

# FINAL REPORT

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

ESTCP Project EW-201140

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Teri Hall  
Curtis H. Fischer  
**Lockheed Martin**

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# Table of Contents

List of Acronyms .....	iv
List of Figures .....	vii
List of Tables .....	ix
Acknowledgements .....	ix
Executive Summary .....	xi
1.0 Introduction .....	1
1.1 Background .....	1
1.1.1 Current State of Technology in DoD .....	2
1.1.2 Technology Opportunity .....	3
1.2 Objective of the Demonstration .....	3
1.3 Regulatory Drivers .....	5
2.0 Technology Description .....	7
2.1 Technology Overview .....	7
2.2 Technology Development .....	13
2.2.1 Grid Tied Microgrid Functions .....	14
2.2.2 Grid Independent Functions .....	15
2.2.3 Always Active Functions .....	17
2.3 Advantages And Limitations Of The Technology .....	17
3.0 Performance Objectives .....	20
3.1 Summary Of Performance Objectives and Results .....	21
3.2 Performance Objectives Descriptions .....	22
3.2.1 Reduce Facility Energy Usage .....	22
3.2.2 Reduce Fuel Usage and GHG Emissions of Backup Generators .....	23
3.2.3 Increase Power Availability During Grid Independent Operation .....	23
3.2.4 Energy Surety .....	24
3.2.5 Reduction in Back Up Generator Usage .....	24
3.2.6 System Economics .....	25
3.2.7 Power Quality Assessment .....	25
3.2.8 Reduction of Transient Power Flow Caused by Renewable Energy .....	25
3.2.9 Power Factor Improvement .....	26
3.2.10 Electricity Arbitrage .....	26

4.0 Facility/Site Description .....	27
4.1 Facility/Site Location And Operations.....	27
4.1.1 Demonstration Site Description.....	27
4.1.2 Key Operations .....	28
4.1.3 Personnel.....	29
4.2 Facility/Site Conditions.....	30
5.0 Test Design .....	31
5.1 Conceptual Test Design .....	31
5.1.1 Peak Shaving Test.....	31
5.1.2 Grid Failure Test.....	32
5.1.3 Grid Independent Test.....	33
5.2 Baseline Characterization.....	35
5.2.1 Reference Conditions.....	35
5.2.2 Baseline Collection Period.....	35
5.2.3 Existing Baseline Data .....	35
5.2.4 Baseline Estimation .....	35
5.2.5 Data Collection Equipment.....	36
5.3 Design And Layout Of Technology Components.....	37
5.3.1 Major Subsystems and Components.....	37
5.3.2 Communications Design.....	50
5.3.3 Failure Modes and Effects Analysis (FMEA) .....	51
5.4 Operational Testing.....	51
5.4.1 Operational Testing of Cost and Performance.....	51
5.4.2 Technology Transfer or Decommissioning .....	52
5.5 Sampling Protocol.....	52
5.5.1 Sampling Protocol for Baseline Measurements.....	52
5.5.2 Sampling Protocol for Data in the Microgrid Control System (MCS).....	53
5.6 Sampling Results.....	54
6.0 Performance Assessment.....	64
6.1 Reduce Facility Energy Usage .....	64
6.2 Reduce Fuel Usage And Ghg Emissions Of Backup Generators During Grid Independent Operations .....	64
6.3 Increase power availability during grid independent operations .....	65

6.4	Energy Surety .....	65
6.5	System Economics .....	65
6.6	Power Quality Assessment.....	65
6.7	Reduction of Transient Power Flow Caused by Renewable Energy .....	66
6.8	Power Factor Improvement.....	66
6.9	Electricity Arbitrage.....	67
6.10	Impact of PV and Resulting Power Factor .....	67
7.0	Cost Assessment.....	68
7.1	Cost Model .....	68
7.2	Cost Drivers.....	68
7.2.1	Electric Utility Costs.....	69
7.2.2	Generator Costs.....	70
7.2.3	Solar PV Costs .....	70
7.2.4	Energy Storage Costs .....	70
7.2.5	Switchgear Costs.....	70
7.2.6	Monitoring and Control Costs .....	71
7.3	Cost Analysis And Comparison .....	71
8.0	Implementation Issues .....	75
9.0	References .....	76
	<b>Appendix A Points of Contact .....</b>	<b>78</b>
	<b>Appendix B Action Items and Lockheed Martin Responses .....</b>	<b>81</b>

## List of Acronyms

Acronym	Definition
AESIS	Army Energy Security Implementation Strategy
AFCESA	Air Force Civil Engineering Support Agency
AFRL	Air Force Research Laboratory
AMI	Advanced Metering Infrastructure
A	Ampere
Ah	Ampere-hour
ATS	Automatic Transfer Switch
BCT	Brigade Combat Team
BEAR	Basic Expeditionary Airfield Resources
BLCC	Building Life Cycle Cost
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CBI	Common Bus Interface
CERDEC	Communications Electronics Research Development and Engineering Center
CERL	Construction Engineering Research Laboratory
CHP	Combined Heat and Power
CMMI	Capability Maturity Model Integrated
CMTP	Contractor Master Test Plan
CNIC	Commander of the Navy Installations Command
CO <sub>2</sub>	Carbon Dioxide
CONUS	Continental United States
COR	Contracting Officer Representative
CSV	Comma Separated Value
DCS	Distributed Control System
D/R	Demand/Response
DER	Distributed Energy Resources
DoD	Department of Defense
DoE	Department of Energy
DPW	Directorate of Public Works
ECIP	Energy Conservation Investment Program
EISA	Energy Independence and Security Act
EPDF	Enlisted Personnel Dining Facility
ESM	Energy Surety Microgrid

<b>Acronym</b>	<b>Definition</b>
ESPC	Energy Savings Performance Contract
ESTCP	Environmental Security Technology Certification Program
EV	Electric Vehicle
FEMP	Federal Energy Management Program
FMEA	Failure Modes and Effects Analysis
FPGA	Field Programmable Gate Array
Genset	generation set or generator set
GFE	Government Furnished Equipment
GHG	Greenhouse Gas
HI Power	Hybrid Intelligent Power
HMI	Human Machine Interface
HWIL	Hardware in the Loop
HVAC	Heating Ventilation and Air Conditioning
IDIQ	Indefinite Delivery, Indefinite Quantity
IEEE	Institute of Electrical and Electronic Engineers
IID	Island Interconnection Device
IMCOM	US Army Installation Management Command
IP	Internet Protocol
IRAD	Independent Research and Development
ISO	International Organization for Standardization
ISBPS	Integrated Smart BEAR Power System
JCTD	Joint Capability Technology Demonstration
kW	Kilowatt
LAN	Local Area Network
MFC	Missiles and Fire Control
MDC	Microgrid Development Center
MDMS	Meter Data Management System
MILCON	Military Construction
MIT	Massachusetts Institute of Technology
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MOU	Memorandum of Understanding
MW	Megawatt
NAVFAC	Naval Facilities Engineering Command
NEMA	National Electrical Manufacturers Association
O&M	Operations and Maintenance

<b>Acronym</b>	<b>Definition</b>
ODBC	Open Database Connectivity
OPC	Open Platform Communications
PCC	Point of Common Coupling
PDRR	Pre-Deployment Readiness Review
PLC	Programmable Logic Controller
PF	Power Factor
PO	Performance Objectives
PPA	Power Purchase Agreements
PV	Photovoltaic
R&D	Research and Development
RDSI	Renewable and Distributed Systems Integration
SCADA	Supervisory Control and Data Acquisition
SERDP	Strategic Environmental Research and Development Program
SFMC	Soldier and Family Medical Clinic
SIR	Savings-to-Investment Ratio
SOP	Standard Operating Procedures
SPIDERS	Smart Power Infrastructure Demonstration for Energy Reliability and Security
SRM	Sustainment, Restoration, and Modernization
SQL	Structured Query Language
TCP	Transport Control Protocol
TOC	Tactical Operations Centers
TRL	Technology Readiness Level
TRR	Test Readiness Review
UESC	Utility Energy Service Contract
UFC	Unified Facilities Criteria
UMCS	Utility Monitoring and Control System
UPS	Uninterruptible Power Supply
USACE	United States Army Corps of Engineers
V	Volt(s)
VA	Volt-Ampere
VAR	Volt-Ampere Reactive
VARh	Volt-Ampere Reactive - hours
W	Watts
Wh	Watt-hours



## List of Figures

Figure 2-1 Lockheed Martin’s Flexible Microgrid Architecture .....	8
Figure 2-2 Microgrid Planning Tool Screenshot .....	10
Figure 2-3 Advantages of Microgrids vs. Traditional Power Systems .....	12
Figure 2-4 Typical Backup Generator Alternator Efficiency Curves .....	16
Figure 2-5 Resource Optimization significantly reduces the amount of fuel required.....	18
Figure 4-1 Location of Brigade Combat Team (BCT-1) on Fort Bliss Map .....	27
Figure 4-2 Location of EPDF on BCT-1 Installation Map .....	28
Figure 4-3 Fort Bliss DPW Chain of Command in the U.S. Army .....	29
Figure 5-1 Facility Distribution Transformer Disconnection Switch .....	33
Figure 5-2 Data Loggers and Power Meters used for Baseline Measurements .....	36
Figure 5-3 T-MAG-SCT-200 and T-MAG-SCT-600 AC Current Sensors.....	36
Figure 5-4 System Block Diagram .....	37
Figure 5-5 EPDF Floor Plan with Microgrid Components Labeled.....	38
Figure 5-6 MCS Rack .....	38
Figure 5-7 MCS Human Machine Interface Screenshot.....	39
Figure 5-8 Three Energy Storage Containers at the EPDF.....	40
Figure 5-9 Absolyte GP Battery Cycle Life vs. Depth of Discharge.....	40
Figure 5-10 Existing Backup Generator and Automatic Transfer Switch .....	41
Figure 5-11 New Woodward easYgen Controller .....	42
Figure 5-12 Generator Test Load Bank .....	42
Figure 5-13 Existing Transformer and New Switchgear .....	43
Figure 5-14 SEL-700G0+ Protective Relay.....	44
Figure 5-15 National Instruments cRIO-9024 .....	44
Figure 5-16 Load Breakers in Main Switchboard prior to Motor Operators Installation.....	45
Figure 5-17 Motor Operator.....	46
Figure 5-18 PVPowered PVP100kW-480 Inverter.....	47
Figure 5-19 Kyocera KD210GX-LPU Solar Panel Modules .....	47
Figure 5-20 FieldServer LonWorks Gateway FS-B2011 .....	48
Figure 5-21 1st UMCS page for EPDF Microgrid.....	49
Figure 5-22 2nd UMCS page for EPDF Microgrid .....	49
Figure 5-23 EPDF Microgrid Control Network.....	50

Figure 5-24 National Instruments MAX Screenshot .....	54
Figure 5-25 Peak Shaving Example.....	55
Figure 5-26 Peak Shaving During Summer Months.....	56
Figure 5-27 Grid State Transition Examples .....	57
Figure 5-28 System Bus Voltage and Frequency .....	57
Figure 5-29 Facility Import Power .....	58
Figure 5-30 Power Factor .....	58
Figure 5-31 Baseline Measurements of Power Factor at EPDF .....	58
Figure 5-32 High Speed Waveform Capture During Utility Interruption Event .....	59
Figure 5-33 Renewable Smoothing During Daylight Hours .....	60
Figure 5-34 Power Factor Improvement for a Sample Period.....	61
Figure 5-35 Electricity Arbitrage for a Sample Week .....	62
Figure 5-36 Electricity Arbitrage for a Sample Day.....	63
Figure 7-1 Load profile of a Ft Bliss BCT complex over a year (Zhivov, 2010).....	71
Figure 7-2 Duration at a given Ft Bliss BCT load annually .....	72
Figure 7-3 Daily Duration at or above a given Ft Bliss BCT load .....	73
Figure 7-4 Power Factor impact on the Demand Charge for Ft. Bliss monthly electric bill .....	74

## List of Tables

Table 2-1 Typical EPDF Microgrid Energy Source and Load Composition.....	9
Table 2-2 Measured EPDF Load Data.....	9
Table 4-1 Key Site Leaders at Fort Bliss .....	30
Table 5-1 Fort Bliss EPDF Backup Circuit Sample Data.....	53
Table 5-2 Daily Energy Arbitraged (6/2/13 to 6/8/13) .....	62
Table 7-1 Cost Model for the Intelligent Microgrid Solution.....	69

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## Executive Summary

Microgrid Enabled Distributed Energy Solutions (MEDES) is the first DoD grid-tied microgrid to integrate renewable resources, onsite 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 distribution grid and facility loads at one of the Brigade Combat Team (BCT) Complexes at Fort Bliss.

Currently the US 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 US 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 onsite 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. If your facility is arbitraging daily it's also important to know about your battery storage's depth of discharge vs. cycle life.

### OBJECTIVES OF THE DEMONSTRATION

The technical objective of the Lockheed Martin's MEDES project was to demonstrate 1) reduced greenhouse gas 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 analysis tool using the methods in NIST Handbook 135<sup>(1,2)</sup>. 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 Building Life Cycle Cost (BLCC) methodology was used as the performance metric since 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 were 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

photovoltaic (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 for all DERs, load centers, fault events, 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 (Islanding).

## **DEMONSTRATION RESULTS**

The project can be categorized into three phases of execution: baseline design and performance documentation, technology implementation, and 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 kW which is a 14.4% reduction when compared to the 305kW peak load observed by DPW in prior years
- Successfully reducing fuel usage and Greenhouse Gas (GHG) emissions of backup generators during grid independent operations
- Successfully increased islanded load from 30-50kW to 50-80kW (a 37.5% to 40% increase in load supported during grid independent operations)
- Energy Surety - Successfully measured the ESS picking up system load within 2 cycles of AC power interruption

- Successfully calculated a SIR of 1.51 and a payback of 8.89 years
- Successful power quality assessment and Power Factor Improvement (> 0.9PF during peak hours)
- Electricity Arbitrage - Successfully demonstrated an average energy output of 21.35 kWh per day at peak hours

## **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 LM 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 Distributed Energy Resources since 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 since the DPW Building Operations Command Center (BOCC) data collection did not have the resolution of individual feeders in their energy measurements. As the Ft. 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<sup>(3,4,5)</sup>. 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 manage 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 Department of Defense (DoD) installations.

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 is performing this technical and economic demonstration of an Intelligent Microgrid Solution with the 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 design and performance documentation, technology implementation, and 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.

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) / Environmental Security Technology Certification Program (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.*<sup>(6)</sup>

### **1.1.1 Current State of Technology in DoD**

There are currently no guidelines for installing microgrids on DoD facilities. DoD depends on the local utility grid for normal operating power and has limited back up emergency generators for critical loads that provide power for short durations. The *DoD Energy Manager's Handbook* states that “Installations should develop local risk assessments and plans” but that additional energy security guidelines are under development.<sup>(7)</sup> DoD installations are required to have an energy security plan which has resulted in back-up Uninterruptible Power Supply (UPS) and diesel generators for emergency loads under the guidelines presented in UFC 3-520-01 section 3-8 and for C4ISR facilities under guidance such as the USACE Technical Manual series 689 to 698<sup>(8)</sup>.

Several DoE/DoD microgrid programs are underway for installations to be completed over the next few years including DoE's Renewable and Distributed Systems Integration (RDSI) program, the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Joint Capability Technology Demonstration program, and ESTCP's Microgrid Installation Energy Initiative. There are also relevant projects funded by Energy Savings Performance Contracts (ESPC), Utility Energy Service Contracts (UESC), Energy Conservation Investment Program (ECIP), and district ear marks. Massachusetts Institute of Technology (MIT) Lincoln Laboratories has assembled a comprehensive survey of microgrid efforts within the US military.

The Department of Defense (DoD), in an Energy Security Memorandum of Understanding (MOU) with the Department of Energy (DoE), recognized the significant impact that microgrid technology could have on military installations and has initiated several programs for demonstrating such technology. At the 2011 DoE Microgrid Workshop, validated microgrid planning tools were identified as one of the most important areas needing research and development<sup>(9)</sup>.

Some aspects of microgrid functionality exist in the commercial market; they exist in critical facilities with back-up power systems, such as data centers and hospitals. However, these facilities justify paying 2 to 3 times more for energy reliability and they do not have sustainability objectives. Microgrid functionality also exists at petrochemical complexes containing large on-site power generation that can interact with the grid or island from the grid to maintain essential operations at the complex in the event of a grid failure. However, these

facilities are a niche segment where the microgrid is justified in a unique situation, and renewable energy is typically not part of the power generation mix.

### **1.1.2 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 onsite 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<sub>2</sub>/yr. for every kWh of onsite 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 of the continental US.

With the Enlisted Personnel Dining Facility (EPDF) Microgrid 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. As an example, the wind turbines recently installed at US Naval Base Guantanamo Bay, an installation that maintains its own power grid fed with large diesel generators, now requires significant percentages of spinning reserve, >20%, to counteract the intermittency and power quality impact of the wind turbines, reducing or eliminating the positive impact the renewable energy source could have had on greenhouse gas emissions or 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 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 BCT-1 complex. The data obtained from the Dining Facility microgrid and base wide energy measurements during this demonstration program have been used to design a comprehensive microgrid solution sized for a BCT complex circuit.

While implementing microgrid solutions, the size of a BCT is effective for implementation across DoD. The ESTCP demonstration of the microgrid solution on a smaller BCT portion cost effectively provides the quantitative evidence of the benefits of our intelligent microgrid solution. To the facility and higher level installation management organizations, the demonstration provides quantitative evidence of the microgrid's ability to reduce energy costs and optimize the use of Distributed Energy Resources (DERs). To the end user, the demonstration instills confidence in the technology's readiness and ability to enhance mission effectiveness.

US Army Corps of Engineers (USACE) Construction Engineering Research Laboratory (CERL) is shaping the microgrid guidelines and requirements for DoD installations. CERL's microgrid group worked with Lockheed Martin throughout the project to ensure that the results from this demonstration will influence DoD policy, practices, guidelines, and standards.

In addition, Lockheed Martin works closely with USACE/IMCOM, NAVFAC/CNIC, and AFRL/AFCEA to better understand their installation energy challenges and to help them understand the technology and benefits of microgrid architecture. Since energy security and renewable energy are unfunded initiatives, continuing efforts are underway to understand and develop contract mechanisms combining Government Furnished Equipment (GFE), public capital investment, and private financing at a scale that is large enough to reach economic viability.

Intelligent microgrid solutions will transition to DoD end users through traditional means including appropriated funds, as part of MILCON, ECIP, or SRM projects, and leveraging third party financing arrangements when appropriate, such as power purchase agreements (PPAs) or energy savings performance contracts (ESPCs). Lockheed Martin is one of 16 companies awarded in late 2008 a 10-year, \$5B limit Indefinite Delivery Indefinite Quantity (IDIQ) under Department of Energy's (DOE's) Federal Energy Management Program (FEMP) super ESPC program. This technology transfers to all military service fixed installations as well as tactical facilities such as forward operating bases and mobile airbases. The EPDF Microgrid is a good example of how the technology could be transitioned to a well-defined fixed installation customer in a standardized fashion. The modern BCT takes advantage of MILCON transformation and the establishment of Centers of Standardization within the US Army Corps of Engineers to reduce the non-recurring design effort required during new construction by offering standardized, nearly complete designs of key facilities that can be adapted quickly and confidently for a specific sites needs while taking advantage of the latest technology

improvements. Through this ESTCP activity and continuing activities with organizations such as the US Army Corps of Engineers Construction Engineering Research Laboratory (CERL), Lockheed Martin can support the establishment of design/build or adapt/build standards and a microgrid planning methodology within the major facility commands, such as Naval Facilities Engineering Command (NAVFAC) and US Army Installation Management Command (IMCOM) and organizations such as the US Army Corps of Engineers (USACE), that allows for nearly complete power infrastructure designs to be created rapidly and consistently. This results in less site-specific final design efforts, significantly reducing the non-recurring engineering typically required to incorporate distributed energy assets and intelligent power management into existing or new facilities, while enhancing safety through standardization. Regulatory hurdles associated with ‘islanding’ microgrid power architectures are being addressed with release of the Institute of Electrical and Electronic Engineers (IEEE) 1547.4<sup>(3,4)</sup> and 1547.8<sup>(5)</sup> guidance. 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.

In addition to benefitting DoD installations, Intelligent Microgrid Solutions installed over the next decade will create jobs and support further economic growth. Hundreds of US companies have invested in developing the technology to improve the way we generate and distribute electrical power. Because of the regulated nature of the electric grid, implementation of these technologies requires support from the Federal government. The last century of US history shows that national investment in the electric grid resulted in economic development.

Intelligent Microgrid Solutions will also facilitate wide spread adoption of electric vehicles (EVs) charged with electricity from renewable sources. Being that oil imports represented 50% of the trade deficit in 2010<sup>(6,10)</sup> and that number will increase with increasing oil prices, EVs using renewable energy are one of the most significant opportunities to reduce our nation’s trade deficit. The challenges associated with large numbers of electric vehicles on the utility grid and solutions that Intelligent Microgrid Solutions could offer are not included in the scope of this ESTCP project, yet should be considered for future evaluation.

### 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)*<sup>(11,12,13,14,15,16)</sup>. 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*<sup>(17,18)</sup>. 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.”<sup>(17)</sup>*

## 2.0 TECHNOLOGY DESCRIPTION

This project will demonstrate 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 Enlisted Personnel Dining Facility (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 novel solution that was demonstrated includes three components:

1) **Microgrid Planning Tools.** These tools allow power engineers to design a microgrid, determining the optimal arrangement and control of the distributed energy assets, loads, switchgear, and fault protection based on cost, emissions, and security.

2) **Microgrid Controls and Data Acquisition.** The control system architecture has a bi-level arrangement. Fast-acting distributed controllers at each piece of equipment react automatically to ensure power delivery, quality, and safety. The higher-level Microgrid Control System (MCS) maintains a historical database, houses the optimization algorithms, and provides a user interface for data analysis and operator control. Figure 5-4 shows all the major components that were installed to implement this bi-level control arrangement.

