FINAL REPORT

Strategic Microgrid Controls for Closely Sited Military Facilities

ESTCP Project EW-201603

DECEMBER 2019

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Electricore, Inc.

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This project demonstrated a microgrid control framework creating a centrally managed dispatchable generation hub as the power base for networked utility feeder interconnected facilities. The dispatchable generation hub is a microgrid managing diesel-based energy generation, renewable generation, demand, and storage assets for power export to support the demand of closely sited military installations.

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ACRONYMS AND ABBREVIATIONS

AFCEC	Air Force Civil Engineer Center
AFI	Air Force Instructions
ANG	Air National Guard
ATS	Automatic Transfer Switches
AW	Attack Wing
BMS	Battery Management System
CERL	Construction Engineering Research Laboratory
CERDEC	Communications-Electronics Research, Development and Engineering Center
CE	Consumers Energy
COTS	Commercial off-the-shelf
DG	Distributed Generation
DOD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
EW	Energy and Water
HASP	Health and Safety Plan
HMI	Human Machine Interface
IEEE	Institute of Electrical and Electronics Engineers
kV	Kilovolt
KVAR	Kilovolt-amperes reactive
kW	Kilowatt
Li-ion	Lithium-ion
LV	Low Voltage
MI	Michigan
MING	Michigan National Guard
MISO	Midcontinent Independent System Operator
MOU	Memorandum of Understanding
MPH	Miles per hour
MV	Medium Voltage
MW	Megawatt
MWh	Megawatt-hours
NIPR	Non-Classified Internet Protocol Router
NRE	Non-recurring engineering
O&M	Operation and Maintenance

PCC	Point of Common Coupling
PV	Photovoltaics
ROI	Return on investment
Sempra	San Diego Gas & Electric Utility
TTOD	Technology Transfer and Outreach Division
VA	Veterans Affairs
VAR	Volt-amperes reactive

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ABSTRACT

INTRODUCTION AND OBJECTIVES

This project demonstrated a microgrid control framework creating a centrally managed dispatchable generation hub as the power base for networked utility feeder interconnected facilities. The dispatchable generation hub is a microgrid managing diesel-based energy generation, renewable generation, demand, and storage assets for power export to support the demand of closely sited military installations.

TECHNOLOGY DESCRIPTION

The technology solution demonstrated provided a microgrid control architecture constituted of scalable commercial-off-the-shelf controllers, protection relays and switchgear suitable for all MV distribution with MV / LV generation assets. The updates made in installing the control framework was limited to upgrade of equipment like legacy backup generators (to make them dispatchable) and manual switches (to enable automation) at the utility point of connection (baseline in most DoD buildings for this demonstrated technology). The over-the-fence connection of the microgrid required extensive interaction with the region's utility provider, CE, and an amendment to the existing interconnect agreement. The system design was based on two backup generators, PV (current and ongoing development) and an energy storage system optimized for power applications.

PERFORMANCE AND COST ASSESSMENT

The successful field demonstration verified autonomous microgrid power quality management (frequency, voltage, reactive power compensation) to respond to grid conditions or control signals with planned energy storage. Prediction and compensation for intermittencies from renewable energy was demonstrated using energy storage to maintain power quality in islanded and grid-connected modes with efficient use of generators during sustained intermittencies and non-optimal (cloud covered or light wind) periods.

IMPLEMENTATION ISSUES

The greatest risk to adoption and enterprise wide success for the demonstrated solution is regulatory compliance. The value from the monetization of the DER and demand response capability of the demonstration must meet the intertie and parallel operating requirements of States, territories and regions where the system would operate, including but not limited to, IEEE 1547 and ANSI C84.1, and specifically complying with MPSC R460.601 – R460.656 under the jurisdiction of the Michigan Public Service Commission. This could manifest as emissions abatement, renewable penetration limits and mission impeding demand response requirements.

A potential disadvantage with implementation of the demonstrated system is the installation of required switchgear and protection to existing backup generation. Backup generation as standby generation has limited protection and switching hardware. When the backup DG is intertied with the distribution there are increased protection and switching hardware that add cost and complexity. This cost can be mitigated by performing optimization simulations and studies to determine the generation vs cost tradeoff for each installation.

PUBLICATIONS

The team submitted multiple publications featuring the project including two conference papers/poster presentations, “Customized microgrid at Fort Custer advances energy resilience,” and “Microgrid Enables Military Facility to Participate in Utility Services.”

EXECUTIVE SUMMARY

INTRODUCTION

Department of Defense (DOD) installations have invested in backup power solutions, energy storage and renewable generation assets to improve energy security and to reduce operations costs in alignment with operational energy goals. Operation of dispersed (physically and electrically) assets is typically limited to designated facilities or exporting of power to reduce net consumed energy. Conventional designs for the backup generation systems have placed greatly oversized power sources, as much as 75%, without appropriate controls, protection or interconnectivity to share power with other co-located mission critical facilities during utility blackouts. These installations also have no means of safely and by remote control disconnecting from the utility or resynchronizing without complete service disruption. This inability to utilize existing backup DG for baseload also leaves any available renewable energy sources unusable as most are compliant with IEEE 1547 and cannot operate without a stable, regulated reference for voltage and frequency. The ability to exploit renewable sources would displace inefficiently burned fuel for the DG that may not be available for resupply during a contingency. Where geographically adjacent military installations and other federal facilities have excess generation capacity locally, they are unable to share this power due to a lack of appropriate controls, switchgear and protection at the point of common coupling (PCC) compatible with the power providing utility. These closely sited facilities do not possess technology to allow sharing of generation resources, resulting in duplication of assets. To fully realize the value of the dispersed generation assets and export power in compliance with interconnection regulations and governing standards a novel microgrid control framework will be developed and demonstrated that integrates DG, energy storage and renewables into a dispatchable generation hub. Instituting "over the fence" cooperation and sharing of power resources can address the interconnection limitations, enhance energy surety and resilience and reduce collective microgrid installation costs at closely sited facilities. Successful implementation of the microgrid establishes a whole new level of regional energy resiliency available on demand to the military and the utility company.

The Project Team successfully demonstrated a microgrid control architecture constituted of scalable commercial-off-the-shelf (COTS) controllers, protection relays and switchgear suitable for all medium voltage (MV) distribution with medium voltage/ low voltage (LV) generation assets.

As a dispatchable generation hub with controls for exporting power and operating within the regulations of an interconnect agreement, Ft. Custer is capable of selling energy from the integrated assets, including photovoltaics (PV) with power optimized storage, and any future added DG.

The demonstrated controls are applicable to any DoD facility with excess generation capacity for sale to the regional ancillary and demand services markets available while retaining the capability of islanding and use of the same assets for energy surety during contingencies.

OBJECTIVES

The objective of the project was to demonstrate a microgrid control framework creating a centrally managed dispatchable generation hub as the power base of a network of utility feeder interconnected facilities. The approach included the upgrade of legacy equipment, specifically legacy backup generators and manual switches at the utility point of common coupling (PCC). Additional energy storage capacity was added to meet minimum ESTCP RFP requirements for continuous and peak power demand. Controls and communications installed are expandable and will easily accommodate renewable generation growth.

The successful field demonstration verified autonomous microgrid power quality management (frequency, voltage, reactive power compensation) to respond to grid conditions or control signals with planned energy storage. Prediction and compensation for intermittencies from renewable energy was demonstrated using energy storage to maintain power quality in islanded and export modes with efficient use of generators during sustained intermittencies and non-optimal (cloud covered) periods.

The microgrid was demonstrated for a total of 53 hours (49 hours of islanded operation and 4 hours of grid-connected with max power export). Performance objectives of the project are listed below.

Table 1. Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Export energy value as compared to the MISO Reserve Market real time pricing	$/MWh	Real time power exported to the utility distribution in MWh	Monetization of exported power from Ft. Custer to CE validating value proposition for DoD as an energy seller	Met; microgrid owner will complete interconnect agreement that will define $/MWh
Dispatch and grid synchronization of distributed generation for base load	kW, kVARs, Volts, Hertz, seconds	Generator output power measurements, microgrid voltage and frequency measurements	Synchronization of each generator and base load support	Exceed with onsite PV in parallel with DG supporting a peak baseload of 750 kW
Dispatch and transition of base load between DG	kW, kVARs, Volts, Hertz, seconds	Generator output power measurements, microgrid voltage and frequency measurements	Successful transition of base load between generation	Exceed with smooth transitions of 350 kW base load between DGs
Intentional islanding of microgrid from utility on base energy manager or utility command	kW, kVARs, Volts, Hertz, seconds	Utility command, microgrid HMI command, distribution feeder voltage and frequency measurements, generator output power measurements, microgrid voltage and frequency measurements	Successful islanding of microgrid from utility distribution feeder following start-up and synchronization of distributed generation servicing base load	Exceed by islanding without losing Solar PV in under 2 minutes. Fluctuation in frequency was around 0.3 Hz and voltage fluctuation once islanded was under 1%

Table 1. Performance Objectives (Continued)

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Resynchronization of microgrid to utility on base energy manager or utility command	kW, kVARs, Volts, Hertz, seconds	Utility command, microgrid HMI command, distribution feeder voltage and frequency measurements, generator output power measurements, microgrid voltage and frequency measurements	Successful reconnection of microgrid to utility distribution feeder with seamless transition of base load and shut down of distributed generation in no more than 5 minutes	Exceed. Achieved resync within 30 sec.
Controlled export of power to utility distribution feeder from microgrid in compliance with interconnection agreement and regulations	kW, kVARs, Volts, Hertz, seconds	Islanded microgrid synchronizes to utility feeder. DG increases power to base load demand level. PV power is exported to utility feeder	Complies with IEEE 1547 and ANSI C84.1 standards. Complies with MPSC R460.601 – R460.656, and interconnection agreement capacity restriction	Met the requirement meeting the standards
Ramp rate control of PV power transitions with support from energy storage	kW, kVARs, Volts, Hertz, seconds	Microgrid voltage and frequency measurement. Microgrid load power measurements. PV DC power measurement. Storage inverter output measurement.	60 second effective ramp down of power given PV reduction (due to cloud passing overhead). With and without ramp rate control enabled, collect data over typical solar days.	Exceeded while grid-tied or islanded Only saw a 35 kW change in net output at bus for a 144 kW change in solar PV through energy storage support
High penetration PV and control of PV power ramp rate for generator stability	kW, kVARs, Volts, Hertz, seconds	Microgrid voltage and frequency measurement. Microgrid load power measurements. PV dc power measurement, storage inverter and generator output measurement,	Generator output voltage stability given a 60% PV DC power step (up or down). Stability is defined as voltage maintained within +10%/-12%, and frequency within 60.3Hz/59.3Hz. Based on total generation the PV penetration would be 36.5% of generation. The 60% PV DC power step will be based on actual PV output at the time of testing with the goal of executing the test during maximum production.	Met. Demonstrated 48 consecutive hours with PV

TECHNOLOGY DESCRIPTION

The technology solution demonstrated provided a microgrid control architecture constituted of scalable commercial-off-the-shelf controllers, protection relays and switchgear suitable for all MV distribution with MV / LV generation assets. The updates made in installing the control framework was limited to upgrade of equipment like legacy backup generators (to make them dispatchable) and manual switches (to enable automation) at the utility point of connection (baseline in most DoD buildings for this demonstrated technology). The over-the-fence connection of the microgrid required extensive interaction with the region's utility provider, CE (local utility), and an amendment to the existing interconnect agreement. The demonstrated solution offers safe and efficient power sharing for Joint Base energy-resiliency and security at a savings of approximately 50% through maximized use of legacy infrastructure and distributed energy resources.

The system design was based on two backup generators, PV (current and ongoing development) and an energy storage system optimized for power applications.

The microgrid control architecture is based on the Eaton Power Xpert Energy Optimizer™ that utilizes COTS substation automation components. The System controller is based on a substation gateway and data aggregation software platform performing algorithm implementation, data acquisition and distribution, protocol translation, and to provide secure remote access to distributed microgrid elements such as the subject DG and PCC of this program, but also building management systems. These features allow direct compatibility with utility communications and controls. Collocated with the DG and PCC controllers are distribution processor gateways that provide secure communications and control along with data acquisition. Figure 1 below illustrates the microgrid control architecture overlaying a single line diagram of the Ft Custer power system.

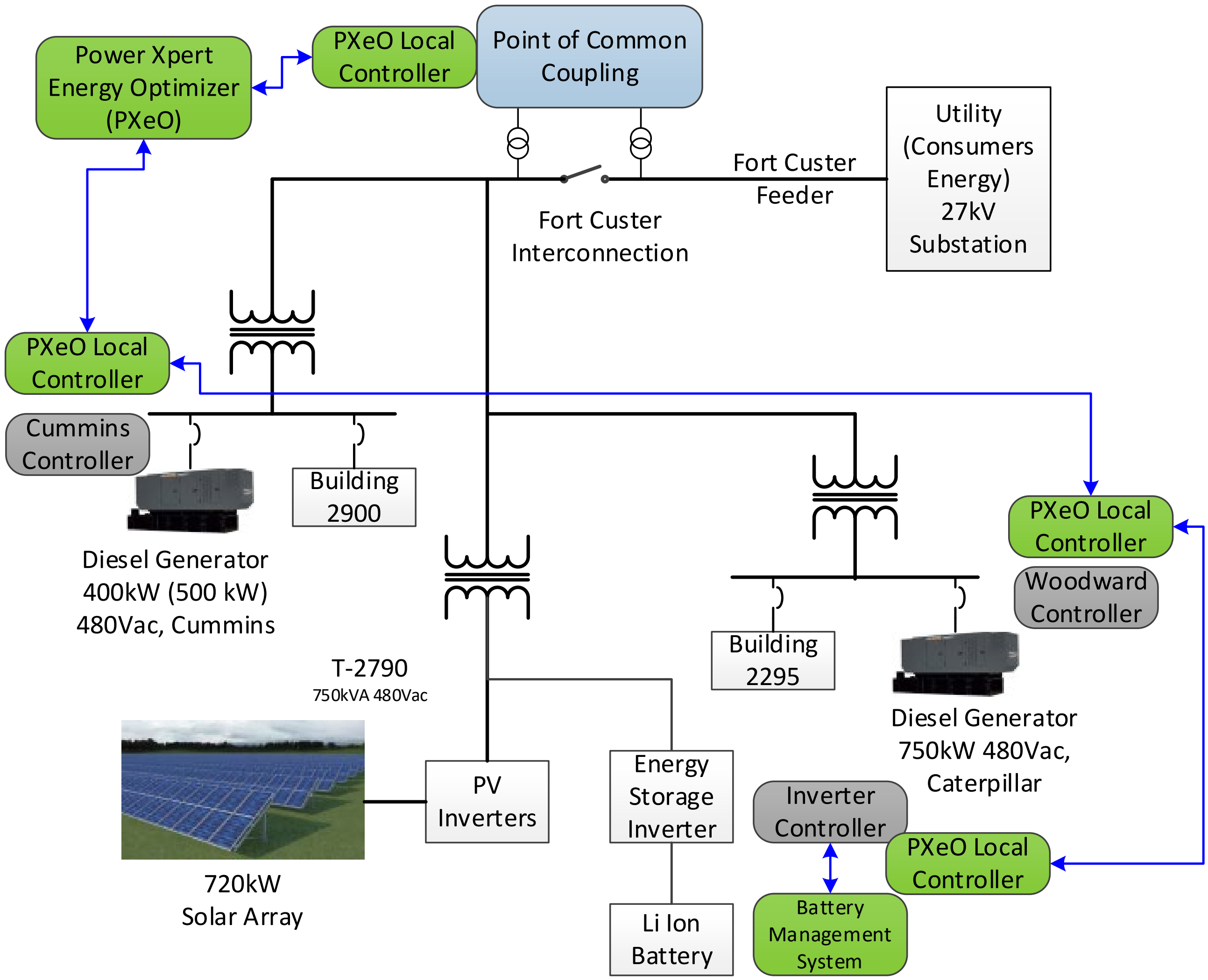

Figure 1. Microgrid Control Architecture Overlaying a Single Line Diagram of the Ft Custer Power System

COST ASSESSMENT

The demonstrated controls are applicable to any DOD facility with excess generation capacity for sale to the regional ancillary and demand services markets available while retaining the capability of islanding and use of the same assets for energy surety during contingencies. Considering the aggregate of Ft. Custer DG assets were available for dispatch by CE to sell into the Reserve Energy Market, an estimated ROI is 20,447 hours (2.5 years) of export operation. This estimate is based on an average price from the MISO Reserve Energy Market of \$30.57/MWh with the Ft. Custer asset aggregation of 2MW. Further, the installed microgrid controls can manage any additional PV or larger capacity battery storage.

If there were public, utility or private assets within the distribution system of Ft Custer, those assets operating at 2.5MW for an aggregated 20,447 hours would pay for the proposed microgrid system with enhancements. The aggregate was shown as continuous dispatch of available resources based on natural gas generation to be installed for demand reduction, peak and reserve market exploitation. The state of Michigan has rights to all-natural gas generated from oil exploration and intended to use this gas as the fuel for the speculated generators. Capital and logistics cost for the generators has not been determined as it is beyond the scope of this effort, demonstrating the reliable, predictable and repeatable integration of generation to enable the study of potential for monetizing excess energy from available resiliency assets.

Excluding the demonstration period, Ft. Custer does not plan to continuously export power as a commodity at this time. The goal of the project was to demonstrate the efficacy of the microgrid controls and protection in demand response and reserve markets, if desirable, by the owning command. Given the need for additional generation by MISO and CE, the placement of dispatchable tier 4 generators and other DER would allow 24/7 power production or effective net zero energy for a facility.

Cost advantages for Ft. Custer can be realized through cost effective operations in regulated energy markets or providing ancillary services in deregulated energy markets - As a dispatchable generation hub, Ft. Custer is capable of selling energy through an aggregator into the Real-Time and Operating Reserves market and the developing demand response market. The value of the exported energy will be valued based on the $/MWh to monetize the available generation capacity from Ft. Custer. Demand response program participation value (also in $/MWh) is determined in cooperation with Consumers Energy.

Table 2. Breakeven Period

Breakeven Period	Power Exported
2.33 Years	2MW
9.34 Years	500 kW
18.67 Years	250kW

* Exporting 8760 Hours/Year (Full Time)

This estimate is based on an average price from the MISO Reserve Energy Market of $30.57/MWh with the Ft. Custer asset aggregation of 2MW. If the state uses this ESTCP-supported capability for future Natural Gas generation and utility-scale storage in partnership with Consumer's Energy, it would result in a reduced breakeven period.

IMPLEMENTATION ISSUES

The greatest risk to adoption and enterprise wide success for the demonstrated solution is regulatory compliance. The value from the monetization of the DER and demand response capability of the demonstration must meet the intertie and parallel operating requirements of States, territories and regions where the system would operate, including but not limited to, IEEE 1547 and ANSI C84.1, and specifically complying with MPSC R460.601 – R460.656 under the jurisdiction of the Michigan Public Service Commission. This could manifest as emissions abatement, renewable penetration limits and mission impeding demand response requirements.

A potential disadvantage with implementation of the demonstrated system is the installation of required switchgear and protection to existing DG. Backup generation has limited protection and switching hardware. When the backup DG is intertied with the distribution there are increased protection and switching hardware that add cost and complexity. This cost can be mitigated by performing optimization simulations and studies to determine the generation vs cost tradeoff for each installation.

An additional risk includes communication and coordination between grid operators and microgrid operators, especially in the context of power export to nearby facilities and ownership of infrastructure and equipment. If nearby facilities coordinate with each other, they must keep in mind the electrical infrastructure separating their facilities is generally owned by the local utility, which will seek to mitigate risk to its own equipment

Additional considerations are the training for base energy managers and support operations. Continuity plans during key staff transitions will be critical to continued operation, maintenance and safety of the demonstrated system.

Excluding the demonstration period, Ft. Custer does not plan to continuously export power as a commodity at this time. The goal of the project was to demonstrate the efficacy of the microgrid controls and protection in demand response and reserve markets, if desirable, by the owning command. Given the need for additional generation by MISO and CE, the placement of dispatchable tier 4 generators and other DER would allow 24/7 power production or effective net zero energy for a facility.

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1.0 INTRODUCTION

This project demonstrated a microgrid control framework creating a centrally managed dispatchable generation hub as the power base for networked utility feeder interconnected facilities. The dispatchable generation hub is a microgrid managing diesel-based energy generation, renewable generation, demand, and storage assets for power export to support demand of closely sited military installations. This enhancement to microgrids to support neighboring facilities is an advancement on the state of the art.

1.1 BACKGROUND

Department of Defense (DOD) installations have invested in back-up power solutions, energy storage and renewable generation assets to improve energy security and to reduce operations costs in alignment with operational energy goals. Operation of dispersed (physically and electrically) assets is typically limited to designated facilities or exporting of power to reduce net consumed energy. Conventional designs for the backup distributed generation (DG) systems have placed greatly oversized power sources, as much as 75%, without appropriate controls, protection or interconnectivity to share power with other co-located mission critical facilities during utility blackouts. These installations also have no means of safely and by remote control disconnecting from the utility or resynchronizing without complete service disruption. This inability to utilize existing backup DG for baseload also leaves any available renewable energy sources unusable as most are compliant with IEEE 1547 and cannot operate without a stable, regulated reference for voltage and frequency. The ability to exploit renewable sources would displace inefficiently burned fuel for the DG that may not be available for resupply during a contingency. Where geographically adjacent military installations and other federal facilities have excess generation capacity locally, they are unable to share this power due to a lack of appropriate controls, switchgear and protection at the point of common coupling (PCC) compatible with the power providing utility. These closely sited facilities do not possess technology to allow sharing of generation resources, resulting in duplication of assets. To fully realize the value of the dispersed generation assets and export power in compliance with interconnection regulations and governing standards a novel microgrid control framework will be developed and demonstrated that integrates DG, energy storage and renewables into a dispatchable generation hub. Instituting “over the fence” cooperation and sharing of power resources can address the interconnection limitations, enhance energy surety and resilience and reduce collective microgrid installation costs at closely sited facilities. Successful implementation of the microgrid establishes a whole new level of regional energy resiliency available on demand to the military and the utility company.

