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Conservation Voltage Reduction/Volt VAR Optimization EM&V Practices

EPA United States Environmental Protection Agency

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1 EXECUTIVE SUMMARY

There is renewed interest in conservation voltage reduction (CVR) and voltage/VAR optimization (VVO) as a potentially cost-effective way to deliver energy efficiency benefits to customers without the need to recruit participants. Increasingly, utility regulators are allowing associated energy savings to count toward voluntary energy efficiency goals or mandatory energy efficiency resource standards. In addition, grid modernization efforts are improving the tools that distribution system operators can use to optimize voltage. While performance varies by circuit, many utilities find 1 to 4% savings on initial deployment.[1]

This document provides background on methods for assessing energy savings potential, data tracking considerations, and current impact evaluation processes. In summary, it is generally considered best practice to use an on/off experimental design to evaluate the energy efficiency impact of CVR. The data collected via the on/off design can then be used to model the impact of the grid efficiency operation, using either a regression-based approach or calibrated simulation modelling. Ex-post impacts can be estimated by calibrating with data collected from ongoing CVR/VVO experimentation and verified local conditions.

Due to increased interest in energy efficiency programs for low-income communities and the well-recognized and unique challenges in delivering programs to low-income households, this document also discusses approaches for assessing the energy efficiency benefits to these communities.

[1] Source: U.S. Department of Energy. Evaluation of Conservation Voltage Reduction (CVR) on a National Level. July 2010. http://www.pnl.gov/main/publications/external/technical_reports/PNNL-19596.pdf, accessed October 26, 2016.

2 INTRODUCTION

Throughout the United States, electricity is required to be delivered to most customers within a range of acceptable voltages. For example, residential customer voltage is typically required to be maintained between 114 V and 126 V (for normal 120-V service).[2] Delivering electricity closer to the lower end of this voltage range can result in customer energy savings because some equipment operates more efficiently at voltages in the lower end of the acceptable range. For example, voltage reduction on open-loop loads such as unregulated motors (e.g., ventilation motors) will lead to energy savings. Not all customer devices will save energy from reducing voltage. For many water heaters, operating at the lower end of the voltage range reduces immediate demand, but ultimately uses the same amount of energy to reach a target water temperature setting. Other loads, like today's fluorescent lamp ballasts, are likely to draw about the same amount of power regardless of voltage.[3] Utilities that implement these programs have reported 1 to 4% savings from initial deployments.[4]

In alternating current (AC) systems, current and voltage can be out of phase due to operating characteristics of equipment that requires a magnetic field to operate, such as a motor.[5] This is referred to as reactive power and is measured in Volt-Amperes Reactive or VAR.[6] Transmission and distribution system operators need to provide reactive power to maintain electric power flow since motors and other devices requiring reactive power to operate are widely used in industrial, commercial and residential settings. Some of the same technologies and strategies used to adjust system voltage can be used to better manage reactive power.[7]

Conservation voltage reduction (CVR) is the intentional operation of the transmission and distribution system to provide customer voltages in the lower end of the acceptable range, with the goal of achieving energy and demand reductions for customers. When utilities manage and optimize voltage and reactive power simultaneously (combining the voltage management associated with CVR with reactive power management), it is referred to as volt/VAR optimization (VVO). VVO focuses on circuit-level operations and reduces energy losses by reducing reactive power flow along the distribution circuit. Since the flow of reactive power affects power system voltages, management of costs and performance of operating a power system may improve if voltage control and reactive power are well integrated.[8] VVO/CVR optimization typically results in savings on both the customer side of the meter as well as on the distribution system, with savings typically concentrated on the customer side of the meter. Estimates of savings attributable to the customer side of the meter may exceed 90 percent.[9]

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[2] ANSI C84.1, "Electric Power Systems and Equipment—Voltage Ratings (60 Hertz)," specifies the nominal voltage ratings and operating tolerances for 60-hertz electric power systems above 100 V.

[3] Source: EPA Energy and Environment Guide to Action, pp. 7-112 – 7-113. https://www.epa.gov/sites/production/files/2016-03/documents/guide_action_chapter7.0.pdf, accessed March 8, 2017.

[4] Source: U.S. Department of Energy. Evaluation of Conservation Voltage Reduction (CVR) on a National Level. July 2010.

[5] Source: EPA Energy and Environment Guide to Action, pp. 7-112 – 7-113.

[6] VAR is the unit used to express reactive power. The term is an abbreviation of volt-ampere reactive.

