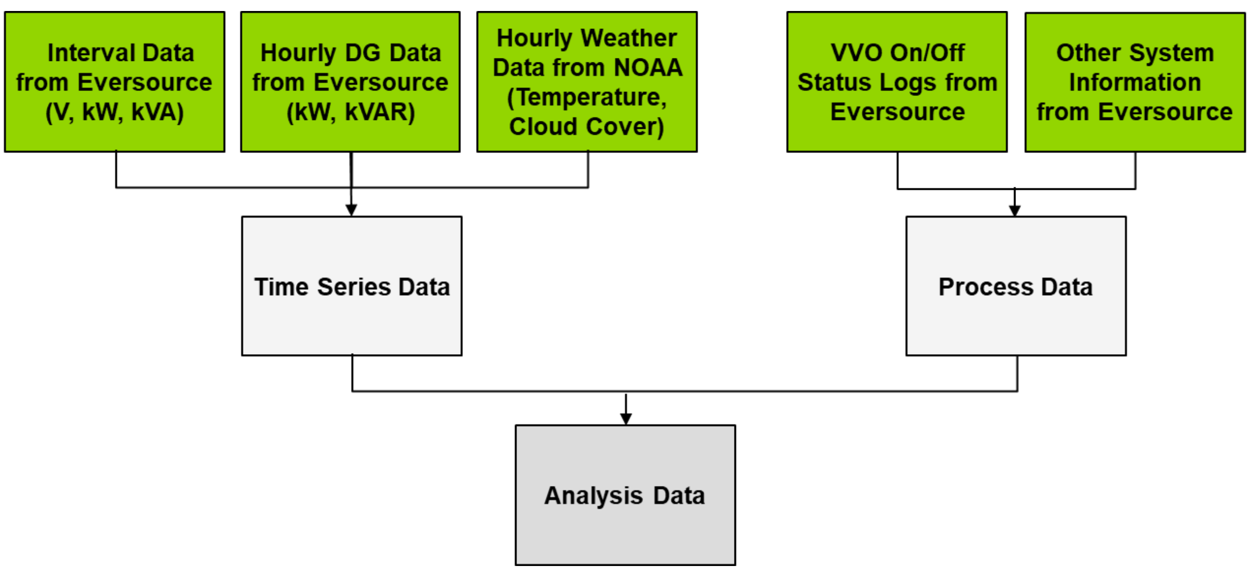
4.2.2.2 Evaluation Methodology

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 understand the impacts of VVO on energy and voltage. 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, and apparent power. The team then integrated hourly energy generation data from Eversource for large distributed generation facilities connected to VVO feeders. Lastly, hourly dry bulb temperature and hourly cloud cover data from NOAA for Westfield Barnes Municipal Airport were joined to SCADA and distributed generation interval data.[61]

To construct the process data, Guidehouse integrated time-stamped logs of VVO state changes between VVO On (engaged) and Off (disengaged) states and other VVO system information from Eversource. Other system information included information regarding VVO operations that deviated from the VVO state changes provided to the evaluation team, such as unexpectedly long or short VVO events that were not reflected in VVO status logs. 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 59 summarizes data observations made by the evaluation team and the resulting data cleaning steps that were executed.

Table 59. Data Cleaning Conducted for Eversource Analysis

Data Observation	Data Cleaning Step
VVO testing began in December 2020 at the Podick substation but was paused on December 21, 2020 for substation maintenance.	Remove Podick substation from the analysis data, as there was not sufficient M&V testing conducted for Guidehouse to use in the evaluation.
Several periods of recorded jumps and drops in real and apparent power data.	Remove hours where real or apparent power are abnormally high or low.
Two periods of data outages covering December 5–6, 2020 and December 18–19, 2020.	Flag and remove the two affected time periods from the analysis data.
Extended period over which VVO was engaged at the Piper substation, spanning January 12–13, 2021.	Revise VVO status flags to reflect that VVO remained engaged on January 12–13, 2021.
Two extended periods over which VVO was disengaged at the Piper substation, spanning January 14–21, 2021 and January 28–Feb. 18, 2021.	Revise VVO status flags to reflect that VVO remained disengaged during the two affected time periods.
Numerous VVO events were either shorter or longer than 24 hours, with many longer events coinciding with holidays and weekends.	Remove all VVO events shorter than 20 hours and longer than 24 hours to reduce the risk of VVO estimates being biased by oversampling holidays and weekends.

Source: Guidehouse

Table 60 indicates the number of 15-minute intervals contained in the analysis dataset for the Agawam substation. After data cleaning, there were around 3,000 VVO On and 2,800 VVO Off quarter-hours remaining for use in the analysis. Much of the data removed during data cleaning

[61] Westfield Barnes Municipal Airport was selected due to it having a quality controlled local climatological dataset and due to its being in close proximity to the Agawam, Piper, 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

was removed due to extended periods over which VVO was engaged or disengaged. Detailed data attrition information is in the Appendix.

Table 60. 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	2,943	3,067	2,984	2,986	2,985	2,986	2,956
VVO Off	2,709	2,784	2,852	2,852	2,852	2,852	2,827
Removed by Data Cleaning	2,988	2,789	2,804	2,802	2,803	2,802	2,857
Winter 2020/21 Total	**8,640**	**8,640**	**8,640**	**8,640**	**8,640**	**8,640**	**8,640**

Source: Guidehouse analysis

Table 61 indicates the number of 15-minute intervals contained in the analysis dataset for the Piper substation. After data cleaning, there were around 3,000 VVO On and 2,800 VVO Off quarter-hours remaining for use in the analysis for feeders 21N4 and 21N5. However, due to extended periods over which VVO was disengaged, less data remained for use in the analysis for feeders 21N6 through 21N9, which had around 2,200 VVO On quarter-hours and 1,800 VVO Off quarter-hours remaining for use in the analysis after data cleaning. Detailed data attrition information is in the Appendix.

Table 61. Count of VVO On, VVO Off, and Removed Quarter-Hours for Piper

Number of Quarter-Hours	21N4	21N5	21N6	21N7	21N8	21N9
VVO On	2,955	2,977	2,204	2,123	2,206	2,184
VVO Off	2,791	2,826	1,787	1,773	1,788	1,789
Removed by Data Cleaning	2,894	2,837	4,649	4,744	4,646	4,667
Winter 2020/21 Total	**8,640**	**8,640**	**8,640**	**8,640**	**8,640**	**8,640**

Source: Guidehouse analysis

Table 62 indicates the number of 15-minute intervals contained in the analysis dataset for the Silver substation. After data cleaning, there were between 2,300 and 2,700 VVO On and between 2,100 and 2,600 VVO Off quarter-hours remaining for use in the analysis. 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. Detailed data attrition information is in the Appendix.

Table 62. Count of VVO On, VVO Off, and Removed Quarter-Hours for Silver

Number of Quarter-Hours	30A1	30A2	30A3	30A4	30A5	30A6
VVO On	2,719	2,312	2,373	2,379	2,423	2,349
VVO Off	2,633	2,259	2,097	2,252	2,327	2,205
Removed by Data Cleaning	3,288	4,069	4,170	4,009	3,890	4,086
Winter 2020/21 Total	**8,640**	**8,640**	**8,640**	**8,640**	**8,640**	**8,640**

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 confirm exogenous patterns were controlled for. Table 63 summarizes observations made during this inspection and the resulting data analysis steps that were implemented.

Table 63. Data Analysis Summary for Eversource

Data Observation	Data Analysis Step
Distributed generation hourly data were received for numerous solar facilities connected to VVO feeders, with data covering roughly 28 MW of nominal capacity.	All distributed energy data connected to each feeder were scaled up to each feeder's nominal capacity, then scaled distributed energy data were added to feeder-level energy to control for solar generation.
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 December, January, and February.	Monthly fixed effects were incorporated into regression modeling to capture energy and voltage differences observed across each month.
Numerous feeders were identified with nonresidential 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 winter 2020/21 M&V test period.	Holiday fixed effects were included in regression models to control for typical holiday energy and voltage.

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 winter 2020/21. Table 64 shows the energy baseline calculated using VVO Off data collected during winter 2020/21 from the Agawam, Piper, and Silver substations.

Table 64. Eversource VVO Energy Baseline

Metric	Baseline Total Energy Use
Baseline Energy	113,470 MWh

Source: Guidehouse analysis

To calculate total baseline energy use, Guidehouse used models constructed to estimate energy savings to calculate what energy usage would have been in each hour of winter 2020/21 for each VVO feeder had VVO been disabled for the entirety of the season. Guidehouse then summed this calculated energy usage across all hours of winter 2020/21 for each VVO feeder to calculate feeder-level baseline energy usage. This feeder-level baseline energy usage was then summed across all feeders to calculate a baseline total energy use for the winter 2020/21 time period. Baseline energy use is provided by VVO feeder in the Appendix.

PM-2: Energy Savings
Table 65 provides the evaluated energy savings for Eversource for peak energy hours, off-peak energy hours, and winter 2020/21 overall. The ± figure indicates 90% confidence bounds associated with energy savings estimates.

Table 65. Eversource VVO Net Energy Reduction

Energy Period	Net Energy Reduction	
	MWh†	%
Peak Energy Hours	558 ± 78 MWh	0.97 ± 0.14%
Off-Peak Energy Hours	251 ± 99 MWh	0.46 ± 0.18%
Winter 2020/21 Total	**853 ± 124 MWh**	**0.75 ± 0.11%**

*Percentage energy savings provided for each period is the load-weighted average of percentage savings estimated for each feeder.
†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.
Source: Guidehouse analysis

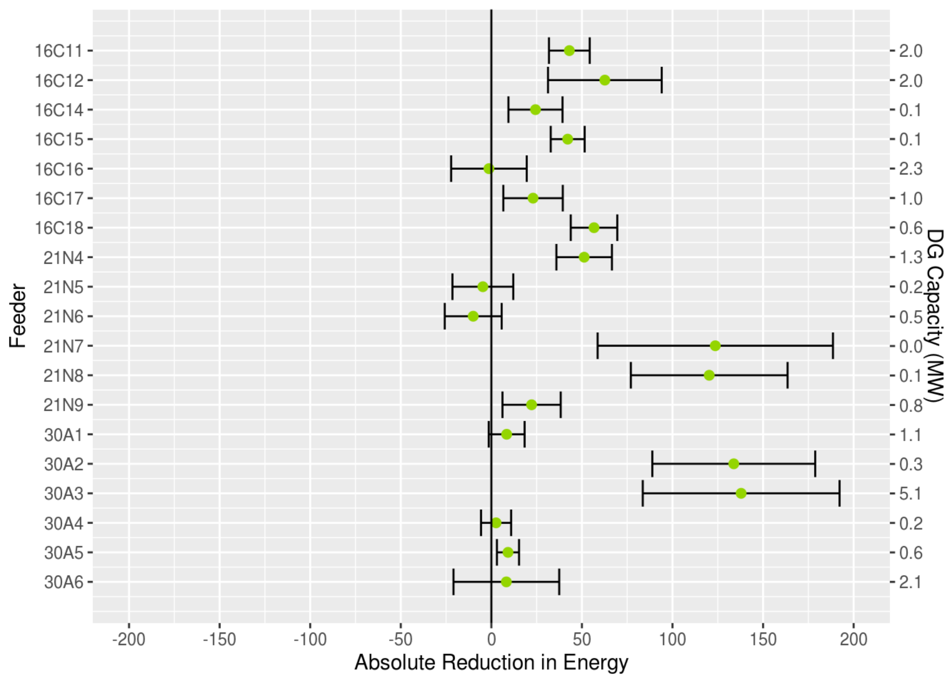
Regression estimates indicate a statistically significant reduction in energy use associated with VVO, with 853 MWh (0.75%) in energy savings realized during the winter 2020/21 M&V period.[62] Regression estimates indicate that there were statistically significant reductions in energy use during peak and off-peak energy hours. However, savings during peak energy hours

[62] 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).

exceeded those observed during off-peak energy hours, with peak energy savings of 558 MWh (0.97%) as compared to off-peak energy savings of 251 MWh (0.46%).

