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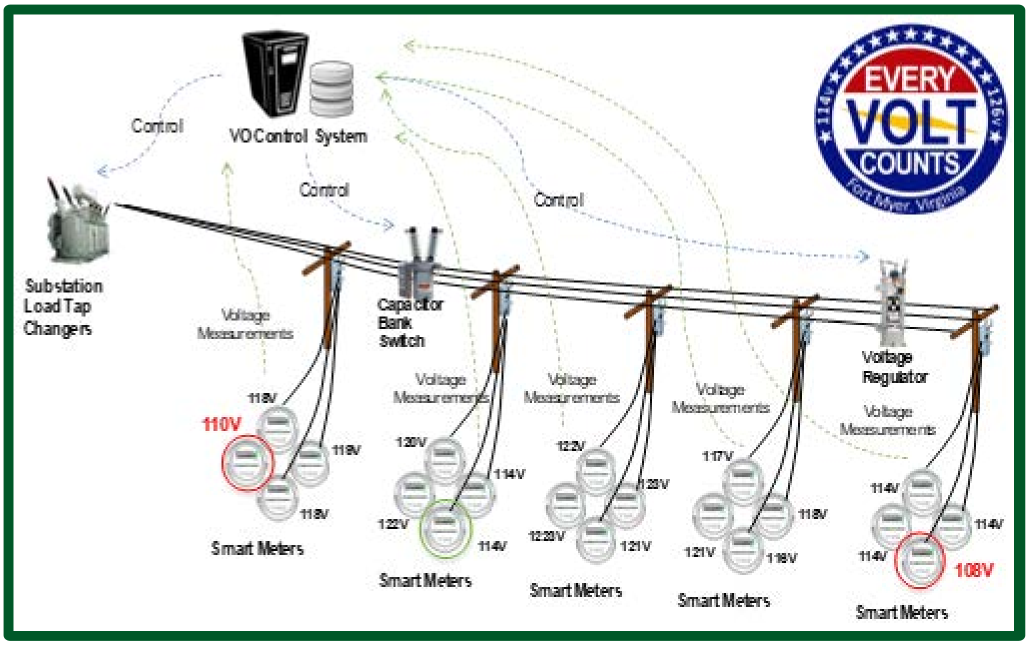

Utilization of Advanced Conservation Voltage Reduction (CVR) for Energy Reduction on DoD Installations

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This project entitled Utilization of Advanced Conservation Voltage Reduction (CVR) for Energy Reduction on DoD Installations successfully demonstrated how Conservation Voltage Reduction (CVR), applied on the Fort Myer distribution system and combined with MicroCVR in buildings, could save between 3% and 6% in installation electricity consumption. In fact, the project demonstrated 8% to 10% savings based on the combined technology. Under this project, energy savings occurred passively without requiring changes in human behavior. The project exploited infrastructure investments that the Defense Department had already made without requiring nonstandard modifications to the system.

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ACRONYMS AND ABBREVIATIONS

AMI	Advanced Metering Infrastructure
ANSI	American National Standards Institute
CO_2	Carbon Dioxide
CVR	Conservation Voltage Reduction
DoD	Department of Defense
DMS	Distribution Management System
DPW	Department of Public Works
DVI	Dominion Voltage, Inc.
DVP	Dominion Virginia Power
EDGE®	Energy Distribution & Grid Efficiency
EISA	Energy Independence and Security Act of 2007
EO	Executive Order
EPA	U.S. Environmental Protection Agency
EPACT 2005	Energy Policy Act of 2005
ESTCP	Environmental Security Technology Certification Program
FIM	Feeder Intelligence Module
JBMHH	Joint Base Myer-Henderson Hall
kW	Kilowatt
kWh	Kilowatt-hour
LTC	Load Tap Changer
MicroCVR	Micro Conservation Voltage Reduction
MW	Megawatt
M&V	Measurement and Verification
NAESCO	National Association of Energy Services Companies
O&M	Operation and Maintenance
RFC	Repeat Failure Count
SCADA	Supervisory Control and Data Acquisition
SCR	Silicon Controlled Rectifier

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EXECUTIVE SUMMARY

This project entitled *Utilization of Advanced Conservation Voltage Reduction (CVR) for Energy Reduction on DoD Installations* successfully demonstrated how Conservation Voltage Reduction (CVR), applied on the Fort Myer distribution system and combined with MicroCVR in buildings, could save between 3% and 6% in installation electricity consumption. In fact, the project demonstrated 8% to 10% savings based on the combined technology. Under this project, energy savings occurred passively without requiring changes in human behavior. The project exploited infrastructure investments that the Defense Department had already made without requiring nonstandard modifications to the system.

OBJECTIVES OF THE DEMONSTRATION

This project sought to demonstrate how Fort Myer can achieve 3-6% savings annually in both building and system electricity use through an automated system, without having to change human behavior. Dominion's solution will ensure that reductions in voltage are unnoticed by, and have no impact on, end users. This project was built upon Dominion's proven CVR use at the utility level. Applied at the installation level on the electrical distribution system, Dominion projected it would result in a 2-4% automated energy reduction based on its experience at the utility level. Adding Micro Conservation Voltage Reduction (MicroCVR), which implements this solution at building-level, will create an additional 1-2 % automated reduction, for a total range of 3-6% overall.

TECHNOLOGY DESCRIPTION

CVR is an automated system-level voltage reduction technology that optimizes voltage to continuously reduce energy consumption. MicroCVR builds off the same electrical principles and effectively performs this same function at the building-level but improving performance by using high-speed voltage regulation and appliance level monitoring. Combining these two technologies was an innovative, state-of-the-art approach which has not yet been made commercially available. Dominion Virginia Power (DVP) showed that the installation's electrical distribution systems can work with high variation loads caused by renewable generation, improve reliability, and enhance and secure critical facility loads.

DEMONSTRATION RESULTS

The project performance results exceeded the demonstration's stated objectives and expectations.

Performance Objective	Metric	Success Criteria	Result
Site-wide CVR	Energy - kWh	3% reduction compared to baseline	**Result: 3.7%**
Building-level micro CVR Building 421 – Barracks A	Energy - kWh	1.5% reduction compared to baseline	**Result: 5% reduction**
Compatibility of MicroCVR with highly variable loads or renewable generation	Voltage stability (V)	25% reduction in variation of voltages relative to the non MicroCVR case	**Result: 50% reduction**
Highly secure voltage supply	Voltage stability (V)	Maintain secure voltages to within 1% of the expected voltage set point	**Result: 1.5% of set point**

High availability of the combined solutions yielded **3.7%** in annual energy savings for the twelve months of operations. This equated to over $91,500 of annual bill relief for the Fort and 654 metric tons of avoided carbon dioxide (CO_2) for the environment.

IMPLEMENTATION ISSUES

During the course of this demonstration, no operational issues were experienced. On July 17, 2017, the Rader Clinic (Building 525) located on the 568 circuit raised a concern that the medical equipment was set to operate between 119-121 volts and that the lower voltage being served under the project was affecting the equipment's performance. Dominion's review of Energy Distribution & Grid Efficiency (EDGE) performance for each of this excursion event indicated that the voltage control solution responded appropriately to the event moving the circuit to higher voltage delivery levels in response to the excursion. At the time of this publication, the customer's internal investigation of the affected equipment had not been completed. Dominion took no further action.

1.0 INTRODUCTION

In response to the Virginia General Assembly legislation enacting a statutory goal of 10% reduction in retail energy consumption over 2006 levels by 2022, Dominion Virginia Power (DVP) focused on the implementation of a novel Conservation Voltage Reduction (CVR) program that leveraged Advanced Metering Infrastructure (AMI) to implement an adaptive voltage control algorithm. In parallel, Dominion developed an operational statistical method to directly measure energy savings and provide circuit level performance verification. Now commercialized and improved in Dominion Voltage Inc.'s EDGE® solution, this technology was used to demonstrate the value of voltage conservation to military installations. Combined with dedicated building-level voltage control in the form of MicroCVR, this was a low-cost way to reduce energy consumption that did not require changes in human behavior and was not noticeable to the end user. This demonstration showcased the value of CVR and MicroCVR to military installations.

1.1 BACKGROUND

The Department of Defense (DoD) continues to be the largest federal consumer of energy and needs to reduce its energy consumption. Supplying energy to DoD buildings is a significant portion of the DoD budget. According to the 2015 DoD Annual Energy Management Report, DoD is the single largest consuming entity in the United States, with its overall energy usage comparable to the state of Oregon's annual commercial consumption.[1] The Department's total energy bill was $16.7 billion. DoD spent $3.9 billion on installation energy, which included $3.7 billion to power, heat, and cool buildings.[2] Challenges exist for the DoD as a greater reliance on conducting missions at fixed installations and enduring locations will lead to an increased reliance on energy from fixed installations to meet future energy reduction goals.[3]

Current energy conservation methods principally require changes in human behavior or require significant investment in new technology. Changing human behavior has always been proved challenging, oftentimes unsustainable, and requires significantly increasing investments in technology development. Effecting these changes is difficult in the current fiscal environment. Eliminating the need for human intervention through automated processes can help the Department to meet its goals. Automated voltage control to reduce electricity consumption is an emerging utility industry tool but had not been applied at the building or installation level. Continuous high voltage on power equipment beyond needed demand leads to an overuse of electricity, thermal waste, higher energy bills, and unnecessary carbon production. Current voltage reduction solutions do not allow for precise voltage control and prevent the integration of highly variable load and generation commonly found in a microgrid or from renewable energy sources. Current available market solutions do not independently isolate voltage supply to critical load processes on military bases. As a result, military bases continue to consume more energy than necessary to meet their true needs.

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[1] Energy Information Administration (EIA), U.S. States, State Profiles and Energy Estimates [online source] (Washington, D.C. 2011, accessed March 9, 2016), available from http://www.eia.gov/state/
[2] Department of Defense Annual Energy Management Report Fiscal Year 2015, page 17, http://www.acq.osd.mil/eie/Downloads/IE/FY%202015%20AEMR.pdf
[3] Department of Defense Annual Energy Management Report Fiscal Year 2015, page 19.

This technology can assist DoD with reaching their energy reduction goals in a cost-effective, non-intrusive manner. It exploits infrastructure investments that DoD has already made, such as smart meters, without requiring nonstandard modifications to the system. Current voltage reduction solutions do not allow for precise voltage control and some may even prevent the integration of highly variable load in a microgrid or from renewable energy generation sources. Although Dominion is a recognized market leader in the utility scale voltage conservation solutions, it is not aware of other DoD customers using CVR elsewhere on its distribution system. Accordingly, while there may different methods for reducing voltage, there is no substitute for EDGE® technology and AMI-based precision voltage control solution.

1.2 OBJECTIVES OF THE DEMONSTRATION

This project successfully demonstrated how CVR, applied on the Fort Myer distribution system and combined with MicroCVR in buildings, could save between 3% and 6% in installation electricity consumption. In fact, the project demonstrated 8 % to 10 % savings based on the combined technology. Under this project, energy savings occurred passively without requiring changes in human behavior. The project exploited infrastructure investments that the Department had already made without requiring nonstandard modifications to the system. Voltage reductions would have no noticeable impact by end users. Supplementing this primary objective, DVP also demonstrated that the installation's electrical distribution systems could be compatible with high variation loads, adjust to voltage complexities introduced by renewable generation, while improving reliability and enhancing secure, critical facility loads. DVP's technical objective sought to achieve a combined CVR/MicroCVR energy reduction between of 3% and 6% (test building results will be extrapolated to the non-test buildings) while providing a high variation load and generation platform using the same technology.

There were two demonstration measurements used to validate the performance of the CVR/MicroCVR energy platform. The first was a measure of kWh savings resulting from controlling the installation's delivery voltages in the most optimum levels for equipment energy efficiency. The second was a measure of the variation level experienced from a defined load and/or generation change simulating the behavior of the distribution system to high variation loads and renewable generation. This was measured using the standard voltage rise time and overshoot for a step input of power. The measurement was made on the input and output of the MicroCVR voltage controller using the VirtuGrid voltage sensors, GridEdge Monitoring and iVolt monitoring.

Measurements of performance was based on statistical comparison between a baseline operating period without CVR/MicroCVR that is matched or paired with operating conditions with CVR/MicroCVR in service. These CVR/MicroCVR measurements were used to measure the improvement in kWh performance between matched states of the distribution system under similar loading conditions. For the high variation load and renewable generation tests, the system was configured to allow steady state voltage response measurements in rise time and overshoot compared without CVR/MicroCVR and then compared the same repeated tests with CVR/MicroCVR running. These tests were used to calculate the increased amount of load and renewable generation that could be tolerated. Both comparisons were used to determine the kWh savings value using the cost of power and the capacity increase benefit for installing renewable generation.

1.3 REGULATORY DRIVERS

The technology being installed and operated under this project addressed the following federal energy market drivers:

Driver/Source	Energy Performance Target	Project Attribute
Installation Energy EO 13423/EISA 2007	Reduce by 3%/year from FY08-15 and 30% energy reduction by 2015	Primary project objective was to reduce annual primary metered consumption at Fort Myer by 3 – 6 %.
Energy Metering EPAct 2005/EISA 2007	Meter electricity by Oct. 2012; and, Meter natural gas and steam by Oct 2016	Additional metering instrumentation required for this project assisted Fort Myer in achieving this goal.
Federal Policy Directive	All new Federal buildings, entering the design phase in 2020 or later, are designed to achieve zero net energy by FY 2030.	Secondary voltage and power quality variability associated with distributed renewable generation were addressed by localized high-speed low voltage regulation demonstration at Fort Myer.

With the successful implementation and demonstration of this technology, CVR can be leveraged across military installations as a policy for those installations which have smart meters to significantly improve the energy efficiency while increasing the installation's capacity to high variation loads and renewable generation.

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2.0 TECHNOLOGY DESCRIPTION

CVR is an automated system-level voltage reduction technology that optimizes voltage to continuously reduce energy consumption. MicroCVR builds off the same electrical principles and effectively performs this same function at the building-level but improving performance by using high-speed voltage regulation and appliance level monitoring. Combining these two technologies was an innovative, state-of-the-art approach which has not yet been made commercially available. DVP showed that the installation's electrical distribution systems can work with high variation loads caused by renewable generation, improve reliability, and enhance and secure critical facility loads.

2.1 TECHNOLOGY OVERVIEW

Sensing load requirements and making very precise reductions in voltage that meet the load without oversupplying voltage can achieve significant energy savings. Dominion used its patented EDGE® software suite which used a state-of-the-art integrated approach to plan, manage, and validate energy efficiency opportunities by precise voltage control. Through EDGE®, voltage measurements from smart meters were received and processed by the software to precisely control voltage regulation equipment in the higher efficiency range of the American National Standards Institute (ANSI) band at the most efficient range for the connected equipment. EDGE®, by design, is a modular system that can be added incrementally to distribution systems on a feeder by feeder basis to capture the energy savings benefits of voltage conservation. In addition to CVR, which has only been applied at the utility level, Dominion introduced MicroCVR, a building-level application of voltage control similar to EDGE®, in order to gain even higher levels of building energy efficiency. MicroCVR for building high-speed precision voltage control also provided three new functions inside a building - well beyond current commercial availability. These functions include: 1) direct monitoring of voltages at the key load points in buildings such as compressors and condensers to provide more accurate voltage measurement at the point of use, 2) reducing the impact due to the variability of renewable energy sources while maintaining tight voltage bandwidth for critical load operation, and 3) providing independent, isolated, and highly secure voltage supply to critical loads.

In **Figure 1** below, a graphical depiction of the CVR operations scheme is provided below:

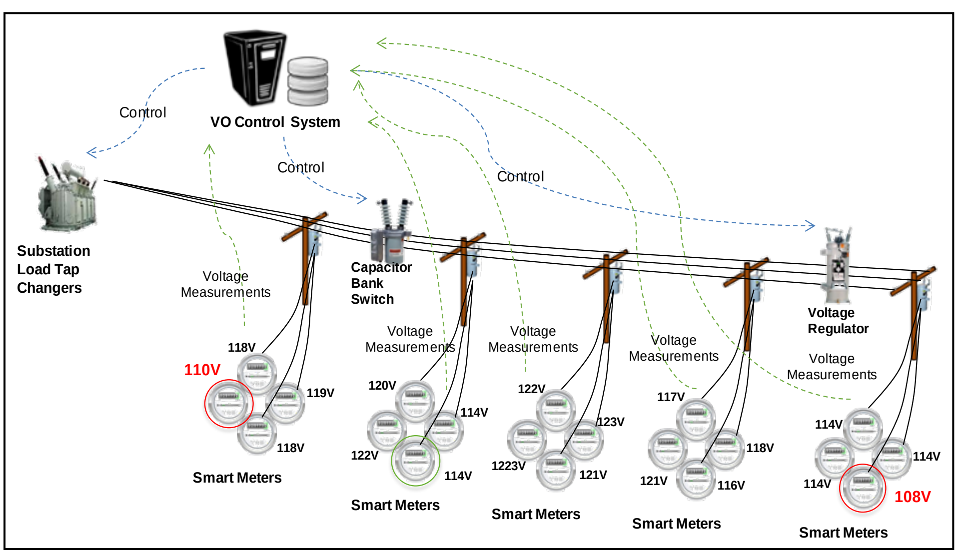

Figure 1. Graphical Depiction of CVR Operations

In **Figure 2**, the voltage regulation design for CVR installed at Fort Myer is provided here:

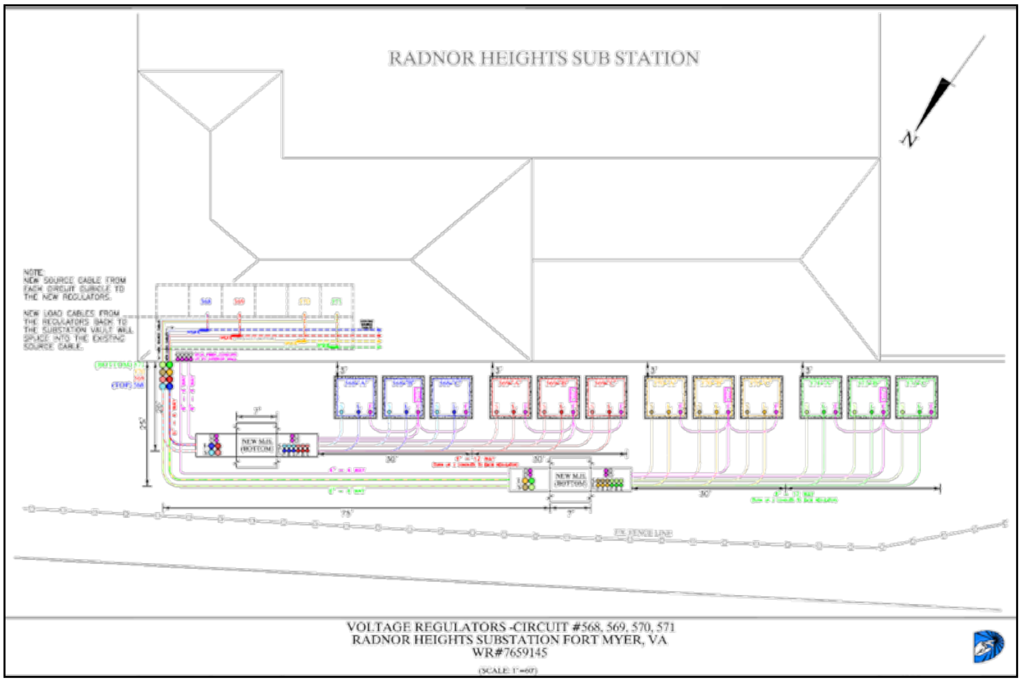

Figure 2. CVR Voltage Regulation Design

In **Figure 3**, the voltage regulation design for MicroCVR at Fort Myer is provided here:

