Opinion Dynamics

Boston | Headquarters

617 492 1400 tel
617 497 7944 fax
800 966 1254 toll free

1000 Winter St
Waltham, MA 02451

Ameren Illinois Company 2019 Voltage Optimization Program Impact Evaluation Report

Final
April 30, 2020

Table of Contents

Table of Tables

Table of Figures

Table of Equations

1. Executive Summary

This report presents the impact evaluation results from Ameren Illinois Company's (AIC) Voltage Optimization (VO) energy efficiency program implemented during 2019. The objective of the 2019 impact evaluation was to determine energy and peak demand savings associated with the VO program.

1.1 Background

VO is a form of energy efficiency technology implemented by electric utilities at the distribution substation or circuit level that optimizes voltage levels along distribution circuits to reduce electricity usage. AIC's VO Program implements hardware, software and communications solutions using VO technologies. There are two main VO technologies: Conservation Voltage Reduction (CVR) and Volt-VAR Optimization (VVO). CVR reduces customer energy consumption by reducing line voltage and VVO improves the power factor to reduce line losses. Once implemented, VO technologies are intended to operate 24 hours a day, 365 days a year.

By 2024, AIC anticipates deploying VO on 1,047[1] circuits. Prior to the program launch, AIC identified multiple technology upgrades required to deploy the VO Program successfully. In 2017, AIC began installing VO hardware, software, and communications components on a subset of the 1,047 eligible circuits[2] on a phased basis. As defined in the AIC Voltage Optimization Plan,[3] AIC will claim savings only for VO circuits that were operational during a full calendar year. Therefore, 2019 represents the first year in which AIC is claiming energy savings for the program.

In 2018, Opinion Dynamics conducted a series of evaluation activities to ensure data sufficiency and program evaluability. In 2019, our evaluation activities included estimating the energy and peak demand savings from 19 circuits that were deployed during 2018 and therefore evaluated in the 2019 program year.[4]

[1] The number of circuits planned for VO deployment was determined based on calculated assumptions, industry results, and past AIC VO pilot results. The actual number of circuits with VO could fluctuate based on deployment results.

[2] AIC staff used voltage level as the primary criteria for establishing the initial pool of potential candidate circuits and excluded circuits served by voltage levels > 20 kilovolt (kV) or that serve only exempt customers (a customer whose highest 15-minute demand is at or greater than 10 MW). In addition, only circuits that were estimated to be cost-effective based on a TRC test were deemed "eligible."

[3] Ameren Illinois Voltage Optimization Plan, filed in ICC Docket 18-0211 on January 25, 2018. Accessed at: https://www.icc.illinois.gov/downloads/public/edocket/463457.pdf

[4] Note that AIC also deployed VO on 125 additional circuits during 2019. These 125 circuits will be evaluated as part of the 2020 evaluation.

1.2 2019 VO Program Savings

1.2.1 Annual Savings

In 2019, the evaluation team estimated energy and peak demand savings for the 19 operational circuits. Overall, the VO Program achieved 9,175 MWh of energy savings and 0.817 MW of peak demand savings (Table 1).

Table 1. 2019 VO Program Annual Savings

	Energy Savings (MWh)	Demand Savings (MW)	Gas Savings (Therms)
Ex Ante Gross Savings	7,849[a]	N/A[b]	N/A
Gross Realization Rate	117%	N/A	N/A
Verified Gross Savings	9,175	0.817	N/A
NTGR	N/A	N/A	N/A
Verified Net Savings	9,175	0.817	N/A

[a] Ex ante gross savings sourced from AIC. Ex ante gross savings assumes 0.80 CVR factor and 3% voltage reduction across the 19 measured circuits.
[b] There are no ex ante demand savings estimates for this program.

1.2.2 Cumulative Persisting Annual Savings

Table 2 summarizes cumulative persisting annual savings (CPAS) and the weighted average measure life (WAML) for the 2019 VO Program.[5] The overall WAML for the VO Program is 15 years. For additional detail around CPAS and measure life, please see Appendix B of this report.

Table 2. 2019 VO Program CPAS and WAML

Measure	Measure Life	First-Year Verified Gross Savings (MWh)	NTGR	CPAS – Verified Net Savings (MWh)							Lifetime Savings (MWh)
				2018	2019	2020	2021	…	2030	…	
Voltage Optimization – 2019 Cohort	15.0	9,175	N/A		9,175	9,175	9,175	…	9,175	…	137,619
2019 CPAS		**9,175**	**N/A**		**9,175**	**9,175**	**9,175**	**…**	**9,175**	**…**	**137,619**
Expired 2019 CPAS					0	0	0		0		
Expiring 2019 CPAS					0	0	0		0		
WAML	**15.0**										

[5] For background on CPAS and WAML, please review the forthcoming Ameren Illinois Residential Program Annual Impact Evaluation Report or Business Program Annual Impact Evaluation Report.

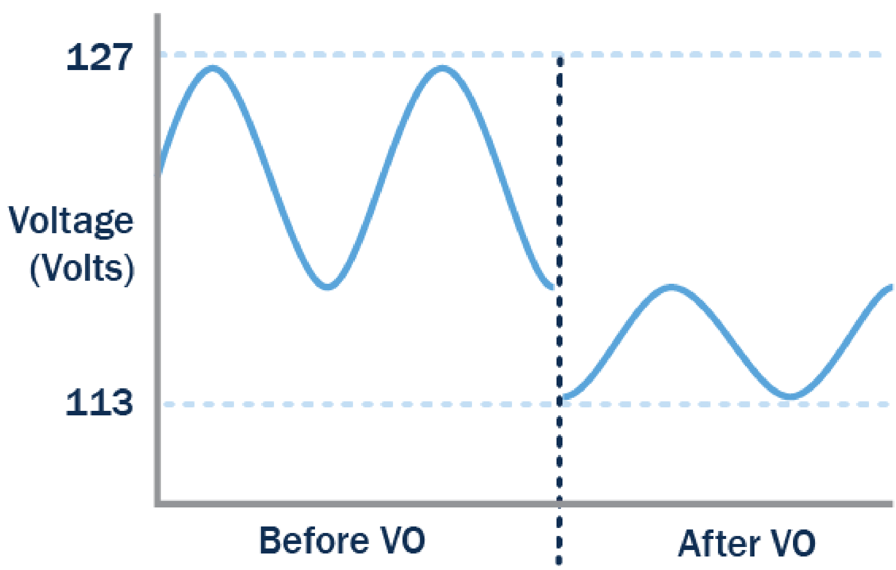
2. Overview of VO Program

Illinois Senate Bill 2814 (the Future Energy Jobs Act [FEJA]) Section 8-103(b-20) defined voltage optimization as an energy efficiency measure. It directed AIC to make a cost-effective voltage optimization investment as part of its energy efficiency portfolio.