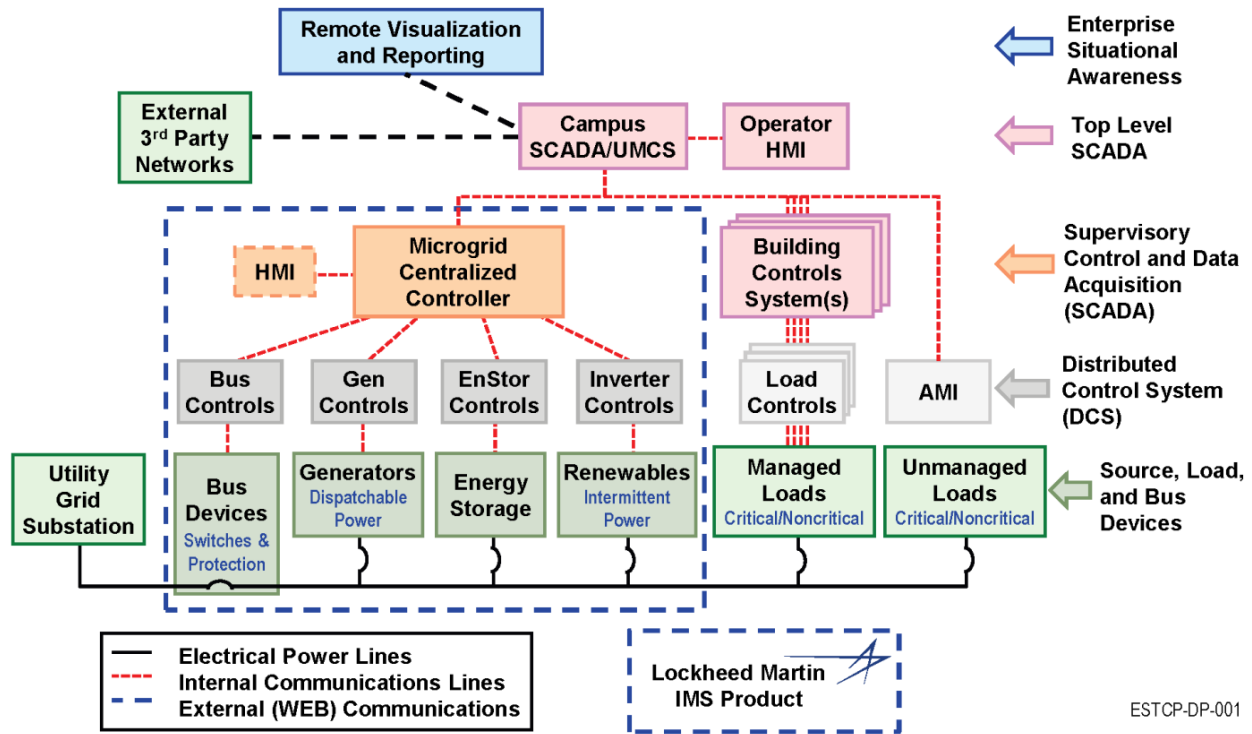
3) **Microgrid Optimization Algorithms.** The optimization algorithms calculate the optimum set points to operate each connected device to achieve lower energy costs and improve stability of the system. The algorithms run autonomously and in parallel; their status is reported back to the facility's energy operator. If required the algorithms can be disabled (e.g. for equipment maintenance). Further details regarding the specific goals of these algorithms are explained in Section 2.2.

Successful integration of intermittent and renewable Distributed Energy Resources (DERs) at penetration levels mandated by government will require transitioning emerging power conversion and control technologies to commercial applications. Our microgrid architecture addresses these challenges and our Microgrid Development Center (MDC) provides the resources to validate and test these technologies.

#### Microgrid Architecture

Figure 2-1 shows how the Lockheed Martin microgrid architecture provides a flexible platform to integrate multiple types of DERs, 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).



**Figure 2-1 Lockheed Martin's Flexible Microgrid Architecture**

The centralized controller also provides aggregate real-time monitoring data for all DERs, load centers, fault events, and financial performance. The data shown in Table 2-1 is based off 2010 energy usage data given to Lockheed Martin by Fort Bliss Directorate of Public Works (DPW). Some estimates were extrapolated from that data based on site visits and discussions with Fort Bliss, including breakout power of Sources and Loads. Lockheed Martin received data solely for the EPDF (Table 2-2) from the Fort Bliss DPW. The information includes energy consumption data for the EPDF BCT-1 from 2/7/2011 to 9/21/2011. The peak kW value was measured directly and is expected to be the actual yearly peak, as the missing months average much lower peaks than the summer months when this peak was captured. The average kW value was averaged over the given time period from the 15-minute kW demand data. It is expected that the actual yearly average demand is slightly less than this value due to the missing information from the (typically less energy-intensive) winter months. The yearly energy consumption was calculated based on the average instantaneous value and so the actual yearly energy consumption value is most likely slightly less for the same reason as the average kW value. As part of the MEDES effort, power data for the EPDF was collected from October 2011 to December 2013.

**Table 2-1 Typical EPDF Microgrid Energy Source and Load Composition**

Loads	Peak (MW)	Ave (MW)	Energy MWh/yr
<b>Total</b>	<b>5</b>	<b>2.8</b>	<b>24,528</b>
Critical/Emergency	1.5	1	
Essential Operations	1.5	0.8	
Nonessential	2	1	
Sources	Rated (MW)	Annual Utilization	Load (%)
<b>Utility Grid</b>	<b>10</b>		<b>83%</b>
<b>On-Site Sources</b>	<b>5</b>		<b>18%</b>
Central Generator	1	5%	2%
Back-Up Generators	1	5%	2%
Solar / Wind	2	17%	12%
Energy Storage	1	5%	2%

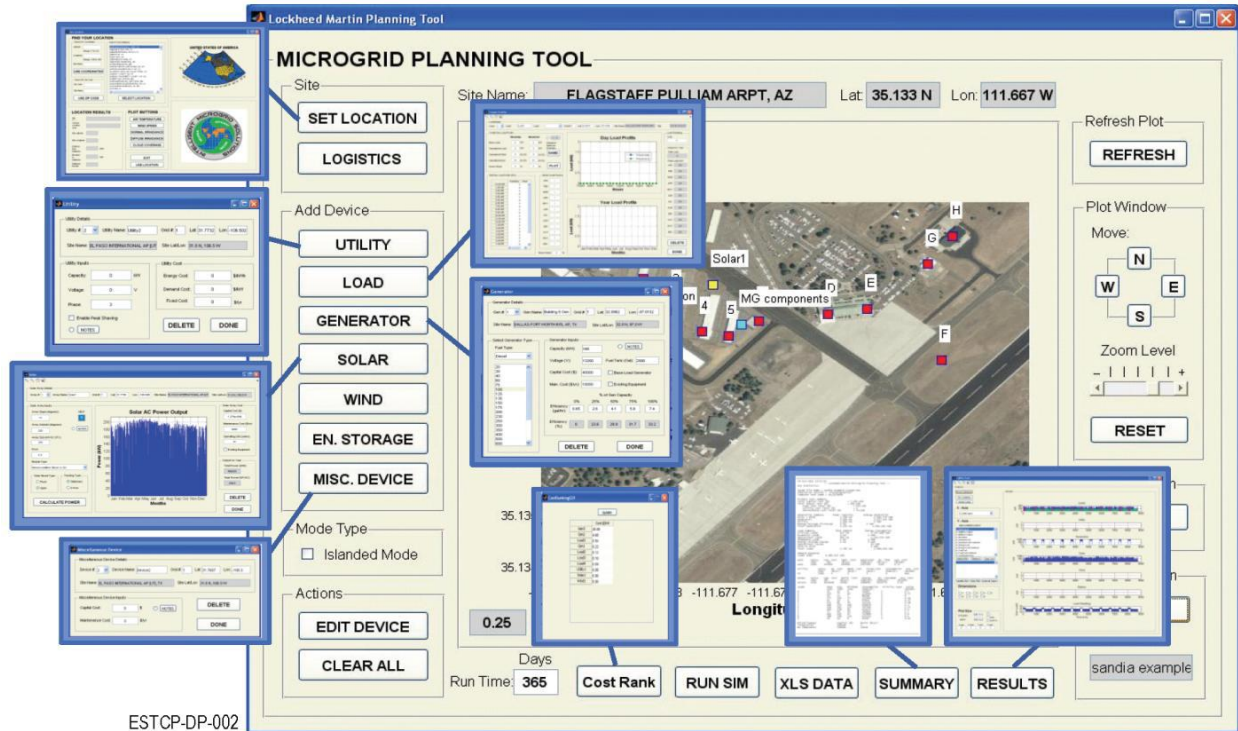
**Table 2-2 Measured EPDF Load Data**

Loads	Peak (kW)	Ave (kW)	Energy MWh/yr
<b>All</b>	<b>305</b>	<b>151</b>	<b>1322.76</b>

### Microgrid Planning Tools

The Microgrid Planning Tool Suite (Figure 2-2) provides comprehensive capabilities to analyze and recommend microgrid solutions for a specific facility. By taking into account site-specific mission, facility, electrical, and renewable characterization data, the tools objectively quantify anticipated microgrid benefits. Inputs include existing generation and fuel storage, power consumption patterns, and existing electrical distribution feeder and connections between the critical facilities. The tools use this information to evaluate whether additional generation and distribution hardware is needed, identify specific opportunities for incorporating fuel-saving renewable technologies, and perform optimization and power flow analyses. The planning tools generate a solution set of feasible microgrid architectures that meet energy surety, financial, and performance constraints as defined by the customer’s needs.





ESTCP-DP-002

*Figure 2-2 Microgrid Planning Tool Screenshot*

## Microgrid Components

**Microgrid Centralized Controller and Optimization Algorithms.** This offering includes optimization algorithms to efficiently and effectively operate and schedule the Microgrid's sources and loads to deliver a reliable system that can minimize operational cost. Housed in the microgrid centralized controller, algorithms perform power flow analysis, short term optimization, and long-term forecasted planning. The power flow analysis ensures electrical stability of the microgrid under various source configurations. The short-term optimization offers a means to optimize for surety or cost efficiency given the current load conditions and available sources. The long-term optimization algorithms can accommodate daily and monthly information to take into account weather conditions, upcoming events which significantly change the characteristic load profile, and also maintenance schedules to determine the best means to plan the microgrid sources and loads. The microgrid centralized controller also coordinates load scheduling, use of renewables or energy storage during peak grid hours, and advance startup of generators for predicted load increases. The controller solution suite can be tailored to meet a variety of customer needs and microgrid requirements to provide cost effective operation while enhancing system performance.

**Distributed Controllers.** The distributed controller provides high-speed control functions for equipment protection against faults, high-speed relay coordination for synchronization and fault coordination, and high frequency data acquisition to capture off-nominal events. The distributed controller's hardware platform is designed for modularity and flexibility, with systems deployed in thousands of locations worldwide. Customization of this platform with innovative embedded logic has enabled comprehensive integration for DER and load management in microgrid applications, as evidenced by their use in our MDC. Although the distributed controllers perform

optimally in a microgrid guided by a centralized controller, they are designed to operate autonomously in the event that communication with the centralized controller is lost.

**Dispatchable Generators** provide either base load power or back-up power. Base power is feasible in situations where combined heat and power (CHP) can be utilized, or where there are incentives for distributed equipment, or where there is a local fuel source. Back-up generation is required where there are emergency and critical loads. Dispatchable generators provide swing power to follow instantaneous load demand when the microgrid is islanded. They can also perform peak-shaving or demand response functions while paralleled to the utility to create a potential revenue (savings) stream. In the Intelligent Microgrid Solution, several generators within the microgrid can synchronize for parallel operation. This improves reliability and redundancy.

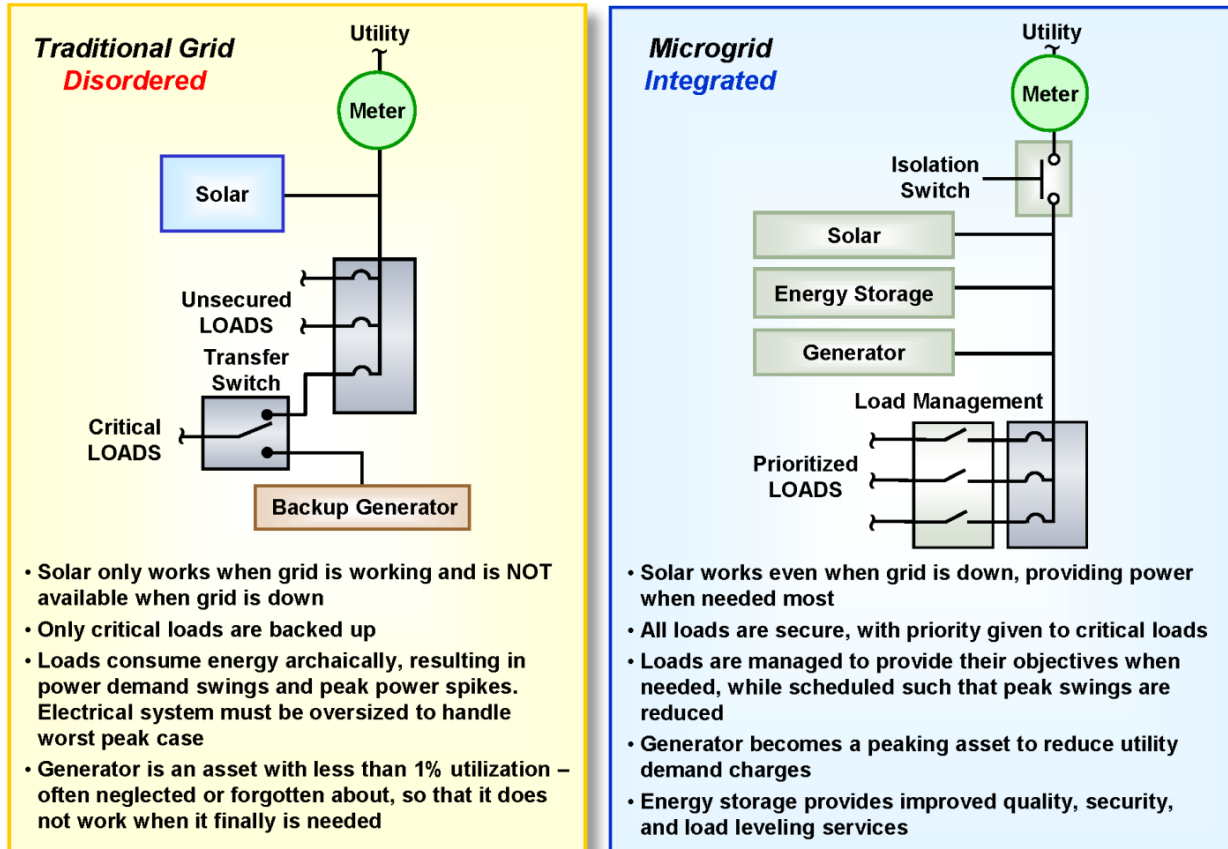
**Renewable Energy** (wind and solar) provides environmentally clean energy with low operational cost (no fossil fuel cost) and no need for logistics support. However, renewable energy is intermittent and requires fast acting spinning reserves or energy storage to provide transient buffering, otherwise, its contribution must remain well below the minimum power demand.

**Energy Storage** can provide several functions in a microgrid. It provides a means to smooth rapid transients caused by either loads or renewable energy. It can provide grid stability functions to improve power quality, filter harmonics, and support grid voltage. It can perform peak shaving and demand response functions. It can also perform supply shifting, to match renewable energy availability with load demand. It can also perform supply shifting to take advantage of time of use, or on-peak scheduling where it charges at low utility prices and discharges at high prices.

A microgrid with a **Point of Common Coupling** (PCC) to the utility grid provides the ability to supply peak shaving power through the PCC. The microgrid also enables the ability to isolate from the utility grid (island) providing secure power to mission critical loads, and utilize renewable energy within the microgrid while islanded to reduce fuel consumption of the combustion-driven power generation sources.

### **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 2-3). 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.



ESTCP-DP-003

*Figure 2-3 Advantages of Microgrids vs. Traditional Power Systems*

## Technology History

Lockheed Martin has a long history of power management solutions for ground combat vehicles, electric ships, aircraft, spacecraft, nuclear facilities, and portable power. Since 2009, Lockheed has invested in IRAD and capital associated with intelligent energy source management, load control, energy storage and integration of renewable energy resources. As part of this investment, our Microgrid Development Center (MDC) designs, develops and integrates rapid development and deployment efforts. Intelligent Microgrid Solutions for DoD installations has leveraged the technology from two operational energy microgrid programs.

The Air Force Integrated Smart BEAR Power System (ISBPS) Program was to equip U.S. forces with light-weight, air-transportable assets used to establish mobile air bases. ISBPS is an intelligent system that integrated a variety of energy sources, including renewables, into the existing Basic Expeditionary Airfield Resources (BEAR) power grid, with goals to reduce fuel consumption by 25 percent, alleviate logistics burdens and improve power availability. Key ISBPS capabilities include operating in both grid-tied and grid-independent modes. The system independently sustained critical power loads when the primary grid was unavailable, supplementing conventional diesel generation with solar and wind power. The system was designed for rapid deployment and to fit in standard shipping containers.

For the U.S. Army Communications, Electronics, Research, Development and Engineering Center (CERDEC) HI Power program, Lockheed Martin provided design, development, and integration of a Brigade Combat Team microgrid comprised of a Common Bus Interface (CBI), centralized controller, energy storage, and generator mod kits. This demonstration project leveraged algorithms and controls developed for the HI Power programs that enabled optimal use of multiple energy resources including energy storage.

### **Potential for DoD**

Lockheed Martin's Intelligent Microgrid Solution provides a foundation on which DoD's continued investments in renewable energy will result in reduced energy costs and reduced carbon emissions while simultaneously providing a secure, reliable, mission-extending capability. Without the intelligent power management inherent in our microgrid solution, the increased use of renewable energy resources often results in lower reliability, higher cost energy threatening mission readiness and effectiveness and suboptimal carbon reductions. In the site specific example of the EPDF Microgrid, the microgrid control of the BCT's electrical loads may reduce peak power levels through load scheduling lowering utility demand charges. A solar array with even small amounts of energy storage interconnected to the EPDF Microgrid can provide power during the peak demand of heating ventilation and air conditioning (HVAC) loads which further reduces peak demand charges as well as carbon emissions, and also reduces fuel use by back-up generators, when the power grid is unavailable, extending mission operational capability. With microgrid control, the BCT's emergency power assets can reduce energy costs, rather than sitting dormant, by operating during periods when electricity rates are higher than the cost of gas that fuels those emergency assets offsetting the capital expenditure. And when combined heating, cooling, and power is utilized, and/or biomass fuels where available, carbon emissions reductions are further increased. With the addition of energy storage in areas where there is significant differences in time-of-use or peak electricity charges, further reductions in energy costs can be realized when using the microgrid's central control algorithms.

The impact microgrids could make on achieving DoD goals is significant. If only 30% of the electrical distribution feeders on the 250 DoD installations with larger than 5 MW average loads are outfitted with microgrids there would be 172 feeder sized (<10 MW) microgrid systems.

## **2.2 TECHNOLOGY DEVELOPMENT**

This project focused on leveraging existing Lockheed Martin software, 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. There are two primary modes of steady state operation Grid Tied Mode and Grid Independent Mode (Island).

## **2.2.1 Grid Tied Microgrid Functions**

Grid tied mode is the normal mode of operation for the system; that is, operating with utility power. In this mode, the PCC/ protective relay is closed, thus connecting the microgrid to the utility grid. In addition, all of the load breakers in the system are closed. In the preliminary design assessment, automatic load shedding/management was not seen as desirable or beneficial and has not been included in this mode. If load shedding is desired, an operator can manually shut off one or more feeder breakers from the MCS HMI. It should be noted that in this mode the solar PV system is also completely uncurtailed allowing for maximum production of solar power to be used by the EPDF or the distribution grid.

### **2.2.1.1 Peak Shaving**

With modifications to the controls, the generator can now be paralleled to the utility to provide power to the microgrid's electrical bus. The MCS commands the generator to start and output power as needed to implement a peak shaving algorithm. The algorithm is 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 in order 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 5-25, 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 Power Factor Improvement**

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, apply a penalty/fee into their electricity rate structures for customers that have a poor power factor. As can be seen in Figure 5-31, power factor at the EPDF is quite poor around roughly 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 5-34, one can see how the ESS's reactive output changes in response to the changing power factor.

### **2.2.1.3 Electricity Arbitrage**

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”<sup>(19)</sup>. 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 5-35, 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.

### **2.2.1.4 Renewable Energy Smoothing**

Solar PV and wind power systems are inherently intermittent; solar 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 Programmable Logic Controller (see Figure 5-15), that monitors the PV inverter’s AC power output and reacts to sudden drops in production with increased output from the ESS. This can be observed in Figure 5-32.

## **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, solar 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 in grid independent mode, unfortunately that was no longer possible when some of the automation equipment (see Figure 5-17) were unable to be fitted in the existing main switchboard. Thus the critical load and the uncontrollable loads are powered on the bus when the system is islanded, since the controllable loads were shed right by the PLC during the transition from Grid Tied mode to Grid Independent mode. 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.

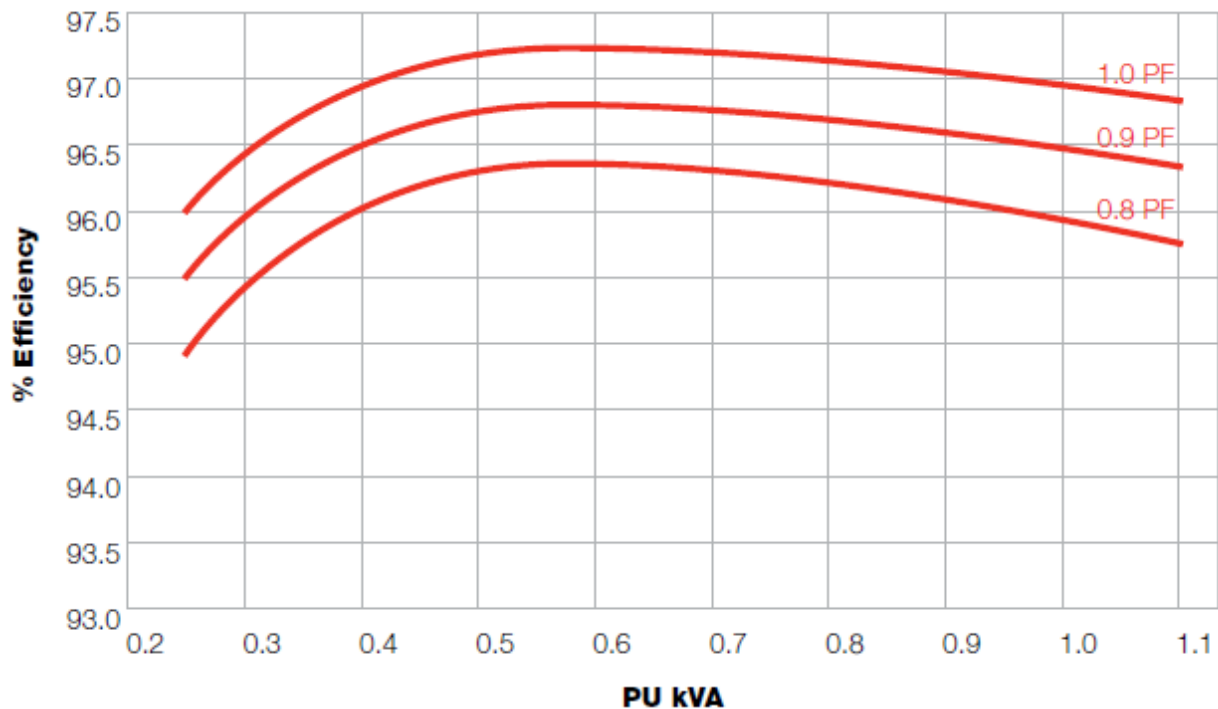
### **2.2.2.1 PV Management**

Unlike Grid Tied mode operations, when in Grid Independent mode (a.k.a., Islanded mode) 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 but not too much. As seen in Figure 5-27, this in effect is aimed to maximize PV usage in islanded scenarios.

### 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 aims to improve the power factor at the generator’s circuit breaker instead of the PCC. The main reason why one would want to optimize the Power Factor at the generator’s connection to the bus is to improve engine efficiency which ultimately reduces diesel fuel use.