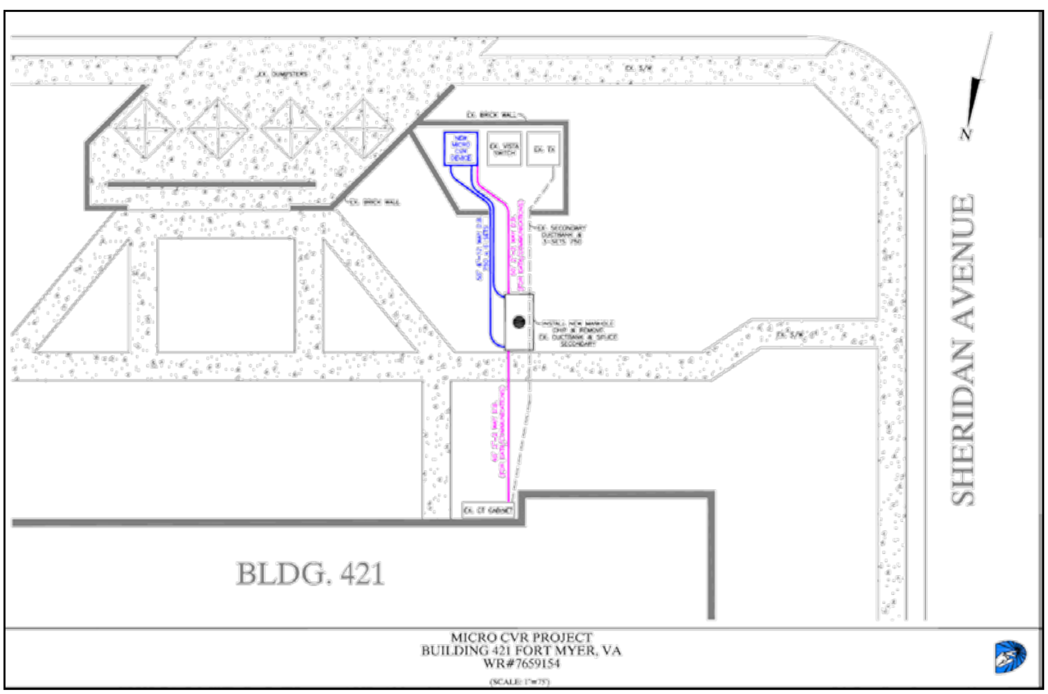

Figure 3. MicroCVR Voltage Regulation Design

In **Figure 4**, a photograph and graphical data collection diagram of the MicroCVR technology installed at the Fort Myer location is provided here:

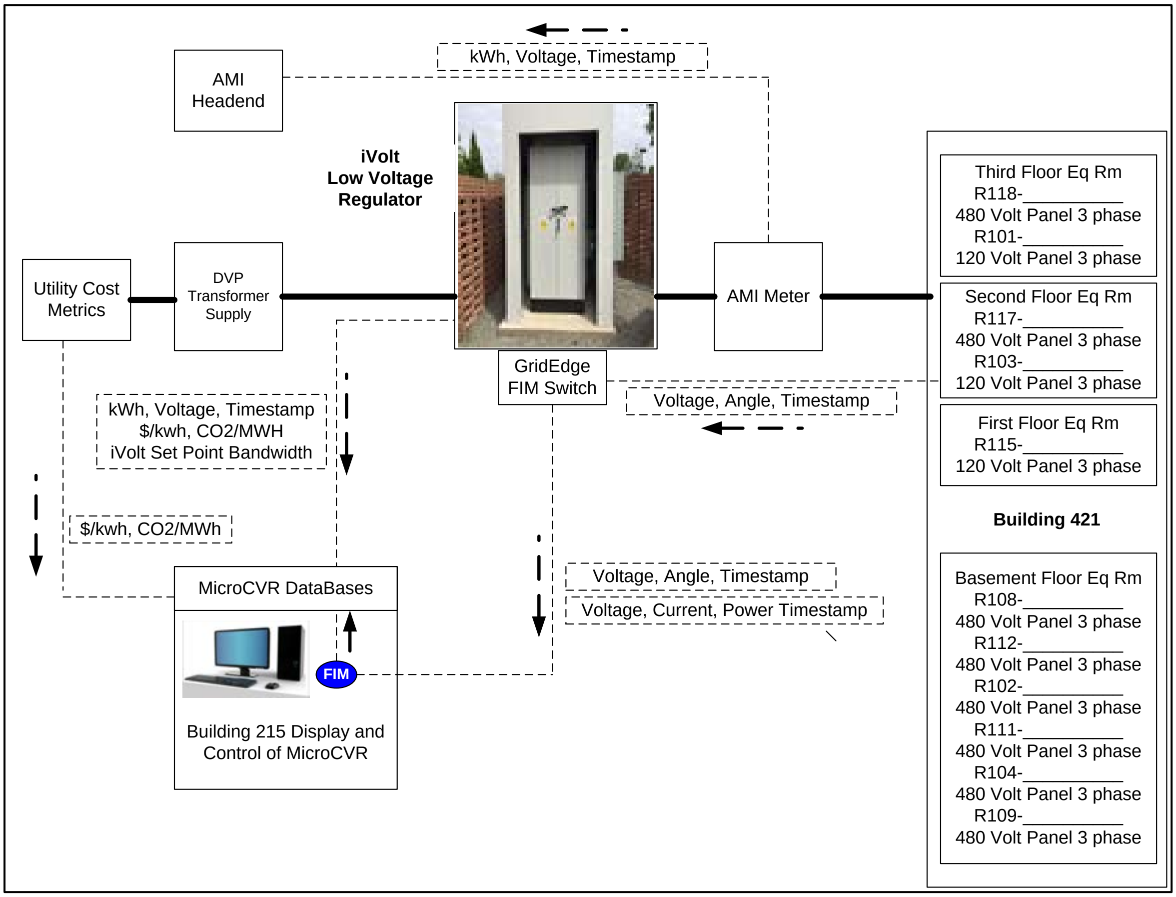

Figure 4. iVolt Low Voltage Regulation Equipment at Fort Myer

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The combination of CVR and MicroCVR did result in reduced energy consumption at Fort Myer. The anticipated and resulting reduction ***exceeded*** the demonstration's performance objective of 3-6% when it was applied across an installation. MicroCVR also improved system performance by optimizing and regulating the voltage independent of the primary voltage control activity.

Figure 5 provides a summary of the EDGE® advantages below:

	Model Based	Primary Based	EDGE	MicroCVR
Simplicity	LOW	MEDIUM	HIGH	HIGH
Accuracy	LOW	MEDIUM	HIGH	HIGH
Adaptability	LOW	MEDIUM	HIGH	HIGH
Sustainability	LOW	MEDIUM	HIGH	HIGH

No Detailed Circuit Model Required: EDGE uses AMI meters and Substation Monitoring, eliminating the need for a detailed circuit model. MicroCVR uses equipment voltage monitors and feeder information modules to monitor building equipment eliminating the need for a detailed circuit model.

Delivers Precision Voltage: EDGE measures voltage down to the customer site, creating moa more complete picture of the distribution system. MicroCVR measures voltage down to the customer equipment, allowing high speed voltage regulation at the lower utilization level increasing CVR savings.

Adapts to Change: EDGE adjusts dynamically to seasonal changes and new customer load, allowing saving to continue overtime. MicroCVR adjusts dynamically to equipment load increases maintaining the voltage within a 1.5% of the setpoint and uses the utilization voltages of the single building increasing savings significantly.

Validates Real Savings: EDGE measures actual changes in energy usage, providing a simple but effective verification process. MicroCVR uses its high speed capability to sample the increase in usage over a short time period by raising the output voltage to the input voltage level directly measuring the impact to real and reactive power. This power sampling provides a simple and accurate method to measure MicroCVR savings.

Figure 5. Summary of EDGE/MicroCVR Advantages over Model Based and Primary Based Solutions

Primary distribution lines carry the medium voltage power to distribution transformers located near the customer's premises. Distribution transformers again lower the voltage to the utilization voltage of household appliances and typically feed several customers through secondary distribution lines at this voltage.

With respect to **Figure 5**, “Primary Based” refers to the CVR process of managing voltage levels by controlling Load Tap Changers (LTCs), voltage regulators and capacitor banks in the primary side of the distribution network without visibility of deliver voltage to end-users.

EDGE® monitors the voltages at the customer premises to ensure CVR actions do not violate ANSI voltage regulation standard C84.1 (+/- 5% of 120 Volts). The customer voltage data is fed back to CVR software to optimize set point control and coordination of voltage control equipment (LTC, voltage regulators and capacitor banks).

The MicroCVR technology supplements improved high-speed voltage control for the secondary side loads for the low voltage regulator. Existing technology is limited by long response times for mechanical switch operation to control voltage usually in the range of .5 to 1 minute and high maintenance costs for increased levels of switching. The iVolt low voltage regulator used in the demonstration was able to use its Silicon Controlled Rectifier (SCR) technology to switch sub second, requiring no maintenance, and can be continuously switched from one voltage level to another.

3.0 PERFORMANCE OBJECTIVES

One of the performance objectives was to reduce energy consumption. Performance objectives for energy efficiency were targeted at measuring the circuit thermal performance (I^2R losses in conductors and equipment) and customer equipment efficiency reductions from operating at the most efficient voltage level at the appliances (CVR efficiency). The DVP-installed solution worked to simultaneously optimize these two losses as well as measure the aggregated loss savings from both loss sources. This was accomplished by optimizing the voltage on the distribution system as well as at one facility.

3.1 TABLE 1 SUMMARY OF PERFORMANCE OBJECTIVES

DVP's project delivery team investigated and collected energy and voltage performance data before, during, and at conclusion system operation demonstration in order to evaluate the technical objectives of the project. A summary of performance objectives can be found in **Table 1** below.

Table 1. ESCTP Project EW-201519 Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria & Result
Quantitative Performance Objectives			
Site-wide conservation voltage reduction (CVR)	Energy - kWh	Meter readings of energy used by DVP at Fort Myer master meter delivery point	3% reduction compared to baseline **Result: 3.7%**
Building-level micro CVR Building 421 – Barracks A	Energy - kWh	Meter readings of energy used by Barracks A at premise meter delivery point	1.5% reduction compared to baseline **Result: 5% reduction**
Compatibility of MicroCVR with highly variable loads or renewable generation	Voltage stability (V)	VirtuGrid Voltage Measurements using GridEdge and VirtuGrid Voltage Sensors	25% reduction in variation of voltages relative to the non MicroCVR case **Result: 50% reduction**
Highly secure voltage supply	Voltage stability (V)	VirtuGrid Voltage Measurements using GridEdge and VirtuGrid Voltage Sensors	Maintain secure voltages to within 1% of the expected voltage set point **Result: 1.5% of set point**

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4.0 FACILITY/SITE DESCRIPTION

The site selected was Joint Base Myer-Henderson Hall in Arlington, VA. Voltage conservation was demonstrated across the entire installation. DVP demonstrated MicroCVR at Building 421 (barracks). The CVR was installed at DVP to regulate twelve single phase regulators located adjacent to the Radnor Heights substation, located on Fort Myer. Building 215 housed the monitoring for MicroCVR.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

Fort Myer, Virginia, is located across the Potomac River from Washington, D.C., adjacent to Arlington National Cemetery. It is part of Joint Base Myer-Henderson Hall (JBMHH) which provides installation services and support to military members, civilians, retirees and their families with a quality of life commensurate with the quality of their service. Fort Myer also provides base support to the the U.S. Army Military District of Washington and the Joint Force Headquarters - National Capital Region (MDW/JFHQ-NCR) which facilitates deployment of forces for Homeland Defense and Defense Support to Civil Authorities in the National Capital Region.[4]

A map with electrical circuit overlay is provided in **Figure 6**.

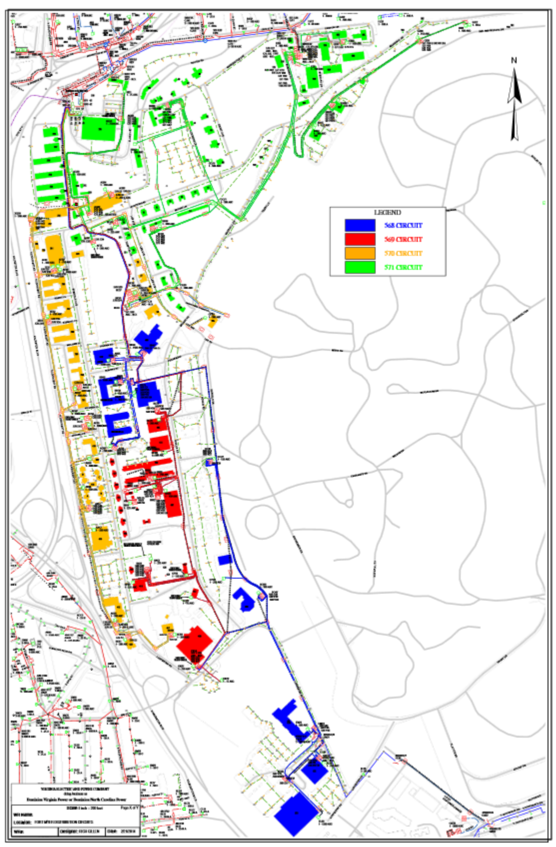

Figure 6. Fort Myer Electrical Circuit Overlay

[4] JBMM-HH website, http://www.jbmhh.army.mil/web/jbmhh/AboutJBMHH/MissionVisionValues.html

The voltage conservation site is located adjacent to Dominion Virginia Power's Radnor Heights Substation. Dominion maintains restricted access at this location and serves the base from this substation. This project site supports the on-site canine ordnance detection training area. Military operations interact within the vicinity by utilizing the area around the Radnor Heights Substation to place unexploded ordnance training materials that the detection dogs can locate.

The MicroCVR site is located at a barracks on Fort Myer. The facilities are within an existing brick wall surround adjacent to the housing of military personnel. Within the vicinity of the site, there are green trash dumpsters and no known military operations within this demonstration area.

There were no other concerns or issues related to the selected demonstration site.

5.0 TEST DESIGN

DoD, as the largest federal consumer of energy, needs to reduce its energy consumption. Automated voltage control to reduce electricity consumption is an emerging utility industry tool, but has not been applied at the building or installation level. Continuous high voltage on power equipment beyond needed demand leads to an overuse of electricity, thermal waste, higher energy bills, and unnecessary carbon production. Current voltage reduction solutions do not allow for precise voltage control and prevents the integration of high variable load such as renewable generation or conditions commonly found within microgrid systems. Currently available market solutions do not independently isolate voltage supply to critical load processes on military bases. As a result, military bases consume more energy than necessary to meet their true needs. Compounding this problem with the new requirements for high variability renewable resources may produce voltage performance not compatible with the requirements of sensitive base production processes.

This demonstration successfully addressed whether CVR could be installed at an installation with MicroCVR on one building and still achieves the targeted energy reduction within the 3-6% range. The demonstration also simultaneously improved secondary voltage performance with MicroCVR by improving secondary voltage variation within 1% of set point and all voltage variation within +/- 5% steady state bandwidth.

5.1 CONCEPTUAL TEST DESIGN

As shown in **Table 1**, the test design demonstrated achievement of the four performance targets. The first test design element demonstrated energy efficiency improvement for the base level loads from area-wide CVR application from EDGE. Second, the test design demonstrated energy efficiency improvement for the building-level loads from MicroCVR application from VirtuGrid. The third test design element demonstrated building-level control during a high variability load and generation event performed under the MicroCVR objective. And finally, the test design demonstrated building-level voltage performance improvement from MicroCVR caused by high variability load and generation.

Installing CVR and MicroCVR on Joint Base Myer-Henderson Hall (JBMHH) resulted in an energy reduction of 5-10% and simultaneously controlled the negative voltage variation effects from the installation of renewable energy or other high variation generation and loads.

Voltage set points at the circuit voltage regulators and at the low voltage regulator were the independent variables. These variables were used to optimize energy efficiency and minimize voltage variation for this demonstration.

Energy consumption at the totalized base level, the building-level, and the device utilization level, as well as voltage magnitude for all non-controlled voltages along the power delivery path within the base were considered the dependent variables.

The controlled variables for this test were the averages of ambient temperature of the base, the humidity, and the connected base load, including the connected building load. Since there is a variation that is not directly controllable, DVP will be using a pairing technique to match “pairs” to hold these values constants for the measurement using a paired t statistical technique.

DVP gathered baseline voltage and usage data and then compare it to the optimized voltage and usage data after the CVR and MicroCVR technologies were installed and operational. Three types of comparison techniques were used to demonstrate the performance. For the area-wide energy efficiency calculation, a paired t statistical process will be applied to determine the average energy efficiency improvement between the base data and the CVR "ON" data. For the building efficiency improvement, the MicroCVR provided an hour-by-hour loss tracking calculation based on the building distribution system losses and the allocation of the measured building power to each voltage measurement location based on a voltage sampling technique. Hourly values were compared from the base data to the MicroCVR "ON" data to determine the efficiency improvement. The variation control testing involved the evaluation of the GridEdge and VirtuGrid sensors at the low voltage regulator which provided voltage sampling of the MicroCVR performance. The data was analyzed during the demonstration testing of high variation load and generation at the building-level and at the base area level to determine the performance. After this was completed, the base data test without the MicroCVR was compared to the data with MicroCVR "ON".

The Test was separated into the following Seven Phases:

Phase 1: Existing Baseline Data Preparation

The existing kilowatt-hour (kWh) metering data for the four circuits provided by DVP on hourly intervals for the previous 12 months served as existing baseline data for the base level CVR analysis and calculations. Added to this data was the hourly meter data from each of the AMI meters at the building locations. Local weather data was collected based on hourly temperature and humidity. This information was provided to Phase 2 for the circuit voltage study.

Phase 2: Base Level Voltage Study

The existing voltage levels over the previous were analyzed using the EDGE Planner application to determine outlier voltages and build the information for the EDGE setting that will be applied to the control algorithm for the base wide CVR. Any extreme outliers were documented, and appropriate responses developed to resolve or manage their performance.

Phase 3: Installation and Commissioning

CVR and MicroCVR control systems were installed and commissioned at DVP, the substation, four circuits, as well as the building location. All controls and data recording equipment and communication systems were completed.

Phase 4: Baseline Operation

Once the CVR and MicroCVR was commissioned and made operational, the baseline characterization was executed. In this phase, the system was placed in monitor only mode with the CVR and MicroCVR voltage controls not operating. All sensors were used to establish baseline performance levels for kWh and voltage while recording all independent, dependent and control variables previously discussed.

Phase 5: CVR and MicroCVR "ON" Operation

After the Baseline operation was established the CVR and MicroCVR equipment was turned on, providing optimization control to the set points of the circuit regulators and the low voltage regulator. All sensors were used to establish CVR and MicroCVR performance levels for kWh and voltage while recording all independent, dependent, and control variables previously discussed.

Phase 6: Voltage Variation Performance Testing

Two tests were run to determine the response of the MicroCVR system to high variation load and generation testing at the building-level and at the base area level to determine steady state performance of voltage level, variation range, and low voltage regulator response time and control accuracy. All sensors were used to establish MicroCVR performance levels for kWh and voltage while recording all independent, dependent, and control variables previously discussed. As described in more detail in Section 5, data collection included one year of background data in addition to 90 days of test data collection after the installation of the initial VirtuGrid control and monitoring system.

Phase 7: Analysis and Reporting

The results of the analysis were compiled for review and the data and levels of attainment were processed and documented to determine the success of the systems. These results were appropriately presented and discussed for clarification with the ESTCP Program Office team.

5.2 BASELINE CHARACTERIZATION

The baseline characterization was broken into two sets of data. The first was the collection of existing baseline data on kWh for the base level usage and combining it with the weather data from the local weather station for hourly intervals over a one-year 8760-hour period. The second process occurred after the installation of the CVR and MicroCVR equipment. During this 90-day period kWh and voltage data was taken on an hourly basis to determine the base operating condition. This information was combined with the existing baseline data to provide a clear baseline for overall operating conditions at the site.

