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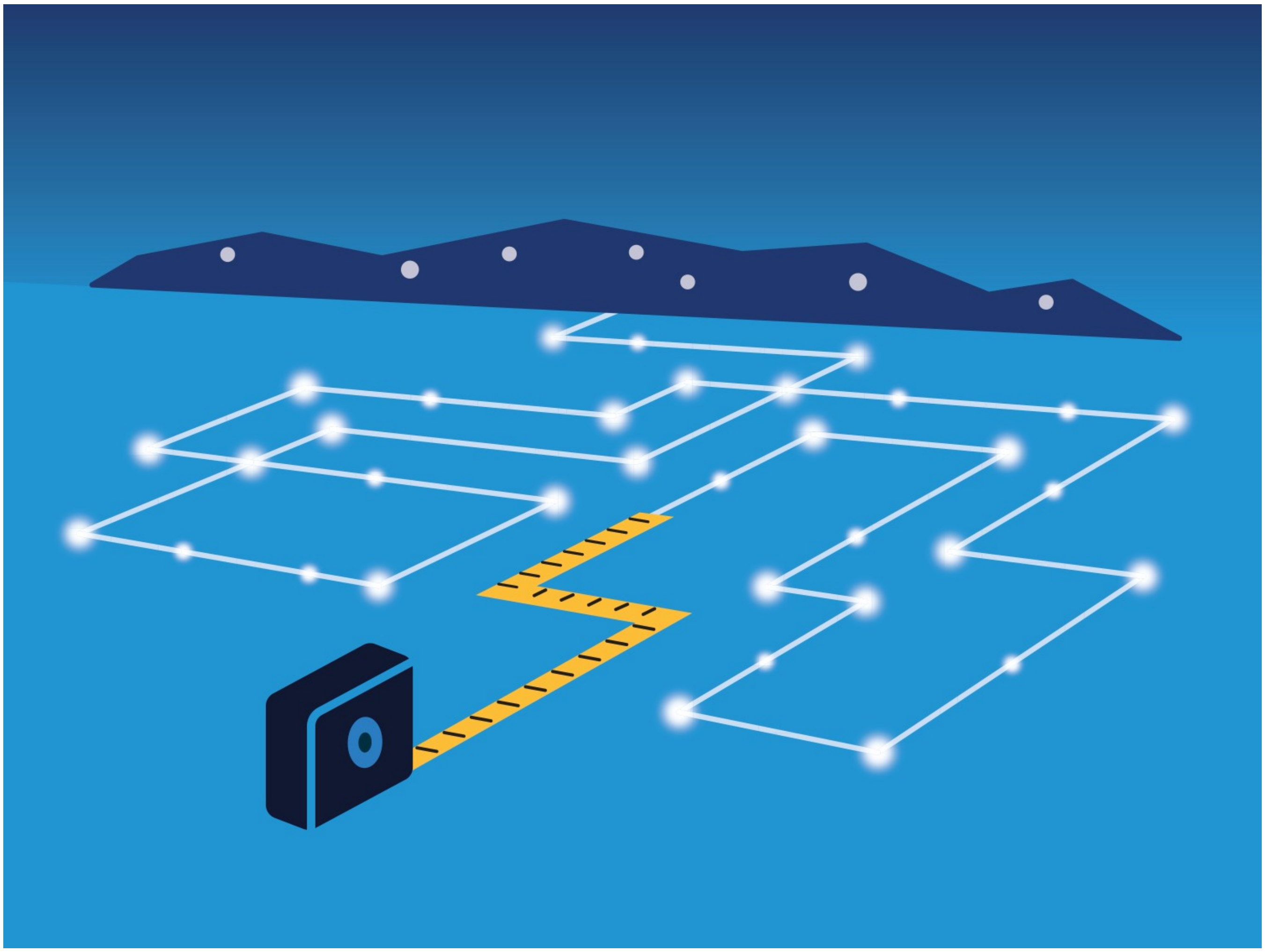

Ameren Illinois Company 2020 Voltage Optimization Program Impact Evaluation Report

Final
April 8, 2021

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1. Executive Summary

This report presents the impact evaluation results from Ameren Illinois Company's (AIC) Voltage Optimization (VO) energy efficiency program implemented during 2020. The objective of the 2020 impact evaluation was to determine energy and peak demand savings associated with the VO program in 2020 as well as verify continued operation of voltage optimization for a sample of previously evaluated circuits.

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 circuits.[1] 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 on a phased basis.[2] 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, 2020 represents the second 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 evaluated in the 2019 program year. In 2020, our evaluation activities included estimating energy and peak demand savings from 125 circuits that were deployed in 2019, as well as verification of the continued operation of circuits previously evaluated in 2019.

[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

1.2 2020 VO Program Savings

1.2.1 Annual Savings

The evaluation team estimated energy and peak demand savings for the 125 circuits that became operational in 2020. Overall, the VO Program achieved 72,669 MWh of energy savings and 11.50 MW of peak demand savings (Table 1).

Table 1. 2020 VO Program Annual Savings

	Energy Savings (MWh)	Demand Savings (MW)	Gas Savings (Therms)
Ex Ante Gross Savings	52,861[a]	N/A[b]	N/A
Gross Realization Rate	137%	N/A	N/A
Verified Gross Savings	72,669	11.50	N/A
NTGR	N/A	N/A	N/A
Verified Net Savings	72,669	11.50	N/A

[a] Ex ante gross savings sourced from AIC. Ex ante gross savings assume 0.80 CVR factor and 3% voltage reduction across the 125 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 2020 VO Program. The overall WAML for the VO Program is 15 years. For additional detail around CPAS and measure life, please see Section 4.1.3 of this report.

Table 2. 2020 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 – 2020 Cohort	15.0	72,669	N/A			72,669	72,669	...	72,669	...	1,090,030
2020 CPAS		**72,669**	**N/A**			**72,669**	**72,669**	**...**	**72,669**	**...**	**1,090,030**
Expiring 2020 CPAS						**0**	**0**	**...**	**0**	**...**	
Expired 2020 CPAS						**0**	**0**	**...**	**0**	**...**	
WAML	**15.0**										

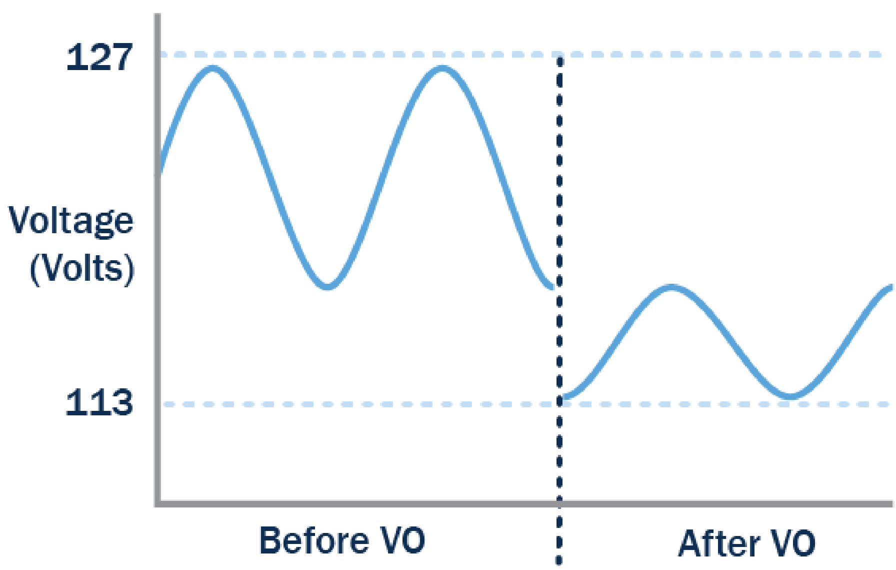
2. Overview of VO Program

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 reactive power flows on a circuit,[4] and then lower the voltage to reduce end-use customer energy consumption and utility distribution system losses. VVO optimizes capacitor bank[5] operations to improve power factor[6] and reduce system losses. CVR utilizes voltage regulators, transformer load tap changers, and capacitors to control and reduce end-user 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 end-uses 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 end-use load reduction, and to a lesser extent, distribution line loss reductions. AIC's VO program was

[4] Reactive power is measured in Volt-Amperes Reactive or VAR.
[5] Capacitor banks are groupings of several capacitors and are used to store or condition electricity (e.g., by correcting power factor).
[6] Power factor is the ratio of working power (kW) to apparent power (kVA). Higher power factors indicate higher efficiency.

