Massachusetts Grid Modernization Program Year 2023 Evaluation Report: Volt-VAR Optimization (VVO)

Prepared for:

Massachusetts Electric Distribution Companies

Submitted by:

Guidehouse Inc.
125 High Street
Suite 401
Boston, MA 02110

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guidehouse.com

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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 each EDC's preauthorized VVO investments toward meeting the Department of Public Utilities (Department) grid modernization objectives for Program Year (PY) 2023.

Evaluation Process

The Department requires a formal evaluation process, including an evaluation plan and evaluation studies, for the EDCs' preauthorized grid modernization plan investments. Guidehouse is completing the evaluation to establish a uniform statewide approach and to facilitate coordination and comparability. The evaluation is to measure and assess progress toward achieving the Department's grid modernization objectives. The evaluation uses the Department-established Performance Metrics along with a set of Case Studies to understand if the GMP investments are meeting the Department's objectives.

The original Evaluation Plan developed by Guidehouse[1] was submitted to the Department by the EDCs on May 1, 2019 in dockets D.P.U. 15-120/15-121/15-122. Modifications to this original Evaluation Plan were required to enable evaluation of PY 2022 through PY 2025. These modifications included an 1) extension of the evaluation window from the four year term spanning 2018 – 2021[2] (hereon referred to as Term 1) to incorporate the new four year term spanning 2022 – 2025 (hereon referred to as Term 2), 2) revisions required to reflect the new Term 2 investment activity, and 3) revisions required to remove Infrastructure Metrics and increase the number of ADA and M&C case studies included in evaluation. Modifications to the original Evaluation Plan were filed on February 7, 2024.[3] The modified Evaluation Plan has been used to develop the analysis and evaluation provided below in this document.

Table 1 illustrates the key Performance Metrics relevant for the VVO evaluation by EDC.

[1] Guidehouse had previously filed as "Navigant Consulting" and did so during the initial evaluation plan filing.

[2] The Department approved the EDC's Term 1 GMPs on May 10, 2018 in D.P.U. 15-120/15-121/15-122, In that Order, the Department 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 Department issued an order extending the 3-year grid modernization plan investment term to a 4-year term, which introduced a 2021 program year. In addition, on July 1, 2020, Eversource filed a request for an extension of the budget authorization associated with grid modernization investments that was docketed as D.P.U. 20-74. The 2018-2021 GMP term results provided for Eversource reflect this updated filing.

[3] On February 7, 2024, Eversource, National Grid, and Unitil filed evaluation plans with the Department for the period spanning 2022-2025 in dockets D.P.U. 21-80/21-81/21-82.

Table 1. VVO Evaluation Metrics

Type	VVO Evaluation Metrics	ES	NG	UTL
PM-1	VVO Baseline	✓	✓	✓
PM-2	VVO Energy Savings	✓	✓	✓
PM-3	VVO Peak Load Impact	✓	✓	✓
PM-4	VVO Distribution Losses without Advanced Metering Functionality (AMF)	✓	✓	✓
PM-5	VVO Power Factor	✓	✓	✓
PM-6	VVO – GHG Emissions	✓	✓	✓
PM-7	Voltage Complaints	✓	✓	✓

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

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

Source: Stamp Approved Performance Metrics, July 25, 2019

Data Management

Guidehouse worked with the EDCs to collect data to complete the VVO evaluation for the assessment of Performance Metrics. A consistent methodology was used across Investment Areas and EDCs for evaluating and illustrating EDC progress toward the GMP metrics.

Table 2 summarizes data sources used throughout the VVO evaluation for PY 2023. Section 3.1.1 details each of the data sources.

Table 2. VVO Data Sources

Data Source	Description
VVO Supplemental Data Template	Includes additional information unique to the VVO Investment Area spanning inputs required for the Performance Metrics. Data covers actual versus planned VVO schedule, IT work schedule, system events, and voltage complaints. Information was requested at the feeder-level where possible.
EDC system information	Includes feeder characteristics (e.g., rated primary voltage, rated capacity, circuit 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)	Includes circuit head end data (voltage, real power, current, apparent power or reactive power, power factor) and VVO status flags (e.g., VVO On/Off)
VVO system information	Includes time-stamped log of VVO state changes between on and off states and any other VVO modes.
Weather data	Includes hourly temperature data from selected weather stations and collected by the National Oceanic and Atmospheric Administration (NOAA). [4]
Solar insolation data	Includes quarter-hourly solar insolation data collected by the National Renewable Energy Laboratory (NREL) to capture changes in load and voltage due to solar generation.[5]

Source: Guidehouse analysis

[4] 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

[5] Documentation on the NREL dataset used in this analysis can be found here: NSRDB | What is the NSRDB (nrel.gov)

Key Findings and Recommendations

Table 3 includes the Performance Metrics results and key findings for circuits that went through VVO On/Off testing during PY 2023, all of which were National Grid and Unitil circuits. Table 4 includes the Performance Metrics results and key findings for circuits that completed VVO On/Off testing prior to PY 2023, all of which were Eversource circuits.[6]

Table 3. Performance Metrics Results for Circuits with VVO On/Off Testing During PY 2023

Performance Metrics		National Grid		Unitil	
Circuits Included in Evaluation		43		3	
PM-1	PY 2023	5,184,073 MWh		253,380 MWh	
PM-2	Energy Savings – All Hours VVO On*	5,072 ± 237 MWh	1.275 ± 0.036%	438 ± 42 MWh	1.525 ± 0.146%
	Energy Savings – Actual VVO On Hours†	2,540 ± 121 MWh	1.275 ± 0.036%	229 ± 22 MWh	1.525 ± 0.146%
-	Voltage Reduction‡	0.320 ± <0.001 kV	2.306 ± 0.002%	0.190 ± <0.001 kV	1.341 ± 0.007%
-	CVRf^	0.92		1.14	
PM-3	Peak Load Reduction	1,737 ± 141 kW	1.298 ± 0.102%	20 ± 41 kW	0.363 ± 0.619%
PM-4	Reduction in Distribution Losses	0.77%		0.21%	
PM-5	Change in Power Factor	0.004 ± 0.001	0.394 ± 0.082%	0.001 ± <0.001	0.11 ± 0.009%
PM-6	GHG Reductions (CO_2) All Hours VVO On*	1,466 ± 68 tons CO_2		127 ± 12 tons CO_2	
	GHG Actual VVO-On Hours†	734 ± 35 tons CO_2		66 ± 6 tons CO_2	
PM-7^^	Voltage Complaints	255 (50% increase from 2016 – 2017 baseline period average)		4 (200% increase from 2015 – 2017 baseline period average)	

* Total energy savings are determined by calculating the energy savings across the entirety of each substation's testing period, assuming VVO to be engaged during the entire period.
† Actual VVO On Hours are the number of hours in the clean analysis data that were VVO engaged between each substation's testing period.
‡ Voltage results are removed for Maplewood and West Salem circuits due to limited/poor quality voltage data within SCADA data received.
^ CVRf value is calculated as change in percent energy savings divided by change in percent voltage savings. Maplewood and West Salem circuits were excluded from this calculation due to limited/poor quality voltage data within SCADA data received.

[6] It can be difficult to reliably compare the results from the Performance Metrics analysis between Eversource, National Grid, and Unitil. For example, there are differences in the granularity of telemetry (e.g., 5-minute versus 15-minute), data quality at different times of the year (e.g., sustained pauses in VVO On/Off testing for one EDC, data outages during On/Off testing for another EDC). As such, certain portions of the M&V period, such as the Spring season, may be represented more for one EDC than the other. Additionally, there are numerous differences in DG penetration, customer types, and geographic areas served by Eversource, National Grid, and Unitil feeders that limit the ability to directly compare Eversource, National Grid, and Unitil VVO outcomes.

^^ The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.
Note: Townsend, East Bridgewater, Easton, Stoughton, Maplewood, and West Salem circuits evaluated had a system voltage of 13.8 kV while East Methuen and East Dracut circuits evaluated had a system voltage of 13.2 kV.
Source: Guidehouse analysis

Table 4. Performance Metrics Results for Circuits that Completed VVO On/Off Testing Prior to PY 2023

Performance Metric	Appendix 1 Metric	Aggregate Results
PM-1	Annual Energy Delivered w/o VVO (MWh)	576,933 MWh
PM-2	Annual Energy Savings w/ VVO (MWh)	1,270 MWh
	Annual Peak Load w/o VVO (MW)	2.5 MW
PM-3	Annual Peak Load Reduction w/ VVO (MW)	-0.99 MW
	Distribution Losses w/o VVO (MWh)	12,058 MWh
PM-4	Reduction of Distribution Losses w/ VVO (MWh)	-388 MWh
	Power Factor w/o VVO	0.9576
PM-5	Power Factor w/ VVO	0.9577
	GHG Emissions w/o VVO (metric tons)	167 tons CO_2
PM-6	Reduction of GHG Emissions w/ VVO (metric tons)	367 tons CO_2
PM-7	# Voltage Complaints, Plan Year	63 complaints
	Change # of Voltage Complaints (Baseline minus Plan Year)*	15 complaint increase

* The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.
Source: Guidehouse analysis

Guidehouse has the following key findings to provide for Eversource circuits that completed On/Off testing prior to PY 2023:

- Eversource did not conduct VVO On/Off testing in PY 2023 at any VVO substations.[7] In order to estimate the Performance Metrics, Guidehouse combined evaluation results from the PY 2022 evaluation as well data received for the PY 2023 evaluation. Guidehouse included the Performance Metrics impacts from the PY 2022 evaluation, the SCADA interval data from Eversource that contained time-stamped measurements of voltage, real power, apparent power, and reactive power for PY 2023, and time-stamped logs of VVO state changes between VVO On (engaged) and Off (disengaged) states contained within the SCADA data provided by Eversource for PY 2023.

- During the PY 2022 M&V period, Eversource's Agawam, Piper, Podick, and Silver substations realized 0.41% energy savings and 1.24% voltage reduction associated with VVO, equating to a CVR factor of 0.60. Using these results and substation SCADA collected during PY 2023, Eversource's Agawam, Piper, Podick, and Silver substations realized 1,270 MWh energy savings associated with VVO. Energy savings of 1,270 MWh yielded a 367 short ton reduction of CO_2 emissions. Lastly, VVO circuits experienced an

[7] Eversource did not conduct VVO On/Off testing at substations that were in-service for more than one full calendar year and had already completed On/Off testing previously. This is in-line with the Stamp Approved Performance Metrics outlined in Performance Metrics Compliance Filing, D.P.U. 21-80/21-81/21-82 (2023). Further discussion on VVO On/Off testing and the recommendation to limit the testing period can be found in AG-4-6, D.P.U. 22-40 (2023).

increase (0.99 MW) in peak load and an increase in distribution losses when VVO was engaged (388 MWh).

- For Eversource, a total of 63 voltage complaints were received from customers connected to the Agawam, Piper, Podick, and Silver VVO circuits during the PY 2023 M&V period. This is a 31% increase relative to the average voltage complaints per year received between 2015 – 2017. The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.
- Eversource reported conducting deployment of VVO investments throughout PY 2023. Eversource anticipates completing additional deployment during PY 2024 and PY 2025. Once VVO investments are deployed, Eversource plans to control VVO within its ADMS system. Eversource plans to complete its ADMS investment and commission and enable VVO at its Term 2 substations in PY 2025. Therefore, Guidehouse will not conduct any regression-based estimation of Performance Metrics for Eversource until the PY 2025 evaluation. Until then, all Performance Metrics will continue to be estimated for only the Agawam, Piper, Podick, and Silver substations using PY 2022 evaluation results and SCADA collected during the evaluation period of interest (e.g., PY 2023).

Guidehouse has the following key findings to provide for National Grid and Unitil circuits that underwent On/Off testing during PY 2023:

- During the PY 2023 M&V period, National Grid's East Bridgewater, East Dracut, East Methuen, Easton, Maplewood, Stoughton, and West Salem substations realized 2,540 MWh (1.3%) energy savings and 0.320 kV (2.3%) voltage reduction associated with VVO. National Grid's CVR factor was 0.92.[8] During the same M&V period, Unitil's Townsend substation realized 229 MWh (1.5%) energy savings and 0.19 kV (1.3%) voltage reduction associated with VVO. Unitil's CVR factor was 1.14. National Grid energy savings of 2,540 MWh yielded a 734 short ton reduction in CO_2 emissions. Unitil energy savings of 229 MWh yielded a 66 short ton reduction of CO_2 emissions.
- National Grid VVO circuits experienced a statistically significant decrease in peak load (1.3%), a statistically significant increase in power factor (0.39%), and a decrease in distribution losses (0.77%) when VVO was engaged. Unitil VVO circuits experienced a statistically insignificant decrease in peak load (0.36%), a statistically significant increase in power factor (0.11%), and a decrease in distribution losses (0.21%).
- For National Grid, a total of 255 voltage complaints were received from customers connected to the East Bridgewater, East Dracut, East Methuen, Easton, Maplewood, Stoughton, and West Salem VVO circuits during the period. This is a 50% increase relative to the average voltage complaints per year received between 2016 – 2017. For Unitil, a total of 4 voltage complaints were received from customers connected to the Townsend VVO circuits during the period. This is a 200% increase relative to the average voltage complaints per year received between 2015-2017. The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.

[8] Both National Grid and Unitil aggregated CVRf calculations only include estimates from feeders that experienced a minimum change in voltage of ±0.25%. Certain feeders with changes in voltage greater than ±0.25% were also excluded from aggregated CVRf calculations due to highly unstable voltage and energy responses to VVO On/Off testing. Feeders excluded from this calculation are all of National Grid's Maplewood 16W feeders and West Salem 29W feeders. Unitil's Townsend 15W16 and 15W17 feeders are also removed from aggregated CVRf results due to unreliable voltage and energy responses to VVO On/Off testing.

In 2024 and beyond, Guidehouse recommends that Eversource, National Grid, and Unitil:

- Continue to monitor performance of the VVO scheme after M&V has been completed, such as ensuring capacitor banks and pole-top regulators are responding as anticipated to VVO/ADMS commands. The EDC's performance metric estimates are reflective of the VVO scheme as it was in PY 2023. Continuously monitoring the VVO scheme to ensure all line devices are responding as anticipated will be important in ensuring evaluated performance is maintained.
- Provide SCADA data for one or two "placebo" circuits (i.e., circuits without VVO schemes) for the PY 2024 and PY 2025 evaluations. Using data provided for two "placebo" circuits within the PY 2023 evaluation, Guidehouse identified that the EDC's On/Off testing data was biased by extended pauses to the On/Off testing conducted. In some cases, this led to an oversampling of hotter days when VVO was engaged relative to when VVO was disengaged, and in others this led to an oversampling of cooler days when VVO was engaged relative to when VVO was disengaged. This poses a threat to the RCT program design of On/Off testing and required the data to be rebalanced via a matching algorithm summarized in Section 2.1.3. Providing SCADA for "placebo" circuits will allow Guidehouse to assess whether testing data for the VVO circuits needs to be rebalanced.
- Increase the cadence of VVO On/Off testing. Guidehouse recommends shifting from week on / week off testing to either testing daily (i.e., day on / day off), every other day, every two days, every three days, or every four days (i.e., four days on / four days off). Increasing the cadence of testing will improve the likelihood of balance in temperatures, day types, and other factors that influence grid conditions. This ultimately allows for the RCT design of VVO On/Off testing to yield unbiased Performance Metric estimates.
- Once a schedule with increased cadence has been determined for VVO On/Off testing, the EDCs should make every effort to comply with the pre-determined schedule. If compliance is achieved, there should be a balance of temperatures and other conditions correlated with system demand, voltage, and power factor, thereby leading to VVO impact estimates that are unbiased. Failure to comply, such as pausing On/Off testing and leaving VVO in its engaged or disengaged state for an extended period of time, will increase the likelihood of an invalid RCT in the PY 2024 and PY 2025 evaluations. If an invalid RCT is identified, Guidehouse will need to rebalance the data using the approach outlined in Section 2 to reduce the risk of biased VVO impact estimates.
- To identify causes of lower performance during peak demand hours, Unitil may consider investigating data collected at pole-top regulators and capacitor banks to determine whether there are differences in how voltage is lowered and flattened during peak hours (4:00 p.m. to 10:00 p.m., non-holiday weekdays between May 1 and September 30) relative to all other hours of the day. It may be the case that Townsend circuits' line devices were not responding as expected to VVO signals during the identified peak period.
- To identify causes of lower performance, particularly for the West Salem substation (which underwent estimated energy increases when VVO was engaged) and the Easton substation (which underwent estimated peak demand increases when VVO was engaged), consider assessing data collected from devices along each connected circuit. For example, end-of-line feeder monitor voltage data will enable an investigation of whether voltage is performing as expected at the end-of-line when VVO is engaged. In addition, if data are collected for points between the circuit head-end and end-of-line, assess of whether certain zones of a circuit are under- or over-performing relative to the aggregate impact detected using SCADA collected at the circuit head-end.

1. Introduction to Massachusetts Grid Modernization

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

1.1 Massachusetts Grid Modernization Plan Background

The following subsections summarize the progression of Massachusetts Grid Modernization Plans (GMPs) filed by the three Massachusetts Electric Distribution Companies (EDCs): Eversource, National Grid, and Unitil.

1.1.1 Grid Modernization Term 1 (2018-2021)

On May 10, 2018, the Department issued its Order approving the EDCs' GMPs for 2018-2020 in dockets D.P.U. 15-120/15-121/15-122.[9,10] In the Order, the Department preauthorized grid-facing investments over three years (2018-2020) for each EDC and adopted a three-year (2018-2020) regulatory review construct for preauthorization of grid modernization investments. On May 12, 2020, the Department issued an Order[11] in dockets 15-120/15-121/15-122 extending the three-year grid modernization plan investment term to a four-year term, which introduced a 2021 program year.

During the GMP term spanning 2018-2021 (hereon referred to as Term 1) 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/ALF)
- Communications/IoT (Comms)
- Workforce Management (WFM)

A certain level of spending for each of these GMP Investment Areas was preauthorized by the Department, with the expectation they would advance the achievement of Department's grid modernization objectives:[12]

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

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

[11] D.P.U. 15-120; D.P.U. 15-121; D.P.U. 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).

[12] D.P.U. 15-120/15-121/15-122, at 106 (2018).

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

For Term 1, the Department's preauthorized budget for grid modernization varied by Investment Area and EDC. Eversource originally had the largest preauthorized budget at $133 million, with ADA and M&C representing the largest share ($44 million and $41 million, respectively). National Grid's preauthorized budget was $82.2 million, with ADMS representing over 50% ($48.4 million). Unitil's preauthorized budget was $4.4 million and VVO made up 50% ($2.2 million).

On July 1, 2020, Eversource filed a request for an extension of the budget authorization associated with grid modernization investments that was docketed as D.P.U. 20-74.[13] The budget extension, approved by the Department on February 4, 2021,[14] included $14 million for ADA, $16 million for ADMS/ALF, $5 million for Communications, $15 million for M&C, and $5 million for VVO.[15] These values are included in the Eversource total budget by Investment Area in.

Table 5. Term 1 (2018-2021) Preauthorized Budget, $M

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

Source: Term 1 Order and Eversource initial filing submitted in D.P.U. 20-74.

1.1.2 Grid Modernization Term 2 (2022-2025)

On July 2, 2020, the Department issued an Order[16] that triggered further investigation into modernization of the electric grid. In the order, the DPU required that the EDCs file a grid modernization plan on or before July 1, 2021. In accordance with this order, the EDCs filed grid modernization plans for a 4-year period spanning 2022-2025 (hereby referred to as Term 2).[17] In these plans, the EDCs outlined continued investment in the areas that received investment

[13] Eversource's request for an extension of the budget authorization was docketed as D.P.U. 20-74.

[14] D.P.U. 20-74 (2021).

[15] The Department allowed flexibility to these budgets to accommodate changing technologies and circumstances. For example, EDCs can shift funds across the different preauthorized investments if a reasonable explanation for these shifts is supplied.

[16] Investigation by the Department of Public Utilities on its own Motion into the Modernization of the Electric Grid – Phase Two, D.P.U. 20-69 (2020).

[17] On July 1, 2021, Eversource, National Grid, and Unitil each filed a grid modernization plan with the DPU for the period spanning 2022-2025. The Department docketed these plans as D.P.U. 21-80, 21-81, and 21-82, respectively.

during Term 1 (referred to as Track 1 Investment Areas), and investment in new Investment Areas (Track 2 Investment Areas).

Table 6 summarizes the Department pre-authorized Term 2 GMP investment areas, which includes Track 1 and Track 2 investments, and EDC-reported Department objectives that are addressed by each of the investment areas. Table 7 provides more detail on the new Track 2 grid modernization investments excluding Advanced Metering Infrastructure (AMI).[18]

Table 6. Overview of Term 2 Investment Areas

			DPU Objectives		
Investment Area	**Term**	**Description**	**Optimize System Performance**	**Optimize System Demand**	**Integrate DER**
Advanced Distribution Automation (ADA)	1 2	National Grid-only investment for Term 2. ADA allows for isolation of outage events with automated restoration of unaffected circuit segments	✓		
Advanced Distribution Management Systems (ADMS)	1 2	New capabilities in real-time system control with investments in developing accurate system models and enhancing Supervisory Control and Data Acquisition (SCADA) and outage management systems (OMS) to control devices for system optimization and provide support for distribution automation and VVO with high penetration of DER.	✓	✓	✓
Advanced Load Flow (ALF)	1 2	Eversource-only investment for Term 2 to integrate, into a single software, both their existing Distributed Generation (DG) tools and customer interconnection portal. Eversource also plans to use a simulation of locational load and generation based on variables such as customer behavior and energy market prices.	✓	✓	✓

[18] AMI is not included in the scope of evaluation, as there are no Performance Metrics tied to the deployment of AMI during the 2022-2025 GMP Term, and progress of the AMI deployment is projected to be limited during the course of the term.

Investment Area	Term	Description	DPU Objectives: Optimize System Performance	DPU Objectives: Optimize System Demand	DPU Objectives: Integrate DER
Communications/IoT (Comms)	1 2	Fiber middle-mile, field area communications systems and IT	✓	✓	✓
Distributed Energy Resources Management System (DERMS)	2	Software that forms the hub of DER management functions and integrates with other applications such as a Demand Response Management System (“DRMS”) and ADMS, to create the DERMS Platform. Includes two demonstration projects proposed by National Grid to test new tools, and plans for Unitil to install ground-fault overvoltage protection and make voltage regulator and load tap chamber upgrades (DER Mitigation).	✓	✓	✓
Monitoring and Control (M&C)	1 2	Remote monitoring and control of devices in the substation for circuit monitoring or online devices for enhanced visibility outside the substation	✓		✓
Volt/VAR Optimization (VVO)	1 2	Control of line and substation equipment to optimize voltage, reduce energy consumption, and increase hosting capacity	✓	✓	✓
Workforce Management (WFM)	1 2	Unitil-only investment for Term 2 to improve workforce and asset utilization related to outage management and storm response	✓		

Source: Grid Mod RFP – SOW (Final 8-8-18).pdf; 2022-2025 EDC Grid Modernization Plans; Guidehouse

Table 7. Overview of Term 2, Track 2 Investments

Investment	Investment Area	EDC	Description
Interconnection Automation	**ALF**	**Eversource**	Eversource-only investment for Term 2 to integrate, into a single software, both their existing Distributed Generation (DG) tools and customer interconnection portal.
Probabilistic Power Flow Modeling	**ALF**	**Eversource**	Eversource-only investment that can provide simulation of locational load and generation based on variables such as customer behavior and energy market prices.
Distributed Energy Resources Management System	**DERMS**	**All EDCs**	Software that forms the hub of DER management functions and integrates with other applications such as a Demand Response Management System (“DRMS”) and ADMS, to create the DERMS Platform.
Dynamic DER Interface	**DERMS**	**Eversource**	This investment will upgrade the existing communication and control capability at Eversource and customer-owned large inverter-based DER facilities. These enhancements will enable the DER assets to be commissioned and integrated into the Company’s eECS/ADMS/DERMS control platform to provide real-time monitoring and control capabilities to system operators in support of VVO and other optimization algorithms.
Advanced Short-Term Load Forecasting	**DERMS**	**National Grid**	Improve granular short-term forecasting capabilities to address substation and circuit constraints.
Active Resource Integration	**DERMS**	**National Grid**	Field test a new flexible interconnection option that could enable the Company to accelerate DG interconnections and increase the energy production of DGs per unit of system capacity.
Local Export Power Control	**DERMS**	**National Grid**	Explore the net zero thermal impact capabilities of customer owned Power Control Systems as a tool to lower interconnection costs and expedite interconnection timelines by reducing the need for distribution impact studies for such DER facilities.
DER Mitigation	**DERMS**	**Unitil**	Implement overvoltage protection improvements on the 69 kV side of several distribution substations to mitigate the risk of ground-fault overvoltages. The implementations include modifications to substation and sub-transmission line surge protection, and the addition of voltage transformers and overvoltage relaying schemes where necessary.

Source: 2022-2025 EDC Grid Modernization Plans.

The Department issued an order approving a preauthorized budget for Track 1 investments on October 7, 2022 and an order approving a preauthorized budget for Track 2 investments on

November 30, 2022,[19] in D.P.U. 21-80/21-81/21-82. The preauthorized budget for grid modernization varies by Investment Area and EDC. National Grid has the largest preauthorized budget at $331.8 million, with Communications and VVO representing the largest share ($103 million and $76 million, respectively). Eversource's preauthorized budget is $197.4 million, with M&C representing about 50% ($76.3 million). Unitil's preauthorized track one budget is $10.3 million with VVO making up more than 50% ($5.4 million).

Table 8. Term 2 (2022-2025) Preauthorized Budget, $M

Investment Areas	Eversource	National Grid	Unitil	Total
ADA	--	$37.70	--	**$37.70**
ADMS*	$21.90	$61.00	$1.50	**$84.40**
ALF	$5.00	-	-	**$5.00**
Comms	$38.00	$102.80	$0.82	**$141.62**
DERMS	$16.00	$31.00	$1.20	**$48.20**
M&C	$76.30	$4.10	$1.10	**$81.50**
VVO	$40.40	$76.40	$5.40	**$122.20**
WFM	--	--	$0.25	**$0.25**
IT/OT	--	$18.80	--	**$18.80**
Total	***$197.60***	***$331.80***	***$10.27***	***$539.67***

* Given as $1.66M minus DERMS cost from DPU Order, Oct. 7, 2022, and calculated from DPU Order, Nov. 30, 2022.

Note: The Term 2 preauthorized budget presented excludes Program Management and M&V dollars that were preapproved for each of the three EDCs.

Source: Department Order on Previously Deployed Technologies, D.P.U. 21-80/21-81/21-82 (2022), and Department Order on New Technologies, D.P.U. 21-80/21-81/21-82 (2022).

1.1.3 Evaluation Goals and Objectives

The DPU requires a formal evaluation process (including an evaluation plan and evaluation studies) for the EDCs' preauthorized GMP investments. Guidehouse is completing the evaluation to enable a uniform statewide approach and to facilitate coordination and comparability.

The evaluation measures the progress made toward the achievement of DPU's grid modernization objectives. It uses the DPU-established Performance Metrics, as well as Case Studies that illustrate the performance of specific technology deployments, to help determine if the investments are meeting the DPU's GMP objectives.[20]

1.1.4 Metrics for Evaluation

The DPU-required evaluation involves Performance Metrics and Case Studies of grid modernizing investments. Case studies apply exclusively to the ADA and M&C investment

[19] Massachusetts DPU 21-80/DPU 21-81/DPU 21-82 Order on New Technologies and Advanced Metering Infrastructure Proposals issued November 30, 2022.

[20] The evaluation of GMP investments no longer includes analysis of Infrastructure Metrics (IMs) per the Order, Heading Officer Memorandum, D.P.U. 21-80/21-81/21-82 (2023).

areas as part of the evaluation to help facilitate understanding of how the technology performs in specific instances (e.g., in remediating the effects of a line outage).

1.1.4.1 Performance Metrics

The Performance Metrics assess the performance of all the GMP investments. Table 9 summarizes the Performance Metrics used for the various Investment Areas.[21] This report discusses Performance Metrics that pertain specifically to the ADMS/ALF Investment Area.

Table 9. Performance Metrics Overview

Metric		Description	Applicable IA	Metric Responsibility*
PM-1	**VVO Baseline**	Establishes a baseline impact factor for each VVO-enabled circuit which will be used to quantify the peak load, energy savings, and greenhouse gas (GHG) impact measures.	VVO	All
PM-2	**VVO Energy Savings**	Quantifies the energy savings achieved by VVO using the baseline established for the circuit against the annual circuit load with the intent of optimizing system performance.	VVO	All
PM-3	**VVO Peak Load Impact**	Quantifies the peak demand impact VVO/CVR has on the system with the intent of optimizing system demand.	VVO	All
PM-4	**VVO Distribution Losses without Advanced Metering Functionality (Baseline)**	Quantifies the improvement that VVO/CVR is providing toward minimizing distribution line losses.	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

[21] Performance Metrics outlined in Performance Metrics Compliance Filing, D.P.U. 21-80/21-81/21-82 (2023)

Metric		Description	Applicable IA	Metric Responsibility*
PM-8	**Increase in Circuits and Substations with DMS Power Flow and Control Capabilities**	Examines the deployment and data cleanup associated with deployment of ADMS, primarily by counting and tracking the number of circuits and substations per year.	ADMS/ ALF	All
PM-9	**Control Functions Implemented by Circuit**	Examines the control functions of DMS power flow and control capabilities, focused on the control capabilities including VVO-CVR and FLISR.	ADMS/ ALF	All
PM-10	**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	NG
PM-ES-1	**Advanced Load Flow – Percent Milestone Completion**	Examines the fully developed ALF capability across Eversource's circuit population.	ADMS/ ALF	ES
PM-UTL1	**Customer Minutes of Outage Saved per Circuit**	Tracks time savings from faster AMI outage notification than customer outage call, leading to faster outage response and reduced customer minutes of interruption.	M&C	UTL
PM-NG-1	**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

* Column indicates which EDC is responsible for calculating each metric, for statewide metrics, all EDCs are responsible

Source: Stamp Approved Performance Metrics outlined in D.P.U. 21-80/21-81/21-82, (2024).

1.2 VVO Investment Area Overview

As a part of grid modernization, the Massachusetts EDCs are investing to enable VVO on selected circuits 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 circuits, install equipment, and commission software. Once the software commissioning is complete, and as circuits complete their conditioning and equipment installation, they will become VVO enabled.

Table 10 summarizes preauthorized budget for VVO for Eversource, National Grid, and Unitil.

Table 10. GMP Preauthorized Budget for VVO

Period	Eversource	National Grid	Unitil	Total
Term 1 (2018 – 2021)	$13.00	$10.60	$2.22	**$25.82**
Term 2 (2022 – 2025)	$40.40	$76.40	$5.40	**$122.20**

Source: Term 1 Order and D.P.U. 20-74 (for Term 1 information) and Term 2 Track 1 and Track 2 Orders (for Term 2 information).

The following subsection discusses EDC-specific approaches to VVO.

1.2.1 EDC Approach to VVO

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 phase.

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 circuits 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

Table 12 defines the devices and technologies that each EDC has deployed as part of VVO investment. Section 3 (Performance Metrics) below discuss specifics related to each EDCs' goals and objectives in the VVO Investment Area, while Section 2 below explains the evaluation process.

Table 12. Description of Devices Deployed Under VVO Investment

Device	Description	Term
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.	1 2
Line Sensors	Voltage sensors, which relay verified field measurements to allow VVO algorithm to regulate voltage and reactive power appropriately.	1 2
Load Tap Changer (LTC) Controls	Transformer load tap changers, which automatically adjust circuit voltage based on local measurement. First of the two devices required to regulate voltage on a distribution circuit.	1 2
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.	1 2
Micro-capacitors*	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 circuits.	1 2
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 circuits.	1

* Microcapacitors and Grid Monitoring Line Sensors are VVO devices that are solely being deployed by Eversource. National Grid and Unitil have no plan to deploy these device types at this time. Note that Microcapacitors correspond with Varentec's Edge of Network Grid Optimization (ENGO) hardware, an Eversource investment contained in the Department's GMP annual report template.

Source: Guidehouse

1.2.2 VVO Evaluation Objectives

This evaluation focuses on the progress and effectiveness of the Department preauthorized VVO investments for each EDC toward meeting the Department's grid modernization objectives.[22] Table 13 illustrates the key Performance Metrics relevant for the VVO evaluation.

Table 13. VVO Evaluation Metrics

Metric Type	VVO Evaluation Metrics	ES	NG	UTL
PM	VVO Baseline	✓	✓	✓
PM	VVO Energy Savings	✓	✓	✓
PM	VVO Peak Load Impact	✓	✓	✓
PM	VVO Distribution Losses w/o AMF	✓	✓	✓
PM	VVO Power Factor	✓	✓	✓
PM	VVO GHG Emissions	✓	✓	✓
PM	Voltage Complaints	✓	✓	✓

Source: Guidehouse Stage 3 Evaluation Plan filed February 7, 2024.

Table 14 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 measuring the energy, peak demand, greenhouse gas (GHG), power factor, line loss,

[22] D.P.U. 15-120/15-121/15-122, at 106 (2018).

and voltage complaint impacts of installing the VVO investments and operating VVO (Performance Metrics).

Table 14. VVO M&V Objectives and Associated Research Questions

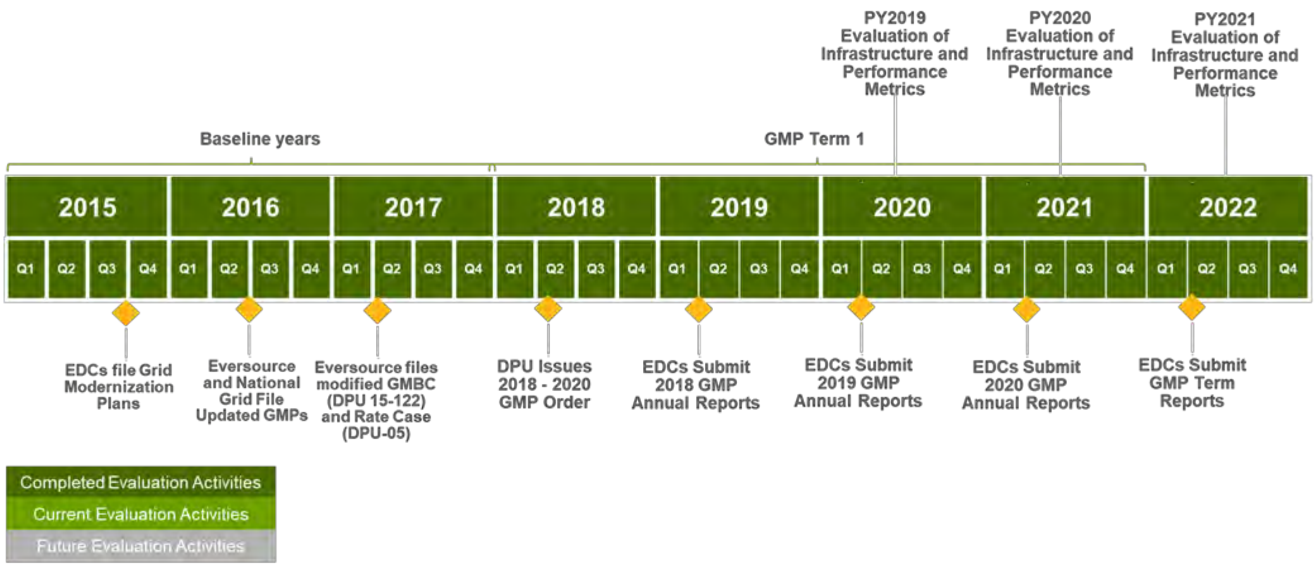
VVO M&V Objective	Associated Research Questions
Energy and Peak Savings by Circuit	• How many energy savings were realized from VVO operating on VVO enabled circuits? • What is the impact on peak load from VVO operating on VVO enabled circuits? • What is the impact on loss reductions and circuit-level power factor associated from VVO operating on VVO enabled circuits? • How much GHG emissions reduction was enabled from VVO operating on VVO enabled circuits?
Voltage Complaints	• What is the impact of VVO-related investments on the number of voltage complaints?