2.1 Voltage Optimization Background

VO is a form of energy efficiency technology implemented by electric utilities at the distribution substation or circuit level that optimizes voltage levels along distribution circuits to reduce electricity usage by reducing power consumed by connected loads. AIC defines VO as a combination of VVO and CVR, which are implemented first to reduce the VAR[6] flows on a circuit, and then lower the voltage to reduce enduse customer energy consumption and utility distribution system losses. VVO optimizes capacitor bank operations to improve power factor and reduce system losses. CVR utilizes voltage regulators, transformer load tap changers, and capacitors to control and reduce enduser voltages, which, in turn, lowers customers' energy consumption. In other words, these technologies reduce distribution line voltage by regulating voltage in the lower portion of the allowable range. Historically, utilities have regulated voltage in the upper portion of the range to avoid low-voltage violations. Regulating voltage in the lower portion of the range does not compromise power quality. At lower voltage due to VO technologies (Figure 1), most enduses use less energy.

Figure 1. Illustration of VO Effect on Voltage



VO technologies can operate 24 hours a day, 365 days a year. Energy savings are predominantly driven through enduse load reduction, and to a lesser extent, distribution line loss reductions. AIC's VO program was developed to provide energy savings, not peak demand savings. However, there will naturally be some demand reduction on some circuits during the hours of operation of the system in a given year.

[6] This is referred to as reactive power and is measured in Volt-Amperes Reactive or VAR.

2.2 Program Description

In order to comply with Section 8-103B(b-20) of FEJA and to achieve energy savings to support its energy efficiency portfolio goals, AIC developed the VO Program as described in the Ameren Illinois Voltage Optimization Plan.[7] Per the plan, AIC anticipates deploying VO on all circuits for which it is estimated to be cost-effective by 2024. The number of circuits for VO deployment was determined to be 1,047, based on calculated assumptions, industry results, and past AIC VO pilot results. The actual number of circuits with VO could fluctuate based on deployment results.

Before the program launch, AIC identified multiple technology upgrades required to deploy VO. In 2017 AIC began installing VO hardware, software, and communications components on a subset of the 1,047 eligible circuits on a phased basis using four different VO vendor solutions: Utilidata, DVI, OSI, and ABB. AIC staff used voltage level as the primary criteria for establishing the initial pool of potential candidate circuits and excluded circuits served by voltage levels > 20 kilovolt (kV), or that served only exempt customers (a customer whose highest 15-minute demand is at or greater than 10 MW). Throughout 2019, AIC continued to deploy VO on a subset of eligible circuits, with 125 circuits made operational by the close of 2019.

VO is a major part of AIC's 2018-2021 energy efficiency plan. Per AIC's most recent compliance filing,[8] VO is expected to produce 7,650 MWh in energy savings in 2019, about 2% of AIC's estimated 2019 portfolio goal. However, VO deployment is expected to ramp up dramatically throughout the remainder of the plan period. It is expected to produce over 68,000 incremental MWh, nearly 20% of AIC's estimated total annual portfolio goal in 2021.[9] Table 3 provides AIC's original implementation plan and savings estimates for the VO program.

Table 3. VO Implementation Plan

Year Ending	2018	2019	2020	2021	2022	2023	2024	2025
Estimated Cumulative Persisting Annual Savings (MWh)	0	7,650	59,994	128,433	201,725	275,006	348,287	421,568
% Annual Cumulative Persisting Savings	0%	0.03%	0.21%	0.46%	0.72%	0.98%	1.25%	1.50%
Estimated Incremental # of Circuits Deployed	19	130	170	182	182	182	182	0
Estimated Incremental Construction Cost (Capital Cost)	$2M	$14M	$18M	$19M	$19M	$19M	$19M	$0
Estimated Incremental Total Investment Cost (Construction Capital, Construction O&M, Upfront Capital)	$5M	$17M	$20M	$20M	$20M	$20M	$20M	$0

Source: Ameren Illinois Voltage Optimization Plan.

[7] Ameren Illinois Voltage Optimization Plan, filed in ICC Docket 18-0211 on January 25, 2018. Accessed at: https://www.icc.illinois.gov/downloads/public/edocket/463457.pdf

[8] Appendix B to AIC's 2018-2021 EE Plan, revised as part of the February 19, 2019 compliance filing in ICC Docket 17-0311. Accessed at: https://icc.illinois.gov/downloads/public/edocket/492911.pdf

[9] AIC's most recent compliance filing indicates that 68,441 incremental MWh are expected from VO in 2021, which is an increase from original estimates provided in the Voltage Optimization plan – hence the disagreement between this value and Table 3.

2.3 VO Circuits Summary

Table 4 presents the 2019 evaluated VO circuits. This table includes the substation and circuit name for each circuit as well as various circuit characteristics that may, potentially, affect voltage reductions. Notably, AIC prioritized low income customers as part of its VO deployment.[10]

Table 4. 2019 Evaluated VO Circuits

Substation	Circuit	Division	Line Length (Miles)	% Res.	% Comm.	% Large C&I	Voltage Level (kV)	Year Deployed	Low Income Customers
Northwest	B00002	1	12.398	92.90%	7.00%	0.10%	7.62	2018	469
Northwest	B00003	1	11.951	87.70%	11.80%	0.40%	7.62	2018	179
Ridge	C52001	3	13.637	89.80%	10.10%	0.10%	7.2	2018	587
Ridge	C52002	3	9.85	90.60%	9.40%	0.00%	7.2	2018	436
Limit	D31015	3	9.225	76.90%	22.90%	0.20%	7.2	2018	473
Bethalto	J34357	5	23.828	98.10%	1.80%	0.10%	7.2	2018	422
Bethalto	J34377	5	28.604	90.20%	9.60%	0.10%	7.2	2018	819
Belleville 44th Street	J83140	6	15.823	95.10%	4.80%	0.10%	7.2	2018	799
Caseyville Gardens	K11376	5	17.404	93.40%	6.40%	0.20%	7.2	2018	566
E. Belleville	L93132	6	18.664	90.70%	9.00%	1.00%	7.2	2018	411
Mt. Vernon 27th St	P58155	6	16.085	94.30%	5.50%	0.10%	7.2	2018	615
Mt. Zion Rte 121	P69173	3	81.865	91.70%	8.20%	0.10%	7.2	2018	414
Quincy 24th and Cherry	V40556	2	11.317	98.50%	1.40%	0.10%	7.2	2018	410
Quincy 28th and Adams	V41533	2	12.01	90.70%	9.30%	0.00%	7.2	2018	419
Quincy 30 & Hamp	V42572	2	7.474	86.50%	13.10%	0.50%	7.2	2018	188
Quincy 36 & College	V45574	2	4.042	46.00%	51.10%	2.80%	7.2	2018	52
Charleston S. EIU	X35501	4	14.4	87.90%	11.80%	0.30%	7.2	2018	398
Shelbyville-West	Y79500	4	18.337	87.00%	12.20%	0.90%	7.2	2018	296
Tuscola East CP	Y98532	4	10.018	81.30%	17.90%	0.80%	7.2	2018	175