The Project Team consisting of Electricore, Eaton, Go Electric, the Michigan National Guard (MING), Construction Engineering Research Laboratory (CERL), and Consumers Energy (CE) successfully demonstrated a microgrid control architecture constituted of scalable commercial-off-the-shelf (COTS) controllers, protection relays and switchgear suitable for all medium voltage (MV) distribution with medium voltage/ low voltage (LV) generation assets.

As a dispatchable generation hub with controls for export power operating within the regulations of an interconnect agreement, Ft. Custer is capable of selling energy from the integrated assets, including photovoltaics (PV) with power optimized storage, and any future added DG.

The demonstrated controls are applicable to any DoD facility with excess generation capacity for sale to the regional ancillary and demand services markets available while retaining the capability of islanding and use of the same assets for energy surety during contingencies.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of the project was to demonstrate a microgrid control framework creating a centrally managed dispatchable generation hub as the power base of a robust network of utility feeder interconnected facilities. The approach included the upgrade of legacy equipment, specifically legacy backup DG and manual switches at the utility point of common coupling (PCC). Additional energy storage capacity was added to meet minimum ESTCP RFP requirements for continuous and peak power demand. Controls and communications installed are expandable and will easily accommodate renewable generation growth.

The successful field demonstration verified autonomous microgrid power quality management (frequency, voltage, reactive power compensation) to respond to grid conditions or control signals with planned energy storage. Prediction and compensation for DG intermittencies from renewable energy was demonstrated using energy storage to maintain power quality in islanded and export modes with efficient use of generators during sustained intermittencies and non-optimal (cloud covered or light wind) periods.

The microgrid was demonstrated for a total of 53 hours (49 hours of islanded operation and 4 hours of grid-connected with max power export).

1.3 REGULATORY DRIVERS

Please see Table 3 below for a list of regulations, directives, and drivers that were focused on under the project installation and demonstration.

Table 3. Regulations, Directive, and Drivers Addressed by Project

Authority	Regulation, Directive, Standard or Driver	Relevant Aspect	Project Contribution	Applicable Project Technology or Practice
Executive Order	EO 13423	Sec. 2. (b) ensure that (i) at least half of the statutorily required renewable energy consumed by the agency in a fiscal year comes from new renewable sources, and (ii) to the extent feasible, the agency implements renewable energy generation projects on agency property for agency use;	(i) Use of on-site renewable energy. (ii) Storage of unused renewable energy for later use. (iii) Operation of renewable energy during utility interrupt.	(i) Energy storage. (ii) Microgrid seamless transition of distribution network during islanding.
Executive Order	EO 13514	Sec. 2. (ii) increasing agency use of renewable energy and implementing renewable energy generation projects on agency property	(i) Use of on-site renewable energy. (ii) Storage of unused renewable energy for later use. (iii) Operation of renewable energy during utility interrupt.	(i) Energy storage. (ii) Microgrid seamless transition of distribution network during islanding.
Legislative Mandate	Energy Policy Act of 2005	SEC. 911. ENERGY EFFICIENCY. (a) IN GENERAL.— (1) OBJECTIVES.—The Secretary shall conduct programs of energy efficiency research, development, demonstration. Such programs shall take into consideration the following objectives: (A) Increasing the energy efficiency of, buildings, and industrial processes. (B) Reducing the demand of the United States for energy, especially energy from foreign sources. (C) Reducing the cost of energy and making the economy more efficient and competitive. (D) Improving the energy security of the United States. (E) Reducing the environmental impact of energy-related activities. (2) PROGRAMS.—Programs under this subtitle shall include research, development, demonstration of (B) cost-effective technologies, for retrofit, to improve the energy efficiency and environmental performance of buildings, using a whole-buildings approach, including onsite renewable energy generation.	(i) Energy efficiency research, development and demonstration. (ii) Increase energy efficiency through maximizing use of renewable energy. (iii) Reduce demand for energy through maximum capture, storage and use of renewable energy. (iv) Reduce the cost of energy through generation, storage and maximized used of renewable energy. (v) Improve energy security through islanded microgrid, export of power to other nearby critical facilities. (vi) Maximize use of renewable energy to minimize environmental impact. (vii) Retrofit of existing assets (viii) Use of on-site renewable energy.	(i) Development and demonstration at Ft. Custer of advanced microgrid controls. (ii) Energy storage maximizes use of renewable energy. (iii) Microgrid seamless transition provides energy security during utility interrupt. (iv) Maximized use of existing Ft. Custer generation assets.

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2.0 TECHNOLOGY DESCRIPTION

The technology solution demonstrated provided a microgrid control architecture constituted of scalable commercial-off-the-shelf controllers, protection relays and switchgear suitable for all MV distribution with MV / LV generation assets. The updates made in installing the control framework was limited to upgrade of equipment like legacy backup generators (to make them dispatchable) and manual switches (to enable automation) at the utility point of connection (baseline in most DoD buildings for this demonstrated technology). The over-the-fence connection of the microgrid required extensive interaction with the region's utility provider, CE, and an amendment to the existing interconnect agreement. The complexity of the required interconnect agreement did not allow actual islanding of the two closely-sited installations for this demonstration, but this type of approach could be pursued. The demonstrated solution could offer safe and efficient power sharing for Joint Base energy resiliency and security at a savings of approximately 50% through maximized use of legacy infrastructure and distributed energy resources.

The system design was based two backup generators, PV (current and ongoing development) and an energy storage system optimized for power applications.

2.1 TECHNOLOGY OVERVIEW

The demonstration validated that energy surety and resilience can be accomplished by the development of a base power generation microgrid exporting energy to installations with critical demand. If interconnect agreements are worked out, it may be possible to wheel energy over the fence line to serve adjacent critical military customers, but this was not reduced to practice during this demonstration.

The microgrid control architecture is based on the Eaton Power Xpert Energy Optimizer™ that utilizes COTS substation automation components. The System controller is based on a substation gateway and data aggregation platform performing data acquisition and distribution, protocol translation and to provide secure remote access to distributed microgrid elements such as the subject DG and PCC of this program. These features allow direct compatibility with utility communications and controls. Collocated with the DG and PCC controllers are distribution processor gateways that provide secure communications and control along with data acquisition. Figure 1 above illustrates the microgrid control architecture overlaying a single line diagram of the Ft Custer power system.

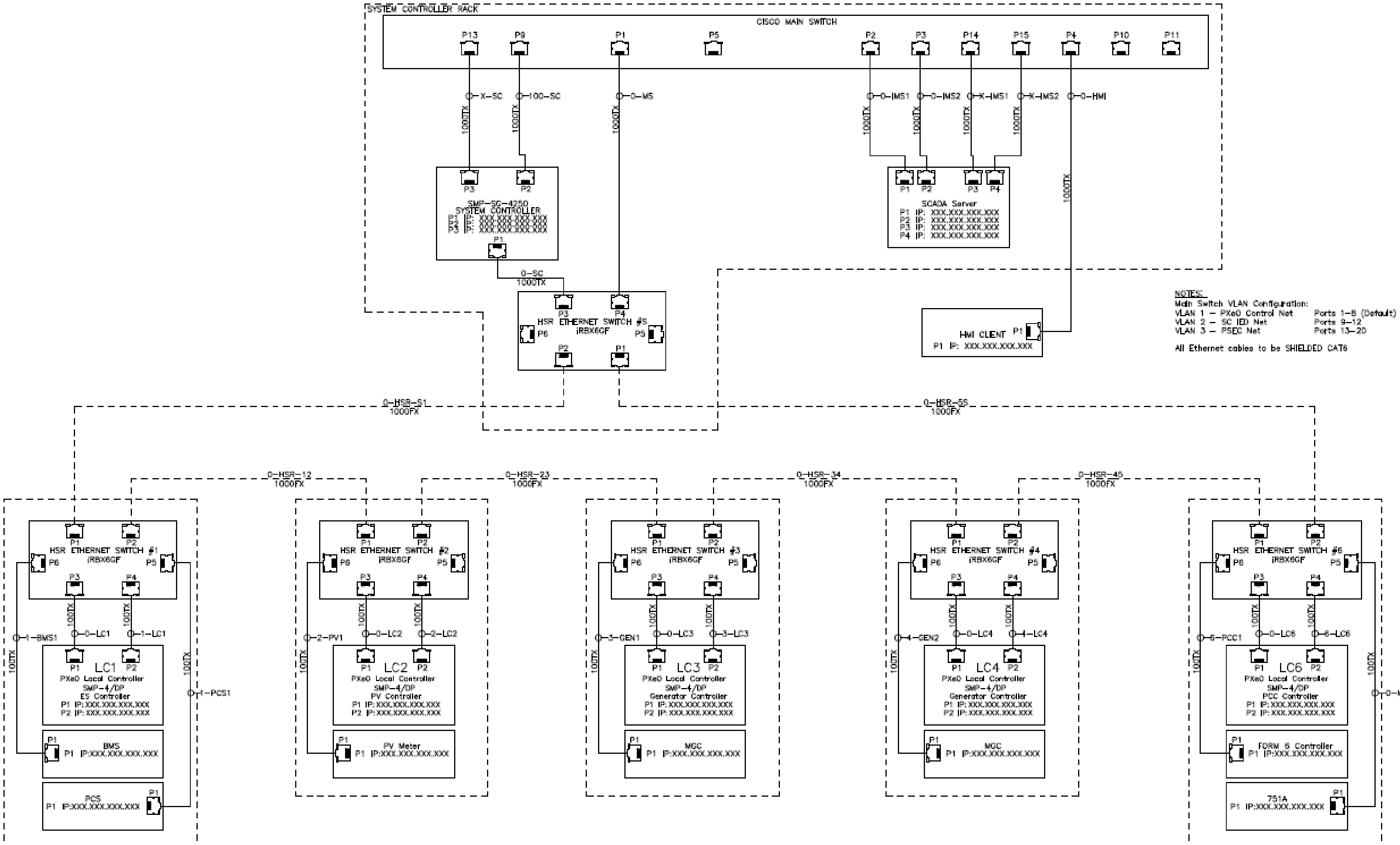

Figure 2. Communications Block Diagram

2.2 TECHNOLOGY DEVELOPMENT

Enhancements to the site's diesel generators that provide base load generation during islanding were made during installation phase of the project. The generators were previously installed with automatic transfer switches (ATS) to provide power to buildings 2900 and 2295 exclusively when the utility is unavailable. Integration into the microgrid required dismantling the ATS switch gear and replacing it with appropriately rated parallel operation switch gear and dispatch communications/controls. To ensure continued back-up generation functionality the enhancements included the ability to manual configure as an ATS if needed. The integration of back-up or stand-alone diesel generation as microgrid assets began with the modification of the legacy Tactical Quiet Generators for demonstration of demand dispatching and paralleling of different power rated units for the US Army CERDEC Hybrid Intelligent Power System program. The development of utility substation automation platforms for microgrid controls led to the adaptation of the generator interface that was employed under this project.

The system also incorporated the Woodward easYgen control system for the building 2295 generator (Figure 4) and the Cummins PowerCommand 3.3 control system for the building 2900 generator (Figure 3) as the DG controllers. All required generator operation is executed via communications from the system controller in addition to acquisition of real time performance and status data.

The effective operation of various OEM controllers and generators supports the transferability and scalability of the microgrid control architecture.

Figure 3. Building 2900 Cummins Generator

Figure 4. Building 2295 CAT Generator

The existing PCC with the utility for Ft. Custer is a gang operated pole mounted switch located along Denso Road with the meter being located outside the base fence line. Automation of the PCC was completed with the installation of pad mounted switch gear on the Ft. Custer side of the gang mounted switch. This allows for manual isolation with the pole mounted fuses remaining in place for fault protection. The pad mounted switch gear selected for this system was the Cooper Power Systems PWVE three phase recloser modified to include additional sensors with islanding and synchronization applications. The PWVE recloser is designed for feeder protection, sectionalizing, and transformer high-side protection. The PWVE is a nominal 24.9kV rated electronically controlled, pad-mounted automatic circuit recloser featuring three-phase vacuum interruption in a weatherproof and tamper-resistant enclosure. The fault current from the utility is well below the nominal interruption capacity of the PWVE. The PWVE provides a compact and secure package that has been used in substations, commercial, and residential areas making it ideally suited for the security and safety concerns of Ft. Custer while requiring minimal site improvements. Figure 5 below shows unmounted PWVE recloser.

Figure 5. PWVE Outside of Enclosure

The power quality and stability of the microgrid is supported by the deployment of power storage. The storage system's primary function is to support the PV system by "leveling" the output when dispatching power (to the utility or microgrid) and providing ramp rate control of power output. The system's secondary purpose is to support microgrid stability by providing kW and VAR support. The storage system includes a grid interface inverter capable of operating in parallel with the grid (utility). The inverter will also operate in parallel with the legacy generators while Ft. Custer is islanded. The storage inverter does not act as a standalone source when generators or utility are not providing the base load demand. The previously identified system controller monitors the system and provides P and Q (or frequency and voltage) commands to the inverter for power flow management.

Figure 6. Energy Storage Added to Support Existing PV (in the background)

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

As a dispatchable generation hub with controls for export power operating within the regulations of an interconnect agreement, Ft. Custer is capable of selling energy from the integrated assets, including PV with power optimized storage, and any future added DG.

The State of MI has rights to considerable natural gas reserves. The dispatchable generation hub microgrid controls are readily integrated with future, modern natural gas powered grid tied DG or CHP allowing sale of energy into the MISO Reserves Market through an aggregator at the cost of capital investment and addition of the proposed microgrid controls.

The demonstrated controls are applicable to any DOD facility with excess generation capacity for sale to the regional ancillary and demand services markets available while retaining the capability of islanding and use of the same assets for energy surety during contingencies. Considering the aggregate of Ft. Custer DG assets were available for dispatch by CE to sell into the Reserve Energy Market, an estimated ROI is 20,447 hours (2.5 years) of export operation.

This estimate is based on an average price from the MISO Reserve Energy Market of \$30.57/MWh with the Ft. Custer asset aggregation of 2MW.

Excluding the demonstration period, Ft. Custer does not plan to continuously export power as a commodity at this time. The goal of the project was to demonstrate the efficacy of the microgrid controls and protection in demand response and reserve markets, if desirable, by the owning command. Given the need for additional generation by MISO and CE, the placement of dispatchable tier 4 generators and other DER would allow 24/7 power production or effective net zero energy for a facility.

Cost advantages for Ft. Custer can be realized through cost effective operations in regulated energy markets or providing ancillary services in deregulated energy markets - As a dispatchable generation hub, Ft. Custer is capable of selling energy through an aggregator into the Real-Time and Operating Reserves market and the developing demand response market. The value of the exported energy will be valued based on the \$/MWh to monetize the available generation capacity from Ft. Custer. Demand response program participation value (also in \$/MWh) is determined in cooperation with Consumers Energy (Table 2).

The estimate is based on an average price from the MISO Reserve Energy Market of \$30.57/MWh with the Ft. Custer asset aggregation of 2MW. If the state uses this ESTCP-supported capability for future Natural Gas generation and utility-scale storage in partnership with Consumer's Energy, it would result in a reduced breakeven period.

The greatest risk to adoption and enterprise wide success for the demonstrated solution is regulatory compliance. The value from the monetization of the DER and demand response capability of the demonstration must meet the intertie and parallel operating requirements of States, territories and regions where the system would operate. This could manifest as emissions abatement, renewable penetration limits and mission impeding demand response requirements. Additional considerations are the training for base energy managers and support operations. Continuity plans during key staff transitions will be critical to continued operation, maintenance and safety of the demonstrated system.

Table 4. Identified Performance Risks and Mitigation Strategy

Risk Item	Mitigation Plan	Likelihood	Consequence
Regulatory issues prevent over the fence power sharing	Proactively work with utility (on team) and state regulators	High	Export PV/renewable power only which is not regulated
Power optimized battery storage size may not be sufficient to accomplish all project objectives	Rigorously test capability of proposed battery system, pursue outside cost share	Low	Inability to maintain frequency control
Air Force Instructions (AFI) prevent the use of diesel gensets at the ANG Base for the microgrid	Discussing with AFCEC Office of Energy Surety to endorse and approve waiver.	Medium	Only buildings sharing the same mission at the ANG Base may use the same genset; microgrid is not feasible.
Neighboring industrial customers lose power during demonstration of power transfer between facilities	Create new electrical wiring pathway directly between facilities	Medium	Limit power export to PV production periods

A potential disadvantage with implementation of the demonstrated system is the installation of required switchgear and protection to existing DG. Backup generation has limited protection and switching hardware. When the backup DG is intertied with the distribution there are increased protection and switching hardware that add cost and complexity. This cost can be mitigated by performing optimization simulations and studies to determine the generation vs cost tradeoff for each installation.

Table 5. Identified Cost Risks and Mitigation Strategy

Risk Item	Mitigation Plan	Likelihood	Consequence
Cannot meet DoD's cybersecurity requirements	Utilize self-contained fiber optic communication network off NIPR	High	Unacceptable vulnerability to cyberattack
Available PV site and/or Generator is beyond existing microgrid	Expand microgrid zone of operation	Low	Increased effort to integrate needed equipment

One of the major goals of this project was to explore the barriers to adoption of this radically new microgrid technology framework, and carefully document procedures so the approach can be explored at other facilities with an already-established starting point and considerations that must be taken into account. A summary of implementation issues and lessons learned is provided in Section 8.

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3.0 PERFORMANCE OBJECTIVES

The key accomplishments for this project was the dispatching of legacy assets and controlled export of energy to the utility feeder, as well as, the connection of the two closely sited facilities and the potential ability for them to actively share resources.

Connected facilities allow leverage of all existing resources in the region, potentially reducing the investment required for separate microgrids. Successful implementation of the microgrid establishes a whole new level of energy resiliency available on demand to the military and the utility company. The implementation of the dispatchable generation hub at Ft. Custer could allow the 110th AW and Veterans Affairs (VA) campus to operate as an extended microgrid during contingencies if a coordinated response from CE is enabled.

Table 6. Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Export energy value as compared to the MISO Reserve Market real time pricing	$/MWh	Real time power exported to the utility distribution in MWh	Monetization of exported power from Ft. Custer to CE validating value proposition for DoD as an energy seller	Met; microgrid owner will complete interconnect agreement that will define $/MWh
Dispatch and grid synchronization of distributed generation for base load	kW, kVARs, Volts, Hertz, seconds	Generator output power measurements, microgrid voltage and frequency measurements	Synchronization of each generator and base load support	Exceed with onsite PV in parallel with DG supporting a peak baseload of 750 kW
Dispatch and transition of base load between DG	kW, kVARs, Volts, Hertz, seconds	Generator output power measurements, microgrid voltage and frequency measurements	Successful transition of base load between generation	Exceed with smooth transitions of 350 kW base load between DGs
Intentional islanding of microgrid from utility on base energy manager or utility command	kW, kVARs, Volts, Hertz, seconds	Utility command, microgrid HMI command, distribution feeder voltage and frequency measurements, generator output power measurements, microgrid voltage and frequency measurements	Successful islanding of microgrid from utility distribution feeder following start-up and synchronization of distributed generation servicing base load	Exceed by islanding without losing Solar PV in under 2 minutes. Fluctuation in frequency was around 0.3 Hz and voltage fluctuation once islanded was under 1%
Resynchronization of microgrid to utility on base energy manager or utility command	kW, kVARs, Volts, Hertz, seconds	Utility command, microgrid HMI command, distribution feeder voltage and frequency measurements, generator output power measurements, microgrid voltage and frequency measurements	Successful reconnection of microgrid to utility distribution feeder with seamless transition of base load and shut down of distributed generation in no more than 5 minutes	Exceed. Achieved resync within 30 sec.
Controlled export of power to utility distribution feeder from microgrid in compliance with interconnection agreement and regulations	kW, kVARs, Volts, Hertz, seconds	Islanded microgrid synchronizes to utility feeder. DG increases power to base load demand level. PV power is exported to utility feeder	Complies with IEEE 1547 and ANSI C84.1 standards. Complies with MPSC R460.601 – R460.656, and interconnection agreement capacity restriction	Met the requirement meeting the standards
Ramp rate control of PV power transitions with support from energy storage	kW, kVARs, Volts, Hertz, seconds	Microgrid voltage and frequency measurement. Microgrid load power measurements. PV DC power measurement. Storage inverter output measurement.	60 second effective ramp down of power given PV reduction (due to cloud passing overhead). With and without ramp rate control enabled, collect data over typical solar days.	Exceeded while grid-tied or islanded Only saw a 35 kW change in net output at bus for a 144 kW change in solar PV through energy storage support
High penetration PV and control of PV power ramp rate for generator stability	kW, kVARs, Volts, Hertz, seconds	Microgrid voltage and frequency measurement. Microgrid load power measurements. PV dc power measurement, storage inverter and generator output measurement,	Generator output voltage stability given a 60% PV DC power step (up or down). Stability is defined as voltage maintained within +10%/-12%, and frequency within 60.3Hz/59.3Hz. Based on total generation the PV penetration would be 36.5% of generation. The 60% PV DC power step will be based on actual PV output at the time of testing with the goal of executing the test during maximum production.	Met. Demonstrated 48 consecutive hours with PV

Export energy value as compared to the MISO Reserve Market real time pricing

- Purpose: Provide records of exported energy, demand and availability during the demonstration that can be assessed against the historical market value of energy during the period. This will indicate the potential monetized value of DG, DER and demand to offset installation, operating and maintenance costs of microgrids.