*Figure 2-4 Typical Backup Generator Alternator Efficiency Curves*

As can be seen in Figure 2-4 the efficiency of a generator is a function of both the amount of load on the generator (the Per Unit 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”<sup>(20)</sup>.

### **2.2.3 Always Active Functions**

Some software monitoring and control functionality is always available regardless of the state of the microgrid.

#### **2.2.3.1 Grid State Transitioning**

Because utility interruptions/outages can happen at any moment, the microgrid is always 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) so they can regulate voltage and frequency in addition to carrying the entire load. As can be seen in Figure 5-32, there is slight voltage sag in voltage, but that gets corrected by the ESS within 2 electrical cycles. The PV Inverter sees the small voltage sag and turns off its power production to be compliant with IEEE1547. The PLC also begins to open the load breakers connected to all the low priority loads so only the critical ones are powered while islanded. 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 seeing 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 5-27.

While islanded, the MCS will continually monitor the utility side of the PCC. After it detects a valid and nominal voltage on the utility bus for the duration of 5 minutes (again in accordance with IEEE1547), it will command the protective relay to attempt a reconnection. When the protective relay is told to reconnect, it adjusts the generators frequency and voltage to match the utility's, closes in the PCC breaker when the timing is right, and signals the generator to stop acting as the bus master since the utility is now the bus master. Once this is complete the MCS will resume its Grid Tied mode algorithms.

#### **2.2.3.2 Situational Awareness of Distributed Energy Assets**

A local HMI is accessible on either of the MCS Servers (see Figure 5-7). It provides information regarding the live status of each microgrid component as well as a user interface to control them manually. To view historical data stored by the historian, each server has a trend viewing tool from National Instruments (see Figure 5-24). It can be used to analyze power data, plot graphs, or export them as Comma Separated Value (CSV) files.

In addition to the local HMI at the EPDF there is a few new HMI screens (see Figure 5-21 and Figure 5-22) created at DPW's Building Operations Command Center (BOCC) where users can view device telemetry as well as the status of the above mentioned software algorithms.

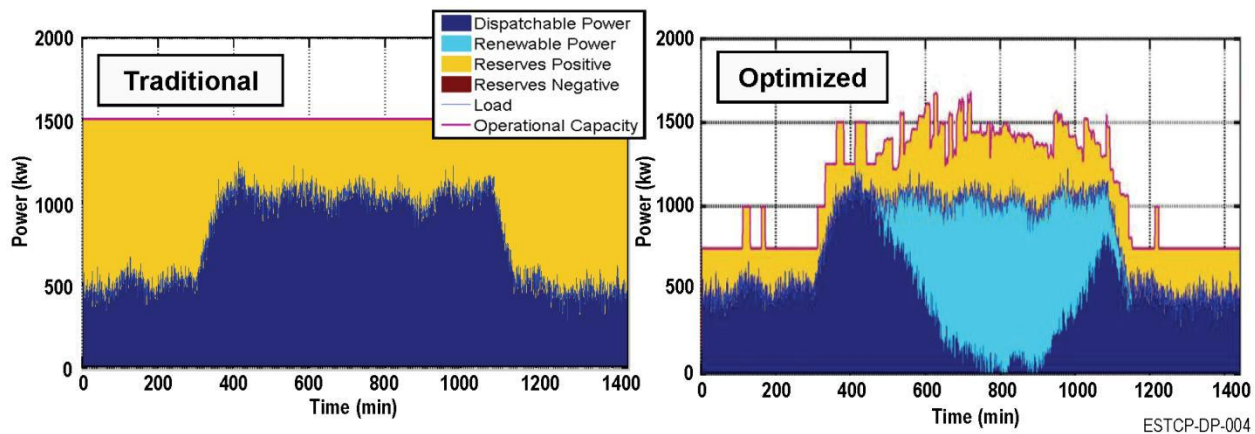
## **2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY**

Energy Security has been carried out with battery UPS and back-up diesel generators on specific critical loads. These systems are overdesigned by requirements for growth which 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 MW of peak shaving potential can result in \$50K to \$100K 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 2-5 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<sub>2</sub> emissions.



**Figure 2-5 Resource Optimization significantly reduces the amount of fuel required**

Renewable Energy is being added to bases as small 10's to 100's of kW sizes. Recently, a few MW size installations have been added and more recently larger systems (20+MW) are in the works under Power Purchase Agreements (PPAs). Small and large systems do not support grid independent operation of back-up power systems – when they are needed the most. And large projects (20MW+) challenge utilities to maintain grid stability due to the intermittent nature of renewable, which require large and costly spinning reserves.

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 DOE Microgrid Workshop Report <sup>(9)</sup>, 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/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 are challenging. The solution must 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 overall goal of the proposed project was 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.

#### **ENERGY SECURITY**

The operating time of the facility critical loads was to be 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.

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

Energy Surety was to be attained through the demonstration of facility isolation during periods of grid failure and seamless reconnection when the grid returns and stabilizes. The data requirements of this objective included power flow measurements across the Point of Common Coupling (PCC) and the microgrid bus voltage during these events.

Reduction of transient power flow caused by renewable energy was also to be demonstrated. By installing an energy storage system to operate in conjunction with the existing photovoltaic system, the microgrid is capable of offsetting any occlusions that may occur during the day. The Microgrid Control System monitors the output from the solar inverter during the day and if output drops considerably, the energy storage system supplies the difference. This capability will help prevent voltage fluctuations and the need for additional frequency regulation by the utility. Data requirements for this were power flow measurements from the solar inverter and the energy storage system.

#### **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 Enlisted Personnel Dining Facility (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." <sup>(21)</sup> 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 can be improved, avoiding the power factor adjustment charge. The data requirements for this include power factor as 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 for this include 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 also collected and compared to the cost of running the generator in the baseline configuration.

### 3.1 SUMMARY OF PERFORMANCE OBJECTIVES AND RESULTS

Performance Objective	Metric	Data Requirements	Success Criteria	Results
<b>Quantitative Performance Objectives</b>				
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 Greenhouse Gas (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 30-50kW to 50-80kW. 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	< 5 cycles of AC power for all EPDF loads	Successfully measured the ESS picking up system load within 2 cycles of AC power interruption.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
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.
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 1Hz 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: W/s	Measurements of PV and Energy Storage power flows	< 500W/second 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 PF of the EPDF during peak hours 5AM to 8PM , Monday - Friday	Successful
Electricity Arbitrage	kWhr(s) stored during off peak demand and kWhr(s) used during on peak demand	Energy Storage System kWhrs used	>20kWhrs 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.

## 3.2 PERFORMANCE OBJECTIVES DESCRIPTIONS

### 3.2.1 Reduce Facility Energy Usage

This objective demonstrated the ability of the microgrid to reduce peak electrical demand from the utility provider arising during peak usage hours.

- **Purpose.** To demonstrate the cost savings achievable by the microgrid in terms of utility peak demand charges in line with the policy of reducing energy costs at DoD installations
- **Metric.** Facility peak electrical demand
- **Data.** Utility rate structure, fuel rates, Microgrid Power Flow measurements

- **Analytical Methodology.** Direct comparison of baseline peak electrical demand and microgrid peak electrical demand
- **Success Criteria.** Greater than 10% reduction of peak electrical demand

### 3.2.2 Reduce Fuel Usage and GHG Emissions of Backup Generators

This objective demonstrated the ability of the microgrid to integrate new/existing renewable energy resources and energy storage during grid independent operations to supplement the existing backup generators. By offsetting some of the power requirements, less fuel is consumed and less GHGs are emitted by the generator.

- **Purpose.** To demonstrate the fuel savings and the reduction of GHGs associated with the microgrid in line with the policies of reducing energy costs and GHG emissions at DoD installations
- **Metric.** Use of energy storage and photovoltaic system on critical loads during grid independent scenarios (kWh), calculated GHG emissions (metric tons) and fuel usage during grid independent operations
- **Data.** Power flow measurements of energy storage and PV during grid independent scenarios, calculated release of GHG based on fuel consumption data, calculated fuel consumption data based on generator output and present fuel costs
- **Analytical Methodology.** For fuel consumption, calculated numbers were derived using the manufacturer's specification sheet and the generator output data, in both the baseline configuration and the microgrid configuration. These numbers will then be directly compared to determine success. For GHG emissions, suggested Environmental Protection Agency (EPA) calculations were performed based on the calculated fuel consumption rates to arrive at emission data for both baseline and microgrid configurations. These levels of emissions will then be directly compared to determine success.
- **Success Criteria.** Greater than 20% fuel use reduction and greater than 20% GHG emission reduction

### 3.2.3 Increase Power Availability During Grid Independent Operation

This objective demonstrated the ability of the microgrid to supply power to any subset of loads during grid independent operations.

- **Purpose.** In order to achieve greater energy security and mission capabilities, the facility operator may need to supply power to loads not defined as critical. In the present configuration, this is not possible. With the microgrid, the operator can choose to supply power to loads in addition to the critical loads during grid independent operations.
- **Metric.** Amount of additional load (kW) served during grid independent operations
- **Data.** Breaker status of additional loads, power flow to additional loads
- **Analytical Methodology.** Direct comparison of baseline configuration critical loads served versus microgrid loads served

- **Success Criteria.** Servicing additional load beyond critical load during grid independent operation

### 3.2.4 Energy Surety

This objective demonstrated the ability of the microgrid to provide minimal power interruption to critical loads and to reconnect with the grid upon its return and stabilization.

- **Purpose.** During a loss of the utility grid, the critical loads are isolated from the facility main bus and are powered by traditional backup generators. With the microgrid, non-critical loads are isolated from the facilities main bus leaving the critical loads and allowing the microgrid to serve prioritized non-critical loads based on power source availability within the microgrid. This objective demonstrated the microgrid is capable of providing this level of energy surety.
- **Metric.** Time of interruption during grid disturbances was used to verify success. Typical time of outages on similarly sized systems are on the order of 10-20 seconds. The microgrid can decrease this substantially.
- **Data.** Measurement of microgrid bus voltage
- **Analytical Methodology.** Direct comparison of microgrid downtime versus baseline configuration downtime
- **Success Criteria.** Less than existing system configuration delay from grid failure to bus powered

### 3.2.5 Reduction in Back Up Generator Usage

This objective demonstrated the ability of the microgrid to utilize renewable resources while operating in a grid independent configuration. This capability is lacking from most grid-interactive renewable installations. It also demonstrated how the microgrid allows the facility to stay under power longer during periods of grid disturbance/outage. When the energy storage component and the available renewable distributed energy resources are sized correctly, the facility critical loads can operate indefinitely.

- **Purpose.** This objective demonstrated the capability of the microgrid to extend the facility operating time and decrease the load demand on the backup generator while operating independent from the bulk power grid.
- **Metric.** Energy production during grid independent operations
- **Data.** Measurement of solar PV and energy storage system power outputs
- **Analytical Methodology.** Comparison of calculated operational duration of the baseline configuration (backup generator only) versus the microgrid configuration
- **Success Criteria.** >20% reduction in backup generator load during grid independent operation in daylight hours

### 3.2.6 System Economics

This objective demonstrated the economic advantages of having a microgrid and all the flexibility it provides.

- **Purpose.** The objective demonstrated the return on investment benefits provided by a microgrid versus that of investing in a traditional system configuration.
- **Metric.** Savings to Investment Ratio (SIR) as calculated by the Building Life Cycle Cost (BLCC) program
- **Data.** Usage as a function of time and utility billing rate schedules
- **Analytical Methodology.** Calculation of the BLCC of a microgrid installation using the government's BLCC calculation program
- **Success Criteria.** Savings to Investment Ratio (SIR) greater than 1.5 when extrapolated to a full BCT

### 3.2.7 Power Quality Assessment

This objective demonstrated the ability to monitor and assess power quality within the microgrid during grid-provided and grid independent modes of operation.

- **Purpose.** In line with the desires of DoD for expanded energy usage information, metering was installed on the facility that offers additional capabilities such as remote data collection and event waveform capture.
- **Metric.** Ability to provide event oscillography, waveform capture, remote monitoring of building power quality
- **Data.** Power, voltage, and power factor data of the microgrid
- **Analytical Methodology.** Demonstrate the ability to capture Power Quality data
- **Success Criteria.** Capture data to assess power quality of the microgrid

### 3.2.8 Reduction of Transient Power Flow Caused by Renewable Energy

This objective demonstrated the microgrid's capability to control renewable energy transient behavior experienced by utilities when renewable sources approach a significant percentage of system generation.

- **Purpose.** This objective demonstrated how energy storage coupled with renewable energy sources can be used to reduce the transient nature of those sources. With the current 100kW PV Inverter, a solar occlusion could see a reduction in renewable energy as seen by the Utility in the order of ~ 100kW/s.
- **Metric.** Smoothing of intermittent transients introduced to the utility grid. The metric of choice was maximum transient Watts/second seen by the Utility.
- **Data.** Measurements of PV and energy storage power flows



- **Analytical Methodology.** The total combined power flow of the energy storage and PV systems during an occlusion was compared with a stand-alone PV system occlusion and the results extrapolated to a larger system comprising a high percentage of renewable sources to demonstrate the effectiveness of this type of deployment
- **Success Criteria.** Less than 500W/second transient reduction as seen by the Utility due to Renewable Energy

### 3.2.9 Power Factor Improvement

This objective demonstrated the ability of the microgrid to improve power factor at the EDPG thus eliminating the power factor adjustment charge.

- **Purpose.** To demonstrate the cost savings achievable by the microgrid in terms of power factor improvement in line with the policy of reducing energy costs at DoD installations
- **Metric.** EPDF total Power Factor
- **Data.** Power Factor measured at the Protective Relay/Point of Common Coupling between the EPDF loads and the Utility Connection
- **Analytical Methodology.** Direct comparison of baseline power factor and microgrid power factor
- **Success Criteria.** Greater than 0.9 PF of the EPDF during peak hours 5AM to 8PM , Monday - Friday

### 3.2.10 Electricity Arbitrage

This objective demonstrated the ability of the microgrid to reduce peak electrical demand from the utility provider arising during peak usage hours by storing energy when the kWhr price is low, and expending that energy when the kWhr price is high.

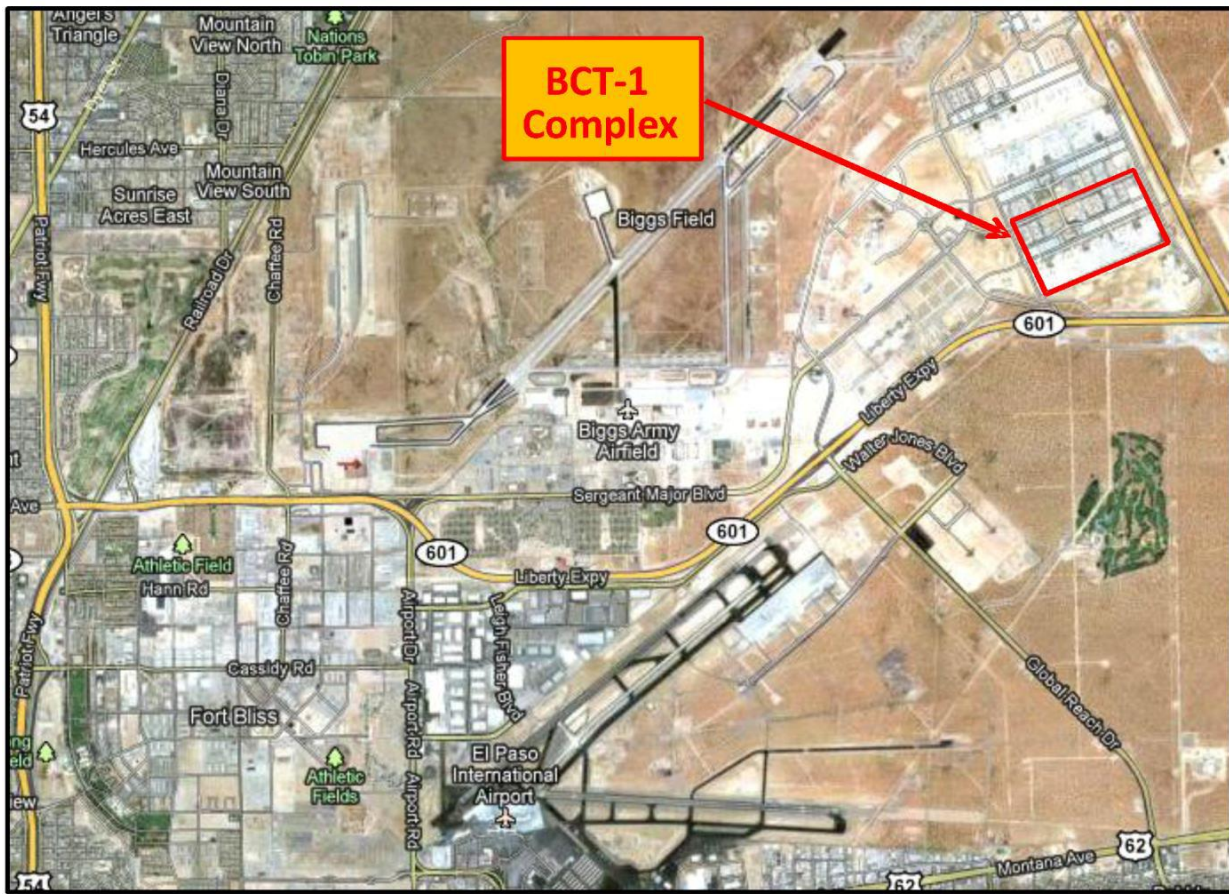
- **Purpose.** To demonstrate the cost savings achievable by the microgrid in terms of electricity arbitrage in line with the policy of reducing energy costs at DoD installations
- **Metric.** Number of kWhr(s) stored during off peak demand and kWhr(s) used during on peak demand
- **Data.** Energy Storage System kWhrs used
- **Analytical Methodology.** Direct comparison of baseline kWhrs used from the Utility's perspective versus kWhrs used in conjunction with the microgrid
- **Success Criteria.** Greater than 20kWhrs stored during off peak demand and used during on peak demand.

## 4.0 FACILITY/SITE DESCRIPTION

The Enlisted Personnel Dining Facility (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 4.1-1). The Enlisted Personnel Dining Facility (EPDF) of the BCT-1 complex served as the demonstration site.

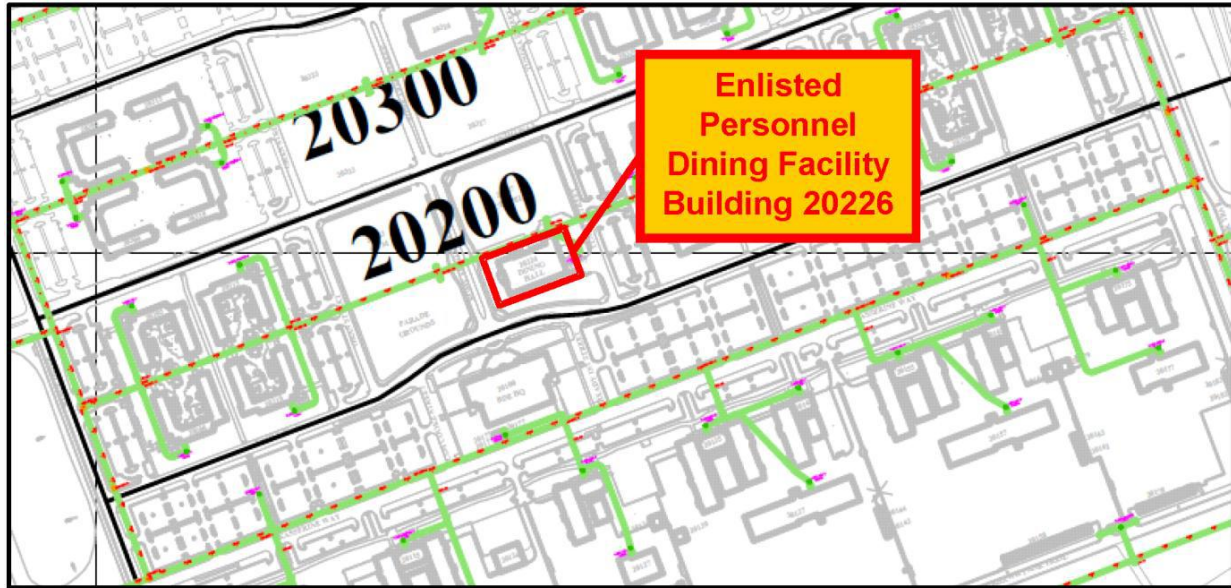


ESTCP-DP-005

*Figure 4-1 Location of Brigade Combat Team (BCT-1) on Fort Bliss Map*

#### 4.1.1 Demonstration Site Description

The EPDF of the BCT-1 complex at Fort Bliss provides a scalable size for a microgrid demonstration with a transition path to a base-wide microgrid, followed by future DoD-wide microgrid implementations. The EPDF is located on the BCT-1 campus map in Figure 4-1 as the building number 20226.



ESTCP-DP-006

*Figure 4-2 Location of EPDF on BCT-1 Installation Map*

The BCT complex is served by a 13.8 kV feeder loop. The EPDF has a 1500 kVA building transformer that converts the feeder loop medium voltage to 480 VAC. For this demonstration, power transfer was conducted at 480 VAC. The EPDF also has an existing 100 kW solar PV array, suitable for demonstrating use of renewable energy in combination with load management to achieve energy cost savings during islanded scenarios.

As a dining facility, the loads that are considered critical load equipment with near-continuous operation required are the refrigeration and freezer equipment. If utility power were ever lost, these loads were supported by the backup generator on an automatic transfer switch. The critical load demand profile along with the legacy energy sources were well suited for demonstrating seamless power transfer for energy surety as well as peak shaving for energy cost reduction.

#### **4.1.2 Key Operations**

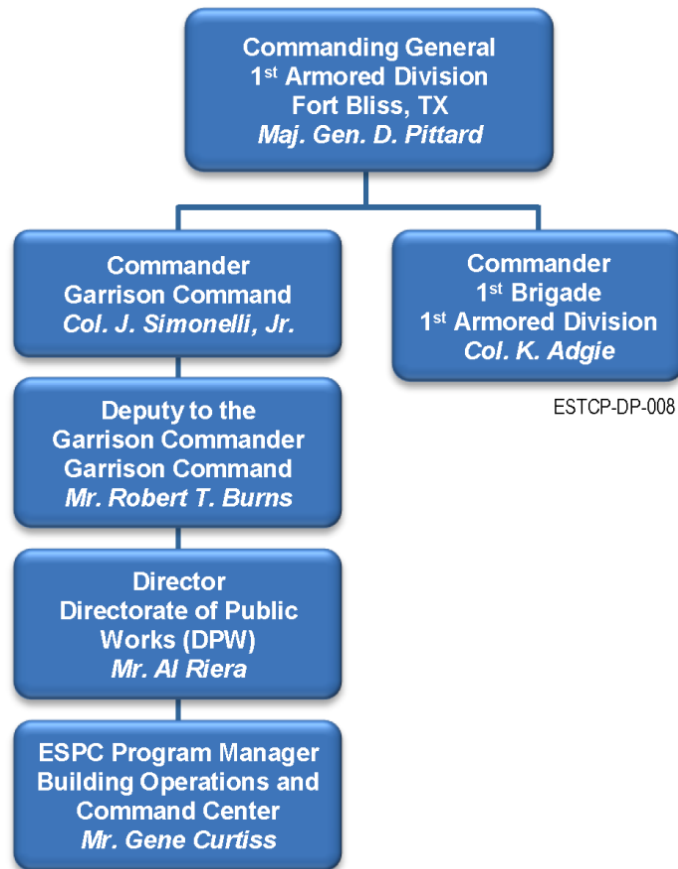
There are extensive military operations in the vicinity of the EPDF demonstration site. The BCT-1 complex at the base serves as a platform to quickly project military force anywhere in the world. The majority of the BCT-1 buildings serve Brigade activities, including the Brigade / Battalion Headquarters, EPDF, and Company Operations facilities and Tactical Equipment Maintenance Facilities for Field Artillery, Brigade Support, Special Troops, Combined Arms, and Reconnaissance, Surveillance, and Target Acquisition. Unaccompanied Enlisted Personnel Housing and the EPDF provide housing and food for all troops engaged in military training, equipment test and maintenance, and practicing military maneuvers as part of BCT-1.