Source: AIC

[10] Ameren Illinois Voltage Optimization Low Income Prioritization Strategy, February 2019. Accessed at: https://s3.amazonaws.com/ilsag/AIC_VO_Low_Income_Prioritization_Strategy_February_2019_FINAL.pdf

3. Evaluation Approach

3.1 Research Objectives

Per the ICC Final Order in Docket 18-0211, the 2019 evaluation approach is governed by the AIC VO Plan mentioned above as well as a stipulated agreement reached between AIC and intervening parties,[11] which prescribes the use of an algorithmic approach to estimating electric *energy* savings from VO for the 2019 and 2020 program years.[12] Concurrently, the evaluation team will determine whether any modifications are needed to the algorithmic approach or its underlying parameter assumptions.[13]

In this report, the VO evaluation team addresses the following key research questions:

- What are the estimated energy savings from VO calculated with the algorithmic approach?
- What are the estimated peak demand savings from VO?

Additionally, our team conducted a limited process evaluation, which included annual interviews with program staff as well as a mid-year data review. This activity aided the evaluation team's understanding of the status of the program, informed the team of key developments made as the program matures, and ensured the evaluability of the program based on data availability and coverage.

3.2 Verified Impact Analysis Approach

As described above, this evaluation estimated annual energy savings and peak demand savings resulting from the VO Program. The 2019 evaluation claims savings for the 19 circuits, which were operational as of January 1, 2019.

Energy Savings Methodology

The method used to calculate savings due to VO in 2019 is an algorithmic approach that utilizes parameter assumptions established via a pilot study in AIC territory, along with other primary research findings from similar studies conducted in other jurisdictions. The algorithm includes a conservation voltage reduction factor (CVR_f), annual energy use, and the percent change in voltage. Key assumptions include an expected 3% voltage reduction across VO circuits and a corresponding electricity reduction of 2.4%, which results in an assumed 0.8 CVR_f.[14] This approach is a common method for calculating energy savings due to VO and has been used previously in other jurisdictions.

[11] Stipulated agreement filed on March 22, 2018 in ICC Docket 18-0211. Accessed at: https://www.icc.illinois.gov/downloads/public/edocket/469727.pdf

[12] The AIC VO Plan and stipulation do not address the methodology to be used in determining peak demand savings but indicate that an assessment of peak demand savings should be conducted. The evaluation team therefore developed methodology to do so, which is described later in this report.

[13] Results from this research will be provided in a separate, forthcoming deliverable supporting the development of IL-TRM V9.0.

[14] For additional information on energy savings calculation approaches, see Opinion Dynamics (2019) AIC Voltage Optimization Evaluation Plan for the 2018-2021 Plan Period.

The algorithm used for AIC's VO program evaluation is shown in Equation 1.

Equation 1. AIC VO Savings Algorithm

$$Annual\ Energy\ Savings_i = Annual\ Energy\ Use_{2014-2016_i} * CVR_f * \%\Delta V_i$$

Where:

- $Annual\ Energy\ Use_{2014-2016_i}$ = the average annual customer energy use for circuit *i* over the 2014-2016 timeframe, excluding the exempt customers.
- CVR_f = the estimate of the conservation voltage reduction factor (deemed as 0.80), defined as the percent change in energy usage divided by the percent change in voltage.[15]
- $\%\Delta V_i$= the percent change in voltage for circuit *i* resulting from VO implementation relative to VO turned off, calculated with randomly 3-day VO-on periods and 3-day VO-off periods using a regression model to control for exogenous factors that may contribute to changes in voltage (e.g., weather).

The evaluation team estimated each algorithmic input, as outlined in Table 5.

Table 5. Algorithmic Approach Input and Description

Input	Description	Approach
Annual Energy Use	The average annual customer energy use over the 2014-2016 timeframe excluding the exempt customers per circuit	Calculated sum of circuit-specific energy consumption drawn from AIC. Source: "AVG_MWH_QF" value in "Circuit Characteristics Dataset 1047 Circuits 2018 File_9.23.19 Update.xlsx"
CVRf	The estimate of the conservation voltage reduction factor, which represents the percent change in load for each percent change in voltage	Deemed value of 0.80
%ΔV	The percent change in voltage resulting from VO implementation relative to VO turned off for each circuit	Calculated with randomly 3-day VO-on periods and 3-day VO-off periods using an hourly regression model to control for exogenous factors that may contribute to changes in voltage (e.g., weather) for each circuit

Peak Demand Savings Methodology

To provide estimates of peak demand savings, the evaluation team conducted a pooled regression model for all 19 circuits. This analysis estimated energy savings for non-holiday weekdays between June 1 and August 31, which is defined as the peak period 1-5 PM Central Prevailing Time in the IL-TRM V7.0.[16] As outlined in the Stipulation, this evaluation report includes "an impact evaluation of the peak demand reduction savings at the time of the evaluation to determine what peak demand reduction has been achieved by the VO investments. The Stipulating Parties agree that such information would not impact the energy savings goals set in this ICC Docket No. 18-0211, but the information, if quantifiable, would be used to conduct future TRC calculations when considering future investments, including and in addition to those identified in the VO Plan

[15] Per the Stipulation, Ameren Illinois' proposed deeming of its 0.8 CVR factor shall apply to 2019 and 2020 claimed savings, from circuits on which VO is installed in 2017, 2018 and 2019.
[16] Illinois Statewide Technical Reference Manual Version 7.0, Volume 1, Section 3.6.

approved in ICC Docket No. 18-0211. The peak demand savings evaluation results for VO will also be submitted to the IL-TRM Update Process."[17]

Consideration of Net Effects

Because AIC is the sole operator and "participant" in the VO Program, no adjustments to savings are made to reflect net effects (free-ridership and spillover) often present for other energy efficiency programs.