- Metric: value in $/MWh, $/kWh and $/kW

- Data: Recorded power exported to the CE Clark road circuit distribution feeder in kWh and MWh. MISO market reports applicable to CE participation. Demand response value as applicable to CE participation.

- Success Criteria: The determination of success is based on the valuation of the exported energy and demand as greater than the cost of consumed energy and limited export of PV based on conventional interconnection agreement.

Dispatch and grid synchronization of distributed generation for base load

- Purpose: This demonstration shows that the microgrid control architecture is able to be dispatched to meet the current baseload and stabilize the microgrid voltage and frequency. This will enable islanding the microgrid from the utility feeder without power disruption.
- Metric: kW, kVARs, Volts, Hertz, seconds
- Without automatic dispatching and synchronization of the generation to transfer the baseload from the utility islanding will not be possible without service disruption.
- Data: Microgrid voltage and frequency measurements. Generator output power measurements. Load power measurements. PCC frequency, voltage and phase measurements.
- Success Criteria: Synchronization and islanding from the utility with the baseload supported by both generators. No loss of microgrid loads, due to lack of available power or microgrid voltage and frequency oscillations.

Dispatch and transition of base load between DG

- Purpose: This demonstration shows that the microgrid control architecture is able to be dispatch between the available generators to meet the current baseload and stabilize the microgrid voltage and frequency. This will enable optimization of sources for the microgrid demand.
- Metric: kW, kVARs, Volts, Hertz, seconds
- Without automatic dispatching and synchronization of the generation to transfer the baseload while islanded operation will not be possible without service disruption.

- Data: Microgrid voltage and frequency measurements. Generator output power measurements. Load power measurements.
- Success Criteria: Stable transfer of the baseload between generators without power quality issues (IEEE 1547 compliance). No loss of microgrid loads, due to lack of available power or microgrid voltage and frequency oscillations.

Intentional islanding of microgrid from utility on base energy manager or utility command

- Purpose: This demonstration shows that the microgrid control architecture is able to dispatch and control assets with frequency, phase and voltage commands with synchronization verification for stabile microgrid islanding when initiated from the SCADA. This will enable base energy manager and utility operator directed islanding.
- Metric: kW, kVARs, Volts, Hertz, seconds
- Without operator directed islanding, resilient operation during contingencies will not be possible.
- Data: Microgrid voltage and frequency measurements. Generator output power measurements. Load power measurements. PCC frequency, voltage and phase measurements. Time from command issuance to islanding execution.
- Success Criteria: Effective execution of islanding command from SCADA. No loss of microgrid loads, due to lack of available power or microgrid voltage and frequency oscillations. Successful islanding of microgrid from utility distribution feeder following start-up and synchronization of distributed generation servicing base load

Resynchronization of microgrid to utility on base energy manager or utility command

- Purpose: This demonstration shows that the microgrid control architecture is able to dispatch and control assets with frequency, phase and voltage commands with synchronization verification for stabile microgrid reconnection to the utility when initiated from the SCADA. This will enable base energy manager and utility operator directed reconnection from islanded operation.
- Metric: kW, kVARs, Volts, Hertz, seconds
- Without operator directed reconnection to the utility, recovery following contingencies will not be possible without service disruption.
- Data: Microgrid voltage and frequency measurements. Generator output power measurements. Load power measurements. PCC frequency, voltage and phase measurements. Time from command issuance to resynchronization execution.
- Success Criteria: Effective execution of resynchronization and reconnection to the utility feeder following command from SCADA. No loss of microgrid loads, due to lack of available power or microgrid voltage and frequency oscillations. Successful reconnection of microgrid to utility distribution feeder with transition of base load and shut down of distributed generation.

Controlled export of power to utility distribution feeder from microgrid in compliance with interconnection agreement and regulations

- Purpose: The current demonstration goals will control the export of power in compliance with the amended interconnect agreement between Consumers Energy Company and Michigan Army National Guard.
- Metric: kW, kVARs, Volts, Hertz, seconds
- Without controlled export of energy from the generation hub to the utility, safe and reliable support of mission critical operations of adjacent microgrids is not possible.
- Data: Microgrid voltage and frequency measurements. Generator output power measurements. Load power measurements. PCC frequency, voltage and phase measurements. PCC power flow data.
- Success Criteria: Effective export of renewable energy to the utility feeder while local DG meets baseload demand. No loss of microgrid loads, due to lack of available power or microgrid voltage and frequency oscillations. Power export complies with IEEE 1547 and ANSI C84.1 standards. Power export complies with MPSC R460.601 – R460.656, and interconnection agreement capacity restriction.

Ramp rate control of PV power transitions with support from energy storage

- Purpose: Demonstrate the ability of microgrid control architecture to manage ramp rates of PV with storage support to mitigate variable solar (available power) while islanded, with minimal DG online.
- Metric: kW, kVARs, Volts, Hertz.
- Typical PV inverters go offline when the utility is not present. A PV inverter, combined with storage inverter support and microgrid controls, can power a microgrid without generators, given variable PV power and power demand within the PV available output capacity.
- Data: Microgrid voltage and frequency measurement. Microgrid load power measurements. PV DC power measurement. Storage inverter output measurement.
- Success Criteria: 60 second effective ramp down of power given PV reduction (due to cloud passing overhead). With and without ramp rate control enabled, collect data over typical solar days. Stable bus is defined as voltage maintained within +10%/-12%, and frequency within 60.3Hz/59.3Hz. The 50% level is selected based on power (and not energy) optimized battery.

High penetration PV and control of PV power ramp rate for generator stability

- Purpose: Demonstrate the ability of the storage system to maintain a stable islanded microgrid bus during PV power steps (by ramping total power), when islanded with generators and PV sources.
- Metric: kW, kVARs, Volts, Hertz, seconds.

- A solar irradiation step can result in microgrid instabilities, given generator and high penetration PV sources (approximately 18% in this microgrid). By using storage to ramp power (up or down to the final value as needed) over a longer time, the generator output is stabilized resulting in a stable microgrid bus.
- Data: Microgrid voltage and frequency measurement. PV dc power measurement, storage inverter and generator output measurement.
- Success Criteria: Generator output voltage stability given a 60% PV DC power step (up or down). Stability is defined as voltage maintained within +10%/-12%, and frequency within 60.3Hz/59.3Hz.

4.0 FACILITY/SITE DESCRIPTION

The selected facility for the demonstration was the Ft. Custer Training Center in Southwest Michigan. Ft. Custer is a 7,500-acre National Guard Training Center; hosting the Michigan Army National Guard, Michigan Air National Guard, Army reserve, Navy Reserve and Marine Corps Reserve for individual and small unit training.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The sites selected for this demonstration are strategic and important. Ft. Custer is a center of activity to support the region during any natural or man-made disasters. The 110^{th} ANG facility is also critical, operating continuously as an unmanned air vehicle control center and designated as the state-wide command and control location in the event the state government is unable to operate from headquarters. The estimated distance is 2.21 miles direct gate to gate. Access to immediate and uninterrupted electricity is critical to missions of both facilities.

The presence of extensive existing assets – generators, solar generation, electrical distribution infrastructure, allowed for a sophisticated microgrid demonstration. The strong technical knowledge of the host leadership allowed for detailed discussions on mission requirements and risk assessment.

Please see Figure 7 below for a site map.

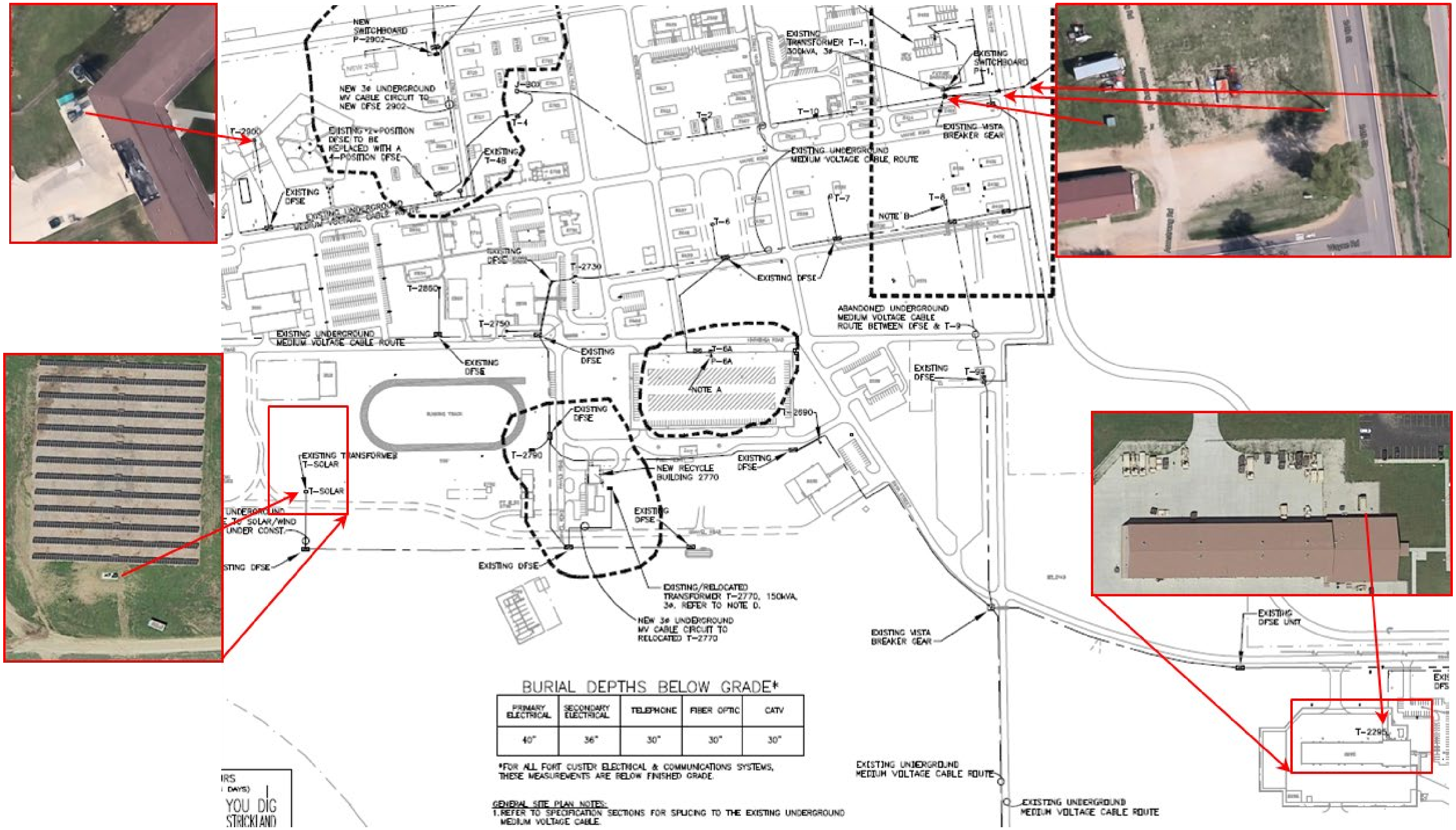
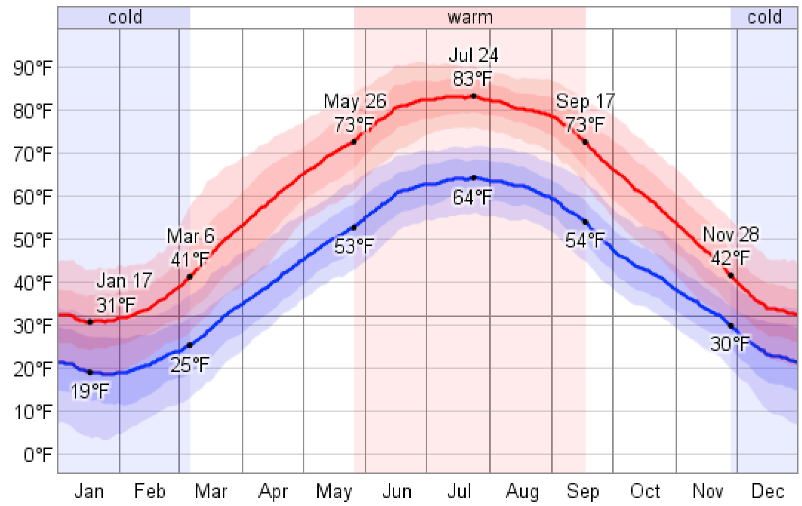


Figure 7. ESTCP - Ft. Custer Generation Layout

4.2 FACILITY/SITE CONDITIONS

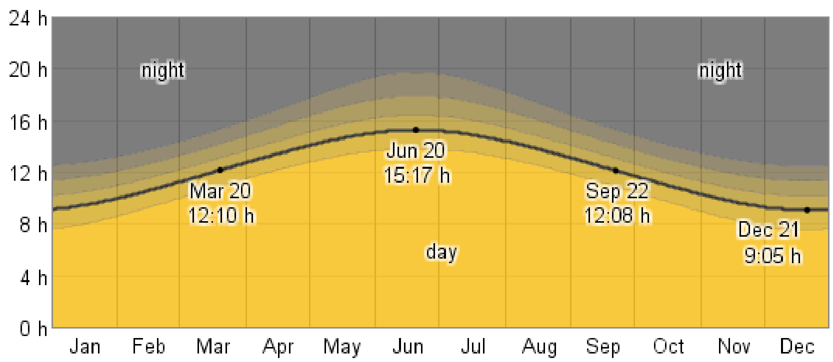
In order to robustly test the microgrid technology, a "four season" site was chosen to conduct the testing. Ft. Custer has a humid continental climate with hot summers and no dry season. Over the course of a year, the temperature typically varies from 19$^{\circ F}$ to 83$^{\circ F}$ and is rarely below 3$^{\circ F}$ or above 91$^{\circ F}$.



The daily average low (blue) and high (red) temperature with percentile bands (inner band from 25th to 75th percentile, outer band from 10th to 90th percentile).

Figure 8. Ft. Custer, MI; Daily High and Low Temperatures

The length of the day varies significantly over the course of the year. The shortest day comes in winter with just 9:06 hours of daylight; the longest day comes during summer with 15:17 hours of daylight. The median cloud cover ranges from 39% (mostly clear) to 99% (overcast).



The number of hours during which the Sun is visible (black line), with various degrees of daylight, twilight, and night, indicated by the color bands. From bottom (most yellow) to top (most gray): full daylight, solar twilight (Sun is visible but less than 6Â° from the horizon), civil twilight (Sun is not visible but is less than 6Â° below the horizon), nautical twilight (Sun is between 6Â° and 12Â° below the horizon), astronomical twilight (Sun is between 12Â° and 18Â° below the horizon), and full night.

Figure 9. Daily Hours of Daylight and Twilight

The relative humidity typically ranges from 42% to 94% over the course of the year. The course typical wind speeds vary from 0 mph to 17 mph, rarely exceeding 23 mph.

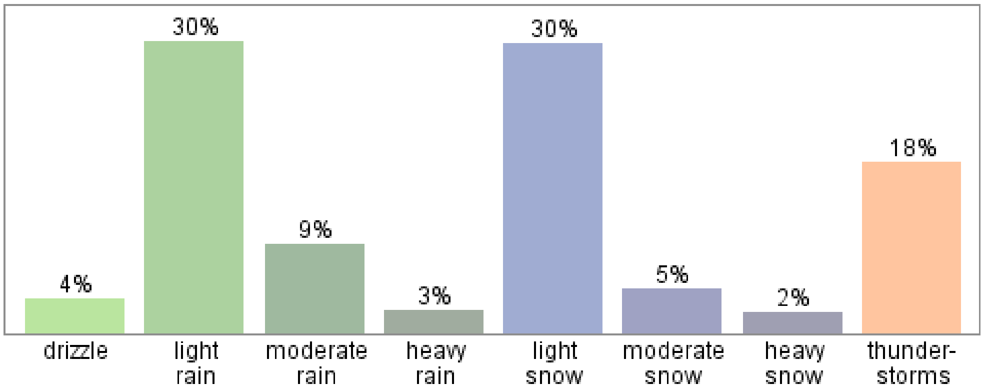


Figure 10. Types of Precipitation throughout the Year

The table below shows a list of the desired facility/site conditions that were evaluated when selecting Ft. Custer as the host site. Ft. Custer met or exceeded all site criteria or offered alternatives to ensure a successful demonstration. In addition, the site had existing facility electrical distribution.

Table 7: Site Selection Criteria

Parameter (units)	Preferred Value(s)	Relative Importance (1-5, with 1 being highest)	Ft. Custer
Peak demand for four (4) consecutive hours	> 1 MW	5	6 consecutive hours
Close proximity to other federal facilities	< 1 mile	4	1 mile and 3 miles
Existing legacy generators	> 1 MW	1	1.15 MW (1.25 MW)
Existing legacy solar generation of 200 kW or greater	> 200kW	2	720 kWdc
Interconnect agreement with local utility	In place or at least applied for	2	In place (awaiting signature)
Historical peak demand	> 1 MW	2	1.1 MW
Single PCC with utility feeder	27 kV	3	Seamless islanding and reconnection

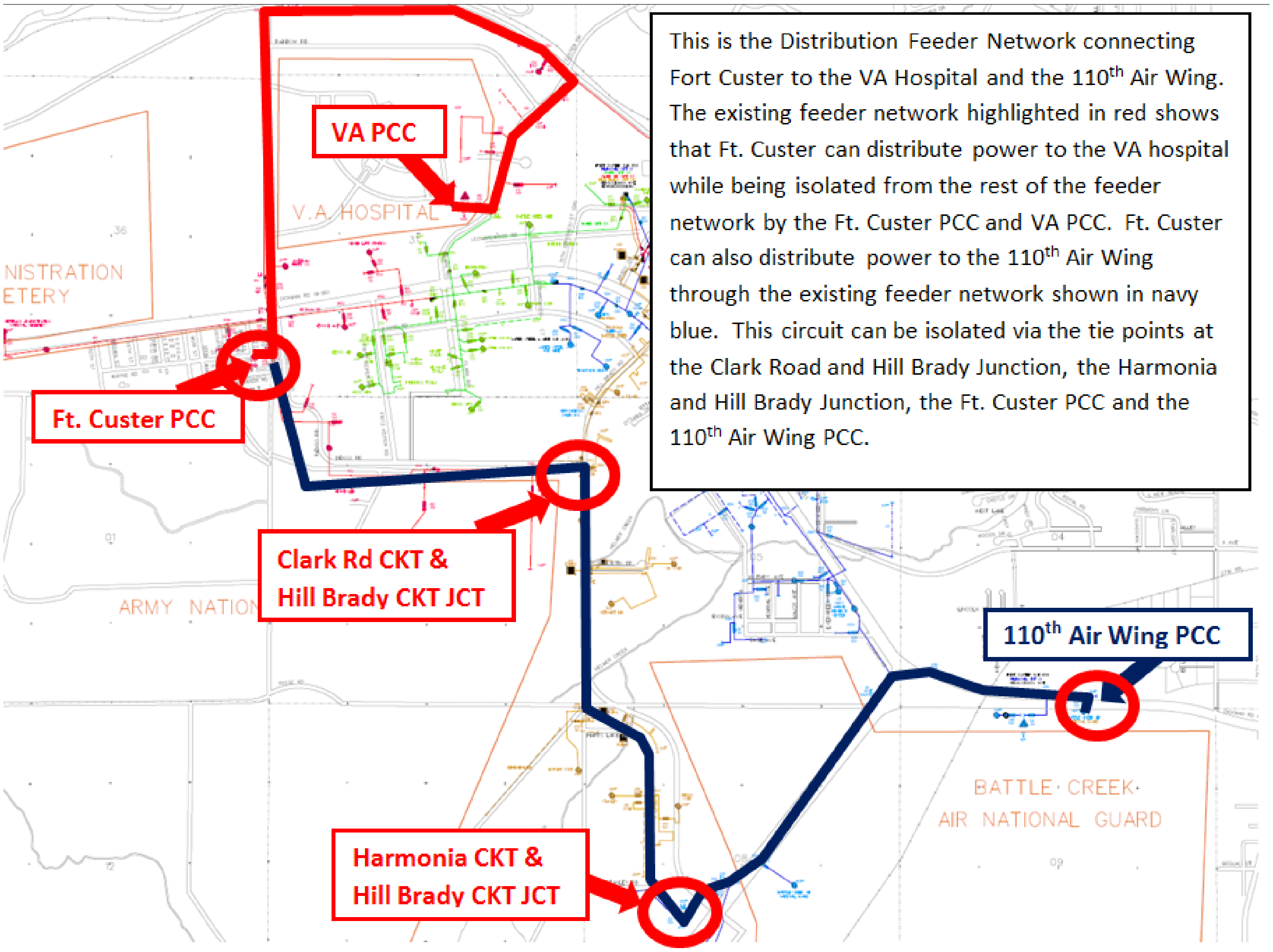


Figure 11. Ft. Custer Division Feeder Network

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5.0 TEST DESIGN

In order to track and analyze the performance of the microgrid, the following parameters were monitored, and data points were recorded in the system database. New data points were generated based on change of value for each variable.

