Memorandum

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Andy Parker; Ameren

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VO TRM Working Group

From: **Carly Olig, Ethan Young, and Paul Higgins; Guidehouse**
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Date: **October 8, 2020**

Re: **Supporting Documentation for Voltage Optimization TRM Measure**

INTRODUCTION

This memo provides supporting documentation for a deemed conservation voltage reduction factor (CVRf) in the voltage optimization (VO) measure being recommended as a new measure for version 9.0 of the Illinois Technical Reference Manual (TRM). Based on our research, the Guidehouse team is recommending a statewide energy CVRf of 0.80 and separate peak demand CVRf values of 1.02 for ComEd and 0.68 for Ameren Illinois Company (Ameren).

ComEd and Ameren began their VO programs in 2018.[1] Each has been implementing a testing protocol that entails turning on and off the VO controls on a schedule to enable measuring the savings.[2] VO is being recommended as a new measure for TRM v9.0. VO is a smart grid technology that uses distributed sensors, communications infrastructure, remote controls, and integrating/optimizing software to flatten voltage profiles and lower average voltage levels on an electric power distribution grid. Lowering the voltage reduces the instantaneous power consumed by customers on VO enabled feeders, which in turn results in energy and demand savings.

The CVRf relates the change in voltage (kV) from VO to a change in energy consumption (MWh). It is used along with baseline energy usage (i.e., energy consumed in the absence of VO) and the voltage reduction from VO to produce energy savings, as shown in Equation 1.[3]

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[1] With ComEd first claiming savings in CY2018 and Ameren in CY2019.

[2] Both utilities used VO On/Off testing to accommodate the need for evaluation. VO On/Off testing is an experimental design that involves enabling and disabling the VO system under a predefined schedule for the purposes of testing its functionality. By following a predefined schedule, the VO On/Off design enables modeling of the impact of VO while controlling for factors that may vary over time, such as weather or weekday vs. weekend loads.

[3] Small adjustments to Equation 1 result in a corollary equation for peak demand savings.

Equation 1. Energy Savings Equation

$$EnergySavings = EnergyBaseline * \%\Delta V * CVR_f$$

$$CVR_f = \frac{\%\Delta MWh}{\%\Delta V}$$

The rest of this memo describes how the Guidehouse team determined the recommended statewide energy CVRf of 0.80 and the separate peak demand CVRf values of 1.02 for ComEd and 0.68 for Ameren. The other components of Equation 1 are not discussed in this memo as they are not being considered for deemed values in the TRM.[4] The next section discusses the methodology, followed by sections on the results, analysis limitations, and conclusions. An Appendix provides supplemental information on the methodology and results.

METHODOLOGY

Data

The section below describes data sources and data cleaning steps used for the Guidehouse team analysis of VO.

Data Sources

To estimate the CVRf for VO-enabled feeders, the Guidehouse team used Supervisory Control and Data Acquisition (SCADA) interval data and VO system On/Off logs for VO-enabled feeders,[5] as well as hourly weather data imported from the National Oceanic and Atmospheric Administration (NOAA). Details surrounding the coverage of the data are provided below.

Ameren and ComEd provided VO On/Off status logs and SCADA data containing demand and voltage readings at hourly and half-hourly intervals, respectively. Ameren's SCADA data spanned June 1, 2019 through February 29, 2020, and ComEd's SCADA data spanned January 1, 2018 through January 31, 2020. VO On/Off status logs provided by both utilities spanned the entire range of VO active dates for each VO-enabled feeder.

In order to ensure sufficient VO On/Off cycling data were employed in the analysis, the Guidehouse team utilized feeders that began VO On/Off testing by July 1, 2019. Given the date ranges of SCADA data available for the analysis, this ensured at least seven and eight months of VO On/Off testing data could be employed for Ameren and ComEd, respectively, and that the On/Off testing would cover the summer peak, the winter peak, and either the fall or spring shoulder season. Using these date cutoffs, a total of 369 VO feeders – including 299 of 550 ComEd VO feeders and 70 of 77 Ameren VO feeders activated by the end of 2019 – were eligible for the analysis.

For the peak demand CVRf, we only required data during the peak season, which runs from June 1 through August 31. Feeders active for VO On/Off testing by August 1, 2019 and with applicable SCADA and VO On/Off status logs available were eligible for the peak analysis. This amounted to a total of 387 feeders, with 70 feeders for Ameren and 317 feeders for ComEd.

Following the receipt of VO On/Off status logs and SCADA interval data from the utilities, the Guidehouse team imported weather data from NOAA's National Climatic Data Center (NCDC) server

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[4] Descriptions of how these values are calculated can be found in the TRM measure itself. See TRM version 9.0, volume 4, measure 6.2.1.

[5] The VO system On/Off logs show when VO was enabled (on) and disabled (off).

of Quality Controlled Local Climatological Data (QCLCD) based on each feeder's location. All 317 eligible ComEd VO feeders and 70 eligible Ameren feeders listed above had applicable weather data available, although with some anomalous data readings and gaps in coverage. Based on the absolute temperatures and the temperatures at nearby stations, the Guidehouse team concluded that a handful of values above 100 degrees were erroneous, and these values were removed. Where data were missing or removed for fewer than 4 consecutive hours, data were filled using linear interpolation. Where data were missing or removed for more than 4 consecutive hours, temperatures were pulled from the next-closest weather station.

Data Cleaning

Energy

Common elements of data cleaning executed across both utilities included removal of repeated and interpolated values, missing values, and outliers of demand and voltage readings from the analysis data. In addition, periods were removed from the analysis data if they were found to be inconsistent with usual On/Off testing conditions. Some examples in which this occurred were for time periods in which the VO cycling schedule was not followed or periods in which feeders were down for maintenance or upgrades. Each of the steps, which differed slightly based on data quality for each utility, are provided with additional detail in Table 3 in the Appendix.

Data cleaning resulted in a reduction in the number of feeders used in the CVRf analysis from 369 to 246 across the utilities. For Ameren, we were able to utilize 94.05% of the available data and keep all 70 eligible feeders in our analysis; most of the data removed was due to excludable time periods when VO was scheduled to be on but was off for a reason stakeholders agreed could be ignored by the analysis (see Table 3 in the Appendix for more details). For ComEd, we were able to utilize 50% of the available data and keep 176 of the 299 eligible feeders (59%) in our analysis; the majority of the data lost was due to removal of data inconsistent with the expected On/Off testing cycle (see Table 3 in the Appendix for more details).

For sensitivity, we tested an additional data cleaning step for the feeder-level CVRf modeling with seasonal interaction terms. A data cleaning step was introduced to ensure that each season included in the model with seasonal interaction terms contained at least 60 days of clean VO On/Off cycling data. This removed 6 feeder-season combinations for Ameren (but retained all 70 feeders) and 167 feeder-season combinations for ComEd (and removed 1 feeder entirely resulting in 175 feeders). In the Results section, we present finding from this sensitivity test along with findings from the basic cleaning approach described above.

Peak

For analysis of peak demand, we utilized the same data cleaning steps as the energy analysis for repeated and interpolated values, missing values, and outliers of demand and voltage readings from the analysis data. An additional data cleaning step was introduced to restrict the analysis data to non-holiday weekdays from June 1 through August 31. Although peak periods occur between 1:00 and 4:59 PM central prevailing time on these 64 days, we kept all 24 hours of these days within the dataset. Underlying demand that occurs during off-peak periods may influence peak-period demand and could also influence peak savings estimates, including load shifting between peak and off-peak periods. By keeping all 24 hours of the peak period days within the dataset, we are accounting for these potential load shifts between peak and off-peak periods.

For the peak demand analysis, we introduced a similar sufficiency check to that used in the seasonal analysis, requiring that the feeder's peak period data contained at least 20 peak days[6] of clean VO

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[6] This represents approximately one months' worth of peak days.

On/Off cycling data. This resulted in the analysis including 70 feeders for Ameren and 264 feeders for ComEd.

Regression Methodology

Estimation of Energy CVRf

The Guidehouse team ran two models to estimate the energy CVRf: one without seasonal interactions (which we'll refer to as the basic model) and one with seasonal interactions[7] (which we'll refer to as the seasonal model). The team added the seasonal interaction terms to better capture seasonal variation in the model coefficients because we did not have a full year of On/Off testing data for most of the feeders.

Basic Model

To provide feeder-level estimates of CVRf for VO-enabled feeders, we estimated feeder-specific regression models for MW and kV shown in Equations 2 and 3, respectively.[8]

Equation 2. VO Energy Model

$$MW_{it} = \alpha_{MW} VO_{it} + \sum_{h=1}^{24} \beta_h \tau_{WD,h} + \sum_{h=1}^{24} \gamma_h \tau_{WE,h} + \delta CDH_{it} + \theta CDH_{it}^2 + \rho HDH_{it} + \varphi HDH_{it}^2 + \varepsilon_{it}$$

Equation 3. VO Voltage Model

$$kV_{it} = \alpha_{kV} VO_{it} + \sum_{h=1}^{24} \beta_h \tau_{WD,h} + \sum_{h=1}^{24} \gamma_h \tau_{WE,h} + \delta CDH_{it} + \theta CDH_{it}^2 + \rho HDH_{it} + \varphi HDH_{it}^2 + \omega_{it}$$

where

i, t, and h	index feeder, time-interval, and each of the 24 hours of the day, respectively.
MW_{it}	is real power (MW) measured on feeder *i* at time *t.*
kV_{it}	is voltage (kV) measured on feeder *i* at time *t.*
VO_{it}	is an indicator equal to 1 when VO is on for feeder *i* during time *t*, and 0 otherwise. The coefficient α captures the impact of VO on load or voltage net of the effects of the other included variables.[9]
$\tau_{WD,h}$ and $\tau_{WE,h}$	are hourly fixed effects for weekdays and weekends, respectively. The corresponding β and γ coefficients capture the hourly load and voltage shapes during the weekend and weekdays respectively.