Figure 16 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 winter 2020/21 M&V period, 13 experienced statistically significant reductions in energy. Of these 13 feeders, feeders 21N7, 21N8, 30A2, and 30A3 realized the greatest energy savings.

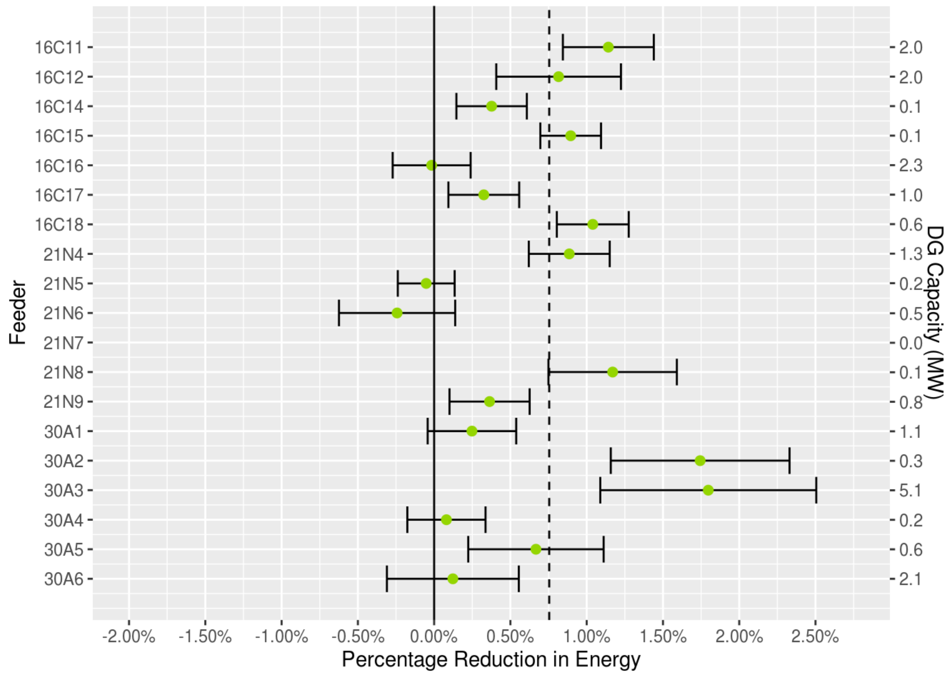
Figure 16. Net Energy Reduction (MWh) for Eversource VVO Feeders



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, and the dashed line denotes load-weighted average percentage MWh savings.

Figure 17. Net Energy Reduction (%) for Eversource VVO Feeders



Source: Guidehouse analysis

To further understand VVO energy savings, Guidehouse estimated the winter 2020/21 M&V period CVR factor, which provides an estimate of percentage energy savings possible with every percentage reduction in voltage. Equation B-1 in the Appendix highlights how the CVR factor is calculated using an estimated percentage change in energy and in voltage.

To calculate the CVR factor for Eversource, Guidehouse estimated changes in voltage associated with VVO. Table 66 provides the evaluated voltage reductions for Eversource, with 90% confidence bounds associated with voltage reductions estimates indicated by the ± figure.

Table 66. Eversource VVO Average Hourly Voltage Reduction

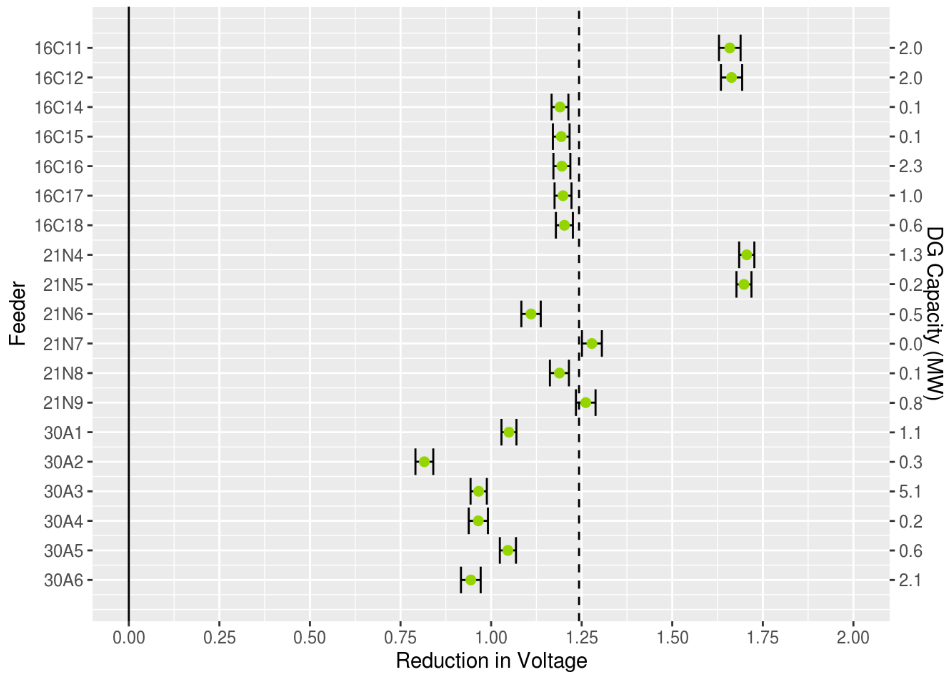
Energy Period	Average Hourly Voltage Reduction*	
	V	%
Peak Energy Hours	1.12 ± 0.01 Volts	0.91 ± 0.01%
Off-Peak Energy Hours	1.37 ± 0.02 Volts	1.11 ± 0.01%
Winter 2020/21 Total	**1.24 ± 0.01 Volts**	**1.01 ± 0.01%**

*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

Regression estimates indicate a statistically significant reduction in voltage associated with VVO, with a 1.24 V (1.01%) voltage reduction realized during the winter 2020/21 M&V period. Regression estimates indicate that there were statistically significant reductions in voltage during peak and off-peak energy hours. However, voltage reductions during peak energy hours were lower than those observed during off-peak energy hours, with peak voltage reductions of 1.12 V (0.91%) as compared to off-peak voltage reductions of 1.37 V (1.11%).

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, and the dashed line denotes the load-weighted average voltage reduction. All 19 feeders experienced statistically significant reductions in voltage when VVO was engaged.

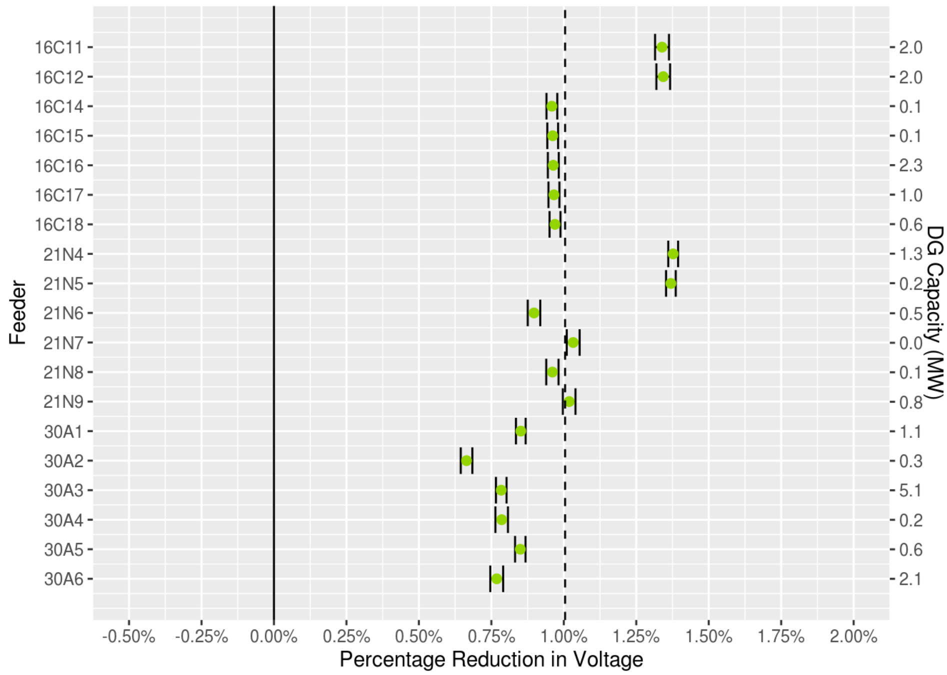
Figure 18. Average Hourly Voltage Reduction (V) for Eversource VVO Feeders



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, and the dashed line denotes the load-weighted average percentage voltage reduction.

Figure 19. Average Hourly Voltage Reduction (%) for Eversource VVO Feeders



Source: Guidehouse analysis

Following 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. Table 67 provides the CVR factors for Eversource.

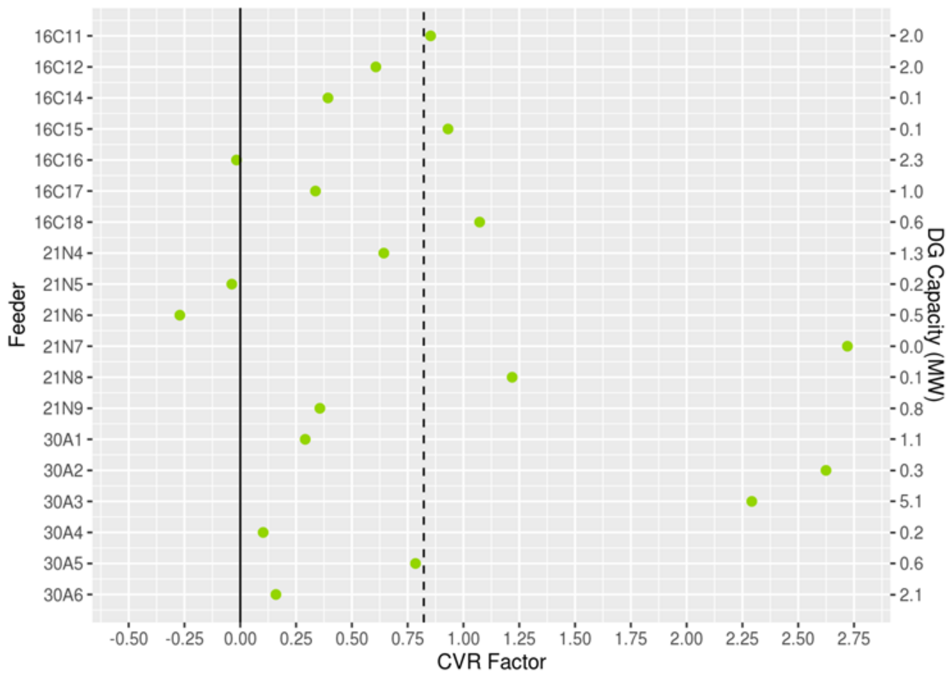
Table 67. Eversource VVO CVR Factors

Energy Period	CVR Factor*
Peak Energy Hours	1.27
Off-Peak Energy Hours	0.39
Winter 2020/21 Total	**0.82**

*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 winter 2020/21 time period was 0.82, in line with what may be expected from a year of VVO M&V testing. Since energy reductions were higher and voltage reductions were lower during peak energy hours, the CVR factor was greater during peak energy hours than off-peak energy hours. The team observed CVR factors of 1.27 during peak energy hours and 0.39 during off-peak energy hours. Figure 20 provides the CVR factors for the winter 2020/21 M&V period for each feeder.

