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Cost and Performance Report

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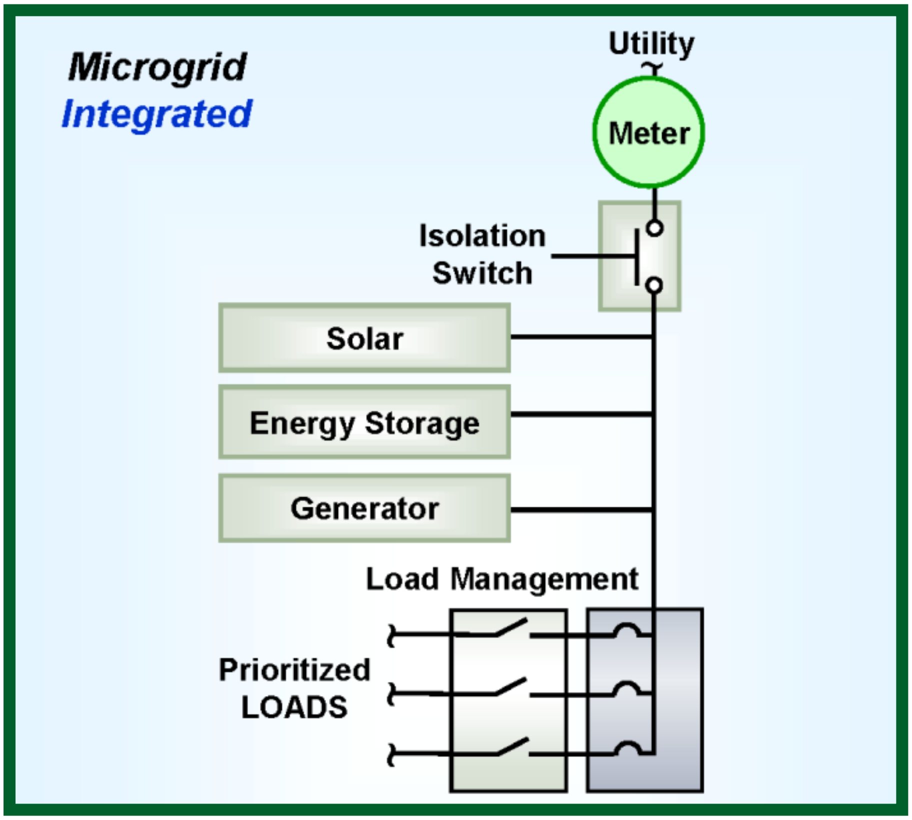

Microgrid Enabled Distributed Energy Solutions (MEDES) - Fort Bliss Military Reservation

April 2014

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ACRONYMS AND ABBREVIATIONS

AC	alternating current
AMI	Advanced Metering Infrastructure
BCT	Brigade Combat Team
BLCC	Building Life Cycle Cost
BOCC	Building Operations Command Center
CDF	customer damage function
CO_2	Carbon Dioxide
CoN	Certificate of Networthiness
CONUS	Continental United States
COTS	commercial off-the-shelf
CSV	comma separated value
D/R	Demand/Response
DER	distributed energy resource
DIACAP	Defense Information Assurance Certification Accreditation Program
DoD	Department of Defense
DOE	Department of Energy
DPW	Department of Public Works
EISA	Energy Independence and Security Act
EPA	Environmental Protection Agency
EPAct05	Energy Policy Act of 2005
EPDF	Enlisted Personnel Dining Facility
EPEC	El Paso Electric Company
ERDC	Engineer Research & Development Center
ESS	Energy Storage System
ESTCP	Environmental Security Technology Certification Program
GHG	Greenhouse Gas
HMI	Human Machine Interface
HVAC	heating ventilation and air conditioning
IEEE	Institute of Electrical and Electronic Engineers
kW	kilowatt
kWh	kilowatt hour
MCS	Microgrid Control System
MDC	Microgrid Development Center
MDMS	Meter Data Management System
MDT	Mountain Daylight Time

MEDES	Microgrid Enabled Distributed Energy Solutions
MPPT	maximum power point tracking
MW	megawatt
NEC	Network Enterprise Center
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
PCC	Point of Common Coupling
PLC	Programmable Logic Controller
PF	power factor
PU	per unit
PV	photovoltaic
SCADA	Supervisory Control and Data Acquisition
SERDP	Strategic Environmental Research and Development Program
SIR	Savings-to-Investment Ratio
TCP	Transport Control Protocol
UMCS	Utility Monitoring and Control System
UPS	uninterruptible power supply
USACE	U.S. Army Corps of Engineers
W/s	watts per second

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Lockheed Martin would like to acknowledge the U.S. Army Corps of Engineers (USACE) Construction Engineering Research Laboratory (CERL) for their Department of Defense (DoD) liaison support. Their research on Net Zero Clusters, specifically focusing on a Fort Bliss Brigade Combat Team (BCT) complex as a case study, was invaluable in the cost assessment phase of the project. The BCT complex analysis, together with actual Fort Bliss energy usage data and the Environmental Security Technology Certification Program (ESTCP) demostration results, we were able to show the economic benefits of deploying microgrids at BCT complexes. Their expertise and broad knowledge regarding DoD microgrid implementation was also important to the success of the project. Specific thanks go to Harold Sanborn and Melanie Johnson.

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EXECUTIVE SUMMARY

The Microgrid Enabled Distributed Energy Solutions (MEDES) demonstration project is the first Department of Defense (DoD) grid-tied microgrid to integrate renewable resources, on-site generation, and energy storage with facility loads and the utility distribution network. As prime contractor, Lockheed Martin designed and built the microgrid system, intelligently integrating distributed diesel generation, solar photovoltaic (PV) array, and grid-scale energy storage with the medium voltage utility grid and facility loads at one of the Brigade Combat Team (BCT) Complexes at Fort Bliss.

Currently the United States (U.S.) power grid is largely centralized with a handful of large utilities handling the majority of power production in the country. In 1996, a sagging power line in Oregon brushed up against a tree, and then within minutes, 12 million electricity customers in eight states lost power. Such is the vulnerability of the aging U.S. power grid. In order to remedy this systemic risk from large scale blackouts a new more decentralized system can be used in which a cluster of on-site power generation devices/assets can service local loads in the event of power loss from the Utility. A microgrid is a localized set of generation, energy storage, and loads that normally operate connected to a traditional utility grid. There is a single point of common coupling with the utility grid that can be disconnected if the microgrid needs to be able to operate without utility power in the event of utility failure.

The primary benefit of a microgrid is energy surety/resiliency/mission sustainment; however there can be advantages in found in energy cost savings depending on one's electric rate structure. The Energy Manager needs to fully understand their electric provider's rate structure and the load profile of their facilities in order to effectively design a microgrid to help in energy costs. For instance, if some utilities have time of use rates it may be beneficial to use energy during non-peak hours for storage and use that stored energy during peak hours.

OBJECTIVES OF THE DEMONSTRATION

The technical objective of the Lockheed Martin's MEDES project was to demonstrate 1) reduced greenhouse gas (GHG) emissions, 2) lower capital expenditure, 3) lower operating costs, and 4) enhanced energy security via a microgrid consisting of distributed energy resources and load management capabilities. The technology demonstration took place at Fort Bliss, Texas.

The cost elements of the microgrid captured during the demonstration were put into a Building Life Cycle Cost (BLCC) analysis tool using the methods in the National Institute of Standards and Technology (NIST) Handbook 135.[1,2] The system economics performance objective was to demonstrate the economic advantages of having a Microgrid versus a conventional system configuration. The Savings-to-Investment Ratio (SIR), using the BLCC methodology was used as the performance metric since this is the key metric through which energy projects are considered for DoD infrastructure project funding. The success criterion of reaching a SIR greater than 1.5 when extrapolated to a full BCT was achieved.

TECHNOLOGY DESCRIPTION

The technology utilized for the Lockheed Martin's MEDES project included an intelligent microgrid controls and data acquisition system with distributed diesel generation, a solar PV array, and grid-scale energy storage integrated with the medium voltage utility distribution grid and facility loads of the Enlisted Personnel Dining Facility (EPDF).

The Lockheed Martin microgrid controls architecture provided a flexible platform to integrate multiple types of distributed energy resources (DER), energy storage, and load management. The architecture is comprised of distributed controllers which locally manage each DER connected to the common power bus. The distributed controller also manages load centers to provide monitoring and load scheduling capability. The distributed controllers communicate with the microgrid centralized controller which provides the overarching control and optimization of the microgrid, including Demand/Response (D/R) algorithms, an Advanced Metering Infrastructure (AMI), and Meter Data Management System (MDMS). The centralized controller also provides aggregate real-time monitoring data of relevant DERs, loads, faults, and financial performance.

The microgrid optimization functions were designed to avoid/lower energy costs and increase energy surety with the following features: peak shaving, electricity arbitrage, power factor improvement, renewable smoothing, integration with the existing building management system, and the ability to near seamlessly transition between Grid Tied and Grid Independent modes.

DEMONSTRATION RESULTS

The project can be categorized into three phases of execution: 1) baseline design and performance documentation, 2) technology implementation, and 3) technology performance validation. The baseline design was performed by conducting site surveys and preliminary power flow measurements to document the baseline design. The baseline performance documentation consisted of two tasks: 1) obtaining energy consumption data at the demonstration site by installing power measurement instrumentation and data acquisition systems and 2) obtaining energy consumption data of the larger installation utilizing the existing metering system and performing load surveys. After the baseline design and performance data were captured, the detailed design of the microgrid was developed and major components were procured. The project design, preparation, permitting and procurement phase started after contract signing in June 2011 and continued until April 2012. Construction was performed from December 2012 to March 2013 with configuration and acceptance testing occurring in April 2013 and final commissioning in May 2013. Performance measurements and verification were continued until the project was concluded in December 2013.

In addition to showing the economic benefits of deploying microgrids at BCT complexes, the EPDF Microgrid resulted in:

- Successfully reducing peak utility demand to 261 kilowatts (kW) which is a 14.4% reduction when compared to the 305 kW peak load observed by Fort Bliss's Department of Public Works (DPW) in prior years.

- Successfully reducing fuel usage and GHG emissions of backup generators during grid independent operations.
- Successfully increased islanded load from 30-50 kW to 50-80 kW (a 37.5% to 40% increase in load supported during grid independent operations).
- Successfully picked up system load within two cycles of utility interruption enhancing Energy Surety.
- Successfully met economic criteria with a SIR of 1.51 and a payback of 8.89 years.
- Successfully increased Power Factor (PF) Improvement (> 0.9 PF during peak hours) and power quality assessment.
- Successfully demonstrated an average energy output of 21.35 kilowatt hours (kWh) per day at peak hours for Electricity Arbitrage.

IMPLEMENTATION ISSUES

Retrofitting the generators to operate within the microgrid proved to be a significant challenge. Generators at the time of installation are either installed as a standalone backup generator or a paralleling generator. While standalone generator controls reference system voltage and system frequency, parallel generators utilize/manage real and reactive power as well as system voltage and frequency. Generator grounding schemes are also different between paralleling generators and backup generators and a hybrid grounding system suitable for both types of generator installations was developed. Also, standalone backup generators do not have a restricted run time but when using them to parallel with the utility, an air permit must be obtained for the unit from the relevant authority, in this case from the Texas Commission on Environmental Quality. The process for obtaining this permit must be started as early in the process as possible due to the length of time required.

Retrofitting the existing electrical infrastructure was a challenge, especially with the existing switchboard layout restricting the addition of motor operators (to allow for load shedding). The Lockheed Martin team installed as many motor operators as physically possible in the existing switchboard such that load shed capability was maximized to avoid purchasing of a completely brand new switchboard.

There are inherent challenges in integrating multiple DERs because the electrical bus requires a master DER. While grid tied, the utility is always the bus master, but when the microgrid islands, the bus master functionality passes first to the energy storage system until the generator comes online. The handoff of that functionality between the energy storage system and the generator is a high speed, time critical event. The interfaces between DERs have to be carefully coordinated, timed, and tested thoroughly to ensure no conflicts of authority.

Although not a major issue, separate data loggers were used to collect baseline data for the BCT feeders because the DPW Building Operations Command Center (BOCC) data collection did not have the resolution of individual feeders in their energy measurements. As the Fort Bliss power distribution is upgraded, more resolution could be available in these measurements to support future energy projects.

Regulatory hurdles associated with ‘islanding’ microgrid power architectures are being addressed with release of the Institute of Electrical and Electronic Engineers (IEEE) 1547.4 and 1547.8 guidance.[3,4,5] The approach will allow DoD end users to implement a proven, consistent solution that addresses renewable energy and environmental mandate compliance, energy cost reduction, and energy security goals.

1.0 INTRODUCTION

Lockheed Martin Intelligent Microgrid Solutions manages on-site power generation and consumption within a campus either interconnected with a utility grid or in a mode independent of the utility grid in the event the utility grid is not reliable. Such technology is needed where efficient, reliable and secure power is required, including the Department of Defense (DoD) installations.