[7] Source: EPA Energy and Environment Guide to Action, p. 7-113.

[8] Ibid.

[9] Source: EPRI Green Circuit Distribution Efficiency Case Study 1023518 Technical Report, 2011. Table B-5. ["End-Use VO Energy Saved" compared to "Total Energy Savings" can vary from 69% (Sub 3) to 95% (Sub 2)]. http://www.epri.com/search/Pages/results.aspx?k=Green%20Circuits:%20Distribution%20Efficiency%20Case%20Studies, accessed March 8, 2017.

3 DETERMINING POTENTIAL

Energy efficiency potential studies help guide energy efficiency program planning. They can be used to justify initiatives, support 'go' or 'no-go' decisions about programs and prioritize investments that support initiatives. Potential studies are particularly important to grid efficiency measures as variation in savings across circuits can be quite significant, with some circuits exhibiting little or no opportunity for savings without significant capital investment.

3.1 VVO and CVR Energy Savings Potential

At the system level, the savings potential from VVO or CVR operations is driven by a variety of factors, including the customer class distribution, line density and percent loading. Potential savings may be estimated using a variety of methods ranging from basic to rigorous. The level of rigor desired will be driven by the business case objective. Estimates can be developed sequentially, with more rigorous analyses building on prior, simpler analyses. More rigorous analyses require greater data, effort and expertise. The various methods available for CVR potential estimation are also appropriate for VVO potential estimation, with VVO savings estimates also accounting for loss reduction impacts from improved reactive power dispatch. Several approaches are discussed in the subsections below.

3.1.1 Using Third-Party Sources

Voltage reduction potential can be estimated using a combination of existing voltage information from the circuit(s) under study (e.g., available field measurement data) and savings impact estimates from other studies such as pilot initiatives within the utility system or results from deployments in other regions or jurisdictions.

Both the voltage control strategy and the system characteristics of the CVR/VVO operation should be considered when assessing the applicability of third-party data. For example, Pacific Northwest National Laboratories (PNNL) conducted a national study that simulated CVR implementation on prototypical feeders.[10] The study derived estimates by feeder type and region using assumed load compositions by region. Use of this PNNL study would require making appropriate decisions about how to adapt the PNNL results to align with local system characteristics/conditions. As noted earlier, the savings achieved due to voltage reduction vary based on the magnitude of the voltage drop and type of load served by the circuit.

3.1.2 Developing a CVR Factor through Experimentation

A key component in estimating potential customer savings is the CVR factor, which is a commonly used indicator of the relationship between energy savings and changes in voltage from CVR operations.[11] CVR factors can be developed in-house through pilots and experimentation using field measurements of voltage down the line, and corresponding measurements of the resulting load changes. However, CVR factors can be difficult to estimate without collecting a sizeable amount of load and voltage data, or information that characterizes load types.

Once established, CVR factors can be applied to additional circuits, transformers, or even households to estimate savings potential. The broad application of CVR factors, whether adapted from third-party sources or developed through measurement on the same system, should be thoughtfully applied.

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[10] Source: U.S. Department of Energy. Evaluation of Conservation Voltage Reduction (CVR) on a National Level. July 2010.

[11] Formally, a CVR Factor is the ratio between the percentage change in energy and the associated percentage change in voltage. But other ratios can be useful in managing voltage optimization operations such as the percentage change in kW, kVAR, and kVARh to the associated change in voltage.

Selecting circuits for pilot studies and implementation depends on the objectives of the CVR/VVO deployment. Common system characteristics and the cost/complexity of implementation should be considered when selecting appropriate pilot circuits for estimating benefits. While stable and uniform circuits might serve as a convenient test bed for pilot implementation, if the larger deployment involves frequent configuration changes, pilot results would need to be adapted to accommodate this difference. Often, circuits with newer substation and transformer infrastructure, newer meter deployments and communicating line device controllers reduce the effort and cost of deployments and provide data to support pilot evaluations. Customer diversity may also be an objective for pilot experimentation and potential estimation. For example, utilities with long rural circuits might study them to understand the impacts of CVR/VVO at the ends of their lines. Utilities seeking to provide relief to low-income communities may prioritize CVR/VVO deployment to those circuits to inform broader implementation.

3.1.3 Monitoring with Matched Circuits Pre-Post

Pre-post designs with matched circuits can be useful for pilot monitoring and other research objectives for optimizing VVO and CVR strategies, including energy efficiency potential estimation—particularly for systems where it is difficult to remotely manage voltage or transformer level savings.