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[7] Seasons are defined as follows; spring: March through May; summer: June through August; fall: September through November; and winter: December through February.

[8] The Guidehouse team tested several other model specifications but chose those shown in Equation 2 and Equation 3 based on fit statistics, including Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), root mean squared error (RMSE), and adjusted R squared.

[9] Note that while the dependent variable in Equation 2 is MW_{it}, the instantaneous *power demand* measured on feeder *i* at time *t,* the coefficient α captures the average impact of VO on the *energy consumed* by the loads connected to feeder *i* over the estimation period, as well as the average demand reduction. This reflects the fact that the energy saved on the feeder as a result of VO consists of the summation of instantaneous power reductions resulting from VO when it was engaged during this period.

CDH_{it} and CDH_{it}^2	are cooling degree-hours (CDH), base 65 degrees Fahrenheit, for feeder *i* during time *t* and its square, to capture the (possibly nonlinear) impacts of temperature on cooling load. The corresponding coefficients δ and θ capture the impact of CDH and its square on load or voltage.
HDH_{it} and HDH_{it}^2	are heating degree-hours (HDH), base 65 degrees Fahrenheit, for feeder *i* during time *t* and its square, to capture the (possibly nonlinear) impacts of temperature on heating load. The corresponding coefficients ρ and φ capture the impact of HDH and its square on load or voltage.
ε_{it} and ω_{it}	are the random error terms for the energy and voltage models.

Note that in both equations, fitting the model to On/Off testing data for a given feeder will yield a value for the α coefficient on the VO_{it} indicator. This value will be an estimate of the average hourly energy reduction (in Equation 2) or voltage reduction (in Equation 3) from VO being engaged on that feeder, relative to when it is disengaged. These estimates can be used to determine the estimated average *percentage* energy and voltage reductions for each feeder, as shown in Equations 4 and 5.

Equation 4. Feeder-Level Average VO Energy Savings Estimate

$$\%\Delta MW_i = \frac{\alpha_{MW,i}}{\mu_{MW,i}^{Off}}$$

Equation 5. Feeder-Level Average VO Voltage Reduction

$$\%\Delta kV_i = \frac{\alpha_{kV,i}}{\mu_{kV,i}^{Off}}$$

Where $\mu_{MW,i}^{Off}$ and $\mu_{kV,i}^{Off}$ represent the mean baseline MW and kV levels for feeder i. Baselines of the mean MW and kV values correspond to the periods when VO was off during the On/Off testing periods included in our modelling.

We then used the percentage energy savings and voltage reductions to generate a feeder-specific CVR factor for each feeder, as shown in Equation 6.

Equation 6. Calculation of Feeder-Level CVR Factors

$$CVRf_i = \frac{\%\Delta MW_i}{\%\Delta kV_i}$$

After feeder-level CVRf estimates were generated, a statewide load-weighted average was calculated, as shown in Equation 7. Here, a load-weighted average was calculated as the summation of the product of each feeder's $CVRf_i$ and $\mu_{MW,i}^{Off}$, its average energy usage during the VO-off period, divided by the summation of all 246 feeders' average energy usage during the VO off period.

Equation 7. Calculation of Statewide CVR Factors

$$CVRf_{Statewide} = \frac{\sum_{i=1}^{246} CVRf_i * \mu_{MW,i}^{Off}}{\sum_{i=1}^{246} \mu_{MW,i}^{Off}}$$

Seasonal Model

We estimated feeder-specific seasonal VO impacts on energy usage and voltage using models similar to those shown in Equations 2 and 3. For the seasonal model, each term in those equations was interacted with $Season_t$, a 4-level variable indicating whether time *t* falls in the spring, summer, winter, or fall season. Interaction of $Season_t$ with other covariates allows for seasonal differences in load shapes, temperature effects, and other seasonal characteristics that drive demand or voltage but may not be fully captured in the available data.

By interacting VO_{it} with $Season_t$, we were able to generate separate average energy and voltage reductions for each season and feeder. In what follows, we refer to the feeder- and season-specific average energy and voltage reductions as $\alpha_{MW,i}^{Season}$ and $\alpha_{kV,i}^{Season}$, respectively. For each feeder, we then calculated a seasonal percentage change in energy and voltage using Equations 8 and 9.

Equation 8. Feeder-Level Average VO Energy Savings Estimate

$$\%\Delta MW_i^{Season} = \frac{\alpha_{MW,i}^{Season}}{\mu_{MW,i}^{Season}}$$

Equation 9. Feeder-Level Average VO Voltage Reduction

$$\%\Delta kV_i^{Season} = \frac{\alpha_{kV,i}^{Season}}{\mu_{kV,i}^{Season}}$$

Where $\mu_{MW,i}^{Season}$ and $\mu_{kV,i}^{Season}$ represent the season-specific mean baseline MW and kV levels for feeder i. As previously, the baseline corresponds to periods when VO was off during the On/Off testing periods included in our modelling. We then used the resulting estimates to generate a seasonal feeder-specific CVRf, shown in Equation 10.

Equation 10. Calculation of Feeder-Level CVR Factors

$$CVRf_i^{Season} = \frac{\%\Delta MW_i^{Season}}{\%\Delta kV_i^{Season}}$$

After obtaining the feeder-level seasonal CVRf estimates, we calculated a feeder-level all-seasons weighted average CVRf estimate via Equation 11.

Equation 11. Calculation of All Seasons Feeder-Level CVR Factors

$$CVRf_i^{AllSeasons} = \frac{\sum_{Season=Spring}^{Winter} CVRf_i^{Season} * Hours_i^{Season}}{\sum_{Season=Spring}^{Winter} Hours_i^{Season}}$$

Where $CVRf_i^{Season}$, the season-specific CVRf for feeder i, is weighted by $Hours_{Season}$, the number of hours contained in each season for feeder i. One final, statewide load-weighted average CVRf was then calculated via Equation 12 below.

Equation 12. Calculation of All Seasons Statewide CVR Factors

$$CVRf_{Statewide}^{AllSeasons} = \frac{\sum_{i=1}^{246} CVRf_i^{AllSeasons} * \mu_{MW,i}^{Off}}{\sum_{i=1}^{246} \mu_{MW,i}^{Off}}$$

Where, as previously, $\mu_{MW,i}^{Off}$ and $\mu_{kV,i}^{Off}$ represent the baseline MW and kV levels for feeder i when VO was off during the On/Off testing periods included in our modelling.

Estimation of Peak Demand CVRf

For the summer peak demand savings estimation, the Guidehouse team subset the data to contain only summer peak period days: non-holiday weekdays from June 1 through August 31. Although peak periods occur between 1:00 and 4:59 PM central prevailing time on these 64 days, we kept all 24 hours of these days within the dataset, for reasons explained in the peak data cleaning section above.

The Guidehouse team conducted pooled regression analyses separately for each utility, as shown in Equations 13 and 14 below. A pooled model for each utility was used for this analysis, rather than a weighted average of feeder-specific models, because the peak analysis includes much less data (just 64 peak days) than the energy analysis. The lower volume of data leads to less certainty and more variability in the feeder-specific modelling.

Equation 13. Summer Peak Demand Regression Model

$$MW_{it} = \eta_i + \sum_{h=1}^{24} \beta_h \tau_{WD,h} + \alpha_{MW} VO_{it} + \lambda_{MW} VO_{it} \cdot offpeak_t + \delta CHD_{it} + \theta CDH_{it}^2 + \varepsilon_{it}$$

Equation 14. Summer Peak Voltage Regression Model

$$kV_{it} = \eta_i + \sum_{h=1}^{24} \beta_h \tau_{WD,h} + \alpha_{kV} VO_{it} + \lambda_{MW} VO_{it} \cdot offpeak_t + \delta CHD_{it} + \theta CDH_{it}^2 + \omega_{it}$$

Where:

i, t, and h	index feeder, time-interval, and each of the 24 hours of the day, respectively.
MW_{it}	is demand (MW) on feeder *i* at time *t.*
kV_{it}	is voltage (kV) on feeder *i* at time *t.*
η_i	is a feeder fixed effect for feeder *i*, controlling for fixed feeder characteristics that may affect power demand or voltage.
τ_h	is an hourly fixed effect for each hour of the day *h*. The coefficient β captures the hourly load and voltage shapes.
VO_{it}	is an indicator equal to 1 when VO is on for feeder *i* at time *t,* and 0 otherwise. The coefficient α captures the impact of VO on load or voltage during peak hours.
$offpeak_t$	is an off-peak indicator equal to 1 when time *t* is between 12:00 AM through 12:59 PM and 5:00 PM through 11:59 PM in Central Prevailing Time, and 0 otherwise. The coefficient λ captures the impact of VO on the load or voltage during off-peak hours.
CDH_{it} and CDH_{it}^2	are CDH, base 65 degrees Fahrenheit, for feeder *i* during time *t* and its square to capture nonlinear impacts of temperature on cooling load. The coefficients δ and θ capture the impact of CDH and its square on the load or voltage.
ε_{it} and ω_{it}	are the cluster-robust error terms for feeder *i* during time *t.*[10]

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[10] Cluster-robust errors account for heteroskedasticity and autocorrelation at the feeder level.