Construction, installation, and verification of the demonstration project required power to the building to be disconnected for periods of time. These times were coordinated with the Fort Bliss Program Manager for Energy Savings Performance Contracting (ESPC) and DPW to minimize the impact on those served by the EPDF. Lockheed Martin ensured that the subcontractors contacted the DPW to coordinate down times for electrical work and equipment installation or

check out. Lockheed Martin also coordinated down times for system check out, commissioning and verification.

### 4.1.3 Personnel

Key leaders at Fort Bliss were responsive and timely in coordinating with Lockheed Martin and providing information needed to design and plan the demonstration project. They collaborated and took action to find space for demonstration equipment, provide historical power system data for the system design, and worked with Lockheed Martin and BCT personnel to designate building down times. Details of the leadership chain of command at Fort Bliss at the time of installation, integration, and commissioning are shown in Figure 4-3.



**Figure 4-3 Fort Bliss DPW Chain of Command in the U.S. Army**

The primary point of contact for the Lockheed Martin demonstration is the Fort Bliss DPW Energy Manager and the Fort Bliss DPW Resource Efficiency Manager. Representatives of the legacy infrastructure and equipment at Fort Bliss have also been forthcoming and helpful in coordinating information to develop the demonstration. Key Fort Bliss contacts are listed in Table 4-1, with a detailed list of program points of contact provided in Appendix A.

*Table 4-1 Key Site Leaders at Fort Bliss*

Contact	Organization / Position
<b>BJ Tomlinson</b>	DPW / Renewable Energy Project Manager
<b>Gene Curtiss</b>	DPW / Program Manager for Energy Savings Performance Contracting
<b>Dennis Wike</b>	DPW / Fort Bliss Resource Efficiency Manager
<b>Robert Lopez</b>	DPW / Energy Manager
<b>Mike Gomez</b>	Pride Power / High-voltage Supervisor
<b>Derek Williamson</b>	Johnson Controls Inc. / Site Supervisor

## **4.2 FACILITY/SITE CONDITIONS**

The EPDF at Ft 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) <sup>(22)</sup> thus 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 thus giving the project a real world load profile to test against.

## 5.0 TEST DESIGN

The traditional approach to electricity usage results in many inefficiencies for DoD installations and for underutilization of existing renewable energy resources. It also 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 has been 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. The details of these tests and the associated performance objectives were described in more detail in the following paragraphs.

#### 5.1.1 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”.

**Independent Variable.** The amount of locally generated energy was manipulated in the form of generator and energy storage power output. Also, the produced solar power was monitored and recorded.

**Dependent Variable.** During this test, the facility load demand from the bulk power grid was monitored. This demand directly impacts the cost of energy for the facility in the form of kWh charges and peak demand charges.

**Controlled Variable.** In this case, the controlled variable was the total load demand of the facility. The additional locally generated energy subtracted from the energy demanded from the bulk power grid and resulted in cost savings and facility energy usage reductions from the perspective of the bulk power grid. Also, the utility rate schedule and the demand charge were controlled variables as they had been negotiated in advance with the electric utility provider.

**Hypothesis.** By integrating new and existing renewable energy sources and existing backup generators, energy cost reductions can be achieved. For this demonstration, the peak usage of the infrastructure within the microgrid can be shaved by 10% with the use of distributed energy resources.

**Test Design.** In order to test the reduction of facility energy usage, facility peak load demand times were identified by the microgrid Central Controller and during these periods of time, sources were utilized to shave this peak and reduce peak demand charges. In the case of this demonstration, the diesel generator was the primary source used to peak shave dynamically, while the energy storage system contributed in a static fashion while performing an energy arbitrage function. The results of the test are presented in section 6.

**Test Phases.** This test consisted of several phases of execution including baseline characterization, equipment installation, commissioning, data collection, and final analysis.

The baseline characterization was accomplished by installing a data acquisition system composed of power meters and associated data loggers and recording the logged data for the duration of the project. Periodically, this data was extracted and used to characterize the facility loading. From this characterization, peak demand and peak demand times were identified and targeted for test runs.

The equipment installation phase consisted of the installation of all new equipment and the modifications to the existing electrical infrastructure needed to support the equipment. This included integration efforts and was followed by the commissioning of the system as a whole.

The data collection phase entailed capturing the new system data with the existing data collection system and the data historian subsystem of the microgrid and extracting this data following the testing.

### 5.1.2 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.

**Independent Variable.** The availability of the bulk power grid was manipulated in this test by shutting the feed to the facility down for a predetermined amount of time. The facility load demand was also manipulated in the form of a non-critical load shed when utility power was lost.

**Dependent Variable.** During this test, the down time of the facility bus voltage was monitored and recorded. This downtime demonstrated the ability of the microgrid to minimize the interruption of power to the facility loads deemed critical.

**Controlled Variable.** For this test, the controlled variable was the simulation of the loss of the bulk power grid. Originally, this was to be controlled via a manual switch on the transformer that feeds the facility (Figure 5-1). However, due to standard operating procedures and safety considerations of the local distribution service contractor, the utility power was interrupted at the medium voltage switchgear directly upstream from the facility distribution transformer. This alteration in no way influenced the outcome of the test due to the fact that the microgrid islands itself no matter where the point of service interruption occurs.



ESTCP-DP-009

**Figure 5-1 Facility Distribution Transformer Disconnection Switch**

**Hypothesis.** The ability of traditional backup systems to respond to utility power outages is currently time limited due to the nature of combustion generator sets and their associated turn on and warm up times. This downtime can be reduced significantly with the introduction of an intelligent energy storage element that can respond much more rapidly to such outages.

**Test Design.** In order to test the energy surety performance objective, a utility power outage was simulated by turning off the electrical feed to the facility at the distribution loop switchgear. The voltage of the facility distribution bus was monitored and the time lapse between voltage loss and return was recorded and compared to the existing interrupt time of several minutes. Once the data had been captured, the utility voltage was restored to the Point of Common Coupling and the system reconnected itself to the utility.

**Test Phases.** Following the installation and integration of the system components, the test was scheduled with the base personnel and the facility operators so as to minimize impact to the existing mission of the facility. The test was performed and the data was acquired from the installed data acquisition system. The baseline data set acquired was the interrupt time of the present system configuration. For the data analysis, refer to Section 6.0.

### 5.1.3 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 table 1 not tested in the previous two tests, with the exception of the system economics performance objective.

**Independent Variables.** During this test, the photovoltaic and energy storage components were utilized. Also, the total amount and numbers of loads served during a grid independent event were recorded.

**Dependent Variables.** The fuel consumption and associated operating time of the backup generator were measured and recorded to be compared with baseline measurements/calculations. Also, the status of additional feeder breakers used to feed loads not available in the traditional system configuration were monitored and recorded along with their demand levels. The power



quality of the microgrid bus was also closely monitored to ascertain if any issues were present on the bus.

**Controlled Variable.** The absence of the bulk power grid was maintained for the duration of this test.

**Hypotheses.** By introducing the availability of both renewable photovoltaic power and energy storage in this microgrid configuration, the available mission operational time of the backup generator can be increased greater than 20% over present system configurations. With appropriate renewable source and energy storage system sizing, this operational time could be increased without limit.

By reducing the operational load on the backup generator, fuel consumption is reduced accordingly and so are greenhouse gas emissions. For the purposes of this demonstration, fuel consumption and GHG emissions are to be reduced by greater than 20%.

The microgrid configuration also allows the flexibility to increase the mission of the facility to include other loads not included in the traditional backup system configuration.

**Test Design.** The facility was separated from the bulk power grid for the duration of this test. In order to test the performance objective “Reduce fuel usage and Greenhouse Gas (GHG) emissions of backup generators during grid independent operations”, all available photovoltaic power was used as well as all available energy storage capabilities to serve critical loads. During this operation, the power output and calculated fuel consumption of the backup generator was recorded. Also, GHG emissions are to be calculated for both configurations and compared to determine reduction percentage levels. In order to test the performance objective “Reduction in Back Up Generator Usage”, the output of the photovoltaic and energy storage systems was recorded. These were compared with the traditional configuration generator load to determine the increase in available energy during daytime grid independent operations. The power quality of the microgrid was closely monitored for any indications of abnormality. Finally, to test the performance objective “Increase power availability during grid independent operations,” non-critical load was added during this period of grid-independent operation and the additional load demand was recorded as well as the status of the associated feeder breaker(s). This data were sufficient to ascertain success of this particular objective. For analysis, see section 6.0.

**Test Phases.** Following the installation and integration of the system components, the test was scheduled with the base personnel and the dining facility operators as a part of pre-test preparation so as to minimize impact to the existing mission of the facility. Once a suitable testing schedule had been identified, the test was performed and the relevant data was acquired from the data acquisition system.

The baseline data was collected prior to the system operational phase. It consists of the facility and critical load demand data and the output from the photovoltaic system, which was previously designed to output at greatly reduced renewable energy power levels when the facility was operating in emergency backup mode to prevent back feeding of the generator.

For the data analysis performed, refer to Section 6.0.

## **5.2 BASELINE CHARACTERIZATION**

### **5.2.1 Reference Conditions**

The facility energy consumption data was collected from the energy monitoring and metering system described in Section 5.2.5. 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 has logged monthly electrical demand for the facility for a period of time via their Building Operations Command Center (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 (see Section 5.2.5).

### **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.

## 5.2.5 Data Collection Equipment

The metering of the facility electrical demand was performed with metering equipment on each feeder circuit and the incoming facility main feed. These meters are T-VER-E50B2 power meters manufactured for Onset Computer Corp. They are accompanied by HOBO UX120-017M data loggers, one for each meter used for long term data storage.



*Figure 5-2 Data Loggers and Power Meters used for Baseline Measurements*

The sensors used to detect current are the AC current transducers manufactured by Magnelab show in Figure 5-3.



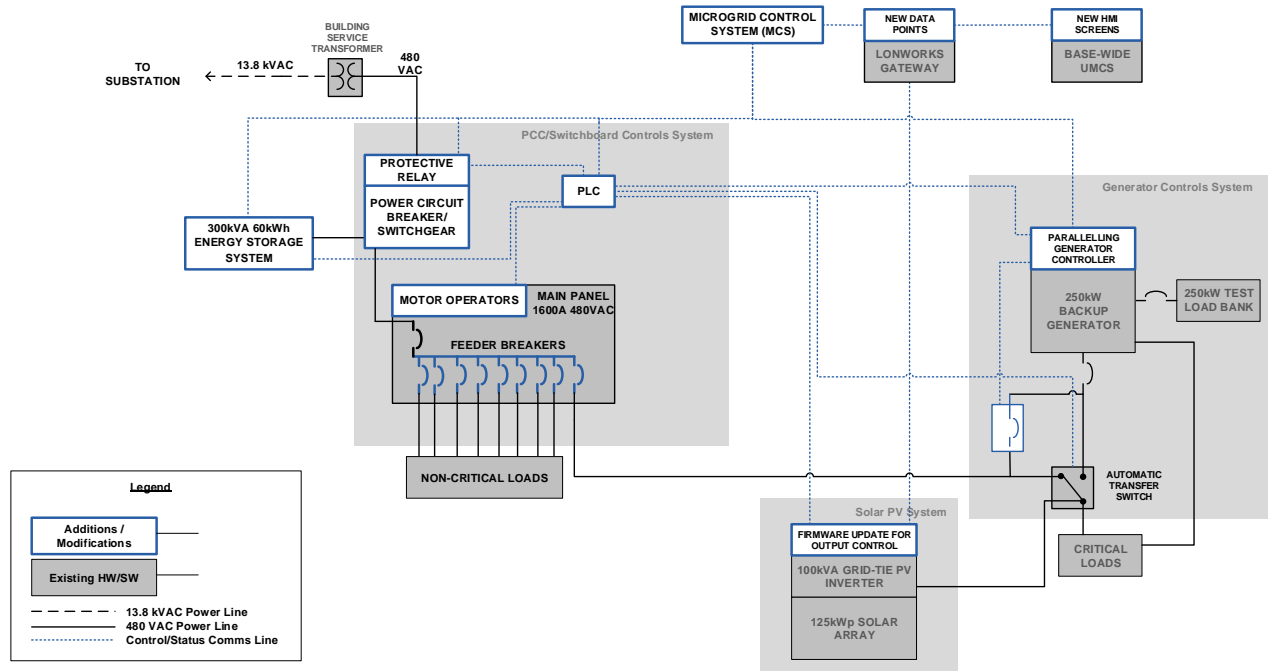
*Figure 5-3 T-MAG-SCT-200 and T-MAG-SCT-600 AC Current Sensors*

### 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

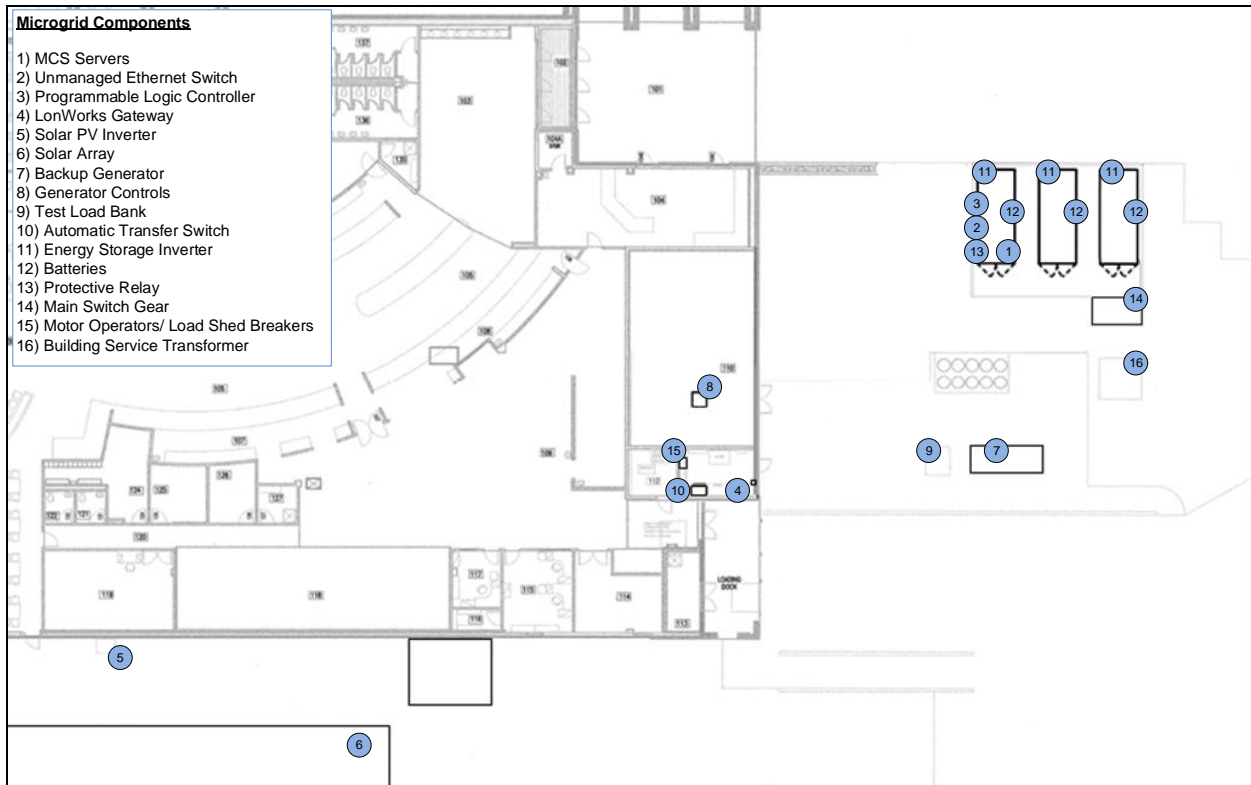
Several additions were made to the building's existing power system.



**Figure 5-4 System Block Diagram**

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.

A partial floor plan of the EPDF is provided in Figure 5-5 with labeled points of interest.



**Figure 5-5 EPDF Floor Plan with Microgrid Components Labeled**

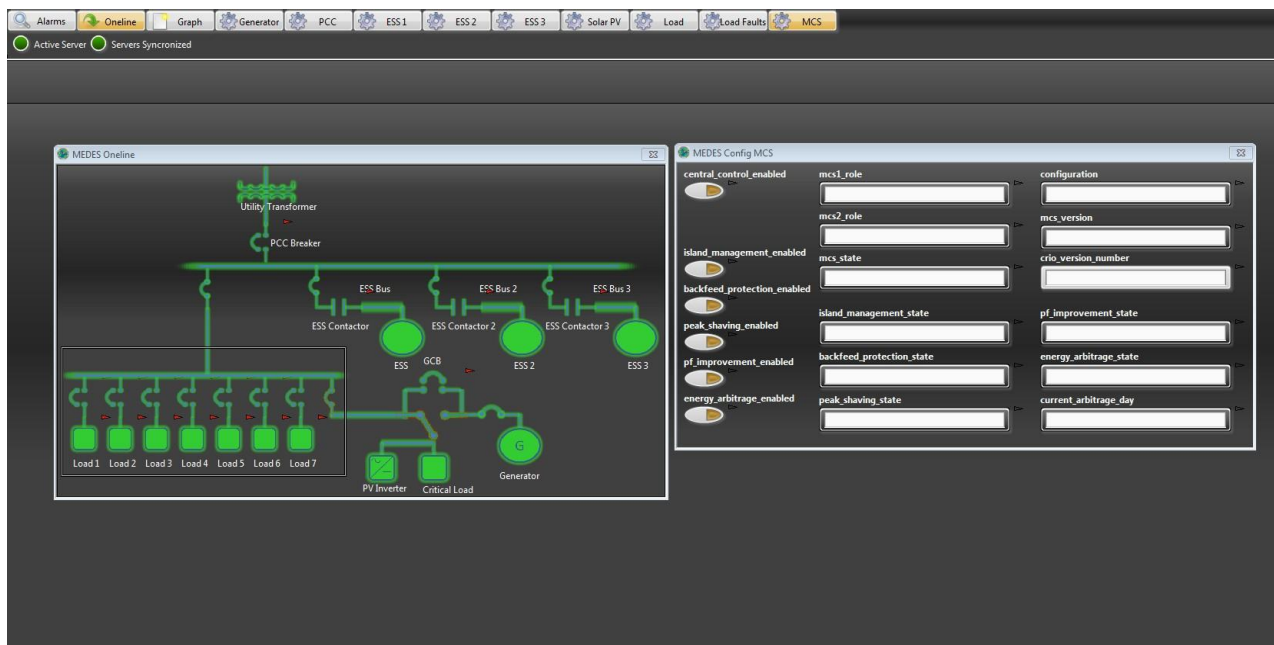
### 5.3.1.1 Microgrid Control System (MCS)

The MCS is a server rack containing two Dell PowerEdge R515 servers, one UPS, one Keyboard Video Mouse (KVM) switch, and a rack mounted Keyboard and Monitor Module (KMM).



**Figure 5-6 MCS Rack**

Each MCS server runs Windows Server 2008 R2 and hosts a number of software applications such as the control algorithms, data acquisition system, database management system, and the Microgrid’s Human Machine Interface (HMI). A MCS server can be configured to have one of two possible roles: a primary MCS Server configuration and a secondary MCS Server configuration. Each server was loaded with identical software, except the primary server was configured to actively run the optimization algorithms and control DERs. The secondary server was a “hot” backup and only would command the DERs if it detected that the primary MCS Server had stopped working. This redundant control system helped to ensure availability of the system, and minimizes downtime if maintenance work was required on one of the servers.



**Figure 5-7 MCS Human Machine Interface Screenshot**

The optimization and stabilization control algorithms are discussed further in section 2.2.

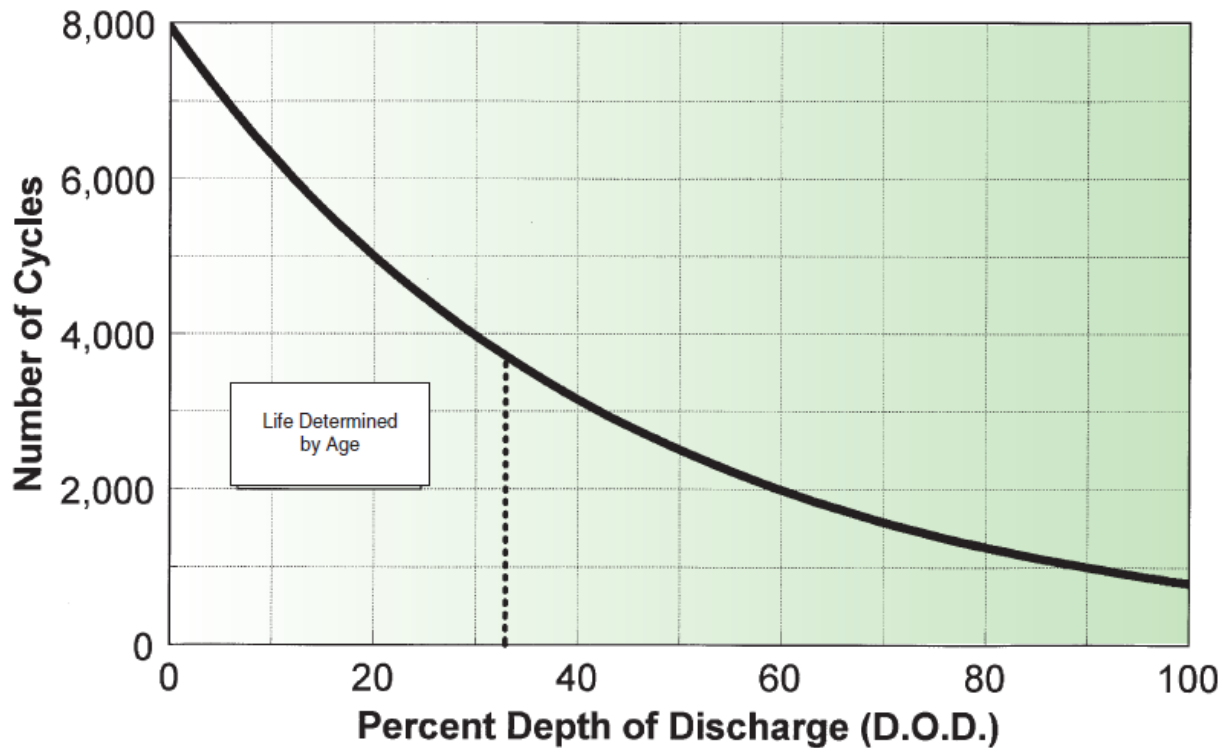
### 5.3.1.2 Energy Storage System (ESS)

The Energy Storage System (ESS) consists of three 20-foot International Organization for Standardization (ISO) 6346 shipping containers each holding 20 kWh of battery storage and a 100 kVA inverter. Together as a system the ESS provides 60 kWh of energy with a 300 kVA output rating and is connected on the 480V main bus. Three additional breakers were added to the new switchboard for the ESS interface.