Figure 20. Eversource VVO CVR Factors



Source: Guidehouse analysis

PM-3: Peak Load Impact

In the Stage 3 Plan, Guidehouse stated that peak load impacts of VVO would be examined by using the ISO-NE definition of the summer on-peak period, which corresponds with 1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays. Given the M&V period being examined within this evaluation corresponds with winter 2020/21, peak load impacts of VVO are not provided in this report.

PM-4: Distribution Losses

In the Stage 3 Plan, Guidehouse stated that it will calculate distribution losses using hourly data for real and reactive power. Based on regression analysis conducted on distribution losses for the winter 2020/21 M&V period, Guidehouse identified results that varied considerably across VVO feeders. Guidehouse believes this can be attributed to a limited period of analysis (i.e. one season) which may be resolved once VVO On / Off testing has been conducted across additional seasons. In addition, Guidehouse believes this can be attributed to the statistical models attempting to detect a small percentage change of a small magnitude of line losses, which would not be resolved with additional seasons of VVO On / Off testing. Guidehouse will re-examine the impact of VVO on distribution losses once M&V testing has been conducted across additional seasons.

PM-5: Power Factor

In the Stage 3 Plan, Guidehouse stated that power factors will be examined for hours where power is >75% of each feeder's peak annual demand. Given the M&V period being examined within this evaluation corresponds with winter 2020/21, very few hours had power >75% of each feeder's peak annual demand. Guidehouse does not provide the evaluated impact of VVO on the power factor observed for each VVO feeder due to insufficient data.

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.[63]

Table 68 provides emissions reductions associated with VVO, with 90% confidence bounds indicated by the ± figure. Based on energy savings attributed to VVO at the Agawam, Piper, and Silver substations, emissions reductions amounted to 0.137 short tons (274 lbs.) of NO_X, 0.034 short tons (68 lbs.) of SO_2, and 422 short tons of CO_2.

Table 68. Eversource VVO Emissions Reductions

Metric	NO_X	SO_2	CO_2
Winter 2020/21 Emissions Reduction	0.137 ± 0.020 tons	0.034 ± 0.005 tons	422 ± 61 tons

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 2020 and during winter 2020/21. Voltage complaints are provided only for the Agawam, Piper, and Silver substations, as these substations received VVO M&V testing during the winter 2020/21 time period. Discussion below highlights key observations for voltage complaints, comparing the count of voltage complaints received during winter 2020/21 to the average number of voltage complaints from the 2015–2017 baseline period.[64] Table 69 summarizes voltage complaints for the Agawam substation.

[63] 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

[64] 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. 2018–2020) 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.

Table 69. Count of Voltage Complaints for Agawam Substation

Number of Voltage Complaints	16C11	16C12	16C14	16C15	16C16	16C17	16C18	Total
Customers*	1,310	76	1,624	1,275	2,599	2,367	3,021	**12,272**
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**
Winter 2020/21	0	0	1	0	2	1	1	**5**

** Count of customers served by each feeder was extracted from 2020 GMP Annual Report, Appendix 1.*

Source: Guidehouse analysis

Voltage complaints vary considerably across years and across VVO feeders, ranging from 10 complaints received in 2015 to 23 complaints received in 2020. Looking at 2015–2017 baseline period, there were 15 voltage complaints received, amounting to three to four voltage complaints per season. Based on voltage complaints data received, a total of five voltage complaints were reported along the Agawam feeders during winter 2020/21, which is slightly above the baseline period average number of complaints per season.

Table 70 summarizes the count of voltage complaints for the Piper substation. Voltage complaints vary considerably across years and across VVO feeders, ranging from four complaints received in 2018 to 11 complaints received in 2019 and 2020. Looking at 2015–2017 baseline period, there were five voltage complaints received, amounting to one to two voltage complaints per season. Based on voltage complaints data received, a total of three voltage complaints were reported along the Piper feeders during winter 2020/21, all of which were complaints received from customers connected to feeder 21N9. Three voltage complaints was slightly above the baseline period average number of complaints per season.

Table 70. Count of Voltage Complaints for Piper Substation

Number of Voltage Complaints	21N4	21N5	21N6	21N7	21N8	21N9	Total
Customers*	2,278	830	779	2	558	2,394	**6,841**
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**
Winter 2020/21	0	0	0	0	0	3	**3**

* Count of customers served by each feeder was extracted from 2020 GMP Annual Report, Appendix 1.

Source: Guidehouse analysis

Table 71 summarizes the count of voltage complaints for the Silver substation. Voltage complaints vary considerably across years and across VVO feeders, ranging from seven complaints received in 2015 to 20 complaints received in 2017. Looking at 2015–2017 baseline period, there were 15 voltage complaints received, amounting to three to four voltage complaints per season. Based on voltage complaints data received, a total of five voltage complaints were reported along the Silver feeders during winter 2020/21, all of which were generated by customers connected to feeders 30A1 and 30A2, slightly above the baseline period average number of complaints per season.

Table 71. Count of Voltage Complaints for Silver Substation

Number of Voltage Complaints	30A1	30A2	30A3	30A4	30A5	30A6	Total
Customers*	2,437	2,259	242	792	1,631	965	**8,326**
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**
Winter 2020/21	3	2	0	0	0	0	**5**

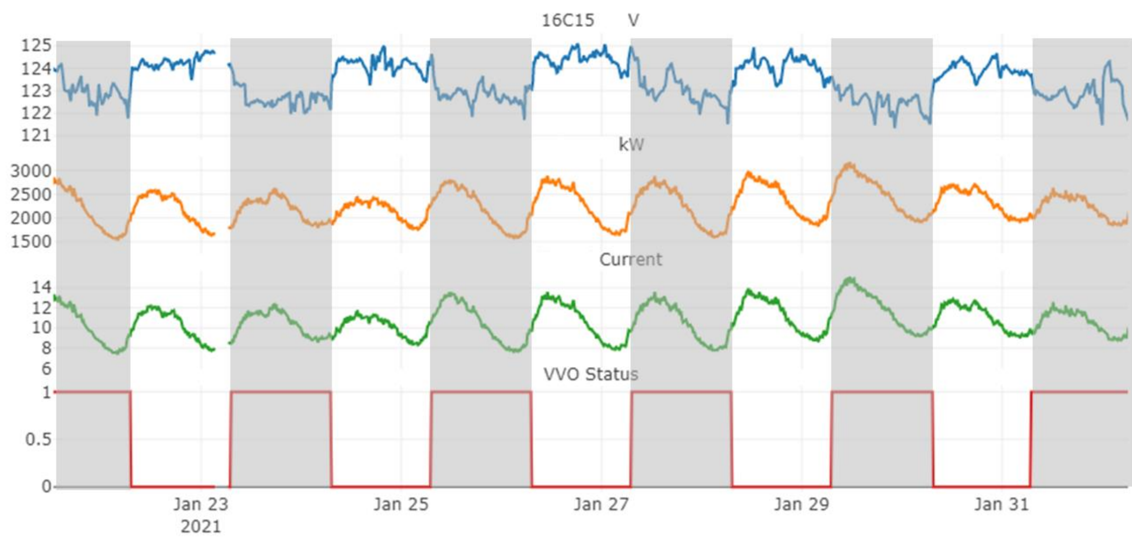
* Count of customers served by each feeder was extracted from 2020 GMP Annual Report, Appendix 1.

Source: Guidehouse analysis

4.2.2.4 Additional Analysis to Understand Evaluated Performance of VVO

Guidehouse identified a 1% voltage reduction associated with VVO, although Guidehouse usually expects to see voltage reductions in the range of 2% to 4% when VVO is engaged. To determine the cause of the lower evaluated voltage impact of VVO, the evaluation team conducted additional visual analysis of voltage to determine whether voltage followed an expected pattern when VVO was engaged. In this visual analysis, the team compared voltage measurements against VVO engaged status to determine whether voltage dropped and jumped with when VVO status switched between the engaged and disengaged states. Figure 21 highlights voltage, demand, current, and VVO status for feeder 16C15, which experienced a 0.96% reduction in voltage when VVO was engaged.

Figure 21. Voltage, Demand, Current, and VVO Status for Feeder 16C15, January 21–February 1



Source: Guidehouse analysis

Based on Figure 21, on the days where VVO was engaged (shaded in gray) voltage appears to rise and fall in a manner consistent with VVO switching between disengaged and engaged. More specifically, voltage appears to drop within the first few hours of VVO switching from disengaged to engaged, then remains somewhat low until VVO is disengaged, at which point voltage jumps to a new higher steady state. However, while this pattern is expected, measured voltage is usually expected to drop and jump by a larger magnitude as VVO switches between being disengaged and engaged. For instance, had a 2% to 4% reduction in voltage been observed during the winter 2020/21 M&V period for feeder 16C15, measured voltage would have been in the neighborhood of between 119.5 and 122 volts when VVO was engaged. Guidehouse recommends exploring VVO settings to determine whether the voltage setpoints can be lowered further along VVO feeders, which may yield greater energy savings.[65]

4.2.2.5 Key Findings and Recommendations

Guidehouse's VVO evaluation findings indicate that VVO allowed Eversource to realize energy savings and voltage reductions during the winter 2020/21 M&V period. More specifically:

65 Eversource is assessing how to further lower the initially-conservative VVO voltage settings across the full length of the circuit in order to enable further voltage reductions and associated energy reductions.

- During the winter 2020/21 M&V period, the Agawam, Piper, and Silver substations realized 853 MWh (0.75%) energy savings and 1.24 V (1.01%) voltage reduction associated with VVO. The CVR factor, which provides an estimate of energy savings possible with voltage reductions, was 0.82.
- Reductions in energy use were found to be greater during peak energy hours relative to off-peak energy hours, with peak energy savings of 558 MWh (0.97%) as compared to off-peak energy savings of 251 MWh (0.46%). Conversely, voltage reductions were greater during off-peak energy hours compared to peak energy hours, with off-peak voltage reductions of 1.37 V (1.11%) as compared to peak voltage reductions of 1.12 V (0.91%). As such, the CVR factors were 1.27 during peak energy hours and 0.39 during off-peak energy hours.
- Energy savings of 853 MWh realized during the winter 2020/21 M&V period yielded a 422 short ton reduction in CO_2 emissions, a 274 lb. reduction in NO_X emissions, and a 68 lb. reduction in SO_2 emissions.
- A total of 13 voltage complaints were received from customers connected to the Agawam, Piper, and Silver VVO feeders during the winter 2020/21 M&V period. Guidehouse did not identify a substantial increase or decrease in voltage complaints during the winter 2020/21 M&V period.

In 2021 and beyond, Guidehouse recommends that Eversource:

- Explore voltage setpoints to determine whether further voltage reductions can be achieved when VVO is engaged.
- Identify whether there is an impact of reverse power flow from distributed generation on VVO operation. The impact of reverse power flow on VVO operations may have a large impact on the evaluated performance of VVO for the upcoming spring and summer 2021 M&V periods. This will be particularly important for the Podick substation, which has numerous VVO feeders with a large nominal distributed generation capacity.

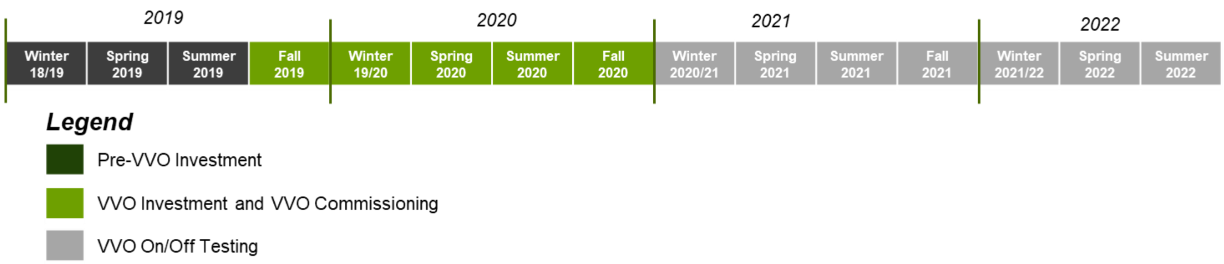
4.2.3 National Grid

This section discusses National Grid's VVO Performance Metrics results following the winter 2020/21 VVO M&V period.