- Caterpillar generator real power
- Caterpillar generator reactive power
- Caterpillar generator Phase A voltage
- Caterpillar generator Phase B voltage
- Caterpillar generator Phase C voltage
- Cummins generator real power
- Cummins generator reactive power
- Energy storage system real power
- Energy storage system reactive power
- Photo voltaic system real power
- Photo voltaic system reactive power
- Point of common coupling real power
- Point of common coupling reactive power
- Point of common coupling grid voltage
- Point of common coupling load voltage
- Point of common coupling slip frequency
- Point of common coupling angle between load and grid
- Point of common coupling grid frequency

5.1 CONCEPTUAL TEST DESIGN

The microgrid underwent operational testing in two (2) distinct phases: islanded operation and grid-connected operation with maximum power export. In addition, ramp rate for high penetration PV operation underwent operational testing outside the main two testing windows, to fully demonstrate PV ramp rate control.

5.2 BASELINE CHARACTERIZATION

This project added functionality to Ft. Custer's electrical distribution system that did not previously exist. The baseline for each performance objective can be assumed to be zero or non-existent. The team did not collect baseline data; however, the following documents were used during the program to provide supplemental information in the design of the microgrid:

- Energy consumption information from Ft. Custer for each transformer in Ft. Custer's electrical distribution system.
- The nameplates for each transformer and settings of switchgear.
- Fault studies.
- Economic analysis of microgrid using 2015-2016 PV data.
- MISO Reserve Market historical energy pricing.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The microgrid is comprised of the following components as shown in the Figure 1 above:

- Power Xpert Energy Optimizer system, including local controllers, SMP-SG-4250 system controller, SCADA server, and HMI client
- PWVE automatic recloser
- 800kW, 480VAC Caterpillar diesel generator with Woodward easYgen control system and parallel operation switchgear
- 750kW, 480VAC Cummins diesel generator with Cummins PowerCommand 3.3 control system and parallel operation switchgear
- 720kW solar array with PV inverters
- Saft Intensium Mini Li Ion power-optimized energy storage with Go Electric inverter and battery management system

5.4 OPERATIONAL TESTING

The microgrid underwent operational testing in two (2) distinct phases: islanded operation and grid-connected operation with maximum power export. In addition, ramp rate for high penetration PV operation underwent operational testing outside the main two testing windows, to fully demonstrate PV ramp rate control.

Per IEEE 2030.8 section 5 Functional testing requirements of the core functions, the controls of assets integrated into the microgrid at Ft. Custer was not tested specifically to the standard approved June of 2018. The draft of the standard was not available nor a consideration at the time of proposal, though the target functions were understood and exercised within the scope and available funding. The spirit of the standard was tested with consideration of section 5 Functional testing requirements of the core functions. The section of the standard not considered for testing under this project is section 7.1.2 Transition – unplanned islanding test as this was outside the scope of the project. Black Start function was also outside the scope of this project due to funding limitations. The data collected for each of the defined demonstration scenarios are similar to the measurements specified for each test; P, Q, V, F and seconds. An analysis of the data from the defined demonstration tests have not been made for the prescribed dispatch and transition test criteria.

5.4.1 ISLANDED OPERATION

Islanded operation was tested from 8:35PM, October 9, 2018 through 9:50PM, October 11, 2018 (local time EDT), for a total of 49 hours and 15 minutes.

For this operational test, the Caterpillar diesel genset produced a consistent 400kW over the course of the testing period. The Cummins genset varied its real power output to accommodate changes in base load and varied from 130kW to 400kW over the course of the demonstration, its low output coinciding with sudden ramping PV output.

The Cummins 500DFEK Standby Generator is EPA Tier 2 (Prime Power Maximum run time unlimited). The CAT 750 ekW Mission Critical is EPA Tier 2 (OEM Maximum expected run time 500hours per year as standby generator).

PV output was limited over the course of this demonstration as the weather remained mostly cloudy. Maximum PV output achieved was momentary 169kW, necessitating further PV ramp rate testing outside of the islanded testing window.

Over this testing window, the energy storage system inverter was functional between 6:21AM, October 10, 2018 and 12:52PM, October 10, 2018, and between 1:39PM, October 10, 2018 and the end of the testing window (9:50PM, October 11, 2018). In total, energy storage system data points were recorded for 38 hours and 42 minutes. Thus, islanded operation was initiated without the use of the energy storage system.

Figure 12 below shows the real power output of all microgrid components over the entirety of the testing period.

Figure 13 shows the reactive power output of all microgrid components over the entirety of the testing period.

Figure 14 shows relevant grid stability parameters, PCC voltage and frequency, over the entirety of islanded operation. Voltage varies between 14001 and 15019 V, and frequency varies between 59.6 and 60.3 Hz over the entirety of the demonstration.

Figure 12. Real Power Output by Component for 48-Hour Islanded Operation

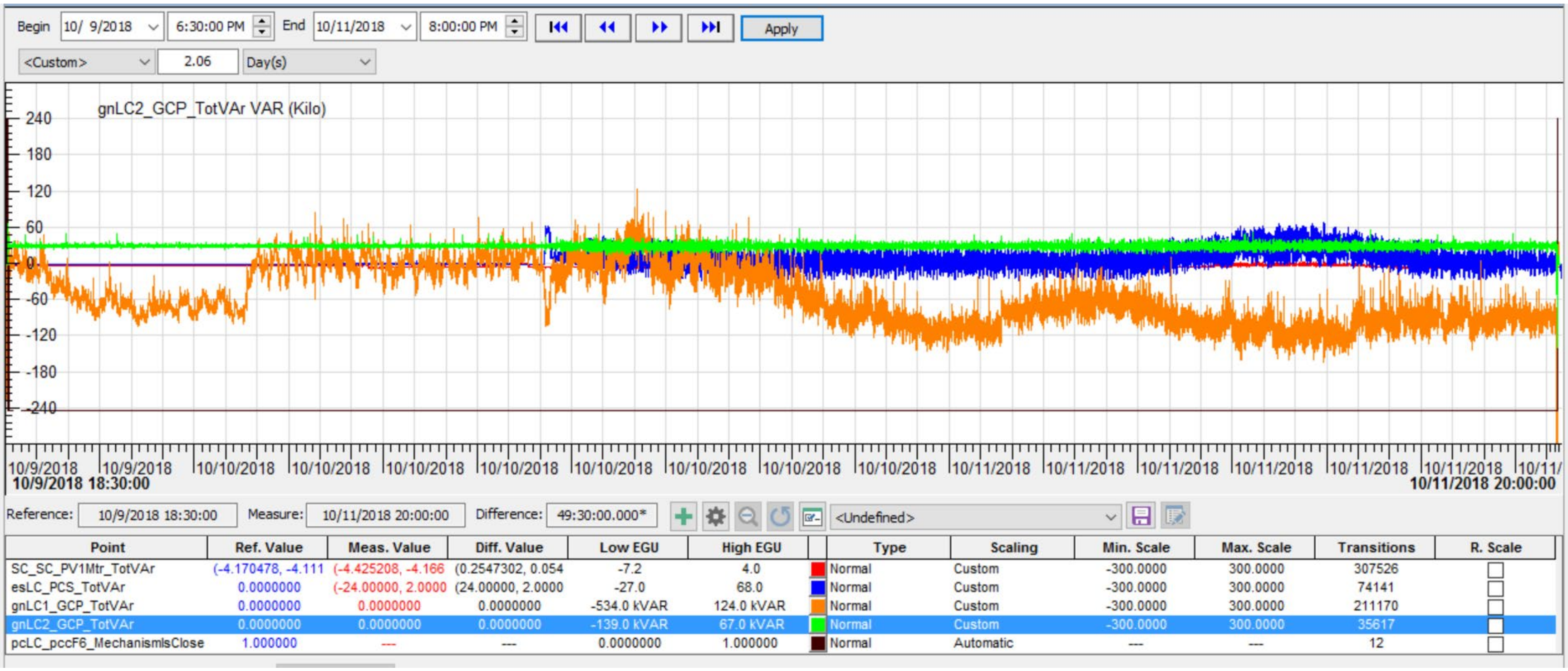
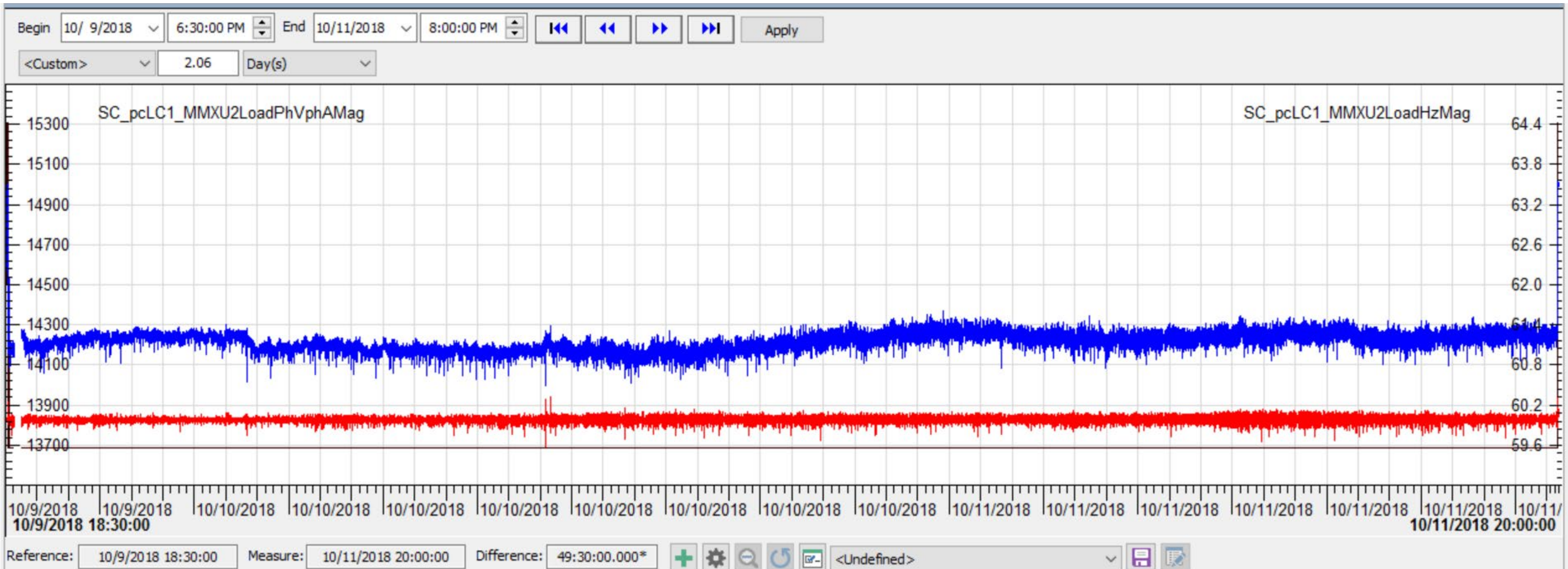


Figure 13. Reactive Power Output by Component for 48-Hour Islanded Operation



Point	Ref. Value	Meas. Value	Diff. Value	Low EGU	High EGU		Type	Scaling	Min. Scale	Max. Scale	Transitions	R. Scale
pcLC_pccF6_MechanismIsClose	1.000000	---	---	0.0000000	1.000000		Normal	Automatic	---	---	12	☐
SC_pcLC1_MMXU2LoadPhVphA	(14923.00, 14988.	---	---	14001.0	15019.0		Normal	Custom	13500.00	15500.00	280324	☐
SC_pcLC1_MMXU2LoadHzMag	(60.00000, 60.020	---	---	59.6	60.3		Normal	Custom	59.00000	65.00000	185529	☑

Figure 14. Reference Voltage and Frequency for 48-Hour Islanded Operation

5.4.1.1 Islanded Initiation

Islanding was officially initiated at 8:35PM on October 9th, with both generators starting up one minute before initiating islanding. Both generators were allowed to ramp up to approach base load before officially entering islanding mode. As initiation occurred at night, PV output was negligible. Figure 15 below shows real power output of all microgrid components upon initiation of islanding.

Figure 16 below shows reactive power output of all microgrid components upon initiation of islanding.

Figure 17 below shows relevant grid stability parameters, PCC voltage and frequency, for the beginning of the demonstration. Voltage drops over the first thirty seconds of islanded operation, but stabilizes shortly afterward, while frequency remains relatively stable. It was confirmed that Consumers utility voltage was about 5% above rated value; the islanded operation was performed at the rated voltage. Voltage drop was not because of any control issues

Figure 15. Real Power Output by Component for Islanded Initiation

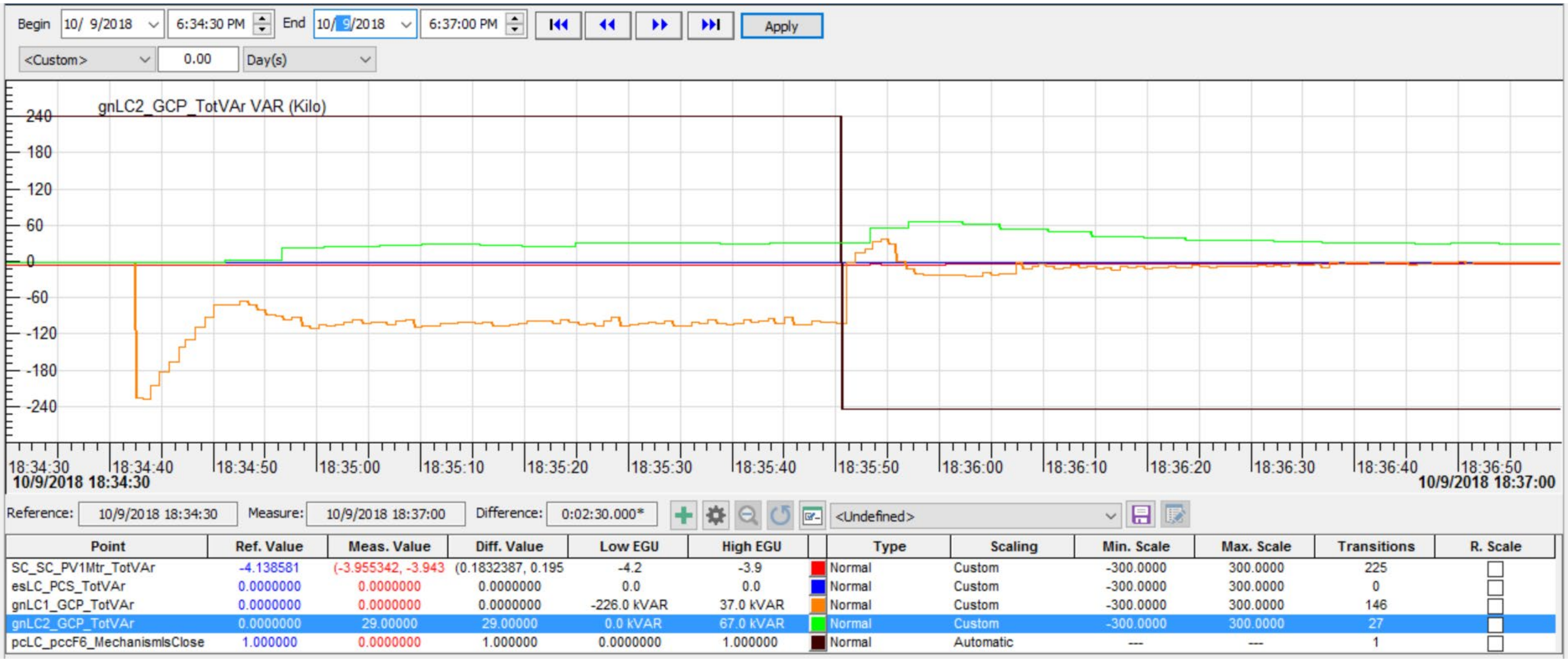


Figure 16. Reactive Power Output by Component for Islanded Initiation

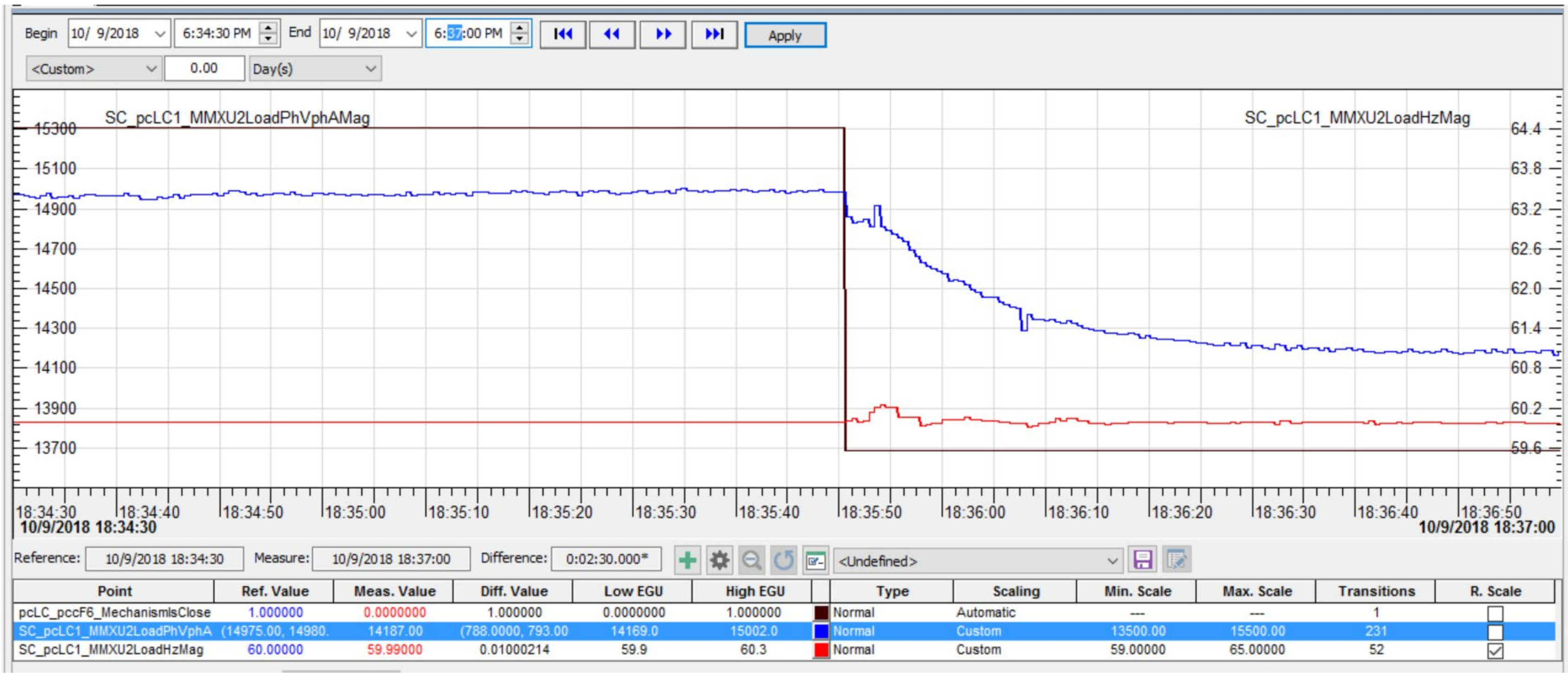


Figure 17. Reference Voltage and Frequency for Islanded Initiation

5.4.1.2 Islanded Termination

Islanded operation terminated at 9:50PM on October 11th, with both generators and the energy storage system operating at this point. After reclosing the connection to the utility grid, both generators ramped back down to zero output, with the Caterpillar generator bearing the brunt of reactive power compensation. Figure 18 below shows real power output for each microgrid component upon termination of islanding.

Figure 19 shows reactive power output for each microgrid component upon termination of islanding.

Figure 20 shows relevant grid stability parameters, PCC voltage and frequency, for the end of the demonstration. Voltage rises and stabilizes over approximately half a second, while frequency remains relatively stable.