The changes in peak-period demand and voltage associated with VO for each utility are given by α_{MW}^{peak} and α_{kV}^{peak}. Percentage changes in peak demand and peak voltage for each utility were then estimated as shown in Equations 15 and 16 below.

Equation 15. Statewide Peak VO Demand Savings Estimate

$$\%\Delta MW_{Statewide}^{peak} = \frac{\alpha_{MW}^{peak}}{\mu_{MW,i}^{peak}}$$

Equation 16. Statewide Peak VO Voltage Reduction

$$\%\Delta kV_{Statewide}^{peak} = \frac{\alpha_{kV}^{peak}}{\mu_{kV,i}^{peak}}$$

Where $\mu_{MW,i}^{peak}$ and $\mu_{kV,i}^{peak}$ are mean baseline MW and kV levels for feeder i when VO was off during the peak period. The peak CVRf for each utility was then estimated as shown in Equation 17.

Equation 17. Statewide Peak CVRf

$$CVRf_{Statewide}^{peak} = \frac{\%\Delta MW_{Statewide}^{peak}}{\%\Delta kV_{Statewide}^{peak}}$$

RESULTS

Energy CVRf

Table 1 below summarizes the statewide load-weighted average energy CVRf findings across three different iterations of feeder-level regression modeling. The first model is the basic model shown in Equation 2 and Equation 3. The latter model is the seasonal model, appending seasonal interaction terms throughout Equation 2 and Equation 3, under two different data cleaning methodologies; the base cleaning methodology described in the energy data cleaning section above and then the data cleaning sensitivity around days of clean VO On/Off cycling data (also described in the energy data cleaning section above). Estimating the basic model yielded a statewide load-weighted average CVRf of 0.789, and estimating the seasonal model with varying data cleaning yielded a statewide[11] load-weighted average CVRf of 0.807 and 0.809.

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[11] The Guidehouse team has chosen to only show statewide energy CVRf results rather than specific utility results because of limitations to each utility's data (as discussed in the Limitations of the Current Analysis section of this document). Across the two utilities, load-weighted average CVRf estimates ranged from 0.74 to 0.83. As the results were all relatively clustered around 0.80, we felt comfortable recommending a single statewide value.

Table 1. Statewide Load-Weighted Average CVRf Results

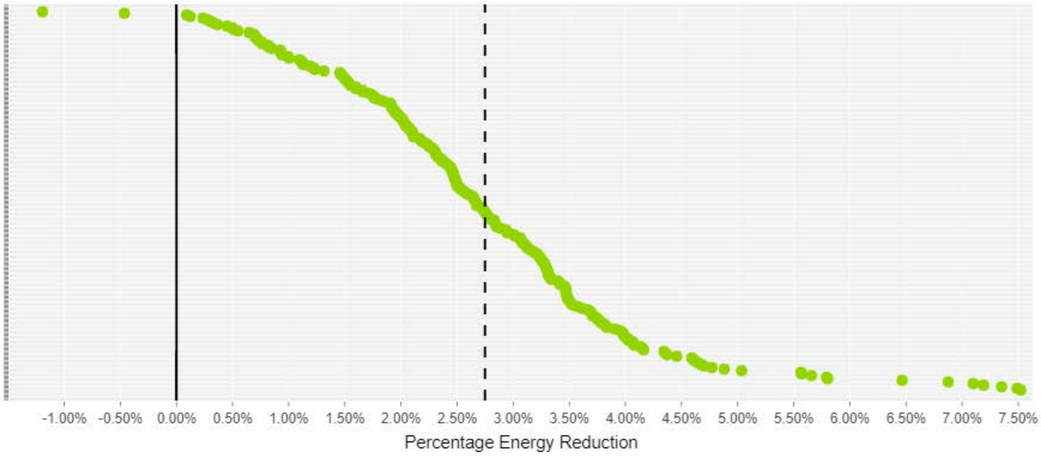
Model	Cleaning	Feeders	Feeder-Season Combinations	Load-Weighted Average CVRf
Basic	Base	246	NA	0.789
Seasonal	Base	246	900	0.807
	Feeder-Season Sufficiency*	245	726	0.809

* The Guidehouse team also tested a model where feeders were removed if any season was missing sufficient data. This resulted in a statewide CVRf of 0.74 but further reduced the sample size of feeders from 246 to 135. Given the already limited sample of feeders available for analysis, the team did not believe this evaluation approach was worth pursuing.
Source: Guidehouse team analysis

While there is little variation from 0.80 in the statewide load-weighted average CVRf across models and cleaning regimens, the Guidehouse team observed significant variation in feeder-level energy savings, voltage reductions, and CVRf across all three models highlighted in Table 1. Discussion surrounding Figure 1, Figure 2, and Figure 3 below relate to the all seasons, feeder-level findings under the estimation of the seasonal model with base cleaning.

Figure 1 illustrates the observed distribution of percentage energy savings; note that positive values on the horizontal axis represent savings while negative values are dissavings, indicating that VO increased the usage on a feeder. These estimates vary widely, spanning -4.84 percent to 31.75 percent. The figure is cut-off to show just -1% to 7.5%.[12]

Figure 1. Distribution of Feeder-Level Percentage Energy Savings*



Source: Guidehouse team analysis
* The figure above trims energy savings values less than -1.50% and greater than 7.50%. Three feeders had energy savings below -1.50% and seven feeders had energy savings above 7.5%.

Figure 2 illustrates the observed distribution of percentage voltage reductions. These estimates are more tightly distributed than the modeled energy savings, spanning a range of 1.41 percent to 5.82 percent.

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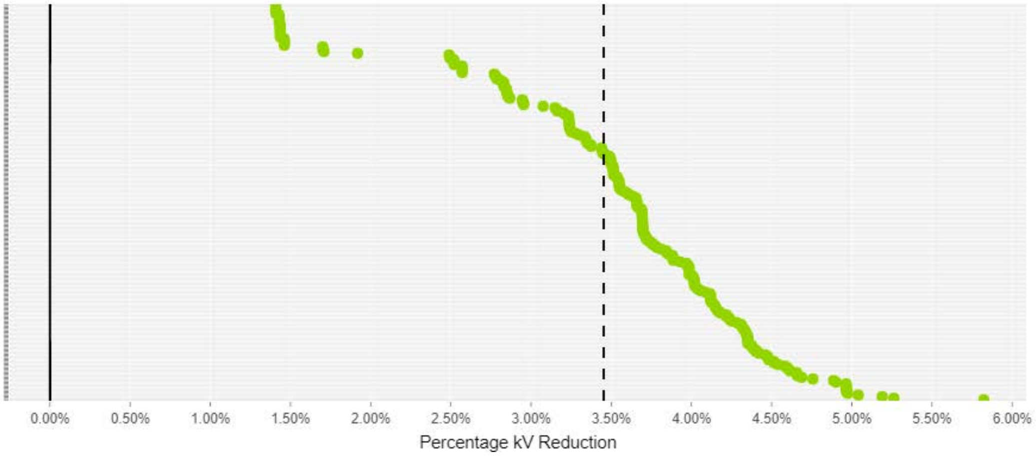
[12] Three feeders had energy savings below -1.50% and seven feeders had energy savings above 7.5%.

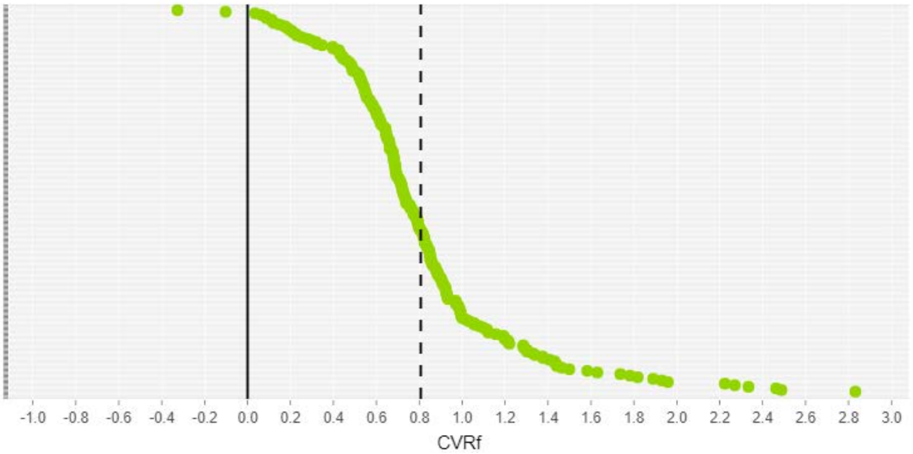
Figure 2. Distribution of Feeder-Level Percentage Voltage Reductions



Source: Guidehouse team analysis

Figure 3 illustrates the observed distribution of all seasons feeder-level CVRf results. As percentage energy and percentage voltage reductions varied widely, so too did the observed CVRf estimates, which range from -1.99 to 9.04.

Figure 3. Distribution of Feeder-Level Energy CVRf Results*



* The figure above trims energy CVRf values that are less than -1 and greater than 3. Three feeders had an energy CVRf below -1 and four feeders had an energy CVRf above 3.
Source: Guidehouse team analysis

Variation in CVRf across feeders was expected under feeder-level modeling, given the variation in factors such as load mix, overall loading, peakedness, and distributed energy resources, that can affect the energy savings and voltage reductions from VO. The original goal of this analysis was to utilize the distribution of feeder-level CVR factors in a model with feeder characteristics to create a lookup table with different CVR factors for feeders based on feeder characteristics. This analysis did not result in a meaningful model between CVRf and feeder characteristics. We have included details of the predictive CVRf modelling in the Appendix for completeness.