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.

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. Based on calculated assumptions, industry results, and past AIC VO pilot results, AIC anticipates deploying VO on a total of 1,047 circuits. 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 greater than or equal to 10 MW).

VO is a major part of AIC's 2018–2021 energy efficiency plan. Per AIC's most recent compliance filing,[8] VO was expected to produce 52,346 MWh in energy savings in 2020, about 16% of AIC's estimated 2020 portfolio goal. VO deployment ramped up dramatically from 2019 and will continue to do so throughout the remainder of the plan period. In 2019 it produced approximately 2% of AIC's estimated total annual portfolio goal and is expected to produce 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 November 12, 2020 errata to the February 19, 2019 compliance filing in ICC Docket 17-0311. Accessed at: https://icc.illinois.gov/docket/P2017-0311/documents/305055/files/531929.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.

AIC completed 125 circuits in 2019 that were evaluated as part of the 2020 evaluation. These circuits reflect a broad mix of AIC's service territory and delivered VO to an estimated 43,745 low income customers. For a detailed list of circuits evaluated in 2020, see Appendix A.

3. Evaluation Approach

3.1 Research Objectives

The 2020 VO evaluation approach is primarily governed by the Illinois Technical Reference Manual for Energy Efficiency (IL-TRM) Version 9.0,[10] which prescribes the use of an algorithmic approach to estimating electric energy and peak demand savings from VO.[11] In addition, we leveraged a previously-agreed upon methodology and approach to verify the continued operation of previously installed VO circuits during 2020.[12]

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

- What are the estimated energy savings from VO?
- What are the estimated peak demand savings from VO?
- Did the 19 evaluated circuits from 2019 continue to operate over a 90% threshold in 2020?

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 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 2020 evaluation estimated energy and peak demand savings for the 125 circuits that were operational as of January 1, 2020.

3.2.1 Energy Savings Methodology

The IL-TRM requires the use of an algorithmic approach to evaluating VO energy savings. The algorithmic approach combines deemed parameter values with measured reductions in voltage to calculate energy savings. The algorithm used for AIC's VO program energy savings 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 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.

[10] Illinois Technical Reference Manual for Energy Efficiency Version 9.0, Volume 4, Measure 6.2.1. Accessed at: https://ilsag.s3.amazonaws.com/IL-TRM_Effective_010121_v9.0_Vol_4_X-Cutting_Measures_and_Attach_09252020_Final.pdf

[11] While IL-TRM V8.0, which does not characterize Voltage Optimization, was technically in effect for prescriptive measures during 2020, we use the IL-TRM V9.0 characterization of Voltage Optimization by agreement of all parties to ensure transparency and clarity.

[12] Ameren Illinois Company Voltage Optimization Verification and Exclusion Approach, accessed at: https://ilsag.s3.amazonaws.com/AIC-2019-Voltage-Optimization-Operation-Verification-Memo-FINAL-2020-04-17.pdf

- $\%\Delta V_i$= the percent change in voltage for circuit *i* resulting from VO implementation relative to the pre-period, using a regression model to control for exogenous factors that may contribute to changes in voltage (e.g., weather).

3.2.2 Peak Demand Savings Methodology

Peak demand savings are also estimated with an algorithmic approach. The peak period is defined as 1:00 p.m.–5:00 p.m. (CDT) on non-holiday weekdays from June 1 to August 31.[13] The algorithm used for AIC's VO peak demand program evaluation is shown in Equation 2.

Equation 2. AIC VO Peak Demand Savings Algorithm

$$Peak\ Demand\ Savings_i = Avg\ Peak\ Demand_{2014-2016_{i,PEAK}} * CVR_{f,PEAK} * \%\Delta V_{i,PEAK}$$

Where

- $Avg\ Peak\ Demand_{2014-2016_{i,PEAK}}$ = the average demand in the peak hour for circuit *i* over the 2014–2016 timeframe during the peak period adjusted by a calibration factor that captures the relationship between peak demand and average demand in the peak period, excluding exempt customers.[14]
- $CVR_{f,PEAK}$ = the estimate of the peak conservation voltage reduction factor (deemed as 0.68), defined as the percent change in energy usage divided by the percent change in voltage during the peak period.
- $\%\Delta V_{i,PEAK}$= the percent change in voltage for circuit *i* resulting from VO implementation relative to the peak hours of the pre-period, using a regression model to control for exogenous factors that may contribute to changes in voltage (e.g., weather). Per the guidance in the IL-TRM, this is to be calculated in the same manner as energy savings but with the intention of measuring peak demand savings rather than total energy savings.

3.2.3 Verification of Continued Operation

VO savings are deemed for 15 years after completion of the initial evaluation of a circuit and no retroactive changes can subsequently be made to deemed savings.[15] Therefore, in the Illinois evaluation framework, impact evaluation for VO does not require retroactive or ongoing verification.

Nevertheless, in 2020, Opinion Dynamics, AIC, and ICC Staff agreed that ongoing verification of VO should be conducted for process purposes to provide information to stakeholders and other parties as to the level of continued VO operation and, if needed, to provide context as to why VO may not have operated continuously. After the initial evaluation of each year of VO circuits, parties agreed that Opinion Dynamics would conduct verification activities to assess the degree to which VO continued to operate throughout each year. The acceptable threshold of operation was set to ensure that circuits operated over a 90% threshold.[16]

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[13] Illinois Technical Reference Manual for Energy Efficiency, Version 9.0, Volume 1, Section 3.7.
[14] Peak demand was unavailable for four circuits for the period 2014–2016. Per AIC's guidance, we substituted peak demand from 2017–2019.
[15] Illinois Energy Efficiency Policy Manual Version 2.0, Section 11.2. Accessed at: https://ilsag.s3.amazonaws.com/IL_EE_Policy_Manual_Version_2.0_Final_9-19-19.pdf
[16] See Ameren Illinois Company Voltage Optimization Verification and Exclusion Approach memo here: https://ilsag.s3.amazonaws.com/AIC-2019-Voltage-Optimization-Operation-Verification-Memo-FINAL-2020-04-17.pdf

As part of the 2020 evaluation, we conducted ongoing verification of VO circuits evaluated in 2019. To determine whether these 2019 circuits operated over a 90% threshold during 2020, the evaluation team conducted the following analytical activities:

- Selected a random sample of ten of the 19 circuits evaluated in 2019;
- Requested operation log summaries and voltage data for the sample of VO circuits. Our variable of interest for this effort included the VO status (e.g., "on/off") for specific hours throughout the 2020 at a circuit level;
- Removed excludable events;[17]
- Divided the total number of hours in which the status logs indicated that VO was on by the total number of non-excludable hours in the year;
- Performed further verification to observe if operations logs and voltage data aligned by investigating hours that should be classified as excludable events; and
- Performed visual inspections against the operations logs to ensure that the patterns in the operations logs matched the patterns shown in the voltage data. This final step was designed to determine if operations logs and voltage data aligned enough so that we could rely only on operations logs in the future.

3.2.4 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) that are often present for other more traditional energy efficiency programs.

3.3 Sources and Mitigation of Error

Because we relied on regression models to estimate the change in voltage and peak demand, there will be some uncertainty in the estimates. We therefore 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 by carefully examining the model diagnostics and goodness-of-fit statistics.
- **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 evaluation model diagnostics, though the relatively simple models used in the impact analysis are unlikely to have problems with multi-collinearity.

[17] For the rationale behind and definition of excludable events, please see the Verification and Exclusions memo.

- **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.

4. 2020 VO Program Verified Savings

In this section, we present the results of the impact evaluation of the 2020 VO Program. Additional details on the impact analysis methodology used for this evaluation are presented in Appendix B.

4.1 Initiative Annual Savings Summary

The 2020 VO Program achieved 72,669 MWh of verified net energy savings and 11.50 MW of verified net peak demand savings. Table 4 presents the 2020 VO annual energy and peak demand savings. Detailed results by circuit are available in Appendix B.

