ComEd Voltage Optimization Program Impact Evaluation Report

Energy Efficiency / Demand Response Plan:
Program Year 2018 (CY2018)
(1/1/2018-12/31/2018)

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ComEd Voltage Optimization Impact Evaluation Report

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1. Introduction

This report presents the results of the impact evaluation of ComEd's CY2018 Voltage Optimization (VO) Program. It presents a summary of the energy and demand impacts for the total program and broken out by relevant substation details. The appendix presents the impact analysis methodology. CY2018 covers January 1, 2018 through December 31, 2018.

2. Program Description

The VO Program comprises ComEd's plan to install hardware and software systems on a significant fraction of its electric power distribution grid to achieve voltage and reactive power optimization (volt-var optimization, or VVO) over the 2018-2025 time frame. VVO is a smart grid technology that uses distributed sensors, two-way communications infrastructure, remote controls on substation transformer load-tap changers and line capacitor banks, and integrating/optimizing software to flatten voltage profiles and lower average voltage levels on an electric power distribution grid. ComEd is working with an automation-optimization hardware and software vendor[1] to implement the VO program on selected parts of its distribution grid over the 2018-2025 period.

Unlike energy efficiency programs that achieve savings by providing financial incentives to encourage customers to adopt energy-efficient equipment or behavioral suggestions to encourage them to adopt no-cost energy-saving behaviors, the VO Program involves no direct customer engagement. Instead, savings is achieved by operating the voltage and reactive power controls on VO-enabled feeders and substations in a manner designed to maintain the voltages delivered to affected customers in the lower part of the allowable voltage range.[2]

The program installed and commissioned VO systems on a total of 164 feeders at 38 substations in CY2018, as shown in the following table.[3]

Table 2-1. CY2018 Volumetric Findings Detail

Participation	Count
VO-Enabled Substations	38
VO-Enabled Feeders	164

Source: ComEd tracking data and Navigant team analysis.

3. Program Savings Detail

Table 3-1 summarizes the incremental energy savings the VO Program achieved in CY2018. This evaluation did not assess gas savings. The evaluation methodology produces an estimate of net savings directly so no net-to-gross adjustment is needed. The program did not claim and the evaluation did not examine gas savings.

[1] Open Systems International (OSI) of Medina, Minnesota.
[2] The bulk of the energy savings that occurs is thus expected to occur on the customer side of the meter.
[3] VO did not go live on many of these feeders until the very end of 2018. ComEd also worked on installing VO on other substations and feeders during CY2018. Table 2-1 shows only those on which installation, commissioning and system testing were completed by December 31, 2018.

Table 3-1. CY2018 Total Annual Incremental Electric Savings

Savings Category	Energy Savings (kWh)	Demand Savings (kW)	Summer Peak Demand Savings (kW)†
Electricity			
Ex Ante Gross Savings	99,381,000	-	-
Program Gross Realization Rate	0.66	NA	NA
Verified Gross Savings	66,014,049	7,536	NA
Program Net-to-Gross Ratio (NTG)	NA	NA	NA
Verified Net Savings	66,014,049	7,536	NA
Converted from Gas*			
Ex Ante Gross Savings	NA	NA	NA
Program Gross Realization Rate	NA	NA	NA
Verified Gross Savings	NA	NA	NA
Program Net-to-Gross Ratio (NTG)	NA	NA	NA
Verified Net Savings	NA	NA	NA
Total Electric Plus Gas			
Ex Ante Gross Savings	99,381,000	-	-
Program Gross Realization Rate	0.66	NA	NA
Verified Gross Savings	66,014,049	7,536	NA
Program Net-to-Gross Ratio (NTG)	NA	NA	NA
Verified Net Savings	66,014,049	7,536	NA

NA = Not applicable
* Gas savings were not estimated for this program.
† Peak demand savings were not estimated for this program.
Note: The coincident Summer Peak period is defined as 1:00-5:00 PM Central Prevailing Time on non-holiday weekdays, June through August.
Source: ComEd tracking data and Navigant team analysis.

4. Cumulative Persisting Annual Savings

The total ex ante gross savings for the VO Program and the cumulative persisting annual savings (CPAS) for the measures installed in CY2018 are shown in the following tables and figure. The total CPAS for the program is 66,014,049 kWh. This evaluation did not assess gas savings.

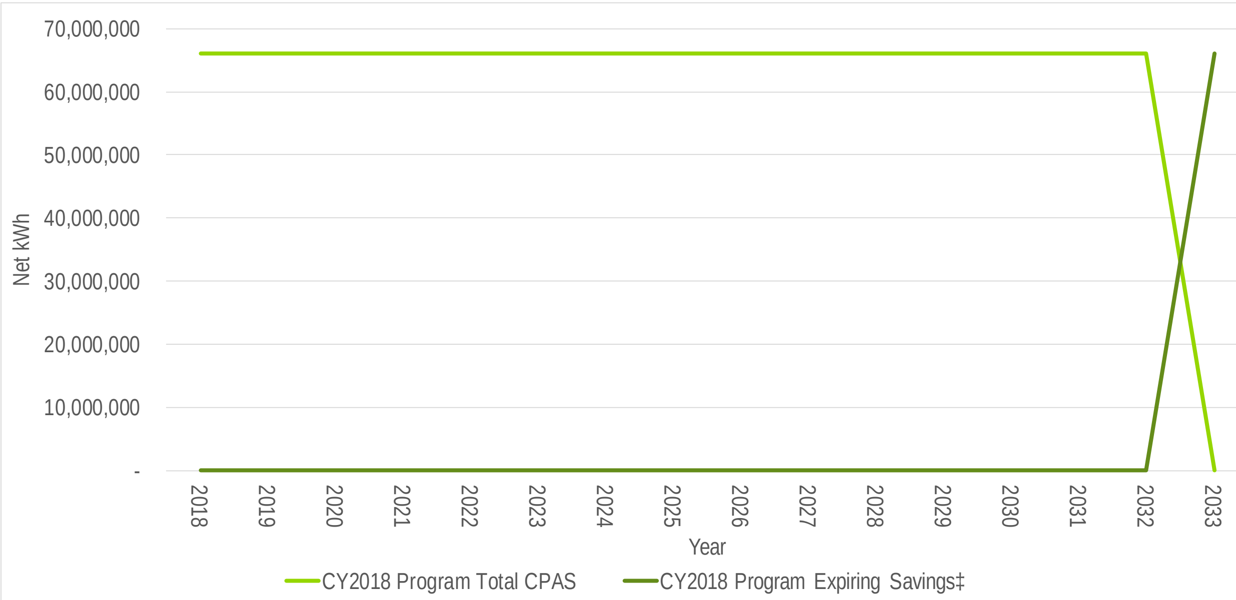
Table 4-1. Cumulative Persisting Annual Savings (CPAS) – Electric

End Use Type	Research Category	EUL	CY2018 Verified Gross Savings	NTG*	Lifetime Net Savings†	Verified Net kWh Savings 2018	2019	2020	2021	2022	2023	2024	2025	2026
All	VO	15.0	66,014,049	1.00	990,210,735	66,014,049	66,014,049	66,014,049	66,014,049	66,014,049	66,014,049	66,014,049	66,014,049	66,014,049
CY2018 Program Total Electric CPAS			66,014,049		990,210,735	66,014,049	66,014,049	66,014,049	66,014,049	66,014,049	66,014,049	66,014,049	66,014,049	66,014,049
CY2018 Program Expiring Electric Savings‡							-	-	-	-	-	-	-	-

End Use Type	Research Category	2027	2028	2029	2030	2031	2032	2033
All	VO	66,014,049	66,014,049	66,014,049	66,014,049	66,014,049	66,014,049	
CY2018 Program Total Electric CPAS		66,014,049	66,014,049	66,014,049	66,014,049	66,014,049	66,014,049	-
CY2018 Program Expiring Electric Savings‡		-	-	-	-	-	-	66,014,049

Note: The green highlighted cell shows program total first year electric savings.
* The VO Program does not have a NTG ratio assigned to it, but the methodology Navigant used to measure its energy savings produces a net savings estimate, which is the equivalent of assigning it a NTG value of 1.0.
† Lifetime savings are the sum of CPAS savings through the EUL.
‡ Expiring savings are equal to CPAS Yn-1 - CPAS Yn + Expiring Savings Yn-1.
Source: ComEd tracking data and Navigant analysis.

Figure 4-1. Cumulative Persisting Annual Savings



‡ Expiring savings are equal to CPAS Yn-1 - CPAS Yn + Expiring Savings Yn-1.
Source: Navigant analysis

5. Program Savings by Measure

The evaluation analyzed savings for the Voltage Optimization Program at the feeder and substation levels and does not have measure-level savings.[4]

6. Impact Analysis Findings and Recommendations

6.1 Impact Parameter Estimates

The evaluation team used a conservation voltage reduction (CVR) factor value of 0.80 to produce CY2018 verified savings, but did not empirically verify this value. We will report a verified estimate and associated sample statistics based on the combined CY2018-CY2019 sample next year.[5]

6.2 Other Impact Findings and Recommendations

The evaluation team has developed several recommendations based on findings from the CY2018 evaluation, as follows:

Finding 1: Navigant's verified CY2018 energy savings for the VO program is 66,014,049 kWh, implying a realization rate of 0.66 relative to ComEd's ex ante energy savings estimate of 99,381,000 kWh.

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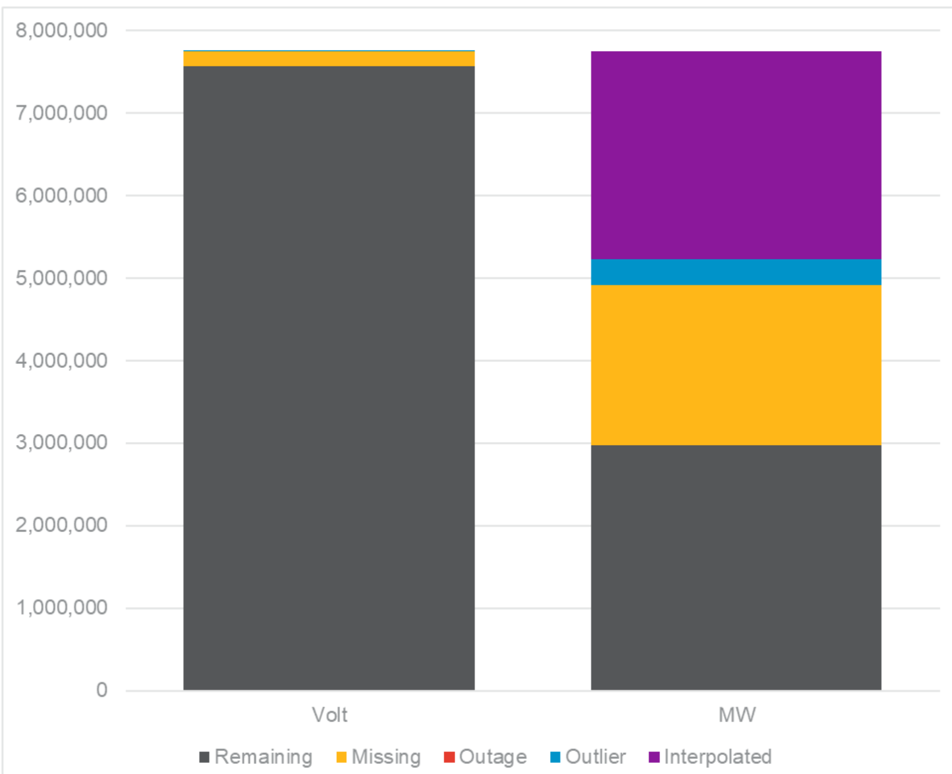
[4] See Section 10 below for detailed savings results.
[5] See Section 7 below for details.

Finding 2: Navigant's verified average voltage reduction from VO in CY2018 is 2.9 percent, implying a realization rate of 0.91 relative to ComEd's ex ante VO voltage reduction of 3.2 percent.[6]

Finding 3: Navigant also examined the impacts of the feeder conditioning steps undertaken on many of the CY2018 VO feeders prior to VO installation.[7] Since the voltage and energy impacts from feeder conditioning were not statistically significant, they are not included in the above findings. We intend to continue researching feeder conditioning effects in CY2019.

Finding 4: Data Quality. Navigant relied on two types of feeder-level time-series data for its impact evaluation: 30-minute interval readings on real power (MW) obtained from each VO-enabled substation's SCADA system[8], and averaged customer AMI data for voltage.[9] The voltage data was, by and large, quite clean. However, we removed large amounts of the SCADA power data during data cleaning prior to the analysis. In aggregate, approximately 62 percent of the available time-series observations for MW were removed, the majority of which because the values were missing or interpolated. Less than 3 percent of the AMI-sourced voltage data was removed during data cleaning. (See Figure 6-1.)

Figure 6-1. Aggregate Data Cleaning Results



Source: ComEd tracking data and Navigant team analysis.

[6] ComEd VO team, personal communication.
[7] Feeder conditioning may include adding LTC controls, capacitor banks, and voltage regulators, as well as load balancing, phase balancing, and reconductoring.
[8] SCADA stands for Supervisory Control and Data Acquisition, and represents the primary means by which data are collected and stored on distribution substation and feeder status and performance at regular intervals.
[9] Feeder-level load-weighted averages of interval voltage readings from customer AMI meters at 30-minute intervals were provided by ComEd.