3.3 Sources and Mitigation of Error

Because this evaluation was reliant upon a statistical analysis to estimate the change in voltage and peak demand, we also designed our analysis to address the following types of error:

- **Model Specification Error:** The most difficult type of modeling error, in terms of bias and the ability to mitigate it, is specification error. In this type of error, variables that predict model outcomes are included when they should not be or excluded when they should not be, possibly producing biased estimates. The team addressed this type of error in the peak demand savings analysis by using a fixed-effects model, which adjusts for constant differences from one circuit to the next using circuit-specific intercepts. Over time, time periods where VO is on versus other periods where VO is off in a randomized experiment can drift apart due to attrition, causing an imbalance between the groups that must be addressed in the model specification. When there is an imbalance in consumption, weather, or other factors between the VO on and off periods, model specification error can become much more pronounced. For this reason, the team also included models that control for weather conditions in both the peak demand savings and 2019 evaluated savings analyses to account for differences in temperatures experienced by the VO on and off periods.
- **Measurement Errors:** Measurement error can come from variables such as weather data, which are commonly included in consumption analysis models. If an inefficient base temperature is chosen for calculating degree-days or if an incorrect climate zone weather station is chosen, the model results could be subject to measurement error. We addressed this type of error by very carefully choosing the closest weather station for each circuit in the model. Specifying an incorrect time period (either VO-on or VO-off) can also lead to measurement error. Our team worked extensively with AIC to ensure that all data anomalies were discussed and addressed, where feasible.
- **Multi-Collinearity**: This type of modeling error can both bias the model results and produce substantial variances in the results. The team dealt with this type of error by using model diagnostics such as variance inflation factor (VIF), though the relatively simple models used in the impact analysis have essentially no chance of problems with multi-collinearity.
- **Heteroskedasticity:** This type of modeling error can result in imprecise model results due to variance changing across circuits with different levels of consumption. The team addressed this type of error by using robust standard errors. Most statistical packages offer a robust standard error option and make conservative assumptions in calculating the errors, which has the effect of making significance tests conservative as well.

[17] Stipulated agreement filed on March 22, 2018 in ICC Docket 18-0211. Accessed at: https://www.icc.illinois.gov/downloads/public/edocket/469727.pdf

4. 2019 VO Program Verified Savings

Within this section, we present the results of the impact evaluation of the 2019 VO Program. Additional details on the impact analysis methodology used for this evaluation are presented in Appendix A.

4.1 Initiative Annual Savings Summary

The 2019 VO Program achieved 9,175 MWh of energy savings and 0.817 MW of peak demand savings. Table 6 presents the 2019 VO annual energy and peak demand savings.

Table 6. 2019 VO Program Annual Savings

	Energy Savings (MWh)	Demand Savings (MW)	Gas Savings (Therms)
Ex Ante Gross Savings	7,849[a]	N/A[b]	N/A
Gross Realization Rate	117%	N/A	N/A
Verified Gross Savings	9,175	0.817	N/A
NTGR[c]	N/A	N/A	N/A
Verified Net Savings	9,175	0.817	N/A

[a] Ex ante gross savings sourced from AIC. AIC assumed a 3% voltage reduction for VO distribution circuits and a corresponding electricity reduction of 2.4%. To arrive at ex ante savings, the assumed values were applied to a 2014-2016 baseline period for each VO circuit.
[b] There are no ex ante demand savings estimates for this program.
[c] NTGR is assumed to be 1.0, since absent the VO Program, deliberate changes to distribution voltage would not have been made.

Factors driving program performance include the following:

- The VO Program exceeded its ex ante gross energy savings due to larger estimated percent changes in voltage than assumed values (3.00% ex ante compared to 3.51% verified average).
- The greater changes in voltage resulted in greater than expected energy savings and a gross realization rate of 117%.
- The VO Program achieved 0.817 MW of peak demand savings, representing 0.043 MW per circuit per hour on average. Our team found that peak demand savings are highly variable by circuit and over time.

4.1.1 Detailed Energy Savings

The following tables present energy savings impacts across, as well as for, each of the 19 circuits calculated using the annual energy savings algorithm, which includes average annual customer energy use over the 2014-2016 timeframe excluding exempt customers, CVR_f,[18] and percent change in voltage resulting from VO implementation relative to the baseline.[19] We estimated a percent change in voltage for each circuit and applied that to the assumed baseline and CVR_f for each circuit. Table 7 summarizes the total results across all 19 circuits (see Appendix A for circuit-level percent change in voltage results).

[18] The estimate of the conservation voltage reduction factor, which represents the percent change in load for each percent change in voltage.
[19] For 2019, we used “off” periods to reflect the baseline condition.

Table 7. Ex Ante and Verified Algorithmic Inputs and Associated Energy Savings

Metric	Annual Gross Energy Use (MWh)[b]	CVR_f	Average Percent Change in Voltage	Annual Gross Energy Savings (MWh)
Ex Ante	327,042	0.80	3.00%[a]	7,849
Realization Rate	100%	100%	117%	117%
Verified	327,042	0.80	3.51%	9,175

[a] Reflects assumed values from AIC VO Plan.
[b] Reflects values sourced from AIC.

Table 8 provides ex ante, verified, and associated annual energy savings realization rates by circuit. There was variation in terms of the verified and ex ante savings by circuit, with some circuits under or over performing. Notably, there were no circuit characteristics that discernably drove variations in performance.

Table 8. 2019 VO Program Electric Energy Annual Savings by Circuit

Circuit	Ex Ante Gross MWh	Gross Realization Rate	Verified MWh
B00002	456	113%	516
B00003	498	112%	559
C52001	776	108%	837
C52002	343	93%	320
D31015	485	125%	607
J34357	420	119%	499
J34377	378	129%	489
J83140	470	117%	551
K11376	530	104%	551
L93132	315	116%	364
P58155	331	132%	438
P69173	325	115%	374
V40556	335	119%	399
V41533	373	113%	420
V42572	425	124%	525
V45574	306	115%	351
X35501	259	145%	376
Y79500	519	107%	555
Y98532	302	147%	442

4.1.2 Detailed Peak Demand Savings

We estimated peak demand savings using a pooled regression analysis approach given variability of load across circuits. The estimated average peak demand reduction is 0.043 MW per circuit per hour. To calculate aggregated peak demand savings for the summer peak period for all 19 circuits, we multiplied average peak demand savings per circuit per hour by the total number of circuits (Table 9).