Table 4. 2020 VO Program Annual Savings

	Energy Savings (MWh)	Peak Demand Savings (MW)	Gas Savings (Therms)
Ex Ante Gross Savings	52,861[a]	N/A[b]	N/A
Gross Realization Rate	137%	N/A	N/A
Verified Gross Savings	72,669	11.50	N/A
NTGR	N/A	N/A	N/A
Verified Net Savings	72,669	11.50	N/A

[a] Ex ante gross savings sourced from AIC. Ex ante gross savings assume 0.80 CVR factor and 3% voltage reduction across the 125 measured circuits.
[b] There are no ex ante demand savings estimates for this program.

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 4.12% verified average).
- The greater changes in voltage resulted in greater than expected energy savings and a gross realization rate of 137%.
- The VO Program achieved 11.50 MW of peak demand savings, representing 0.104 MW per circuit per hour on average[18]. Our team found that peak demand savings are highly variable by circuit.

4.1.1 Detailed Energy Savings

The following tables present average energy savings impacts across the 125 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,[19] and percent change in voltage resulting from VO implementation relative to the baseline. We used a regression model to estimate a percent change in voltage for each circuit and applied that to the assumed baseline and CVR_f for each circuit. Table 5 summarizes the total results across all 125 circuits (see Appendix B for circuit-level percent change in voltage results).

[18] This was calculated as a weighted average on all circuits, using the annual peak demand as a weight.
[19] The estimate of the conservation voltage reduction factor, which represents the percent change in load for each percent change in voltage.

Table 5. Ex Ante and Verified Algorithmic Inputs and Associated Energy Savings

Metric	Annual Gross Energy Use (MWh)	CVR_f	Average Percent Change in Voltage	Annual Gross Energy Savings (MWh)
Ex Ante[a]	2,202,555	0.8	3.00%	52,861
Realization Rate	N/A	N/A	137%	137%
Verified	2,202,555	0.8	4.12%	72,669

[a] Ex ante gross savings sourced from AIC. Ex ante gross savings assumes 0.80 CVR factor and 3% voltage reduction across the 125 measured circuits.

4.1.2 Detailed Peak Demand Savings

We estimated peak demand savings using an individual regression analysis approach for each circuit given variability of load across circuits. The percent voltage reduction for each circuit was multiplied by the peak period CVR_f of 0.68 (deemed) and the annual peak demand baseline value (MW). The resulting annual demand savings were summed across circuits to determine the total peak demand reduction of 11.50 MW. The average percent change in voltage during peak demand periods was 3.04%, as shown in Table 6. AIC does not report ex ante demand savings, and therefore there are no ex ante savings or realization rates reported.

Table 6. 2020 VO Electric Peak Demand Savings by Measure

Metric	Annual Demand (MW)	CVR_f	Average Percent Change in Voltage	Annual Demand Savings (MW)
Verified	556	0.68	3.04%	11.5

4.1.3 Cumulative Persisting Annual Savings

Table 7 presents CPAS and WAML for the 2020 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 Program is 15 years.

Table 7. 2020 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 – 2020 Cohort	15.0	72,669	N/A			72,669	72,669	...	72,669	...	1,090,030
2020 CPAS		**72,669**	**N/A**			**72,669**	**72,669**	**...**	**72,669**	**...**	**1,090,030**
Expiring 2020 CPAS						**0**	**0**	**...**	**0**	**...**	
Expired 2020 CPAS						**0**	**0**	**...**	**0**	**...**	
WAML	**15.0**										

4.1.4 Verification of Continued Operations

The evaluation team found that the ten randomly sampled 2019 circuits operated above the 90% threshold in 2020. For more information on the verification approach, see Appendix D.

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

5. 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:** The VO Program continues to provide a substantial amount of energy savings to the AIC portfolio and exceed AIC's initial expectations for achieved savings.
- **Key Finding #2:** Average percent changes in voltage due to VO were 30% higher than planning values but have substantial variation across circuits (2.48%–7.42% average change in voltage). In other words, for 117 of the 125 circuits, the percent change in voltage was estimated to be larger than the planned value of 3.0%.
  - Recommendation: Consider updating planning values to reflect the percent change in voltage derived from evaluated values. As the pool of VO-enabled circuits continues to grow, consider incorporating an assessment of voltage variations by circuit characteristics. This approach can also support a more accurate assessment of the ex ante cost-effectiveness for each circuit screened for inclusion in the program.
- **Key Finding #3:** The sampled 2019 VO circuits operated above the 90% threshold when accounting for exclusions in 2020, confirming that VO circuits continue to operate and supporting the assumption that VO will operate continuously after installation.

Appendix A. 2020 Circuits Summary

Table 8 presents detailed circuit characteristics for VO circuits evaluated in 2020. This table includes the substation and circuit name for each circuit as well as various circuit characteristics that may, potentially, affect voltage reductions. AIC prioritized low income customers as part of its VO deployment.[21]

Table 8. 2020 Evaluated VO Circuits

Substation	Circuit	Division	Line Length (Miles)	% Res.	% Comm.	% Large C&I	Voltage Level (kV)	Year Deployed	Low Income Customers
BARTONVILLE	A17025	Division 1	19.61	89.86%	10.07%	0.06%	7.62	2019	563
BARTONVILLE	A17026	Division 1	15.46	95.24%	4.63%	0.13%	7.62	2019	904
ALLEN	A91003	Division 1	30.68	94.42%	5.58%	0.00%	7.62	2019	183
ALLEN	A91004	Division 1	36.11	83.88%	15.82%	0.30%	7.62	2019	117
CHESTER	B44001	Division 1	7.83	95.11%	4.70%	0.19%	7.62	2019	518
CHESTER	B44002	Division 1	12.32	94.95%	4.93%	0.12%	7.62	2019	619
CHESTER	B44003	Division 1	2.06	76.92%	17.95%	5.13%	7.62	2019	33
SHERIDAN	B80001	Division 1	1.5	98.19%	1.81%	0.00%	7.62	2019	89
SHERIDAN	B80002	Division 1	29.67	97.11%	2.89%	0.00%	7.62	2019	659
SHERIDAN	B80003	Division 1	23.46	89.98%	9.87%	0.15%	7.62	2019	455
SHERIDAN	B80004	Division 1	19.89	84.61%	15.07%	0.32%	7.62	2019	406
NORTHMOOR	D16001	Division 1	12.95	94.29%	5.28%	0.43%	7.62	2019	262
NORTHMOOR	D16002	Division 1	14.15	81.63%	17.77%	0.60%	7.62	2019	182
NORTHMOOR	D16003	Division 1	9.51	98.46%	1.41%	0.13%	7.62	2019	217
NORTHMOOR	D16004	Division 1	9	93.37%	6.43%	0.20%	7.62	2019	307
JEFFERSON	D48001	Division 1	38.28	90.03%	9.76%	0.20%	7.62	2019	400
JEFFERSON	D48002	Division 1	14.94	89.59%	9.84%	0.57%	7.62	2019	216
JEFFERSON	D48003	Division 1	18.07	89.06%	10.31%	0.63%	7.62	2019	260
BEVERLY MANOR	D89001	Division 1	38.32	89.05%	10.77%	0.09%	7.62	2019	230
BEVERLY MANOR	D89002	Division 1	19.59	93.62%	6.33%	0.05%	7.62	2019	859
BEVERLY MANOR	D89003	Division 1	33.34	91.86%	8.05%	0.09%	7.62	2019	296
OSAGE	D92001	Division 1	21.6	95.26%	4.42%	0.33%	7.62	2019	378
OSAGE	D92002	Division 1	22.35	93.96%	5.89%	0.15%	7.62	2019	861
OSAGE	D92003	Division 1	6.97	62.67%	33.33%	4.00%	7.62	2019	21
WEST BLOOMINGTON	H00163	Division 3	19.98	93.64%	6.36%	0.00%	7.2	2019	900
WESTVILLE WEST MAIN	H06135	Division 4	45.95	92.36%	7.53%	0.11%	7.2	2019	830
BELLEVILLE 8TH ST	J87111	Division 6	10.22	90.42%	9.25%	0.32%	7.2	2019	289