The DoD recognizes that 99% of the power provided to its Continental United States (CONUS) operations is provided by off-site generation; which leaves critical mission functions at risk when that power is lost. Integrating microgrids into DoD facilities can mitigate this risk; however, acceptance will not occur until the technology is proven given that the integration of intermittent and dispatchable generation has historically been challenging. Lockheed Martin performed this technical and economic demonstration of an Intelligent Microgrid Solution with Environmental Security Technology Certification Program (ESTCP) to enable a larger microgrid implementation at Fort Bliss, and as a model for more microgrid projects across DoD.

The project can be categorized into three phases of execution: baseline 1) design and performance documentation, 2) technology implementation, and 3) technology performance validation. The baseline design was performed by conducting site surveys and preliminary power flow measurements to document the baseline design. The baseline performance documentation consisted of two tasks: 1) obtaining energy consumption data at the demonstration site by installing power measurement instrumentation and data acquisition systems and 2) obtaining energy consumption data of the larger installation utilizing the existing metering system and performing load surveys. After the baseline design and performance data were captured, the detailed design of the microgrid was developed and major components were procured. The project design, preparation, permitting and procurement phase started after contract signing in June 2011 and continued until April 2012. Construction was performed from December 2012 to March 2013 with configuration and acceptance testing occurring in April 2013 and final commissioning in May 2013. Performance measurements and verification were continued until the project concluded in December 2013.

This project demonstrated how an Intelligent Microgrid Solution allowed an installation to integrate large fractions of on-site renewable energy generation, optimize operation of on-site dispatchable generation and intelligently manage facility loads and coordinate these capabilities to provide economic grid connected and grid independent operational capability. This was shown using the hardware installation at Fort Bliss, El Paso, TX.

1.1 BACKGROUND

The project fits under the Strategic Environmental Research and Development Program (SERDP)/ESTCP Microgrid Installation Energy Initiative as described:

> *The current state-of-the-art power grid includes minimal renewable or clean energy, no intelligent distribution, minimal or no energy storage, ad hoc dispatch, uncontrolled load demands, and excessive distribution losses. Microgrids can improve operating efficiency,*

enhance the use of renewables, and increase the reliability of electric power delivery systems, making any mission-critical load more resilient and secure.

Methods are being developed to enable DoD to better plan, analyze, and evaluate the operational benefits and risks of deploying microgrids on its installations. Advanced controls can optimize functions such as dispatch of distributed generation power resources, load shedding, islanded operation, and energy efficiency by controlling the major electrical loads. This capability would facilitate the introduction of dynamically stable, modular, and cost-effective energy microgrids that could seamlessly operate in grid-parallel and off-grid modes, leading to significant reductions in DoD energy costs and carbon dioxide output.(6)

1.1.1 Technology Opportunity

Energy savings, renewable energy, and energy security objectives are often addressed individually with energy managers having to develop projects that also comply with the vast array of federal and local regulations, policies, and constraints. Energy efficiency upgrades and load management programs are developed to address energy savings mandates. Separately, renewable energy mandates are often addressed through the purchase of renewable energy credits or installation of grid-tied renewable energy systems, often without improving energy security. Intelligent Microgrid Solutions allow an installation's energy team to comply with on-site renewable energy generation mandates, optimize operation of legacy power generation, and intelligently manage facility loads to provide energy savings as well as provide grid independent operational capability for an installation's mission critical facilities.

Lockheed Martin's systems approach to microgrid design should be applicable and provide value to the majority of DoD's greater than 480 fixed installations. The environmental benefits provided by intelligent microgrid solutions will be prevalent in the major military bases of the southwest and coastal regions, with reductions of over 1 ton of CO_2/year for every kWh of on-site renewable energy generation. The energy savings, energy security, reliability, and power quality improvements provided by intelligent microgrid solutions will be prevalent at critical military bases and those that are located on the congested power grid in the northeast CONUS.

With the Microgrid Enabled Distributed Energy Solutions (MEDES) demonstration as an example implementation of an intelligent microgrid, return on investment and payback time can be estimated. In comparison with current approaches to reduce carbon emissions and energy costs by implementing renewable energy solutions, the intelligent microgrid solution provides improved integration of the renewable energy sources with the local power grid, maximizing the fuel-reducing benefit while minimizing the power quality problems inherent with many intermittent renewable resources. The inherent intermittency and resulting power quality issues of renewable power sources at high penetration levels can often affect energy costs. With an intelligent microgrid solution using Lockheed Martin's microgrid planning tools, a microgrid can be designed and installed that provides the appropriate controls and hardware necessary to eliminate the need for increased spinning reserve, reducing fuel use to realize the benefit of the renewable energy.

1.2 OBJECTIVE OF THE DEMONSTRATION

The technical objective of the effort was to demonstrate 1) reduced greenhouse gas (GHG) emissions, 2) lower capital expenditure, 3) lower operating costs, and 4) enhanced energy security via a microgrid consisting of distributed energy resources and load management capabilities. The technology demonstration took place at Fort Bliss, Texas.

The microgrid demonstration and technology performance validation occurs on a subset of a larger installation demonstrating the key operational performance, costs and benefits of the microgrid using the same control software and hardware that would be implemented in a multi-megawatt scale microgrid. The components of a microgrid, including renewable energy, dispatchable generation, energy storage, load shedding, and an island interconnection device have been integrated into the Enlisted Personnel Dining Facility (EPDF) of the Brigade Combat Team (BCT)-1 complex.

1.3 REGULATORY DRIVERS

DoD energy mandates relevant to microgrids include both renewable energy and energy security mandates. Renewable energy mandates include Section 203 of the Energy Policy Act of 2005 (EPAct05), *Executive Order 13423, National Defense Authorization Acts of 2007 & 2010, Executive Order 13514, and the Energy Independence & Security Act of 2007 (EISA).*(11,12,13,14,15,16) The combination of these mandates drives renewable energy penetration at DoD installations to levels greater than 20%, which can require a microgrid to provide the reliable, secure integration of those intermittent renewable sources. Energy security mandates and objectives come from both congressional and DoD service branch sources. A DoD service branch example is the combination of documents that make up the Army energy security execution strategy. These include the *Installation Management Campaign Plan*, and the *Army Energy Security Implementation Strategy (AESIS) 2009*.(17,18) The Installation Management Campaign Plan captures each of these strategies in the following statement:

> *"We will address installation dependency on the national grid for electric power at a time when these systems capacities are being taxed and vulnerabilities are better understood. To meet these and other challenges, we will effectively execute programs that recognize energy as a key mission enabler and address the priorities outlined in the Army Energy Security Implementation Strategy, the Army Sustainability Campaign Plan and other Army guidance and Federal mandates. The Installation Management Energy Portfolio provides authority, resource tools, example projects, and actions available to installations in order to improve our energy security posture."* (17)

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2.0 TECHNOLOGY DESCRIPTION

This project demonstrated that operating existing energy assets as a microgrid is more cost effective, cleaner, and more secure than traditional operations.

2.1 TECHNOLOGY OVERVIEW

The technology utilized for the Lockheed Martin's MEDES project included an intelligent microgrid controls and data acquisition system with distributed diesel generation, a solar photovoltaic (PV) array, and grid-scale energy storage integrated with the medium voltage utility distribution grid and facility loads of the EPDF.

The microgrid optimization functions were designed to avoid/lower energy costs and increase energy surety with the following features: peak shaving, electricity arbitrage, power factor improvement, renewable smoothing, integration with the existing building management system, and the ability to near seamlessly transition between Grid Tied and Grid Independent modes (Islanding).

The Lockheed Martin microgrid controls architecture provided a flexible platform to integrate multiple types of distributed energy resources (DER), energy storage, and load management (Figure 1). The architecture is comprised of a bi-level arrangement with distributed and centralized controllers. Fast-acting distributed controllers locally manage each DER, reacting automatically to ensure power delivery, quality, and safety. The distributed controllers communicate with the higher-level centralized controller—the Microgrid Control System (MCS)—which provides the overarching control and optimization of the microgrid, including Demand/Response (D/R) algorithms, an Advanced Metering Infrastructure (AMI), and Meter Data Management System (MDMS). The MCS maintains a historical database, houses the optimization algorithms, and provides a user interface for data analysis and operator control and also provides aggregate real-time monitoring data for all DERs, load centers, fault events, and financial performance. Figure 1 shows all the major components that were installed to implement this bi-level control arrangement.

Comparison with Existing Technology

Intelligent Microgrid Solutions differ from traditional back-up power by including Smart Grid communications, renewable energy, multiple disparate generators, utility market interaction and optimization algorithms such that their services become economically attractive to an expanded electric consumer market (Figure 2). Microgrids provide an architecture and process for integrating energy systems including: advanced metering, building environmental controls, facility distribution circuit controls, and utility demand response programs. The energy savings realized through optimization of the entire energy system often justifies the cost of adding Microgrid integration and control.

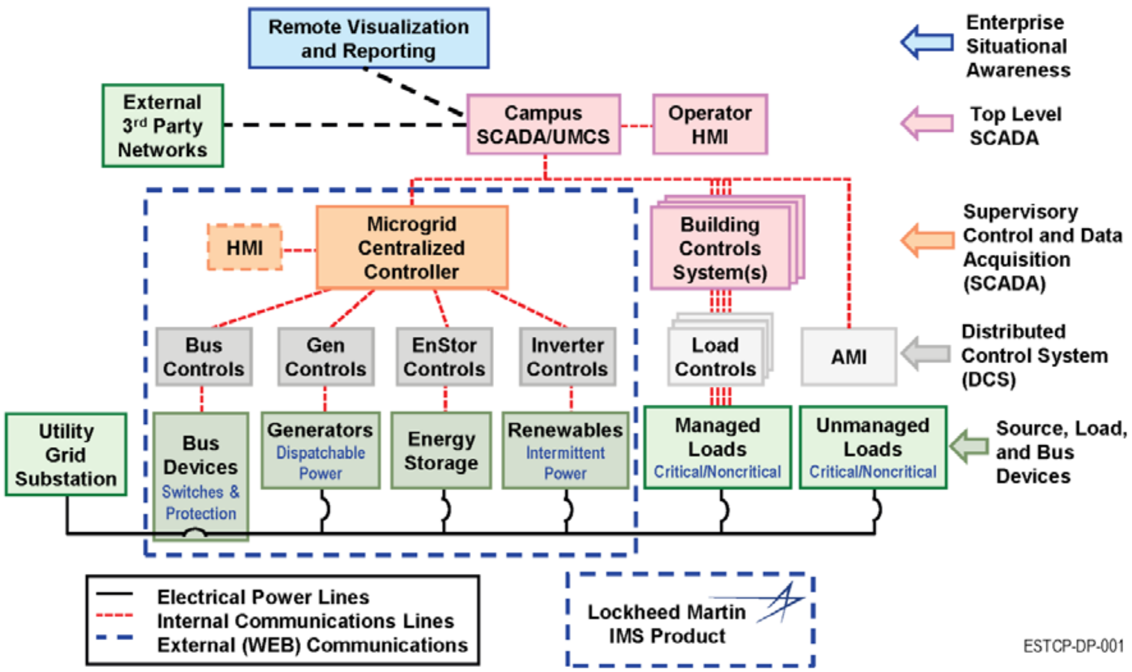

Figure 1. Lockheed Martin's flexible microgrid architecture.

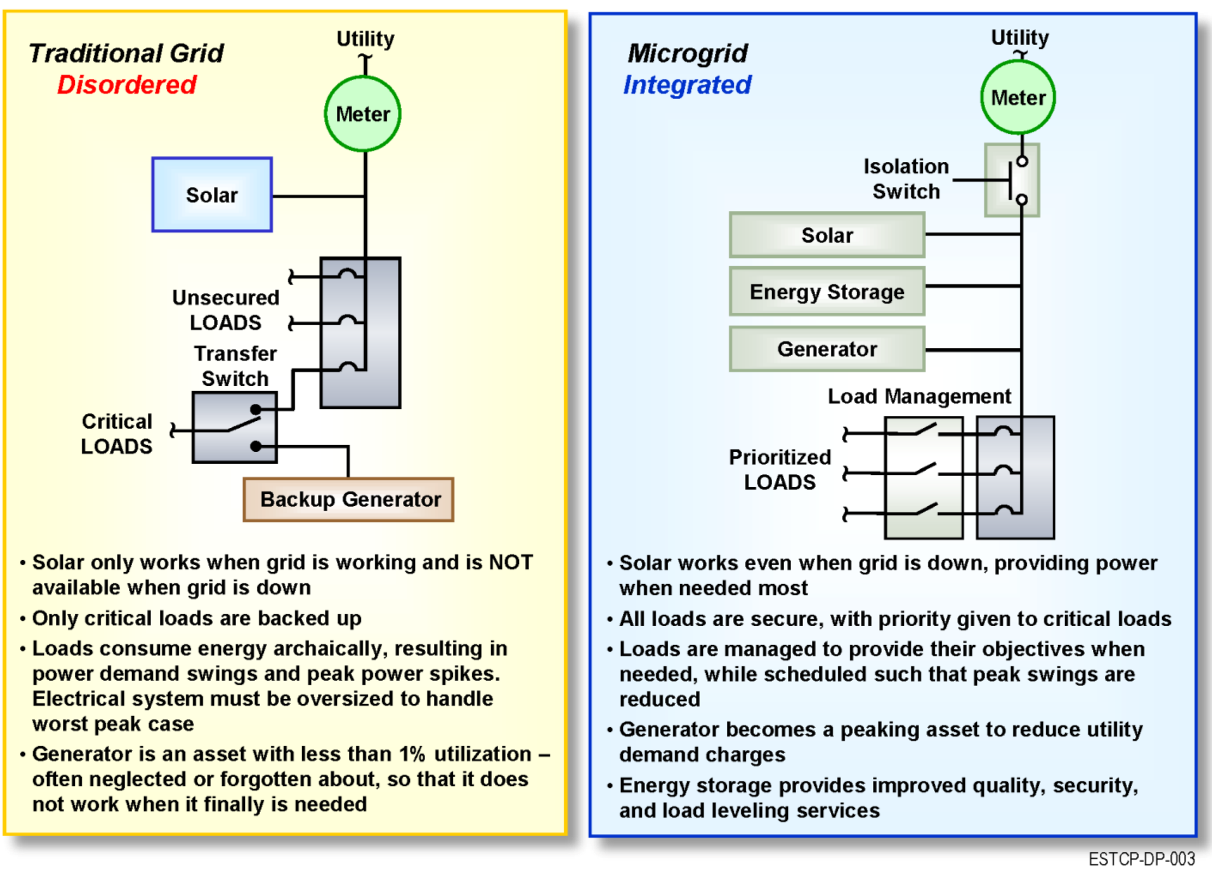

Figure 2. Advantages of microgrids versus traditional power systems.