Finding 5: SCADA data interpolation. Navigant encountered many cases where the SCADA system did not record real and reactive power values on all VO-enabled feeders at 30-minute intervals as expected. Instead, for many feeders fewer than 10 readings per day were recorded for extended periods, with interpolated values inserted in the remaining intervals.[10] Besides reducing the quantity of usable data available for analysis (with 30-minute intervals 48 readings per day are expected), it may also understate the actual range of values experienced each day for these feeders, including the daily peaks. This affected both the accuracy and the precision of the savings estimates.

Recommendation 1: Ensure that the SCADA systems at all VO substations record actual readings every 30 minutes for every VO-enabled feeder.

Finding 6: SCADA missing, bad quality and outlier data. Navigant removed large amounts of data due to values that were missing, flagged as "bad quality" readings by the SCADA system, incorrectly scaled or quantized[11], or anomalous, unexplained spikes. Some of the power spikes appear to have resulted from load-shifting events that were not recorded in the events log. In the absence of other information, these data were also removed.

Recommendation 2: Clean SCADA data prior to sending it to the evaluation team to identify and, if necessary, correct, anomalous outliers.

Recommendation 3: Ensure that all events that result in large changes in measured load are recorded in the events log, including dates and times of the start and stop of each event.

Finding 7: Sparseness of on/off test data precluded using a statistical model to directly measure CY2018 energy savings. The analytical approach described in Navigant's CY2018 evaluation plan for measuring VO impacts assumed that data would be collected from a representative sample of the CY2018 VO feeders that were operated on a preset alternating (4-day-on/4-day-off) schedule.[12] The plan anticipated having the sample feeders cycle between VO-on and VO-off (or baseline) volt-var control states on a regular, preset schedule, with a sufficient number starting this process by summer 2018 to enable direct comparison of measured loads on each feeder over the full range of expected weather and load conditions (i.e., summer, winter, and shoulder seasons) to permit the measurement of the VO impacts. Delays with the commissioning and tuning of the expected rollouts of VO feeders in the test sample meant that on/off cycling did not commence until very late in the year, and did not succeed in capturing the expected number of "on" observations; more concerning than the relatively scant numbers was the fact that nearly all of the available test data came from the winter months, much of it from January and February 2019 (see Figure 6-2).[13] Following discussions with ComEd and ICC Staff, Navigant concluded that the lack of VO-on test data during the non-winter periods of CY2018 precluded the use of its statistical modeling approach, described in Section 8 below, to measure verified energy savings.

Finding 8: But it did not preclude using a statistical model to measure the CY2018 VO voltage reductions and baseline energy usage values used to calculate energy savings with the CVR factor-based method. For these tasks, the lack of summer and shoulder VO-on test data is less impactful. While VO energy savings is highly seasonal, the voltage impacts are much less so. And the ability to model baseline (i.e., VO-off) energy usage is unaffected by the dearth of VO-on observations because the latter are not used to estimate baseline load profiles. For these reasons, Navigant believes that on balance, the risk of

[10] When this occurs, runs of adjacent values lie along a straight line between pairs of vertices, which represent actual reads. Navigant understands that the "historian" component of the SCADA system software inserts interpolated values automatically when it is asked to produce time-series values for a period when fewer than the full complement of reads is available. We are not sure why actual reads were not made at every 30-minute interval.

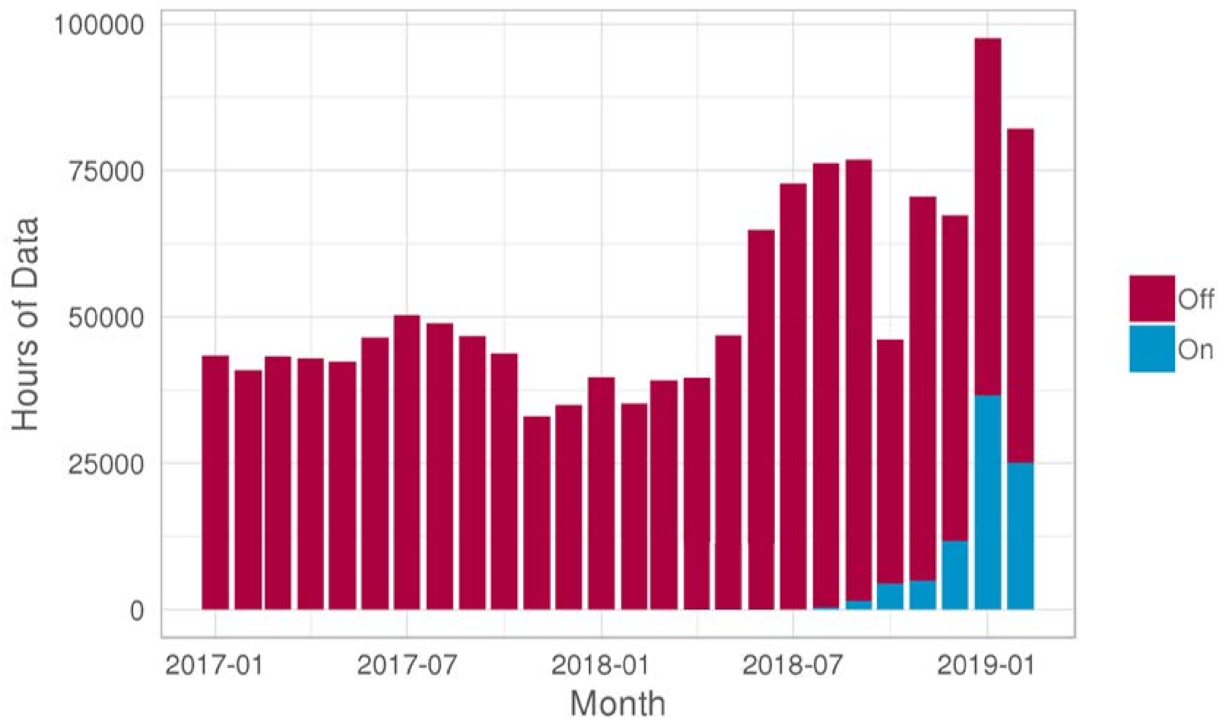
[11] I.e., rounded too aggressively, to the point where observed data values all fall on a few common values for extended periods.

[12] See ComEd Voltage Optimization Program CY2018 to CY2021 Evaluation Plan, pp. 3-4.

[13] Navigant agreed to include SCADA test data from January and February 2019 in its training set for the CY2018 VO feeders to enlarge the size of the sample, but this did not alleviate the dearth of test data during the other seasons.

possibly missing some minor seasonality in the VO voltage impacts by using our modeling approach is outweighed by the greater risk of obtaining biased voltage reduction results, which would be the probable result of calculating the voltage reductions as differences in seasonal means without controlling for the effects of weather, time of day, day of week, and other likely confounders. Similarly, we believe that using our statistically modeled energy baselines is preferable to using ComEd's baselines.

Figure 6-2. Hours of Test Sample Data Available by VO Status and Month



Source: ComEd tracking data and Navigant team analysis.

Finding 9: Inability to measure summer peak period demand reductions: Because Navigant opted to use a CVR factor-based method to verify VO energy savings in CY2018, we were unable to measure peak demand reductions. Doing so would have required using a statistical model that recognizes time-of-day, day-of-week, and weather effects during the summer season. By construction, CVR factor-based methods assume a constant VO effect (per unit voltage reduction) in every hour of the year.[14]

Finding 10: The experimental design for measuring the program's savings produced too little data from 2018 feeders to support a robust estimation of the VO savings for the 2018 program. Navigant will reexamine the issue in CY2019, when more complete on/off test data will be available.

Recommendation 4: ComEd should strive to get VO on/off testing started on the CY2019 feeders as early in the year as possible so as to have on/off test data available during the

[14] In its evaluation of the CY2019 VO feeders, Navigant will use the definition of summer peak provided by PJM's Manual 18B (i.e., between the hour ending 15:00 and the hour ending 18:00, prevailing local time, during all days from June 1 through August 31 inclusive, that do not fall on a weekend day or federal holiday) to estimate peak demand impacts.

summer, winter, and shoulder seasons in order to demonstrate the impact of VO on energy usage and demand over the full range of expected weather and load conditions.[15]

7. Appendix 1. CVR Factor-Based Methods

As discussed in Section 6, Navigant determined, in consultation with ComEd and ICC Staff, that the interval power (MW) data provided by ComEd contained insufficient observations on feeders that were cycling between VO-on and VO-off control states to support the use of its statistical modeling approach, described in Section 8, to directly measure VO energy savings in CY2018. Instead, we employed a CVR factor (CVRf) based approach to calculate energy savings, which relies on an equation shown in Equation 7-1.

Equation 7-1. CVR Factor Methodology

$$Energy\ Savings_i = BaselineEnergyUse_i \cdot CVRf \cdot \%\Delta V_i$$

where the components of the equation are defined as follows:

- The i subscripts index feeders
- $Energy\ Savings_i$ is the annualized CY2018 VO energy savings on feeder i
- $BaselineEnergyUse_i$ is the estimated annual energy usage on feeder i in CY2018 that would have occurred in the absence of VO
- $CVRf$ is a constant average CVR factor (or voltage elasticity of energy usage)[16]
- $\%\Delta V_i$ is the average annualized percentage voltage reduction achieved from VO on feeder i.

To determine the verified energy savings, Navigant applied the above calculation at the feeder level, and the feeder-level results were then aggregated across feeders to obtain the aggregate program savings.

Navigant wishes to stress the intrinsic limitations of using a CVRf-based method to estimate the energy savings derived from a VO program. Most importantly, unless the $CVRf$ value in Equation 7-1 is empirically based – that is, unless feeder- or substation-specific models were used to estimate the $CVRf$ components (i.e., $\%\Delta E$ and $\%\Delta V$) using current or recent data collected from the feeders to which it is being applied, the magnitude of the average VO energy impact per unit voltage reduction (the “energy bang for the voltage reduction buck,” so to speak) is being *assumed* rather than measured. It also assumes that it is constant over time as well as across feeders – neither of which is true in general.[17] Nonetheless, the CVRf-based method is the main alternative to feeder-level statistical modeling that is seen in the industry literature. Based on our discussions with ComEd and ICC Staff, Navigant produced three CVRf-based energy savings estimates, each using a different set of assumptions, which are shown in Table 7-1.

[15] Navigant will use the additional data collected on the CY2018 VO feeders in 2019 to refine the statistical models used to estimate savings on the VO feeders added in CY2019 and beyond.
[16] $CVRf = \%\Delta E / \%\Delta V$, where E is energy and V is volts.
[17] In Navigant’s experience evaluating VVO programs for other electric utilities, CVR factors generally vary by time of day, day of week (i.e., weekends vs. weekdays), season, as well as by feeder and substation. This is because how energy consumption on a feeder circuit responds to voltage reductions depends on the characteristics of the loads being served by each feeder. In addition, the extent to which a VVO system is able effectively to lower voltages depends on how heavily loaded the feeder is. These factors are not constant over time or across feeders.

Table 7-1. Alternative CVR Factor-Based Methods

Required Component	Method ComEd CVRf*	 Ameren CVRf V1	 Ameren CVRf V2
$BaselineEnergyUse$	ComEd-supplied baseline values	Navigant baseline (non-VO) model	Navigant baseline (non-VO) model
$CVRf$	0.80	0.80	0.61
$\%\Delta V$	ComEd-supplied SCADA-sourced estimates	Navigant model w/ AMI-sourced data	Navigant model w/ AMI-sourced data

* Navigant did not verify the BaselineEnergyUse and %ΔV values ComEd provided for these estimates.

The first method, labeled "ComEd CVRf" in Table 7-1, uses a 0.8 CVRf value and feeder-level voltage reductions and energy baselines provided by ComEd to Navigant for the calculations. The second method, labeled "Ameren CVRf V1," also uses a 0.8 CVRf value, but uses Navigant's statistically modeled voltage reductions and energy baselines. The third method, labeled "Ameren CVRf V2," is identical to the second except it uses a CVRf value of 0.61.

The three CVRf-based methods shown in Table 7-1 differ in three respects: the CVRf value, the 2018 energy baselines, and the voltage reduction estimates used. We address each of these choices briefly before presenting the aggregate energy impacts produced by the three methods. Regarding the choice of CVRf value, which is a constant representing the average percentage energy reduction experienced on VO-enabled feeders per unit percentage voltage reduction, Navigant believes the choice could be based either on a review of the available industry literature, or on the available evidence from prior research in ComEd's service territory, or a combination of the two. ComEd provided us with the 0.8 CVRf value, based on a pilot project it performed at its Oak Park substation several years ago. The project involved extended day-on/day-off testing over several seasons and used a VVO system that differed in some respects from the one that ComEd later selected for its VO rollout beginning in CY2018, but which Navigant believes was similar in its key components.[18]

The 0.61 CVRf value, on the other hand, is representative of the broader industry experience with VVO as embodied in the database ComEd compiled from its review of the industry literature.[19] The mean and standard deviation of the CVRf values in the database are 0.61 and 0.45, respectively.