Peak Demand CVRf

Table 2 below summarizes peak demand CVRf results for Ameren and ComEd feeders. Because the results between the two utilities were quite disparate, the Guidehouse team is recommending a separate peak demand CVRf for each utility.

Table 2. Statewide Peak Demand CVRf Results

Utility	Percent MW Reduction	Percent kV Reduction	CVRf
Ameren	2.15%	3.15%	0.68
ComEd	2.94%	2.89%	1.02

Source: Guidehouse team analysis

LIMITATIONS OF THE CURRENT ANALYSIS

There are some limitations to the current analysis that should be recognized. First, the number of feeders that could be used in the analysis was limited. Our analysis included 70 Ameren feeders and 176 ComEd feeders. As of the end of 2019, Ameren had activated VO on 77 feeders and ComEd had activated it on 550. Both utilities' VO programs are in their infancy, and each utility plans to activate hundreds, if not thousands, more feeders in the coming years. Given this, there is no guarantee that the relatively limited number of feeders being analyzed under current analysis are representative of the numerous feeders that are to receive VO investments over the coming years.[13]

Further, there are limitations in the seasonal coverage of the data that could be used in the analysis. Ameren feeders used in the analysis began VO On/Off testing on June 1, 2019, leaving only the summer, fall, and winter data available for Ameren. ComEd had initiated VO On/Off testing earlier on, with numerous feeders beginning VO On/Off testing in 2018. However, 100 of 176 feeders eligible for analysis had coverage of the spring months, and only 60 of these feeders had at least 60 days of clean VO cycling spring period data. Additionally, many data points and feeders were removed from the ComEd data, as many VO status flags were inconsistent with the expected On/Off testing cycle.[14]

Monthly data coverage across the two utilities is shown in Figure 7 below. The majority of the available analysis data span summer, fall, and winter. June through January had the highest data availability, consistent with feeders included in the analysis being active by July 1, 2019 and ComEd SCADA data being available through January 31, 2020. Data availability was lowest beginning in February, as February 2020 SCADA data were limited to Ameren feeders, and remain low in March, April, and May. Coverage of a full calendar year is therefore limited and outcomes from VO in a full year may be markedly different than observed under our current analysis.

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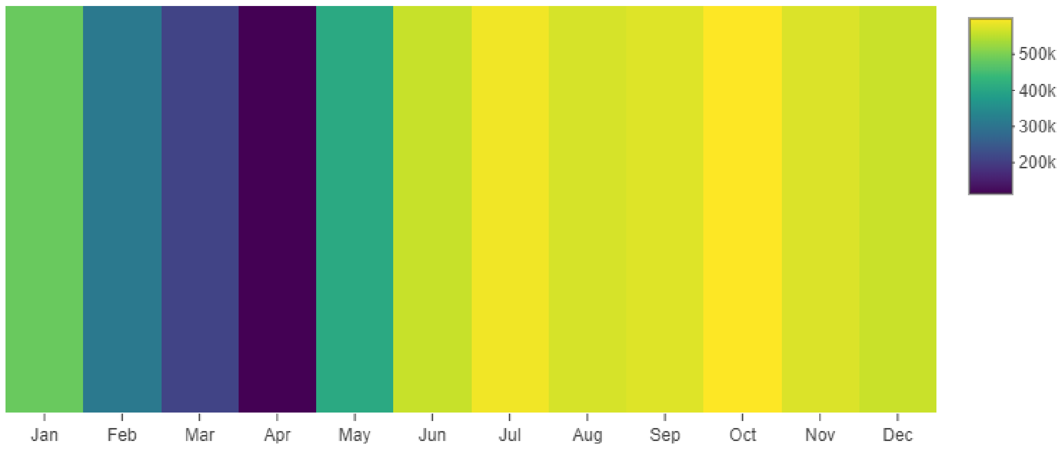
[13] Ameren's sample includes 70 feeders out of the eventual 1,047 circuits that Ameren will deploy by 2024. These circuits were selected based on their potential to be representative of the population. However, the number of available circuits for on/off testing represents the number that it was feasible for Ameren to deploy by June 1, 2019 to meet the Ameren Illinois Voltage Optimization Settlement Stipulation (ICC Docket No. 18-0211) deadline. Based on a power analysis conducted by the evaluation team, the ideal sample size would have been nearly double this amount (n=131). ComEd plans to install VO on 1,665 feeders at 226 substations by the end of CY2021, and 2,958 feeders at 450 substations through CY2025.

[14] Additional detail surrounding data cleaning due to inconsistency in VO On/Off status flags can be found in Table 2.

Figure 4. Monthly Data Coverage



Source: Guidehouse team analysis

CONCLUSION

This analysis utilized VO On/Off testing data conducted across numerous Ameren and ComEd feeders during 2018 and 2019. On/Off testing enabled a statewide estimation of the CVRf associated with the technology. As discussed in the Introduction, the CVRf relates the change in voltage (kV) from VO to a change in energy (MWh) and is used along with baseline energy usage (i.e., energy usage in the absence of VO) and the voltage reduction from VO to produce energy savings.

To determine the energy CVRf using applicable VO feeders, the team estimated a mix of utility-specific, feeder-specific, and statewide regression models with varying model specifications and data cleaning methodologies. Determination of final regression specifications and data cleaning methodologies was conducted via statistical robustness checks, balancing both statistical power and data attrition. When estimated across 246 feeders, multiple well-performing model specifications and data cleaning methodologies resulted in estimated CVRf in the neighborhood of 0.80, ranging from 0.74 and 0.83. Given this finding, the Guidehouse team is recommending an energy CVRf of 0.80.

To determine the peak demand CVRf, the Guidehouse team estimated a pooled regression model for each utility. A pooled regression model was chosen over the load-weighted average of feeder specific models for this analysis due to the lower volume of data. As the peak demand CVRf results were quite disparate across the two utilities, we recommend a peak demand CVRf of 1.02 for ComEd and 0.68 for Ameren.

At the time of this analysis, 246 feeders had sufficient VO On/Off testing data collected to facilitate analysis of the energy CVRf associated with VO. These feeders exhibited substantial variation in characteristics, including but not limited to urban/rural composition, customer mix, and heating and cooling climate zones. However, this is only a fraction of the feeders the utilities eventually intend to equip with VO. For this reason, there is a non-trivial possibility that the feeders analyzed in the current analysis may not be representative of the feeders that will receive VO deployments over the coming years.

Further, there are limitations to the seasonal coverage of the data used in the energy savings analysis. The majority of the available analysis data span summer, fall, and winter seasons, and the analysis could only incorporate limited spring data. Coverage of a full calendar year is therefore limited and outcomes from VO in a full year may be markedly different than observed under our current analysis.

Finally, there is no reason to believe that the CVRf is a constant over time. The relationship between voltage and energy reduction depends heavily on the mix of end-use loads being supplied with power, which changes over time. For example, one change that has occurred in the recent past is the shift from incandescent lightbulbs to LEDs. An expected change in the near future is increased levels of distributed energy resources such as solar and wind. There may well be other changes that we are unable to predict.

The VO TRM Working Group agreed to a review deadline for this measure of January 1, 2023. Consistent with the definition of Review Deadline in TRM Volume 1 (Overview),[15] the working group collectively acknowledges that this date does not represent a commitment or obligation to revise TRM content by this date. Rather, it serves as a pledge to reconvene as a working group prior to the deadline date to discuss and review this measure in the TRM as part of ongoing efforts to ensure that the TRM performs as reliably as possible.

APPENDIX

Data Cleaning Methodology

Table 3 below provides a detailed outline of data cleaning steps conducted for the estimation of energy CVRf and peak demand CVRf conducted by the Guidehouse team. Note that the data cleaning steps varied by utility, as each utility had their own sets of nuances in SCADA data and VO On/Off status logs that needed to be addressed. Further, data cleaning steps vary slightly depending on whether estimation was being conducted for the purpose of estimating the energy CVRf or the peak demand CVRf.[16]

Table 3. VO Data Cleaning Steps by Utility

Utility	Step	Description
Ameren	Missing values	Remove missing and non-numeric values in kV and MW from the analysis data.
	Interpolated or repeated values	Prior evaluations of VO have revealed that SCADA systems commonly interpolate or repeat data inputs across gaps in time series caused by equipment failures, comms failures, or inappropriately broad bandwidths. Interpolation was flagged in cases where a constant slope in MW or kV was detected across two or more time points. Repeated values were flagged in cases where an exact value was repeated for two or more time points. Interpolated and repeated values in kV and MW data were removed from the analysis.
	Negative and zero kV values	Negative and zero values in kV data were flagged and removed from the analysis data.

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[15] See page 22 in Volume 1, Version 8.0 of the TRM.

[16] Information on how much data was dropped for each utility is included in the Data Cleaning section of the document.