4.2.3.1 Performance Metrics Analysis Timeline

Figure 22 highlights National Grid's key Performance Metrics analysis periods. Under current progress in VVO device deployment and VVO commissioning, National Grid plans to conduct VVO On/Off testing at its six VVO substations on a substation-specific schedule spanning winter 2020/21 through at least winter 2021/22. This report provides Performance Metrics analysis for the winter 2020/21.

Figure 22. 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

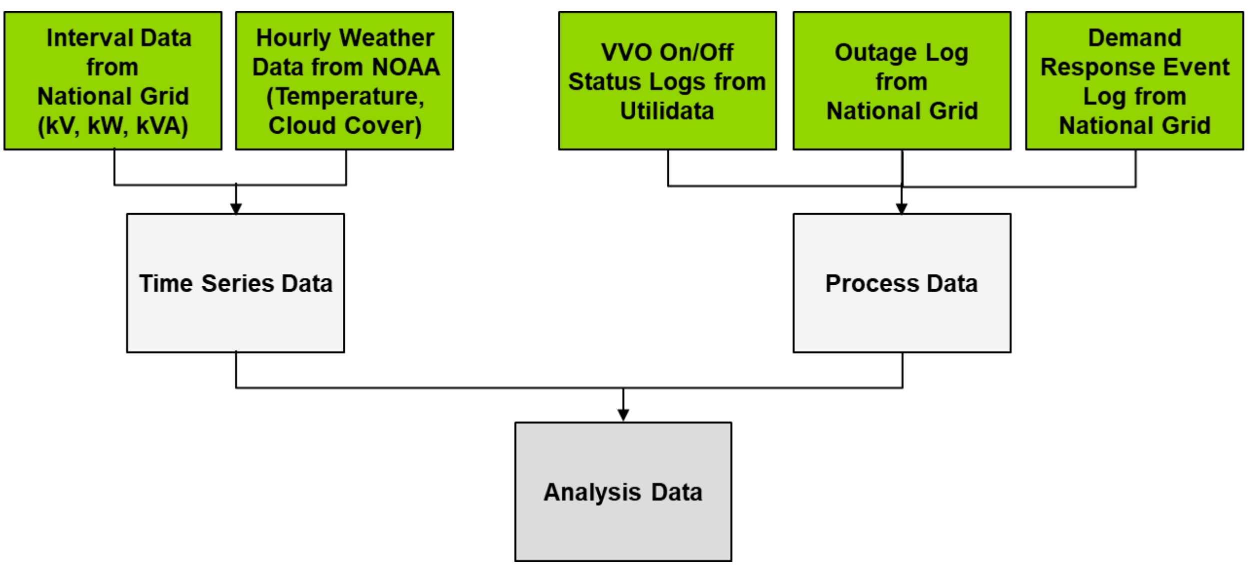
4.2.3.2 Evaluation Methodology

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 understand the impacts of VVO on energy and voltage. Figure 23 summarizes the data integration process used to construct the analysis dataset for the National Grid Performance Metrics analysis.

Figure 23. 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.[66]

To construct the process data, Guidehouse integrated time-stamped logs of VVO state changes between VVO On (engaged) and Off (disengaged) states from Utilidata, outage logs indicating when customers connected to the Stoughton substation experienced unplanned outages, and DR event information. 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 72 summarizes data observations made by the evaluation team and the resulting data cleaning steps that were executed.

Table 72. Data Cleaning Conducted for National Grid Analysis

Data Observation	Data Cleaning Step
VVO M&V testing is slated to begin in spring 2021 and summer 2021 at the East Methuen and Maplewood substations, respectively.	Remove data tied to the East Methuen and Maplewood substations, as M&V testing has not yet begun.
There were some periods in which voltage, real power, and apparent power were repeated, interpolated, or outlier observations.	Remove hours where anomalous data readings were flagged.
National Grid called a DR event on January 29.	Remove all data for January 29 to ensure VVO regression estimates are not capturing the impacts of the DR event.
Customers connected to the Stoughton substation experienced several unplanned outages.	Remove hours affected by unplanned service outages.
National Grid disabled VVO at the Stoughton substation from February 14 through the end of the winter 2020/21 M&V period.	Remove this time period to ensure factors driving VVO to be disabled do not affect VVO regression estimates.
Numerous VVO events were either shorter or longer than 24 hours, with many longer events coinciding with holidays and weekends.	Remove all VVO events shorter than 20 hours and longer than 24 hours to reduce the risk of VVO estimates being biased by oversampling holidays and weekends.

Source: Guidehouse

Table 73 indicates the number of hours contained in the analysis dataset for the Stoughton substation. After data cleaning, there were around 760 VVO On and 790 VVO Off hours remaining for use in the analysis. Much of the data removed during data cleaning were removed for the time period spanning February 14 through 28, which was flagged as a period where VVO was disengaged. Detailed data attrition information is provided in the Appendix.

[66] 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 Stoughton substation. 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 73. Count of VVO On, VVO Off, and Removed Hours for Stoughton

Number of Hours	913W17	913W18	913W43	913W47	913W67	913W69
VVO On	756	762	767	767	764	765
VVO Off	791	792	787	792	791	788
Removed by Data Cleaning	613	606	606	601	605	607
Winter 2020/21 Total	**2,160**	**2,160**	**2,160**	**2,160**	**2,160**	**2,160**

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 ensure exogenous patterns were controlled for. Table 74 summarizes observations made during this inspection and the resulting data analysis steps that were implemented.

Table 74. 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 December, January, and February.	Monthly fixed effects were incorporated into regression modeling to capture energy and voltage differences observed across each month.
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.
Numerous holidays coincided with the winter 2020/21 M&V test period.	Holiday fixed effects were included in regression models to control for typical holiday energy and voltage.

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 winter 2020/21. Table 77 provides the energy baseline calculated using VVO Off data collected during winter 2020/21 from the Stoughton substation.

Table 75. National Grid VVO Energy Baseline

Metric	Baseline Total Energy Use
Baseline Energy	32,442 MWh

Source: Guidehouse analysis

To calculate total baseline energy use, Guidehouse used models constructed to estimate energy savings to calculate what energy usage would have been in each hour of winter 2020/21 for each VVO feeder had VVO been disabled for the entirety of the season. Guidehouse then summed this calculated energy usage across all hours of winter 2020/21 for each VVO feeder to calculate feeder-level baseline energy usage. This feeder-level baseline energy usage was then summed across all feeders to calculate a baseline total energy use for the winter 2020/21 time period. Baseline energy use is provided by VVO feeder in the Appendix.

PM-2: Energy Savings

Table 76 provides the evaluated energy savings for National Grid for peak energy hours, off-peak energy hours, and winter 2020/21 overall. The ± figure indicate 90% confidence bounds associated with energy savings estimates.

Table 76. National Grid VVO Net Energy Reduction

Energy Period	Net Energy Reduction	
	MWh	%*
Peak Energy Hours	228 ± 41 MWh	1.37 ± 0.24%
Off-Peak Energy Hours	- 49 ± 43 MWh	- 0.30 ± 0.27%
Winter 2020/21 Total†	**170 ± 59 MWh**	**0.52 ± 0.18%**

*Percentage energy savings provided for each period is the load-weighted average of percentage savings estimated for each feeder.
†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.
Source: Guidehouse analysis

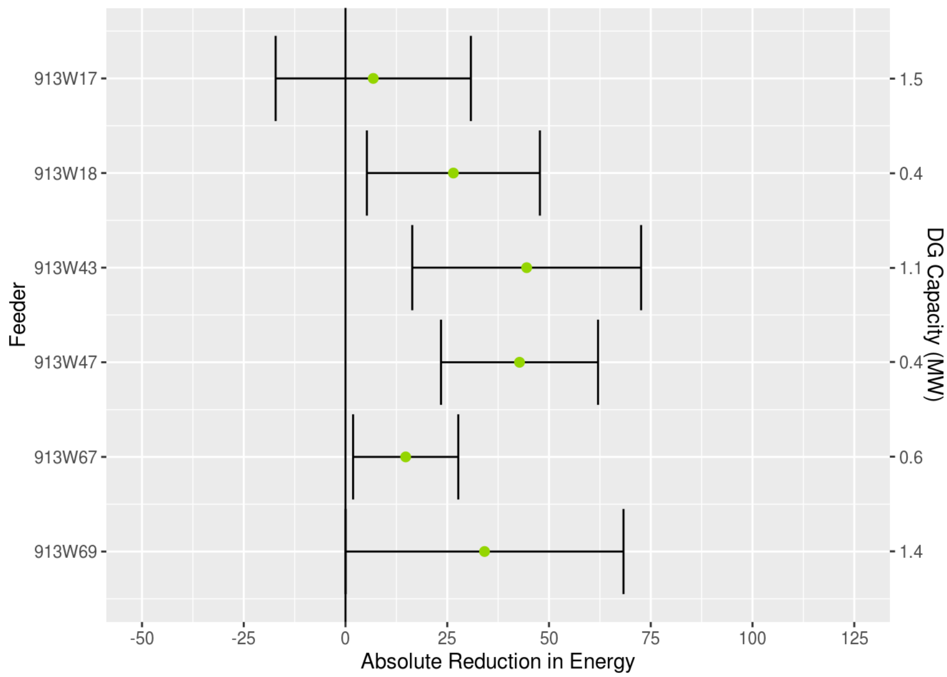
Regression estimates indicate a statistically significant change in energy use associated with VVO, with 170 MWh (0.52%) energy savings realized during the winter 2020/21 M&V period.[67] Regression estimates indicate that there were statistically significant reductions in energy use during peak energy hours, although there were statistically significant increases in energy use during off-peak energy hours. Peak energy savings totaled to 228 MWh (1.37%) as compared to an increase in off-peak energy of 49 MWh (0.30%).

Figure 24 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 six

[67] 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).

feeders that were included in the winter 2020/21 M&V period, all but 913W17 experienced statistically significant reductions in energy.

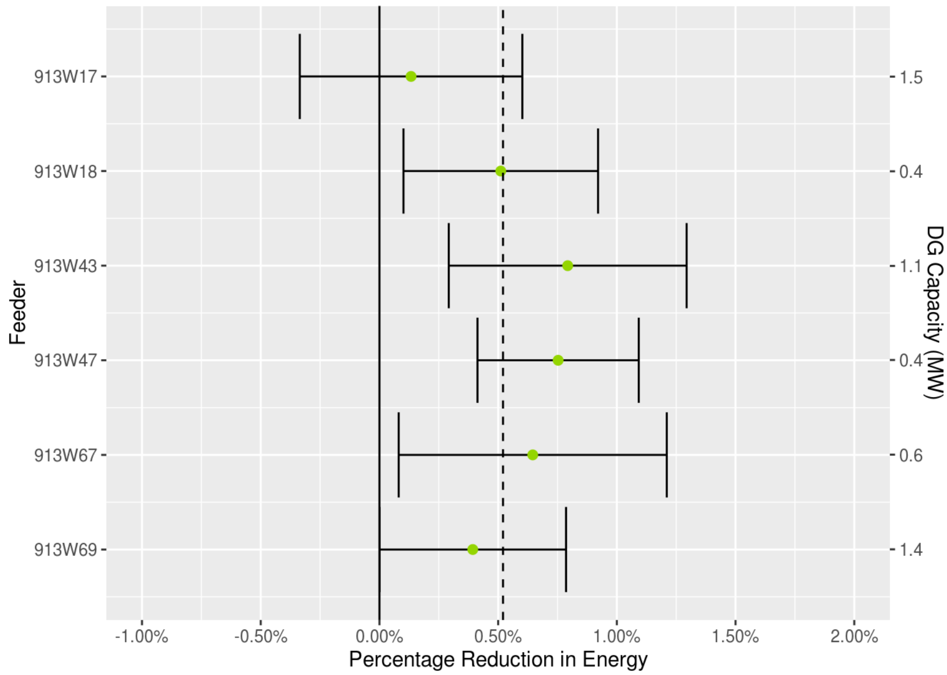
Figure 24. Net Energy Reduction (MWh) for National Grid VVO Feeders



Source: Guidehouse analysis

Figure 25 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, and the dashed line denotes the weighted average percentage MWh savings.