In choosing between the two CVRf options, Navigant chose to give greater weight to the fact that the 0.8 value, despite being based on a single pilot study, had been empirically derived from a test conducted on ComEd's equipment (i.e., Oak Park substation and feeders). While Navigant's subsequent research in CY2019 may determine a different value, we believe that 0.8 is the most prudent option for CY2018.

Regarding the choice of which of the two voltage reduction estimates to use, Navigant considered two factors: the data on which each was based, and the methodology used to calculate the voltage reductions. ComEd's voltage reductions were based on substation-level voltage time-series readings collected from the SCADA systems of the substations housing the CY2018 VO-enabled feeders. ComEd indicated that they estimated their voltage reductions by comparing the "2018 measured and available VO-on profile and corresponding 2017 VO-off profile" voltage readings and differencing them to obtain the winter seasonal voltage reduction profile. "Then, normal distribution of that pattern was utilized to establish seasonal VO-on profile[s] for other seasons with corresponding 2017 VO-off data…. Finally, the mean 2018 seasonal measured VO-off and measured/estimated VO-on difference were utilized to estimate % of voltage reduction."[20] Navigant's methodology relied on AMI-sourced voltage time-series

[18] ComEd, personal communication.
[19] It also comports with Navigant's previous evaluation experience with VO-type programs for other clients.
[20] VoltageDeviationMethod.pptx, provided by ComEd to Navigant on April 9, 2019.

readings comprising the load-weighted means at each interval of the voltages measured at the meters mapped to each VO-enabled feeder. It used a statistical modeling approach, described in the next section, to measure the voltage reductions.

Navigant believes that its voltage reduction estimates are preferable to those provided by ComEd, on both data and methodological grounds. We chose to use load-weighted averages of the customer AMI voltage readings on each feeder in each interval rather than substation-level readings from the SCADA system, per prior agreement with ComEd, because 1) substation-level voltages are expected to be generally higher than the corresponding voltages measured at customers' meters (although this may not be universally true, for example on lines with significant connected distributed generation resources during periods of peak DG generation); and 2) the bulk of VO savings occurs behind customers' meters, which makes the relevant metric the voltage reduction delivered to customers rather than the reduction measured at the substation.[21]

Finally, Navigant believes that ComEd's method for calculating the VO-induced voltage reductions likely overstates the magnitude of the reductions because it doesn't adequately control for potentially confounding factors. ComEd's mean-difference approach does allow for seasonal differences, but it can't adjust for inter-year differences in seasonal weather conditions. Nor does it address time-of-day, day-of-week, month of year, or weather effects of durations shorter than seasonal.

Regarding the choice of which set of 2018 energy baselines to use, Navigant again considered the data on which each was based, and the methodology used to predict the counterfactual non-VO load profiles on each VO-enabled feeder. ComEd's energy usage baselines, like Navigant's, were based on feeder-level, 30-minute interval power (MW) readings collected by each VO-enabled substation's SCADA system. ComEd applied the MATLAB default outlier scrub that removes observations that fall more than three scaled median absolute deviations away from the median.[22] ComEd did not remove interpolated values. For feeders lacking MW data, ComEd substituted proxy values calculated from interval ampere readings and assumed, constant power-factor values.

Navigant used the statistical modeling approach described in the next section to predict its 2018 energy baselines. As previously noted, Navigant applied a rigorous data-cleaning algorithm, including removal of interpolated values, and chose not to substitute amps-based proxies for the missing MW readings due to concerns over the likelihood of the measurement errors introduced by using assumed, constant power factors.

In choosing between the two energy baseline options, Navigant believes that its estimates are preferable to those provided by ComEd, on both data and methodological grounds. We are not confident that ComEd's data cleaning approach was adequate and believe the risk of introducing substantial measurement errors by substituting amps-based proxies for missing power data outweighs the loss of precision from dropping erroneous observations. Nor are we comfortable that ComEd's method adequately controlled for potential confounding factors.

For all of these reasons, Navigant selected the "Ameren CVRf V1" method to produce the verified energy savings for the CY2018 VO Program.

The energy savings results of the three alternative CVRf-based methods are shown in Table 7-2.

[21] We acknowledge ComEd's concern that some customer meters might be mapped incorrectly. However, we do not believe this to be a sufficient reason to abandon the data: given the sheer number of customers on each feeder, and the robustness of the mean as a measure of the central tendency of a distribution, we think it unlikely that a few mismapped meters would materially affect the mean values that ComEd provided.

[22] ComEd, personal communication.

Table 7-2. Alternative CVRf-Based CY2018 VO Energy Savings Estimates

CVRf Method	CVRf	Energy Savings (kWh)	Energy Savings Upper 90% CI (kWh)	Energy Savings Lower 90% CI (kWh)
Ameren V2	0.61	50,335,712	50,601,845	50,069,579
Ameren V1	0.80	66,014,049	66,363,076	65,665,022
ComEd*	0.80	94,072,591	NA	NA

* 90% confidence bounds are not provided for the ComEd CVRf-based savings estimate.
Source: ComEd tracking data and Navigant analysis.

The uncertainty associated with each estimate, as embodied in their respective 90 percent confidence intervals, was obtained from the bootstrapping estimation methodology Navigant used to produce the Ameren V1 and V2 estimates of the CY2018 energy baseline and VO voltage reductions.[23] Note that the confidence intervals understate the true uncertainties associated with these estimates because the CVRf values were treated parametrically rather than as sample statistics with associated uncertainties of their own. Since the feeder-level energy baselines and voltage reductions supplied by ComEd were treated parametrically rather than statistically modeled, no confidence bounds were calculated for this energy savings estimate.

8. Appendix 2. Description of Navigant's Modeling Approach

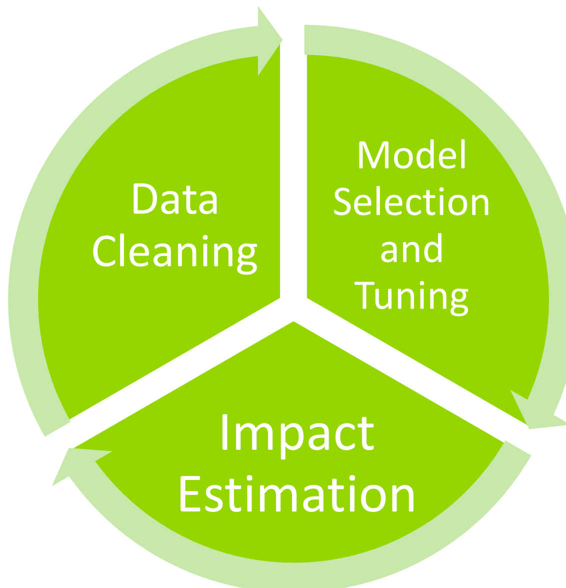
As indicated above, Navigant employed a statistical modeling approach to estimate the baseline energy usage and mean voltage reduction achieved on each VO-enabled feeder in CY2018. This section provides an overview of this methodology. As previously noted, due to a lack of sufficient on/off test data Navigant did not use this method for directly measuring the verified energy savings for the CY2018 VO feeders reported in Sections 3 and 4 of this report.

The overarching logic of Navigant's model uses all of the available empirical feeder-level data (30-minute interval power (MW) readings from the SCADA system, 30-minute interval average voltage readings from the AMI meters connected to each feeder, and static feeder characteristics) to develop statistical models to represent each CY2018 VO feeder's annual load and voltage profiles.[24] The fitted feeder-level models are then used to simulate annual voltage and load profiles under three scenarios: pre-feeder conditioning (FC), post-FC/pre-VO, and VO-enabled. The FC impacts are measured by comparing each feeder's post-FC/pre-VO annualized profile to the corresponding pre-FC baseline profile. The VO impacts, in turn, are measured by comparing the annualized post-VO/VO-on profiles to the corresponding post-VO/VO-off profiles. The vertical distance between each pair of simulated load profiles, summed over the time intervals in CY2018, yields the estimated energy savings. The load-weighted mean of the vertical distances between each pair of simulated voltage profiles gives the estimated voltage reduction. A key feature of this approach is that, in effect, each VO-enabled feeder serves as its own control.[25]

Navigant employed an iterative approach to its modeling approach, starting with data cleaning, proceeding to model selection and tuning, then to impact estimation, as illustrated in Figure 8-1. This iterative process was repeated multiple times: the modeled results were analyzed for plausibility, and the results used to refine the data cleaning and model tuning steps.

[23] See Section 8 for a description.
[24] ComEd provided Navigant with interval power and voltage data for each VO-enabled feeder from January 2017 through February 2019, as well as an extensive table of static feeder characteristics.
[25] I.e., the VO effects are measured by comparing each feeder's voltage and power demand profile during VO-enabled and VO-disabled periods; differencing the profiles ensures that any non-modeled inter-feeder heterogeneity is differenced out of the estimated impacts.

Figure 8-1. Overview of Methodology



An in-depth and granular data assessment and cleaning methodology was the cornerstone of Navigant's analysis, and recurred repeatedly while we fitted, tuned, and assessed the quality of the models. Clean data fed into model selection and tuning, where the load and voltage profiles on each feeder was modeled. After fitting each model and assessing its quality, the three annualized load and voltage profiles were calculated at 30-minute intervals for all of CY2018. Differencing these profiles yielded the impact of VO without feeder conditioning, feeder conditioning without VO, and both VO and feeder conditioning. Any results which Navigant deemed unrealistic were analyzed in-depth and tied into the subsequent round of data cleaning.

A discussion of each of these modeling steps is provided in the following sections.

8.1 Data Cleaning

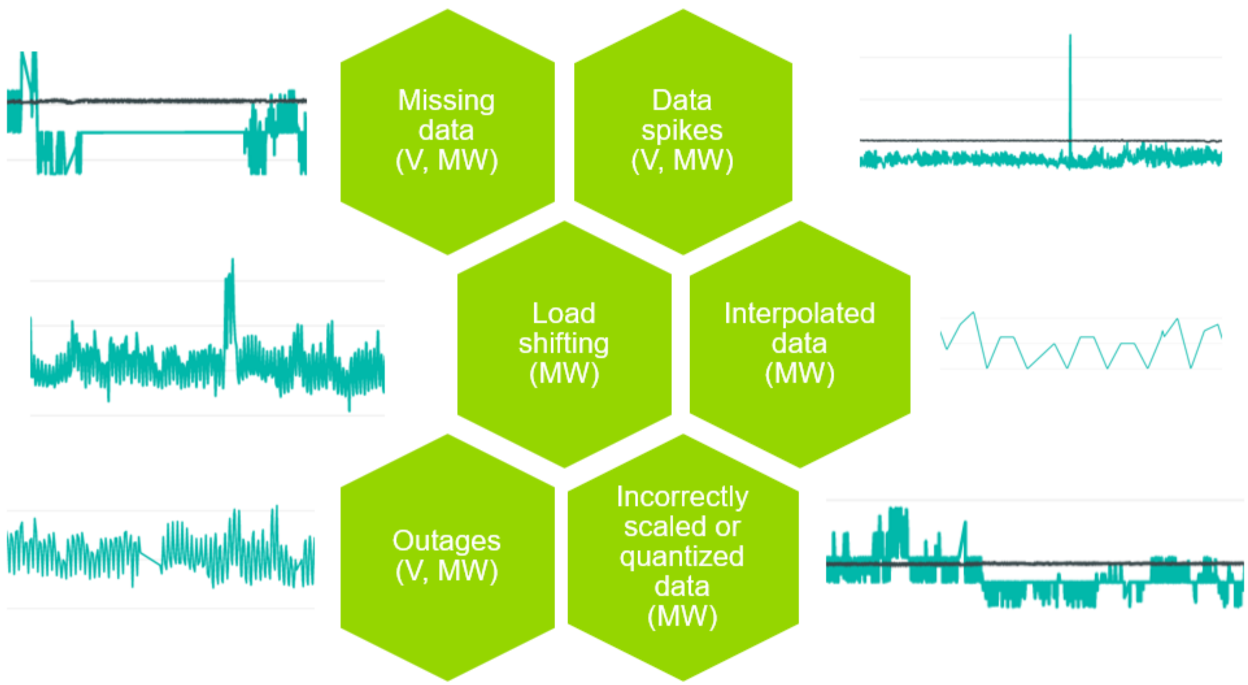
The data Navigant used as the basis of its analysis consisted of four broad types:

- Substation and bus-level data
- Feeder-level data at 30-minute intervals, including time-series values for power, current, voltage, and reactive power readings from the beginning of 2017
- Feeder characteristic data, such as conductor length, rated load, load factor, feeder conditioning data, regional, and customer-type load composition data
- Weather data at 30-minute intervals, which was downloaded from the National Oceanic and Atmospheric Administration's FTP site for each substation zip code

Navigant encountered several types of data issues, including (see Figure 8-2):

- **Missing data:** a large portion of the interval power data had missing values or had been marked as bad quality by the SCADA system. At ComEd's suggestion Navigant investigated the possibility of substituting proxy values for the missing power data using amperage interval

Figure 8-2. Main Data Issues



readings and an assumed power factor but concluded that 30-minute interval real power values cannot be reliably estimated from interval amperage readings without also having measured interval observations on power factor, reactive power, or apparent power.