Utility	Step	Description
	Outliers	Outliers were screened on a feeder-by-feeder basis. Outliers are defined as hourly values that are greater than 3 times the standard deviation from the mean kV or MW for that specific feeder. Outliers on kV and MW were flagged and removed from the analysis.
	Excludable times	Ameren has expressed that a subset of VO events should be excluded in this analysis. The ICC verified whether or not specific VO events could be excluded. Types of VO events that were approved for exclusion were those that (1) had a circuit outage for any reason, (2) had repair or maintenance causing VO to be disabled, (3) had switching occurring (where VO was disabled due to any necessary switching event), and (4) had experienced a failure in information or communication technology. All events and associated kV and MW were dropped from the analysis.
	Feeder-season sufficiency *(seasonal effects model only)*	Evidence of improved goodness-of-fit under controls for seasonality led the research team to implement a series of models that control for seasonal impacts of VO. For each feeder, if a season did not contain at least 60 days of clean VO cycling data then the feeder-season combination was removed from the analysis.
	Peak day sufficiency *(peak demand CVRf only)*	The Guidehouse team required feeders eligible for peak demand analysis begin VO On/Off testing by August 1, 2019. Peak demand modeling included data spanning June 1 through August 31 non-holiday weekdays. This cleaning step required that the feeder's peak period data contain at least 20 peak days (approximately 1/3 of the total peak days) of clean VO On/Off cycling data.
ComEd	Remove extended VO on or off periods	For the feeders being analyzed, a VO On/Off cycling schedule was supposed to be followed consisting of 4 days on, 4 days off. Despite this, some feeders experienced periods of disruption to the On/Off cycling schedule. The Guidehouse team flagged periods of disruption as being 12 or more sustained days of either VO On or VO Off, which may indicate that one change to VO status was missed. If VO was On or Off for 12 or more days, the first 4 days of this 12 day period were used for analysis. All remaining time points with the same VO status beyond these 4 days were removed from the analysis. If VO was On or Off for 12 or fewer days, all time points associated with that VO status were retained for analysis, which allows for one VO status change to be missed for any feeder.
	Ensure seven months of VO cycling *(energy CVRf only)*	After removing the periods of sustained VO On and VO Off data, the Guidehouse team found some of the 299 feeders live by July 1, 2019 had relatively few time series data points to conduct analysis on. Given this, the Guidehouse team removed feeders that have fewer than 7 months of VO cycling data after removal of extended VO On or Off periods.
	Ensure 20 peak days of VO cycling *(peak demand CVRf only)*	After removing the periods of sustained VO On and VO Off data, the Guidehouse team found some of the 317 feeders live by August 1, 2019 had relatively few time series data points to conduct analysis on. Given this, the Guidehouse team removed feeders that had fewer than 20 peak days of VO cycling data after removal of extended VO On or Off periods.
	Removal of interpolated or repeated values	Prior evaluations of VO have revealed that SCADA systems commonly interpolate or repeat data inputs across gaps in time series caused by equipment failures, comms failures, or inappropriately broad bandwidths. Interpolation was flagged in cases where a constant slope in MW or kV was detected across two or more time points. Repeated values were flagged in cases where an exact value was repeated for two or more time points. Interpolated and repeated values in kV and MW data were removed from the analysis.

Utility	Step	Description
	Negative and zero kV values	Negative and zero values in kV data were flagged and removed from the analysis data.
	Outliers on MW	Outliers on MW were screened on a feeder-by-feeder basis. MW data points were flagged and removed differently depending on whether a feeder had distributed energy resources (DERs) connected. For feeders with DERs, MW data points were removed if they were lower than 50% of the feeder's peak load minus the feeder's total MW DER capacity, retaining some negative and zero MW values. For feeders without DERs, MW data points were removed if they were less than 10% of the feeder's peak load, removing all negative and zero MW values. For feeders with and without DERs, MW data points were removed if they were above 110% of the feeder's peak load.
	Outliers on kV	Outliers on kV were screened on a feeder-by-feeder basis. kV data points were removed if they were above 1.10 p.u. and below 0.90 p.u. of the nominal Line to Line (LL) voltage level.
	Missing values	Remove missing and non-numeric values in kV and MW from the analysis data.
	Insufficient observations after data cleaning *(energy CVRf only)*	The data cleaning steps above sometimes led to large swaths of data to be dropped for a specific feeder. If a feeder did not maintain at least 7 months of VO cycling data after data removal of interpolated & repeated values, zero & negative values, and outliers then the feeder was removed from the final analysis dataset.
	Insufficient observations after data cleaning *(peak demand CVRf only)*	If a feeder did not maintain at least 20 peak days of VO cycling data after data removal of interpolated & repeated values, zero & negative values, and outliers then the feeder was removed from the final analysis dataset.
	Feeder-season sufficiency *(seasonal effects model only)*	Evidence of improved goodness-of-fit under controls for seasonality led the research team to implement a series of models that control for seasonal impacts of VO. For each feeder, if a season did not contain at least 60 days of clean VO cycling data then the feeder-season combination was removed from the analysis.
	Peak day sufficiency *(peak demand CVRf only)*	The Guidehouse team required feeders eligible for peak demand analysis begin VO On/Off testing by August 1, 2019. Peak demand modeling included data spanning June 1 through August 31 non-holiday weekdays. This cleaning step required that the feeder's peak period data contain at least 20 peak days (approximately 1/3 of the total peak days) of clean VO On/Off cycling data.

Source: Guidehouse team

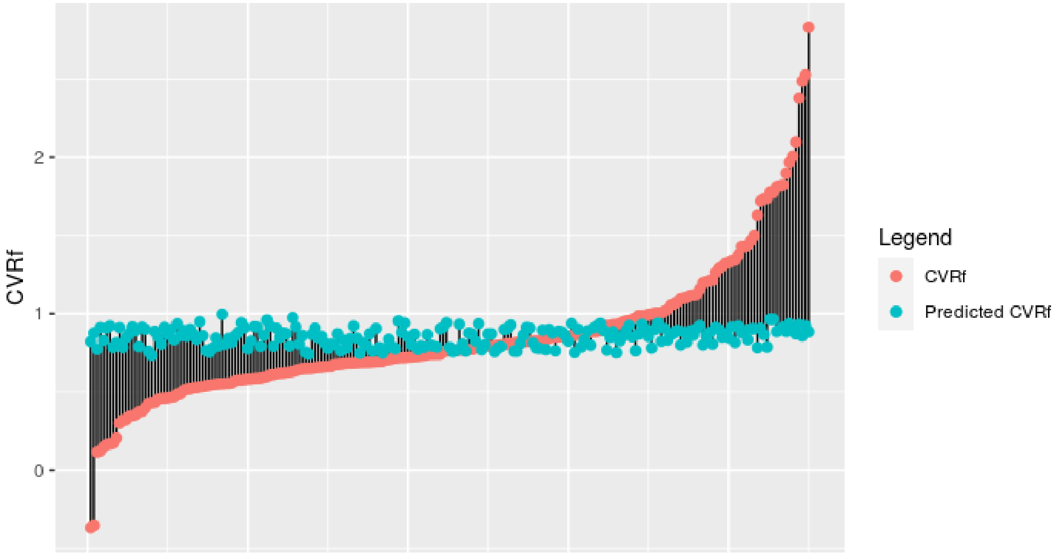
Building a Predictive CVRf Model

The Guidehouse team explored the possibility of creating a lookup table of CVR factors, based on a model relating feeder-level CVR factors and their associated feeder characteristics. The team hypothesized that factors such as load mix, DERs, etc., would impact the voltage reductions and subsequent energy savings from VO in a predictable way. This analysis did not result in a meaningful model between CVRf and feeder characteristics, but we are presenting the methodologies we employed here for completeness.

To facilitate a second-stage analysis, the Guidehouse team pulled together an array of feeder characteristics to determine whether energy CVR factors could be explained by observable characteristics. These included characteristics such as heating & cooling weather zones, urban/rural designations, percent of connected load that is residential or non-residential, length of the feeders in miles, and number of customers connected to the feeders.[17]

The Guidehouse team then attempted to explain variations in the feeder-level CVR factor as a function of available feeder characteristics. This was first conducted via regularized regression methods, including ridge regression, lasso regression, and elastic net regression. As shown in Figure 8, this was not terribly successful. The figure shows predicted versus actual CVRf values under the elastic net regression; the model was only capable of fitting CVRf values of 0.80 +/- 0.20, in contrast to the actual feeder-level energy CVRf values, which ranged between -1.00 and 3.00. Under numerous permutations of modeling using regularized regression the best-performing model's R^2 was at most 19 percent with a root mean squared error (RMSE) of 0.41.

Figure 5. Elastic Net Model – Predicted Versus Actual Energy CVRf



Source: Guidehouse team analysis

Following the observed poor fits obtained using regularized regression methods, the team then employed random forest modeling to investigate whether a nonlinear relationship was evident between feeder-level CVR factors and feeder characteristics. As shown in Figure 9 below, model fit under random forest models was slightly improved, particularly when examining predictions at the lower and upper tails of the CVRf distribution. Under random forest modeling, model R^2 was 56 percent with a RMSE of 0.37, an improvement over the regularized regression model.