A pre-post experimental design with matched circuits is analogous to the quasi-experimental design used in demand side management (DSM) program evaluations where a randomized control trial (RCT) design is not feasible.[12] Under a pre-post design with matched circuits, operations are initiated at a point in time and energy impacts are estimated by comparing the energy consumption and voltage prior to implementation (i.e., the "pre" period) to the consumption after initiating operations (i.e., the "post" period). The impacts are estimated using a statistical model to normalize weather and other exogenous factors that can impact energy consumption.

Additionally, to control for economic effects, controlled circuits are matched to non-controlled circuits that have similar characteristics and are subject to the same economic effects. The economic effects are "netted out" of the CVR circuits by subtracting off any energy differences between the pre- and post-periods, after normalizing for weather.

The matching procedure for circuit pairs usually considers multiple candidate circuits to be matched to treatment circuits that represent the prior condition before treatment and that are statistically similar in important characteristics. These characteristics include the following if available:

- Annual and seasonal energy consumption
- Peak demand
- Daily and seasonal load shape
- Customer count and distribution by rate class/sub-class (e.g., residential, commercial, industrial)
- Presence/penetration of other demand response or energy efficiency programs among customers on the candidate circuits
- Temperature sensitivity of the circuit load[13]

[12] Provencher, B. and B. Glinsmann. "I can't use a Randomized Controlled Trial – NOW WHAT? Comparison of Methods for Assessing Impacts from Opt-In Behavioral Programs." International Energy Program Evaluation Conference: Getting it Done! Evaluation Today, Better Programs Tomorrow. Chicago, IL. 2013a. https://www.iepec.org/conf-docs/conf-by-year/2013-Chicago/042.pdf, accessed March 8, 2017.

[13] This refers to characteristics such as how sharply circuit load increases with respect to temperature changes for both hot and cold temperatures.

In practice, finding a sufficiently close match is highly challenging, and there is no guarantee that a circuit with a close (initial) match will not deviate from the CVR circuit in terms of the economic influences (e.g., an increase/decrease in business activity or customer connections/disconnections affecting load).

3.1.4 Electric Distribution and Planning Models

Finally, distribution system models can be calibrated with local system or performance data to simulate the voltage control strategy and estimate the resulting energy efficiency savings. Common modelling tools for this application include CymeDist, Synergi, and Open DSS. Potential savings impacts can be cost-effectively estimated circuit wide using calibrated simulations based on data from a utility's Supervisory Control and Data Acquisition (SCADA) system, CVR factor estimates and/or other data sources.[14] This approach simulates energy consumption with CVR/VVO in operation compared to energy consumption under normal operations. Data requirements are considerably higher to estimate impacts down to the household level.

The simulation approach can assess the order of magnitude for potential voltage reduction for CVR/VVO operations.[15] For example, voltage measurement data at the substation can be used to calibrate modelled estimates of low voltage areas to determine how much an implementation scheme might reduce voltage on the system. Field data collection is suitable closer to actual implementation to verify initial estimates on selected circuits or where calibrated modelling of the power system is not feasible.

In addition to estimating savings under conditions of historical operations, power system modelling has other advantages. Modelling can also potentially be used to simulate the effect of future adjustments to the system, such as modified control algorithms or control points. Additionally, these models can produce annual 8,760-hour load shapes for use in DSM planning and cost-effectiveness testing.

[14] Supervisory Control and Data Acquisition (SCADA) systems are commonly used for remote monitoring and control of electricity distribution operations.

[15] To leverage SCADA data for CVR potential estimation, CVR must be implemented circuit wide and not operated to isolate customer segments below the transformer.

4 DATA TRACKING CONSIDERATIONS

A robust source of data and a similarly robust data tracking system are critical to effective pilot assessment, ongoing program management and subsequent program evaluation. Establishing a quality data tracking system enables grid efficiency measures to be an effective part of the energy efficiency portfolio. The following steps outline an example of the data tracking development process:

1. Articulate data tracking needs
2. Define data requirements
3. Establish data quality standards
4. Document, assign and test the data management processes
5. Implement data tracking system and ongoing savings monitoring

Establishing a stable and operational tracking system to support VVO or CVR project implementation and evaluation often requires the involvement of appropriate expertise during the planning phase. Among the required skilled personnel necessary to establish a tracking process are distribution system operators, SCADA personnel and information technology (IT) personnel. Their involvement can help ensure data is collected, transmitted and stored in enterprise-grade historian databases and meets quality standards.