Table 9. 2019 VO Electric Peak Demand Savings by Measure

Metric	Peak Demand Savings (MW)
Average Circuit Demand Per Circuit Per Hour	0.043
Number of Circuits	19
Average Peak Period Demand Savings	0.817

4.1.3 Cumulative Persisting Annual Savings

Table 10 presents CPAS and WAML for the 2019 Voltage Optimization Program. The total verified gross savings for the Program are summarized, and CPAS in each year of the 2018-2021 Plan are presented.[20] The WAML for the Initiative is 15.0 years.

Table 10. 2019 VO Program CPAS and WAML

Measure	Measure Life	First-Year Verified Gross Savings (MWh)	NTGR	CPAS – Verified Net Savings (MWh)							Lifetime Savings (MWh)
				2018	2019	2020	2021	...	2030	...	
Voltage Optimization – 2019 Cohort	15.0	9,175	N/A		9,175	9,175	9,175	...	9,175	...	137,619
2019 CPAS		**9,175**	**N/A**		**9,175**	**9,175**	**9,175**	**...**	**9,175**	**...**	**137,619**
Expiring 2019 CPAS					**0**	**0**	**0**		**0**		
Expired 2019 CPAS					**0**	**0**	**0**		**0**		
WAML	**15.0**										

[20] For further detail, including achieved CPAS in years not presented in this table, please see the summary CPAS spreadsheet provided with this report.

4.2 Conclusions and Recommendations

Based on the results of this evaluation, the evaluation team offers the following key findings and recommendations for VO moving forward:

- Key Finding #1: Average percent changes in voltage due to VO are generally consistent with planning values but have substantial variation across circuits.
  - Recommendation: As the pool of VO-enabled circuits continues to grow, consider incorporating an assessment of voltage variations by circuit characteristics, paying particular attention to the deployment of behind-the-meter distributed generation (DG) penetration, which may produce reverse power flows.
- Key Finding #2: Both SCADA and AMI data sources can be leveraged to estimate changes in voltage, baseline, CVR_f as well as peak demand. In particular, baseline data could use a pre-period baseline (e.g., before VO deployment), or an 'off' period (e.g., a random experiment where the software turns off for three days and then on for three days). As a result, the baseline development for any given evaluation can vary depending on the extant data for each circuit, and the experimental design timeline.
  - Recommendation: Develop a strategy for upcoming VO circuits to ensure consistency in approach for future evaluations. Where feasible, collect up to 12 months of pre-period baseline AMI or SCADA data for each circuit. We understand that the AIC Voltage Optimization team already has plans in place to collect one year of pre-VO voltage data in the future.

Appendix A. Detailed Impact Analysis Methodology

Data Ingestion and Review

Opinion Dynamics used the following data to perform the energy and peak demand savings evaluation: 1) supervisory control and data acquisition (SCADA) extracts, 2) advanced metering infrastructure (AMI) data extracts, 3) VO status and operation logs, 4) circuit characteristics, and 5) hourly weather data. Our team conducted preliminary analyses on each data set using a range of data sources, dates, and baselines. The triangulation of these sources demonstrate consistencies across data and analytical results.

- **SCADA data extracts.** The SCADA data extracts contain hourly usage (MW), voltage (kV), and reactive power (MR) readings. Overall, the data are of high quality with no missing time points and few time intervals containing sequences with zero reads, which indicate either SCADA system to grid sensor connectivity failures or large substation events. AIC scheduled VO on and VO off time periods show the stepwise voltage decreases when VO is enabled. To estimate peak demand savings, we used hourly power readings (measured in kW and MW) from SCADA system data from June 1, 2019, through August 31, 2019, reflecting the peak demand period for AIC.
- **AMI data extracts.** AIC provided AMI data containing hourly demand (kWh), instantaneous voltage, and average instantaneous voltage at four different base voltages. Because there may be over 1,000 AMI meters on a given circuit, AIC provided average voltage and kWh data. For a given circuit, the AMI data reflects normalized voltage based on the voltage class (e.g., 120V, 240V, 480V) where each AMI meter was located on the circuit. To estimate changes in voltage, we used average voltage readings (measured in kV) from AMI system data from June-December 2019. AMI data reflects the preferred source for all evaluations in Illinois and measures consumption at the customer meter, rather than the circuit level.
- **System operation log.** This file contains the VO on and off schedule, as well as critical system operation events that could cause data anomalies such as outages. AIC provided a log with a summary tab containing circuit-level historical milestones and additional circuit-specific tabs with more detailed information.
- **Circuit characteristics.** This dataset for all circuits planned for VO-deployment (n=1,047)[21] contained descriptive information about the circuits as well as usage data from 2014 through 2016 for VO remains a key input in the algorithmic approach as it establishes a baseline.
- **Hourly weather data.** The evaluation team sourced weather data from NOAA, which we mapped to circuits by GPS coordinates.

[21] While an initial pool of 1,047 circuits was selected for VO deployment, the specific circuits are subject to change based on feasibility of deployment. If substitutions are made to the eligible pool, AIC will inform Opinion Dynamics of those changes.

Energy Savings

Data Cleaning

We summarize the results of our data cleaning effort for the 2019 impacts below (see Table 11). The following data cleaning steps were conducted prior to modeling:

- **Remove duplicate observations:** Observations with duplicated values across all variables were flagged and removed from the analysis.
- **Time periods without weather data:** We downloaded weather data from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information. We used circuit longitude and latitude to find the weather station that was closest to each circuit's location. There are instances where the weather data for a particular weather station was not recorded, and so we removed these time periods from the analysis.
- **Interpolated values:** Prior evaluations of VO have revealed that SCADA systems commonly interpolate across gaps in time series caused by equipment failures, communications failures, or inappropriately broad bandwidths. For both the AMI and SCADA data, interpolation was flagged in cases where a constant slope in MW or kV were detected across two or more time points. Interpolated values in kV and MW data were removed from the analysis.
- **Negative and zero values:** Negative and zero values in kV and MW data were flagged and removed from the analysis. This data cleaning step should be revisited if or when behind-the-meter distributed generation (DG) penetration rises to the level where reverse power flows are a possibility.
- **Outliers:** Outliers were screened on a circuit-by-circuit basis. Outliers are currently defined as hourly values that are greater than three times the standard deviation from the mean kV or MW for that specific circuit. Outliers on kV and MW were flagged and removed from the analysis.
- **Excludable time periods:** Certain instances occur in which it is best practice, or it is required to disable VO to support system changes, growth, outages, and planned/unplanned maintenance. AIC has expressed that a subset of VO events should be excluded in this analysis. The Illinois Commerce Commission (ICC) verified whether or not specific VO events could be excluded from the analysis. 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.