**Figure 5-8 Three Energy Storage Containers at the EPDF**

The microgrid utilized the ESS to perform source shifting, renewable energy stabilization and power quality functions both while grid tied and when islanded. Princeton Power Systems was selected as the subcontractor for the ESS containers, inverters, and other electrical equipment. For this project lead acid Absolyte GP Batteries were used. Assuming that the average depletion of the ESS at the end of the day is about 33% depth of discharge (67% full), the batteries should last 3500 charge cycles.



**Figure 5-9 Absolyte GP Battery Cycle Life vs. Depth of Discharge**

Effort for proper integration of the ESS included running underground conduit for the power and control wires and mounting the outdoor units on a new concrete pad.

### 5.3.1.3 Generator Controls System

The dining facility has a 250kW diesel generator, (Cummins model DQAA-5952220, 480/277V, 3-phase) connected by an automatic transfer switch (ATS) to a dedicated subpanel servicing critical loads (freezer power for the EPDF).



*Figure 5-10 Existing Backup Generator and Automatic Transfer Switch*

The ATS, a Cummins model BTPC-400, 400A, was used to transfer the critical loads from the utility to the generator in the case of a power outage. The transfer switch senses the power outage, starts the generator and transfers the critical load. This device was left in place. A jumper in the terminal block disables it during microgrid operation, but allows easy restoration back to legacy conditions. The transfer switch operation has been modified to make the transfer switch inactive while the microgrid is active. If the operators choose to disable the microgrid, the transfer switch will immediately take over its previous functionality. There is an additional circuit breaker that parallels the transfer switch. Its operation will replace the transfer switches function via a motor operator on the circuit breaker.

The original generator controller has been replaced with a Woodward easYgen (see Figure 5-11) for the required paralleling operation. The new controller allows legacy operation and has been configured to allow the operators to return to legacy operating mode with no reprogramming.





**Figure 5-11 New Woodward easYgen Controller**

A paralleling circuit from the generator to the main switch board was added to get power to the microgrid bus, yet leave the existing ATS in place.

There was an existing 250KW load bank used for generator testing. Previously, the power generated during the scheduled maintenance was wasted. The microgrid system will now allow this power to be used in the building instead of wasting it as heat in the load bank.

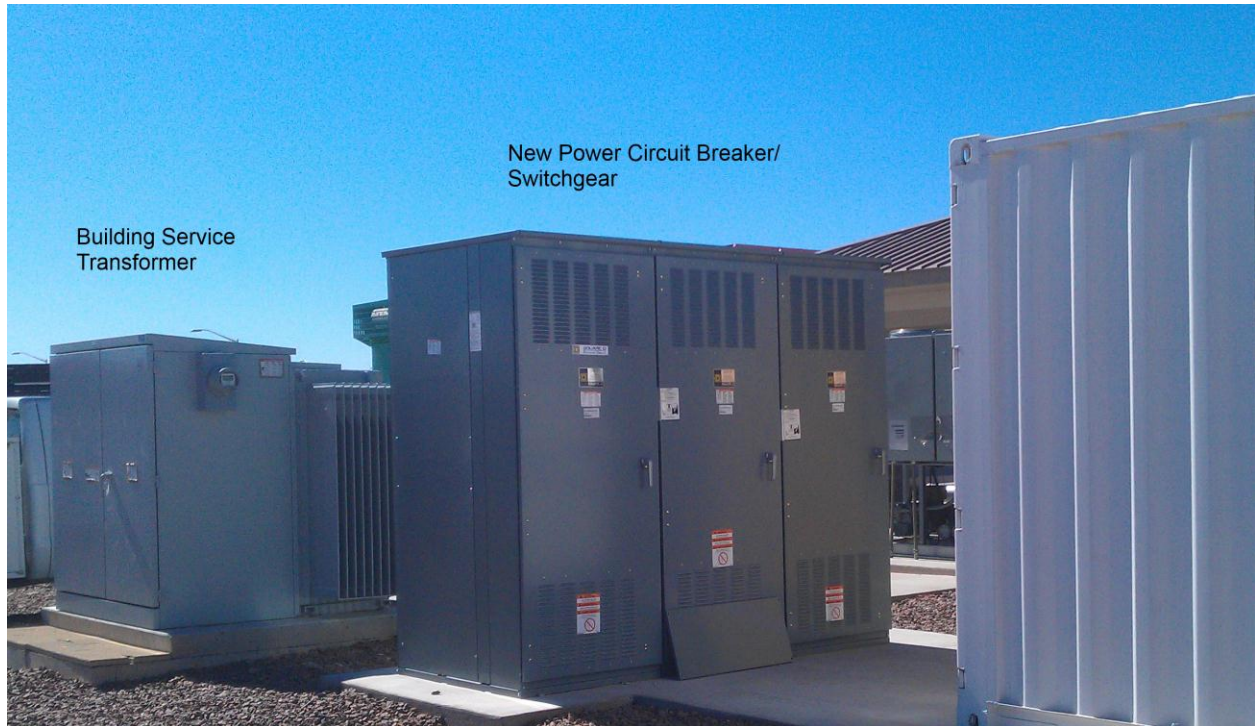


**Figure 5-12 Generator Test Load Bank**

### 5.3.1.4 PCC/Switchboard Controls System

The Point of Common Coupling (PCC)/Switchboard controls system was composed of new switchgear, a protective relay at the point of common coupling, a Programmable Logic Controller (PLC), new Motor Operators installed on top of the load breakers, and a main panel for the EPDF.

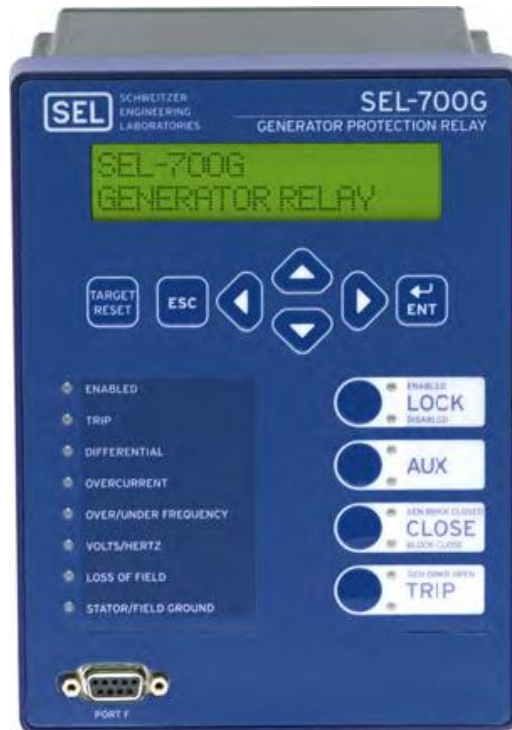
The Power Circuit Breaker/Switchgear allows the Utility to be disconnected from the EPDF in less than five cycles. This was also the distribution point for the 300kW ESS. It housed the equipment that constitutes the PCC for the microgrid.



*Figure 5-13 Existing Transformer and New Switchgear*

The new switchgear equipment as seen in Figure 5-13 was located outside, next to the building service transformer. This addition fully utilizes previously present power cables that connected the transformer to the main circuit breaker. The ESS connects to the EPDF bus at this location, which keeps the EPDF electrical room free from most of the modification effort.

A Schweitzer Engineering Laboratories SEL-700G0+ Protective Relay (see Figure 5-14) monitored the utility and microgrid sides of the microgrid isolation switch to allow compliance with IEEE 1547. It ensured that power is not fed back to the utility grid from the microgrid when the grid is down and ensures synchronization between the utility grid and the islanded microgrid before reconnecting them.



**Figure 5-14 SEL-700G0+ Protective Relay**

The Protective Relay provided power metering at the point of common coupling so that the MCS could monitor the power flow in and out of the microgrid. It was used by the MCS to detect when the utility grid came back online after an outage.

A programmable logic controller (PLC) controlled the motorized load shed breakers in the switchgear and monitors the power measurements. It had inputs/outputs to/from the generator controller and protective relay. With the MCS commands and the other inputs, it controlled the appropriate load breakers via the Motor Operators to ensure power delivery, quality and safety. As seen in Figure 5-15, the PLC used was a National Instruments cRIO-9024 with a real-time 800MHz PowerPC CPU and an integrated FPGA. Additional high speed digital input/output channels and analog output channel modules were used to interface with devices and sensors.



**Figure 5-15 National Instruments cRIO-9024**

The PLC operated under the VxWorks Real-time Operating System to ensure that critical tasks, such as coordinating with the generator, load breakers, and ESS inverters during grid mode

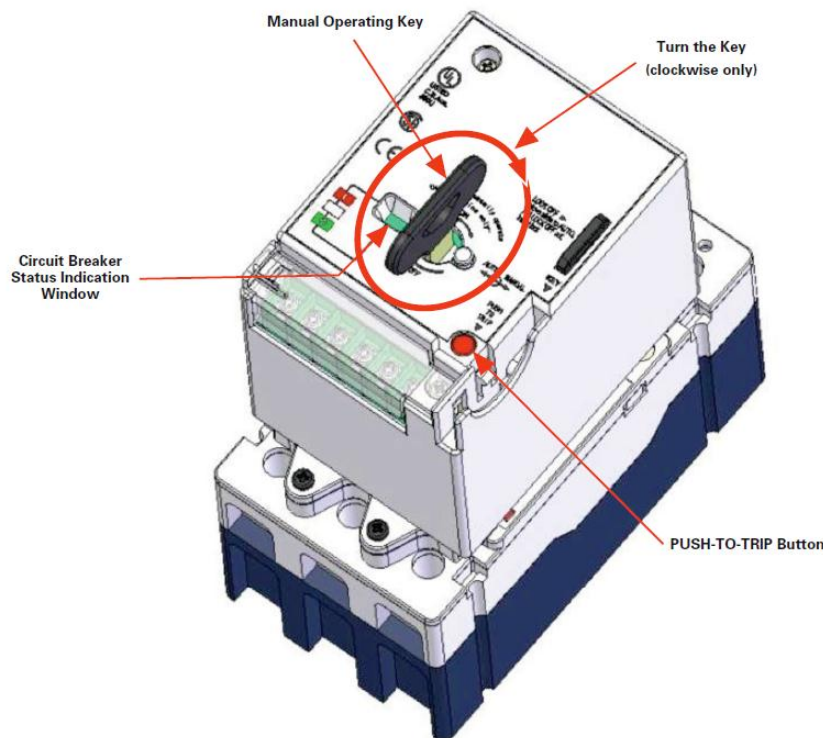
transition, were executed in deterministic high speed manner. The hard real-time nature of the PLC was critical for the renewable smoothing function and the grid transition function.

The building's main switchboard served as the microgrid bus under the "Facility Microgrid" definition in IEEE 1547.4. The switchboard shown in Figure 5-16 is an Eaton Cutler Hammer: POW-R-LINE C. 1600A, 480/277V, 3-phase unit.



***Figure 5-16 Load Breakers in Main Switchboard prior to Motor Operators Installation***

Motor operators were added to some of the major switchboard breakers to allow for the remote control of these breakers. The motor operators as seen in Figure 5-17 were designed to be attached to the existing breakers with no switchboard modifications. As discussed below, not all of the originally planned operators were installed due to conflict with the present infrastructure in the main switchboard.



**Figure 5-17 Motor Operator**

### 5.3.1.5 Solar PV System

The Solar PV System included a 125 kW DC array of Kyocera KD210GX-LPU modules (see Figure 5-19) and a 100 kW PV Powered (now called Advanced Energy) inverter for 480/277V, 3-phase operation. Prior to commissioning the microgrid, the PV inverter operated without external controls and reported status to the UMCS over the LonWorks<sup>(23)</sup> device network.

The PV Inverter operated per UL1741/IEEE1547 which includes the utility grid interconnection requirements. When the utility output is outside the operating range (w.r.t. voltage or frequency) the PV Inverter automatically disconnects from the grid for 5 minutes before trying to reconnect to a stable grid (reference Figure 5-27). The maximum PV Inverter output during islanding is automatically adjusted so that there is at least a 20kW load on the generator – preventing the generator from being back fed by the PV Inverter which may destabilize the 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.



*Figure 5-18 PV Powered PVP100kW-480 Inverter*



*Figure 5-19 Kyocera KD210GX-LPU Solar Panel Modules*

The PV inverter received a software upgrade from the manufacturer that allowed the inverter's output to be curtailed by the MCS to prevent the inverter from producing more power than the loads required in an islanded grid mode (see section 2.2.2.1 for more details).

### 5.3.1.6 LonWorks Gateway

The FieldServer LonWorks Gateway in Figure 5-20 serves as a bridge between the microgrid control network and the existing Ft Bliss Local Area Network (LAN), as well as a gateway to access data from the PV Inverter.



*Figure 5-20 FieldServer LonWorks Gateway FS-B2011*

The LonWorks Gateway's software configuration was updated to allow both the UMCS and MCS system to collect data from the PV inverter, and to allow for a few select data points to be sent from the MCS to UMCS.

### 5.3.1.7 UMCS

Most large DoD fixed facilities have an existing Building Management System (BMS), SCADA or similar system that fulfills the role of a UMCS as defined in the UFGS-25 10 10 specification<sup>(22)</sup>. The UFGS-25 10 10 specification recommends using a LonWorks, BACnet, Modbus, OPC, and/or the Niagara Framework to implement a device network. At Fort Bliss, the UMCS consists of a Johnson Controls Inc. provided/managed system called Metasys™.

Metasys™ pulls data from the base's LonWorks devices including data that contains status information about the microgrid. Johnson Controls was subcontracted to create the new HMI screens (see Figure 5-21 and Figure 5-22) in Metasys™. This allows personnel at the DPW's Building Operations Command Center (BOCC) to monitor real-time device telemetry data from the microgrid, set alarms based off the data, and store trending information.

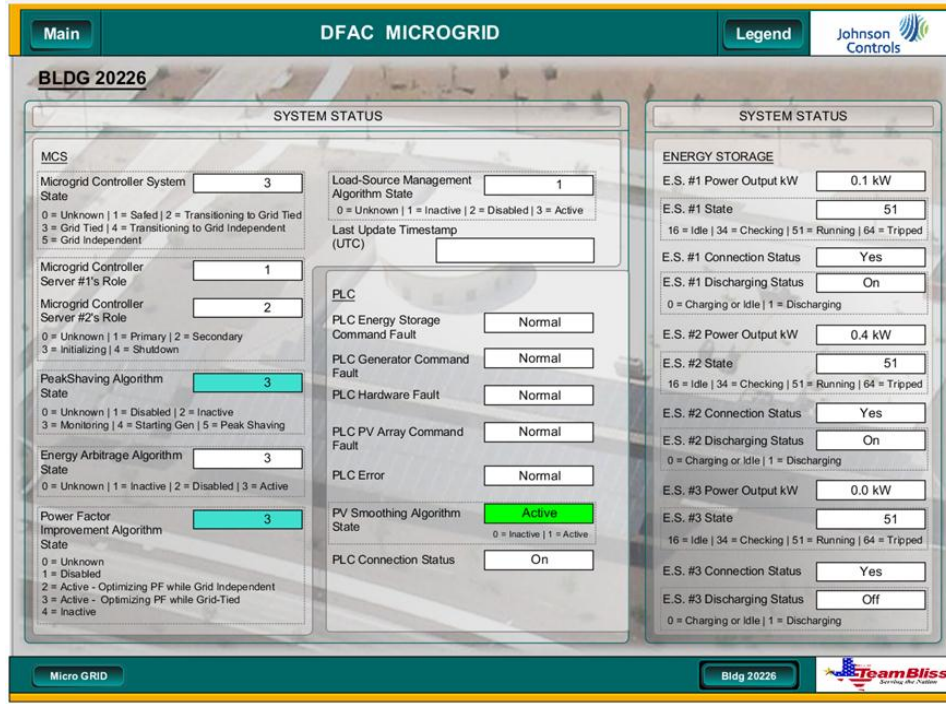


Figure 5-21 1st UMCS page for EPDF Microgrid

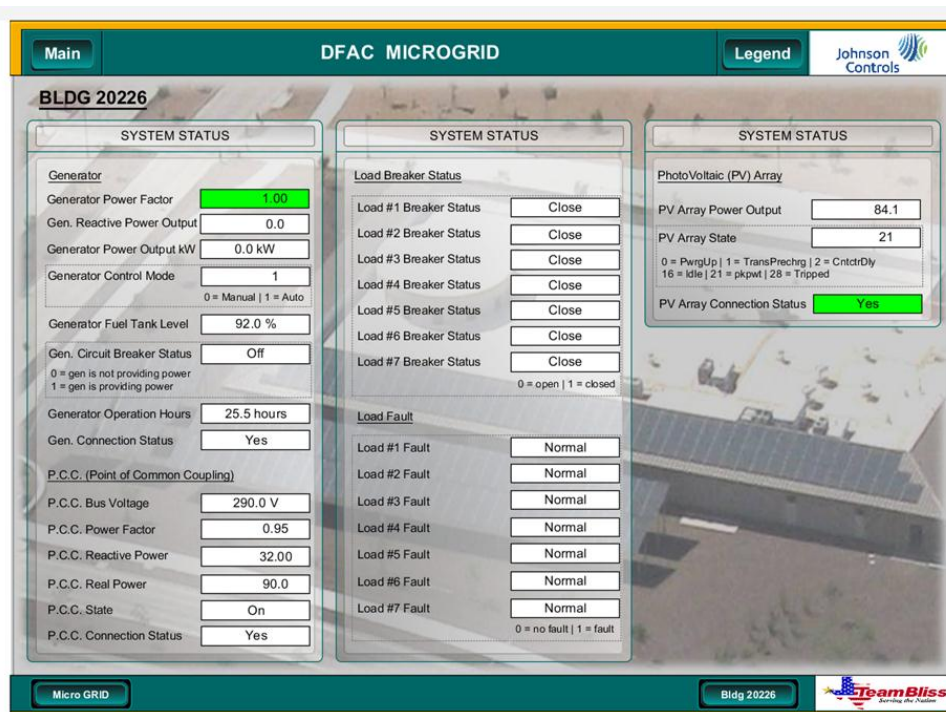
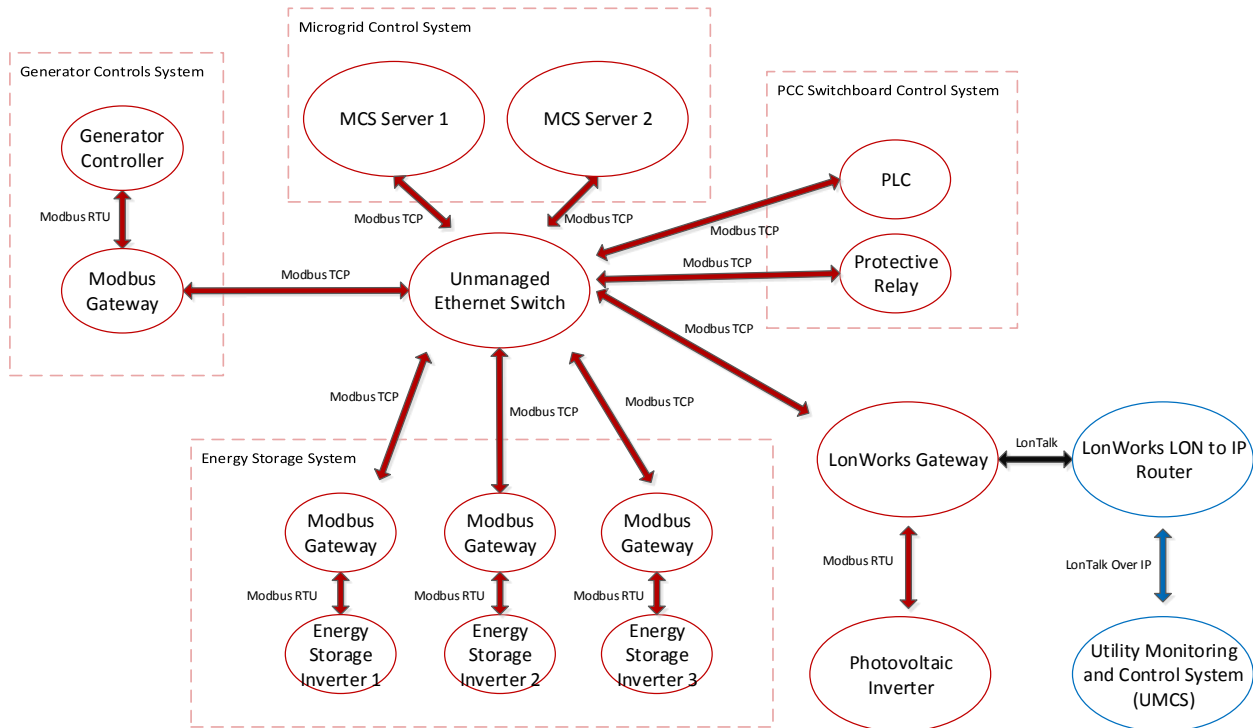


Figure 5-22 2nd UMCS page for EPDF Microgrid



### 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 Microgrid Control Subsystem (MCS) at a periodic interval using the Modbus/TCP protocol. Likewise, commands that originate at the MCS are communicated to the DERs and distributed controllers using Modbus/TCP.



**Figure 5-23 EPDF Microgrid Control Network**

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. For instance the Generator Controller natively communicates via a Modbus RTU on a serial RS-45 physical link, but with the Modbus Gateway messages can be converted to Modbus/TCP on an Ethernet link to facilitate communications with the MCS.

The backbone of the control network includes 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 polls the LonWorks Gateway using the LonTalk protocol (standardized as ANSI/CEA-709.1-C)<sup>(23)</sup>. In response to the UMCS, the LonWorks Gateway provides the

latest data it received from the MCS. This isolated the microgrid control network, shown in red, from the Ft Bliss LAN, shown in blue, and vice versa.

Since the EPDF Microgrid control network is completely contained on the building side of the LonWorks to IP router, Certificate of Networkness (CoN) and Defense Information Assurance Certification Accreditation Program (DIACAP) processes need not be applied to the Lockheed Martin demonstration. This approval has been coordinated with the Fort Bliss DPW and Network Enterprise Center at the base. The Lockheed Martin scope of work does not include addressing cyber security issues that may be associated with the UMCS.

### **5.3.3 Failure Modes and Effects Analysis (FMEA)**

A Failure Modes and Effects Analysis (FMEA) document was created for the controls portion of the microgrid. Described herein is the top-down approach to the failure modes and effects analysis. This FMEA assumes a failure at the system level and then identifies how that failure can occur. For each of the failure modes identified, the corresponding system mode of operation has been identified. A mode is defined as a condition of a system in which it provides some known set of functions.

In addition to the corresponding system mode, the cause of each failure and its local effect has been identified. The local effect refers to the system component or subsystem that is directly affected by the failure. Subsystems that are indirectly affected by the failure are identified as “next level higher” effects, and system functionality that is disabled or partially disabled is categorized as an “end effect.” Finally, for each failure mode that is identified for the system, the method of failure detection is identified as well, so that actions to avoid catastrophic failures or mitigate any performance degradation can be developed.