- **Load or voltage spikes:** spikes are inexplicable deviations from expected load or voltage that typically only last for a single or small handful of adjacent timestamps. Positive spikes were excluded using prescribed cutoffs of greater than 5 standard deviations from the mean value. All negative values were excluded. Navigant excluded some additional spikes that were non-negative and less than five standard deviations from the mean when they appeared to be causing implausible model results.
- **Load shifting:** apparent load shifting among feeders was an added complexity. Though Navigant believes these data are correct, our statistical models are unable to accommodate them unless ComEd provided time-stamped event logs, which proved infeasible in most cases. Power data was compared across substation and was excluded from the model if it was determined that load-shifting had taken place.
- **Interpolated data:** much of the feeder-level load data had to be dropped due to interpolation, the phenomenon whereby on 4-8 actual reads were taken per day and stored by the SCADA system, with the rest of the 30-minute data consisting of linear interpolations between pairs of actual measurements. Such data is not suitable for impact measurement, since the interpolated power readings would be unrelated to actual weather and other model covariates and was removed.
- **Outages:** a file containing outages was obtained from ComEd and was used to exclude readings which occurred during known system outages.
- **Incorrect scaling or quantization:** Upon visual inspection, some of the feeder-level power data had extreme variance that lasted only for discrete time periods or was rounded to the nearest fourth or tenth of a megawatt. Time periods on a few feeders containing these issues were removed from the analysis.

The impacts of these data cleaning steps on the final sample size available for the analysis are shown in Table 8-1.

Table 8-1. Data Cleaning Impacts on Sample Size

Description	MW Observations		Voltage Observations	
	(#)	(%)	(#)	(%)
Initial Count	7,752,025	100.00%	7,752,025	100.00%
Removed: outage	819	0.01%	0	0.00%
Removed: outlier	316,087	4.08%	1,889	0.02%
Removed: missing	1,939,994	25.03%	182,772	2.36%
Removed: interpolated	2,523,174	32.55%	0	0.00%
Final Count	2,971,951	38.34%	7,567,364	97.62%

Source: ComEd tracking data and Navigant team analysis.

8.2 Model Selection and Tuning

The goal of model selection and tuning is to generate models which can be used to simulate three counterfactual states during CY2018:

VO-enabled
- What would the feeder load or voltage have been during CY2018 if VO had enabled for the entire year?

Feeder conditioned
- What would the load or voltage have been during CY2018 if feeder conditioning had been completed prior to the start of 2018?

VO and feeder conditioned
- What would load or voltage have been during 2018 if VO had been enabled for the entire year *and* FC had been completed prior to the start of 2018?

Navigant considered several approaches to modeling these counterfactual simulated states, given the available data, including structural linear regression models, simple CVR factor-based approaches, and supervised machine-learning approaches. Ultimately, we chose the machine-learning methods because of their superior ability to consider multiple, complex model specifications, including lagged terms and interaction terms, make accurate predictions, while avoiding overfitting. A Random-Forest approach was used to estimate the voltage models, and a Gradient-Boosted Decision Trees approach was used to estimate the load models.

The general specification for these models is shown in Equation 1.

Equation 8-1. Voltage Optimization Model

$$X_{i,t} = f(load\text{-}shape,\ weather,\ feeder\ characteristics,\ VO\ status, FC\ status, Events, \Delta LRs)$$

where:

- i and t index the feeder and time interval, respectively;
- $X_{i,t}$ is the interval load in MW units or voltage measured on feeder i during time interval t. Interval power is measured at feeder head-ends at the substation, while voltage is measured as the load-weighted average of interval voltage readings from the AMI meters of the connected customer service points on each feeder;
- $load\text{-}shape$ refers to the model elements included to capture underlying time-varying patterns observed in the data that repeat at daily, weekly, seasonal and annual periods, including hour of day, week of year, day of year, weekend, elapsed days since Jan 1, 2017, and holidays;
- $weather$ refers to the model elements included to capture weather-related variations, including heating and cooling degree-days, normalized heat build-up, and lagged values of these features;
- $feeder\ characteristics$ refers to various static (or infrequently-changing) characteristics of each VO-enabled feeder, such as average or typical load shares (by customer type), conductor miles, geographic location, load factor, 2017 annual peak, rated load, rated primary voltage, and number of capacitor banks and regulators;
- $VO\ status$ refers to whether the VO controls are enabled or disabled during time interval t;
- $Events$ comprises a set of binary flags indicating whether a load-shifting event falls within time interval t;
- $FC\ status$ refers to whether time interval t falls before, during, or after the feeder-conditioning phase; and
- ΔLR comprises a set of binary flags indicating when a given load-regime change has occurred.

To tune the models, Navigant employed bootstrapped cross-validation, a technique in which a series of k models are fit to different bootstrapped resamples drawn with replacement from a subset of the data set. For each bootstrap resample, a randomly-selected 20 percent of the data was held back to permit out-of-sample prediction testing of the model. Once the models were fitted, predictions were made and assessed using the hold-out validation samples, by comparing each of the k model predictions produced to the hold-out sample data. The size and distribution of these cross-validation root mean-square errors (RMSE) allowed us to assess the model's quality. Besides examining the overall RMSE of each out-of-sample prediction, we also examined the RMSE during VO-enabled periods.[26]

Navigant gave extra weight to the RMSE during VO-enabled periods, since most of the feeders had late 2018 go-live dates and, therefore, the amount of VO-enabled data was small. To achieve suitable VO-periods RMSE values, Navigant replicated the VO-enabled data that was fed into the sample model during the estimation phase to ensure the model fit well during these periods.

8.3 Impact Estimation

After each model was fitted to the bootstrap resamples drawn from the training data set, the counterfactual simulations were produced. Simulations of CY2018 load and voltage profiles at every 30-minute interval were made for each scenario. Using these three predictions, the following difference profiles were calculated at level for both load and voltage:

$$\Delta FC = base\ - FC$$
$$\Delta VO = FC\ - VO\&FC$$

[26] For its final model runs, Navigant set k equal to 20.

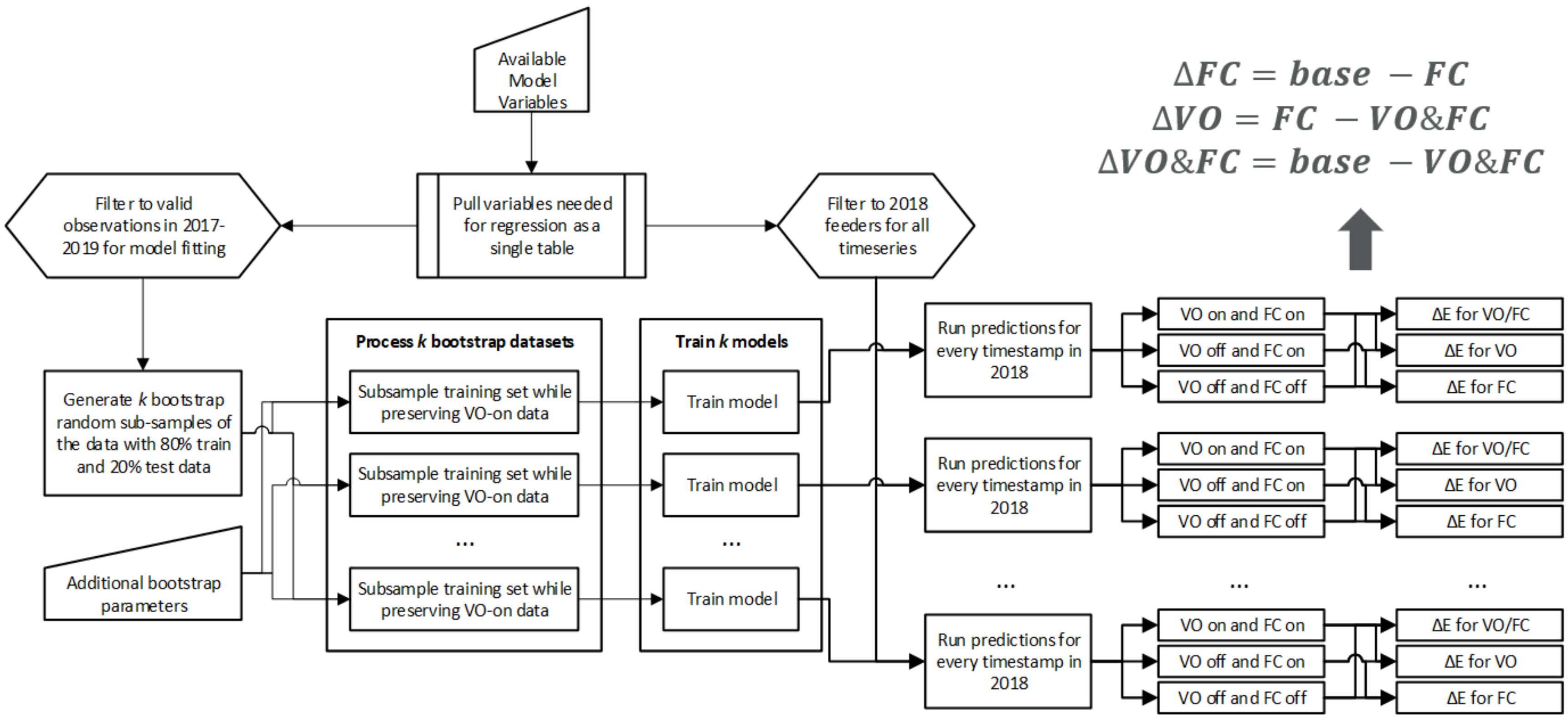
$$\Delta VO\&FC = base - VO\&FC$$

Afterward, each of these were aggregated to generate distributions of savings and percent savings for all VO feeders and substations during 2018. The methodology to calculate energy savings takes the average difference for each metric at the feeder and cross-validation set level. For the load models, the feeder-level averages are multiplied by 8,760 to generate annualized MWh savings. To generate average percent savings, the percent savings was calculated at each timestamp and then aggregated across intervals using a weighted mean with the baseline predicted loads as weights.

The uncertainty bounds were generated empirically using the distributions of outputs from the cross-validation splits.

Figure 8-3 provides an overview of Navigant's analytical approach.

Figure 8-3. Modeling Logic Flowchart



Note: VO impacts and their 90% confidence bounds are estimated as the mean and the 5th and 95th percentiles, respectively, of the bootstrapped results shown in the righthand column of the diagram.

9. Appendix 3. Detailed Results

Table 9-1 below shows the substations and feeders on which VO was installed, commissioned, and successfully launched in CY2018. Note that only four substations had go-live dates prior to November 30, 2018. And of these, as shown in Figure 6-2 above, relatively few VO-on observations were generated.

Table 9-1. CY2018 VO Substations and Feeders

Substation	Substation Name	# of VO-Enabled Feeders	Sample?	Initial Ex Ante Energy Savings (MWh)	Final Ex Ante Energy Savings (MWh)	Planned Go-Live Month	Commissioning Start Date	Go-Live Date
TSS48	Highland Park	9	Added	3,387	3,387	Aug	8/13/2018	8/13/2018
TDC505	Oak Park	15	Original	8,499	8,499	Aug	10/16/2018	10/16/2018
TSS134	LaGrange	18	Original	13,204	13,204	Sep	9/28/2018	10/16/2018
TSS55	Hegwisch	12	Added	3,132	3,132	Aug	10/16/2018	10/16/2018
TSS118	Wallace	14	Original	9,186	9,186	Aug	11/30/2018	11/30/2018
DCD351	Hodgkins	1	No	1560	780	Oct	11/30/2018	12/7/2018
DCD69	Broadview	1	Added	693	693	Oct	11/30/2018	12/7/2018
DCW29	Winfield Twp	2	No	1230	1230	Nov	11/30/2018	12/7/2018
DCW346	Addison	1	Added	2,011	2,011	Sep	11/30/2018	12/7/2018
DCD62	Hillside	2	Added	1,348	1,348	Oct	12/31/2018	12/13/2018
DCC80	Glenview	1	Added	555	555	Oct	12/14/2018	12/14/2018
DCD114	Stickney	1	Added	726	726	Oct	12/14/2018	12/14/2018
DCD242	Bridgeview	1	Added	585	585	Oct	12/14/2018	12/14/2018
DCD46	North Lake	1	No	1568	784	Nov	12/14/2018	12/14/2018
DCE59	Algonquin	1	No	924	924	Oct	12/14/2018	12/14/2018
DCW202	Elgin	1	No	783	783	Oct	12/14/2018	12/14/2018
DCW30	Wheaton	2	Added	3,572	3,572	Oct	11/30/2018	12/14/2018
DCW354	York Center	1	Added	831	831	Aug	12/14/2018	12/14/2018
DCW71	Aurora	2	Added	1,764	1,764	Oct	12/14/2018	12/14/2018
TSS78	Franklin Park	18	Original	5,021	5,021	Sep	11/30/2018	12/14/2018
DCD63	Schiller Park	3	No	2043	2043	Nov	12/21/2018	12/21/2018
DCW216	Dundee/Meadowdale	1	Added	805	805	Oct	12/21/2018	12/21/2018
TDC414	Roberts Road	11	No	7451	7451	Dec	12/21/2018	12/21/2018
TDC457	Park Forest	8	No	4496	4496	Dec	12/21/2018	12/21/2018
TDC470	Orland Park	8	Original	6030	6030	Nov	12/21/2018	12/21/2018
DCS48	Otter Creek	2	No	780	780	Dec	12/31/2018	12/31/2018
DCD16	Lyons Twp	1	No	887	887	Dec	12/31/2018	12/31/2018
DCD80	Broadview	1	No	847	847	Dec	12/31/2018	12/31/2018
DCE28	Algonquin	3	No	1861	1861	Dec	12/31/2018	12/31/2018
DCE72	Fox River Grove	1	No	668	668	Oct	12/31/2018	12/31/2018
DCG99	Palos Heights	1	No	767	767	Dec	12/31/2018	12/31/2018
DCW236	Roselle	3	Added	3,732	3,732	Sep	12/31/2018	12/31/2018
DCW28	Sunset Park	1	No	679	679	Nov	12/31/2018	12/31/2018
DCW31	Milton TWN	2	Added	1,681	1,681	Aug	12/31/2018	12/31/2018
DCW343	Elmhurst	1	Added	768	768	Aug	12/31/2018	12/31/2018
DCW348	Bensenville	1	No	677	677	Nov	12/31/2018	12/31/2018
DCW51	Randall Road	1	Added	2,299	1,150	Oct	12/31/2018	12/31/2018
TDC549	Berkley	11	No	5044	5044	Nov	12/31/2018	12/31/2018
Total	**38**	**164**	**21**	**102,094**	**99,381**			

Source: ComEd tracking data and Navigant team analysis.