Point	Ref. Value	Meas. Value	Diff. Value	Low EGU	High EGU	Type	Scaling	Min. Scale	Max. Scale	Transitions	R. Scale
SC_SC_PV1Mtr_TotW	0.09740200	0.1020760	0.004674003	0.1	0.1	Normal	Custom	-200.0000	500.0000	228	
gnLC1_GCP_TotW	331.0000	0.0000000	331.0000	0.0 kW	342.0 kW	Normal	Custom	-200.0000	500.0000	116	
esLC_PCS_TotW	-7.000000	0.0000000	7.000000	-9.0	79.0	Normal	Custom	-200.0000	500.0000	39	
gnLC2_GCP_TotW	176.0000	0.0000000	176.0000	-6.0 kW	202.0 kW	Normal	Custom	-200.0000	500.0000	20	
pcLC_pccF6_MechanismIsClose	0.0000000	1.000000	1.000000	0.0000000	1.000000	Normal	Automatic	---	---	1	

Figure 18. Real Power Output by Component for Islanded Termination

Figure 19. Reactive Power Output by Component for Islanded Termination

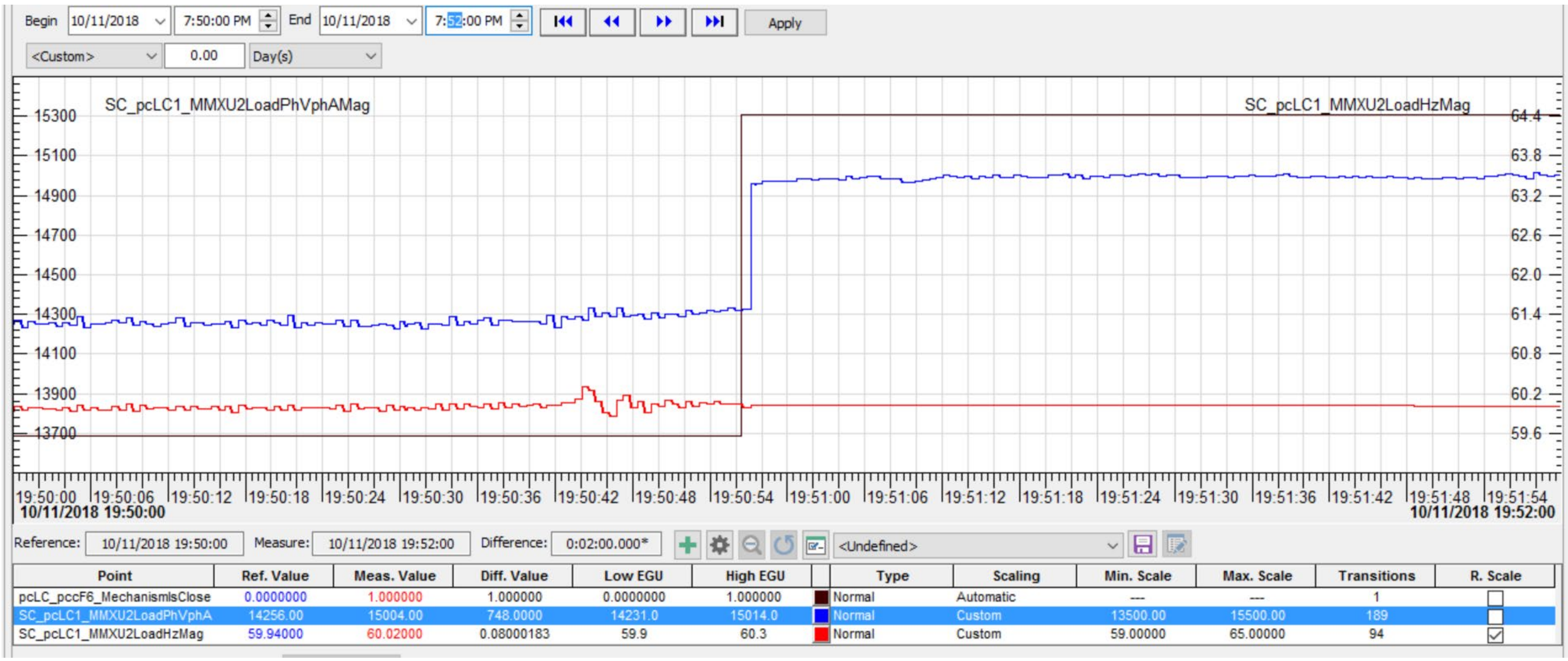


Figure 20. Reference Voltage and Frequency for Islanded Termination

5.4.2 GRID-CONNECTED OPERATION WITH MAX POWER EXPORT

Grid-connected operation was tested from 7:50AM, October 12, 2018 through 11:50AM, October 12, 2018 (local time EDT), for a total of 4 hours. The purpose of this demonstration was to show genset assets handling baseload and voltage/frequency regulation, and allowing for the export of renewable energy (PV).

For this demonstration, the Caterpillar genset operated at 600kW for the first two (2) hours, 675kW for the next hour, and 750kW for the final hour. This testing procedure was used to minimize risk of damaging this generator. The Cummins genset operated at a consistent 400kW for the entirety of the testing period, its derated maximum.

PV output was limited due to cloudy conditions, with a momentary maximum output of 124.9kW.

Over this testing window, the energy storage system inverter was not functional.

Figure 21 below shows real power output for each microgrid component, as well as the net real power output as measured across the point of common coupling. This final value, shown in brown, has a negative value associated with net power export, and a positive value for importing power.

Figure 22 below shows reactive power output for each component over the same time period.

Figure 23 below shows relevant grid stability parameters, PCC voltage and frequency, for the entirety of the demonstration. Voltage and frequency remain relatively stable, as the utility grid is being used as the reference.

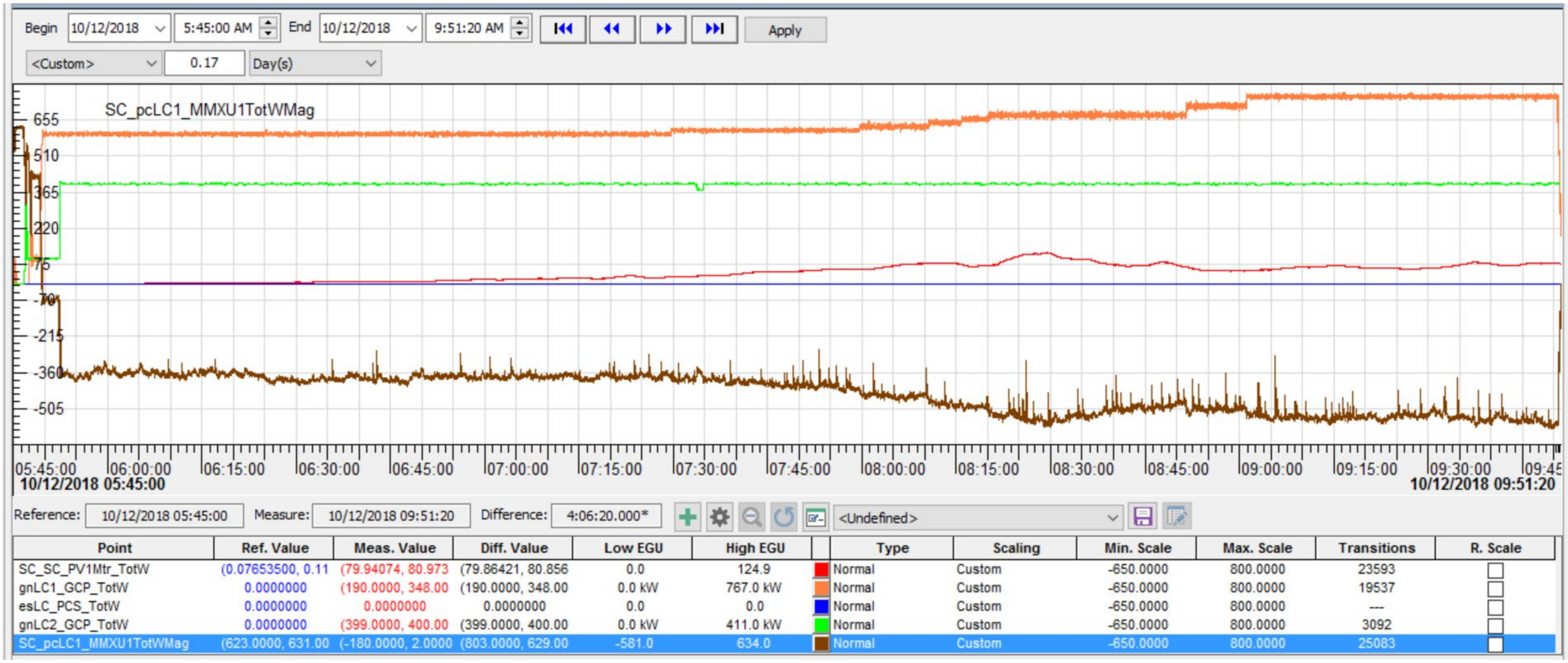


Figure 21. Real Power Output by Component for 4-Hour Grid Operation

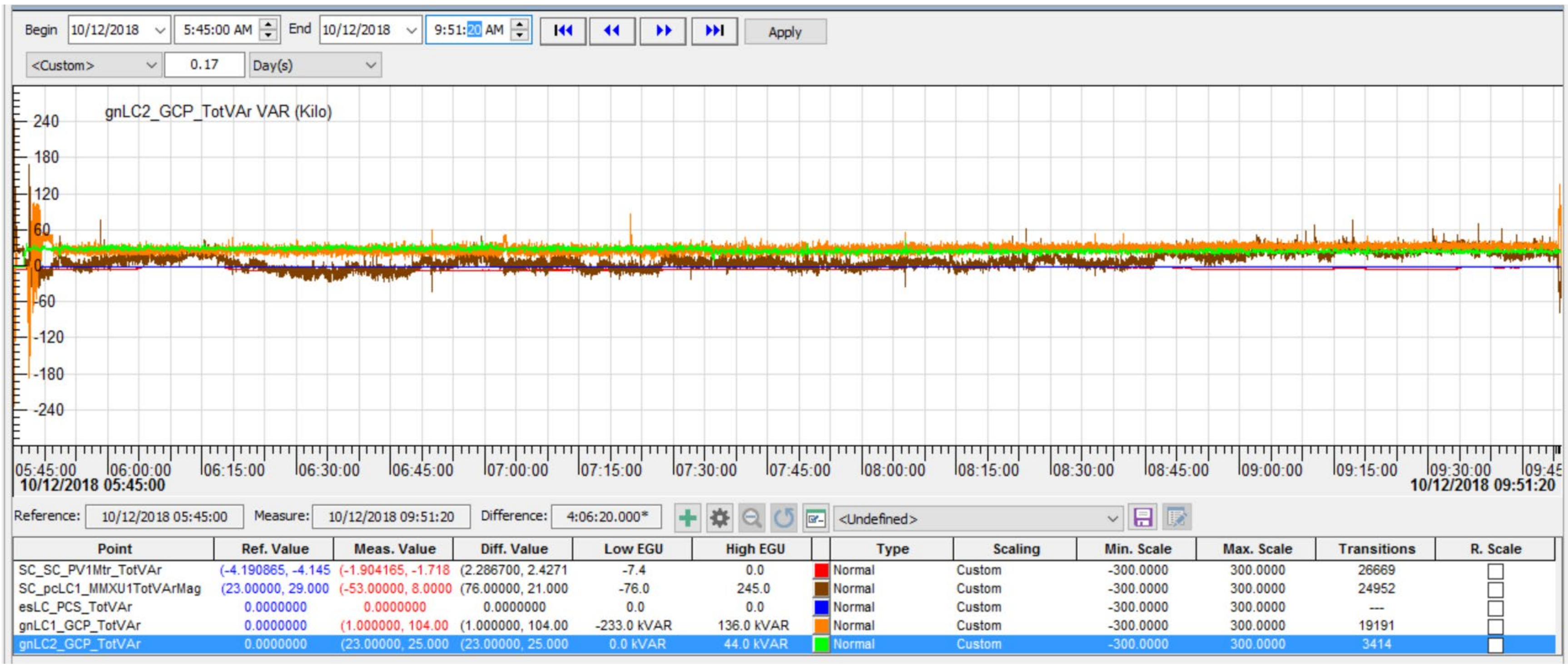


Figure 22. Reactive Power Output by Component for 4-Hour Grid Operation

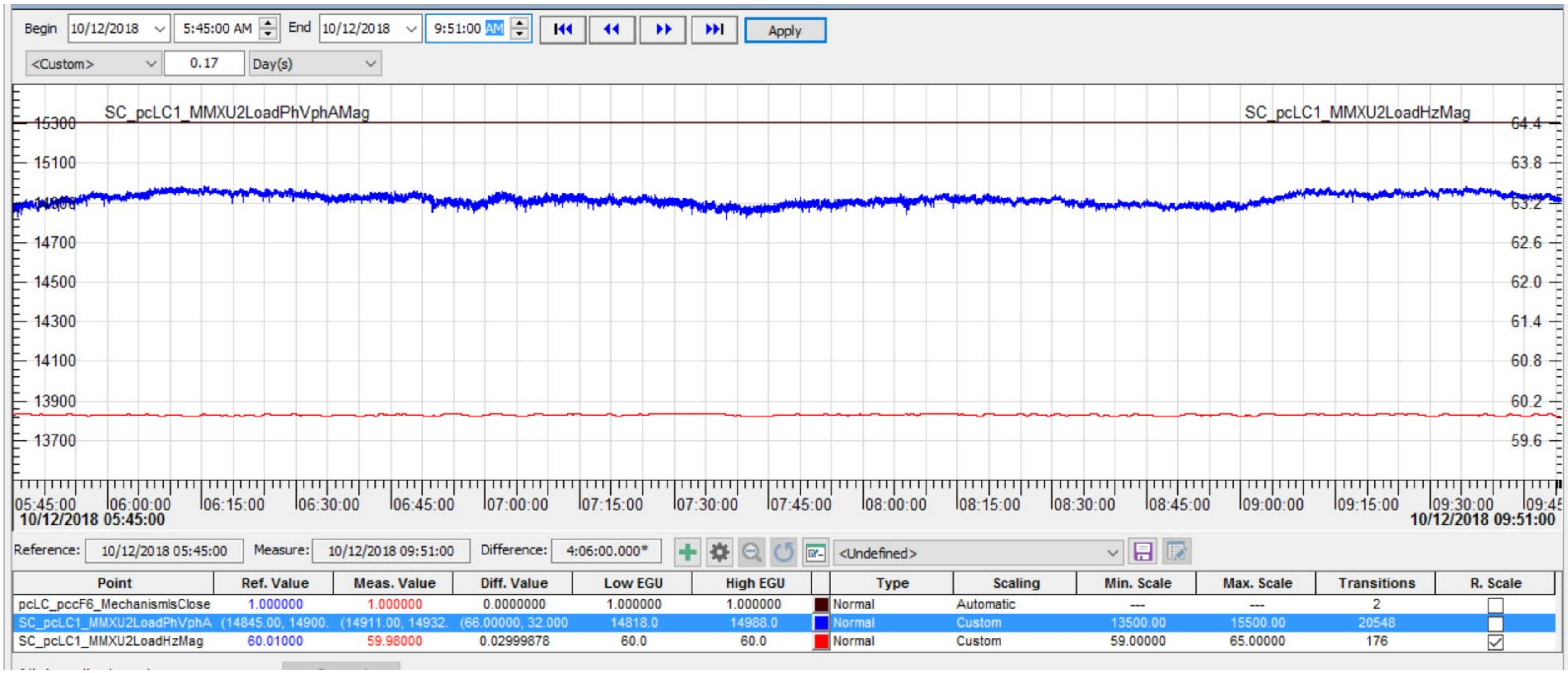


Figure 23. Reference Voltage and Frequency for 4-Hour Grid Operation

5.4.2.1 Grid-Connected Operation Initiation

The grid-connected demonstration fully commenced at 7:50AM on October 12th. The initiation included negligible PV output. Figure 24 below shows real power output for each microgrid component for this initial time period. Again, brown represents output across the point of common coupling. Figure 25 shows reactive power output for each component over the same time period.

Figure 26 below shows relevant grid stability parameters, PCC voltage and frequency, for the beginning of the demonstration. Voltage and frequency remain relatively stable, as the utility grid is being used as the reference.

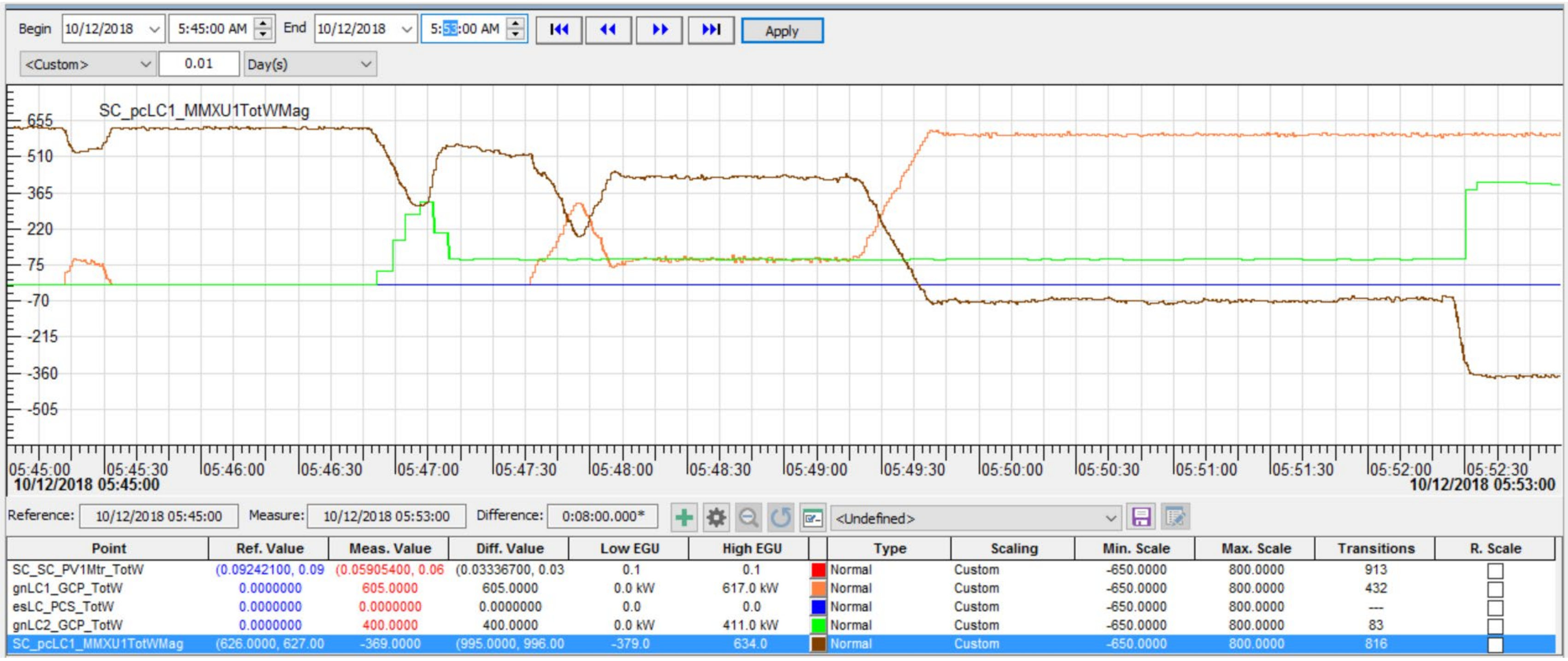
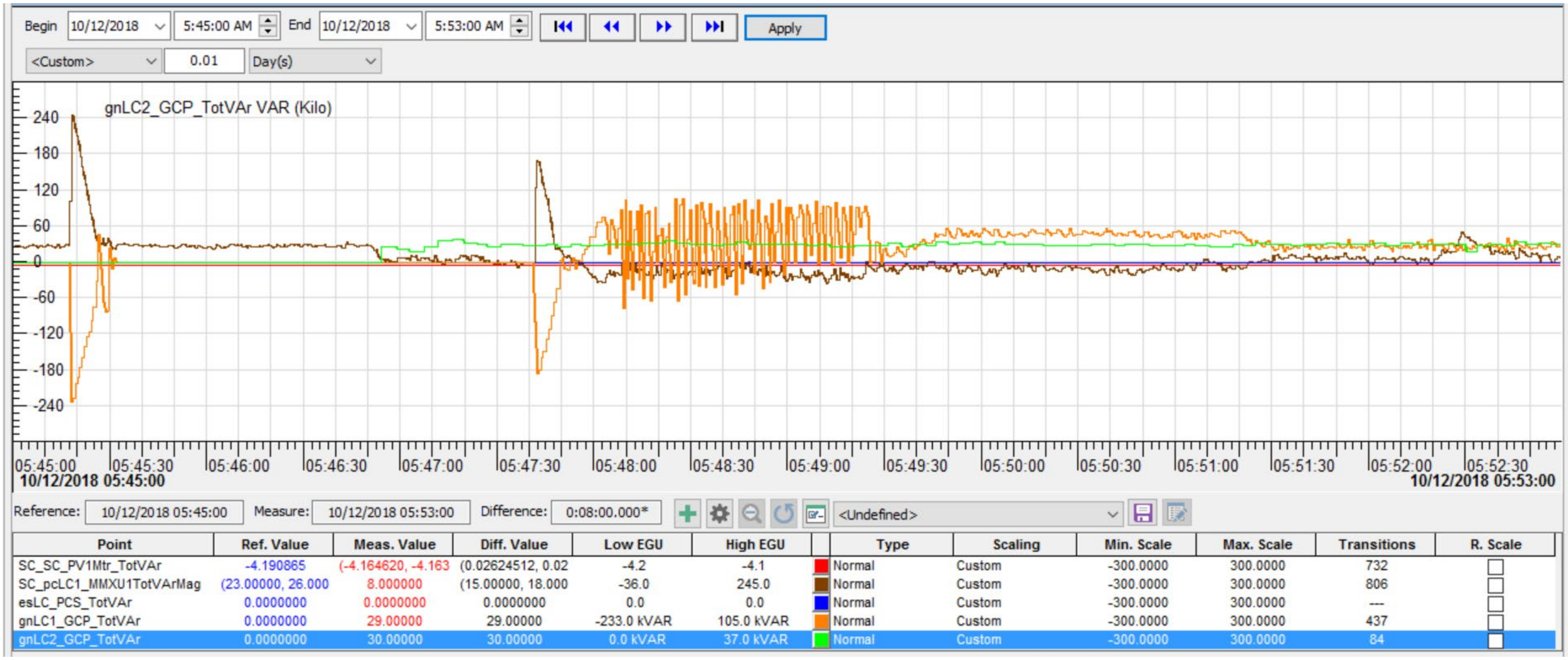