The existing kWh and voltage metering data for the four circuits was provided by DVP on hourly intervals for the previous 12 months which served as existing baseline data for the base level CVR analysis and calculations. Local weather data was collected on hourly temperature and humidity. This information was provided to Phase 2 for the circuit voltage study.

Once the CVR and MicroCVR were commissioned and made operational, the baseline characterization was executed. In this phase, the system was placed in monitor mode with the CVR and MicroCVR voltage controls not operating. All sensors were used to establish baseline performance levels for kWh and voltage while recording all independent, dependent, and control variables previously discussed.

The existing data collection period was one year prior to installation of the equipment to cover all seasons. The baseline operating data collection period was 90 days. The entire baseline period was one year and 90 days prior to turning CVR and MicroCVR to the "ON" operating state.

Phase 1: Existing Baseline Data Preparation

The existing kWh metering data for the four circuits was provided by DVP on hourly intervals for the previous 12 months which served as existing baseline data for the base level CVR analysis and calculations. Added to this data was the hourly meter data from each of the AMI meters at the building locations. Local weather data was collected on hourly temperature and humidity. This information was provided to Phase 2 for the circuit voltage study.

In the collection of baseline data for the hourly intervals, DVP used linear estimation routines to recover individual hours that may be lost due to data errors. The corrections were only applied if data is measured on both sides of the data and had no major movement between the before and after hour (less than 5% movement). DVP considered this as being very accurate if applied in this manner for Temperature, Humidity, Voltage, and kWh data.

A more sophisticated method would have been used if more than one hour of data was lost. This would have involved matching the data to an exact set of conditions on another day and using linear regression projecting the missing data using a historical data reference. This data used to project met very strict requirements associated with matching the two days and be in a close time period to the projected data to make sure there were not load connection issues.

All load data obtained by estimation was tagged to make sure it is not used inappropriately in evaluation and modeling routines.

The following data collection equipment was used for the various systems used in this CVR – MicroCVR system.

CVR application:

1. Revenue grade power meters (AMI Type) for the kWh measurement at the input to the base for measuring load and at the input to buildings to measure load. The revenue grade meters were used to measure the voltage inputs for the CVR software system, EDGE®.
2. The Distribution Management System (DMS) sensors used to control the Dominion Virginia Power distribution network was used to measure set points for the voltage regulators (including the bandwidth tolerance) at each circuit supplying the Base, Voltage levels at the supply substation, and the tap position of the individual regulators at each circuit.

MicroCVR System:

1. The Remotes (REMs) located at the building being monitored were measuring voltage magnitude at 11 locations within the building.
2. The Feeder Information Module (FIM) measured voltages at the iVolt primary and at the meter base supplying the building being monitored.
3. The GridEdge monitoring system was measuring energy, voltage, current, and power factor at input and output of the iVolt low voltage regulator. This independent system had a sampling rate once every 10 seconds which is able to document the power, voltage and current information from the iVolt software system.

The iVolt sensing system was used to measure the iVolt set point and bandwidth as well as operating parameters for the low voltage regulator performance.

5.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

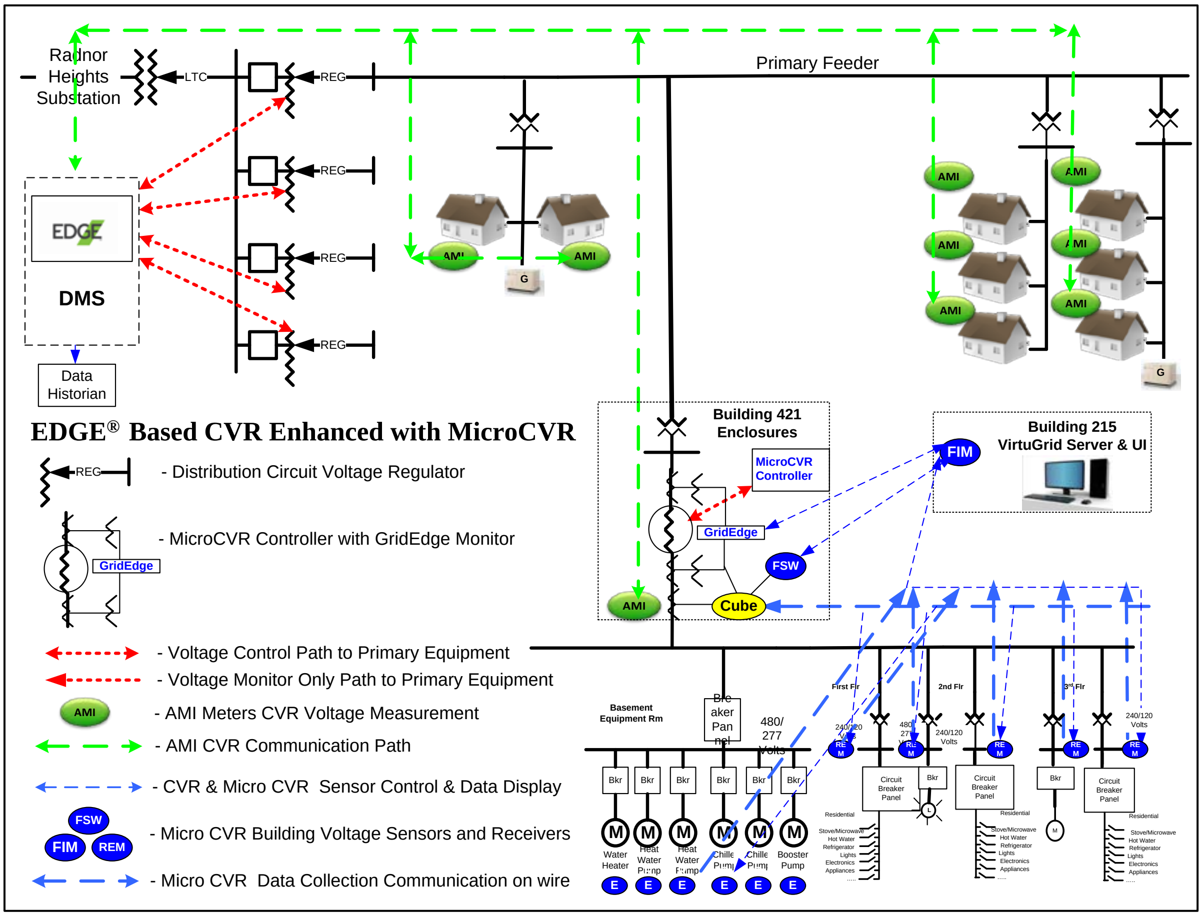

Figure 7. General Schematic of CVR with MicroCVR System

This system design showed the value of CVR and MicroCVR on a military installation. It remains a low-cost way to reduce energy consumption which doesn't require change in human behavior and remains unnoticeable to end users. In addition, the demonstration showcased its ability to make the base compatible with high variation loads and renewable generation sources using the same technologies.

Figure 7 is a schematic overview of the CVR and MicroCVR control systems proposed in the design. CVR was provided by a commercial product called EDGE®. The EDGE® software was used to successfully optimize the voltage levels over the military base for maximizing energy efficiency of the aggregated equipment load. This was accomplished by leveraging another commercially available product, AMI, for measuring and feeding back the voltages at the entrances to the building facilities at the military base. These measured voltages were supplied back to the EDGE® software and used to adjust the voltage set points for four sets of circuit regulators supplying the base as shown in **Figure 8** and **Figure 9**. These voltage regulators were also commercially available devices.

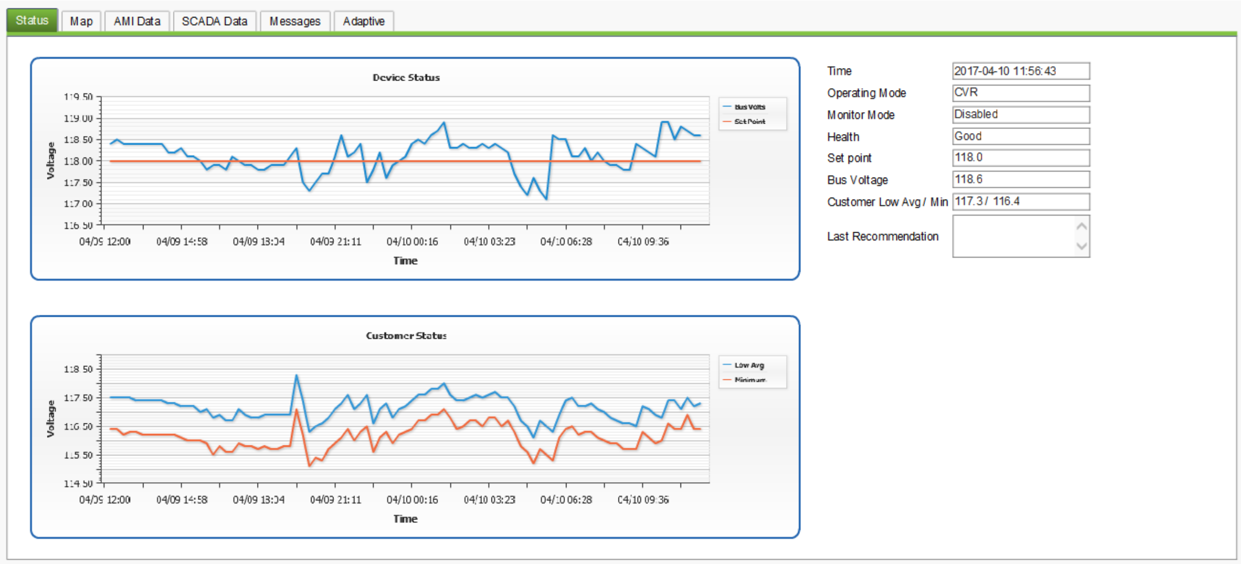

Figure 8. EDGE Operating on Circuity 569 in Early April 2017

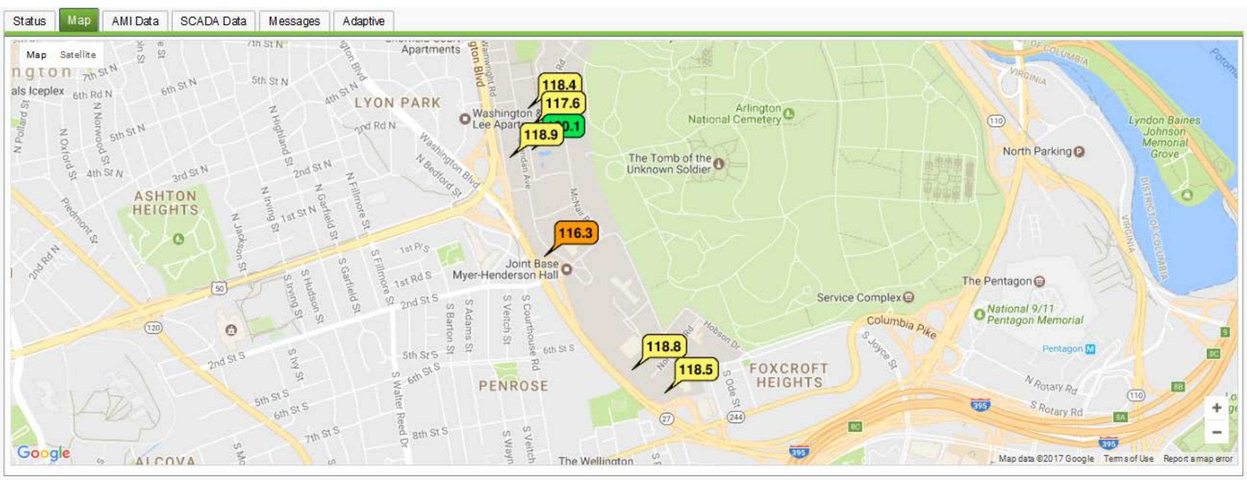

Figure 9. Meters Feedback Used to Control Voltage Regulation Equipment on Circuit 569

As shown in **Figure 7**, MicroCVR was added to the CVR system for high-speed control of voltages at the utilization level in one of the buildings on the military base in order to demonstrate that high-speed voltage controllers used in addition to base wide CVR can incrementally increase the energy efficiency performance due to the higher speed and direct measurement of building equipment levels using remote sensors. MicroCVR, in this configuration, is still not a commercially available product.

MicroCVR, in addition to improving energy efficiency, provided two additional benefits. The first was management of voltages at a building where high variation loads or generation was temporarily connected. It "smoothed" the voltage variation making this type of generation and load more compatible with other traditional base loads used today. The second benefit was that MicroCVR was used to "buffer" critical loads from power system variation by allowing dedicated high-speed voltage regulation and monitoring for critical facilities.

These two systems were designed into a voltage optimization and stabilization system that operates to implement all the benefits simultaneously across the base with targeting specific critical areas for improved performance and reliability.

Figure 7 outlined the major components of the CVR/MicroCVR system. Starting from the top left of the figure, the EDGE® CVR controls are shown collecting voltage data from the AMI meters located across the base at the input to the building electrical facilities. This CVR control system works to measure the state of the voltage ranges across the base to optimize the set point levels of the four sets of voltage regulators supplying the base. This control system was the first step in improving energy efficiency of the connected loads based on optimum voltage control. At Building 421 an incremental voltage control system was deployed which was faster and more specific to the supplied loads. It regulated the voltages inside of the building to a local optimum level based on the measurements of the remotes, communicated to Building 215 FIM and the control of the high-speed low voltage regulator located at the entrance to Building 421 electrical service.

The system design incorporated two levels of voltage control at Fort Myer with different equipment being installed to achieve the project objectives. The base wide CVR application was specifically designed to integrate into the existing control system allowing the optimization of voltages from the electrical substation to the meter at building electrical supply. This system did not replace the existing systems but optimized their settings. This system was designed to return to local control if the CVR system did not function. During this project, default settings returned all voltages to set points used to previously operate the base without optimization. DVP manually removed the voltage control system from service using the controls at the Regional Operation Center returning the system to its pre-CVR control state.

The second system was applied to Building 421. It was the high-speed voltage control that optimized the local voltages from the meter to the appliance utilization points. This system operated on a set-point voltage but the voltage was only changed locally at Fort Myer. This was designed intentionally to make sure the MicroCVR system control was isolated from any possible physical path from outside of Fort Myer. The MicroCVR monitoring system was used to monitor the operation of the utilization points in the building allowing optimization of the building appliances. Changes in set point were made manually at the control device for security purposes. The high-speed voltage regulator was designed to fail to normal even if it was in service. It was also built with a full disconnect and bypass system which would allow the building to be completely isolated from this system for maintenance or any other reason. The MicroCVR was tested using step changes in load and/or generation to demonstrate its ability to make high variation loads and generation compatible with critical loads at a base. This test was performed as described later in the document in a monitored and controlled test procedure.

The new components integrated seamlessly into the existing distribution system owned by DVP. The CVR system demonstrated its “fail to normal” functionality.

Figure 7 showed the high-level system control schematic. The EDGE® controller provided voltage control recommendations to the voltage regulation equipment outside the substation using feedback from the AMI meter collection system to place this system at an optimum voltage level.

EDGE®, located within DVP's DMS control, was designed for and met all the security requirements for this system. It directly interfaced with the DMS to implement the regulator control system on each circuit using distribution and substation level security procedures and standards. The CVR system was "turned off" and returned to a pre-CVR control from the DMS control center when required for bypass operation.

The MicroCVR controller operated independently and at a different timescale than the CVR control by measuring voltage at the building-level and using a high-speed controller to respond to voltage variability. The monitoring system used to manually monitor the set point and the resulting equipment voltage performance did not directly change settings on the low voltage regulator. The engineering design was based on having the same settings over long periods of time which were optimized and checked using the MicroCVR data and the low voltage regulator performance. Because of this configuration, the security of the set point for the controller was always maintained. The MicroCVR monitor ran continuously, recording the performance and setting "tune ups" were only required on a seasonal basis based on the measurements, engineering analysis, and a manual set point change when required. The high-speed voltage controller was designed to fail to normal operation or to an adjustment change of zero volts. This mode of operation connected the input voltage to the output voltage with no change, which defaults to the status of the building prior to the installation of MicroCVR. The system was also designed with a manual bypass and disconnect system allowing the local operator to close an alternate path around the low voltage regulator and operate two disconnects between the low voltage controller input and output, completely removing the unit from service.

Given these design characteristics the CVR/MicroCVR system was fully integrated into the existing system and did not replace any existing systems. In addition, it provided a service of optimizing voltage beyond present operating levels and, when required, was removed from service and returned the system to either a monitor only mode or placed the system in the same mode it operated in prior to the CVR/MicroCVR installation.

5.4 OPERATIONAL TESTING

5.4.1 Steady State or Normal CVR Operation:

Dominion Voltage, Inc's (DVI's) (Energy Distribution & Grid Efficiency (EDGE®) Manager is a voltage optimization program that allowed DVP to control CVR function while observing real-time circuit conditions. Using AMI voltage data as feedback, Manager executed a precise voltage control set-point recommendation to the voltage regulation devices at the head of each circuit. By changing the set points of voltage regulators, Manager regulated the voltage at the bellwether meters to the more efficient –5% band (114-120 volts on a 120-volt basis).

To control device set points, EDGE® Manager was integrated with the existing Supervisory Control and Data Acquisition (SCADA) system. In this plan, EDGE® Manager worked with the voltage settings of regulators of the four feeders. For each of the four regulators, EDGE® Manager changed the voltage set point or *band center*. This setting was used by the control, along with its bandwidth setting, to determine when to change the tap in order to raise or lower the voltage.

The distribution facilities under EDGE® control were divided into nodes. A node is defined as a set of distribution facilities under a top-level voltage control device on the grid. Typically, a node consists of a LTC or a Regulator and the circuits fed from its regulated bus. All down-line voltage regulators and line capacitor banks were included in the node. Alternatively, a node may consist of a substation circuit voltage regulator and the single circuit it feeds, as well as any down-line line regulators and capacitor banks. EDGE® Manager does not control substation capacitor banks in the same manner as voltage regulation devices. In this case, there were no additional down-line line regulators and capacitor banks for each of the four feeders.

5.4.1.1 CVR

CVR mode is a gradual process that changes device settings based on AMI feedback to optimize the distribution voltage profile. CVR's goal is energy efficiency. From the set of bellwether meters, EDGE® Manager calculated the minimum meter voltage and the low average statistic. (The low average is the average of the lowest X meters, where X is configurable in EDGE® Planner.) The optimal voltage is shown in **Figure 10**. The actual low average should be greater than the Low Average Voltage Acceptable parameter and less than the High Low Average Voltage Acceptable parameter, and the actual minimum voltage should be greater than the Minimum Voltage Acceptable parameter.

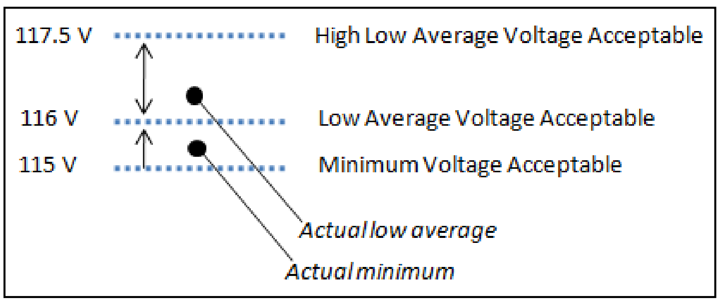

Figure 10. Optimal Voltage Graphical Representation

For voltage regulators, EDGE® Manager raised and lowered the device set point, one volt at a time, to keep the minimum and low average in their target bands.

5.4.2 Steady State or Normal MicroCVR Operation:

MicroCVR is a voltage optimization and variation control program that allows the customer to control MicroCVR function while observing real-time building voltage conditions. Using remotes (REM) to collect voltage data as feedback, MicroCVR executed a high-speed (sub second) precision voltage control to building appliance. By monitoring the equipment utilization voltages, using high-speed control and identifying when manually changing set points of the low voltage regulator was required, MicroCVR regulated the voltage at appliance utilization level to the more efficient –5% band (110-118 volts on a 120-volt basis).

