# FINAL REPORT

## Hybrid Micro-grid with High Penetration Wind for Islanding and High Value Grid Services

## ESTCP Project EW-201606

DECEMBER 2020

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**Raytheon Integrated Defense Systems**



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**14. ABSTRACT** Dependence on the national electric grid threatens the ability of the Department of Defense (DoD)to secure and sustain affordable power to perform missions on installations nation-wide. The integration of micro-grids offers a potential means to improve energy security at reduced cost. However, current State-of-the-Art DoD micro-grids generally use diesel generators as their primary power source. The cost of diesel fuel, fuel logistics, and environmental restrictions generally limit the use of generators in grid-tied service. This, in turn, limits achievable tangible economic benefits to motivate 3rd party financing of micro-grid implementation and sustainment. To address this challenge, EW-201606 sought to demonstrate technical feasibility, provide a business framework, path find policy and procedural issues, and provide implementation guidance for high penetration Renewable Energy (RE) and energy storage micro-grids. This entailed demonstrating reliable islanding using high penetration wind and energy storage, cyber-secure execution of regulation services for ISO-NE, and demand management capabilities.

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AF | Air Force |
| ATRR | Alternative Technology Regulating Resource |
| ATO | Authority to Operate |
| ANGB | Air National Guard Base |
| ANG | Air National Guard |
| AFCEC | Air Force Civil Engineering Command |
| ATS | Automatic Transfer Switch |
| AGC | Automatic Generator Control |
| | |
| BESS | Battery Energy Storage System |
| | |
| COTS | Commercial Off The Shelf |
| CES | Customized Energy Solutions |
| CO | Commanding Officer |
| CSIRO | Commonwealth Scientific and Industrial Research Organization |
| C-HIL | Controller Hardware-in-the-Loop |
| CONOPS | Concept of Operations |
| COINE | Community of Interest Network Enclave |
| CT | Current Transformer |
| | |
| DoD | Department of Defense |
| DLA | Defense Logistics Agency |
| DCGS | Distributed Common Ground Station |
| DG | Distributed Generator |
| DR | Distributed Resource |
| | |
| ESS | Energy Storage System |
| ESCO | Energy Services Company |
| ESPC | Energy Savings Performance Contract |
| EPM | East Penn Manufacturing |
| | |
| FERC | Federal Energy Regulatory Commission |
| | |
| HR-PSoC | High Rate- Partial State of Charge |
| HAF | Headquarters Air Force |
| HVAC | Heating, Ventilation, and Air Conditioning |
| | |
| ISO-NE | Independent System Operator-New England |
| IRP | Installation Restoration Program |
| IA | Information Assurance |
| ICS | Industrial Control System |
| IW | Intelligence Wing |
| ISA | Interconnect Service Agreement |
| IATT | Interim Authority to Test |

| | |
|---|---|
| JBCC | Joint Base Cape Cod |
| JIE | Joint Information Environment |
| | |
| LMP | Lead Market Participant |
| LoG-RT | Loss of Grid Ride Through |
| | |
| MCS | Micro-grid Control System |
| MCAS | Marine Corps Air Station |
| MOU | Memorandum of Understanding |
| | |
| NIST | National Institute of Standards |
| NREL | National Renewable Energy Laboratory |
| | |
| O&M | Operations and Maintenance |
| | |
| PV | Photovoltaic |
| PO | Performance Objective |
| PCS | Power Conversion System |
| PF | Power Factor |
| PT | Potential Transformer |
| | |
| RE | Renewable Energy |
| RTE | Regulation Test Environment |
| RMF | Risk Management Framework |
| RTDR | Real Time Demand Response |
| RPIE | Real Property Installed Equipment |
| RTO | Regional Transmission Operator |
| | |
| SoA | State-of-the-Art |
| SIR | Savings to Investment Ratio |
| SPB | Simple Payback |
| SAF | Secretary of the Air Force |
| SCADA | Supervisory Control and Data Acquisition |
| SoC | State of Charge |
| | |
| USAF | United States Air Force |
| USACE | United States Army Corps of Engineers |
| UPS | Uninterruptible Power Supply |
| | |
| VLAN | Virtual Local Area Network |

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# ABSTRACT


## INTRODUCTION AND OBJECTIVES

Dependence on the national electric grid threatens the ability of the Department of Defense (DoD) to secure and sustain affordable power to perform missions on installations nation-wide. The integration of micro-grids offers a potential means to improve energy security at reduced cost. However, current State-of-the-Art DoD micro-grids generally use diesel generators as their primary power source. The cost of diesel fuel, fuel logistics, and environmental restrictions generally limit the use of generators in grid-tied service. This, in turn, limits achievable tangible economic benefits to motivate 3rd party financing of micro-grid implementation and sustainment.

To address this challenge, EW-201606 sought to demonstrate technical feasibility, provide a business framework, path find policy and procedural issues, and provide implementation guidance for high penetration Renewable Energy (RE) and energy storage micro-grids. This entailed demonstrating reliable islanding using high penetration wind and energy storage, cyber-secure execution of regulation services for ISO-NE, and demand management capabilities.

### TECHNOLOGY DESCRIPTION

Two primary technologies were employed in the EW-201606 demonstration. The first was the UltraBattery® lead carbon (lead-acid / ultra-capacitor) Battery Energy Storage System (BESS). The UltraBattery® was developed to compete with Li-ion in High Rate Partial State of Charge (HR-PSoC) applications such as frequency regulation, and renewable generation smoothing. The second was the Intelligent Power and Energy Management (IPEM) Microgrid Control System (MCS). The IPEM MCS combined “fast” distributed COTS controls with a cyber-secure central supervisory micro-grid controller and control architecture, building off of an earlier successful IPEM prototype demonstrated at MCAS Miramar under ESTCP project EW-201242.

### PERFORMANCE AND COST ASSESSMENT

Due to Air Force policy restrictions surrounding the use of the micro-grid critical load generator, demonstration efforts were limited to grid tied operation, specifically focusing on cyber-secure provision of frequency regulation services using the BESS. The system successfully completed 335hrs of Independent System Operator – New England (ISO-NE) Regulation Test Environment (RTE) testing with an average performance score of 97.4%. This enabled the system to enter full market operations, achieving an average hourly gross revenue of $24.80/hr at 1MW regulating capacity, equivalent to $217K/year for 24/7 operations. This outcome, to our knowledge, is the first demonstrated example of cyber-secure frequency regulation in the US Air Force.

### IMPLEMENTATION ISSUES

EW-2016006 shed light on several key implementation issues, most of which were non-technical in nature. The most significant issue was the constraints surrounding the use of critical load generators, and lack of Air Force policy regarding micro-grids. These factors ultimately proved to be a major stumbling block and prevented islanding demonstration. Reconciliation of relevant Air Force (e.g., Air Force Instruction 32-1062) and DoD policy (e.g., DODI 4170-11: Installation Energy Management) remains an issue to implementation of micro-grids at Air Force installations.

Extensive efforts were made to the optimize micro-grid design and operations to local market conditions, while conforming to policies put forth by the utility, ISO, and DoD. Careful attention to these factors would be essential to any project seeking to replicate aspects of the design.

**PUBLICATIONS**

Multiple publications were made focusing on conference presentations and trade journal articles.

# EXECUTIVE SUMMARY

## INTRODUCTION

Dependence on the national electric grid threatens the ability of the Department of Defense (DoD) to secure and sustain affordable power to perform missions on installations nation-wide. The integration of Renewable Energy (RE) provides a clean, sustainable means to improve energy security at reduced cost. However, RE sources introduce unpredictable ramp rates and intermittences that can disrupt power systems. These effects are particularly problematic in micro-grids with limited system inertia, leading to poor power quality, especially at high RE penetration levels. The introduction of energy storage to compensate for RE intermittency is a known solution for smoothing and managing RE variability [1]. However, efforts to install cyber-secure hybrid micro-grids for the DoD that cost effectively exploit energy storage are in their infancy. To address this challenge, EW-201606 sought to demonstrate a high penetration RE and energy storage hybrid micro-grid (renewable generation, energy storage and conventional generation). The design and control approach enables integration of high penetration wind and the execution of high value grid services (Figure 1).

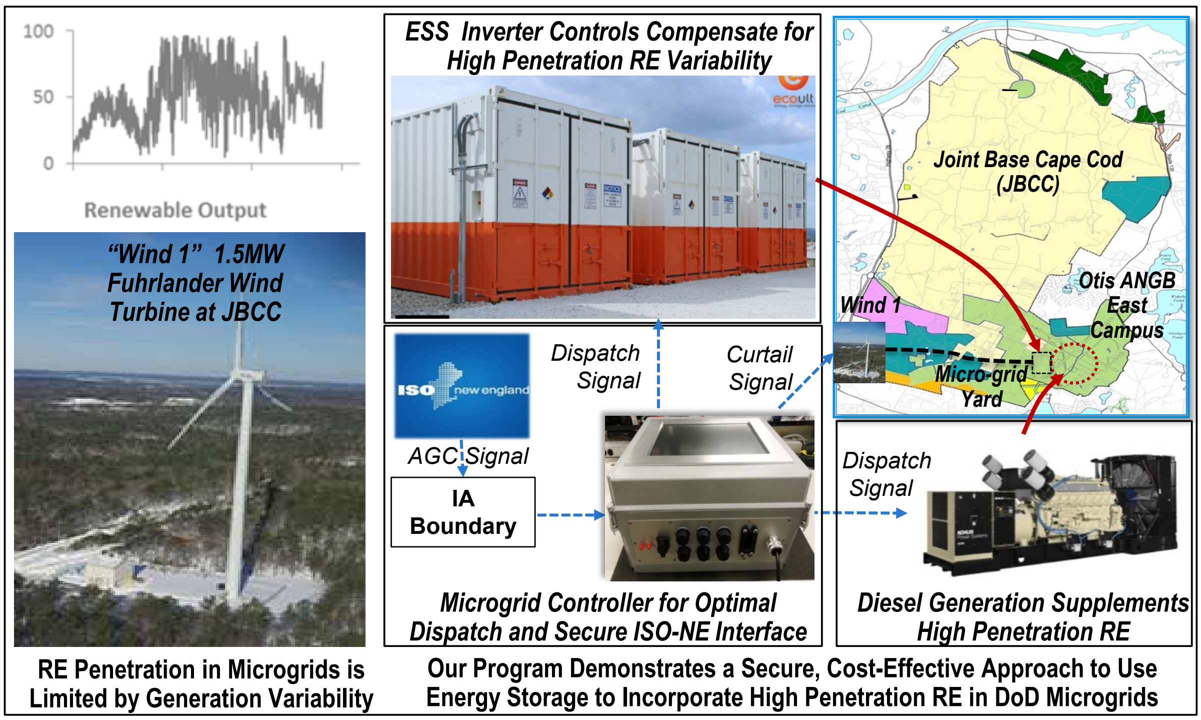



**Figure 1. EW-201606 Program Summary Graphic**

Current State-of-the-Art (SoA) DoD micro-grids generally use diesel generators as their primary power source. This is driven by the low-cost and availability of diesel generation at DoD facilities. Diesel generators are sometimes supplemented by low-to-moderate penetration RE, limited by dynamic response and turn-down restrictions of diesel generation technology. The cost of diesel fuel, fuel logistics and environmental restrictions generally limit the use of diesel generators in grid-tied service to create economic value. As such, diesel generation-centric micro-grids do not align with future micro-grid financing trends, which entail the use of third-party funding requiring tangible, short term economic benefits.

High penetration RE and energy storage micro-grids are a potential solution to the performance and economic challenges facing DoD micro-grid deployment. Battery energy storage provides the dynamic response required to address high penetration RE intermittency. Energy storage technologies are clean, present minimal logistical burden, and exhibit response characteristics ideally suited to the highest value grid-interactive functions, such as provision of frequency regulation services.

EW-201606 sought to demonstrate technical feasibility, provide a business framework, path find policy and procedural issues, and provide implementation guidance for high penetration RE and energy storage micro-grids. Economic benefit analysis focused on Battery Energy Storage System (BESS) and micro-grid control system (MCS) installation focusing on cost savings and revenues capable of attracting Energy Savings Company (ESCO) and utility investment. By focusing on robustly quantifying tangible financial benefits, EW-201606 sought to provide the data required to motivate replication through 3rd party financed follow-on projects at other DoD locations.

**OBJECTIVES**

There are two primary objectives of the demonstration project: 1) provide 120 hours of reliable islanding using high penetration wind and energy storage, supplemented by minimized diesel generation, maintaining power quality to meet IEEE 1547.4 guidance; and 2) demonstrate cyber-secure execution of regulation services for ISO-NE and demand management using a BESS and MCS, generating revenue and cost savings to support a < 5 year Simple Payback (SPB) and Savings to Investment ratio (SIR) of >2.

EW-201606 sought to validate demonstration system performance by 1) demonstrating the ability to maintain power quality in the presence of high penetration RE by measuring voltage, frequency and harmonics during islanded operation, 2) quantifying islanding efficiency improvements by measuring fuel consumption during 120hr islanding demonstration(s), 3) establishing a cyber-secure interface to ISO-NE and qualify our BESS as an Alternative Technology Regulating Resource (ATRR) through testing in ISO-NE's Regulation Resource Test Environment (RTE), 4) following the DoD Risk Management Framework (RMF) for DoD Information Technology (DODI 8510.01) to obtain ATO, and 5) measuring demand management performance of the system to support demand response, capacity tag management, and/or behind the meter demand management functions. The economic benefits derived from 3) and 5) were used to calculate overall simple payback and SIR in accordance with NIST Handbook 135 BLCCA [11] procedures.

EW-201606 demonstration outcomes show that provision of high-value grid services can be accomplished in a cyber-secure manner, maximizing tangible value to attract outside investment. While the benefits captured here are specific to this system at Otis Air National Guard Base (ANGB), we believe them to be indicative of those obtainable for other implementations. As such, EW-201606 establishes a precedent applicable many USAF and DoD installations with >1MW of RE in place or under development.

The primary technology transition objective for EW-201606 was to handoff the demonstration system for Otis ANGB operational use at project completion. This included transitioning grid services operations to an entity capable of representing and operating the system in the energy markets.

Working closely with the Air National Guard (ANG), we selected Customized Energy Solutions (CES) to operate the EW-201606 BESS in the ISO-NE frequency regulation markets, and CPower to operate the generator in the ISO-NE Real Time Demand Response (RTDR) markets. These selections were formalized through ANG and AFCEC efforts that established or amended existing contracts with CES and CPower and the Defense Logistics Agency (DLA). More broadly, project results have been disseminated via conferences and publications targeting DoD personnel involved in operation and acquisition of facility power systems, and ESCOs that provide third party financing to DoD energy projects. Many work products from EW-201606 have been documented in the form of technical documents that are available upon request, and serve as an implementation guide for other DoD facilities. Project results have leveraged, and provided feedback to inform revisions of IEEE 2030.8, USAF AFI 32-1062, ISO-NE ATRR metering, Eversource interconnect, and DoD Information Assurance (IA) standards.

## TECHNOLOGY DESCRIPTION

There are two primary technologies that were employed in the EW-201606 demonstration.

The first is the UltraBattery® Energy Storage System (ESS). The UltraBattery® ESS employs the UltraBattery®, a lead carbon (lead-acid / ultra-capacitor) based energy storage technology (Figure 2). UltraBattery® technology was developed to address a specific degradation mechanism in traditional lead acid batteries when subjected to High Rate Partial State of Charge (HR-PSoC) operation, which is typically required for functions such as frequency regulation, and renewable generation smoothing.

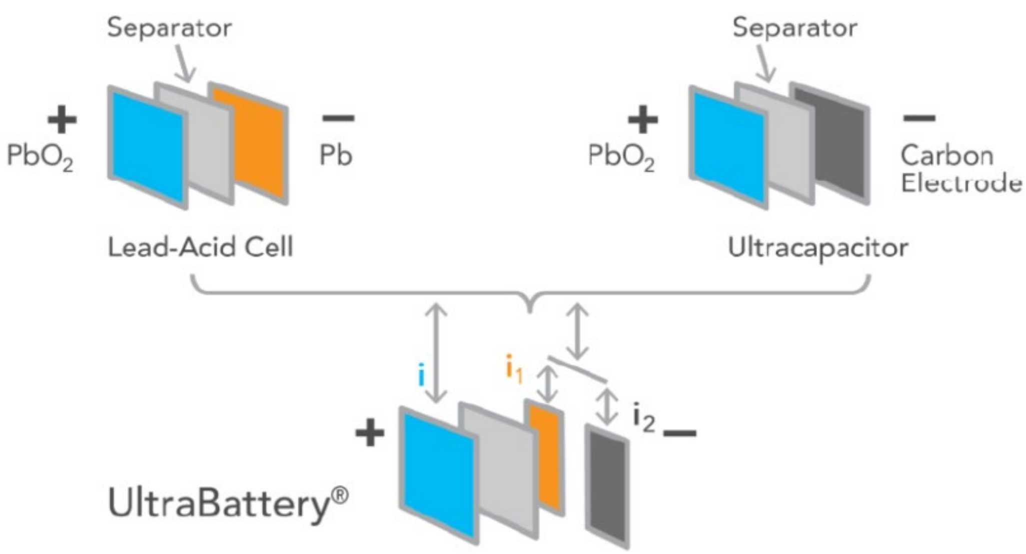



**Figure 2. Depiction of UltraBattery® Technology**

The second technology is the Microgrid Control System (MCS). It combines "fast" distributed controls with a central supervisory micro-grid controller. The "fast" distributed controls are an aggregation of commercially available control technology manufactured by Dynapower, Woodward, ASCO, AMSC, and Ecoult. Raytheon's Intelligent Power and Energy Management (IPEM) supervisory controller is a pre-commercial micro-grid controller that was first deployed to control a solar photovoltaic (PV) and flow battery storage micro-grid under ESTCP project EW-201242 at MCAS Miramar.

## PERFORMANCE ASSESSMENT

Project Performance Objectives (POs) are shown in Table 1 below and fall into two categories. Category 1 POs pertained to power system performance and efficiency in islanded operation, whereas Category 2 POs pertain to system economics and demonstration of cyber-secure methods required to perform high-value, ISO-interactive grid services. Quantitatively demonstrating achievement of the POs was sought to de-risk the implementation of similar systems on other DoD facilities, and provide the data required to make investment decisions on pursuing such projects.

**Table 1. Performance Objectives**

| Performance Objective | Metric | Data Requirements | Success Criteria |
|---|---|---|---|
| **Category 1: Manage High Penetration RE Ramp Rates and Intermittency to Maintain Power Quality** | | | |
| Maintain power quality in the micro-grid over 120 hours of continuous islanded operation with high-penetration (>90% instantaneous) wind generation | Voltage, Frequency, Harmonics | Voltage, Frequency and Harmonics | Power quality measurements meet guidance of IEEE1547.4 |
| Optimize ESS and conventional generation dispatch and RE curtailment to minimize diesel fuel consumption over 120hrs of continuous islanded operation | Diesel Fuel Consumption | Total diesel fuel consumption over 120hrs of continuous operation | Demonstrate >30% reduction in fuel consumption relative to diesel-only operation |
| **Category 2: Demonstrate Cyber-Secure Methods to Provide Revenue Generation and Cost Savings** | | | |
| Establish a cyber-secure interface to ISO NE, obtain ATO, and complete testing to qualify as an ATRR in ISO NE's test environment | ESS meets ISO-NE OP-14 requirements for use as an ATRR, overall system receives ATO | Completion of ISO-NE ATRR testing protocol. Completion and submission of RMF accreditation package | ESS qualifies as ISO-NE ATRR, receipt of ATO |
| Demonstrate cost savings through demand management using BESS, generator, and wind, aggregate with economic benefits of regulation services and demand response to maximize ROI and SIR associated with system implementation | Cost avoidance and revenue generation potential | Measured average demand reduction (kW) and ISO-NE approved regulating capacity (kW) | Measured demand reduction benefits and regulation performance support < 5 year simple payback and SIR > 2 as analyzed by NREL's REopt tool per NIST Hdbk 135 |

Due to Air Force policy restrictions surrounding the use of the micro-grid critical load generator, demonstration efforts were limited to Category 2 POs measured through grid tied operation. In particular, efforts focused on cyber-secure provision of frequency regulation services using the BESS. The system successfully completed 335hrs of Independent System Operator – New England (ISO-NE) Regulation Test Environment (RTE) testing with an average performance score of 97.4%. This enabled the system to enter full market operations, achieving an average hourly gross revenue of $24.80/hr at 1MW regulating capacity, equivalent to $217K/year for 24/7 operations. Based upon discussions with CES, such extrapolations are reasonable and potentially conservative for multiple reasons:

1. Testing to date was performed at a reduced ramp rate due to early issues encountered with SoC management. Improved SoC management was subsequently implemented and should increase the supportable ramp rate, increasing hourly revenues.