Source: Guidehouse Stage 3 Evaluation Plan filed February 7, 2024

2. VVO Evaluation Process

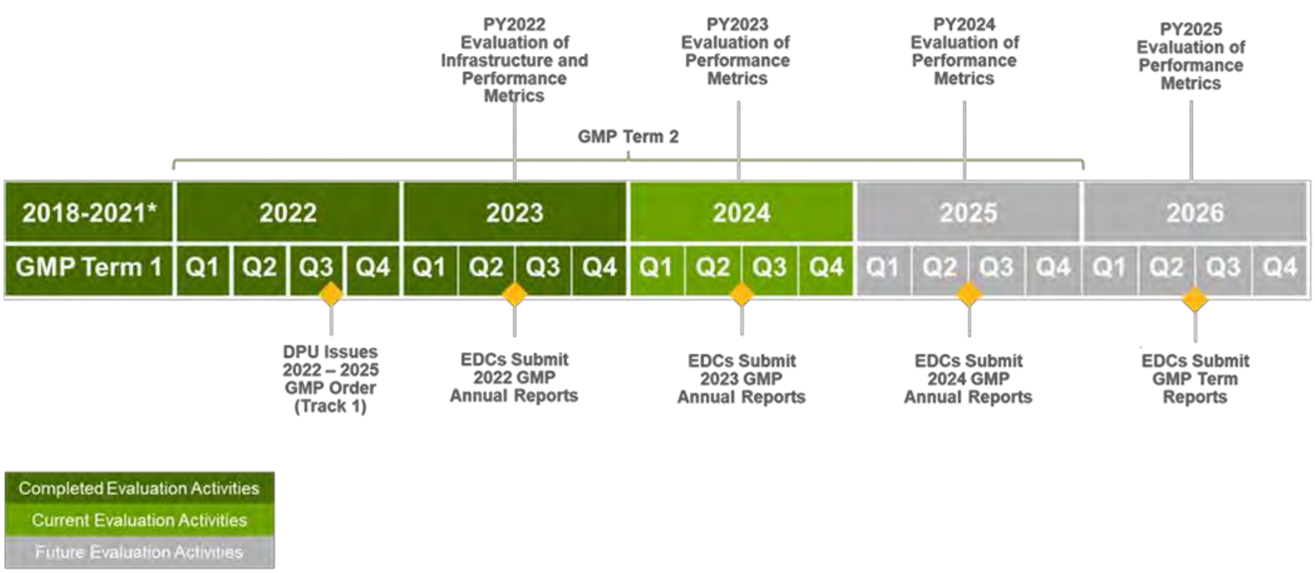
This section presents a high-level overview of the Guidehouse methodologies for the evaluation of Performance Metrics. Figure 1 highlights the Term 1 filing background and timeline of the GMP Order and the evaluation process, and Figure 2 indicates the expected timeline for Term 2.

Figure 1. Term 1 Evaluation Timeline



Source: Guidehouse review of the Department orders and GMP process

Figure 2. Term 2 Evaluation Timeline



Source: Guidehouse review of the Department orders and GMP process

2.1 Performance Metrics Analysis

Guidehouse evaluated Performance Metrics for Eversource, National Grid, and Unitil. Table 15 describes the Performance Metrics evaluated for PY 2023.

Table 15. Performance Metrics Overview

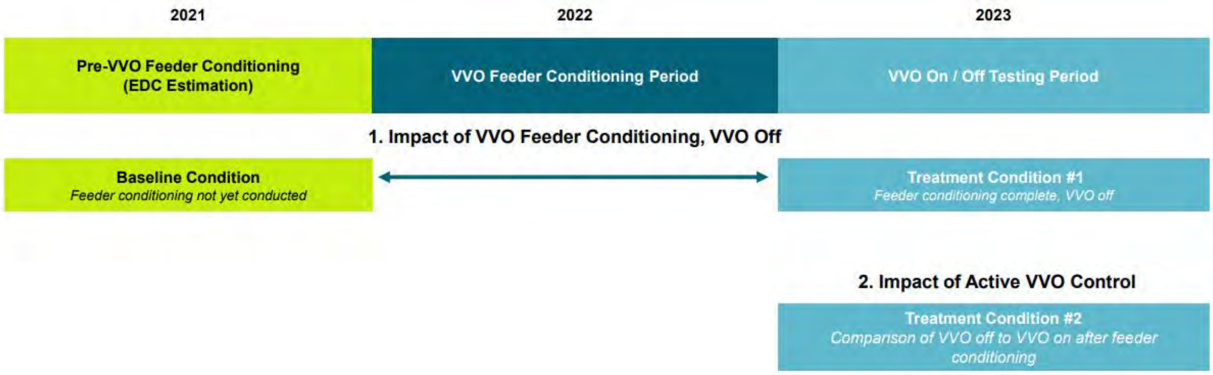
PM	Performance Metrics	Description
PM-1	**VVO – Baseline**	Establishes a baseline impact factor for each VVO enabled circuit which will be used to quantify the peak load, energy savings, and GHG impact measures
PM-2	**VVO – Energy Savings**	Quantifies the energy savings achieved by VVO using the baseline 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**	Quantifies the improvement that VVO/CVR is providing toward minimizing distribution losses.
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: Performance Metrics stamp approved on February 1, 2024 in D.P.U 21-80/21-81/21-82.

2.1.1 Scope of Performance Metrics Analysis

Guidehouse's Performance Metrics evaluation aims to assess the impacts of active VVO control for substations with VVO capability. Figure 3 below highlights the scope of potential VVO impacts that may be realized in a VVO scheme. This includes impacts from the circuit conditioning stage (Impact #1), where, for example, regulators are commissioned into the system prior to initiation of VVO, and regulators can be set at a lower voltage setpoint to reduce the circuit voltage. Per the Stage 3 Evaluation Plan, Guidehouse has estimated the impact of active VVO control (Impact #2 in Figure 3).

Figure 3. Scope of Impacts for an Illustrative VVO System Commissioned by 2023



Source: Guidehouse

Quantifying the impact of active VVO control requires interval measurements of circuit-level voltage and power demand while the voltage and reactive power controls are operated in both baseline (non-VVO, or VVO Off) and VVO (VVO On) modes. 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. Following a consistent On/Off testing schedule that covers these time periods helps to ensure that the VVO impact estimates provided reflect what may be reasonably expected during a calendar year.

Given only Impact #2 in Figure 3 is being assessed in this evaluation, Performance Metric estimates provided in this report may be conservative estimates of the full impact of implementing a VVO scheme. For instance, during discussions conducted in early 2024, Unitil reported that during the feeder conditioning stage they had lowered the bandcenters for the Townsend substation's LTC by 1.9% and 1.2% from the pre-conditioned baseline state for circuits 15W16 and 15W17, respectively.

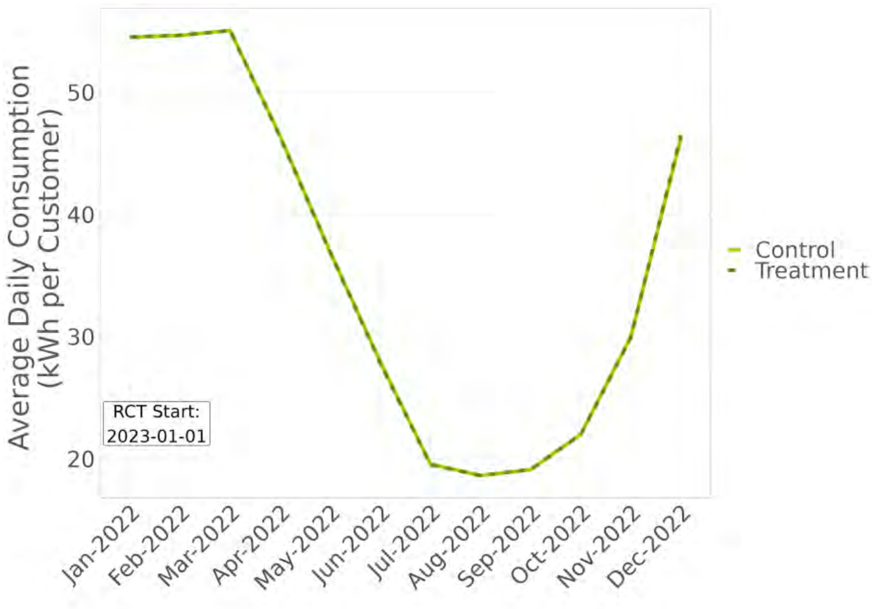
Guidehouse is currently conducting planning discussions with Unitil to determine whether the data necessary for evaluation of these impacts is available for the Townsend substation and other comparable substations without VVO. If the data exist, Guidehouse will work with the EDCs to determine the best course of action for quantifying the impacts of circuit conditioning.

2.1.2 Assessment of Randomized Control Trial

Evaluators and utilities rely on a randomized controlled trial (RCT) approach to estimate savings attributed to active VVO control, wherein days during the VVO testing period are randomly divided between a group where VVO is turned On and a group where VVO is turned Off. When testing is implemented with minimal interruptions to the On/Off testing schedule, random assignment leads to an unbiased estimate of the savings caused by the intervention. This is because On/Off testing should enable the collection of similar streams of data recorded during hot days, cold days, days with high solar insolation, etc.

Prior to estimating final Performance Metric impacts, Guidehouse assessed the data received to determine whether the RCT design of VVO On/Off testing yielded balanced data. To validate an RCT within the energy efficiency / demand response space, one can compare load between the two groups prior to when an intervention is occurring. The illustrative example below in Figure 4 is from a separate program evaluation using an RCT design that shows, prior to the intervention, the treatment and control groups have very similar usage. In this example, similarity in pre-intervention usage is necessary to ensure that quantified impacts attributed to program treatment are not also due to underlying differences in consumption unrelated to the program.

Figure 4. Illustrative Example of a Valid RCT Program Design

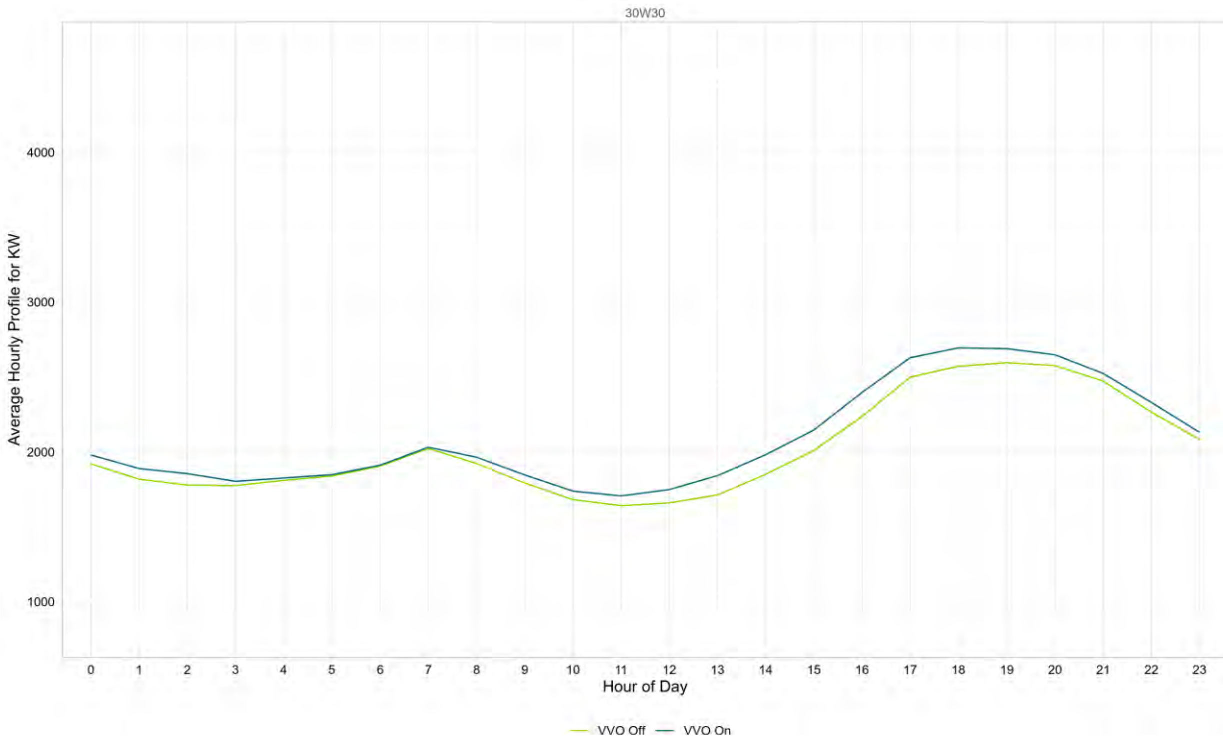


Source: Guidehouse

To validate the RCT design for National Grid and Unitil, Guidehouse investigated the differences in demand across days for Unitil “placebo” circuits 30W30 and 40W42. These circuits have similar characteristics to Unitil’s Townsend substation’s VVO circuits (e.g., line length, connected distributed generation, and customer count). Since these “placebo” circuits did not go through VVO On/Off testing, Guidehouse superimposed Townsend’s VVO On/Off testing schedule to see if there were meaningful differences in load profiles for these circuits when VVO was engaged versus when VVO was disengaged. Differences should be minimal to none, as circuits 30W30 and 40W42 did not undergo VVO On/Off testing.

Figure 5 shows Unitil circuit 30W30 average load profiles when Unitil activated VVO control on its Townsend circuits (i.e., VVO On) and when Unitil deactivated VVO control (i.e., VVO Off). When comparing these load profiles, it is apparent that there were meaningful differences in load across the two superimposed periods. The conclusion from Figure 5 is that there is likely an imbalance in observable characteristics that influence demand between VVO On and Off days, and so the RCT program design is likely to be invalid.

Figure 5. Average Load Profile Between Unitil VVO On and Off Days, "placebo" Circuit 30W30

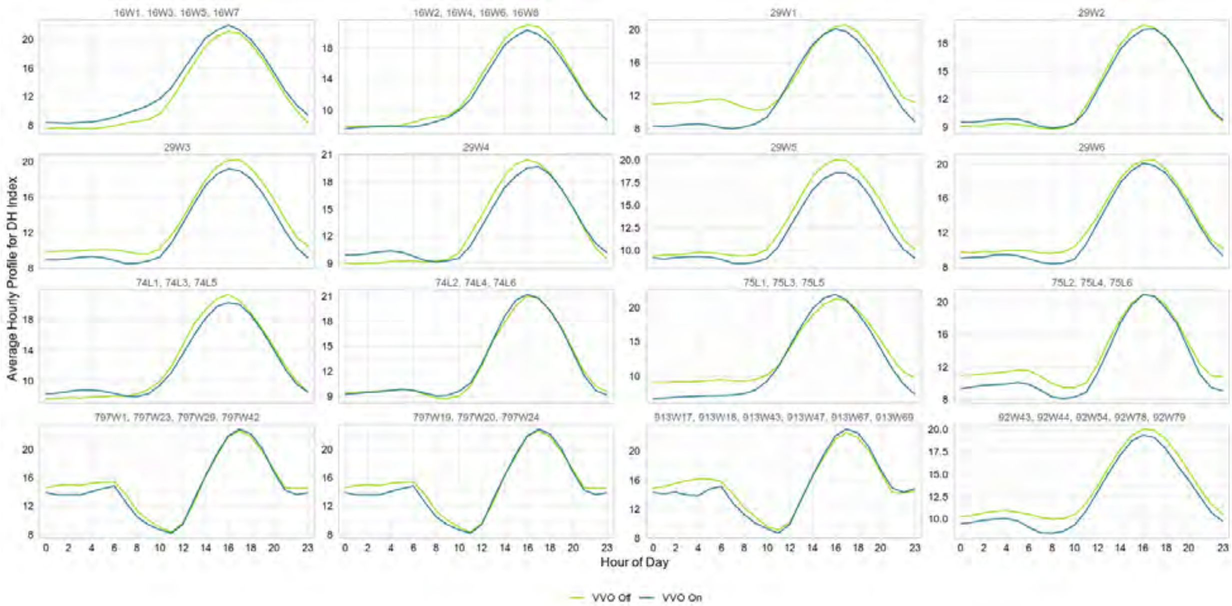


Source: Guidehouse analysis

Differences in load between VVO Off and VVO On days can be an indicator of bias in the RCT program design. However, given Guidehouse is estimating differences in load between VVO On and VVO Off days to estimate VVO energy savings, assessing balance solely using "placebo" circuit load profiles is not sufficient, as load is endogenous to estimation of energy savings. For this reason, Guidehouse also based its assessments of RCT balance by analyzing the balance of temperature and solar insolation between VVO On and VVO Off days. Given temperature and solar insolation have an impact on observed circuit load, marked differences in temperature and solar insolation between VVO On and VVO Off days would be indicative of an invalid RCT program design.

Figure 6 presents an assessment of differences in average DH index profiles for each group of National Grid circuits that underwent VVO On/Off testing in PY 2023. As is apparent, some circuits oversampled higher-DH index days when VVO was disengaged (indicated by the green line being above the blue line), and other circuits oversampled lower-DH index days (indicated by the blue line being above the green line). For example, Maplewood odd-numbered circuits (16W) had oversampled higher-DH index days when VVO was disengaged relative to when VVO was engaged. Given the DH index is positively correlated with demand, this difference indicates that there is likely an oversampling of higher-demand days when VVO was disengaged relative to when VVO was engaged. Therefore, if the data were to be left as-is and used in regression modeling, the estimated impact of VVO for the odd-numbered Maplewood substation circuits would be biased upward, as the impact would include the true impact of VVO control as well as the impact of differences in temperature and solar insolation between VVO On and VVO Off days.

Figure 6. Average National Grid DH Index Profiles between VVO On and Off Days, Before Matching



Source: Guidehouse analysis

Based on extensive review of VVO On/Off status logs, substation SCADA, temperature data, and solar insolation data, Guidehouse identified that the RCT design of the VVO On/Off testing was invalid for the following reasons:

- Unitil On/Off testing was conducted in a consistent manner throughout the second half of 2023, testing in a week on / week off cadence from May 28 through December 31, 2023. While the On/Off schedule was followed according to plan, there were several heat waves that occurred in the summer months that coincided with weeks where VVO was engaged. This led to an oversampling of higher-temperature days when VVO was engaged relative to when VVO was disengaged.

- National Grid On/Off testing was not conducted in a consistent manner. When conducted correctly, On/Off testing follows a pre-determined schedule (e.g., testing from January 1 through December 31) in a pre-determined cadence (e.g., day on / day off), differing across VVO substations and station banks. However, instead of following a pre-determined schedule, every VVO circuit underwent random, and sometimes extended, pauses to On/Off testing, with VVO either being left in its engaged state or its disengaged state during these extended pauses. For some circuits, this led to an oversampling of higher-temperature days when VVO was engaged relative to when VVO was disengaged (e.g., VVO On/Off testing was paused for several West Salem 29W circuits throughout the summer and VVO was left in its engaged state). For other circuits, this led to an oversampling of lower-temperature days when VVO was engaged relative to when VVO was disengaged.

Based on the above findings, Guidehouse provides targeted recommendations in Section 4 to increase the likelihood of a valid RCT program design in future years.

2.1.3 Rebalancing the Randomized Control Trial via Matching

When random assignment proves infeasible or ineffective, quasi-experimental design (QED) evaluation methods can be used. Quasi-experimental approaches rely on a non-random comparison group. For VVO, Guidehouse can use a Euclidean distance matching technique, which seeks to create an "as-if" RCT by balancing distributions of observable variables when the treated (VVO On) and non-treated (VVO Off) are not equal.[23] Given findings from Guidehouse's assessment of the RCT design of VVO On/Off testing, isolating an unbiased impact specific to the program is not possible without perfect model specification, which is very unlikely to achieve.

To rebalance the RCT design of VVO On/Off testing, Guidehouse conducted the following six steps:

1. Superimpose each LTC or circuit's VVO On/Off schedule onto "placebo" circuit load data for circuits 30W30 and 40W42[24];
2. When VVO is disengaged, via regression modeling estimate "placebo" circuit impact of cooling degree hours (base 65F), heating degree hours (base 65F), and solar insolation on "placebo" circuit load;
3. Calculate a degree-hour (DH) index, which combines and weights cooling degree hours, heating degree hours, and solar insolation based on their anticipated impact on "placebo" circuit load;
4. Bifurcate each circuit's DH index data into two streams, VVO On and VVO Off;
5. For each VVO On day, selecting a VVO Off day match based on a comparison of VVO On and VVO Off day DH index profiles; and
6. If matches made underlying differences in temperature profiles worse than prior to matching, Guidehouse flipped the order of matching, instead matching VVO On days to VVO Off days.

Steps 1-3: Construct Degree-Hour Index for Use in Matching

Guidehouse constructed a DH index to assess differences in a combination of three variables: cooling degree hours (base 65F), heating degree hours (base 65F), and solar insolation. More detail on the construction of the DH index is provided in Appendix 4.2C.1. At a high level, the DH index provides an overall assessment of differences in conditions that are correlated with circuit loads without the need to directly assess differences in "placebo" circuit loads. The DH index was calculated on a LTC or circuit-specific basis via addition of weighted cooling degree hours, heating degree hours, and solar insolation. Weights were determined for each LTC or

[23] Angrist, J. D., & Pischke, J.-S. (2013). *Mostly harmless econometrics: An empiricists companion* (pp. 69). Content Technologies Inc.

[24] In most cases, VVO control is conducted for all circuits connected to one LTC. This was the case for the Maplewood, East Methuen, East Bridgewater, East Dracut, Easton, and Stoughton substations. In some cases, such as for West Salem 29W circuits, VVO control is conducted at the circuit-level. As such, Guidehouse conducted assessments of balance at the LTC-level for all circuits except for circuits connected to West Salem 29W, which received circuit-specific VVO control and therefore circuit-specific balance checks.

circuit via linear regression conducted on “placebo” circuits to determine sensitivity of load to the three variables when VVO is disengaged.

Steps 4-6: Conduct Matching and Assess Match Quality

Once the DH index was calculated, Guidehouse selected a matched VVO Off day for each VVO On day. This process involved finding the VVO Off day in each circuit’s VVO On/Off testing period with DH index profile that most closely matched the DH index profile of each VVO On day. Guidehouse calculated the Euclidean distance[25] in DH index profiles for daytime hours (10am – 10pm) between each VVO On day and all potential VVO Off day candidates. Guidehouse then selected the top VVO Off days associated with the lowest differences in observed DH index profiles. Put more simply, for each VVO On day, the process included the following steps:

1. Calculate the average DH index profile between 10am and 10pm for each VVO On day.
2. Calculate the average DH index profile between 10am and 10pm for each VVO Off day.
3. Calculate the Euclidean distance between the VVO On day’s DH index profile and each VVO Off day’s DH index profile.
4. Select the VVO Off day associated with the lowest Euclidean distance (i.e., the VVO Off day whose DH index profile is most similar to that of the VVO On day).

Matches were selected with replacement, meaning that a given VVO Off day could be matched to multiple VVO On days.

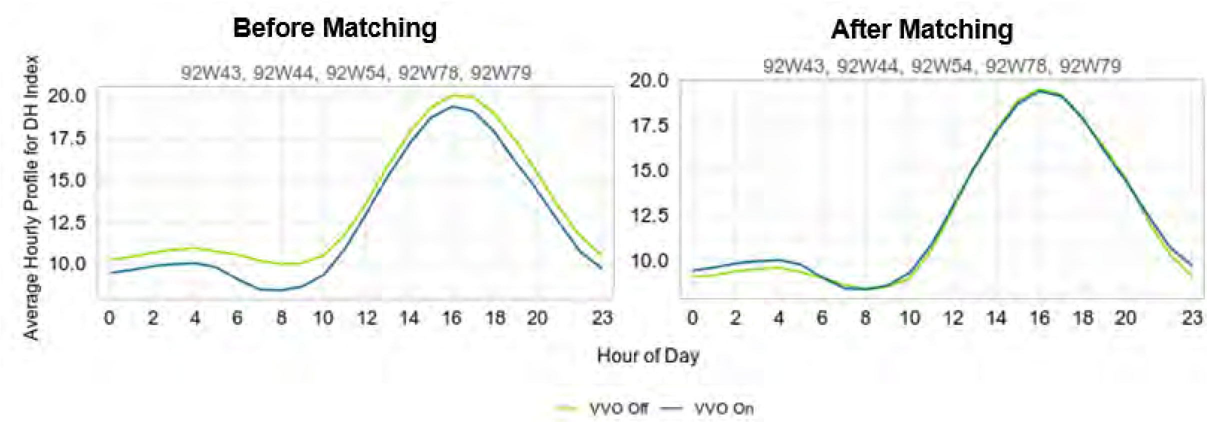
If matches made underlying differences in temperature profiles worse than prior to matching, Guidehouse flipped the order of matching, instead matching VVO On days to VVO Off days. This was sometimes required, as some circuits had extended periods in which VVO was On during the VVO On/Off testing period. This limited the number of candidate VVO Off days that would serve as a suitable match for a VVO On day, thereby requiring matching of VVO On days to a smaller set of VVO Off days. Appendix C.3 details the match direction (i.e., VVO On matched to VVO Off, or VVO Off matched to VVO On) selected for each National Grid and Unitil circuit.

Figure 7 illustrates the average hourly DH index profiles between VVO On days and VVO Off days before matching and after matching for National Grid’s Easton substation. Before matching, VVO On days had markedly higher temperature profiles relative to VVO Off days. After matching, there is near-perfect overlap in VVO On and VVO Off day temperature profiles, with some hours having slightly lower temperatures and some hours having slightly higher temperatures when VVO was engaged than when VVO was disengaged. The similarity in temperature profile across many of the 24 hours suggests that the demand of the Easton circuits would be similar between VVO On and VVO Off days in the absence of active VVO

[25] A Euclidean distance is calculated by taking the square root of the sum of squared differences between the two vectors. In the context of matching VVO Off and VVO On days, the Euclidean distance is the squared difference between an observed DH index on a VVO On day and observed DH index on VVO Off days. VVO Off days matched to each VVO On day were VVO Off days that minimized the Euclidean distance in the DH index. Put more simply, matched VVO Off days were days that had observed DH index values most like DH index values observed on VVO On days.

control. Therefore, compared to all VVO Off days, the matched VVO Off days serve as a better approximation of baseline (i.e., counterfactual) conditions during VVO On days.

Figure 7. Average DH Index Profiles Before and After Matching, National Grid Easton Substation



Source: Guidehouse analysis

The process of matching is not expected to produce perfect controls, but instead to find the most comparable set of days as possible for use in the regression analysis. Difference-in-differences regression approaches, which model the difference in (a) the load profiles between circuits with VVO and circuits without VVO, and (b) the load profiles between VVO On and VVO Off days, can control for a remaining imbalance between VVO On and VVO Off days after matching. However, National Grid and Unitil circuits have heterogeneous load profiles due to differences in length, loading conditions, customer mix, and other factors. This makes the identification of comparable circuits for use in approaches such difference-in-differences modeling a time-intensive effort. Further, even with a comparable circuit, availability of required SCADA is not always guaranteed. Instead, Guidehouse improved the balance in DH index profiles via Euclidean distance matching to shrink differences in DH index profiles between VVO On and VVO Off days, then conducted regression modeling on matched data for each individual circuit to estimate the impact of VVO on voltage, demand, energy, and other outcome variables.

2.1.4 Estimating VVO Performance Metrics

After conducting matching and constructing a set of matched analysis data, Guidehouse estimated the impacts of active VVO control (Impact #2 in Figure 3) for each individual circuit that underwent VVO On/Off testing. Guidehouse then aggregated these granular impacts to present impacts of VVO across all circuits for each EDC, which are presented in Section 3.

To estimate VVO impacts, Guidehouse estimated statistical regression models using matched data. Each model estimated changes in energy, peak demand, power factor, and voltage on a per-circuit basis as a function of VVO status (i.e., whether the time interval is VVO engaged or disengaged), season, weekday/weekend, temperature, solar insolation, and hourly fixed effects. Formal model specifications with additional input variable detail may be found in Appendix A, and EDC-specific discussions of performance metric results in Section 3.2 provide additional details on the analysis approach utilized by Guidehouse.

All estimates of uncertainty presented in this report are derived from standard errors that have been clustered at the individual circuit level. Since the current analysis includes estimating impacts relative to baseline conditions on VVO Off days, the VVO impacts can be considered as incremental relative to any impacts realized by VVO conditioning (i.e., incremental to Impact #1 in Figure 3).

3. VVO Performance Metrics

3.1 Data Management

Guidehouse worked with the EDCs to collect data to complete the evaluation for the assessment of VVO Performance Metrics. The sections that follow highlight Guidehouse's data sources and data QA/QC processes used in the evaluation of Performance Metrics.

3.1.1 Data Sources

Guidehouse used numerous datasets to evaluate Performance Metrics. The subsections that follow summarize the data sources used to evaluate Performance Metrics.

3.1.1.1 VVO Supplemental Data Template

The VVO supplemental data collection template includes additional information unique to the VVO Investment Area. Table 16 summarizes the information requested and included in the analysis. The EDCs provided data to the team in the data collection template or submitted it in a separate file. Guidehouse requested information at the circuit level where possible.

Table 16. VVO Supplemental Data

Information	Description
Actual/Planned VVO Schedule	Actual and updated planned VVO deployment start/end dates by circuit, including circuit conditioning, load rebalancing, phase balancing, VVO commissioning, VVO enabled, and On/Off testing.
Customer DR Events	DR events (time-stamped log of any systemwide DR (or similar), for example: ISO-NE DR, EDC direct load control programs, EDC behavioral DR programs).
Voltage Complaints	Voltage-related complaints based on voltage perturbation (e.g., high voltage, low voltage, flicker) and duration (e.g., multiple days, sporadic).

Source: Guidehouse Stage 3 Evaluation Plan filed February 7, 2024

3.1.1.2 Additional VVO Data Required for Performance Metrics Evaluation

Table 17 summarizes the additional data inputs required for Performance Metrics analysis. Excluding both the weather data and solar insolation data, the evaluation team obtained all fields from the EDCs.

Table 17. Additional Data Required for Evaluation Performance Metrics

Data Type	Description
EDC system information	• Circuit characteristics (e.g., rated primary voltage, rated capacity, circuit 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)	• Circuit head end data (voltage, real power, current, apparent power or reactive power, power factor) • VVO status flags (e.g., VVO On/Off)
VVO system information	• Time-stamped log of VVO state changes between on and off states and any other VVO modes
Weather data	• Hourly temperature data from selected weather stations and collected by the National Oceanic and Atmospheric Administration (NOAA)
Solar insolation data	• Quarter-hourly solar insolation data collected by the National Renewable Energy Laboratory (NREL) to capture changes in load and voltage due to solar generation

Source: Guidehouse Stage 3 Evaluation Plan filed February 7, 2024

3.1.2 Data QA/QC Process

Guidehouse reviewed all data provided for the Performance Metrics analysis upon receipt of requested data. The Quality Assessment/Quality Control (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 circuit receiving VVO investments and include variables needed to facilitate analysis of Performance Metrics, including voltage, real power, and reactive or apparent power.
- Time series data are complete in time and extent of devices and do not include erroneous data (e.g., interpolated values and outliers).
- Voltage complaints data have been received for each circuit receiving VVO investments and are at an adequate level of detail for analysis.

After the 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 the Performance Metrics analysis.

3.2 VVO Performance Metrics Analysis and Findings

Guidehouse presents findings from the Performance Metrics analysis for the VVO Investment Area in the following subsections.

3.2.1 Statewide Comparison

This section summarizes the Performance Metrics analysis results and key findings for Eversource, National Grid, and Unitil. Results and key findings are provided for circuits that either conducted VVO On/Off testing in PY 2023 (National Grid and Unitil) or completed VVO On/Off testing prior to PY 2023 (Eversource).

It can be difficult to reliably compare the results from Performance Metrics analysis between Eversource, National Grid, and Unitil. For example, there are differences in the granularity of telemetry (e.g., 5-minute versus 15-minute), data quality at different times of the year (e.g., sustained pauses in VVO On/Off testing for one EDC, data outages during On/Off testing for another EDC). As such, certain portions of the M&V period, such as the Spring season, may be represented more for one EDC than the other. Additionally, there are numerous differences in DG penetration, customer types, and geographic areas served by Eversource, National Grid, and Unitil circuits that limit the ability to directly compare Eversource, National Grid, and Unitil VVO outcomes. Lastly, since Eversource did not conduct On/Off testing in PY 2023,[26] all results Eversource results have been extrapolated using 2023 substation SCADA and PY 2022 evaluation results.

3.2.1.1 Performance Metrics Analysis Results

Table 18 includes the PY 2023 Performance Metrics results for National Grid and Unitil, which includes all circuits that went through VVO On/Off testing during PY 2023.

Table 18. Performance Metrics Results from On/Off Testing Conducted in PY 2023

Performance Metrics		National Grid		Unitil	
Circuits Included in Evaluation		43		3	
PM-1	PY 2023 Baseline	5,184,073 MWh		253,380 MWh	
PM-2	Energy Savings – All Hours VVO On†	5,072 ± 237 MWh	1.275 ± 0.036%	438 ± 42 MWh	1.525 ± 0.146%
	Energy Savings – Actual VVO On Hours†	2,540 ± 121 MWh	1.275 ± 0.036%	229 ± 22 MWh	1.525 ± 0.146%
-	Voltage Reduction‡	0.320 ± <0.001 kV	2.306 ± 0.002%	0.190 ± <0.001 kV	1.341 ± 0.007%
-	CVRf^	0.92		1.14	
PM-3^	Peak Demand Reduction	1,737 ± 141 kW	1.298 ± 0.102%	20 ± 41 kW	0.363 ± 0.619%
PM-4	Reduction in Distribution Losses	0.77%		0.21%	
PM-5	Change in Power Factor	0.004 ± 0.001	0.394 ± 0.082%	0.001 ± <0.001	0.11 ± 0.09%
PM-6	GHG Reductions (CO_2) All Hours VVO On*	1,466 ± 68 tons CO_2		127 ± 12 tons CO_2	
	GHG Actual VVO-On Hours†	734 ± 35 tons CO_2		66 ± 6 tons CO_2	
PM-7	Voltage Complaints	255 (50% increase from 2015 – 2017 baseline period average)		4 (200% increase from 2015 – 2017 baseline period average)	

* Total energy savings are determined by calculating the energy savings across the entirety of each substation's testing period, assuming VVO to be engaged during the entire period.

[26] Eversource did not conduct VVO On/Off testing at substations that were in-service for more than one full calendar year and had already completed On/Off testing previously. This is in-line with the Stamp Approved Performance Metrics outlined in Performance Metrics Compliance Filing, D.P.U. 21-80/21-81/21-82 (2023). Further discussion on VVO On/Off testing and the recommendation to limit the testing period can be found in AG-4-6, D.P.U. 22-40 (2023).

† Actual VVO On Hours are the number of hours in the clean analysis data that were VVO engaged between each substation's testing period.
‡ Voltage results are removed for Maplewood and West Salem circuits due to limited/poor quality voltage data within SCADA data received.
^ CVRf value is calculated as change in percent energy savings divided by change in percent voltage savings. Maplewood and West Salem circuits were excluded from this calculation due to limited/poor quality voltage data within SCADA data received.
^^ The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.
Note: Townsend, East Bridgewater, Easton, Stoughton, Maplewood, and West Salem circuits evaluated had a system voltage of 13.8 kV while East Methuen and East Dracut circuits evaluated had a system voltage of 13.2 kV.
Source: Guidehouse analysis

Table 19 includes the PY 2023 Performance Metrics results for Eversource, which includes circuits that completed VVO On/Off testing prior to PY 2023. The following EDC-specific subsections provide further detail.