Figure 25. Net Energy Reduction (%) for National Grid VVO Feeders



Source: Guidehouse analysis

To further understand VVO energy savings, Guidehouse estimated the winter 2020/21 M&V period CVR factor, which provides an estimate of percentage energy savings possible with every percentage reduction in voltage. Equation B-1 in the Appendix highlights how the CVR factor is calculated using an estimated percentage change in energy and in voltage.

To calculate the CVR factor for National Grid, Guidehouse estimated changes in voltage associated with VVO. Table 77 provides the evaluated voltage reductions for National Grid, with 90% confidence bounds associated with voltage reductions estimates indicated by the ± figure.

Table 77. National Grid VVO Average Hourly Voltage Reduction

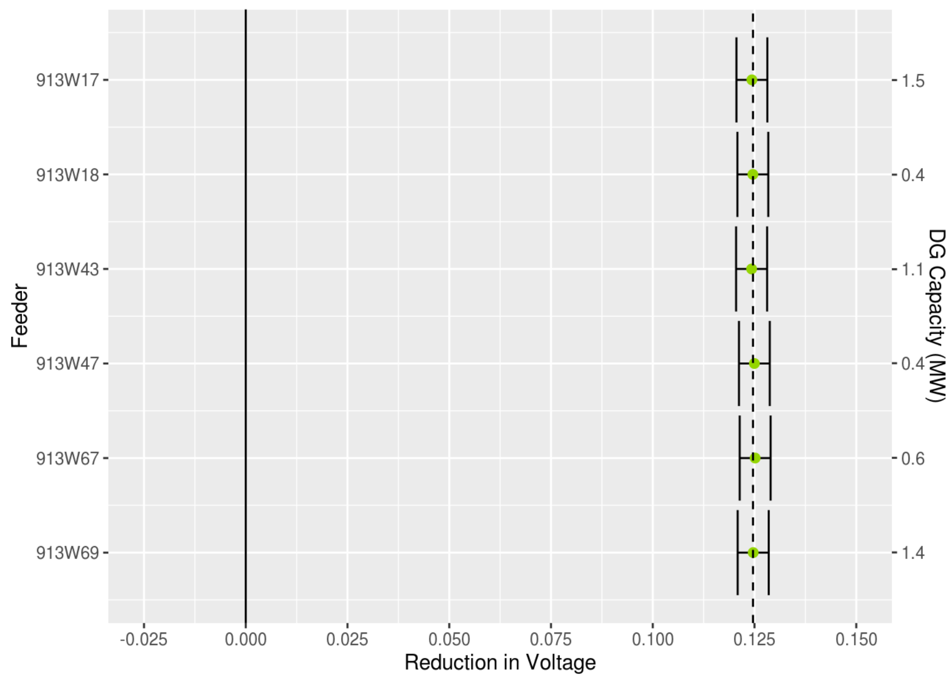
Energy Period	Average Hourly Voltage Reduction*	
	kV	%
Peak Energy Hours	0.14 ± 0.01 kV	0.96 ± 0.02%
Off-Peak Energy Hours	0.12 ± 0.01 kV	0.81 ± 0.02%
Winter 2020/21 Total	**0.12 ± 0.01 kV**	**0.88 ± 0.01%**

*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

Regression estimates indicate a statistically significant reduction in voltage associated with VVO, with a 0.12 kV (0.88%) voltage reduction realized during the winter 2020/21 M&V period. Regression estimates indicate that there were statistically significant reductions in voltage during peak and off-peak energy hours. However, voltage reductions during peak energy hours were greater than those observed during off-peak energy hours, with peak voltage reductions of 0.14 kV (0.96%) as compared to off-peak voltage reductions of 0.12 kV (0.81%).

Figure 26 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 six feeders, tied to the same transformer bank with one voltage measurement provided, experienced a statistically significant average hourly voltage reduction of 0.12 kV, as indicated by the dashed line.

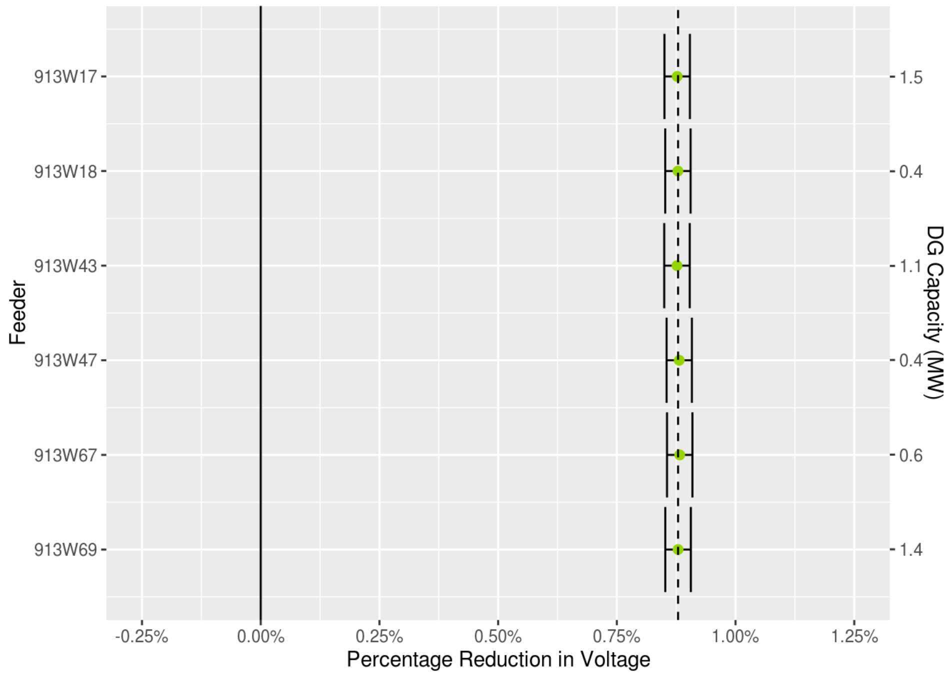
Figure 26. Average Hourly Voltage Reduction (kV) for National Grid VVO Feeders



Source: Guidehouse analysis

Figure 27 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. All six feeders, tied to the same transformer bank with one voltage measurement provided, experienced a statistically significant average hourly voltage reduction of 0.88%, as indicated by the dashed line.

Figure 27. Average Hourly Voltage Reduction (%) for National Grid VVO Feeders



Source: Guidehouse analysis

Following estimation of percentage energy savings and percentage voltage reductions attributed to VVO, Guidehouse calculated 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. Table 78 provides the CVR factors for National Grid.

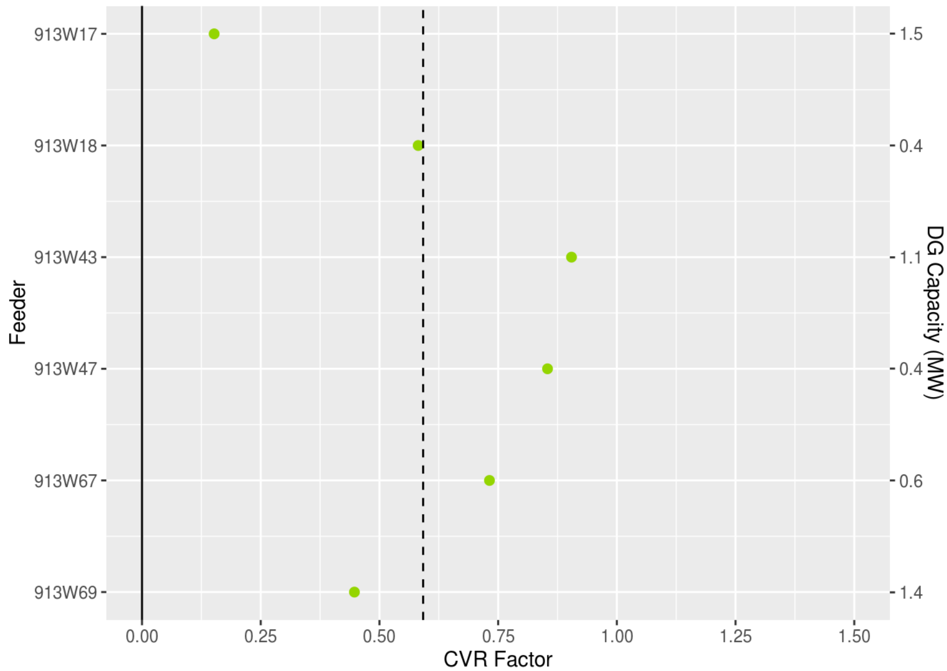
Table 78. National Grid VVO CVR Factors

Energy Period	CVR Factor*
Peak Energy Hours	1.43
Off-Peak Energy Hours	-0.37
Winter 2020/21 Total	**0.60**

*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 winter 2020/21 time period was 0.60, on the lower end of what may be expected from a year of VVO M&V testing. Since energy reductions were significantly higher during peak energy hours, the CVR factor was greater during peak energy hours than off-peak energy hours. The team observed CVR factors of 1.43 during peak energy hours and -0.37 during off-peak energy hours. Figure 28 provides the CVR factors for the winter 2020/21 M&V period for each feeder.

Figure 28. National Grid VVO CVR Factors



Source: Guidehouse analysis

PM-3: Peak Load Impact

In the Stage 3 Plan, Guidehouse stated it would examine peak load impacts of VVO by using the ISO-NE definition of the summer on-peak period, which corresponds with 1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays. Given the M&V period being examined within this evaluation corresponds with winter 2020/21, peak load impacts of VVO are not provided in this report.

PM-4: Distribution Losses

In the Stage 3 Plan, Guidehouse stated that it will calculate distribution losses using hourly data for real and reactive power. Based on regression analysis conducted on distribution losses for the winter 2020/21 M&V period, Guidehouse identified results that varied considerably across VVO feeders. Guidehouse believes this can be attributed to a limited period of analysis (i.e. one season) which may be resolved once VVO On / Off testing has been conducted across additional seasons. In addition, Guidehouse believes this can be attributed to the statistical models attempting to detect a small percentage change of a small magnitude of line losses, which would not be resolved with additional seasons of VVO On / Off testing. Guidehouse will re-examine the impact of VVO on distribution losses once M&V testing has been conducted across additional seasons.

PM-5: Power Factor

In the Stage 3 Plan, Guidehouse stated that power factors will be examined for hours where power is >75% of each feeder's peak annual demand. As the M&V period examined within this evaluation corresponds with winter 2020/21, very few hours had power >75% of each feeder's peak annual demand. Guidehouse did not provide the evaluated impact of VVO on the power factor observed for each VVO feeder due to insufficient data.

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.[68]

Table 79 provides emissions reductions associated with VVO, with 90% confidence bounds indicated by the ± figure. Based on energy savings attributed to VVO at the Stoughton substation, emissions reductions amounted to 0.027 short tons (54 lbs.) of NO_X, 0.007 short tons (14 lbs.) of SO_2, and 84 short tons of CO_2.