2. Regulation prices are expected to increase over the winter months during colder weather.
3. Repair of a failed inverter module should allow regulation capacity to be increased to between 1 and 1.6MW.

This outcome, to our knowledge, is the first demonstrated example of cyber-secure frequency regulation in the US Air Force.

## COST ASSESSMENT

Cost assessment were performed using realized costs and a combination of realized and projected cost savings / revenues. Details of the cost analysis model created by NREL can be found in [19], and are generally consistent with NIST Handbook 135 BLCCA [11] procedures.

Cost drivers included capital equipment and electricity costs, offset by revenues realized through participation in market programs. The following describes the key cost drivers that impacted the outcome of the cost assessment.

An analysis was performed to compare the economic differential costs associated with operating the Wind 1 turbine in its current "in front of the meter" configuration (Virtual Net Metering) into the Eversource Energy 24.9kV system vs. "behind the meter" connected to the JBCC 12.47kV system. This analysis used Virtual Net Metering credit data from FY14 to FY17 and found the average credit to be $0.1476/kWh. This value was compared with the average energy cost paid by JBCC for its electricity in FY2017, found to be $0.145/kWh. As can be observed, this data indicates it is incrementally unfavorable to move the turbine behind the meter as part of the micro-grid. However, this does not take into account potential demand response reductions, which may or may not be realized due to the intermittency of the turbine generator and possibility its power output may not coincide with periods of high demand. We also acknowledge that this analysis should be updated with more recent (e.g., FY2020) data for re-assessment.

Potential Real Time Demand Response (RTDR) revenues were provided by CPower Energy Management. CPower currently manages AFCEC IRP's demand response program which operates by curtailing existing ground water pumps. Prior to the micro-grid losing access to the DCGS generator, it was added to this existing contract with DLA with a potential load reduction of 1200kW. If the generator were available to the micro-grid, average annual gross and net revenues were projected to be $51,184/MW-year and $35,829/MW-year, respectively. It is noteworthy that these revenues represent a significant decrease from the original assessment made earlier in the program that indicated gross revenues of $132,960/MW-year from 6/1/2018-5/31/2019. This reduction reflects reductions in electricity costs determined through forward capacity auctions.

Potential frequency regulation revenues were initially predicted by Raytheon and NREL independently using data from 2015 and 2016. Frequency regulation compensation is complex to calculate due to market variations. As such, Raytheon's initial estimate assumed the ISO-NE average rate for 2015 of $333K/MW-year ($20M for 60MW-year) with persistent use and 0.9 utilization (0.95 scoring and 0.95 up-time), less 10% Lead Market Participant (LMP) fee. This was compared to an independent analysis performed by NREL that determined average revenues of $304K/MW-year based on 2016 market data. These projections are compared with the realized potential gross revenue of $217/MW-year in November / December 2020. Deducting the LMP fee and assuming 0.9 up-time, the realized net frequency regulation revenue would be $178K/MW-year, a 47% decrease from the initial projection. This decrease is likely the result of a general trend of reducing prices in the ISO-NE regulation market.

Capital equipment costs were determined using actual incurred costs and totaled $4,385,618. The costs listed below were direct, and did not include Raytheon pass-through costs. Moreover, while A/E design costs were included, we excluded demonstration and developmental costs that would not be re-preformed in a subsequent deployment with significant re-use of equipment designs and software configurations.

O&M costs were estimated through development of an extended demonstration proposal to continue to the demonstration of BESS operations in the ISO-NE regulation market through CY2021. Ongoing micro-grid maintenance costs of $114K were estimated for CY2021, comprised of $85K to maintain the micro-grid and $29K to maintain the MCS. We also included a battery replacement cost of $413,370 in year 10, estimated by East Penn Manufacturing. We excluded the IA costs as the would typically be accomplished under a separate budget line and activity broadly addressing installation Industrial Control System (ICS) security.

Life Cycle Cost analysis was performed using the aforementioned model created by NREL using the data above for a period of 25 years. This analysis assumed a real discount rate of 3%, electricity cost escalation rate of 1.3%, and differential O&M costs of $88,000 (increase) associated with the maintenance of the micro-grid vs. maintenance of 4 separate standby generators at $6500/ generator/ year [15].

Using the originally predicted values from analysis performed in 2017, the analysis results in a Simple Payback of 8.6 and 10- and 20-year Savings to Investment ratios of 1.42 and 1.82, respectively. However, using updated values based on 2020 rates and measured performance, this reduces to 21 and 0.82 / 0.75.

While the SPB and SIR values predicted do not meet the objectives for either projection, it is important to view them in comparison to alternative solutions. For example, with current operations, the total cost to maintain the system over the 21-year simple payback period would be $546K while providing back-up power to 4 (vs. 34) buildings. Alternatively, a diesel generator-based alternative micro-grid design that exploits the existing generator for demand response only could reduce installed capital costs to between $1M and $1.75M. Assuming $29K of annual micro-grid O&M for the control system only, this results in a predicted SPB of between 49.1 and 84.2 years.

## IMPLEMENTATION ISSUES

EW-2016006 shed light on several key implementation issues, most of which were non-technical in nature. The most significant issue was the constraints surrounding the use of critical load generators and lack of Air Force policy regarding micro-grids, which ultimately proved to be a major stumbling block and prevented full micro-grid implementation.

### *AFI 32-1062 Constraints*

Air Force Instruction (AFI) 32-1062 "ELECTRICAL SYSTEMS, POWER PLANTS AND GENERATORS", dated 15 January 2015 contains several restrictions that were identified early in the project and assessed to be addressable by obtaining a waiver as described within the document. The basis for this belief was rooted in the apparent inconsistency with this older AFI and newer DoD guidance, embodied in DODI 4170-11: Installation Energy Management.

Specifically, AFI 32-1062 Para. 1.5.9.1 of AFI 32-1062 states "EAID or RPIE generators (DCGS generator is a RPIE) or any generator owned by another agency will not operate in parallel with any real property electrical system (i.e., transformer, switchgear, or utility) unless authorized by AFCEC/CO." Para. 1.5.9.2 states "Variable renewable energy sources do not operate in parallel with mission-critical generation.". Lastly, Para 2.2 states "Only dedicated standby generators may be authorized to support mission-essential functions. (T-1) Generators authorized to support mission-essential functions will be installed and connected to provide power only to mission-essential functions within a single facility in the event there is a loss of commercial power. (T-1) Using one standby system to support multiple facilities is not authorized due to simultaneous risk to multiple missions. (T-1) If unique circumstances exist where one standby system is required to support multiple facilities, an authorization request must be submitted to AFCEC/CO for approval. (T-1)."

The process to submit a waiver to AFCEC/CO is not defined in the AFI, and significant investigation was undertaken by 102nd IW personnel to identify the appropriate channels and personnel. These investigations were accomplished while coordinating implementation of generator modifications in parallel to maintain project schedule. Eventually, subject matter experts at AFCEC (Mr. Rexford Bellville and Mr. Tarone Watley) were identified and advised "AFCEC approves prime power when/if utility power is not available or considered reliable and a single generator for multiple facilities but approving a single generator for multiple facilities that are not a single mission is not in accordance with AF policy and CO approval authority. …there [was] no AF Policy on microgrids or criteria to develop one and in order to move forward with that we would need something from each separate mission owner stating their power reliability/backup requirement and if sharing a generator with other missions in fact satisfy that in order for us to make the recommendation to SAF/HAF."

In contrast, DODI 4170-11: Installation Energy Management Para, dated 16 March, 2016 contains several requirements that appear inconsistent with the restrictions noted above, Specifically, Para 3.c.2.b states:

1. Energy resilience solutions are not limited to traditional standby or emergency generators. They can include integrated, distributed, or renewable energy sources; diversified or alternative fuel supplies; and movements to alternative locations, as well as upgrading, replacing, and maintaining current energy generation systems, infrastructure, and equipment on military installations and at facilities. Alternative locations that require a continuous supply of energy in the event of an energy disruption or emergency shall also be subject to energy resilience requirements.
2. When selecting distributed or renewable energy systems and emergency generators for energy resilience, they shall be properly designed to have the ability to prepare for and recover from energy disruptions that impact mission assurance. Their design shall include automatic transfer switching, inverters, and black-start capabilities to minimize energy resilience risks.

> DoD Components shall also determine fueling or storage requirements for the selected energy generation systems. DoD Components shall follow relevant UFCs for safe and cost effective designs of energy generation systems that minimize risks to mission assurance when complying with energy resilience requirements stated in this instruction.

Clearly, the DODI envisions the use of other generation sources (beyond standby generators) for energy resilience, which aligns with the implementation of micro-grids to support critical loads.

Ultimately, it was determined that the most viable path forward was to retain a dedicated critical load generator, and seek a waiver for a micro-grid dedicated generator that would back-up non-critical loads. The micro-grid generator would then serve as a redundant back-up to the standby critical load generator under the concept that the non-critical loads would be served a single generator supporting multiple building loads as envisioned in the AFI. A waiver would still be required; however, this was deemed more feasible as it can be interpreted to be within the envisioned bounds of AFI 32-1062 as written. Ultimately, revision of AFI 32-1062 will be needed if micro-grids are to be implemented using existing critical load generation, or to replace dedicated critical load standby generators.

***Local Energy Market Factors***

The techno-economics associated with EW-201606 outcomes are a strong function of the local market conditions and policies. The grid services targeted (frequency regulation and real time demand response) were chosen to maximize the economic value of the installed equipment while ensuring the reliability and resilience benefits of the micro-grid.

In ISO-NE markets, frequency regulation has generally been the most lucrative application of energy storage; however, it is also the arguably the most operationally intensive. Constraints surrounding minimum capacity (1MW) and metering must be satisfied to participate. As we have experienced in demonstration efforts, the regulation signal may also deviate from the provided reference, requiring adaptability and flexibility. The aforementioned criteria must be satisfied while simultaneously meeting utility interconnect requirements (e.g., export prevention), which may conflict with micro-grid design constraints. External connections and associated methods to mitigate information assurance security risks are required.

The approach pursued to employ the DCGS generator for RTDR was pursued largely due to the build vintage of the engine "grandfathering" eligibility for the program, and permitting for non-emergency use being feasible. The DCGS generator is a Tier 2 generator and if not for this "grandfathering" would have required significant emissions mitigation upgrades to participate. In many other locations, the outcome would have been different.

In summary, any efforts to replicate the design or aspects of the design should carefully consider local market conditions and policies as part of the conceptual design process and choose economic functions that best align with the available opportunities and equipment. A more detailed accounting of such considerations is captured in the final report for EW19-5163.

# 1.0 INTRODUCTION

Dependence on the national electric grid threatens the ability of the Department of Defense (DoD) to secure and sustain affordable power to perform missions on installations nation-wide. The integration of Renewable Energy (RE) provides a clean, sustainable means to improve energy security at reduced cost. However, RE sources introduce unpredictable ramp rates and intermittences that can disrupt power systems. These effects are particularly problematic in micro-grids with limited system inertia, leading to poor power quality, especially at high RE penetration levels. The introduction of energy storage to compensate for RE intermittency is a known solution for smoothing and managing RE variability [1]. However, efforts to install cyber-secure hybrid micro-grids for the DoD that cost effectively exploit energy storage are in their infancy. To address this challenge, EW-201606 sought to demonstrate a high penetration RE and energy storage hybrid micro-grid (renewable generation, energy storage and conventional generation). The design and control approach enables integration of high penetration wind and the execution of high value grid services (Figure 3).

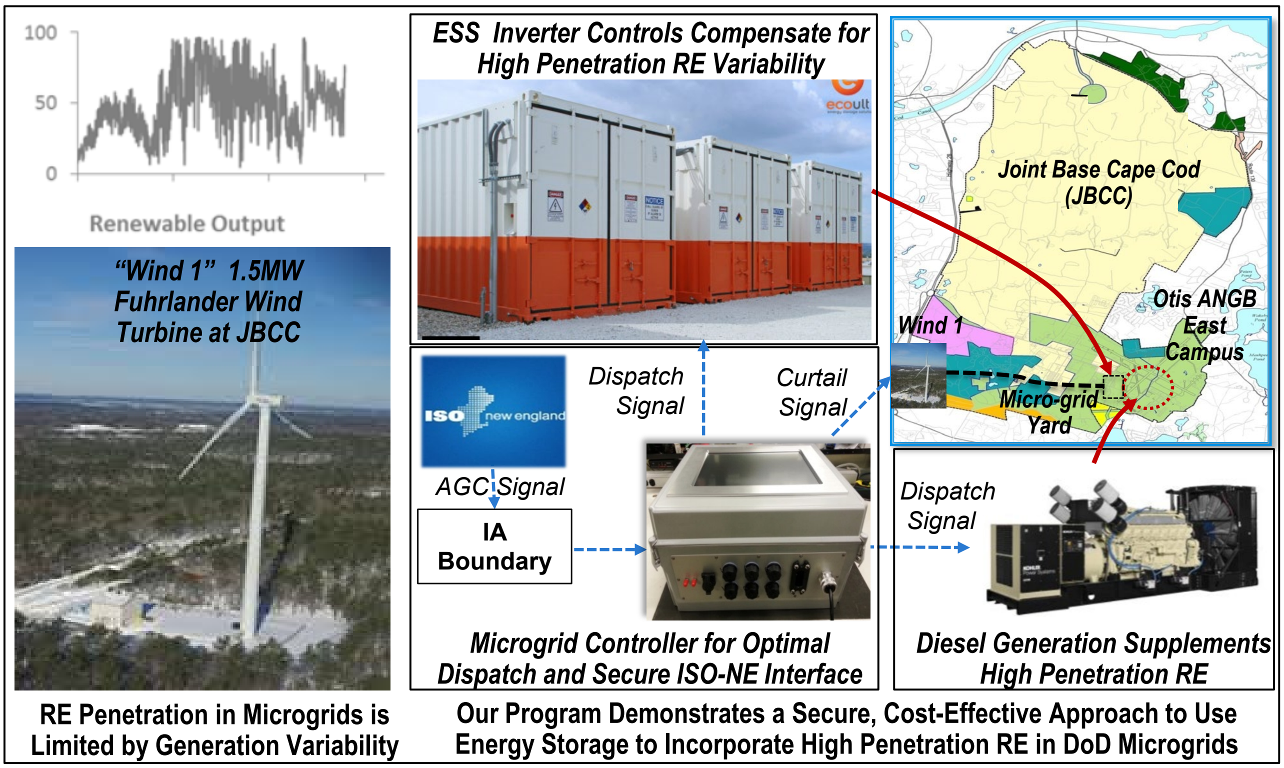



**Figure 3. EW-201606 Program Summary Graphic**

## 1.1 BACKGROUND

Current State-of-the-Art (SoA) DoD micro-grids generally use diesel generators as their primary power source. This is driven by the low-cost and availability of diesel generation at DoD facilities. Diesel generators are sometimes supplemented by low-to-moderate penetration RE, limited by dynamic response and turn-down restrictions of diesel generation technology.

The cost of diesel fuel, fuel logistics and environmental restrictions generally limit the use of diesel generators in grid-tied service to create economic value. As such, diesel generation-centric micro-grids do not align with future micro-grid financing trends, which entail the use of third party funding requiring tangible, short term economic benefits.

High penetration RE and energy storage micro-grids are a potential solution to the performance and economic challenges facing DoD micro-grid deployment. Battery energy storage provides the dynamic response required to address high penetration RE intermittency. Energy storage technologies are clean, present minimal logistical burden, and exhibit response characteristics ideally suited to the highest value grid-interactive functions, such as provision of regulation services.

EW-201606 sought to demonstrate technical feasibility, provide a business framework, path find policy and procedural issues, and provide implementation guidance for high penetration RE and energy storage micro-grids. Economic benefit analysis focused on Battery Energy Storage System (BESS) and micro-grid control system (MCS) installation focusing on cost savings and revenues capable of attracting Energy Savings Company (ESCO) and utility investment. By focusing on robustly quantifying tangible financial benefits, EW-201606 sought to provide the data required to motivate replication through 3rd party financed follow-on projects at other DoD locations.

## 1.2 OBJECTIVE OF THE DEMONSTRATION

There were two primary objectives of the demonstration project: 1) provide 120 hours of reliable islanding using high penetration wind and energy storage, supplemented by minimized diesel generation, maintaining power quality to meet IEEE 1547.4 guidance; and 2) demonstrate cyber-secure execution of regulation services for ISO-NE and demand management using a BESS and MCS, generating revenue and cost savings to support a < 5 year Simple Payback (SPB) and Savings to Investment ratio (SIR) of >2.

EW-201606 sought to validate demonstration system performance by 1) demonstrating the ability to maintain power quality in the presence of high penetration RE by measuring voltage, frequency and harmonics during islanded operation, 2) quantifying islanding efficiency improvements by measuring fuel consumption during 120hr islanding demonstration(s), 3) establishing a cyber-secure interface to ISO-NE and qualify our BESS as an Alternative Technology Regulating Resource (ATRR) through testing in ISO-NE's Regulation Resource Test Environment (RTE), 4) following the DoD Risk Management Framework (RMF) for DoD Information Technology (DODI 8510.01) to obtain ATO, and 5) measuring demand management performance of the system to support demand response, capacity tag management, and/or behind the meter demand management functions. The economic benefits derived from 3) and 5) were used to calculate overall simple payback and SIR in accordance with NIST Handbook 135 BLCCA [11] procedures.

EW-201606 demonstration outcomes show that provision of high-value grid services can be accomplished in a cyber-secure manner, maximizing tangible value to attract outside investment. While the benefits captured here are specific to this system at Otis Air National Guard Base (ANGB), we believe them to be indicative of those obtainable for other implementations. As such, EW-201606 establishes a precedent applicable many USAF and DoD installations with >1MW of RE in place or under development.

The primary technology transition objective for EW-201606 was to handoff the demonstration system for Otis ANGB operational use at project completion. This included transitioning grid services operations to an entity capable of representing and operating the system in the energy markets. Working closely with the Air National Guard (ANG), we selected Customized Energy Solutions (CES) to operate the EW-201606 BESS in the ISO-NE frequency regulation markets, and CPower to operate the generator in the ISO-NE Real Time Demand Response (RTDR) markets. These selections were formalized through ANG and AFCEC efforts that established or amended existing contracts with CES and CPower and the Defense Logistics Agency (DLA). More broadly, project results have been disseminated via conferences and publications targeting DoD personnel involved in operation and acquisition of facility power systems, and ESCOs that provide third party financing to DoD energy projects. Many work products from EW-201606 have been documented in the form of technical documents that are available upon request, and serve as an implementation guide for other DoD facilities. Project results have leveraged, and provided feedback to inform revisions of IEEE 2030.8, USAF AFI 32-1062, ISO-NE ATRR metering, Eversource interconnect, and DoD Information Assurance standards.

