



IEEE Guide for Assessing, Measuring, and Verifying Volt-Var Control and Optimization on Distribution Systems

IEEE Power and Energy Society

Developed by the
Transmission and Distribution Committee

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STANDARDS

IEEE Guide for Assessing, Measuring, and Verifying Volt-Var Control and Optimization on Distribution Systems

Developed by the

Transmission and Distribution Committee
of the
IEEE Power and Energy Society

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Abstract: Electric utilities are seeking to improve the overall efficiency and performance of the distribution system while helping to achieve energy and demand savings. Distribution volt-var optimization (VVO) can play a major role in accomplishing these objectives while maintaining safety, preserving assets, and meeting all operating constraints such as loading and voltage levels. Initial studies and experience show there is significant potential for energy savings, demand management and loss reduction through improved management of distribution voltage profiles and reactive power flow. Consistent methods are needed for verifying the benefits achieved by VVO systems that have already been implemented. Guidelines for modeling system loads as well as distributed resources and their response to voltage and var changes are needed along with methods for performing the evaluations to estimate total benefits. These benefits can then be evaluated as a function of the investment requirements for the improved VVO on a feeder by feeder or substation by substation basis and deployment priorities can be developed.

Keywords: conservation voltage reduction (CVR), demand reduction, IEEE 1885™, loss reduction, measurement and verification, volt-var optimization (VVO)

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Introduction

This introduction is not part of IEEE Std 1885™-2022, IEEE Guide for Assessing, Measuring, and Verifying Volt-Var Control and Optimization on Distribution Systems.

Utilities have been transforming the distribution system for multiple years by adding remote control, sensing and communication systems. This technology transformation has provided the opportunity to improve the operational efficiency of the distribution system with real-time load balancing, voltage and power factor optimization, and automated restoration as well as control and optimization of distributed energy resources. With these new capabilities comes the need to measure and verify the benefits associated with these advanced operational efficiencies. This guide is intended to provide insight into how measurement and verification can be accomplished for voltage and var control optimization.

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1. Overview

Volt-var control (VVC) has been used by electric utilities for many years to maintain acceptable customer voltage levels on the distribution system as well as to maintain power factor to reduce losses and provide reactive support for the electric transmission system. VVC in its simplest form can include locally controlled capacitor and line regulation devices operating independently but reacting to system conditions.

In recent years, grid modernization has changed the way electric utilities design and operate their electric distribution systems. The methods and objectives for VVC have expanded considerably beyond simply maintaining acceptable voltage and power factor. VVC has become volt-var optimization (VVO), which has the expanded objectives to increase overall efficiency, reduce electrical demand, promote energy conservation, improve power quality, and (in some cases) mitigate the adverse consequences of intermittent renewables.

VVO allows for more optimal voltage control capabilities including peak demand voltage reduction (PVR) and conservation voltage reduction (CVR). PVR involves lowering the voltage during peak demand periods to reduce system demand. CVR involves operating the distribution feeder at a voltage that is in the lower portion of acceptable voltage ranges for energy conservation. Industry studies and utility implementations show there is significant potential for energy savings, demand management, and loss reduction through improved management of distribution voltage profiles and reactive power flow. VVO systems can include both PVR and CVR as well as optimization of power factor, loss reduction, and distributed generation (DG) integration.

With the expanded consideration and implementation of VVO systems, which in many cases includes one or both forms of voltage reduction (VR), consistent methods are needed for verifying the benefits achieved by these systems. Energy and demand savings benefits can justify significant expenditures for VVO. These benefits can then be evaluated as a function of the investment requirements for the improved optimization on a feeder-by-feeder or substation-by-substation basis and deployment priorities can be developed.

It is especially challenging to identify the actual energy efficiency improvements associated with VVO voltage reduction because energy efficiency cannot be measured directly. The stochastic (random) nature of customer loading makes it very difficult to determine the actual benefit at any given point in time. As a result, various techniques can be used to estimate the benefits achieved by energy efficiency projects. This guide describes some of the measurement and verification (M&V) techniques that can be used to estimate the energy and demand savings benefits associated with VR over time with a reasonable level of confidence. The annexes provide supporting details on VVC and optimization methodologies as well as details on load-to-voltage (LTV) sensitivities.

1.1 Scope

This guide provides practical methods for assessing, evaluating, and verifying the benefits and impact of electric power demand and energy consumption of VVO on electric power distribution systems.