Lockheed Martin is willing to share the FMEA for this project; if interested parties would like to receive a copy of the FMEA then please contact the project PI or Co-PI (see Appendix A for contact information). The FMEA primarily addresses the following categories of failure modes: breaker control failures, device control failures, and central controller-related failures, and grid disconnection and reconnection failures. The mitigation strategies mainly rely on being able to revert to operation that is equivalent to the legacy configuration the EPDF power distribution system. The mitigations may be enacted autonomously by the system in some cases or require manual actions by the operator that have been written into the operating procedures.

## **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 system described in Section 5.2.5. Following system commissioning, generator, energy storage, and photovoltaic system data were collected and

archived internally via the SCADA software and its associated historian package in order to supplement this data set. Data has been 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 have received training on the operation and use of the system during the course of the commissioning. As a part of this training, Lockheed Martin has included operating manuals on all new equipment and the system as a whole. Lockheed Martin also included the option for the base personnel to return the system to its original configuration if so desired.

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 are three main data acquisition systems: the sub-meters installed for baseline measurements, the MCS, and lastly the base wide UMCS. Primarily data were used from the MCS historian(s) to determine success of most objectives. The sub-meters were used mainly for comparison purposes and initial algorithm settings. The UMCS data was not used in this report, but it did provide DPW an independent way to record status of each DER and determine efficiency as needed.

#### **5.5.1 Sampling Protocol for Baseline Measurements**

The sub-meter data acquisition system consisted of 11 pairs of Onset model T-VER-E50B2 power meters and HOBO model UX120-017x data loggers (see Figure 5-1) in addition to their associated current sensors. These meters collected power data at various points on the electrical bus such as: the main building feed and each of the branch feed breakers in the main switchgear panel for the dining facility. This data was used to compare the baseline system power usage and cost prior to modification to the system after the microgrid system with energy storage and peak shaving was installed. The following is a sample of the data taken from one meter/logger combination.

**Table 5-1 Fort Bliss EPDF Backup Circuit Sample Data**

#	Date Time, GMT-06:00	Ah, Ah	Energy, Wh	VARh, VARh	VAR, VAR	VA,VA	Volts, V	Power Factor, PF	Power, W	Amps, A
1	8/10/2011 4:20	3.38	896	278	16680	56288.2	277.6	0.955	53760	202.8
2	8/10/2011 4:21	3.4	903	280	16800	56724.9	278.1	0.955	54180	204
3	8/10/2011 4:22	3.3	870	283	16980	54892.3	277.2	0.951	52200	198
4	8/10/2011 4:23	3.41	909	270	16200	56895.1	278.1	0.959	54540	204.6

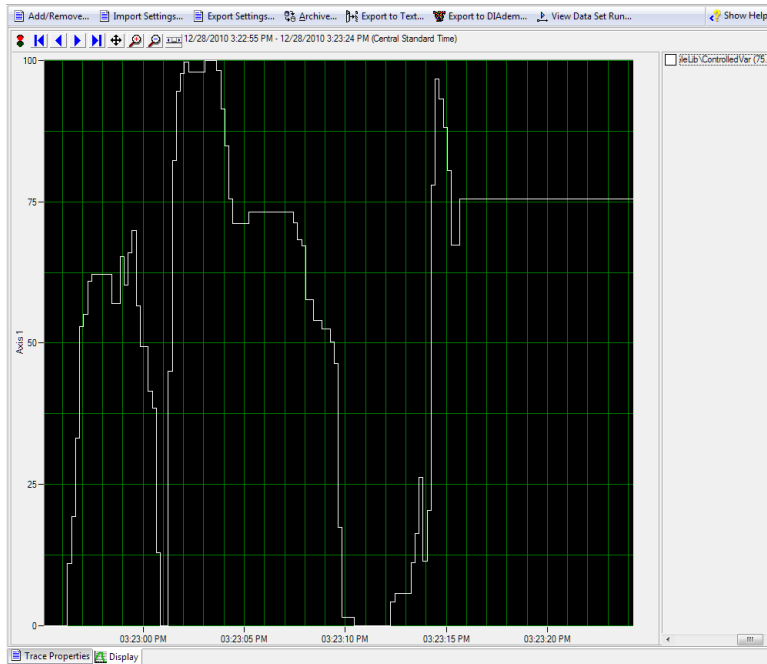
In this example, the time/date stamp shows that data were read every minute. In the actual installation data are read every 15 minutes. The first three pieces of data here (Ah, Energy, VARh) are the raw data from the meter, which are then translated into the other more readable parameters (VAR, VA, Volts, etc.). These values have been used in the analysis. The data is taken on the three phase, Line-to-Line 480VAC system. The logger combines the individual phase values into one overall value. Therefore individual phase data is unavailable from this system.

This data was collected automatically by the system described above. The data logger can store more than 4,000,000 measurements. The data was manually download from the 11 loggers approximately once per quarter for reporting purposes. The data was collected with a personal computer with manufacturer supplied software called HOBOWare™ which was then imported into a Microsoft® Excel spreadsheet.

### 5.5.2 Sampling Protocol for Data in the Microgrid Control System (MCS)

The data aggregated in the MCS was collected from the distributed controllers. Some of the distributed controllers are sampling power data at a sub-millisecond rates however the MCS polls the distributed controllers at a slower rate on the order of once per second. The devices that are polled by the MCS are the PLC, the ESS inverters, the generator controller, the solar PV inverter, and the protective relay. The distributed controllers use combinations of current transformers and electronics to calculate the current, voltage and other power related measurements.

OPC Server software on the MCS is configured to read/write a list of tags (a.k.a., data points) which map to specific Modbus registers on the distributed controllers. The live data on the OPC Server is read by the optimization algorithms and the historian. The historian is built using National Instruments LabVIEW Data logging and Supervisory Control (DSC) Module. It stores device telemetry in a specialized time-series database called Citadel 5. The Citadel database can be accessed via a standard ODBC connection similar to a SQL database; its data can also be viewed directly on the MCS servers using the National Instruments Measurement and Automation Explorer (MAX) application.



*Figure 5-24 National Instruments MAX Screenshot*

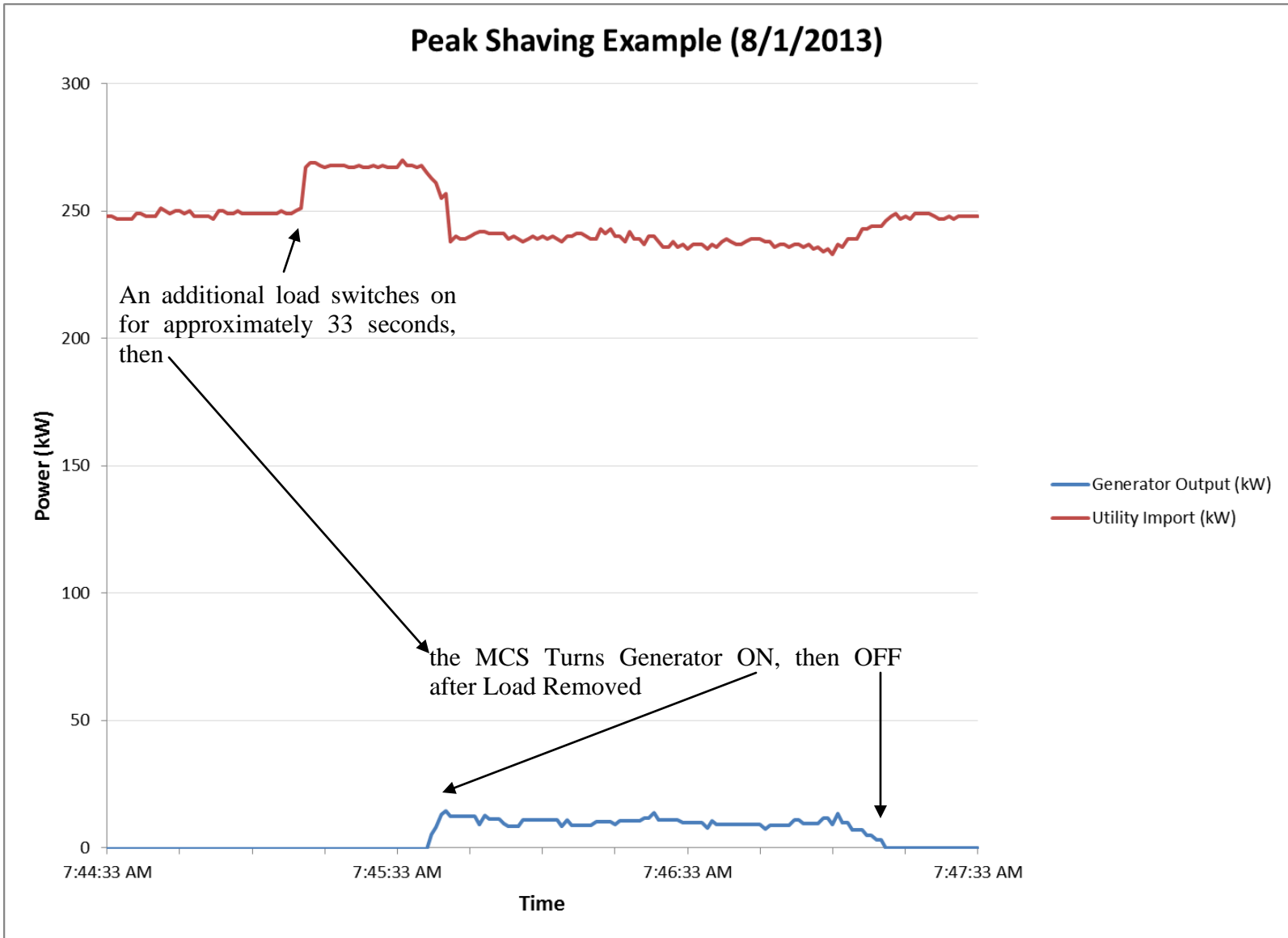
Using MAX an engineer can plot all the telemetry trend data recorded by the historian and export it to Comma Separated Value (CSV) format as needed. As funding has allowed, periodic visits were made by Lockheed Martin personnel to visit the EPDF Microgrid to copy the historian database on each server and bring it back to Lockheed Martin's MDC for data analysis and report generation.

## 5.6 SAMPLING RESULTS

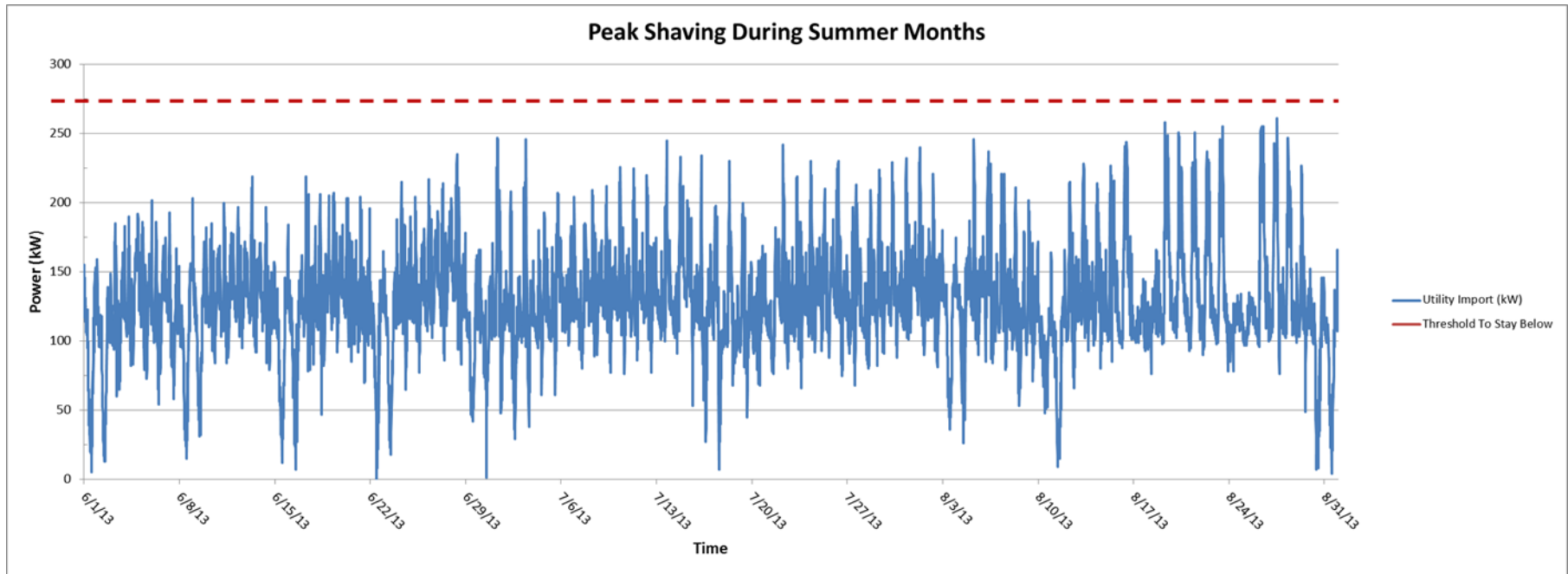
The data collected by the baseline data acquisition system, composed of the Onset energy meters and associated data loggers, has been summarized in section 5.5.

Although 15 minute interval data was sufficient for baseline characterization, the bulk of the analysis has been carried out with the MCS historian data recorded at one second intervals. Each historian recorded roughly 2GB 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 CSV files for sampling purposes, and finally processed with Microsoft® Excel to generate graphs and tables.

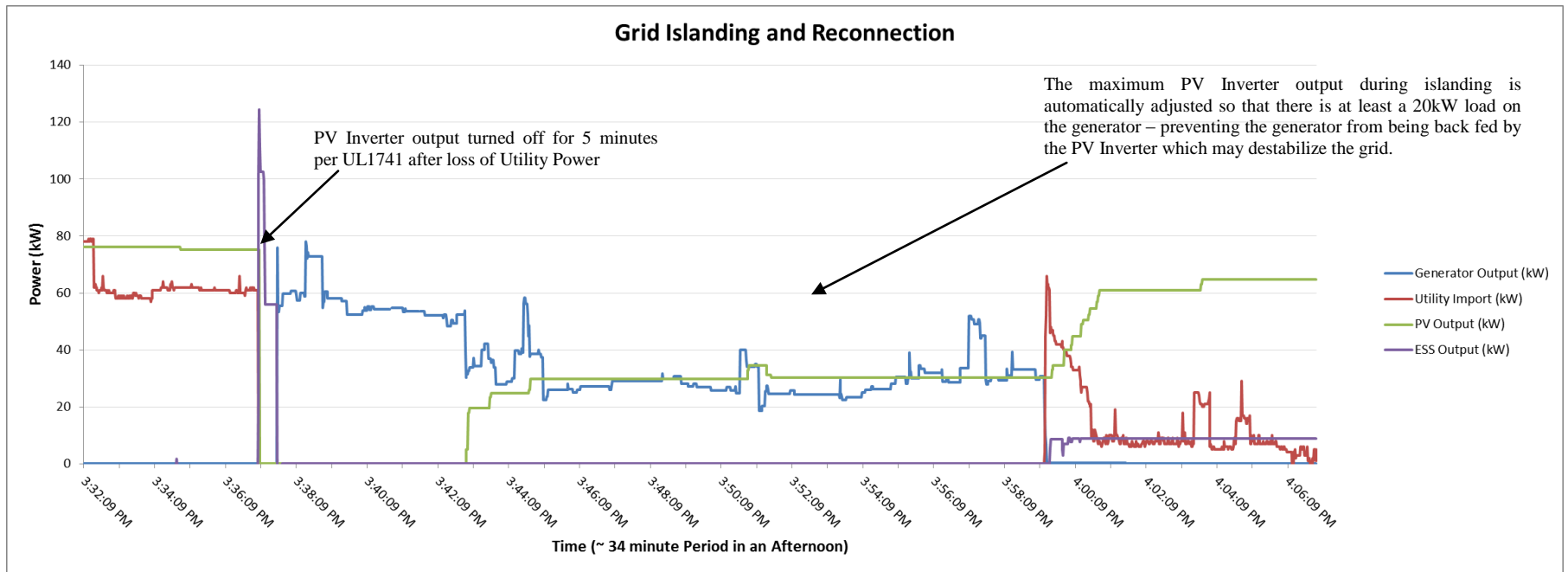
A few of the main data points considered in the analysis are shown at varying levels of fidelity, as the viewing tool allows for a customized extraction interval for the data. For example, taking a look at the import power for the facility, a view of 1 second data for the entire duration of the demonstration would be unwieldy (Microsoft® Excel can only plot up to 1,048,576 rows), whereas if the data is extracted on 10-minute intervals instead, the data becomes convenient enough to work within a spreadsheet. Analysis and discussion of the graphs and tables are provided in the performance assessment section.