## 1.3 REGULATORY DRIVERS

EW-201606 is motivated by and aligns with federal, DoD and service-specific policies including the Energy Independence and Security Act of 2007 [2], Executive Order 13693: Planning for Federal Sustainability in the Next Decade [3], DODI 4170-11: Installation Energy Management [4], and Air Force Energy Flight Plan [5]. The Air Force Energy Flight Plan calls out 3 strategic goals: 1) Improve Resiliency, 2) Optimize Demand, and 3) Assure Supply. EW-201606 sought to make progress against all 3 of these goals by 1) Demonstrating the ability to respond to disruptions in supply from the electric grid via islanded operation (improved resilience), 2) Reducing the energy required to operate the islanded system by employing existing renewable generation assets (optimized demand), and 3) Providing a means to employ existing renewable assets more efficiently and effectively during islanded operation to assure supply.

The Air Force Energy Flight Plan also notes a focus on performance contracting (e.g., UESC and ESPC) and third party financing mechanisms as part of the "Optimize Demand" goal. EW-201606 was focused on demonstrating a system approach that is aligned with this objective by providing tangible economic value in the form of cost savings and revenues. This economic value underpins the business case to replicate the system, or aspects of the system, as part of third party financed programs, without relying upon other aspects of the program to pay for the energy security and resilience-focused systems and equipment.

Beyond DoD and Air Force policy alignment, EW-201606 serves to path find implementation of new policy and standards in several key areas.

1) Micro-grid Control: IEEE 2030.7 and 2030.8 were developed as micro-grid controller and micro-grid controller test standards in parallel with EW-201606 execution. Working with IEEE 2030.8 Vice Chair Erik Limpaecher's group at MIT-LL, EW-201606 developed and executed an IEEE 2030.8 micro-grid test plan using Controller Hardware-in-the-Loop (C-HIL) techniques. To our knowledge, this activity served as one of the first test cases where the IEEE 2030.8 standard was applied to a micro-grid control system using C-HIL testing.

2) Cyber Security / Information Assurance: ETL-11-1 (Civil Engineer Industrial Control System Information Assurance Compliance) [6], UFC 4-010-06 (Cybersecurity of Facility Related Control Systems) [7], and DODI 8510.01 (DoD Risk Management Framework (RMF) [8] were all relevant to the demonstration project. The UFC and application of DODI 8510.01 were relatively new to the DoD in general and the Air National Guard in particular. EW-201606 served to path find the application of these standards through submission of an Interim Authority to Test (IATT) application to AFCEC and Self Attested ATO application to USACE.

3) Micro-grids for Critical Facilities / Missions: The usability of assets connected to critical facilities / missions can impact the design and implementation of micro-grids at DoD installations. For example, AFI 32-1062 [9] restricts the use of standby generators to a single building / mission, which is not fully compatible with DODI 4170-11 [4]. Ultimately, the restrictions associated with AFI 32-1062 served as a major impediment to some aspects of demonstration execution. However, EW-201606 did make progress towards highlighting issues, interpretation, and application of such guidance in future micro-grids.

4) ISO-NE Markets: At the time of its development, the EW-201606 demonstration system was to be the first micro-grid in Independent System Operator – New England (ISO-NE) actively participating in the demand response and frequency regulation programs. During the program, markets continued to evolve, spurred on by the rapid expansion of energy storage deployment and due to FERC Order 841 [10], which requires Independent System Operators / Regional Transmission Operators (ISO/RTOs) to update market rules to allow expanded participation of energy storage. Ultimately, the EW-201606 micro-grid demonstration efforts have successfully served as a "first-of-its-kind" example of how DoD micro-grids (and micro-grids in general) can participate in the evolving ISO-NE market.

5) Utility Policies: The EW-201606 demonstration system was the first micro-grid that successfully completed an Interconnect Service Agreement (ISA) with Eversource Energy in Eastern Massachusetts (and possibly beyond). As part of the process to arrive at the ISA, EW-201606 had to path find how to apply Eversource policies and procedures that were developed for individual Distributed Generation (DG) installations to micro-grids.

## 2.0 TECHNOLOGY DESCRIPTION

### 2.1 TECHNOLOGY OVERVIEW

There are two primary technologies that were employed in the EW-201606 demonstration.

The first is the UltraBattery® Energy Storage System (ESS). The UltraBattery® ESS employs the UltraBattery®, a lead carbon (lead-acid / ultra-capacitor) based energy storage technology (Figure 4). UltraBattery® technology was developed to address a specific degradation mechanism in traditional lead acid batteries when subjected to High Rate Partial State of Charge (HR-PSoC) operation, which is typically required for functions such as frequency regulation, and renewable generation smoothing.

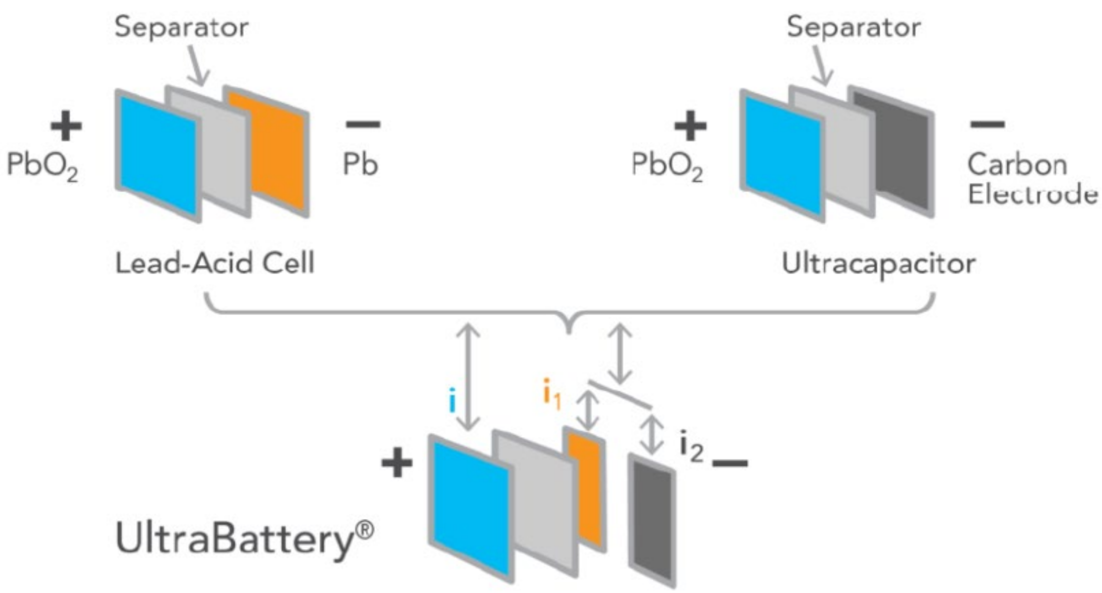



**Figure 4. Depiction of UltraBattery® Technology**

The UltraBattery® ESS (Figure 5) combines strings of UltraBatteries within Storage Blocks. The DC output from each Storage Block is combined and fed into the Power Conditioning Unit (PCU), which consists of a Power Conditioning System (PCS, a.k.a., inverter), protection / controls, and a transformer. Each Storage Block is managed by a dedicated Storage Block controller, which is in turn managed by a Master ESS controller.

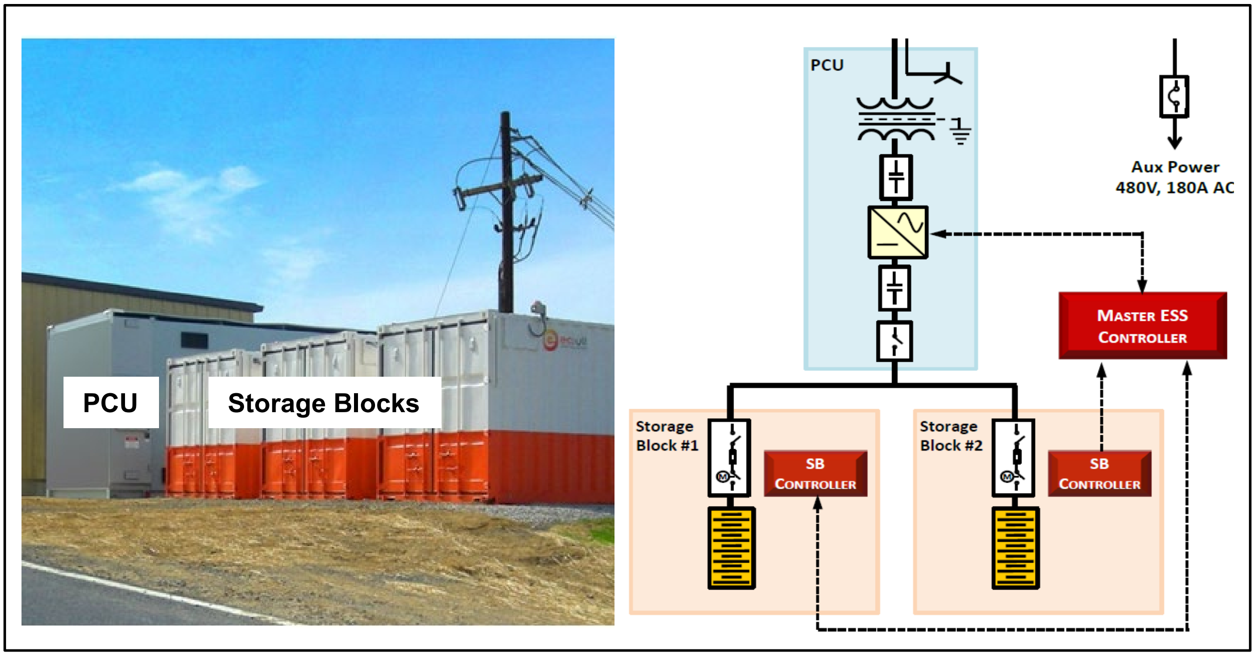



**Figure 5. UltraBattery® ESS at EPM (Left), and Otis ANGB Configuration (Right)**

The technology underlying Ultrabattery® was originally developed by Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO), which established Ecoult in 2007 to commercialize the technology. Ecoult was acquired by US-based East Penn Manufacturing (EPM) in 2010, one of the world's largest producers of lead acid batteries. When EW-201606 began, EPM was in the process of scaling production to meet anticipated ESS market needs. Unfortunately, market pressures and financial impacts from the COVID-19 outbreak have resulted in EPM deciding to divest its interest in Ecoult and Ultrabattery® technology as of December 2020. Nonetheless, Ultrabattery®-based ESSs have been demonstrated to support RE integration in a remote 3MW hybrid microgrid on King Island, Tasmania, and to smooth 660kW grid-tied wind turbine in New South Wales, Australia [12]. A 3MW Ultrabattery® ESS currently provides regulation services to PJM at the East Penn factory in Lyons, PA [13]. Ecoult deployed an 800kW Ultrabattery® ESS at Aqua, a water utility in King of Prussia, PA, to provide frequency regulation and Loss of Grid Ride Through / islanding capability (Figure 6). The Aqua system represents a half-scale version of the Ultrabattery® ESS that was deployed at Otis Air National Guard Base / Joint Base Cape Cod under EW-201606.

**Figure 6. 800kW UltraBattery® ESS at Aqua (King of Prussia, PA)**

The second technology is the Microgrid Control System (MCS, Figure 7). It combines "fast" distributed controls with a central supervisory micro-grid controller. The "fast" distributed controls are an aggregation of commercially available control technology manufactured by Dynapower, Woodward, ASCO, AMSC, and Ecoult. Raytheon's Intelligent Power and Energy Management (IPEM) supervisory controller is a pre-commercial micro-grid controller that was first deployed to control a solar photovoltaic (PV) and flow battery storage micro-grid under ESTCP project EW-201242 at MCAS Miramar. The IPEM Controller employed in EW-201606 represents the "2nd Generation" IPEM controller design, featuring increased functionality and improved cyber-security. The Otis ANGB micro-grid IPEM configuration represents a prototypical IPEM control system that Raytheon would offer commercially to subsequent DoD micro-grid projects.

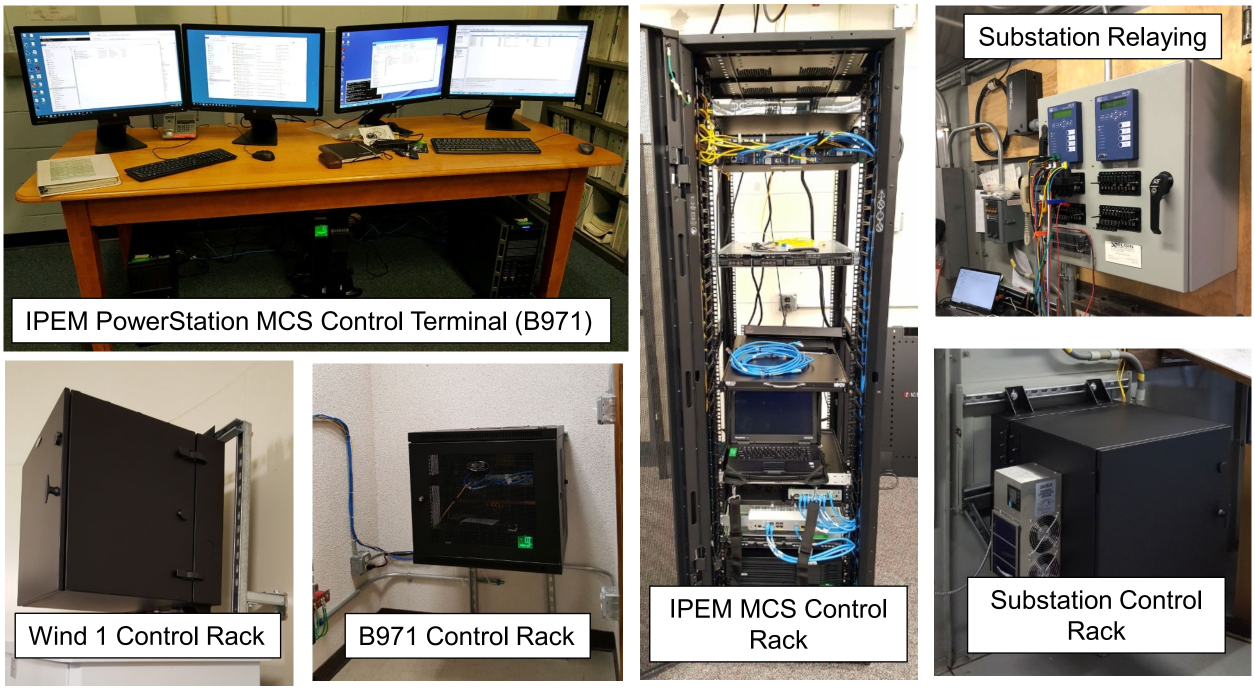



**Figure 7. Micro-grid Control System Elements**

The Dynapower CPS2000 ESS PCS provides grid forming capability, managing power quality during islanding, and enables unplanned seamless transition to islanding via LoG-RT. Local Woodward ProAct II and Marathon DVR200EC+ generator and ASCO 7000 series Automatic Transfer Switch (ATS) controls enable an existing standby generator to parallel with the grid and source power into the micro-grid. Additional high speed comparator-based controls reside within the micro-grid switchgear to provide fast generation shedding in the event the ESS encounters a charge acceptance limitation due to RE intermittency or an unexpected rapid drop in demand. The Intelligent Power and Energy Management (IPEM) micro-grid controller provides a supervisory control interface for micro-grid operations and automatic dispatch / curtail of DR assets to meet economic (grid tied) or ESS state of charge management (islanded) objectives. The MCS architecture enables implementation of cyber-secure connections with external entities (e.g., battery monitoring, ISO-NE frequency regulation dispatch).

To reduce risk associated with MCS deployment and operation, Raytheon made a capital investment into a Typhoon HIL Controller Hardware-in-the-Loop (C-HIL) test facility to enable high fidelity laboratory testing of the MCS based upon an IEEE 2030.8 "Standard for the Testing of Microgrid Controllers" derived test plan jointly developed with MIT Lincoln Laboratory [14]. The C-HIL test facility features identical or nearly identical micro-grid, ATS, generator, PCS inverter, and ESS controls as will reside in the deployed system (Figure 6). Testing was carried out in the lab on the C-HIL prior to field deployment and documented in an extensive report, available upon request.

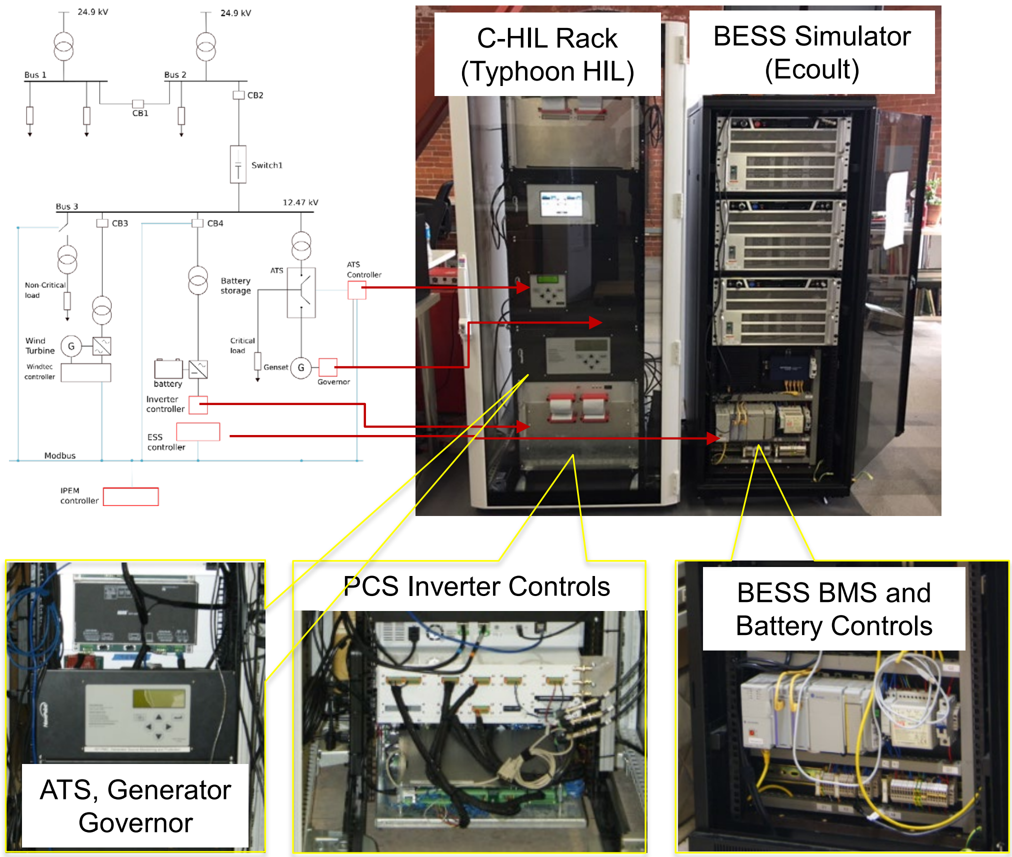



**Figure 8. Micro-grid C-HIL Test Facility**

The technology demonstrated in EW-201606 has the potential to be applied to a multitude of DoD installation applications seeking a cost-effective approach to improve energy security and resiliency. Ideal candidates will have existing RE infrastructure and standby generation that can be modified for grid-parallel operation. A multitude of site design specific issues and local market conditions will dictate the degree to which the demonstration system from EW-201606 is suitable for replication.