[21] 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

Substation	Circuit	Division	Line Length (Miles)	% Res.	% Comm.	% Large C&I	Voltage Level (kV)	Year Deployed	Low Income Customers
BELLEVILLE 8TH ST	J87120	Division 6	10.37	93.51%	6.03%	0.45%	7.2	2019	264
BELLEVILLE 8TH ST	J87150	Division 6	8.02	91.68%	8.15%	0.17%	7.2	2019	270
BELLEVILLE MARIKNOLL	J99121	Division 6	8.8	91.91%	7.92%	0.18%	7.2	2019	585
BELLEVILLE MARIKNOLL	J99127	Division 6	8.56	94.78%	5.22%	0.00%	7.2	2019	342
BELLEVILLE MARIKNOLL	J99128	Division 6	15.11	87.50%	11.96%	0.54%	7.2	2019	559
BELLEVILLE MARIKNOLL	J99141	Division 6	31.2	95.74%	4.16%	0.10%	7.2	2019	789
BELLEVILLE MARIKNOLL	J99151	Division 6	10.98	76.77%	22.24%	0.98%	7.2	2019	86
BELLEVILLE PONTIAC	K01236	Division 6	12.2	95.39%	4.48%	0.13%	7.2	2019	115
BELLEVILLE PONTIAC	K01238	Division 6	18.85	91.92%	7.91%	0.17%	7.2	2019	313
BELLEVILLE PONTIAC	K01239	Division 6	14.82	80.20%	19.53%	0.27%	7.2	2019	179
BELLEVILLE PONTIAC	K01240	Division 6	40.35	96.83%	3.11%	0.06%	7.2	2019	333
BELLEVILLE PONTIAC	K01241	Division 6	34.89	90.98%	8.88%	0.14%	7.2	2019	237
CENTRALIA SOUTH PLEASANT ST	K27150	Division 6	38.96	94.07%	5.61%	0.32%	7.2	2019	583
CENTRALIA SOUTH PLEASANT ST	K27153	Division 6	14.45	85.21%	14.36%	0.43%	7.2	2019	441
CHESTER	K32932	Division 6	10.97	80.61%	18.91%	0.48%	7.2	2019	207
CHESTER	K32935	Division 6	24.69	89.27%	10.05%	0.68%	7.2	2019	191
CLINTON RT 54	K39153	Division 3	46.56	82.41%	17.08%	0.52%	7.2	2019	587
CLINTON RT 54	K39154	Division 3	31.52	87.93%	11.55%	0.51%	7.2	2019	256
COLLINSVILLE REESE DR	K52400	Division 5	16.66	85.45%	13.56%	1.00%	7.2	2019	262
COLLINSVILLE REESE DR	K52401	Division 5	22.41	95.20%	4.75%	0.05%	7.2	2019	665
COLLINSVILLE REESE DR	K52421	Division 5	4.26	82.18%	16.50%	1.32%	7.2	2019	144
CHAMPAIGN OAK ST	K76541	Division 4	9.49	78.99%	20.75%	0.26%	7.2	2019	448
CHAMPAIGN OAK ST	K76542	Division 4	12.4	88.79%	10.89%	0.33%	7.2	2019	584
CHAMPAIGN OAK ST	K76543	Division 4	3.16	91.45%	8.47%	0.08%	7.2	2019	1033
CHAMPAIGN OAK ST	K76545	Division 4	2.76	88.71%	11.15%	0.14%	7.2	2019	758
CHAMPAIGN OAK ST	K76546	Division 4	7.54	91.59%	8.29%	0.12%	7.2	2019	785
CHAMPAIGN OAK ST	K76547	Division 4	3.3	81.80%	17.51%	0.69%	7.2	2019	613
DECATUR BALTIMORE AVE	K89141	Division 3	14.26	71.40%	27.48%	1.13%	7.2	2019	110
DECATUR BALTIMORE AVE	K89142	Division 3	21.75	92.78%	7.09%	0.13%	7.2	2019	420
DECATUR MOUND RD	L12125	Division 3	24.58	93.69%	5.95%	0.36%	7.2	2019	500
DECATUR MOUND RD	L12126	Division 3	8.13	89.72%	10.28%	0.00%	7.2	2019	516
DECATUR MOUND RD	L12128	Division 3	12.07	73.71%	24.96%	1.33%	7.2	2019	250
DECATUR RT. 48 SOUTH	L23145	Division 3	56.24	88.07%	11.62%	0.31%	7.2	2019	271

Substation	Circuit	Division	Line Length (Miles)	% Res.	% Comm.	% Large C&I	Voltage Level (kV)	Year Deployed	Low Income Customers
DECATUR RT. 48 SOUTH	L23146	Division 3	10.35	95.60%	4.33%	0.07%	7.2	2019	425
DECATUR RTE 51	L24123	Division 3	26.49	96.80%	2.82%	0.38%	7.2	2019	504
DECATUR WALNUT GROVE	L35137	Division 3	15.27	96.05%	3.88%	0.07%	7.2	2019	562
DANVILLE FRANKLIN ST	L73160	Division 4	17.85	96.33%	3.67%	0.00%	7.2	2019	694
DANVILLE LIBERTY LN	L79157	Division 4	23.49	86.85%	12.34%	0.81%	7.2	2019	302
DANVILLE LIBERTY LN	L79158	Division 4	5.73	90.27%	9.31%	0.42%	7.2	2019	248
DANVILLE LIBERTY LN	L79159	Division 4	10.75	98.61%	1.28%	0.11%	7.2	2019	298
DANVILLE LIBERTY LN	L79180	Division 4	9.85	78.39%	20.72%	0.89%	7.2	2019	210
EAST BELLEVILLE	L93133	Division 6	16.52	89.85%	9.53%	0.62%	7.2	2019	448
EAST BELLEVILLE	L93134	Division 6	22.9	90.42%	8.73%	0.85%	7.2	2019	93
EAST BELLEVILLE	L93149	Division 6	24.48	96.60%	3.35%	0.06%	7.2	2019	453
FORSYTH	M26164	Division 3	54.61	88.21%	11.29%	0.50%	7.2	2019	270
GALESBURG FREMONT RD	M36184	Division 1	8.52	83.27%	16.11%	0.62%	7.2	2019	431
GALESBURG FREMONT RD	M36185	Division 1	18.42	94.93%	4.95%	0.12%	7.2	2019	739
GALESBURG FREMONT RD	M36189	Division 1	42.21	87.23%	11.68%	1.09%	7.2	2019	285
GRANITE CITY PARKVIEW	M81403	Division 5	16.2	93.12%	6.88%	0.00%	7.2	2019	402
GRANITE CITY PARKVIEW	M81405	Division 5	25.12	89.33%	10.47%	0.20%	7.2	2019	364
HILLSBORO	N35851	Division 5	84.72	84.19%	15.81%	0.00%	7.2	2019	442
HILLSBORO	N35852	Division 5	47.34	89.09%	10.45%	0.46%	7.2	2019	602
JACKSONVILLE WEST SIDE	N54107	Division 2	24.1	82.05%	17.29%	0.66%	7.2	2019	64
LITCHFIELD	N95823	Division 5	40.73	86.18%	13.52%	0.31%	7.2	2019	523
LITCHFIELD	N95824	Division 5	24.3	73.95%	25.87%	0.18%	7.2	2019	214
MAHOMET	P17108	Division 4	43.48	96.25%	3.75%	0.00%	7.2	2019	611
MONTICELLO	P52306	Division 4	15.67	95.11%	4.66%	0.23%	7.2	2019	259
MT VERNON 11TH ST SUB	P57101	Division 6	6.73	66.44%	33.33%	0.23%	4.16	2019	184
MT VERNON 11TH ST SUB	P57102	Division 6	6.73	66.44%	33.33%	0.23%	4.16	2019	184
MT VERNON 11TH ST SUB	P57103	Division 6	6.73	66.44%	33.33%	0.23%	4.16	2019	184
MT VERNON 11TH ST SUB	P57104	Division 6	6.73	66.44%	33.33%	0.23%	4.16	2019	184
MT VERNON 27TH ST	P58156	Division 6	8.41	89.34%	9.98%	0.68%	7.2	2019	259
MT VERNON 27TH ST	P58159	Division 6	8.56	49.48%	49.06%	1.46%	7.2	2019	148
NASHVILLE	P73157	Division 6	30.62	80.27%	19.34%	0.39%	7.2	2019	301
NASHVILLE	P73158	Division 6	10.35	90.01%	9.58%	0.41%	7.2	2019	251
OTTAWA	Q34360	Division 1	26.68	88.59%	11.05%	0.36%	7.2	2019	524
OTTAWA	Q34366	Division 1	14.41	93.64%	6.26%	0.11%	7.2	2019	316