To control device set points, The DVP MicroCVR operator monitored the voltage profiles collected by the FIM from the Remotes located in Building 421. The operator, on a seasonal basis, manually changed the voltage bandwidth and set point for the low voltage regulator based on engineering analysis at the service entrance to Building 421. For the high-speed low voltage regulator, the MicroCVR operator changed the voltage set point or band center.

This setting was used by the low voltage regulator control, along with its bandwidth setting, to determine when to change the tap to raise or lower the voltage to the building appliances.

The facilities under MicroCVR control were located in various parts of the building, mostly near circuit breaker panels. The voltage at each location was sampled once every five minutes and transmitted back to the FIM over the reverse path of the power flow to the appliances. This enabled the MicroCVR monitoring system to securely monitor the performance of the building while maintaining measured voltages in the optimum band and within the required bandwidth. The communication system used a time domain multiplex scheme that provided continuous data to Building 215 for the periodic review and analysis. This data was used to tune the high-speed low voltage regulator set point and bandwidth.

For the MicroCVR low voltage controller, an additional monitoring system - GridEdge - was employed to provide high sample rate, 10 second, monitoring of the voltage control itself which operates much faster than the 5-minute sampling for the appliance loads to assure that the MicroCVR controller is operating as expected. The VirtuGrid voltage sensors were used to do high-speed sampling of voltage for determining sub second response times (16 kHz sampling).

5.4.2.1 MicroCVR

CVR mode is a gradual process that changes device settings based on AMI feedback to optimize the distribution voltage profile. MicroCVR mode is a high-speed voltage regulation that precisely maintains voltage levels on its output in response to load and generation variation. Its goal is both energy efficiency and minimizing voltage variation. From the set of remotes, MicroCVR monitored the minimum average appliance voltages throughout the building electrical system. The optimal voltage range shown in Figure 17. The actual steady state low performance should be greater than the minimum optimum low voltage limit and less than the optimum high voltage limit, and the actual minimum voltage during the equipment turn on time should be greater than the Minimum low-voltage limit.

The graphs in **Figure 11** show the actual performance measured by the VirtuGrid voltage sensors during the normal operation of the building loads. It can be seen from the graphs that the operation is well within the limits of operation and represent a major improvement in the voltage performance. Responses to disturbance are corrected by the iVolt in less than one cycle (16 msec) and the 1.5 % bandwidth is maintained by the high-speed voltage regulator.

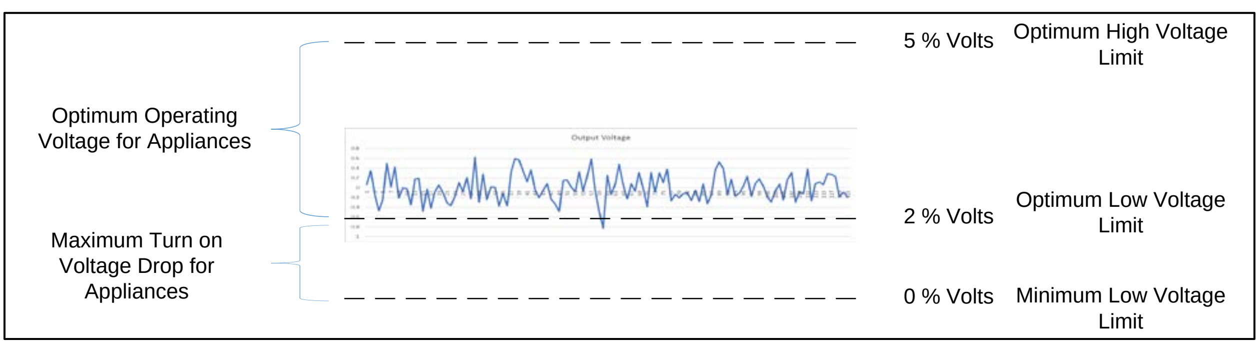

Figure 11. Graphical Representation of Optimal Voltage Range

For high-speed low voltage regulators, the MicroCVR operator chose a set point and bandwidth that raised and lowered the device taps to keep the minimum and low average in their target bands while keeping the appliance turn on voltage above the required minimum. Because this changed with seasonal load changes in the building, it was monitored, and manual set points changes were made to optimize the appliance operating bands. This maximized the energy efficiency from voltage conservation within the building.

MicroCVR also must demonstrate its ability to control voltage variations due to high variability loads and renewable generation. **Figure 12** demonstrates the methodology used to document the variability control of the low voltage regulator.

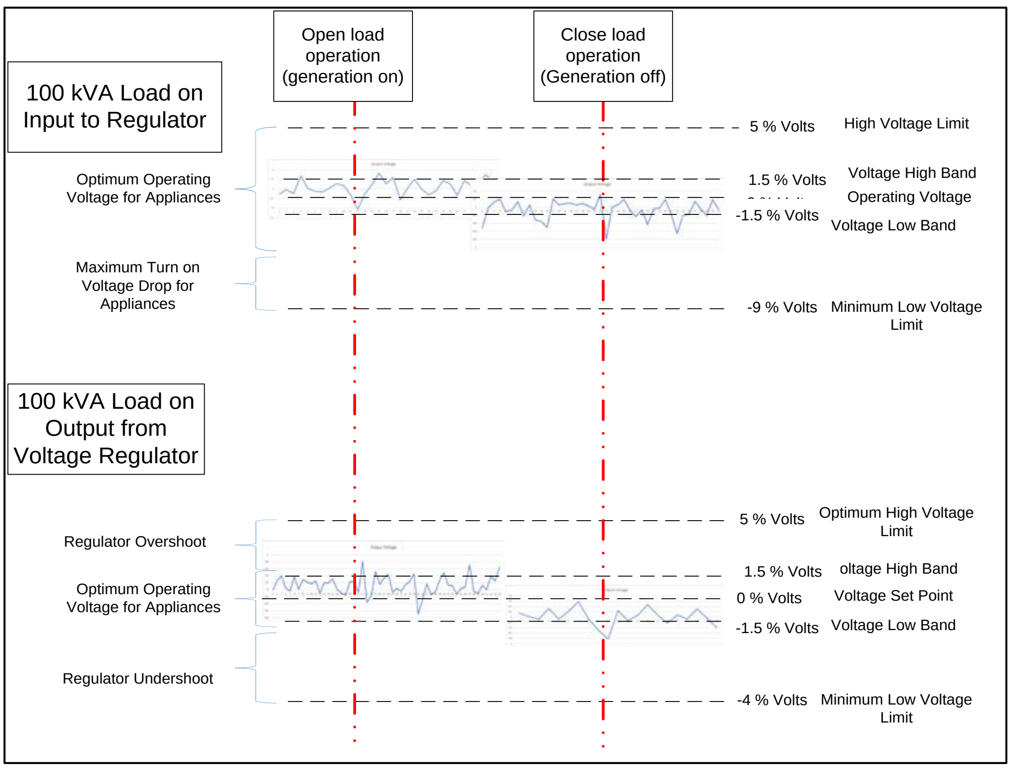

Figure 12. Graphical Representation of Low Voltage Regulator Variability Control

Each point is a sampled voltage from the input and output of the regulator. The diagram graphically demonstrates the ability of the monitoring system to measure the response of the voltage regulator output to a systematic input of power variation at either the input or the output. The time between the points documents the rise time of the system input and the system output as well as the overshoot for the generation step change and the undershoot for the load step change. This graphic method of determining the ability of MicroCVR to control the voltage variation for specific inputs of power change enabled the calculation of the limits of the low voltage regulator to mitigate higher levels of variation using the system model of the building supply system. This diagram only represents two steps in power, but the testing plan will propose multiple steps of switching generation and or load to fully test this capability and calculate the system’s ability to host successfully high variation load and generation with a clear understanding of the resulting performance of other critical loads on the base.

5.4.3 System Commissioning

CVR: During system commissioning, initially the system was run in Monitor Mode. Once satisfied with behavior of the system in Monitor mode for a couple of days, the system mode was changed to normal CVR running mode.

MicroCVR: During system commissioning the MicroCVR system was placed in monitoring mode only. The low voltage controller was bypassed until the commissioning of the full monitor system was complete. The GridEdge low voltage controller monitor was placed in operation and the commissioning procedures for this sensing system followed to assure proper operation and availability for the high variable load test. In tandem with the GridEdge commissioning, the Remotes, FIM Switch, and FIM were commissioned, testing the communication paths and the end-to-end measurements of voltage magnitude and angle. The display system in Building 215 was commissioned and information from the low voltage controller, GridEdge, and appliance monitoring system was successfully displayed. Once the monitoring systems were completed, the startup and testing of the low voltage controller was executed based on its commissioning procedure. This was accomplished by connecting the iVolt low voltage regulator to the system through closing the disconnect switches and opening the bypass switch. Once this process was completed, an initial set point was manually loaded on the iVolt and the system was placed in full operation. During system commissioning, the system was initially run in Monitor Mode. Once satisfied with behavior of the system in Monitor mode for a couple of days, the system mode was changed to normal MicroCVR running.

5.4.3.1 CVR Monitor Mode (controlled testing)

Monitor Mode was a feature that allowed EDGE® Manager to make set point recommendations to the operator without changing the actual setting on the device controls. When this was in effect, the UI displayed AMI and SCADA data along with set point recommendations, but no commands were issued to the devices. When using Monitor Mode with CVR, typically the recommendation will be to lower the set point from its default value. Because the device set point was not actually changed, this recommendation will be repeated every interval, for example "SET POINT LOWER from 124.0 to 123.0."

5.4.3.2 MicroCVR Monitor Mode

MicroCVR used two sets of devices to monitor the operation of the voltage control zone. The first set was based on the GridEdge technology and it monitored the specific input and output performance of the low voltage controller. This system was independent of the controller and provided 10-second sampling of the voltage and power levels for the MicroCVR voltage controller. **Figure 13** is a voltage output sample for a low voltage controller under high variation load testing operation. Because this system was independent of the controller it was monitoring the system when the controller is active and when it was inactive for establishing a base of comparison to determine the effects of MicroCVR operation.

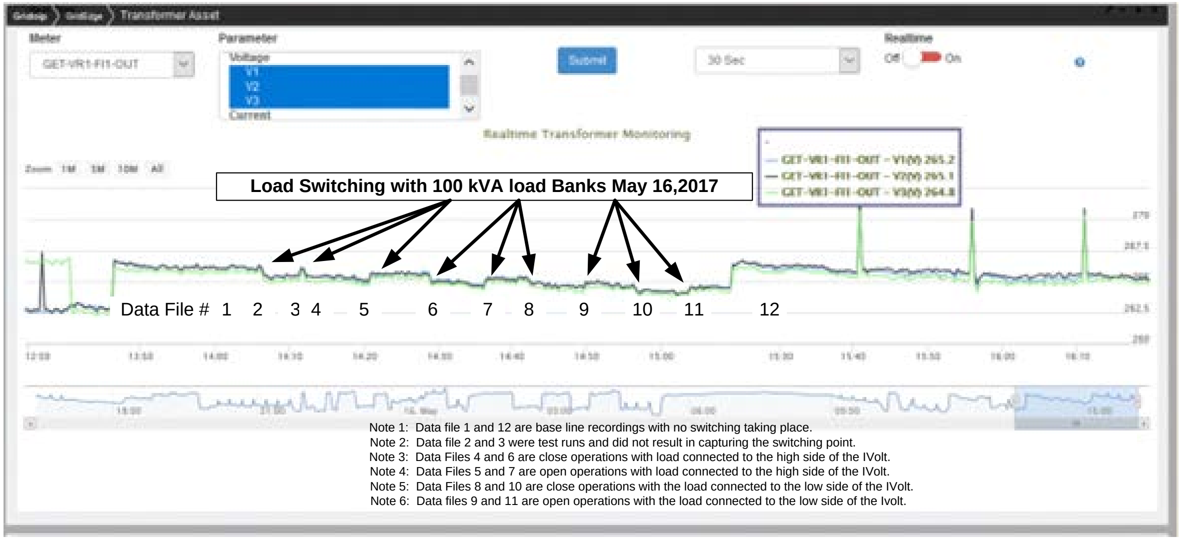

Figure 13. Time Series Voltage Output of High Variation Load Testing May 16, 2017

Figure 14 is a high-level schematic of the MicroCVR system demonstrating how the sensors are collecting data from the 11 remotes and monitoring the building voltage profiles. This process is used to optimize the set point of the high-speed voltage regulator resulting in the MicroCVR savings for the building.

Figure 15 below is the power monitoring mode which provides input and output power for the low voltage unit providing total power input to the facility under MicroCVR control. This measurement provided high-speed sampling of the actual power flows for the base condition without MicroCVR to the operating condition with MicroCVR “ON”. At this same location, electrically was the revenue metering for the building to relate the short time power measurements to the three phase power usage measurements for the building. This compact measurement system provided very accurate and clear monitoring of the power operation for the building facility. The third monitoring system was the VirtuGrid voltage sampling system that monitors voltage magnitudes and angles at 11 power delivery locations within Building 421. These sensors collect samples of voltage levels and angles which were sampled every five minutes using “on wire” communication of the values using a time domain multiplex communication in six second blocks. This monitoring system continuously scanned the voltage performance of the power delivery to determine the state of the electrical system at any given time. **Figure 13** is an output of the high variation load testing data coming from the GridEdge voltage sampling system.

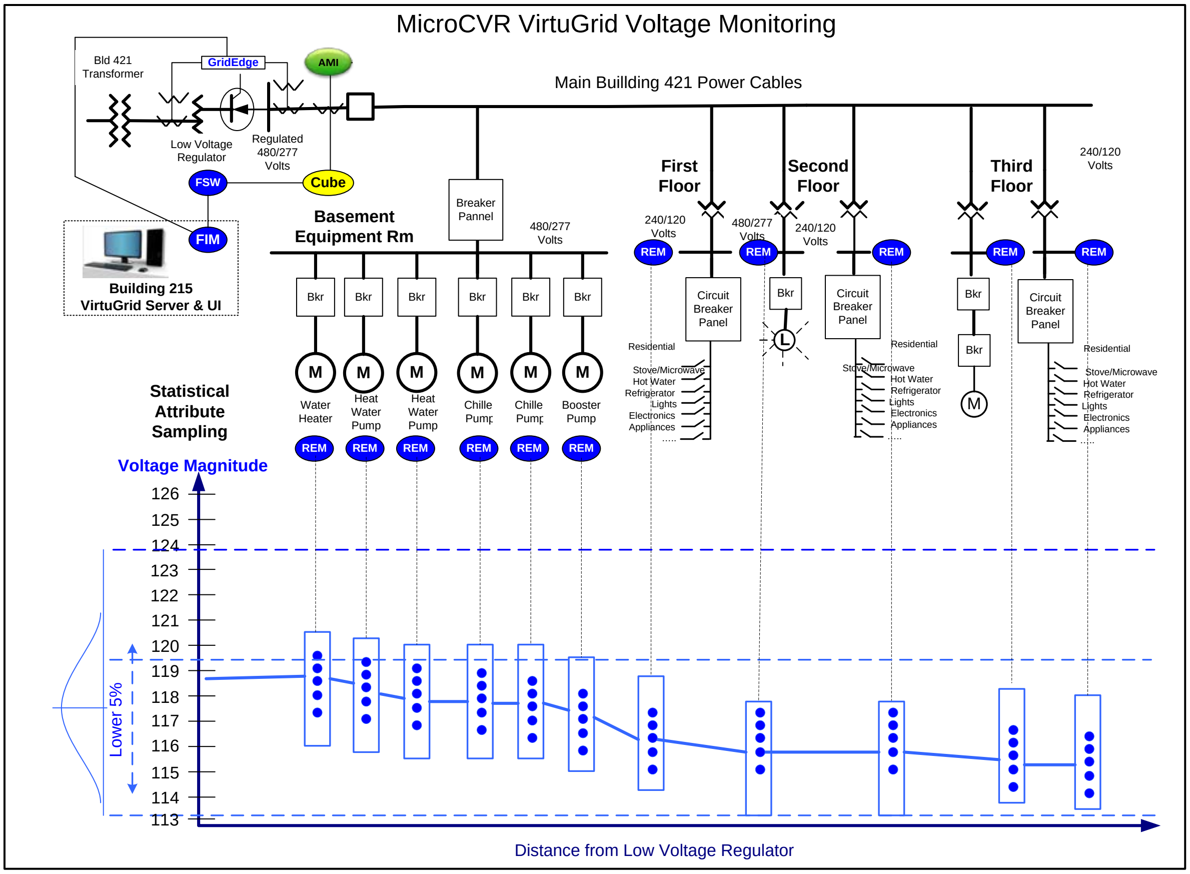

Figure 14. MicroCVR VirtuGrid Voltage Monitoring Schematic

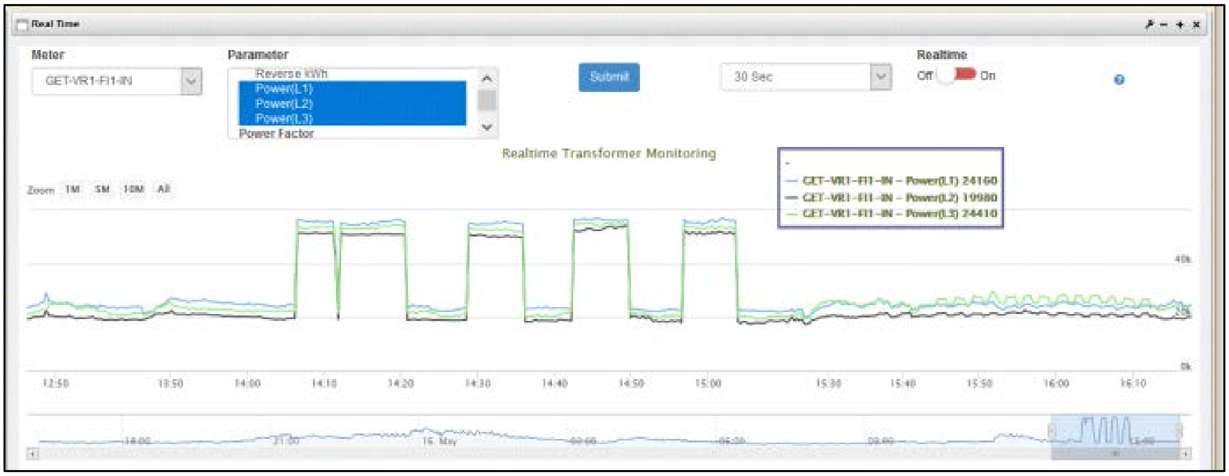

Figure 15. Power Monitoring Mode Output for 100 KVA High Variation Load Testing May 16, 2017

5.4.4 Failsafe Modes

EDGE® Manager is designed to gracefully handle interruptions to its data inputs. For insufficient AMI data, Manager will gradually return each device to its default settings and remains in CVR mode at the default settings. When AMI data is restored, Manager automatically resumes its voltage reduction algorithms. For missing or abnormal SCADA data, Manager retries a few times before determining that a problem exists, at which time it attempts to issue default settings to all devices and goes to Disabled mode. In this case, the node remains in Disabled mode until an operator returns it to CVR.

5.4.4.1 CVR AMI Backout

EDGE® Manager relies on AMI data to determine whether the voltage control device settings need to be raised or lowered. Therefore, when AMI data was unavailable, Manager gradually returned each device to its default settings until AMI data is restored. Sufficient AMI data is defined as follows. All numerical values are configurable in EDGE® Planner.

- 60% of the bellwether meters must have a valid voltage read.
- To be valid, the voltage for a given meter must be:
  - greater than or equal to 100 volts on a normalized (120-volt) base, and
  - received within 15 minutes prior to CVR processing.

Typically, the EDGE®-to-AMI integration is configured to read the bellwether meters every 12 to 15 minutes. Readings below 100 volts are ignored because they indicate either bad data or a serious operations issue that cannot be fixed by changing the regulator's set point.