## 2.2 TECHNOLOGY DEVELOPMENT

The development efforts undertaken under EW-201606 focused in four areas:

1) Micro-grid systems engineering to develop a Concept of Operations (CONOPs) and functional requirements. The outcome of this development effort is captured in a CONOPs document, which can be made available upon request.
2) Design efforts following traditional ANG design/build construction practices. Outcomes of these efforts are captured in 100% design submittals for each part of the system. These design drawings can be available upon request.
3) Development, test and evaluation of micro-grid controls per IEEE 2030.8 using C-HIL techniques. Results were documented in an extended report, and an abbreviated version. Both of these can be made available upon request.

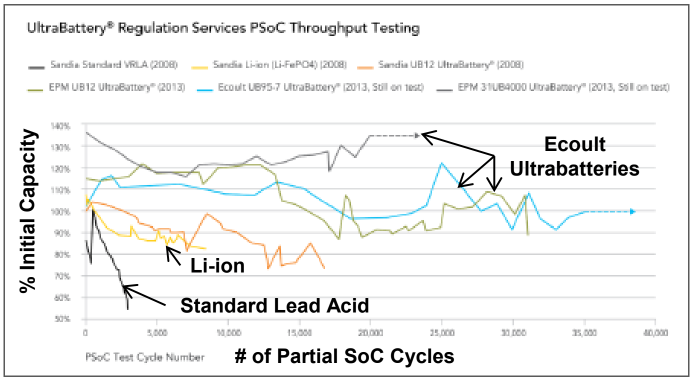
4) Security / Network Engineering and Information Assurance efforts to define the system security architecture and network design, security controls, and security CONOPs. The results from these efforts comprise documentation that was submitted to AFCEC as part of an IATT application, and to USACE as part of a "Self Attested ATO". These documents are restricted in distribution, but maybe able to be provided upon request.

In addition to the aforementioned development efforts, design work was accomplished by Ecoult/ EPM to design and manufacture the BESS system and Microgrid Switchgear employed in the project, and by Raytheon to design and implement the customized micro-grid controls. These efforts are reflected in the aforementioned design submittals, but are not explicitly documented for distribution.

## 2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Performance Advantages: The micro-grid design in EW-201606 sought to improve performance by leveraging the versatility and enhanced functionality enabled by battery energy storage when coupled and coordinated with existing renewable and standby generation assets. The use of inverter-based grid forming maximizes utilization of existing RE Distributed Resources (DR) during islanding. By operating the micro-grid with high RE penetration, diesel fuel consumption is minimized, reducing logistical challenges and potentially extending achievable islanding duration. It also provides a means to achieve both planned and unplanned seamless transition to islanding, enabling pseudo UPS-like functionality. The micro-grid architecture supports the use of an existing standby generator as micro-grid support and grid services assets while retaining its existing standby / emergency functionality. This minimizes the need for additional generation equipment and risk to mission critical facilities. The versatility associated with coordinated use of energy storage, renewable, and traditional generation maximizes the grid-tied functions that the system can provide, including frequency regulation, demand management, demand response, and export prevention. This maximizes economic value, which is critical to offsetting the increased capital cost relative to conventional approaches.

UltraBattery® ESS technology has been designed for longevity when subject to High Rate, Partial State of Charge (HR-PSoC) operation which typifies frequency regulation and micro-grid renewable integration applications. While it was developed to address shortcomings with traditional lead acid, it was attempting to compete primarily with Li-ion chemistries (Figure 9, left). The UltraBattery® ESS is also capable of high efficiency energy shifting (Figure 9, right), providing potential utility in longer duration demand management functions. The UltraBattery® comes from lead-acid heritage; therefore it is scalable, domestically manufactured, safe (not flammable/explosive), and recyclable. This is in contrast with Li-ion technology, which presents varying thermal runaway risks (depending on specific Li-ion chemistry) and features more complex manufacturing and reclamation, frequently using overseas sources.



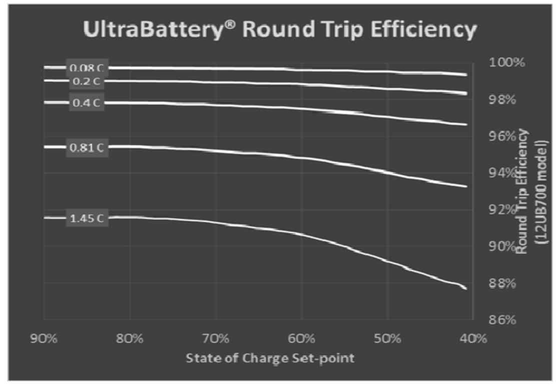




**Figure 9. UltraBattery Performance Data**

The EW-201606 MCS approach was structured to minimize control vulnerabilities that could compromise micro-grid reliability / availability while enabling cyber-secure use of the best available commercially available control technologies, many of which are already in use at DoD facilities. Time-critical (i.e. cycle-speed) control required to maintain voltage and frequency and provide protection is accomplished locally and is self-contained within each DG. This approach allowed the design to take advantage of the proven capabilities of commercial DG controls, minimizing the reliability impact of potential communication issues, and providing a means to recover from them in the event they occur. The only distributed time-critical controls in the system provide specialized protection for the ESS and are implemented using high reliability, simple comparator circuits.

The IPEM Controller supervisor provides a convenient interface to the multiple disparate commercial control systems and greatly simplifies their coordinated use within the micro-grid. The efficacy of combining high performance commercial controls with our IPEM supervisor was proven on EW-201242, which demonstrated islanded operation of a 100kW building level micro-grid through coordinated operation of a flow battery, solar PV, and building automation (HVAC) controls (Figure 10). In the EW-201242 islanding demonstration, grid forming was handled by the ESS inverter and the IPEM Controller managed transitions, PV production, and building load through the building automation system (Tridium JACE) interface.


**Figure 10. MCAS Miramar Micro-grid Demonstration Picture and Data**

Equally importantly to power and energy management functions, our IPEM MCS architecture provides a cyber-secure "wrapper" on the commercial DG controls, minimizing the need to customize them to meet DoD-specific cyber-security requirements. This "wrapper" also provides a means to secure external interfaces to the micro-grid, which are required to perform frequency regulation and other high value grid services. Lastly, our MCS architecture provides a cyber-secure portal by which system performance data can be transmitted for offsite monitoring purposes.

Cost Advantages: The micro-grid demonstrated in EW-201606 improves operational cost by providing functionality that can reduce behind the meter energy and operation and maintenance (O&M) costs, as well as generate revenue in the energy markets. As described in [15], standby generator O&M costs can be appreciable ($6500/yr). The EW-201606 demonstration system design was intended to provide coverage for 34 buildings, only 4 of which currently have dedicated back-up generators. If all 34 buildings were critical loads with dedicated back-up generators, their potential annual O&M costs (~$221K) would far exceed the costs associated with maintaining the ESS and a single diesel generator (~$97K).

For operational energy cost reduction, our demonstration efforts focused on how micro-grid assets can be used to provide demand response and frequency regulation. We chose these specific functions based on the specific Distributed Generation (DG) available at Otis ANGB, and the local ISO-NE market. Frequency regulation and islanding with high penetration renewables both require HR-PSoC operation, aligning with our BESS technology selection. ISO-NE (along with PJM) are the most financially advantageous of the ISO/RTO markets for frequency regulation [16]. Projections based on 2015 ISO-NE data and an analysis completed by NREL based on 2016 data [17] indicated average values of $333K and $304K/MW-year. Despite a decline in regulation market prices since 2016, 2020 demonstration data indicates anticipated revenues of $217K/MW-year. The existing standby generator we have modified to provide micro-grid support was built at such a time that it does not require an emissions upgrade and is permitted for 50hrs of non-emergency use. This makes it cost effective to employ the generator in ISO-NE's Real Time Demand Response (RTDR) program, which, between 2010 and 2016 had a maximum requirement of 13hr 10min of total run time [18]. CPower predicted value or RTDR, set by the rolling Forward Capacity Auction, would average $51,184/MW-year from 6/2020 – 5/2025 [18]. NREL also examined behind the meter opportunities for BESS demand charge reduction using their REopt tool [19]. However, the incremental savings was found to be $23,025/year in year 1, which is far lower than the potential value of performing frequency regulation. As such, the focus of demonstration activity was on frequency regulation using the BESS and demand management using the generator.

Lastly, although not a major driver of operating cost, it should be mentioned that the reduced fuel consumption of fuel during islanded operation can provide benefit. Assuming an average load of 750kW, the anticipated fuel consumption costs for a diesel-only micro-grid would be $21,276 for a 120hr islanding event assuming fuel costs from [18]. Initial analysis has shown the potential to reduce this by >30%, creating $6,383 of additional potential savings.

Performance Limitations: The primary technical performance limitation associated with the EW-201606 system stems from its reliance on the BESS as the "heart" of the system for islanding. The BESS provides grid-forming and LoG-RT functions. When it is not available, the micro-grid is not available. Future designs would benefit from a redundant ESS configuration, the challenge residing in how to implement this affordably while providing adequate coverage. It should also be noted that system performance is dependent on the existing infrastructure present at Otis ANGB / Joint Base Cape Cod (JBCC). Fortunately, ANG efforts undertaken in parallel with execution of EW-201606 migrated overhead electrical distribution underground for the majority of the Otis ANGB East Campus. As such, while there are some sections where the micro-grid is still vulnerable to overhead line faults, they are substantially reduced from the anticipated state at the beginning of the project. Lastly, the EW-201606 design does not currently feature any communication or control redundancy. Implementation of fiber rings and redundant controllers is certainly feasible at increased cost. In this project we did not have a specific availability or reliability specification and elected to minimize cost.

Cost limitations of the system reside in the increased complexity and maintenance requirements relative to a single diesel generator-based alternative configuration. BESS and micro-grid yard O&M costs are $85K in year 1 of deployment. An additional $29K is needed to maintain the MCS, including technical support, minor software updates, and recurring license renewals. Lastly, maintenance of information assurance (IA) security posture is a notable non-trivial task which can add cost, depending on the capabilities of the installation staff. Operating and maintaining the demonstration system requires personnel with particular skillsets, especially as it pertains to maintaining the Information Assurance (IA) posture required to obtain and maintain ATO.

This may require training existing personnel or hiring new personnel to address these needs. Future capabilities, such as the DISA Joint Information Environment (JIE) or AFCEC COINE are under development to address such shortcomings. At Otis ANGB where there is no resident IA staff, these costs amount to $99K/year of contracted labor, or 31hrs/month. Combined, these costs necessitate the system provide cost savings and revenues to fund and offset these O&M burdens.

## 3.0 PERFORMANCE OBJECTIVES

Project Performance Objectives (POs) are shown in Table 2 below and fall into two categories. Category 1 POs pertained to power system performance and efficiency in islanded operation, whereas Category 2 POs pertain to system economics and demonstration of cyber-secure methods required to perform high-value, ISO-interactive grid services. Category 1 POs aligned with ESTCP Installation Energy "Energy and Water Security" criteria whereas Category 2 POs align with "Cost Avoidance" criteria. Quantitatively demonstrating achievement of the POs was sought to de-risk the implementation of similar systems on other DoD facilities, and provide the data required to make investment decisions on pursuing such projects.

**Table 2. Performance Objectives**

| Performance Objective | Metric | Data Requirements | Success Criteria |
|---|---|---|---|
| **Category 1: Manage High Penetration RE Ramp Rates and Intermittency to Maintain Power Quality** | | | |
| Maintain power quality in the micro-grid over 120 hours of continuous islanded operation with high-penetration (>90% instantaneous) wind generation | Voltage, Frequency, Harmonics | Voltage, Frequency and Harmonics | Power quality measurements meet guidance of IEEE1547.4 |
| Optimize ESS and conventional generation dispatch and RE curtailment to minimize diesel fuel consumption over 120hrs of continuous islanded operation | Diesel Fuel Consumption | Total diesel fuel consumption over 120hrs of continuous operation | Demonstrate >30% reduction in fuel consumption relative to diesel-only operation |
| **Category 2: Demonstrate Cyber-Secure Methods to Provide Revenue Generation and Cost Savings** | | | |
| Establish a cyber-secure interface to ISO NE, obtain ATO, and complete testing to qualify as an ATRR in ISO NE's test environment | ESS meets ISO-NE OP-14 requirements for use as an ATRR, overall system receives ATO | Completion of ISO-NE ATRR testing protocol. Completion and submission of RMF accreditation package | ESS qualifies as ISO-NE ATRR, receipt of ATO |
| Demonstrate cost savings through demand management using BESS, generator, and wind, aggregate with economic benefits of regulation services and demand response to maximize ROI and SIR associated with system implementation | Cost avoidance and revenue generation potential | Measured average demand reduction (kW) and ISO-NE approved regulating capacity (kW) | Measured demand reduction benefits and regulation performance support < 5 year simple payback and SIR > 2 as analyzed by NREL's REopt tool per NIST Hdbk 135 |

The following elaborates on each PO shown in Table 1.

### Category 1, PO #1

- Name and Definition: Maintain power quality in the micro-grid over 120 hours of continuous islanded operation with high-penetration (>90% instantaneous) wind generation.
- Purpose: The purpose of the PO was to demonstrate the technical feasibility of the demonstration micro-grid approach, specifically the use of a grid-forming BESS and high penetration wind generation serving as the primary sources in a hybrid micro-grid.

This contrasts with current practice, which typically entails the use of diesel generators as the primary source. By demonstrating this PO, the project sought to create the technical data needed to establish the viability of the approach and enable low-risk replication.

- Metric: The metric was the duration of islanding supported (hrs) and power quality during the demonstration (e.g., voltage, frequency, harmonics). The range of acceptable values for power quality metrics are defined in IEEE 1547.4 [26], which is supported by other IEEE and ANSI standards (e.g., IEEE 1547 [21], ANSI C84.1 [20]). Ideally, micro-grid power quality will meet the requirements prescribed in these specifications for grid-connected Distributed Resource (DR) equipment. However, IEEE 1547.4 does provide allowance for deviations from the ranges specified when acceptable to the power system.
- Success Criteria: Success was defined as successfully islanding the system for 120hrs while maintaining power quality within the required limits of connected loads. This is the criteria defined in IEEE 1547.4. Comparisons were to be made to grid connected DR standards. Ultimately, this objective was not tested.

**Category 1, PO #2**

- Name and Definition: Optimize ESS and conventional generation dispatch and RE curtailment to minimize diesel fuel consumption over 120hrs of continuous islanded operation.
- Purpose: The purpose of the PO was to demonstrate the benefits of employing high penetration wind generation as a means to reduce fuel consumption in a hybrid micro-grid. This sought to quantify one of the benefits of the demonstrated practice relative to current practice, which typically entails the use of diesel generators as the primary source. By demonstrating this PO, the project sought to create data to further support implementation of the demonstrated approach.
- Metric: The metric is the reduction in fuel consumption (gallons) over the 120hr demonstration relative to what it would have been if the existing diesel generator only would have been used to power the micro-grid.
- Success Criteria: Success was defined as achieving a measured reduction in fuel consumption of >30% over the 120hr islanding demonstration. Ultimately, this objective was not tested.

**Category 2, PO #1**

- Name and Definition: Establish a cyber-secure interface to ISO-NE, obtain ATO, and complete testing to qualify as an ATRR in ISO-NE’s Regulation Test Environment (RTE)
- Purpose: The purpose of the PO was to demonstrate the feasibility of employing a BESS as a frequency regulation asset for the regional ISO while serving as a back-up generation source for mission critical loads. Achievement entails addressing both technical and DoD policy / procedure challenges.
- Metric: There were two metrics associated with this PO: 1) completion of DoD RMF Assessment and granting of ATO to operate the system with an external connection to ISO-NE; 2) Validation of the ability of the system to provide >1MW (1.6MW target) of regulating capacity via participation in ISO-NE’s ATRR evaluation requirements.

- Success Criteria: Success for the first metric is defined as successfully obtaining ATO from the responsible AO such that the system can be operated. An interim measure of success is obtaining IATT the demonstration system. Success for the second metric is defined as obtaining approval from ISO-NE to operate the BESS in the frequency regulation market, which requires demonstrating adequate performance at or above a regulating capacity of 1MW with satisfactory performance. This objective was tested and successfully completed.

**Category 2, PO #2**

- Name and Definition: Demonstrate cost savings through demand management using BESS, generator, and wind, aggregate with economic benefits of regulation services and demand response to maximize ROI and SIR associated with system implementation
- Purpose: The purpose of the PO was to demonstrate the economic benefits associated with implementation of the demonstration system. The results from this PO ought to inform both Government and third party financier decision making regarding implementation of the demonstrated approach in future projects.
- Metric: There were two metrics that will be calculated for this PO: 1) SPB, and 2) 5-, 10-, and 20- year SIR.
- Success Criteria: Success for this metric is obtaining a SPB of <5 years and 5-, 10-, and 20- SIR of >2. This objective was tested but fell short of the success criteria.

# 4.0 FACILITY/SITE DESCRIPTION

## 4.1 FACILITY/SITE LOCATION AND OPERATIONS

The demonstration site for EW-201606 was JBCC in MA. JBCC contains 22,000 acres square miles of land incorporating Otis ANGB, Camp Edwards (Army National Guard), US Coast Guard Base Cape Cod, US Coast Guard Air Station, Cape Cod, Air Force 6th Space Warning Squadron, and the Massachusetts National Guard. Power to most of JBCC is provided by 102nd Intelligence Wing (IW) at Otis ANGB. The 102nd IW owns and operates distribution infrastructure serving 4.5MW of peak load using seven 12.47kV feeders. The demonstration system connects into the East Feeder, which will be re-configured, along with the East Auxiliary and Flightline Feeders, to provide a "Micro-grid Feeder" (Figure 11). The Micro-grid Feeder was configured to power Otis ANGB's East Campus, the site of the 102nd IW's critical loads.

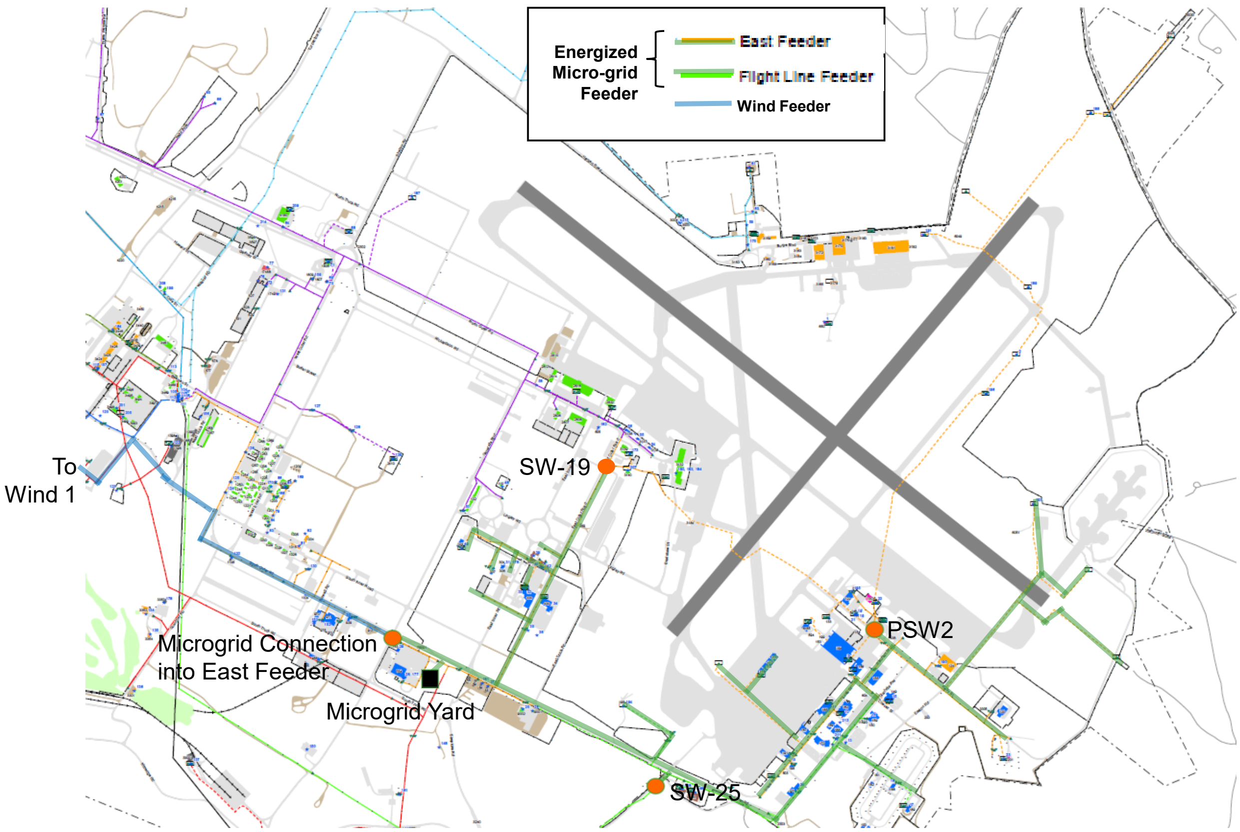



**Figure 11. Otis ANGB Micro-grid Feeder Configuration**

Based upon load data provided by the 102nd IW, the Micro-grid Feeder was expected to exhibit a maximum average of 0.9MW and 1.2MW peak of total demand, providing service to 34 buildings to be supported by the demonstration micro-grid (Figure 12).