Substation	Circuit	Division	Line Length (Miles)	% Res.	% Comm.	% Large C&I	Voltage Level (kV)	Year Deployed	Low Income Customers
PINCKNEYVILLE	Q64918	Division 6	5.65	75.74%	23.63%	0.63%	4.16	2019	202
SALEM	Q83168	Division 6	18.88	67.11%	31.82%	1.07%	7.2	2019	124
SALEM	Q83172	Division 6	15.97	80.98%	18.44%	0.58%	7.2	2019	414
SOUTH JACKSONVILLE	R06209	Division 2	11.41	89.87%	9.92%	0.21%	7.2	2019	369
SOUTH JACKSONVILLE	R06212	Division 2	13.18	90.19%	9.81%	0.00%	7.2	2019	287
SOUTH OTTAWA	R07381	Division 1	27.74	96.09%	3.71%	0.20%	7.2	2019	626
SOUTH OTTAWA	R07382	Division 1	42.86	92.57%	7.24%	0.20%	7.2	2019	827
URBANA PERKINS RD	R60553	Division 4	2.93	9.38%	84.38%	6.25%	7.2	2019	1
URBANA PERKINS RD	R60554	Division 4	11.11	89.00%	10.67%	0.25%	7.2	2019	509
URBANA PHILO RD	R61242	Division 4	25.11	91.64%	8.07%	0.28%	7.2	2019	270
VANDALIA	R73840	Division 5	11.51	58.06%	39.03%	2.90%	7.2	2019	107
CAMBRIA	S09521	Division 6	14.9	97.84%	1.83%	0.33%	7.2	2019	151
CARBONDALE WALL ST	S15560	Division 6	14.72	84.45%	14.62%	0.93%	7.2	2019	321
CARTERVILLE	S22594	Division 6	11.11	92.63%	6.79%	0.58%	7.2	2019	274
WEST FRANKFORT	T06503	Division 6	24.52	83.07%	16.48%	0.45%	7.2	2019	182
WEST FRANKFORT IDA	T08502	Division 6	24.27	89.10%	9.94%	0.96%	7.2	2019	190
CANTON N	U31565	Division 2	10.56	90.68%	8.41%	0.91%	7.2	2019	183
CANTON N	U31598	Division 2	24.85	85.98%	13.55%	0.47%	7.2	2019	213
CANTON S	U32579	Division 2	7.82	95.39%	4.40%	0.21%	7.2	2019	210
CANTON S	U32594	Division 2	23.98	84.56%	15.03%	0.40%	7.2	2019	250
QUINCY 15ANDKOCHS LN	V36002	Division 2	14.54	89.08%	10.28%	0.64%	7.2	2019	150
ARTHUR	X12525	Division 4	1.36	22.73%	59.09%	18.18%	7.2	2019	3
ARTHUR	X12526	Division 4	33.34	67.37%	31.05%	1.58%	7.2	2019	67
CHARLESTON	X29548	Division 4	3.78	86.08%	11.81%	2.11%	7.2	2019	130
MATTOON	Y07001	Division 4	1.41	79.37%	19.38%	1.25%	4.16	2019	60
OLNEY N	Y36559	Division 4	13.35	95.66%	3.86%	0.48%	7.2	2019	316
OLNEY S	Y37593	Division 4	11.37	60.21%	37.37%	2.08%	7.2	2019	111
PAXTON	Y55003	Division 4	5.97	77.71%	21.88%	0.42%	4.16	2019	166
TAYLORVILLE E	Y89535	Division 4	8.68	90.60%	9.04%	0.35%	7.2	2019	212
EFFINGHAM NW	Z17522	Division 4	2.29	0.00%	86.67%	13.33%	7.2	2019	N/A
EFFINGHAM NW	Z17554	Division 4	4.07	73.17%	23.90%	2.93%	7.2	2019	92

Source: AIC

Appendix B. Detailed Impact Analysis Methodology

Data Ingestion and Review

Opinion Dynamics used the following data to perform the energy and peak demand savings evaluation: (1) advanced metering infrastructure (AMI) data extracts, (2) supervisory control and data acquisition (SCADA) extracts, (3) VO status and operation logs, (4) circuit characteristics, and (5) hourly weather data.

- **AMI data extracts.** AIC provided AMI data containing hourly demand (kWh), instantaneous voltage, and average instantaneous voltage at four different base voltages. AMI data is the preferred source for all evaluations in Illinois and measures consumption at the customer meter, rather than the circuit level. Because there may be over 1,000 AMI meters on a given circuit, AIC provided average normalized 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.
- **SCADA[22] data extracts.** Five circuits did not have sufficient AMI data for the evaluation. As a result, the evaluation team requested SCADA data to estimate change in voltage for those circuits. SCADA data extracts contain hourly usage (MW), voltage (kV), and reactive power (MR) readings by phase. The SCADA voltage data was averaged across the observations for all three phases and converted to normalized voltage (to match the AMI data) using the nominal voltage of each circuit.
- **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. Within the operations log, the evaluation team flagged certain time frames as excludable adhering to guidance in the Verification and Exclusions memo: Circuit Outage, Repair/Maintenance, Switching, and Technology Events.[23] For 2020, Worldwide Pandemic/Orders by Civil Authorities were also flagged as excludable.
- **Circuit characteristics.** This dataset for all circuits planned for VO-deployment (n=1,047)[24] contained descriptive information about the circuits as well as usage data from 2014 through 2016 because VO remains a key input in the algorithmic approach as it establishes the algorithmic baseline. Peak demand was unavailable for four circuits for the period 2014–2016. Per AIC's guidance we substituted peak demand from 2017–2019.
- **Hourly weather data.** The evaluation team sourced weather data from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information, which we mapped to circuits using GPS coordinates. We then calculated the cooling and heating degree hours, using base temperatures of 75°F and 65°F[25], respectively, to generate the weather parameters used in modeling.

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[22] SCADA is an acronym for supervisory control and data acquisition, a computer system for gathering and analyzing real time data.
[23] See Ameren Illinois Company Voltage Optimization Verification and Exclusion Approach memo here: https://ilsag.s3.amazonaws.com/AIC-2019-Voltage-Optimization-Operation-Verification-Memo-FINAL-2020-04-17.pdf
[24] 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.
[25] These base temperatures are commonly used in the industry.

Energy Savings

Data Cleaning

We summarize the results of our data cleaning effort for the 2020 impacts below (see Table 9). 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 NOAA. 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.
- **Negative and zero values:** Negative and zero values in kV and MW data were flagged and removed from the analysis.
- **Outliers:** Outliers were screened on a circuit-by-circuit basis. Outliers are 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:** In some circumstances it is best practice, or it is required, to disable VO to support system changes, growth, outages, and planned/unplanned maintenance. AIC has indicated 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); (4) had experienced a failure in information or communication technology; and (5) any event flagged for worldwide pandemic or outages ordered by civil authorities.
- **'On' and 'off' testing:** Every circuit experienced some period of 'On' and 'Off' testing after the go live date. For some circuits, this period extends into the post period of 2020. 'Off' events during 'On' and 'Off' testing were flagged and removed from the analysis if they occurred in 2020.
- **'On' in pre-period:** To construct a pre-period, 'On' events were flagged and removed in 2019. This includes natural 'On' events as well as those occurring during 'On' and 'Off' testing.
- **Zero hour on 'on' and 'off' period:** There were some hours where the AMI voltage data and the status logs clearly did not align. Typically, these occurred on hour zero of the day in which an excludable event was scheduled to occur. These periods are particularly noticeable during 'On' and 'Off' testing periods, they were flagged and removed from the analysis during 'On' and 'Off' testing periods.

Table 9 provides a summary of the data cleaning results for this analysis. Results include all 125 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. Overall, 16% of observations were dropped. No circuits were removed from the energy savings analysis due to data insufficiency.