The volume of data necessary to produce tracking estimates also depends on the objectives of the program's tracking needs. Many data points, such as customer counts by circuit or transformer, are often complete and detailed, but managing a similar level of interval energy and voltage data requires enterprise-scale databases to support storage, manipulation and analysis of the data.

Often it is necessary to specify samples to match the scope of the analysis to the program's need for precision in estimating impacts. This is especially true when the analytical requirements include estimating impacts from interval data. The more precise the estimate of impacts need to be, the larger the sample size must be, and the larger the overall data management burden. Considerations for specifying an appropriate sample to meet the desired precision requirements include the following:

- Historical load or energy usage
- Granularity of customer energy use data (e.g., 15-minute or one-hour interval data)
- Granularity of SCADA MW and voltage data
- Customer segments or rate class
- Customer end-use data, if available (e.g., indicators of electric space heating or electric water heating)

5 EVALUATING ENERGY EFFICIENCY IMPACTS

The purpose of energy efficiency impact estimation is to isolate the energy consumption change due to voltage management interventions on distribution circuits over time, controlling for other factors that also influence energy consumption. The energy impact of CVR is dependent on the following factors:

- Magnitude of energy use
- Voltage reduction resulting from CVR/VVO implementation
- CVR factor (representing behavior of load to reduced voltage)
- Feeder and distribution system design (mix of end-use loads)

As noted previously, the energy impacts of CVR/VVO are expected to be small in comparison to total consumption (less than 4% in most cases and zero in some cases), and are therefore difficult to measure and evaluate. Adding to the challenge is the fact that voltage can fluctuate on circuits due to reasons other than VVO/CVR control (i.e., circuit switching, transmission source voltages, etc.), further complicating evaluation of the program impact.

The International Performance Measurement and Verification Protocol (IPMVP), Volume I, Concepts and Options for Determining Savings, is the EM&V industry recognized protocol for evaluating energy conservation measures. Though written with building energy efficiency measures in mind, this framework also works for EM&V of voltage control measures that deliver energy savings. Methods that are consistent with IPMVP and applicable to grid-controlled efficiency measures are listed below and discussed in detail later in this section:

- Consumption data analysis using utility or fuel supplier invoices or meter readings of whole facilities using the on/off experimental designs and the regression-based approaches described in Section 5.3.1.
- Simulation modelling that is calibrated to some actual performance data for the system or facility being modelled, for example power flow models mentioned in Section 5.3.2.

5.1 Impact Evaluation Summary

An on/off experimental design evaluation approach is generally recommended for EM&V purposes where operations can be turned on and off remotely per a predefined schedule. In this approach, data is collected over the course of a year with half of the days representing “on” days, and the other half representing “off” days. Table 1 summarizes the most common data elements to capture for energy savings estimation, measurement and analysis.

The measurement data collected via the on/off design can be used to model the impact of the grid efficiency operation, normalizing for weather and other factors that vary from one day to the next. Section 5.3.1 describes the regression-based approach.

Alternatively, simulation modelling can be used for estimating energy savings impacts of CVR/VVO. Ex-post impacts can be estimated by calibrating with data collected from ongoing CVR/VVO experimentation and verified local conditions. This modelling approach is described in Section 5.3.2.

5.2 On/Off Experimental Design

In general, the preferred approach for evaluating CVR/VVO is to measure and compare energy usage while operations are switched on or off every other day over an entire year. The Northwest Energy Efficiency Alliance's *Distribution Efficiency Initiative* was the first major CVR demonstration project that used this type of design. Over the course of a year, half of the days would represent "on" days, and half would represent "off" days, and the impact of the grid efficiency operation is then modelled, normalizing for weather and other factors.[16]

The primary advantages of this type of evaluation design are linked to the fact that the controlled circuits can serve as their own baselines, since both on and off days each will have a similar distribution of temperature and other weather metrics, and time, or seasonally dependent economic effects. However, a key disadvantage of this evaluation design is that half of the savings are lost in any evaluation year due to "off" operation.

If daily switching of voltage operations is not feasible, less frequent "on/off" cycling may support evaluation. There are other variations of this design that may also support savings estimates. For example, conducting on/off switching in a sample of periods throughout the year (e.g., two-week periods covering each season). However, the risk with extending the time in a static position or using sampled time periods is a higher likelihood of the final distribution of on and off days being imbalanced with respect to key factors such as weather that may ultimately affect the validity of the energy savings estimates.

5.3 Common VVO and CVR Data Tracking Values

The following table provides a list of common data tracking elements that are necessary for assessing CVR/VVO impacts.

