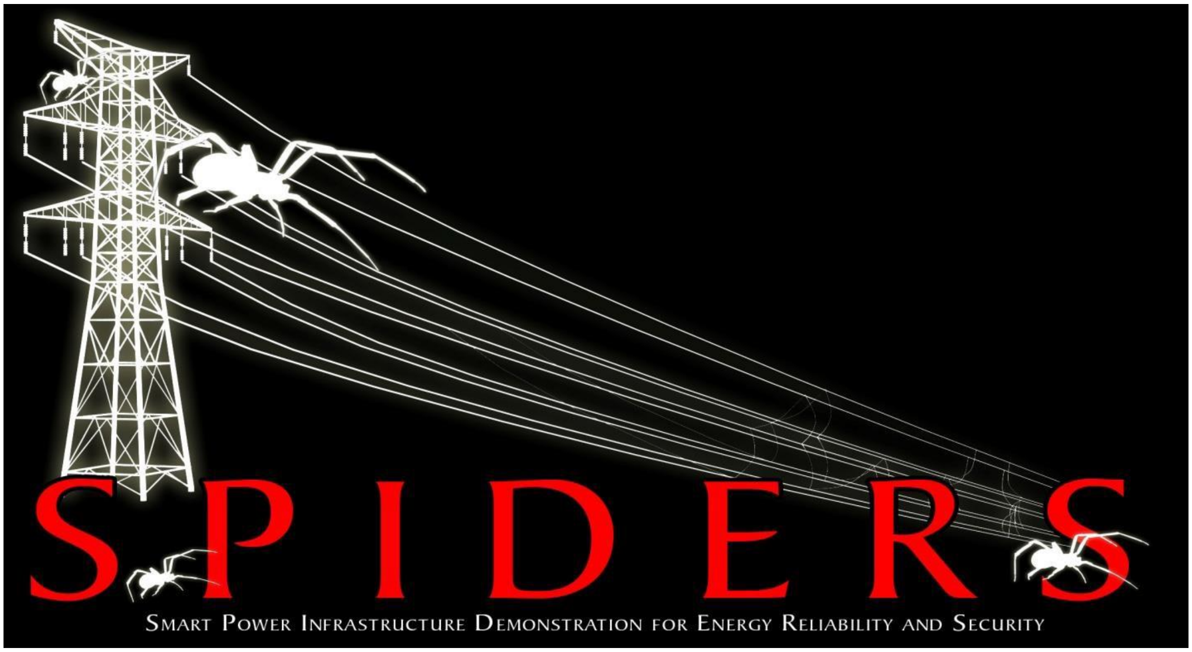

Technology Transition Final Public Report

Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS)

Joint Capability Technology Demonstration (JCTD)

Version 1.0

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SUBJECT: Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) (Post Phase 3 Camp Smith, Hawaii), Technology Transition Final Public Report

This SPIDERS "Final Program Public Report" summarizes the key outcomes generated during the third phase of the Joint Capabilities Technology Demonstration (JCTD), which was implemented at Camp Smith, Hawaii, during 2014/15. The report is intended to be the final program report for the JCTD and, as such, includes brief summaries of the Phase 1 and Phase 2 projects conducted at Joint Base Pearl Harbor-Hickam, Hawaii, and Fort Carson, Colorado, respectively with the Camp Smith summary.

The SPIDERS JCTD was a 4-year, three-phase effort to demonstrate a cybersecure microgrid with integration of smart grid technologies, distributed and renewable generation and energy storage on military installations for enhanced mission assurance. The SPIDERS JCTD supports multiple interagency objectives and is a strong collaboration of partners, lead by the Department of Defense (DOD) partners include Department of Energy (DOE), Department of Homeland Security (DHS), and individual military services (Army, Marines, and Navy). Results of the initiative are intended to help inform infrastructure investment decisions at DOD and non-DOD facilities. The DOD with SPIDERS initiative cosponsor DOE, provide overarching guidance and strategic direction.

The operational objectives of the SPIDERS JCTD are to demonstrate technical capability to:

1. Protect defense critical infrastructure from loss of power because of physical disruptions or cyber-attack to the bulk electric grid
2. Sustain critical operations during prolonged utility power outages
3. Integrate renewable energy sources, energy storage, and other distributed generation to power defense critical infrastructure in times of emergency
4. Manage DOD installation electrical power and consumption efficiently to reduce petroleum demand, carbon "bootprint," and cost

Phase 1, conducted at Joint-Base Pearl Harbor-Hickam, Hawaii, demonstrated on a limited scale all elements of capability except vehicle-to-grid (V2G) energy storage and demand-side management.

Phase 2 increased the scale of demonstration and included V2G energy-storage capability and demand-side management.

Phase 3 further increased the scale and complexity and demonstrated ability to support full base operation with capability of long-term power using onsite utility/industrial quality generating equipment integrated with renewable solar energy and stationary energy storage, as well as the ability to provide ancillary services to the local utility.

This public report is intended to inform federal/non-federal agencies and industry with timely information regarding the progress of the JCTD. This report and the August 27, 2015 “Industry Day” presentations will be posted on the Federal Energy Management Program website.

Sincerely,

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Executive Summary

The 2011 Implementation Directive (ID) for the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Joint Capability Technology Demonstration (JCTD) established an objective to **"demonstrate a secure microgrid architecture with the ability to maintain operational surety through secure, reliable, and resilient electric power generation and distribution. The results of the JCTD will help inform infrastructure investment decisions at DOD [Department of Defense] facilities needed to reduce the unacceptably high risk of extended electric grid outages."** The SPIDERS JCTD demonstrated the practicality and benefits of creating microgrids within existing military infrastructure. There are key features of microgrids that provide benefits related to energy reliability, security, cost, and environmental impacts, all of which are objectives of the DOD. To be clear, however, the underlying benefit and justification for the application of microgrids is mission assurance, which may be jeopardized by lack of electrical energy security and reliability. The results of the JCTD help inform infrastructure investment and decisions at DOD facilities regarding practices needed to reduce the "unacceptably high risk" of extended electric grid outages. The JCTD initiative is under the co-sponsorship of the DOD, Department of Energy (DOE), and Department of Homeland Security (DHS).

The SPIDERS JCTD addresses four critical requirements needed to demonstrate enhanced electrical power surety for national security:

1. Protect task-critical assets from loss of power due to of cyber-attack.
2. Integrate renewable and other distributed generation to power task-critical assets in times of emergency.
3. Sustain critical operations during prolonged power outages.
4. Manage installation electrical power and consumption efficiency to reduce petroleum demand, carbon "boot print," and cost.

The SPIDERS JCTD supports multiple interagency objectives through strong collaboration with the operational DOD Combatant Commands (U.S. Pacific Command and U.S. Northern Command), DOE, DHS, and the individual military services (Air Force, Army, Navy, and Marines Corps). The U.S. Army Corps of Engineers' Engineer Research and Development Center-Construction Engineering Research Laboratory (ERDC-CERL) provides technical management of the program. Naval Facilities Engineering Command (NAVFAC) provides transition management for the results of the program. Additional support was provided by the U.S. Army Tank and Automotive Research and Development Engineering Center (TARDEC) for electric vehicle integration in SPIDERS Phase 2. The national laboratory system members (Pacific Northwest National Laboratory, Oak Ridge National Laboratory, Sandia National Laboratories, National Renewable Energy Laboratory, and Idaho National Laboratory) and private sector subcontractors support the development, implementation, and evaluation of the SPIDERS microgrids.

The SPIDERS JCTD is a three-phase program. Phase 1 was a limited-scale demonstration of a cybersecure microgrid at Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii in 2012 and 2013. Each subsequent phase moved to a different demonstration site and each subsequent phase demonstrated a progressively more complex and larger scope of installation. Phase 2 progress demonstrations were completed at Fort Carson, Colorado, in 2013 and 2014, with an "Industry Day" event and demonstration in April 2014. The final Phase 3 demonstration at Camp Smith, Hawaii was completed in late 2015, with an "Industry Day" event in August 2015. The three phases of the SPIDERS JCTD include the following infrastructure:

- Phase 1 created a microgrid at JBPHH consisting of a single distribution feeder, two electrically isolated loads, two isolated diesel generators, and an isolated photovoltaic (PV) array.

- Phase 2 at Fort Carson consisted of three distribution feeders, seven building loads, three diesel generators, and a 1-megawatt segment of an onsite PV array, as well as five bidirectional electric vehicle chargers.
- Phase 3 at Camp H.M. Smith, Hawaii, used new and existing generation sources to form a microgrid to support the loads of the complete installation. The installation includes stationary prime power diesel generators that meet U.S. Environmental Protection Agency Tier 4i emissions standards for continuous use. In addition, a battery system was used to demonstrate near instantaneous transition from utility power to microgrid operation for a subsection of the site. The system has provisions for cost-reduction strategies, including power factor correction, peak demand management and load sheading/ coordination in conjunction with the local utility. The addition of prime power generation can enable coordination with the utility provider to increase grid stability and lower the cost of electricity to the military customer.

In addition to focusing on electrical infrastructure modifications, each phase also has a cybersecurity facet, which is discussed in this report.

Security Note:

Understandably, security of operational military bases is critical and this report cannot compromise military security. In some cases protection of base security may be in conflict with the mission of the JCTD to inform the public regarding the results of the JCTD. There are two viable options in such a case: the JCTD results may be discussed at a very high level, providing only qualitative information, or quantitative information can be discussed in a fictional case. The Industry Day presentations provided SPIDERS JCTD information in qualitative form. This report constructs a fictional example “Camp JCTD” as a reference model. It is internally consistent and demonstrates the analysis use at the JPBHH, Fort Carson, and Camp Smith phases of the project, but the detailed data are fictional, electrical routing is fictional, and control details shown are examples.

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Acronyms and Abbreviations

AC	alternating current
AMI	Advanced Metering Infrastructure
ATS	automatic transfer switch
CNSSI	Committee on National Security Systems Instruction
COTS	commercial off the shelf
DBT	Design Basis Threat
DC	direct current
DHS	Department of Homeland Security
DOD	Department of Defense
DODI	Department of Defense Instruction
DOE	Department of Energy
EPA	U.S. Environmental Protection Agency
ERDC-CERL	Engineer Research and Development Center-Construction Engineering Research Laboratory
FEDS	Facility Energy Decision System
ft^2	square foot (feet)
genset	generator set
GUI	graphical user interface
HMI	Human Machine Interface
ICS	industrial control system
IMT	Integrated Management Team
ISIM	Integrated Storage and Inverter Module
JBPHH	Joint Base Pearl Harbor-Hickam
JCTD	Joint Capability Technology Demonstration
kV	kilovolt
kW	kilowatt
kWh	kilowatt-hour
kWh/ ft^2/yr	kilowatt-hours per square foot per year
LNG	liquefied natural gas
MW	megawatt
NAVFAC	Naval Facilities Engineering Command
NDT	neutral deriving transformer
NIST	National Institute of Standards and Technology
PLC	programmable logic controller
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic
SCADA	supervisory control and data acquisition
SNL	Sandia National Laboratories
SPIDERS	Smart Power Infrastructure Demonstration for Energy Reliability and Security
TARDEC	U.S. Army Tank and Automotive Research and Development Engineering Center
V	Volt
V2G	vehicle-to-grid
WWT	wastewater treatment

SECTION 1

1Background

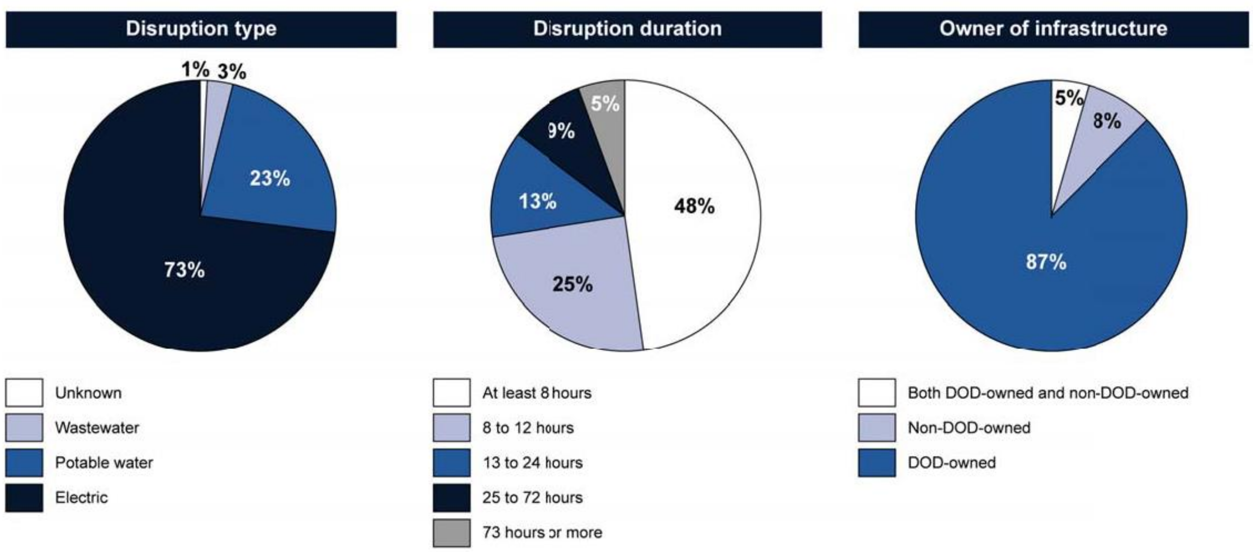
In 2008, the Defense Science Board Task Force on Department of Defense (DOD) Energy Strategy issued the report "More Fight-Less Fuel." This milestone report was produced at the direction of the Under Secretary of Defense for Acquisition, Technology, and Logistics. The Task Force concluded that the DOD faces two primary energy challenges:

- "Unnecessarily high and growing battlespace fuel demand…"
- "Military installations are almost completely dependent on a fragile and vulnerable commercial power grid, placing critical military and Homeland defense missions at unacceptable risk of extended outage."

The Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Joint Capability Technology Demonstration (JCTD) primarily addresses technology issues related to the second of these two challenges, while maintaining and demonstrating the ability to integrate renewable energy and reduce fuel demand.

Figure 1-1, from the United States Government Accountability Office Report on Improvements in DOD Reporting and Cybersecurity Implementation Needed to Enhance Utility Resilience Planning (GAO-15-749; July 23, 2015), illustrates the relative significance of energy system disruption on DOD installations.

FIGURE 1-1
Energy System Disruptions on DOD Installations

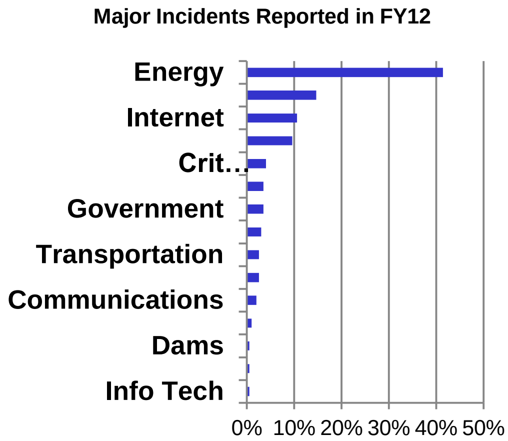


Source: GAO analysis of Department of Defense (DOD) information. | GAO-15-749

From DOD Reporting and Cybersecurity Implementation Needed to Enhance Utility Resilience Planning Figure 3:: Information on Disruptions Lasting 8 Hours or Longer, Fiscal Years 2012 through 2104, Reported to GAO by 18 DOD Installations inside and outside the Continental United States (GAO, 2015)

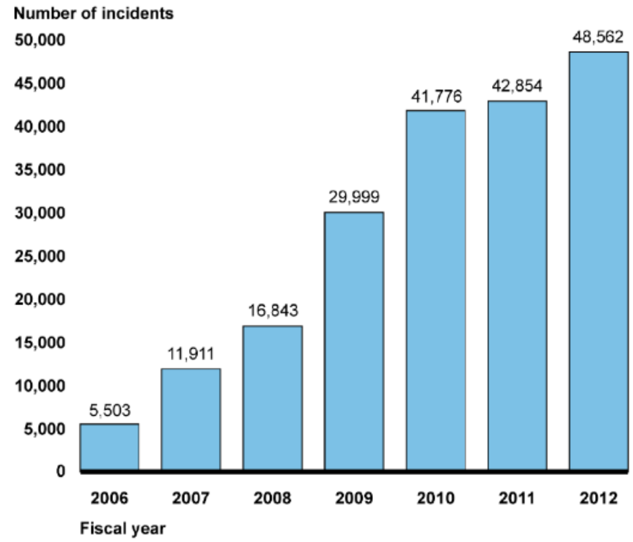
The cybersecurity challenge is illustrated on Figures 1-2 and 1-3, which show the trend of an increasing cybersecurity problem with respect to infrastructure.

FIGURE 1-2
Incidents Reported in FY12 by Target



Source: DHS ICS-CERT Monitor, Oct-Dec 2012

FIGURE 1-3
Growth of Incidents Reported 2006 - 2012



Source: GAO Report 13-187, "Cybersecurity," February 2013

The SPIDERS JCTD is an implementation of the Task Force's recommendations, which included the launch of a comprehensive program to assess and mitigate site-specific risks based on mission criticality, risk, and duration of outage. The most cost-effective risk-mitigation options are to be developed using methods such as greater efficiency, renewable sources, islanding, distributed generation, and higher commercial grid reliability where necessary. The first two of these options target fuel consumption and carbon "boot print."

Historically, it generally has been assumed that interruptions of the commercial power grid would be localized, infrequent, and of short duration. With this mentality, only the most critical facility elements were provided with backup generation or uninterruptible power supplies. However, various factors have prompted the need to reassess this assumption:

- Increased optimization and integration of utility grid operations during normal operation creates interdependency among grid operators and the potential for larger scale outages resulting from a domino effect.
- A steadily increasing percentage of less-consistent power sources (such as private renewable sources) are being integrated into grid systems.
- Internet-based control and data acquisition are increasingly integrated into a growing number of infrastructures, which also opens up the exponential growth in the number and sophistication of cyber threats to industrial control systems.
- Decades of deregulation have reduced investment in infrastructure.

These factors leave the nation's power grid (and indirectly the military's) increasingly vulnerable to sabotage or natural disasters, potentially resulting in widespread failures.

The SPIDERS JCTD explores a possible avenue for mitigating the potential effects of the military's dependence on the power grids of the Contiguous United States via the creation of microgrids within the military facilities. At their essence, microgrids are portions of the electrical infrastructure that can sustain themselves without an operational utility source. Although this definition would include any traditional emergency generator supporting a critical asset, microgrids are commonly assumed to have multiple generation resources operating in parallel to support independent loads. The goal of the SPIDERS JCTD is to show how this could be implemented at existing facilities with existing assets or existing assets plus targeted additions.

DOE Definition of Microgrids:

> A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode. (DOE Microgrid Exchange Group, 2010)

SECTION 2

2 Summary of SPIDERS JCTD Phases 1, 2, and 3

2.1 SPIDERS Phase 1 at Joint Base Pearl Harbor-Hickam, Hawaii

The Phase 1 SPIDERS JCTD focused on a circuit-level demonstration of cybersecurity and integrated renewable energy. SPIDERS completed a technical demonstration at a Joint Base Pearl Harbor-Hickam (JBPHH) critical facility from December 3 to 7, 2012. Because the JBPHH facility serves multiple areas of the installation, its continued operation during a power event is critical to avoid environmental damage. The facility's clear electrical boundaries made it a good first demonstration site. Phase 1 of the SPIDERS JCTD demonstrated a single distribution circuit serving two electrically isolated critical loads at JBPHH. Isolated generators were integrated with a small photovoltaic (PV) array within the circuit to form a small functional cyber-secure microgrid.

The Naval Facilities Engineering Command (NAVFAC) Hawaii Commanding and Operations Officer, NAVFAC Pacific leadership, Pacific Command J81, and the SPIDERS Integrated Management Team witnessed multiple tests as outlined in the approved technical demonstration test plan, which included a fully loaded black start (an emergency utility failure simulation) and a seamless transition to commercial utility power.

The controls design between diesel generators provided a novel example of paralleling discrete generators to each other and the utility source using fiber-optic control cables among multiple switches, circuits, and breakers that distribute electricity over different distribution busses.

The items below are a short list of notable achievements from the field testing:

- Power export from previously isolated generation assets to the installation's distribution system during loaded generator testing at over 1-megawatt (MW) net export (This effectively "slows the meter" during monthly generator testing or could be used to support the utility during peak demand periods. Conceptually, this technique could also be used to peak shave demand where generation sources have the appropriate permits.)
- Fully loaded black start operation by opening a substation distribution breaker (This simulates a full commercial power outage at the critical load circuit.)
- Seamless (no interruption to the critical load) paralleling to the commercial grid when the microgrid reconnects to commercial power and when proactively islanded from the utility
- Paralleling and load-sharing of diesel generators using fiber-optic cabling over long distances to simulate operation of a geographically larger microgrid
- Significant penetration from renewables during islanded operation with stable electrical performance, without the assistance of energy storage devices
- Enhanced generator testing capability under user-defined load conditions

NAVFAC Hawaii Operations Officer viewing a Human Machine Interface (HMI) of the SPIDERS Microgrid at JBPHH.

- Onsite system performance capability to capture, monitor and data log electrical stability metrics, waveform information, and other vital system statistics to support JCTD transition activities

2.2 SPIDERS Phase 2 at Fort Carson, Colorado

Fort Carson is a large 137,000-acre U.S. Army installation located near Colorado Springs, Colorado, with a population of approximately 14,000. Initially built in 1942, it is currently the home of multiple Army units including the 4th Infantry Division and 10th Special Forces Group. The Fort Carson SPIDERS microgrid demonstration focused on a cluster of seven buildings in a densely developed area of the Post. The selected buildings represented a variety of categories with respect to critical operations.

The existing medium-voltage distribution system was used to interconnect most of the generation sources and loads. Bypass breakers were added to connect the normal and emergency power sides of existing generator automatic transfer switches (ATSs) to allow microgrid generators to share excess capacity with other loads on the microgrid. Automatic synchronizers permit parallel operation of generators and with the utility. Microgrid boundary isolation and segmentation switches were added to allow the microgrid to be segmented into three distinct sections. This enables the microgrid control system to energize the microgrid gradually, thus maintaining stability in the system. In microgrid mode, the building service transformers "step up" power from the low-voltage generators to the Post's medium-voltage distribution system. In normal mode, the transformers "step down" the distribution voltage to the voltage used within the buildings.

2.2.1 PV Renewable Resource

Fort Carson has an existing 2-MW PV solar array, of which 1 MW was connected to the microgrid. The existing PV array was connected by a microgrid boundary isolation switch. No modifications were made to the PV inverters.

Fort Carson PV Array

Without a microgrid, a typical renewable energy resource such as the Fort Carson PV array would automatically disconnect from the grid during a power outage or distribution instability. This is a required safety feature because the renewable energy resource could back-feed the grid and thus energize circuits. Workers (and equipment) who may have been isolated from forward-feeding power could be exposed to back-fed energy. Formation of the isolated microgrid allows the safe reintroduction of renewable energy during a grid failure. This is done by disconnecting the microgrid from the primary grid before reconnecting the renewable resource. Careful management of the microgrid generators and loads prevents the renewable resource from creating reverse power conditions.

By establishing a microgrid, the Fort Carson PV array was able to contribute to the post's load during the simulated grid failure and significantly reduce the fuel consumed by emergency generators.

2.2.2 Electric Vehicles

Through collaboration with the U.S. Army Tank and Automotive Research and Development Engineering Center (TARDEC), the SPIDERS microgrid at Fort Carson included advanced bi-directional vehicle chargers to integrate the battery capacity of electric vehicles in both microgrid and normal operations. Five bi-directional high-capacity electric charging stations manufactured by Coritech were connected to the microgrid. The electric vehicle fleet consisted of three Smith Electric vehicles (trucks, under contract with TARDEC) and two Boulder Electric vehicles (under a Cooperative Research and Development Agreement with the U.S. Army Engineer Research and Development Center-Construction Engineering Research Laboratory [ERDC-CERL]).

Boulder Electric truck

Electric vehicles were used to support the microgrid as an energy storage resource. In addition to basic energy storage capabilities, the vehicle-charging stations also provide power factor correction support to the microgrid through reactive power injection which helps to lower the Post's utility cost.