1.2 Purpose

The purpose of this guide is to provide some demonstrated practical methods to estimate and verify the potential energy savings and demand reduction that can be achieved with distribution system VVO methodologies.

This guide presents methods for distribution system modeling/measurements, load modeling/measurements, and performing assessment studies and pilot projects to project and verify the potential or actual benefits.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall equals is required to*).^{6,7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should equals is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may equals is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can equals is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

There are no normative references in this standard.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁸

conservation voltage reduction (CVR): The practice of using voltage reduction (up to 24 h a day) to promote energy conservation.

load-to-voltage sensitivity (LTVS): A parameter that applies to a single electrical load or appliance type that indicates how the electric power used by the device varies as the voltage at the terminals of the device is varied.

⁶The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

⁸*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

measurement and verification for volt-var control and optimization: The methodology for determining the benefits achieved by volt-var optimization that involves measurement of specified electrical parameters and analysis of these parameters.

peak demand voltage reduction (PVR): The practice of using voltage reduction only during peak load conditions for peak demand reduction purposes.

voltage reduction (VR): The general practice of intentionally keeping the service delivery voltage as low as possible (within the acceptable range specified by national or regional regulatory organizations).

volt-var control (VVC): The general term that encompasses the entire topic of managing voltage and reactive power flow on the electric distribution system to achieve utility-specified operating objectives. Operating objectives can always include maintaining acceptable conditions and improving feeder efficiency and performance.

volt-var optimization (VVO): The general term that encompasses the entire topic of managing voltage and reactive power flow on the electric distribution system to achieve optimal performance. Optimal performance objectives can include for example minimizing energy consumption and electrical losses and reducing peak electrical demand.

3.2 Acronyms and abbreviations

AMI	advanced metering infrastructure
CBECS	Commercial Buildings Energy Consumption Survey
CVR	conservation voltage reduction
CVR_f	conservation voltage reduction factor
DER	distributed energy resource
DG	distributed generation
DMS	distribution management system
IED	intelligent electronic device
IVVC	integrated volt-var control
KPI	key performance indicator
LTC	load tap changer
LTV	load to voltage
LTVS	load-to-voltage sensitivity
M&V	measurement and verification
OLPF	online power flow
PVR	peak demand voltage reduction
RECS	Residential Energy Consumption Survey
SCADA	supervisory control and data acquisition
VR	voltage reduction
Vreg	voltage regulator
VVC	volt-var control
VVO	volt-var optimization

4. Determining VVO CVR savings

This clause describes some typical operating objectives for VVO and the key performance indicators (KPIs) and metrics required to perform M&V of VVO CVR savings. The measurements required are described in detail, including the establishment of a baseline voltage profile. Typical sources of measurement data are described along with the measurement intervals that can be utilized. Finally, selection of substations and feeders for VVO deployment is described.

4.1 VVO objectives and benefits

The latest VVO solutions allow the electric utility to combine both independent voltage and var control systems. Independent voltage and var systems can often compete with their objectives and result in unnecessary equipment switching and inefficient operation. Generally, the utility's objective with system improvement projects is to replace those independent systems with a single efficient VVO system that could be focused on several operating objectives. VVO operating objectives and benefits may include the following:

- Maintain voltage levels as specified by national or regional standards or requirements
- Reduce energy demand through reduced voltage and var flow
- Reduce power loss on distribution and transmission (maintain acceptable PF)
- Reduce peak demand through reduced voltage and var flow
- Reduce or maintain the number of operations for specified pieces of electrical equipment [load tap changers (LTCs), regulators, and switched capacitors]
- Manage the voltage and var impact of distributed energy resources (DERs)

Some VVO solutions may have a strategy that focuses on several of these objectives at the same time while others may be limited to a specific objective such as reduced peak demand.

4.2 VVO CVR KPIs and metrics

This subclause discusses the KPIs and metrics that could be utilized to determine how well the VVO CVR solution is performing. Measurement and verification techniques discussed in this guide describe possible mechanisms for computing the metrics. The KPIs used by the electric utility may vary depending on the specific operating objectives for the VVO solution. Not all of the metrics are described with examples.

VVO KPIs/metrics may include some or all of the following items. The focus of this guide is on KPIs/Metrics 1 through 5.