Table 79. National Grid VVO Emissions Reductions

Metric	NO_X	SO_2	CO_2
Winter 2020/21 Emissions Reduction	0.027 ± 0.010 tons	0.007 ± 0.002 tons	84 ± 29 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 2016 and 2020 and during winter 2020/21.[69] Voltage complaints are shown only for the Stoughton substation, as this substation was the only substation to receive VVO M&V testing during the winter 2020/21 time period. Table 80 summarizes voltage complaints for the Stoughton substation.

Table 80. Count of Voltage Complaints for Stoughton Substation

Number of Voltage Complaints	913W17	913W18	913W43	913W47	913W67	913W69	Total
Customers	1,364	1,560	2,148	1,804	753	3,746	**11,375**
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**
Winter 2020/21	1	1	0	1	1	1	**5**

* Count of customers served by each feeder was extracted from 2020 GMP Annual Report, Appendix 1.
Source: Guidehouse analysis

[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

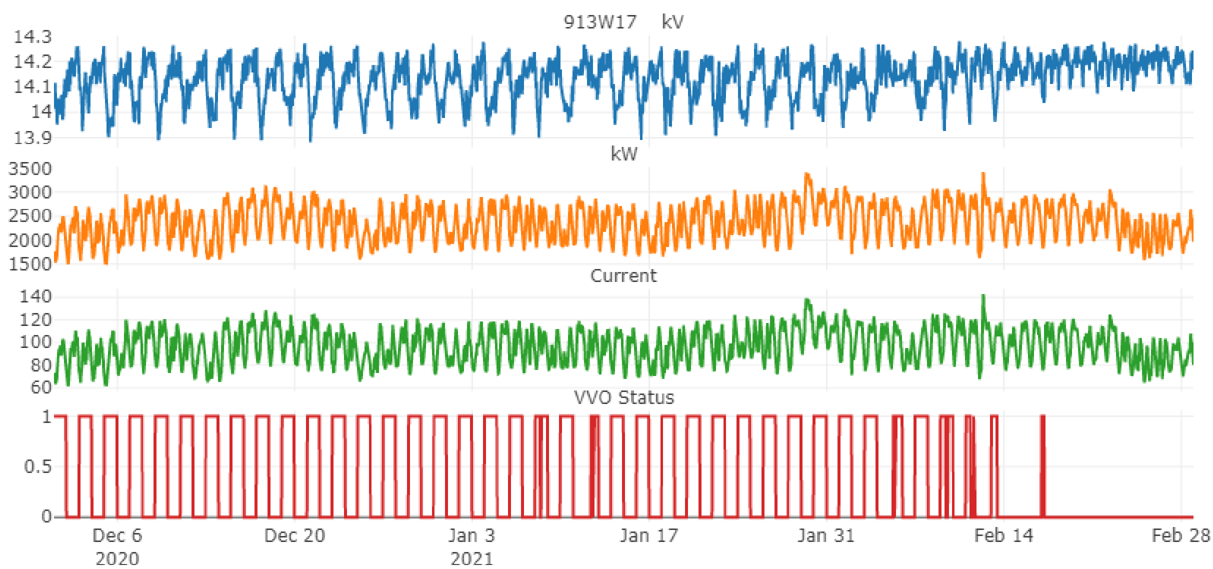
[69] Since 2016 is the earliest date at which voltage complaints data are available, Guidehouse limited its summary of voltage complaints to January 1, 2016 through February 28, 2021.

Voltage complaints vary considerably across years and across VVO feeders, ranging from 14 complaints in 2019 to 32 complaints in 2016. Looking at 2016–2017 baseline period,[70] there were 26 voltage complaints received, amounting to between six and seven voltage complaints per season. Based on voltage complaints data received, a total of five voltage complaints were reported along the Stoughton feeders during winter 2020/21, slightly below the baseline period average number of complaints per season.

4.2.3.4 Additional Analysis to Understand Evaluated Performance of VVO

Guidehouse's regression analysis using voltage data detected reductions in voltage of around 0.88%, although voltage reductions between 2% and 4% are usually expected when VVO is engaged. To better understand why VVO did not perform as expected, the evaluation team conducted additional visual analysis of voltage to determine whether voltage followed an expected pattern when VVO was engaged. In this visual analysis, the team compared voltage measurements to VVO engaged status to determine whether voltage dropped and jumped with when VVO status switched between the engaged and disengaged states. Figure 29 highlights voltage, demand, current, and VVO status for feeder 913W17, which experienced a 0.88% reduction in voltage during the winter 2020/21 M&V period.

Figure 29. Voltage, Demand, Current, and VVO Status for Feeder 913W17



Source: Guidehouse analysis

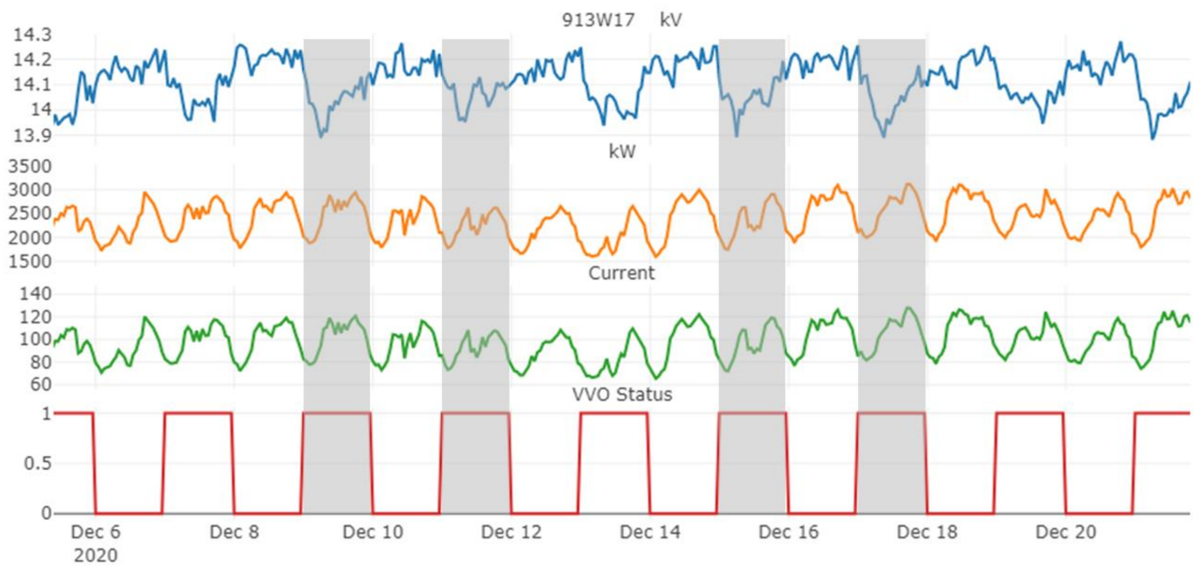
Based on visual analysis of Figure 29, voltage cycled with VVO and underwent large drops when VVO status switched from being disengaged and engaged. However, voltage did not stay at a lower level throughout days where VVO was engaged, instead following a pattern of low and then increasing voltage on days where VVO was engaged. On the other hand, when VVO

[70] 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. 2018–2020) 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.

was disengaged voltage stayed more level throughout the day as compared to days where VVO was engaged. Guidehouse usually expects to observe a sustained lower voltage on days where VVO is engaged, then a level shift upwards in voltage when VVO is disengaged, remaining high until VVO is engaged again.

To clarify the underlying voltage patterns observed when VVO was engaged and disengaged, Figure 30 plots the voltage, demand, current, and VVO status for the same feeder, this time zoomed into a 2-week period in December. Time windows highlighted in gray indicate voltage measurements made on days where VVO was engaged and where voltage underwent an upward trend throughout the day.

Figure 30. Voltage, Demand, and VVO Status for Feeder 913W17, December 5–21



Source: Guidehouse analysis

Based on Figure 30, voltage dropped within the first few hours of this switch on days where VVO switched from being disengaged to engaged. However, beginning midmorning during the shaded days, voltage began to increase, and this occurred in a manner that was not observed on days where VVO was disengaged. Had observed voltage when VVO was engaged mirrored voltage when VVO was disengaged, offset slightly by the effect of VVO, it is possible that evaluated voltage reductions and energy savings for National Grid would have been larger. Guidehouse recommends that National Grid explore VVO settings and other equipment settings to understand why voltage increased throughout the day on days where VVO was engaged.

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 winter 2020/21 M&V period. More specifically:

- During the winter 2020/21 M&V period, the Stoughton substation realized 170 MWh (0.52%) energy savings and 0.12 V (0.88%) voltage reduction associated with VVO. The CVR factor, which provides an estimate of energy savings possible with voltage reductions, was 0.60.

- Reductions in energy use were found to be greater during peak energy hours relative to off-peak energy hours, with peak energy savings of 228 MWh (1.37%) as compared to an increase in off-peak energy of 49 MWh (0.30%). Voltage reductions were also greater during peak energy hours compared to off-peak energy hours, with peak voltage reductions of 0.14 kV (0.96%) as compared to off-peak voltage reductions of 0.12 V (0.81%). As such, the CVR factors were 1.42 during peak energy hours and -0.37 during off-peak energy hours.

- Energy savings of 170 MWh realized during the winter 2020/21 M&V period yielded an 84 short ton reduction in CO_2 emissions, a 54 lb. reduction in NO_X emissions, and a 14 lb. reduction in SO_2 emissions.

- A total of five voltage complaints were received from customers connected to the Stoughton VVO feeders during the winter 2020/21 M&V period. Guidehouse did not identify a substantial increase or decrease in voltage complaints during the winter 2020/21 M&V period.

In 2021 and beyond, Guidehouse recommends that National Grid:

- Explore VVO settings and other equipment settings to understand the voltage measurements. More specifically, the evaluation team recommends that National Grid investigate why transformer-level voltage followed a pattern of low and then increasing voltage on days where VVO was engaged while remaining relatively flat on days where VVO was disengaged. This pattern is not expected to arise when VVO is engaged and may have reduced the evaluated performance of VVO for the winter 2020/21 M&V period.
- Explore voltage setpoints to determine whether voltage can be further reduced when VVO is engaged.
- Identify whether there is an impact of reverse power flow from distributed generation on VVO operation. The impact of reverse power flow on VVO operation may have a large impact on the evaluated performance of VVO for the upcoming spring and summer 2021 M&V periods.

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

PY2020'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 follow:

Device Deployment:

- Eversource device deployment exceeded initially planned devices in line sensors, while device deployment fell short of original plans on all other pre-approved device types.[71] In addition, Eversource commissioned two new device types: microcapacitors and grid monitoring line sensors. These devices should supplement the overall VVO investment and allow Eversource to gather additional data integral to the DMS.
- National Grid device deployment also exceeded initially planned devices, primarily due to National Grid's decision to install midline regulators on VVO substations, as well as LTC controls to allow for four additional Maplewood feeders to receive VVO.
- Unitil device deployment fell short of plan due to delays in FAN implementation. Despite completing construction work on regulators and capacitor banks throughout 2020, since ADMS is planned to be a control system for VVO, delays in FAN implementation interfered with deployment of the devices before the close of the year.