Figure 9-1 illustrates the scope of the SCADA data interpolation problem described above. Each row represents one CY2018 VO feeder, and the time dimension is measured along the horizontal axis. Since 30-minute interval data should produce 48 unique observations per day, the light-green colored areas show where the number of actual readings logged was in the 4-8 per day range. Gray gaps indicate missing data.

Figure 9-1. SCADA Data Interpolations Heat Map

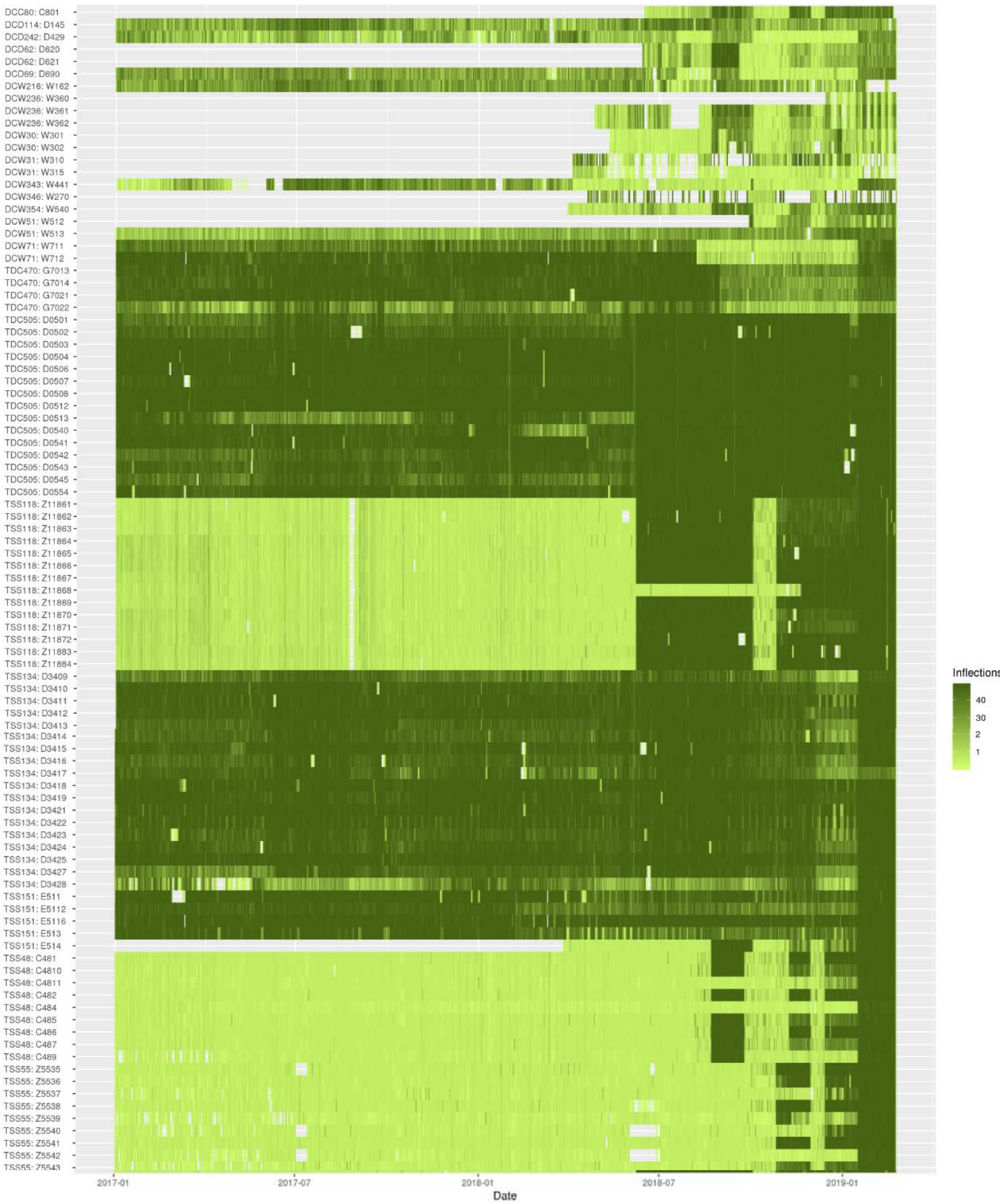
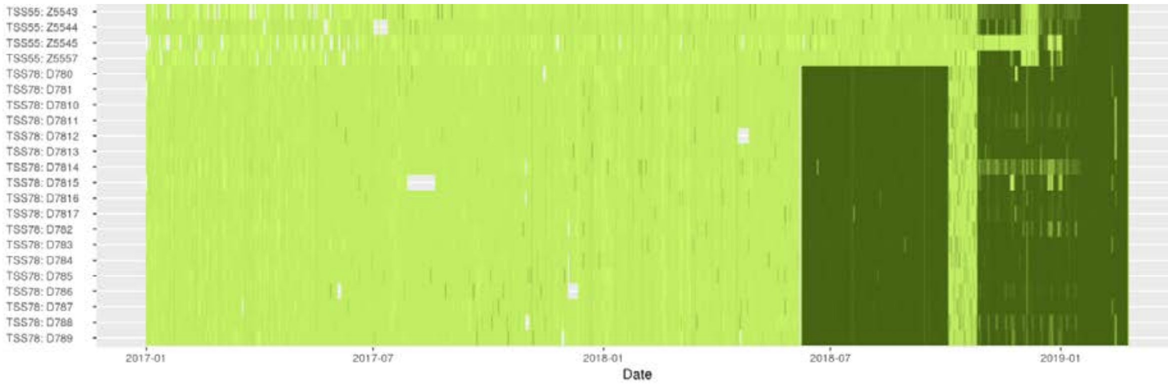


Figure 8-1. SCADA Data Interpolations Heat Map (Continued)



Source: ComEd tracking data and Navigant team analysis.

10. Appendix 4. Impact Analysis Detail

Table 10-1 presents the verified CY2018 VO Program impacts by feeder. The "Ameren 0.8 CVRf" method was used to produce these values.[27]

Table 10-1. CY2018 Verified VO Energy Savings and Voltage Reductions by Feeder

Substation	Feeder	CVRf	Savings Point Estimate (kWh)	Savings Upper 90% CI (kWh)	Savings Lower 90% CI (kWh)	Voltage Reduction (%)	Baseline Point Estimate (MWh)
DCC80	C801	0.80	252,696	265,074	240,319	3.42	9,229.79136
DCD114	D145	0.80	111,741	119,794	103,689	2.61	5,354.15164
DCD16	D164	0.80	683,097	712,318	653,876	3.26	26,162.40861
DCD242	D429	0.80	8,620	10,833	6,408	0.72	1,491.04697
DCD351	D5112	0.80	196,030	204,932	187,129	3.55	6,896.54265
DCD46	D4601	0.80	283,316	307,499	259,133	3.37	10,522.69628
DCD62	D620	0.80	522,609	540,606	504,613	4.11	15,903.50800
DCD62	D621	0.80	495,242	510,329	480,155	2.97	20,830.90415
DCD63	D631	0.80	225,810	239,876	211,744	3.36	8,411.29164
DCD63	D632	0.80	216,368	238,724	194,012	3.10	8,733.83421
DCD63	D633	0.80	169,564	185,651	153,476	3.06	6,928.54738
DCD69	D690	0.80	71,780	76,992	66,568	1.42	6,317.67703
DCD80	D8100	0.80	243,547	251,779	235,315	3.41	8,923.03906
DCE28	E285	0.80	499,640	528,316	470,964	4.01	15,569.55682
DCE28	E286	0.80	215,520	242,631	188,410	3.53	7,636.31840
DCE28	E287	0.80	391,707	416,608	366,806	3.62	13,522.90836
DCE59	E595	0.80	771,414	804,852	737,976	3.78	25,543.26302
DCE72	E725	0.80	204,951	211,149	198,754	3.27	7,845.02401

[27] The key difference between the "Ameren 0.8 CVRf" method and the "ComEd 0.8 CVRf" method is that the former uses Navigant's modeled voltage reductions, which relied on AMI-sourced voltage data rather than ComEd's voltage reductions, which were calculated as the gross differences between the pre- and post-install voltage means measured at the substation. See Table 7-1.

Substation	Feeder	CVRf	Savings Point Estimate (kWh)	Savings Upper 90% CI (kWh)	Savings Lower 90% CI (kWh)	Voltage Reduction (%)	Baseline Point Estimate (MWh)
DCG99	G995	0.80	733,072	816,188	649,956	3.91	23,431.35049
DCS48	S485	0.80	419,848	437,929	401,768	3.72	14,094.70405
DCS48	S486	0.80	162,308	209,248	115,367	3.65	5,551.02594
DCW202	W022	0.80	157,792	164,984	150,600	2.81	7,016.97485
DCW216	W162	0.80	145,960	154,376	137,543	3.08	5,916.31430
DCW236	W360	0.80	201,478	218,439	184,517	3.02	8,337.31105
DCW236	W361	0.80	591,232	604,855	577,610	3.35	22,029.69171
DCW236	W362	0.80	495,043	507,515	482,570	3.50	17,695.81166
DCW28	W280	0.80	596,784	623,040	570,528	3.55	21,017.00503
DCW29	W290	0.80	335,400	396,619	274,182	3.34	12,563.86307
DCW29	W291	0.80	422,579	440,978	404,180	3.24	16,281.82580
DCW30	W301	0.80	471,207	486,325	456,089	3.25	18,120.84791
DCW30	W302	0.80	578,437	591,059	565,816	3.74	19,316.63470
DCW31	W310	0.80	184,707	197,818	171,596	1.93	11,944.52368
DCW31	W315	0.80	101,598	134,871	68,325	2.15	5,911.36938
DCW343	W441	0.80	148,794	155,515	142,073	3.17	5,875.28277
DCW346	W270	0.80	514,022	541,118	486,926	3.09	20,815.01252
DCW348	W484	0.80	649,321	669,590	629,052	3.41	23,818.18109
DCW354	W540	0.80	717,979	749,567	686,390	3.52	25,483.10022
DCW51	W512	0.80	763,055	782,328	743,783	3.74	25,531.49369
DCW71	W711	0.80	257,813	262,975	252,651	3.59	8,982.63399
DCW71	W712	0.80	313,179	318,864	307,494	3.77	10,396.93571
TDC414	G140	0.80	681,470	693,749	669,192	3.25	26,170.95351
TDC414	G141	0.80	473,088	482,991	463,185	3.34	17,712.45168
TDC414	G142	0.80	401,022	413,971	388,072	3.57	14,030.52141
TDC414	G143	0.80	345,538	360,831	330,245	3.46	12,497.41245
TDC414	G144	0.80	558,844	576,060	541,629	3.21	21,733.75682
TDC414	G145	0.80	651,755	666,365	637,146	3.30	24,686.99570
TDC414	G146	0.80	435,874	446,636	425,111	3.28	16,614.08953
TDC414	G147	0.80	563,500	577,896	549,105	3.10	22,686.43343
TDC414	G148	0.80	595,264	603,247	587,282	3.42	21,768.89741
TDC414	G1481	0.80	363,358	377,817	348,898	3.01	15,069.02726
TDC414	G149	0.80	474,259	486,413	462,105	3.38	17,536.35495
TDC457	F571	0.80	130,288	145,533	115,043	2.07	7,879.82999
TDC457	F572	0.80	400,290	431,135	369,446	2.13	23,498.46344
TDC457	F573	0.80	449,010	475,709	422,312	2.49	22,519.31261
TDC457	F574	0.80	378,919	405,145	352,692	2.36	20,104.92994
TDC457	F575	0.80	398,977	419,458	378,495	2.65	18,797.34937
TDC457	F576	0.80	109,757	133,007	86,507	0.79	17,457.67108