Table 19. Eversource Performance Metrics Results for Circuits that Completed VVO On/Off Testing Prior to PY 2023

Performance Metric	Appendix 1 Metric	Eversource
PM-1	Annual Energy Delivered w/o VVO (MWh)	576,933 MWh
PM-2	Annual Energy Savings w/ VVO (MWh)	1,270 MWh
	Annual Peak Load w/o VVO (MW)	2.5 MW
PM-3	Annual Peak Load Reduction w/ VVO (MW)	-0.99 MW
	Distribution Losses w/o VVO (MWh)	12,058 MWh
PM-4	Reduction of Distribution Losses w/ VVO (MWh)	-388 MWh
	Power Factor w/o VVO	0.9576
PM-5	Power Factor w/ VVO	0.9577
	GHG Emissions w/o VVO (metric tons)	167 tons CO_2
PM-6	Reduction of GHG Emissions w/ VVO (metric tons)	367 tons CO_2
PM-7	# Voltage Complaints, Plan Year	63 complaints
	Change # of Voltage Complaints (Baseline minus Plan Year)*	15 complaint increase

* The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.
Source: Guidehouse analysis

3.2.1.2 Key Findings and Recommendations

Guidehouse has the following key findings to provide for Eversource circuits that completed On/Off testing prior to PY 2023:

- Eversource did not conduct VVO On/Off testing in PY 2023 at any VVO substations.[27] In order to estimate the Performance Metrics, Guidehouse combined evaluation results from the PY 2022 evaluation as well data received for the PY 2023 evaluation. Guidehouse included the Performance Metrics impacts from the PY 2022 evaluation, the SCADA

[27] Eversource did not conduct VVO On/Off testing at substations that were in-service for more than one full calendar year and had already completed On/Off testing previously. This is in-line with the Stamp Approved Performance Metrics outlined in Performance Metrics Compliance Filing, D.P.U. 21-80/21-81/21-82 (2023). Further discussion on VVO On/Off testing and the recommendation to limit the testing period can be found in AG-4-6, D.P.U. 22-40 (2023).

interval data from Eversource that contained time-stamped measurements of voltage, real power, apparent power, and reactive power for PY 2023, and time-stamped logs of VVO state changes between VVO On (engaged) and Off (disengaged) states contained within the SCADA data provided by Eversource for PY 2023.

- During the PY 2022 M&V period, Eversource's Agawam, Piper, Podick, and Silver substations realized 0.41% energy savings and 1.24% voltage reduction associated with VVO, equating to a CVR factor of 0.60. Using these results and substation SCADA collected during PY 2023, Eversource's Agawam, Piper, Podick, and Silver substations realized 1,270 MWh energy savings associated with VVO. Energy savings of 1,270 MWh yielded a 367 short ton reduction of CO_2 emissions. Lastly, VVO circuits experienced an increase (0.99 MW) in peak load and an increase in distribution losses when VVO was engaged (388 MWh).
- For Eversource, a total of 63 voltage complaints were received from customers connected to the Agawam, Piper, Podick, and Silver VVO circuits during the PY 2023 M&V period. This is a 31% increase relative to the average voltage complaints per year received between 2015 – 2017. The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.
- Eversource reported conducting deployment of VVO investments throughout PY 2023. Eversource anticipates completing additional deployment during PY 2024 and PY 2025. Once VVO investments are deployed, Eversource plans to control VVO within its ADMS system. Eversource plans to complete its ADMS investment and commission and enable VVO at its Term 2 substations in PY 2025. Therefore, Guidehouse will not conduct any regression-based estimation of Performance Metrics for Eversource until the PY 2025 evaluation. Until then, all Performance Metrics will continue to be estimated for only the Agawam, Piper, Podick, and Silver substations using PY 2022 evaluation results and SCADA collected during the evaluation period of interest (e.g., PY 2023).

Guidehouse has the following key findings to provide for National Grid and Unitil circuits that underwent On/Off testing during PY 2023:

- During the PY 2023 M&V period, National Grid's East Bridgewater, East Dracut, East Methuen, Easton, Maplewood, Stoughton, and West Salem substations realized 2,540 MWh (1.3%) energy savings and 0.320 kV (2.3%) voltage reduction associated with VVO. National Grid's CVR factor was 0.92. During the same M&V period, Unitil's Townsend substation realized 229 MWh (1.5%) energy savings and 0.19 kV (1.3%) voltage reduction associated with VVO. Unitil's CVR factor was 1.14. National Grid energy savings of 2,540 MWh yielded a 734 short ton reduction in CO_2 emissions. Unitil energy savings of 229 MWh yielded a 66 short ton reduction of CO_2 emissions.
- National Grid VVO circuits experienced a statistically significant decrease in peak load (1.3%), a statistically significant increase in power factor (0.39%), and a decrease in distribution losses (0.77%) when VVO was engaged. Unitil VVO circuits experienced a statistically insignificant decrease in peak load (0.36%), a statistically significant increase in power factor (0.11%), and a decrease in distribution losses (0.21%).
- For National Grid, a total of 255 voltage complaints were received from customers connected to the East Bridgewater, East Dracut, East Methuen, Easton, Maplewood, Stoughton, and West Salem VVO circuits during the period. This is a 50% increase relative to the average voltage complaints per year received between 2016 – 2017. For Unitil, a

total of 4 voltage complaints were received from customers connected to the Townsend VVO circuits during the period. This is a 200% increase relative to the average voltage complaints per year received between 2015-2017. The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.

In 2024 and beyond, Guidehouse recommends that Eversource, National Grid, and Unitil:

- Continue to monitor performance of the VVO scheme after M&V has been completed, such as ensuring capacitor banks and pole-top regulators are responding as anticipated to VVO/ADMS commands. The EDC's performance metric estimates are reflective of the VVO scheme as it was in PY 2023. Continuously monitoring the VVO scheme to ensure all line devices are responding as anticipated will be important in ensuring evaluated performance is maintained.
- Provide SCADA data for one or two "placebo" circuits (i.e., circuits without VVO schemes) for the PY 2024 and PY 2025 evaluations. Using data provided for two "placebo" circuits within the PY 2023 evaluation, Guidehouse identified that the EDC's On/Off testing data was biased by extended pauses to the On/Off testing conducted. In some cases, this led to an oversampling of hotter days when VVO was engaged relative to when VVO was disengaged, and in others this led to an oversampling of cooler days when VVO was engaged relative to when VVO was disengaged. This poses a threat to the RCT program design of On/Off testing and required the data to be rebalanced via a matching algorithm summarized in Section 2.1.3. Providing SCADA for "placebo" circuits will allow Guidehouse to assess whether testing data for the VVO circuits needs to be rebalanced.
- Increase the cadence of VVO On/Off testing. Guidehouse recommends shifting from week on / week off testing to either testing daily (i.e., day on / day off), every other day, every two days, every three days, or every four days (i.e., four days on / four days off). Increasing the cadence of testing will improve the likelihood of balance in temperatures, day types, and other factors that influence grid conditions. This ultimately allows for the RCT design of VVO On/Off testing to yield unbiased Performance Metric estimates.
- Once a schedule with increased cadence has been determined for VVO On/Off testing, the EDCs should make every effort to comply with the pre-determined schedule. If compliance is achieved, there should be a balance of temperatures and other conditions correlated with system demand, voltage, and power factor, thereby leading to VVO impact estimates that are unbiased. Failure to comply, such as pausing On/Off testing and leaving VVO in its engaged or disengaged state for an extended period of time, will increase the likelihood of an invalid RCT in the PY 2024 and PY 2025 evaluations. If an invalid RCT is identified, Guidehouse will need to rebalance the data using the approach outlined in Section 2 to reduce the risk of biased VVO impact estimates.
- To identify causes of lower performance during peak demand hours, Unitil may consider investigating data collected at pole-top regulators and capacitor banks to determine whether there are differences in how voltage is lowered and flattened during peak hours (4:00 p.m. to 10:00 p.m., non-holiday weekdays between May 1 and September 30) relative to all other hours of the day. It may be the case that Townsend circuits' line devices were not responding as-expected to VVO signals during the identified peak period.
- To identify causes of lower performance, particularly for the West Salem substation (which underwent estimated energy increases when VVO was engaged) and the Easton substation (which underwent estimated peak demand increases when VVO was engaged), National Grid should consider assessing data collected from devices along each connected

circuit. For example, end-of-line feeder monitor voltage data will enable an investigation of whether voltage is performing as expected at the end-of-line when VVO is engaged. In addition, if data are collected for points between the circuit head-end and end-of-line, assess of whether certain zones of a circuit are under- or over-performing relative to the aggregate impact detected using SCADA collected at the circuit head-end.

3.2.2 Eversource

This section discusses Eversource's VVO Performance Metrics results for PY 2023.

3.2.2.1 Evaluation Methodology

Guidehouse worked with Eversource to collect data necessary to complete the evaluation of the VVO Performance Metrics. The sections that follow highlight the analysis data construction, analysis data cleaning, and the analysis approach.

Table 20 below details Eversource's VVO substations. In PY 2022, Eversource had completed VVO On/Off testing at all four of its Term 1 substations, which included the Agawam, Piper, Podick, and Silver substations. In PY 2023, Eversource enabled VVO throughout the course of the year at all four of its Term 1 substations.[28] For its remaining substations, Eversource reported conducting deployment of VVO investments throughout PY 2023. Eversource anticipates completing additional deployment during PY 2024 and PY 2025. Once VVO investments are deployed, Eversource plans to control VVO within its ADMS system. Eversource plans to complete its ADMS investment and commission VVO at its Term 2 substations in PY 2025.

Table 20. Eversource VVO Substations

Substation	
Agawam*	Duxbury
Piper*	Franconia
Podick*	Gunn
Silver*	Mashpee
Amherst	Montague
Breckwood	Orchard
Cross Road	Oswald
Cumberland	Wareham
Doreen	

* Substations that have completed VVO On/Off testing prior to PY 2023.

Source: Guidehouse analysis of 2023 EDC Data

Since Eversource did not conduct VVO On/Off testing in PY 2023, Guidehouse did not estimate PM impacts using a regression methodology. Instead, Guidehouse estimated impacts

[28] Eversource did not conduct VVO On/Off testing at substations that were in-service for more than one full calendar year and had already completed On/Off testing previously. This is in-line with the Stamp Approved Performance Metrics outlined in Performance Metrics Compliance Filing, D.P.U. 21-80/21-81/21-82 (2023). Further discussion on VVO On/Off testing and the recommendation to limit the testing period can be found in AG-4-6, D.P.U. 22-40 (2023).

using regression-based impact estimates from the most-recent PY 2022 evaluation, for which the VVO substations underwent On/Off testing. For the PY 2023 evaluation period, this included 26 circuits across the Agawam, Piper, Podick, and Silver substations.

Analysis Data Construction

To assess the Performance Metrics, Guidehouse combined information from the PY 2022 evaluation as well data received for the PY 2023 evaluation. Guidehouse included the Performance Metrics impacts from the PY 2022 evaluation, the SCADA interval data from Eversource that contained time-stamped measurements of voltage, real power, apparent power, and reactive power for PY 2023, and time-stamped logs of VVO state changes between VVO On (engaged) and Off (disengaged) states contained within the SCADA data provided by Eversource for PY 2023. This information was combined to generate the results from the equations in Appendix B.

Analysis Approach

During PY 2023, Eversource did not conduct VVO On/Off testing on its Term 1 substations, which included the Agawam, Piper, Podick, and Silver substations. Instead, Eversource engaged VVO throughout the course of 2023, with periodic times where VVO was disengaged at Eversource's discretion. Table 21 provides the proportion of hours where VVO was either engaged or disengaged for each VVO circuit within PY 2023. Guidehouse used the PY 2023 VVO statuses, substation SCADA, voltage complaints data, and PY 2022 evaluation results to estimate PY 2023 Performance Metrics.

Table 21. Eversource PY 2023 VVO Statuses

Substation	Circuits	% of year VVO Off	% of year VVO On
Agawam	16C11-16C12	29.9%	70.1%
	16C14-16C18	73.8%	26.2%
Piper	21N4-21N5	68.9%	31.1%
	21N6-21N9	35.0%	65.0%
Podick	18G2-18G5	50.0%	50.0%
	18G6-18G8	52.2%	47.8%
Silver	30A1, 30A3, 30A5	50.6%	49.4%
	30A2, 30A4, 30A6	56.1%	43.9%

Source: Guidehouse analysis

To estimate Performance Metrics results for PY 2023, Guidehouse conducted the following general steps:

1. Integrated PY 2023 substation SCADA data and time-stamped logs of VVO state changes between VVO On and Off states for each VVO substation.

2. Combined PY 2023 substation SCADA data and VVO status data with estimated Performance Metrics impacts from the most recent evaluation (PY 2022) in which the substation conducted VVO On/Off testing.

3. Estimated impacts using the methodology outlined in Appendix B.

3.2.2.2 Performance Metrics Results

PM-1 through PM-6

Guidehouse estimated the impact of VVO on Performance Metrics for Eversource substations that have completed VVO On/Off testing. Table 22 summarizes the PM-1 through PM-7 results for Eversource.

Table 22. Overall Performance Metrics Results for Circuits that Completed VVO On/Off Testing Prior to PY 2023

Performance Metric	Appendix 1 Metric	Aggregate Results
PM-1	Annual Energy Delivered w/o VVO (MWh)	576,933 MWh
PM-2	Annual Energy Savings w/ VVO (MWh)	1,270 MWh
	Annual Peak Load w/o VVO (MW)	2.5 MW
PM-3	Annual Peak Load Reduction w/ VVO (MW)	-0.99 MW
	Distribution Losses w/o VVO (MWh)	12,058 MWh
PM-4	Reduction of Distribution Losses w/ VVO (MWh)	-388 MWh
	Power Factor w/o VVO	0.9576
PM-5	Power Factor w/ VVO	0.9577
	GHG Emissions w/o VVO (metric tons)	167 tons CO_2
PM-6	Reduction of GHG Emissions w/ VVO (metric tons)	367 tons CO_2
PM-7	# Voltage Complaints, Plan Year	63 complaints
	Change in # of Voltage Complaints (Baseline minus Plan Year)*	15 complaint increase

* The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.

Source: Guidehouse analysis

PM-7: Voltage Complaints

Guidehouse received voltage complaint logs from Eversource to facilitate the Performance Metrics analysis. Guidehouse tabulated voltage complaints received by VVO circuit between 2015 and 2023. Discussion below highlights key observations for voltage complaints and compares the count of voltage complaints received during 2023 to the average number of voltage complaints from the 2015–2017 baseline period.

Table 23 indicates the number of voltage complaints reported during the baseline period (defined in the stamp approved Metrics as 2015-2017) for the Agawam substation. Data indicate an increase (4) in voltage complaints in 2023 relative to the baseline.

Table 23. Count of Voltage Complaints for Agawam Substation

Number of Voltage Complaints	16C11	16C12	16C14	16C15	16C16	16C17	16C18	Total
Customers*	1,350	80	1,632	1,270	2,563	2,388	3,054	12,337
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
Baseline†	**1**	**0**	**2**	**3**	**6**	**3**	**3**	**15**
2018	0	0	2	0	3	8	1	14
2019	4	0	1	0	5	5	4	19
2020	5	3	0	3	6	4	2	23
2021	1	0	1	2	7	2	2	15
2022	2	1	4	0	1	4	3	15
2023	**1**	**0**	**4**	**3**	**4**	**7**	**0**	**19**

* Count of customers served by each circuit was extracted from the 2022 Grid Modernization Annual Report filed in D.P.U 23-30, Appendix B.
† The baseline number of voltage complaints is calculated as the average number of voltage complaints between 2015 and 2017, rounded up to the nearest whole number.
Note: The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.

Source: Guidehouse analysis

Table 24 indicates the number of voltage complaints reported during the baseline period (defined in the stamp approved Metrics as 2015-2017) for the Piper substation. Data indicates a decrease (1) in voltage complaints in 2023 relative to the baseline.

Table 24. Count of Voltage Complaints for Piper Substation

Number of Voltage Complaints	21N4	21N5	21N6	21N7	21N8	21N9	Total
Customers*	2,299	829	787	2	557	2,404	6,878
2015	1	1	2	0	0	2	6
2016	2	1	0	0	0	3	6
2017	4	2	1	0	0	2	9
Baseline†	**3**	**2**	**1**	**0**	**0**	**3**	**7**
2018	1	0	0	0	0	3	4
2019	2	1	0	0	3	5	11
2020	6	3	1	0	0	1	11
2021	5	1	0	0	0	8	14
2022	2	1	0	0	0	3	6
2023	**2**	**1**	**1**	**0**	**1**	**1**	**6**

* Count of customers served by each circuit was extracted from the 2022 Grid Modernization Annual Report filed in D.P.U 23-30, Appendix B.
† The baseline number of voltage complaints is calculated as the average number of voltage complaints between 2015 and 2017, rounded up to the nearest whole number.

Note: The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.

Source: Guidehouse analysis

Table 25 indicates the number of voltage complaints reported during the baseline period (defined in the stamp approved Metrics as 2015-2017) for the Podick substation. Data indicate an increase (7) in voltage complaints in 2023 relative to the baseline.

Table 25. Count of Voltage Complaints for Podick Substation

Number of Voltage Complaints	18G2	18G3	18G4	18G5	18G6	18G7	18G8	Total
Customers*	9	2,141	2,347	1,778	1,289	2,226	1,089	10,879
2015	0	3	1	2	1	3	3	13
2016	1	1	4	1	2	11	13	33
2017	0	0	5	4	3	6	5	23
Baseline†	**1**	**1**	**4**	**3**	**2**	**7**	**7**	**23**
2018	0	1	4	6	3	8	14	36
2019	0	6	5	8	1	4	3	27
2020	0	1	4	11	9	8	6	39
2021	0	3	6	7	3	7	5	31
2022	0	0	2	8	1	3	5	19
2023	**2**	**2**	**7**	**2**	**5**	**9**	**3**	**30**

* Count of customers served by each circuit was extracted from the 2022 Grid Modernization Annual Report filed in D.P.U 23-30, Appendix B.

† The baseline number of voltage complaints is calculated as the average number of voltage complaints between 2015 and 2017, rounded up to the nearest whole number.

Note: The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.

Source: Guidehouse analysis

Table 26 indicates the number of voltage complaints reported during the baseline period (defined in the stamp approved Metrics as 2015-2017) for the Silver substation. Data indicate a decrease (8) in voltage complaints in 2023 relative to the baseline.

Table 26. Count of Voltage Complaints for Silver Substation

Number of Voltage Complaints	30A1	30A2	30A3	30A4	30A5	30A6	Total
Customers*	2,519	2,286	239	801	1,659	1,007	8,511
2015	2	1	0	1	1	2	7
2016	4	5	1	1	2	5	18
2017	3	8	2	1	3	3	20
Baseline†	**3**	**5**	**1**	**1**	**2**	**4**	**16**
2018	4	2	0	2	0	2	10
2019	6	5	1	0	2	3	17
2020	5	1	2	4	1	4	17
2021	8	3	0	0	1	5	17
2022	7	1	2	1	1	1	13
2023	**1**	**2**	**2**	**1**	**2**	**0**	**8**

* Count of customers served by each circuit was extracted from the 2022 Grid Modernization Annual report filed in D.P.U 23-30, Appendix B.
† The baseline number of voltage complaints is calculated as the average number of voltage complaints between 2015 and 2017, rounded up to the nearest whole number.
Note: The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.
Source: Guidehouse analysis

3.2.2.3 Key Findings

Guidehouse has the following key findings to provide for the Eversource PY 2023 Performance Metrics evaluation:

- Eversource did not conduct VVO On/Off testing in PY 2023 at any VVO substations.[29] In order to estimate the Performance Metrics, Guidehouse combined evaluation results from the PY 2022 evaluation as well data received for the PY 2023 evaluation. Guidehouse included the Performance Metrics impacts from the PY 2022 evaluation, the SCADA interval data from Eversource that contained time-stamped measurements of voltage, real power, apparent power, and reactive power for PY 2023, and time-stamped logs of VVO state changes between VVO On (engaged) and Off (disengaged) states contained within the SCADA data provided by Eversource for PY 2023.

- During the PY 2022 M&V period, Eversource's Agawam, Piper, Podick, and Silver substations realized 0.41% energy savings and 1.24% voltage reduction associated with VVO, equating to a CVR factor of 0.60. Using these results and substation SCADA collected during PY 2023, Eversource's Agawam, Piper, Podick, and Silver substations realized 1,270 MWh energy savings associated with VVO. Energy savings of 1,270 MWh yielded a 367 short ton reduction of CO_2 emissions. Lastly, VVO circuits experienced an

[29] Eversource did not conduct VVO On/Off testing at substations that were in-service for more than one full calendar year and had already completed On/Off testing previously. This is in-line with the Stamp Approved Performance Metrics outlined in Performance Metrics Compliance Filing, D.P.U. 21-80/21-81/21-82 (2023). Further discussion on VVO On/Off testing and the recommendation to limit the testing period can be found in AG-4-6, D.P.U. 22-40 (2023).

increase (0.99 MW) in peak load and an increase in distribution losses when VVO was engaged (388 MWh).

- For Eversource, a total of 63 voltage complaints were received from customers connected to the Agawam, Piper, Podick, and Silver VVO circuits during the PY 2023 M&V period. This is a 31% increase relative to the average voltage complaints per year received between 2015 – 2017. The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.
- Eversource reported conducting deployment of VVO investments throughout PY 2023. Eversource anticipates completing additional deployment during PY 2024 and PY 2025. Once VVO investments are deployed, Eversource plans to control VVO within its ADMS system. Eversource plans to complete its ADMS investment and commission and enable VVO at its Term 2 substations in PY 2025. Therefore, Guidehouse will not conduct any regression-based estimation of Performance Metrics for Eversource until the PY 2025 evaluation. Until then, all Performance Metrics will continue to be estimated for only the Agawam, Piper, Podick, and Silver substations using PY 2022 evaluation results and SCADA collected during the evaluation period of interest (e.g., PY 2023).

3.2.3 National Grid

This section discusses National Grid's VVO Performance Metrics results for PY 2023.

3.2.3.1 Evaluation Methodology

As summarized in Section 2.1, the Guidehouse evaluation approach entails statistical regression analysis of substation SCADA measurements collected when VVO is engaged (VVO On) and when VVO is disengaged (VVO Off) during each substation's VVO On/Off testing period. During PY 2023, the VVO testing periods were unique across each of National Grid's VVO substations. In addition, many of National Grid's substations conducted both Day On/Day Off as well as Week On/Week Off VVO testing. Table 27 indicates the range of Day On/Day Off and Week On/Week Off VVO testing periods for each substation, transformer or station bank, and circuit during PY 2023.

Table 27. National Grid's VVO On/Off Status Schedule

Substation	Transformer / Station Bank	Circuits	Day On/Day Off Date Range	Week On/Week Off Date Range
East Bridgewater	B97	797W19, 797W20, 797W24	N/A*	10/29/23–12/9/23
	B914	797W23, 797W29, 797W42	N/A*	10/29/23–12/9/23
East Dracut	1XFR	75L1, 75L3, 75L5	6/1/23–10/27/23	10/28/23–12/31/23
	2XFR	75L2, 75L4, 75L6	8/25/23–10/27/23	10/28/23–12/31/23
East Methuen	T1	74L1, 74L3, 74L5	1/12/23-10/28/23	10/29/23–12/31/23
	T2	74L2, 74L4, 74L6	1/12/23–10/28/23	10/29/23–12/31/23
Easton	N/A	92W43 - 92W79	1/12/23–8/31/23	10/29/23–12/9/23
Maplewood	3XFR	16W1, 16W3, 16W5, 16W7	1/12/23–10/28/23	10/29/23–12/31/23
	4XFR	16W2, 16W4, 16W6, 16W8	1/12/23–10/28/23	10/29/23–12/31/23
Stoughton	N/A	913W17 – 913W69	N/A*	10/29/23–12/09/23
West Salem	3XFR	29W1, 29W3, 29W5	1/12/23–4/12/23	10/29/23–12/9/23
	4XFR	29W2, 29W4, 29W6	1/12/23–4/12/23	10/29/23–12/9/23

* The East Bridgewater and Stoughton substations did not undergo Day On/Day Off testing during PY 2023.

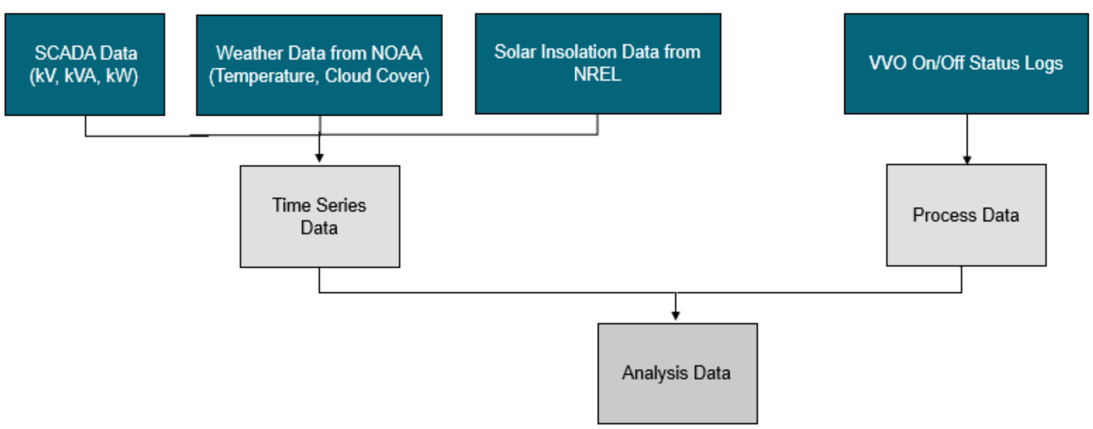
Source: Guidehouse Analysis of National Grid VVO On/Off Testing Schedule

Guidehouse worked with National Grid to collect data necessary to complete the evaluation of the VVO Performance Metrics. The sections that follow highlight the analysis data construction, analysis data cleaning, and the analysis approach.

Analysis Data Construction

To assess Performance Metrics, Guidehouse constructed an analysis dataset. This dataset was used in regression modeling to assess changes in multiple outcome variables, such as energy and peak demand. Figure 8 summarizes the data integration process used to construct the analysis dataset for the National Grid Performance Metrics analysis.[30]

Figure 8. National Grid Analysis Data Construction Flowchart



[30] Guidehouse receives different data types and structures from the EDCs for estimating impacts across the performance metrics. These differences were minimized as much as possible, but any differences that remain may affect the comparability of performance metrics results across the EDCs.

Source: Guidehouse

Guidehouse constructed a final analysis dataset for National Grid Performance Metrics analysis using time series and process data sources. To construct the final dataset, 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 the National Oceanic and Atmospheric Administration (NOAA) for the weather station most proximate to each substation.[31] Lastly, the team integrated quarter-hourly solar insolation data from the National Renewable Energy Laboratory (NREL) to complete the time-series data construction.[32]

To construct the process data, Guidehouse integrated other VVO system information. Other system information included time-stamped logs of VVO state changes between VVO On (engaged) and Off (disengaged) states from Utilidata during the evaluation period. The time series and process data were then joined to construct a final analysis dataset.

Analysis Data Cleaning

After constructing the analysis dataset, the team conducted data cleaning steps to remove interval data that may bias the estimates of VVO impacts. Table 28 summarizes data observations made by the evaluation team and the resulting data cleaning steps that were executed.

Table 28. Data Cleaning Conducted for National Grid Analysis

Data Observation	Data Cleaning Step
Identified a handful of periods of repeated, interpolated, and outlier values in the interval data received, as well as periods of missing VVO-status data.	Removed observations where anomalous data readings were flagged.
Identified different VVO On/Off testing schedules across VVO substations.	Removed observations outside of the VVO On/Off testing period for each VVO substation.

Source: Guidehouse

Table 29 indicates the number of hours contained in the analysis dataset for the substations that underwent VVO On/Off testing in PY 2023. Much of the data removed during data cleaning was due to extended periods over which VVO On/Off testing was paused, particularly for the West Salem substation. Detailed data attrition information is included in Appendix D.

Table 29. Count of VVO On, VVO Off, and Removed Observations for National Grid*

Substation	Circuit	VVO On Observations	VVO Off Observations	Observations Removed by Data Cleaning*	VVO Testing Period Total
East Bridgewater	797W19	5,796	6,273	22	12,084
	797W20	5,796	6,273	15	12,084
	797W23	5,788	6,251	45	12,084

[31] 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

[32] Documentation on the NREL dataset used in this analysis can be found here: NSRDB | What is the NSRDB (nrel.gov)

Substation	Circuit	VVO On Observations	VVO Off Observations	Observations Removed by Data Cleaning*	VVO Testing Period Total
	797W24	5,766	6,273	45	12,084
	797W29	5,789	6,253	42	12,084
	797W42	5,788	6,227	69	12,084
East Dracut	75L1	30,342	26,318	4,876	61,536
	75L2	14,183	18,756	4,177	37,116
	75L3	30,644	26,430	4,462	61,536
	75L4	14,975	19,653	2,488	37,116
	75L5	30,572	26,510	4,454	61,536
	75L6	15,493	20,529	1,094	37,116
East Methuen	74L1	31,444	33,140	2,952	67,536
	74L2	21,900	19,004	2,260	43,164
	74L3	29,629	31,567	6,340	67,536
	74L4	21,916	19,030	2,218	43,164
	74L5	30,472	31,931	5,133	67,536
	74L6	20.503	18,062	4,599	43,164
Easton	92W43	45,632	47,915	497	94,044
	92W44	45,685	47,904	455	94,044
	92W54	45,309	47,383	1,352	94,044
	92W78	45,465	47,750	829	94,044
	92W79	45,126	47,103	1,815	94,044
Maplewood	16W1	22, 527	29,492	4,897	56,916
	16W2	25,257	34,556	1,687	61,500
	16W3	22,773	29,894	4,249	56,916
	16W4	25,707	34,526	1,267	61,500
	16W5	23,735	32,367	814	56,916
	16W6	25,125	34,189	2,186	61,500
	16W7	23,727	32,143	1,046	56,916
	16W8	25,113	34,257	2,130	61,500
Stoughton	913W17	5,508	6,532	56	12,096
	913W18	5,497	6,521	78	12,096
	913W43	5,498	5,652	946	12,096
	913W47	5,512	6,519	65	12,096
	913W67	5,445	5,612	1,039	12,096
	913W69	5,510	6,541	45	12,096
West Salem	29W1	65,140	27,760	1,744	94,644
	29W2	53,358	38,653	2,633	94,644
	29W3	55,642	37,510	1,492	94,644
	29W4	45,506	45,857	3,281	94,644
	29W5	45,033	47,533	2,078	94,644
	29W6	53,374	38,733	2,537	94,644

*Data considered for removal are outliers, repeated, interpolated data points, and potential load shifting from one circuit to another.

Source: Guidehouse analysis

Analysis Approach

After the analysis data was constructed and cleaned, Guidehouse conducted Euclidean distance matching following the methodology summarized in Section 2.1.3. Results from Euclidean distance matching are provided in 4.2Appendix C.

After conducting Euclidean distance matching, Guidehouse conducted statistical regression modeling to assess the impacts of active VVO control via comparison of data logged when VVO was engaged and when VVO was disengaged. Appendix A provides additional details on the modeling approaches utilized to complete the PY 2023 Performance Metrics evaluation.

To inform the regression model specifications utilized for this evaluation, Guidehouse conducted further inspection of the data to control for exogenous patterns unrelated to VVO operation that may bias the estimated impact of VVO. Table 30 summarizes observations made during this inspection and the resulting data analysis steps that were implemented.

Table 30. Data Analysis Summary for National Grid

Data Observation	Data Analysis Step
Numerous circuits had a large nominal capacity of connected solar facilities.	Solar insolation data from NREL were integrated and included in regression analysis to capture changes in variables such as load and voltage due to solar generation.
Numerous circuits were identified with non-residential customers making up a large portion of load, with drops in measured load during holidays and non-business hours.	Day type (i.e., weekday or weekend day) and hour of day fixed effects were incorporated into regression models to capture typical load shapes by day type and control for large drops in demand observed during non-business hours.

Source: Guidehouse

3.2.3.2 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 February 7, 2024, Guidehouse provides a baseline using data collected when VVO was disengaged during the evaluation period, Table 31 provides the energy baseline calculated using VVO Off data collected during PY 2023.[33]

Table 31. National Grid VVO Energy Baseline

Metric	Baseline Total Energy Use
Baseline Energy	5,184,073 MWh

Source: Guidehouse analysis

[33] On February 7, 2024, Eversource, National Grid, and Unitil filed evaluation plans with the DPU for the period spanning 2022-2025. The DPU docketed these plans as DPU 21-80, 21-81, and 21-82, respectively.

To estimate total baseline energy use, Guidehouse conducted regression modeling for each VVO circuit to estimate how energy usage changes when VVO is engaged, controlling for weather, day-of-week, solar insolation, and other observable conditions that influence energy usage but that are not attributed to VVO control. After conducting regression modeling to estimate energy usage, Guidehouse used the regression results to predict what energy usage would have been if VVO were off for the entirety of PY 2023 for each VVO circuit, holding all other observable conditions constant (e.g., allowing weather to remain as it was when VVO was engaged). Guidehouse then calculated the summation of this predicted energy usage across all hours and circuits to calculate a baseline total energy use for PY 2023. Baseline energy use is provided by VVO circuit in 0.

PM-2: Energy Savings

Table 32 provides the aggregated evaluated energy savings for National Grid for PY 2023. The ± figure indicate 90% confidence bounds associated with energy savings estimates. Regression estimates indicate a statistically significant reduction in energy use associated with VVO, with 2,540 MWh (1.3%) energy savings realized during PY 2023.[34]

Table 32. National Grid VVO Net Energy Reductions, Overall

Assumption	Aggregated Energy Reduction	
	MWh	%‡
Energy Savings - All Hours VVO On*	5,072 ± 237 MWh	1.275 ± 0.036%
Energy Savings - Actual VVO On Hours†	2,540 ± 121 MWh	1.275 ± 0.036%

* Total energy reductions were determined by calculating the energy reductions across the entirety of each substation's testing period, assuming VVO to be engaged during the entire period.

† Actual VVO On Hours are the number of hours that were VVO engaged during each substation's testing period for each evaluation circuit.

‡ Energy reductions presented in this table is the load-weighted average of energy reductions estimated for each circuit.

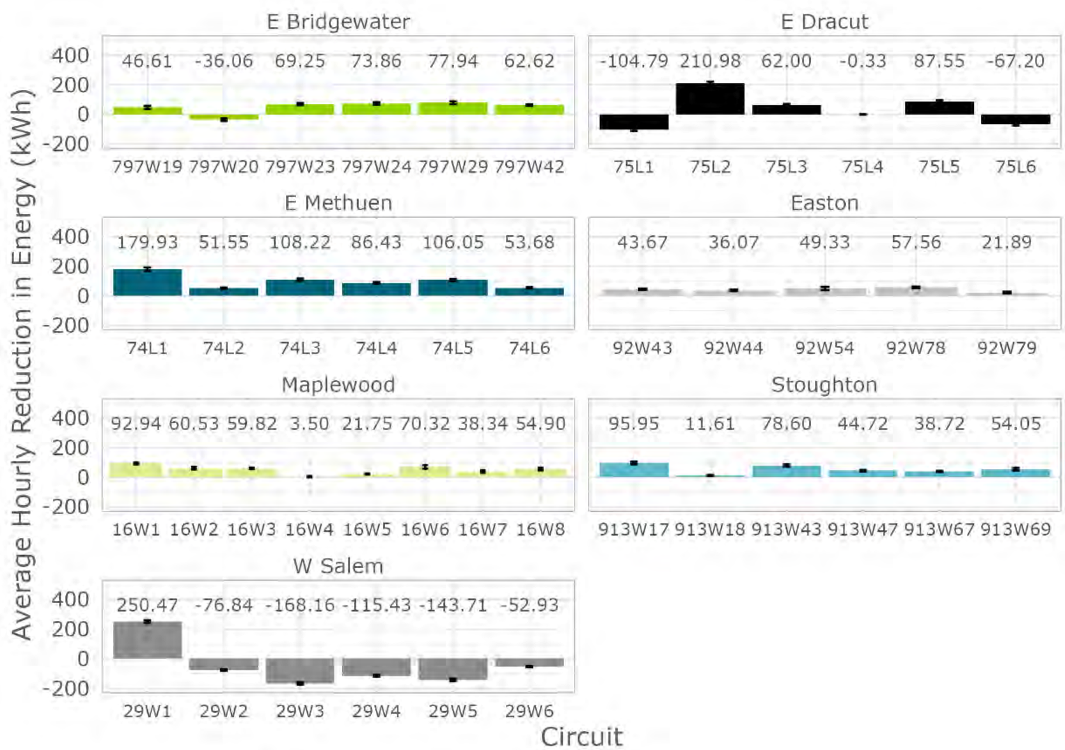
Source: Guidehouse analysis

Figure 9 indicates the estimated average hourly energy reductions for each National Grid circuit in absolute terms (kWh), with the value at the top of each circuit indicating each circuit's estimated average hourly kWh savings. The whiskers overlaid on each circuit's estimated kWh savings estimate provide the associated 90% confidence intervals. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant.

