EXECUTIVE SUMMARY

Strategic Microgrid Controls for Closely Sited Military Facilities

ESTCP Project EW-201603

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ACRONYMS AND ABBREVIATIONS

CE	Consumers Energy
COTS	Commercial off-the-shelf
DG	Distributed Generation
DOD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
HMI	Human Machine Interface
IEEE	Institute of Electrical and Electronics Engineers
KVAR	Kilovolt-amperes reactive
kW	Kilowatt
LV	Low Voltage
MISO	Midcontinent Independent System Operator
MV	Medium Voltage
MW	Megawatt
MWh	Megawatt-hours
PCC	Point of Common Coupling
PV	Photovoltaics
ROI	Return on investment

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1.0 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 Distribution Generation (DG) for baseload also leaves any available renewable energy sources unusable as most are compliant with Institute of Electrical and Electronics Engineers (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.

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2.0 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 PCC. Additional energy storage capacity was added to meet minimum Environmental Security Technology Certification Program (ESTCP) request for proposal 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 in Table 1.

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

3.0 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 were 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, Consumer Energy (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.

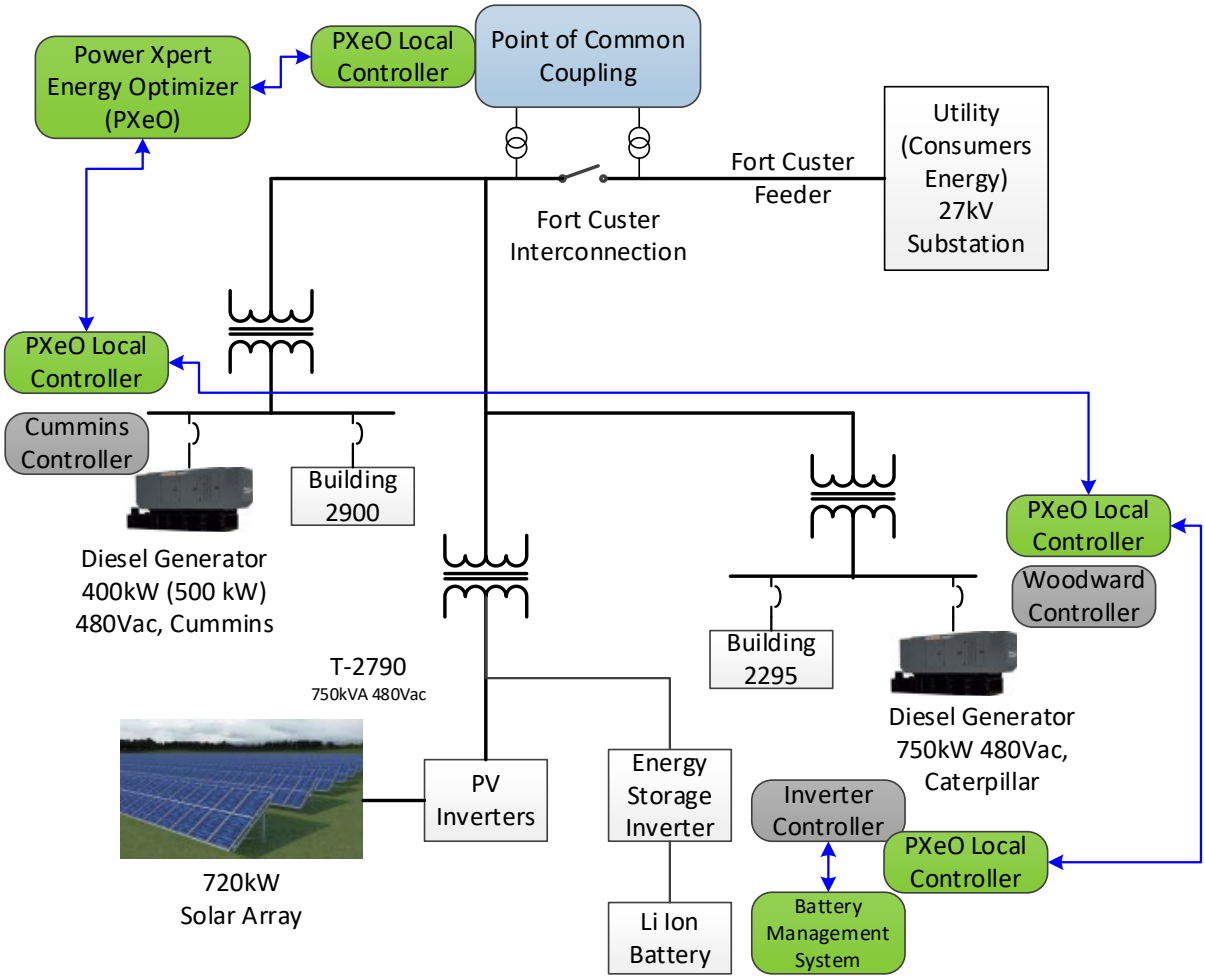

Figure 1. Microgrid Control Architecture Overlaying a Single Line Diagram of the Ft. Custer Power System

4.0 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 return on investment (ROI) is 20,447 hours (2.5 years) of export operation. This estimate is based on an average price from the Midcontinent Independent System Operator (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.

5.0 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.