2.2.3 Electrical Equipment

Three existing generators were directly connected to the distribution grid using bypass breakers at the automatic transfer switches. These bypass breakers allow generator power to energize both the building loads and the distribution system in parallel. Additional controllers were installed at each generator to enable load sharing and parallel operation with other generators or the utility.

Representative outdoor breaker and control equipment (Courtesy Eaton)

Multiple motor-operated sectionalizing switches were installed to replace existing manual switches, to allow dynamic system modification and buildup of the microgrid.

Creation of a microgrid typically does not involve stringing new electrical lines or significantly reconfiguring existing systems. Unless pointed out, very few observers would notice the difference before and after Fort Carson was converted to a microgrid.

2.3 SPIDERS Phase 3 at Camp Smith, Hawaii

The original building on the site of Camp Smith was Aiea Naval Hospital, dedicated in 1942. In 1949, after World War II, the hospital was deactivated and, in 1955, Marine Corps selected the location for the home of Fleet Marine Force Pacific. In 1957, Camp Smith also became headquarters for the Commander in Chief, U.S. Pacific Command. Camp Smith's main site consists of approximately 220 acres and includes multiple administrative buildings, barracks, housing units, and miscellaneous buildings.

Camp Smith has undergone significant building upgrades in the past 20 years. The electrical system consists of multiple distribution systems, serving older buildings, newer building and specialty functions.. Although the base consists of both critical and non-critical facilities, analysis conducted by the engineering team of multiple configurations and alternatives resulted in a decision to put the whole camp on integrated microgrids. This decision was driven by the following:

- The bulk of the site load comes from critical buildings; the value of energy reduction by segmenting non-critical loads during microgrid operation would be marginal.
- Because of the way the existing system is arranged, the costs associated with additional automated transfer switches and controls to disconnect non critical loads would be excessive. In the event of the decision to further reduce fuel consumption during an extended outage, it was decided to allow operators to manually disconnect non-critical loads.
- One of the significant non-critical loads is fitted with significant solar PV capability. By including the building in the microgrid, the PV resource becomes a microgrid resource. During an extended outage, internal building loads could be manually shut down while the building PV system remained on line.
- Power to the base is supplied by Hawaiian Electric Company (HECO). The base anticipates the possibility of entering into a new rate structure agreement with HECO; the base would participate in a HECO curtailment program that would significantly reduce its energy cost. This kind of "smart grid" arrangement would allow HECO to avoid new generation capital cost by requesting Camp Smith to drop off during peak demand. The JCTD microgrid design facilitates this smart grid strategy. NAVFAC Utility

Energy Management engagement on grid stability issues has been instrumental in having active HECO participation since the inception of this phase of the JCTD.

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The primary microgrid components at Camp Smith are presented in the subsections that follow.

2.3.1 New Utility-grade Generators

Multiple large new prime power stationary generator sets (gensets) were installed. The gensets meet U.S. Environmental Protection Agency (EPA) current emission standards and are designed for extended periods of operation. Most of the utility electricity produced on the island is from similar prime power units, thus the Camp Smith installation is equivalent to the local utility. These generators enable the Camp Smith microgrid system to support the local utility, HECO, with services such as demand response, load curtailment, or dispatchable power when grid-tied. They are interconnected with two of the camp's existing large gensets to provide N+1 redundancy when islanded. Camp Smith is negotiating with HECO to use the microgrid as a HECO "smart grid" resource in exchange for a modified electrical rate structure.

2.3.2 Integrated Storage and Inverter Module

The JCTD included demonstration of a "seamless" electrical energy Integrated Storage and Inverter Module (ISIM). The system supplied by GoElectric, Inc. consists of high-speed transfer switches and controls that, in the event of power failure, transfer load to batteries in less than one electrical cycle while maintaining the electrical phase. After a predetermined delay, the system starts a generator and seamlessly brings the genset on line. Among other things, this type of system enables additional smart grid interaction with the utility without impacting operations. The system may also be used for power-factor correction and peak-demand shaving, both of which provide additional cost-reduction opportunities.

2.3.3 Cyber-Secure Microgrid Control System

Camp Smith had an existing supervisory control and data acquisition (SCADA) system using primarily programmable logic controllers (PLCs). PLCs are a relatively common tool used for SCADA systems and industrial control systems (ICSs). The SPIDERS JCTD was able to effectively use the existing systems by inserting technology from IPERC (hardware and software) as a cyber-secure management system above the existing system. The IPERC technology fit well with the Camp Smith's cybersecurity approach, which is based on technology developed by a Department of Energy (DOE)[1] national laboratory team including Sandia National Laboratories (SNL), National Renewable Energy Laboratory, Oak Ridge National Laboratory, and Idaho National Laboratory. This approach is based on a strategy of assigning actors[2] to an enclave. Each enclave operates under a single authority and security policy and provides a trusted environment for actors that need to communicate. Enclaves are identified based on physical location, functional necessities, and/or security concerns. Enclaves become members of one or more "functional domains" if enclave-to-enclave communication is required to accomplish a common objective. Within a functional domain, communication

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[1] Sandia National Laboratories (SNL). 2013. Sandia Report Microgrid Cyber Security Reference Architecture. SAND2013-5472. Version 1.0, Unlimited Release. July.

[2] Actors are generators, switches, computer systems, software, and similar that have the capability of making decisions and exchanging information with other actors through interfaces (source SGIP)

has a common set of characteristics (sources, receivers, speed, and nature of data), which makes whitelisting (the practice of banning all communication except for that which is specifically allowed) much easier (SNL, 2013). During numerous cybersecurity red teaming events and demonstration assessments, other measures such as encryption were also found to provide enhanced cybersecurity above the DOD network accreditation minimums. In addition DHS's Cyber Security Evaluation Tool (CSET) proved valuable in assessing the overall cybersecurity posture of the new microgrids beyond just the network architecture measures.

Although each phase of the SPIDERS JCTD used the same cybersecurity strategy, the Camp Smith demonstration was the most extensive application.

SECTION 3

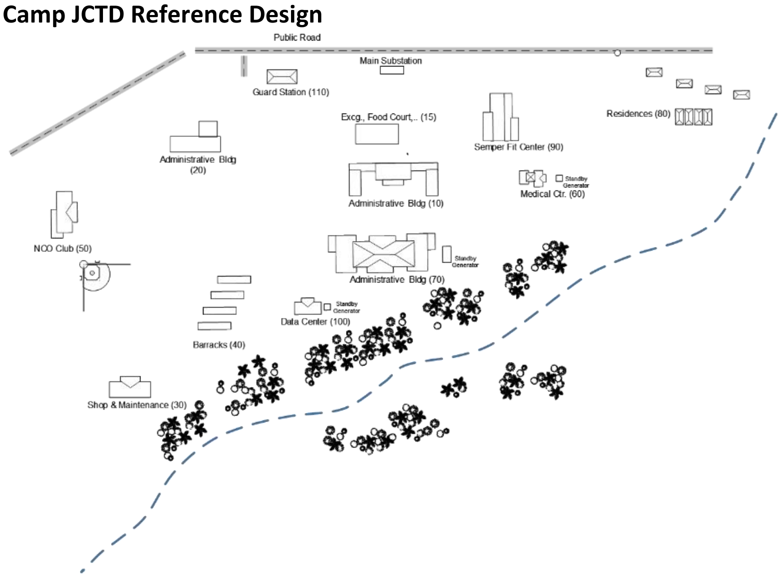
3 SPIDERS JCTD Reference Design

An objective of the SPIDERS JCTD project is to inform the public regarding the cyber-secure microgrid technology while maintaining the confidentiality of information specific to each of the demonstration sites. To accomplish somewhat mutually exclusive objectives, this report introduces a "Reference Design" military base as an example. It is a simplified composite of the three phases and exhibits significant technical characteristics of each phase. The reader may recognize superficial characteristics of an actual base, but specific information is not representative of any one location and should not be relied upon as being "real."

3.1 Camp JCTD Reference Design

The SPIDERS JCTD Reference Design (Camp JCTD) is a hypothetical moderate-sized facility in Hawaii. Camp JCTD houses command functions, administrative operations, a data center, maintenance facilities, and a small medical center. Along with some miscellaneous buildings and functions, Camp JCTD includes onsite barracks and residences to accommodate personnel. No mission-focused manufacturing, maintenance, port/marine, or other such large energy-consuming operations are conducted at Camp JCTD. Figure 3-1 shows a sketch of the buildings considered in the design.

FIGURE 3-1
Camp JCTD Reference Design

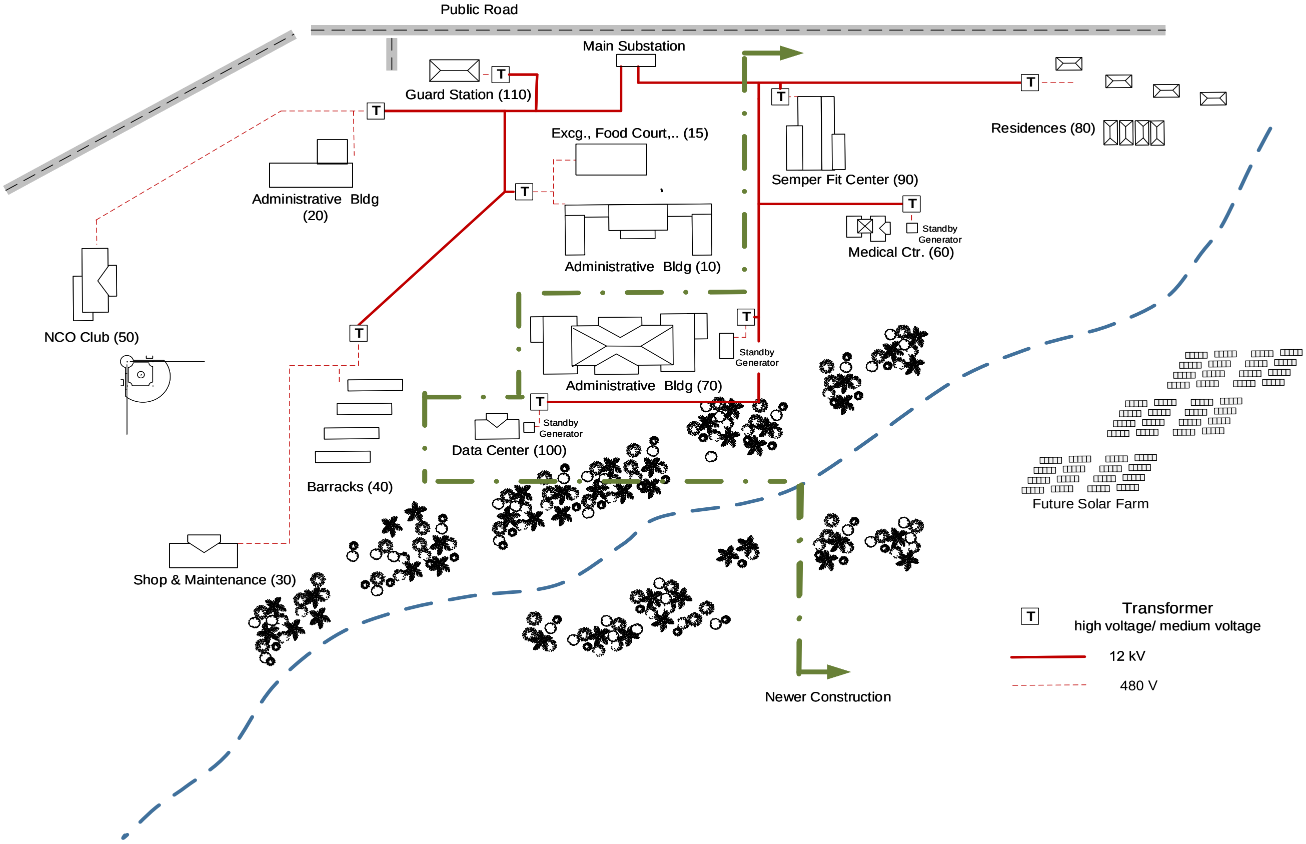


3.1.1 Background:

Most of the significant initial construction for Camp JCTD occurred in the 1940 and 1950s during and just after World War II. A second wave of construction occurred around 2000. Camp JCTD has essentially two high-voltage distributions systems. The west high-voltage distribution system was constructed during the initial construction phase. Both the newer east high-voltage distribution system and the original west system are 12,000V (Figure 3-2).