Figure 24. Real Power Output by Component for Grid Operation Initiation



Point	Ref. Value	Meas. Value	Diff. Value	Low EGU	High EGU		Type	Scaling	Min. Scale	Max. Scale	Transitions	R. Scale
SC_SC_PV1Mtr_TotVAr	-4.190865	(-4.164620, -4.163	(0.02624512, 0.02	-4.2	-4.1		Normal	Custom	-300.0000	300.0000	732	
SC_pcLC1_MMXU1TotVArMag	(23.00000, 26.000	8.000000	(15.00000, 18.000	-36.0	245.0		Normal	Custom	-300.0000	300.0000	806	
esLC_PCS_TotVAr	0.0000000	0.0000000	0.0000000	0.0	0.0		Normal	Custom	-300.0000	300.0000	---	
gnLC1_GCP_TotVAr	0.0000000	29.00000	29.00000	-233.0 kVAR	105.0 kVAR		Normal	Custom	-300.0000	300.0000	437	
gnLC2_GCP_TotVAr	0.0000000	30.00000	30.00000	0.0 kVAR	37.0 kVAR		Normal	Custom	-300.0000	300.0000	84	

Figure 25. Reactive Power Output by Component for Grid Operation Initiation

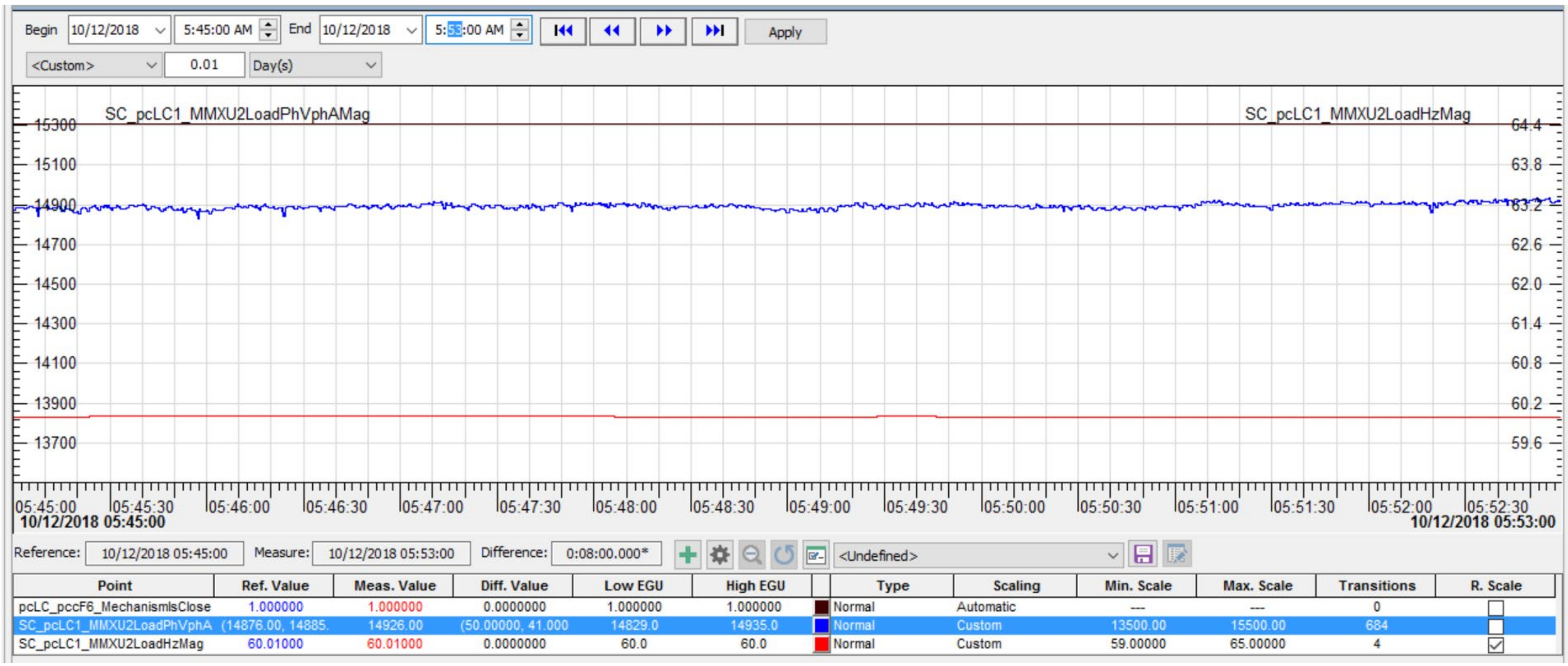


Figure 26. Reference Voltage and Frequency for Grid Operation Initiation

5.4.2.2 Grid-Connected Operation Termination

Figure 27 below shows real power output for each microgrid component at the end of the 4-hour demonstration period. The generators were allowed to run at reduced power output for approximately two hours after this time, but the purpose of this 4-hour period was to demonstrate operation at near-full load. Figure 28 shows the reactive power output by each microgrid component over the same time period.

Figure 29 below shows relevant grid stability parameters, PCC voltage and frequency, for the beginning of the demonstration. Voltage and frequency remain relatively stable, as the utility grid is being used as the reference.

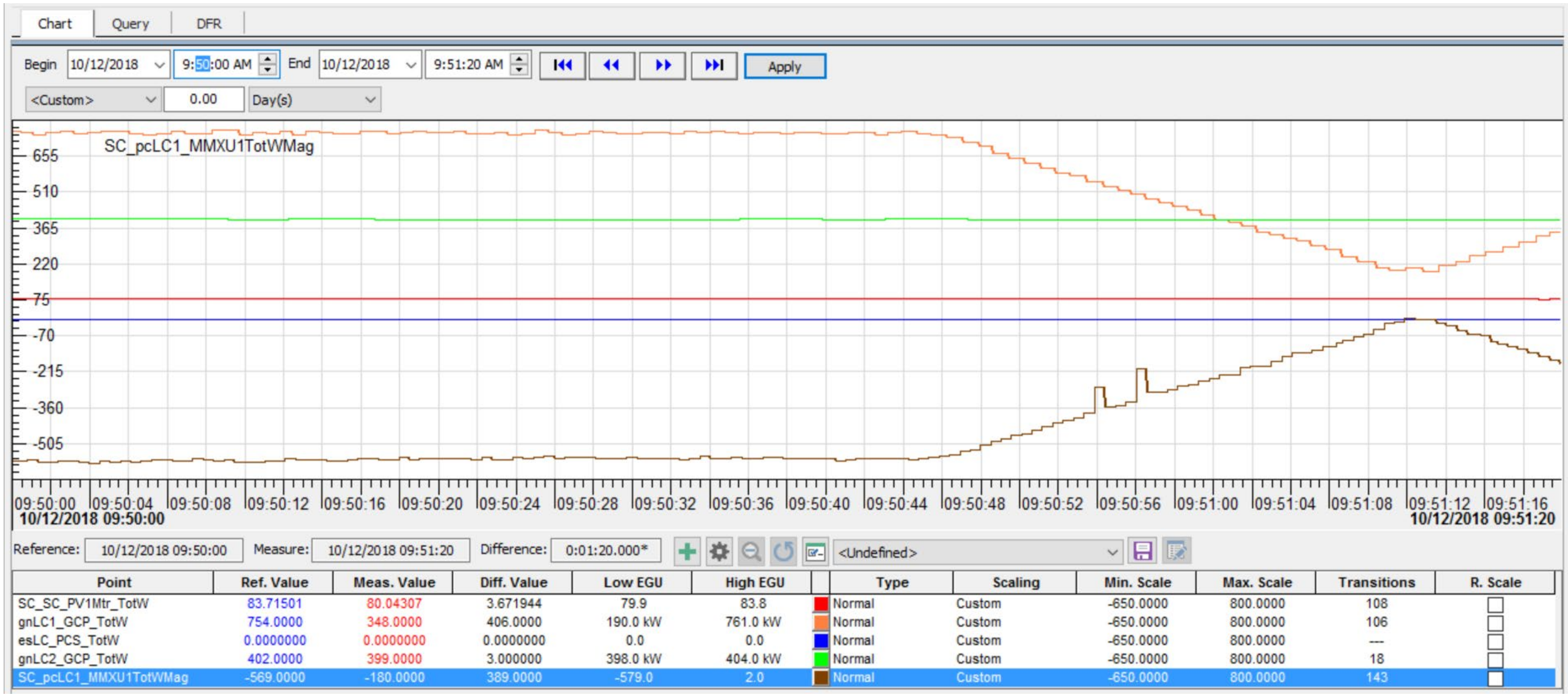


Figure 27. Real Power Output by Component for Grid Operation Termination

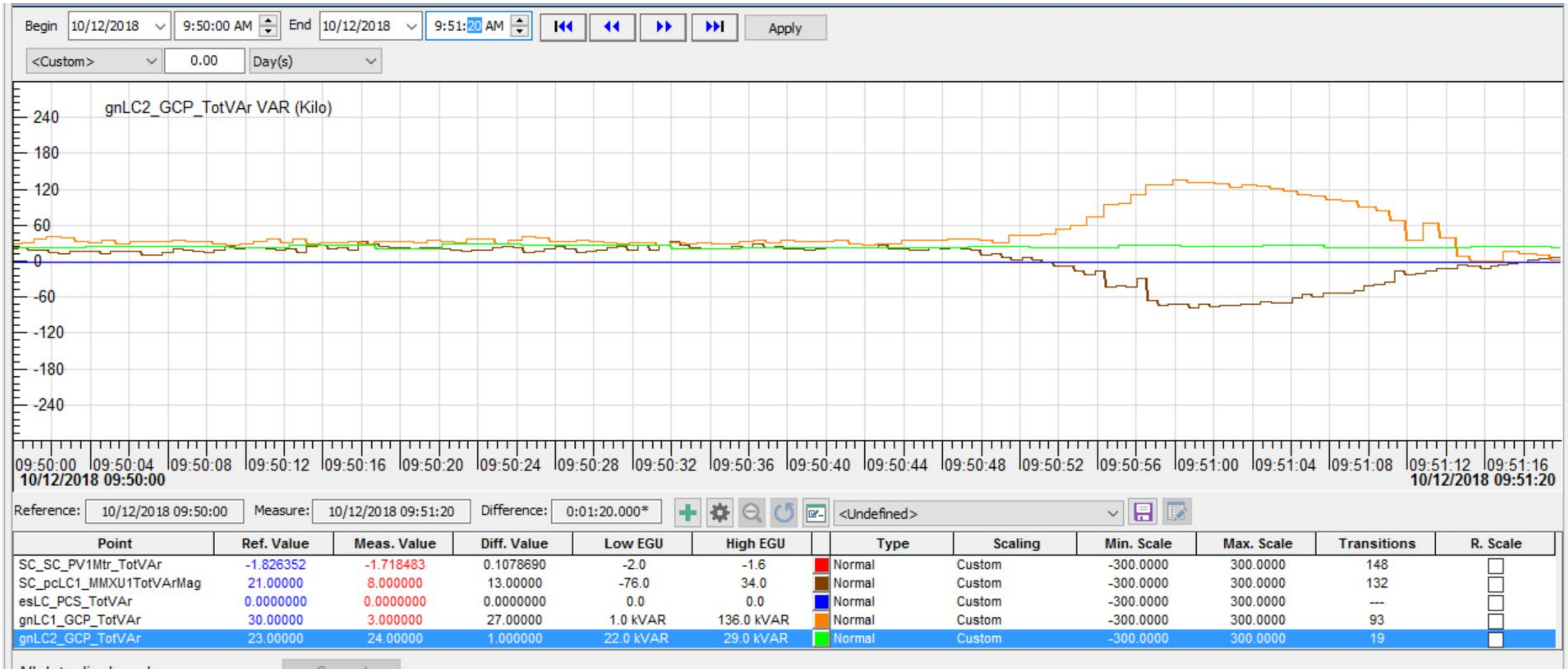
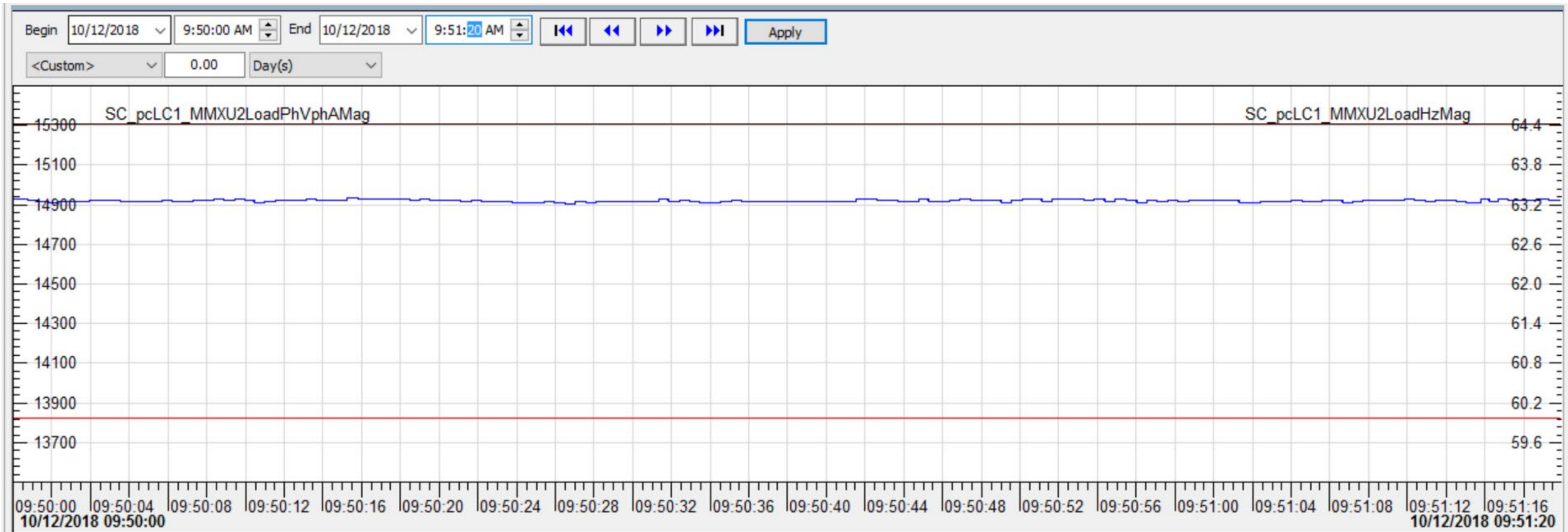


Figure 28. Reactive Power Output by Component for Grid Operation Termination



Point	Ref. Value	Meas. Value	Diff. Value	Low EGU	High EGU	Type	Scaling	Min. Scale	Max. Scale	Transitions	R. Scale
pcLC_pccF6_MechanismIsClose	1.000000	1.000000	0.0000000	1.000000	1.000000	Normal	Automatic	---	---	0	☐
SC_pcLC1_MMXU2LoadPhVphA	14931.00	14924.00	7.000000	14906.0	14936.0	Normal	Custom	13500.00	15500.00	98	☐
SC_pcLC1_MMXU2LoadHzMag	59.98000	59.98000	0.0000000	60.0	60.0	Normal	Custom	59.00000	65.00000	0	☑

Figure 29. Reference Voltage and Frequency for Grid Operation Termination

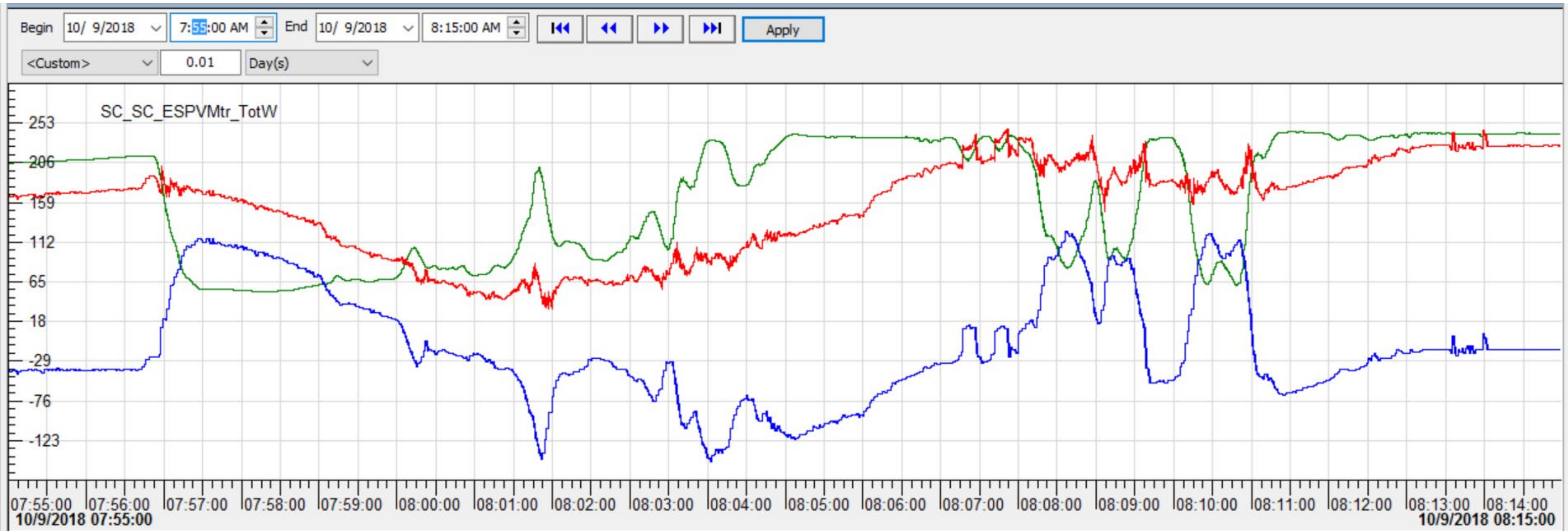
5.4.3 High-Penetration PV Operation

High-penetration PV operation was tested from 9:55AM, October 9, 2018 through 10:15AM, October 9, 2018 (local time EDT), for a total of twenty (20) minutes. This testing period was able to deliver significantly higher PV output than either of the demonstration testing periods. Figure 30 below shows PV and energy storage real power output over the course of this period, with their resultant combined real power output shown in red, with a significantly dampened ramp rate.

Figure 31 shows reactive power output of PV and energy storage during the same period, with combined output also in red.

Figure 32 shows relevant grid stability parameters, PCC voltage and frequency, for the same period.

The PV is paired with the energy storage providing integration of the string inverters with the microgrid controls. Where the PV produces above demand and the microgrid is islanded, the energy storage will consume energy to support load leveling of PV. Where the PV exceeds capacity of the energy storage, curtailment can be accomplished by command to string inverter or opening the switch gear.



Point	Ref. Value	Meas. Value	Diff. Value	Low EGU	High EGU	Type	Scaling	Min. Scale	Max. Scale	Transitions	R. Scale
SC_SC_ESPVMtr_TotW	(166.9588, 167.01	226.6755	(59.71667, 59.662	34.0	246.4	Normal	Custom	-170.0000	300.0000	2610	
SC_SC_PV1Mtr_TotW	(205.9588, 206.01	240.6755	(34.71667, 34.662	54.4	243.5	Normal	Custom	-170.0000	300.0000	1961	
esLC_PCS_TotW	-39.00000	-14.00000	25.00000	-147.0	125.0	Normal	Custom	-170.0000	300.0000	652	