Substation	Feeder	CVRf	Savings Point Estimate (kWh)	Savings Upper 90% CI (kWh)	Savings Lower 90% CI (kWh)	Voltage Reduction (%)	Baseline Point Estimate (MWh)
TDC457	F577	0.80	730,777	774,868	686,686	3.03	30,189.80881
TDC457	F578	0.80	272,022	291,579	252,464	2.83	12,015.72797
TDC470	G7011	0.80	382,770	433,406	332,134	3.24	14,779.31193
TDC470	G7012	0.80	666,793	708,707	624,879	3.46	24,080.62550
TDC470	G7013	0.80	605,349	616,122	594,575	3.16	23,912.93327
TDC470	G7014	0.80	561,982	578,672	545,292	3.15	22,304.76106
TDC470	G7021	0.80	641,906	661,527	622,285	3.35	23,918.73170
TDC470	G7022	0.80	181,648	188,609	174,686	3.10	7,315.78077
TDC470	G7023	0.80	440,603	473,669	407,537	3.14	17,548.49926
TDC470	G7024	0.80	391,006	449,897	332,115	3.49	13,991.18180
TDC505	D0501	0.80	403,547	409,310	397,785	3.10	16,267.32273
TDC505	D0502	0.80	524,831	532,077	517,585	3.09	21,260.27368
TDC505	D0503	0.80	710,892	719,396	702,387	3.25	27,336.24845
TDC505	D0504	0.80	741,259	750,014	732,504	3.30	28,113.76630
TDC505	D0506	0.80	445,118	458,431	431,805	2.24	24,820.04075
TDC505	D0507	0.80	536,061	544,018	528,105	2.98	22,490.48199
TDC505	D0508	0.80	688,909	696,445	681,373	3.24	26,610.96984
TDC505	D0512	0.80	583,412	593,380	573,445	3.29	22,199.20994
TDC505	D0513	0.80	72,947	79,037	66,857	3.22	2,827.51074
TDC505	D0540	0.80	388,491	396,767	380,214	3.42	14,216.62880
TDC505	D0541	0.80	564,811	574,648	554,975	3.13	22,590.70429
TDC505	D0542	0.80	251,419	263,240	239,597	3.03	10,382.57211
TDC505	D0543	0.80	423,042	430,414	415,671	3.27	16,184.57539
TDC505	D0545	0.80	233,312	237,663	228,961	3.58	8,141.40139
TDC505	D0554	0.80	388,050	405,477	370,624	2.96	16,414.78980
TDC549	D4901	0.80	358,522	365,757	351,287	2.44	18,347.90435
TDC549	D4902	0.80	375,883	391,963	359,803	2.65	17,748.28477
TDC549	D4903	0.80	218,817	260,336	177,299	0.86	31,816.48267
TDC549	D4904	0.80	647,381	688,598	606,164	3.17	25,552.79274
TDC549	D4905	0.80	198,183	208,889	187,478	2.80	8,860.33206
TDC549	D4907	0.80	315,518	349,841	281,194	2.15	18,384.82048
TDC549	D4908	0.80	183,444	215,727	151,162	1.36	16,829.56353
TDC549	D4909	0.80	274,123	288,732	259,514	2.22	15,404.33722
TDC549	D4910	0.80	397,094	408,708	385,480	2.21	22,478.87957
TDC549	D4911	0.80	406,063	428,598	383,529	2.38	21,349.84117
TDC549	D4912	0.80	183,788	203,253	164,323	1.41	16,301.49723
TSS118	Z11861	0.80	409,057	426,726	391,388	2.08	24,579.78374
TSS118	Z11862	0.80	377,925	394,670	361,179	1.83	25,852.43057
TSS118	Z11863	0.80	443,647	461,723	425,570	2.20	25,176.26042

Substation	Feeder	CVRf	Savings Point Estimate (kWh)	Savings Upper 90% CI (kWh)	Savings Lower 90% CI (kWh)	Voltage Reduction (%)	Baseline Point Estimate (MWh)
TSS118	Z11864	0.80	350,813	368,694	332,932	2.22	19,783.65991
TSS118	Z11865	0.80	500,798	521,367	480,230	2.10	29,789.37347
TSS118	Z11866	0.80	363,274	376,670	349,879	2.06	22,002.29173
TSS118	Z11867	0.80	367,416	383,920	350,911	1.97	23,321.11880
TSS118	Z11868	0.80	480,206	497,174	463,239	2.12	28,326.76407
TSS118	Z11869	0.80	469,925	494,934	444,916	2.13	27,612.06728
TSS118	Z11870	0.80	346,334	357,378	335,289	2.09	20,690.23716
TSS118	Z11871	0.80	432,735	441,011	424,459	2.17	24,924.91099
TSS118	Z11872	0.80	391,218	406,642	375,794	1.86	26,315.43707
TSS118	Z11883	0.80	287,482	307,257	267,708	1.70	21,079.01569
TSS118	Z11884	0.80	508,612	529,671	487,553	2.24	28,431.18240
TSS134	D3409	0.80	261,087	267,339	254,834	3.19	10,239.83015
TSS134	D3410	0.80	583,928	591,794	576,061	3.22	22,650.51333
TSS134	D3411	0.80	517,502	522,411	512,593	3.30	19,592.43045
TSS134	D3412	0.80	453,652	460,455	446,848	2.95	19,218.30377
TSS134	D3413	0.80	558,885	564,353	553,416	3.29	21,212.93161
TSS134	D3414	0.80	531,500	538,183	524,817	3.32	19,995.11799
TSS134	D3415	0.80	572,944	583,500	562,388	3.28	21,843.04815
TSS134	D3416	0.80	456,573	462,055	451,091	3.19	17,908.45435
TSS134	D3417	0.80	517,805	527,694	507,916	3.37	19,196.56371
TSS134	D3418	0.80	560,662	576,176	545,148	2.82	24,894.67709
TSS134	D3419	0.80	604,227	609,012	599,442	3.34	22,585.94410
TSS134	D3421	0.80	517,010	526,180	507,839	3.21	20,104.62393
TSS134	D3422	0.80	471,902	491,662	452,142	2.92	20,227.40887
TSS134	D3423	0.80	439,499	446,928	432,070	2.76	19,940.71403
TSS134	D3424	0.80	407,606	412,421	402,791	2.90	17,571.73441
TSS134	D3425	0.80	449,677	465,970	433,384	2.21	25,477.29005
TSS134	D3427	0.80	438,390	444,120	432,659	2.60	21,100.86105
TSS134	D3428	0.80	219,947	289,776	150,119	3.21	8,563.02707
TSS48	C481	0.80	679,970	689,460	670,480	2.38	35,644.25239
TSS48	C4810	0.80	605,287	614,581	595,994	3.43	22,042.80470
TSS48	C4811	0.80	88,459	90,989	85,929	2.18	5,064.16668
TSS48	C482	0.80	547,369	556,543	538,195	3.48	19,655.04710
TSS48	C484	0.80	36,686	39,059	34,314	2.94	1,560.17981
TSS48	C485	0.80	487,877	495,347	480,406	3.23	18,894.31282
TSS48	C486	0.80	433,459	440,592	426,326	3.35	16,169.11468
TSS48	C487	0.80	439,939	446,191	433,687	3.26	16,893.98531
TSS48	C489	0.80	49,551	51,701	47,402	2.32	2,671.23252
TSS55	Z5535	0.80	607,702	627,444	587,960	2.88	26,379.08085

Substation	Feeder	CVRf	Savings Point Estimate (kWh)	Savings Upper 90% CI (kWh)	Savings Lower 90% CI (kWh)	Voltage Reduction (%)	Baseline Point Estimate (MWh)
TSS55	Z5536	0.80	195,351	201,268	189,435	3.14	7,770.80171
TSS55	Z5537	0.80	513,481	543,811	483,150	2.90	22,158.87198
TSS55	Z5538	0.80	538,285	555,954	520,615	2.97	22,631.03613
TSS55	Z5539	0.80	102,204	105,524	98,884	3.22	3,967.28671
TSS55	Z5540	0.80	582,769	604,464	561,075	3.07	23,727.14133
TSS55	Z5541	0.80	222,802	236,796	208,807	2.84	9,798.40290
TSS55	Z5542	0.80	54,349	58,302	50,396	2.49	2,724.06795
TSS55	Z5543	0.80	294,301	304,549	284,054	3.08	11,958.84448
TSS55	Z5544	0.80	409,787	422,149	397,425	2.79	18,373.39746
TSS55	Z5545	0.80	60,386	63,288	57,484	3.03	2,487.29725
TSS55	Z5557	0.80	44,858	48,261	41,456	0.83	6,725.82656
TSS78	D780	0.80	603,730	618,231	589,228	2.56	29,463.13768
TSS78	D781	0.80	531,756	549,525	513,986	3.09	21,531.67511
TSS78	D7810	0.80	508,302	521,014	495,591	3.03	20,991.55564
TSS78	D7811	0.80	297,623	306,279	288,966	2.65	14,036.40645
TSS78	D7812	0.80	506,160	521,382	490,938	2.80	22,579.13515
TSS78	D7813	0.80	251,447	267,219	235,676	1.80	17,444.33097
TSS78	D7814	0.80	265,936	275,739	256,132	2.73	12,179.49473
TSS78	D7815	0.80	218,316	225,099	211,532	3.40	8,016.78320
TSS78	D7816	0.80	344,727	351,653	337,801	2.81	15,353.09218
TSS78	D7817	0.80	384,438	391,491	377,386	3.12	15,391.65065
TSS78	D782	0.80	466,496	480,693	452,299	2.67	21,812.19034
TSS78	D783	0.80	453,077	464,168	441,986	3.34	16,943.93477
TSS78	D784	0.80	543,561	564,762	522,359	2.37	28,640.29675
TSS78	D785	0.80	342,713	360,191	325,234	1.98	21,645.80447
TSS78	D786	0.80	331,717	348,240	315,195	2.37	17,530.98180
TSS78	D787	0.80	471,571	488,561	454,581	3.32	17,748.05740
TSS78	D788	0.80	395,277	410,244	380,309	2.53	19,512.54234
TSS78	D789	0.80	483,846	498,417	469,275	2.47	24,504.50799

Source: ComEd tracking data and Navigant team analysis.

Table 10-2 presents the CY2018 VO impacts calculated using the “ComEd 0.8 CVRf” method.

Table 10-2. CY2018 VO Energy Savings and Voltage Reductions by Feeder – ComEd Method

Substation	Feeder	CVRf	ComEd-Supplied Energy Baseline	ComEd-Supplied Voltage Reduction (%)	ComEd Energy Savings
DCC80	C801	0.80	10,426,000	4.45	371,210
DCD114	D145	0.80	18,355,000	5.22	766,002

Substation	Feeder	CVRf	ComEd-Supplied Energy Baseline	ComEd-Supplied Voltage Reduction (%)	ComEd Energy Savings
DCD16	D164	0.80	34,133,000	5.10	1,391,733
DCD242	D429	0.80	7,296,000	6.09	355,450
DCD351	D5112	0.80	30,800,000	4.54	1,117,670
DCD46	D4601	0.80	28,956,000	4.52	1,046,979
DCD62	D620	0.80	21,682,000	4.93	854,843
DCD62	D621	0.80	25,992,000	-0.62	-128,552
DCD63	D631	0.80	20,824,000	4.36	725,758
DCD63	D632	0.80	19,954,000	3.66	584,046
DCD63	D633	0.80	24,751,000	3.89	770,152
DCD69	D690	0.80	20,293,000	4.83	784,048
DCD80	D8100	0.80	30,713,000	3.88	954,457
DCE28	E285	0.80	22,343,000	4.94	883,406
DCE28	E286	0.80	12,330,000	3.34	329,694
DCE28	E287	0.80	18,694,000	5.11	764,226
DCE59	E595	0.80	27,823,000	4.90	1,091,063
DCE72	E725	0.80	29,350,000	4.38	1,027,295
DCG99	G995	0.80	26,029,000	6.58	1,370,616
DCS48	S485	0.80	16,593,000	3.00	398,365
DCS48	S486	0.80	1,985,000	3.00	47,656
DCW202	W022	0.80	6,595,000	2.30	121,546
DCW216	W162	0.80	5,718,000	4.35	199,162
DCW236	W360	0.80	8,052,000	4.33	278,902
DCW236	W361	0.80	25,532,000	4.31	880,405
DCW236	W362	0.80	23,768,000	4.33	823,266
DCW28	W280	0.80	21,718,000	5.77	1,003,204
DCW29	W290	0.80	19,258,000	3.66	563,135
DCW29	W291	0.80	20,363,000	4.82	784,611
DCW30	W301	0.80	22,437,000	3.79	679,733
DCW30	W302	0.80	24,586,000	5.15	1,012,707
DCW31	W310	0.80	12,112,000	1.83	177,213
DCW31	W315	0.80	3,206,000	1.83	46,908
DCW343	W441	0.80	19,850,000	4.21	667,980
DCW346	W270	0.80	22,529,000	5.23	943,244
DCW348	W484	0.80	25,611,000	5.51	1,128,974
DCW354	W540	0.80	31,609,000	5.72	1,446,951
DCW51	W512	0.80	27,668,000	1.01	224,553
DCW71	W711	0.80	27,755,000	4.38	973,046
DCW71	W712	0.80	30,774,000	4.64	1,142,823
TDC414	G140	0.80	33,558,000	3.83	1,028,378