Table 9. Data Cleaning Results for 2020 VO Energy Savings Impacts

Step	Circuits	Records	Change	% Change
Initial	125	2,187,737	NA	NA
Exact Duplicates	125	2,187,737	-	0.0%
Time Periods without Weather Data	125	2,183,881	3,856	0.2%

Step	Circuits	Records	Change	% Change
kV Less than or Equal to 0	125	2,169,197	14,684	0.7%
Outliers	125	2,169,197	-	0.0%
Exclusion Time Periods[a]	125	2,023,590	145,607	6.7%
On in Pre-Period	125	1,847,860	175,730	8.0%
Zero Hour On/Off Period	125	1,831,797	16,063	0.7%
Total	**125**	**1,831,797**	**355,940**	**16.3%**

[a] Includes FLIP events and 'On'/'Off' testing baseline construction (dropping 'Off' events in 2020 and 'On" events in 2019).

Modeling Percent Change in Voltage for Energy Savings

To develop a pre-period baseline for this evaluation, the evaluation team removed 'On' periods in 2019. As a result, the baseline reflects 'Off' periods and voltage levels without VO. The post-period of interest is 2020, where all circuits are active. However, several circuits experienced 'On' and 'Off' testing in the first months of 2020. In these cases, only the 'On' periods are retained. Aside from non-excludable 'Off' periods, the post-period consists of largely 'On' events. The evaluation team used this structure to fit individual models on each circuit.

To estimate changes in voltage, we used a regression model described in Equation 3.

Equation 3. 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 IL-TRM prescribes an algorithmic approach to evaluating VO energy savings. The algorithmic approach combines deemed parameter values with measured savings in voltage to calculate energy savings. Since we apply the estimated change in voltage to the circuit-level annual usage, the results are effectively annualized for the entire year.

The algorithm used for the VO energy savings evaluation is shown in Equation 4.

Equation 4. AIC VO Energy 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.
- $\%\Delta V_i$= the percent change in voltage for circuit *i* resulting from VO implementation relative to the pre-period, using a regression model to control for exogenous factors that may contribute to changes in voltage (e.g., weather).

Detailed Circuit Results: Energy Savings

Table 10 provides each algorithmic input by each circuit, as well as the total estimated savings. For 117 of the 125 circuits, the percent change in voltage was estimated to be larger than the planned value of 3.0%. The overall average percent change in voltage was 4.12%.[26]

Table 10. Ex Ante and Verified Algorithmic Inputs and Associated Energy Savings by Circuit

Circuit	Annual Gross Energy Use (MWh)	CVR_f	Average Percent Change in Voltage	Annual Gross Energy Savings (MWh)
A17025	23,520	0.8	3.52%	663
A17026	15,258	0.8	3.15%	384
A91003	16,940	0.8	3.65%	495
A91004	11,388	0.8	3.12%	284
B44001	13,978	0.8	3.04%	340
B44002	23,025	0.8	3.17%	583
B44003	16,689	0.8	3.59%	479
B80001	1,970	0.8	3.08%	49
B80002	22,139	0.8	3.10%	549
B80003	21,213	0.8	2.99%	508
B80004	15,928	0.8	2.90%	370
D16001	13,682	0.8	2.74%	300
D16002	22,549	0.8	2.64%	476
D16003	8,145	0.8	2.65%	173
D16004	11,331	0.8	2.48%	225
D48001	20,460	0.8	3.76%	616
D48002	10,567	0.8	3.79%	321
D48003	26,893	0.8	3.63%	781
D89001	17,535	0.8	2.80%	392
D89002	19,799	0.8	2.69%	426

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

Circuit	Annual Gross Energy Use (MWh)	CVR_f	Average Percent Change in Voltage	Annual Gross Energy Savings (MWh)
D89003	16,465	0.8	3.15%	415
D92001	16,403	0.8	3.08%	404
D92002	23,292	0.8	3.07%	572
D92003	15,547	0.8	3.09%	384
H00163	17,120	0.8	4.62%	633
H06135	24,175	0.8	4.37%	844
J87111	13,165	0.8	3.35%	353
J87120	11,327	0.8	4.74%	430
J87150	8,180	0.8	4.50%	294
J99121	15,273	0.8	3.90%	476
J99127	9,461	0.8	4.95%	375
J99128	24,005	0.8	4.16%	799
J99141	22,677	0.8	4.47%	810
J99151	17,658	0.8	4.94%	697
K01236	12,920	0.8	5.20%	537
K01238	17,458	0.8	4.62%	646
K01239	19,993	0.8	4.13%	660
K01240	26,061	0.8	4.95%	1,033
K01241	21,907	0.8	4.38%	768
K27150	25,818	0.8	4.22%	872
K27153	25,443	0.8	4.15%	845
K32932	15,085	0.8	3.56%	430
K32935	21,746	0.8	3.55%	617
K39153	28,300	0.8	3.69%	836
K39154	22,322	0.8	3.91%	698
K52400	24,649	0.8	3.32%	655
K52401	24,830	0.8	3.55%	705
K52421	14,060	0.8	3.69%	415
K76541	23,109	0.8	3.38%	624
K76542	20,765	0.8	4.73%	786
K76543	26,317	0.8	4.16%	876
K76545	21,433	0.8	4.00%	686
K76546	14,656	0.8	4.63%	543
K76547	38,523	0.8	4.10%	1,263
K89141	22,127	0.8	4.36%	773
K89142	15,966	0.8	4.07%	520
L12125	21,698	0.8	3.53%	613
L12126	10,414	0.8	4.96%	413
L12128	25,107	0.8	3.33%	668
L23145	16,199	0.8	4.66%	604
L23146	15,788	0.8	4.56%	576
L24123	21,438	0.8	3.84%	659

Circuit	Annual Gross Energy Use (MWh)	CVR_f	Average Percent Change in Voltage	Annual Gross Energy Savings (MWh)
L35137	22,920	0.8	3.83%	703
L73160	19,380	0.8	5.28%	818
L79157	33,742	0.8	4.67%	1,262
L79158	10,679	0.8	4.63%	395
L79159	11,046	0.8	5.19%	459
L79180	20,276	0.8	4.52%	733
L93133	29,175	0.8	4.60%	1,074
L93134	23,332	0.8	4.20%	783
L93149	23,341	0.8	4.76%	889
M26164	21,914	0.8	4.49%	787
M36184	20,112	0.8	3.93%	633
M36185	16,849	0.8	4.51%	608
M36189	18,558	0.8	5.41%	804
M81403	12,158	0.8	4.16%	404
M81405	13,732	0.8	3.77%	414
N35851	17,829	0.8	4.48%	639
N35852	27,899	0.8	4.17%	931
N54107	18,999	0.8	4.63%	704
N95823	25,421	0.8	4.25%	864
N95824	15,185	0.8	3.97%	482
P17108	18,221	0.8	4.34%	632
P52306	13,448	0.8	5.03%	541
P57101	9,288	0.8	3.74%	278
P57102	5,625	0.8	3.63%	163
P57103	7,292	0.8	3.68%	215
P57104	9,125	0.8	3.75%	274
P58156	11,295	0.8	4.30%	389
P58159	26,636	0.8	4.97%	1,060
P73157	20,264	0.8	4.64%	752
P73158	14,049	0.8	4.51%	507
Q34360	23,260	0.8	3.68%	686
Q34366	11,032	0.8	3.92%	346
Q64918	9,038	0.8	4.63%	335
Q83168	15,452	0.8	5.18%	640
Q83172	23,764	0.8	4.78%	908
R06209	17,178	0.8	4.56%	627
R06212	11,132	0.8	4.13%	368
R07381	26,679	0.8	4.36%	930
R07382	23,459	0.8	3.60%	675
R60553	21,787	0.8	4.43%	772
R60554	18,106	0.8	4.92%	713
R61242	19,086	0.8	5.29%	807

Circuit	Annual Gross Energy Use (MWh)	CVR_f	Average Percent Change in Voltage	Annual Gross Energy Savings (MWh)
R73840	18,158	0.8	3.81%	553
S09521	14,136	0.8	5.13%	580
S15560	17,672	0.8	4.42%	625
S22594	17,112	0.8	5.54%	759
T06503	11,069	0.8	4.56%	404
T08502	11,717	0.8	4.72%	442
U31565	11,083	0.8	5.10%	452
U31598	12,744	0.8	4.43%	452
U32579	11,036	0.8	4.12%	364
U32594	11,924	0.8	4.95%	472
V36002	10,765	0.8	4.70%	405
X12525	21,567	0.8	4.40%	760
X12526	18,956	0.8	3.92%	595
X29548	12,032	0.8	4.06%	391
Y07001	8,187	0.8	5.22%	342
Y36559	12,976	0.8	4.45%	461
Y37593	13,010	0.8	4.90%	510
Y55003	8,940	0.8	7.42%	531
Y89535	15,433	0.8	4.32%	533
Z17522	8,738	0.8	3.72%	260
Z17554	15,646	0.8	4.41%	552
Total	**2,202,555**	**0.8**	**4.12%**	**72,669**

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 evaluated a range of model specifications and selected the best fit determined by model diagnostics (R^2 and adjusted R^2). A detailed binder provides the coefficient estimates and model fit statistics for each circuit-level model. All modeled circuit results were statistically significant at the 90% confidence level.