[16] Power distributors using this evaluation design would typically toggle the voltage regulation settings from normal operations to "on," and vice versa, at a set hour each day where the system load is relatively stable (e.g., 4:00 a.m.) regardless of voltage control activity.

Table 1. Common tracking data elements

Measurement Input Data	Customer Data	Program Tracking Metrics
• SCADA data—MW, MVAR, Voltage from each voltage regulating device on the CVR/VVO circuit/transformer—preferably, one- to fifteen-minute intervals • Interval energy (kWh) and voltage specific to each customer service point (if available)—preferably, fifteen-minute or one-hour intervals • Hourly weather data for the circuits being controlled, including temperature and humidity • Indicator of CVR/VVO status for each interval, i.e., “On/Off” • Actual or proxy end-of-line voltage to confirm that voltage remains in the target tolerance band for CVR operations. This can be at the customer utility meter or a specially installed meter point • Time stamp of all collected data • Demand response and energy efficiency program impacts (estimated or measured via separate EM&V and overlapping the CVR/VVO test periods)	• Customer identifiers for customers under voltage control • Hourly load profiles by transformers/circuits under control • Customer segments by transformers or circuits in as much detail as available (e.g., residential, commercial, multifamily and industrial) • Low-income status indicator as relevant • Demand response program enrollment/participation • Energy efficiency program deployments (overlapping the CVR/VVO test periods)	• Energy savings by circuit, transformer, rate class or service territory • Average energy savings by customer, circuit or transformer • Average voltage reduction by customer, circuit or transformer • CVR factor—the ratio of changes in energy savings to changes in voltage

5.4 Energy Impact Modelling for VVO and CVR Programs

Impact models are the mechanisms for turning measurement data collected from an evaluation design into estimates of savings attributed to VVO or CVR operations. Statistical regression and calibrated power flow simulation models are two classes of modelling approaches for estimating impacts. Calibrated simulation modelling of distribution circuits is a proven tool for simulating alternative approaches and "what if" scenarios, such as with a pilot or demonstration—and particularly cost-effective for VVO operations. Statistical modelling provides systematic treatment of a larger number of circuits but does not allow for exploration of modified implementation approaches. Statistical approaches also provide information on the uncertainty of the estimated impacts whereas power flow models do not.

5.4.1 Regression-Based Approaches

Regression-based approaches link energy consumption to predictor variables that are known to be associated with changes in energy consumption. It is recommended that models be tailored as much as possible to the affected circuits, with the modelling units defined as measurements from the circuit under voltage control at an hourly (or more granular) level. There are multiple regression-based approaches and variations on approaches for assessing savings from CVR/VVO programs. Table 2 provides a high-level summary of two approaches for modelling the energy impact of CVR/VVO with regression-based approaches. Note that other regression-based approaches (or modifications of those approaches presented) may result in a similar or improved assessment of savings.

Table 2. Hourly regression modelling approaches for estimating the energy impact of CVR

	Direct Impact Model	Load Voltage Model
Dependent variable	kWh (or kW every hour) at the finest level of measurement—either the customer, transformer or circuit. To derive energy saving estimates, the model compares average load during specified time intervals (hourly or more granular) for a distribution circuit or transformer under voltage control with and without CVR/VVO.	
Example independent or explanatory variables for consideration in the model	• Functions of temperature • Functions of humidity • Day type (weekday or weekend) • Day of the week • Seasonal indicators • Circuit configuration (normal/abnormal)	
Key explanatory variable included in the model	Indicator of CVR/VVO being active: equals one if CVR/VVO is on, otherwise is equal to zero.	Delta volts, the difference between the actual voltage and the expected voltage in a time interval, e.g., if the expected voltage in a given interval was 120 V and the actual voltage was 116 V, the delta volts would be (116 V – 120 V) = -4 V.
Key explanatory variable regression parameter interpretation	The impact of CVR/VVO on the load in the interval compared with CVR/VVO not being on, e.g., a parameter estimate of -1 would indicate that a reduction of 1 kW would be expected for the load when CVR/VVO is on, with all other explanatory factors held constant.	The load impact of the deviation of voltage from its expected value, e.g., a parameter estimate of -1 would indicate that a reduction of 1 kW would be expected for the load when the voltage is 1 volt below the expected voltage, with all other explanatory factors held constant.
Advantages of the modelling approach	The parameter provides the estimated impact of CVR/VVO, directly, over the analysis period.	Allows for estimation of the energy savings at different levels of voltage reduction from a baseline level.
Challenges of the modelling approach	Cannot account for varying levels of intensity for CVR/VVO control settings, i.e., CVR/VVO is treated as completely on or completely off.	Requires additional analysis for estimating savings for a program, using assumed voltage profiles with CVR/VVO on and off. Additionally, this approach assumes a linear relationship between load and voltage with other factors held constant. This assumption may not hold for larger ranges of voltage.