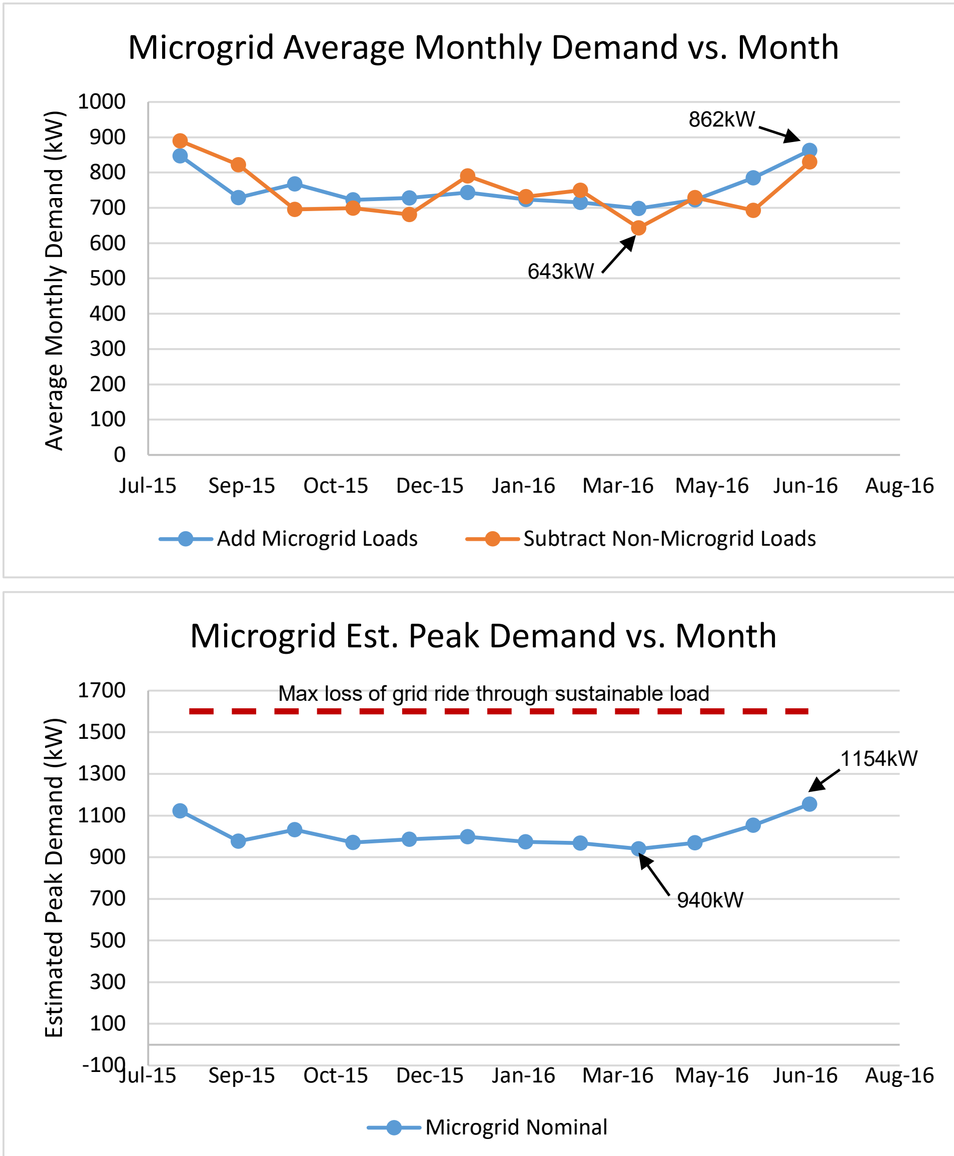



**Figure 12. Otis ANGB Micro-grid Average and Peak Demand**

"Wind 1", a 1.5MW Fuhrlander FL1500 Wind turbine, is located to the west of the substation and is currently virtually net metered into an Eversource Energy 24.9kV feeder. A new "Wind Feeder" was constructed under the project to connect Wind 1 to the Micro-grid Feeder (Figure 13). New fiber accompanies the Wind Feeder conductors, providing communications between Wind 1 and the micro-grid. As of the end of the project the feeder was constructed; however, the final connection at the turbine was not completed. The fiber circuit was completed and tested.

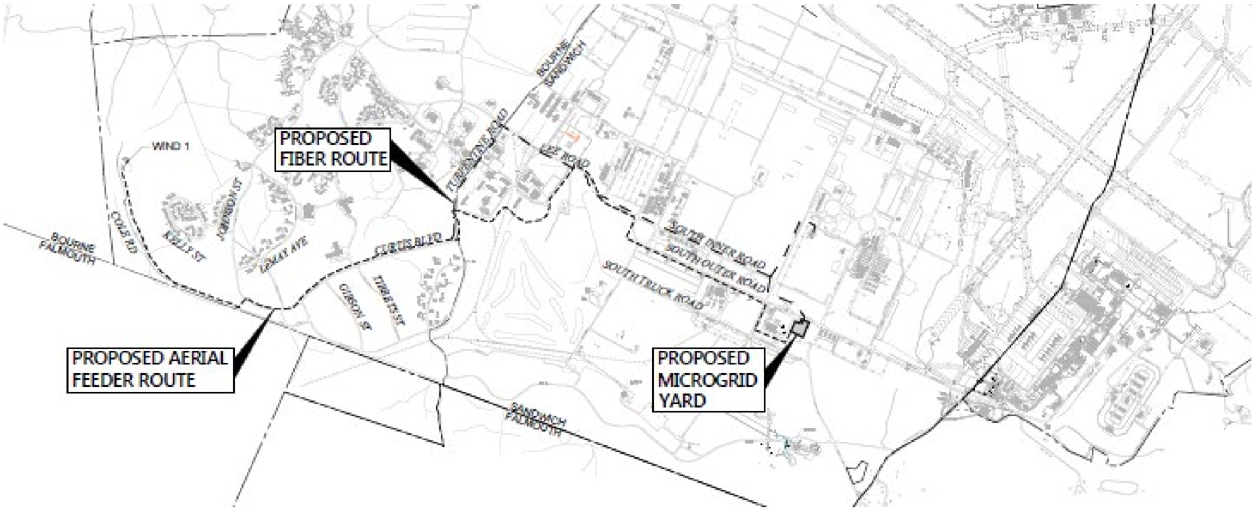



**Figure 13. Depiction of Wind Feeder and Communications**

A 1.6MW 1600REOZM Kohler diesel generator (Figure 14) is located at Building 168 in Otis ANGB's East Campus and provides standby back-up power for Buildings 168 and 169. This generator was modified to enable parallel operation with the Micro-grid Feeder. In its modified configuration, ATS current ratings limit generator output to 1250kW at 0.98PF. The generator was tested for grid parallel operation up to 910kW, at which generator "surging" was observed, causing the generator to trip offline. At the same time, a determination was made by the Base Civil Engineer that the generator could not be used in the micro-grid due to AFI 32-1062 restrictions without obtaining a waiver from AFCEC. Efforts to obtain this waiver were made by base personnel at various times during the project, but as of the completion of the project were not successful. Without access to the generator, the project was not able to troubleshoot the generator "surging" issue, and as such it remains unresolved.

**Figure 14. Kohler 1600REOZM at Building 168**

The key mission of the 102nd IW is the Distributed Ground Command System (DGCS), which supports live-fire missions being conducted throughout the globe. In addition, JBCC is in the process of addressing a significant ground water contamination issue through their Installation Restoration Program (IRP), run by the Air Force Civil Engineering Command (AFCEC). AFCEC is the owner and operator of Wind 1, which provides Virtual Net Metering revenues to help offset IRP operating costs. During the project, the 102nd Air National Guard pursued execution of a Memorandum of Understanding (MOU) with AFCEC to allow AFCEC to be credited for behind the meter production of Wind 1 after it is connected into the new Wind Feeder. An analysis conducted by NREL [19] showed that the current revenues to AFCEC and credits from the 102nd are likely to be comparable ($0.15/kWh vs. $0.145/kWh, blended including energy and demand charges). When it became clear that the micro-grid could not be completed due to loss of access to the DCGS generator, the decision was made to defer connection of "Wind 1" to the micro-grid to a follow-on project.

## 4.2 FACILITY/SITE CONDITIONS

Ultimately, due to loss of access to the DCGS generator, the EW-201606 demonstration effort focused on grid-tied operation of the BESS in the ISO-NE frequency regulation market. The ability to perform this demonstration was most impacted by local site conditions related to the communications infrastructure and electrical interconnect.

1) Existing Dark Fiber Infrastructure. The micro-grid network that connects the various components in the system was able to largely exploit existing dark fiber that had previously been installed. This enabled micro-grid communications to be hosted on a dedicated air gapped network and avoid the need to establish a virtual local area network (VLAN) or method to integrate micro-grid communications with existing Air Force communications networks. The use of a dedicated, air gapped network to support the micro-grid was critical to reducing risk associated with the external control and telemetry connections that were essential to successfully conducting the demonstration.

2) West Main Substation Interconnect. The majority of power supplied to JBCC is sourced at 24.9kV by the utility (Eversource Energy) through the West Main Substation. The West Main Substation supplies power to seven 12.47kV feeders, including the East and Flightline Feeders that comprise the Micro-grid Feeder. In order to secure an Interconnect Service Agreement (ISA) with Eversource Energy, the project was required to forward power protection relaying at the West Main Substation to ensure the Micro-grid would not reduce power being supplied through the substation to <5% the nameplate value of the DG present in the micro-grid. In addition, during the project, there was an (unrelated) failure of one of the two 23kV to 12.47kV transformers in the substation. The failed transformer was the larger, primary unit rated to 7.5MVA. Only the back-up transformer, rated at 5MVA was therefore used for the demonstration effort. Since the load on the substation could approach 4MVA during the summer, this necessitated additional controls be put in place to avoid overloading the substation. Combined, these forward power protection and transformer overload avoidance considerations created an operating band for the system to operate in, enforced by software controls with relay back-up protection.

Although micro-grid operation was not demonstrated due to the aforementioned loss of access to the DCGS generator, generator modifications were completed and parallel operation of the DCGS generator was achieved. This was enabled by the pre-existence of the ASCO 7000 series Automatic Transfer Switch (ATS) which was suitable for modification. Modification was achieved by replacing the standby generator controller with a soft load controller capable of both standby, load following and grid parallel, base load methods of operation.

## 5.0 TEST DESIGN

EW-201606 sought to address two fundamental problems as evidenced by our Performance Objectives:

1) Management of high penetration RE ramp rates and intermittency to maintain power quality in a micro-grid. This problem was addressed in C-HIL testing, but not through field demonstration.
2) Establishing cyber-secure methods to provide revenue generation and cost savings using micro-grid assets. This problem was addressed through field demonstration.

The demonstration questions we will answer are as follows:

1) Can an energy storage-centric micro-grid provide adequate power quality when coupled with high penetration renewables, in this case wind? This question was addressed in C-HIL testing, but not field demonstration.
2) Can the micro-grid achieve ATO with external connections while servicing critical loads? This question was addressed through field demonstration.
3) Can the micro-grid generate revenue and cost savings to realize a compelling simple payback and savings to investment ratio? This question was addressed through field demonstration and techno-economic analysis

### 5.1 CONCEPTUAL TEST DESIGN

Three tests were planned to demonstrate EW-201606 performance objectives.

1) 120 Hour Islanding Test – This test sought to address both Category 1 POs
2) ISO-NE ATRR Test Environment Testing – This test sought to address Category 2 PO #1
3) Demand Management Test – This test, along with the ISO-NE ATRR Test Environment Testing, sought to provide the data required to address Category 2 PO #2

The following provides conceptual test design for each of these tests:

**Test 1) 120 Hour Islanding Test**

- Hypothesis: A hybrid (energy storage, renewable, and diesel generation) micro-grid can provide acceptable power quality over 120hrs of continuous islanded operation with high penetration (>90%) wind generation. By exploiting high penetration wind generation, the micro-grid can reduce fuel consumption by >30% relative to a micro-grid operating off of diesel fuel without wind and storage.
- Independent variable: The independent variable in this test was whether the micro-grid uses wind, storage, and diesel generation during islanding, or if it uses only diesel generation.

- Dependent variable(s): The dependent variables for this test were intended to be power quality (e.g., voltage, frequency, and harmonic content) and fuel consumption during the islanding event. These dependent variables were to be observed through direct measurements of voltage and current during islanding, as well as total fuel consumed.
- Controlled variable(s): The controlled variable for this test was planned to be the load profile during islanding. While we did not plan to control the load per say, we planned to measure it such that the same load profile tested with the hybrid micro-grid can be used to simulate what the fuel consumption would have been in a diesel generation-only islanding test.
- Test Design: The 120 Hour Islanding test was to be conducted by executing a planned transition of the system from grid-tied to islanded operation. Prior to executing the transition, the micro-grid was to be instrumented with a power analyzer to record current and voltage at the main switchgear that interfaces with the "Micro-grid Feeder". Total fuel in the generator at B168 was to be measured / established. Once the micro-grid was islanded, continuous measurements of voltage and current were to be made. Islanding was to continue for 120hrs, or the maximum duration achievable before reaching generator runtime limits. Should the micro-grid be tripped offline during the test, the root cause of the trip was to be investigated and resolved, and the testing would be re-performed with appropriate corrective actions in place. At the end of the islanding event, the voltage and current data was to be analyzed to compare deviations to pre-test grid-tied data, as well as relevant standards (e.g., ANSI C84.1 [20] and IEEE 1547 [21]). Total fuel consumption was to be measured. Fuel consumption for the diesel-only alternative configuration was to be assessed by using the recorded load data and separate fuel consumption (gph) vs. load data.
- Test Phases: The 120 Hour Islanding Test was to be conducted in 3 Phases.
  - Phase 1 entailed pre-test preparation establishing test readiness, including extensive testing activities for micro-grid sub-systems (e.g., BESS, MCS, generator, wind turbine) to establish their independent operability. First, the feeder configuration at JBCC was to be modified to the micro-grid test configuration (Figure 15). The newly formed "Micro-grid Feeder" was to be instrumented and load data was to be taken for analysis and comparison to design assumptions.

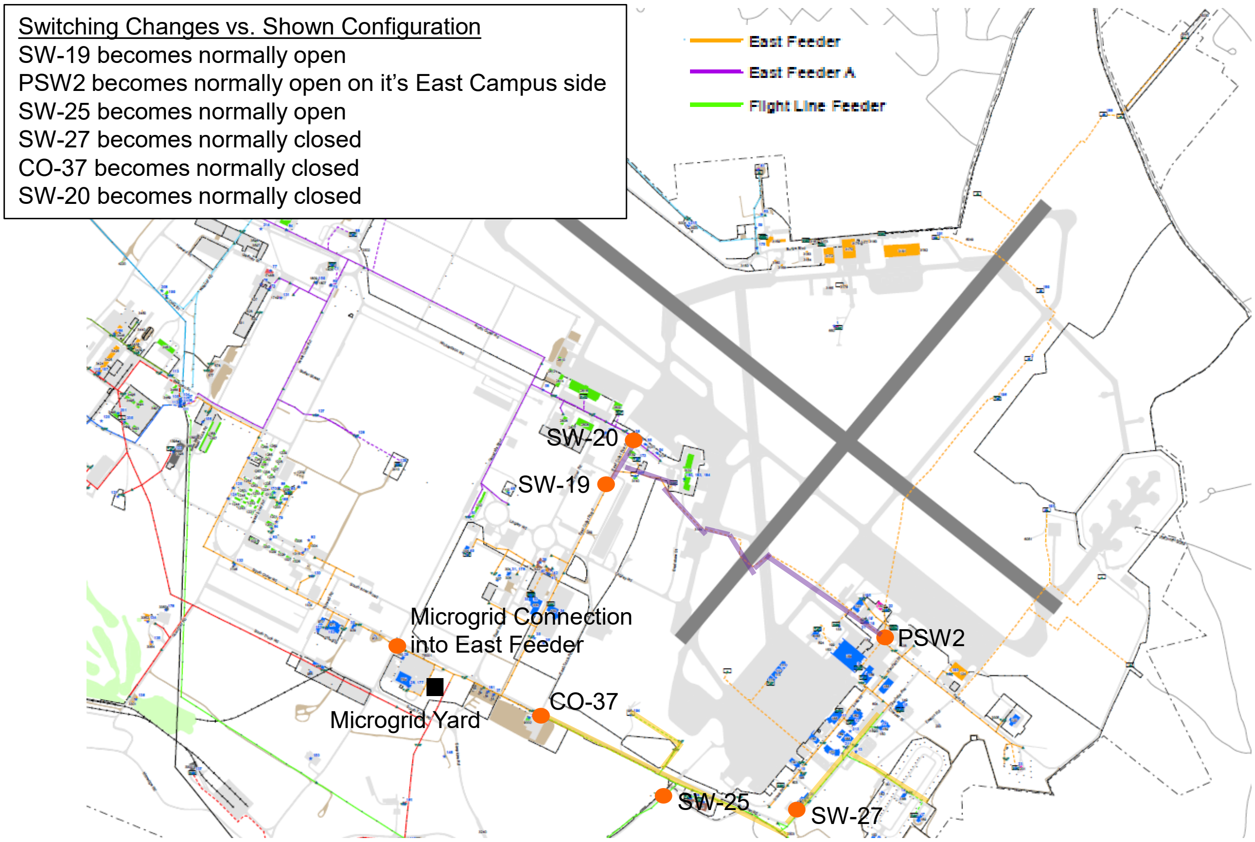



**Figure 15. Feeder Modifications for Micro-grid Testing**

In parallel, BESS unit level testing was be completed as captured in SOW b9428308 "Statement of Work (SOW) for JBCC Hybrid Microgrid Battery Energy Storage System (BESS)" (latest revision) [27]. Generator testing was completed following ATS and generator modifications, and further tested as part of the MCS test activity to verify requirements captured in JBCC Micro-grid CONOPs and Functional Requirements [28]. Wind Turbine SCADA testing was completed following the wtSCADA upgrade, but was planned be tested with new MCS interfaces. Individual sub-system hardware tests were completed using Controller Hardware-in-the-Loop (C-HIL) testing conducted at Raytheon to Document OANG-HIL (latest revision) [14], which employed previously measured load and wind turbine production data. The C-HIL testing activity was used to assess (and inform modification of) MCS control and protective relay settings. "Virtual islanding" was accomplished in the C-HIL environment, including injection of potentially disruptive transients.