A meter read that is below 100 volts or older than 15 minutes is excluded from the valid read percentage. When less than 60% of bellwethers have a valid read, Manager will enter its backout process. For voltage regulators, the backout process will raise the set point by one volt at a time, subject to the delay timer between set point changes (typically 1-2 hours). As each regulator reaches its configured default set point, Manager will stop issuing set points to that device.

The backout process occurs on a per-node basis; unaffected nodes will continue CVR processing. This was adequately demonstrated in December 2016 while Circuits 570 and 571 were disabled due to a cable failure outage. Despite the outage, Circuits 568 and 569 continued to operate under voltage conservation control. A backout is an alertable condition; the most common causes of insufficient AMI data are communication failures between the Manager server and the AMI head-end, and slow communication from the AMI head-end to field devices. The latter may result from prioritization of other business processes over on-demand reads for EDGE®, which is the desired setup to ensure that billing processes are not interrupted. On most AMI systems, communication trouble to individual meters will occur infrequently and sporadically, so the 60% threshold typically prevents this from causing an AMI backout.

The AMI backout process allows EDGE® Manager to automatically handle and recover from any maintenance that makes the AMI head-end unavailable. This means that AMI maintenance does not need to be coordinated with distribution operations, since EDGE® can safely ride through AMI downtime without operator intervention.

5.4.4.2 CVR Repeat Failure Count (SCADA Failures)

Missing or abnormal SCADA data is handled differently from insufficient AMI data. Abnormal states on SCADA points indicate that the distribution system is not operating normally. EDGE® is designed to go to a safe state when this condition is detected. The conditions that are considered abnormal are as follows:

- Communication between EDGE® and the devices via SCADA has failed.
- Breakers or tie switches are in the abnormal state (configurable for any SCADA-addressable point – abnormal is typically OPEN for transformer and circuit breakers and CLOSE for tie switches).
- Bus voltage (or primary voltage for line regulators) is outside configured limits (typically 110-130 volts).
- Device local/remote switch is in LOCAL, indicating that control may only be performed by a field technician at the device control panel.
- Device SCADA control switch or auto/manual switch is set to OFF or MANUAL, indicating that the device is not under control of the SCADA system.

These states trigger a process called Repeat Failure Count (RFC). This counter is incremented on a per-node basis when one of the conditions above is detected. When the RFC counter is incremented, the device that triggered it is marked “out of service” for that CVR interval, and that device does not receive settings. Other devices on the same node will still receive settings. Manager will then try again on the next CVR interval. If any of the above conditions is present again, RFC will be incremented again. There is a configurable limit for RFC, typically three. When a node’s RFC reaches the configured limit, Manager will attempt to issue the default settings to all devices and will change the node to Disabled mode.

When a node is disabled due to RFC, it remains disabled until a user returns it to CVR mode. EDGE’s strategy for handling SCADA failures is to retry a few times to determine whether the abnormal condition is persistent, and then quickly go to a safe state where no more control decisions will be made. This is different from the AMI backout process, which auto-restores after periods of insufficient AMI data. For SCADA failures, once the condition is determined to be persistent, the operator must intervene after confirming that the distribution system is once again operating normally.

Abnormal breaker states are handled slightly differently from the other conditions mentioned above. When an abnormal breaker state is identified, this is considered a critical failure and the configurable RFC limit does not apply. Instead the node is immediately set to default settings and Disabled mode. This is because an abnormal breaker state indicates switching on the node, and Manager is designed to control each node based on the AMI meters assigned to it. If the meters are switched to a different node, Manager’s control decisions will not be accurate. As with RFC, once the node is disabled, the operator must confirm that the system is back to normal before restarting CVR.

The RFC count persists while the node is disabled. Consider a case where a node has reached its RFC limit of three due to the local/remote switch being in LOCAL. If the switch is still in LOCAL and the operator puts the node back into CVR mode, on the first interval, RFC will be incremented to 4 and the node will be disabled immediately.

5.4.5 CVR Adaptive Algorithm

The adaptive algorithm remains EDGE's patented method of reading a small number of bellwether meters to make intelligent decisions about voltage on the entire circuit. When a node is first configured in EDGE® Planner, the user will select the initial bellwether meters based on historical voltage data. The configuration file is uploaded to EDGE® Manager and CVR is initially implemented with the user-selected bellwether set. As the node operates with reduced voltage, any AMI meter that experiences low voltage (typically –5% or 114 volts on a 120-volt base) will send a voltage sag message to the AMI head-end server. EDGE® integrates with the AMI head-end to receive these sag messages.

The adaptive algorithm prioritizes the sag messages to select additional meters (typically two additional meters) to add to the bellwether set on a trial basis. These meters are added to the bellwether set for the next adaptive cycle (typically 24 hours). At the end of the adaptive cycle, the adaptive algorithm compares the performance of the bellwether meters by counting how many times each was included in the *low average* statistic, which is calculated every time CVR runs (typically every 15 minutes). An extra point is awarded to incumbent meters (those that have been in the bellwether set for at least the previous cycle, i.e., all but the two additional meters in the trial set). The meters that were in the *low average* the fewest times are removed from the bellwether set, restoring it to its original count. At this time, the voltage sags reported by meters during the current adaptive cycle are prioritized to select 2 more trial meters for the next adaptive cycle.

The adaptive algorithm allows the bellwether set to gradually adapt to changes in the circuit voltage contours. One common phenomenon is for a circuit to have low voltage during winter in areas that have electric heat, but for the low voltage during summer to shift to other areas which have gas heat and significant air conditioning load. The adaptive algorithm also allows EDGE® to automatically adjust for new connects, existing customers adding load, changes to business occupancy, and other small changes as a circuit's load base evolves.

The adaptive algorithm is the key feature in allowing the entire circuit to be monitored through a small set of bellwether meters. Communication limitations preclude reading every meter every 15 minutes, so by reading the lowest-voltage customers, EDGE® is able to make intelligent voltage control decisions based on a small number of targeted real-time meter reads. Listening for sags from every meter on the circuit ensures that the bellwether set accurately represents the lowest-voltage customers.

Changes to the bellwether set over time can be viewed in Manager and exported for more detailed analysis in Planner.

5.4.5.1 MicroCVR Failsafe Modes

MicroCVR under this project was designed to provide a control process that is completely isolated from the monitoring function. This was the key to providing a low cost, secure solution to energy savings while providing compatibility with high variation loads and renewable generation. The design allowed the two independent monitoring systems to completely fail without any impact to the control of the iVolt low voltage regulation control and implementation. This was implemented in the core design of the control system.

In addition to the separation of the monitoring and control systems, the IVolt has a design that includes an automatic fail to normal (fails to no regulation with direct high side to low side connection). The design included a manual bypass system which was completely isolated from the iVolt equipment. The bypass disconnected the iVolt electrically for maintenance and provided a separate isolated bypass to maintain power to the building.

Control of the building voltages were made only at the Fort Myer site by authorized personnel. The control system was secured physically at the local site and within the site secured in Building 215. The bypass system was secured on Fort Myer property and was secured in the onsite enclosure. All control and monitoring equipment were physically and electronically separate from any electronic systems at Fort Myer.

CVR: Modeling and Simulation

DVP did not foresee any modeling and simulation during operational testing. During commissioning of the system, DVP and its partner, DVI, followed a mutually agreed upon commissioning document while running the system in 'Monitor' mode as described earlier.

MicroCVR: Modeling and Simulation

Model verification and testing was required during the operational testing. DVP executed the commissioning of the iVolt, GridEdge, and VirtuGrid systems of MicroCVR. Once these were completed the system model of building 421 was tested against the data obtained in the monitor mode of the MicroCVR system. The power sampling algorithm used by the iVolt was also tested and verified. This uses the high-speed capability of the iVolt to sample the power level at the incoming voltage level and the optimized level for 5 seconds out of each 15-minute measurement period and determine the actual operating efficiency improvement for the optimized voltage level.

5.5 SAMPLING PROTOCOL

CVR Data Collection Table:

EDGE® Components	Data Items	Purpose of Data	Data Source Off line/ On line	Frequency of Collection	Requester / Processor	Provider
EDGE® Planner	Meter Attribute, Historical Meter Reads for 1-2 months, preferably peak data	Voltage Outlier Analysis	Off -line	Initially and as and when there is addition of New meters	DVI Engineering/Support	Utility
	One-line Diagram	Determination of Node, Zone, Block	Off-line	Initially and as and when there is addition of a New Node	DVI Engineering/Support	Utility
	Node, Device configuration parameters	Initial build or update of EDGE Manager Data Base	Off-line	Initially and as and when there is a change in the parameters of the existing Node or addition of a New Node	DVI Engineering/Support	Utility

CVR Data Collection Table (Continued):

EDGE® Components	Data Items	Purpose of Data	Data Source Off line/ On line	Frequency of Collection	Requester / Processor	Provider
AMI Adapter	Service Point Mapping	Translation of Service Location to Meter Id for SSN Adapter's data requests to meter head end (SIQ)	Off-line	Initially and as and when meters are added or exchanged in existing locations	DVI Engineering / Support	Utility
EDGE® Analytics	System Energy Rate, Customer Energy Rate, and Carbon Emission Rate	Maintenance of Configuration Data	Off-Line	Initially and as and when rates are changed	DVI Engineering / Support	Utility
EDGE® Manager	Real Time Meter Data and SCADA Data	Periodic Run of CVR	On-line	Frequency of CVR cycle	Manager Engine	SSN Adapter, Master Adapter
EDGE® Validator	Weather data, CVR status data, Customer count data and hourly electrical observation data	M&V Analysis	Off-line	Every 6-12 months or as needed	DVI Engineering / Support	Weather Service, Manual export from EDGE Manager, Manual export from CIS and Manual export from SCADA/Historian

MicroCVR Data Collection Table:

MicroCVR Components	Data Items	Purpose of Data	Data Source Off line/ On line	Frequency of Collection	Requester / Processor	Provider
GridEdge	High-speed Three Phase Voltage, Current and Power information on Input and output of iVolt	Engineering Set Point Analysis for iVolt, Engineering iVolt response to high variation load and Generation	On-line	On 10-second sample rates	GridEdge Analytics	GridEdge
VirtuGrid	Voltage Magnitude and Angle Values at Remotes in Building 421	Engineering evaluation of iVolt set point levels and M&V Analysis	On-line	On 16 kHz per second intervals	FIM - Remote Communication System	DVP MicroCVR Operator
iVolt	Set Point, Bandwidth and 15-minute power, voltage, and savings for Voltage Controller	M&V Analysis	On-line	On 15-minute basis	DVP MicroCVR Operator	DVP MicroCVR Operator

MicroCVR Data Collection Table (Continued)

Building 421 AMI Meter	Meter Data and Voltage Data	Revenue Metering Data for Cost and energy savings	Off-line	15 Minute Intervals	AMI Headend	DVP MicroCVR Operator
Analytics & Display Building 215	Hourly calculations of building 421 losses and hourly kWh from GridEdge Data	M&V Analysis	Off-line	Every 1-4 weeks or as needed	DVP MicroCVR Engineering / Support	DVP MicroCVR Operator
Cost Analytics	System Energy Rate, Customer Energy Rate, and Carbon Emission Rate	Maintenance of Configuration Data	Off-line	Initially and as and when rates are changed	DVP MicroCVR Engineering / Support	DVP

CVR: Data Collection Diagram

EDGE® has nine traditional integration points that are required for fully automated operation as schematically identified in **Figure 16**. EDGE® Manager is the only application of the three that required a real-time feed from AMI and the control devices. The integration points are provided in this diagram below:

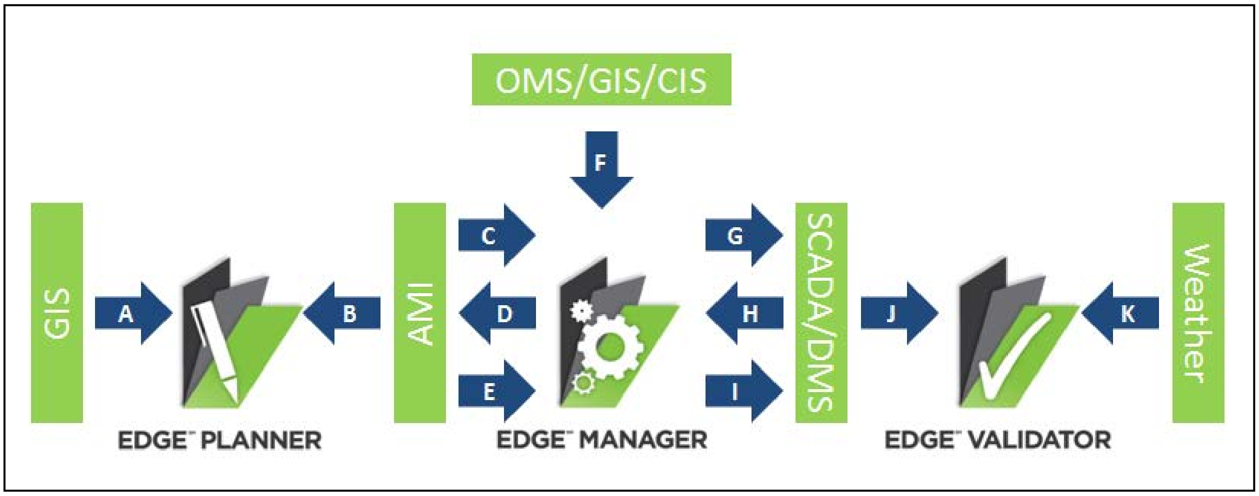

Figure 16. EDGE® System Configuration Diagram

MicroCVR: Data Collection Diagram

MicroCVR has five databases that were supplied with data for the efficiency and voltage control processes. Real-time monitoring was only required by the VirtuGrid sensing network, the AMI network, and the GridEdge sensing network. These were integrated at the Building 215 FIM location to provide display and engineering analysis of the data bases. The remainder of the databases were an off-line collection of limited data and the data created by the engineering analysis for Measurement and Verification (M&V) and high variation load and generation response. The integration points were provided in **Figure 17**.

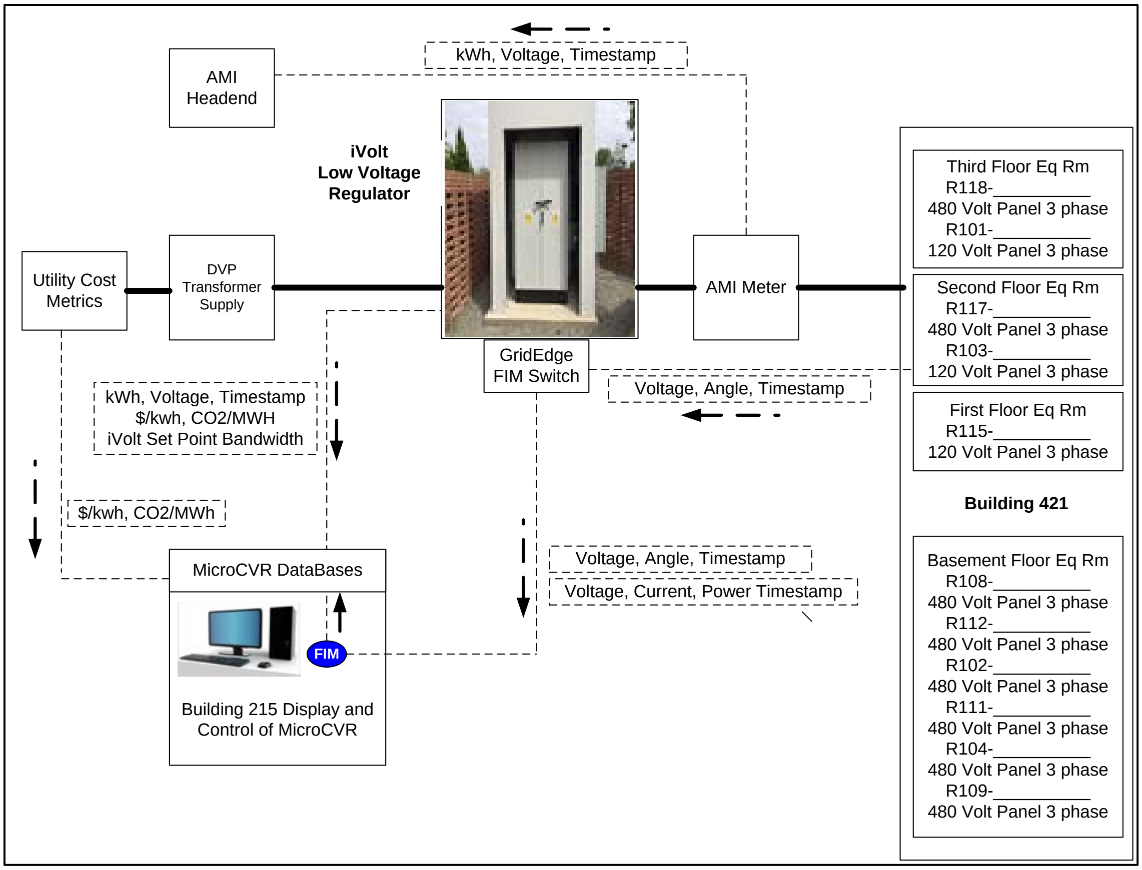

Figure 17. MicroCVR Data Collection Diagram

Further detail on data collection effort can be found in the Final Report.

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6.0 PERFORMANCE ASSESSMENT

6.1 CVR: PERFORMANCE ANALYSIS OVERVIEW

There are a number of Measurement and Verification (M&V) protocols in use in industry to calculate the savings generated through CVR. Some analysis methods, like time-series and regression, can be data intensive. Other methods, like ON-OFF sequencing, can be time intensive, requiring months to a year to yield results. DVI uses a paired-t approach that blends the ON-OFF approach with filters that leverage the benefits of a regression analysis. DVI's approach gives meaningful results in a shorter period of time and allows customers to have little to no down time after beginning their CVR program. The end result of DVI's (and most industry) protocols is a CVR factor which represents the percent change in energy for a percent change in voltage. This CVR factor is then used with hourly load and voltage data to sum energy savings during the CVR deployment.

6.2 MICROCVR: PERFORMANCE ANALYSIS OVERVIEW

MicroCVR performance will measure the power improvement every 15 minutes using a 5 second sampling technique made possible by the iVolt high-speed regulator. In each interval the iVolt will operate the system at the input voltage for 5 seconds and then at the optimized voltage for 5 seconds and determine the difference in power usage at each level. This will be used to calculate the improved power benefit from the improved voltage performance.

The total power losses will be tracked using this process to monitor the MicroCVR "OFF" energy use to MicroCVR "ON" energy use documenting the change in efficiency for each state.

The VirtuGrid software will also measure voltage samples at a rate needed to determine the low voltage regulator response to the high variation load and renewable generation to document MicroCVR's ability to mitigate the voltage variation for the two cases under test. This test will graphically plot the steady state variation in voltage on the input and output side of the low voltage regulator including the rise time, overshoot, and steady state voltage starting and ending point to document the measured impact of this variation with MicroCVR "off" and with MicroCVR "on".

6.3 CVR ON-OFF

The goal for any M&V analysis is a clean view of performance with and without voltage reduction in service. DVI's protocol calculates savings at the CVR Node (substation transformer or circuit) level using substation megawatt (MW) and bus voltage (line voltage) to compare energy usage before and after voltage reduction. This data should be from the same season to avoid skewing due to load changes between heating, cooling and other factors. DVI can perform analysis across time (Summer 2015 versus Summer 2016) or within a season (July 2016 versus August 2016), or it can accommodate a structured day on – day off test run for a minimum of two weeks.