The second wave of construction was highly focused on energy and most of the buildings constructed during this time are Leadership in Energy and Environmental Design (LEED) certified. Typically, a microgrid design would begin with a base-wide energy assessment and energy conservation program. A recent energy audit had been performed under NAVFAC direction, and most of the easy-to-implement low-cost or no-cost energy conservation measures had been implemented. Consequently, the SPIDERS project was able to start immediately with microgrid design.

FIGURE 3-2
Camp JCTD Pre SPIDERS Electrical Distribution System



3.1.2 Camp JCTD Data

Camp JCTD is approximately 200 acres in size. The local climate is very mild with little seasonal change. Except for hot water, heating requirements are minimal. Cooling loads exist year around, although in the winter much of the cooling can be accomplished by natural ventilation. Figure 3-3 shows average temperatures.

Because Camp JCTD's energy consumption is influenced by its air-conditioning loads and the microgrid includes a solar PV resource (with plans for a large solar farm in the future), solar radiation and cloud cover are important factors. Figure 3-4 shows seasonal precipitation and correlation with temperature.

FIGURE 3-3
Weather Data

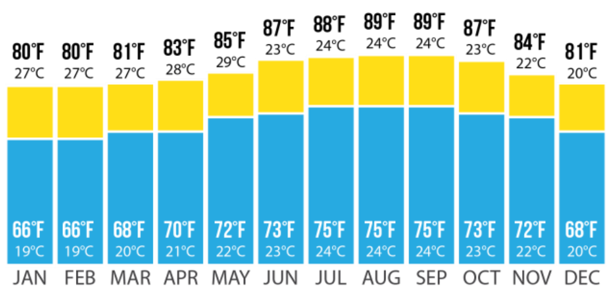
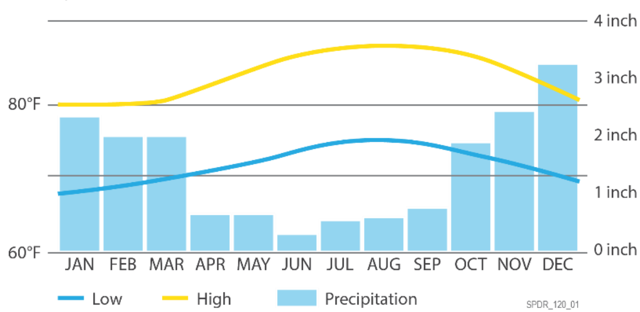


FIGURE 3-4
Precipitation Data



http://www.usclimatedata.com/climate/honolulu/hawaii/united-states/ushi0026

3.1.2.1 Electrical Rate Schedule

Connection	$400/month
Demand	$21.00/kilowatt (kW)/month
Energy	$0.15/kWh

Determination of Demand: The maximum demand for each month is the maximum average load in kW during any 15-minute period as indicated by a demand meter. The billing demand for each month is the highest of the maximum demand for such month, or the mean of maximum demand for the current month and the greatest maximum demand for the preceding 11 months, whichever is higher.

3.1.2.2 Existing Electrical Site Load

Like many installations, Camp JCTD does not have an electrical Advanced Metering Infrastructure (AMI). The primary meter is at the utility connection. Typical load profile over a year is shown on Figure 3-5. Figure 3-6 shows a typical peak season (August) single-day demand profile.

FIGURE 3-5
Camp JCTD Meter Data

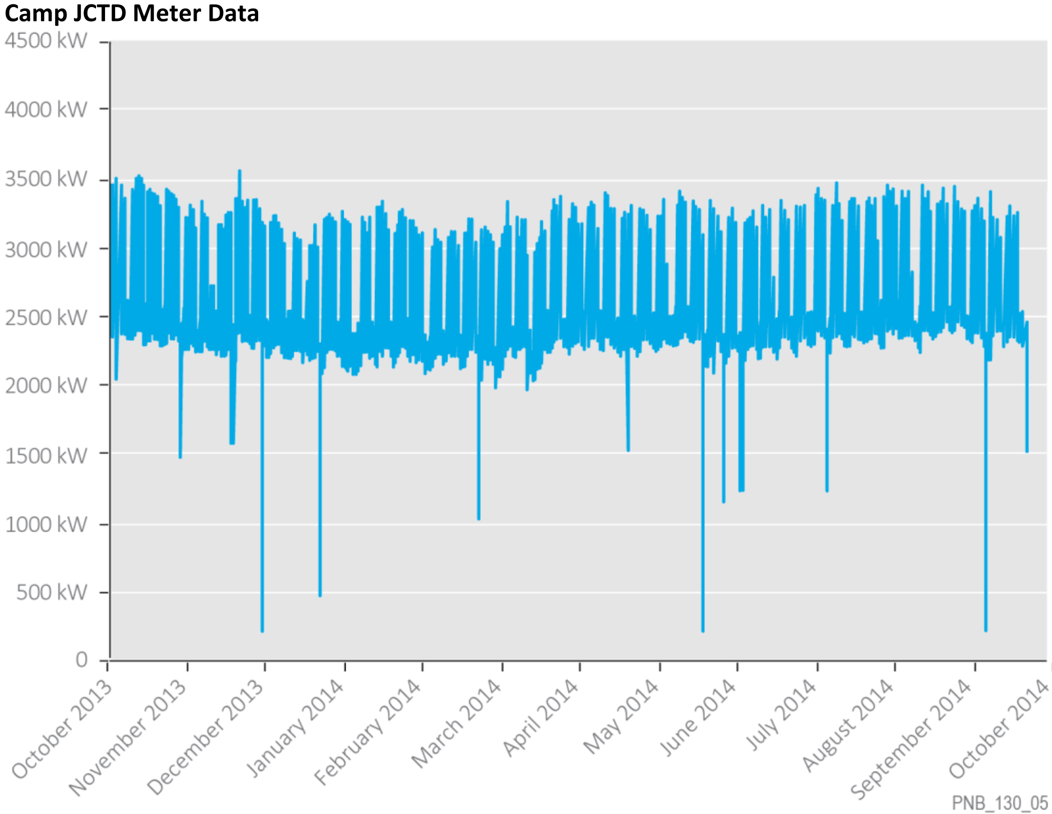
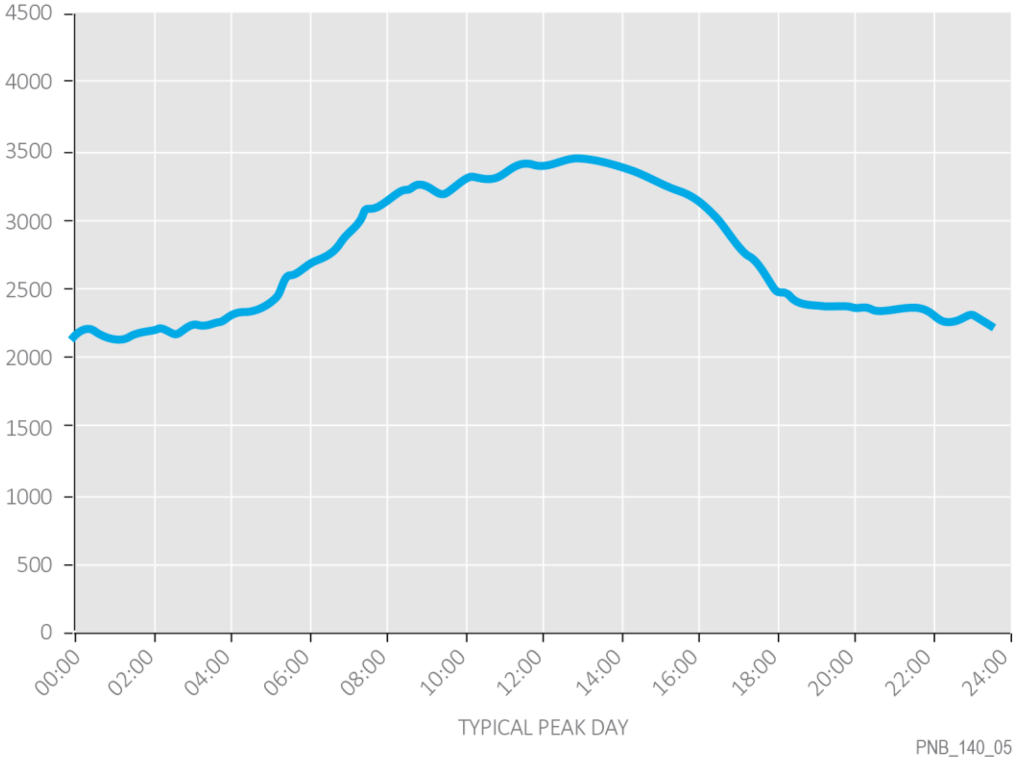


FIGURE 3-6
Camp JCTD Typical Peak Season Single-day Demand Profile (kW)



Based on the annual weather data and annual utility data, August and September are generally the months when peak demand is set; they are also the months when precipitation is low. The Camp JCTD analysis team believes demand peak is set by cooling system loads on days of bright sun, consequently the team believes a future solar farm could be a significant tool for managing the site electrical demand charge. This will be discussed later in the report.

3.1.2.3 Site Electrical Building Loads

Although Camp JCTD does not have an AMI system, a PNNL team estimated the individual building loads during the energy audit it conducted approximately 3 years ago. The PNNL team used the Facility Energy Decision System (FEDS) tool combined with audit observations to categorize buildings; the building categories were used to estimate building electrical loads. Table 3-1 shows the buildings on Camp JCTD and their estimated annual energy loads. For reference, the table also shows the average energy intensity per square foot for each building (calculated from the energy use estimate and building area) and estimated energy use as a percentage of total site for each building.

TABLE 3-1
Camp JCTD PNNL FEDS Data

Building Name	Building No.	Area (ft^2)	Annual Electrical (kWh)	Average Energy Intensity (kWh/ ft^2/ yr.)	Percent of Total Site
Administration Building	10	240,000	3,960,000	16.5	17%
Exchange, Food Auditorium	15	75,500	1,887,500	25.0	8%
Administration Building	20	97,000	2,536,507	26.1	11%
Shop	30	24,000	180,000	7.5	1%
Barracks (total of 4)	40 Series	48,000	384,000	8.0	2%

TABLE 3-1
Camp JCTD PNNL FEDS Data

Building Name	Building No.	Area (ft^2)	Annual Electrical (kWh)	Average Energy Intensity (kWh/ ft^2/ yr.)	Percent of Total Site
NCO Club	50	7,000	154,000	22.0	1%
Medical Center	60	80,000	2,000,000	25.0	8%
Administration Building	70	230,000	8,280,000	36.0	35%
Residences (total of 8)	80 Series	14,400	122,400	8.5	1%
Fitness Center	90	29,900	777,400	26.0	3%
Data Center	100	35,000	3,500,000	100.0	15%
Guard Station	110	3,900	93,600	24.00	0%
Total Site Annual			23,875,407	kWh/year	

ft^2 = square foot (feet)
kWh = kilowatt-hour
kWh/ ft^2/yr. = kilowatt0hours per square foot per year

3.2 Microgrid Conceptual Design Development

Under direction of the SPIDERS JCTD Integrated Management Team (IMT) the initial conceptual design for Camp JCTD was developed by a concept design team consisting of representatives from Camp Smith, Pacific Command, SNL, and other SPIDERS contributors. The conceptual design process generally followed the Energy Surety Design Steps outlined in the SNL course book *Fundamentals of Advanced Microgrid Evaluation, Analysis, and Conceptual Design*.

3.2.1 Boundaries

As a first step, in keeping with the SNL process, the boundaries of the system were established. For the SPIDERS program and in this reference design case, the boundaries are assumed to have previously been established. In actual situations the establishment of microgrid boundaries and perhaps dividing the "system" into multiple microgrids can significantly influence the solution (both technical and cost). Although not part of SPIDERS JCTD scope, establishing proper boundaries is a critical part of a microgrid conceptual design process.

3.2.2 Building Classification

Next, the design team identified and classified critical loads, interdependency, and locations of electrical equipment. This was done via a structured process with stakeholders. Stakeholder meetings were facilitated by the conceptual design team.