- *Metric 1:* Percent reduction in average service delivery voltage when VR is applied
- *Metric 2:* Percent of customer hours that voltage is outside the desired limits specified in the VVO solution when VR is applied
- *Metric 3:* CVR factor or the ratio of per unit change in energy per unit change in voltage

$$CVR_f = \frac{\Delta E / E_0}{\Delta V / V_0}$$

The CVR factor is different from substation to substation, feeder to feeder, and load to load. It is primarily determined by the end-user's load mix and modified in the aggregate load by voltage control devices (e.g., regulators and switched capacitor banks) along the feeder.

- *Metric 4:* Percent change in peak electrical demand of the controlled facility when VR is applied

- *Metric 5:* Energy saved when CVR is applied
- *Metric 6:* Percent reduction in distribution and transmission losses when CVR is applied
- *Metric 7:* Percent of period hours that VR was in effect
- *Metric 8:* Percent change in transformer tap changer operations when CVR was applied
- *Metric 9:* Percent change in feeder capacitor bank failures when CVR was applied
- *Metric 10:* Percent change in feeder capacitor bank operations when CVR was applied

4.3 Example measurements for evaluating CVR performance

To evaluate the KPIs and metrics for CVR projects, field measurements need to be acquired with highly accurate precision time tagged measurements. This is required to correlate control actions with measurements to produce meaningful results. The primary reason is that the expected benefits are usually a small percent of normal operating quantities. For example, the demand reduction or energy consumption reduction associated with CVR may be in the range of 2% to 3% of nominal quantities, so if measurements used in the calculation are only accurate to within 2% to 3% or are not time synchronized, the calculation results can be meaningless since the difference is within the measurement error.

In addition to the input measurements listed below, the electric utility should account for system events, such as feeder reconfiguration or sensing device failures that need to be recognized and possibly excluded from the analysis of VVO CVR benefits. Failure to exclude such “outlier” data may result in inaccurate results.

The following is a list of measurements that may be required for evaluating the KPI metrics associated with VVO CVR performance:

- *Bus or circuit voltage per phase or three-phase averages on each substation transformer:* Monitor and store the bus or circuit voltage on each substation transformer for determining VR at the head end of the circuits while CVR is active versus not active.
- *Status indication to determine whether CVR is active or not:* Status indication for CVR active (voltage reduced), status indication for CVR not active (normal voltage applied). For M&V protocols that are built around a “on” versus “off” comparison, monitor and store the status indication to know whether the CVR system is “on” or “off.”
- *Megawatts and megawatt-hours delivered to each CVR feeder:* Monitor and store megawatts and megawatt-hours as needed to determine demand and energy savings for each circuit while CVR is active versus not active. Recording megawatts and megawatt-hours also identifies average load on feeder, peak load on feeder and total energy delivered for each M&V period.
- *Megavars and megavar-hours delivered to each CVR feeder:* Monitor and store megavars and megavar-hours to determine reactive power and reactive power hours savings for each circuit while CVR is active versus not active.
- *Total megawatts, megavars, megawatt-hours, and megavar-hours on each CVR substation transformer:* Monitor and store total megawatts, megavars, megawatt-hours and megavar-hours to determine savings for each substation while CVR is active versus not active. Recording at the substation should identify total energy delivered, average demand, and reactive power for each substation.
- *Tap position of each CVR substation transformer or substation voltage regulators (Vregs):* Monitor and store the tap position of each substation LTC or voltage regulator to track the amount of tap operations that have occurred while CVR is active versus not active.
- *Tap position of each line Vregs:* Monitor and store the tap position of each line-voltage regulator to track the amount of tap operations that have occurred while CVR is active versus not active.