Figure 30. Real Power Output of PV and Energy Storage

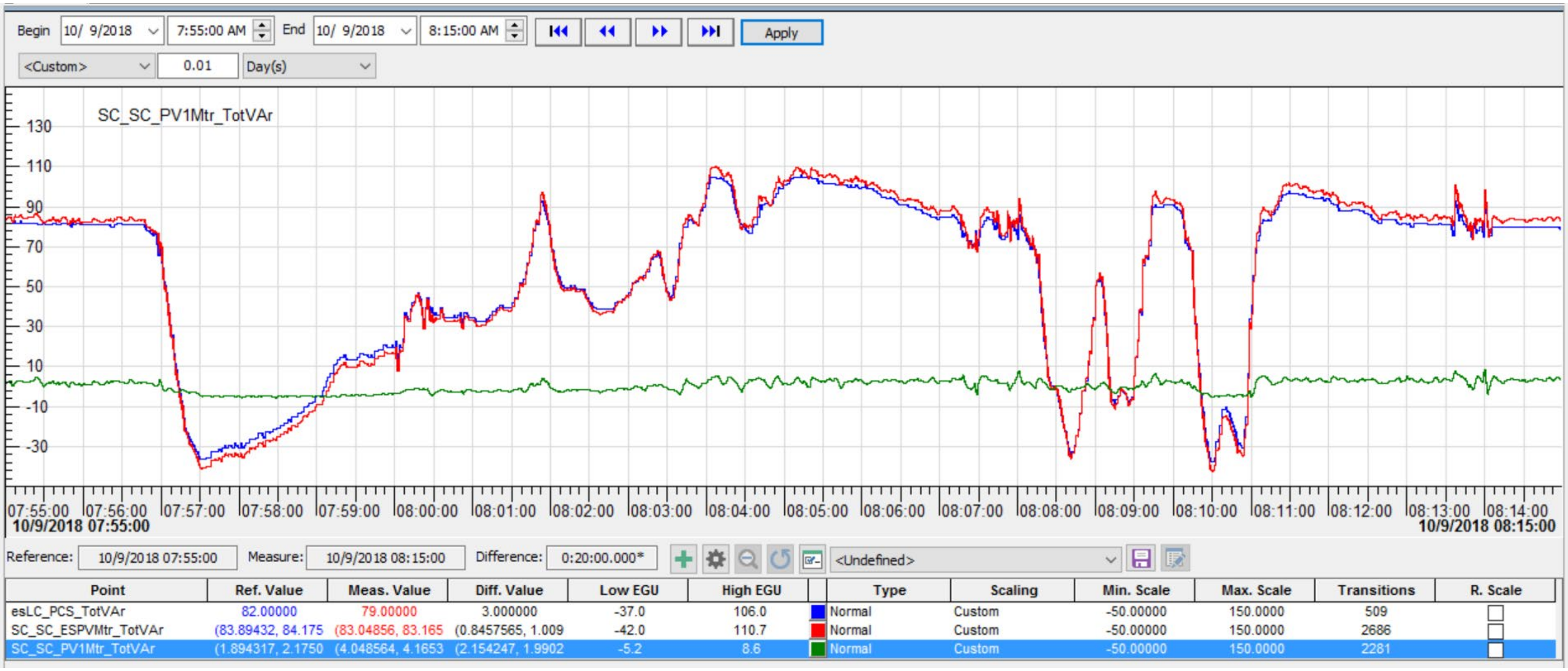
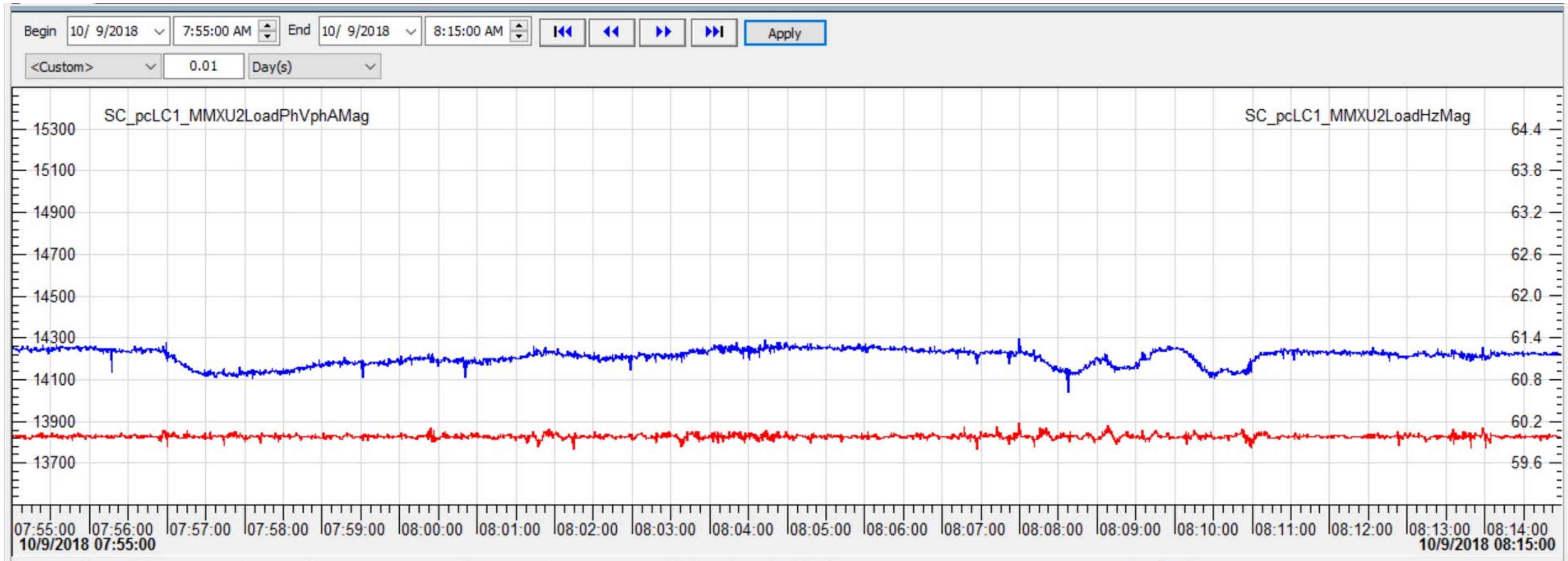


Figure 31. Reactive Power Output of PV and Energy Storage



Point	Ref. Value	Meas. Value	Diff. Value	Low EGU	High EGU	Type	Scaling	Min. Scale	Max. Scale	Transitions	R. Scale
SC_pcLC1_MMXU2LoadHzMag	(59.98000, 60.000	60.00000	(0.02000046, 0.00	59.8	60.2	Normal	Custom	59.00000	65.00000	1393	☑
SC_pcLC1_MMXU2LoadPhVphA	(14252.00, 14259.	(14219.00, 14227.	(33.00000, 32.000	14046.0	14297.0	Normal	Custom	13500.00	15500.00	1778	☐

Figure 32. Reference Voltage and Frequency during High-Penetration PV

5.5 SAMPLING PROTOCOL

In order to track and analyze the performance of the microgrid, the following parameters were monitored at a rate of approximately two (2) samples per second. The data was only recorded if there was a change in its value of >0.2%. No uniform sampling rate was used.

- CAT generator real power (kW)
- CAT generator reactive power (kVA)
- Energy storage system real power (kW)
- Energy storage system reactive power (kVA)
- Photo voltaic system real power (kW)
- Photo voltaic system reactive power (kVA)
- Point of common coupling real power (kW)
- Point of common coupling reactive power (kVA)
- Point of common coupling grid voltage (V)
- Point of common coupling load voltage (V)
- Point of common coupling slip frequency (Hz)
- Point of common coupling angle between load and grid (degrees)

The following variables were monitored at a rate of approximately one (1) sample every five (5) seconds.

- CAT generator Phase A voltage (V)
- CAT generator Phase B voltage (V)
- CAT generator Phase C voltage (V)
- Cummins generator real power (kW)
- Cummins generator reactive power (kVA)

The following variables were monitored at a rate of approximately one (1) sample every ninety (90) seconds.

- Point of common coupling grid frequency (Hz)
- Point of common coupling load frequency (Hz)

The following variable represented the connection between the microgrid and the utility-owned grid and was monitored on a change-of-state basis.

- Point of common coupling switch status (Binary)

Each variable was monitored, and samples collected via standard COTS equipment protocol.

The following variables were not monitored for grid-connected operation:

- Point of common coupling switch status. The status never changes, as this variable is relevant to islanded operation.
- Point of common coupling angle between load and grid. The grid acts as the reference for this demonstration.
- Point of common coupling slip frequency. Again, the grid acts as the reference for this demonstration.
- Energy storage system real power. The Go-Electric inverter was not functional within this testing period.
- Energy storage system reactive power. The Go-Electric inverter was not functional within this testing period.

The following variables were not monitored for islanded operation:

- Point of common coupling real power. No power transfer between the microgrid and utility occurs in islanded operation.
- Point of common coupling reactive power. Again, no power transfer between the microgrid and utility occurs in islanded operation.

5.6 SAMPLING RESULTS

Additional metered sampling results can be found in the below figures. Generator 1 refers to the Caterpillar genset, and Generator 2 refers to the Cummins genset.