2.2 TECHNOLOGY DEVELOPMENT

This project focused on leveraging existing Lockheed Martin software, commercial off-the-shelf (COTS) software and commercially available hardware to build an affordable microgrid which implements a number of microgrid optimization functions designed to avoid/lower energy costs and increase energy surety. The primary item that was modified and developed was the control software in the MCS and the Programmable Logic Controller (PLC) used to implement the following features: peak shaving, electricity arbitrage, power factor improvement, renewable smoothing, integration with the existing building management system, and the ability to near seamlessly transition between Grid Tied and Grid Independent modes (Island).

2.2.1 Grid Tied Microgrid Functions

Grid tied mode is the normal mode of operation for the system—where the Point of Common Coupling (PCC)/protective relay is closed connecting the microgrid to the utility grid. In this mode all of the load breakers in the system are closed. In the preliminary design assessment, automatic load shedding/management was not beneficial to be included in this mode. If load shedding is desired, an operator can manually shut off one or more feeder breakers with the MCS Human Machine Interface (HMI). In this mode the PV system is not curtailed allowing for maximum production of solar power to be used by the EPDF Microgrid or the distribution grid.

2.2.1.1 <u>Peak Shaving</u>

The MCS commands the generator paralleled to the utility to start and output power as needed to implement a peak shaving algorithm—a feedback loop that monitors the amount of power being imported from the utility and commands the generator to provide real power onto the bus to lower utility demand. This algorithm increases the generator output if utility demand is too high and decreases output when utility demand is too low. In Figure 3, the generator is being turned on in response to an increased load demand and the MCS adjusts the generator's power output until it eventually turns the generator off due to a low load demand. From the figure, note that there is a 30 second delay before the generator turns on in response to the rapid additional load of 33 second duration. The algorithm is configurable and was set to keep utility demand below 250 kW in this project. That threshold can be lowered further, but that software limits generator usage to 300 hours per year to comply with Environmental Protection Agency (EPA) regulations

2.2.1.2 <u>Power Factor Improvement</u>

Apparent power (volt-amperes) is the vector sum of real power (watts) and reactive power (volt-ampere reactive). Power Factor is the ratio of real power to the apparent power of the circuit. Power factors below 1.0 require the utility to generate more volt-amperes to supply the rated real power, which increases generation and transmission costs. Many utilities, such as the one that supplies power to Fort Bliss, the El Paso Electric Company (EPEC), apply a penalty/fee into their electricity rate structures for customers that have a poor power factor. Power factor at the EPDF is poor around noontime each day. This is most likely due to the fact that the PV Inverter only supplies real power to the EPDF's loads requiring the utility to provide the reactive power component for the loads thus lowering the Power Factor rating at the PCC.

The Energy Storage System (ESS) can be used for power factor/quality improvements for the microgrid. A feedback loop is used to monitor the PCC's power factor and command the ESS to output reactive power as needed to ensure that the power factor stays above 0.9, thus avoiding the utility's fees. In Figure 4, the ESS's reactive output changes to maintain an acceptable power factor.

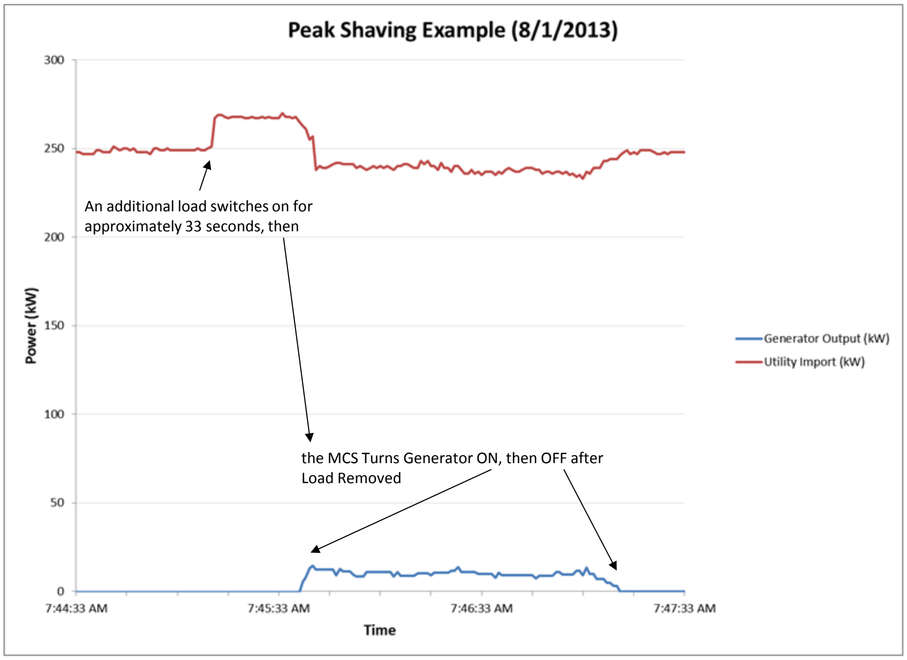

Figure 3. Peak shaving example systems.

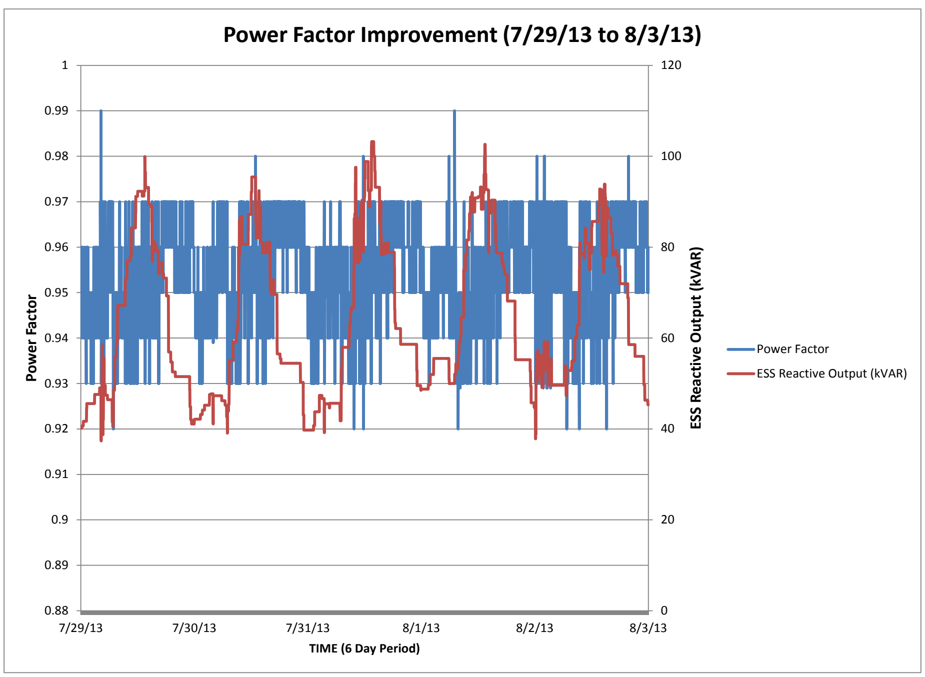

Figure 4. Power factor improvement for a sample period.

2.2.1.3 <u>Electricity Arbitrage</u>

In general, electrical power is considerably cheaper in the middle of the night than during peak demand during the day. This is also the case at Fort Bliss, where their service rate schedule states that the on-peak period shall be between 12:00 P.M through 6:00 PM for the months of June through September at a cost of $0.14335 per kWh. The off-peak period, all other hours not covered in the on-peak period, costs $0.00527 per kWh. This is according to the "El Paso Electric Company Schedule No. 31 Military Reservation Service Rate."[(19)] That is a substantial $0.13808 per kWh difference. By performing electricity arbitrage, the microgrid will take advantage of this rate structure. As can be seen in Figure 5, this algorithm is a daily schedule that charges the ESS (a.k.a., buys energy) at night when prices are cheap and discharges (a.k.a., sells/uses stored energy) when it is expensive at peak hours.

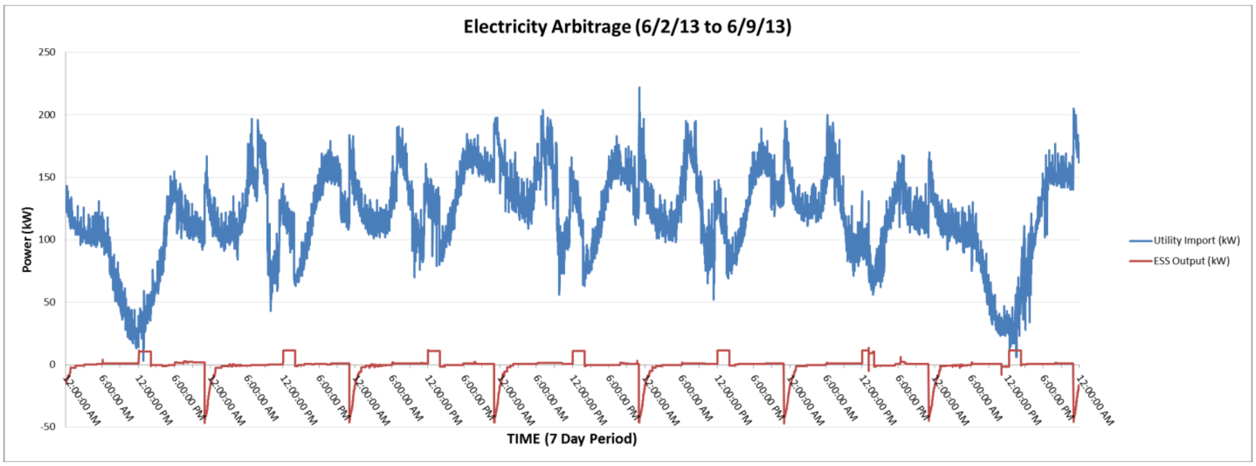

Figure 5. Electricity arbitrage for a sample week.

Table 1. Daily energy arbitraged.
(6/2/13 to 6/8/13)

Day: Noon to 2PM (kWh)	2-Jun	3-Jun	4-Jun	5-Jun	6-Jun	7-Jun	8-Jun
Total ESS Energy Output	21.07714	22.71578	21.54918	22.03387	22.39774	20.55005	19.15556

2.2.1.4 <u>Renewable Energy Smoothing</u>

PV and wind power systems are inherently intermittent; PV systems can drop by 60% within seconds due to a cloud passing over the array. One of the ways to manage the intermittency of solar power production is to use short-term energy storage systems to offset the sudden loss of power. The renewable energy smoothing algorithm is a high speed algorithm implemented in a real-time PLC that monitors the PV inverter's alternating current (AC) power output and reacts to sudden drops in production with increased output from the ESS. See Figure 7 for an energy smoothing example.

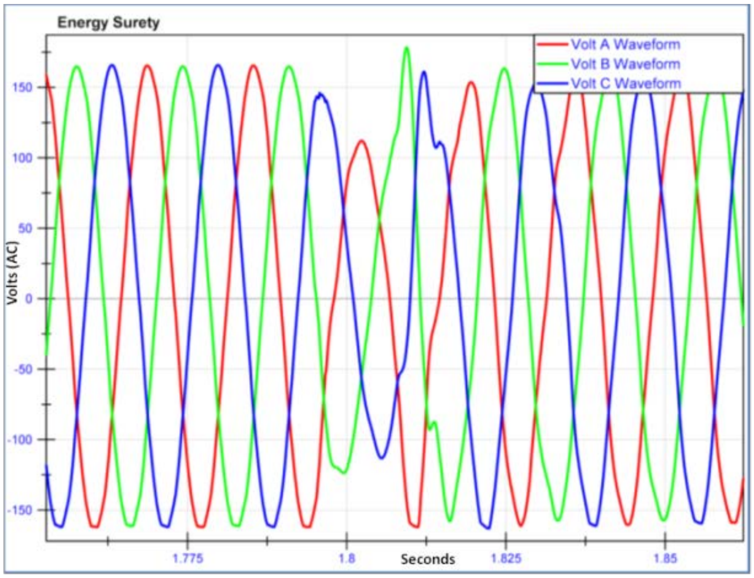

Figure 6. High speed waveform capture –utility interruption event (laboratory).