Regression estimates indicate that many circuits underwent statistically significant decreases in energy when VVO was engaged (32 of 43 circuits that underwent VVO On/Off testing during PY 2023). This is a marked change from prior evaluations and may be reflective of refinements National Grid has made to its VVO control scheme.

[34] Actual VVO On Hours are the number of hours in the clean analysis data that were VVO engaged during the substation's testing period for each evaluation circuit.

Figure 9. Average Hourly Energy Reductions (kWh) for National Grid VVO Circuits



Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.

Source: Guidehouse analysis

Figure 10 indicates the average hourly energy reductions for each National Grid circuit in percentage terms, with the value at the top of each circuit indicating each circuit's percentage savings. The whiskers overlaid on each circuit's percentage savings estimate provide the associated 90% confidence intervals. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant.

Figure 10. Average Hourly Energy Reductions (%) for National Grid VVO Circuits

Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.

Source: Guidehouse analysis

To further understand impacts, Guidehouse estimated reductions in voltage associated with VVO, Table 33 provides the evaluated voltage reductions for National Grid, with 90% confidence bounds associated with voltage reductions estimates indicated by the ± figure. Regression estimates indicate a statistically significant reduction in voltage associated with VVO, with a 0.320 kV (2.3%) voltage reduction realized during PY 2023. Voltage results are removed for Maplewood and West Salem circuits due to insufficient data coverage.

Table 33. National Grid VVO Average Hourly Voltage Reduction, Overall*

Aggregated Voltage Reduction	
(kV)*	(%)*
0.320 ± <0.001 kV	2.306 ± 0.002%

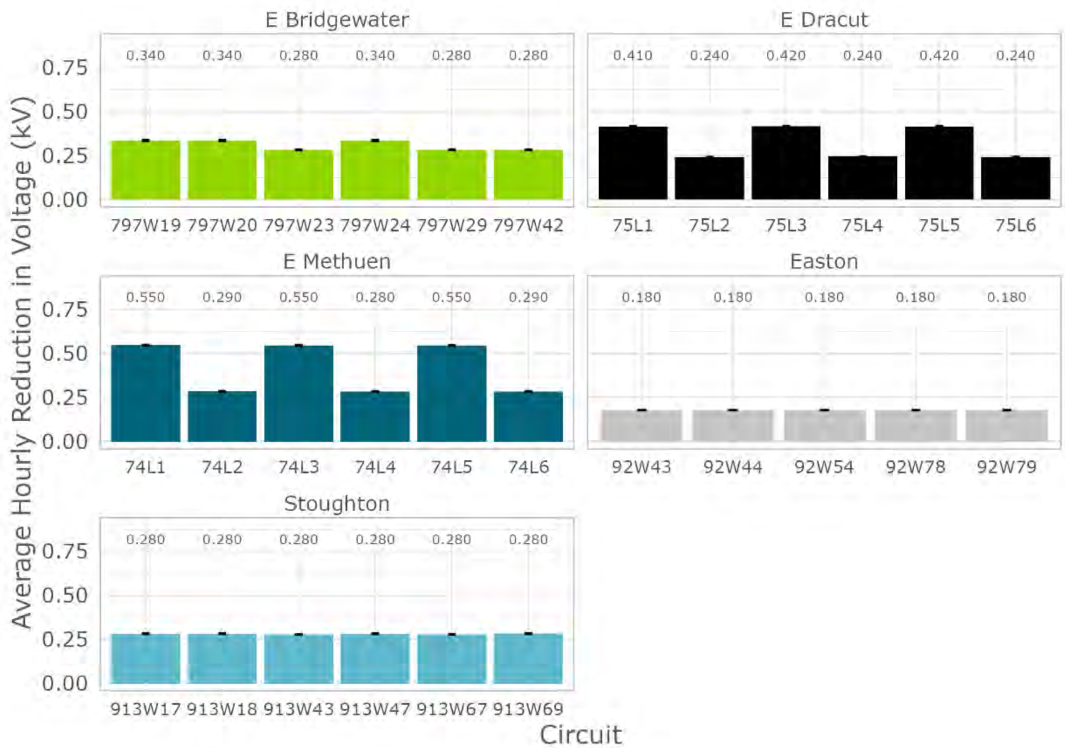
* Absolute and percentage voltage reductions provided for each period is the load-weighted average of absolute and percentage voltage reductions estimated for each circuit.

Note: Voltage results are removed for Maplewood and West Salem due to insufficient data coverage.

Source: Guidehouse analysis

Figure 11 indicates the average hourly voltage reductions for each National Grid circuit, with green points indicating each circuit's voltage reduction. The whiskers overlaid on each circuit's voltage reduction estimate provide the associated 90% confidence intervals, and the dashed line denotes the weighted average voltage reduction. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant. All circuits underwent statistically significant decreases in voltage when VVO was engaged. This is a marked change from prior evaluations and may be reflective of refinements National Grid has made to its VVO control scheme.

Figure 11. Average Hourly Voltage Reductions (kV) for National Grid VVO

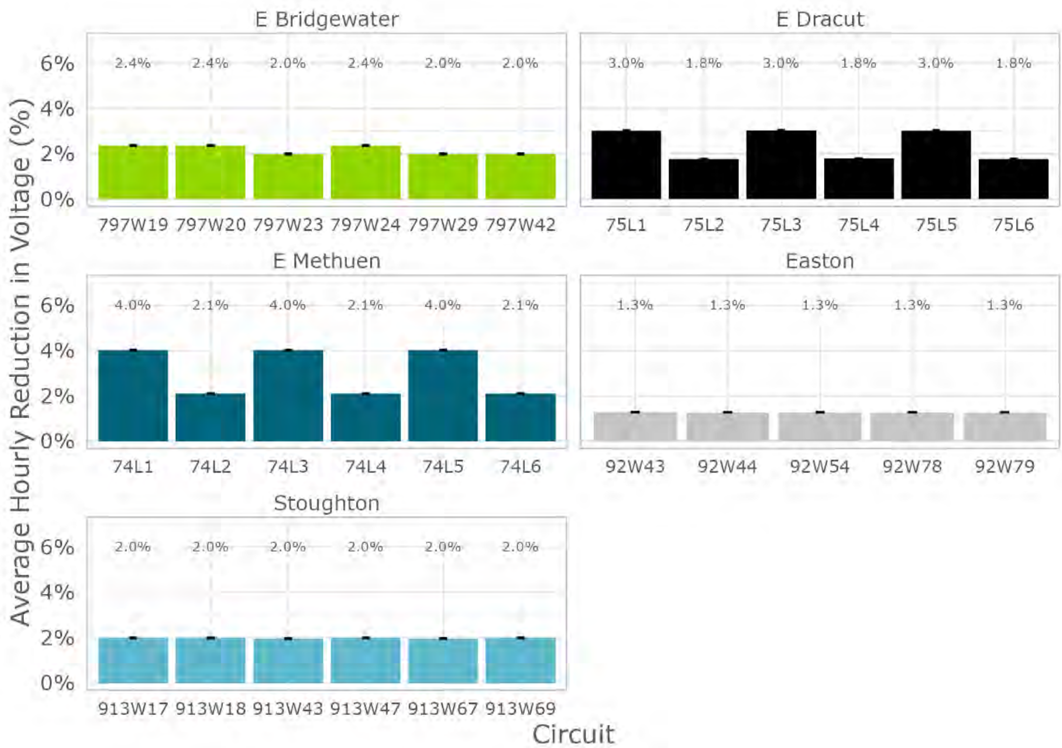


Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.

Source: Guidehouse analysis

Figure 12 indicates the net voltage reductions for each National Grid circuit in percentage terms, with green points indicating each circuit's percentage voltage reduction. The whiskers overlaid on each circuit's percentage voltage reduction estimate provide the 90% confidence intervals. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant. All circuits underwent statistically significant decreases in voltage when VVO was engaged.

Figure 12. Average Hourly Voltage Reductions (%) for National Grid VVO Circuits



Note: Whiskers in this figure *correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.*
Source: Guidehouse analysis

Following an estimation of percentage energy savings and percentage voltage reductions attributed to VVO, Guidehouse calculated the associated CVR factors for each circuit. The CVR factor, which is the ratio of percentage energy savings to percentage voltage reductions, can provide an estimate of the percentage energy savings possible with each percent voltage reduction.

Equation A-1 in the Appendix highlights how the CVR factor is calculated using an estimated percentage reduction in energy and in voltage. Table 34 provides the CVR factor for National Grid. From prior experience evaluating VVO, Guidehouse expects a CVR factor of 0.80 ± 0.40 from a year of VVO M&V testing. Based on evaluation findings, the CVR factor for PY 2023 was 0.92.

Table 34. National Grid VVO CVR Factor, Overall*

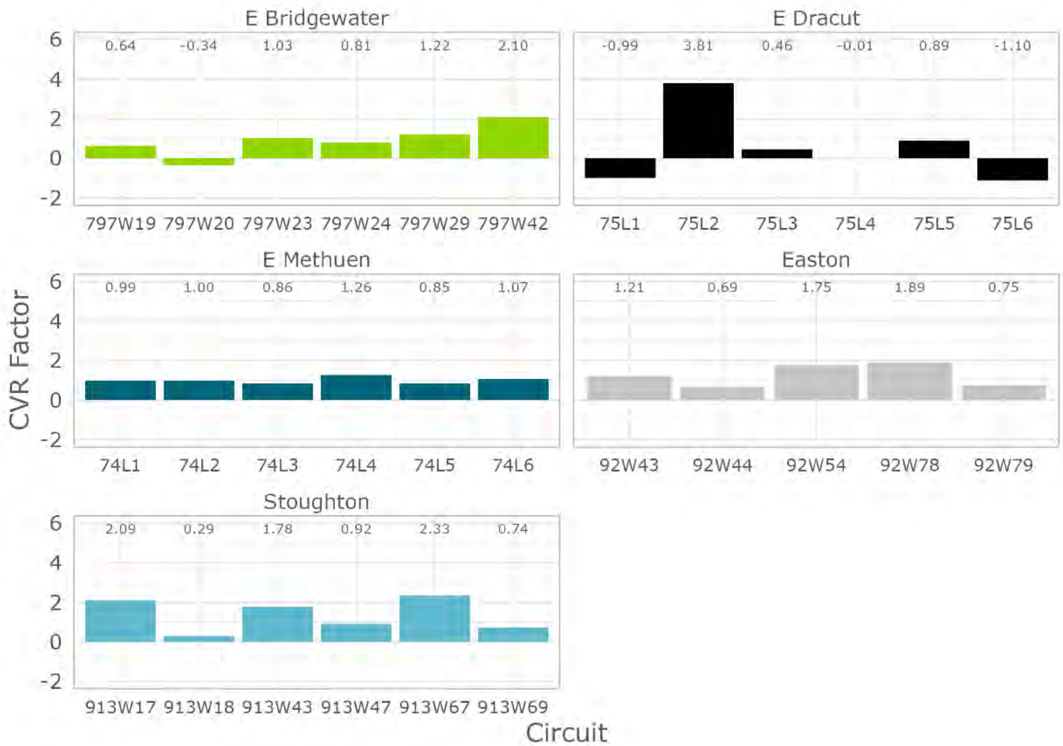
CVR Factor
0.92

* Voltage results are removed for Maplewood and West Salem due to insufficient data coverage.
Source: Guidehouse analysis

Figure 13 provides the CVR factors for PY 2023 for each circuit. Estimated CVR factors ranged from -1.10 to 3.81, with 14 of 29 circuits having a CVR factor in the range of 0.80 ± 0.40, ten of

29 circuits having a CVR factor greater than 1.20. The remaining five circuits either (1) underwent minimal energy reductions when VVO was engaged or (2) underwent estimated increases in energy usage when VVO was engaged.

Figure 13. Changes in CVR Factors for National Grid VVO Circuits*



* Voltage results are removed for Maplewood and West Salem due to insufficient data coverage.
Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.

Source: Guidehouse analysis

Key takeaways based on evaluation findings for energy, voltage, and CVR factors include:

- All circuits connected to the East Methuen, Easton, and Stoughton substations underwent estimated statistically significant reductions in energy consumption when VVO was engaged. In-line with these findings were estimated voltage reductions of between 1.8% and 3.9%, yielding CVR factors ranging from 0.29 to 2.33. Findings suggest that voltage is being regulated as-anticipated along the length of the circuit, dropping and flattening the voltage profile for most connected customers, thereby yielding a reduction in energy consumption being detected at the circuit head-end. National Grid may consider examining data collected at locations between the circuit head-end and the end-of-line to confirm voltage is responding as anticipated.

- All circuits connected to National Grid's Easton substation underwent an average voltage reduction of 1.3%, yielding energy reductions of between 0.90% and 2.40%. This reflects the reduction in voltage and energy realized only during the VVO On/Off testing period and does not capture additional changes relative to the pre-conditioned state (for more discussion of the impacts of circuit conditioning, please refer to Section

2.1.1). In discussions with National Grid, National Grid indicated that the Easton substation underwent a reduction in its LTC setpoint from 124.4V to 122.5V, a 1.5% reduction, while preparing the station for VVO control. This reflects a 1.5% reduction in voltage associated with circuit conditioning and is contained in the data collected when VVO was in the Off state. The impact of VVO quantified via comparison of VVO On/Off testing data was estimated to be 1.3%, meaning the combined impact of circuit conditioning (reported by National Grid as 1.5%) and active VVO control (estimated by Guidehouse as 1.3%) may be as high as 2.8%. If National Grid did achieve a 1.5% reduction in voltage via circuit conditioning, then the energy impacts estimated to range from 0.90% and 2.40% for the Easton substation are likely to be conservative.

- Some circuits connected to the East Bridgewater (circuit 797W20), East Dracut (circuits 75L1, 75L3), and West Salem (circuits 29W2 through 29W6) substations underwent no energy reduction or an increase in energy usage when VVO was engaged. This was in contrast to estimated voltage reductions for these East Dracut and West Salem circuits, which ranged from 2.4% to 3.0%.[35] This may be due to faults in the VVO scheme at sections of these circuits which cannot be diagnosed using substation SCADA. For instance, if voltage did not drop or increased on a section of circuit 797W20 with a heavy commercial and industrial load composition, the increase in consumption in this zone may outweigh energy consumption reductions realized on all other zones of the circuit. National Grid should consider investigating data collected at locations between the circuit head-end and the end-of-line to confirm voltage is responding as anticipated across all sections of these circuits. Additional data will help better identify what is occurring along the circuit and improve the ability to detect instances of the VVO scheme not working as anticipated, as circuit head-end data only provides a glimpse of the aggregate impact, not impacts in specific sections of circuits.

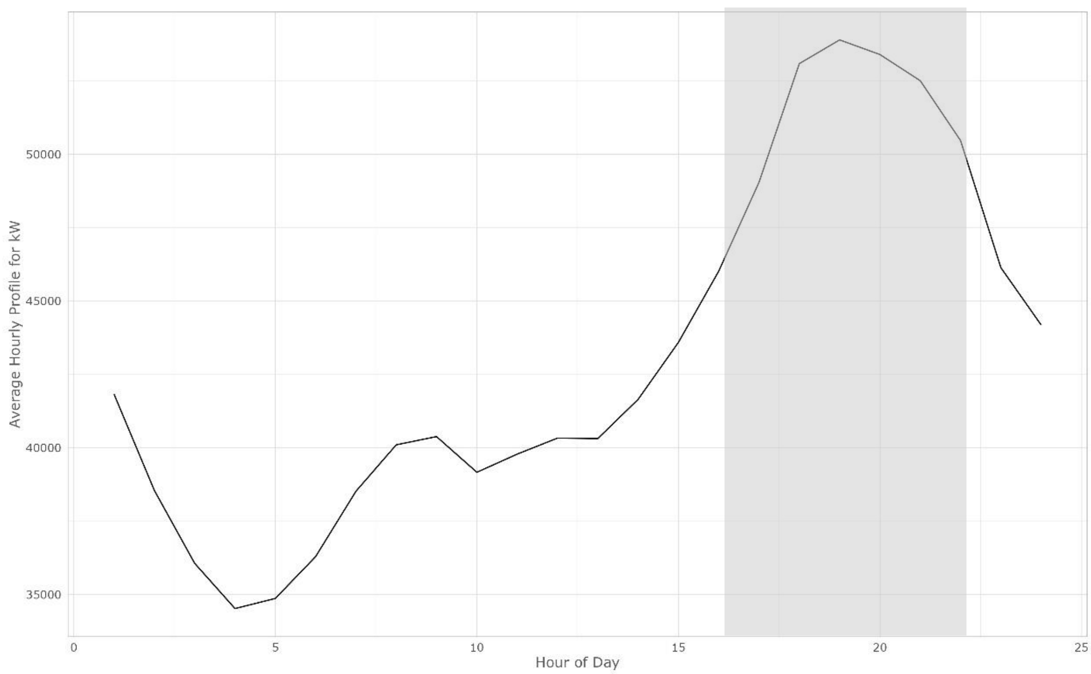
PM-3: Peak Demand Impact

Prior to PY 2023, Guidehouse evaluated the impact of VVO during peak demand using the ISO-NE definition of a peak demand period (1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays. However, peak demand periods for each EDC do not always coincide with the ISO-NE's definition of peak demand. Therefore, for PY 2023, the definition of the peak period was determined based on load data collected from each EDC during PY 2023.

Guidehouse aggregated the SCADA demand data received from National Grid for PY 2023 between June 1 and August 31 on non-holiday weekdays. Using substation SCADA data across all VVO circuits, Guidehouse identified that average demand was generally highest between the hours of 4:00 p.m. and 10:00 p.m. on non-holiday weekdays between May 1 and September 30. Figure 14 shows this average load curve, where 4:00 p.m. to 10:00 p.m. have the highest load across the 24 hours. Guidehouse utilized this period as the peak period with which to estimate reductions in peak demand attributed to VVO.

[35] Voltage results are removed for Maplewood and West Salem circuits due to insufficient data coverage.

Figure 14. Aggregated Average Hourly Load Profile Across National Grid VVO Circuits



Source: Guidehouse analysis

Table 35 details the evaluated peak demand impact across all circuits in absolute and percentage terms. Model estimates indicate a statistically significant 1.3% reduction in demand when VVO was engaged during peak demand hours across the VVO circuits. Guidehouse estimated peak demand reductions for each circuit that underwent On/Off testing and had sufficient data during the flagged peak period. Many circuits underwent statistically significant decreases in peak demand when VVO was engaged. This is a marked change from prior evaluations and may be reflective of refinements National Grid has made to its VVO control scheme.

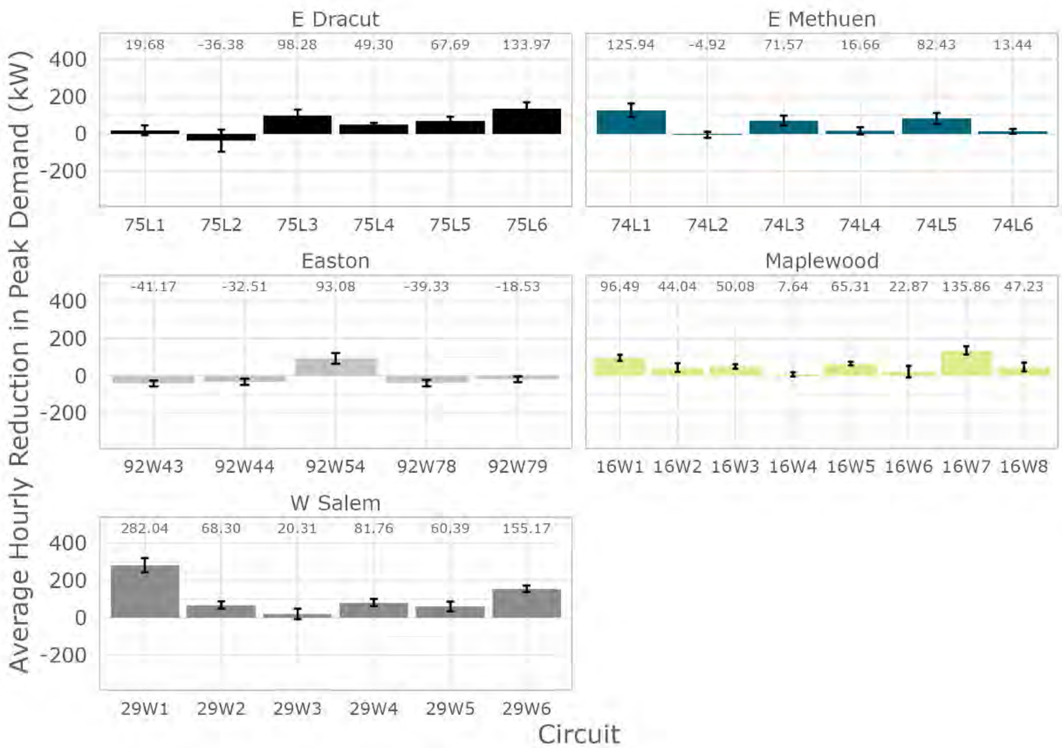
Table 35. National Grid Reduction in Peak Demand, Overall

Peak Load Reduction (kW)†	Peak Load Reduction (%)†
1,737 ± 141 kW	1.298 ± 0.102%

† The percentage peak load reduction presented in this table is the load-weighted average of percentage peak load reductions estimated for each circuit.
Source: Guidehouse analysis

Guidehouse estimated peak demand reductions for each circuit that underwent On/Off testing and had sufficient data during the flagged peak period. Figure 15 indicates the load reductions measured in kW realized during the peak load period, defined as 4:00 p.m. to 10:00 p.m. ET from May 1 to September 30 on non-holiday weekdays. The whiskers overlaid on each circuit's absolute load reduction estimate provide the associated 90% confidence intervals. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant. Many of the circuits included in the analysis experienced a statistically significant reduction in peak load, showing an improvement from previous years.

Figure 15. Peak Demand Reductions (kW) for National Grid VVO Circuits

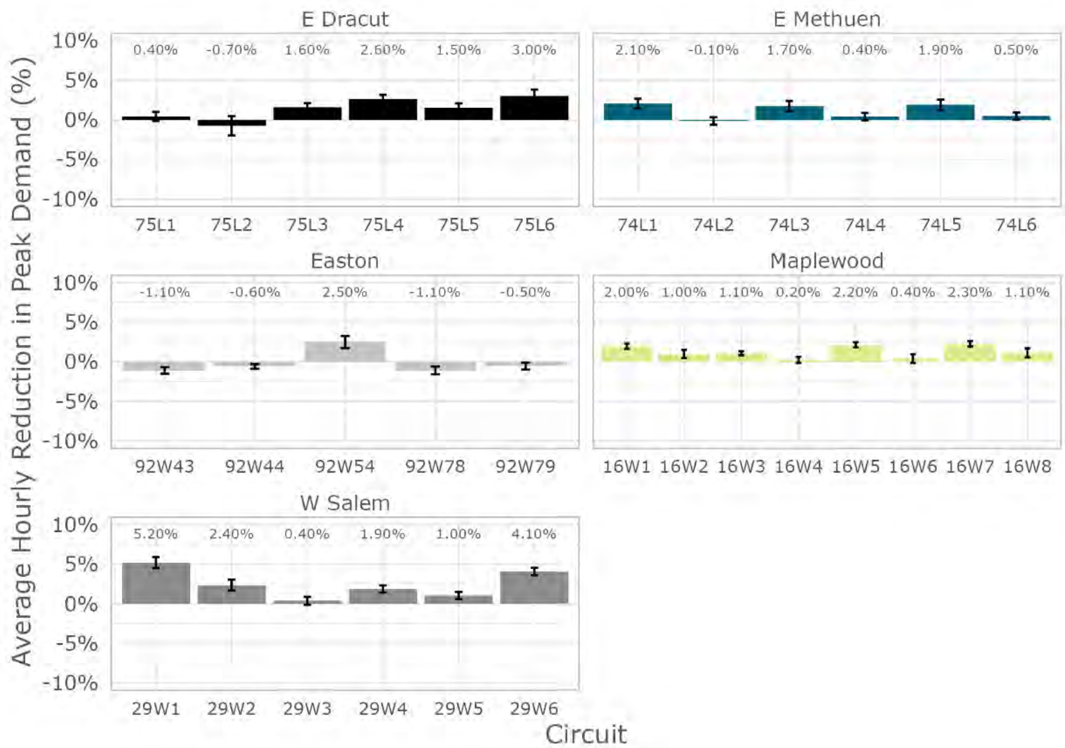


Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. A*n estimate is statistically significant if it does not overlap with zero.*

Source: Guidehouse analysis

Figure 16 indicates the percentage load reductions realized during the peak load period, defined as 4:00 p.m. to 10:00 p.m. ET from May 1 to September 30 on non-holiday weekdays. The whiskers overlaid on each circuit's percent load reduction estimate provide the associated 90% confidence intervals. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant. Many of the circuits included in the analysis experienced a statistically significant reduction in peak load.

Figure 16. Peak Demand Reductions (%) for National Grid VVO Circuits



Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.

Source: Guidehouse analysis

Below are key takeaways from peak demand reductions estimated for National Grid circuits:

- Most East Dracut, East Methuen, and Maplewood circuits underwent statistically significant reductions in peak demand when VVO was engaged. For the East Methuen substation, peak demand reductions correlated well with voltage reductions, where peak demand reduction estimates for East Methuen's odd-numbered circuits were greater than for even-numbered circuits, consistent with more aggressive voltage reductions observed on odd-numbered circuits (3.9%) as compared to even-numbered circuits (2.0%). However, circuits at the East Dracut substation did not have the same correlation, with higher peak demand reductions estimated for even-numbered circuits that underwent a less aggressive voltage reduction (1.6%) when VVO was engaged relative to odd-numbered circuits (3.0%).
- Five of six West Salem circuits underwent statistically significant estimated reductions in peak demand when VVO was engaged, ranging from 1.0% to 5.2%. This is not consistent with the estimated statistically significant increases in energy when VVO was engaged, which ranged from 0.8% to 4.2%. National Grid may consider investigating end-of-line feeder monitor data to determine whether there are differences in how voltage is lowered and flattened during peak hours (4:00 p.m. to 10:00 p.m., non-holiday weekdays between May 1 and September 30) relative to all other hours of the day. It may be the case that West Salem circuits' line devices were not responding as-expected to VVO signals outside of the identified peak period.

- Four of five Easton circuits underwent statistically significant increases in peak demand when VVO was engaged, ranging from 0.5% to 1.1%. Upon investigation of LTC settings and end-of-line feeder monitor voltage data for the Easton substation, National Grid identified that LTC settings may have been "too soft". In this case, during the peak hours, which are hotter hours prone to voltage "sags", the LTC settings when VVO was disengaged allowed for voltage conditions to drop, causing low voltage violations at the end-of-line. In contrast, when VVO was engaged, the National Grid VVO scheme increased voltage to minimize the incidence of low voltage violations. This ultimately led to end-of-line voltage to be greater during peak hours when VVO was engaged relative to when VVO was disengaged, which is beneficial in ensuring customer end-uses are not interrupted by low voltage violations. However, given low voltage violations were reported when VVO was disengaged, this lowered demand relative to when VVO was engaged, which may have led to the negative peak demand impacts estimated for four of the five Easton circuits.

PM-4: Distribution Losses

Guidehouse estimated reductions in distribution losses as a function of VVO during PY 2023. There were some circuits with very little data where kW was greater than 75% of annual peak load for kVA. Given that power factor is an input for the distribution losses equation, these circuits were ultimately removed from the distribution losses calculation due to insufficient observations. The methodology for calculating the percent reduction in distribution losses is shown in Appendix A.

Table 36 details the evaluated percentage change in distribution losses for each National Grid circuits with sufficient data quality. The statistically significant increase in power factor resulted in a marginal reduction in distribution losses of 0.77%.

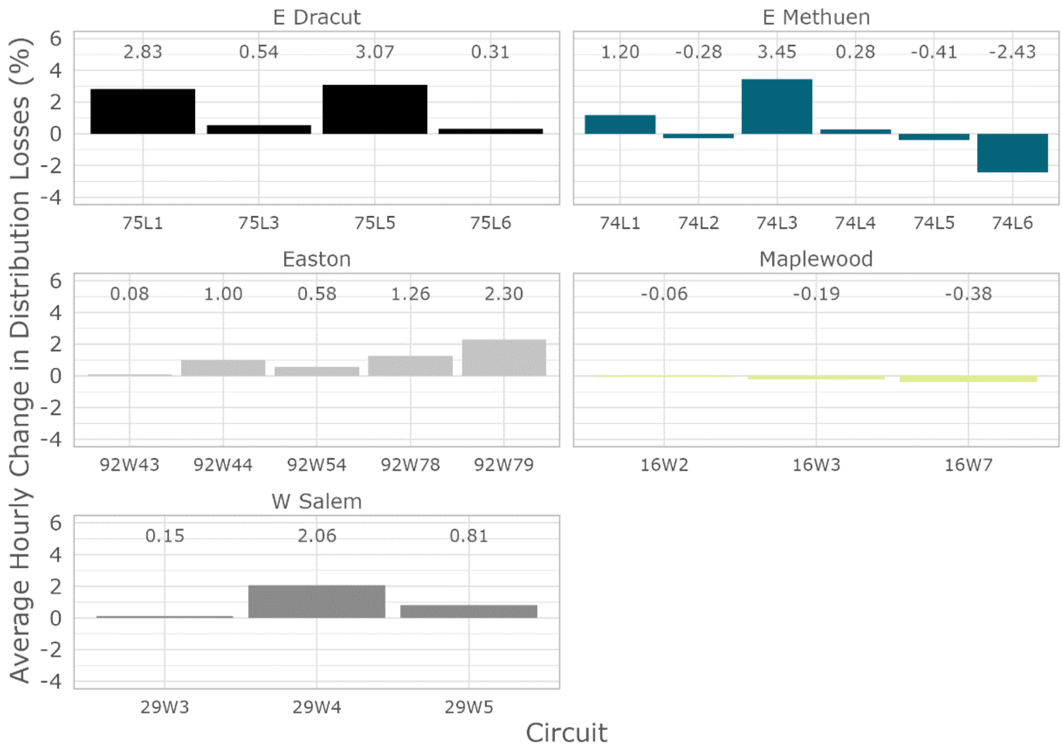
Table 36. National Grid Changes in Distribution Losses, Overall

Changes in Distribution Losses (%)*
0.77%

* The change in distribution losses presented in this table is the load-weighted average of reduction in distribution losses estimated for each circuit.
Source: Guidehouse analysis

Figure 17 indicates the estimated percentage reduction in distribution losses. Distribution losses across the VVO circuits ranged from -0.38% to 3.45%. Many of the circuits (11 of 19) had distribution loss improvements of 0.5% or more.

Figure 17. Changes in Distribution Losses (%) for National Grid VVO Circuits



Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.

Source: Guidehouse analysis

PM-5: Power Factor

Guidehouse evaluated the impact on power factor associated with VVO during PY 2023. Per the stamp-approved Performance Metrics, changes in power factor were analyzed during periods where power was greater than 75% of circuit-specific annual demand. Table 37 details the evaluated change in power factor for each National Grid circuit with sufficient data quality.[36] Estimation of VVO impacts from the PY 2023 M&V period indicate a statistically significant increase in power factor of 0.39%.

Table 37. National Grid VVO Average Hourly Power Factor Change, Overall*

Change in Power Factor	Change in Power Factor (%)
0.004 ± 0.001	0.394 ± 0.082%

* Power factor change presented in this table is the load-weighted average of power factor changes estimated for each circuit.

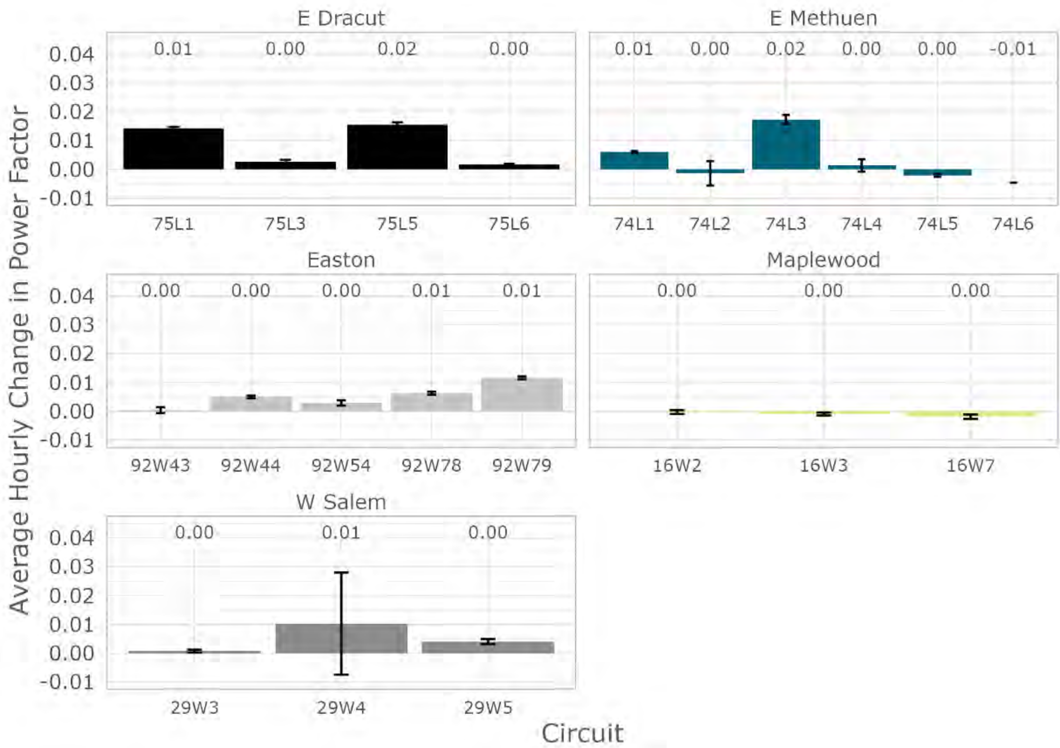
Source: Guidehouse analysis

Figure 18 indicates the average change in power factor for each National Grid circuit in absolute terms, with green points indicating each circuit's absolute power factor change. The

[36] There were some feeders with very little data where kW was greater than 75% of annual peak load for kVA. These feeders were ultimately removed from the power factor models, as they had fewer than 100 hours available for use in regression modeling.

whiskers overlaid on each circuit's absolute power factor change estimate provide the associated 90% confidence intervals. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant. Many circuits underwent statistically significant improvements in their power factors when VVO was engaged.