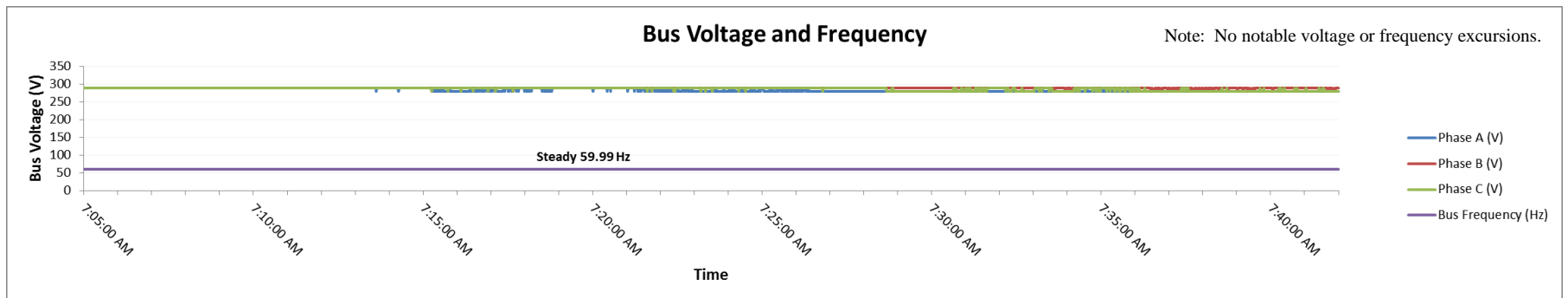
**Figure 5-25 Peak Shaving Example**



*Figure 5-26 Peak Shaving During Summer Months*

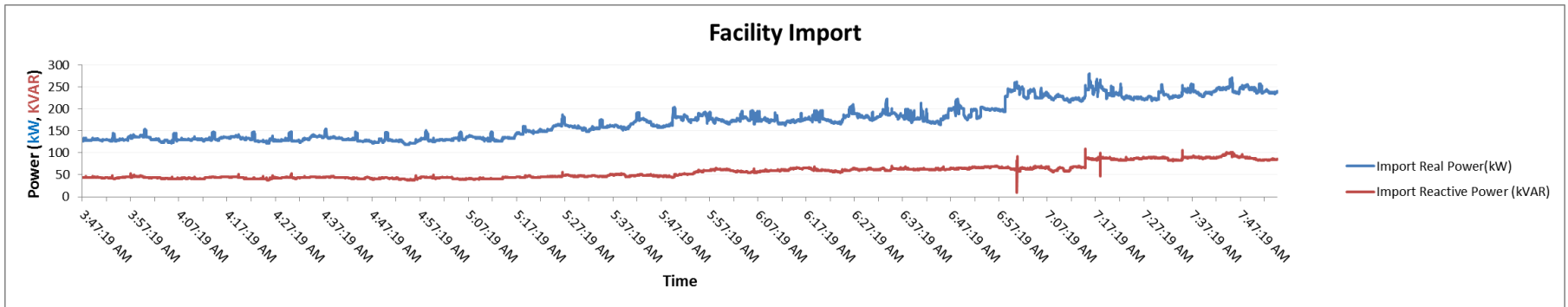


**Figure 5-27 Grid State Transition Examples**

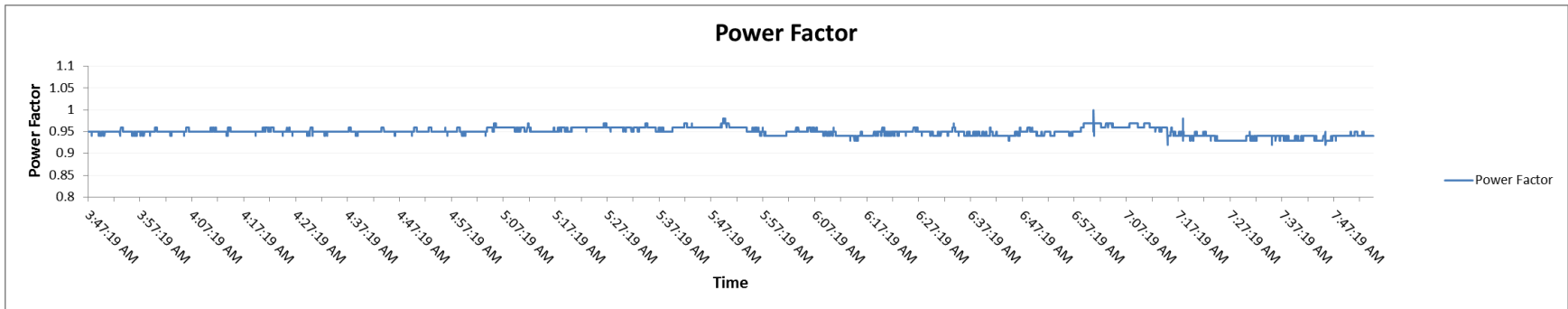


**Figure 5-28 System Bus Voltage and Frequency**

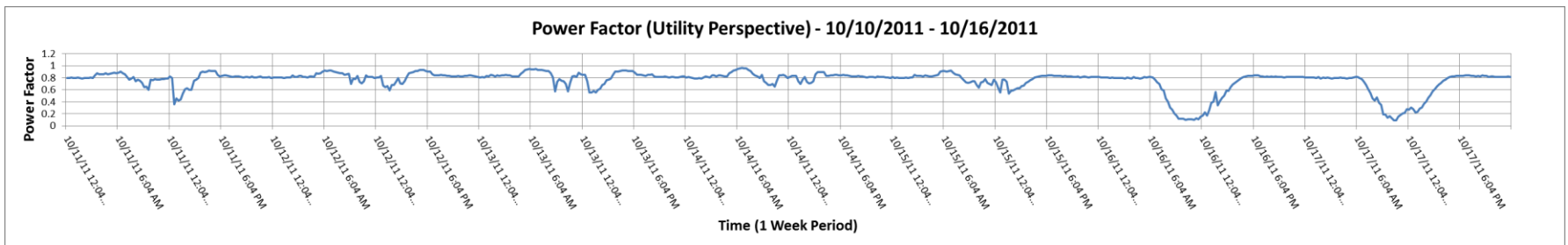




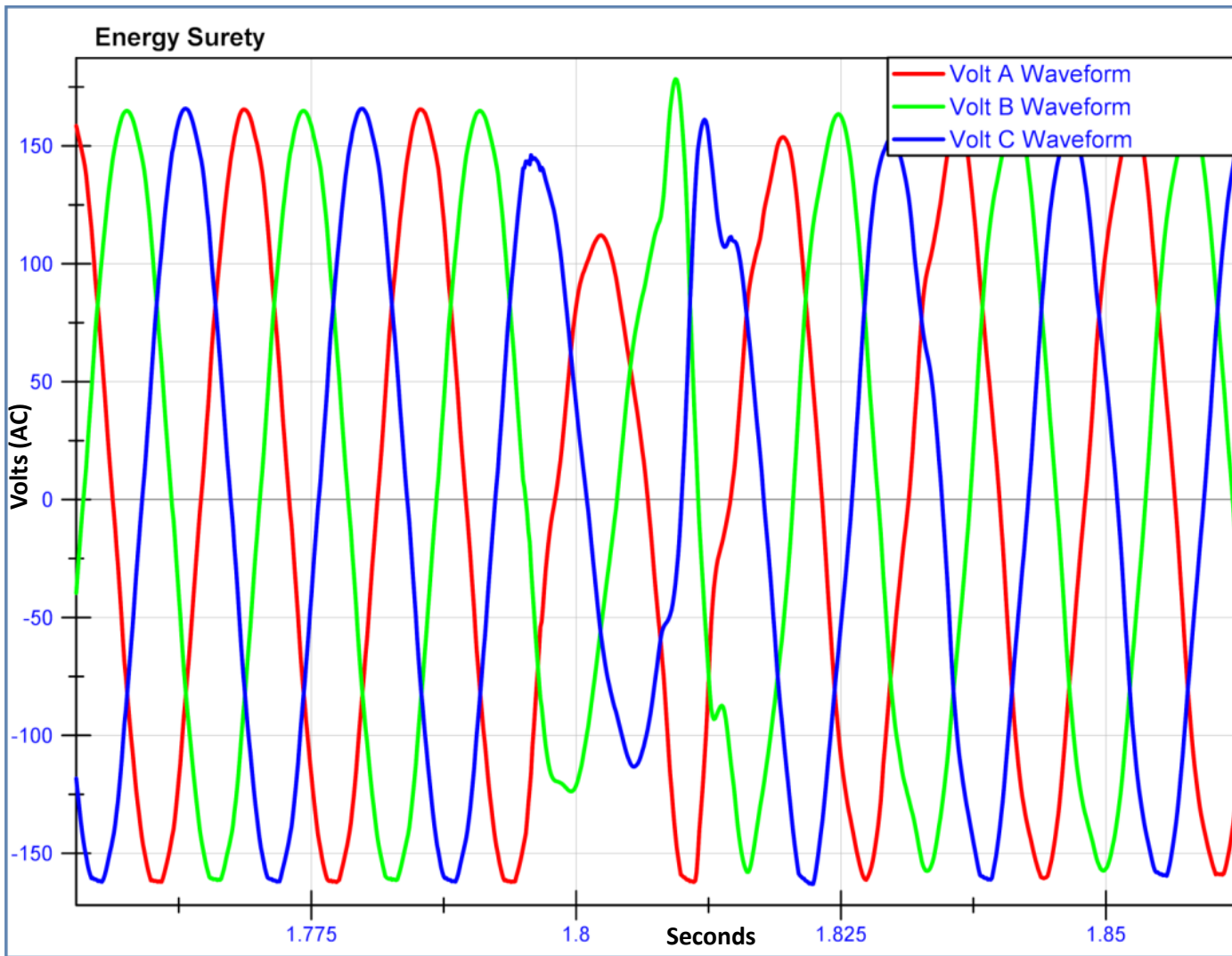
**Figure 5-29 Facility Import Power**



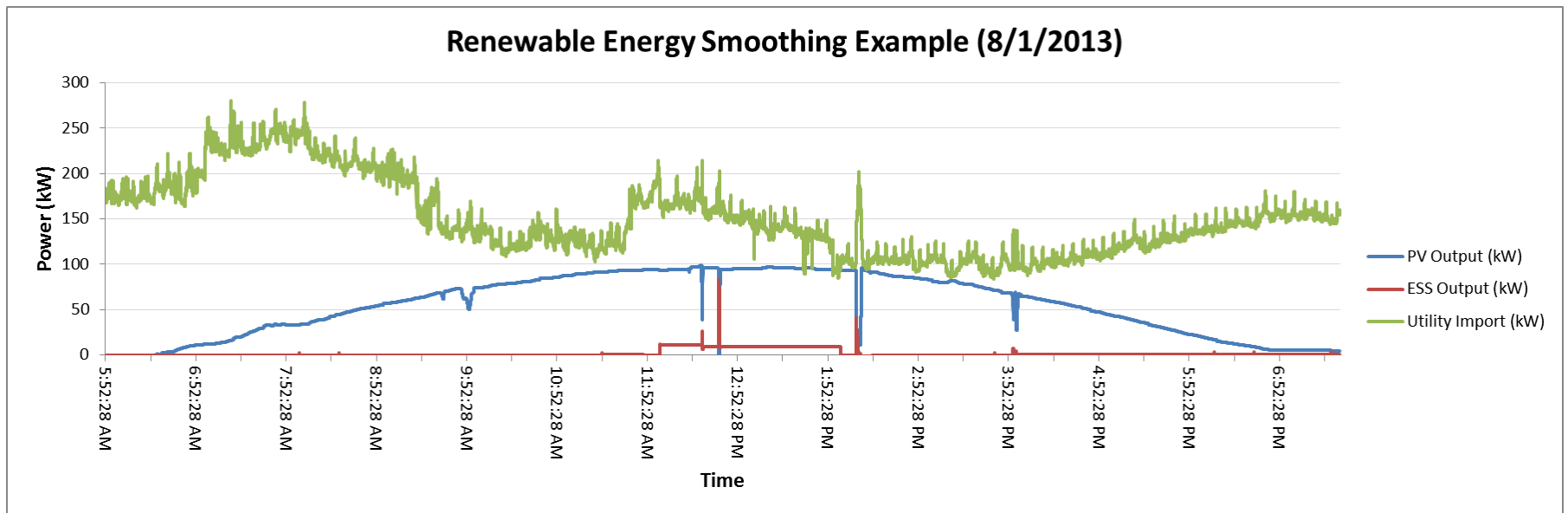
**Figure 5-30 Power Factor**



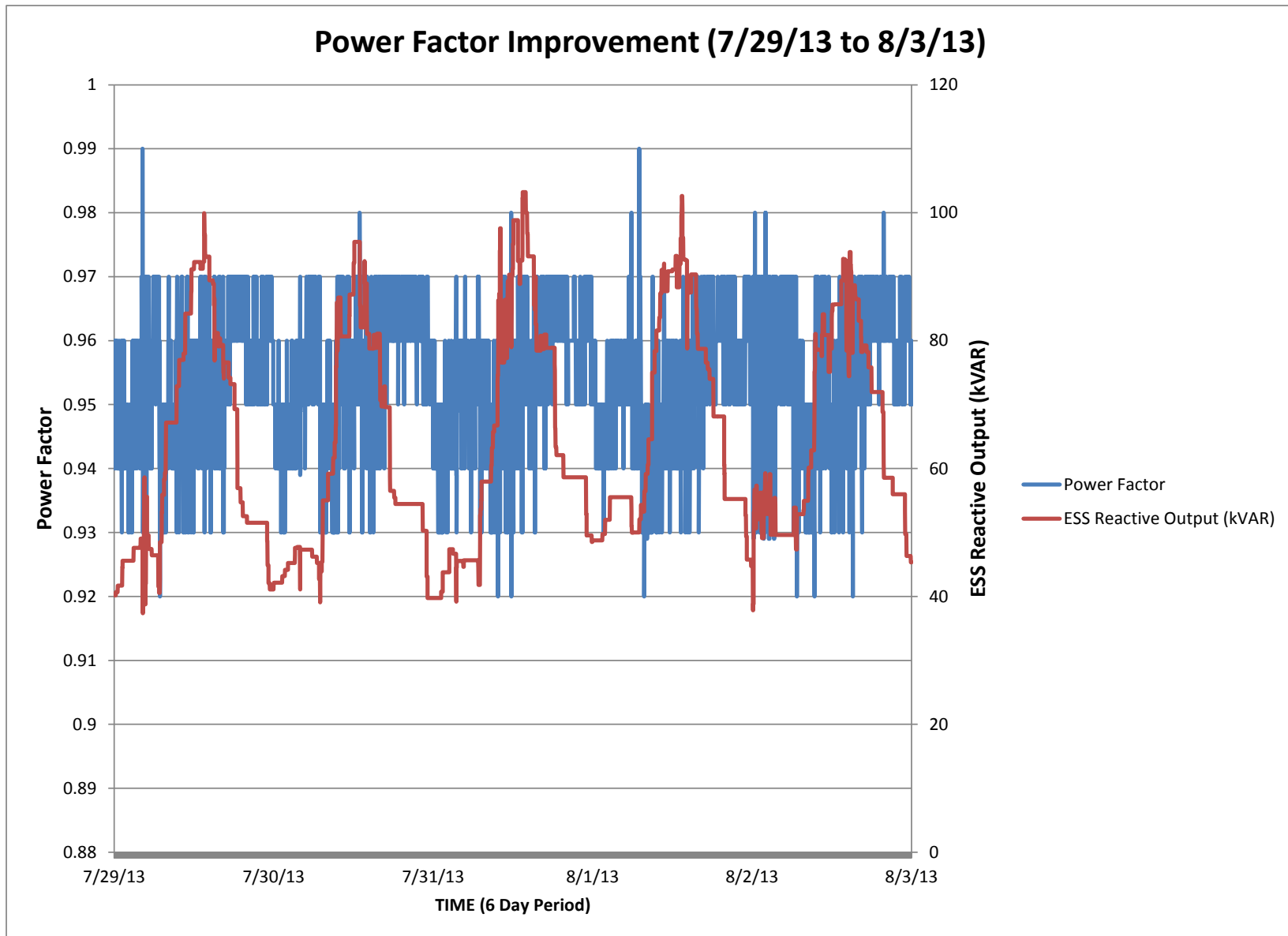
**Figure 5-31 Baseline Measurements of Power Factor at EPDF**



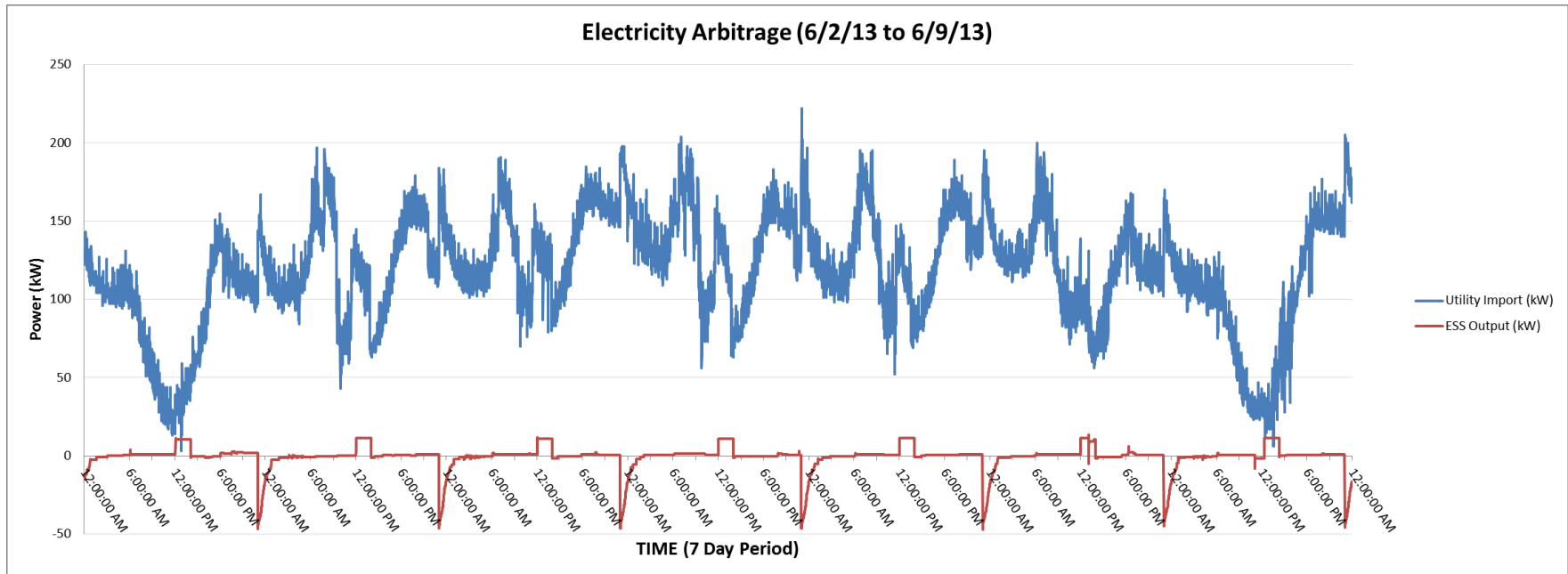
*Figure 5-32 High Speed Waveform Capture During Utility Interruption Event*



**Figure 5-33 Renewable Smoothing During Daylight Hours**



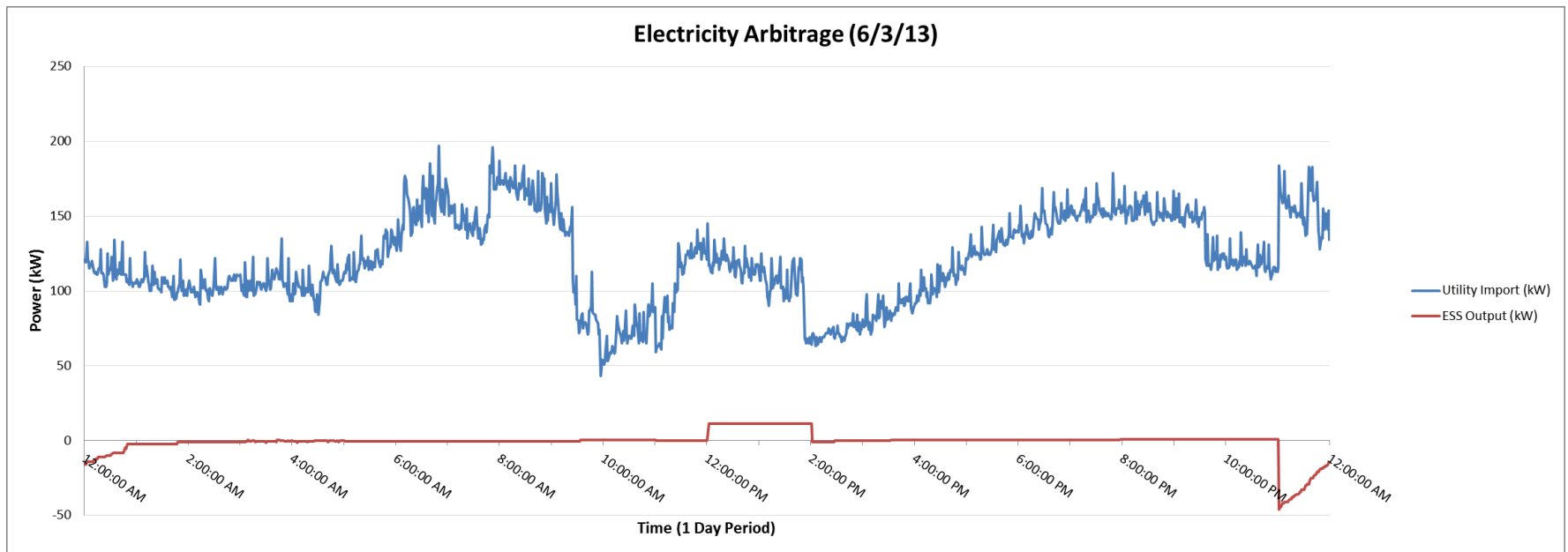
*Figure 5-34 Power Factor Improvement for a Sample Period*



*Figure 5-35 Electricity Arbitrage for a Sample Week*

*Table 5-2 Daily Energy Arbitraged (6/2/13 to 6/8/13)*

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



*Figure 5-36 Electricity Arbitrage for a Sample Day*

## **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 274.5kW (10% less than the 305kW 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. See Figure 5-26 for detailed import power data and the objective import maximum in red during the summer months (2013). 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.

It must be noted that the 1-second data did indicate very short-term excursions above 275 kW of import, and this is to be 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 dining facility, which spike up values as high as 70 kW and disappear just as suddenly a short time later, 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 if done with the energy storage system. 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 with 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 20kW of solar (calculation based on theoretical maximum output of solar inverter). As can be seen from Figure 5-27, during the most comprehensive islanding event, the MCS pushed the output of the solar up to 35 kW of output. By offsetting the generator's load by an additional 15kW 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 greenhouse gas 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 resulted in additional loads placed on the islanded configuration than the design for the baseline configuration. The critical load circuit, during daylight hours, fluctuated between roughly 30-50 kW. In the islanded scenario presented above in Figure 5-27, island load never falls below 50kW 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. Also, high speed waveform capture was performed in Lockheed's Microgrid Development Center (MDC) prior to deployment to the field. These MDC results have been included as an example, but as 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 5-27. From the high speed data captured in the MDC shown in Figure 5-32, it can be seen that the delay between loss of utility and stable bus voltage is about 2 electrical cycles (33.3ms). According to the data shown, this objective was successfully demonstrated.

### **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 Savings to Investment Ratio, using the BLCC methodology was used as the performance metric since this is the key metric by which energy projects are considered for DoD infrastructure project funding. The success criteria of reaching a Savings-to-Investment Ratio (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 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 (refer to Figure 5-28) with consistent real and reactive power (Figure 5-29), and stable Power Factor (Figure 5-30). Data points were captured at a 1Hz 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.



## **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 5-33, 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. 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 in Figure 5-31 show that the EPDF's power factor drops to 0.6 during noon on weekdays corresponding to peak real power generation from the solar PV system. On weekends, the EPDF Microgrid's power factor is worse, it drops to 0.2.

The rate structure of the base includes a power factor penalty for poor power factors Monday through Friday between 5AM and 8PM. The MCS targeted those times for power factor correction. As long as the site does not fall below a power factor of 0.9, no penalty is incurred. As can be seen from the representative week in Figure 5-34, this objective was successfully demonstrated. An important note to consider is how the utility calculates the power factor to apply to the penalty. In this case, the power factor was averaged over a rolling time period and the worst average power factor calculate during the relevant period of time is used to determine the magnitude of the penalty. This integrating function allows the end user to tolerate brief excursions below the limit as long as the system corrects quickly and maintains acceptable levels for the majority of the time.

The inverter reactive power outputs are graphed along with the power factor to show the correlation between the energy storage reactive power production and the power factor improvement. An important consideration for planning high penetration levels of renewable resources is that by offsetting real power requirements and ignoring the corresponding reactive power requirements, a site energy manager may save some money on the demand charges (which measures only real power), but also lose money by having power factor penalties applied to the billing. As the penetration levels of renewable resources continue to increase, it is to be expected that the utility providers will negotiate higher power factor penalties to compensate. This will make the power factor issue more important going forward.

## **6.9 ELECTRICITY ARBITRAGE**

The arbitrage objective is a straight forward exercise in energy storage system scheduling, as shown by Figure 5-35. Figure 5-36 provides a zoomed in view of a single day where one can see the ESS charging from 11PM to 4AM and discharging from 12PM to 2PM. The existing base rate schedule includes a demand charge component that applies to the typically high-demand summer months between 12PM and 6PM. 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 12PM to 2PM to calculate the amount of energy arbitrated for each day and the results are show in Table 5-2. 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. They 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.

## **6.10 IMPACT OF PV AND RESULTING POWER FACTOR**

Though not part of the EPDF Microgrid performance assessment, it is worthy to examine 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. We found the power factor measured at the EPDF would drop below 0.9 and worst case could drop to almost zero. See Figure 5-31 Baseline Measurements of Power Factor at EPDF. The ability to actively manage power factor with energy storage was demonstrated with this project. During demonstration, the energy storage compensated for the PV inverters by injecting dynamic reactive power to maintain a power factor for the EPDF Microgrid above 0.9.

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.

## **7.0 COST ASSESSMENT**

The cost elements of the microgrid captured during the demonstration were put into a Building Life Cycle Cost analysis tool using the methods in NIST Handbook 135 <sup>(1,2)</sup>. 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 Building Life-Cycle Cost (BLCC) assessment to determine a Savings-to-Investment Ratio (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 onsite generation.

### **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 7-1 presents some of the cost elements that were tracked, estimated, and normalized in order to extrapolate to a full BCT complex.

**Table 7-1 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	\$9,500 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 yrs as used in ESTCP demo. Advanced grid-scale storage technologies estimated 20 year life.
Operator Training	Estimate of training costs. 2 days of training plus materials	\$5,000
Salvage Value	Estimate of end-of-life value less removal costs	Minimal

### 7.2.1 Electric Utility Costs

Fort Bliss purchases electricity from El Paso Electric. Detailed electricity rate schedules from El Paso Electric with an effective date of July 2010 were used in the analysis. The complex rate structure includes (as found in El Paso Electric’s Schedules 31, 38, 95 and 98) <sup>(21)</sup>:

- 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 =  $((KW \times 0.95/PF) - KW) \times DC$
- 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 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 onsite 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 took 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 (see Section 5.3.1.5).

### **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**

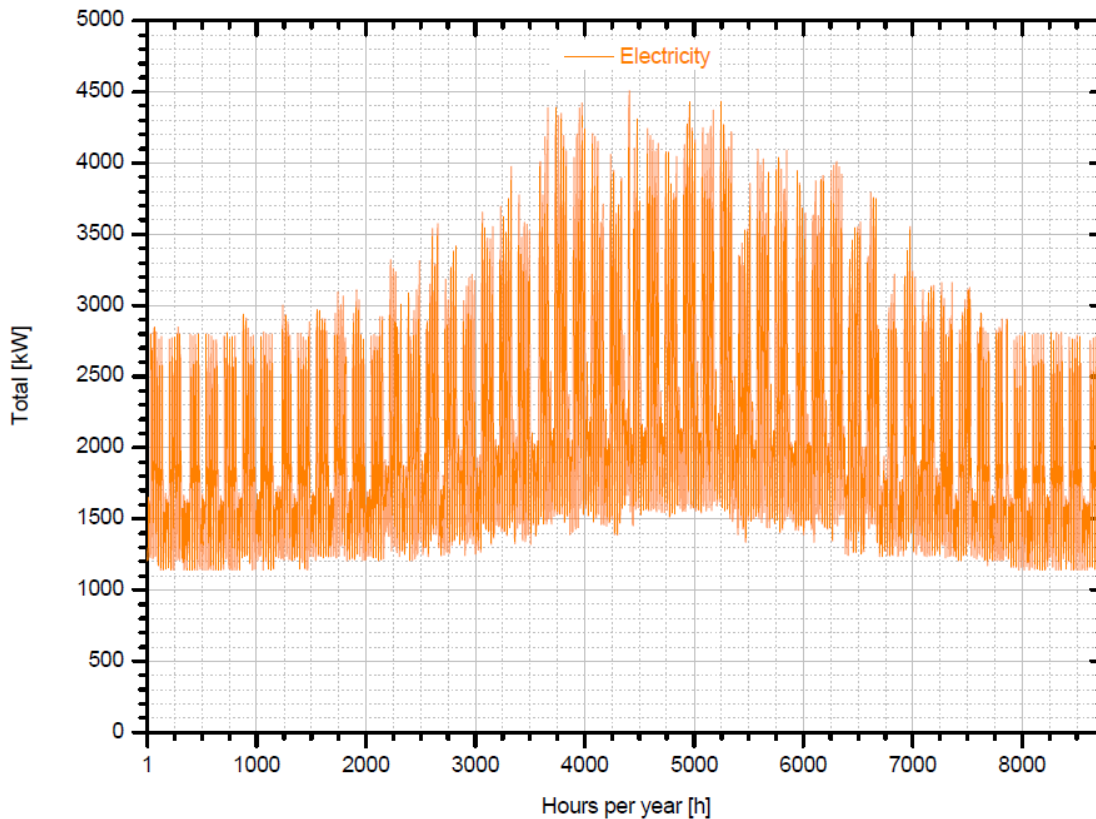
Switches and protection at the microgrid interconnection with the grid as well as switches necessary for load management consist of a broad collection of devices at different voltage and current service ratings. Based on the survey of equipment necessary for this ESTCP demonstration and use in larger 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.