5.6.1 4-Hour Grid-Operation Plots

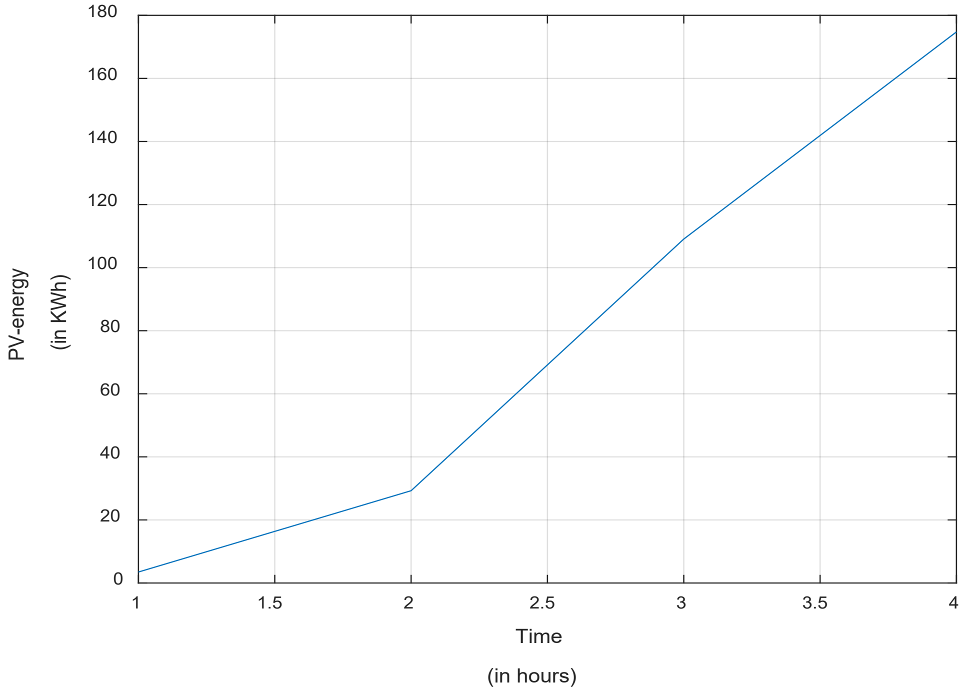


Figure 33. PV Energy in Grid Operation Demonstration

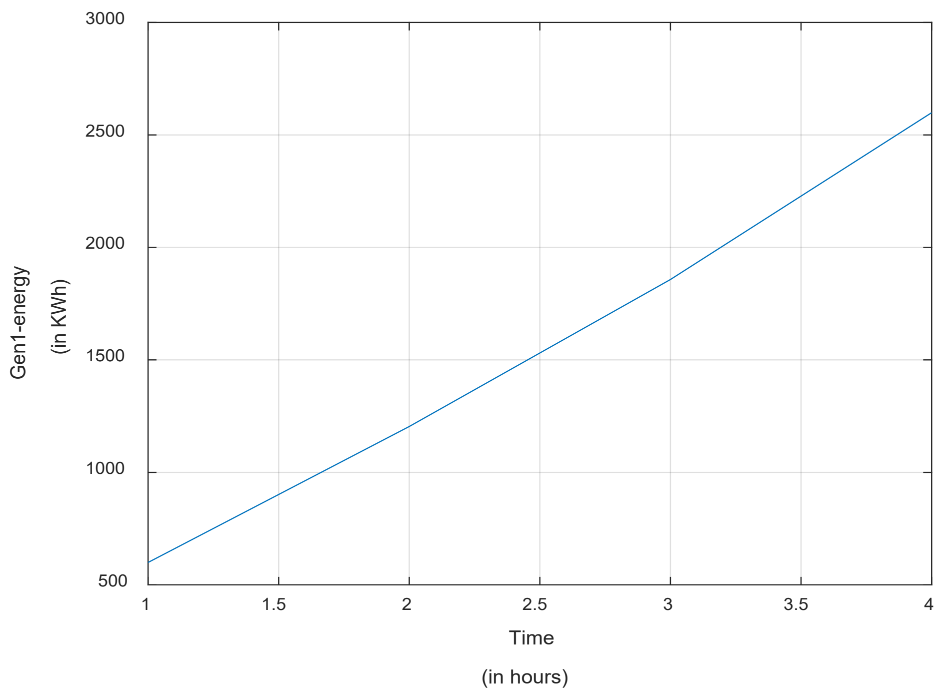


Figure 34. Caterpillar Genset Energy in Grid Operation Demonstration

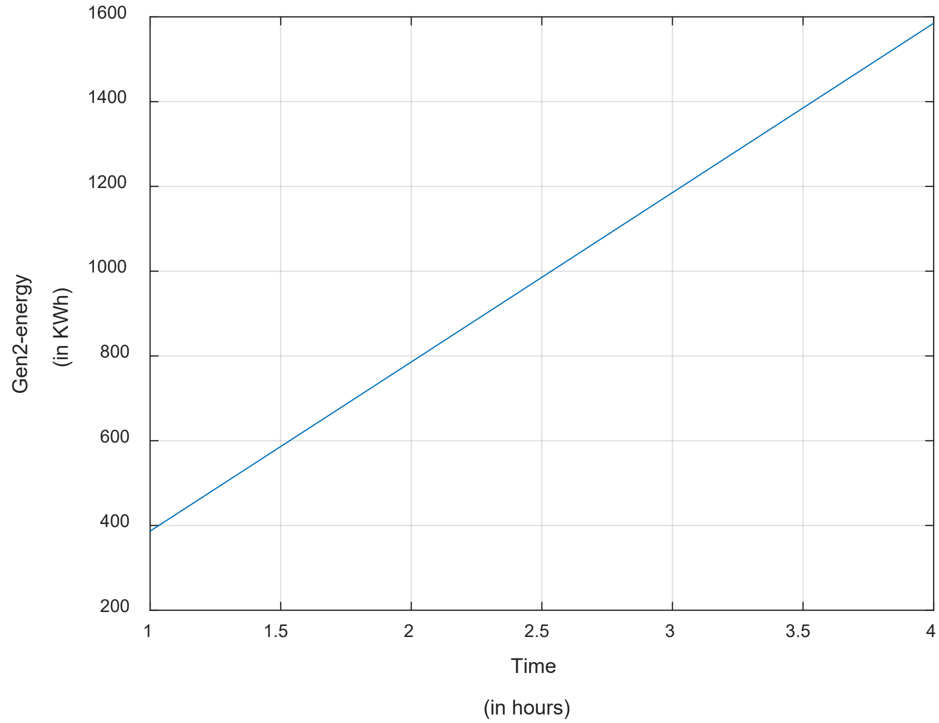


Figure 35. Cummins Genset Energy in Grid Operation Demonstration

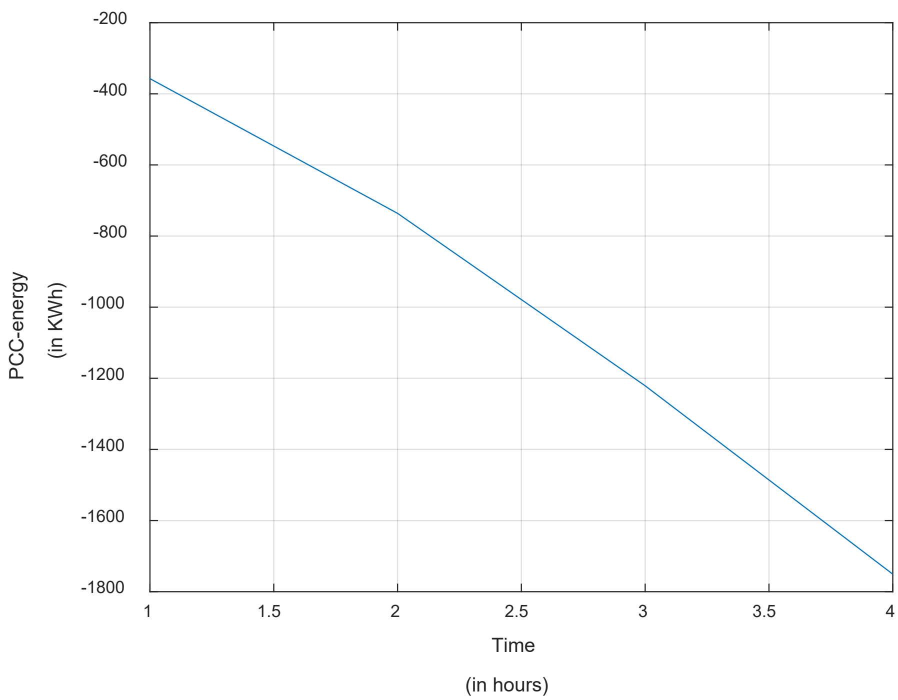


Figure 36. PCC Energy in Grid Operation Demonstration

5.6.2 48-Hour Islanded Operation Plots

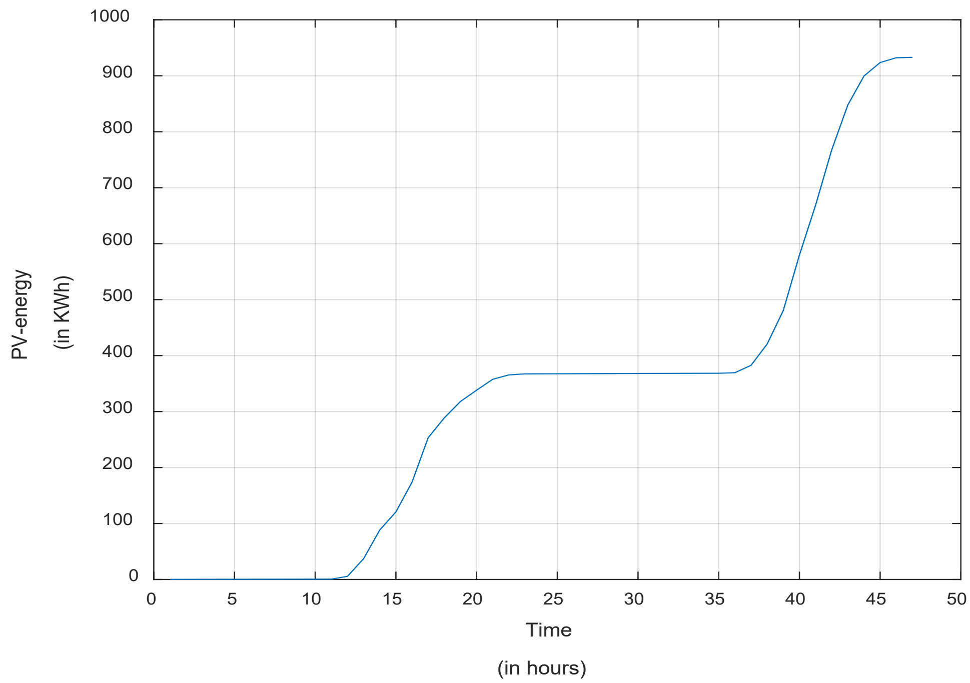


Figure 37. PV Energy in Islanded Operation Demonstration

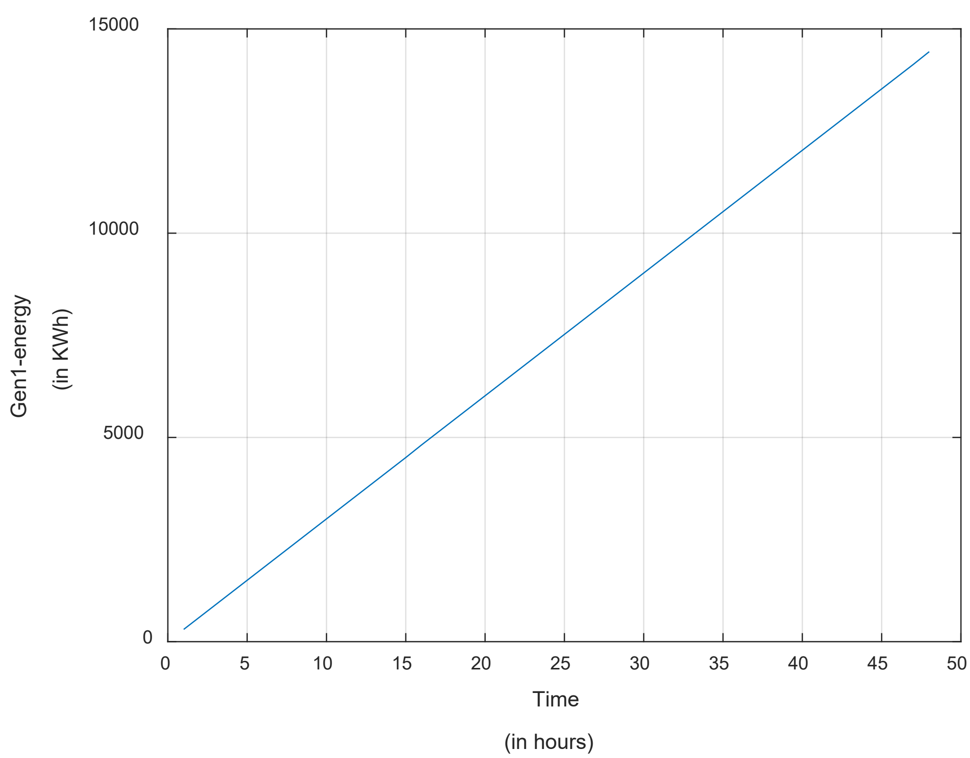


Figure 38. Caterpillar Genset Energy in Islanded Operation Demonstration

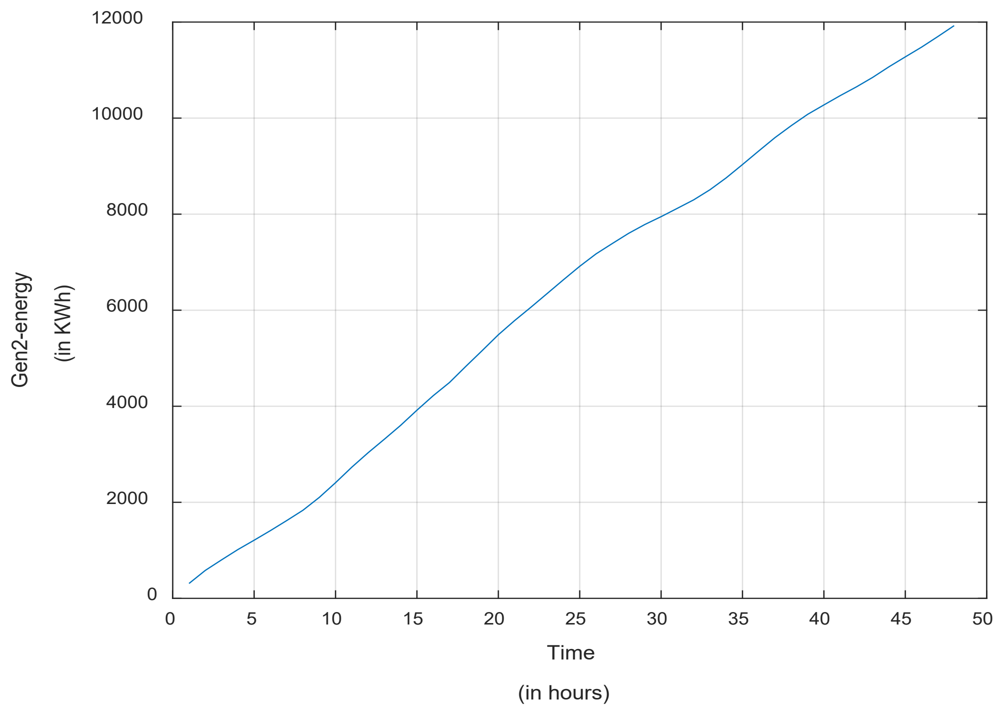


Figure 39. Cummins Genset Energy in Islanded Operation Demonstration

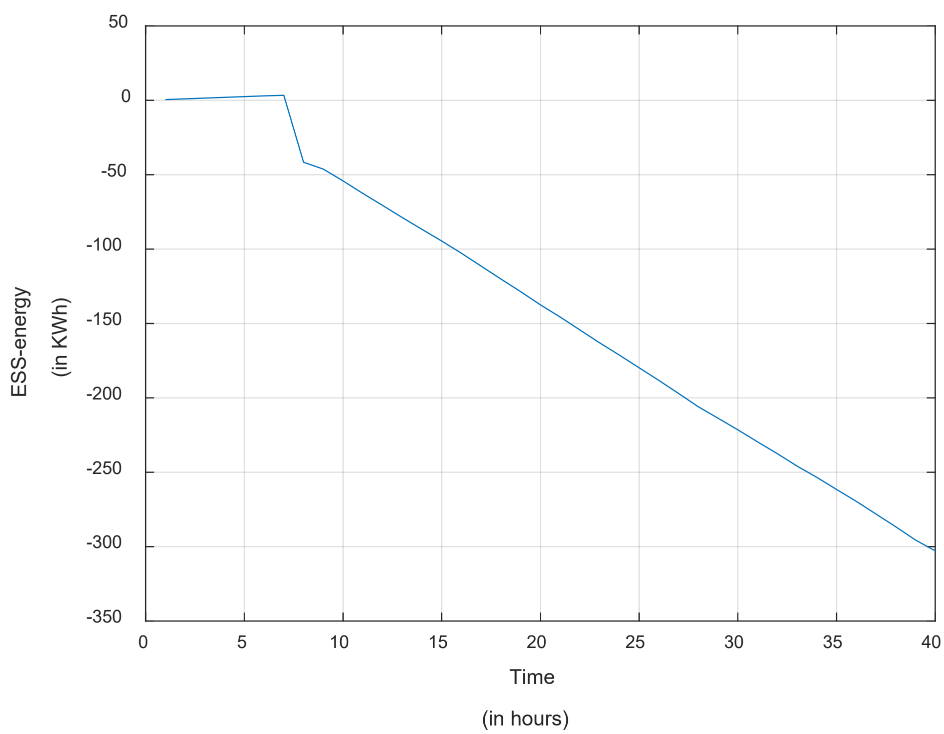


Figure 40. Energy Storage System Energy in Islanded Operation Demonstration

6.0 PERFORMANCE ASSESSMENT

6.1 EXPORT ENERGY VALUE AS COMPARED TO THE MISO RESERVE MARKET REAL TIME PRICING

The success criteria were determined to be the valuation of exported energy and demand being greater than the cost of consumed energy and limited export of PV.

6.2 DISPATCH AND GRID SYNCHRONIZATION OF DISTRIBUTED GENERATION FOR BASE LOAD

The success criteria were determined to be synchronization and islanding from the utility with baseload supported by both generators, with no loss of microgrid loads. This performance objective was confirmed successful at the beginning and termination of the islanded operation demonstration, presented in Section 5.4.1.1 and Section 5.4.2.2.

6.3 DISPATCH AND TRANSITION OF BASE LOAD BETWEEN DG

The success criteria were determined to be stable transfer of the baseload between generators without power quality issues, and no loss of microgrid loads. This performance objective was confirmed successful in the beginning of the islanded operation demonstration, presented in Section 5.4.1.1.

6.4 INTENTIONAL ISLANDING OF MICROGRID FROM UTILITY ON BASE ENERGY MANAGER OR UTILITY COMMAND

The success criteria were determined to be effective execution of islanding SCADA command, with no loss of microgrid loads. This performance objective was confirmed successful in the 48-hour islanding demonstration presented in Section 5.4.1, with

6.5 RESYNCHRONIZATION OF MICROGRID TO UTILITY ON BASE ENERGY MANAGER OR UTILITY COMMAND

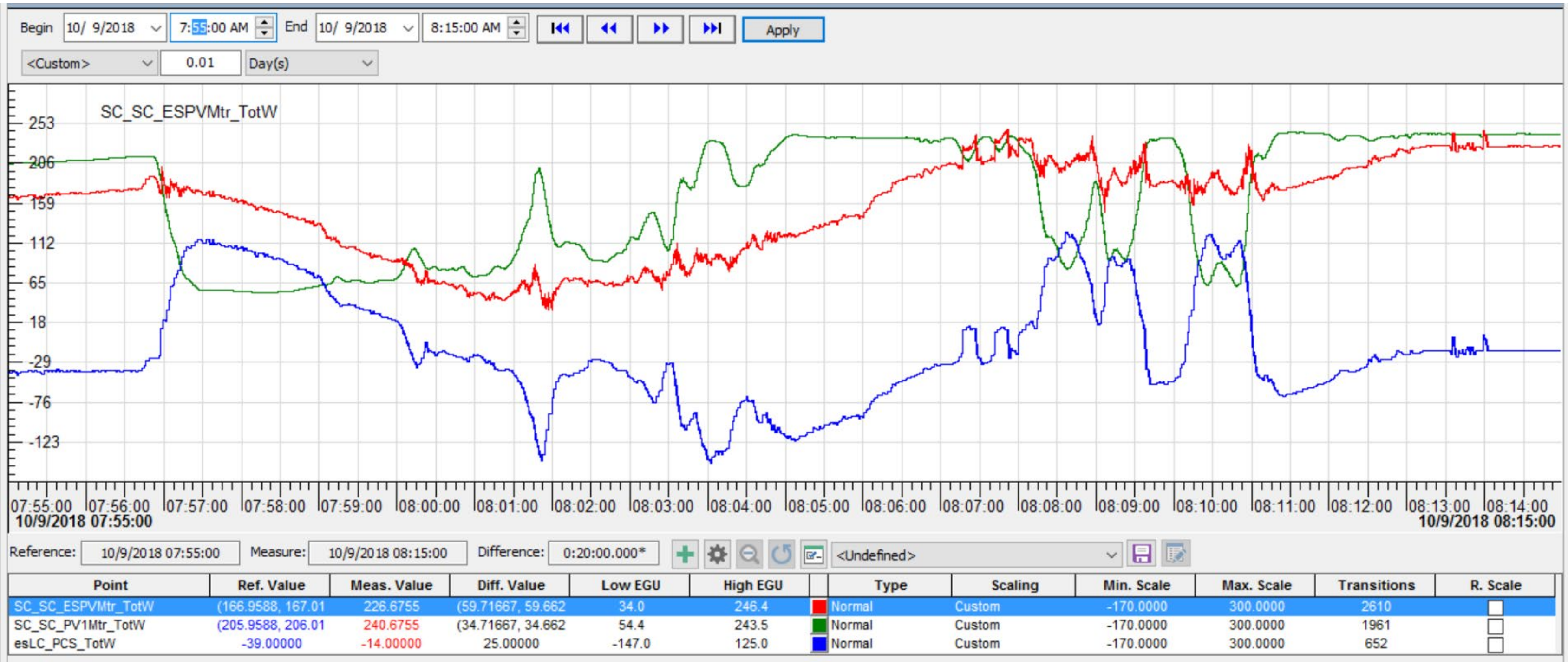
The success criteria were determined to be effective execution of resynchronization and reconnection from islanded operation to the utility feeder following SCADA command, with no loss of microgrid loads. This performance objective was confirmed successful at the end of the 48-hour islanding demonstration, presented in Section 5.4.1.2.

6.6 CONTROLLED EXPORT OF POWER TO UTILITY DISTRIBUTION FEEDER FROM MICROGRID IN COMPLIANCE WITH INTERCONNECTION AGREEMENT AND REGULATIONS

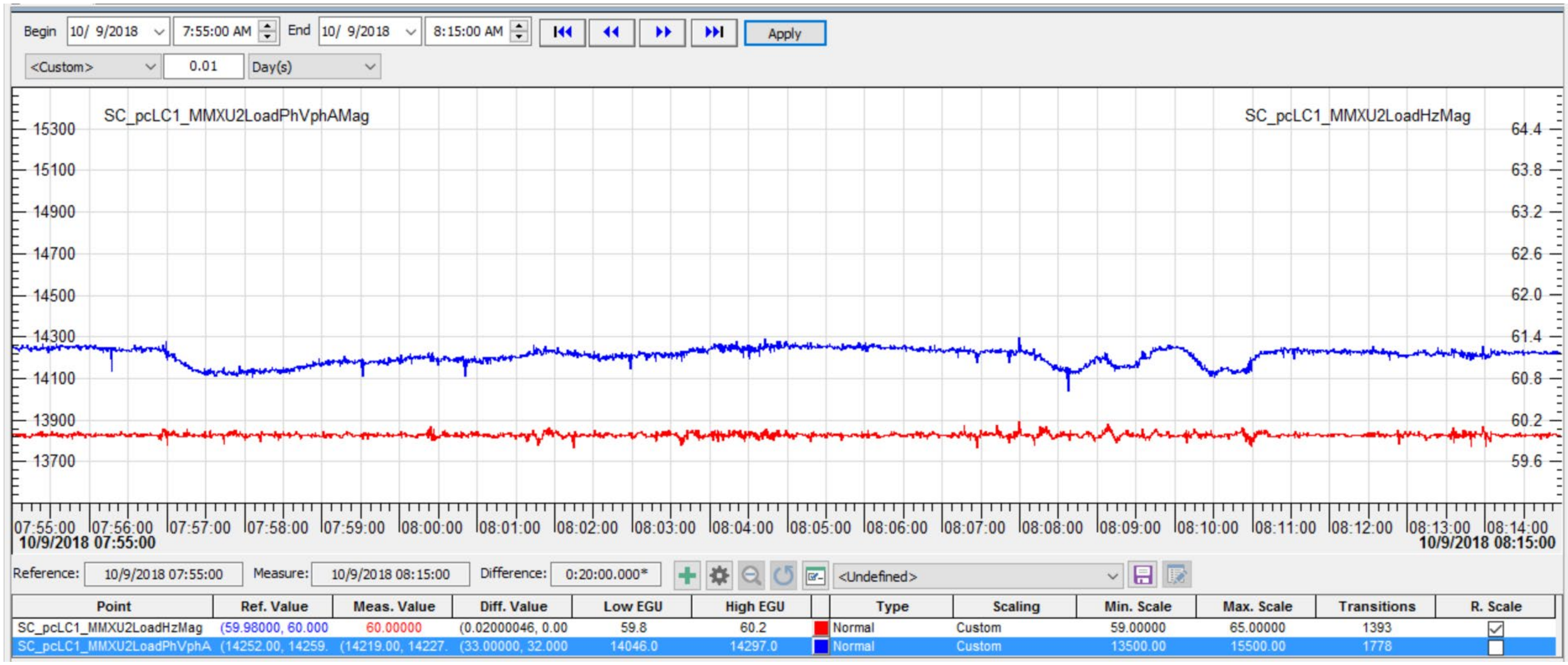
The success criteria were determined to be effective export of renewable energy to the utility feeder while local DG meets baseload demand with no loss in microgrid loads, while complying with IEEE1547, ANSI C84.1, MPSC R460.601 – R460.656, and interconnection agreement capacity restriction. This performance objective was confirmed successful with the 4-hour grid-tied operation demonstration in Section 5.4.2, which showed net export of power across the PCC.

6.7 RAMP RATE CONTROL OF PV POWER TRANSITIONS WITH SUPPORT FROM ENERGY STORAGE

The success criteria for this performance objective were determined to be a 60 second effective ramp down of power given PV reduction in cloudy conditions, with a stable bus of voltage maintained within +10%/-12% and frequency maintained within 60.3Hz/59.3Hz. The following figure represents the period of testing covered in Section 5.4.3, where red represents the combined real power output of PV and the power-optimized energy storage system. Though PV output drops sharply at 9:56AM over the course of thirty seconds, the combined power ramps down a similar amount over the course of approximately four minutes.



In addition, the following figure from Section 5.4.3 represents grid stability parameters over the same span of time. Over this span, voltage varies between 14046 V and 14297 V. This represents a variance of less than 2% throughout the testing window, well within the margin of error represented in the performance objective success criteria. In addition, frequency is maintained between 59.8 and 60.2Hz throughout the testing period, within the margin of error.



Begin 10/ 9/2018 7:55:00 AM End 10/ 9/2018 8:15:00 AM
Apply
<Custom> 0.01 Day(s)
SC_pcLC1_MMXU2LoadPhVphAMag
SC_pcLC1_MMXU2LoadHzMag
15300
15100
14900
14700
14500
14300
14100
13900
13700
64.4
63.8
63.2
62.6
62.0
61.4
60.8
60.2
59.6
07:55:00 07:56:00 07:57:00 07:58:00 07:59:00 08:00:00 08:01:00 08:02:00 08:03:00 08:04:00 08:05:00 08:06:00 08:07:00 08:08:00 08:09:00 08:10:00 08:11:00 08:12:00 08:13:00 08:14:00
10/9/2018 07:55:00
10/9/2018 08:15:00
Reference: 10/9/2018 07:55:00 Measure: 10/9/2018 08:15:00 Difference: 0:20:00.000*
<Undefined>
Point | Ref. Value | Meas. Value | Diff. Value | Low EGU | High EGU | Type | Scaling | Min. Scale | Max. Scale | Transitions | R. Scale
SC_pcLC1_MMXU2LoadHzMag | (59.98000, 60.000 | 60.00000 | (0.02000046, 0.00 | 59.8 | 60.2 | Normal | Custom | 59.00000 | 65.00000 | 1393
SC_pcLC1_MMXU2LoadPhVphA | (14252.00, 14259. | (14219.00, 14227. | (33.00000, 32.000 | 14046.0 | 14297.0 | Normal | Custom | 13500.00 | 15500.00 | 1778

6.8 HIGH PENETRATION PV AND CONTROL OF PV POWER RAMP RATE FOR GENERATOR STABILITY

The success criteria for this performance objective were determined to be generator output voltage maintained within +10%/-12% and frequency within 60.3Hz/59.3Hz given a 60% PV DC power step in either direction. The time span for this test is the same as the previous performance objective, and the output voltage and frequency are displayed in the figure below.

As noted in the previous performance objective evaluation, PV production drops from >200kW to 54.4kW within the span of 30 seconds, a drop of >60% during which generator stability is maintained completely. Again, grid stability parameters remain within successful bounds.

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7.0 COST ASSESSMENT

The demonstrated controls are applicable to any DOD facility with excess generation capacity for sale to the regional ancillary and demand services markets available while retaining the capability of islanding and use of the same assets for energy surety during contingencies. Considering the aggregate of Ft. Custer DG assets were available for dispatch by CE to sell into the Reserve Energy Market, an estimated ROI is 20,447 hours (2.5 years) of export operation. This estimate is based on an average price from the MISO Reserve Energy Market of \$30.57/MWh with the Ft. Custer asset aggregation of 2MW.

Excluding the demonstration period, Ft. Custer does not plan to continuously export power as a commodity at this time. The goal of the project was to demonstrate the efficacy of the microgrid controls and protection in demand response and reserve markets, if desirable, by the owning command. Given the need for additional generation by MISO and CE, the placement of dispatchable tier 4 generators and other DER would allow 24/7 power production or effective net zero energy for a facility.

Cost advantages for Ft. Custer can be realized through cost effective operations in regulated energy markets or providing ancillary services in deregulated energy markets - As a dispatchable generation hub, Ft. Custer is capable of selling energy through an aggregator into the Real-Time and Operating Reserves market and the developing demand response market. The value of the exported energy will be valued based on the \$/MWh to monetize the available generation capacity from Ft. Custer. Demand response program participation value (also in \$/MWh) is determined in cooperation with Consumers Energy.

This estimate is based on an average price from the MISO Reserve Energy Market of \$30.57/MWh with the Ft. Custer asset aggregation of 2MW. If the state uses this ESTCP-supported capability for future Natural Gas generation and utility-scale storage in partnership with Consumer's Energy, it would result in a reduced breakeven period.

The cost assessment is based on the MISO market value at the time of proposal (December 2015) of \$30.57/MWh. The notional capacity of assets was 2MW for simplified discussion. CE is geographically part of the MISO. This market would potentially be able to exploit any dispatchable generation integrated with the control system at Ft. Custer. If there were public, utility or private assets within the distribution system of Ft. Custer, those assets operating at 2.5MW for an aggregated 20,447 hours would pay for the proposed microgrid system with enhancements. The aggregate was shown as continuous dispatch of available resources based on natural gas generation to be installed for demand reduction, peak and reserve market exploitation. The state of Michigan has rights to all-natural gas generated from oil exploration and intended to use this gas as the fuel for the speculated generators. Capital and logistics cost for the generators has not been determined as it is beyond the scope of this effort, demonstrating the reliable, predictable and repeatable integration of generation to enable the study of potential for monetizing excess energy from available resiliency assets.

7.1 COST MODEL

Table 8 below shows the estimated costs elements for the project that were captured by Electricore and project team members.

Table 8. Cost Model

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Hardware and capital costs	Estimates made based on the component costs for demonstration	$700,000 controls & interconnect $330,000 energy storage
Installation costs	labor and material required to install and commission	$400,000.00 controls & interconnect $145,000 energy storage
Consumables (See note 1)	Estimates based on rate of consumables used during the field demonstration	$11,200.00
Facility operational costs (See note 2)	Reduction in energy required vs. baseline data	1. Baseline without PV: $1,056 2. Baseline with PV at 50% Capacity: $384
Maintenance	1. Frequency of required maintenance 2. Labor and material per maintenance action	None during the demonstration
Hardware Lifetime	Estimate based on components degradation during demonstration	10 to 20 years based on usage
Operator training	Estimate of training costs	1. Only training: $4000.00 2. Training and demonstration: $6000.00

Note 1: Commissioning and demonstration used diesel fuel at an average of 500kW for 80 hours.

Note 2: Baseline for operational costs during an outage is to power the critical facility (400kW) with diesel for 8 hours. The energy efficiency implementation provides PV power (300kW) during the outage. Cost of diesel $4/gal.

7.2 COST DRIVERS

The principal cost driver for this project was the hardware and capital costs required for the microgrid. Although the team was able to utilize legacy generation and existing infrastructure for both the host site facilities and Consumers, a battery power-optimized storage system was required to support microgrid stability and provide ramp rate control of power output.

Subsequent to the capital expenditures, the bulk of the project funds were attributed to the actual installation of the system including site preparation, construction, and engineering labor. During the installation process Ft. Custer requested the team's expeditionary approach (drop-in concrete pads and basic interconnects) be replaced with permanent concrete pads and interconnects properly engineered for Michigan's extreme weather conditions.

7.3 COST ANALYSIS AND COMPARISON

The advantage of the installed microgrid is that the core elements identified for Ft. Custer were engineered to provide basic microgrid functionality without the need for extensive communication bridges, translation and adaptation of differing data protocols and custom software/ control development to coordinate the many types of hardware. Use of existing resources allowed the team to reduce payback time for microgrid capability investment over conventional approaches.

As a dispatchable generation hub, Ft Custer is capable of selling energy through an aggregator into the Real-Time and Operating Reserves market. The value of the exported energy is based on the $/MWh to monetize the available generation capacity from Ft. Custer.

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8.0 IMPLEMENTATION ISSUES

The greatest risk to adoption and enterprise wide success for the demonstrated solution is regulatory compliance. The value from the monetization of the DER and demand response capability of the demonstration must meet the intertie and parallel operating requirements of States, territories and regions where the system would operate, including but not limited to, IEEE 1547 and ANSI C84.1, and specifically complying with MPSC R460.601 – R460.656 under the jurisdiction of the Michigan Public Service Commission. This could manifest as emissions abatement, renewable penetration limits and mission impeding demand response requirements.

A potential disadvantage with implementation of the demonstrated system is the installation of required switchgear and protection to existing DG. Backup generation has limited protection and switching hardware. When the backup DG is intertied with the distribution there are increased protection and switching hardware that add cost and complexity. This cost can be mitigated by performing optimization simulations and studies to determine the generation vs cost tradeoff for each installation.

An additional risk includes communication and coordination between grid operators and microgrid operators, especially in the context of power export to nearby facilities and ownership of infrastructure and equipment. If nearby facilities coordinate with each other, they must keep in mind the electrical infrastructure separating their facilities is generally owned by the local utility, which will seek to mitigate risk to its own equipment

Additional considerations are the training for base energy managers and support operations. Continuity plans during key staff transitions will be critical to continued operation, maintenance and safety of the demonstrated system.

Excluding the demonstration period, Ft. Custer does not plan to continuously export power as a commodity at this time. The goal of the project was to demonstrate the efficacy of the microgrid controls and protection in demand response and reserve markets, if desirable, by the owning command. Given the need for additional generation by MISO and CE, the placement of dispatchable tier 4 generators and other DER would allow 24/7 power production or effective net zero energy for a facility.

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APPENDIX A POINTS OF CONTACT

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