Table 11 provides a summary of the data cleaning results for this analysis. Results include all 19 circuits within the analysis. The primary driver for removing observations were occurrences where the VO system was turned off for an excludable event. This group of observations reflect 4% of the total number of observations.

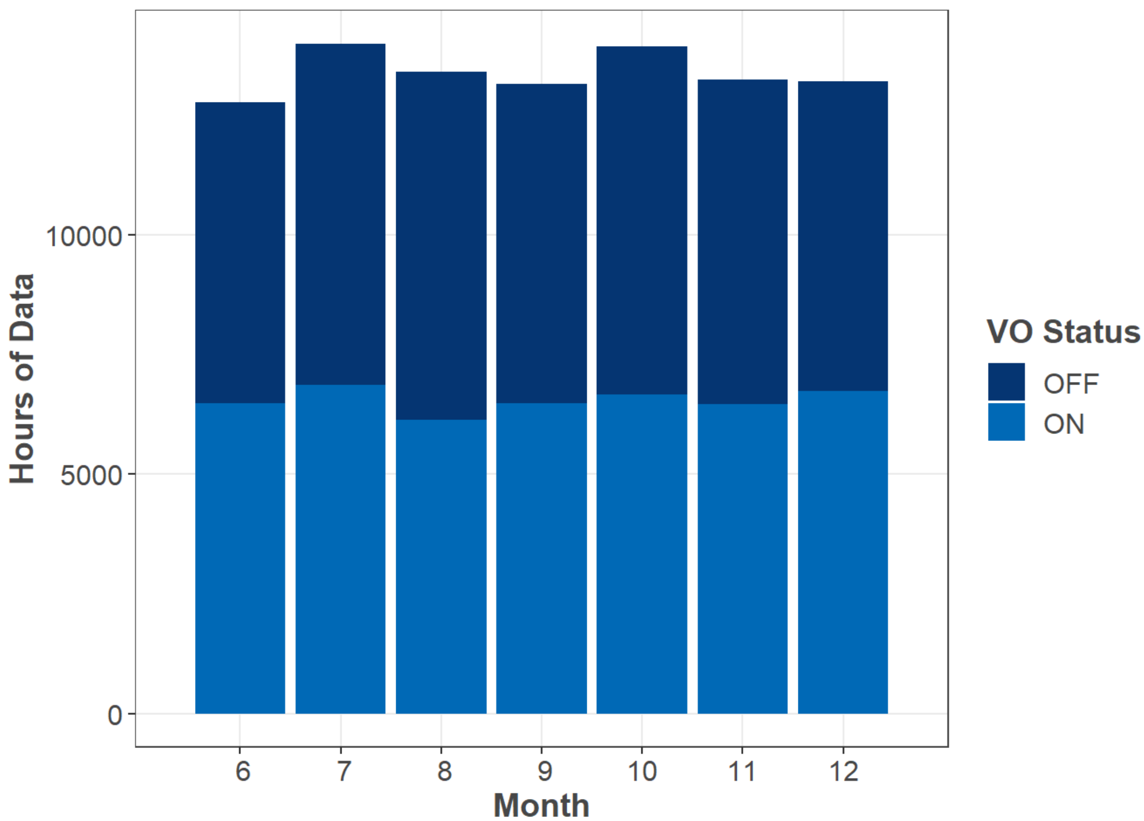
Table 11. Data Cleaning Results for 2019 VO Energy Savings Impacts

Step	Circuits	Records	Change	% Change
Initial	19	97,584	0	0%
Flag and Remove Duplicate Observations	19	97,584	0	0%
Flag and Remove Time Periods without Weather Data	19	97,433	151	0%
Flag and Remove Negative and Zero values	19	97,414	19	0%
Flag and Remove Outliers	19	97,414	0	0%

Modeling Percent Change in Voltage

To develop a baseline, the evaluation team and AIC engineers implemented an "on/off" experimental testing approach on a sample of circuits. As a result, the baseline reflects 'off' periods. Notably, in 2019, the baseline data varies across data sources, and circuits (e.g., do not have full coverage for the "pre" period for either SCADA or AMI data). As a result, we conducted our analysis on the seven months in which on/off testing was deployed. Given that we apply the estimated change in voltage to the circuit-level annual usage from 2014-2016, the results are effectively annualized for the entire year. Figure 2 provides a summary of on/off periods throughout the months of study, demonstrating that the experimental design was deployed with fidelity.

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



To estimate changes in voltage, we used a regression model described in Equation 2.

Equation 2. Voltage Reductions Model

$$kV_{it} = \alpha + \beta_1 VO_t + \beta_2 cdh_t + \beta_3 hdh_t + \beta_4 Weekend_t + \beta_5 VO_t * cdh_t + \beta_6 VO_t * hdh_t + \beta_7 VO_t * Weekend_t + \varepsilon_{it}$$

Where:

- kV_{it} = Kilovolts for circuit *i* at time *t*
- α = model intercept

- β_x = coefficients
- VO_t = set of indicator variables on circuit *i* at time t for VO status where VO status can be fully enabled (VO=1) or fully disabled (VO=0?)
- cdh_t = the number of cooling degree-hours at time *t*
- hdh_t = the number of heating degree-hours at time *t*
- $Weekend_t$ = indicator variable for weekend (weekend = 1) or weekday (weekend = 0)
- ε_{it} = error term

Calculating Annual Energy Savings

The energy savings associated with VO are mainly due to enduse load reductions resulting from a reduction in distribution voltage. Generally, the larger the reduction in line voltage, the larger the enduse energy savings. The relationship between voltage and usage due to VO, commonly expressed in the industry as a CVR_f (Equation 3), is one of the primary methods of demonstrating the efficacy of VO:

Equation 3. CVR_f Equation

$$CVR_f = \frac{\%\ Change\ in\ Energy\ Usage}{\%\ Change\ in\ Voltage}$$

Through AIC's pilot study and a survey of the literature, AIC estimated that VO will lead to a 3% voltage reduction and a corresponding 2.4% usage reduction on circuits in AIC's territory. Based on these results and pilots in the industry at large, AIC is utilizing an assumed CVR_f of 0.80 to calculate savings in 2019 and 2020.

A common method for calculating energy savings due to VO is to use an algorithm that includes the CVR_f, annual energy use, and the percent change in voltage. This type of algorithm is used for AIC's VO program; the specific algorithm used is shown in Equation 4.