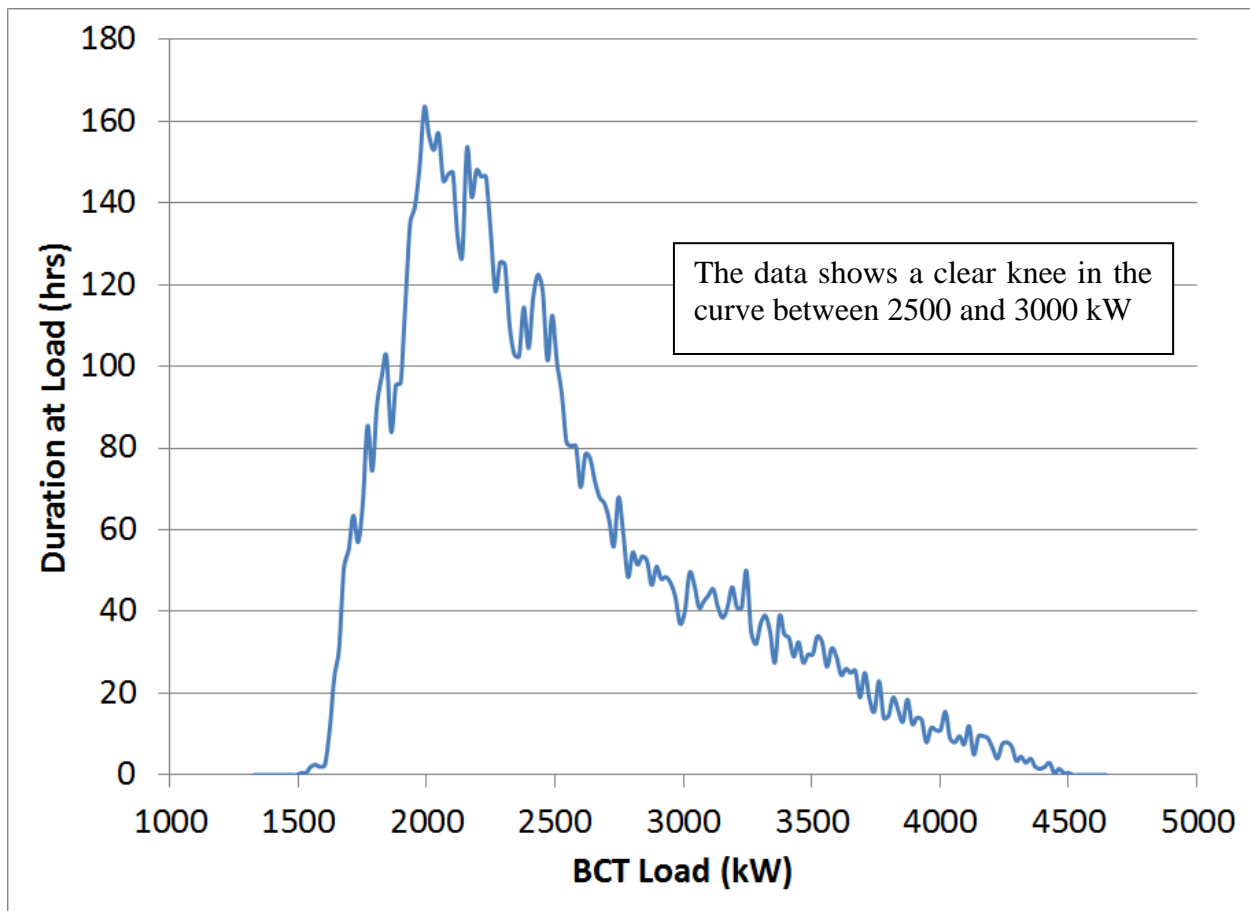
## 7.3 COST ANALYSIS AND COMPARISON

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 Ft Bliss was obtained and scaled to the peak load (4.5MW) and annual energy usage (18.2GWh) of a BCT complex located at Ft Bliss as defined in the US 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).<sup>(24)</sup>



*Figure 7-1 Load profile of a Ft Bliss BCT complex over a year (Zhivov, 2010)*

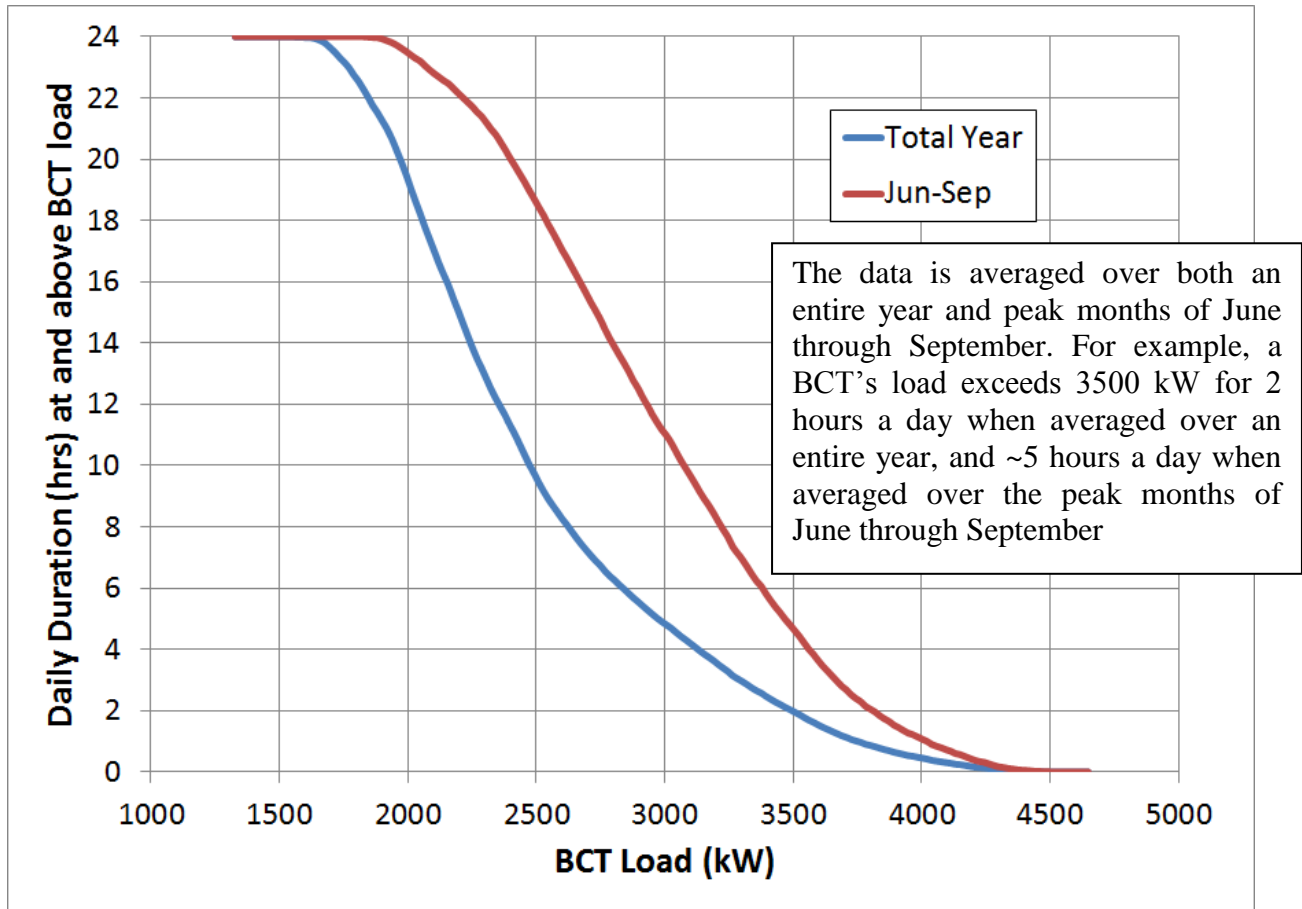
Figure 7-1 shows a broad peak load growing above a base load threshold between 2500 and 3000 kW in the 3<sup>rd</sup> month and falling below the same threshold prior to the last 2 months of a given year. The on-peak energy pricing period of June through September (~3500 hrs to 7500 hrs) clearly corresponds 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 7-2 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 7-1. 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. The 2000 kW also covers the combined 1800 kW of critical and essential loads estimated in Table 2-1. The capacity is evenly split between energy storage and onsite generation to maintain a redundant capability to serve critical loads in an islanded configuration.



**Figure 7-2 Duration at a given Ft Bliss BCT load annually**

Figure 7-3 integrates the data in Figure 7-2 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 Ft Bliss of ~2750 kW as originally shown in Figure 7-2. A runtime of 6 hours also allows the energy storage asset to discharge its capacity within the 6 hour window defined by El Paso Electric’s on peak energy pricing period of 12-6 pm in the months of June through September.

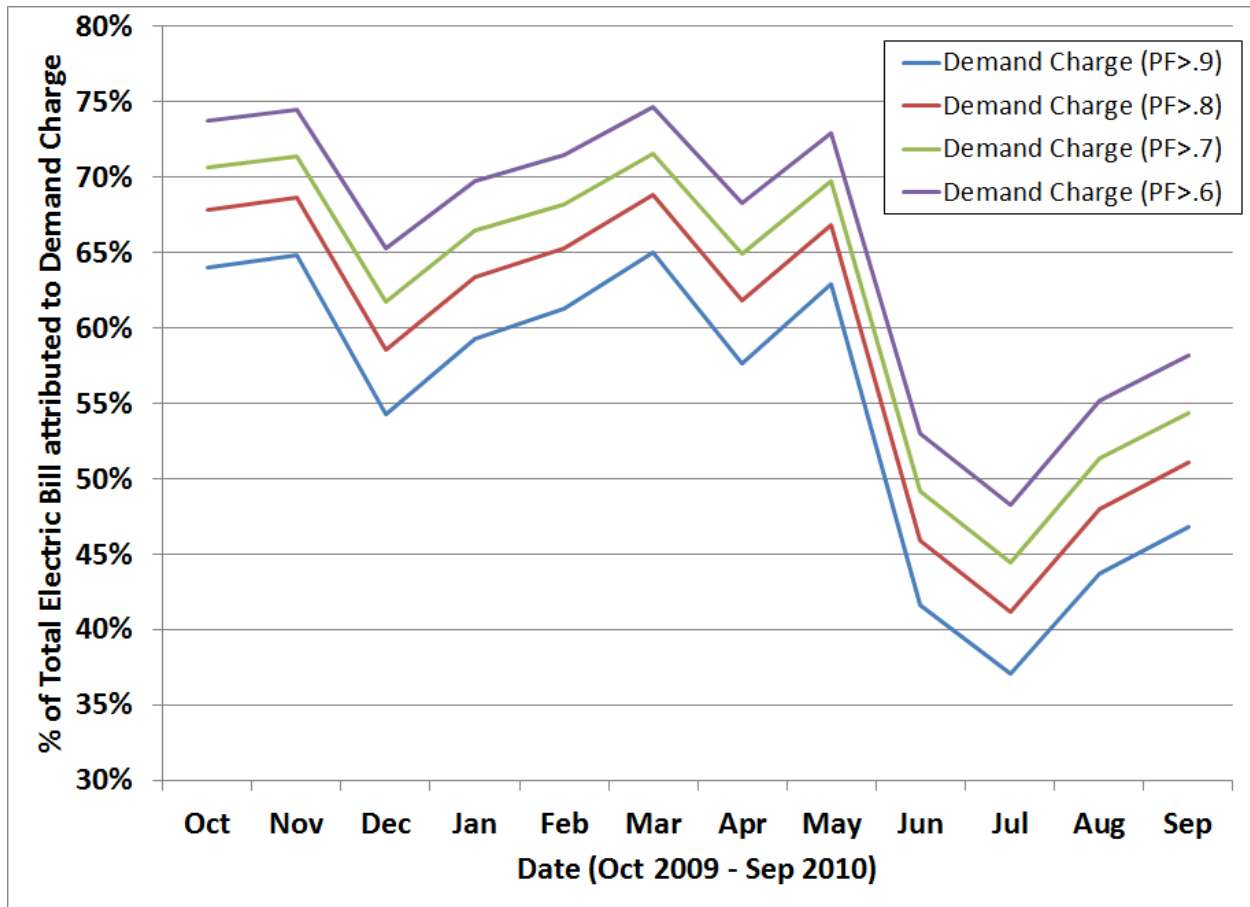


**Figure 7-3 Daily Duration at or above a given Ft Bliss BCT load**

The design points of 1000 kW of onsite gas generation, energy storage with 6 hours of runtime at 1000 kW, along with allocation of the normalized cost drivers defined in Table 7-1 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.





**Figure 7-4 Power Factor impact on the Demand Charge for Ft. Bliss monthly electric bill**

Additionally, energy storage provides power factor correction of the real power produced by onsite 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 onsite renewable energy in 2010, Ft Bliss had a minimum power factor of 0.902 resulting in no penalty. However, as can be seen in Figure 5-31, power factor seen by the utility with renewable penetration of ~30% in the case of the EPDF Microgrid 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 Microgrid at BCT-1 Ft Bliss. This will occur as Ft 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 7-4).

## 8.0 IMPLEMENTATION ISSUES

Retrofitting of existing generators proved to be very challenging. Generators at the time of installation are either installed as a standalone backup generator or a paralleling generator. The electrical designs are unique to each type of generator installation. For example the controls for a standalone generator are much simpler than the controls for a parallel generator; most standalone generator controls are only concerned with system voltage and system frequency. Paralleling generators on the other hand have to consider real and reactive power as well as system voltage and frequency. Synchronization of the 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. The LM team developed a hybrid grounding system suitable for both types of generators installations. It is worthy to note that emergency backup generators do not have a restricted run time when utilized in such a mode. However, 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. Budget must also be considered.

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 LM 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 Distributed Energy Resources. 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 Ft. Bliss power distribution is upgraded, more resolution could be available in these measurements to support future energy projects.

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## APPENDICES

### Appendix A Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
Teri L. Hall	Lockheed Martin MFC P.O. Box 650003, M/S: SP-85, Dallas, Texas 75265-0003 1701 Marshall Drive Grand Prairie, Texas 75051	972-603-2643  teri.hall@lmco.com	Principal Investigator  Microgrid Enabled Distributed Energy Solution
Curtis H. Fischer	Lockheed Martin MFC P.O. Box 650003, M/S: MM-99, Dallas, Texas 75265-0003 1701 Marshall Drive Grand Prairie, Texas 75051	972-603-3715  curtis.fischer@lmco.com	Co- Principal Investigator  Microgrid Enabled Distributed Energy Solution
William L Wright	Lockheed Martin MFC P.O. Box 650003, M/S: MM-99, Dallas, Texas 75265-0003 1701 Marshall Drive Grand Prairie, Texas 75051	972-603-9694  william.l.wright@lmco.com	Lead Power Engineer  Microgrid Enabled Distributed Energy Solution
Rajorshi “Roger” Kar	Lockheed Martin MFC P.O. Box 650003, M/S: MM-99, Dallas, Texas 75265-0003 1701 Marshall Drive Grand Prairie, Texas 75051	972-603-3844  raajorshi.kar@lmco.com	Lead Software Engineer  Microgrid Enabled Distributed Energy Solution
Brad Fiebig	Lockheed Martin MFC P.O. Box 650003, M/S: MM-99, Dallas, Texas 75265-0003 1701 Marshall Drive Grand Prairie, Texas 75051	972-603-9019  brad.fiebig@lmco.com	Business Development Manager  Microgrid Enabled Distributed Energy Solution

<b>POINT OF CONTACT Name</b>	<b>ORGANIZATION Name Address</b>	<b>Phone Fax E-mail</b>	<b>Role in Project</b>
Katie S. Speakes	Lockheed Martin MFC  P.O. Box 650003, M/S: MM-99, Dallas, Texas 75265-0003  1701 Marshall Drive Grand Prairie, Texas 75051	972-603-3181  katie.s.speakes@lmco.com	Contracts Manager, Microgrid Enabled Distributed Energy Solution
Benny J “BJ” Tomlinson	Department of Public Works BLDG. 777 - Rm. 126 Fort Bliss, Texas	915-214-6906  BJ.Tomlinson.civ@mail.mil	Fort Bliss DPW Renewable Energy Project Manager
Donald E Vincent Jr	Department of Public Works BLDG. 777 - Rm. 126 Fort Bliss, Texas	915-568-5172  donald.e.vincent.civ@mail.mil	Fort Bliss DPW
Dennis Wike	Department of Public Works Room 304, Bldg 777, Pleasanton Road Fort Bliss, TX 79916- 6816	Office 915-568-3278 Cell 816-807-4104  dennis.c.wike.ctr@mail.mil	Fort Bliss DPW OMD Resource Efficiency Manager PE, CEM, Leed-AP, REM
Gene Curtiss	Department of Public Works BLDG. 777 - Rm. 126 Fort Bliss, Texas	915-568-6627  gene.curtiss.civ@mail.mil	Energy Savings Performance Contracting BOCC Program Manager
Robert Lopez	Department of Public Works BLDG. 777 - Rm. 126 Fort Bliss, Texas	915-568-7105  Robert.Lopez14.civ@mail.mil	Fort Bliss DPW Energy Manager
Harold Sanborn	US Army Corps of Engineers, Construction Engineering Research Laboratory	586-909-0600  harold.sanborn@us.army.mil	Program Manager, Energy Branch
Melanie Johnson	US Army Corps of Engineers, Construction Engineering Research Laboratory	217-373-5872  melanie.d.johnson@usace.army.mil	Electrical Engineer

<b>POINT OF CONTACT Name</b>	<b>ORGANIZATION Name Address</b>	<b>Phone Fax E-mail</b>	<b>Role in Project</b>
Mike Gomez	Pride Power PO Box 31310, El Paso, TX 79931	915-726-6618 mike.gomez@g.prideindustries.com	High-voltage Supervisor
Derek Williamson	Johnson Controls Inc. 4940 Corporate Drive NW, Suite C, Huntsville, AL 35805-6222	Derek.P.Williamson@jci.com	Site Supervisor

## Appendix B Action Items and Lockheed Martin Responses

### 1) In your Final and Cost & Performance Reports, include the following:

- a. **Provide narrative for a layman's guide to microgrids for military installations to enable energy managers to understand critical issues and make prudent decisions.**

Currently the US 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 US 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 onsite 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. 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 and use that energy when peak hours. If your facility is arbitraging daily it's also important to know about your battery storage's depth of discharge vs. cycle life.

- b. **Address the impact of relatively high penetration PV behind the meter and its impact on the Utility's Power Factor adjustment charge. Indicate whether a capacitor bank or some other type of PF correction technology could be installed behind the meter to mitigate low PF issues.**

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. We found the power factor measured at the EPDF would drop below 0.9 and worst case could drop to almost zero. See Figure 5-31 Baseline Measurements of Power Factor at EPDF. The ability to actively manage power factor with energy storage was demonstrated with this project. During demonstration, the energy storage compensated for the PV inverters by injecting dynamic reactive power to maintain a power factor for the EPDF Microgrid above 0.9.

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.

## 2) In your Final Report discuss:

### a. How the microgrid also lengthens the availability of backup generators, if applicable.

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 this whitepaper by Cummins Power Generation:

<http://www.cumminspower.com/www/literature/technicalpapers/PT-6004-PowerFactorTests-en.pdf>

### b. The technical nuances of electrical systems learned during the project, such as inverter requirements, interfaces among components, etc.

Details provided in section 8.0 Implementation Issues.

### c. The advantages and disadvantages of using diesel generators to shave peak load.

When considering what specific device to use for the purposes of peak shaving one must consider the load profile. If there are known periodic peak loads then a slow reacting generator would be ideal until more cost effective energy storage technologies come to market. For non-periodic unpredictable peak loads a faster acting energy storage system can be justified.

### d. How the IEEE 1547 interconnection standards impact the ability to operate the microgrid/ PV in an islanded mode. Discuss arrangements made with the utility serving the part of Fort Bliss hosting the microgrid.

The IEEE 1547 defines a framework under which to create an island. The standard puts limitations on the connectivity between the utility and the island in terms of when to disconnect for safety reasons. The limitations must be translated into parameters for the system under consideration in terms of protection equipment. The microgrid houses the point of common coupling (PCC) in the new switchboard. The PCC is monitored at all times by a protective relay which is responsible for separating the island from the utility in case of an issue defined by the standard.

As long as the PCC is designed in accordance with the standard and meets all of the required safety limitations, the system designer is free to architect the microgrid in any way they see fit. One thing to consider in architecting the island is that most of the renewable energy inverters are designed to meet the IEEE 1547 standard. This imposes unnecessary limitations on the microgrid, as can be seen in the example of grid independent operations above. Notice the PV inverter waits for some period of time before re-engaging and outputting power on the island.

This is one of the requirements of the IEEE 1547 standard, but in a standalone island, this is unnecessary.

The project did not require additional coordination with the utility because the distribution equipment is owned and operated by DPW at Ft Bliss. If that was not the case, then prior to the start of construction one would need to ascertain the requirements for installing the onsite generation to be parallel with the providing utility company and any distribution operators/owners.

**e. The factors impacting the battery storage requirement, such as the ability to disable the HVAC during a grid outage until the generator is operational.**

Energy storage system sizing must consider key energy security/reliability functions including islanding of critical loads, renewable energy smoothing, and power factor improvement; as well as economic functions such as energy arbitrage and peak shaving. As described in more detail in Section 7.3, the energy storage sizing optimized for the EPDF Microgrid is impacted by the electricity rate schedule defining demand charges and on-peak pricing, the load profile of the BCT complex, and the portion of a BCT's loads that are critical. In the case of a BCT complex, the critical loads are estimated to be 1 MW which defines the necessary energy storage power rating. To ensure the energy storage asset can provide its contribution to the demand reduction through peak shaving over the entire year, a runtime of 6 hours is required based on the daily duration the BCT's loads spent above the demand reduction target, as shown in Figure 7-3. A runtime of 6 hours also allows the energy storage asset to discharge its capacity within the 6 hour window defined by El Paso Electric's on-peak energy pricing period of 12-6 pm in the months of June through September. The energy storage attributes defined above affect the selection criteria for the chemistry. In this case, chemistry optimized for long duration discharge, long cycle life at deep depth of discharge, and a low energy cost (\$/kWh) is optimal.