As part of the process, the Camp JCTD buildings/assets were classified into one of the following categories:

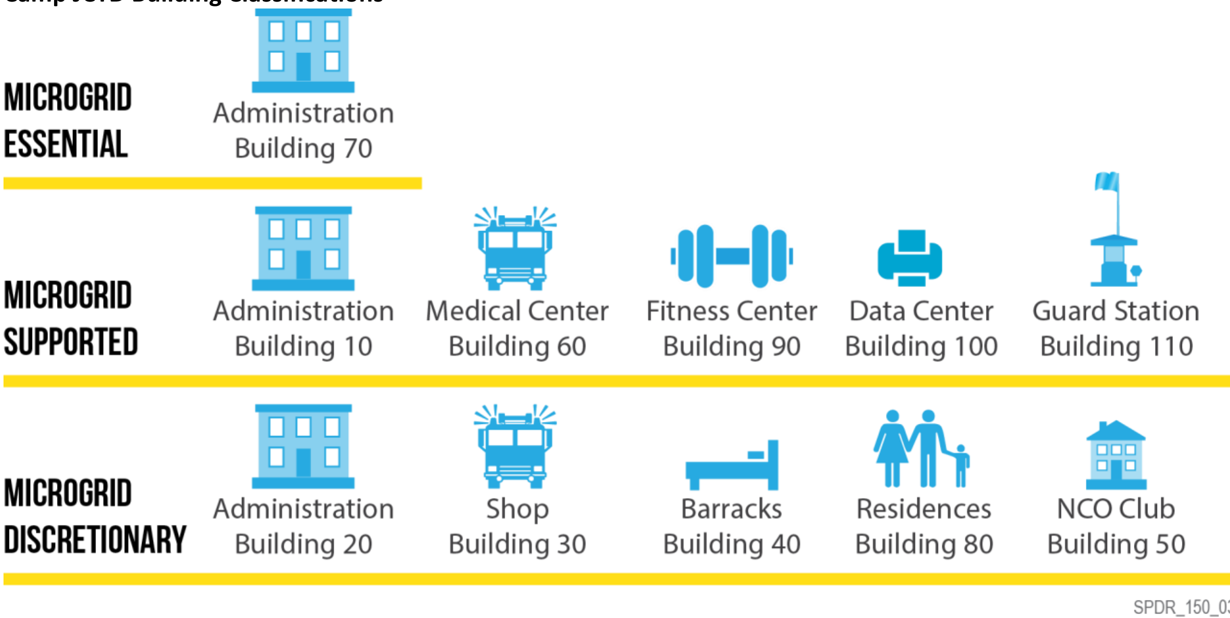
- **Microgrid Essential** – These building or assets are required to support the microgrid as designed, and could include buildings with significant backup generators that support the microgrid, distribution-level PV arrays, or other supplemental resource. At Camp JCTD, one building was classified as microgrid essential, as shown on Figure 3-7.
- **Microgrid Supported** – These buildings or assets are connected to the microgrid and their infrastructure is designed such that their loads are served by the microgrid under most conditions (utility managers can always decide to manually disconnect a building if deemed necessary, but the design assumes these building loads are always carried by the microgrid). These facilities may or may not have generators; if

they do, the generators are not required to be operating to keep the microgrid stable (such as Building 60, Medical Center). A prime example of this would be facilities with only renewable generation assets (such as Building 90, Fitness Center).

- **Microgrid Discretionary** – These buildings have the ability to be connected to the microgrid, but the can also be isolated at the discretion of the installation commander. Ideally, these buildings have automated switches for connecting/disconnecting from the microgrid, but this could be a manual function and still serve the purpose.
- **Non-microgrid** – These buildings are outside the microgrid boundary.

The stakeholder final classification of buildings at Camp JCTD is shown in Figure 3-7.

FIGURE 3-7
Camp JCTD Building Classifications



3.2.3 Defining Critical Infrastructure

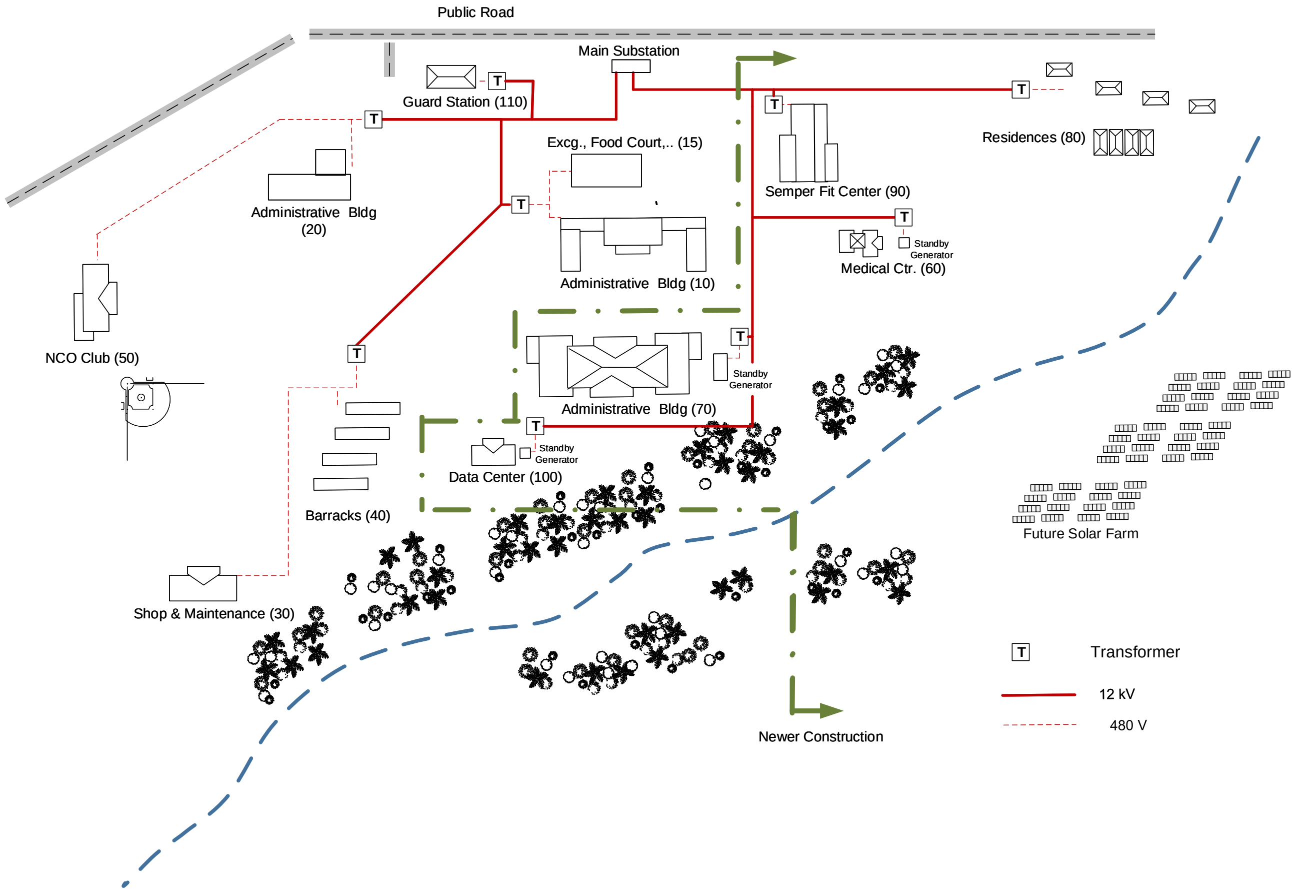
Once buildings were classified, the concept development team worked with the Camp JCTD engineer to research the site's electrical distribution system. The relationship of all infrastructure to critical buildings and critical loads was used to identify critical infrastructure.

[Note: For Camp JCTD, the SPIDERS JCTD scope defined critical infrastructure to be on the base and only electrical. However, one may imagine a situation where a critical building "X" depends on a non-electrical infrastructure service "Y", perhaps a natural gas pressure boosting station located offsite. Service "Y" then becomes critical even though it is not connected to a critical building.]

Electrical routing paths and a map of building locations was developed for Camp JCTD. Figure 3-8 is a high-level map of the building existing physical and load locations along with a general concept of the pre-SPIDERS high-voltage distribution system.

The team identified critical distribution systems, generators, switches, breakers, and similar, as noted on Figure 3-8.

FIGURE 3-8
Pre-SPIDERS Electrical Distribution System



Note: The line separating newer (eastern) construction from the legacy (western) construction. This demarcation ultimately influenced the design concept.

3.2.4 Design Basis Threats

Following stake holder meetings and development of building classifications and load map, attention was turned toward establishing the Design Basis Threat (DBT) and performance goals. This was done again with stakeholder teams facilitated by the conceptual design team. DBT development included interviews and discussion with the local utility and presentation of utility information to the Camp JCTD stakeholder team.

Based on discussions with city, county, local utility, Camp JCTD command, and Camp JCTD engineering, DBTs were identified. DBTs include hazards such as hurricane, flooding (resulting from excessive rain), local utility service risk, and cyber-attacks on the power grid. These DBTs were ranked, as shown in Table 3-2.

TABLE 3-2
Camp JCTD Design Basis Threat Analysis

Design Basis Threat	Probability	Impact
Flooding	Red	Red
Cyber Attack	Red	Red
Hurricane	Red	Yellow
Utility Outage	Red	Yellow
Earthquake	Yellow	Yellow
Volcanic Eruption	Yellow	Blue

Legend:
High — Red
Medium — Yellow
Low — Blue

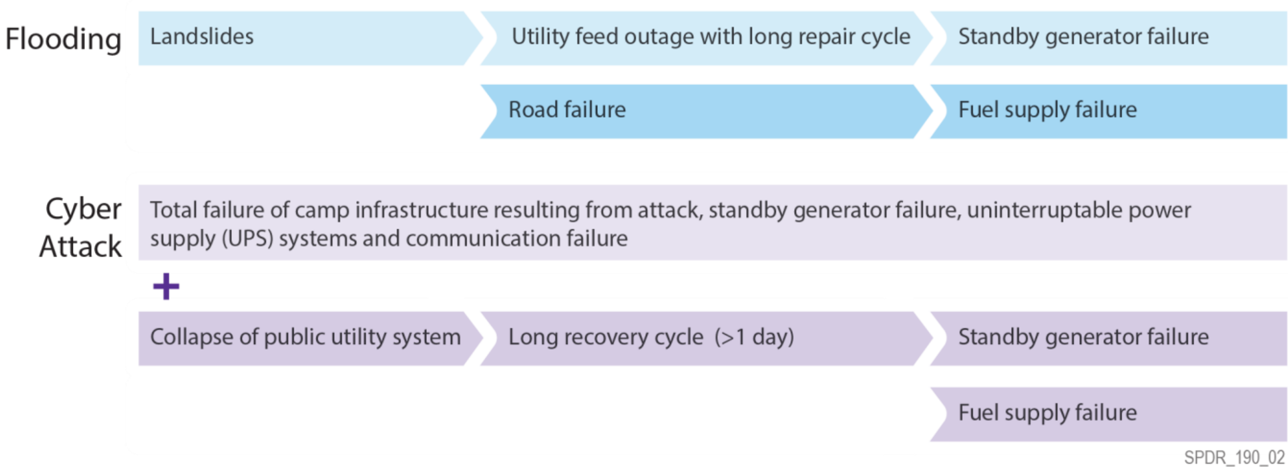
In addition to cyber-attack, the following assumptions were associated with DBTs:

- Torrential rain associated with tropical storms (not necessarily hurricanes) are common. Because Camp JCTD sits on a hill, landslides caused by flooding could be a serious event.
- Hurricanes are common but utility systems in Hawaii are well hardened against the wind. Impact is expected to be medium.
- Utility outages are common in Hawaii, but are typically isolated and usually relatively short duration.
- Small earthquakes are common, but large events are few and systems are designed to be resistant.
- The probability of volcanic eruption is low on the older islands. On islands with active volcanic activity, eruptions cause localized events.

3.2.5 Performance Goals

Performance goals were developed with Camp JCTD executives, the Camp JCTD engineer, and local electrical utility. Final performance goals were ultimately determined based on the requirement to maintain the base's mission integrity. In the case of Camp JCTD, the most important utility system performance goal defined was the ability to operate microgrid-essential and microgrid-supported buildings for up to 5 days with one emergency refueling and up to 3 days without any refueling capability. (Because of where Camp JCTD is located, it was anticipated that flooding could wash out roads, and up to 2 days after the flooding event would be needed for temporary repair or a workaround solution.)