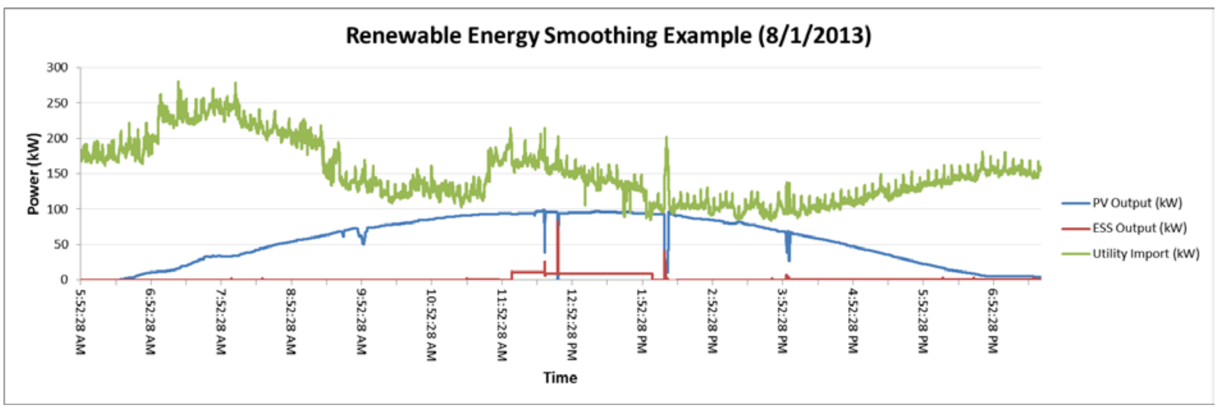

Figure 7. Renewable smoothing during daylight hours.

2.2.2 Grid Independent Functions

In Grid Independent mode there is no utility power and the main circuit breaker for the building is opened to island the microgrid. During this mode, the generator, PV system, and the ESS are providing all the power for the loads. Originally it was planned that the MCS would manage the loads of the EPDF Microgrid in grid independent mode, unfortunately that was no longer possible when some of the automation equipment—motor operators, were unable to be fitted in the existing main switchboard. This resulted in both the critical loads and the uncontrollable loads powered on the bus when the system was islanded. Although load management was not performed to the extent originally planned, the MCS does manage the PV Inverter and correct for poor power factor using the ESS.

2.2.2.1 PV Management

In Grid Independent mode (a.k.a., Islanded) the generator is the bus master and regulates the frequency and voltage of the microgrid bus. When the PV inverter is enabled in an islanded microgrid, it can possibly back feed power into the generator if it's a particularly sunny day or if the load on the microgrid is very small (or both). When power is back fed into the generator, then the generator's protection equipment trips off. Turning off protects the generator from damage and prevents the bus from destabilizing since the bus frequency and voltage are not being regulated.

To remedy this situation the MCS actively curtails the PV output to ensure it does not back feed the generator and risk a microgrid blackout. Instead of turning the PV off or curtailing it to a very small static amount the MCS uses a feedback loop that monitors the amount of load on the generator and adjusts the PV curtailment set-point to ensure that the generator is carrying some of the load. As seen in Figure 8, this in effect is aimed to maximize PV usage in islanded scenarios.

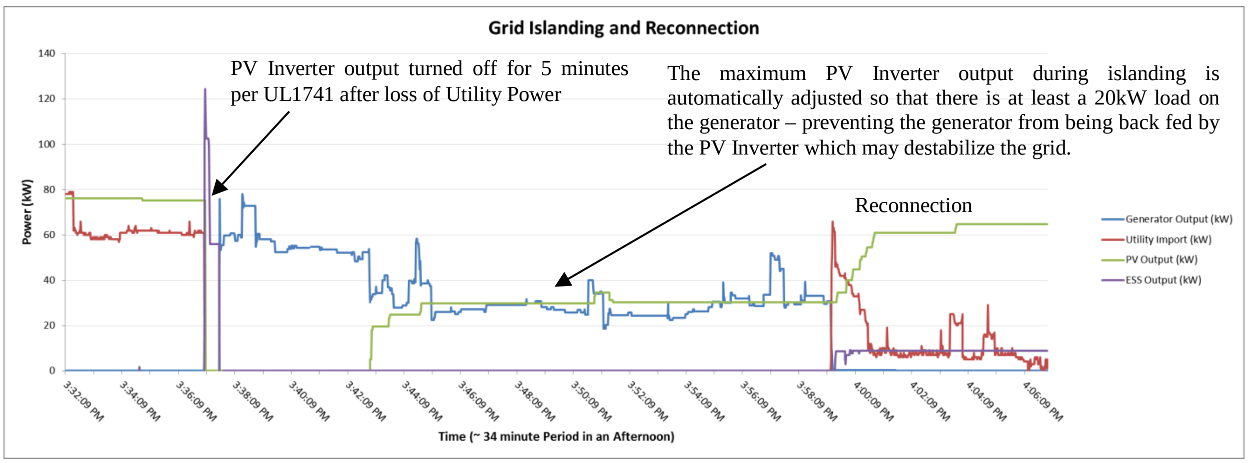

Figure 8. Grid state transition example.

2.2.2.2 Power Factor Improvement

Similar to Power Factor Improvement during Grid Tied mode, in Grid Independent mode the MCS will adjust the reactive power output of the ESS. Unlike in Grid Tied mode the MCS improves the power factor at the generator's circuit breaker instead of the PCC. This improves the engine efficiency which ultimately reduces diesel fuel use. As can be seen in Figure 9, the efficiency of a generator is a function of both the amount of load on the generator (the per unit [PU] kVA represents the ratio of load demand to the generator's nameplate rating) and the load's power factor. Some additional information about diesel generators and the importance of power factor can be found in Cummins Power Generation's White Paper on "Rated power factor tests and installation acceptance of emergency and standby power systems."(20)

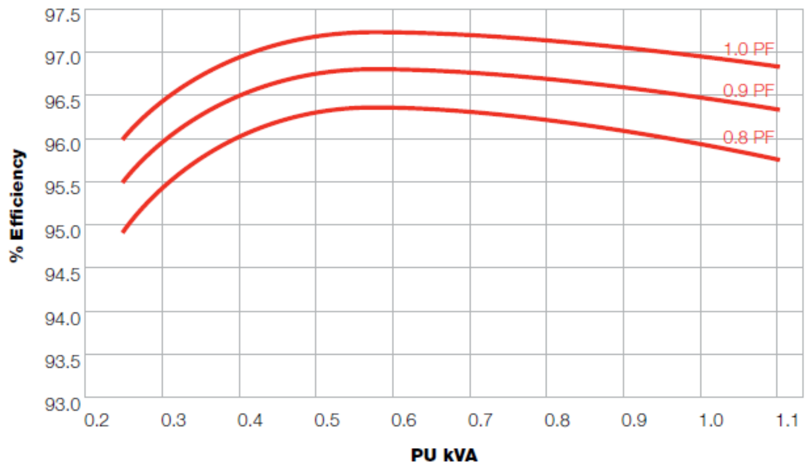

Figure 9. Typical backup generator alternator efficiency curves.

2.2.2.3 Grid State Transitioning

Because utility interruptions/outages can happened at any moment, the microgrid is always made ready to island. When a fault on the utility side of the PCC is detected by the Protective Relay it immediately opens the breaker at the PCC to separate the microgrid from the utility grid. Microseconds after that the PLC commands the ESS inverters to become the bus master (a.k.a., voltage mode)—regulating both voltage and frequency in addition to carrying the entire load. As can be seen in Figure 6, there is slight voltage sag in voltage, but that gets corrected by the ESS within 2 electrical cycles. The PV Inverter senses the small voltage sag and turns off its power production to be compliant with Institute of Electrical and Electronic Engineers (IEEE) 1547.(4) The PLC then opens the load breakers connected to all the low priority loads so only the critical loads are powered while in island mode. Meanwhile the MCS commands the generator to start and synchronize to the bus. Once the generator has connected the ESS Inverters go back to current mode thus letting the generator become the bus master. Finally, the MCS starts up its Grid Independent mode algorithms. Eventually after a stable bus for 5 minutes the PV Inverter will automatically begin power production. This islanding event and the system's overall transition to Grid Independent mode is depicted in Figure 8.

While islanded, the MCS will continually monitor the utility side of the PCC. After detecting a valid and nominal voltage on the utility bus for the duration of 5 minutes, in accordance with IEEE1547 (4), it will command the protective relay to attempt a reconnection. When the protective relay reconnects, the generators frequency and voltage are adjusted to match the utility's parameters, before the PCC breaker closes – signaling the generator to yield to the utility as the bus master. Grid Tied mode algorithms are then resumed by the MCS.

2.2.2.4 Situational Awareness of Distributed Energy Assets

The local HMI was accessible on either of the MCS servers and provides information regarding the live status of each microgrid component as well as a user interface to control them manually. Microgrid operational data is stored by the Historian, which can be exported for post operation analysis. In additional to the local HMI at the EPDF Microgrid, device telemetry is collected and displayed at Fort Bliss's Department of Public Work's (DPW) Building Operations Command Center (BOCC) where users can view status and analyze microgrid performance.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Energy security has been carried out with battery uninterruptible power supply (UPS) and back-up diesel generators on specific critical loads. These systems are overdesigned by requirements for growth that add unnecessary capital and maintenance cost. The back-up units are essentially a non-utilized asset and must be tested weekly and monthly for maintenance and to verify performance. These are wasteful exercises of fuel and personnel. These tests often go unperformed and the units prove non-functional when needed. During operation of the back-up generators, they often run at minimum power output in an inefficient operating region, which wastes fuel. In addition, only loads on the critical circuits can be powered and there is no flexibility of operation.

The Intelligent Microgrid Solution utilizes back-up generation assets for utility cost saving services and can participate in providing utility ancillary services for additional revenue. Each megawatt (MW) of peak shaving potential can result in $50,000 to $100,000 cost savings per year. It also integrates back-up generation during grid independent mode to optimize the use of back-up generation, allows flexibility to serve dynamically selected loads, and optimizes generator operation to save fuel. Figure 10 shows a typical scenario where intelligently operating generators and incorporating renewable energy during a day of operating grid independent saved 38% of fuel and CO_2 emissions.

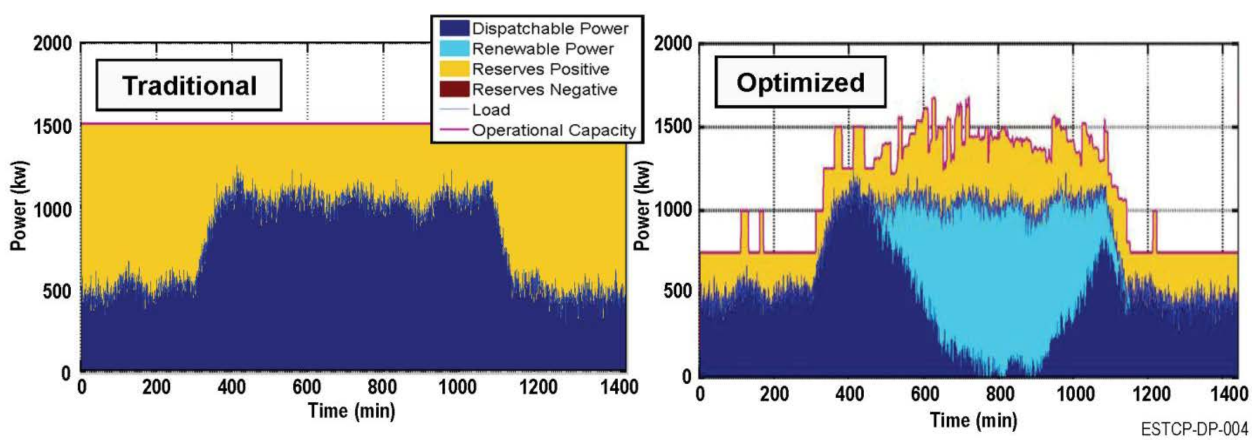

Figure 10. Resource optimization significantly reduces the amount of fuel required.

By being able to utilize all renewable resources to a much greater extent during an islanding event, the microgrid can reduce base line load on the backup generator. When the loading on the generator is reduced, the fuel consumption is correspondingly reduced. This, in turn, lengthens the time of availability of the generator. With an appropriately sized energy storage system and renewable resources, the microgrid could run the island indefinitely without using a generator.

When the generator is forced to run at a poor power factor, more fuel is consumed for the same amount of power output. During Grid Independent mode, microgrid functions such as power factor improvement help to improve the fuel efficiency of the backup generator thus lengthening its availability (see paper by Cummins Power Generation[20]).