Extensions to this methodology can include time-series approaches for accounting for serial correlation in the modelling errors. Accounting for serial correlation can improve the accuracy of the energy impact models, but time-series modelling may not be feasible in certain applications due to technical complexity.

Since impacts are estimated at the meter level, estimating customer energy savings benefits as a proportion of system benefits, if needed, requires a separate evaluation of system benefits. The simplest approach is to apply a loss factor to meter-level energy savings to estimate system savings, however, this approach does not account for loss reduction from improved reactive power dispatch due to VVO programs. Total system benefits can be determined from further modelling of voltage and load data collected through SCADA. Additionally, end-user load data can be compared to findings from calibrated simulation models of the distribution system to estimate the proportion of customer versus utility energy savings.

5.4.2 Calibrated Modelling of the Distribution System

Distribution planning models simulate the power flow across the grid, document the distribution system architecture and provide operational information to system planners. Their use in recent years for reliability modelling, operations and asset management has been accelerated by the availability of real-time operations data at the distribution level. These models can serve as the basis for assessing the savings potential from CVR/VVO operations and estimating ex-post impacts from them by calibrating with data collected from ongoing CVR/VVO experimentation and verified local conditions.[17]

The basic steps include:

1. Building or updating models of the circuits
2. Calibrating the models with verified data
3. Simulating operation with and without VVO or CVR operations
4. Comparing the two runs to estimate savings

Estimating CVR/VVO impacts using these simulation tools requires expanding the model data inputs. Additional information required includes the electrical characteristics of the secondary and service lines that connect the customer to the primary distribution line and service transformer models typically accommodated in simulation models.[18] Secondary and service drop data can be assumed based on utility standards and/or data gleaned from geographic information system (GIS) and other data sources. Additionally, for calibrating the model to customer level impacts, historical field data, such as SCADA, advanced metering infrastructure (AMI) or other measured load and voltage data, are needed.[19] Data collected from the experimental design can verify simulated operations with actual operations.

In addition to estimating savings under conditions of historical operations, power system modelling has other advantages. These models also simulate impacts down to the individual customer level in mixed use circuits, allowing estimation of impacts of specific customer classes or segments, such as industrial customers or low-income communities.

[17] It is worth emphasizing from Section 2 that impacts from VVO operations can be more readily assessed than CVR operations using these modelling tools. For modelling VVO impacts, the analysis is conducted at the primary circuit level and the electrical characteristics of secondary feeders (from transformer to home) are not necessary. Because CVR is optimized through customer load levels, however, more data are required to encompass the full voltage change from substation to the customer.

[18] The specification for building and documenting electric distribution systems can be found on http://www.multispeak.org. It defines what data needs to be exchanged between software applications to support the business processes commonly applied at utilities.

[19] This additional detail helps to estimate true customer service voltage level and calibrates distribution modelling data with true customer data, and can help demonstrate the verification steps necessary to establish the reliability of the results.

6 ESTIMATING POTENTIAL AND IMPACTS IN LOW-INCOME COMMUNITIES

Many utilities across the United States implement Demand Side Management (DSM) programs that include tailored offerings for low-income communities. It can, however, be costlier to administer DSM programs targeting this customer segment for a variety of reasons. For example, it can be more likely that an installation contractor will identify safety hazards within a low-income premise that must be addressed before an energy efficiency measure can be installed according to code requirements. While site-delivered energy improvements usually provide significant energy savings and other benefits at the premise level, budget constraints often limit the number of premises that can be reached in a given program cycle.

For this reason, as a complementary offering, some jurisdictions have shown increased interest in prioritizing circuits for CVR/VVO to deliver end-use energy savings to low-income communities.[20] Methods for estimating the proportion of energy savings from CVR/VVO that will benefit low-income communities involve comparing and cross checking customer premise identification (ID) codes, physical location addresses, distribution circuit IDs and relevant low-income community definitions.

This section presents approaches for both identifying and estimating energy savings in low-income communities.