Equation 4. AIC VO Savings Algorithm

$$Annual\ Energy\ Savings = Annual\ Energy\ Use_{2014-2016} * CVR_f * \%\Delta V$$

Where:

- $Annual\ Energy\ Use_{2014-2016_i}$ = the average annual customer energy use for circuit *i* over the 2014-2016 timeframe, excluding the exempt customers.
- CVR_f = the estimate of the conservation voltage reduction factor (deemed as 0.80), defined as the percent change in energy usage divided by the percent change in voltage.
- $\%\Delta V_i$= the percent change in voltage for circuit *i* resulting from VO implementation relative to VO turned off, calculated with three-day VO-on periods and three-day VO-off periods using a regression model to control for exogenous factors that may contribute to changes in voltage (e.g., weather).

Detailed Circuit Results

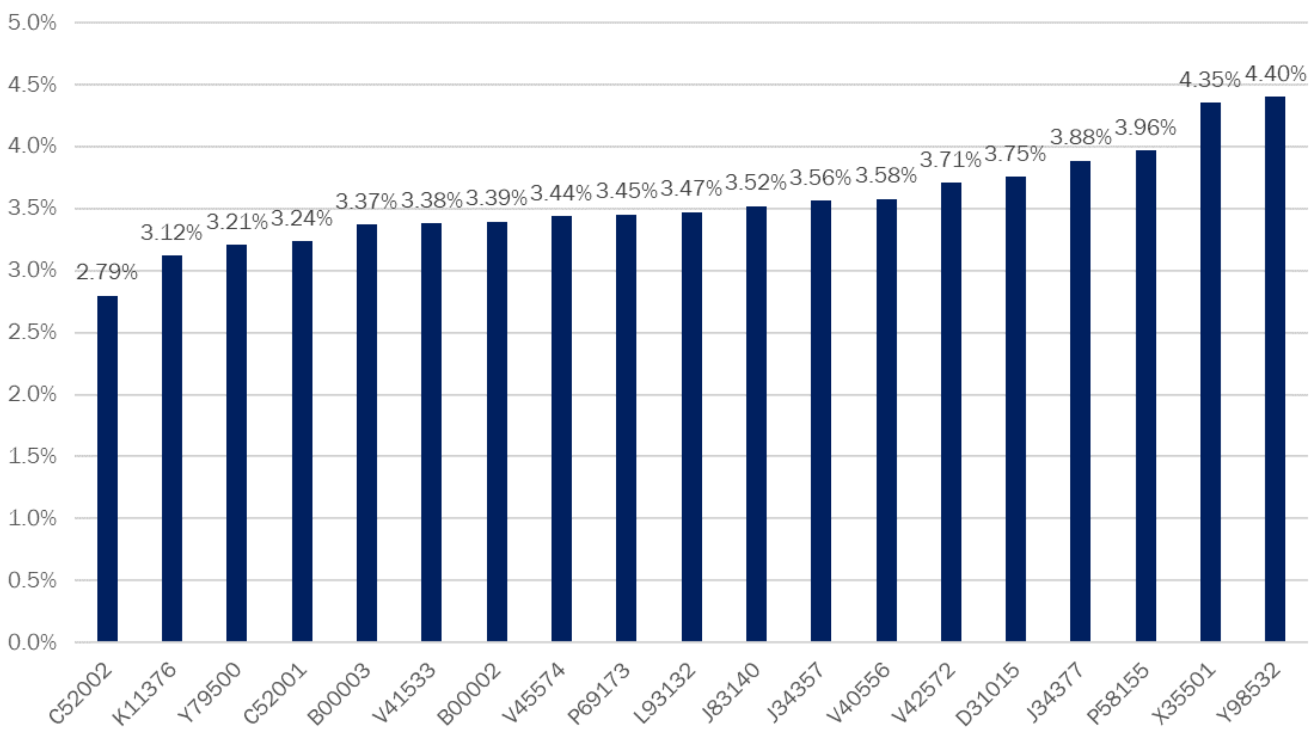
Table 12 provides each algorithmic input by each circuit, as well as the total estimated savings and weighted average.[22] For 18 of the 19 circuits, the percent change in voltage was estimated to be larger than the planned value of 3.0%.

Table 12. Ex Ante and Verified Algorithmic Inputs and Associated Energy Savings by Circuit

Circuit	Annual Gross Energy Use (MWh)	CVR_f	Percent Change in Voltage	Annual Gross Energy Savings (MWh)
B00002	19,002	0.8	3.39%	516
B00003	20,754	0.8	3.37%	559
C52001	32,348	0.8	3.24%	837
C52002	14,312	0.8	2.79%	320
D31015	20,226	0.8	3.75%	607
J34357	17,499	0.8	3.56%	499
J34377	15,746	0.8	3.88%	489
J83140	19,572	0.8	3.52%	551
K11376	22,080	0.8	3.12%	551
L93132	13,135	0.8	3.47%	364
P58155	13,810	0.8	3.96%	438
P69173	13,538	0.8	3.45%	374
V40556	13,957	0.8	3.58%	399
V41533	15,559	0.8	3.38%	420
V42572	17,718	0.8	3.71%	525
V45574	12,767	0.8	3.44%	351
X35501	10,812	0.8	4.35%	376
Y79500	21,637	0.8	3.21%	555
Y98532	12,570	0.8	4.40%	442
Total	**327,042**	**0.8**	**3.51%**	**9,175**

[22] Average percent change in voltage is weighted by annual gross energy use (MWh).

Figure 3. Circuit Specific Percent Change in Voltage



The evaluation team validated the approach through triangulating results across data sources, baselines, and date ranges. Based on this review, we found consistency across all sources in terms of average percent voltage reduction. Our approach is designed to be the most rigorous possible with the data available. We employed regression analysis controlling for exogenous factors, as documented in the evaluation plan, such as weather. To validate our model, we conducted a range of model specifications and select the best fit determined by model diagnostics (R^2 and adjusted R^2). Table 13 shows the model fit statistics for each of the 19 circuits from the preferred regression model. A detailed binder provides the coefficient estimates for each circuit-level model. All modeled circuit results were statistically significant at the 90% confidence level.