Figure 18. Changes in Power Factor (Absolute) for National Grid VVO Circuits

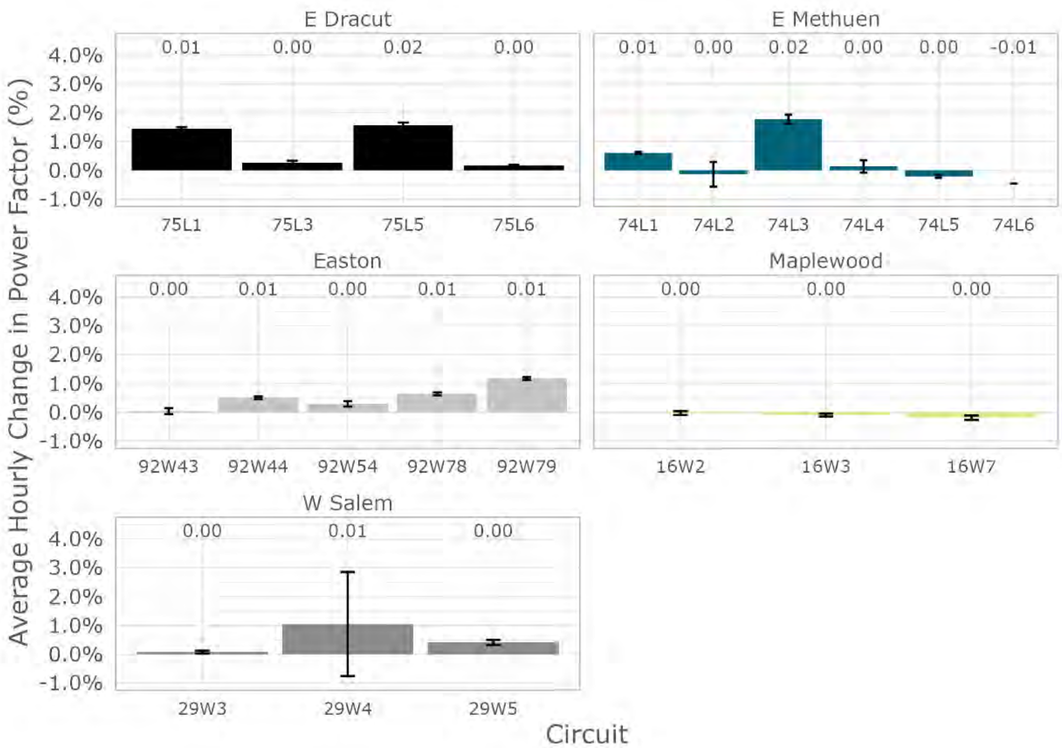


Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.

Source: Guidehouse analysis

Figure 19 indicates the change in power factor for each National Grid circuit in percentage terms, with green points indicating each circuit's percentage power factor change. The whiskers overlaid on each circuit's percentage power factor change estimate provide the associated 90% confidence intervals. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant. Many circuits underwent statistically significant improvements in their power factors when VVO was engaged.

Figure 19. Changes in Power Factor (%) for National Grid VVO Circuits



Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.

Source: Guidehouse analysis

PM-6: GHG Emissions

After estimating energy savings attributed to VVO, Guidehouse calculated the resulting emissions reductions. For 2023, emissions reductions were determined by to be 0.289 metric tons of emissions per MWh saved. This was calculated drawing the 2019 value from DPU 18-110 – DPU 18-119, Massachusetts Joint Statewide Electric and Gas Three Year Energy Efficiency Plan for 2019 – 2021, the 2025 value from DPU 21-120 – DPU 21-129, Massachusetts Joint Statewide Electric and Gas Three-Year Energy Efficiency Plan for 2022-2024, and then linearly interpolating the 2023 value from these two sources.[37] Emissions reductions were determined by multiplying GHG emissions reduction factors by total energy savings attributed to VVO.

Table 38 provides emissions reductions associated with VVO, with 90% confidence bounds indicated by the ± figure. Guidehouse estimated statistically significant reductions in energy use associated with active VVO control. As a result of this reduction in energy consumption,

[37] 2019 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. 2025 emissions factors can be found on page 326 of Massachusetts Joint Statewide Electric and Gas Three Year Energy Efficiency Plans for 2022 – 2024 https://ma-eeac.org/wp-content/uploads/Exhibit-1-Three-Year-Plan-2022-2024-11-1-21-w-App-1.pdf

there is expected to be a reduction in GHGs. The PY 2023 energy reductions resulted in a statistically significant reduction of 734 tons of CO_2 when VVO was engaged in 2023.

Table 38. National Grid VVO GHG Emissions Reductions, Overall

Assumption	CO_2
GHG Reductions – All Hours VVO On*	1,466 ± 68 tons
GHG Reductions – Actual VVO-On Hours†	734 ± 35 tons CO_2

* All VVO hours are the number of hours during the entire evaluation period for each VVO substation.
† Actual VVO On Hours are the number of hours that VVO was engaged during each substation's testing period.
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 circuit between 2016 and 2023. Discussion below highlights key observations for voltage complaints and compares the count of voltage complaints received during 2023 to the average number of voltage complaints from the 2016–2017 baseline period.

Table 39 indicates the number of voltage complaints reported during the baseline period (defined in the stamp approved Metrics as 2016-2017) for the East Bridgewater substation. Data indicate an increase (7) in voltage complaints in 2023 relative to the baseline.

Table 39. Count of Voltage Complaints for East Bridgewater

Number of Voltage Complaints	797W1	797W19	797W20	797W23	797W24	797W29	Total
Customers*	2,821	2,563	1,717	2,650	2,583	2,338	14,672
2016	3	7	3	9	0	3	25
2017	1	3	4	5	8	4	25
Baseline†	**2**	**5**	**4**	**7**	**4**	**4**	**26**
2022	2	5	5	14	3	0	29
2023	**3**	**7**	**5**	**9**	**6**	**3**	**33**

* Count of customers served by each circuit was extracted from the 2022 D.P.U 23-30 Report, Appendix 22-25.
† The baseline number of voltage complaints is calculated as the average number of voltage complaints between 2016 and 2017, rounded up to the nearest whole number.
Note: The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.
Source: Guidehouse analysis

Table 40 indicates the number of voltage complaints reported during the baseline period (defined in the stamp approved Metrics as 2016-2017) for the East Dracut substation. Data indicate an increase (3) in voltage complaints in 2023 relative to the baseline.

Table 40. Count of Voltage Complaints for East Dracut

Number of Voltage Complaints	75L1	75L2	75L3	75L4	75L5	75L6	Total
Customers*	3,041	2,613	2,328	387	3,556	1,485	13,410
2016	4	8	2	0	2	2	18
2017	5	0	3	0	6	1	15
Baseline†	**5**	**4**	**3**	**0**	**4**	**2**	**18**
2022	3	2	2	1	6	2	16
2023	**6**	**4**	**6**	**1**	**2**	**2**	**21**

* Count of customers served by each circuit was extracted from the 2022 D.P.U 23-30 Report, Appendix 22-25.
† The baseline number of voltage complaints is calculated as the average number of voltage complaints between 2016 and 2017, rounded up to the nearest whole number.
Note: The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.
Source: Guidehouse analysis

Table 41 indicates the number of voltage complaints reported during the baseline period (defined in the stamp approved Metrics as 2016-2017) for the East Methuen substation. Data indicate a decrease (8) in voltage complaints in 2023 relative to the baseline.

Table 41. Count of Voltage Complaints for East Methuen Substation

Number of Voltage Complaints	74L1	74L2	74L3	74L4	74L5	74L6	Total
Customers*	3,088	1,574	3,355	1,609	3,162	1,781	14,569
2016	9	2	2	5	10	7	35
2017	6	2	8	1	5	2	24
Baseline†	**8**	**2**	**5**	**3**	**8**	**5**	**31**
2018	3	0	2	3	5	3	16
2019	5	0	2	2	3	2	14
2020	1	1	7	3	2	2	16
2021	3	0	2	1	3	1	10
2022	1	1	2	3	8	1	16
2023	**2**	**2**	**3**	**1**	**13**	**2**	**23**

* Count of customers served by each circuit was extracted from the 2022 D.P.U 23-30 Report, Appendix 22-25.
† The baseline number of voltage complaints is calculated as the average number of voltage complaints between 2016 and 2017, rounded up to the nearest whole number.
Note: The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.
Source: Guidehouse analysis

Table 42 indicates the number of voltage complaints reported during the baseline period (defined in the stamp approved Metrics as 2016-2017) for the Easton substation. Data indicate an increase (14) in voltage complaints in 2023 relative to the baseline.

Table 42. Count of Voltage Complaints for Easton

Number of Voltage Complaints	92W43	92W44	92W54	92W78	92W79	Total
Customers*	1,973	1,779	2,284	1,993	1,655	**9,684**
2016	6	2	5	5	0	18
2017	4	4	7	4	6	25
Baseline†	**5**	**3**	**6**	**5**	**3**	**22**
2022	1	3	5	4	4	17
2023	**6**	**7**	**6**	**8**	**9**	**36**

* Count of customers served by each circuit was extracted from the 2022 D.P.U 23-30 Report, Appendix 22-25.
† The baseline number of voltage complaints is calculated as the average number of voltage complaints between 2016 and 2017, rounded up to the nearest whole number.
Note: The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.

Source: Guidehouse analysis

Table 43 indicates the number of voltage complaints reported during the baseline period (defined in the stamp approved Metrics as 2016-2017) for the Maplewood substation. Data indicate an increase (28) in voltage complaints in 2023 relative to the baseline.

Table 43. Count of Voltage Complaints for Maplewood Substation

Number of Voltage Complaints	16W1	16W2	16W3	16W4	16W5	16W6	16W7	16W8	Total
Customers*	3,683	4,674	3,352	1,131	1,710	5,627	3,891	3,427	27,495
2016	4	3	0	2	3	4	2	2	20
2017	6	3	2	0	5	6	4	5	31
Baseline†	**5**	**3**	**1**	**1**	**4**	**5**	**3**	**4**	**26**
2018	6	3	1	4	1	6	6	7	34
2019	7	10	5	3	1	8	6	10	50
2020	6	7	4	4	3	10	6	8	48
2021	2	7	0	1	1	4	3	3	21
2022	3	6	0	3	1	7	5	20	45
2023	**4**	**18**	**5**	**3**	**1**	**10**	**8**	**5**	**54**

* Count of customers served by each circuit was extracted from the 2022 D.P.U 23-30 Report, Appendix 22-25.
† The baseline number of voltage complaints is calculated as the average number of voltage complaints between 2016 and 2017, rounded up to the nearest whole number.
Note: The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.

Source: Guidehouse analysis

Table 44 indicates the number of voltage complaints reported during the baseline period (defined in the stamp approved Metrics as 2016-2017) for the Stoughton substation. Data indicate an increase (5) in voltage complaints in 2023 relative to the baseline.

Table 44. Count of Voltage Complaints for Stoughton Substation

Number of Voltage Complaints	913W17	913W18	913W43	913W47	913W67	913W69	Total
Customers*	1,350	1,504	2,132	1,796	755	3,603	**11,140**
2016	4	3	0	2	3	4	**2**
2017	6	3	2	0	5	6	**4**
Baseline†	**5**	**3**	**1**	**1**	**4**	**5**	**3**
2018	6	3	1	4	1	6	**6**
2019	7	10	5	3	1	8	**6**
2020	6	7	4	4	3	10	**6**
2021	2	7	0	1	1	4	**3**
2022	3	6	0	3	1	7	**5**
2023	**4**	**18**	**5**	**3**	**1**	**10**	**8**

* Count of customers served by each circuit was extracted from the 2022 D.P.U 23-30 Report, Appendix 22-25.
† The baseline number of voltage complaints is calculated as the average number of voltage complaints between 2016 and 2017, rounded up to the nearest whole number.
Note: The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.
Source: Guidehouse analysis

Table 45 indicates the number of voltage complaints reported during the baseline period (defined in the stamp approved Metrics as 2016-2017) for the West Salem substation. Data indicate an increase (28) in voltage complaints in 2023 relative to the baseline.

Table 45. Count of Voltage Complaints for West Salem Substation

Number of Voltage Complaints	29W1	29W2	29W3	29W4	29W5	29W6	Total
Customers*	3,788	1,653	4,286	2,700	2,915	1,426	16,768
2016	4	0	2	9	2	1	**18**
2017	7	0	2	1	4	4	**18**
Baseline†	6	0	2	5	3	3	**19**
2022	11	2	5	3	6	3	**30**
2023	**11**	**3**	**10**	**4**	**13**	**6**	**47**

* Count of customers served by each circuit was extracted from the 2022 D.P.U 23-30 Report, Appendix 22-25.
† The baseline number of voltage complaints is calculated as the average number of voltage complaints between 2016 and 2017, rounded up to the nearest whole number.
Note: The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.
Source: Guidehouse analysis

3.2.3.3 Key Findings and Recommendations

Guidehouse has the following key findings to provide for the PY 2023 Performance Metrics evaluation:

- During the PY 2023 M&V period, National Grid's East Bridgewater, East Dracut, East Methuen, Easton, Maplewood, Stoughton, and West Salem substations realized 2,540 MWh (1.3%) energy savings and 0.320 kV (2.3%) voltage reduction associated with VVO. National Grid's CVR factor was 0.92.[8] National Grid energy savings of 2,540 MWh yielded a 734 short ton reduction in CO_2 emissions. Overall, these aggregate findings suggest that voltage is being regulated along the length of the circuits, dropping and flattening the voltage profile for most connected customers, thereby yielding a reduction in energy consumption detected at the circuit head-end for several circuits.
- Despite voltage reductions being estimated for all circuits, some circuits connected to the East Bridgewater (circuit 797W20), East Dracut (circuits 75L1, 75L3), and West Salem (circuits 29W2 through 29W6) substations underwent no energy reduction or an increase in energy usage when VVO was engaged. This may be due to faults in the VVO scheme at sections of these circuits, which cannot be diagnosed using substation SCADA. For instance, if voltage did not drop or consumption increased on a section of circuit 797W20 with a heavy commercial and industrial load composition, the increase in consumption in this zone may outweigh energy consumption reductions realized on all other zones of the circuit.
- All circuits connected to National Grid's Easton substation underwent an average voltage reduction of 1.3%, yielding energy reductions of between 0.90% and 2.40%. This reflects the reduction in voltage and energy realized only during the VVO On/Off testing period and does not capture additional changes relative to the pre-conditioned state (for more discussion of the impacts of circuit conditioning, please refer to Section 2.1.1). In discussions with National Grid, National Grid indicated that the Easton substation underwent a reduction in its LTC setpoint from 124.4V to 122.5V, a 1.5% reduction, while preparing the station for VVO control. This reflects a 1.5% reduction in voltage associated with circuit conditioning and is contained in the data collected when VVO was in the Off state. The impact of VVO quantified via comparison of VVO On/Off testing data was estimated to be 1.3%, meaning the combined impact of circuit conditioning (reported by National Grid as 1.5%) and active VVO control (estimated by Guidehouse as 1.3%) may be as high as 2.8%. If National Grid did achieve a 1.5% reduction in voltage via circuit conditioning, then the energy impacts estimated to range from 0.90% and 2.40% for the Easton substation are likely to be conservative.
- National Grid VVO circuits experienced a statistically significant decrease in peak load (1.3%), a statistically significant increase in power factor (0.39%), and a decrease in distribution losses (0.77%) when VVO was engaged. Most East Dracut, East Methuen, and Maplewood circuits underwent statistically significant reductions in peak demand when VVO was engaged. In general, peak demand reductions for these circuits correlated well with voltage reduction estimates, which ranged from 1.6% to 3.9% when VVO was engaged.
- Five of six West Salem circuits underwent statistically significant estimated reductions in peak demand when VVO was engaged, ranging from 1.0% to 5.2%. This is not consistent with the estimated statistically significant increases in energy when VVO was engaged, which ranged from 1.0% to 4.0%. National Grid may consider investigating end-of-line feeder monitor data to determine whether there are differences in how voltage is lowered and flattened during peak hours (4:00 p.m. to 10:00 p.m., non-holiday weekdays between May 1 and September 30) relative to all other hours of the day. It may be the case that West Salem circuits' line devices were not responding to VVO signals as-expected outside of the identified peak period.

- Four of five Easton circuits underwent statistically significant increases in peak demand when VVO was engaged, ranging from 0.5% to 1.1%. Upon investigation of LTC settings and end-of-line feeder monitor voltage data for the Easton substation, National Grid identified that LTC settings may have been “too soft”. In this case, during the peak hours, which are hotter hours prone to voltage “sags”, the LTC settings when VVO was disengaged allowed for voltage conditions to drop, causing low voltage violations at the end-of-line. In contrast, when VVO was engaged, the National Grid VVO scheme increased voltage to minimize the incidence of low voltage violations. This ultimately led end-of-line voltage to be greater during peak hours when VVO was engaged relative to when VVO was disengaged, which is beneficial in ensuring customer end-uses are not interrupted by low voltage violations. However, given low voltage violations were reported when VVO was disengaged, this lowered demand relative to when VVO was engaged, which likely led to the negative peak demand impacts estimated for four of the five Easton circuits.
- For National Grid, a total of 255 voltage complaints were received from customers connected to the East Bridgewater, East Dracut, East Methuen, Easton, Maplewood, Stoughton, and West Salem VVO circuits during the period. This is a 50% increase relative to the average voltage complaints per year received between 2016 – 2017. However, the change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.

In 2024 and beyond, Guidehouse recommends that National Grid:

- Continue to monitor performance of the VVO scheme after M&V has been completed, such as ensuring capacitor banks and pole-top regulators are responding as anticipated to VVO/ADMS commands. National Grid performance metric estimates are reflective of the VVO scheme as it was in PY 2023. Continuously monitoring the VVO scheme to ensure all line devices are responding as anticipated will be important in ensuring evaluated performance is maintained.
- Provide SCADA data for one or two “placebo” circuits (i.e., circuits without VVO schemes) for the PY 2024 and PY 2025 evaluations. Using data provided for two “placebo” circuits within the PY 2023 evaluation, Guidehouse identified that National Grid’s On/Off testing data was biased by extended pauses to the On/Off testing conducted. In some cases, this led to an oversampling of hotter days when VVO was engaged relative to when VVO was disengaged, and in others this led to an oversampling of cooler days when VVO was engaged relative to when VVO was disengaged. This poses a threat to the RCT program design of On/Off testing and required the data to be rebalanced via a Euclidean distance matching algorithm summarized in Section 2.1.3. Providing SCADA for “placebo” circuits will allow Guidehouse to assess whether testing data for the VVO circuits needs to be rebalanced.
- Increase the cadence of VVO On/Off testing. Guidehouse recommends shifting from week on / week off testing to either testing daily (i.e., day on / day off), every other day, every two days, every three days, or every four days (i.e., four days on / four days off). Increasing the cadence of testing will improve the likelihood of balance in temperatures, day types, and other factors that influence grid conditions. This ultimately allows for the RCT design of VVO On/Off testing to yield unbiased Performance Metric estimates.
- Once a schedule with increased cadence has been determined for VVO On/Off testing, the National Grid should make every effort to comply with the pre-determined schedule. If compliance is achieved, there should be a balance of temperatures and other conditions correlated with system demand, voltage, and power factor, thereby leading to VVO impact estimates that are unbiased. Failure to comply, such as pausing On/Off testing and leaving

VVO in its engaged or disengaged state for an extended period of time, will increase the likelihood of an invalid RCT in the PY 2024 and PY 2025 evaluations. If an invalid RCT is identified, Guidehouse will need to rebalance the data using the approach outlined in Section 2 to reduce the risk of biased VVO impact estimates.

- To identify causes of lower performance, particularly for the West Salem substation (which underwent estimated energy increases when VVO was engaged) and the Easton substation (which underwent estimated peak demand increases when VVO was engaged), consider assessing data collected from devices along each connected circuit. For example, end-of-line feeder monitor voltage data will enable an investigation of whether voltage is performing as expected at the end-of-line when VVO is engaged. In addition, if data are collected for points between the circuit head-end and end-of-line, assess of whether certain zones of a circuit are under- or over-performing relative to the aggregate impact detected using SCADA collected at the circuit head-end.

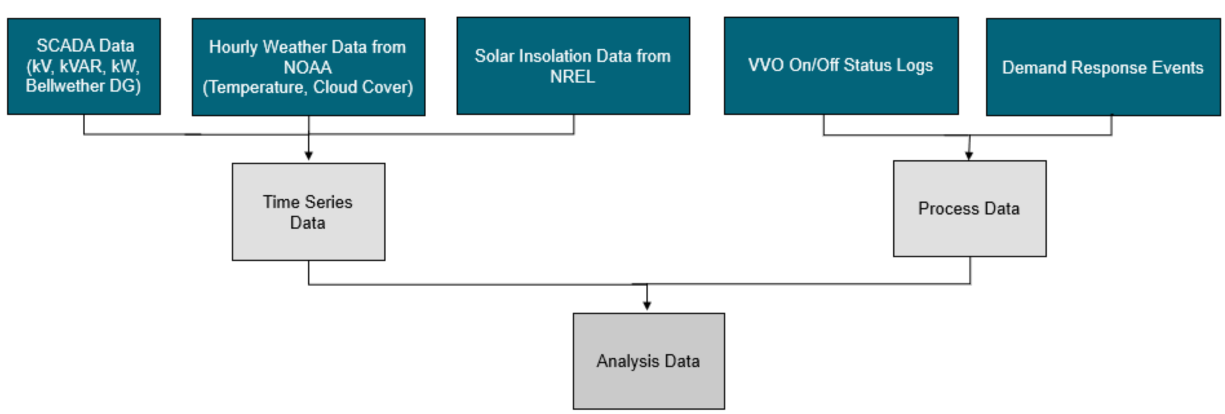
3.2.4 Unitil

Guidehouse worked with Unitil to collect data necessary to complete the evaluation of the VVO Performance Metrics. The sections that follow highlight the analysis data construction, analysis data cleaning, and the analysis approach.

Analysis Data Construction

To assess the Performance Metrics, Guidehouse constructed an analysis dataset. This dataset was used in regression modeling to assess changes in multiple outcome variables, such as energy and peak demand. Figure 20 summarizes the data integration process used to construct the analysis dataset for the Unitil Performance Metrics analysis.[38]

Figure 20. Unitil Analysis Data Construction Flowchart



Source: Guidehouse

Guidehouse constructed a final analysis dataset for the Unitil Performance Metrics analysis using time series and process data. To construct the final dataset, the evaluation team first integrated SCADA interval data from Unitil that contained 15-minute measurements of voltage, real power, and reactive power. The team then integrated hourly dry bulb temperature and

[38] Guidehouse receives different data types and structures from the EDCs for estimating impacts across the performance metrics. These differences were minimized as much as possible, but any differences that remain may affect the comparability of performance metrics results across the EDCs.

hourly cloud cover data from NOAA for Worcester Regional Airport and quarter-hourly solar insolation data from NREL to arrive at a final time series dataset.[39][40]

To construct the process data, Guidehouse integrated other VVO system information. Other system information included time-stamped logs of VVO state changes between VVO On (engaged) and Off (disengaged) states within the SCADA data, and demand response events during the evaluation period. The time series and process data were then joined to construct a final analysis dataset.

Analysis Data Cleaning

After constructing the analysis dataset, the team conducted data cleaning steps to remove interval data that may bias the estimates of VVO impacts. Table 46 summarizes observations made by the evaluation team and the resulting data cleaning steps that were executed.

Table 46. Data Cleaning Conducted for Unitil Analysis

Data Observation	Data Cleaning Step
Identified a handful of periods of repeated, interpolated, and outlier values in the interval data received, as well as periods missing VVO-status data.	Removed observations where anomalous data readings were flagged.
VVO On/Off testing was conducted May 28 through December 31, although substation SCADA was provided for the entire calendar year.	Removed observations outside of the VVO On/Off testing period (all data points prior to May 28).

Source: Guidehouse

Table 47 indicates the number of observations contained in the analysis dataset for the Townsend substation. Much of the data removed during data cleaning was due to extended periods over which VVO was engaged or disengaged. Detailed data attrition information is included in Appendix D.

Table 47. Count of VVO On, VVO Off, and Removed Observations for Unitil

Substation	Circuit	VVO On Observations	VVO Off Observations	Observations Removed by Data Cleaning*	VVO Testing Period Total
Townsend	15W15	10,622	9,691	530	**20,843**
	15W16	10,496	9,615	732	**20,843**
	15W17	10,449	9,333	1,061	**20,843**

*Data were removed from the analysis dataset per the protocol summarized in Table 46.

Source: Guidehouse

Analysis Approach

[39] Worcester Regional Airport was selected due to it having a quality controlled local climatological dataset and due to its being in close proximity to the Unitil substation evaluated this year. 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

[40] Documentation on the NREL dataset used in this analysis can be found here: NSRDB | What is the NSRDB (nrel.gov)

Across the VVO circuits at the Townsend substation, there are Distributed Energy Resources (DERs) connected at different points on the circuits. These DERs vary in size as well as the timing of when they provide additional resources to the circuits.

To account for possible impacts of behind-the-meter DERs, Guidehouse utilized additional data to estimate total circuit load as opposed to substation power flow. Guidehouse calculated behind-the-meter DER load data by using the Bellwether DG data provided by Unitil. Guidehouse scaled this data for each circuit by using the nominal capacity connected to each circuit. Guidehouse then added this scaled data to the substation SCADA load data to generate substation load adjusted for DG (i.e., DG-adjusted substation load). This DG-adjusted substation load was used within the regression models to produce the PM impacts described below.

After the analysis data was constructed and cleaned, Guidehouse conducted Euclidean distance matching following the methodology summarized in Section 2.1.3. Results from Euclidean distance matching are provided in 4.2Appendix C.

After conducting Euclidean distance matching, Guidehouse conducted statistical regression modeling to assess the impacts of active VVO control via comparison of data logged when VVO was engaged and when VVO was disengaged. Appendix A provides additional details on the modeling approaches utilized to complete the PY 2023 Performance Metrics evaluation.

To inform the regression model specifications utilized for this evaluation, Guidehouse conducted further inspection of the data to control for exogenous patterns. Table 48 summarizes observations made during this inspection and the resulting data analysis steps that were implemented.

Table 48. Data Analysis Summary for Unitil

Data Observation	Data Analysis Step
Numerous circuits had a large nominal capacity of connected solar facilities.	Solar insolation data from NREL were integrated and included in regression analysis to capture changes in DG-adjusted load and voltage due to solar generation.
Numerous circuits were identified with non-residential customers making up a large portion of load, with drops in measured DG-adjusted load during holidays and non-business hours.	Day type (i.e., weekday or weekend day) and hour of day fixed effects were incorporated into regression models to capture typical load shapes by day type and control for large drops in DG-adjusted demand observed during non-business hours.
One ISO New England Voltage Reduction Test event was called during PY 2023.*	Intervals that occurred during system-wide voltage reduction tests were flagged in the regression analysis to control for reductions in energy and voltage associated with voltage reduction events.

* https://www.iso-ne.com/event-details?eventId=153338 accessed January 17, 2024
Source: Guidehouse

3.2.4.1 Performance Metrics Results

This section summarizes the Performance Metrics results for Unitil. Each of the subsections separately summarize the evaluation results for each performance metric.

PM-1: Baseline

As detailed in the Stage 3 Plan filed February 7, 2024, Guidehouse provides a baseline using data collected when VVO was disabled during the evaluation period, which spans PY 2023.[41] Table 49 provides the energy baseline calculated using VVO Off data collected during PY 2023.

Table 49. Unitil VVO Energy Baseline

Metric	Baseline Total Energy Use
Baseline Energy	253,380 MWh

Source: Guidehouse analysis

To estimate total baseline energy use, Guidehouse conducted regression modeling for each VVO circuit to estimate how energy usage changes when VVO is engaged, controlling for weather, day-of-week, solar insolation, and other observable conditions that influence energy usage but that are not attributed to VVO control. After conducting regression modeling to estimate energy usage, Guidehouse used the regression results to predict what energy usage would have been if VVO were off for the entirety of PY 2023 for each VVO circuit, holding all other observable conditions constant (e.g., allowing weather to remain as it was when VVO was engaged). Guidehouse then calculated the summation of this predicted energy usage across all hours and circuits to calculate a baseline total energy use for PY 2023. Baseline energy use is provided by VVO circuit in 0.

PM-2: Energy Savings

Table 50 provides the aggregated evaluated energy savings for Unitil for PY 2023 overall. The ± figure indicate 90% confidence bounds associated with energy savings estimates. Regression estimates indicate a statistically significant reduction in energy use associated with VVO, with 211 MWh (1.5%) energy savings realized during PY 2023.[42]

Table 50. Unitil VVO Net Energy Reductions, Overall

Aggregated Energy Reduction		
Assumption	**MWh**	**%‡**
Energy Savings - All Hours VVO On*	438 ± 42 MWh	1.525 ± 0.146%
Energy Savings - Actual VVO On Hours†	229 ± 22 MWh	1.525 ± 0.146%

* Total energy reductions were determined by calculating the energy reductions across the entirety of the Townsend substation's testing period, assuming VVO to be engaged during the entire period.
† Actual VVO On Hours are the number of hours in the clean analysis data that were VVO engaged during the Townsend substation's testing period for each evaluation circuit.
‡ Energy reductions presented in this table is the load-weighted average of energy reductions estimated for each circuit.
Source: Guidehouse analysis

All circuits underwent statistically significant decreases in energy when VVO was engaged. Energy estimates ranged from approximately 1.1% to 1.9%, which aligns with the aggregated voltage reductions of 1.3%. Net energy impacts appear to be negatively correlated with circuit

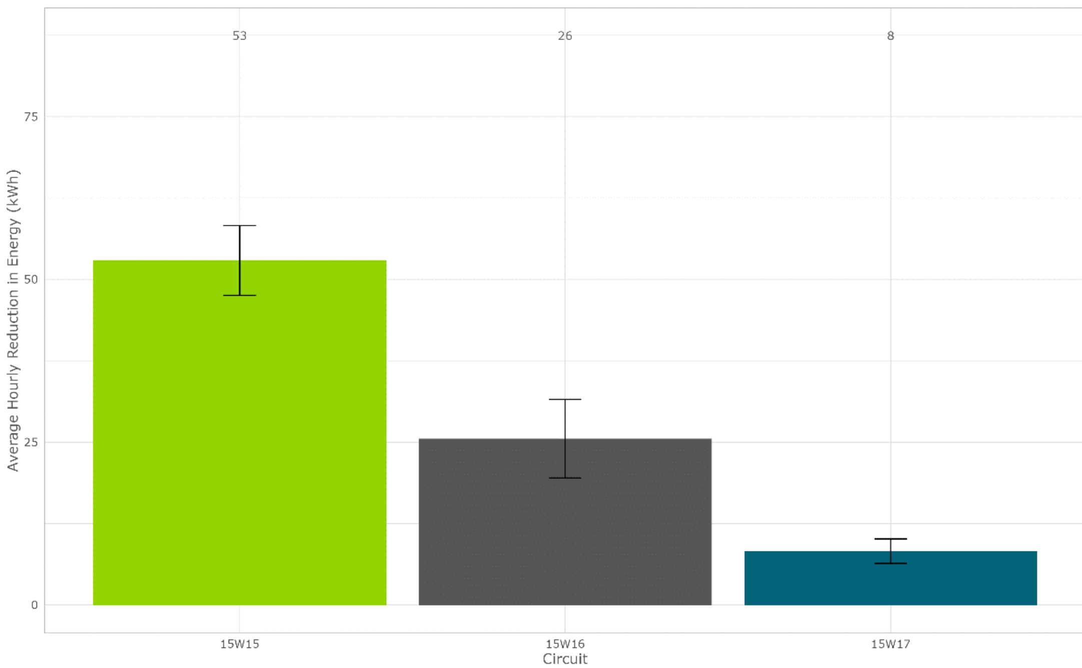
[41] On February 7, 2024, Eversource, National Grid, and Unitil filed evaluation plans with the DPU for the period spanning 2022-2025. The DPU docketed these plans as DPU 21-80, 21-81, and 21-82, respectively.

[42] Actual VVO On Hours are the number of hours in the clean analysis data that were VVO engaged during the Townsend substation's testing period for each evaluation circuit.

length (i.e., longer circuit length equates to small energy reductions). However, there are likely other factors that influence circuit-specific findings (e.g., customer load mix).

Figure 21 indicates the average hourly energy reductions for each Unitil circuit in absolute terms (kWh), with the value at the top of each circuit indicating each circuit's average hourly kWh savings. The whiskers overlaid on each circuit's kWh savings estimate provide the associated 90% confidence intervals. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant. During PY 2023, all 3 circuits experienced statistically significant reductions in energy.

Figure 21. Net Energy Reductions (kWh) for Unitil VVO Circuits

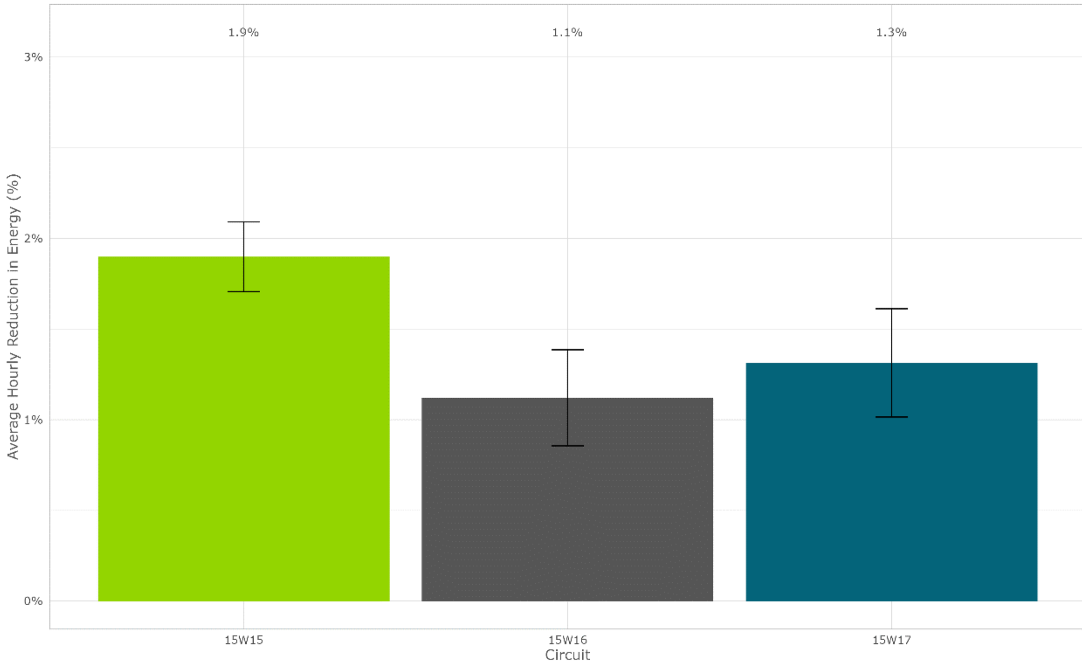


Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.

Source: Guidehouse analysis

Figure 22 indicates the average hourly energy reductions for each Unitil circuit in percentage terms, with the value at the top of each circuit indicating each circuit's percentage kWh savings. The whiskers overlaid on each circuit's percentage kWh savings estimate provide the associated 90% confidence intervals. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant. During PY 2023, all 3 circuits experienced statistically significant reductions in energy.

Figure 22. Net Energy Reductions (%) for Unitil VVO Circuits



Note: Whiskers in this figure correspond to the *90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.*

Source: Guidehouse analysis

To further understand impacts, Guidehouse estimated reductions in voltage associated with VVO, Table 51 provides the evaluated voltage reductions for Unitil, with 90% confidence bounds associated with voltage reductions estimates indicated by the ± figure. Regression estimates indicate a statistically significant reduction in voltage associated with VVO, with a 0.19 kV (1.3%) voltage reduction realized during PY 2023.