6.1 Identifying Low-Income Communities and Potential

Low-income programs can be targeted to households or to geographic areas, and states and utilities often rely on existing or modified Federal definitions to determine eligibility. For example, at the household level, the federal Weatherization Assistance Program defines household eligibility as income of 200% of the state poverty level with considerations for household size and other factors.[21] At the geographic level, the U.S. Department of Housing and Urban Development (HUD) designates Qualified Census Tracts for the Low-Income Housing Tax credit.[22]

When defining low-income community by household, the task of quantifying the saturation of qualifying low-income residents on a circuit can be simplified if a utility can match indicators of low-income status to each utility account. This information is not publicly available at the household level but is generally available for purchase from vendors that sell data—compiled from various sources—on the attributes of individuals and households, if a utility has not already developed such customer intelligence.

When applying a geographic definition of low-income community, census tract data provide the most granular of publicly available geographic data and median income data to use in deriving qualified low-income community status. If a jurisdiction's definition of a low-income community aligns with the definition used by HUD for Qualified Census Tracts, zip code data can be matched to the tract via (https://www.huduser.gov/portal/datasets/qct/dda2000.html#list). Otherwise, median incomes for geographic domains can be obtained from sources such as the U.S. Census Bureau Decennial Census Summary Files or the Consumer Financial Protection Bureau for specific years and jurisdictions.[23] The

[20] While the realized savings from CVR/VVO will vary from customer to customer, a larger number of premises on a given circuit will receive benefit from and contribute to the aggregate savings than in typical DSM programs. In addition, CVR/VVO tends to be less costly to administer because its implementation is within the utilities control avoiding the need to spend time and resources on program recruitment, registration, in-home audits, scheduling and in-home installation of efficiency measures.

[21] U.S. Department of Energy. "Weatherization Assistance Program for Low-Income Persons." http://www.benefits.gov/benefits/benefit-details/580, accessed 10/27/2016

[22] Qualified Census Tracts (or equivalent geographic area defined by the Bureau of Census) are geographic tracts—established for the Low Income Housing Tax credit—in which at least 50% of households have an income of less than 60% of the area median gross income.

[23] Consumer Financial Protection Bureau. http://www.consumerfinance.gov/hmda/#get-the-data

Consumer Financial Protection Bureau provides data by census tracts and metropolitan statistical areas. Utilities can use tools like the U.S. Census Bureau address search tool[24] to map specific addresses listed in its customer information system (CIS) database to corresponding census tracts.

Once a match is established between the low-income community definition and CIS customer records, candidate circuits can be further screened based on a simple proportion of the eligible to non-eligible customers on a circuit.

6.2 Estimating Impacts in Low-Income Communities

A basic approach for quantifying low-income energy savings related to grid efficiency measures at a system or circuit level is to allocate energy savings proportional to a pre-defined low-income population on that system or circuit. Proportional allocations can be weighted based on total consumption or per unit savings estimates by customer class. A similar approach has been used in Pennsylvania.[25] Fundamentally, this approach assumes that the average customer savings across the evaluated circuits under VVO or CVR control does not fundamentally vary by circuit. The number of customers, proportion of customers, peak profiles, peak to energy ratios, housing characteristics, similarity in voltage control treatment and geographic proximity are examples of circuit characteristics that might be used to assess circuit similarities. The proportional allocation factor, however, should represent the customer share of energy savings and not include the share of energy savings realized by the utility.

For jurisdictions where the uncertainty of such proportional allocations remains a concern, a more granular analysis may be required to estimate the benefits to customers or specific customer segments. This is often the case with CVR/VVO measures since those operations apply to the circuit level and implementation cannot be targeted to individual premises. In addition, low-income communities are often located in mixed-use zones, and the circuits that feed low-income customers also feed other customers.

In urban settings, low-income customers are often located in multifamily buildings. Both rural and urban settings usually have mixed use circuits that include a combination of residential, commercial and industrial uses. For jurisdictions where AMI has been deployed, the most direct means for estimating savings to specific groups is to conduct an impact evaluation using a census of interval data from those AMI meters using an on/off methodology. Consumption data analysis of a sample or census of low-income customers using appropriate experimental designs can also achieve the same result. Some methods, however, require an additional computational step to subtract the proportion of energy savings to the low-income community from the estimated total customer energy savings.

[24] U.S. Census Bureau address search tool. https://ask.census.gov/faq.php?id=5000&faqId=127

[25] See: PUC Docket No. M-2008-206887. Energy Efficiency and Conservation Program Final Annual Report, June 1, 2011 through May 31, 2012. Nov. 15, 2012. http://www.puc.state.pa.us/pcdocs/1199606.pdf

The following table summarizes a few common approaches to estimating impacts of VVO and CVR operations to low-income communities.