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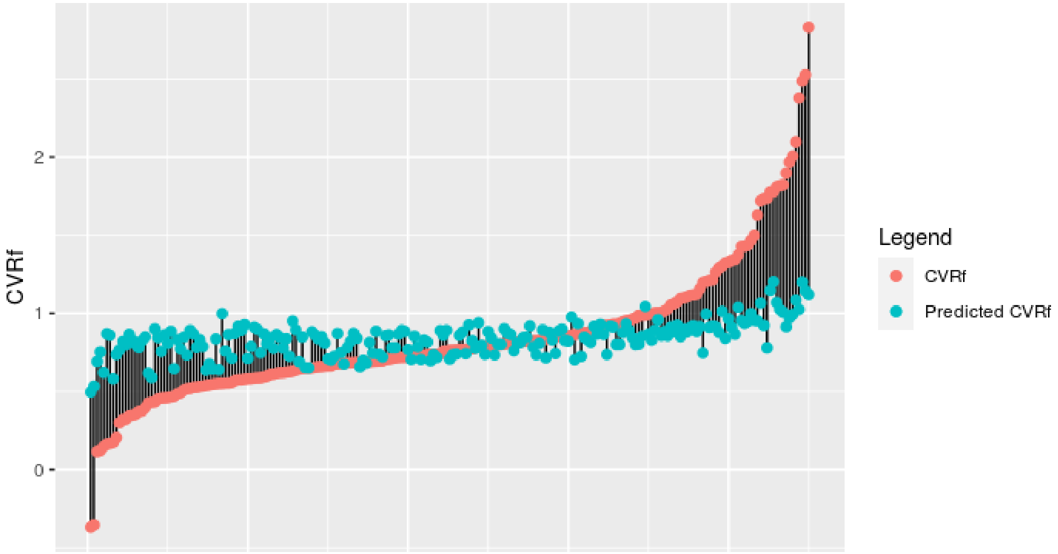
[17] Other characteristics that may drive energy CVRf, such as peak load, rated load, load factors, and distributed generation connected to the VO feeders were inconsistent between utilities or limited in scope. Given these data limitations, these VO feeder characteristics could not be included in the modeling efforts.

Figure 6. Random Forest Model – Predicted Versus Actual Energy CVRf



Source: Guidehouse team analysis

Although random forest modeling yielded improved model performance relative to regularized regression, the model still did a poor job of predicting CVRf. Therefore, we are not comfortable recommending a TRM lookup table be constructed based upon feeder characteristics at this time.

Energy CVRf Feeder-Level Findings

Table 4 below highlights findings from feeder-level regression analysis of energy and voltage reductions detailed in the Seasonal Model section. Corresponding energy CVRf findings for each feeder are provided in the far righthand column. The load-weighted statewide CVRf of 0.807 is provided at the bottom of the table and matches seasonal model, base data cleaning findings highlighted in Table 1.

Table 4. Energy CVRf Feeder-Level Regression Findings

Feeder	% Reduction MWh	SE % Reduction MWh	Adj. R^2 MWh	% Reduction kV	SE % Reduction kV	Adj. R^2 kV	CVRf
Feeder 1	2.451%	0.175%	99.548%	3.373%	0.432%	99.996%	0.727
Feeder 2	2.667%	0.181%	99.524%	3.375%	0.432%	99.996%	0.790
Feeder 3	2.468%	0.182%	99.511%	3.202%	0.434%	99.996%	0.771
Feeder 4	2.303%	0.196%	99.447%	2.832%	0.384%	99.997%	0.813
Feeder 5	3.473%	0.210%	99.399%	3.972%	0.532%	99.992%	0.874
Feeder 6	2.079%	0.226%	99.256%	3.539%	0.476%	99.997%	0.588
Feeder 7	2.409%	0.196%	99.449%	3.344%	0.450%	99.997%	0.720
Feeder 8	2.387%	0.231%	99.218%	3.440%	0.459%	99.998%	0.694
Feeder 9	2.335%	0.213%	99.351%	2.829%	0.381%	99.993%	0.825
Feeder 10	5.802%	0.406%	97.526%	3.560%	0.475%	99.998%	1.630

Feeder	% Reduction MWh	SE % Reduction MWh	Adj. R^2 MWh	% Reduction kV	SE % Reduction kV	Adj. R^2 kV	CVRf
Feeder 11	2.999%	0.374%	97.960%	4.059%	0.542%	99.996%	0.739
Feeder 12	3.774%	0.292%	98.785%	3.150%	0.423%	99.994%	1.198
Feeder 13	1.948%	0.177%	99.520%	3.598%	0.480%	99.998%	0.541
Feeder 14	2.164%	0.178%	99.523%	3.333%	0.445%	99.997%	0.649
Feeder 15	3.184%	0.163%	99.602%	3.809%	0.508%	99.996%	0.836
Feeder 16	2.308%	0.124%	99.765%	3.484%	0.465%	99.998%	0.663
Feeder 17	2.451%	0.159%	99.618%	4.217%	0.562%	99.993%	0.581
Feeder 18	2.171%	0.160%	99.655%	3.279%	0.438%	99.998%	0.662
Feeder 19	0.498%	0.499%	96.560%	4.337%	0.578%	99.998%	0.115
Feeder 20	3.307%	0.155%	99.653%	4.477%	0.560%	99.994%	0.739
Feeder 21	3.698%	0.198%	99.465%	4.353%	0.544%	99.993%	0.850
Feeder 22	3.969%	0.220%	99.294%	4.975%	0.622%	99.991%	0.798
Feeder 23	4.023%	0.195%	99.437%	5.823%	0.729%	99.990%	0.691
Feeder 24	3.470%	0.198%	99.413%	4.253%	0.536%	99.996%	0.816
Feeder 25	3.220%	0.194%	99.441%	4.402%	0.552%	99.993%	0.732
Feeder 26	3.062%	0.197%	99.413%	5.262%	0.663%	99.995%	0.582
Feeder 27	2.739%	0.210%	99.377%	3.757%	0.501%	99.995%	0.729
Feeder 28	3.239%	0.306%	98.618%	3.338%	0.445%	99.995%	0.970
Feeder 29	3.451%	0.330%	98.387%	4.343%	0.579%	99.993%	0.795
Feeder 30	2.758%	0.380%	97.980%	3.970%	0.530%	99.993%	0.695
Feeder 31	3.484%	0.353%	98.286%	3.772%	0.503%	99.995%	0.924
Feeder 32	4.026%	0.414%	97.534%	4.658%	0.622%	99.994%	0.864
Feeder 33	4.373%	0.466%	97.015%	4.385%	0.585%	99.994%	0.997
Feeder 34	8.487%	0.318%	98.430%	4.886%	0.652%	99.995%	1.737
Feeder 35	3.516%	0.410%	97.576%	5.190%	0.692%	99.993%	0.678
Feeder 36	3.287%	0.448%	97.315%	4.599%	0.614%	99.991%	0.715
Feeder 37	2.722%	0.393%	97.812%	4.040%	0.539%	99.993%	0.674
Feeder 38	3.414%	0.422%	97.544%	4.376%	0.584%	99.993%	0.780
Feeder 39	3.612%	0.443%	97.253%	4.235%	0.565%	99.994%	0.853
Feeder 40	2.484%	0.178%	99.522%	3.607%	0.481%	99.995%	0.689
Feeder 41	2.674%	0.161%	99.620%	3.881%	0.518%	99.995%	0.689
Feeder 42	1.930%	0.146%	99.687%	3.164%	0.422%	99.995%	0.610
Feeder 43	2.191%	0.206%	99.401%	3.930%	0.525%	99.994%	0.557
Feeder 44	2.239%	0.134%	99.739%	4.160%	0.560%	99.996%	0.538
Feeder 45	2.535%	0.184%	99.500%	3.509%	0.468%	99.996%	0.722
Feeder 46	3.339%	0.202%	99.407%	4.517%	0.603%	99.994%	0.739
Feeder 47	2.323%	0.324%	98.532%	4.219%	0.563%	99.993%	0.551
Feeder 48	2.036%	0.362%	98.300%	3.734%	0.498%	99.994%	0.545
Feeder 49	3.313%	0.266%	98.963%	4.318%	0.576%	99.995%	0.767

Feeder	% Reduction MWh	SE % Reduction MWh	Adj. R^2 MWh	% Reduction kV	SE % Reduction kV	Adj. R^2 kV	CVRf
Feeder 50	2.495%	0.262%	98.999%	3.667%	0.489%	99.993%	0.680
Feeder 51	2.648%	0.116%	99.799%	4.123%	0.550%	99.993%	0.642
Feeder 52	0.723%	0.367%	98.164%	4.184%	0.558%	99.988%	0.173
Feeder 53	3.470%	0.216%	99.338%	5.041%	0.672%	99.995%	0.688
Feeder 54	2.830%	0.129%	99.748%	4.144%	0.553%	99.996%	0.683
Feeder 55	3.213%	0.219%	99.313%	4.012%	0.535%	99.994%	0.801
Feeder 56	3.413%	0.244%	99.162%	4.136%	0.552%	99.995%	0.825
Feeder 57	3.481%	0.265%	98.935%	4.902%	0.654%	99.994%	0.710
Feeder 58	2.216%	0.256%	99.024%	4.009%	0.535%	99.995%	0.553
Feeder 59	2.457%	0.196%	99.432%	3.784%	0.509%	99.995%	0.649
Feeder 60	2.027%	0.168%	99.588%	4.757%	0.635%	99.990%	0.426
Feeder 61	1.846%	0.168%	99.573%	4.286%	0.572%	99.995%	0.431
Feeder 62	1.188%	0.671%	94.996%	4.240%	0.565%	99.988%	0.280
Feeder 63	2.363%	0.355%	98.540%	3.210%	0.428%	99.992%	0.736
Feeder 64	2.935%	0.187%	99.490%	4.688%	0.625%	99.991%	0.626
Feeder 65	3.073%	0.307%	98.574%	3.883%	0.518%	99.995%	0.792
Feeder 66	3.495%	0.217%	99.439%	3.852%	0.515%	99.988%	0.907
Feeder 67	3.300%	0.370%	98.403%	3.549%	0.474%	99.989%	0.930
Feeder 68	2.846%	0.193%	99.572%	3.075%	0.410%	99.991%	0.925
Feeder 69	4.344%	0.213%	99.441%	3.580%	0.478%	99.988%	1.213
Feeder 70	3.571%	0.225%	99.440%	3.845%	0.513%	99.987%	0.929
Feeder 71	3.704%	0.154%	99.336%	3.752%	0.290%	99.996%	0.987
Feeder 72	1.599%	0.261%	98.084%	1.918%	0.149%	99.994%	0.834
Feeder 73	0.819%	0.272%	97.737%	4.475%	0.345%	99.997%	0.183
Feeder 74	0.931%	0.286%	97.248%	4.020%	0.308%	99.996%	0.232
Feeder 75	3.081%	0.179%	98.835%	3.985%	0.306%	99.996%	0.773
Feeder 76	3.998%	0.172%	98.863%	4.019%	0.308%	99.996%	0.995
Feeder 77	2.473%	0.147%	99.182%	4.018%	0.308%	99.996%	0.616
Feeder 78	2.749%	0.129%	99.362%	4.018%	0.308%	99.996%	0.684
Feeder 79	4.457%	0.253%	97.670%	3.985%	0.306%	99.996%	1.119
Feeder 80	3.532%	0.200%	98.495%	3.984%	0.306%	99.996%	0.886
Feeder 81	3.279%	0.188%	98.662%	3.986%	0.306%	99.996%	0.823
Feeder 82	0.819%	0.195%	98.625%	3.987%	0.306%	99.996%	0.205
Feeder 83	2.291%	0.152%	99.138%	4.019%	0.308%	99.996%	0.570
Feeder 84	1.096%	0.136%	99.488%	1.703%	0.131%	99.997%	0.643
Feeder 85	5.565%	0.335%	96.896%	1.701%	0.131%	99.997%	3.272
Feeder 86	0.506%	0.239%	98.608%	1.703%	0.131%	99.997%	0.297
Feeder 87	2.504%	0.226%	98.645%	2.520%	0.193%	99.996%	0.994
Feeder 88	1.115%	0.248%	98.322%	2.518%	0.193%	99.996%	0.443