VVO Enablement:

- Eversource completed deployment of VVO for the original 2018–2020 plan feeders, with all feeders having VVO enabled on December 2, 2020. VVO enablement was behind Eversource's schedule in the PY2019 Evaluation Report due to ongoing commissioning troubleshooting prior to enabling VVO. However, all four substations had the VVO system enabled by the end of 2020. Eversource has been conducting VVO On/Off testing on the Agawam, Piper, and Silver substations since December 2, 2020 and on the Podick substation since March 4, 2021.
- National Grid had not enabled VVO for all of the original 2018–2020 plan feeders by the end of 2020 as anticipated in the PY2019 Evaluation Report. This is because National Grid had not completed deployment of VVO at the East Methuen and Maplewood substations by the end of the year. National Grid experienced delays in deployment of VVO throughout 2020 due to the addition of midline regulators and additional LTC controls and delays and complexities associated with IT work during the COVID-19 pandemic. However, National Grid enabled VVO and began VVO On/Off testing at its Stoughton substation on December 1, 2020.

[71] Deployment fell short of plans across all other pre-approved device types after full engineering analysis was conducted by Eversource, reducing the number of pre-approved devices required to accommodate VVO operation.

- Unitil VVO enablement fell short of its schedule in the PY2019 Evaluation Report, as Unitil has not completed deployment of VVO on the original 2018–2020 plan feeders due to delays in FAN implementation.

Total Spend:

- Eversource costs for deployment of pre-approved devices exceeded Eversource's plans due to regulator design changes and unplanned commissioning and startup costs incurred prior to enabling VVO. Spend on IT work was lower than planned. Eversource also deployed microcapacitors and grid monitoring line sensors.
- National Grid costs for deployment exceeded plan due to increased spending on regulators, LTC controls, and IT work. Spend on regulators exceeded plan due to the introduction of midline regulators to maximize VVO benefits, which increased capital and labor costs. In addition, spend on LTC controls exceeded plan due to the installation of additional controls and retrofitting of LTCs to receive necessary data. Lastly, spend on IT work also exceeded plan due to increased complexities introduced during the COVID-19 pandemic and cybersecurity concerns requiring software patches and retesting.
- The pace of Unitil investment has been slower than anticipated. As a result, Unitil spending during PY2020 was lower than anticipated. Spending was lower than anticipated for LTC controls and line sensors, while spending was on plan for regulators and capacitor banks, primarily due to the large amount of construction work conducted throughout 2020 even during the COVID-19 pandemic.

The EDCs are slated to continue to deploy VVO investments throughout 2021. In particular:

- Eversource plans to continue VVO On/Off testing throughout the year at all four original 2018–2020 plan substations (Agawam, Piper, Podick, Silver) until sufficient winter, summer, and shoulder season data are collected for Performance Metrics analysis. Eversource also plans to deploy additional VVO investments throughout 2021 at other substations.
- National Grid is slated to continue VVO On/Off testing at its Stoughton and East Methuen substations throughout the year and expects to begin VVO On/Off testing at its Maplewood substation by summer 2021. In addition, National Grid plans to deploy VVO investments on additional feeders connected to the East Bridgewater, East Dracut, and West Salem substations. Engineering and design and construction work have already begun on devices to be installed at these substations, and VVO On/Off testing is expected to begin in summer 2021.
- Unitil is expected to complete the VVO deployment for its original 2018–2020 plan substations throughout 2021. This work will include assembly of communications equipment to facilitate ADMS control of VVO. VVO On/Off testing is expected to begin in winter 2021-2022 at the Townsend and Lunenburg substations and in summer 2022 at the Summer Street substation. In addition, Unitil expects to deploy VVO investments at the West Townsend substation, which is currently expected to begin VVO On/Off testing in fall 2022.

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 winter 2020/21 M&V period. More specifically:

- During the winter 2020/21 M&V period, Eversource's Agawam, Piper, and Silver substations realized 853 MWh (0.75%) energy savings and 1.24 V (1.01%) voltage reduction associated with VVO. The CVR factor, which provides an estimate of energy savings possible with voltage reductions, was 0.82. During the same M&V period, National Grid's Stoughton substation realized 170 MWh (0.52%) energy savings and 0.12 V (0.88%) voltage reduction associated with VVO. National Grid's CVR factor was 0.60.
- Reductions in energy use were found to be greater during peak energy hours relative to off-peak energy hours for both Eversource and National Grid. In addition, Eversource experienced greater voltage reductions during off-peak energy hours, while National Grid experienced greater voltage reductions during peak energy hours.
- Eversource energy savings of 853 MWh yielded a 422 short ton reduction in CO_2 emissions, a 274 lb. reduction in NO_X emissions, and a 68 lb. reduction in SO_2 emissions. National Grid energy savings of 170 MWh yielded an 84 short ton reduction in CO_2 emissions, a 54 lb. reduction in NO_X emissions, and a 14 lb. reduction in SO_2 emissions.
- For Eversource, a total of 13 voltage complaints were received from customers connected to the Agawam, Piper, and Silver VVO feeders during the winter 2020/21 M&V period. For National Grid, a total of five voltage complaints were received from customers connected to the Stoughton VVO feeders during the period. Guidehouse did not identify a substantial increase or decrease in voltage complaints during the winter 2020/21 M&V period.

5.3 Recommendations

For 2021 and beyond, Guidehouse has the following recommendations for the EDCs:

- EDCs explore voltage setpoints to determine whether further voltage reductions can be achieved when VVO is engaged.
- EDCs identify whether there is an impact of reverse power flow from distributed generation on VVO operation. The impact of reverse power flow on VVO operation may have a large impact on the evaluated performance of VVO for the upcoming spring and summer 2021 M&V periods.
- Guidehouse and the EDCs 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. To provide results for reporting of Performance Metrics later in 2021 and 2022, the EDCs should continue with this plan.

- If possible, Unitil should accelerate the VVO On/Off testing start date for the Summer Street substation to December 1, 2021 from June 1, 2022 to enable PM analysis of all three of the original 2018–2020 plan substations can be included in the 2021 Evaluation Report. If VVO On/Off testing begins by December 1, 2021 for all three substations, Guidehouse recommends continuing VVO On/Off testing for these three substations through at least August 31, 2022.
- EDCs should identify and take additional steps to balance load across feeders and phases before the deployment of VVO. This step can yield energy savings that could be attributed to VVO investment.
- EDCs and Guidehouse should work to update stamped-approved performance metrics after completing analysis of all VVO performance metrics, based upon methods included in this evaluation report.

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)
Agawam (13.8 kV)	16C11	4.73	55	0.26	0.32
	16C12	60.53	12	0.72	0.42
	16C14	3.88	105	0.41	0.02
	16C15	3.22	116	0.37	0.02
	16C16	2.73	115	0.31	0.33
	16C17	3.13	82	0.26	0.14
	16C18	2.15	144	0.31	0.10
Piper (13.8 kV)	21N4	3.25	70	0.23	0.18
	21N5	12.53	57	0.71	0.02
	21N6	5.01	53	0.26	0.12
	21N7	2,350	1	0.96	0.00
	21N8	11.29	64	0.72	0.02
	21N9	2.80	101	0.28	0.12
Podick (13.8 kV)	18G2	30.00	2	0.07	0.00
	18G3	1.66	58	0.10	0.59
	18G4	3.19	68	0.22	0.74
	18G5	3.86	44	0.17	0.84
	18G6	3.78	34	0.13	0.73
	18G7	1.93	34	0.07	1.67
	18G8	6.29	23	0.15	1.27
Silver (13.8 kV)	30A1	3.49	68	0.24	0.13
	30A2	4.29	188	0.81	0.03
	30A3	29.34	21	0.61	0.71
	30A4	2.90	73	0.21	0.10
	30A5	3.19	76	0.24	0.12
	30A6	5.28	50	0.26	0.42

Source: Guidehouse analysis of 2020 GMP Annual Report, Appendix 1 filed April 1, 2021. 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**	3.46	80	0.28	0.50
	74L2	4.17	93	0.39	0.12
	74L3	2.32	171	0.40	0.18
	74L4	4.17	186	0.78	0.15
	74L5	3.21	57	0.18	0.11
	74L6	3.03	209	0.64	0.09
Stoughton (13.8 kV)	**913W17**	3.80	97	0.37	0.28
	913W18	2.65	132	0.35	0.10
	913W43	3.58	67	0.24	0.13
	913W47	3.29	112	0.37	0.08
	913W67	4.22	59	0.25	0.19
	913W69	2.69	119	0.32	0.14
Maplewood (13.8 kV)	**16W1**	2.53	209	0.53	0.10
	16W2*	1.80	434	0.78	0.08
	16W3	2.51	219	0.55	0.07
	16W4	5.59	141	0.79	0.13
	16W5	3.08	246	0.76	0.17
	16W6*	2.33	232	0.54	0.11
	16W7*	2.58	274	0.71	0.13
	16W8*	2.69	216	0.58	0.16
Additional Feeders					
East Bridgewater (13.8 kV)	**797W1**	3.30	78	0.26	0.46
	797W19	3.41	68	0.23	0.25
	797W20	6.00	55	0.33	0.04
	797W23	3.61	66	0.24	0.15
	797W24	4.09	48	0.20	0.10
	797W29	3.69	64	0.24	0.13
	797W42	3.84	58	0.22	0.55
East Dracut (13.2 kV)	**75L1**	2.54	188	0.48	0.09
	75L2	3.96	64	0.25	0.08
	75L3	3.77	47	0.18	0.21
	75L4	9.95	46	0.46	0.04
	75L5	2.07	181	0.37	0.10
	75L6	7.12	59	0.42	0.07

Substation	Feeder	Avg Customer Loading (kVA/customer)	Customer Density (customer/mi.)	Load Density (MVA/mi.)	DG Penetration (DG MW/MVA)
West Salem (13.8 kV)	29W1	2.68	164	0.44	0.16
	29W2	3.93	96	0.38	0.51
	29W3	2.19	281	0.61	0.09
	29W4	3.12	153	0.48	0.18
	29W5	2.39	244	0.58	0.13
	29W6	5.43	80	0.43	0.16

Source: Guidehouse analysis of 2020 GMP Annual Report, Appendix 1 filed April 1, 2021. 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	4,019	6	25.09	0.00
	15W16	3.44	36	0.12	0.29
	15W17	2.75	50	0.14	0.26
Lunenburg (13.8 kV)	30W30	3.89	29	0.11	0.26
	30W31	2.39	37	0.09	0.96
Summer Street (13.8 kV)	40W38	64.25	7	0.42	7.00
	40W39	8.06	53	0.43	0.30
	40W40	5.11	86	0.44	0.18
	40W42	1.96	137	0.27	0.11
Additional Feeders					
West Townsend (13.8 kV)	39W18	2.11	38	0.08	0.49
	39W19	2.16	21	0.05	1.15

Source: Guidehouse analysis of 2020 GMP Annual Report, Appendix 1 filed April 1, 2021. 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

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 winter 2020/21 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

$$\begin{aligned}\{kW_{it}, V_{it}\} = {} & \beta_1 Peak_{it} + \beta_2 OffPeak_{it} + \beta_3 VVO_{it} * Peak_{it} + \beta_4 VVO_{it} * OffPeak_{it} + \beta_5 Holiday_{it} \\ & + \beta_6 Daylight_{it} + \sum_{d=1}^{7} \beta_{7d} * \tau_d + \sum_{m=1}^{3} \beta_{8m} * \tau_m + \sum_{d,h=1}^{168} \beta_{9d,h} * \tau_{d,h} \\ & + \sum_{h=1}^{24} \beta_{10h} * \tau_h * Cloud_{it} * Daylight_{it} + \beta_{11} HDH_{it} + \beta_{12} HDH_{it}^2\end{aligned}$$

Where:

$i, t, h, d,$ and m	index feeder, time-interval, each of the 24 hours of the day, day of week, and month 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.
$Peak_{it}$	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. The corresponding coefficient β_1 captures the average real power and voltage observed during peak energy hours.
$OffPeak_{it}$	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.