Table 3. Estimating impacts of CVR/VVO operations in low-income communities

Approach	Description	Extra Computation Steps to Isolate Low-Income Community Impacts	Pros and Cons
Proportional allocation of savings by applying a customer unit savings estimate or CVR factor to the eligible low-income population	Savings factors are developed internally or borrowed from secondary sources and applied to a known low-income community population by multiplying an average household savings value (from the circuit level analysis) by the number of low-income households for the system or circuit.	None, assuming the savings factor represents only the share of energy savings realized by the low-income customer.	• Simple approach • Leverages secondary sources • Average household usage and savings are most applicable to circuits rather than entire systems or jurisdictions • Average household usage can be difficult to estimate on mixed use circuits • Estimating system-wide savings requires applying known savings data to circuits having similar circuit system characteristics • Limited rigor method that might not meet local EM&V regulatory objectives
Calibrated Simulation Modelling	Use modelling tools to estimate savings to low-income communities by simulating circuit operations both with and without controls.	None. The model can separate the customer versus utility energy savings, and energy savings can be estimated down to the household level.	• Can provide savings estimates at circuit, zip code, household level, or other geographic level depending on scope of operation and investment • For CVR/VVO impact estimation, this is particularly data intensive, requiring extensive circuit and customer level detail • Can estimate impacts to individual customers/customer groups separate from impacts to distribution utility • Requires calibrated simulation modelling skill set and modelling application such as CymeDist, Synergi, or Open DSS • Limited understanding of uncertainty in savings estimate

Approach	Description	Extra Computation Steps to Isolate Low-Income Community Impacts	Pros and Cons
Regression analysis with matched control group using billing data for known low-income household populations or neighborhoods	Use linear regression analysis of historic billing data for the affected low-income community and a matched control population (of low-income households) without grid efficiency measures to determine the differences in energy usage between the groups during the period of operation.	None. Customer energy savings impacts are estimated at the meter.	• Can provide savings estimates for specific circuits or zip codes, but limited to available data from utility billing database • Data intensive, requiring at least one year of billing and weather data • Challenge includes identifying treatment and matched control low-income households • Does not require on/off experimentation of VVO or CVR operations
Regression analysis using on/off experimentation with interval load data	For known low-income geographic areas or households, conduct experiments by switching operations on and off per a set schedule, and use linear regression analysis of load data to determine the difference between low-income household loads when on versus off.	None. Customer energy savings impacts are estimated at the meter.	• Can provide savings estimates for specific low-income household groups or individuals • Requires interval load data collection equipment—preferably AMI—and data management systems, and can be costly to implement over multiple circuits simultaneously • Data intensive, requiring at least 9 months of interval load data during experimentation period • Estimating system-wide savings requires applying known savings data to circuits having similar circuit system characteristics

7 DETERMINING PERSISTENCE AND LONG-TERM PLANNING

One area that lacks consensus is how long grid efficiency measures should be credited for energy savings. Recognizing that energy savings derived from voltage reductions due to VVO or CVR operations, and the reaction of energy in response to voltage changes, persistence should account for factors that affect voltage.

Changes in voltage reductions can be attributed to changes in implementation settings or significant changes in distribution voltage profiles due to grid-based changes such as sizeable system upgrades or modifications or distributed solar deployment. Typically, the technologies used to reduce voltage will outlast other factors that change energy savings. Significant load changes that would affect voltage and energy in the aggregate include a sizeable shift of load from one segment to another, or, in the long-run, significant adoption of alternative technologies, which notably affect operational data such as digital loads. However, in system-wide deployments, shifts in load from one circuit to another may restrict the voltage reduction on the circuit taking on additional load while allowing greater voltage reduction on the circuit from which load was transferred.

While best practice is still forming in the industry around guidelines for determining persistence, there is a precedent from the Bonneville Power Administration (BPA) Protocol.[26] In it, BPA implements a three-year monitoring and documentation period that requires annual and monthly reporting to establish that voltage control settings are maintained and that voltage and power factor levels are as expected.

[26] Bonneville Power Administration (BPA). Energy Efficiency Industrial. "Simplified Voltage Optimization (VO) Measurement and Verification Protocol." http://www.bpa.gov/EE/Sectors/Industrial/Documents/Final_Draft_VO_MV_Protocol_4-27-10.pdf