– Phase 2 was to entail test execution. Test execution will be completed as described in "Test Design" above.

– Phase 3 was to entail test data reduction and analysis. Measured fuel consumption during the islanding test was to be compared to predicted fuel consumption for diesel generator-only operation. Power quality data collected during islanding operation was to be compared to feeder data measured during grid-tied operation.

**Test 2) ISO-NE ATRR Testing**

- Hypothesis: A BESS that is part of a DoD micro-grid supporting mission critical facilities can also be used to provide frequency regulation services to the local ISO / RTO and achieve ATO.
- Independent variable: The independent variables in this test are a) the system design and architecture that enable cyber-secure operation with an external connection, and b) the design and operational capability of the BESS that will determine its regulation capacity.
- Dependent variable(s): The dependent variables for this test were a) whether we can successfully achieve the required approvals to establish an external connection to the ISO (required to conduct frequency regulation), and b) the regulation capacity that can be supported by the BESS, as determined through Regulation Test Environment testing.
- Controlled variable(s): The controlled variables in this test were the DoD and ISO requirements by which the dependent variables will be determined. DoD requirements are driven by various information assurance considerations, described in detail in the project Security Architecture [29]. ISO-NE's requirements are captured in OP-14 "Technical Requirements for Generators, Demand Response Resources, Asset Related Demands and Alternative Technology Regulation Resources" [30].
- Test Design: ATRR testing was completed in conjunction with ISO-NE personnel once the system was fully operational and connected to ISO-NE data circuits to receive external commands. ATRR testing consists of two main components: a) a "Minimal Responsiveness" test that validates the connectivity with the ISO interface and ability to accept commands and charge or discharge accordingly, and b) Regulation Test Environment (RTE) testing, described in SOP-RTMKTS.0080.0020 [31]. RTE testing purposes the ATRR into the frequency regulation market in accordance with the submitted parameters of Regulation High Limit, Regulation Low Limit, and Automatic Response Rate. Economic offer parameters were excluded during the Evaluation Phase to ensure participation. While in the RTE the ATRR received the same AGC set point signal as in the full Regulation Market. Performance was monitored for every hour that the ATRR is assigned to provide regulation. By performing well in the RTE, the ATRR was able to transition out of the RTE and into the full Regulation Market.
- Test Phases: ISO-NE ATRR Testing was be conducted in 2 Phases.
  - Phase 1 entailed pre-test preparation establishing the capability of the BESS to meet ISO-NE ATRR requirements and satisfy the necessary IA requirements to establish an external connection to the ISO. This included the execution of BESS SOW testing as described above, including demonstration of frequency regulation using the 24hr AGC signal provided on the ISO-NE webpage as of May 2017. Data circuits were be installed to meet metering and telemetry requirements described in ISO-NE OP-18 "Metering and Telemetering Criteria" [32]. Required IA activities were carried out to submit an IATT application and self-attested ATO IAW NIST SP 800-171 requirements, and to prepare for full ATO under DoD RMF.

– Phase 2 entailed completion of the aforementioned ISO-NE Minimal Responsiveness and RTE testing. Issues identified in successfully completing RTE testing were de-bugged to assess the shortcomings. Parameters employed in successful RTE testing were used when the system transitioned to full market operation and used as the basis of the financial calculations used to monetize the benefit of performing frequency regulation.

**Test 3) Demand Management Test**

- Hypothesis: Cost savings can be obtained through demand management using the BESS, generator, and wind. By aggregating these benefits with economic benefits of regulation services, a < 5 year simple payback and SIR > 2 can be achieved as analyzed by NREL's REopt tool per NIST Handbook 135.
- Independent variable: The independent variable in this test was the combined demand management and frequency regulation capabilities of the micro-grid system.
- Dependent variable(s): The dependent variables for this test were the simple payback and savings to investment ratio that can be achieved based on the demonstrated demand management and regulation capabilities of the micro-grid system.
- Controlled variable(s): The controlled variables in this test were the analysis methods used to establish the monetized value of the demonstrated demand management and regulation capabilities. The analysis was conducted by NREL using REOpt and through assessment of anticipated market revenues based upon historical regulation market data, forward capacity market auction outcomes, and through isolation of capacity tag costs.
- Test Design: Demand management testing was to be conducted using the B168 generator simulating a Real Time Demand Response (RTDR) event IAW ISO-NE RTDR program procedures described in ISO-NE OP-4, Action 2 [33]. Load was to be measured at the West Main Substation using newly installed CTs and PTs and relaying. Upon command and within 30 minutes of notification, the MCS was to be used to start and parallel the generator with the utility grid. The generator was to be base loaded to a maximum of 1.25MW and run for 1hr, similar to a typical seasonal audit. The Demand Reduction Value (DRV) achieved through these actions was to be calculated in accordance with the M-MVDR manual [34] and Market Rule 1 [35] as published by ISO-NE. Once the DRV was established, RTDR capability were to be monetized using Forward Capacity Auction information data, less fuel costs and fees, in conjunction with the selected Lead Market Participant for the system (CPower). These financial benefits were to be combined with the predicted frequency regulation revenues, O&M costs, and REOpt-determined energy costs, in a NIST Handbook 135 analysis. The NIST Handbook 135 analysis was to provide simple payback and SIR values to compare to the performance objective.
- Test Phases: Demand Management Testing was to be conducted in 3 Phases.
  – Phase 1 entailed pre-test preparation establishing the capability of generator to meet the functional and telemetering requirements for participation in the RTDR program. The generator and ATS were modified to provide grid-parallel operation and testing with the MCS was performed to finalize the functional capability.

Initial testing to emulate a demand response event was performed and led to discovery of the aforementioned "surging" issue.

- Phase 2 was to entail completion of the demand management testing as described above. The DRV was to be determined through this testing.
- Phase 3 was to focus on financial analysis to determine simple payback and SIR. Results from ISO ATRR testing and demand management testing was to be used to inform the analysis, along with REopt analysis results, all as described above. This was accomplished using measured frequency regulation performance and anticipated demand response performance, assuming resolution of the "surging" issue.

## 5.2 BASELINE CHARACTERIZATION

Baseline characterization efforts fell into two categories: 1) load and power quality characterization, used to prepare for and analyze islanding test results, and 2) economic analysis baselining, which is used to substantiate financial analyses.

Load and power quality baseline characterization consisted of collecting load and generation data for the feeders at Otis ANGB and the Wind 1 turbine. 1s interval data was collected on the East Feeder (8/4-8/7/2017), Flightline Feeder (8/7-8/13/2017), and for Wind 1 (9/4-9/21/2017). These data were used in C-HIL testing efforts.

Financial baseline data was obtained from the 102$^{nd}$ ANG directly. Utility Bills from 2013 to 2017 were provided to the project and analyzed by NREL to reconcile them with the utility tariff. Similarly, Virtual Net Metering credits for Wind 1 were provided to the project from FY10-FY17. These combined data were used in a NIST Handbook 135 analysis.

## 5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The demonstration system is depicted in Figure 16. The system includes the 1.5MW Fuhrlander FL1500 "Wind 1" turbine (existing), 1.6MW Kohler 1600REOZM diesel generator (existing), and the Otis distribution system, including the West Main Substation and Micro-grid Feeder, which was to be created from the existing East, East Auxiliary, and Flightline Feeders as shown in Figures 11 and 15. New micro-grid infrastructure includes the Micro-grid AC switchgear, transformers, the Wind Feeder, and ATS and generator modifications. The Micro-grid AC switchgear allows the BESS and Wind Feeder to connect to the West Main Substation and Micro-grid Feeder. It also houses metering, protection and control equipment, and the High Speed Disconnect Switch (HSDS). Two new transformers were planned to be installed. The one that was installed allows the BESS to connect to the Micro-grid AC switchgear (480V to 12.47kV), the other that was procured but not installed would allow Wind 1 to connect to the 12.47kV distribution system (690V to 12.47kV). The Wind Feeder (see Figure 13) was constructed to allow Wind 1 to connect to the Micro-grid AC switchgear. However, the final connection between the feeder and Wind 1 turbine (using the procured transformer) was not completed. ATS and generator modifications consisted of ATS and generator controller upgrades completed to enable the 1.6MW Kohler generator to parallel with and support the micro-grid. The modifications included installing a new ASCO Soft Load Controller, re-programming the generator speed controller, and replacing the generator voltage regulator. New technology elements in the system include the 1.6MW/1.2MWh UltraBattery® ESS, and the IPEM Micro-grid Control System.

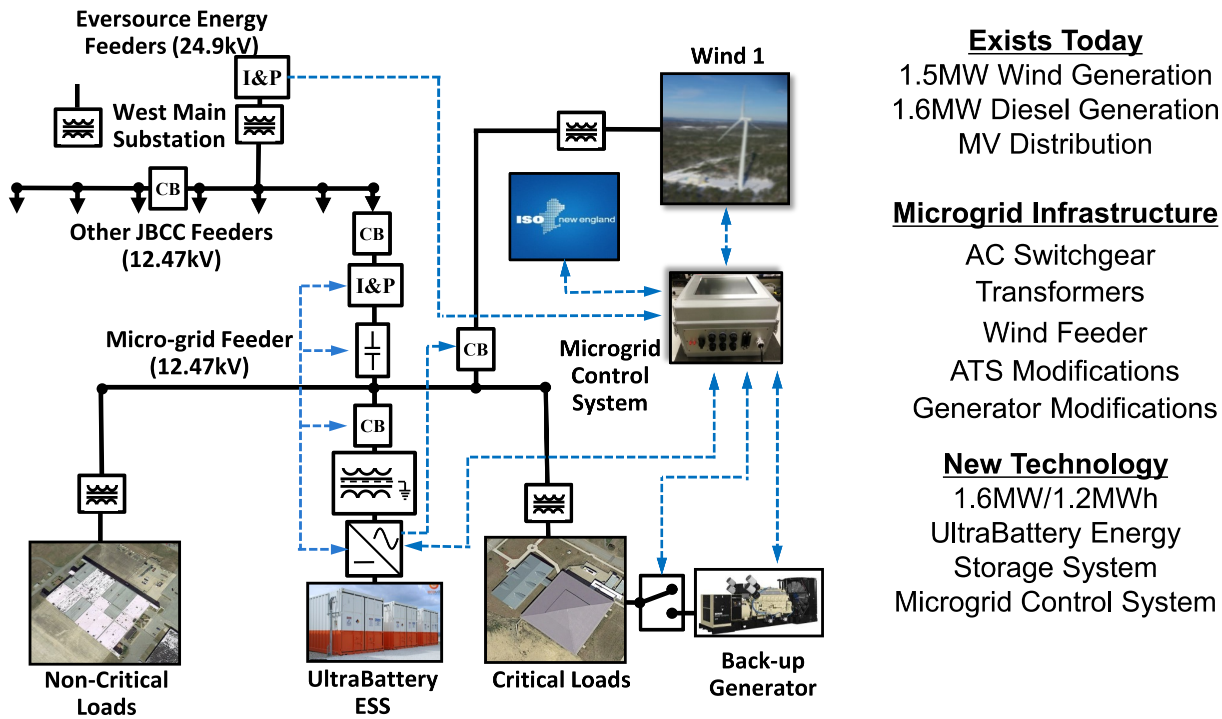



**Figure 16. Demonstration System Depiction**

The following describes major components of the system

1) <u>1.6MW/2MVA/1.2MWh Ultrabattery® Energy Storage System.</u> The Ultrabattery® ESS (Figure 17) serves as the "heart" of the demonstration micro-grid. It consists of 2x Storage Block battery enclosures, 1x Power Conversion System (PCS), a 480V / 12.47kV transformer, a DC combiner box, and a Master Station controller. The Ultrabattery® ESS is located in the Micro-grid Yard. Installation of the Ultrabattery® ESS required construction of concrete pads with embedded conduit, equipment emplacement, and completion of equipment electrical / data connections.

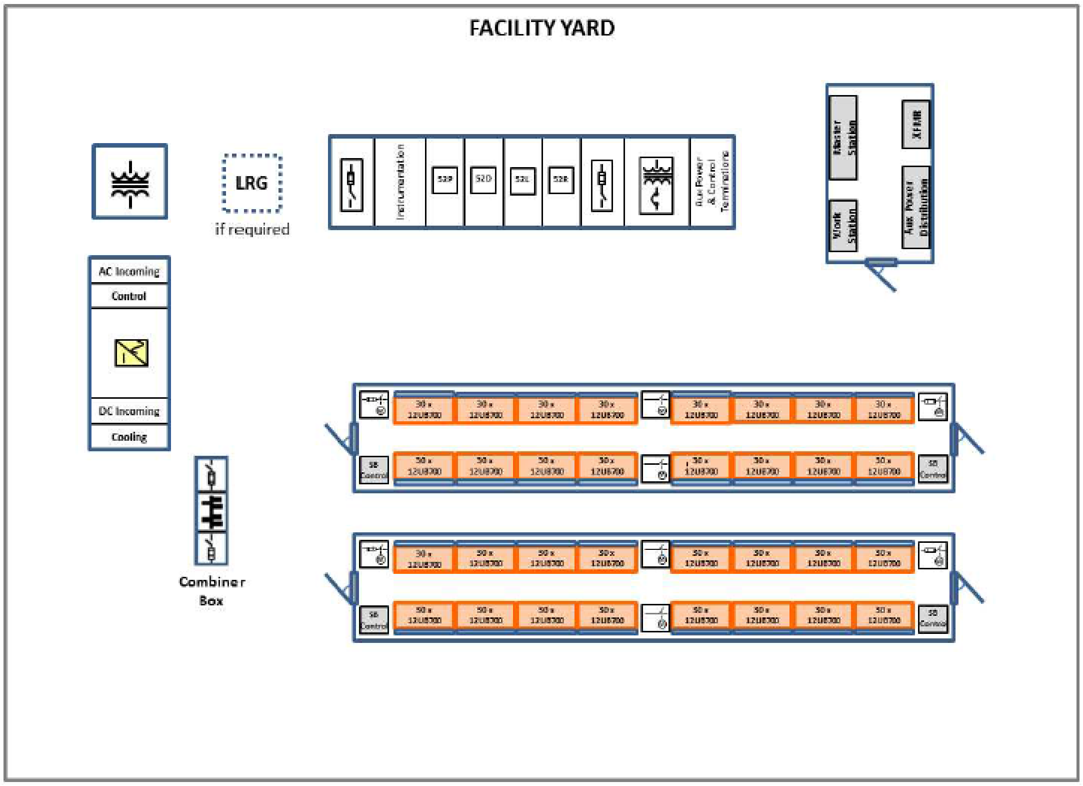



**Figure 17. Depiction of Ultrabattery Energy Storage System and Microgrid Switchgear**

2) Micro-grid AC Switchgear. The Micro-grid AC switchgear (also shown in Figure 17) connects the Ultrabattery® ESS and Wind Feeder to the Micro-grid Feeder. It contains a High Speed Disconnect Switch (HSDS), breakers for each feeder, an Auxiliary Power Transformer, fusing, and instrumentation. It is located in the Micro-grid Yard. Installation of the Micro-grid Switchgear required construction of concrete pads with embedded conduit, equipment emplacement, and completion of equipment electrical / data connections.

3) Micro-grid Yard. The Micro-grid Yard (shown in Figure 17) is a 100' x 100' Fenced Area located just inside the perimeter of Otis ANGB which contains the Ultrabattery® ESS and Micro-grid AC switchgear. It consists of concrete pads with embedded conduit / ductwork, a grounding mesh, stone fill, and a perimeter security fence. Installation of the Micro-grid Yard entailed excavation and construction of pads with embedded conduit, installation of a grounding mesh, running and connection of conductors and data between the Ultrabattery® ESS, Micro-grid Switchgear, intersecting Wind and Micro-grid Feeders, and the existing base fiber plant.

4) Wind Feeder. The Wind Feeder (Figure 13) was built to connect "Wind 1", the 1.5MW Fuhrlander wind turbine, to the Micro-grid Feeder at the Micro-grid Yard. It consists of a new 690V / 12.47kV transformer (not currently installed), new overhead and underground conductor and data with associated poles / hardware, ductwork and manholes, and cut-out switches. Installation of the Wind Feeder required new overhead (including setting and dressing poles and running conductors) and underground (including trenching, installation of ducting and manholes) construction. Feeder construction was terminated at a manhole just outside of the Wind Turbine pending final connection. Completion of the Wind Feeder would entail trenching from this manhole to the pad where the current 690V / 24.9kV transformer resides, removal and replacement of the existing transformer with the procured 690V / 12.47kV transformer, and completion and test of terminations to and from the new transformer.

5) Kohler 1600REOZM and Automatic Transfer Switch (ATS). The Kohler 1600REOZM generator (Figure 14) and ASCO ATS are located within and adjacent to Building 168 in Otis ANGB's East Campus. The Kohler 1600REOZM is a 1.6MW Tier 2 rated standby diesel generator that was modified, along with the ATS, to support the micro-grid and enable its use in demand management applications. ATS modifications consisted of installing an ASCO 7000 Series Soft load Controller, power meters, and controllers, which are part of a pre-fabricated assembly that was installed on the existing ATS in Building 168. The generator hardware modification involved replacement of the voltage regulator, and re-programming of the speed controller. Installation of the ATS and generator modifications entailed replacing the existing ATS door assembly with a new assembly, replacing the voltage regulator on the generator, installation of new relaying and associated CTs, and generator controller programming updates.

6) Micro-grid Control System. The IPEM Micro-grid Control System (MCS, Figure 7) serves as the "brain" of the demonstration micro-grid. The MCS consists of servers, networking gear, security devices and PowerStation user interface terminal. It is located at Building 104, with remote access terminals in Building 971. Installation of the MCS entailed emplacing rack mounted equipment at Building 104, new relaying at the West Main Substation, user terminals at Building 971 (control), and new fiber / data connections between the West Main Substation, Building 104, Building 971, the Micro-grid Yard, and the ATS / Generator at Building 168.

7) Wind Turbine. "Wind 1" is a Furhlander FL1500 doubly fed asynchronous generator capable of sourcing up to 1500kW / 1670kVA at 690V. "Wind 1" is controlled by AMSC's wtSCADA controls, which were upgraded to provide a full-functionality interface with rapid curtailment capability (200kW/s) for use in the micro-grid. Additional controls upgrades included installing a battery UPS and firewall to secure the interface.

### 5.4 OPERATIONAL TESTING

Operational testing was performed on various aspects of the system, including the BESS, Generator, and MCS.

BESS Operational Testing

Extensive BESS testing was performed and documented in a Ecoult document ED03227 "Otis Micro-grid Commissioning Report, Revision B, dated 12 November 2020" [43]. This document captures pre-commissioning and commissioning tests performed prior to demonstration. The following describes capstone tests performed as part of this scope of work.