Table 51. Unitil VVO Average Hourly Voltage Reduction, Overall*

Aggregated Voltage Reduction	
(kV)*	**(%)***
0.190 ± <0.001 kV	1.341 ± 0.007%

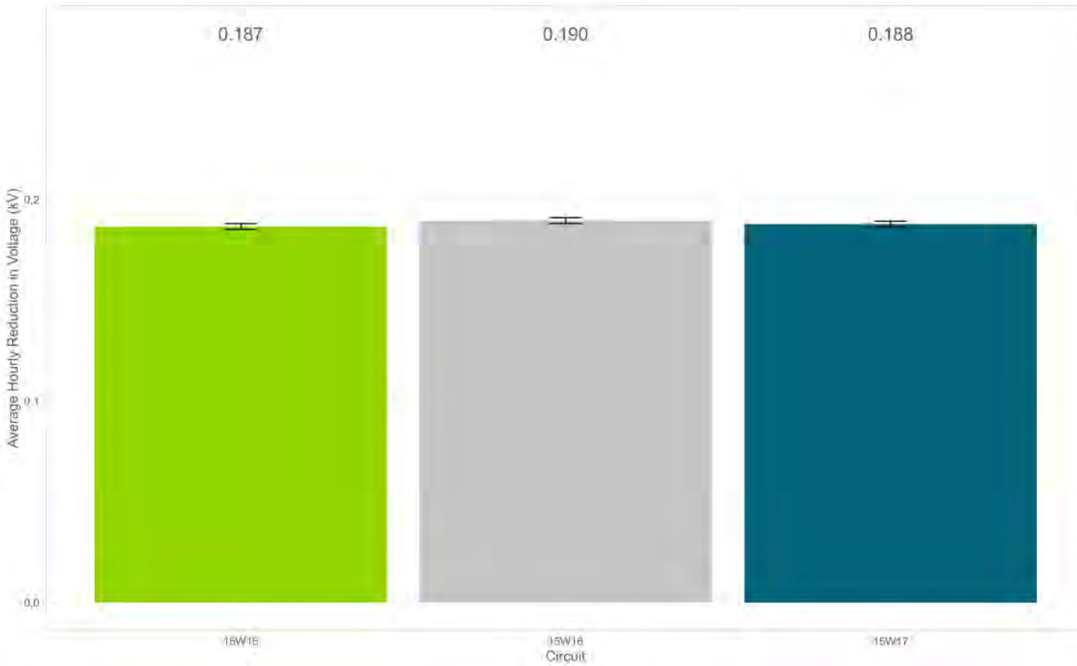
* Voltage reductions presented in this table is the DG-adjusted load-weighted average of voltage reductions estimated for each circuit.
Source: Guidehouse analysis

To support the PY 2023 evaluation, Unitil also provided line-device voltage data collected from end-of-line meters, capacitor banks, and pole-top regulators. While these sources were not included in the regression analysis, Guidehouse confirmed that data collected from line-devices indicated a consistent response to what was observed at the substation, indicating that the VO scheme is working to reduce voltage as expected.

Figure 23 indicates the average hourly voltage reductions for each Unitil circuit, with the value at the top of each circuit indicating each circuit's voltage reductions. The whiskers overlaid on each circuit's voltage reduction estimate provide the associated 90% confidence intervals.

Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant. All the circuits experienced a statistically significant average hourly voltage reduction when VVO was engaged.

Figure 23. Average Hourly Voltage Reductions (kV) for Unitil VVO Circuits

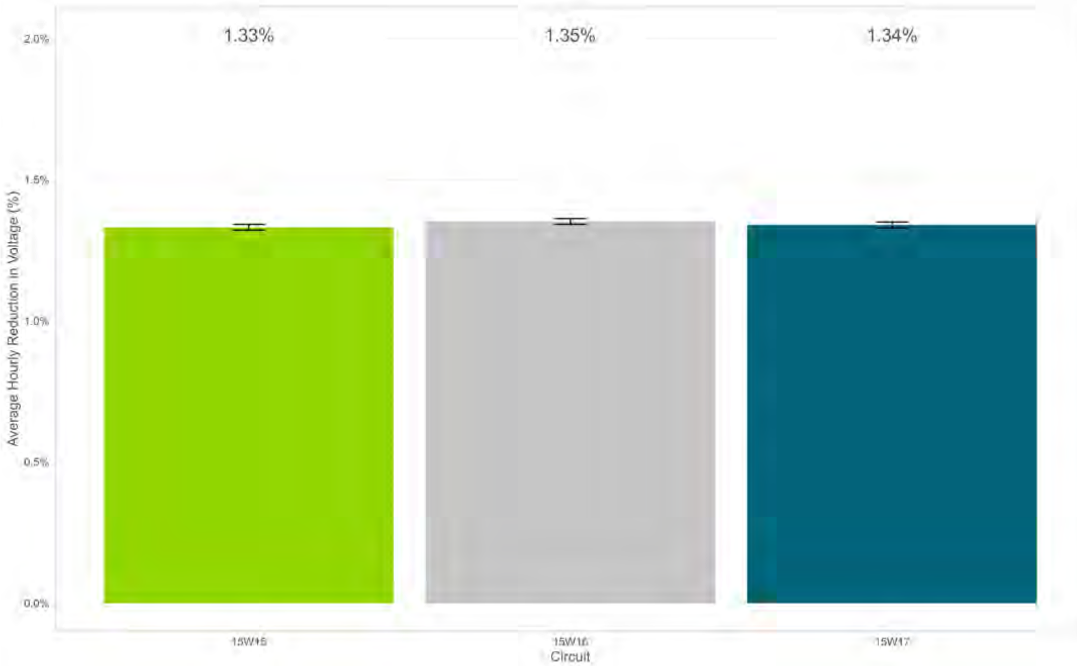


Note: Whiskers in this figure correspond to the 90% *confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.*

Source: Guidehouse analysis

Figure 24 indicates the net voltage reductions for each Unitil circuit in percentage terms, with the value at the top of each circuit indicating each circuit's percentage voltage reductions. The whiskers overlaid on each circuit's percentage voltage reduction estimate provide the 90% confidence intervals. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant. Similar to absolute voltage impacts, all the circuits experienced a statistically significant decrease in voltage when VVO was enabled.

Figure 24. Average Hourly Voltage Reductions (%) for Unitil VVO Circuits



Note: Whiskers in this *figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.*

Source: Guidehouse analysis

Following an estimation of percentage energy reductions and percentage voltage reductions attributed to VVO, Guidehouse calculated the associated CVR factors for each circuit. The CVR factor, which is the ratio of percentage energy reductions to percentage voltage reductions, can provide an estimate of the percentage energy reductions possible with each percent voltage reduction.

Equation A-1 in the Appendix highlights how the CVR factor is calculated using an estimated percentage reduction in energy and in voltage. Table 52 provides the CVR factor for Unitil by circuit and overall.

Table 52. Unitil VVO CVR Factor, Overall*

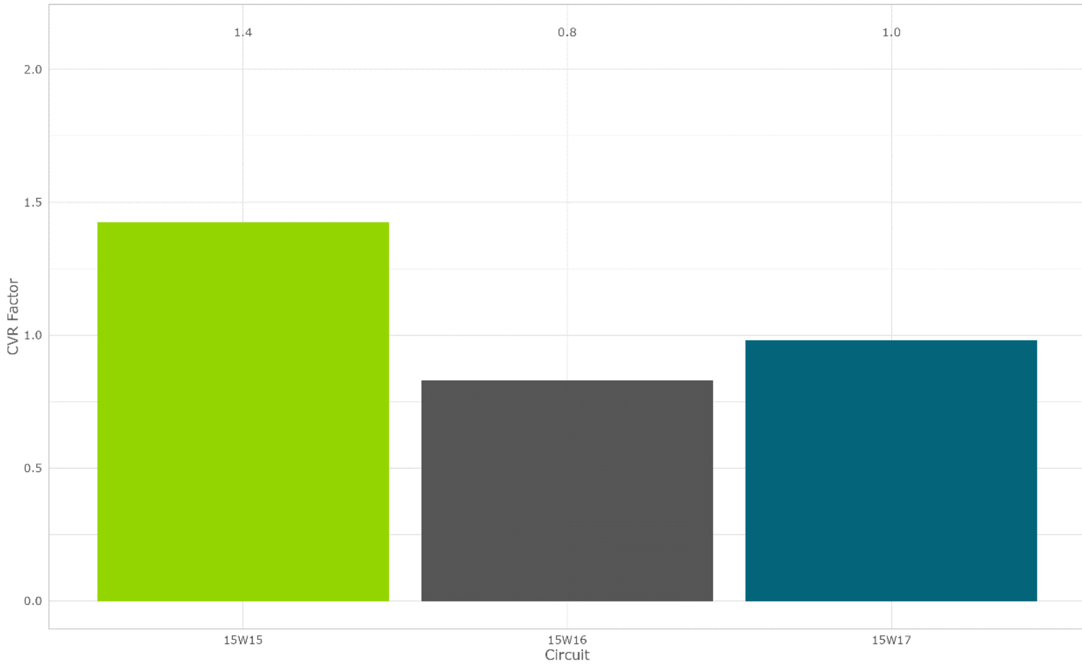
Circuit	CVRf*
15W15	1.43
15W16	0.83
15W17	0.98
Overall	**1.14**

* CVR factor presented in this table is the load-weighted average of CVR factors for all analysis circuits.

Source: Guidehouse analysis

From prior experience evaluating VVO, Guidehouse expects a CVR factor of 0.80 ± 0.40 from a year of VVO M&V testing. Based on evaluation findings, the CVR factor for PY 2023 was 1.14. Figure 25 provides the CVR factors for PY 2023 for each circuit.

Figure 25. CVR Factors for Unitil VVO Circuits



Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.
Source: Guidehouse analysis

Key takeaways based on evaluation findings for energy, voltage, and CVR factors include:

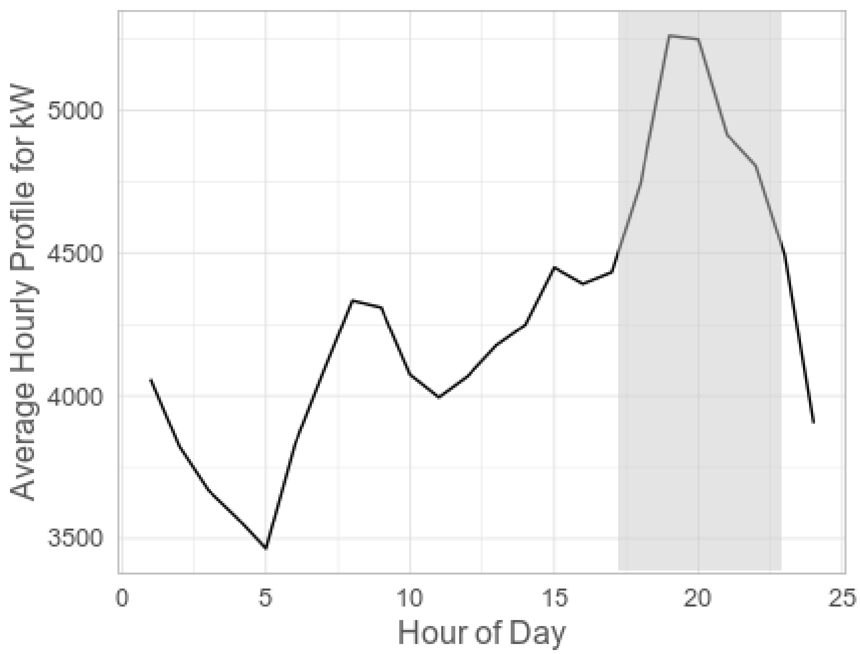
- All Townsend substation VVO circuits underwent estimated statistically significant reductions in energy consumption when VVO was engaged. In-line with these findings were estimated voltage reductions of 1.3%, yielding CVR factors ranging from 0.80 to 1.40. Findings suggest that voltage is being regulated as-anticipated along the length of the circuit, dropping and flattening the voltage profile for most connected customers, thereby yielding a reduction in energy consumption being detected at the circuit head-end.

PM-3: Peak Demand Impact

Prior to PY 2023, Guidehouse evaluated the impact of VVO during peak demand using the ISO-NE definition of peak demand (1:00 p.m. to 5:00 p.m. ET from June 1 to August 31 on non-holiday weekdays). However, peak demand for each EDC does not always coincide with the ISO-NE's definition of peak demand. Therefore, for PY 2023, the definition of the peak period was determined based on SCADA demand data collected from each EDC during PY 2023.

Guidehouse aggregated the SCADA DG-adjusted load data received from Unitil for PY 2023 between June 1 and September 30 on non-holiday weekdays. Using substation SCADA data for circuits 15W16 and 15W17, Guidehouse identified that average DG-adjusted demand was generally highest between the hours of 4:00 p.m. to 10:00 p.m. on non-holiday weekdays between June 1 and September 30.[43] Figure 26 shows this average DG-adjusted load curve, where 4:00 p.m. to 10:00 p.m. have the highest DG-adjusted load across the 24 hours. Guidehouse utilized this period as the peak period with which to estimate reductions in peak demand attributed to VVO.

Figure 26. Aggregate Average Hourly DG-Adjusted Load for Unitil 15W16 and 15W17 Circuits*



* Circuit 15W15 was excluded from the average hourly DG-adjusted load profile given that it is connected to only one large industrial customer.

Source: Guidehouse analysis

Table 53 provides the evaluated peak demand reductions for Unitil, with 90% confidence bounds associated with peak demand reduction estimates indicated by the ± figure. Regression estimates indicate a statistically insignificant decrease in peak demand associated with VVO, with a 20 kW (0.4%) peak demand reduction realized during PY 2023.

Table 53. Unitil Reduction in Peak Demand, Overall

Aggregated Peak Demand Reduction	
(kW)*	(%)*
20 ± 41 kW	0.363 ± 0.619%

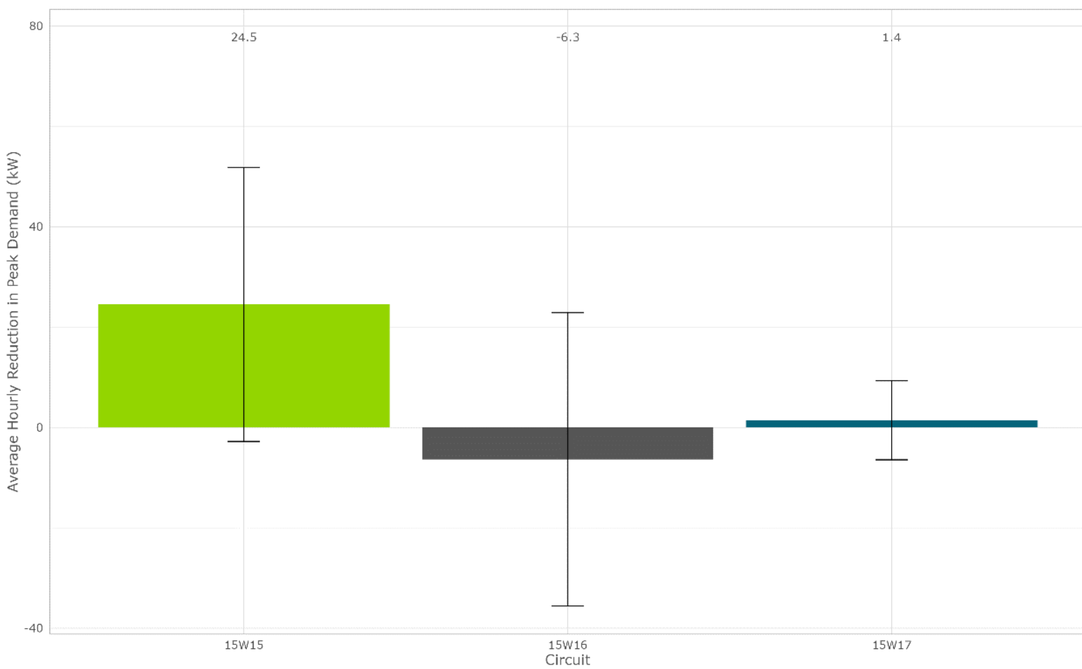
* Peak demand reductions presented in this table is the DG-adjusted load-weighted average of peak demand reductions *estimated for each circuit.*

Source: Guidehouse analysis

[43] Investigation of substation SCADA revealed that consumption was generally greatest between the hours of 4pm and 10pm on non-holiday weekdays between May 1 and September 30. However, since VVO On/Off testing did not commence until late May, Guidehouse defined the peak period as 4pm to 10pm on non-holiday weekdays between June 1 and September 30.

Figure 27 indicates the load reductions measured in kW realized during the peak load period, defined as 4:00 p.m. to 10:00 p.m. ET from June 1 to September 30 on non-holiday weekdays. The value at the top of each circuit indicating each circuit's absolute peak demand reductions. The whiskers overlaid on each circuit's absolute peak demand reduction estimate provide the 90% confidence intervals. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant. All circuits experienced a statistically insignificant change in absolute peak demand when VVO was enabled.

Figure 27. Peak Demand Reductions (kW) for Unitil VVO Circuits

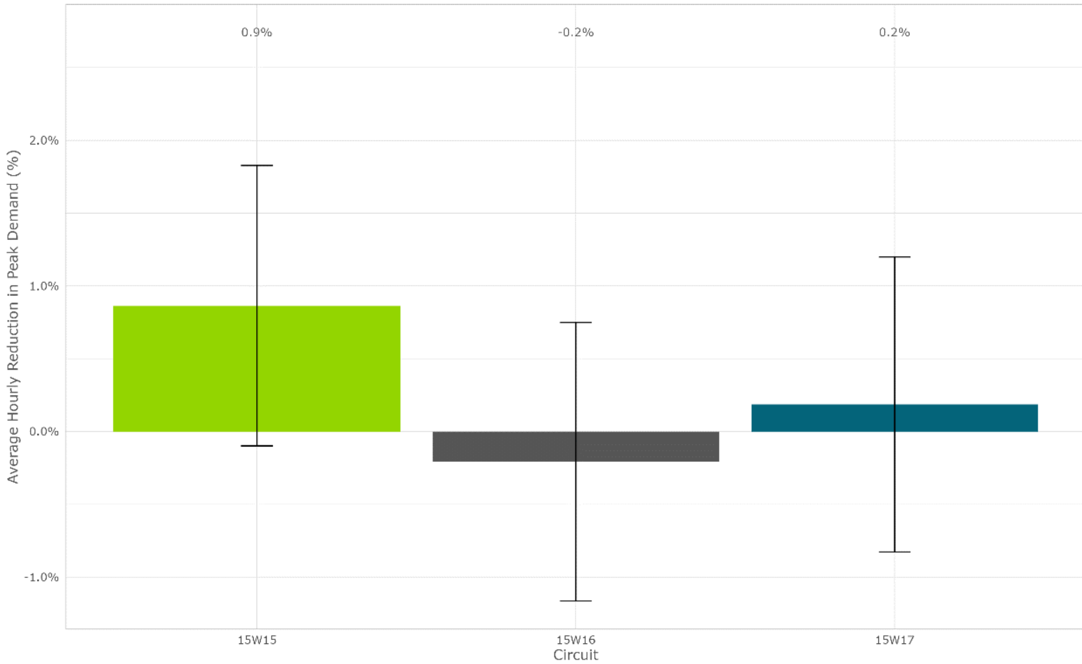


Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.

Source: Guidehouse analysis

Figure 28 indicates the percentage load reductions realized during the peak load period, defined as 4:00 p.m. to 10:00 p.m. ET from June 1 to September 30 on non-holiday weekdays. The value at the top of each circuit indicating each circuit's percentage peak demand reductions. The whiskers overlaid on each circuit's percentage peak demand reduction estimate provide the 90% confidence intervals. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant. Similar to absolute peak demand reductions, all the circuits experienced a statistically insignificant change in percentage peak demand when VVO was enabled.

Figure 28. Peak Demand Reductions (%) for Unitil VVO Circuits



Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically *significant if it does not overlap with zero.*

Source: Guidehouse analysis

Below are key takeaways from peak demand reductions estimated for National Grid circuits:

- Circuits 15W15 and 15W17 underwent statistically insignificant reductions in peak demand when VVO was engaged, whereas circuit 15W16 underwent statistically insignificant increase in peak demand when VVO was engaged. This is not consistent with the estimated statistically significant reductions in energy when VVO was engaged, which ranged from 0.8% to 1.4%. Unitil may consider investigating data collected at pole-top regulators and capacitor banks to determine whether there are differences in how voltage is lowered and flattened during peak hours (4:00 p.m. to 10:00 p.m., non-holiday weekdays between May 1 and September 30) relative to all other hours of the day. It may be the case that Townsend circuits' line devices were not responding as-expected to VVO signals during the identified peak period.

PM-4: Distribution Losses

Guidehouse evaluated reduction in distribution losses as a function of VVO during PY 2023. Circuits 15W16 and 15W17 had very little data where kW was greater than 75% of annual peak load for kVA. Given that power factor is an input for the distribution losses equation, these circuits were ultimately removed from the distribution losses calculation, as they had insufficient observations available for use in regression modeling. The methodology for calculating the percent reduction in distribution losses is shown in Appendix A.

Table 54 details the estimated percentage reduction in distribution losses for circuit 15W15. The statistically significant increase in power factor resulted in a marginal reduction in distribution losses of 0.21%.

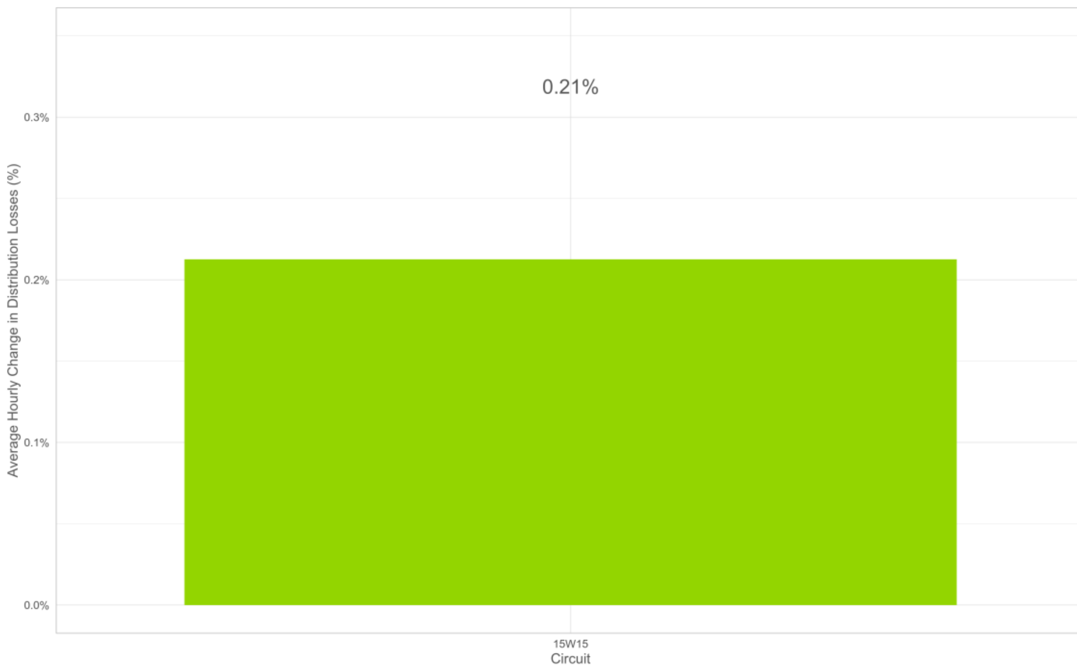
Table 54. Unitil Changes in Distribution Losses, Overall

Circuit	Reduction in Distribution Losses (%)
15W15	0.213%

Source: Guidehouse analysis

Figure 29 indicates the percentage reduction in distribution losses for circuit 15W15 (0.21%).

Figure 29. Changes In Distribution Losses (%) for Unitil VVO Circuits



Source: Guidehouse analysis

PM-5: Power Factor

Guidehouse estimated VVO's impact on power factor associated during PY 2023. Changes in power factor were analyzed during periods where power was greater than 75% of circuit-specific annual demand. Circuits 15W16 and 15W17 had very little data where kW was greater than 75% of annual peak load for kVA. These circuits were ultimately removed from estimation of power factor changes as they had insufficient observations available for use in regression modeling.

Table 55 details the evaluated change in power factor for each Unitil circuit with sufficient data quality.[44] Overall, active VVO control is estimated to have a statistically significant increase in power factor by 0.11%.

[44] There were some feeders with very little data where kW was greater than 75% of annual peak load for kVA. These feeders were ultimately removed from the power factor models, as they had fewer than 100 hours available for use in regression modeling.

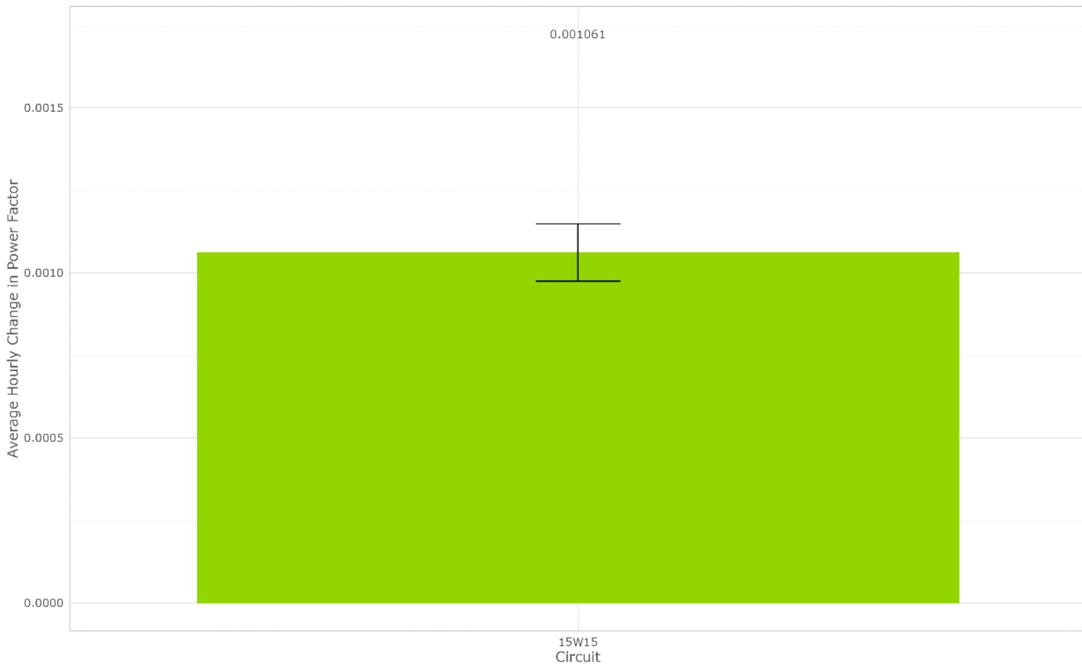
Table 55. Unitil VVO Average Hourly Power Factor Change, Overall

Circuit	Estimated Voltage Reductions	
	(Absolute)	(%)
15W15	0.001 ± <0.001	0.11 ± 0.009%

Source: Guidehouse analysis

Figure 30 indicates a statistically significant change in power factor for Unitil circuit 15W15 in absolute terms, with the value at the top of the circuit indicates the absolute power factor change. The whiskers overlaid on the absolute power factor change estimate provide the associated 90% confidence interval. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant.

Figure 30. Changes in Power Factor (Absolute) for Unitil VVO Circuits

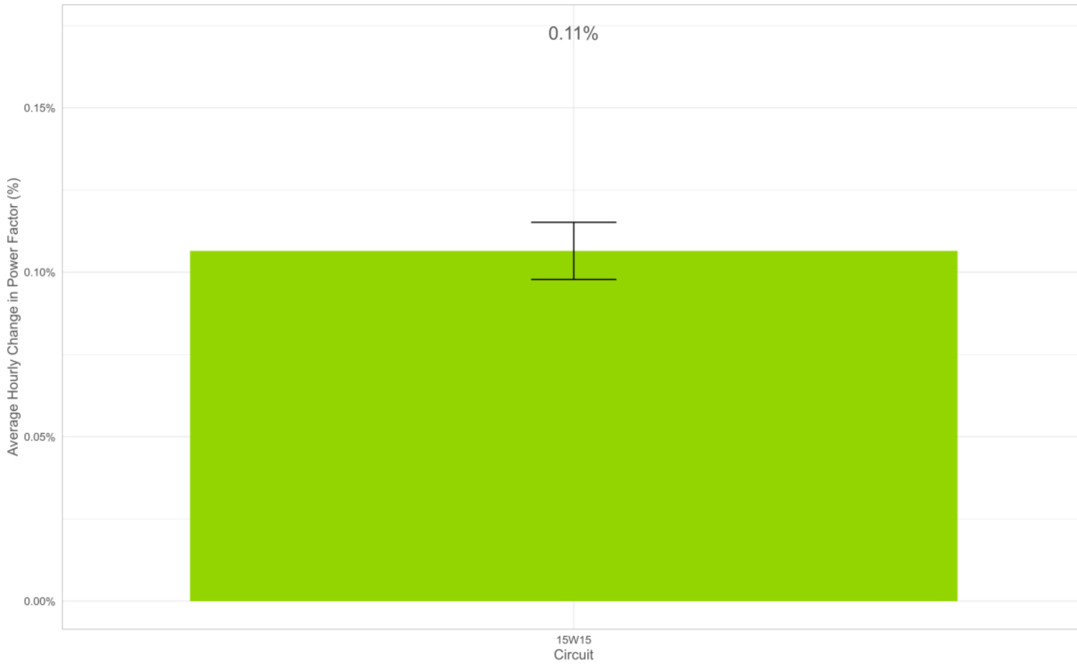


Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.

Source: Guidehouse analysis

Figure 31 indicates the statistically significant change in power factor for Unitil circuit 15W15 in percentage terms, with the value at the top indicating the percentage power factor change. The whiskers overlaid on the percentage power factor change estimate provide the associated 90% confidence interval. Where the confidence interval crosses the zero line, results may be interpreted as statistically insignificant.

Figure 31. Changes in Power Factor (%) for Unitil VVO Circuits



Note: Whiskers in this figure correspond to the 90% confidence intervals associated with the parameter estimates. An estimate is statistically significant if it does not overlap with zero.

Source: Guidehouse analysis

PM-6: GHG Emissions

After evaluating energy savings attributed to VVO, Guidehouse calculated the resulting emissions reductions. For 2023, emissions reductions were determined by to be 0.289 metric tons of emissions per MWh. This was calculated drawing the 2019 value from DPU 18-110 – DPU 18-119, Massachusetts Joint Statewide Electric and Gas Three Year Energy Efficiency Plan for 2019 – 2021, the 2025 value from DPU 21-120 – DPU 21-129, Massachusetts Joint Statewide Electric and Gas Three-Year Energy Efficiency Plan for 2022-2024, and then interpolating the 2023 value from these two sources.[45]

Table 56 provides emissions reductions associated with VVO, with 90% confidence bounds indicated by the ± figure. Guidehouse estimated statistically significant reductions in energy use associated with active VVO control. As a result of this reduction in energy consumption, there is expected to be a reduction in emissions of GHGs.

[45] 2019 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. 2025 emissions factors can be found on page 326 of Massachusetts Joint Statewide Electric and Gas Three Year Energy Efficiency Plans for 2022 – 2024 https://ma-eeac.org/wp-content/uploads/Exhibit-1-Three-Year-Plan-2022-2024-11-1-21-w-App-1.pdf

Table 56. Unitil VVO GHG Emissions Reductions, Overall

Metric	CO_2
GHG Reductions (CO_2) All Hours VVO On*	127 ± 12 tons CO_2
GHG Actual VVO-On Hours†	66 ± 6 tons CO_2

* All VVO hours are the number of hours during the entire evaluation period for the Townsend substation.
† Actual VVO On Hours are the number of hours in the clean analysis data that were VVO engaged for the Townsend substation's testing period.

Source: Guidehouse analysis

PM-7: Voltage Complaints

Guidehouse received voltage complaint logs from Unitil to facilitate Performance Metrics analysis. Guidehouse tabulated voltage complaints received by VVO circuit between 2015-2017, as well as PY 2023.[46] Discussion below highlights key observations for voltage complaints, comparing the count of voltage complaints received during PY 2023 to the average number of voltage complaints from the 2015–2017 baseline period.

Table 57 indicates the number of voltage complaints reported during the baseline period (defined in the stamp approved Metrics as 2015-2017) for the Townsend substation. Data indicate an increase (2) in voltage complaints in 2023 relative to the baseline.

Table 57. Count of Voltage Complaints for Townsend

Number of Voltage Complaints	15W15	15W16	15W17	Total
Customers*	1	1,525	574	**2,110**
2015	0	2	0	**2**
2016	0	1	0	**1**
2017	0	0	1	**1**
Baseline†	0	1	1	**2**
2023	**0**	**3**	**1**	**4**

* Count of customers served by each circuit and the baseline number of voltage complaints was extracted from the 2022 D.P.U 23-30 Report, Appendix 22-25.
† The baseline number of voltage complaints is calculated as the average number of voltage complaints between 2016 and 2017, rounded up to the nearest whole number.
Note: The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.

Source: Guidehouse analysis

3.2.4.2 Key Findings and Recommendations

Guidehouse has the following key findings to provide for the PY 2023 Performance Metrics evaluation:

- During the PY 2023 M&V period, Unitil's Townsend substation realized 229 MWh (1.5%) energy savings and 0.19 kV (1.3%) voltage reduction associated with VVO. Unitil's CVR factor was 1.14.[8] Unitil energy savings of 229 MWh yielded a 66 short ton reduction of CO_2

[46] 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, 2023.

emissions. Energy savings estimates appear to be negatively correlated with circuit length, with 15W15 having the greatest estimated energy savings (1.9%) while being less than 1/10th of a mile in length. This is compared to circuits 15W16 and 15W17 with 1.1% and 1.3% energy savings, respectively, with 15W16 being the longest circuit at over 40 miles.

- Unitil VVO circuits experienced a statistically insignificant decrease in peak load (0.36%), a statistically significant increase in power factor (0.11%), and a decrease in distribution losses (0.21%). This is not consistent with the estimated statistically significant reductions in energy when VVO was engaged, which ranged from 0.8% to 1.4%. Unitil may consider investigating data collected at pole-top regulators and capacitor banks to determine whether there are differences in how voltage is lowered and flattened during peak hours (4:00 p.m. to 10:00 p.m., non-holiday weekdays between May 1 and September 30) relative to all other hours of the day. It may be the case that Townsend circuits' line devices were not responding as-expected to VVO signals outside of the identified peak period.
- For Unitil, a total of 4 voltage complaints were received from customers connected to the Townsend VVO circuits during the period. This is a 200% increase relative to the average voltage complaints per year received between 2015-2017. The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.

In 2024 and beyond, Guidehouse recommends that Unitil:

- Continue to monitor performance of the VVO scheme after M&V has been completed, such as ensuring capacitor banks and pole-top regulators are responding as anticipated to VVO/ADMS commands. Unitil performance metric estimates are reflective of the VVO scheme as it was in PY 2023. Continuously monitoring the VVO scheme to ensure all line devices are responding as anticipated will be important in ensuring evaluated performance is maintained.
- Provide SCADA data for one or two "placebo" circuits (i.e., circuits without VVO schemes) for the PY 2024 and PY 2025 evaluations. Using data provided for two "placebo" circuits, Guidehouse identified that Unitil's On/Off testing data was biased by a confluence of hot days that coincided with VVO On days. This led to an oversampling of hotter days when VVO was engaged relative to when VVO was disengaged, a threat to the RCT program design of On/Off testing. This required the data to be rebalanced via a matching algorithm summarized in Section 2.1.3. Providing SCADA for "placebo" circuits will allow Guidehouse to assess whether testing data needs to be rebalanced.
- Increase the cadence of VVO On/Off testing. Guidehouse recommends shifting from week on / week off testing to either daily testing (i.e., day on / day off), every other day, every two days, every three days, or every four days (i.e., four days on / four days off). Increasing the cadence of testing will improve the likelihood of balance in temperatures, day types, and other factors that influence grid conditions. This ultimately allows for the RCT design of VVO On/Off testing to yield unbiased Performance Metric estimates.
- Once a schedule with increased cadence has been determined for VVO On/Off testing, Unitil should make every effort to comply with the pre-determined schedule. If compliance is achieved, there should be a balance of temperatures and other conditions correlated with system demand, voltage, and power factor, thereby leading to VVO impact estimates that are unbiased. Failure to comply, such as pausing On/Off testing and leaving VVO in its engaged or disengaged state for an extended period of time, will increase the likelihood of an invalid RCT in the PY 2024 and PY 2025 evaluations. If an invalid RCT is identified,

Guidehouse will need to rebalance the data using the approach outlined in Section 2 to reduce the risk of biased VVO impact estimates.