Feeder	% Reduction MWh	SE % Reduction MWh	Adj. R^2 MWh	% Reduction kV	SE % Reduction kV	Adj. R^2 kV	CVRf
Feeder 89	1.716%	0.229%	98.601%	2.519%	0.193%	99.996%	0.681
Feeder 90	1.478%	0.321%	97.473%	2.784%	0.215%	99.994%	0.531
Feeder 91	1.765%	0.178%	99.140%	2.787%	0.215%	99.994%	0.633
Feeder 92	2.106%	0.195%	98.747%	2.778%	0.215%	99.994%	0.758
Feeder 93	3.711%	0.207%	98.613%	2.770%	0.214%	99.994%	1.340
Feeder 94	0.122%	0.224%	98.393%	3.457%	0.266%	99.995%	0.035
Feeder 95	3.507%	0.463%	96.109%	3.441%	0.265%	99.995%	1.019
Feeder 96	0.303%	0.268%	98.196%	3.447%	0.265%	99.995%	0.088
Feeder 97	1.908%	0.410%	96.201%	3.446%	0.265%	99.995%	0.554
Feeder 98	3.784%	0.269%	97.844%	2.849%	0.221%	99.995%	1.328
Feeder 99	7.099%	0.372%	95.692%	2.854%	0.221%	99.995%	2.487
Feeder 100	3.303%	0.153%	99.202%	2.856%	0.221%	99.995%	1.156
Feeder 101	3.017%	0.169%	99.121%	3.660%	0.283%	99.995%	0.824
Feeder 102	3.335%	0.261%	97.947%	3.660%	0.283%	99.995%	0.911
Feeder 103	4.700%	0.245%	98.142%	3.659%	0.283%	99.995%	1.285
Feeder 104	2.599%	0.125%	99.466%	2.828%	0.219%	99.995%	0.919
Feeder 105	9.768%	0.252%	97.753%	2.829%	0.219%	99.995%	3.453
Feeder 106	1.662%	0.241%	98.477%	3.656%	0.283%	99.995%	0.455
Feeder 107	2.425%	0.139%	99.395%	2.849%	0.221%	99.995%	0.851
Feeder 108	0.237%	0.218%	98.508%	2.867%	0.222%	99.995%	0.083
Feeder 109	1.762%	0.214%	98.589%	2.845%	0.221%	99.995%	0.620
Feeder 110	2.064%	0.181%	98.965%	2.847%	0.221%	99.995%	0.725
Feeder 111	2.789%	0.194%	98.881%	2.812%	0.218%	99.995%	0.992
Feeder 112	-1.194%	0.272%	97.822%	3.659%	0.283%	99.995%	-0.326
Feeder 113	2.840%	0.181%	98.828%	4.119%	0.315%	99.994%	0.689
Feeder 114	7.490%	0.366%	95.140%	4.121%	0.315%	99.994%	1.818
Feeder 115	1.999%	0.149%	99.150%	4.119%	0.315%	99.994%	0.485
Feeder 116	5.658%	0.365%	95.212%	4.117%	0.315%	99.994%	1.374
Feeder 117	2.040%	0.183%	98.774%	3.721%	0.286%	99.993%	0.548
Feeder 118	4.133%	0.138%	99.284%	3.706%	0.284%	99.993%	1.115
Feeder 119	5.570%	0.234%	97.957%	3.715%	0.285%	99.993%	1.499
Feeder 120	3.398%	0.246%	98.003%	3.686%	0.283%	99.993%	0.922
Feeder 121	2.947%	0.185%	98.739%	3.716%	0.285%	99.993%	0.793
Feeder 122	2.437%	0.193%	98.763%	3.702%	0.284%	99.993%	0.658
Feeder 123	1.489%	0.135%	99.307%	2.490%	0.195%	99.997%	0.598
Feeder 124	3.982%	0.148%	99.187%	3.548%	0.273%	99.995%	1.122
Feeder 125	3.905%	0.174%	98.859%	3.552%	0.273%	99.995%	1.099
Feeder 126	3.743%	0.209%	98.428%	3.549%	0.273%	99.995%	1.055
Feeder 127	3.317%	0.163%	99.033%	3.550%	0.273%	99.995%	0.934

Feeder	% Reduction MWh	SE % Reduction MWh	Adj. R^2 MWh	% Reduction kV	SE % Reduction kV	Adj. R^2 kV	CVRf
Feeder 128	3.101%	0.235%	97.947%	3.497%	0.268%	99.995%	0.887
Feeder 129	1.125%	0.361%	95.829%	3.513%	0.269%	99.996%	0.320
Feeder 130	2.363%	0.168%	98.984%	3.498%	0.268%	99.995%	0.676
Feeder 131	31.748%	1.420%	74.794%	3.512%	0.269%	99.996%	9.039
Feeder 132	1.130%	0.172%	98.943%	3.515%	0.269%	99.996%	0.321
Feeder 133	1.222%	0.445%	93.262%	3.515%	0.269%	99.996%	0.348
Feeder 134	1.915%	0.212%	98.869%	3.697%	0.285%	99.996%	0.518
Feeder 135	2.851%	0.205%	98.856%	3.692%	0.284%	99.996%	0.772
Feeder 136	0.547%	0.212%	98.851%	3.693%	0.284%	99.996%	0.148
Feeder 137	1.599%	0.158%	99.326%	3.694%	0.284%	99.996%	0.433
Feeder 138	1.464%	0.153%	99.346%	3.693%	0.284%	99.996%	0.396
Feeder 139	4.771%	0.174%	99.160%	3.696%	0.284%	99.995%	1.291
Feeder 140	0.451%	0.177%	99.159%	3.694%	0.284%	99.995%	0.122
Feeder 141	1.948%	0.229%	98.616%	3.697%	0.284%	99.995%	0.527
Feeder 142	2.527%	0.215%	98.778%	3.698%	0.284%	99.995%	0.683
Feeder 143	1.811%	0.199%	98.943%	3.697%	0.284%	99.995%	0.490
Feeder 144	3.244%	0.276%	97.958%	3.695%	0.284%	99.995%	0.878
Feeder 145	10.464%	0.202%	98.851%	3.695%	0.284%	99.996%	2.832
Feeder 146	1.918%	0.177%	99.172%	3.694%	0.284%	99.996%	0.519
Feeder 147	3.165%	0.217%	98.669%	4.033%	0.311%	99.995%	0.785
Feeder 148	2.725%	0.227%	98.391%	4.119%	0.315%	99.994%	0.661
Feeder 149	4.620%	0.190%	98.742%	3.546%	0.273%	99.995%	1.303
Feeder 150	1.972%	0.208%	98.863%	3.693%	0.284%	99.996%	0.534
Feeder 151	-0.464%	0.554%	93.123%	4.540%	0.350%	99.996%	-0.102
Feeder 152	2.663%	0.156%	99.140%	4.334%	0.335%	99.995%	0.615
Feeder 153	2.468%	0.172%	98.894%	3.984%	0.306%	99.996%	0.620
Feeder 154	3.950%	0.245%	98.366%	4.655%	0.358%	99.994%	0.849
Feeder 155	2.832%	0.130%	99.444%	4.170%	0.321%	99.997%	0.679
Feeder 156	3.836%	0.225%	98.498%	4.583%	0.352%	99.997%	0.837
Feeder 157	3.685%	0.284%	97.716%	2.518%	0.193%	99.996%	1.464
Feeder 158	3.063%	0.268%	98.166%	3.496%	0.267%	99.995%	0.876
Feeder 159	2.483%	0.229%	98.253%	3.515%	0.269%	99.996%	0.706
Feeder 160	2.247%	0.210%	98.598%	2.494%	0.195%	99.997%	0.901
Feeder 161	1.314%	0.162%	99.091%	2.492%	0.195%	99.997%	0.527
Feeder 162	3.253%	0.377%	96.490%	3.493%	0.267%	99.995%	0.931
Feeder 163	6.466%	0.305%	96.872%	4.514%	0.347%	99.996%	1.432
Feeder 164	3.752%	0.196%	98.955%	3.630%	0.280%	99.992%	1.033
Feeder 165	3.667%	0.284%	98.077%	4.312%	0.333%	99.997%	0.850
Feeder 166	3.111%	0.230%	98.338%	4.328%	0.334%	99.995%	0.719