Intelligent Microgrid Solutions integrate medium size renewable energy projects (1 to 5 MW) within the facilities on roof tops or parking lots. The size is large enough to make significant impacts and reach economies of scale, yet small enough for rapid implementation with little environmental impact. Renewable energy systems supply power to both grid connected and grid independent configurations with other dispatchable on-site power sources. The addition of energy storage into the microgrid stabilizes renewable power and relieves the utility from intermittent transients.

Implementing a microgrid today is expensive because of the lack of installation experience in the industry and market, the lack of standards for circuit switch and protection equipment in microgrids, and the lack of standards in control and networking devices for microgrids. In the 2011 Department of Energy (DOE) Microgrid Workshop Report[9], industry experts estimated the control and networking costs for a microgrid to be $100,000 per distributed energy resource or building automation system, with a target cost of $10,000. The working group's goal was to achieve a 10 fold reduction in those costs through experience and standardization.

Acceptance of microgrids faces challenges from utilities and facility operations. Utilities view customer operated microgrids as a challenge to their ability to control the grid and they view distributed generation as a loss of their revenue stream. Facility energy operations are often split between the mechanical/heating ventilation and air conditioning (HVAC) group and the electrical/distribution group. Because the skill sets and safety hazards are different between the two groups, integrating the two trades into a single control and network system will be challenging. The solution is to keep a clear dividing line between the equipment on which each group works, with a single simple interface between the two.

3.0 PERFORMANCE OBJECTIVES

The goals of the proposed project were to demonstrate the Lockheed Martin Intelligent Microgrid Solution's ability to provide greenhouse gas emissions reduction, reduce facility energy usage, reduce backup generator usage, and provide enhanced energy security as an integrated system of energy assets under central control.

3.1 ENERGY SECURITY

The operating time of the facility critical loads were extended during periods of grid independent operation by reducing the fuel consumption of the backup generation with a combination of intelligent load management and the integration of renewable resources. The data requirements for this objective were the normal operating time of the backup generation and the extended operating time with the integration of renewable sources.

The extension of backup power to select high priority but non-critical loads to extend the mission capability of the facility during grid disturbances/failures was demonstrated. The data required included the verification of the additional load, beyond serving the critical loads, during grid independent operation.

Energy Surety was attained through the demonstration of facility isolation during periods of grid failure and seamless reconnection when the grid returns and stabilizes. Data requirements included power flow measurements from the PCC and the microgrid bus voltage during these events.

Reduction of transient power flow caused by renewable energy was also demonstrated. By installing an energy storage system to operate in conjunction with the existing photovoltaic system, the microgrid was capable of offsetting any occlusions that may occur during the day. The MCS monitors the output from the solar inverter during the day and if output drops considerably, the energy storage system supplies the difference. Data requirements included power flow measurements from the solar inverter and the energy storage system.

3.2 COST AVOIDANCE

The monthly demand charges were to be reduced by utilizing distributed resources available for peak shaving. The data requirements for this include power consumption (in kW) of the facility in both baseline configuration and microgrid configuration. Based on actual data gathered by the MEDES data acquisition system installed in October 2011, the EPDF had a baseline power factor of 0.8. This power factor value decreased substantially during periods of peak demand. The current rate structure at Fort Bliss dictates a power factor adjustment charge based on the lowest power factor measured during the highest peak demand on a rolling 30 minute window on a monthly basis. This is according to the "El Paso Electric Company Schedule No. 38 Noticed Interruptible Power Service."[21] When the power factor measured is less than 0.9, a cost adjustment is made. By performing power factor improvement, the overall power factor of the EPDF was improved, avoiding the power factor adjustment charge. The data requirements include power factor measured at the protective relay.

In grid independent operation, fuel costs are reduced. This was accomplished through the integration of energy storage and existing solar power onto the bus. The data requirements included the calculated fuel consumption of the backup generator in the baseline configuration and the calculated fuel consumption in the microgrid configuration. The total energy production from the energy storage and the existing photovoltaic system was collected and compared to the cost of running the generator in the baseline configuration.

Table 2. Summary of performance objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Reduce Facility Energy Usage	Energy intensity (kWh), peak demand (kW)	Microgrid power flow measurements, electricity rates	>10% reduction of peak electricity usage as seen by the Utility	Successfully reduced peak utility demand to 261 kW which is a 14.4% reduction when compared to the 305kW peak load observed by DPW in years prior.
Reduce fuel usage and GHG emissions of backup generators during grid independent operations	Use of Energy Storage and PV on critical load during grid independent scenarios (kWh), direct fossil fuel GHG emissions (metric tons) during grid independent operations	Power flow measurements of energy storage and PV during grid independent scenarios, measured or calculated release of GHG based on source of energy, present fuel costs	>20% reduction of backup generator fuel costs during daylight hours in grid independent operations, 20% reduced GHG emissions compared to baseline configuration	Successful
Increase power availability during grid independent operations	Number of additional loads served in grid independent operations (kW)	Breaker status, microgrid load served	>20% more load and facility utilization during grid independent operations	Successfully increased islanded load from 30-50 kW to 50-80 kW. This represents a 37.5% to 40% increase in load supported during grid independent operations.
Energy Surety	Time interval of interruption(s)	Microgrid bus voltage measurements as a function of time	< Five cycles of AC power for all EPDF loads	Successfully measured the ESS picking up system load within two cycles of AC power interruption.
System Economics	Return on Investment as calculated by the BLCC program	Usage as a function of time and utility billing rate schedules	Savings to investment ratio (SIR) greater than 1.5 when extrapolated to a full BCT.	Successfully calculated a SIR of 1.51 and a payback of 8.89 years.

Table 2. Summary of performance objectives (continued).

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Power Quality Assessment	Ability to provide event oscillography, waveform capture, remote monitoring of building power quality	Power, voltage and power factor of the Microgrid	The following data points were captured at a 1 hertz rate: system voltage per phase, system frequency, and real power, reactive power, and power factor as measured from the main circuit breaker to the utility.	Successful
Reduction of Transient Power Flow Caused by Renewable Energy	Smoothing of intermittent transients introduced to the utility grid. Will use reduction of power over time interval: watts per second (W/s)	Measurements of PV and energy storage power flows	< 500 W/s reduction in power caused by renewable energy	Results Mixed
Power Factor Improvement	EPDF total Power Factor	Power factor measured at the Protective relay/point of common coupling between the EPDF loads and the utility connection	>.9 power factor (PF) of the EPDF during peak hours 5 AM to 8 PM , Monday - Friday	Successful
Electricity Arbitrage	Kilowatt hours (kWhr) stored during off peak demand and kWhr used during on-peak demand	Energy Storage System kWhr used	>20 kWhr stored during off peak demand and used during on-peak demand.	Successfully demonstrated an average energy output of 21.35 kWh per day at peak hours.

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4.0 FACILITY/SITE DESCRIPTION

The EPDF at Fort Bliss Army Base was chosen as the demonstration site in the BCT-1 installation. The EPDF is building 20226 of the BCT-1 campus. The BCT-1 campus is located in the northeast portion of Fort Bliss.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The BCT-1 complex at Fort Bliss is located at the northeast side of the base in El Paso, TX (Figure 11). The EPDF of the BCT-1 complex served as the demonstration site.

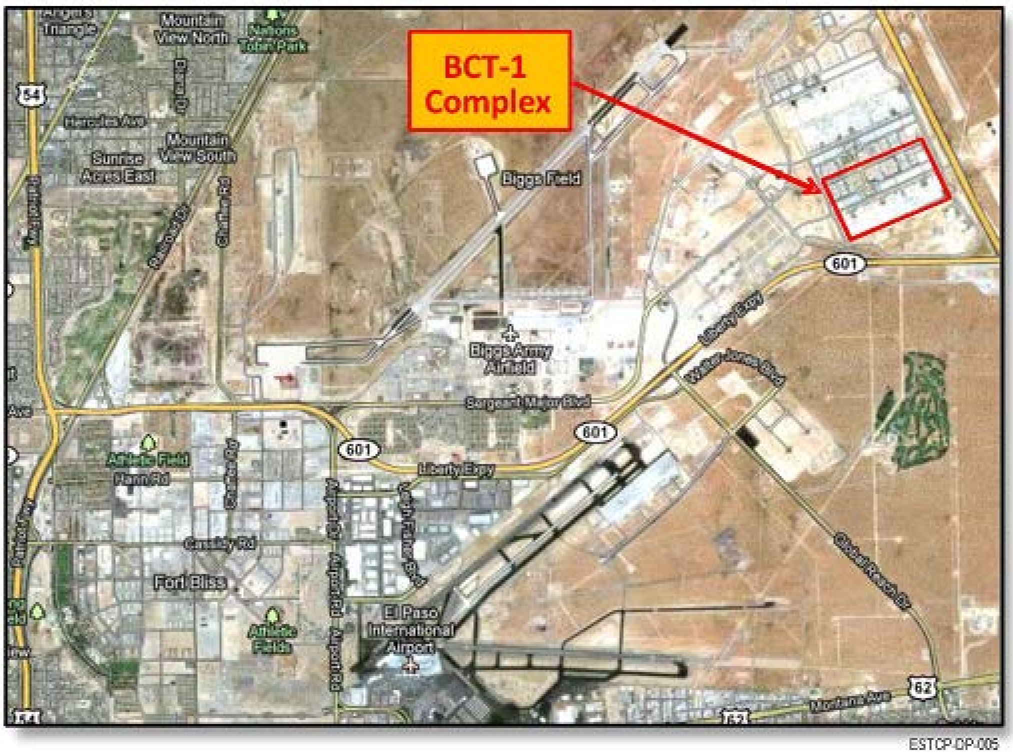

Figure 11. Location of BCT-1 on Fort Bliss Map.

4.2 FACILITY/SITE CONDITIONS

The EPDF at Fort Bliss had a number of benefits that make it ideal for use in this demonstration project. The backup generator was oversized and rarely used. The existing solar PV system supplemented power while grid tied but it was limited to <20% of its full potential output when islanded. There was an existing connection to the base wide Utility Monitoring and Control System (UMCS)[22] therefore allowing DPW a means to receive additional telemetry data from the microgrid. The distribution equipment is owned and operated by DPW thus avoiding extra work to setup an intertie agreement with the utility/distribution company. Most importantly, the soldiers on post were actively using the facility giving the project a real world load profile to test against.

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5.0 TEST DESIGN

The traditional approach to electricity usage resulted in many inefficiencies for DoD installations and for underutilization of existing renewable energy resources. It fails to provide appropriate measures of energy security and greenhouse gas emission reductions. The traditional configuration uses backup combustion generators for support of critical loads only and integrates renewable resources that cannot be fully utilized in grid independent operations. The existing distributed energy resources cannot be utilized to perform tasks such as controlled peak shaving and energy resource optimization.

The detailed description of the system components and interconnections are described in the following sections.

5.1 CONCEPTUAL TEST DESIGN

The overarching test designed for measuring system operational success was carried out via a series of several smaller tests, each designed to verify a particular subset of performance objectives. These smaller tests included a peak shaving test with the microgrid paralleled to the utility; a grid failure test with the microgrid isolating from the utility; and a grid independent test with the microgrid isolated from the utility. Two of these simulated scenarios were performed shortly after system commissioning and following that period, the system was left to operate autonomously for the remainder of the demonstration time in real-life conditions (June-December 2013). The details of these tests and the associated performance objectives are described in the following paragraphs.

Peak Shaving Test: The purpose of this test was to determine the ability of the microgrid to reduce the facility energy usage from the bulk power grid and thereby reduce the monthly utility demand charge. This test yields the measure of success for the performance objective "*Reduce Facility Energy Usage*."

Grid Failure Test: The purpose of this test was to determine the ability of the microgrid to provide minimal interruption to facility loads during a grid failure as well as to reconnect back to the grid upon the return of voltage. This test yielded the measure of success of the performance objective "*Energy Surety*." The grid failure was simulated with the manual opening of the transfer switch and subsequent operation of the system resulted in no unexpected microgrid outages.

Grid Independent Test: The purpose of this test was to ascertain the capabilities of the microgrid while isolated from the bulk power grid. This test yielded the measures of success for all performance objectives in Section 3.1 not tested in the previous two tests, with the exception of the system economics performance objective.

5.2 BASELINE CHARACTERIZATION

5.2.1 Reference Conditions

The facility energy consumption data was collected from the energy monitoring and metering systems. The load data from the critical loads was used to calculate the expected operational time and expected GHG emissions of the backup generator. This data was used to provide a baseline for the performance objective "*Reduce fuel usage and Greenhouse Gas (GHG) emissions of backup generators during grid independent operations*" and "*Reduction in Back Up Generator Usage*." The pre-microgrid generator control parameters were collected to determine the interruption time that previously existed when the bulk power grid went down. This data was used to provide a baseline for assessing the performance objective "*Energy Surety*." The baseline characterization of the performance objective "*Increase power availability during grid independent operations*" was determined by recording the amount of load not served by the existing backup generator within the planned microgrid. The performance objective "*Power Quality Issue Assessment*" used the currently available metering of the facility as a baseline to show improvement in the capabilities to determine power quality problems. Finally, the System Economics performance objective provides the information from a Building Life Cycle Cost (BLCC) study performed on the system.