3.2.6 Performance Risk Vectors



For each of the top DBTs (those having a high impact, as shown in Table 3-2), the concept design team in conjunction with the base engineer and local utility engineer examined "Risk Vectors." It became apparent that the camp had insufficient generating capacity and insufficient fuel storage to withstand an extended outage. Highest level risk vectors were identified as follows:

3.2.7 Develop High-level Options for System Modification and Hardening

The Camp JCTD identified two overarching issues that threaten the performance goals: generator capability and fuel supply.

3.2.7.1 Generator Capability

Standby generators are generally designed for short operation periods; continuous operation is not intended and can result in generator failure. Although any specific generator may not fail if each building is served by a generator and generators are not interconnected to provide backup, it is probable that a single generator's failure may jeopardize the mission.

Some of the Camp JCTD buildings identified as critical did not have standby generators.

3.2.7.2 Fuel Supply

Existing generators have fuel capacity for only a few hours and the camp does not have a large-capacity fuel storage system. If roads become impassable during a DBT event, fuel delivery could be delayed and generators will begin shutting down within hours.

The team identified the following needs:

- Add generator capacity
- Interconnect generators to provide redundancy
- Add significant storage capacity

The following three high-level options were considered:

1. Add building-dedicated generators to unprotected buildings, add fuel storage systems at each generator, and construct an electrical interconnection system including an interconnected control system among the standby generators.
2. Same as Option 1, but replace the need for the interconnecting electrical system with a portable backup generator that could be moved around to serve as a backup to the individual standby generators.
3. Add a central generator set to support unprotected buildings and backup protected buildings. Include a central fuel storage system. Distribute power using the existing medium-voltage system.

3.2.8 Evaluate Options for Performance and Cost

The high-level options were evaluated relative to their performance; that is, their ability to successfully handle DBTs, as well as their performance and cost. As part of the performance and cost evaluation, potential operating cost savings and other “non-cost” benefits were evaluated and included opportunities for demand reduction and energy reduction as part of the evaluation. This was an iterative approach that included circling back to options and developing hybrid options.

3.2.9 Design Solution

Ultimately the evaluation process lead down the following logic path:

1. Existing generators were standby generators and had run-time design limitations. In some cases, the generators were very old and unreliable. Continuous operation for 5 days or more could not be assured. Camp JCTD needed new, continuous-service generators capable of meeting all microgrid-supported design loads. There was also a financial incentive to use generation sources at Camp JCTD during grid-tied operation to provide ancillary services to the utility.
   a. EPA requires stationary generators to meet Tier-4i standards if used in non-backup power modes
   b. Existing standby generators could be used to supply N+1 redundancy to the central system when backup power is required, thus the central system did not need to incur N+1 redundancy cost.
2. Fuel was minimal. Consequently, a new onsite fuel storage facility would be needed.
   a. Natural gas was not an option. The supply system did not currently exist and would be vulnerable to the same threat vectors as the electrical system.
   b. Liquid natural gas (LNG) storage was eliminated as an option:
      i. Handling infrastructure for LNG was not locally well developed.
      ii. Camp JCTD is next to a residential community, safety risks of LNG storage were a concern.
   c. Existing generators are diesel-fired. Introducing generators fired by a new fuel would require new storage systems.

   d. Diesel was selected as the best fuel source. In Hawaii, diesel is a primary fuel source, supplying over 70 percent of the islands' energy. The fuel is readily available in large quantities.

3. Camp JCTD has plans and space for a future solar PV farm. By planning the solar farm into the microgrid as a "Mission Essential" element, peak energy consumption could be reduced during full solar hours.

4. The most cost-effective strategy for engaging the essential, supported, and discretionary elements of the Camp JCTD microgrid is a system of automated "sectionalizing" switches at the distribution voltage system level.

   a. The distribution voltage system includes the "old system" and "new system."

   b. A conceptual strategy was established whereby sectionalizing switches would automatically disconnect microgrid discretionary buildings if load shedding was required, either individually or in groups. If in groups, members of a group could be manually disconnected from the group and the remaining members could be reconnected by manually closing segments of the sectionalizing switch.

3.3 Camp JCTD Post Microgrid Design

As a general approach, because the SPIDERS JCTD is used to investigate the implementation of microgrids at existing facilities, an implicit requirement is that the system needs to be as unobtrusive as possible within the existing infrastructure. This is necessary to avoid cost and disruption. The requirement has been extended by the project team to include the ability to completely revert back to non-SPIDERS operation by turning off SPIDERS mode on the graphical user interface (GUI) of the microgrid control system. Turning off SPIDERS mode on the GUI prevents the supervisory controllers from making decisions or implementing control actions. Thus, the installation of a SPIDERS system does not degrade the existing system in any way. With this "**Do No Harm**" philosophy, the SPIDERS system is designed to "lay over the top" of the existing system instead of being a wholesale replacement of it. In addition to facilitating the transition to a SPIDERS-type system, this also allows the continued use of a traditional transfer switch-based isolation system to be the default mode for compliance with life-safety codes should the SPIDERS control system fail for any reason.

The SPIDERS microgrid solution is based on the following concepts:

Typical of sectionalizing switch

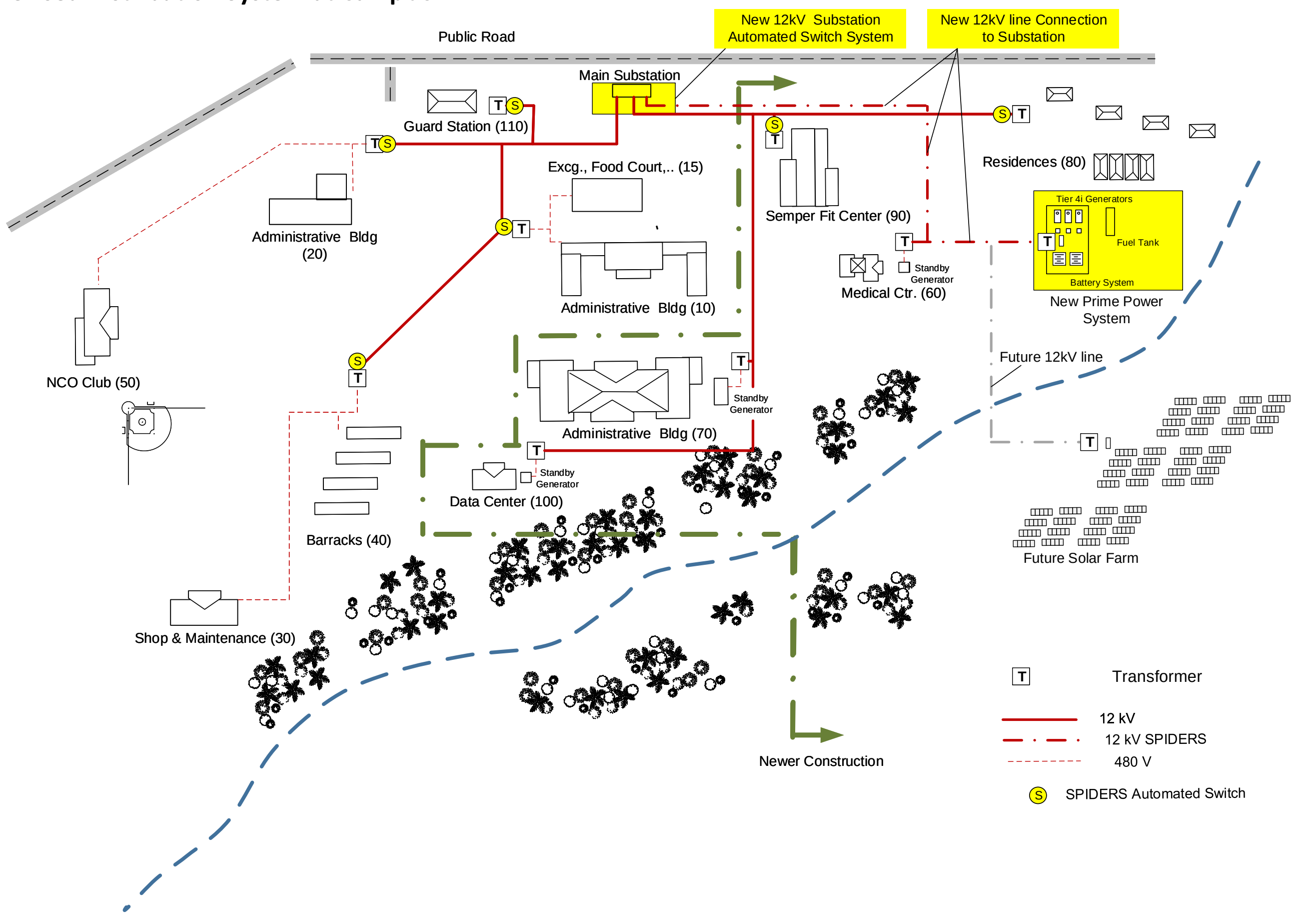
- Use of medium-voltage switching for microgrid segmentation and building
- Use of low-voltage bypass breakers near existing generator ATSs to minimize disruption of the power to facilities during construction (compared to alternative approaches) and allow for maintaining the current backup power operation as the default response to power outages
- Integration of a neutral deriving transformer (NDT) as a ground reference for the microgrid when islanded from the utility and to support single-phase loads within the medium-voltage distribution system while operating as a microgrid
- Continuous availability of adequate spinning reserve in the central prime power diesel generators to carry the design load should PV and/or stationary batteries trip off line

3.3.1 Medium-voltage Distribution and Generating System Modifications

Figure 3-9 shows physical locations of new assets and revisions to the high-voltage distribution system for Camp JCTD.

FIGURE 3-9

Revised Distribution System at Camp JCTD



Segmenting switches, which are critical to the operation of the microgrid, are shown on Figure 3-9. Note the following on Figure 3-9:

1. A “prime power” generator pad has been added to the east of the medical center and a new underground medium-voltage feeder has been added to connect the new generator pad with the existing camp substation and medical center. The Medical Center is supported by the microgrid but not essential to operation.
    a. Camp JCTD had essentially two distribution systems, both starting at the substation. The lowest cost and least complex solution for adding new electrical generation was to connect new generation at the substation and use new substation breaker controls and sectionalizing switches to segment the existing distribution when in microgrid mode.
    b. If the generators had been connected to the eastern distribution system (which was physically closer) a failure of the eastern system could disable the western distribution system.
    c. The generator pad includes a microgrid battery system which is continuously connected to the Medical Center. Manufactured by GoElectric, Inc., the system includes controllers and hardware for “seamless” transfer to generator power.
    d. Upon power failure, the batteries provide energy to the Medical Center while the generators ramp up, synchronize, and stabilize.
2. The Medical Center was disconnected from the eastern high-voltage distribution system and is now connected to the new prime power line. A technology demonstration goal of the SPIDERS JCTD was to

show capability to protect critical loads with near UPS power quality. In the event of power loss, the GoElectric system supports the Medical Center load in approximately 1/4 cycle and maintains its operation until the prime power is running. This system demonstration could apply to any load not needing true UPS-quality power (for example, not a computer). By connecting the Medical Center, the design team hoped to reduce potential damage to medical equipment such as a magnetic resonance imaging machine.