Figure 18 depicts BESS performance using the ISO-NE supplied 24hr frequency regulation test profile. This test was performed to validate the ability of the BESS to follow the ISO-NE AGC signal reliably over a 24hr period. Testing was performed at 1MW ramp rate and regulating capacity, limited by an inverter module failure that is planned be replaced under warranty in January 2021. Testing was performed immediately after a battery refresh cycle, and with starting SoC of 50%

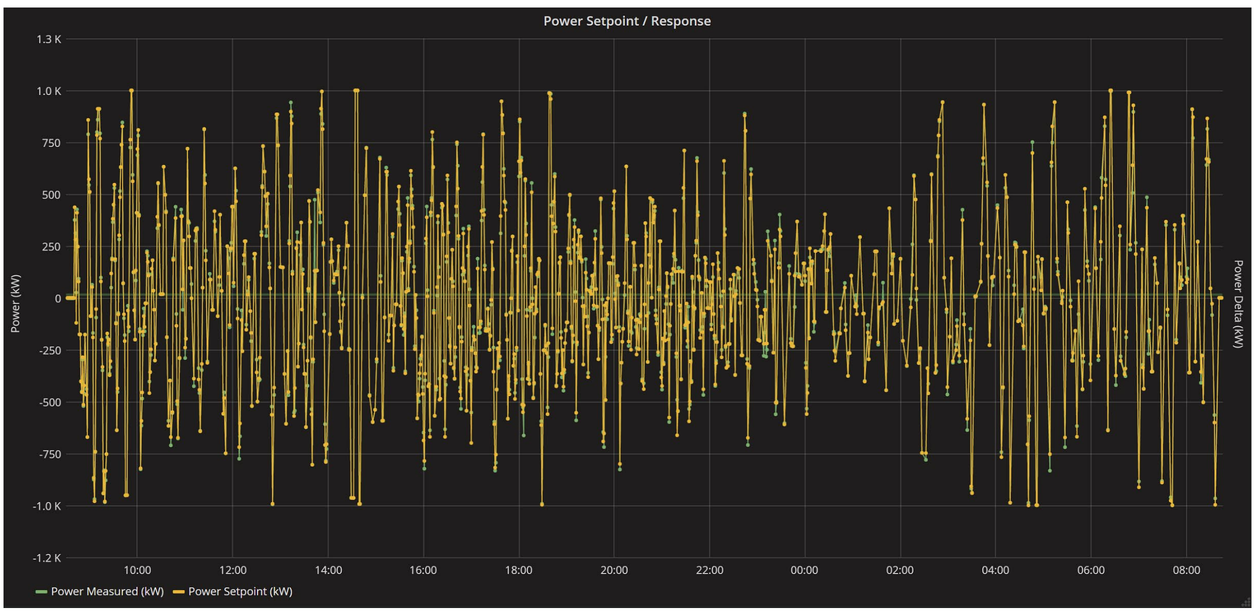



**Figure 18. BESS Performance Against Example ISO-NE Regulation Signal**

Figure 19 depicts a maximum discharge power test performed to validate the capability to the BESS to support a full power (1.6MW) discharge for 30s.

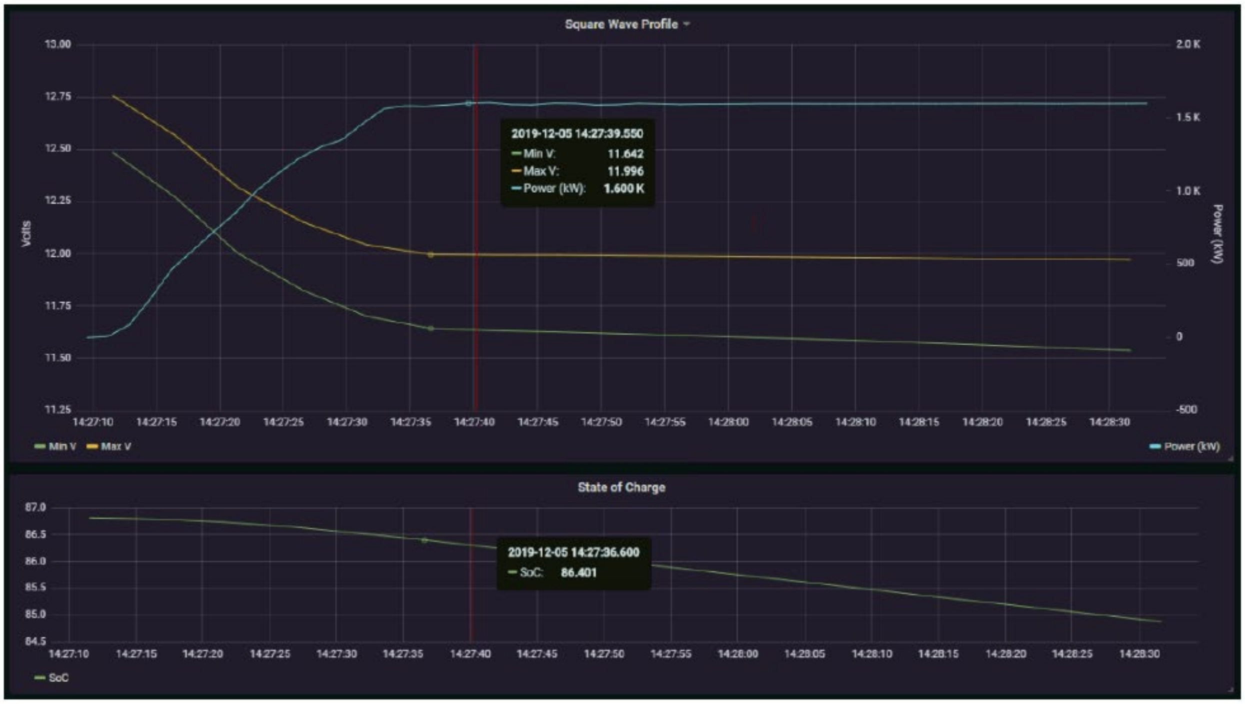



**Figure 19. BESS Maximum Power Discharge Test**

Figure 20 depicts square wave discharge profile (Table 3) testing performed to demonstrate the ability of the BESS to perform various charge and discharge profiles over varying durations of time. Testing was performed immediately after a battery refresh cycle, and with starting SoC of 60%


**Figure 20. BESS Square Wave Testing Profile**

**Table 3. BESS Square Wave Test Profile**

| Step | Time (min) | | AC Discharge or Charge Power (kW) |
|---|---|---|---|
| | Period | Total | |
| 1 | 180 | 180 | 440 |
| 2 | 40 | 220 | 460 |
| 3 | 10 | 230 | 510 |
| 4 | 5 | 235 | 670 |
| 5 | 5 | 240 | 1000 |

In addition to the aforementioned tests, a test was performed to confirm the BESS can perform a Dynamic Transfer from grid tied (PQ) to grid-forming (UF) mode. This testing was performed to with the BESS auxillary loads only, building upon factory acceptance testing that was performed at Dynapower before shipping to Raytheon.

Generator Operational Testing

Limited generator operational testing was performed before the generator was determined to be unavailable to the micro-grid due to the aforementioned AFI 32-1062 issue. This testing focused on demonstrating grid-parallel operation as would be performed when using the generator for Real Time Demand Response (RTDR).

Figure 21 depicts the load measured at the West Main Substation during the generator test. In this test, the generator was started and loaded to 780kW, demonstrating commensurate load reductions at the substation. The base load was then increased to 910kW and the generator continued to exhibit stable operation and commensurate load reduction at the substation. However, when the generator was loaded to 1040kW, instabilities were observed that caused the generator to “surge” with power output fluctuating up and down until the circuit breaker between the ATS and building transformer was tripped. At that point, the generator continued to run, follow, and support the building load. Although the surging was (obviously) an unacceptable operational characteristic, an unintended benefit to this test was that it did illustrate the ability of the generator to transition to standby mode and continue to support B168/169 in the event the connection to the micro-grid was lost.

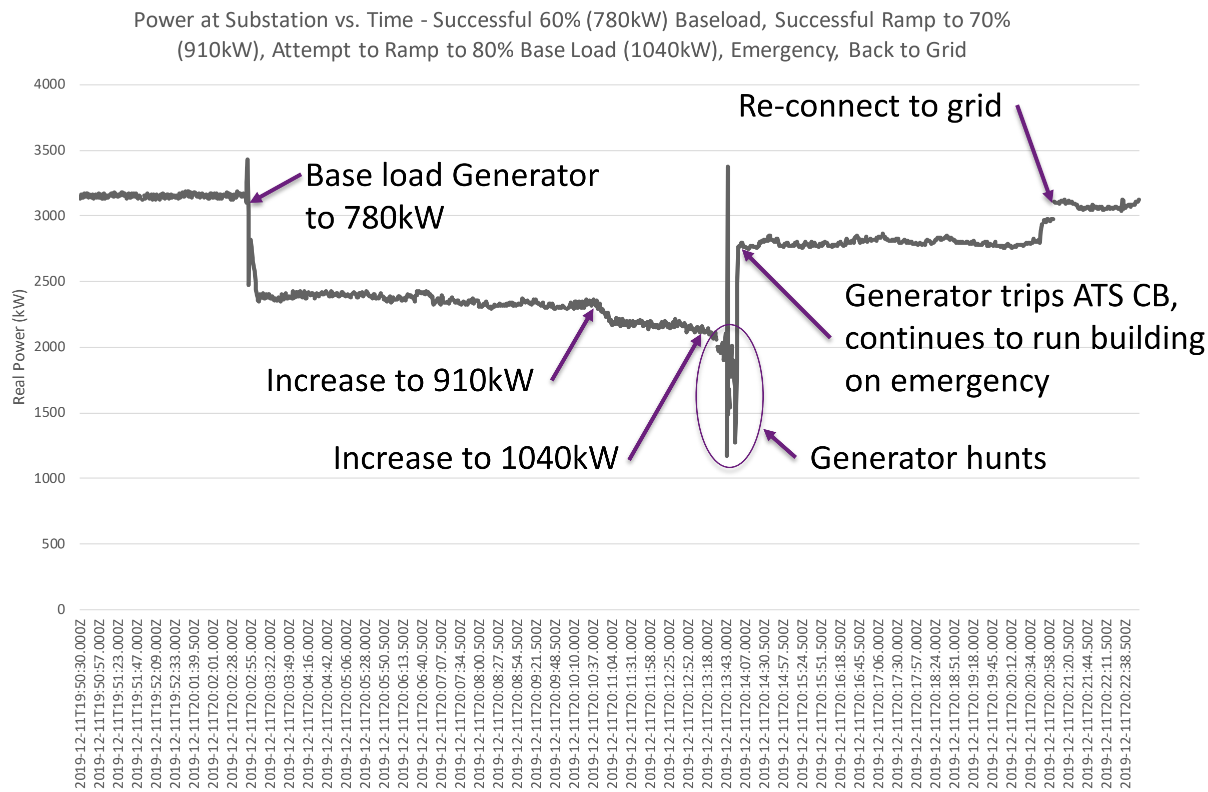



**Figure 21. Generator Testing as Measured at the West Main Substation**

Unfortunately, since the project no longer had access to the generator, the cause of generator surging could not be diagnosed. Troubleshooting efforts were planned and included load bank testing, with the primary hypothesis for surging relating to harmonics being generated by the building UPS interfering with the generator voltage regulator and/or speed controller. As of the writing of this report, the $102^{nd}$ IW is in the process of replacing the DCGS generator with a "right sized" generator for B168/169. As an outcome of this replacement, the DCGS generator may be re-sited and provided to the micro-grid for integration under a future project. Should this come to pass, care will need to be taken to ensure the surging issue is resolved in the new configuration.

Micro-grid Control System Testing

A variety of tests were performed on the MCS to verify interfaces and control functionality. These included interface testing with the BESS , Generator/ATS, Wind 1, West Main Substation relaying, and external interfaces to CES (for ISO-NE frequency regulation) and Ecoult/EPM (for BESS telemetry). Data obtained via these interfaces was aggregated and displayed for operator monitoring as shown in Figure 22. Since JBCC does not have a modern SCADA system to monitor its electrical distribution system, the initial operational value of the MCS was to provide grid-tied monitoring of power flows through the West Main Substation

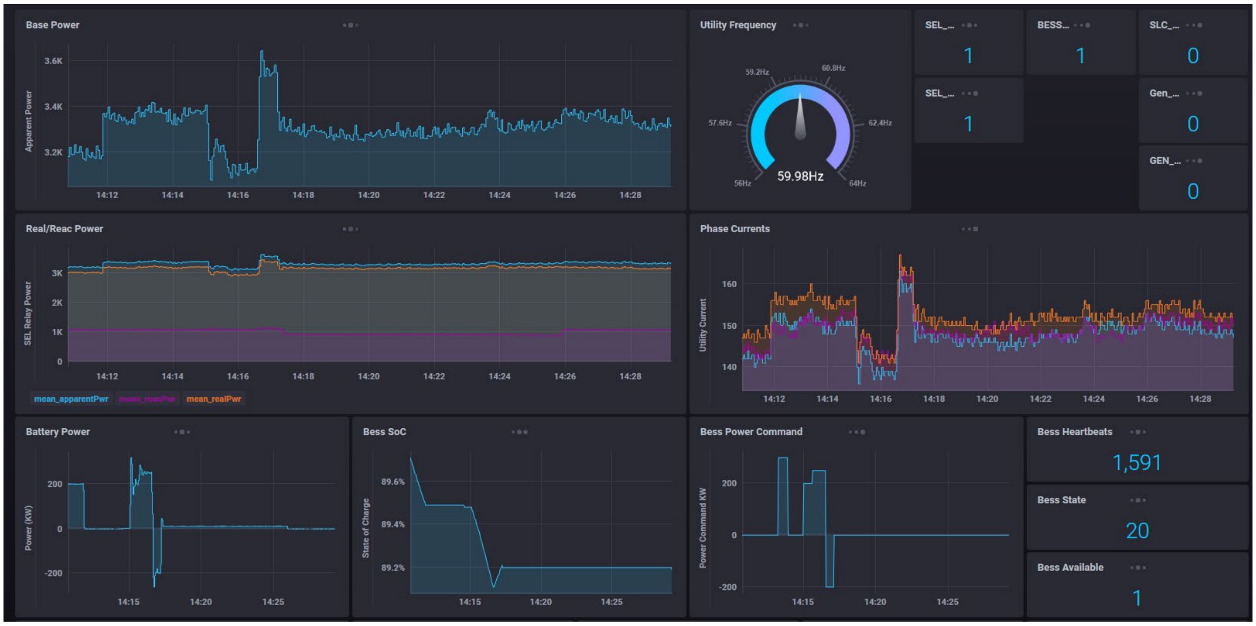



**Figure 22. MCS Display Screen**

Functional operational testing focused on mode transitions and algorithm execution. Some islanding control functions, such as generator fast load shed, were tested and verified. However, testing primarily focused on grid-tied functionality. Figure 23 depicts the performance of the curtailment algorithm that prevents the system from violating forward power protection or transformer throughput limitations as discussed previously. The orange area bounds the maximum allowable discharge while the red area bounds the maximum charge.

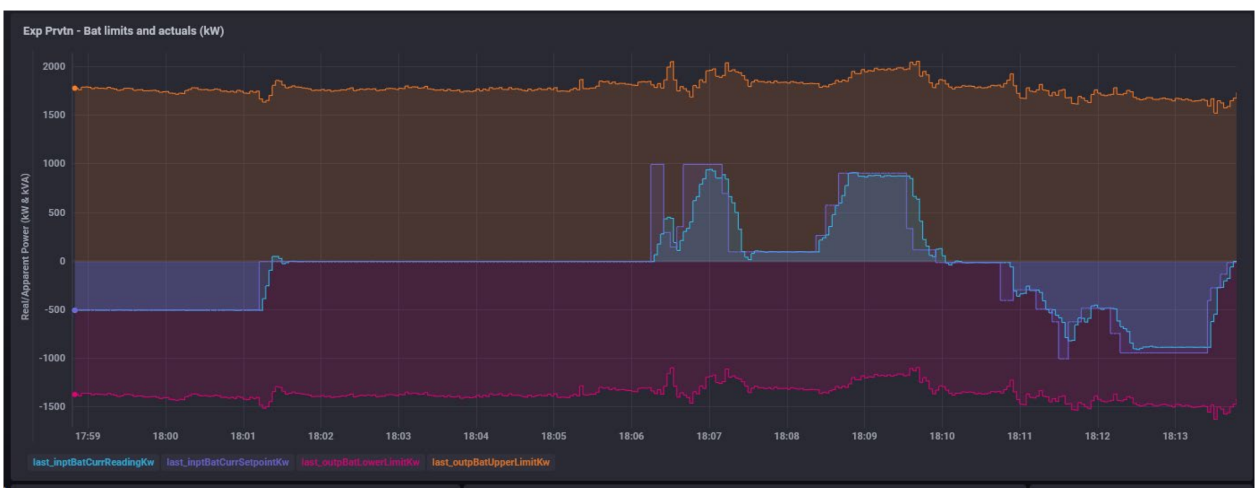



**Figure 23. MCS Curtailment Algorithm Performance**

## 5.5 SAMPLING PROTOCOL

Demonstration efforts focused on testing in the ISO-NE Regulation Test Environment (RTE) in accordance with OP-14 "Technical Requirements for Generators, Demand Response Resources, Asset Related Demands and Alternative Technology Regulation Resources" [30] and SOP-RTMKTS.0080.0020 [31]. Following the "minimal responsiveness test" which simply verifies the ability of the system to respond to ISO-NE issued AGC commands, the BESS receives a typical AGC signal at the defined regulating capacity and ramp rate. A new AGC command is issued every 4 seconds. A revenue grade meter is used to capture BESS response to the AGC signal and score BESS performance. During RTE testing, the scores are used to assess suitability for the ATRR to transition into full market operations.

## 5.6 SAMPLING RESULTS

ISO-NE RTE testing was performed from 10/23/20 – 11/26/20 at a regulating capacity of 1MW. As mentioned previously, an inverter module failure limited the ability of the facility to regulate above 1MW. During this period the BESS performed frequency regulation for 335hrs with an average score of 0.974 (on a scale from 0 to 1, where 1 is perfect performance). Initial testing was conducted during daytime hours before transitioning to 24/7 operations. Figure 24 illustrates a typical report depicting performance of the system with various scoring envelopes / limits.

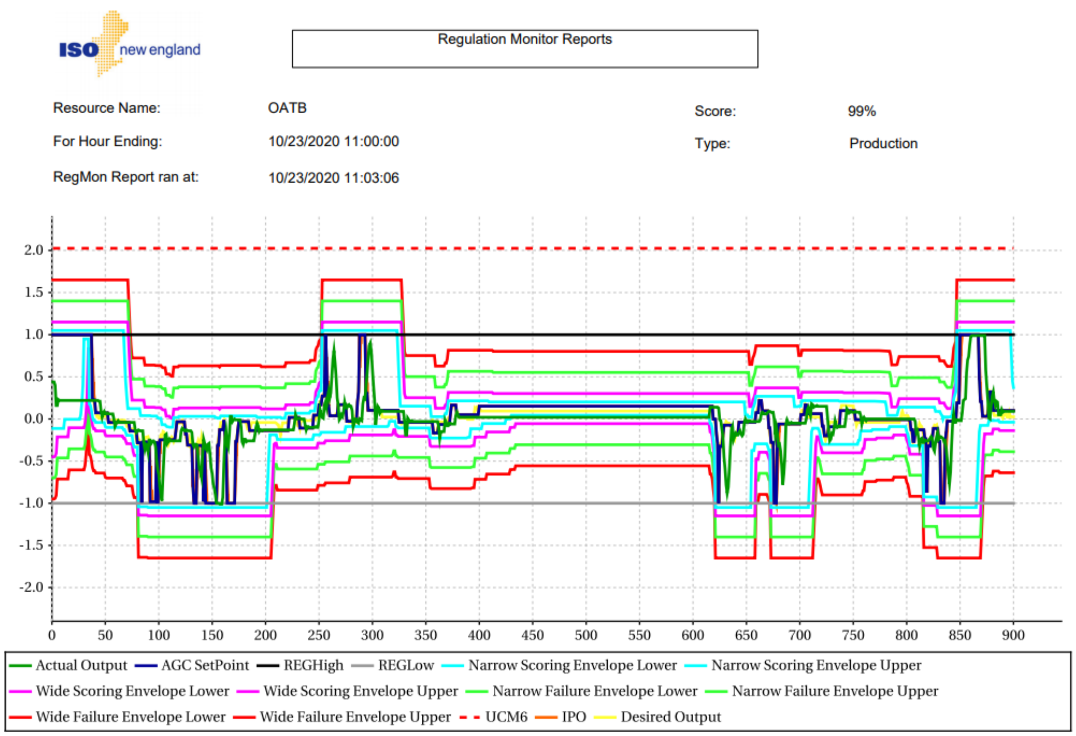



**Figure 24. Typical ISO-NE Regulation Performance Monitoring Report**

As of 11/27/20, the system was granted approval to transition from RTE testing to full market operations. Through 12/06/20 the BESS had logged 154 hours in full market operations, achieving an average score of 0.978. This resulted in gross revenues of $3,825.98 or ~$24.80 for each hour on regulation.