- *On/off position of each switched capacitor bank:* To keep track of the quantity of open/close operations while CVR is active versus not active, monitor and store capacitor switch status.
- *Temperature (or cooling/heating days) and humidity measurements in vicinity of each substation:* Temperature measurements are necessary for M&V protocols that incorporate heating/neutral/cooling zones. Temperature variables that would be considered include ambient temperature, temperature drift, average daily high/low temperatures, and period average temperatures. Temperature and humidity measurements are crucial factors to consider when doing M&V if the bulk of the feeder's load is from air conditioning (inductive load) or from heating (resistive load).
- *Megawatts and megawatt-hours delivered to each non-CVR "similar" circuit used for M&V:* Certain protocols use a "similar circuit" comparison method where it would compare the megawatt and megawatt-hours of a circuit under CVR to a circuit that is not under CVR to estimate savings.
- *Megavars and megavar-hours delivered to each non-CVR "similar" circuit used for M&V:* Certain protocols use a "similar circuit" comparison method where it would compare the megavar and megavar-hours of a circuit under CVR to a circuit that is not under CVR to estimate savings.
- *Total megawatts, megavars, megawatt-hours, and megavar-hours on each non-CVR "similar" substation transformer:* Certain protocols use a "similar circuit" comparison method where it would compare the above variables of a substation that is under CVR to a substation that is not under CVR to estimate savings.
- Additional information VVO CVR M&V analysis should consider while performing pre-implementation estimation and post-implementation type analysis include the following:
 - Customer classifications/type of load on feeder (i.e., residential, commercial, industrial) by %. If not available by circuit, customer classification/type of load % by substation can be utilized.
 - Class of heating/cooling devices operated by utility customers (e.g., heat pumps, natural gas, oil)
 - Customer utilization patterns (Load factor/demand profile)
 - Presence of DG resources
 - Maps of feeder configuration and electrical description (e.g., 13.8kv, etc.)
 - End-of-line voltage measurements to verify VVO CVR does not violate voltage operating limits
 - Substation transformer and feeder impedance data
 - Nominal daily energy conservation systems operation, such as load reduction and peak load shaving events
 - Commercial and Residential energy CVR factors (CVR_f)
 - Voltage control device settings, i.e., capacitors and regulating devices.
 - Length of CVR Protocol period

4.4 Developing a baseline voltage profile

A valid baseline voltage profile should be established before VVO CVR implementation. It is important to have adequate history to obtain an accurate voltage profile over various seasonal variations and to use the same measurement points before and after VVO implementation. The voltage regulation strategy needs to be completely consistent with past practices before VVO was available. This provides a time period of background data to establish the voltage baseline.

4.4.1 Source data for voltage baseline

All of the measurement points should be available in a data historian. A data historian can provide robust data compression tools that allow a virtually continuous record of data.

A data historian plan can use functions that deliver averages based upon all available data. This gives maximum accuracy based on millions of data samples.

4.4.2 Example measurement interval

The preferred measurement interval provides good accuracy and visible trends without overwhelming the analysis with too many data points. In order to provide an example, one utility tested several strategies for extracting data from a data historian. At one extreme, hourly average voltage was calculated for all distribution points for each of the 8760 h per year. Analysis for this example indicated various methods gave similar averages. [Table 1](#) shows some of those results:

Table 1—Example of baseline average

	Sampling Method	Hourly average	Daily Average
Number of data points	93 805 points	2 358 630 averages	97 406 averages
Annual average	123.2 V	123.2 V	123.2 V

In this example the daily average voltage provided the best combination of useful trends, processing time and accuracy. The daily average truly is the average of all data for the day, so nothing is lost. The verification plan uses daily average voltages by individual circuits for the baseline and for verification of savings. This may not be true in all cases. The analysis should check to verify that VR estimates are not materially affected by aggregating the data first to daily averages.

4.5 Daily and hourly average voltage sampling

A data historian can keep many more data samples than necessary to perform analysis. Even considering internal data compression, there are often many voltage samples preserve—even in a single minute. Fortunately, data historians can provide the capability to report a single number which is the time weighted average over time intervals requested by the user. This provides very accurate information *based on all available data*. A typical daily average voltage reported by historian is a single number based on a few hundred to a few thousand data points.

4.6 Selecting feeders/substations for VVO/CVR deployment

The factors to be considered in the feeder/substation selection process should be influenced by the VVO operating objectives. For example, if peak demand reduction is the primary VVO operating objective, then feeders/substations that are frequently voltage-limited (i.e., a significant number of customers are already at the low end of the established voltage guidelines range prior to VR) during peak load conditions should not be selected assuming no other voltage mitigation i.e., a capacitor or line Vreg, has or will be applied

If feeder/substation selection is associated with a proof-of-concept demonstration on a small number of feeders, the electric utility should avoid selecting the “ideal” feeders/substations that would appear to provide the maximum benefits. The results of a demonstration conducted on “ideal” feeders may overstate the potential benefits from “non-ideal” feeders, which, in turn, may not produce the predicted benefits.

[Table 2](#) lists the factors that should be considered when selecting substations and feeders for VVO/CVR implementation.⁹

⁹Information on references can be found in [Clause 2](#).