6.3.1 CVR: Statistical Methodologies

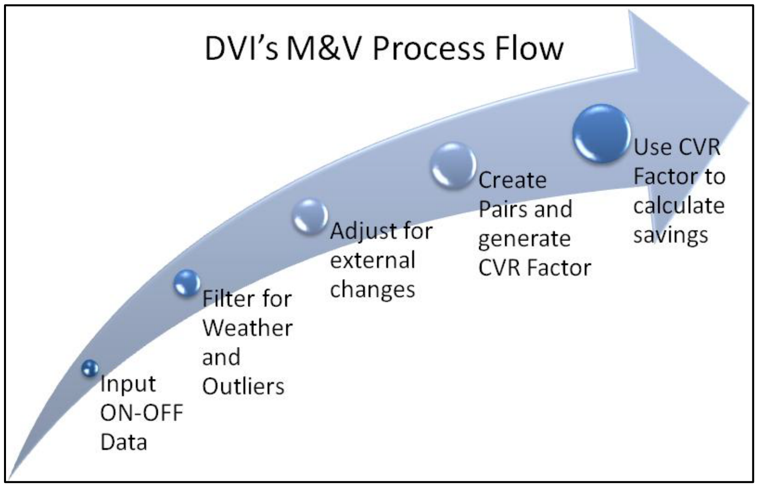

Figure 18. DVI Measurement & Verification Process Flow

The Validator Process was based on a well-established statistical comparison technique called paired-T. This calculation compared two samples of data to determine the average shift in a variable mean from one sample set to the other. Documentation of the details of paired-T analysis can be found in a number of standard statistics publications and is readily available in standard software packages. **Figure 18** is a high-level description of the process being applied to the voltage regulator and circuit MW and voltage data. The value being calculated was the CVR factor which establishes the average difference between the % ratio of the [MW (sample 1) – MW (sample2)]/ Voltage (sample 1)-Voltage (sample 2). Sample 1 is taken from the MW and Voltage data when CVR is "off" and Sample 2 is taken from the data when CVR is "on." Sets of samples are paired using the rules of **Figure 19**. This matching of two samples from the "off" and "on" states creates one pair of samples. At least 30 of these pairs are required for the calculation of the average difference between the two sample sets to have statistical significance.

CVR OFF		CVR ON
TX #1		TX #1
Temperature	± 1^0	Temperature
Prior 6 hr Temp	± 1^0	Prior 6 hr Temp
Prior 72 hr Temp	± 1^0	Prior 72 hr Temp
Humidity	± 1%	Humidity
168 Hourly Index	± 1 Index	168 Hourly Index
MW	± 5%	MW
Volts	>1	Volts
Custom	Linear	Custom
Outlier	± 5 MAD	Outlier

Figure 19. CVR Calculation Process

There are three requirements for the paired-T analysis to work. First, the paired samples must be independent. This requires that for each sample taken from either sample 1 or sample 2 to be paired, the values can only be used one time in the analysis. Once they are used, the samples are removed from the data sets to choose the next pair. The second requirement is that the data sets must be normal data sets. This is checked statistically for each analysis. Normality is checked using the Anderson-Darling normality test. Third, the number of paired-T samples must be greater than 30 to be statistically significant. This calculation will be shown for each set of the analysis. Once these three requirements are met, the paired-T analysis is implemented, and the average difference is determined within a confidence interval determined by the variation of the paired samples. Dominion Energy Virginia is using a 95% confidence level for the CVR analysis.

One of the methods of limiting the variation in the calculation is to separate the samples into consistent groups. For the MW and Voltage data, this is done by grouping the sample data into like hours that are consistent with each other. The technique developed to do this is a linear regression technique. Using linear regression, the consistency of the variables is checked and sample hours that represent like data are determined by using the linear regression constants to check consistency between hours that are grouped together. In addition, each data set is grouped into a seasonal grouping as well. The result of this grouping process is to break the sample data up into winter, spring, summer, and fall groups first. Then using the linear regression break the hours for each seasonal day (1 to 24) into like groups for paired-T testing. This technique will minimize the variation in the paired-T calculation for average difference from one sample group to another.

EDGE® Validator's primary goal was to determine the average CVR factor for a particular EDGE® node for a particular season then use that CVR factor to calculate the energy savings during that season. An EDGE® node is a substation transformer and all its down-line facilities and meters, and a node's CVR factor is an attribute of the connected loads. Loads may be generally classified by their percentage of constant impedance (square dependence between voltage and load), constant current (linear dependence between voltage and load), and constant power (no dependence between voltage and load). Industry research has studied the voltage dependence of individual appliances. Validator calculates the overall CVR factor for the node. In this instance at Fort Myer, each node represents each gang configured bank of single phase regulators serving each circuit sourced from the Radnor Heights substation.

EDGE® Validator calculated CVR factor using a process that pairs hours from the CVR ON period with hours from the CVR OFF period. The pairing compares the change in a number of measurements found to be statistically significant in their effect on loading:

- Temperature
- Average temperature over the past 6 hours
- Average temperature over the past 72 hours
- Relative humidity
- Hourly index – a factor calculated by Validator that measures NON-weather-related loading characteristics for each hour of the week, e.g. load at 10 p.m. on Thursday tends to be higher than weather characteristics would predict

- Megawatts – used to exclude pairs with large changes in load due to factor other than CVR (such as switching)
- Voltage – used to ensure a minimum change in voltage, to avoid dividing by near-zero in the CVR_f equation.

For all parameters except voltage, the difference between the ON and OFF hours must be less than or equal to the configured value in order for the hours to form a pair. For voltage, the difference must be greater than or equal to the configured value.

EDGE® Validator compared every ON hour with every OFF hour, using the pairing parameters in the above list. All candidate pairs that fell within the parameter limits were given a pairing score, with smaller differences (more similar hours) receiving a higher score. Validator then selected the pair with the highest score, added that pair to its collection, and excluded all other candidate pairs that use the same ON and OFF hour as the selected pair. Then it proceeded to select the next highest score. In this way, Validator generated as many pairs as possible such that:

- All pairs meet the specified pairing parameters.
- Each hour belongs to only one pair.
- The highest-scoring pairs are selected first.

Because Validator used the highest score rather than a randomized pairing order, this method also ensures that the same pairing inputs will produce the same results every time the analysis is run.

Once Validator has a collection of valid pairs, it calculated the CVR factor for each pair by dividing the percent change in energy by the percent change in voltage.

$$\mathrm{CVR_f} = \frac{\%\Delta \mathrm{E}}{\%\Delta \mathrm{V}}$$

At this point in the process, outlier pairs were removed from the population, based on the specified Outlier parameter which used the median absolute deviation. From this final population, the mean CVR factor was calculated and displayed in the Validator user interface.

By convention in the statistics field, the minimum number of pairs required is 30, but the best results come with populations of nearly 100 pairs, or more. The standard deviation should not be much larger than the mean. The p-value was calculated to show the statistical significance of the resulting CVR factor. If the p-value was out of bounds, the standard deviation was too large, or insufficient pairs were found, the analysis would be repeated with relaxed pairing parameters with the goal to generate more pairs and a more statistically sound result.

The megawatt filter excluded pairs with a large difference in power (typically > 5% difference), but since the M&V process was looking for a difference in power (energy savings), it has an asymmetric effect. Therefore, a calibrating CVR factor was specified for the pairing process, which adjusted the megawatt filter to be symmetrical around the change in power expected from that calibrating CVR_f. The methodology used here began with a calibrating CVR_f of zero while adjusting the pairing parameters to achieve enough pairs. Once sufficient pairs were found, the resulting CVR_f was fed back as the calibrating CVR_f, which typically caused the resulting CVR_f to increase.

This process was iterated until the resulting CVR_f equaled the calibrating CVR_f, which was then used as the final CVR factor for that season.

Once a CVR factor is determined, it is used to calculate the energy savings across the ON period. This process reversed the CVR factor equation with the newly calculated CVR factor to look at the energy saved during each ON hour based on the voltage reduction recorded for that hour. Voltage reduction was calculated as the baseline voltage (average voltage during the OFF period) minus the hourly voltage for the ON hour. (Any voltage increases will have a negative effect on energy savings.)

$$\%\Delta E = CVR_f \times \%\Delta V$$

Using the measured energy for the time period which was imported for that hour, the percent change in energy for each hour was converted to a baseline energy for that hour, or the energy (in MWh) that would have been used if CVR were off.

$$\text{Calculated Baseline Energy} = \frac{\text{Measured Energy}}{(1 - \%\Delta E)}$$

Then the calculated baseline energy was summed across the entire ON period, and the measured energy was subtracted to calculate the total MWh savings, and then converted to an overall savings percentage.

$$\text{MWh Saved} = \text{Calculated Baseline Energy} - \text{Measured Energy}$$

$$\%\ \text{Energy Savings} = \frac{\text{MWh Saved}}{\text{Calculated Baseline Energy}} \times 100\%$$

This percent savings, along with the MWh measured and saved, were displayed in the Validator user interface.

The weighted percent voltage reduction was then back-calculated using the CVR factor and the energy savings result from Validator. This was different from the %ΔV value in the preceding equations, which is calculated using baseline voltage and measured voltage, without considering CVR factor. The weighted percent voltage reduction was an average voltage reduction weighted by the amount of energy saved. This adjusted for the fact that nodes typically achieve the greatest voltage reduction overnight, when load is low, achieving a larger percent reduction in a smaller quantity of energy.

$$\text{Weighted \% Voltage Reduction} = \frac{\%\ \text{Energy Savings}}{CVR_f}$$

Results from the interim measurement and verification process conducted in March 2017 are provided below. A weekly CVR ON/OFF schedule was executed on all four nodes from December 05, 2016 to February 19, 2017 in order to collect data required to calculate CVR factors for each node. Data for the “CVR ON” period of November 10, 2016 to March 3, 2017 was used for the energy savings calculations.

The calculated Winter CVR factors are provided in **Figure 20** below:

Node	Season	# Pairs	CVR_f	σ	p-value	95% Confidence
568	Winter	91	**0.90**	0.65	0.0000	0.77 – 1.04
569	Winter	58	**0.61**	1.01	0.0001	0.35 – 0.87
570	Winter	124	**1.01**	0.86	0.0000	0.86 – 1.16
571	Winter	119	**1.24**	0.64	0.0000	1.13 – 1.36

Figure 20. Winter CVR Factors Results for Fort Myer Circuits

The calculated energy savings for the time period November 10, 2016 and March 3, 2017 is provided in the **Figure 21** below.

Node	Season	CVR_f	Voltage Reduction (%)	Energy Savings (%)	Energy Savings (MWh)
568	Winter	0.90	3.28%	**2.95%**	64
569	Winter	0.61	3.36%	**2.05%**	22
570	Winter	1.01	3.24%	**3.27%**	45
571	Winter	1.24	3.29%	**4.08%**	33

Figure 21. Energy Savings Range Fort Myer Circuits over Winter M&V Period

The calculated Summer CVR factors are provided in **Figure 22** below:

Node	Season	# Pairs	CVR_f	σ	p-value
568	Summer	163	1.03	0.65	0.0000
569	Summer	180	0.95	0.56	0.0000
570	Summer	185	1.11	0.93	0.0000
571	Summer	213	1.13	0.49	0.0000

Figure 22. Summer CVR Factors Results for Fort Myer Circuits

The calculated energy savings for the time period June 26, 2017 and July 31, 2017 is provided in the **Figure 23** below:

Node	Season	CVR_f	Voltage Reduction (%)	Energy Savings (%)	Energy Savings (MWh)
568	Summer	1.03	4.65%	4.78%	50.2
569	Summer	0.95	4.78%	4.54%	23.8
570	Summer	1.11	4.41%	4.90%	55.3
571	Summer	1.13	4.88%	5.52%	37.2

Figure 23. Energy Savings Range Fort Myer Circuits over Summer M&V Period

6.3.2 Project Performance Results

By calculating a winter CVR factor and a summer CVR factor, Dominion was able to statistically support its energy savings projection for the twelve-month period of project performance as provided in **Figure 24**. The following table and graphical summaries in **Figure 25** and **Figure 26** summarize the monthly performance by circuit over the project period:

Month	Energy Savings (MWH)	Cumulative Energy Savings (MWH)	Bill Relief ($000)	Cumulative Bill Relief ($000)
July	**115.2**	**115**	**$7.0**	**$7.0**
August	**196.5**	**312**	**$11.5**	**$18.5**
September	**201.3**	**513**	**$11.9**	**$30.4**
October	**140.4**	**653**	**$8.5**	**$39.0**
November	**132.1**	**786**	**$8.6**	**$47.5**
December	**55.4**	**841**	**$3.5**	**$51.1**
January	**51.0**	**892**	**$3.3**	**$54.3**
February	**61.4**	**953**	**$4.0**	**$58.3**
March	**86.8**	**1,040**	**$5.6**	**$63.9**
April	**132.3**	**1,173**	**$8.5**	**$72.4**
May	**160.7**	**1,333**	**$10.2**	**$82.6**
June	**145.5**	**1,479**	**$9.2**	**$91.8**

Figure 24. Energy Savings Performance at Fort Myer over Report Period

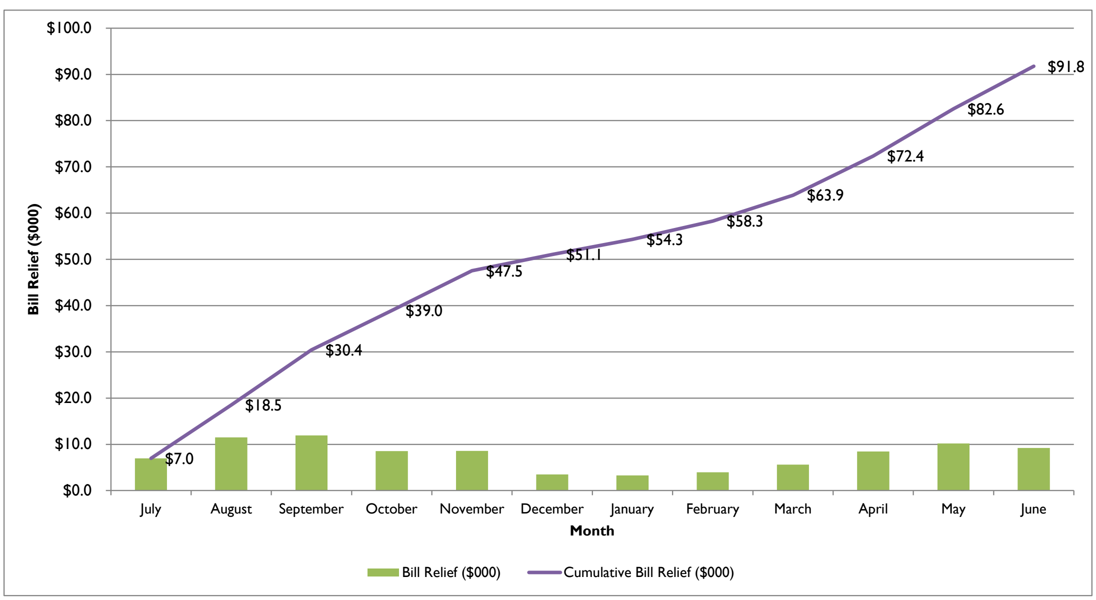

Figure 25. Energy Savings (Dollars) Performance at Fort Myer over Demonstration Period

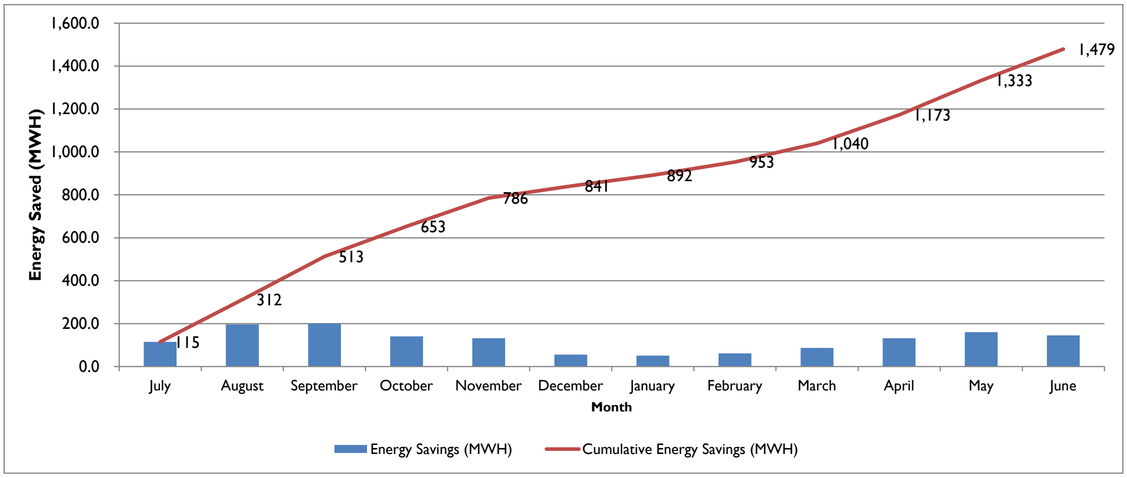

Figure 26. Energy Savings (kWh) Performance at Fort Myer over Demonstration Period

Total project monthly performance by circuit is provided in **Figure 27** below:

Project Performance Period	568 Circuit	569 Circuit	570 Circuit	571 Circuit	Summary
Summer CVR_f	1.03	0.95	1.11	1.13	
Winter CVR_f	0.90	0.61	1.01	1.24	
Billed Energy (kWh)	12,852,829	6,391,448	11,976,487	7,113,169	38,333,932
Energy Saved (kWh)	497,058	216,930	466,708	298,102	1,478,798
Estimated Energy Saved (%)	3.7%	3.3%	3.8%	4.0%	**3.7%**
Avoided CO_2 (Metric tons)	219.8	95.9	206.4	131.8	653.9
Bill Relief Rate ($/kWh)	**$30,930**	**$13,445**	**$28,908**	**$18,487**	**$91,770**

Figure 27. Energy Savings Performance by Circuit over Demonstration Period

6.4 MICROCVR ON-OFF

MicroCVR uses a processing routine to establish the power improvement every 15 minutes using a 5 second sampling technique made possible by the iVolt high-speed regulator. In each interval the iVolt will operate the system at the input voltage for 5 seconds and then at the optimized voltage for 5 seconds and determine the difference in power usage at each level. This will be used to calculate the improved power benefit from the improved voltage performance. This analysis provides hourly utilization data for each point where the MicroCVR is “on” and where the MicroCVR is “off.” This loss tracking is then used to calculate the power to voltage factor for each location and document the change in voltage to change in power under each set of conditions and at each remote location.

Using MicroCVR method, the CVR factor can be determined at both the remote locations (e.g. usage points in building 421) and at the aggregated location at the iVolt. The calculation of the remote CVR factor is based on using the ZIP model for each load and solving the ZIP model factors using multiple voltage measurements at the remote locations. By doing this combination of simulation and measurement an hour-by-hour value of energy savings and CVR losses can be explicitly tracked at the aggregation point and at the remote points.

6.4.1 MicroCVR: Statistical Methodologies

Using the direct measurement of power to voltage every 15 minutes, combined with the sampling voltage capability of the VirtuGrid provides an excellent method for measuring the variability effects of switched secondary loads on the accuracy of the CVR factor calculation. All past methodologies for calculating the CVR factor of loads use either a direct measurement of energy use when the equipment is running or the voltage of the supply when the equipment is running. In reality the equipment in many cases is running for only portions of the time and the voltage is varying from "on" to "off" operation. Using the sampling routine allows a normalized average voltage to be used and this more closely represents the CVR factor actual performance.

In addition to measuring the variability effects, the VirtuGrid system will measure the voltage and power at the source directly with the GridEdge monitor and sample it at the source and the delivery points with the VirtuGrid remote sensors. This will allow the statistical calculation of average savings to be calculated at the source point, the series losses between the source and the remote over the same period, and finally the remote point where the actual point by point CVR factors and saving benefits can be clearly measured. This will add significant accuracy and granularity to the CVR value with the MicroCVR system.

6.5 CVR: GRAPHICAL METHODOLOGIES

There was no plan to use graphical technique for performance analysis, but, graphs, charts and scatter plots were used for visual presentation of EDGE® similar to those found in **Figure 28** and **Figure 29**.