- To identify causes of lower performance, particularly during peak demand hours, Unitil may consider investigating data collected at pole-top regulators and capacitor banks to determine whether there are differences in how voltage is lowered and flattened during peak hours (4:00 p.m. to 10:00 p.m., non-holiday weekdays between May 1 and September 30) relative to all other hours of the day. It may be the case that Townsend circuits' line devices were not responding as-expected to VVO signals during the identified peak period.

4. Key Findings and Recommendations

The subsections that follow present key findings for VVO Performance Metrics and recommendations for the VVO investment area for each of the EDCs.

4.1 Key Findings

Guidehouse has the following key findings to provide for the PY 2023 Performance Metrics evaluation:[47]

4.1.1 Key Findings for Circuits that Completed On/Off Testing Prior to PY 2023

- Eversource did not conduct VVO On/Off testing in PY 2023 at any VVO substations.[48] To estimate the Performance Metrics, Guidehouse combined evaluation results from the PY 2022 evaluation as well data received for the PY 2023 evaluation. Guidehouse included the Performance Metrics impacts from the PY 2022 evaluation, the SCADA interval data from Eversource that contained time-stamped measurements of voltage, real power, apparent power, and reactive power for PY 2023, and time-stamped logs of VVO state changes between VVO On (engaged) and Off (disengaged) states contained within the SCADA data provided by Eversource for PY 2023.

- During the PY 2022 M&V period, Eversource's Agawam, Piper, Podick, and Silver substations realized 0.41% energy savings and 1.24% voltage reduction associated with VVO, equating to a CVR factor of 0.60. Using these results and substation SCADA collected during PY 2023, Eversource's Agawam, Piper, Podick, and Silver substations realized 1,270 MWh energy savings associated with VVO. Energy savings of 1,270 MWh yielded a 367 short ton reduction of CO_2 emissions. Lastly, VVO circuits experienced an increase (0.99 MW) in peak load and an increase in distribution losses when VVO was engaged (388 MWh).

- For Eversource, a total of 63 voltage complaints were received from customers connected to the Agawam, Piper, Podick, and Silver VVO circuits during the PY 2023 M&V period. This is a 31% increase relative to the average voltage complaints per year received between 2015 – 2017. The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.

- Eversource reported conducting deployment of VVO investments throughout PY 2023. Eversource anticipates completing additional deployment during PY 2024 and PY 2025.

[47] Findings from the evaluation of Performance Metrics indicate that VVO allowed Eversource, National Grid, and Unitil to realize energy savings and voltage reductions during PY 2023. It can be difficult to reliably compare the results from Performance Metrics analysis between Eversource, National Grid, and Unitil. For example, there are differences in the granularity of telemetry (e.g., 5-minute versus 15-minute), data quality at different times of the year (e.g., sustained pauses in VVO On/Off testing for one EDC, data outages during On/Off testing for another EDC). As such, certain portions of the M&V period, such as the Spring season, may be represented more for one EDC than the other. Additionally, there are numerous differences in DG penetration, customer types, and geographic areas served by Eversource, National Grid, and Unitil feeders that limit the ability to directly compare Eversource, National Grid, and Unitil VVO outcomes.

[48] Eversource did not conduct VVO On/Off testing at substations that were in-service for more than one full calendar year and had already completed On/Off testing previously. This is in-line with the Stamp Approved Performance Metrics outlined in Performance Metrics Compliance Filing, D.P.U. 21-80/21-81/21-82 (2023). Further discussion on VVO On/Off testing and the recommendation to limit the testing period can be found in AG-4-6, D.P.U. 22-40 (2023).

Once VVO investments are deployed, Eversource plans to control VVO within its ADMS system. Eversource plans to complete its ADMS investment and commission and enable VVO at its Term 2 substations in PY 2025. Therefore, Guidehouse will not conduct any regression-based estimation of Performance Metrics for Eversource until the PY 2025 evaluation. Until then, all Performance Metrics will continue to be estimated for only the Agawam, Piper, Podick, and Silver substations using PY 2022 evaluation results and SCADA collected during the evaluation period of interest (e.g., PY 2023).

4.1.2 Key Findings for Circuits that Underwent On/Off Testing in PY 2023

- During the PY 2023 M&V period, National Grid's East Bridgewater, East Dracut, East Methuen, Easton, Maplewood, Stoughton, and West Salem substations realized 2,540 MWh (1.3%) energy savings and 0.320 kV (2.3%) voltage reduction associated with VVO. National Grid's CVR factor was 0.92. During the same M&V period, Unitil's Townsend substation realized 229 MWh (1.5%) energy savings and 0.19 kV (1.3%) voltage reduction associated with VVO. Unitil's CVR factor was 1.14.[8] National Grid energy savings of 2,540 MWh yielded a 734 short ton reduction in CO_2 emissions. Unitil energy savings of 229 MWh yielded a 66 short ton reduction of CO_2 emissions.
- National Grid VVO circuits experienced a statistically significant decrease in peak load (1.3%), a statistically significant increase in power factor (0.39%), and a decrease in distribution losses (0.77%) when VVO was engaged. Unitil VVO circuits experienced a statistically insignificant decrease in peak load (0.36%), a statistically significant increase in power factor (0.11%), and a decrease in distribution losses (0.21%).
- For National Grid, a total of 255 voltage complaints were received from customers connected to the East Bridgewater, East Dracut, East Methuen, Easton, Maplewood, Stoughton, and West Salem VVO circuits during the period. This is a 50% increase relative to the average voltage complaints per year received between 2016 – 2017. For Unitil, a total of 4 voltage complaints were received from customers connected to the Townsend VVO circuits during the period. This is a 200% increase relative to the average voltage complaints per year received between 2015-2017. The change in voltage complaints from baseline to 2023 is not attributable solely to VVO and may also be attributed to other grid-level changes that have occurred over time.

4.2 Recommendations

In 2024 and beyond, Guidehouse recommends that Eversource, National Grid, and Unitil:

- Continue to monitor performance of the VVO scheme after M&V has been completed, such as ensuring capacitor banks and pole-top regulators are responding as anticipated to VVO/ADMS commands. The EDC's performance metric estimates are reflective of the VVO scheme as it was in PY 2023. Continuously monitoring the VVO scheme to ensure all line devices are responding as anticipated will be important in ensuring evaluated performance is maintained.
- Provide SCADA data for one or two "placebo" circuits (i.e., circuits without VVO schemes) for the PY 2024 and PY 2025 evaluations. Using data provided for two "placebo" circuits within the PY 2023 evaluation, Guidehouse identified that the EDC's On/Off testing data was biased by extended pauses to the On/Off testing conducted. In some cases, this led to an oversampling of hotter days when VVO was engaged relative to when VVO was disengaged, and in others this led to an oversampling of cooler days when VVO was

engaged relative to when VVO was disengaged. This poses a threat to the RCT program design of On/Off testing and required the data to be rebalanced via a matching algorithm summarized in Section 2.1.3. Providing SCADA for “placebo” circuits will allow Guidehouse to assess whether testing data for the VVO circuits needs to be rebalanced.

- Increase the cadence of VVO On/Off testing. Guidehouse recommends shifting from week on / week off testing to either testing daily (i.e., day on / day off), every other day, every two days, every three days, or every four days (i.e., four days on / four days off). Increasing the cadence of testing will improve the likelihood of balance in temperatures, day types, and other factors that influence grid conditions. This ultimately allows for the RCT design of VVO On/Off testing to yield unbiased Performance Metric estimates.
- Once a schedule with increased cadence has been determined for VVO On/Off testing, the EDCs should make every effort to comply with the pre-determined schedule. If compliance is achieved, there should be a balance of temperatures and other conditions correlated with system demand, voltage, and power factor, thereby leading to VVO impact estimates that are unbiased. Failure to comply, such as pausing On/Off testing and leaving VVO in its engaged or disengaged state for an extended period of time, will increase the likelihood of an invalid RCT in the PY 2024 and PY 2025 evaluations. If an invalid RCT is identified, Guidehouse will need to rebalance the data using the approach outlined in Section 2 to reduce the risk of biased VVO impact estimates.
- To identify causes of lower performance during peak demand hours, Unitil may consider investigating data collected at pole-top regulators and capacitor banks to determine whether there are differences in how voltage is lowered and flattened during peak hours (4:00 p.m. to 10:00 p.m., non-holiday weekdays between May 1 and September 30) relative to all other hours of the day. It may be the case that Townsend circuits’ line devices were not responding as expected to VVO signals during the identified peak period.
- To identify causes of lower performance, particularly for the West Salem substation (which underwent estimated energy increases when VVO was engaged) and the Easton substation (which underwent estimated peak demand increases when VVO was engaged), National Grid should consider assessing data collected from devices along each connected circuit. For example, end-of-line feeder monitor voltage data will enable an investigation of whether voltage is performing as expected at the end-of-line when VVO is engaged. In addition, if data are collected for points between the circuit head-end and end-of-line, assess of whether certain zones of a circuit are under- or over-performing relative to the aggregate impact detected using SCADA collected at the circuit head-end.

Appendix A. Detailed Information for Performance Metrics Analysis: Circuits Undergoing VVO On/Off Testing During PY 2023

A.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 A-1 highlights how the CVR factor is calculated using an estimated percentage reduction in energy and percentage reduction in voltage.

Equation A-1. CVR Factor Calculation

$$CVRf = \frac{\%\Delta\, Energy}{\%\Delta\, Voltage}$$

A.2 Regression Methodology for Estimating VVO-Related Energy and Voltage Reductions

For circuits going through VVO On/Off testing during PY 2023, Guidehouse conducted regression modeling to assess the impacts of VVO on measured circuit-level real power and voltage. To estimate the impact of VVO on circuit-level real power and voltage observed during PY 2023, Guidehouse estimated a regression model of real power and a regression model of voltage for each individual circuit. Equation A-2 summarizes the regression model specification used to estimate real power and voltage as a function of VVO.

Equation A-2. Regression Model of Energy and Voltage

$$\begin{aligned}\{kW_{it}, kV_{it}\} = & \sum_{season=1}^{4} \beta_{1season} * \tau_{season} + \beta_2 VVO_{it} + \beta_3 Holiday_t + \beta_4 DR\ Flag_t \\ & + \sum_{wknd=1}^{2} \beta_{5wknd} * \tau_{wknd} + \sum_{h=1}^{24} \beta_{6h} * \tau_h + \sum_{wknd,h=1}^{48} \beta_{7wknd,h} * \tau_{wknd,h} \\ & + \beta_8 Clear\ Sky\ GHI_{it} + \beta_9 Cloud_{it} + \beta_{10} Clear\ Sky\ GHI_{it} * Cloud_{it} + \beta_{11} CDH_{it} \\ & + \beta_{12} HDH_{it} + \varepsilon_{it}\end{aligned}$$

Where:

$i, t, h, and\ wknd$	index circuit, time-interval, each of the 24 hours of the day, and weekend respectively.
kW_{it}	is real power (kW) measured at circuit i at time t.
kV_{it}	is voltage (kV) measured at circuit i at time t.
τ_{Season}	are seasonal fixed effects for each meteorological season. The corresponding $\beta_{1Season}$ coefficients capture the average real power or voltage for each meteorological season.
VVO_{it}	is an indicator equal to 1 when VVO is engaged for circuit i at time t. The coefficient β_2 captures the average hourly impact of VVO on energy or voltage during the entire analysis period.
$Holiday_t$	is an indicator equal to 1 when a holiday occurred at time t. The coefficient β_3 captures the average hourly impact of VVO on real power or voltage during holidays.
$DR\ Flag_t$	is an indicator equal to 1 when a demand response event occurred at time t. The coefficient β_4 captures the average hourly impact of VVO on real power or voltage during the demand response events.
τ_{wknd}	are fixed effects for a weekday or weekend. The corresponding β_{5wknd} coefficients capture the average daily real power or voltage for a weekday or weekend.
τ_h	are hourly fixed effects for each hour h. The corresponding β_{6h} coefficients capture the average hourly energy or voltage across the PY 2023 analysis period.
$Clear\ Sky\ GHI_{it}$	is solar insolation data at circuit i at time t. β_8 captures reductions in energy or voltage due to solar insolation across the PY 2023 analysis period.
$Cloud_{it}$	is a categorical variable denoting hourly cloud cover conditions recorded by NOAA, intended to control for distributed solar generation connected to VVO circuits. Cloud cover multiplied by $Clear\ Sky\ GHI_{it}$ forces the regression model to provide an estimate of real power or voltage associated with distributed solar during hours where solar radiation is present. The coefficient β_{10} captures this average real power or voltage observed during hours when distributed solar facilities are producing electricity.
CDH_{it}	are cooling degree-hours (CDH), base 65°F, for circuit i at time t to capture the impacts of temperature on cooling load for each hour of day h. The corresponding coefficients β_{11} captures the impact of CDH across the PY 2023 analysis period.

HDH_{it}	are heating degree-hours (CDH), base 65°F, for circuit i at time t to capture the impacts of temperature on heating load for each hour of day h. The corresponding coefficients β_{12} captures the impact of HDH on real power or voltage across the PY 2023 analysis period.
ϵ_{it}	is an error term for circuit i at time t and captures unexplained variation in real power or voltage.

A.3 Regression Methodology for Estimating VVO-Related Peak Load Reductions

Equation A-3 summarizes the regression model specification used to estimate peak load as a function of VVO for the circuits that went through VVO On/Off testing during PY 2023.

Equation A-3. Regression Model of Peak Load

$$Peak_{it} = \beta_1 VVO_{it} + \sum_{h=1}^{24} \beta_{2h} * \tau_h + \sum_{d=1}^{7} \beta_{3d} * \tau_d + \beta_4 DR\ Flag_t + \beta_5 Clear\ Sky\ GHI_{it} + \beta_6 Cloud_{it} + \beta_7 Clear\ Sky\ GHI_{it} * Cloud_{it} + \beta_8 CDH_{it} + \epsilon_{it}$$

Where:

i, t, h, d	index circuit, time-interval, each of the 24 hours of the day, and day of week respectively.
$Peak\ kW_{it}$	is peak load (kW) measured at circuit i at time t.
VVO_{it}	is an indicator equal to 1 when VVO is engaged for circuit i at time t. The coefficient β_1 captures the average hourly impact of VVO on peak load.
τ_d	are fixed effects for each day of the week d. The corresponding β_{3d} coefficients capture the average daily peak load for each day of the week.
τ_h	are hourly fixed effects for each hour h. The corresponding β_{2h} coefficients capture the average hourly peak load.
$DR\ Flag_t$	is an indicator equal to 1 when a demand response event occurred at time t. The coefficient β_4 captures the average hourly impact of VVO on peak demand during the demand response events.
$Clear\ Sky\ GHI_{it}$	is solar insolation data at circuit i at time t. β_5 captures reductions in peak load.
$Cloud_{it}$	is a categorical variable denoting hourly cloud cover conditions recorded by NOAA, intended to control for distributed solar generation connected to VVO circuits. Cloud cover multiplied by $Clear\ Sky\ GHI_{it}$ forces the regression model to provide an estimate of peak load associated with distributed solar during hours where solar radiation is present. The coefficient β_7 captures this average peak load observed during hours when distributed solar facilities are producing electricity.
CDH_{it}	are cooling degree-hours (CDH), base 65°F, for circuit i at time t to capture the impacts of temperature on cooling load for each hour of day h. The corresponding coefficients β_8 captures the impact of CDH across the peak load period.

ϵ_{it}	is an error term for circuit i at time t and captures unexplained variation in peak load.

A.4 Regression Methodology for Power Factor

Equation A-4 summarizes the regression model specification used to estimate power factor as a function of VVO for the circuits that went through VVO On/Off testing during PY 2023.

Equation A-4. Regression Model of Power Factor

$$PF_{it} = \beta_1 VVO_{it} + \sum_{h=1}^{24} \beta_{2h} * \tau_h + \sum_{d=1}^{7} \beta_{3d} * \tau_d + \beta_4 DR\ Flag_t + \beta_5 Clear\ Sky\ GHI_{it} + \beta_6 Cloud_{it} + \beta_7 Clear\ Sky\ GHI_{it} * Cloud_{it} + \beta_8 CDH_{it} + \epsilon_{it}$$

Where:

i, t, h, d	index circuit, time-interval, each of the 24 hours of the day, and day of week respectively.
PF_{it}	is power factor measured at circuit i at time t.
VVO_{it}	is an indicator equal to 1 when VVO is engaged for circuit i at time t. The coefficient β_1 captures the average hourly impact of VVO on power factor during the entire analysis period.
τ_d	are fixed effects for each day of the week d. The corresponding β_{3d} coefficients capture the average daily power factor for each day of the week.
τ_h	are hourly fixed effects for each hour h. The corresponding β_{2h} coefficients capture the average hourly power factor.
$DR\ Flag_t$	is an indicator equal to 1 when a demand response event occurred at time t. The coefficient β_4 captures the average hourly impact of VVO on power factor during the demand response events.
$Clear\ Sky\ GHI_{it}$	is solar insolation data at circuit i at time t. β_5 captures reductions in power factor.
$Cloud_{it}$	is a categorical variable denoting hourly cloud cover conditions recorded by NOAA, intended to control for distributed solar generation connected to VVO circuits. Cloud cover multiplied by $Clear\ Sky\ GHI_{it}$ forces the regression model to provide an estimate of power factor associated with distributed solar during hours where solar radiation is present. The coefficient β_7 captures this average power factor observed during hours when distributed solar facilities are producing electricity.
CDH_{it}	are cooling degree-hours (CDH), base 65°F, for circuit i at time t to capture the impacts of temperature on cooling load for each hour of day

h. The corresponding coefficients β_8 captures the impact of CDH on power factor.

ϵ_{it} is an error term for circuit i at time t and captures unexplained variation in power factor.

A.5 Distribution Losses Methodology

Guidehouse evaluated change in distribution losses as a function of VVO during PY 2023. To estimate the impact of VVO on circuit-level distribution losses, Guidehouse used a distribution losses equation for each individual circuit.[49] Equation A-5 summarizes the equation used to estimate the change in distribution losses as a function of VVO for the VVO circuits that went through VVO On/Off testing during PY 2023.

Equation A-5. Distribution Losses Equation

$$\%\,Loss\ Reduction = 100 - 100\left(\frac{PF_{VVO\ Off}}{PF_{VVO\ On}}\right)^2$$

Where:

$PF_{VVO\ Off}$ Power factor when VVO is in the disengaged state.

$PF_{VVO\ On}$ Power factor when VVO is in the engaged state.

[49] https://www.nepsi.com/resources/calculators/loss-reduction-with-power-factor-correction.htm accessed January 17, 2024

Appendix B. Detailed Information for Performance Metrics Analysis: Circuits that Completed VVO Testing Prior to PY 2023

Since Eversource did not conduct VVO On/Off testing in PY 2023,[50] Guidehouse did not estimate PM impacts using a regression methodology. Instead, Guidehouse estimated impacts using regression-based impact estimates from the most-recent PY 2022 evaluation, for which the VVO substations underwent On/Off testing. For the PY 2023 evaluation period, this included 26 circuits across the Agawam, Piper, Podick, and Silver substations.

To estimate Performance Metrics results for PY 2023, Guidehouse conducted the following general steps:

1. Integrated PY 2023 substation SCADA data and time-stamped logs of VVO state changes between VVO On and Off states for each VVO substation.
2. Combined PY 2023 substation SCADA data and VVO status data with estimated Performance Metrics impacts from the most recent evaluation (PY 2022) in which the substation conducted VVO On/Off testing.
3. Estimated impacts using the methodology outlined below for each metric.

The subsections below detail how each metric was calculated.

B.1 Annual Energy Delivered without VVO

Guidehouse estimated the impact of VVO on performance metrics for circuits that completed VVO testing prior to PY 2023. Equation B-1 summarizes the equation used to estimate the annual energy delivered without VVO for the VVO circuits that completed VVO On/Off testing prior to PY 2023.

Equation B-1. Annual Energy Delivered without VVO Equation

$$kWh = kWh_{off} + \frac{kWh_{on}}{(1 - \%E)}$$

Where:

[50] Eversource did not conduct VVO On/Off testing at substations that were in-service for more than one full calendar year and had already completed On/Off testing previously. This is in-line with the Stamp Approved Performance Metrics outlined in Performance Metrics Compliance Filing, D.P.U. 21-80/21-81/21-82 (2023). Further discussion on VVO On/Off testing and the recommendation to limit the testing period can be found in AG-4-6, D.P.U. 22-40 (2023).

kWh_{off}	Total kWh delivered when VVO was disengaged in PY 2023.
kWh_{on}	Total kWh delivered when VVO was engaged in PY 2023.
$\%E$	Average hourly percent change in energy attributed to VVO estimated for the PY 2022 evaluation.

B.2 Annual Energy Savings with VVO

Equation B-2 summarizes the equation used to estimate the annual energy savings with VVO for the VVO circuits that completed VVO On/Off testing prior to PY 2023.

Equation B-2. Annual Energy Savings with VVO Equation

$$kWh = \left(kWh_{off} + \frac{kWh_{on}}{(1 - \%E)}\right) - (kWh_{off} + kWh_{on})$$

Where:

kWh_{off}	Total kWh delivered when VVO was disengaged in PY 2023.
kWh_{on}	Total kWh delivered when VVO was engaged in PY 2023.
$\%E$	Average hourly percent change in energy attributed to VVO estimated for the PY 2022 evaluation.

B.3 Annual Peak Load without VVO

Guidehouse utilized the PY 2022 definition of the peak period as 1:00 – 5:00 pm on non-holiday weekdays from June 1 through August 31. In PY 2023, all circuits were either (1) VVO engaged during the flagged peak period, or (2) VVO disengaged during the flagged peak period. Equation B-3 summarizes the equation used to estimate the annual peak load without VVO for VVO disengaged circuits that completed VVO On/Off testing prior to PY 2023.

Equation B-3. Annual Peak Load without VVO for VVO Disengaged Circuits in PY 2023

$$kW = kW_{off}$$

Where:

kW_{off}	Average kW during the peak period when VVO was disengaged in PY 2023.

Equation B-4 summarizes the equation used to estimate the annual peak load without VVO for VVO engaged circuits that completed VVO On/Off testing prior to PY 2023.

Equation B-4. Annual Peak Load without VVO for Engaged Circuits in PY 2023

$$kW = \frac{kW_{on}}{(1 - \%D)}$$

Where:

kW_{on}	Average kW during the peak period when VVO was engaged in PY 2023.
$\%D$	Average percent hourly change in peak demand attributed to VVO from PY 2022 evaluation.

B.4 Annual Peak Load Reduction with VVO

Guidehouse utilized the PY 2022 definition of the peak period as 1:00 – 5:00 pm on non-holiday weekdays from June 1 through August 31. In PY 2023, all circuits were either (1) VVO engaged during the flagged peak period, or (2) VVO disengaged during the flagged peak period. The annual peak load with VVO for VVO disengaged circuits that completed VVO On/Off testing prior to PY 2023 equaled zero. Equation B-5 summarizes the equation used to estimate the annual peak load with VVO for VVO engaged circuits that completed VVO On/Off testing prior to PY 2023.

Equation B-5. Annual Peak Load Reduction with VVO for VVO Engaged Circuits in PY 2023

$$kW = \frac{kW_{on}}{(1-\%D)} - kW_{on}$$

Where:

kW_{on}	Average kW during the peak period when VVO was engaged in PY 2023.
$\%D$	Average percent hourly change in peak demand attributed to VVO for the PY 2022 evaluation.

B.5 Distribution Losses without VVO

Equation B-6 summarizes the equation used to estimate the distribution losses without VVO for the VVO circuits that completed VVO On/Off testing prior to PY 2023.

Equation B-6. Distribution Losses without VVO

$$kWh = (1 - PF_{baseline}) * \frac{E_{baseline}}{PF_{baseline}}$$

Where:

$PF_{baseline}$	Baseline power factor for PY 2023, reflecting as if VVO was disengaged all year (derived via Equation B-8)
$E_{baseline}$	Baseline kWh delivered for PY 2023, reflecting as if VVO was disengaged all year (derived via Equation B-1).

B.6 Reduction of Distribution Losses with VVO

Equation B-7 summarizes the equation used to estimate the distribution losses with VVO for the VVO circuits that completed VVO On/Off testing prior to PY 2023.

Equation B-7. Distribution Losses with VVO

$$kWh = \left(\frac{1 - PF_{baseline}}{PF_{baseline}} * E_{baseline}\right) - \left(\frac{1 - PF_{2023}}{PF_{2023}} * E_{2023}\right)$$

Where:

$PF_{baseline}$	Baseline power factor for PY 2023, reflecting as if VVO was disengaged all year (derived via Equation B-8).
$E_{baseline}$	Baseline kWh delivered for PY 2023, reflecting as if VVO was disengaged all year (derived via Equation B-1).
PF_{2023}	Weighted average power factor with the VVO investment operational in PY 2023, weighted by the number of VVO On and Off hours.
E_{2023}	Total annual kWh delivered with the VVO investment operational in PY 2023.

B.7 Power Factor without VVO

Equation B-8 summarizes the equation used to estimate the power factor without VVO for the VVO circuits that completed VVO On/Off testing prior to PY 2023.

Equation B-8. Power Factor without VVO

$$PF_{baseline} = \frac{PF_{off} * T_{off} + \dfrac{PF_{on} * T_{on}}{(1 - \%PF)}}{T_{off} + T_{on}}$$

Where:

PF_{off}	Average power factor when VVO was disengaged in PY 2023.
T_{off}	Total number of hours when VVO was disengaged in PY 2023.
PF_{on}	Average power factor when VVO was engaged in PY 2023.
T_{on}	Total number of hours when VVO was engaged in PY 2023.
$\%PF$	Estimated percent reduction in power factor attributed to VVO for the PY 2022 evaluation.

B.8 Power Factor with VVO

Equation B-9 summarizes the equation used to estimate the distribution losses with VVO for the VVO circuits that completed VVO On/Off testing prior to PY 2023.

Equation B-9. Power Factor with VVO

$$PF_{2023} = \frac{PF_{off} * T_{off} + PF_{on} * T_{on}}{T_{off} + T_{on}}$$

Where:

PF_{off}	Average power factor when VVO was disengaged in PY 2023.
T_{off}	Total number of hours when VVO was disengaged in PY 2023.
PF_{on}	Average power factor when VVO was engaged in PY 2023.
T_{on}	Total number of hours when VVO was engaged in PY 2023.

B.9 GHG Emissions without VVO

Equation B-10 summarizes the equation used to estimate the GHG emissions without VVO for the VVO circuits that completed VVO On/Off testing prior to PY 2023.

Equation B-10. GHG Emissions without VVO

$$Metric\,Tons\,of\,CO_2 = 0.289 * \frac{\left(kWh_{off} + \frac{kWh_{on}}{(1 - \%E)}\right)}{1000}$$

Where:

0.289	For 2023, the GHG emissions reduction factor (short tons) was estimated to be 0.289 metric tons of emissions per MWh. This was calculated by drawing the 2019 value from DPU 18-110 – DPU 18-119, Massachusetts Joint Statewide Electric and Gas Three Year Energy Efficiency Plan for 2019 – 2021, the 2025 value from DPU 21-120 – DPU 21-129, Massachusetts Joint Statewide Electric and Gas Three-

	Year Energy Efficiency Plan for 2022 – 2024, and then interpolating the 2023 value from these two sources.
kWh_{off}	Total kWh delivered when VVO was disengaged in PY 2023.
kWh_{on}	Total kWh delivered when VVO was engaged in PY 2023.
$\%E$	Average hourly percent change in energy attributed to VVO for the PY 2022 evaluation.

B.10 Reduction of Emissions with VVO

Equation B-11 summarizes the equation used to estimate the reduction of emissions with VVO for the VVO circuits that completed VVO On/Off testing prior to PY 2023.

Equation B-11. Reduction of Emissions with VVO

$$Metric\ Tons\ of\ CO_2 = 0.289 * \frac{\left\{\left(kWh_{off} + \frac{kWh_{on}}{(1-\%E)}\right) - \left(kWh_{off} + kWh_{on}\right)\right\}}{1000}$$

Where:

0.289	For 2023, the GHG emissions reduction factor (short tons) was estimated to be 0.289 metric tons of emissions per MWh. This was calculated by drawing the 2019 value from DPU 18-110 – DPU 18-119, Massachusetts Joint Statewide Electric and Gas Three Year Energy Efficiency Plan for 2019 – 2021, the 2025 value from DPU 21-120 – DPU 21-129, Massachusetts Joint Statewide Electric and Gas Three-Year Energy Efficiency Plan for 2022 – 2024, and then interpolating the 2023 value from these two sources.
kWh_{off}	Total kWh delivered when VVO was disengaged in PY 2023.
kWh_{on}	Total kWh delivered when VVO was engaged in PY 2023.
$\%E$	Average hourly percent change in energy attributed to VVO for the PY 2022 evaluation.

Appendix C. Detailed RCT Checks, Matching Results

Upon review of VVO On/Off status logs, substation SCADA, temperature data, and solar insolation data, Guidehouse followed the approach outlined in Section 2 to:

- Construct each LTC/circuit's degree-hour (DH) index[51];
- Assess the balance of the Randomized Control Trial (RCT) for each National Grid and Unitil circuit; and
- If imbalanced, rebalance the RCT via Euclidean distance matching.

This section summarizes the balance of National Grid and Unitil DH indexes between VVO On and VVO Off days prior to matching, as well as the balance of DH indexes between matched VVO On and Off days after matching.

Guidehouse based its assessments of RCT balance by analyzing the balance of temperature and solar insolation via a DH index between VVO On and VVO Off days. Given temperature and solar insolation (inputs to the DH index) have an impact on observed circuit load, marked differences in temperature and solar insolation between VVO On and VVO Off days would be indicative of an invalid RCT program design.

C.1 Construction of Degree-Hour (DH) Index

Guidehouse constructed a DH index to assess differences between days where VVO was On (engaged) and days where VVO was Off (disengaged) using a combination of three variables: (1) cooling degree hours (base 65F), (2) heating degree hours (base 65F), and (3) solar insolation. The DH index provides an overall assessment of differences in conditions between VVO On and Off days that are correlated with circuit loads without the need to directly assess differences in "placebo" circuit loads, which are endogenous to the energy and peak load regression estimation.

The DH index was calculated on an LTC- or circuit-specific basis via weighted cooling degree hours, heating degree hours, and solar insolation. Weights were determined for each LTC or circuit via linear regression conducted on "placebo" circuits to determine sensitivity of load to the three variables when VVO was disengaged. These weights were calculated separately for each LTC or circuit due to the varied VVO schedule at the LTC- or circuit-level.

Equation C-1 summarizes the regression equation used to determine weights for the DH index. For each LTC or circuit, coefficients β_1, β_2, and β_3 were used to calculate the DH Index for any time interval with recorded CDH, HDH, and solar insolation data available.

Equation C-1. Model to Estimate DH Index Weights

$$kW_{it} = \beta_1 Clear\ Sky\ GHI_{it} + \beta_2 CDH_{it} + \beta_3 HDH_{it} + \varepsilon_{it}$$

[51] In most cases, VVO control is conducted for all circuits connected to one LTC. This was the case for the Maplewood, East Methuen, East Bridgewater, East Dracut, Easton, and Stoughton substations. In some cases, such as for West Salem 29W circuits, VVO control is conducted at the circuit-level. As such, Guidehouse conducted assessments of balance at the LTC-level for all circuits except for circuits connected to West Salem 29W, which received circuit-specific VVO control and therefore circuit-specific balance checks.

Where:

i, t	index "placebo" circuit i at time t.
kW_{it}	is real power (kW) measured at "placebo" circuit i at time t.
$Clear\ Sky\ GHI_{it}$	is solar insolation data at "placebo" circuit i at time t. β_1 captures reductions in energy due to solar insolation across VVO Off hours during PY 2023 analysis period.
CDH_{it}	are cooling degree-hours (CDH), base 65°F, for "placebo" circuit i at time t to capture the impacts of temperature on cooling load. The corresponding coefficient β_2 captures the impact of CDH across VVO Off hours during the PY 2023 analysis period.
HDH_{it}	are heating degree-hours (HDH), base 65°F, for "placebo" circuit i at time t to capture the impacts of temperature on heating load for each hour of day h. The corresponding coefficients β_3 captures the impact of HDH on real power across VVO Off hours during the PY 2023 analysis period.
ϵ_{it}	is an error term for "placebo" circuit i at time t and captures unexplained variation in real power.

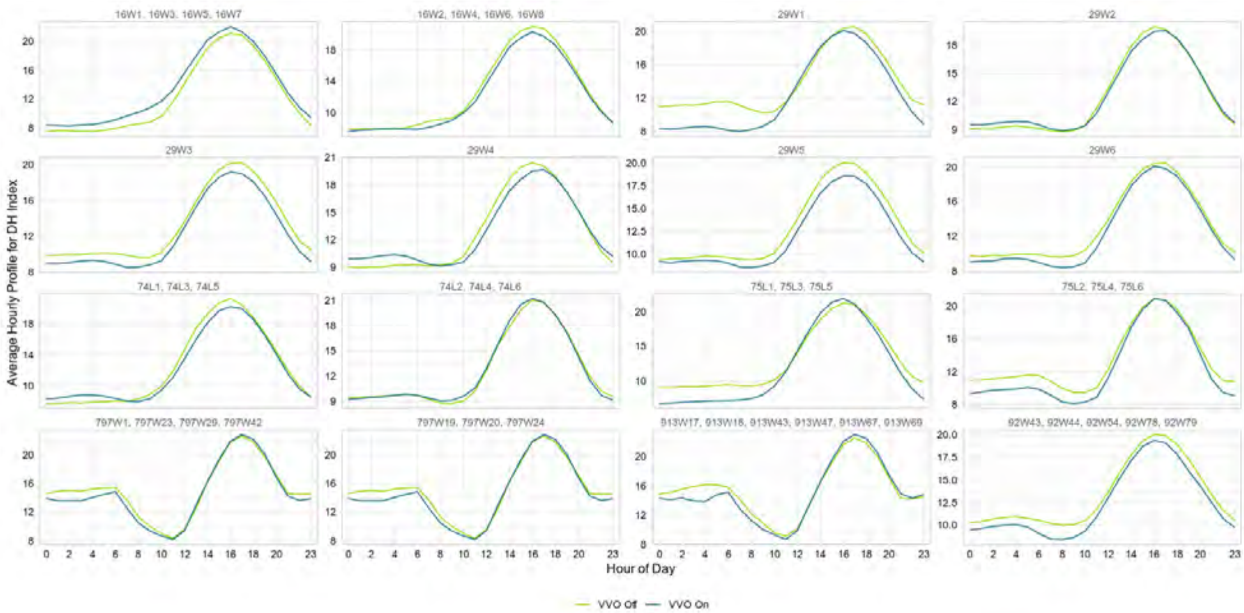
C.2 Assessment of Randomized Control Trial

To validate the RCT design of VVO On/Off testing for National Grid and Unitil, Guidehouse superimposed each LTC's or circuit's VVO On/Off testing data onto the calculated DH index. Guidehouse then calculated average 24-hour profiles for the DH index on VVO On days and VVO Off days to compare differences in the two profiles.

C.2.1 National Grid

Figure C-1 presents an assessment of differences in average DH index profiles for each group of National Grid circuits that underwent VVO On/Off testing in PY 2023. As is apparent, some circuits oversampled higher-DH index days when VVO was disengaged (indicated by the green line being above the blue line), and other circuits oversampled lower-DH index days (indicated by the blue line being above the green line). For example, Maplewood odd-numbered circuits (16W) had oversampled higher-DH index days when VVO was disengaged relative to when VVO was engaged. Given the DH index is positively correlated with demand, this difference indicates that there is likely an oversampling of higher-demand days when VVO was disengaged relative to when VVO was engaged. Therefore, if the data were to be left as-is and used in regression modeling, the estimated impact of VVO for the odd-numbered Maplewood substation circuits would be biased upward, as the impact would include the true impact of VVO control as well as the impact of differences in temperature and solar insolation between VVO On and VVO Off days.