Substation	Feeder	CVRf	ComEd-Supplied Energy Baseline	ComEd-Supplied Voltage Reduction (%)	ComEd Energy Savings
TDC414	G141	0.80	25,335,000	4.27	864,714
TDC414	G142	0.80	13,869,000	4.27	473,366
TDC414	G143	0.80	12,567,000	3.83	385,113
TDC414	G144	0.80	25,428,000	3.83	779,236
TDC414	G145	0.80	32,202,000	3.83	986,824
TDC414	G146	0.80	20,758,000	4.27	708,495
TDC414	G147	0.80	30,481,000	4.27	1,040,353
TDC414	G148	0.80	21,637,000	4.27	738,497
TDC414	G1481	0.80	17,797,000	4.27	607,433
TDC414	G149	0.80	24,726,000	3.83	757,723
TDC457	F571	0.80	8,355,000	1.58	105,855
TDC457	F572	0.80	31,423,000	1.58	398,117
TDC457	F573	0.80	32,117,000	1.58	406,910
TDC457	F574	0.80	28,265,000	1.58	358,106
TDC457	F575	0.80	23,035,000	2.09	384,869
TDC457	F576	0.80	26,037,000	2.09	435,026
TDC457	F577	0.80	35,631,000	2.09	595,323
TDC457	F578	0.80	17,698,000	2.09	295,698
TDC470	G7011	0.80	22,350,000	3.58	639,460
TDC470	G7012	0.80	31,374,000	3.58	897,648
TDC470	G7013	0.80	24,363,000	3.58	697,055
TDC470	G7014	0.80	27,588,000	3.58	789,326
TDC470	G7021	0.80	25,013,000	2.55	509,305
TDC470	G7022	0.80	7,663,000	2.55	156,031
TDC470	G7023	0.80	29,392,000	2.55	598,468
TDC470	G7024	0.80	22,784,000	2.55	463,919
TDC505	D0501	0.80	22,970,000	4.26	781,936
TDC505	D0502	0.80	43,496,000	4.26	1,480,673
TDC505	D0503	0.80	29,494,000	4.26	1,004,023
TDC505	D0504	0.80	34,175,000	4.31	1,177,588
TDC505	D0506	0.80	31,238,000	4.31	1,076,387
TDC505	D0507	0.80	26,432,000	4.31	910,783
TDC505	D0508	0.80	31,303,000	4.30	1,077,274
TDC505	D0512	0.80	35,540,000	4.30	1,223,088
TDC505	D0513	0.80	3,571,000	4.31	123,048
TDC505	D0540	0.80	15,504,000	4.26	527,781
TDC505	D0541	0.80	24,560,000	4.26	836,062
TDC505	D0542	0.80	16,447,000	4.26	559,882
TDC505	D0543	0.80	12,516,000	4.26	426,065

Substation	Feeder	CVRf	ComEd-Supplied Energy Baseline	ComEd-Supplied Voltage Reduction (%)	ComEd Energy Savings
TDC505	D0545	0.80	8,235,000	4.30	283,403
TDC505	D0554	0.80	20,625,000	4.31	710,688
TDC549	D4901	0.80	18,175,000	-0.04	-5,554
TDC549	D4902	0.80	17,723,000	-0.04	-5,416
TDC549	D4903	0.80	31,300,000	-0.04	-9,565
TDC549	D4904	0.80	31,635,000	-0.04	-9,668
TDC549	D4905	0.80	10,710,000	-0.04	-3,273
TDC549	D4907	0.80	25,072,000	0.76	153,260
TDC549	D4908	0.80	19,171,000	0.76	117,188
TDC549	D4909	0.80	18,157,000	0.76	110,990
TDC549	D4910	0.80	26,824,000	0.76	163,970
TDC549	D4911	0.80	20,613,000	0.76	126,003
TDC549	D4912	0.80	20,375,000	0.76	124,548
TSS118	Z11861	0.80	31,891,000	1.47	374,043
TSS118	Z11862	0.80	31,847,000	1.47	373,527
TSS118	Z11863	0.80	25,665,000	1.47	301,020
TSS118	Z11864	0.80	25,154,000	1.42	285,307
TSS118	Z11865	0.80	28,937,000	1.42	328,215
TSS118	Z11866	0.80	22,491,000	1.42	255,102
TSS118	Z11867	0.80	30,107,000	1.43	344,400
TSS118	Z11868	0.80	29,811,000	1.43	341,014
TSS118	Z11869	0.80	31,179,000	1.43	356,663
TSS118	Z11870	0.80	20,668,000	1.43	236,425
TSS118	Z11871	0.80	29,173,000	1.43	333,716
TSS118	Z11872	0.80	29,923,000	1.43	342,295
TSS118	Z11883	0.80	21,175,000	1.47	248,357
TSS118	Z11884	0.80	32,308,000	1.47	378,934
TSS134	D3409	0.80	13,662,000	4.31	471,197
TSS134	D3410	0.80	33,306,000	4.31	1,148,711
TSS134	D3411	0.80	26,485,000	4.31	913,457
TSS134	D3412	0.80	22,996,000	4.31	793,123
TSS134	D3413	0.80	27,777,000	4.31	958,018
TSS134	D3414	0.80	27,675,000	4.31	954,500
TSS134	D3415	0.80	28,841,000	4.33	998,522
TSS134	D3416	0.80	24,612,000	4.33	852,107
TSS134	D3417	0.80	15,313,000	4.33	530,161
TSS134	D3418	0.80	28,161,000	4.31	971,262
TSS134	D3419	0.80	28,434,000	4.31	980,677
TSS134	D3421	0.80	27,120,000	4.33	938,938

Substation	Feeder	CVRf	ComEd-Supplied Energy Baseline	ComEd-Supplied Voltage Reduction (%)	ComEd Energy Savings
TSS134	D3422	0.80	20,243,000	3.40	550,221
TSS134	D3423	0.80	34,983,000	3.40	950,866
TSS134	D3424	0.80	17,424,000	3.40	473,598
TSS134	D3425	0.80	34,169,000	3.40	928,741
TSS134	D3427	0.80	30,901,000	3.40	839,914
TSS134	D3428	0.80	2,771,000	3.40	75,318
TSS48	C481	0.80	35,790,000	1.77	505,851
TSS48	C4810	0.80	25,985,000	3.67	763,417
TSS48	C4811	0.80	5,130,000	1.77	72,507
TSS48	C482	0.80	25,786,000	3.67	757,570
TSS48	C484	0.80	1,436,000	3.67	42,188
TSS48	C485	0.80	27,891,000	3.67	819,413
TSS48	C486	0.80	21,415,000	3.67	629,154
TSS48	C487	0.80	22,977,000	3.67	675,044
TSS48	C489	0.80	3,096,000	1.77	43,758
TSS55	Z5535	0.80	27,104,000	3.57	773,245
TSS55	Z5536	0.80	14,065,000	3.58	403,328
TSS55	Z5537	0.80	22,055,000	3.58	632,449
TSS55	Z5538	0.80	25,789,000	3.58	739,402
TSS55	Z5539	0.80	3,871,000	3.57	110,435
TSS55	Z5540	0.80	21,448,000	3.58	614,940
TSS55	Z5541	0.80	20,162,000	3.58	576,988
TSS55	Z5542	0.80	3,327,000	3.58	95,389
TSS55	Z5543	0.80	11,484,000	3.57	328,277
TSS55	Z5544	0.80	22,752,000	3.57	650,380
TSS55	Z5545	0.80	3,087,000	3.57	88,068
TSS55	Z5557	0.80	7,321,000	3.57	209,275
TSS78	D780	0.80	26,679,000	2.82	602,390
TSS78	D781	0.80	20,517,000	2.82	463,257
TSS78	D7810	0.80	26,024,000	2.39	497,745
TSS78	D7811	0.80	18,846,000	2.39	360,456
TSS78	D7812	0.80	30,233,000	2.39	578,248
TSS78	D7813	0.80	26,823,000	2.39	513,027
TSS78	D7814	0.80	16,143,000	2.39	308,757
TSS78	D7815	0.80	8,233,000	2.82	185,895
TSS78	D7816	0.80	18,312,000	2.39	350,243
TSS78	D7817	0.80	16,955,000	2.41	326,567
TSS78	D782	0.80	22,186,000	2.41	427,320
TSS78	D783	0.80	20,993,000	2.82	474,005

Substation	Feeder	CVRf	ComEd-Supplied Energy Baseline	ComEd-Supplied Voltage Reduction (%)	ComEd Energy Savings
TSS78	D784	0.80	31,681,000	2.41	610,201
TSS78	D785	0.80	24,315,000	2.41	468,326
TSS78	D786	0.80	23,228,000	2.41	447,390
TSS78	D787	0.80	17,513,000	2.82	395,430
TSS78	D788	0.80	24,823,000	2.39	474,775
TSS78	D789	0.80	29,396,000	2.39	562,240

Source: ComEd-supplied energy baselines and voltage reductions and Navigant team analysis.

Table 10-3 presents the CY2018 VO Program impacts calculated using the "Ameren 0.61 CVRf" method.[28]

Table 10-3. CY2018 VO Program Impacts – 0.61 CVRf

Substation	Feeder	CVRf	Savings Point Estimate (kWh)	Savings Upper 90% CI (kWh)	Savings Lower 90% CI (kWh)	Voltage Reduction (%)	Baseline Point Estimate (MWh)
DCC80	C801	0.61	192,681	202,119	183,243	3.42	9,229.79136
DCD114	D145	0.61	85,203	91,343	79,063	2.61	5,354.15164
DCD16	D164	0.61	520,861	543,142	498,580	3.26	26,162.40861
DCD242	D429	0.61	6,573	8,260	4,886	0.72	1,491.04697
DCD351	D5112	0.61	149,473	156,260	142,686	3.55	6,896.54265
DCD46	D4601	0.61	216,028	234,468	197,589	3.37	10,522.69628
DCD62	D620	0.61	398,490	412,212	384,768	4.11	15,903.50800
DCD62	D621	0.61	377,622	389,126	366,118	2.97	20,830.90415
DCD63	D631	0.61	172,180	182,906	161,455	3.36	8,411.29164
DCD63	D632	0.61	164,981	182,027	147,934	3.10	8,733.83421
DCD63	D633	0.61	129,292	141,559	117,025	3.06	6,928.54738
DCD69	D690	0.61	54,732	58,706	50,758	1.42	6,317.67703
DCD80	D8100	0.61	185,704	191,981	179,428	3.41	8,923.03906
DCE28	E285	0.61	380,975	402,841	359,110	4.01	15,569.55682
DCE28	E286	0.61	164,334	185,006	143,662	3.53	7,636.31840
DCE28	E287	0.61	298,676	317,663	279,689	3.62	13,522.90836
DCE59	E595	0.61	588,203	613,699	562,707	3.78	25,543.26302
DCE72	E725	0.61	156,275	161,001	151,550	3.27	7,845.02401
DCG99	G995	0.61	558,967	622,343	495,591	3.91	23,431.35049
DCS48	S485	0.61	320,134	333,921	306,348	3.72	14,094.70405
DCS48	S486	0.61	123,759	159,552	87,967	3.65	5,551.02594
DCW202	W022	0.61	120,316	125,800	114,832	2.81	7,016.97485

[28] The 0.61 CVRf value was chosen for comparison because it is the mean CVRf value in the database ComEd compiled from a review of the industry literature, and thus is, in some sense, representative of the experience of other electric utilities that have implemented CVR or VVO on their distribution networks.