5.2.2 Baseline Collection Period

The planned baseline data collection period extended from November 2011 to July 2012. This yielded detailed baseline data over both hot and cold weather extreme conditions. It also allowed for the identification of heavy facility electrical demand periods. These time periods were used to evaluate candidate peak shaving operation times.

5.2.3 Existing Baseline Data

The DPW at Fort Bliss logged monthly electrical demand for the facility for a period of time via their BOCC. This data was analyzed to see if it could be used to augment the baseline data pool, but the BOCC measurements were not at a resolution required to see the energy use from individual feeders. Instead, power meters were placed on the feeders to the BCT to collect baseline data.

5.2.4 Baseline Estimation

The operational time of the backup generator in the baseline configuration was estimated based on the known critical load demand data obtained and the manufacturer's fuel usage data. The GHG emissions and the fuel consumption were obtained as byproducts of this estimation. Maintenance of generators may reduce GHG emissions, but this data were not collected.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The following section describes the design of the Intelligent Microgrid Solution as it specifically applies to the work that was done in this ESTCP demonstration project.

5.3.1 Major Subsystems and Components

Several additions were made to the building's existing power system. Originally, the plan was to utilize the existing main switchboard and add new circuits on to it. However, following the contract modification, it became necessary to redesign the electrical additions. The resulting system incorporated a new switchboard upstream from the existing switchboard. This new switchboard housed the connections for the energy storage systems and the equipment comprising the PCC. Also, the generator paralleling equipment was also to be housed in the original switchboard, but to maintain consistency with industry standards, subcontractors placed the paralleling equipment in an adjacent mechanical room and run the power feeds to the existing generator breaker connection. The load shedding features were also modified prior to the final commissioning as the selected motor operators would not fit on all of the desired circuit breakers.

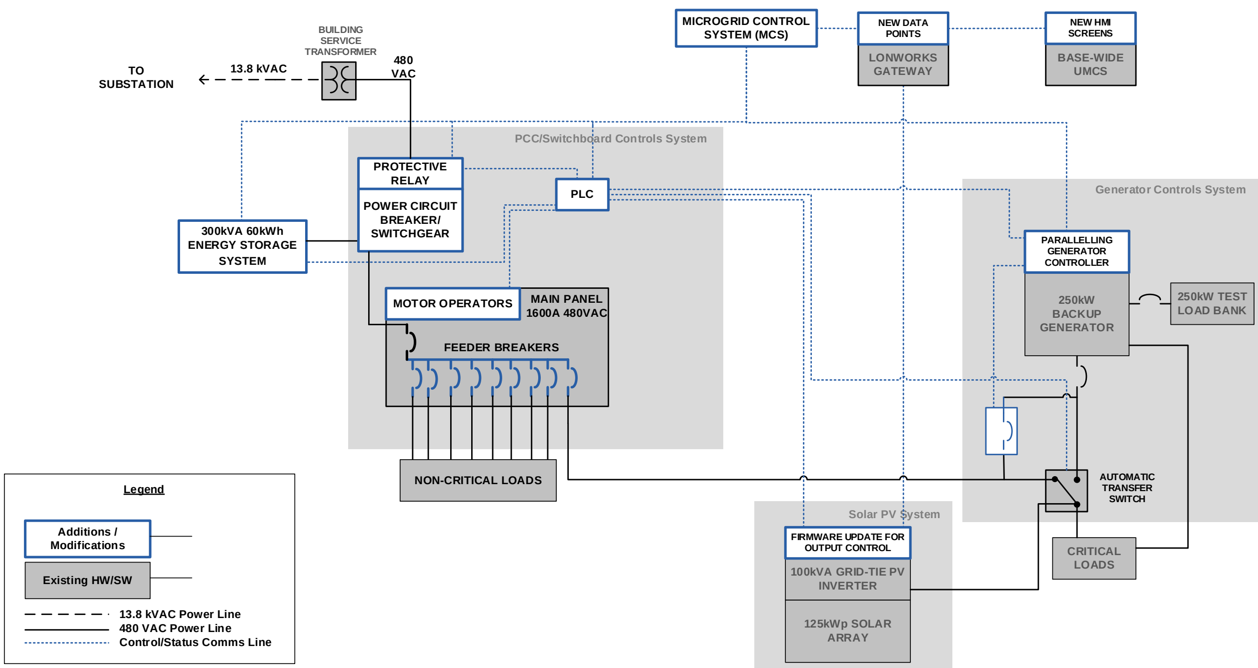

Figure 12. EPDF microgrid system block diagram.

5.3.2 Communications Design

Communications is a key design element for any microgrid. Ideally the communications design allows for easy integration with existing systems and provides an open design for growth. For this demonstration project, power data is measured by DERs and distributed controllers which are then polled for status information by the MCS at a periodic interval using the Modbus/Transport Control Protocol (TCP). Likewise, commands that originate at the MCS are communicated to the DERs and distributed controllers using Modbus/TCP.

Many industrial control devices do not natively use Ethernet as their physical link but instead communicate using serial RS-485. Gateways are used to translate both the application layer messages to Modbus/TCP and to convert the DERs' native physical link to Ethernet. The backbone of the control network included an unmanaged Ethernet switch, which can be easily scaled up to support additional devices in the future as is commonly done with stackable Ethernet switches in office environments.

The UMCS periodically polled the LonWorks Gateway using the LonTalk protocol (standardized as ANSI/CEA-709.1-C).[(23)] In response to the UMCS, the LonWorks Gateway provided the latest data it received from the MCS.

Since the EPDF Microgrid control network was completely contained on the building side of the LonWorks to IP router, Certificate of Networthiness (CoN) and Defense Information Assurance Certification Accreditation Program (DIACAP) processes were not required for the Lockheed Martin demonstration. This approval was coordinated with the Fort Bliss DPW and U.S. Army Corps of Engineers (USACE) Network Enterprise Center (NEC) at the Fort Bliss. The Lockheed Martin scope of work did not include addressing cyber security issues that may have been associated with the UMCS.

5.4 OPERATIONAL TESTING

5.4.1 Operational Testing of Cost and Performance

Data collection methodology was unchanged for the duration of the demonstration. Through initial baseline characterization, system installation, integration, and adjustment, system commissioning, system operation, and demonstration completion data collection has consisted of extracting the data from the metering systems. Following system commissioning, generator, energy storage, and photovoltaic system data were collected and archived internally via the Supervisory Control and Data Acquisition (SCADA) software and its associated historian package in order to supplement this data set. Data was extracted from the data loggers approximately quarterly. The complete pool of data was sufficient to assess the performance objectives.

5.4.2 Technology Transfer or Decommissioning

Appropriate personnel at the demonstration site were trained on the operation and use of the system during the course of the commissioning. As a part of this training, Lockheed Martin supplied operating manuals for the EPDF Microgrid and on any new equipment installed. Lockheed Martin also included the option for the base personnel to return the system to its original configuration if so desired by the flip of a switch.

It is hoped that this site will be continually used as a test bed for future microgrid projects unfolding across different sections of the base. The appropriate personnel can become acquainted with the technology and the financial benefits of a larger microgrid can be investigated using in situ equipment backed up with verifiable results.

5.5 SAMPLING PROTOCOL

There were three main data acquisition systems: the sub-meters installed for baseline measurements, the MCS (with historian), and lastly the base wide UMCS. The MCS historian data collected from the two servers was the primary data source for analysis. The sub-meters were used mainly for comparison purposes and initial algorithm settings. The UMCS data will not be presented in this report, but does provide DPW an independent way to record status of each DER and determine efficiency as needed.

5.6 SAMPLING RESULTS

The baseline characterization data was collected by energy meters and associated data loggers, described in more detail in the *Microgrid Enabled Distributed Energy Solutions (MEDES)*, Final Technical Report.[25] While 15-minute interval data was sufficient for baseline characterization, the bulk of the analysis was carried out with the MCS historian data recorded at 1 second intervals. Each historian (from each server) recorded roughly 2 gigabyte (GB) worth of data for the period of performance. The entire 4GB of raw data is too large and cumbersome to place in an appendix of this report; however, portions of the historian data were extracted from its native data format to comma separated value (CSV) files for sampling purposes, and finally processed with Microsoft® Excel to generate graphs and tables.

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6.0 PERFORMANCE ASSESSMENT

6.1 REDUCE FACILITY ENERGY USAGE

In order to measure the success of this objective, the imported real power from the utility was extracted from the historian data and the data set was examined to make sure the real power import did not rise above 274.5 kW (10% less than the 305 kW peak measurements provided by DPW). The extracted data was taken at 15-minute intervals to give a dataset slightly less erratic than 1-second data appeared. The maximum demand recorded in the 15-min interval data was 261 kW (8/27/13 at 12:55PM) representing a 14.4% reduction in peak demand for the summer.

Note that the 1-second data did indicate very short-term excursions above 275 kW of import, as expected. The use of a diesel generator, which requires some small amount of time to warm up dependent on size, and the nature of the loads on the EPDF, which spike up values as high as 70 kW and disappear just as suddenly a short time later (Figure 3, for example), contribute to a built-in latency that causes the instantaneous import power to exceed the desired limit temporarily until the system can respond. For future studies, the same peak shaving would be more responsive, the more the energy storage system is utilized. The intent of this demonstration was not to use the energy storage system for peak shaving since it was already tasked with the electricity arbitrage function, as well as the renewable energy smoothing function.

Additional system monitoring over a longer period of time would facilitate improving the peak shaving function system parameters. With the data collected, the peak shaving function successfully demonstrated the ability of the microgrid to determine import levels approaching a limit and adjusting the system accordingly.

6.2 REDUCE FUEL USAGE AND GHG EMISSIONS OF BACKUP GENERATORS DURING GRID INDEPENDENT OPERATIONS

The goal of this objective was to demonstrate the capability of the microgrid to incorporate a greater fraction of renewable energy, in this case solar, in an islanded configuration. The baseline configuration utilized the generator and 20% of the existing PV array to feed only the critical load circuits. This amounted to a maximum of 20 kW of solar (calculation based on theoretical maximum output of solar inverter). As can be seen from Figure 8, during the most comprehensive islanding event, the MCS pushed the solar output up by 35 kW. By offsetting the generator’s load by an additional 15 kW above the baseline configuration solar output, the goal of 20% fuel use and greenhouse gas reduction was exceeded.

As discussed in the following section, modifications had to be made to the load shedding scheme during installation, and these modifications led to a larger load on the island than in the baseline configuration. However, even when the additional load is taken into account, the microgrid was successful at reducing the generator fuel consumption and GHG emissions.

6.3 INCREASE POWER AVAILABILITY DURING GRID INDEPENDENT OPERATIONS

A related objective was to show the ability to add more loads and extend the mission of the facility during periods of time in which the grid is unavailable. There were some modifications that had to be made to the original plan in the field due to equipment limitations. It was not possible for motor operators to fit on all of the feeder breakers, so not all of the loads could be shed in the islanded configuration. This was responsible for additional loads placed on the islanded configuration than in the baseline configuration. The critical load circuit, during daylight hours, fluctuated between roughly 30-50 kW. In the islanded scenario, island load never falls below 50 kW and even rises to ~80 kW. This additional load placed on the bus substantially surpassed 20% of the baseline average of 30-50 kW.

6.4 ENERGY SURETY

This objective demonstrated the ability of the microgrid to provide a reliable source of power in all conditions, specifically in the scenario where the grid becomes unavailable. The test for this was carried out by disconnecting the facility distribution transformer from the distribution loop. High speed waveform capture was performed in Lockheed Martin's Microgrid Development Center (MDC) prior to deployment to the field (Figure 6). From the figure, the delay between loss of utility and stable bus voltage is about two electrical cycles (33.3ms) – successfully demonstrating the objective. High speed data was not captured at the EPDF Microgrid due to lack of proper instrumentation. Historian data from the MCS Servers were captured, as shown in Figure 8.

6.5 SYSTEM ECONOMICS

The system economics performance objective was to demonstrate the economic advantages of having a microgrid versus a conventional system configuration. The SIR, using the BLCC methodology, was used as the performance metric because this is the key metric by which energy projects are considered for DoD infrastructure project funding. The success criteria of reaching a SIR greater than 1.5 when extrapolated to a full BCT was achieved. Section 7.0 provides more detail.

6.6 POWER QUALITY ASSESSMENT

This objective demonstrated the EPDF Microgrid's ability to maintain visualization of the system state at all times. By closely monitoring all critical electrical parameters of the electrical system, the microgrid can be prepared to take whatever action is necessary to stabilize the system following any disturbances. In the four hour morning sample data collected, there were no drastic voltage or frequency fluctuations from the grid with consistent real and reactive power and stable Power Factor (Figure 13). Data points were captured at a 1 hertz rate: system voltage per phase, system frequency, and real power/reactive power and power factor, as measured from the main circuit breaker to the utility.