Table 13. 2019 VO Evaluated Savings Preferred Model Fit Statistics

Circuit	R^2	Adjusted R^2
B00002	0.88	0.88
B00003	0.89	0.89
C52001	0.91	0.91
C52002	0.89	0.89
D31015	0.81	0.81
J34357	0.88	0.88
J34377	0.91	0.91
J83140	0.92	0.92
K11376	0.80	0.80
L93132	0.92	0.92
P58155	0.88	0.88

Circuit	R^2	Adjusted R^2
P69173	0.89	0.89
V40556	0.92	0.92
V41533	0.90	0.90
V42572	0.88	0.88
V45574	0.91	0.91
X35501	0.86	0.86
Y79500	0.87	0.87
Y98532	0.92	0.92

Measure Life and Cumulative Persisting Annual Savings

The FEJA-defined measure life of 15 years was applied for this measure.[23]

Peak Demand Savings

Data Cleaning

A similar set of data cleaning steps were performed for the peak demand savings estimate:

- **Interpolated values:** Prior evaluations of VO have revealed that SCADA systems commonly interpolate across gaps in time series caused by equipment failures, communications failures, or inappropriately broad bandwidths. Interpolation was flagged in cases where a constant slope in MW or kV were detected across two or more time points. Interpolated values in kV and MW data were removed from the analysis.
- **Negative and zero values:** Negative and zero values in kV and MW data were flagged and removed from the analysis. This data cleaning step should be revisited if or when behind-the-meter DG penetration rises to the level where reverse power flows are a possibility.
- **Outliers:** Outliers were screened on a circuit-by-circuit basis. Outliers are currently defined as hourly values that are greater than three times the standard deviation from the mean kV or MW for that specific circuit. Outliers on kV and MW were flagged and removed from the analysis.
- **Excludable Times:** Types of VVO events that were approved for exclusion were those that (1) had a circuit outage for any reason, (2) had repair or maintenance, causing VVO to be disabled, (3) had switching occurring (where VVO 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.

[23] 220 ILCS 5/8-103B(b-20) of Illinois Senate Bill 2814 (the Future Energy Jobs Act).

Table 14 provides a summary of the data cleaning results for this analysis. After sub-setting on the peak demand period, the data cleaning reduced the total number of observations by 3%.

Table 14. Data Cleaning Results for Peak Demand Savings

Step	Circuits	Records	Change	% Change
Initial	19	209,304	0	0%
Flag and Remove Interpolated Values	19	209,242	62	0%
Flag and Remove Negative and Zero Values	19	206,651	2,591	1%
Flag and Remove Outliers	19	206,317	334	0%
Subset to June 1 - August 31 Non-Holiday Weekdays	19	57,855	148,462	72%
Remove Excludable Time Periods	19	56,377	1,478	3%

Modeling Peak Demand

To provide estimates of peak demand changes, the evaluation team conducted regression modeling by pooling the circuits together. Data used in the analysis were restricted to include only non-holiday weekdays between June 1 and August 31.

Pooled estimation of changes in MW associated with the VO system being active was estimated in Equation 5:

Equation 5. Peak Demand Savings Model

$$MW_{it} = \alpha_i + \gamma_h + \beta_1 VO_{it} + \beta_2 VO_{it} offpeak_t + \beta_3 CDH_{it} + \beta_4 CDH_{it}^2 + \varepsilon_{it}$$

Where:

- MW_{it} = MW for circuit i at time t
- α_i = circuit fixed effect, control for fixed circuit characteristics that may affect VO savings
- γ_h = the average MW for circuit i during hour-of-day h during a weekday
- β_x = coefficients
- VO_{it} = set of indicator variables on circuit i at time t for VO status where VO status can be fully enabled (VO =1) or fully disabled
- $offpeak_t$ = set of indicator variables equal to 1 between 12 am through 12:59 pm and 5 pm through 11:59 pm
- CDH_{it} and CDH_{it}^2 = cooling degree hours, base 65, and its square to capture nonlinear impacts of temperature on the cooling load
- ε_{it} = error term
- In the model specification, we isolate the VO treatment during 1 pm to 5 pm time period via the specification of two VO treatment terms: one active during the "On" period (VO_{it}), and one active during the "On" period of off-peak weekday hours ($VO_{it} * offpeak_t$). Therefore, peak savings during 1 pm to 5 pm period are represented by β_1 in Equation 5.

The core estimated change in peak-period MW and peak-period kV attributed to the VO system being powered on is given by α, hereby referred to as αMW and αkV. Percentage changes in energy (MWh) and voltage (kV) were estimated as follows:

$$\%\Delta MWh = \frac{\alpha_{MW}}{\mu_{MW}^{OFF}}$$

$$\%\Delta kV = \frac{\alpha_{kV}}{\mu_{kV}^{OFF}}$$

- Where μ_{MW}^{OFF} indicates the mean MW observed during the peak hours' system off period, multiplied by the number of peak-hours between June 1 and August 31, and μ_{kV}^{OFF} indicates the mean kV observed during the peak hours' system off period.

Table 15 shows the per-circuit and aggregate peak demand savings results for these 19 feeders. The evaluation team detected 1.51% (or 0.817 MW) in peak demand savings. This estimate was statistically significant at the 90% confidence level.

Table 15. Peak Demand Savings Estimated Savings

Circuits	Aggregate (MW)		Per Circuit (MWh/Hour)		Standard Error	% Savings
	Baseline	Savings	Baseline	Savings		
19	54.15	0.817	2.85	0.04	0.0124	1.51%

The evaluation team validated the modeling approach through triangulating results across data sources, baselines, and date ranges. We employed regression analysis controlling for exogenous factors, as documented in the evaluation plan, such as weather. To validate our model, we conducted a range of model specifications and select the best fit determined by model diagnostics (R^2, adjusted R^2). Table 16 shows the fit statistics from the preferred peak demand regression model.

Table 16. Peak Demand Savings Preferred Model Fit Statistics

R^2	Adjusted R^2
0.895	0.895

Appendix B. Cumulative Persisting Annual Savings

Table 17 provides CPAS and WAML for the 2019 VO Program through 2047. Lifetime savings for the 2019 VO Program are 137,619 MWh.

Table 17. 2019 VO Program CPAS and WAML Through 2047

Measure Category	Measure Life	First-Year Verified Gross Savings (MWh)	NTGR	CPAS (Verified Net MWh)														
				2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Voltage Optimization - 2019 Cohort	15.0	9,175	N/A		9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175
2019 CPAS		9,175	N/A		9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175
Expiring 2019 CPAS					0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expired 2019 CPAS					0	0	0	0	0	0	0	0	0	0	0	0	0	0

Measure Category	Measure Life	First-Year Verified Gross Savings (MWh)	NTGR	CPAS (Verified Net MWh)														
				2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047
Voltage Optimization - 2019 Cohort	15.0	9,175	N/A	9,175	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2019 CPAS		9,175	N/A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expiring 2019 CPAS				9,175	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expired 2019 CPAS				9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175	9,175
WAML	15.0																	

Notes
• Measure life is deemed at 15 years by FEJA.

For more information, please contact:

Hannah Howard
Managing Director / V.P.

510-214-0183 tel
510-444-5222 fax
hhoward@opiniondynamics.com

1000 Winter Street
Waltham, MA 02451