	The corresponding coefficient β_2 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_3 captures the average hourly impact of VVO on real power or voltage during the peak energy period, and the coefficient β_4 captures the average hourly impact of VVO on real power or voltage during the off-peak energy period. $\beta_3 + \beta_4$ 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_5 captures the average real power or voltage observed on holidays during the winter 2020/21 analysis period.
$Daylight_{it}$	is an indicator equal to 1 when feeder i at time t falls within a daylight hour. The coefficient β_6 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_{7d} coefficients capture the average daily real power or voltage for each day of the week.
τ_m	are fixed effects for each month m. The corresponding β_{8m} coefficients capture the average monthly real power or voltage for each month of the winter 2020/21 analysis period.
$\tau_{d,h}$	are hourly fixed effects for each hour h and each day of week d. The corresponding $\beta_{9d,h}$ coefficients capture the average hourly real power or voltage for each day of the week.
τ_h	are hourly fixed effects for each hour h, and
$Cloud_{it}$	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_{10h} 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_{11} and β_{12} capture the impact of HDH and its square on real power or voltage.

B.3 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.3.1 Eversource

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 (Winter 2020/21)	8,640	8,640	8,640	8,640	8,640	8,640	8,640
1. Remove Short and Long Events	6,134	6,134	5,947	5,947	5,947	5,947	5,947
2. Remove Interpolated Values	5,990	5,990	5,911	5,912	5,911	5,912	5,911
3. Remove Repeated Values	5,987	5,987	5,909	5,910	5,909	5,910	5,909
4. Remove Outlier Observations	5,934	5,977	5,908	5,910	5,909	5,910	5,884
5. Remove December 5-6 and December 18-19	5,861	5,904	5,836	5,838	5,837	5,838	5,812
6. Remove Manually Flagged Points	5,652	5,851	5,836	5,838	5,837	5,838	5,783
Final Dataset	5,652	5,851	5,836	5,838	5,837	5,838	5,783
Observations Removed	2,988	2,789	2,804	2,802	2,803	2,802	2,857

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*	2,240	2,372	2,282	2,282	2,282	2,282	2,253
VVO On *Weekend*	703	695	702	704	703	704	703
VVO Off *Weekday*	2,037	2,166	2,127	2,127	2,127	2,127	2,102
VVO Off *Weekend*	672	618	725	725	725	725	725
Removed	2,988	2,789	2,804	2,802	2,803	2,802	2,857
Winter 2020/21 Total	8,640	8,640	8,640	8,640	8,640	8,640	8,640

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 (Winter 2020/21)	8,640	8,640	8,640	8,640	8,640	8,640
1. Remove Short and Long Events	6,134	6,134	8,640	8,640	8,640	8,640
2. Remove Interpolated Values	5,990	5,989	4,216	4,216	4,216	4,216
3. Remove Repeated Values	5,987	5,986	4,165	4,166	4,165	4,165
4. Remove Outlier Observations	5,982	5,983	4,159	4,164	4,163	4,163
5. Remove December 5-6 and December 18-19	5,910	5,911	4,156	4,162	4,159	4,138
6. Remove Manually Flagged Points	5,746	5,803	4,084	4,090	4,087	4,066
Final Dataset	5,746	5,803	3,991	3,896	3,994	3,973
Observations Removed	2,894	2,837	4,649	4,744	4,646	4,667

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*	2,280	2,302	1,726	1,671	1,727	1,705
VVO On *Weekend*	675	675	478	452	479	479
VVO Off *Weekday*	2,053	2,088	1,334	1,333	1,336	1,337
VVO Off *Weekend*	738	738	453	440	452	452
Removed	2,894	2,837	4,649	4,744	4,646	4,667
Winter 2020/21 Total	8,640	8,640	8,640	8,640	8,640	8,640

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 (Winter 2020/21)	8,640	8,640	8,640	8,640	8,640	8,640
1. Remove Short and Long Events	8,640	8,640	8,640	6,229	6,038	6,229
2. Remove Interpolated Values	6,229	6,038	6,038	5,832	5,763	5,559
3. Remove Repeated Values	5,869	5,422	5,433	4,709	4,807	4,608
4. Remove Outlier Observations	5,433	4,654	4,907	4,704	4,805	4,607
5. Remove December 5-6 and December 18-19	5,427	4,649	4,805	4,631	4,750	4,554
6. Remove Manually Flagged Points	5,352	4,581	4,735	4,631	4,750	4,554
Final Dataset	5,352	4,571	4,470	4,631	4,750	4,554
Observations Removed	3,288	4,069	4,170	4,009	3,890	4,086

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*	2,183	1,793	1,941	1,895	1,857	1,847
VVO On *Weekend*	536	519	432	484	566	502
VVO Off *Weekday*	2,000	1,704	1,677	1,704	1,723	1,688
VVO Off *Weekend*	633	555	420	548	604	517
Removed	3,288	4,069	4,170	4,009	3,890	4,086
Winter 2020/21 Total	8,640	8,640	8,640	8,640	8,640	8,640

Source: Guidehouse analysis

B.3.2 National Grid

Table B-7. Count of Hours Remaining by Data Cleaning Step for Stoughton

Data Cleaning Step	913W17	913W18	913W43	913W47	913W67	913W69
Initial Dataset (Winter 2020/21)	2,160	2,160	2,160	2,160	2,160	2,160
1. Remove Short and Long Events	1,584	1,584	1,584	1,584	1,584	1,584
2. Remove Interpolated Values	1,583	1,583	1,583	1,583	1,581	1,583
3. Remove Repeated Values	1,583	1,583	1,583	1,583	1,580	1,581
4. Remove Outlier Observations	1,581	1,583	1,582	1,583	1,579	1,581
5. Remove January 29 DR Event Day	1,557	1,559	1,558	1,559	1,555	1,557
6. Remove Unplanned Outages	1,547	1,554	1,554	1,559	1,555	1,553
Final Dataset	1,547	1,554	1,554	1,559	1,555	1,553
Observations Removed	613	606	606	601	605	607

Source: Guidehouse analysis

Table B-8. Count of VVO On, VVO Off, and Removed Hours for Stoughton

Number of Hours	913W17	913W18	913W43	913W47	913W67	913W69
VVO On *Weekday*	519	519	527	527	524	526
VVO On *Weekend*	237	237	240	240	240	239
VVO Off *Weekday*	552	552	549	552	551	548
VVO Off *Weekend*	239	240	238	240	240	240
Removed	613	606	606	601	605	607
Winter 2020/21 Total	2,160	2,160	2,160	2,160	2,160	2,160

Source: Guidehouse analysis

B.4 Detailed Energy Savings and Voltage Reductions

This section details energy savings, voltage reduction, and CVR factor estimates for the winter 2020/21 time period by VVO circuit. Results are provided separately by EDC.

B.4.1 Eversource

Table B-9. Eversource Energy Savings and Voltage Reductions by Feeder

Feeder	Energy Baseline (MWh)	Net Energy Reduction		Average Hourly Voltage Reduction		CVR Factor	GHG Reductions (Tons CO_2)
		MWh	%	V	%		
16C11	3,758	43 ± 11	1.15 ± 0.30	1.66 ± 0.03	1.34 ± 0.02	0.86	21 ± 6
16C12	7,821	63 ± 31	0.79 ± 0.40	1.66 ± 0.03	1.34 ± 0.02	0.59	31 ± 16
16C14	6,485	24 ± 15	0.38 ± 0.23	1.19 ± 0.02	0.96 ± 0.02	0.39	12 ± 7
16C15	4,717	42 ± 9	0.89 ± 0.20	1.19 ± 0.02	0.96 ± 0.02	0.93	21 ± 5
16C16	8,144	-1 ± 21	-0.02 ± 0.26	1.20 ± 0.02	0.96 ± 0.02	-0.02	-1 ± 10
16C17	7,041	23 ± 16	0.33 ± 0.23	1.20 ± 0.02	0.97 ± 0.02	0.34	11 ± 8
16C18	5,430	57 ± 13	1.05 ± 0.24	1.20 ± 0.02	0.97 ± 0.02	1.08	28 ± 6
21N4	5,750	51 ± 15	0.90 ± 0.27	1.71 ± 0.02	1.38 ± 0.02	0.65	25 ± 8
21N5	9,012	-5 ± 17	-0.05 ± 0.19	1.70 ± 0.02	1.37 ± 0.02	-0.04	-2 ± 8
21N6	4,126	-10 ± 16	-0.24 ± 0.38	1.11 ± 0.03	0.90 ± 0.02	-0.27	-5 ± 8
21N7	4,654	124 ± 65	2.55 ± 1.34	1.28 ± 0.03	1.03 ± 0.02	2.47	61 ± 32
21N8	10,371	120 ± 43	1.15 ± 0.41	1.19 ± 0.03	0.96 ± 0.02	1.20	59 ± 21
21N9	6,094	22 ± 16	0.37 ± 0.26	1.26 ± 0.03	1.02 ± 0.02	0.36	11 ± 8
30A1	3,394	8 ± 10	0.25 ± 0.29	1.05 ± 0.02	0.85 ± 0.02	0.29	4 ± 5
30A2	7,614	134 ± 45	1.77 ± 0.59	0.82 ± 0.02	0.66 ± 0.02	2.66	66 ± 22
30A3	7,705	138 ± 54	1.79 ± 0.71	0.97 ± 0.02	0.78 ± 0.02	2.28	68 ± 27
30A4	3,233	3 ± 8	0.08 ± 0.26	0.96 ± 0.03	0.79 ± 0.02	0.10	1 ± 4

Feeder	Energy Baseline (MWh)	Net Energy Reduction		Average Hourly Voltage Reduction		CVR Factor	GHG Reductions (Tons CO_2)
		MWh	%	V	%		
30A5	1,365	9 ± 6	0.68 ± 0.45	1.05 ± 0.02	0.85 ± 0.02	0.80	5 ± 3
30A6	6,755	8 ± 29	0.12 ± 0.43	0.94 ± 0.03	0.77 ± 0.02	0.16	4 ± 14
Overall*	**113,470**	**853 ± 124**	**0.75 ± 0.11**	**1.24 ± 0.01**	**1.01 ± 0.02**	**0.82**	**422 ± 61**

* 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 percentage energy savings, hourly voltage reductions, percentage voltage reductions, and CVR factors provided are load-weighted averages of these estimates provided for each feeder.

Source: Guidehouse analysis

B.4.2 National Grid

Table B-10. National Grid Energy Savings and Voltage Reductions by Feeder

Feeder	Energy Baseline (MWh)	Net Energy Reduction		Average Hourly Voltage Reduction		CVR Factor	GHG Reductions (Tons CO_2)
		MWh	%	V	%		
913W17	5,094	7 ± 24	0.13 ± 0.47	0.12 ± 0.01	0.88% ± 0.02	0.15	3 ± 12
913W18	5,154	27 ± 21	0.52 ± 0.41	0.12 ± 0.01	0.88% ± 0.02	0.59	13 ± 10
913W43	5,594	45 ± 28	0.80 ± 0.50	0.12 ± 0.01	0.88% ± 0.02	0.91	22 ± 14
913W47	5,663	43 ± 19	0.76 ± 0.34	0.12 ± 0.01	0.88% ± 0.02	0.86	21 ± 10
913W67	2,286	15 ± 13	0.65 ± 0.57	0.13 ± 0.01	0.88% ± 0.02	0.73	7 ± 6
913W69	8,651	34 ± 34	0.40 ± 0.40	0.12 ± 0.01	0.88% ± 0.02	0.45	17 ± 17
Overall	**32,442**	**170 ± 24**	**0.52 ± 0.18**	**0.12 ± 0.01**	**0.88% ± 0.01**	**0.60**	**84 ± 29**

* 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 percentage energy savings, hourly voltage reductions, and percentage voltage reductions provided are load-weighted averages of estimates provided for each feeder.

Source: Guidehouse analysis