3. The future PV system will be connected at the new generator pad.
    a. The microgrid be used to stabilize the PV system's variations.
    b. PV power can be integrated with the prime power system operation

3.3.2 Concept of Operations

The first principle of the SPIDERS microgrid Concept of Operation is to **"Do No Harm."** Upon a power-failure event, each building or load responds as designed in the pre-SPIDERS mode. The exception is the Medical Center, which is a special part of the JCTD; its response is discussed below. Upon loss of utility power, Camp JCTD operations have the following responses:

- **First 1 second**
    - **Data Center Building 100.** The Data Center is equipped with a kinetic energy UPS. The UPS system is effectively in series with the grid power; upon loss of power, stored kinetic energy continues to drive the unit's internal generator without interruption for a short duration. The Data Center is a Mission Essential facility that also has a backup generator. Upon loss of power, the building's ATS initiates the generator and, once up to speed, the generator provides power to critical loads within the Data Center. The Data Center continues to operate on generator power until internal control logic "sees" an extended period of electrical supply stability at the Data Center feeder. The SPIDERS microgrid has no impact on the Data Center's initial response.
    - **Fitness Center (Building 90) Solar System**. Electrical codes require solar power to immediately drop off the utility distribution system if voltage or frequency is outside certain boundaries. This is a safety requirement to avoided back-feeding the system and potentially injuring utility workers. When a loss of supply voltage is detected, existing relays in the solar power control systems drop the Fitness Center's panels off line. As is typical with these systems, the Fitness Center PV systems will begin coming back on line in a predetermined sequence approximately 3 to 5 minutes after the supply power has been restored and stabilized. The SPIDERS microgrid has no impact on the Fitness Center solar system.
    - **New Medium Connection**. The new line is disconnected from the utility substation and the Medical Center and prime power system become a sub microgrid within Camp JCTD.
    - **Medical Center (Building 60)**. The SPIDERS JCTD targeted the Medical Center as a demonstration example for newer technology. The Medical Center has an existing standby (emergency) generator. Typically, in the event of grid failure, the Medical Center generator would be up and running in less than 30 seconds. While the Medical Center experiences a very short period of "black," it also experiences potential power surges and sudden frequency shifts.

      However, the SPIDERS microgrid demonstrates a new operation. The Medical Center is connected to a new resource, the microgrid prime power station, which consists of multiple generators and a large battery system with high-speed "seamless" capabilities. With the new system, upon loss of utility power, the Medical Center is connected to a sub-microgrid supplied by battery power from the GoElectric system. The Medical Center has no noticeable loss of power. The battery is sufficient to power the Medical Center until the generators are up and running. Within the first minute, the generators are in phase and take over supplying power to the Medical Center. Although equipped with an emergency generator, the facility does not recognize a loss of power and, therefore, the facility's emergency generator will not be required to respond. If, however, the batteries and prime power generators fail, the Medical Center standby generator will come on line as usual.

- **Minute 0 to 1.** Except for actions in the first second described above, Camp JCTD sits black, waiting for grid power to return.
- **Minute 1 to 10.** After a predetermined wait period existing standby generators connected to the Administrative Building (Building 70) are started. Once generators are up to speed, Building 70 disconnects from the medium-voltage system and connects to generators.

  The remainder of Camp JCTD stays "black" and in pre-SPIDERS mode and would remain "black" until utility power returned.
- **Minute 10 to 15.** The sub-microgrid formed with the Medical Center is extended. Formation of the microgrid can be manually started at any time by the camp engineering operations. In this automatic mode, the microgrid waits 10 minutes for return of utility power. The microgrid is formed as follows:
  - New breaker controls at the substation disconnect Camp JCTD from the local utility's power grid.
  - Simultaneously, new automation on distribution switches open and disconnect the camp's subsections from the distribution system.
  - After disconnecting the camp from the utility and disconnecting the high-voltage distribution system from loads (a process that takes less than 10 seconds), the new prime power supply line is reconnected at the substation (Note: it had been disconnected in the first <1 second). The east and west distributions are energized. The Medical Center (Building 60) is connected to the prime power station and Administration (Building 70) is added to the microgrid. The building 70 generators provide N+1 backup to the prime power generators, as a result building 70 is microgrid essential. The Data Center (Building 100) remains disconnected using existing standby generation. The design team did not want to integrate the Data Center generators as an essential element of the microgrid.
  - In an orderly fashion (at the option of the Camp JCTD engineer), the opened segmenting switches are closed and the following buildings brought back on line using prime power:
    - Guard Station (Building 110)
    - Administration (Building 10) and the Exchange (Building 15)
    - Administration (Building 20)
    - Fitness Center (Building 90) (solar power comes on line after 3 minutes)
  - After each load is added, the system checks itself. If all is in order, standby generators at the Data Center and Administration (Building 70) are allowed to drop off during the efficiency optimization phase.
  - Camp JCTD is in full microgrid mode. Discretionary loads are added manually at the option of the Camp JCTD engineer. For long outages, it is anticipated that certain loads within buildings may be shut down, thus freeing capacity for discretionary loads.

When the future solar farm is operational, it will be integrated into the system as the microgrid is formed.

When utility power is returned and stable, the operators will begin microgrid shutdown. The prime power system will synchronize to utility power, the substation will connect to the utility, and the prime power system will begin shutting down. Any solar power available will remain on line as usual.

3.4 Microgrid Cybersecurity Controls Overview

The fundamental SPIDERS JCTD concept stems from DOE's "Energy Surety Microgrid" approach to energy assurance. Distributed generation and storage are placed on the load side of the grid and on a local basis;

storage and generation are matched to the critical loads. As with traditional backup power, when a utility grid outage occurs, the local single building systems “island” and detach from the base high-voltage distribution system. The difference in the microgrid mode is that the complete base detaches from the utility grid; after the base is detached, the individual single building systems reattach to the base distribution system.

3.4.1 Microgrid Control

As discussed, this project was designed to minimize cost and retain functional existing infrastructure. The cyber-secure microgrid control system was, therefore, designed to “lay over the top” of the existing electrical and control systems. Individual control systems for the microgrid components (for example, some generator controls, individual breaker trip units, and automatic low voltage transfer switches) were present prior to the start of the project start. However, in many cases they could not be controlled as a single coordinated system. Where necessary, components were upgraded with the addition of commercial off-the-shelf (COTS) controllers that also provided the ability to communicate and accept commands from a supervisory control system.

The SPIDERS control system used COTS control elements. Control system design support and master controllers were provided by IPERC. These component controllers were overlain with a master controller to provide microgrid supervision, management, and cybersecurity. The component-level controls continue to operate autonomously, but the overall coordination and sequencing commands originate with the master control system. This allows components to respond extremely quickly in response to instantaneous demands or electrical safety issues while still being managed as part of the coordinated microgrid. The SPIDERS control system is accessed through an HMI and operated through a GUI. The GUI allows the system operator’s access to monitor and control the system, and download historical information.

Example secure microgrid charging station
Image Courtesy IPERC

Unlike traditional centralized SCADA systems, the SPIDERS supervisory control is provided by a community of distributed intelligent power controllers with embedded software that can be installed on a wide range of power sources, distribution gear, and/or end loads that make up a microgrid.

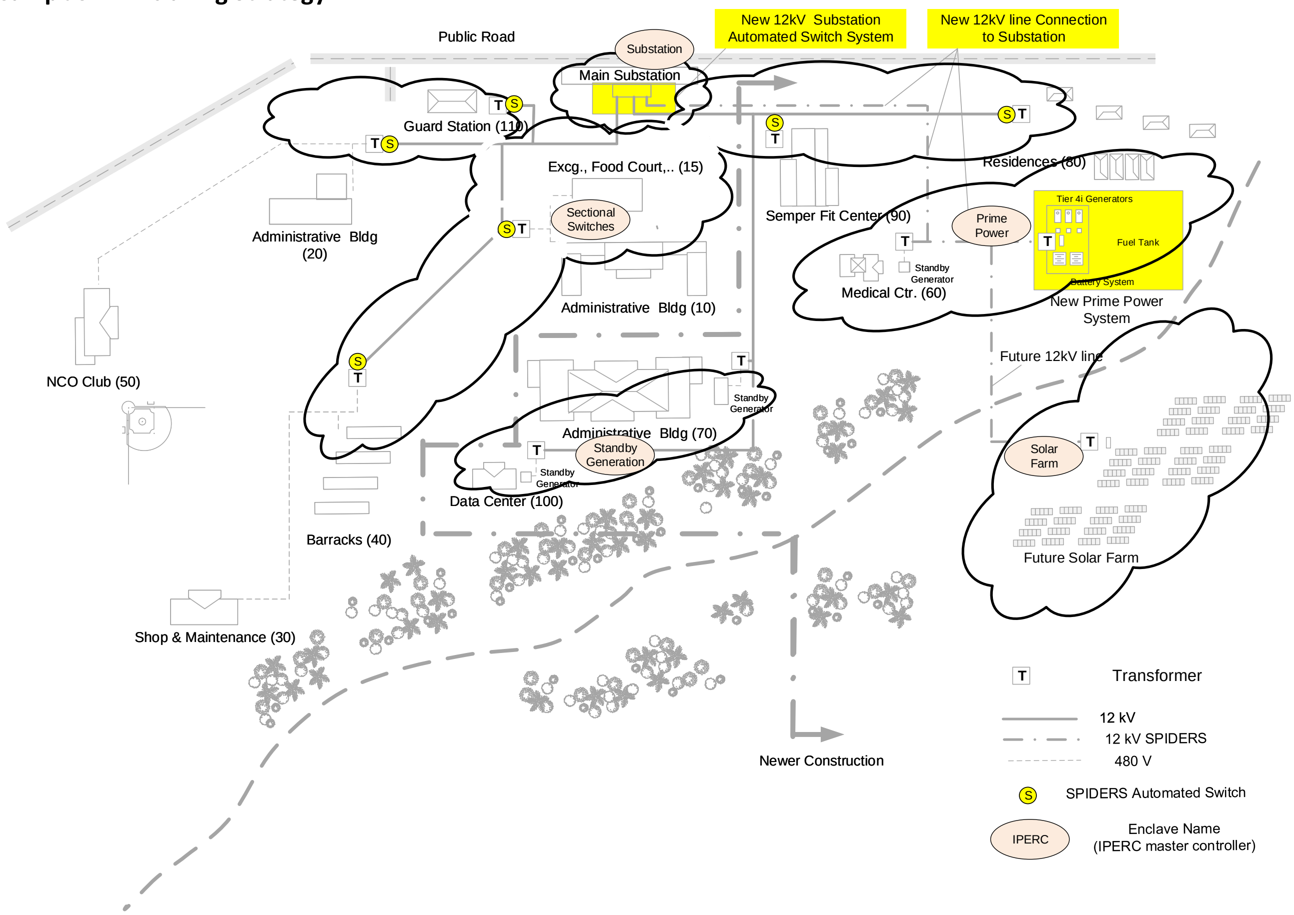
Network elements are connected with a common communication system, creating a responsive, resilient “collective intelligence” that continuously optimizes performance. The system employs a set of general rules of operation that accommodate the overall desired behavior of the system during normal operation and also when contingencies or equipment failures occur. The system can, therefore, accommodate changing conditions of the equipment without the need to be reprogrammed. This also eases the adaptation to arbitrary additions and deletions of equipment and facilitates incorporating algorithms for increased sophistication and inevitable load growth.

3.4.2 Cybersecurity Enclaves

As previously noted, the SPIDERS cybersecurity approach makes use of concepts developed by collaboration among the DOD National Laboratories. This approach employs the practice of forming enclaves and is described in the SNL Report “Microgrid Cyber Security Reference Architecture” (SNL, 2013).

The technology was applied at Camp JCTD by dividing the microgrid system into groups of actors and segregating these groups into “enclaves.” Figure 3-10 shows the enclaving strategy for Camp JCTD.

FIGURE 3-10
Camp JCTD Enclaving Strategy

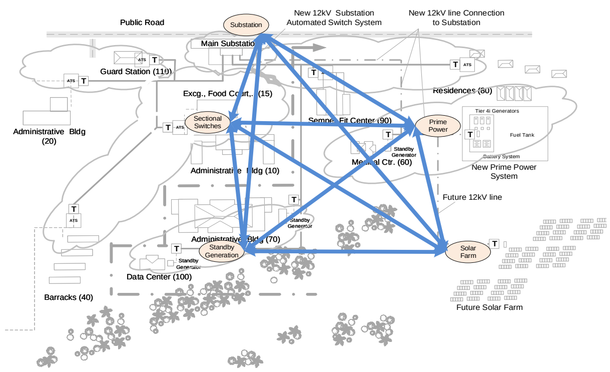


Enclaves are generally shielded from any outside communication; communication with other enclaves is only through a highly secure device. In the Camp JCTD case, the device was an IPERC controller specifically designed for secure control of microgrids. Communication between enclaves and with the outside world (if allowed) is “denied by default.” That is, unless a specific communication is allowed (“whitelisted”), it is denied.

Within an enclave, communication is unrestricted among actors. Within the enclave, vendor-supplied control systems are allowed to operate equipment and standard ICSs manage and control processes and operations.