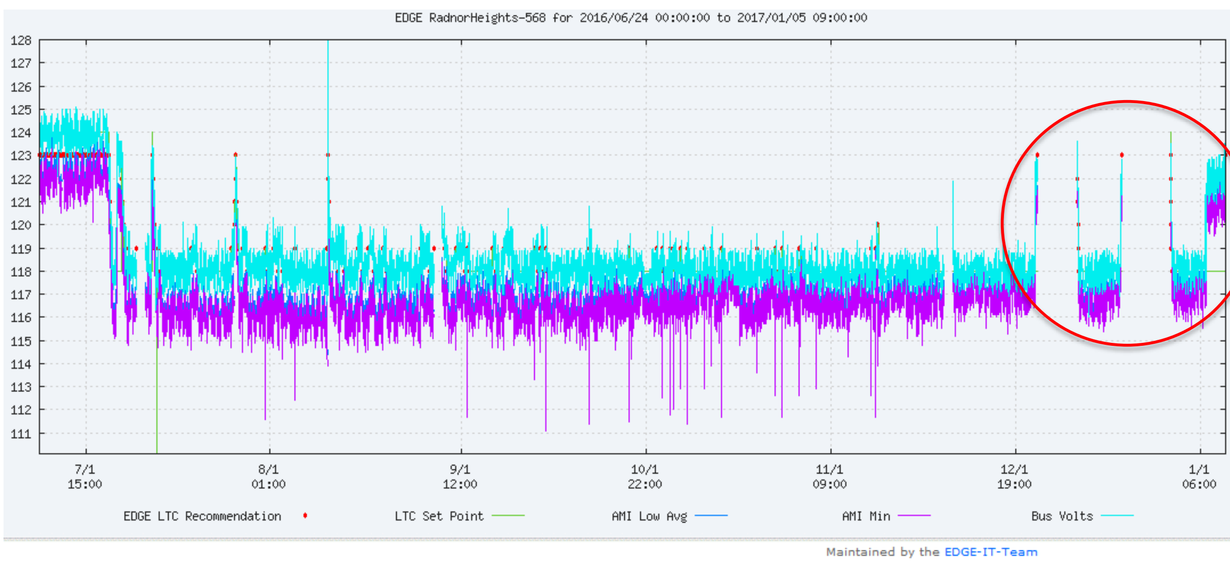

Figure 28. Time Series Performance Highlighting Week-on/Week-Off Performance for the 568 Circuit June 24, 2016 through January 5, 2017

In **Figure 28** and **Figure 29**, the time series plot captures the voltage regulator set point recommendation, voltage regulator set point, voltage regulator bus voltage, average low AMI bellwether meter readings, and minimum AMI voltage bellwether meter reading. Circled in red, the EDGE® history plot in **Figure 28** shows voltage performance during week-on and week-off voltage control operations. This activity generates measurement pairs used to calculate circuit energy savings under similar loading conditions. The gaps in the plot exists indicate that EDGE® is disabled and unable to record the telemetry data from the Distribution Management System.

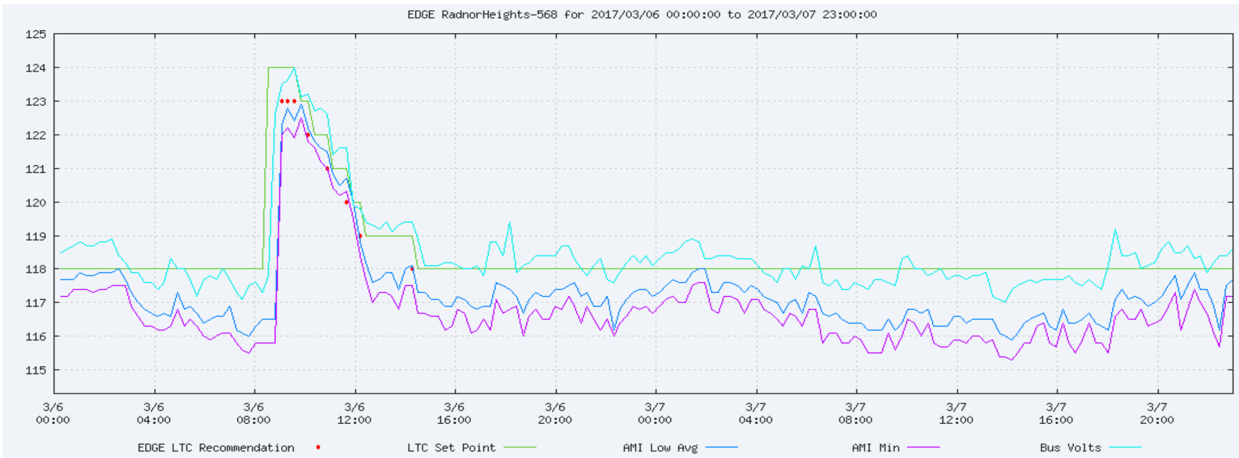

Figure 29. Time Series Performance Highlighting Edge® System Stepping the 568 Circuit into Voltage Control March 6, 2017

7.0 COST ASSESSMENT

7.1 COST MODEL

Dominion developed an expected life cycle operational cost assessment for the combined CVR and MicroCVR technologies. Key cost elements and cost assessment parameters are provided in **Table 2** below.

Utilization of Advanced Conservation Voltage Reduction (CVR) for Energy Reduction on DoD Installations

Table 2. Cost Model for an Energy Technology

Cost Element	Data Tracked During the Demonstration
Hardware capital costs	Estimates made based on component costs for demonstration
Installation costs	Labor and material required to install
Project operational costs	Reduction in energy required vs. baseline data
Maintenance	Frequency of required maintenance Labor and material per maintenance action
Hardware lifetime	Estimate based on components degradation during demonstration.
Operator training	Estimate of training costs
Salvage Value	Estimate end- of-life value less removal costs
Benefit Element	**Data Tracked During the Demonstration**
Master Meter Energy Saved	Provided by Dominion Energy Virginia over project period
Study Period Parameters	**Key Project Dates**
Start Date	September 2015
Planning Construction Period	October 2015 to June 2016
In Service Date - Actual	July 1, 2016
Demonstration Period - Actual	July 2016 to July 2017
Master Meter Energy Readings	Per Fort Myer Account number XXXXX7501
Paired-T Data Collection	As provided in project's validation study
Life Cycle Assumptions	**Data to be Modeled**
Discount Rate	Sourced to OMB Circular A-94
Inflation Assumption	CPI-U per Bureau of Labor Statistics
Life Cycle Timeframe	Estimated at 10 years

As stated in **Section 1.3**, there were two demonstration measurements that were used to validate the performance of the CVR/MicroCVR energy platform. The first was a measure of kWh savings resulting from controlling the base delivery voltages in the most optimum levels for equipment energy efficiency. The second measure was the level of variation experienced from a defined load and/or generation change simulating the behavior of the distribution system to high variation loads and renewable generation. This was measured using the standard voltage rise time and overshoot for a step input of power.

For this demonstration project, DVP utilized Fort Myer's existing monthly bill serving the master meter at Fort Myer and the existing measurement instrumentation installed at the installation. Capital investment and operations and maintenance costs were recorded and serve as the basis for the cost elements of the life cycle cost assessment.

Benefits, specifically the energy savings volume, were derived from the results of the paired-t energy savings validation effort. Actual energy saved was applied to the monthly master metered energy supply bill provided by DVP for the twelve-month demonstration period. The economic savings calculations also factored same period changes, if any, to the GS-4 rate, or price, to which the calculated energy was applied.

7.2 COST DRIVERS

The primary cost drivers for the CVR application is the voltage control equipment, smart meters, and communication infrastructure needed to implement the voltage control scheme. Substation transformers with load tap changing equipment, voltage regulators, and capacitor banks are commonly found across U.S. electric distribution systems. Determining how the control solution is configured will depend on each individual military installation's distribution topology. Ownership, control, and location of electric service delivery equipment will drive the solution's cost economics. The voltage control software is the last cost component of the solution.

This project had specific cost tracks for the CVR and microCVR applications. For the CVR application, the largest labor and material costs was associated with the purchase and installation twelve single phase regulation devices. Additional time was required to install these units outside the Radnor Heights substation to comply with local historical standards.

Figure 30. Single Phase Voltage Regulation Equipment Site Installations Conditions Prior, During, and at Completion on March 2016

For the microCVR application, the largest labor and material costs was associated with the purchase, testing, and installation of the Sollatek iVolt low voltage regulation unit and the associated monitoring equipment installed inside Building 421. Additional time was required to customize and pour the pad outside Building 421 and return the area into compliant with local historical standards.

7.3 COST ANALYSIS AND COMPARISON

During the performance period Dominion accumulated and reported its costs to the ESTCP Program Office consistent with the project and contract requirements. The table below identifies the major cost elements for the project, amount incurred during the demonstration period, and cost-effective estimate for comparison purposes:

Cost Element	Demonstration Cost	Operational Cost Estimate
Hardware capital costs	CVR Only ~ $850,000 CVR and μCVR ~ $1.35M	CVR Only ~$850,000 (CVR Only) CVR and μCVR ~ $1.35M
Installation costs	Approximately $1,100,000 (includes Engineering, Construction, Project Management, and Contract Administration)	~$550,000 (reduced due to unusual site conditions and constraints at Fort Myer location)
Project operations costs	Minimal	Minimal
Maintenance	Annual planned maintenance Annual software maintenance	Annual planned maintenance Annual software maintenance
Hardware lifetime	27 years for CVR equipment 15 years for μCVR equipment.	27 years for CVR equipment 15 years for μCVR equipment.
Operator training	Two weeks training for operators.	Two weeks training for operators.
Salvage Value	Assumed to be zero for microCVR.	Assumed to be zero for microCVR.
Benefit Element	**Data Analyzed During Demonstration**	**Operational Estimate**
Retail Savings Rate	Range - 5.86 to 6.50 ¢/kWh	Varies – See break-even table
Energy Saved - kWh	1,478,798 (for 12 months)	Varies – See break-even table
Energy Saved - $	$91,770 (for 12 months excludes demand charge benefit)	Varies – See break-even table

Using the Office of Management and Budget A-94 Circular 10-year discount rate of 2.1%, Dominion is providing the ESTCP Program Office with annual savings, net present value, simple payback, and break-even cost analysis for over a 10-year planning horizon against a range of U.S. retail electric rates for the combined CVR and microCVR technology as well as CVR on a stand-alone basis using the operational cost estimate assumptions.

Assumptions for Combined CVR and μCVR Technologies - Installation Cost: $1.35M

	Annual Savings ($)			NPV		
Retail Cost ($/kWh)	**2.7%**	**3.7%**	**4.7%**	**2.7%**	**3.7%**	**4.7%**
$0.05	$52,027	$71,193	$90,360	($869,077)	($701,328)	($533,579)
$0.06	$62,432	$85,432	$108,433	($778,010)	($576,711)	($375,413)
$0.07	$72,837	$99,671	$126,505	($686,943)	($452,095)	($217,246)
$0.08	$83,242	$113,910	$144,577	($595,876)	($327,478)	($59,080)
$0.09	$93,648	$128,148	$162,649	($504,809)	($202,861)	$99,087
$0.10	$104,053	$142,387	$180,721	($413,742)	($78,244)	$257,253
$0.11	$114,458	$156,626	$198,793	($322,675)	$46,372	$415,420
$0.12	$124,864	$170,864	$216,865	($231,608)	$170,989	$573,586
$0.13	$135,269	$185,103	$234,937	($140,541)	$295,606	$731,753

Green = 10 Years or less Positive NPV

	Simple Payback (Years)			BreakEven Cost		
Retail Cost ($/kWh)	**2.7%**	**3.7%**	**4.7%**	**2.7%**	**3.7%**	**4.7%**
$0.05	26.0	19.0	15.0	$464,897	$636,169	$807,440
$0.06	21.7	15.8	12.5	$557,876	$763,402	$968,928
$0.07	18.6	13.6	10.7	$650,856	$890,636	$1,130,416
$0.08	16.2	11.9	9.4	$743,835	$1,017,870	$1,291,904
$0.09	14.4	10.6	8.3	$836,815	$1,145,103	$1,453,392
$0.10	13.0	9.5	7.5	$929,794	$1,272,337	$1,614,880
$0.11	11.8	8.6	6.8	$1,022,773	$1,399,571	$1,776,368
$0.12	10.8	7.9	6.2	$1,115,753	$1,526,805	$1,937,856
$0.13	10.0	7.3	5.8	$1,208,732	$1,654,038	$2,099,344

Green = 10 Years or less

Assumptions for CVR Technology Only - Installation Cost: $0.85M

	Annual Savings ($)			NPV		
Retail Cost ($/kWh)	**2.7%**	**3.7%**	**4.7%**	**2.7%**	**3.7%**	**4.7%**
$0.05	$52,027	$71,193	$90,360	($374,423)	($206,674)	($38,925)
$0.06	$62,432	$85,432	$108,433	($283,356)	($82,057)	$119,241
$0.07	$72,837	$99,671	$126,505	($192,289)	$42,560	$277,408
$0.08	$83,242	$113,910	$144,577	($101,222)	$167,176	$435,574
$0.09	$93,648	$128,148	$162,649	($10,155)	$291,793	$593,741
$0.10	$104,053	$142,387	$180,721	$80,912	$416,410	$751,907
$0.11	$114,458	$156,626	$198,793	$171,979	$541,027	$910,074
$0.12	$124,864	$170,864	$216,865	$263,046	$665,643	$1,068,241
$0.13	$135,269	$185,103	$234,937	$354,113	$790,260	$1,226,407

Green = 10 Years or less Positive NPV

	Simple Payback (Years)			BreakEven Cost		
Retail Cost ($/kWh)	**2.7%**	**3.7%**	**4.7%**	**2.7%**	**3.7%**	**4.7%**
$0.05	16.3	11.9	9.4	$464,897	$636,169	$807,440
$0.06	13.6	9.9	7.8	$557,876	$763,402	$968,928
$0.07	11.6	8.5	6.7	$650,856	$890,636	$1,130,416
$0.08	10.2	7.4	5.9	$743,835	$1,017,870	$1,291,904
$0.09	9.0	6.6	5.2	$836,815	$1,145,103	$1,453,392
$0.10	8.1	5.9	4.7	$929,794	$1,272,337	$1,614,880
$0.11	7.4	5.4	4.3	$1,022,773	$1,399,571	$1,776,368
$0.12	6.8	5.0	3.9	$1,115,753	$1,526,805	$1,937,856
$0.13	6.3	4.6	3.6	$1,208,732	$1,654,038	$2,099,344

Green = 10 Years or less

8.0 IMPLEMENTATION ISSUES

From a regulations perspective, no additional permits above those already needed to provide electric service were required.

During the course of this demonstration, only a single end-user concern was received. On Monday July 17th, 2017, Rader Clinic (Building 525) located on the 568 circuit raised a concern that the medical equipment was set to operate between 119-121 volts and that the lower voltage being served under the project was affecting the equipment's performance.

Dominion immediately pulled the raw phase level reads for premise 393362964-0003 from May 18 through July 18; 1330 hours (on a 277-volt basis, then converted to 120V basis) to determine if there were voltage anomalies. In addition, On July 18th at 1100 hours, Dominion personnel field-checked the service transformer serving the location and found 267 volts phase-to-ground (115.6V), 486 volts phase-to-phase with the tap setting properly tapped at 13.8.

Dominion had just re-entered the fourth week of the voltage control schedule needed to conduct the summer CVR factor analysis required for the project's final measurement and verification phase. Dominion retrieved voltage data from premise ID 393362964-0003 covering the period June 1 through July 18; 1330 hrs. Visual inspection of time series data indicated following four voltage excursions at Building 525 over this period:

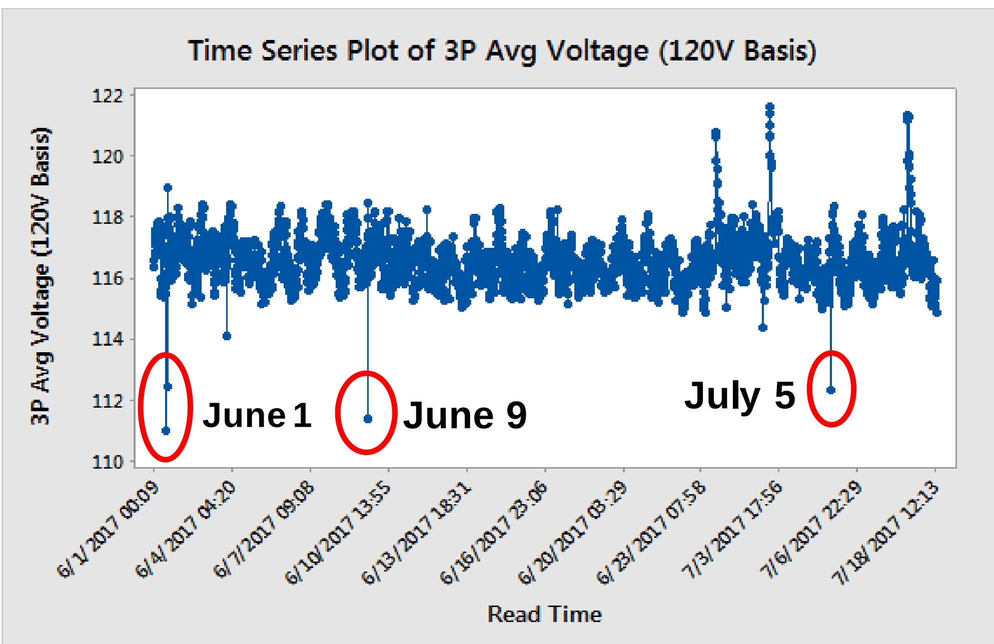

Figure 31. Time Series Three Phase Voltage for Building 525 June 1 to July 18, 2017

Read Time	Raw Voltage	3P Avg Voltage (120V Basis)	Day of Week	Month	Hour
6/1/2017 12:15	256.60	111.03	Thursday	6	12
6/9/2017 17:22	257.70	111.41	Friday	6	17
7/5/2017 21:27	259.80	112.36	Wednesday	7	21
6/1/2017 13:03	259.90	112.42	Thursday	6	13

Figure 32. Voltage Excursions Event Table for Building 525 June 1 to July 18, 2017

Dominion found that the EDGE® solution reacted appropriately to the June 1st voltage excursion events by twice moving set point up by two volts:

Read Time	Raw Voltage	3P Avg Voltage (120V Basis)	Day of Week	Month	Hour
6/1/2017 12:15	256.60	111.03	Thursday	6	12
6/1/2017 13:03	259.90	112.42	Thursday	6	13

Figure 33. Voltage Excursions for Building 525 June 1, 2017

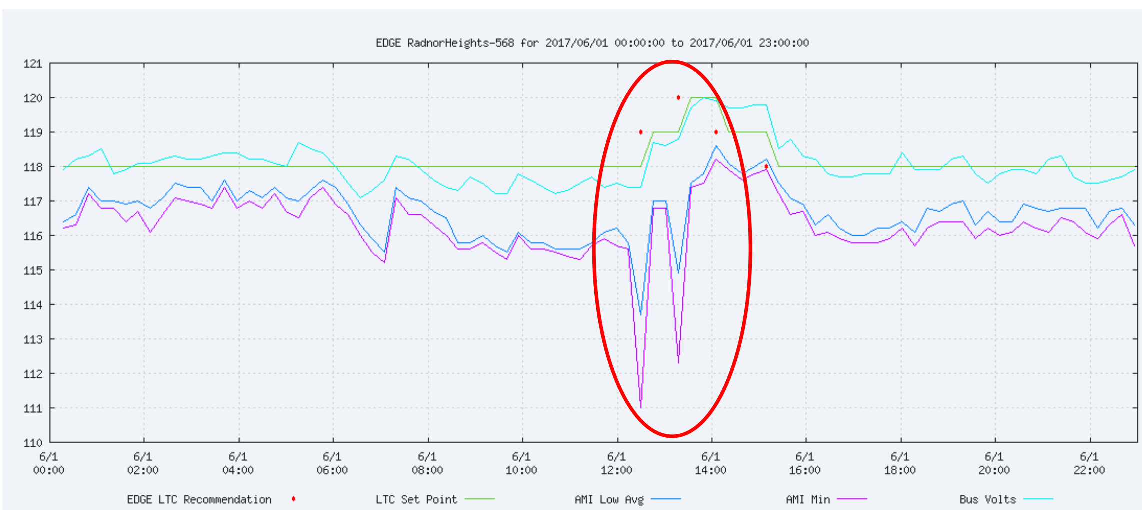

Figure 34. Edge® Voltage Control Plot for 568 Circuit June 1, 2017

EDGE® reacted appropriately to June 9th voltage excursion event by moving set point up by one volt:

Read Time	Raw Voltage	3P Avg Voltage (120V Basis)	Day of Week	Month	Hour
6/9/2017 17:22	257.70	111.41	Friday	6	17

Figure 35. Voltage Excursions Event Table for Building 525 June 9, 2017

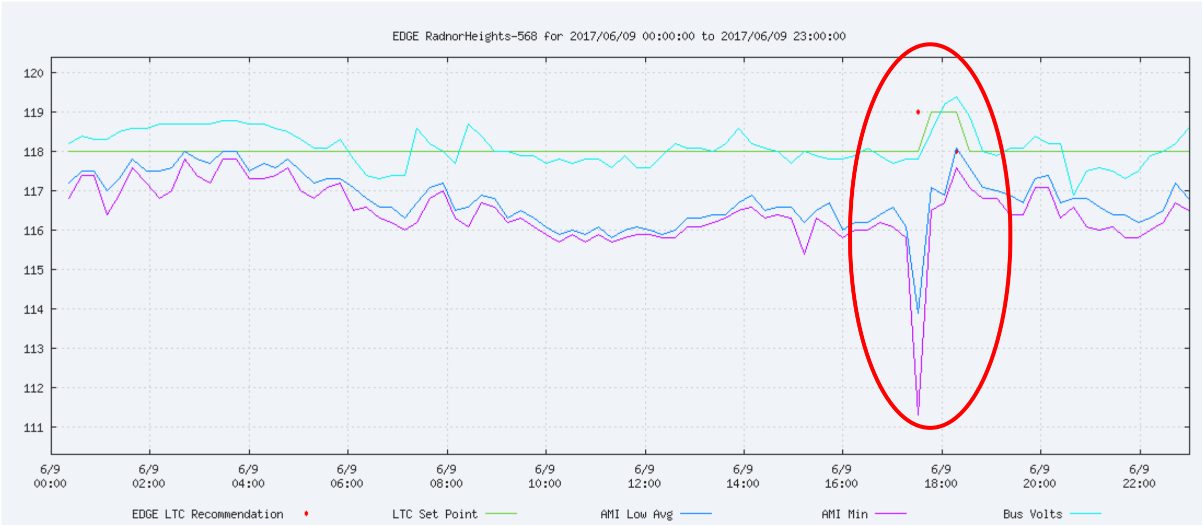

Figure 36. EDGE® Voltage Control Plot for 568 Circuit June 9, 2017

EDGE® reacted appropriately to July 5th voltage excursion events by moving set point up by one volt:

Read Time	Raw Voltage	3P Avg Voltage (120V Basis)	Day of Week	Month	Hour
7/5/2017 21:27	259.80	112.36	Wednesday	7	21

Figure 37. Voltage Excursion for Building 525 July 5, 2017

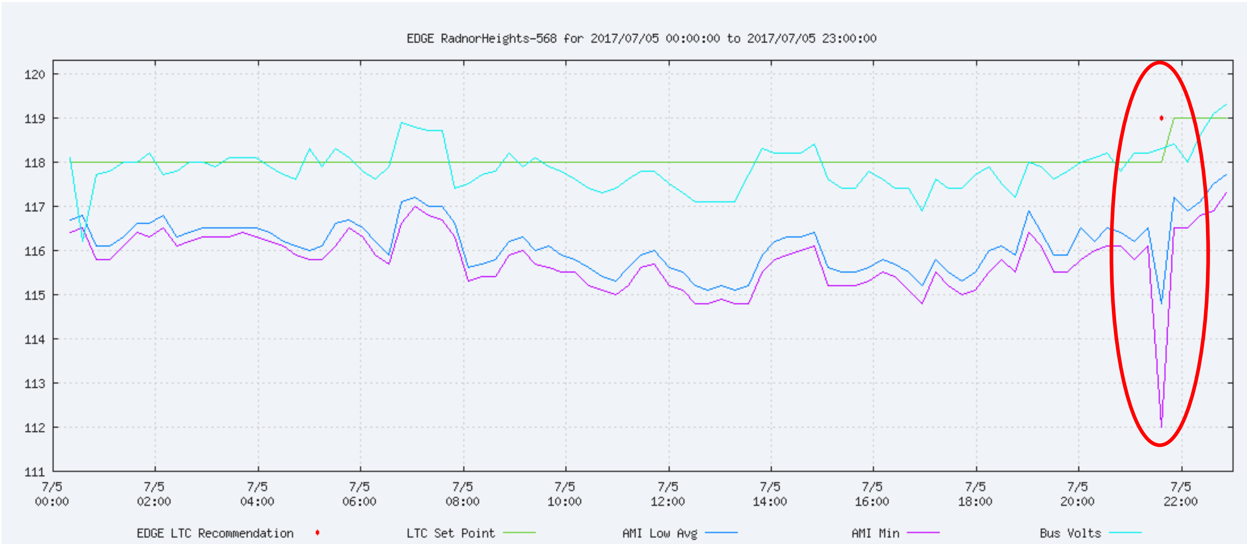

Figure 38. EDGE® Voltage Control Plot for 568 Circuit July 5, 2017

Individual phase analysis shows concentration of voltage readings compliant with ANSI C.84 standard.

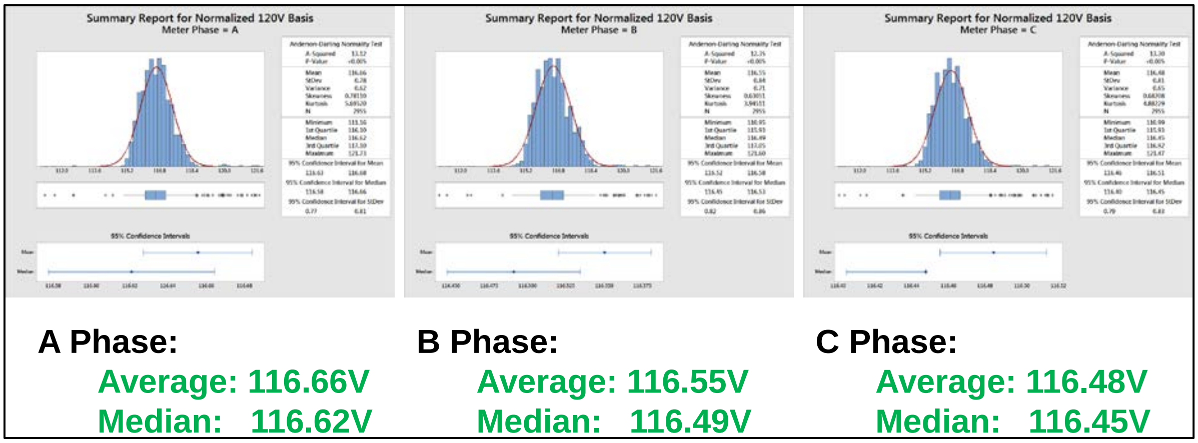

Figure 39. Phase Level Voltage Distribution Building 525 June 1 to July 18, 2017

Dominion reviewed 8,865 voltage readings at Premise ID 393362964-0003 from the period covering June 1 to July 18. Instantaneous voltage excursions occurred during four reading events over this period. A review of EDGE® performance for each of these excursions indicated that the voltage control solution responded appropriately to each event moving the circuit to higher voltage delivery levels in response to the excursions. Investigation into the specific customer equipment was required to determine if power conditioning equipment will be required to address performance issues inside the building. No further action was taken by Dominion. At the time of this report, results from the investigation into the building's equipment were not available for inclusion.

During the construction and implementation of this solution for Fort Myer and the ESTCP Office, Dominion did not have issues with equipment that would not work with the CVR solution. The technologies deployed for the two primary tracks, CVR and MicroCVR, are mature technologies on a stand-alone basis. For this project, the low voltage regulation equipment was demonstrated to be compatible with the installation level voltage control scheme in providing enhanced voltage control at Building 421.

Due to Dominion's technical requirements for both sizing and control, it had to source its high-speed low-voltage regulation supplier from the United Kingdom. Logistics and engineering design coordination created a challenge during the construction planning process. While the regulation equipment is built to standards for interior environments, the outdoor enclosure required some customized design and engineering to maintain safe operations under the harsh operating conditions outside the building.

In order to develop and configure a high-speed measurement system to demonstrate high-speed control, redundant measurement sensing equipment was designed to provide an independent, more granular voltage read for voltage control measurements. From a technology adoption perspective, the redundant sensing equipment would not be necessary as the measurement system built into the low voltage regulator provided sufficient measurement evidence to adequately capture and precisely measure the voltage changes during CVR operations as well as during the high variability load testing conducted in April 2017.

Dominion has also determined that the VirtuGrid assets, in their current form, were not compatible with the long-term nature of the Privatization contract and will no longer be used after the demonstration. The company turned the VirtuGrid system off in late July and moved the iVolt into a safer voltage delivery level with the absence of the VirtuGrid measurement system.

With respect to the post-project performance of the microCVR system, the Fort Myer Department of Public Works (DPW) staff and Dominion's Privatization management team and staff agreed that continued use of the low voltage regulator would also be inconsistent with the Privatization contract. The combination of higher than expected recurring annual maintenance costs, remotely sourced and supported technology, and less than cost-efficient replacement risk was not a position in which Dominion or the Army wanted to be placed. The installed unit's original design basis was for interior conditions. Engineering modifications to harden the design for exterior utility grade performance and safe operations were cost prohibitive. While the iVolt low voltage regulator provided exceptional performance during this project, the replacement cost risk made the longer term operational maintenance ownership risks higher than the economic savings derived from a low retail cost of electricity serving the installation. As a result, the microCVR equipment will be removed from service at the conclusion of this project.

To encourage implementation broader adoption of the use of CVR technology throughout DoD, Dominion Energy Virginia will brief the results at DoD sponsored and independent subject matter conferences, such as at the National Association of Energy Services Companies (NAESCO) Annual Conference or the World Energy Engineering Congress and continue its outreach efforts with industry organizations such as the Association of Energy Engineers.

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9.0 REFERENCES

EnergyBIZ Magazine explaining Microgrid -
http://energycentral.fileburstcdn.com/EnergyBizMagazine/2013/SeptOct13.pdf

Microgrid project Demonstration - http://www.esc-east.org/presentations/HE-130-201.pdf

M&V Protocol by RTF CVR Subcommittee -
http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CB0QFjAAahUKEwj4-J_A-tjIAhWEkx4KHWFVDzk&url=http%3A%2F%2Frtf.nwcouncil.org%2Fsubcommittees%2Fcvr%2FDraft_CVR%2520Protocol%2520wEfficiency.docx&usg=AFQjCNEkKc-eCxMPPHuvsfmz_TppblPQVw&sig2=4nrJZFOTaY6di7E61OfXgw&bvm=bv.105841590,d.dmo

MicroCVR Controller (Solatek iVolt)
VirtuGrid - http://www.sollatek.com/power-optimisation-iVolt/

http://tdworld.com/smart-grid/lockheed-martin-and-dominion-introduce-new-grid-location-technology

Distribution Efficiency Initiative 'Market Progress Evaluation Report, No.1' -
www.nwalliance.org

American Council for an Energy Efficient Economy
Report Number U1402 -
http://aceee.org/sites/default/files/publications/researchreports/u1402.pdf

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APPENDIX A POINTS OF CONTACT

Point of Contact Name	Organization Name	Phone Email	Role in Project
Brandon Stites	Dominion Energy Virginia	brandon.stites@dominionenergy.com 804.775.5551	Lead Principal Investigator
Vick Atwal	Dominion Energy Virginia	vick.atwal@dominionenergy.com 703.838.2288	Privatization Base Manager – Fort Myer
Jamie Roberson	Dominion Energy Virginia	jamie.r.roberson@dominionenergy.com 703.939.7535	Privatization Base Lead Designer – Fort Myer
Jarryd Coates	Dominion Energy Virginia	jarryd.a.coates@dominionenergy.com 703.268.8192	Lead Contractor Liaison
Tom Wimer	Dominion Energy Virginia	tom.wimer@dominionenergy.com 757.393.3816	Financial Project Support
Tarek Abdallah	U.S. Army Research & Development Center	tarek.a.abdallah@us.army.mil 217.418.4480	Co-Principal Investigator
Cyrus Jabbari	DPW, O&M - Fort Myer	cyrus.a.jabbari.civ@mail.mil 703.696.8692	DoD Liaison
James Laven	GridEdge Technologies	jameslaven@gridedgetek.com 713.452.0271	MicroCVR Software Support Lead
Dr. Glenn Skutt	PowerHub System	gskutt@pwrhub.com 540.250.2870	Communications Consultant
Bruce Ensley	Dominion Voltage, Inc.	bensley@dvigridsolutions.com 804.771.4005	Project Support
Phil Powell	Dominion (Contractor)	phillip_powell@msn.com 804.441.4772	Lead Technical Advisor

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APPENDIX B MONTHLY CIRCUIT PERFORMANCE

Project Performance Period	568 Circuit	569 Circuit	570 Circuit	571 Circuit	Summary	
Summer CVR_f	1.03	0.95	1.11	1.13		
Winter CVR_f	0.90	0.61	1.01	1.24		
July						
Billed Energy (kWh)	1,289,565	633,225	1,341,608	781,435	4,045,832	
Avg Voltage Reduction %	2.51%	3.37%	2.38%	2.97%		
System Availability %	99.95%	99.96%	99.95%	99.85%		
Energy Saved (kWh)	33,329	20,265	35,372	26,250	115,216	2.8%
Bill Relief Rate ($/kWh)	0.0606	0.0606	0.0606	0.0606	**$6,982**	
August						
Billed Energy (kWh)	1,292,009	630,881	1,357,598	774,415	4,054,904	
Avg Voltage Reduction %	4.57%	4.77%	4.36%	4.75%		
System Availability %	99.86%	99.86%	100.00%	100.00%		
Energy Saved (kWh)	60,706	28,611	65,587	41,616	196,521	4.8%
Bill Relief Rate ($/kWh)	0.0586	0.0586	0.0586	0.0586	**$11,516**	
September						
Billed Energy (kWh)	1,308,183	643,257	1,396,020	762,380	4,109,840	
Avg Voltage Reduction %	4.64%	4.80%	4.39%	4.83%		
System Availability %	100.00%	100.00%	100.00%	100.00%		
Energy Saved (kWh)	62,437	29,358	67,866	41,672	201,332	4.9%
Bill Relief Rate ($/kWh)	0.0592	0.0592	0.0592	0.0592	**$11,919**	
October						
Billed Energy (kWh)	985,170	488,364	922,317	462,081	2,857,932	
Avg Voltage Reduction %	4.59%	4.74%	4.61%	4.74%		
System Availability %	100.00%	100.00%	100.00%	100.00%		
Energy Saved (kWh)	46,511	22,020	47,101	24,777	140,410	4.9%
Bill Relief Rate ($/kWh)	0.0608	0.0608	0.0608	0.0608	**$8,537**	
November						
Billed Energy (kWh)	1,061,351	543,157	886,883	504,973	2,996,364	
Avg Voltage Reduction %	4.71%	4.77%	4.77%	4.69%		
System Availability %	100.00%	100.00%	98.92%	98.62%		
Energy Saved (kWh)	45,020	15,804	42,283	28,981	132,088	4.4%
Bill Relief Rate ($/kWh)	0.0650	0.0650	0.0650	0.0650	**$8,586**	
December						
Billed Energy (kWh)	957,944	508,413	782,954	507,037	2,756,348	
Avg Voltage Reduction %	4.70%	4.77%	5.00%	4.41%		
System Availability %	52.97%	53.00%	43.06%	32.68%		
Energy Saved (kWh)	21,478	7,836	17,022	9,056	55,392	2.0%
Bill Relief Rate ($/kWh)	0.0634	0.0634	0.0634	0.0634	**$3,512**	
January						
Billed Energy (kWh)	1,006,228	504,324	835,929	533,319	2,879,800	
Avg Voltage Reduction %	4.26%	4.09%	5.03%	5.00%		
System Availability %	65.96%	63.27%	22.51%	24.30%		
Energy Saved (kWh)	25,450	7,967	9,555	8,029	51,001	1.8%
Bill Relief Rate ($/kWh)	0.0641	0.0641	0.0641	0.0641	**$3,269**	
February						
Billed Energy (kWh)	910,194	454,077	743,022	483,827	2,591,120	
Avg Voltage Reduction %	4.60%	4.60%	4.64%	4.56%		
System Availability %	54.21%	57.14%	54.29%	54.28%		
Energy Saved (kWh)	20,412	7,280	18,884	14,858	61,434	2.4%
Bill Relief Rate ($/kWh)	0.0645	0.0645	0.0645	0.0645	**$3,962**	
March						
Billed Energy (kWh)	915,275	448,772	749,624	505,925	2,619,596	
Avg Voltage Reduction %	4.73%	4.82%	4.93%	4.82%		
System Availability %	100.00%	99.99%	51.30%	51.30%		
Energy Saved (kWh)	38,942	13,195	19,148	15,526	86,811	3.3%
Bill Relief Rate ($/kWh)	0.0645	0.0645	0.0645	0.0645	**$5,599**	
April						
Billed Energy (kWh)	966,159	460,905	802,984	512,411	2,742,460	
Avg Voltage Reduction %	4.76%	4.80%	5.09%	4.82%		
System Availability %	100.00%	100.00%	87.22%	87.47%		
Energy Saved (kWh)	47,376	21,049	39,450	24,452	132,328	4.8%
Bill Relief Rate ($/kWh)	0.0640	0.0640	0.0640	0.0640	**$8,469**	
May						
Billed Energy (kWh)	1,090,614	534,013	1,040,194	609,022	3,273,844	
Avg Voltage Reduction %	4.58%	4.56%	4.70%	4.64%		
System Availability %	100.00%	99.99%	100.00%	100.00%		
Energy Saved (kWh)	51,426	23,179	54,141	31,993	160,739	4.9%
Bill Relief Rate ($/kWh)	0.0635	0.0635	0.0635	0.0635	**$10,207**	
June						
Billed Energy (kWh)	1,070,137	542,059	1,117,354	676,343	3,405,892	
Avg Voltage Reduction %	4.62%	4.64%	4.71%	4.67%		
System Availability %	86.43%	85.10%	86.43%	86.43%		
Energy Saved (kWh)	43,973	20,365	50,299	30,890	145,527	4.3%
Bill Relief Rate ($/kWh)	0.0633	0.0633	0.0633	0.0633	**$9,212**	
Billed Energy (kWh)	12,852,829	6,391,448	11,976,487	7,113,169	38,333,932	Total
Energy Saved (kWh)	497,058	216,930	466,708	298,102	1,478,798	**3.7%**
Estimated Energy Saved (%)	3.7%	3.3%	3.8%	4.0%	**3.7%**	
Avoided CO_2 (Metric tons)	219.8	95.9	206.4	131.8	653.9	
Bill Relief Rate ($/kWh)	**$30,930**	**$13,445**	**$28,908**	**$18,487**	**$91,770**	

Figure B1. Monthly Circuit Performance Results July 2016 through June 2017

ESTCP Office
4800 Mark Center Drive
Suite 17D08
Alexandria, VA 22350-3605
(571) 372-6565 (Phone)
E-mail: estcp@estcp.org
www.serdp-estcp.org