Feeder	% Reduction MWh	SE % Reduction MWh	Adj. R^2 MWh	% Reduction kV	SE % Reduction kV	Adj. R^2 kV	CVRf
Feeder 167	2.076%	0.304%	97.274%	4.374%	0.337%	99.995%	0.475
Feeder 168	3.812%	0.238%	98.101%	4.310%	0.332%	99.995%	0.884
Feeder 169	-4.332%	0.693%	88.748%	3.511%	0.269%	99.996%	-1.234
Feeder 170	3.480%	0.262%	97.851%	4.606%	0.354%	99.997%	0.756
Feeder 171	1.528%	0.260%	98.394%	1.709%	0.132%	99.997%	0.894
Feeder 172	4.606%	0.200%	98.756%	3.536%	0.272%	99.995%	1.303
Feeder 173	-4.841%	0.670%	89.945%	3.494%	0.267%	99.995%	-1.386
Feeder 174	7.523%	0.520%	92.886%	3.842%	0.296%	99.995%	1.958
Feeder 175	7.191%	0.270%	98.607%	3.234%	0.249%	99.995%	2.224
Feeder 176	1.904%	0.253%	98.920%	2.954%	0.229%	99.995%	0.645
Feeder 177	0.331%	0.336%	98.134%	2.946%	0.228%	99.995%	0.112
Feeder 178	2.310%	0.352%	98.008%	3.238%	0.249%	99.995%	0.713
Feeder 179	3.138%	0.302%	98.423%	3.238%	0.249%	99.995%	0.969
Feeder 180	5.792%	0.246%	98.869%	3.251%	0.250%	99.996%	1.782
Feeder 181	4.155%	0.689%	91.720%	3.234%	0.249%	99.995%	1.285
Feeder 182	0.730%	0.391%	97.848%	3.240%	0.250%	99.995%	0.225
Feeder 183	7.352%	0.279%	98.662%	3.239%	0.249%	99.995%	2.270
Feeder 184	1.514%	0.337%	98.197%	3.240%	0.249%	99.995%	0.467
Feeder 185	6.877%	0.260%	98.737%	2.946%	0.228%	99.995%	2.334
Feeder 186	1.502%	0.277%	98.703%	2.954%	0.229%	99.995%	0.508
Feeder 187	2.649%	0.183%	99.436%	3.235%	0.249%	99.995%	0.819
Feeder 188	2.781%	0.248%	98.980%	3.235%	0.249%	99.995%	0.860
Feeder 189	14.300%	0.309%	98.039%	3.249%	0.250%	99.996%	4.401
Feeder 190	2.564%	0.243%	98.007%	4.462%	0.344%	99.997%	0.575
Feeder 191	4.648%	0.374%	96.320%	3.887%	0.300%	99.994%	1.196
Feeder 192	2.635%	0.307%	97.471%	4.091%	0.315%	99.994%	0.644
Feeder 193	3.283%	0.253%	98.063%	3.884%	0.298%	99.991%	0.845
Feeder 194	5.036%	0.260%	98.223%	4.661%	0.358%	99.995%	1.080
Feeder 195	2.112%	0.353%	96.670%	4.965%	0.375%	99.995%	0.425
Feeder 196	8.224%	0.348%	96.293%	4.352%	0.333%	99.995%	1.890
Feeder 197	4.077%	0.218%	98.596%	4.966%	0.376%	99.995%	0.821
Feeder 198	4.880%	0.209%	98.738%	4.966%	0.376%	99.995%	0.983
Feeder 199	2.942%	0.124%	99.547%	4.966%	0.376%	99.995%	0.592
Feeder 200	4.591%	0.191%	98.964%	4.966%	0.376%	99.995%	0.925
Feeder 201	0.925%	0.217%	98.616%	4.351%	0.333%	99.995%	0.212
Feeder 202	3.261%	0.203%	98.795%	4.966%	0.376%	99.995%	0.657
Feeder 203	2.881%	0.204%	98.784%	4.352%	0.333%	99.995%	0.662
Feeder 204	1.002%	0.198%	99.076%	1.428%	0.112%	99.998%	0.702
Feeder 205	2.103%	0.232%	98.616%	1.461%	0.114%	99.998%	1.440

Feeder	**% Reduction MWh**	**SE % Reduction MWh**	**Adj. R^2 MWh**	**% Reduction kV**	**SE % Reduction kV**	**Adj. R^2 kV**	**CVRf**
Feeder 206	3.466%	0.157%	99.281%	4.351%	0.333%	99.995%	0.797
Feeder 207	2.498%	0.336%	97.020%	3.302%	0.255%	99.993%	0.757
Feeder 208	0.941%	0.172%	99.235%	1.461%	0.114%	99.998%	0.644
Feeder 209	4.672%	0.215%	98.650%	4.423%	0.342%	99.995%	1.056
Feeder 210	4.068%	0.186%	99.156%	4.149%	0.320%	99.995%	0.981
Feeder 211	0.363%	0.192%	99.063%	1.430%	0.112%	99.998%	0.254
Feeder 212	2.273%	0.240%	98.571%	1.436%	0.111%	99.998%	1.583
Feeder 213	2.019%	0.142%	99.480%	1.436%	0.111%	99.998%	1.406
Feeder 214	0.091%	0.308%	97.716%	1.437%	0.111%	99.998%	0.063
Feeder 215	0.276%	0.242%	98.632%	1.435%	0.111%	99.998%	0.192
Feeder 216	4.162%	0.274%	98.068%	4.616%	0.356%	99.996%	0.902
Feeder 217	4.355%	0.245%	98.646%	4.402%	0.340%	99.997%	0.989
Feeder 218	1.230%	0.134%	99.533%	1.430%	0.112%	99.998%	0.860
Feeder 219	1.744%	0.301%	97.722%	1.429%	0.112%	99.998%	1.220
Feeder 220	0.687%	0.107%	99.708%	1.429%	0.112%	99.998%	0.481
Feeder 221	0.699%	0.217%	98.839%	1.430%	0.112%	99.998%	0.489
Feeder 222	3.825%	0.283%	97.950%	4.481%	0.345%	99.996%	0.854
Feeder 223	1.977%	0.160%	99.350%	1.436%	0.111%	99.998%	1.377
Feeder 224	0.701%	0.082%	99.828%	1.437%	0.111%	99.998%	0.488
Feeder 225	-2.852%	0.297%	97.916%	1.436%	0.111%	99.998%	-1.986
Feeder 226	2.106%	0.251%	98.359%	1.461%	0.114%	99.998%	1.442
Feeder 227	0.647%	0.227%	98.693%	1.461%	0.114%	99.998%	0.443
Feeder 228	0.760%	0.234%	98.621%	1.461%	0.114%	99.998%	0.520
Feeder 229	0.931%	0.128%	99.567%	1.408%	0.110%	99.998%	0.661
Feeder 230	0.849%	0.181%	99.179%	1.408%	0.110%	99.998%	0.603
Feeder 231	2.014%	0.269%	98.238%	1.408%	0.110%	99.998%	1.430
Feeder 232	0.765%	0.236%	98.614%	1.408%	0.110%	99.998%	0.543
Feeder 233	0.995%	0.112%	99.677%	1.437%	0.111%	99.998%	0.692
Feeder 234	2.770%	0.208%	98.890%	1.436%	0.111%	99.998%	1.930
Feeder 235	3.469%	0.195%	99.008%	1.408%	0.110%	99.998%	2.463
Feeder 236	3.125%	0.199%	98.915%	4.349%	0.332%	99.995%	0.719
Feeder 237	1.655%	0.230%	98.642%	4.155%	0.319%	99.992%	0.398
Feeder 238	3.317%	0.201%	98.888%	3.652%	0.284%	99.996%	0.908
Feeder 239	2.675%	0.280%	98.157%	3.160%	0.241%	99.994%	0.847
Feeder 240	4.067%	0.280%	98.045%	3.350%	0.255%	99.993%	1.214
Feeder 241	3.988%	0.252%	98.447%	3.349%	0.254%	99.993%	1.191
Feeder 242	2.574%	0.155%	99.346%	2.570%	0.197%	99.996%	1.001
Feeder 243	1.552%	0.172%	99.222%	2.570%	0.197%	99.996%	0.604
Feeder 244	1.455%	0.213%	98.847%	2.571%	0.197%	99.996%	0.566

Feeder	% Reduction MWh	SE % Reduction MWh	Adj. R^2 MWh	% Reduction kV	SE % Reduction kV	Adj. R^2 kV	CVRf
Feeder 245	2.491%	0.177%	99.159%	2.570%	0.197%	99.996%	0.969
Feeder 246	1.540%	0.194%	98.993%	2.570%	0.197%	99.996%	0.599
Statewide	NA	NA	NA	NA	NA	NA	0.807

Source: Guidehouse team analysis