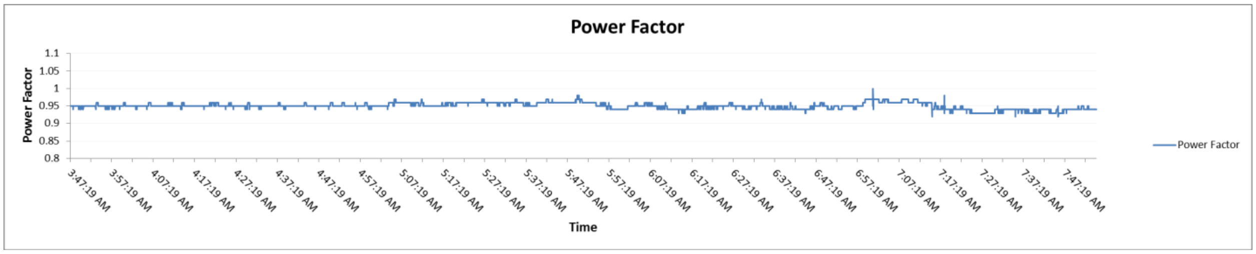

Figure 13. Power factor (4 hour sample).

6.7 REDUCTION OF TRANSIENT POWER FLOW CAUSED BY RENEWABLE ENERGY

The goal of this objective was to demonstrate the EPDF Microgrid's capability to smooth out short-term transients caused by rapidly fluctuating renewable energy sources. A good example is the sudden occlusion of a large PV array on a sunny day. The output of the array may drop as much as 80% or higher of its capacity in a few seconds. The corresponding rise in demand from the utility can be very problematic in situations where the renewable resource capacity is a large fraction of the local load demand.

As illustrated in Figure 7, the microgrid responds instantly to the drop in PV output power to compensate. This example also shows that although the algorithm was successful at rapidly detecting the roll off of solar production and ramping up the energy storage system to compensate, the power levels of the response do not coincide with the amount of the drop due to a misapplied scale factor. Hence the statement "Results Mixed" in Section 3.1, Summary of Performance Objectives table, is listed under the Results column. The renewable smoothing function worked as designed at Lockheed Martin's MDC.

6.8 POWER FACTOR IMPROVEMENT

This objective demonstrated the ability to correct the power factor of the microgrid with the ESS. Prior to installation of the microgrid, the baseline measurements indicated that the EPDF's power factor drops to 0.6 during noon on weekdays corresponding to peak real power generation from the PV system. On weekends, the EPDF Microgrid's power factor is worse, it dropped to 0.2.

This project highlighted the impact of relatively high penetration of PV behind the meter on the utility power factor adjustment charges. As seen in the demonstration site PV system, PV systems installed behind the meter typically use commercial PV inverters that export only real power when behind the meter loads typically require both real and reactive power to operate. This drives the power factor rating lower and requires the utility power provider to compensate by delivering more reactive power. Utility power providers charge for this service in the form of a utility power factor adjustment charges. The rate structure of the base includes a power factor penalty for poor power factors Monday through Friday between 5 AM and 8 PM. The MCS targeted those times for power factor correction by utilizing the energy storage compensation for the PV inverters by injecting dynamic reactive power to maintain a power factor for the EPDF Microgrid above 0.9. The ability to actively manage power factor with energy storage was demonstrated as can be seen from the representative week in Figure 4.

Other non-energy storage solutions for overcoming power factor adjustment charges could include passive capacitor banks and synchronous condensers. Upon implementation, capacitor banks would need to constantly be switched in causing some life cycle concerns, while synchronous condensers are generator based and typically used in environments not sensitive to cost. The energy storage solution provides a dynamic reactive power injection in which the operation cycle is only limited to inverter and energy storage cycle life.

6.9 ELECTRICITY ARBITRAGE

The arbitrage objective is a straight forward exercise in energy storage system scheduling, as shown by a sample week in Figure 5. The ESS charges from 11 PM to 4 AM and discharges from 12 PM to 2 PM during peak demand. The existing base rate schedule includes a demand charge component that applies to the typically high-demand summer months between 12 PM and 6 PM. By providing a set amount of energy from the energy storage system during this time, the microgrid allows the operator to offset some of the load demand. This will save the operator money by essentially buying inexpensive energy during the night time hours and using it during the peak charge hours. Power output from the ESS was summed up during the hours of 12 PM to 2 PM to calculate the amount of energy arbitraged for each day and the results are shown in Table 1. The average value of energy per day supplied by the EPDF Microgrid in this case is 21.35 kWh, exceeding the goal of the objective.

One important consideration for energy managers is the cost of maintenance and replacement of the energy storage technology. The energy managers need to determine if the system can save more money than it costs to operate. This can be complicated if the system performs more than one function, as in the case of the EPDF Microgrid.

7.0 COST ASSESSMENT

The cost elements of the microgrid captured during the demonstration were put into a BLCC analysis tool using the methods in National Institute of Standards and Technology (NIST) Handbook 135.[1,2] The economic benefits from energy security or providing ancillary services to a utility were not included in the results. The National Renewable Energy Laboratory (NREL) customer damage function (CDF) methodology was considered to attempt to capture the economic benefit gained from the energy security attributes of the EPDF Microgrid; however, a CDF survey was not available during this contract's period of performance.

7.1 COST MODEL

A site survey was performed to collect the electricity rate schedules and obtain the 1 line electrical schematic of the site. This data was used to form a BLCC assessment to determine a SIR and simple payback; key variables used when rating potential DoD energy infrastructure projects. Available manufacturer data, DOE's PVWatts application, and Lockheed Martin modeling and simulation platforms were used for penetration levels of solar PV energy, energy storage, and the on-site generation.

Table 3. Cost model for the intelligent microgrid solution.

Cost Element	Data Tracked During the Demonstration	Cost Estimate
Hardware Capital Costs	Estimate of major equipment cost including solar retrofits, Genset retrofits, new energy storage, new switchgear, and new controls.	PV Retrofit = $50/kW (limited inverter mods) Genset Retrofit = $60/kW (mod for grid-tie) Energy Storage = $700/kWh (lead-acid system; Advanced solution estimate $400/kWh) Switchgear = $100/kW of load served Controls = $20/kW of controlled loads/sources
Installation Costs	Estimate of labor and material	Design and installation accounts for 16% of costs
Consumables	Estimates based on rate of consumable use during demo	$500 annually (ESTCP demo fuel and electricity costs)
Facility Operational Costs	Reduction in energy costs vs. baseline data	$9500 in savings annually vs. baseline (ESTCP demo scale project)
Maintenance	Frequency of maintenance; labor and material cost per maintenance action	1 trip per year estimated at $2500
Hardware Lifetime	Estimate based on components degradation during demonstration	20 years for industrial electrical equipment and electronics was estimated. Lead acid energy storage estimated less than 10 years as used in ESTCP demo. Advanced grid-scale storage technologies estimated 20 year life.
Operator Training	Estimate of training costs. Total of 2 days of training plus materials	$5000
Salvage Value	Estimate of end-of-life value less removal costs	Minimal

7.2 COST DRIVERS

The cost model assumptions needed to extrapolate the ESTCP demo to a full-scale cost assessment, such as BCT loads, capital and operational costs of microgrid components were evaluated during the demonstration. Table 3 presents some of the cost elements that were tracked, estimated, and normalized in order to extrapolate to a full BCT complex.

7.2.1 Electric Utility Costs

Fort Bliss purchases electricity from EPEC. Detailed electricity rate schedules from EPEC with an effective date of July 2010 were used in the analysis. The complex rate structure includes (as found in EPEC's Schedules 31, 38, 95 and 98) (21):

- A fixed customer charge of $500 /mo.
- A demand charge of $16.78 per kW per month, where maximum demand is defined as the highest measured 30 minute average kW demand, not less than 15,000 kW or less than 65% of the highest measured demand in the last 12 month period.
- A power factor adjustment is added to the demand charge if the PF falls below 0.9 lagging anytime during the 30 minute peak interval, where the Adjustment = ((KW x 0.95/PF) – KW) x DC.
- An energy charge for on-peak of $0.14335/kWh and off-peak of $0.00527/kWh, where on-peak is defined as the time from 12 PM to 6 PM Mountain Daylight Time (MDT), Monday through Friday for the months of June through September. A military discount factor of 20% is additionally applied these rates, in addition to a Fixed Fuel Factor of $0.029/kWh.

7.2.2 Generator Costs

The on-site back-up generation set (a.k.a., Genset) used during the demonstration was diesel-fueled. The Genset was modified for grid-tied operation at a normalized cost of ~$60/kW. Gas fueled Gensets, rather than diesel, are preferred for economic reasons. Although conversion of diesel Gensets to dual-fuel or gas is possible, it was not within the scope of this project to perform the modification. For extrapolated EPDF Microgrid cost analysis, a new gas-fed Genset, intended for extended operation, was used. Extended use generation with both voltage and current control was determined to be $1500/kW. This is above the $700-$1000/kW cost of back-up only generation available commercially. Section 7.3 covers sizing rationale.

7.2.3 Solar PV Costs

This demonstration takes advantage of an existing solar array. Future microgrid implementations can expect installed solar PV costs less than $3/W. Existing PV installations that used inverters with maximum power point tracking (MPPT) grid-tied inverters will require replacement or modification to allow for substantial use in islanded microgrid configurations. Modification of inverters to accept current control was determined to be $50/kW of inversion. It should be stated that not all grid-tied inverters can be modified to allow for current control. The EPDF Microgrid PV Inverter operated per UL1741/IEEE1547[3,4] which includes the utility grid interconnection requirements. When the utility output is outside the operating range (i.e. voltage or frequency) the PV Inverter automatically disconnects from the grid for 5 minutes before trying to reconnect to a stable grid.

Note: A protective relay (SEL-700G0) could be configured to operate per UL1741/IEEE1547 when using a non-UL1741 inverter. This will limit the interaction of the inverters to only operate in the islanded configuration.

7.2.4 Energy Storage Costs

Energy Storage for facilities is rapidly evolving, and pricing ($/kW and $/kWh) varies between technologies and capabilities. Prices are coming down as companies focus on MW size energy storage and production volumes increase. Extensive review of both currently available and near-term advanced solutions indicate nominal costs falling from an average of $700/kWh to $400/kWh while lifetime expands from less than 1000 deep discharge cycling to greater than 4500 cycles. Section 7.3 covers sizing rationale.

7.2.5 Switchgear Costs

Switches and protection at the microgrid interconnection with the grid as well as switches necessary for load management, consist of a broad collection of devices at different voltage and current service ratings. Based on the survey of equipment necessary for this ESTCP demonstration and use in larger BCT Microgrid applications, the cost was determined to be $100 per kW of load served on average.

7.2.6 Monitoring and Control Costs

The combination of equipment and software necessary for microgrid monitoring and control including central servers, distributed discrete logic hardware, sensors, communications and associated software is site specific and affected by the number of nodes, compatibility of existing hardware, and accessibility of existing networks. The data gathered on these costs was normalized to the total amount (kW) of loads and sources controlled by the microgrid. This was determined to be $20/kW on average.

7.3 COST ANALYSIS AND COMPARISON

To explain the lifecycle cost benefits of a microgrid installed to serve a full-scale BCT complex, the costs associated with designing, procuring, and installing the necessary generation, energy storage, switchgear, monitoring and controls was estimated based on insights from the sub-scale ESTCP demonstration as well as a survey of costs at larger scales needed for a BCT complex. These cost drivers were described in Section 7.2. In order to extrapolate the electricity costs and benefits captured at a full BCT complex, detailed energy usage of Fort Bliss was obtained and scaled to the peak load (4.5 MW) and annual energy usage (18.2 GWh) of a BCT complex located at Fort Bliss, as defined in the U.S. Army Engineer Research & Development Center's (ERDC) technical paper, "*Towards a Net Zero Building Cluster Energy Systems Analysis for a Brigade Combat Team Complex*" (Zhivov et al, 2010).

Figure 14 shows a broad peak load growing above a base load threshold between 2500 and 3000 kW in the 3rd month and falling below the same threshold prior to the last 2 months of a given year. The on-peak energy pricing period of June through September (~3500 hrs to 7500 hrs) clearly corresponds to the peak energy intensity of the BCT modeled by ERDC. To determine the optimal peak shaving and energy arbitrage capacity design point to use for the BLCC analysis of the EPDF Microgrid it was useful to analyze the duration a BCT spends above a given load annually. Figure 15 shows the duration spent at a specific BCT load over a year. The data shows a clear knee in the curve between 2500 and 3000 kW which corresponds closely with hourly BCT electrical load modeled by ERDC as shown in Figure 14. This provides rationale for the combined peak shaving capacity of 2000 kW provided by energy storage and gas generation assets in a full BCT complex.

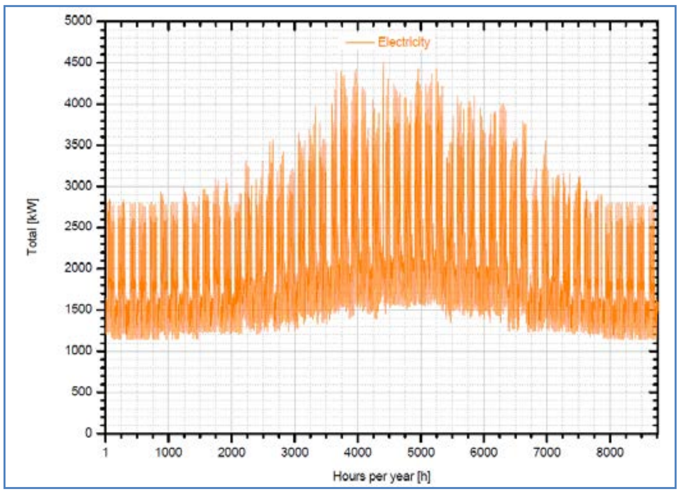

Figure 14. Load profile of a Fort Bliss BCT complex over a year (Zhivov, 2010).