Measure Life and Cumulative Persisting Annual Savings

The FEJA-defined measure life of 15 years was applied for this measure.[27]

Peak Demand Savings

Data Cleaning

Data cleaning for the peak demand analysis included all of the steps undertaken for the energy savings model, plus the following additional cleaning steps:

[27] 220 ILCS 5/8-103B(b-20) of Illinois Senate Bill 2814 (the Future Energy Jobs Act).

- **Include Peak Period Only:** The peak demand model only includes observations during the peak period, defined as the hours of 1:00 p.m.–5:00 p.m. (CDT) on non-holiday weekdays between June and August.
- **Less than 20 Days in Peak Period:** Circuits with less than twenty days in the peak period were removed from the analysis.
- **No Baseline Peak Period:** One circuit was removed (M36189) for insufficient pre-period data to conduct the analysis. The average percentage peak voltage savings of all circuits (3.07%) was assigned to M36189 instead.

Table 11 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 0.46%. One circuit was removed from the analysis due to insufficient peak period data. This was a SCADA circuit (M36189) where the entire peak period expressed “0” voltage, resulting in insufficient pre-period baseline data for conducting the analysis.

Table 11. Data Cleaning Results for Peak Demand Savings

Step	Circuits	Records	Change	% Change
Initial Count	125	302,340	N/A	N/A
Less than 20 days in Peak Period	125	302,322	18	0.01%
No Baseline in Peak Period	124	300,953	1,369	0.45%
Total	**124**	**300,953**	**1,387**	**0.46%**

Modeling Percent Change in Voltage for Demand Savings

To develop a baseline, the evaluation team took the cleaned data used for annual impacts and subset to the peak period. Individual models were run by circuit, and savings were aggregated similarly to the annual savings, taking into account the peak CVR_f and the annual peak demand (MW). As with the energy savings model, the demand savings model uses 2019 as the pre-period. The model is only run on peak hours within the summer peak period subset.

To estimate changes in voltage, we used a regression model described in Equation 5.

Equation 5. Voltage Reductions Model

$$kV_{it} = \alpha + \beta_1 VO_t + \beta_2 cdh_t + \beta_3 VO_t * cdh_t + + \varepsilon_{it}$$

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*
- ε_{it} = error term

Calculating Peak Demand Savings

Peak demand savings are also estimated with an algorithmic approach. The peak period is defined as 1:00 p.m.–5:00 p.m. (CDT) on non-holiday weekdays from June 1 to August 31.[28]

The algorithm used for the VO peak demand evaluation is shown in Equation 6.

Equation 6. AIC VO Peak Demand Savings Algorithm

$$Peak\ Demand\ Savings_i = Avg\ Peak\ Demand_{2014-2016_{i,PEAK}} * CVR_{f,PEAK} * \%\Delta V_{i,PEAK}$$

Where

- $Avg\ Peak\ Demand_{2014-2016_{i,PEAK}}$ = the demand in the peak hour for circuit *i* over the 2014–2016 timeframe during the peak period adjusted by a calibration factor that captures the relationship between peak demand and average demand in the peak period, excluding exempt customers. [29]
- $CVR_{f,PEAK}$ = the estimate of the peak conservation voltage reduction factor (deemed as 0.68), defined as the percent change in energy usage divided by the percent change in voltage during the peak period.
- $\%\Delta V_{i,PEAK}$= the percent change in voltage for circuit *i* resulting from VO implementation relative to the peak hours of the pre-period, using a regression model to control for exogenous factors that may contribute to changes in voltage (e.g., weather). Per the guidance in the TRM, this is to be calculated in the same manner as energy savings but with the intention of measuring peak demand impact rather than total energy savings.

Detailed Circuit Results: Peak Demand Savings

Table 12 provides each algorithmic input by each circuit, as well as the total estimated peak demand savings. The overall peak demand voltage savings was 3.04%.[30]

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

Circuit	Annual Peak Demand (MW)	CVR_f (peak)	Average Percent Change in Peak Voltage	Annual Demand Savings (MW)
A17025	6.19	0.68	3.13%	0.13
A17026	3.63	0.68	3.67%	0.09
A91003	8.28	0.68	4.34%	0.24
A91004	3.18	0.68	2.30%	0.05
B44001	3.43	0.68	2.96%	0.07
B44002	6.19	0.68	2.96%	0.12
B44003	3.73	0.68	4.59%	0.12
B80001	1.21	0.68	2.39%	0.02
B80002	6.80	0.68	2.45%	0.11
B80003	5.48	0.68	3.00%	0.11
B80004	3.98	0.68	2.46%	0.07
D16001	3.52	0.68	0.67%	0.02

[28] Illinois Technical Reference Manual for Energy Efficiency, Version 9.0, Volume 1, Section 3.7.
[29] Peak demand was unavailable for four circuits for the period 2014–2016. Per AIC's guidance we substituted peak demand from 2017–2019.
[30] Average percent change in voltage is weighted by annual peak demand (MW).

Circuit	Annual Peak Demand (MW)	CVR_f (peak)	Average Percent Change in Peak Voltage	Annual Demand Savings (MW)
D16002	5.97	0.68	0.46%	0.02
D16003	2.83	0.68	0.51%	0.01
D16004	3.40	0.68	0.10%	0.00
D48001	5.34	0.68	1.78%	0.06
D48002	3.05	0.68	1.80%	0.04
D48003	6.90	0.68	1.64%	0.08
D89001	5.82	0.68	2.61%	0.10
D89002	5.94	0.68	2.37%	0.10
D89003	4.29	0.68	2.91%	0.09
D92001	4.20	0.68	1.18%	0.03
D92002	6.34	0.68	1.11%	0.05
D92003	4.05	0.68	1.14%	0.03
H00163	5.20	0.68	3.05%	0.11
H06135	6.58	0.68	2.89%	0.13
J87111	3.60	0.68	2.96%	0.07
J87120	3.16	0.68	3.82%	0.08
J87150	3.73	0.68	3.58%	0.09
J99121	3.95	0.68	3.45%	0.09
J99127	2.94	0.68	4.10%	0.08
J99128	5.82	0.68	3.27%	0.13
J99141	4.85	0.68	3.22%	0.11
J99151	4.32	0.68	4.64%	0.14
K01236	3.93	0.68	5.30%	0.14
K01238	4.36	0.68	3.84%	0.11
K01239	5.57	0.68	3.43%	0.13
K01240	8.57	0.68	4.34%	0.25
K01241	7.31	0.68	3.11%	0.15
K27150	7.18	0.68	3.19%	0.16
K27153	6.59	0.68	2.61%	0.12
K32932	4.87	0.68	2.77%	0.09
K32935	4.96	0.68	2.52%	0.09
K39153	6.38	0.68	2.35%	0.10
K39154	5.89	0.68	2.71%	0.11
K52400	5.18	0.68	2.18%	0.08
K52401	6.85	0.68	2.91%	0.14
K52421	2.65	0.68	3.53%	0.06
K76541	6.05	0.68	3.07%	0.13
K76542	5.27	0.68	4.09%	0.15
K76543	5.37	0.68	4.72%	0.17
K76545	4.24	0.68	3.50%	0.10
K76546	3.86	0.68	4.26%	0.11
K76547	8.17	0.68	3.48%	0.19