Figure C-1. National Grid DH Index Profiles between VVO On and Off Days, Before Matching

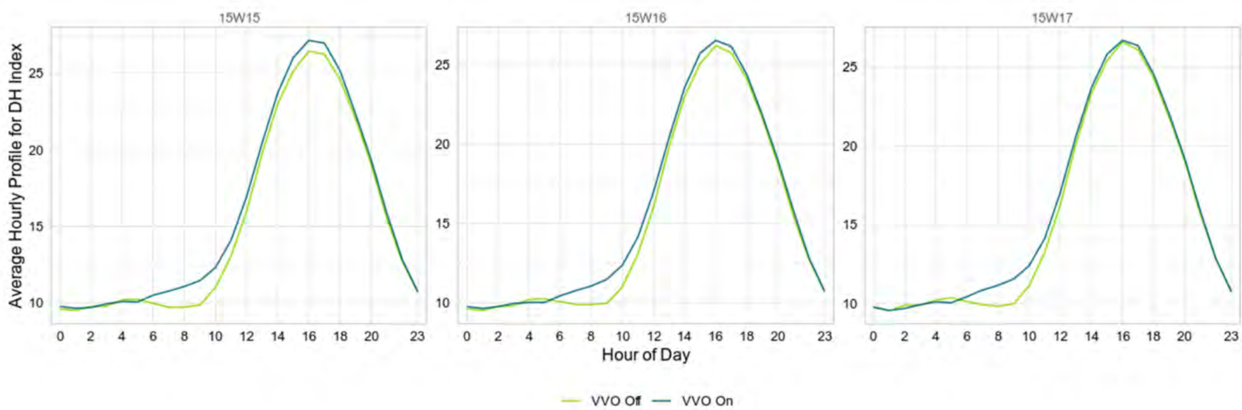


Source: Guidehouse analysis

C.2.2 Unitil

Figure C-2 presents an assessment of differences in average DH index profiles for each Unitil circuit that underwent VVO On/Off testing in PY 2023. As is apparent, some circuits oversampled higher-DH index days when VVO was engaged (indicated by the green line being above the blue line). Given the DH index is positively correlated with demand, this difference indicates that there is likely an oversampling of higher-demand days when VVO was engaged relative to when VVO was disengaged. Therefore, if the data were to be left as-is and used in regression modeling, the estimated impact of VVO would be biased downward, as the impact would include the true impact of VVO control as well as the impact of differences in temperature and solar insolation between VVO On and VVO Off days.

Figure C-2. Average Unitil DH Index Profiles between VVO On and Off Days, Before Matching



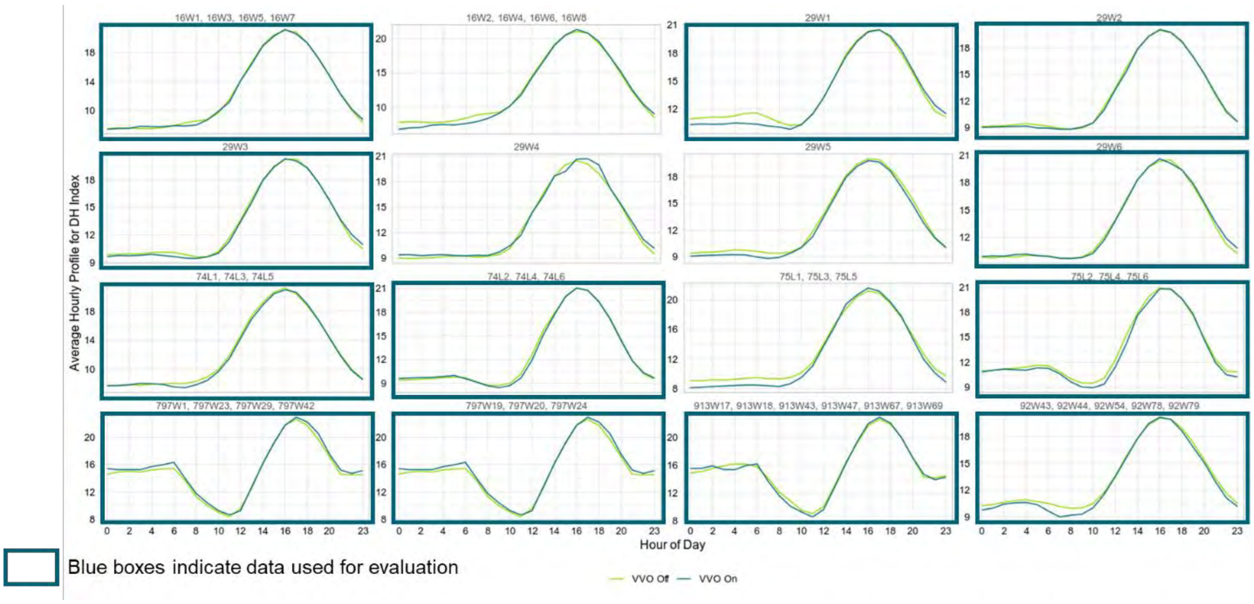
Source: Guidehouse analysis

C.3 Rebalancing the Randomized Control Trial via Euclidean Distance Matching

C.3.1 National Grid

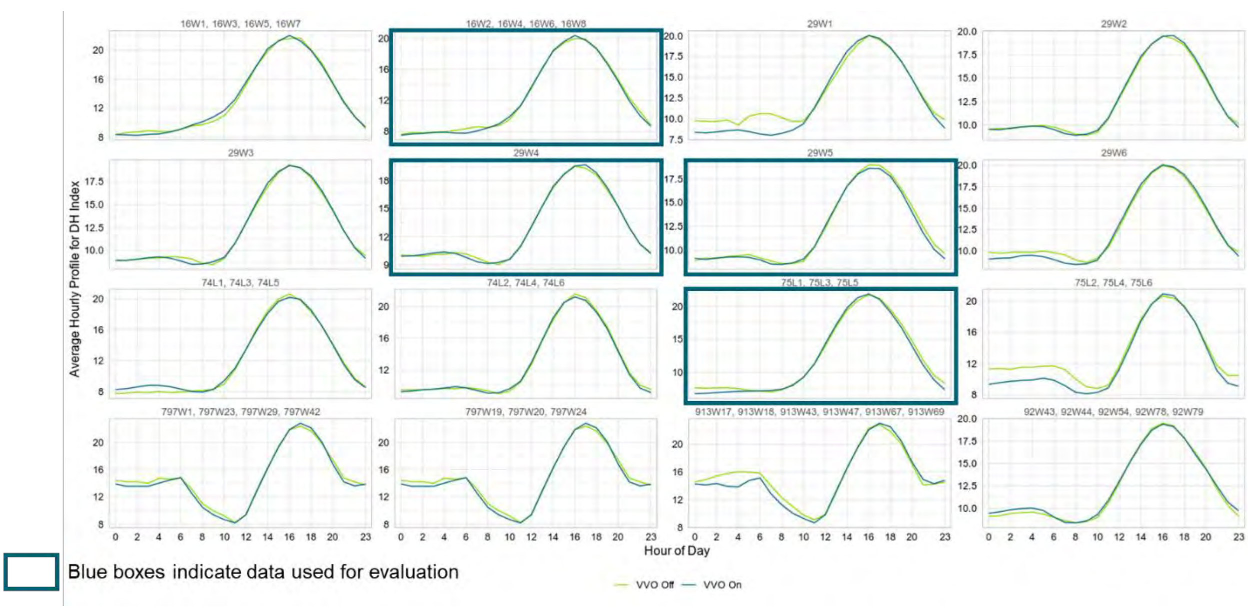
Figure C-3 and Figure C-4 below highlight the outcomes of the matching approach detailed in Section 2.1.3, with blue-boxed panels indicating the matched data that Guidehouse ultimately utilized to quantify VVO Performance Metrics. Across the board, matching improved balance in the observed DH index values between VVO On days and VVO Off days. All circuits' matched datasets were used in evaluation, with all but four LTCs/circuits exhibiting an improvement in balance in DH index after conducting Euclidean distance matching of VVO On days to VVO Off days. The remaining LTCs/circuits underwent a larger improvement in balance in the DH index after conducting Euclidean distance matching of VVO Off days to VVO On days.

Figure C-3. Average National Grid DH Index Profiles between VVO On and Off Days, After Matching VVO On Days to VVO Off Days



Source: Guidehouse analysis

Figure C-4. Average National Grid DH Index Profiles between VVO On and Off Days, After Matching VVO Off Days to VVO On Days

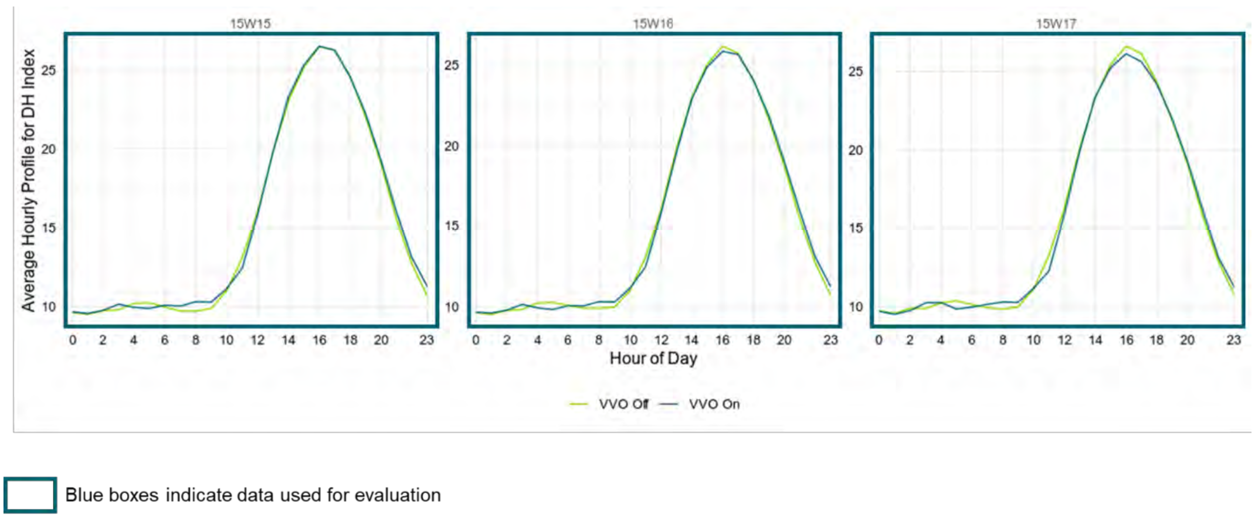


Source: Guidehouse analysis

C.3.2 Unitil

Figure C-5 below highlights the outcomes of the matching approach detailed in Section 2.1.3, with blue-boxed panels indicating the matched data that Guidehouse ultimately utilized to quantify VVO Performance Metrics. Across the board, matching improved balance in the observed DH index values between VVO On days and VVO Off days. All circuits' matched datasets were used in evaluation, with all circuits exhibiting an improvement in balance in DH index after conducting Euclidean distance matching of VVO On days to VVO Off days.

Figure C-5. Average Unitil DH Index Profiles between VVO On and Off Days, After Matching VVO On Days to VVO Off Days



Source: Guidehouse analysis

Appendix D. Detailed Performance Metrics Results

This section details circuit-specific performance metrics estimates for the PY 2023 period by VVO circuit. Results are provided separately by EDC.

D.1.1 Eversource

Table D-1. Eversource Performance Metrics Results by Circuit

Substation	Circuit	Annual Energy Delivered w/o VVO (kWh)	Annual Energy Savings w/ VVO (kWh)	Annual Peak Load w/o VVO (kW)	Annual Peak Load Reduction w/ VVO (kW)	Distribution Losses w/o VVO (kWh)	Reduction of Distribution Losses w/VVO (kWh)	Power Factor w/o VVO	Power Factor w/ VVO	GHG Emissions w/o VVO (Metric Tons CO_2)	Reduction of GHG Emissions w/ VVO (Metric Tons of CO_2)
Agawam	16C11	6,970,541	91,213	815	-16	N/A	N/A	N/A	N/A	2,014	26
	16C12	29,710,762	275,252	3,307	101	2,200,698	119,956	0.9310	0.9340	8,586	80
	16C14	24,780,489	84,769	2,672	N/A	N/A	N/A	N/A	N/A	7,162	24
	16C15	21,677,659	41,053	2,151	N/A	141,980	-15,152	0.9935	0.9928	6,265	12
	16C16	42,371,373	23,776	3,749	N/A	1,081,972	5,231	0.9751	0.9752	12,245	7
	16C17	27,507,203	80,887	3,041	N/A	237,946	-7,441	0.9914	0.9911	7,950	23
	16C18	20,774,252	21,166	1,570	N/A	N/A	N/A	N/A	N/A	6,004	6
Piper	21N4	20,644,220	61,653	2,501	N/A	N/A	N/A	N/A	N/A	5,966	18
	21N5	37,963,615	45,942	4,143	N/A	N/A	N/A	N/A	N/A	10,971	13
	21N6	18,039,204	136,475	2,577	14	819,588	-15,222	0.9565	0.9554	5,213	39
	21N7	34,149,867	91,849	3,575	-33	3,912,887	-8,133)	0.8972	0.8968	9,869	27
	21N8	41,355,541	174,127	5,082	30	97,651	-10,475	0.9976	0.9974	11,952	50
	21N9	26,176,338	170,227	2,911	-87	N/A	N/A	N/A	N/A	7,565	49
Podick	18G2	3,310,753	-36,909	272	N/A	118,282	-1,378	0.9655	0.9655	957	-11
	18G3	21,146,547	-118,404	2,257	N/A	458,450	-4,795	0.9788	0.9787	6,111	-34
	18G4	15,746,696	-222,460	1,728	N/A	N/A	N/A	N/A	N/A	4,551	-64
	18G5	18,795,564	-132,440	2,504	N/A	N/A	N/A	N/A	N/A	5,432	-38
	18G6	18,862,724	44,488	2,578	N/A	N/A	N/A	N/A	N/A	5,451	13
	18G7	12,979,554	-121,313	1,028	N/A	1,841,203	-20,976	0.8758	0.8755	3,751	-35
	18G8	18,379,474	-213,426	3,776	N/A	656,522	-438,453	0.9655	0.9660	5,312	-62

Substation	Circuit	Annual Energy Delivered w/o VVO (kWh)	Annual Energy Savings w/ VVO (kWh)	Annual Peak Load w/o VVO (kW)	Annual Peak Load Reduction w/ VVO (kW)	Distribution Losses w/o VVO (kWh)	Reduction of Distribution Losses w/VVO (kWh)	Power Factor w/o VVO	Power Factor w/ VVO	GHG Emissions w/o VVO (Metric Tons CO_2)	Reduction of GHG Emissions w/ VVO (Metric Tons of CO_2)
Silver	30A1	20,206,719	-98,691	2,470	-91	N/A	N/A	N/A	N/A	5,840	-29
	30A2	19,373,946	206,459	1,835	-60	N/A	N/A	N/A	N/A	5,599	60
	30A3	25,591,616	413,465	3,277	-91	N/A	N/A	N/A	N/A	7,396	119
	30A4	12,959,498	208,165	1,404	-80	491,058	8,924	0.9635	0.9636	3,745	60
	30A5	5,838,804	12,690	973	N/A	N/A	N/A	N/A	N/A	1,687	4
	30A6	31,619,658	29,879	2,931	-366	N/A	N/A	N/A	N/A	9,138	9
	Overall	576,932,617	1,269,892	2,505	-986	12,058,238	-387,915	0.9576	0.9577	166,734	367

Note: Line loss, power factor, and peak load impacts were not estimated for circuits with “N/A” in the table. Per the stamp approved metrics, 2022 evaluation power factor reductions and, as a result, line loss reductions were only estimated for circuits with sufficient data collected when kW was >75% of annual peak load (MVA). In addition, peak load reductions were only estimated for circuits with VVO engaged during the peak period in PY 2023.

Source: Guidehouse analysis

D.1.2 National Grid

Table D-2. National Grid Performance Metrics Results by Circuit

Substation	Circuit	Energy Baseline (MWh)	Net Energy Reduction (MWh)*†	Voltage Reduction (kV)	CVRf	Peak Load Reduction (kW)	Distribution Loss Reduction (%)	Power Factor Change	GHG Reductions (tons CO_2) †
East Bridgewater	797W19	27,391	47 ± 11	0.34 ± 0	0.6	N/A	N/A	N/A	6 ± 2
	797W20	39,353	-36 ± 8	0.34 ± 0	-0.3	N/A	N/A	N/A	-5 ± 1
	797W23	29,663	69 ± 7	0.28 ± 0	1.0	N/A	N/A	N/A	10 ± 1
	797W24	33,906	74 ± 8	0.34 ± 0	0.8	N/A	N/A	N/A	10 ± 1
	797W29	28,278	78 ± 9	0.28 ± 0	1.2	N/A	N/A	N/A	11 ± 1
	797W42	13,197	63 ± 5	0.28 ± 0	2.1	N/A	N/A	N/A	9 ± 1
East Dracut	75L1	147,593	-105 ± 8	0.41 ± 0	-1.0	20 ± 26	1.45	0.010 ± 0.001	-77 ± 6
	75L2	75,600	211 ± 9	0.24 ± 0	3.8	N/A	N/A	N/A	72 ± 3
	75L3	184,291	62 ± 8	0.42 ± 0	0.5	98 ± 32	0.54	0 ± 0.001	46 ± 6
	75L4	39,964	0 ± 2	0.24 ± 0	0.0	N/A	N/A	N/A	0 ± 1
	75L5	136,900	88 ± 8	0.42 ± 0	0.9	68 ± 25	3.08	0.02 ± 0.001	64 ± 6
	75L6	89,623	-67 ± 8	0.24 ± 0	-1.1	N/A	0.31	0 ± 0	-25 ± 3
East Methuen	74L1	213,536	180 ± 11	0.55 ± 0	1.0	126 ± 37	1.20	0.01 ± 0	136 ± 8
	74L2	74,345	52 ± 4	0.29 ± 0	1.0	-5 ± 16	-0.28	0 ± 0.004	27 ± 2
	74L3	140,230	108 ± 8	0.55 ± 0	0.9	72 ± 26	3.45	0.02 ± 0.002	77 ± 6
	74L4	98,205	86 ± 6	0.28 ± 0	1.3	17 ± 19	0.28	0 ± 0.002	46 ± 3
	74L5	143,060	106 ± 8	0.55 ± 0	0.8	82 ± 30	-0.41	0 ± 0.001	78 ± 6
	74L6	67,814	54 ± 4	0.29 ± 0	1.1	13 ± 13	-2.43	-0.01 ± 0.007	27 ± 2
Easton	92W43	195,429	44 ± 5	0.18 ± 0	1.2	-41 ± 16	0.08	0 ± 0.001	48 ± 5
	92W44	284,143	36 ± 5	0.18 ± 0	0.7	-33 ± 16	1.00	0.01 ± 0.001	40 ± 5
	92W54	151,576	49 ± 11	0.18 ± 0	1.8	93 ± 29	0.58	0 ± 0.001	54 ± 12
	92W78	164,284	58 ± 5	0.18 ± 0	1.9	-39 ± 18	1.26	0.01 ± 0.001	63 ± 6
	92W79	156,667	22 ± 7	0.18 ± 0	0.8	-19 ± 15	2.30	0.01 ± 0.001	24 ± 7
Maplewood	16W1	134,311	93 ± 6	N/A	N/A	96 ± 16	N/A	N/A	50 ± 3
	16W2	157,579	61 ± 8	N/A	N/A	44 ± 23	-0.06	0 ± 0.001	37 ± 5
	16W3	140,221	60 ± 5	N/A	N/A	50 ± 12	-0.19	± 0.001	33 ± 2
	16W4	110,096	4 ± 4	N/A	N/A	8 ± 12	N/A	N/A	2 ± 3
	16W5	95,782	22 ± 4	N/A	N/A	65 ± 10	N/A	N/A	12 ± 2

Substation	Circuit	Energy Baseline (MWh)	Net Energy Reduction (MWh)*†	Voltage Reduction (kV)	CVRf	Peak Load Reduction (kW)	Distribution Loss Reduction (%)	Power Factor Change	GHG Reductions (tons CO_2) †
	16W6	185,715	70 ± 12	N/A	N/A	23 ± 31	N/A	N/A	43 ± 8
	16W7	178,197	38 ± 8	N/A	N/A	136 ± 22	-0.38	0 ± 0.001	22 ± 5
	16W8	136,245	55 ± 9	N/A	N/A	47 ± 24	N/A	N/A	33 ± 5
Stoughton	913W17	20,342	96 ± 9	0.28 ± 0	2.1	N/A	N/A	N/A	13 ± 1
	913W18	17,843	12 ± 4	0.28 ± 0	0.3	N/A	N/A	N/A	2 ± 0
	913W43	18,308	79 ± 8	0.28 ± 0	1.8	N/A	N/A	N/A	10 ± 1
	913W47	21,514	45 ± 5	0.28 ± 0	0.9	N/A	N/A	N/A	6 ± 1
	913W67	6,837	39 ± 4	0.28 ± 0	2.3	N/A	N/A	N/A	5 ± 1
	913W69	32,219	54 ± 9	0.28 ± 0	0.7	N/A	N/A	N/A	7 ± 1
West Salem	29W1	284,305	250 ± 9	N/A	N/A	N/A	N/A	N/A	393 ± 14
	29W2	130,633	-77 ± 5	N/A	N/A	N/A	N/A	N/A	-99 ± 6
	29W3	287,358	-168 ± 7	N/A	N/A	N/A	0.15	0 ± 0.001	-225 ± 10
	29W4	199,483	-115 ± 7	N/A	N/A	N/A	2.06	0.010 ± 0.018	-126 ± 7
	29W5	294,751	-144 ± 8	N/A	N/A	N/A	0.81	0 ± 0.001	-156 ± 9
	29W6	197,285	-53 ± 5	N/A	N/A	N/A	N/A	N/A	-68 ± 6
	Overall†	5,184,073	1,696 ± 49	0.32 ± 0	0.9	1,737 ± 141	0.77	0 ± 0.001	734 ± 35

* Overall energy savings is the sum of each circuit's energy savings, and due to model noise, a manual sum of savings across periods may not equal the amount provided in the Total row. Overall voltage reductions and CVR factors provided are load-weighted averages of these estimates provided for each circuit. Aggregate CVRf value presented here is the load-weighted average of every circuit-specific CVRf value for which there was enough data to estimate CVRf. Similarly, aggregate peak load reduction is the load-weighted average of every circuit-specific peak load reduction estimate for which there was enough data to estimate peak load reduction.

† Calculation uses actual number of VVO On hours spanning the analysis period. Actual VVO On Hours are the number of hours VVO was engaged for each substation during PY 2023.

Source: Guidehouse analysis

D.1.3 Unitil

Table D-3. Unitil Performance Metrics Results by Circuit*

Circuit	Energy Baseline (MWh)	Net Energy Reduction (MWh)*†	Voltage Reduction (kV)	CVRf	Peak Load Reduction (kW)	Distribution Loss Reduction (%)	Power Factor Change	GHG Reductions (tons CO_2) †
15W15	124,369	53 ± 5	0.19 ± 0	1.4	25 ± 27	0.21	0.001 ± 0	41 ± 4
15W16	101.559	26 ± 6	0.19 ± 0	0.8	-6 ± 29	N/A	N/A	19 ± 5
15W17	27,452	8 ± 2	0.19 ± 0	0.9	1 ± 8	N/A	N/A	6 ± 1
Overall†	253,380	87 ± 8	0.19 ± 0	1.1	20 ± 41	0.21%	0.001 ± 0	66 ± 6

* Overall energy savings is the sum of each circuit's energy savings, and due to model noise, a manual sum of savings across periods may not equal the amount provided in the Total row. Overall voltage reductions and CVR factors provided are load-weighted averages of these estimates provided for each circuit. Aggregate CVRf value presented here is the load-weighted average of every circuit-specific CVRf value for which there was enough data to estimate CVRf. Similarly, aggregate peak load reduction is the load-weighted average of every circuit-specific peak load reduction estimate for which there was enough data to estimate peak load reduction.

† Calculation uses actual number of VVO On hours spanning the analysis period. Actual VVO On Hours are the number of hours VVO was engaged for each substation during PY 2023.

Source: Guidehouse analysis

Appendix E. Overall Data Attrition from Data Cleaning

The tables in this section provide a detailed summary of data attrition from cleaning steps applied to analysis datasets. Detailed data attrition results are provided separately by EDC and substation.

E.1.1 National Grid

Table E-1. Count of Observations Remaining by Data Cleaning Step for East Bridgewater

Data Cleaning Step	797W19	797W20	797W23	797W24	797W29	797W42
Initial Dataset (PY 2023)	**12,084**	**12,084**	**12,084**	**12,084**	**12,084**	**12,084**
1. Remove Missing VVO Status	6	6	6	6	6	6
2. Remove Interpolated	4	0	14	11	21	28
3. Remove Repeated	12	9	24	25	15	34
4. Remove Outliers	0	0	1	3	0	1
5. Remove Anomalous Readings	0	0	0	0	0	0
Final Dataset	**12,062**	**12,079**	**12,039**	**12,039**	**12,042**	**12,015**
Observations Removed	22	15	45	45	42	69

Source: Guidehouse analysis

Table E-2. Count of VVO On, VVO Off, and Removed Observations for East Bridgewater

Number of Observations	797W19	797W20	797W23	797W24	797W29	797W42
VVO On *Weekday*	4,063	4,068	4,073	4,046	4,072	4,068
VVO On *Weekend*	1,726	1,728	1,715	1,720	1,717	1,720
VVO Off *Weekday*	4,552	4,552	4,537	4,554	4,534	4,517
VVO Off *Weekend*	1,721	1,721	1,714	1,719	1,719	1,710
Removed	22	15	45	45	42	69
PY 2023 Total	**12,084**	**12,084**	**12,084**	**12,084**	**12,084**	**12,084**

Source: Guidehouse analysis

Table E-3. Count of Observations Remaining by Data Cleaning Step for East Dracut

Data Cleaning Step	75L1	75L2	75L3	75L4	75L5	75L6
Initial Dataset (PY 2023)	**61,536**	**37,116**	**61,536**	**37,116**	**61,536**	**37,116**
1. Remove Missing VVO Status	12	12	12	12	12	12
2. Remove Interpolated	3,233	2,190	3,123	1,219	3,170	502
3. Remove Repeated	1,592	1,953	1,260	1,108	1,202	499
4. Remove Outliers	39	22	67	149	70	81
5. Remove Anomalous Readings	0	0	0	0	0	0
Final Dataset	**56,660**	**32,939**	**28,537**	**17,314**	**57,082**	**36,022**
Observations Removed	4,876	4,177	4,462	2,488	4,454	1,094

Source: Guidehouse analysis

Table E-4. Count of VVO On, VVO Off, and Removed Observations for East Dracut

Number of Observations	75L1	75L2	75L3	75L4	75L5	75L6
VVO On *Weekday*	22,006	9,929	22,272	10,558	22,187	10,918
VVO On *Weekend*	8,336	4,254	8,372	4,417	8,385	4,575
VVO Off *Weekday*	18,657	13,317	18,794	13,985	18,707	14,541
VVO Off *Weekend*	7,661	5,439	7,636	5,668	7,803	5,988
Removed	**4,876**	**4,177**	**4,462**	**2,488**	**4,454**	**1,094**
PY 2023 Total	61,536	37,116	61,536	37,116	61,536	37,116

Source: Guidehouse analysis

Table E-5. Count of Observations Remaining by Data Cleaning Step for East Methuen

Data Cleaning Step	74L1	74L2	74L3	74L4	74L5	74L6
Initial Dataset (PY 2023)	**67,536**	**43,164**	**67,536**	**43,164**	**67,536**	**43,164**
1. Remove Missing VVO Status	12	12	12	12	12	12
2. Remove Interpolated	1,332	1,219	3,281	1,159	2,758	2,362
3. Remove Repeated	1,170	1,029	3,024	1,030	2,277	2,224
4. Remove Outliers	184	0	23	17	86	1
5. Remove Anomalous Readings	254	0	0	0	0	0
Final Dataset	**64,584**	**40,904**	**61,196**	**40,946**	**62,403**	**38,565**
Observations Removed	2,952	2,260	6,340	2,218	5,133	4,599

Source: Guidehouse analysis

Table E-6. Count of VVO On, VVO Off, and Removed Observations for East Methuen

Number of Observations	74L1	74L2	74L3	74L4	74L5	74L6
VVO On *Weekday*	22,579	15,940	21,342	15,885	21,923	14,856
VVO On *Weekend*	8,865	5,960	8,287	6,031	8,549	5,647
VVO Off *Weekday*	23,247	13,012	22,283	13,065	22,412	12,316
VVO Off *Weekend*	9,893	5,992	9,284	5,965	9,519	5,746
Removed	2,952	2,260	6,340	2,218	5,133	4,599
PY 2023 Total	**67,536**	**43,164**	**67,536**	**43,164**	**67,536**	**43,164**

Source: Guidehouse analysis

Table E-7. Count of Observations Remaining by Data Cleaning Step for Easton

Data Cleaning Step	92W43	92W44	92W54	92W78	92W79
Initial Dataset (PY 2023)	**94,044**	**94,044**	**94,044**	**94,044**	**94,044**
1. Remove Missing VVO Status	6	6	6	6	6
2. Remove Interpolated	373	417	936	533	425
3. Remove Repeated	57	30	52	177	42
4. Remove Outliers	61	2	358	113	193
5. Remove Anomalous Readings	0	0	0	0	1,149
Final Dataset	**93,547**	**93,589**	**92,692**	**93,215**	**92,229**
Observations Removed	497	455	1,352	829	1,815

Source: Guidehouse analysis

Table E-8. Count of VVO On, VVO Off, and Removed Observations for Easton

Number of Observations	92W43	92W44	92W54	92W78	92W79
VVO On *Weekday*	30,255	30,314	30,149	30,147	29,963
VVO On *Weekend*	15,377	15,371	15,160	15,318	15,163
VVO Off *Weekday*	36,423	36,445	36,115	36,298	35,980
VVO Off *Weekend*	11,492	11,459	11,268	11,452	11,123
Removed	497	455	1,352	829	1,815
PY 2023 Total	**94,044**	**94,044**	**94,044**	**94,044**	**94,044**

Source: Guidehouse analysis

Table E-9. Count of Observations Remaining by Data Cleaning Step for Maplewood

Data Cleaning Step	16W1	16W2	16W3	16W4	16W5	16W6	16W7	16W8
Initial Dataset (PY 2023)	**56,916**	**61,500**	**56,916**	**61,500**	**56,916**	**61,500**	**56,916**	**61,500**
1. Remove Missing VVO Status	6	6	6	6	6	6	6	6
Remove Interpolated	936	807	620	359	348	1,095	504	1,043
3. Remove Repeated	843	756	453	266	304	975	444	922
4. Remove Outliers	72	118	90	636	156	110	92	159
5. Remove Anomalous Readings	3,040	0	3,080	0	0	0	0	0
Final Dataset	**52,019**	**59,813**	**52,667**	**60,233**	**56,102**	**59,314**	**55,870**	**59,370**
Observations Removed	4,897	1,687	4,249	1,267	814	2,186	1,046	2,130

Source: Guidehouse analysis

Table E-10. Count of VVO On, VVO Off, and Removed Observations for Maplewood

Number of Observations	16W1	16W2	16W3	16W4	16W5	16W6	16W7	16W8
VVO On *Weekday*	16,565	18,841	16,721	19,207	17,389	18,766	17,399	18,776
VVO On *Weekend*	5,962	6,416	6,052	6,500	6,346	6,359	6,328	6,337
VVO Off *Weekday*	21,010	23,964	21,279	23,997	22,798	23,678	22,679	23,686
VVO Off *Weekend*	8,482	10,592	8,615	10,529	9,569	10,511	9,464	10,571
Removed	4,897	1,687	4,249	1,267	814	2,186	1,046	2,130
PY 2023 Total	**56,916**	**61,500**	**56,916**	**61,500**	**56,916**	**61,500**	**56,916**	**61,500**

Source: Guidehouse analysis

Table E-11. Count of Observations Remaining by Data Cleaning Step for Stoughton

Data Cleaning Step	913W17	913W18	913W43	913W47	913W67	913W69
Initial Dataset (PY 2023)	**12,096**	**12,096**	**12,096**	**12,096**	**12,096**	**12,096**
1. Remove Missing VVO Status	6	6	6	6	6	6
2. Remove Interpolated	28	48	48	32	78	34
3. Remove Repeated	9	23	27	6	81	2
4. Remove Outliers	13	1	2	21	11	3
5. Remove Anomalous Readings	0	0	863	0	863	0
Final Dataset	**12,040**	**12,018**	**11,150**	**12,031**	**11,057**	**12,051**
Observations Removed	56	78	946	65	1,039	45

Source: Guidehouse analysis

Table E-12. Count of VVO On, VVO Off, and Removed Observations for Stoughton

Number of Observations	913W17	913W18	913W43	913W47	913W67	913W69
VVO On *Weekday*	3,791	3,778	3,783	3,792	3,751	3,792
VVO On *Weekend*	1,717	1,719	1,715	1,720	1,694	1,718
VVO Off *Weekday*	4,804	4,800	3,938	4,793	3,907	4,816
VVO Off *Weekend*	1,728	1,721	1,714	1,726	1,705	1,725
Removed	56	78	946	992	1,039	45
PY 2023 Total	**12,096**	**12,096**	**12,096**	**12,096**	**12,096**	**12,096**

Source: Guidehouse analysis

Table E-13. Count of Observations Remaining by Data Cleaning Step for West Salem

Data Cleaning Step	29W1	29W2	29W3	29W4	29W5	29W6
Initial Dataset (PY 2023)	**94,644**	**94,644**	**94,644**	**94,644**	**94,644**	**94,644**
1. Remove Missing VVO Status	1,020	1,074	894	1,470	1,194	1,062
2. Remove Interpolated	0	0	0	0	0	0
3. Remove Repeated	0	0	0	0	0	0
4. Remove Outliers	147	118	21	370	307	34
5. Remove Anomalous Readings	577	1,441	577	1,441	577	1,441
Final Dataset	**92,900**	**92,011**	**93,152**	**91,363**	**92,566**	**92,107**
Observations Removed	1,744	2,633	1,492	3,281	2,078	2,537

Source: Guidehouse analysis

Table E-14. Count of VVO On, VVO Off, and Removed Observations for West Salem

Number of Observations	29W1	29W2	29W3	29W4	29W5	29W6
VVO On *Weekday*	44,144	35,888	36,616	29,086	30,415	36,240
VVO On *Weekend*	20,996	17,470	19,026	16,420	14,618	17,134
VVO Off *Weekday*	21,790	29,511	29,584	35,812	35,283	29,236
VVO Off *Weekend*	5,970	9,142	7,926	10,045	12,250	9,497
Removed	1,744	2,633	1,492	3,281	2,078	2,537
PY 2023 Total	**94,644**	**94,644**	**94,644**	**94,644**	**94,644**	**94,644**

Source: Guidehouse analysis

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Table E-15. Count of Observations Remaining by Data Cleaning Step for Townsend

Data Cleaning Step	15W15	15W16	15W17
Initial Dataset (PY 2023)	**20,843**	**20,843**	**20,843**
1. Remove Missing VVO Status	0	0	0
2. Remove Interpolated	295	295	345
3. Remove Repeated	94	99	148
4. Remove Outliers	141	338	568
Final Dataset	**20,313**	**20,111**	**19,782**
Observations Removed	**530**	**732**	**1,061**

Source: Guidehouse analysis

Table E-16. Count of VVO On, VVO Off, and Removed Observations for Townsend

Number of Observations	15W15	15W16	15W17
VVO On *Weekday*	7,498	7,388	7,336
VVO On *Weekend*	3,124	3,108	3,114
VVO Off *Weekday*	6,897	6,826	6,649
VVO Off *Weekend*	2,794	2,789	2,684
Removed	530	732	1,061
PY 2023 Total	**20,843**	**20,843**	**20,843**

Source: Guidehouse analysis

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