## 6.0 PERFORMANCE ASSESSMENT

As indicated by the average scoring during RTE testing and into full market operations, BESS performance was determined to be consistent with expectations and acceptable for continued market operations. At the average achieved hourly revenue of $24.80/hr, extrapolated annual revenues would be ~$217K for 24/7 operations. Based upon discussions with CES, such extrapolations are reasonable and potentially conservative for multiple factors:

1) Testing to date was performed at a reduced ramp rate due to early issues encountered with SoC management. Improved SoC management was subsequently implemented and should increase the supportable ramp rate, increasing hourly revenues.
2) Regulation prices are expected to increase over the winter months during colder weather.
3) Repair of the failed inverter module should allow regulation capacity to be increased to between 1 and 1.6MW.

However, the main challenge that has become apparent through testing is maximizing time in the market. Multiple factors influence the ability to maintain the BESS in the market as evidenced through demonstration results to date:

1) SoC Management: Despite the energy neutral nature of the ISO-NE signal, losses and short term energy imbalances result in SoC drift that can result in BESS SoC drifting down to a range where it becomes unable to follow the AGC signal. Figure 25 illustrates this phenomena. To address this issue, CES has implemented an SoC management algorithm that removes the BESS from the market for re-charge when needed. Longer-term, a modified algorithm will be implemented that biases the regulation signal to manage SoC rather than removing the BESS from the market. However, this cannot be accomplished until the inverter module repair is completed.

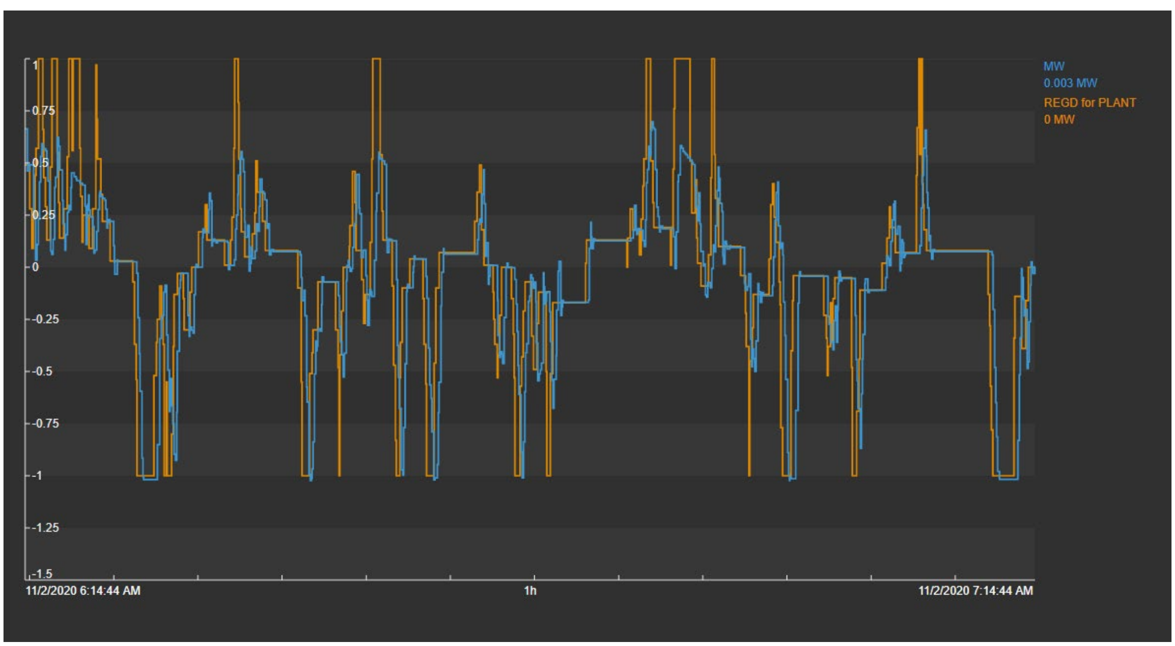



**Figure 25. BESS Following ISO-NE Regulation Signal with Low SoC**

2) Battery Refresh: UltraBattery electrochemistry of requires periodic complete charge / discharge cycles to maintain reliable operation. Refresh interval is dependent on the operation incurred between refreshes and refresh duration varies from 4-8hrs depending on the rate at which the refresh is conducted. Based on the sample ISO-NE regulation signal available on the ISO-NE webpage (illustrated in Figure 18), we initially anticipated refreshes would need to be performed every two weeks. However, as shown in Figures 24 and 25, the typical ISO-NE signal we have seen in testing has been notably different than the sample signal and exhibits infrequent high rate charge and discharge with otherwise relatively little lower rate / longer duration activity. We believe this has accelerated electrochemical activity that can result in overvoltage faults, necessitating more frequent refresh. As such, moving forward, refresh will be completed on a weekly basis.

Beyond these two primary factors, other factors influencing up-time have included communications intermittencies and other BESS faults unrelated to battery electrochemistry. Scheduled downtime / O&M activities will also need to be considered. Based on the aforementioned factors, we estimate reasonable up-time objectives would be in the 0.8-0.9 range.

## 6.1 RELIABILITY ASSESSMENT

During the demonstration period reliability has been impacted primarily by BESS faults and communications issues.

The most frequent BESS fault encountered was due to battery overvoltage. We believe this fault was primarily caused by a combination of high rate, short duration charge / discharge cycling as shown in Figures 24 and 25, and downtime incurred prior to re-entering market operations which is known to affect overvoltage faults. Mitigations have been implemented through the aforementioned SoC management and reduced refresh intervals, the impact of which are planned to be characterized through proposed follow-on demonstration efforts. On two instances faults were encountered caused by e-stop, hydrogen, and smoke alarms internal to the BESS. Telemetry verified there were no underlying issues associated with voltage, temperature, or other factors that could indicate a battery problem. The leading hypothesis for these issues is temporary power fluctuations that can impact sensor components; however root cause of these faults has not yet been identified.

Communications reliability issues have stemmed primarily from intermittencies associated with the Modbus TCP connection between CES and the site. Sometimes the Modbus client will disconnect from the server briefly and attempt an immediate reconnect, but if the socket from the prior connection did not close properly, the reconnect attempt will fail indefinitely. In those instances the Modbus server would need to be restarted to re-establish communications. Continuous improvements during the demonstration phase have introduced mitigations to these intermittent disruptions.

# 7.0 COST ASSESSMENT

## 7.1 COST MODEL

Cost assessment were performed using realized costs and a combination of realized and projected cost savings / revenues. Details of the cost analysis model created by NREL can be found in [19], and are generally consistent with NIST Handbook 135 BLCCA [11] procedures.

## 7.2 COST DRIVERS

Cost drivers included capital equipment and electricity costs, offset by revenues realized through participation in market programs. The following describes the key cost drivers that impacted the outcome of the cost assessment.

<u>Wind Turbine</u>

An analysis was performed to compare the economic differential costs associated with operating the Wind 1 turbine in its current "in front of the meter" configuration (Virtual Net Metering) into the Eversource Energy 24.9kV system vs. "behind the meter" connected to the JBCC 12.47kV system. This analysis used Virtual Net Metering credit data from FY14 to FY17 and found the average credit to be $0.1476/kWh. This value was compared with the average energy cost paid by JBCC for its electricity in FY2017, found to be $0.145/kWh. As can be observed, this data indicates it is incrementally unfavorable to move the turbine behind the meter as part of the micro-grid. However, this does not take into account potential demand response reductions, which may or may not be realized due to the intermittency of the turbine generator and possibility its power output may not coincide with periods of high demand. We also acknowledge that this analysis should be updated with more recent (e.g., FY2020) data for re-assessment.

<u>Demand Response</u>

Potential Real Time Demand Response (RTDR) revenues (Table 4) were provided by CPower Energy Management. CPower currently manages AFCEC IRP's demand response program which operates by curtailing existing ground water pumps. Prior to the micro-grid losing access to the DCGS generator, it was added to this existing contract with DLA with a potential load reduction of 1200kW. If the generator were available to the micro-grid, average annual gross and net revenues were projected to be $51,184/MW-year and $35,829/MW-year, respectively. It is noteworthy that these revenues represent a significant decrease from the original assessment made earlier in the program that indicated gross revenues of $132,960/MW-year from 6/1/2018-5/31/2019. This reduction reflects reductions in electricity costs determined through the forward capacity auction.

**Table 4. Projected Demand Response Revenues**

***Program Revenues For***
**Active Demand Capacity Resource**

| Commitment Period | ISO-NE kW Reduction | | ISO-NE Payments | | Customer Share | |
|---|---|---|---|---|---|---|
| | Summer (8 months) | Winter (4 months) | $/kW-mth | Annual Gross | Rate | Annual Revenue |
| June 1, 2019 - May 31, 2020 | - | 1,200 | $ 7.03 | $ 33,744 | 70% | $ 23,621 |
| June 1, 2020 - May 31, 2021 | 1,200 | 1,200 | $ 5.30 | $ 76,277 | 70% | $ 53,394 |
| June 1, 2021 - May 31, 2022 | 1,200 | 1,200 | $ 4.63 | $ 66,672 | 70% | $ 46,670 |
| June 1, 2022 - May 31, 2023 | 1,200 | 1,200 | $ 3.80 | $ 54,720 | 70% | $ 38,304 |
| June 1, 2023 - May 31, 2024 | 1,200 | 1,200 | $ 3.80 | $ 54,720 | 70% | $ 38,304 |
| June 1, 2024 - May 31, 2025 | 1,200 | 1,200 | $ 3.80 | $ 54,720 | 70% | $ 38,304 |
| | | | Total Customer Benefit | | | $ 238,597 |

Frequency Regulation

Potential frequency regulation revenues were initially predicted by Raytheon and NREL independently using data from 2015 and 2016. Frequency regulation compensation is complex to calculate due to market variations. As such, Raytheon's initial estimate assumed the ISO-NE average rate for 2015 of $333K/MW-year ($20M for 60MW-year) with persistent use and 0.9 utilization (0.95 scoring and 0.95 up-time), less 10% Lead Market Participant (LMP) fee. This was compared to an independent analysis performed by NREL that determined average revenues of $304K/MW-year based on 2016 market data. These projections are compared with the realized potential gross revenue of $217/MW-year in November / December 2020 described earlier in this report. Deducting the LMP fee and assuming 0.9 up-time, the realized net frequency regulation revenue would be $178K/MW-year, a 47% decrease from the initial projection. This decrease is likely the result of a general trend in the regulation market.

Capital Costs

Capital equipment costs were determined using actual incurred costs and totaled $4,385,618 (Table 5). The costs listed below were direct, and did not include Raytheon pass-through costs. Moreover, while A/E design costs were included, we excluded demonstration and developmental costs that would not be re-preformed in a subsequent deployment with significant re-use of equipment designs and software configurations.

**Table 5. Micro-grid Capital Costs**

| Costs | Value |
|---|---|
| BESS / Switchgear | $ 2,636,696 |
| BESS / Switchgear Siting | $ 726,284 |
| Microgrid Control System | $ 475,734 |
| Generator Upgrades / Modifications | $ 113,442 |
| Design Fee | $ 310,696 |
| Microgrid Installation and Comissioning | $ 122,766 |
| | $ 4,385,618 |

O&M Costs

O&M costs were estimated through development of an extended demonstration proposal to continue to the demonstration of BESS operations in the ISO-NE regulation market through CY2021. Ongoing micro-grid maintenance costs of $114K were estimated for CY2021, comprised of $85K to maintain the micro-grid and $29K to maintain the MCS. We also included a battery replacement cost of $413,370 in year 10, estimated by East Penn Manufacturing. We excluded the IA costs discussed in Section 2.3 as these would typically be accomplished under a separate budget line and activity broadly addressing installation Industrial Control System (ICS) security.

## 7.3 COST ANALYSIS AND COMPARISON

Life Cycle Cost analysis was performed using the aforementioned model created by NREL using the data above for a period of 25 years. This analysis assumed a real discount rate of 3%, electricity cost escalation rate of 1.3%, and differential O&M costs of $88,000 (increase) associated with the maintenance of the micro-grid vs. maintenance of 4 separate standby generators at $6500/generator/year [15].

Using the originally predicted values from analysis performed in 2017, the analysis results in a Simple Payback of 8.6 and 10- and 20-year Savings to Investment ratios of 1.42 and 1.82, respectively. However, using updated values based on 2020 rates and measured performance, this reduces to 21 and 0.82 / 0.75.

While the SPB and SIR values predicted do not meet the objectives for either projection, it is important to view them in comparison to alternative solutions. For example, with current operations, the total cost to maintain the system over the 21 year simple payback period would be $546K while providing back-up power to 4 (vs. 34) buildings. Alternatively, a diesel generator-based alternative micro-grid design that exploits the existing generator for demand response only could reduce installed capital costs to between $1M and $1.75M. Assuming $29K of annual micro-grid O&M for the control system only, this results in a predicted SPB of between 49.1 and 84.2 years.

# 8.0 IMPLEMENTATION ISSUES

EW-2016006 shed light on several key implementation issues, most of which were non-technical in nature. The most significant issue was the constraints surrounding the use of critical load generators and lack of Air Force policy regarding micro-grids, which ultimately proved to be a major stumbling block and prevented full micro-grid implementation.

<u>AFI 32-1062 Constraints</u>

Air Force Instruction (AFI) 32-1062 "ELECTRICAL SYSTEMS, POWER PLANTS AND GENERATORS", dated 15 January 2015 contains several restrictions that were identified early in the project and assessed to be addressable by obtaining a waiver as described within the document. The basis for this belief was rooted in the apparent inconsistency with this older AFI and newer DoD guidance, embodied in DODI 4170-11: Installation Energy Management.

Specifically, AFI 32-1062 Para. 1.5.9.1 of AFI 32-1062 states "EAID or RPIE generators (DCGS generator is a RPIE) or any generator owned by another agency will not operate in parallel with any real property electrical system (i.e., transformer, switchgear, or utility) unless authorized by AFCEC/CO." Para. 1.5.9.2 states "Variable renewable energy sources do not operate in parallel with mission-critical generation.". Lastly, Para 2.2 states "Only dedicated standby generators may be authorized to support mission-essential functions. (T-1) Generators authorized to support mission-essential functions will be installed and connected to provide power only to mission-essential functions within a single facility in the event there is a loss of commercial power. (T-1) Using one standby system to support multiple facilities is not authorized due to simultaneous risk to multiple missions. (T-1) If unique circumstances exist where one standby system is required to support multiple facilities, an authorization request must be submitted to AFCEC/CO for approval. (T-1).

The process to submit a waiver to AFCEC/CO is not defined in the AFI, and significant investigation was undertaken by 102$^{nd}$ IW personnel to identify the appropriate channels and personnel. These investigations were accomplished while coordinating implementation of generator modifications in parallel to maintain project schedule. Eventually, subject matter experts at AFCEC (Mr. Rexford Bellville and Mr. Tarone Watley) were identified and advised "AFCEC approves prime power when/if utility power is not available or considered reliable and a single generator for multiple facilities, but approving a single generator for multiple facilities that are not a single mission is not in accordance with AF policy and CO approval authority. …there [was] no AF Policy on microgrids or criteria to develop one and in order to move forward with that we would need something from each separate mission owner stating their power reliability/backup requirement and if sharing a generator with other missions in fact satisfy that in order for us to make the recommendation to SAF/HAF."

In contrast, DODI 4170-11: Installation Energy Management Para, dated 16 March, 2016 contains several requirements that appear inconsistent with the restrictions noted above, Specifically, Para 3.c.2.b states:

1. Energy resilience solutions are not limited to traditional standby or emergency generators. They can include integrated, distributed, or renewable energy sources; diversified or alternative fuel supplies; and movements to alternative locations, as well as upgrading,

replacing, and maintaining current energy generation systems, infrastructure, and equipment on military installations and at facilities. Alternative locations that require a continuous supply of energy in the event of an energy disruption or emergency shall also be subject to energy resilience requirements.

2. When selecting distributed or renewable energy systems and emergency generators for energy resilience, they shall be properly designed to have the ability to prepare for and recover from energy disruptions that impact mission assurance. Their design shall include automatic transfer switching, inverters, and black-start capabilities to minimize energy resilience risks. DoD Components shall also determine fueling or storage requirements for the selected energy generation systems. DoD Components shall follow relevant UFCs for safe and cost-effective designs of energy generation systems that minimize risks to mission assurance when complying with energy resilience requirements stated in this instruction.

Clearly, the DODI envisions the use of other generation sources (beyond standby generators) for energy resilience, which aligns with the implementation of micro-grids to support critical loads. Ultimately, it was determined that the most viable path forward was to retain a dedicated critical load generator, and seek a waiver for a micro-grid dedicated generator that would back-up non-critical loads. The micro-grid generator would then serve as a redundant back-up to the standby critical load generator under the concept that the non-critical loads would be served a single generator supporting multiple building loads as envisioned in the AFI. A waiver would still be required; however, this was deemed more feasible as it can be interpreted to be within the envisioned bounds of AFI 32-1062 as written. Ultimately, revision of AFI 32-1062 will be needed if micro-grids are to be implemented using existing critical load generation, or to replace dedicated critical load standby generators.

<u>Local Energy Market Factors</u>

The techno-economics associated with EW-201606 outcomes are a strong function of the local market conditions and policies. The grid services targeted (frequency regulation and real time demand response) were chosen to maximize the economic value of the installed equipment while ensuring the reliability and resilience benefits of the micro-grid.

In ISO-NE, frequency regulation has generally been the most lucrative application of energy storage; however, it is also the arguably the most operationally intensive. Constraints surrounding minimum capacity (1MW) and metering must be satisfied to participate. As we have experienced in demonstration efforts, the regulation signal may also deviate from the provided reference, requiring adaptability and flexibility. The aforementioned criteria must be satisfied while simultaneously meeting utility interconnect requirements (e.g., export prevention), which may conflict with micro-grid design constraints. External connections and associated methods to mitigate information assurance security risks are required.

The approach pursued to employ the DCGS generator for RTDR was pursued largely due to the build vintage of the engine “grandfathering” eligibility for the program, and permitting for non-emergency use being feasible. The DCGS generator is a Tier 2 and if not for this “grandfathering” would have required significant emissions mitigation upgrades to participate. In many locations, the outcome would have been different.

In summary, any efforts to replicate the design or aspects of the design should carefully consider local market conditions and policies as part of the conceptual design process and choose economic functions that best align with the available opportunities and equipment. A more detailed accounting of such considerations is captured in the final report for EW19-5163.

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## APPENDIX A POINTS OF CONTACT

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