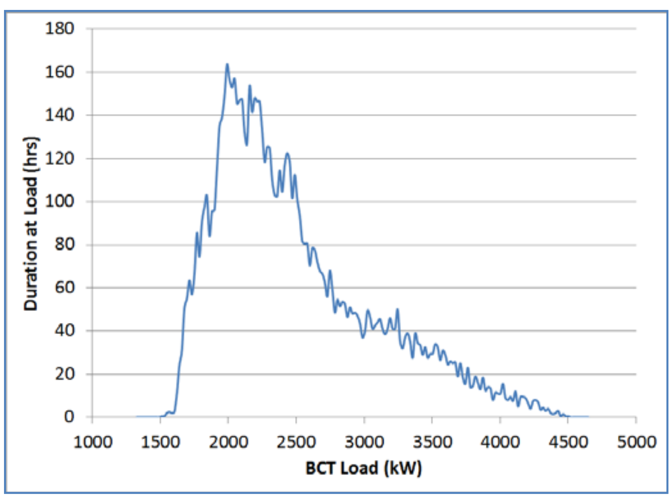

Figure 15. Duration at a given Fort Bliss BCT load annually.

Figure 16 integrates the data in Figure 15 and normalizes to 24 hours to show the daily duration spent at and above a given BCT load averaged over an entire year and averaged over the peak energy intensity period between June and September. This figure illustrates the rationale for the energy storage runtime design point used in the BLCC analysis. To ensure the energy storage asset can provide its contribution to the demand reduction through peak shaving over the entire year it can be seen that 6 hours is the daily duration spent above the knee in the demand curve at Fort Bliss of ~2750 kW as originally shown in Figure 15. A runtime of 6 hours also allows the energy storage asset to discharge its capacity within the 6 hour window defined by EPEC's on peak energy pricing period of 12-6 pm in the months of June through September.

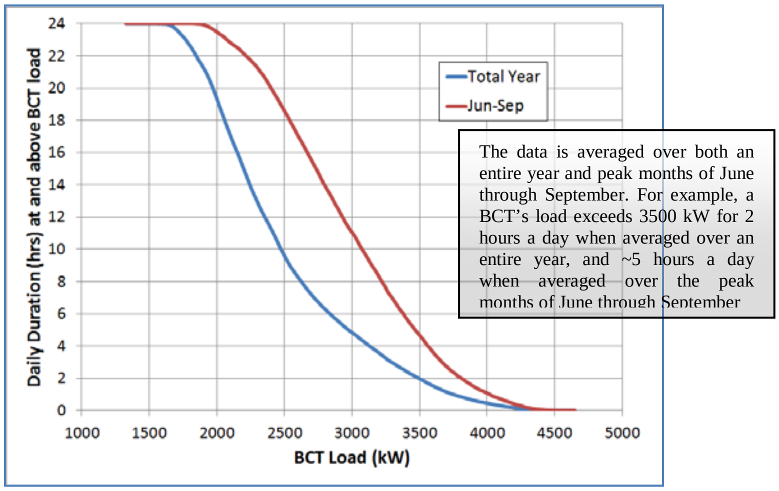

Figure 16. Daily Duration at or above a given Fort Bliss BCT load.

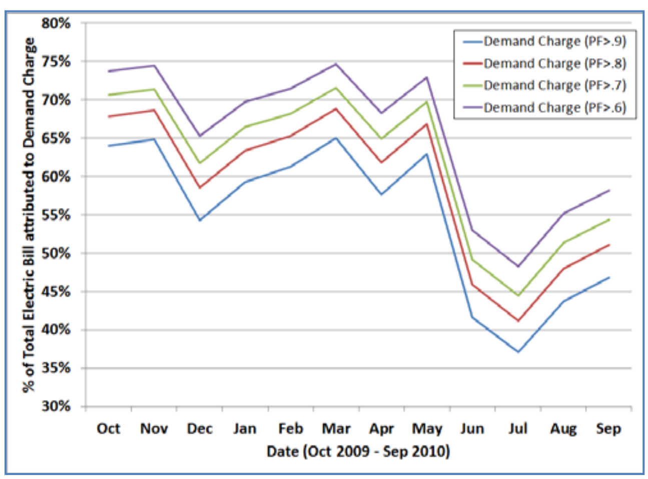

Figure 17. Power factor impact on the demand charge for Fort Bliss monthly electric bill.

The design points of 1000 kW of on-site gas generation, energy storage with 6 hours of runtime at 1000 kW, along with allocation of the normalized cost drivers defined in Table 3 results in an SIR of 1.51 and a payback of 8.89 years when using the NIST BLCC cost analysis methodology. This exceeds the success criteria defined at the beginning of the project for the system economics performance objective.

It should be noted that the SIR is most sensitive to energy storage costs. An SIR of 1.51 occurs with an energy storage cost assumption of $400/kWh. If energy storage costs of $800/kWh are assumed, typical of today's energy storage options, the SIR falls below 1.0. While energy storage is critical to the energy security functions of a microgrid, the impact of energy storage costs on a microgrid's economic benefits should not be underestimated. Availability of energy storage solutions that provide 20 years of durability at prices less than $400/kWh is critical to the success of microgrids.

Energy storage provides power factor correction of the real power produced by on-site renewable energy. The economic benefit is created by reducing the power factor penalties imposed by the utility for power factors below 0.9. With essentially no on-site renewable energy in 2010, Fort Bliss had a minimum power factor of 0.902 resulting in no penalty. However, as power factor seen by the utility with renewable penetration of ~30% in the case of the EPDF site, can be as low as 0.6. This can be even lower during periods of low daytime loads, such as the weekends in the case of the EPDF at BCT-1 Fort Bliss. This will occur as Fort Bliss progresses towards achieving NetZero Energy goals. Capacitor banks can be installed to improve power factor, but at an installed cost of ~$50 per kVAR of reactive power. Because low power factor occurs during peak renewable source output, which also corresponds to peak demand, the energy storage power electronics, sized to provide critical and essential apparent power needs, can be used concurrently to provide the necessary reactive power during the peak renewable output events. This is because the energy storage asset will not be needed to provide peak shaving during times when renewable energy output is at its highest. The savings not only includes the cost avoidance of a capacitor bank, but also the avoidance of ~10-12% increase in the electric bill due to power factor penalties associated with high penetration of renewables (see Figure 17).

8.0 IMPLEMENTATION ISSUES

Retrofitting the generators to operate within the microgrid proved to be a significant challenge. Generators at the time of installation are either installed as a standalone backup generator or a paralleling generator. While standalone generator controls reference system voltage and system frequency, parallel generators utilize/manage real and reactive power as well as system voltage and frequency. Synchronization of the parallel generator circuit breaker is a time critical operation where the generator controls must close the breaker only when both sides of the bus are synchronized. Generator protection is correspondingly much more complicated for paralleling generators. Generator grounding schemes are also different between paralleling generators and backup generators and a hybrid grounding system suitable for both types of generator installations was developed. Also, standalone backup generators do not have a restricted run time but when using them to parallel with the utility, an air permit must be obtained for the unit from the relevant authority, in this case from the Texas Commission on Environmental Quality. The process for obtaining this permit must be started as early in the process as possible due to the length of time required.

Retrofitting of existing electrical infrastructure is a challenge; the existing switchboard was laid out in such a manner that installation of all motor operators (to allow for load shedding) was impossible without substantial rework of the switchboard or purchasing of a completely brand new switchboard. The Lockheed Martin team installed as many motor operators as physically possible in the existing switchboard such that load shed capability was maximized.

There are also inherent challenges integrating the multiple DERs. One major issue is the fact that the electrical bus always needs a master DER. While grid tied, the utility is always the bus master, but when the microgrid islands, another source must be ready to take over that function immediately. Furthermore, when the transition occurs and the generator finally comes online, the master function passes to the generator in the EPDF Microgrid. The handoff of that functionality between the energy storage system and the generator is a very high speed, time critical event and requires a great deal of attention. The interfaces between DERs have to be carefully coordinated, timed, and tested thoroughly to ensure no conflicts of authority.

Although not a major issue, separate data loggers were used to collect baseline data for the BCT feeders since the DPW BOCC data collection did not have the resolution of individual feeders in their energy measurements. As the Fort Bliss power distribution is upgraded, more resolution could be available in these measurements to support future energy projects.

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9.0 REFERENCES

1. *NIST Life-Cycle Costing Manual for the Federal Energy Management Program (FEMP)*, Handbook 135.

2. *NIST Building Lifecycle Cost Program, 5.3-10.*

3. *IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems*, IEEE 1547.4-2011, 20 July 2011.

4. *IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems*, IEEE 1547-2003, 20 July 2011.

5. *IEEE Draft Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Std 1547,* IEEE 1547.8, Not yet released.

6. SERDP, ESTCP. *Installation Energy Initiatives.* s.l.: http://www.serdp.org/Featured-Initiatives/Installation-Energy, 2011.

7. *Department of Defense Energy Manager's Handbook.* s.l.: Office of Deputy Under Secretary of Defense (ODUSD) Installations and Environment (I&E), 2005.

8. USACE Technical Manual Series TM 5-689 to TM 5-698, circa 2006, reference: http://armypubs.army.mil/eng/

9. *Department of Energy Microgrid Workshop Report*, Office of Electricity Delivery and Energy Reliability Smart Grid R&D Program, August 31, 2011. San Diego, CA. http://energy.gov/sites/prod/files/Microgrid%20Workshop%20Report%20August%202011.pdf

10. *US Census Bureau*, http://blogs.census.gov/globalreach/2011/02/trade-deficit-increases-to-498-billion-in-2010.html

11. *Energy Policy Act of 2005* (EPAct05), H.R. 6, Pub. L. 109–58, is a bill passed by the United States Congress on July 29, 2005, and signed into law by President George W. Bush on August 8, 2005, at Sandia National Laboratories in Albuquerque, NM.

12. *Executive Order 13423*, Strengthening Federal Environmental, Energy, and Transportation Management, was signed on January 24, 2007.

13. *John Warner National Defense Authorization Act (NDAA) of 2007*, H.R. 5122, Pub. L. 109-364, was a bill passed in the United States Congress on September 29, 2006 and signed by President George W. Bush on October 17, 2006.

14. *National Defense Authorization Act (NDAA) for Fiscal Year 2010* (H.R. 2647, Pub. L. 111–84, 123 Stat. 2190.) is a law in the United States signed by President Barack Obama on October 28, 2009.

15. *Executive Order 13514, Federal Leadership in Environmental, Energy, and Economic Performance* that U.S. President Barack Obama issued on October 5, 2009. This executive order mandates that at least 15 percent of existing federal buildings and leases meet Energy Efficiency Guiding Principles by 2015, and that annual progress be made toward 100 percent conformance of all federal buildings, with a goal of 100% of all new federal buildings achieving zero-net-energy by 2030.

16. *Energy Independence and Security Act of 2007 (EISA 2007)* established energy management goals and requirements while also amending portions of the National Energy Conservation Policy Act (NECPA), signed into law on December 19, 2007.

17. *Installation Management Campaign Plan (IMCP)*, Version 4.0, November 2011, represents the combined strategy for the Installation Management Command (IMCOM), the Office of the Assistant Chief of Staff for Installation Management (OACSIM) and the Assistant Secretary of the Army (Installations, Energy and Environment) (ASA (IE&E)).

18. *Army Energy Security Implementation Strategy (AESIS) 2009*, 13 Jan 2009, establishes five strategic energy security goals and outlines a broad approach for accomplishing them.

19. *El Paso Electric Company Schedule No. 31 Military Reservation Service Rate*, Docket 37690, July 30, 2010.

20. *Rated power factor tests and installation acceptance of emergency and standby power systems*, Power topic, Iverson, Jim, 2006. http://www.cumminspower.com/www/literature/technicalpapers/PT-6004-PowerFactorTests-en.pdf

21. *El Paso Electric's Schedules 31, 38, 95 and 98 http://www.nmprc.state.nm.us/consumer-relations/company-directory/electric/el-paso-electric/index.html*

22. *Unified Facilities Guide Specifications*, Section 25 10 10 Utility Monitoring and Control System (UMCS) Front End and Integration, May 2010. http://www.wbdg.org/ccb/DOD/UFGS/UFGS%2025%2010%2010.pdf

23. *Department of Defense Unified Facilities Criteria*, LonWorks Utility Monitoring and Control System, UFC3-401-01, 1 June 2011.

24. *Towards a Net Zero Building Cluster Energy Systems Analysis for a Brigade Combat Team Complex*", Alexander Zhivov, Richard J. Liesen, Franklin H. Holcomb, U.S. Army Engineer Research & Development Center, Champaign, IL, Paper No. ES2010-90487, pp. 1017-1030; 14 pages, May 17, 2010.

25. *Microgrid Enabled Distributed Energy Solutions (MEDES)*, Final Technical Report, EW-2011-40, 23 April 2014, © 2014 Lockheed Martin Corporation.

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