Circuit	Annual Peak Demand (MW)	CVR_f (peak)	Average Percent Change in Peak Voltage	Annual Demand Savings (MW)
K89141	5.26	0.68	2.69%	0.10
K89142	4.35	0.68	2.54%	0.07
L12125	5.06	0.68	2.02%	0.07
L12126	2.82	0.68	4.88%	0.09
L12128	5.94	0.68	2.46%	0.10
L23145	4.67	0.68	2.93%	0.09
L23146	4.59	0.68	2.74%	0.09
L24123	6.52	0.68	2.24%	0.10
L35137	4.68	0.68	1.84%	0.06
L73160	5.49	0.68	4.47%	0.17
L79157	7.77	0.68	3.08%	0.16
L79158	2.56	0.68	3.09%	0.05
L79159	3.33	0.68	3.55%	0.08
L79180	4.48	0.68	3.66%	0.11
L93133	6.52	0.68	3.44%	0.15
L93134	6.76	0.68	3.03%	0.14
L93149	6.04	0.68	4.15%	0.17
M26164	5.92	0.68	3.04%	0.12
M36184	3.87	0.68	2.80%	0.07
M36185	4.67	0.68	3.01%	0.10
M36189[a]	4.18	0.68	3.08%	0.09
M81403	3.37	0.68	1.87%	0.04
M81405	3.21	0.68	1.91%	0.04
N35851	4.52	0.68	2.93%	0.09
N35852	7.07	0.68	2.33%	0.11
N54107	4.76	0.68	3.90%	0.13
N95823	5.63	0.68	2.76%	0.11
N95824	4.21	0.68	2.76%	0.08
P17108	4.97	0.68	3.18%	0.11
P52306	3.42	0.68	3.61%	0.08
P57101	2.38	0.68	2.03%	0.03
P57102	1.62	0.68	1.65%	0.02
P57103	1.38	0.68	2.10%	0.02
P57104	1.94	0.68	2.12%	0.03
P58156	1.38	0.68	3.08%	0.03
P58159	6.18	0.68	2.89%	0.12
P73157	5.49	0.68	2.91%	0.11
P73158	3.37	0.68	3.27%	0.08
Q34360	5.43	0.68	1.91%	0.07
Q34366	2.88	0.68	1.84%	0.04
Q64918	2.66	0.68	2.94%	0.05
Q83168	3.11	0.68	4.55%	0.10

Circuit	Annual Peak Demand (MW)	CVR_f (peak)	Average Percent Change in Peak Voltage	Annual Demand Savings (MW)
Q83172	5.51	0.68	3.37%	0.13
R06209	4.87	0.68	3.48%	0.12
R06212	3.41	0.68	3.01%	0.07
R07381	6.61	0.68	2.18%	0.10
R07382	5.88	0.68	2.23%	0.09
R60553	4.51	0.68	3.58%	0.11
R60554	3.50	0.68	3.61%	0.09
R61242	5.34	0.68	4.71%	0.17
R73840	4.12	0.68	3.05%	0.09
S09521	3.07	0.68	4.86%	0.10
S15560	3.39	0.68	3.02%	0.07
S22594	3.64	0.68	4.77%	0.12
T06503	2.43	0.68	3.56%	0.06
T08502	2.31	0.68	3.83%	0.06
U31565	2.34	0.68	4.39%	0.07
U31598	2.97	0.68	3.33%	0.07
U32579	2.40	0.68	2.72%	0.04
U32594	2.08	0.68	2.39%	0.03
V36002	2.42	0.68	2.87%	0.05
X12525	3.88	0.68	5.46%	0.14
X12526	4.33	0.68	3.18%	0.09
X29548	3.21	0.68	3.86%	0.08
Y07001	1.45	0.68	4.55%	0.04
Y36559	3.00	0.68	3.65%	0.07
Y37593	3.45	0.68	3.87%	0.09
Y55003	1.98	0.68	5.89%	0.08
Y89535	3.44	0.68	3.23%	0.08
Z17522	1.67	0.68	3.83%	0.04
Z17554	3.04	0.68	5.49%	0.11
Total	**555.88**	**0.68**	**3.04%**	**11.50**

[a] This feeder did not have sufficient baseline data to complete the analysis of percent change in voltage and was assigned the average percent change in voltage.

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 evaluated a range of model specifications and selected the best fit determined by model diagnostics (R^2 and adjusted R^2). A detailed binder provides the coefficient estimates and model fit statistics for each circuit-level model. All modeled circuit results were statistically significant at the 90% confidence level.

Appendix C. Cumulative Persisting Annual Savings

Table 13 provides CPAS and WAML for the 2020 VO Program through 2048. Lifetime savings for the 2020 VO Program are 1,090,030 MWh.

Table 13. 2020 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 - 2020 Cohort	15.0	72,669	N/A			72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669
2020 CPAS		72,669	N/A			72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669
Expiring 2020 CPAS						0	0	0	0	0	0	0	0	0	0	0	0	0
Expired 2020 CPAS						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 - 2020 Cohort	15.0	72,669	N/A	72,669	72,669	0	0	0	0	0	0	0	0	0	0	0	0	0
2020 CPAS		72,669	N/A	72,669	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expiring 2020 CPAS				0	72,669	0	0	0	0	0	0	0	0	0	0	0	0	0
Expired 2020 CPAS				0	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669	72,669
WAML	15.0																	

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

Appendix D. Verification of Continued Operations

Opinion Dynamics conducted a verification analysis on the 2019 cohort of VO circuits. Since VO savings are deemed for 15 years after completion of the initial evaluation of a circuit and no retroactive changes are subsequently made to the savings, verification is necessary to confirm continued operation.

In 2020, Opinion Dynamics, AIC, and ICC Staff agreed that ongoing verification of VO should be conducted for process purposes to provide information to stakeholders and other parties as to the level of continued VO operation and, if needed, to provide context as to why VO may not have operated continuously. After the initial evaluation of each year of VO circuits, parties agreed that Opinion Dynamics would conduct verification activities to assess the degree to which VO continued to operate throughout each year. The acceptable threshold of operation was set to ensure that circuits operated over a 90% threshold.[31]

The purpose of this verification is to provide information to stakeholders and other parties as to the level of continued operation of VO throughout the 15-year deemed period of savings, and, if needed, to provide context as to why VO may not have operated continuously throughout the period.

The evaluation team conducted the following activities to determine whether these circuits operated over a 90% threshold.

- **Sample Selection:** The evaluation team randomly selected 10 of the 19 circuits evaluated in 2019 using a cross-sectional sample design, which optimizes the sample for each cohort while minimizing the overall sample size across all cohorts. We performed sample selection retrospectively and provided AIC no knowledge of which circuits would be sampled until after the evaluation period had passed. Table 14 presents the sample of the 2019 VO circuits evaluated as part of the 2020 circuit verification.

Table 14. Sample of 2019 Evaluated VO Circuits

Substation	Circuit	Division
Northwest	B00002	1
Northwest	B00003	1
Caseyville Gardens	K11376	5
E. Belleville	L93132	6
Mt. Vernon 27th St	P58155	6
Mt. Zion Rte 121	P69173	3
Quincy 24th and Cherry	V40556	2
Quincy 28th and Adams	V41533	2
Charleston S. EIU	X35501	4
Tuscola East CP	Y98532	4

Source: AIC

- **Review and request operation log summaries and voltage data for the sample.** Our variable of interest for this effort included the VO status (e.g., 'On' and 'Off') for specific hours throughout the year at a circuit level and the voltage data. We were able to rely on the VO status summaries for this analysis since we generally expected VO to run for nearly all hours in a year.

[31] See Ameren Illinois Company Voltage Optimization Verification and Exclusion Approach memo here: https://ilsag.s3.amazonaws.com/AIC-2019-Voltage-Optimization-Operation-Verification-Memo-FINAL-2020-04-17.pdf

- **Data cleaning.** Opinion Dynamics did not perform any data cleaning prior to the verification activities, with the exception of removing excludable events. Excludable events are discussed in more detail in Appendix B. For the purposes of verification, we additionally excluded any 'On'/'Off' testing that extended into 2020.
- **Calculated operation status.** We calculated the proportion of hours that each circuit's VO status was 'On' for a given year. We then divided the total number of hours in which the status logs indicated that VO was on by the total number of non-excludable hours in the year.
- **Conducted quality control.** We then performed further verification to observe if operations logs and voltage data aligned by investigating hours that should be classified as "excludable events." Further, the evaluation team visually inspected the operations logs to ensure that the patterns in the operations logs matched the patterns shown in the data. This final step was designed to determine if operations logs and voltage data aligned enough so that we could rely only on operations logs in the future.

The evaluation team found that all of the 2019 verified VO circuits were "On" for more than 90% of the non-excludable hours in 2020.

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