Substation	Feeder	CVRf	Savings Point Estimate (kWh)	Savings Upper 90% CI (kWh)	Savings Lower 90% CI (kWh)	Voltage Reduction (%)	Baseline Point Estimate (MWh)
DCW216	W162	0.61	111,294	117,712	104,877	3.08	5,916.31430
DCW236	W360	0.61	153,627	166,560	140,695	3.02	8,337.31105
DCW236	W361	0.61	450,815	461,202	440,427	3.35	22,029.69171
DCW236	W362	0.61	377,470	386,980	367,959	3.50	17,695.81166
DCW28	W280	0.61	455,048	475,068	435,028	3.55	21,017.00503
DCW29	W290	0.61	255,743	302,422	209,063	3.34	12,563.86307
DCW29	W291	0.61	322,217	336,246	308,187	3.24	16,281.82580
DCW30	W301	0.61	359,295	370,823	347,768	3.25	18,120.84791
DCW30	W302	0.61	441,058	450,682	431,434	3.74	19,316.63470
DCW31	W310	0.61	140,839	150,836	130,842	1.93	11,944.52368
DCW31	W315	0.61	77,469	102,839	52,098	2.15	5,911.36938
DCW343	W441	0.61	113,456	118,580	108,331	3.17	5,875.28277
DCW346	W270	0.61	391,941	412,602	371,281	3.09	20,815.01252
DCW348	W484	0.61	495,107	510,563	479,652	3.41	23,818.18109
DCW354	W540	0.61	547,459	571,545	523,372	3.52	25,483.10022
DCW51	W512	0.61	581,830	596,525	567,134	3.74	25,531.49369
DCW71	W711	0.61	196,582	200,519	192,646	3.59	8,982.63399
DCW71	W712	0.61	238,799	243,134	234,464	3.77	10,396.93571
TDC414	G140	0.61	519,621	528,984	510,259	3.25	26,170.95351
TDC414	G141	0.61	360,729	368,280	353,179	3.34	17,712.45168
TDC414	G142	0.61	305,779	315,653	295,905	3.57	14,030.52141
TDC414	G143	0.61	263,473	275,134	251,812	3.46	12,497.41245
TDC414	G144	0.61	426,119	439,246	412,992	3.21	21,733.75682
TDC414	G145	0.61	496,963	508,103	485,824	3.30	24,686.99570
TDC414	G146	0.61	332,354	340,560	324,147	3.28	16,614.08953
TDC414	G147	0.61	429,669	440,646	418,692	3.10	22,686.43343
TDC414	G148	0.61	453,889	459,975	447,803	3.42	21,768.89741
TDC414	G1481	0.61	277,060	288,085	266,035	3.01	15,069.02726
TDC414	G149	0.61	361,622	370,890	352,355	3.38	17,536.35495
TDC457	F571	0.61	99,344	110,969	87,720	2.07	7,879.82999
TDC457	F572	0.61	305,221	328,741	281,702	2.13	23,498.46344
TDC457	F573	0.61	342,370	362,728	322,013	2.49	22,519.31261
TDC457	F574	0.61	288,926	308,923	268,928	2.36	20,104.92994
TDC457	F575	0.61	304,220	319,837	288,603	2.65	18,797.34937
TDC457	F576	0.61	83,690	101,418	65,962	0.79	17,457.67108
TDC457	F577	0.61	557,217	590,837	523,598	3.03	30,189.80881
TDC457	F578	0.61	207,416	222,329	192,504	2.83	12,015.72797
TDC470	G7011	0.61	291,862	330,472	253,252	3.24	14,779.31193
TDC470	G7012	0.61	508,429	540,389	476,470	3.46	24,080.62550

Substation	Feeder	CVRf	Savings Point Estimate (kWh)	Savings Upper 90% CI (kWh)	Savings Lower 90% CI (kWh)	Voltage Reduction (%)	Baseline Point Estimate (MWh)
TDC470	G7013	0.61	461,578	469,793	453,364	3.16	23,912.93327
TDC470	G7014	0.61	428,511	441,237	415,785	3.15	22,304.76106
TDC470	G7021	0.61	489,453	504,415	474,492	3.35	23,918.73170
TDC470	G7022	0.61	138,506	143,815	133,198	3.10	7,315.78077
TDC470	G7023	0.61	335,960	361,173	310,747	3.14	17,548.49926
TDC470	G7024	0.61	298,142	343,047	253,238	3.49	13,991.18180
TDC505	D0501	0.61	307,705	312,099	303,311	3.10	16,267.32273
TDC505	D0502	0.61	400,184	405,709	394,659	3.09	21,260.27368
TDC505	D0503	0.61	542,055	548,540	535,570	3.25	27,336.24845
TDC505	D0504	0.61	565,210	571,885	558,535	3.30	28,113.76630
TDC505	D0506	0.61	339,403	349,554	329,252	2.24	24,820.04075
TDC505	D0507	0.61	408,747	414,813	402,680	2.98	22,490.48199
TDC505	D0508	0.61	525,293	531,039	519,547	3.24	26,610.96984
TDC505	D0512	0.61	444,852	452,452	437,252	3.29	22,199.20994
TDC505	D0513	0.61	55,622	60,266	50,978	3.22	2,827.51074
TDC505	D0540	0.61	296,224	302,535	289,913	3.42	14,216.62880
TDC505	D0541	0.61	430,669	438,169	423,168	3.13	22,590.70429
TDC505	D0542	0.61	191,707	200,721	182,693	3.03	10,382.57211
TDC505	D0543	0.61	322,570	328,191	316,949	3.27	16,184.57539
TDC505	D0545	0.61	177,900	181,218	174,582	3.58	8,141.40139
TDC505	D0554	0.61	295,889	309,176	282,601	2.96	16,414.78980
TDC549	D4901	0.61	273,373	278,890	267,856	2.44	18,347.90435
TDC549	D4902	0.61	286,611	298,872	274,350	2.65	17,748.28477
TDC549	D4903	0.61	166,848	198,506	135,191	0.86	31,816.48267
TDC549	D4904	0.61	493,628	525,056	462,200	3.17	25,552.79274
TDC549	D4905	0.61	151,115	159,278	142,952	2.80	8,860.33206
TDC549	D4907	0.61	240,582	266,754	214,410	2.15	18,384.82048
TDC549	D4908	0.61	139,876	164,492	115,261	1.36	16,829.56353
TDC549	D4909	0.61	209,019	220,158	197,879	2.22	15,404.33722
TDC549	D4910	0.61	302,784	311,640	293,929	2.21	22,478.87957
TDC549	D4911	0.61	309,623	326,806	292,441	2.38	21,349.84117
TDC549	D4912	0.61	140,138	154,980	125,296	1.41	16,301.49723
TSS118	Z11861	0.61	311,906	325,378	298,433	2.08	24,579.78374
TSS118	Z11862	0.61	288,168	300,936	275,399	1.83	25,852.43057
TSS118	Z11863	0.61	338,281	352,064	324,497	2.20	25,176.26042
TSS118	Z11864	0.61	267,495	281,129	253,861	2.22	19,783.65991
TSS118	Z11865	0.61	381,859	397,542	366,175	2.10	29,789.37347
TSS118	Z11866	0.61	276,997	287,211	266,783	2.06	22,002.29173
TSS118	Z11867	0.61	280,154	292,739	267,569	1.97	23,321.11880

Substation	Feeder	CVRf	Savings Point Estimate (kWh)	Savings Upper 90% CI (kWh)	Savings Lower 90% CI (kWh)	Voltage Reduction (%)	Baseline Point Estimate (MWh)
TSS118	Z11868	0.61	366,157	379,095	353,219	2.12	28,326.76407
TSS118	Z11869	0.61	358,318	377,387	339,248	2.13	27,612.06728
TSS118	Z11870	0.61	264,079	272,501	255,658	2.09	20,690.23716
TSS118	Z11871	0.61	329,960	336,271	323,650	2.17	24,924.91099
TSS118	Z11872	0.61	298,304	310,064	286,543	1.86	26,315.43707
TSS118	Z11883	0.61	219,205	234,283	204,127	1.70	21,079.01569
TSS118	Z11884	0.61	387,817	403,874	371,759	2.24	28,431.18240
TSS134	D3409	0.61	199,079	203,846	194,311	3.19	10,239.83015
TSS134	D3410	0.61	445,245	451,243	439,246	3.22	22,650.51333
TSS134	D3411	0.61	394,595	398,339	390,852	3.30	19,592.43045
TSS134	D3412	0.61	345,909	351,097	340,722	2.95	19,218.30377
TSS134	D3413	0.61	426,150	430,319	421,980	3.29	21,212.93161
TSS134	D3414	0.61	405,269	410,365	400,173	3.32	19,995.11799
TSS134	D3415	0.61	436,870	444,919	428,821	3.28	21,843.04815
TSS134	D3416	0.61	348,137	352,317	343,957	3.19	17,908.45435
TSS134	D3417	0.61	394,826	402,367	387,286	3.37	19,196.56371
TSS134	D3418	0.61	427,505	439,334	415,675	2.82	24,894.67709
TSS134	D3419	0.61	460,723	464,372	457,074	3.34	22,585.94410
TSS134	D3421	0.61	394,220	401,212	387,227	3.21	20,104.62393
TSS134	D3422	0.61	359,825	374,892	344,759	2.92	20,227.40887
TSS134	D3423	0.61	335,118	340,782	329,453	2.76	19,940.71403
TSS134	D3424	0.61	310,800	314,471	307,128	2.90	17,571.73441
TSS134	D3425	0.61	342,879	355,302	330,455	2.21	25,477.29005
TSS134	D3427	0.61	334,272	338,642	329,903	2.60	21,100.86105
TSS134	D3428	0.61	167,710	220,955	114,465	3.21	8,563.02707
TSS48	C481	0.61	518,477	525,713	511,241	2.38	35,644.25239
TSS48	C4810	0.61	461,532	468,618	454,445	3.43	22,042.80470
TSS48	C4811	0.61	67,450	69,379	65,521	2.18	5,064.16668
TSS48	C482	0.61	417,369	424,364	410,374	3.48	19,655.04710
TSS48	C484	0.61	27,973	29,782	26,164	2.94	1,560.17981
TSS48	C485	0.61	372,006	377,702	366,309	3.23	18,894.31282
TSS48	C486	0.61	330,513	335,952	325,074	3.35	16,169.11468
TSS48	C487	0.61	335,454	340,221	330,686	3.26	16,893.98531
TSS48	C489	0.61	37,783	39,422	36,144	2.32	2,671.23252
TSS55	Z5535	0.61	463,373	478,426	448,319	2.88	26,379.08085
TSS55	Z5536	0.61	148,955	153,467	144,444	3.14	7,770.80171
TSS55	Z5537	0.61	391,529	414,656	368,402	2.90	22,158.87198
TSS55	Z5538	0.61	410,442	423,915	396,969	2.97	22,631.03613
TSS55	Z5539	0.61	77,930	80,462	75,399	3.22	3,967.28671

Substation	Feeder	CVRf	Savings Point Estimate (kWh)	Savings Upper 90% CI (kWh)	Savings Lower 90% CI (kWh)	Voltage Reduction (%)	Baseline Point Estimate (MWh)
TSS55	Z5540	0.61	444,362	460,904	427,820	3.07	23,727.14133
TSS55	Z5541	0.61	169,886	180,557	159,216	2.84	9,798.40290
TSS55	Z5542	0.61	41,441	44,455	38,427	2.49	2,724.06795
TSS55	Z5543	0.61	224,405	232,218	216,591	3.08	11,958.84448
TSS55	Z5544	0.61	312,463	321,889	303,036	2.79	18,373.39746
TSS55	Z5545	0.61	46,044	48,257	43,831	3.03	2,487.29725
TSS55	Z5557	0.61	34,204	36,799	31,610	0.83	6,725.82656
TSS78	D780	0.61	460,344	471,401	449,287	2.56	29,463.13768
TSS78	D781	0.61	405,464	419,013	391,914	3.09	21,531.67511
TSS78	D7810	0.61	387,580	397,273	377,888	3.03	20,991.55564
TSS78	D7811	0.61	226,937	233,538	220,337	2.65	14,036.40645
TSS78	D7812	0.61	385,947	397,554	374,341	2.80	22,579.13515
TSS78	D7813	0.61	191,729	203,754	179,703	1.80	17,444.33097
TSS78	D7814	0.61	202,776	210,251	195,301	2.73	12,179.49473
TSS78	D7815	0.61	166,466	171,638	161,293	3.40	8,016.78320
TSS78	D7816	0.61	262,854	268,135	257,573	2.81	15,353.09218
TSS78	D7817	0.61	293,134	298,512	287,757	3.12	15,391.65065
TSS78	D782	0.61	355,703	366,529	344,878	2.67	21,812.19034
TSS78	D783	0.61	345,471	353,928	337,014	3.34	16,943.93477
TSS78	D784	0.61	414,465	430,631	398,299	2.37	28,640.29675
TSS78	D785	0.61	261,318	274,646	247,991	1.98	21,645.80447
TSS78	D786	0.61	252,935	265,533	240,336	2.37	17,530.98180
TSS78	D787	0.61	359,573	372,528	346,618	3.32	17,748.05740
TSS78	D788	0.61	301,398	312,811	289,986	2.53	19,512.54234
TSS78	D789	0.61	368,933	380,043	357,823	2.47	24,504.50799

Source: ComEd tracking data and Navigant team analysis.

11. Appendix 5. Total Resource Cost Detail

Table 11-1, below, shows the Total Resource Cost (TRC) table. It includes only the cost-effectiveness analysis inputs available at the time of finalizing this impact evaluation report. Additional required cost data (e.g., measure costs, program level incentive and non-incentive costs) are not included in this table and will be provided to evaluation later.

Table 11-1. Total Resource Cost Savings Summary

End Use Type	Research Category	Units	Quantity	Effective Useful Life	Verified Gross Savings (kWh)	Verified Gross Peak Demand Reduction (kW)	Verified Gross Savings (Therms)	Gross Heating Penalty (Therms)	NTG Ratio (kWh)	Verified Net Savings (kWh)	Verified Net Peak Demand Reduction (kW)	Verified Net Savings (Therms)	Net Heating Penalty (Therms)
N/A	VO	NA	NA	15.0	66,014,049	NA	NA	NA	1.0	66,014,049	NA	NA	NA

Source: ComEd tracking data and Navigant team analysis.