Generally, enclaves are created from actors that have a logical need to work together or are in physical proximity. Enclaves generally work autonomously; it is a design objective to minimize the need for communication between enclaves. Whitelisting communication becomes relatively easy because the need to communicate is limited.

Limiting communication outside of an enclave reduces the need for communication bandwidth. The SPIDERS team’s analysis found **that limiting communication bandwidth within the network is an effective strategy for reducing vulnerability to denial-of-service cyber-attack**.



Inter-Enclave Communication

At Camp JCTD the IPERC master controllers are each capable of full system control and all communicate with each other. This allows a failed unit to be replaced by any of its equals. The inter-enclave communication is highly flexible (although whitelisted and possibly bandwidth restricted).

3.4.3 Cybersecurity

As control systems naturally evolve to become more like enterprise information technology systems, the security of those controls must also evolve. The SCADA systems that have been used over the last several decades were not developed to handle the potential cyber-attack threats of the current era. Nonetheless, an enormous existing infrastructure is in place that needs to be protected; protective measures are being widely applied across industry and government. This is primarily being accomplished by overlaying security measures on top of existing systems. A good starting point for implementing security measures can be the use of the following security guidelines:

- **National Institute of Standards and Technology (NIST) 800-82**, Guide to Industrial Control System Security
- **NIST 800-53**, App 1 Security Controls, Enhancements, and Supplemental Guidance
- **DOD Instruction (DODI) 8500.2**, DOD IA Certification and Accreditation Process
- **Committee on National Security Systems Instruction (CNSSI) 1253 App I**, ICS Security Overlay Vendor and DOD Security Guides for Network, OS, Application, and similar

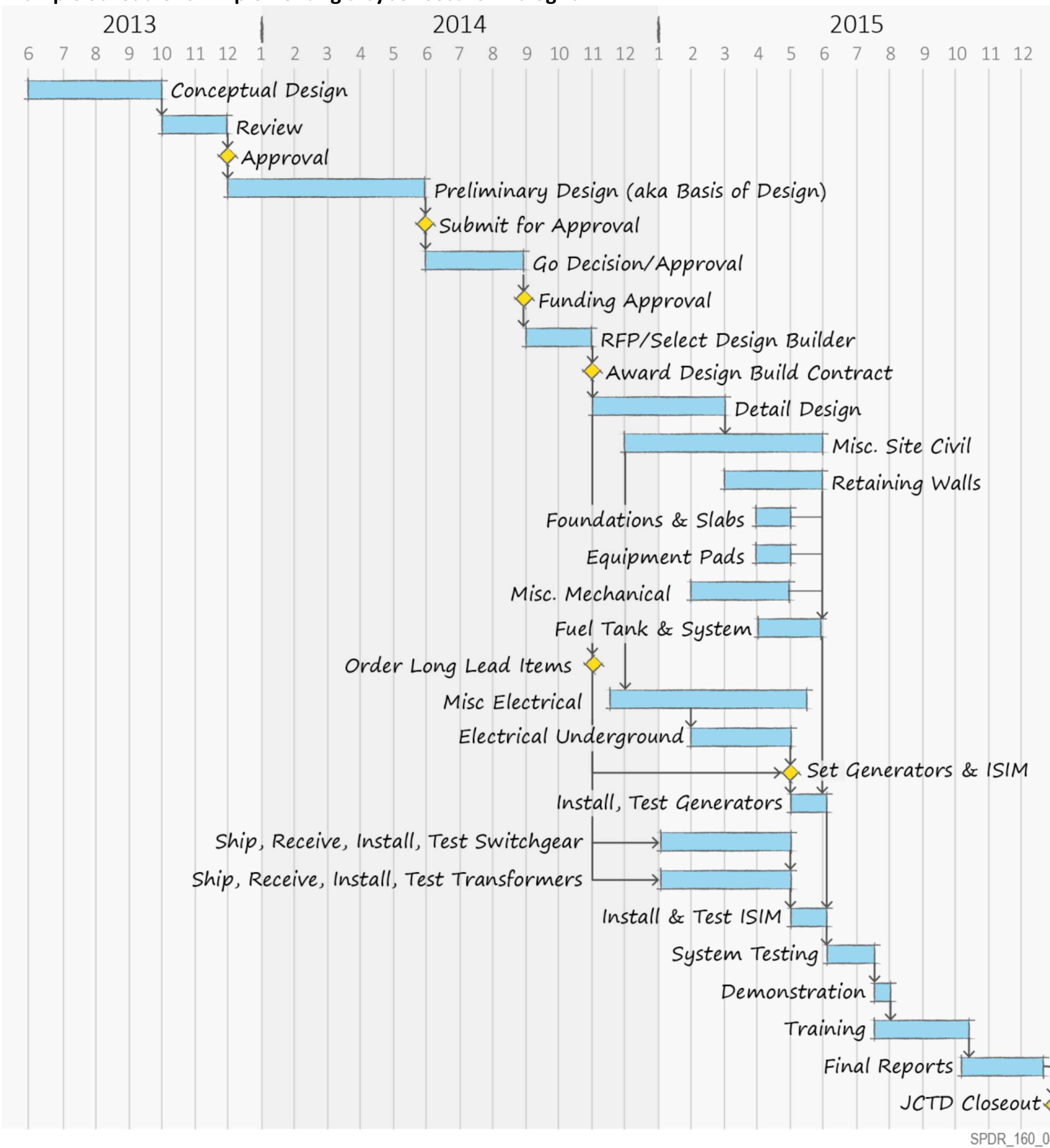
Risk management assessments of the Camp JCTD system have been conducted including the following:

- Department of Homeland Security Cybersecurity Evaluation Tool (CET)
- JCTD Red Team Attacks and component penetration testing
- DOD Information Certification and Accreditation Process
- Independent static code analysis to discover and correct vulnerabilities within the software code

3.5 Schedule

Implementation of a cyber-secure microgrid may have substantial variation in schedule. A representative schedule is shown on Figure 3-11.

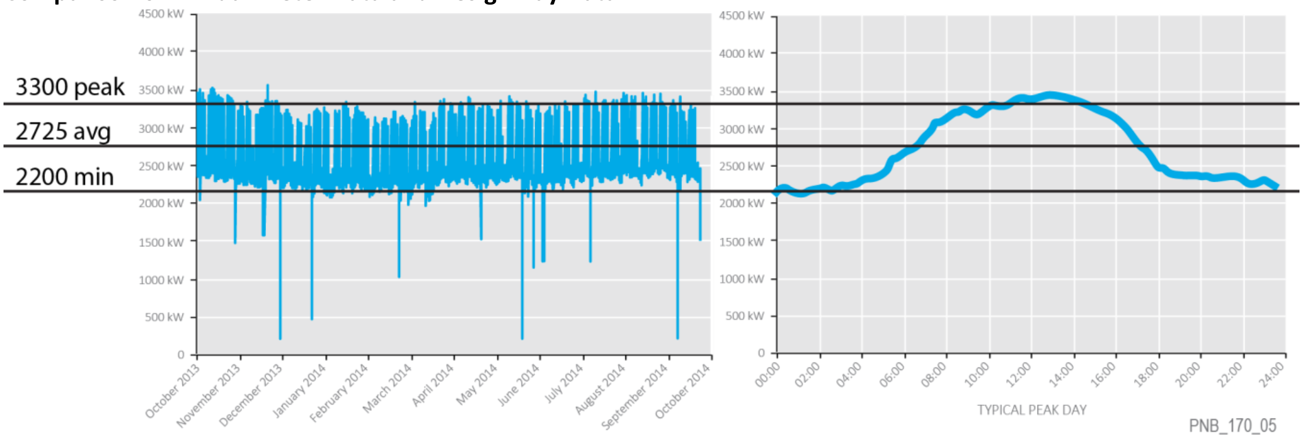
FIGURE 3-11
Example Schedule for Implementing a Cyber-secure Microgrid



3.6 Operating Impact

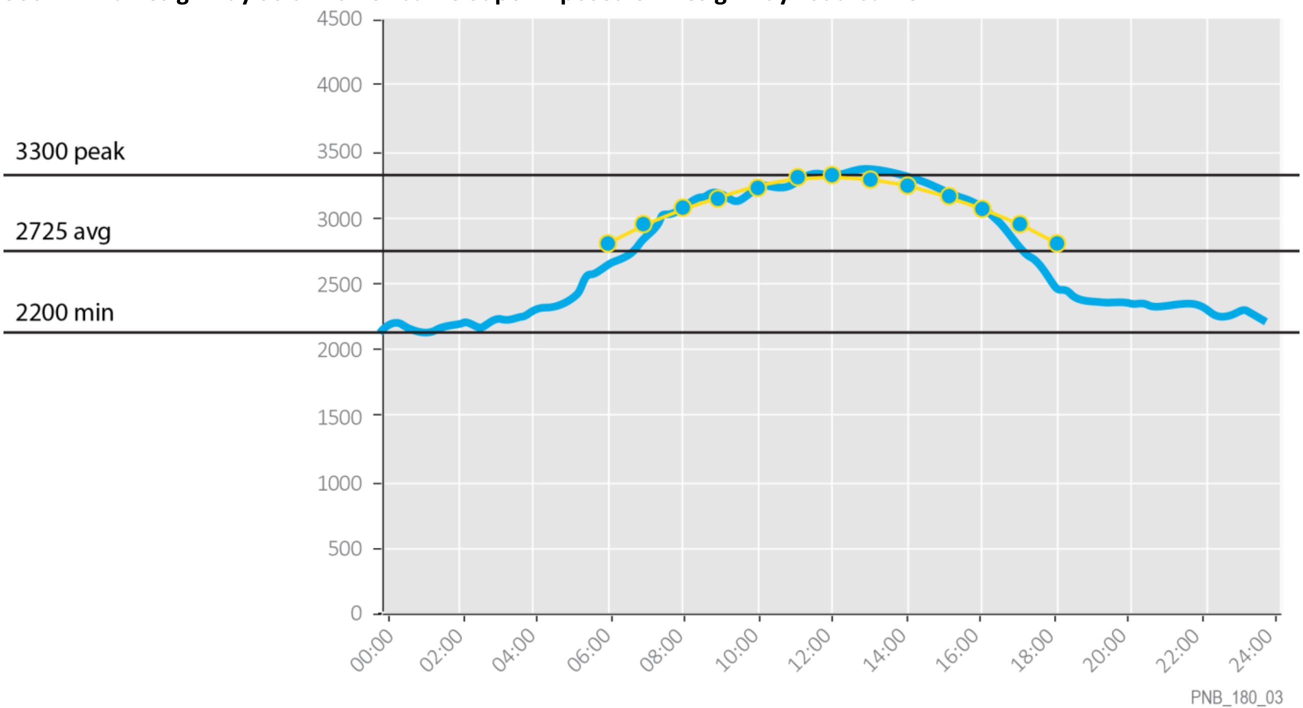
The design team used the available meter data to size the Camp JCTD system (see Figure 3-12). The prime power plant was sized at a design capacity of 3,000 kW (slightly above annual average base load of 2,725 kW). The design peak load of 3,300 kW with the load of the microgrid discretionary buildings removed (see Table 3-1 and Figure 3-7) should be less than 3,000 kW. The 3,000-kW target was met with three generator units, each at 1,000 kW. Using three units will allow one unit to swing off line at night and the remaining two will approximately match the design day nighttime load of 2,200 kW minus discretionary load.

FIGURE 3-12
Comparison of Annual Meter Data and Design Day Data



Integration of renewable solar energy with the microgrid is a strategy for Camp JCTD. Figure 3-13 shows how a 500-kW alternating-current (AC) solar PV farm power output would integrate with the Camp JCTD design day load.

FIGURE 3-13
500 kW AC Design Day Solar Power Curve Superimposed on Design Day Load Curve



In microgrid mode with assistance of batteries, the prime power system should be able to operate on clear days with only two of the 1,000-kW generators. This will substantially reduce fuel consumption and extend operating time without refueling.

3.7 Cost Impact of Solar and Microgrid

Solar Farm: Preliminary estimates of a solar PV farm at Camp JCTD at approximately 500-kW AC power will provide an annual energy production of approximately 900,000 kWh. At the Camp JCTD energy rate, this is worth approximately $135,000. The microgrid can take no credit for this savings because the PV would provide the same savings in the absence of a microgrid.

Microgrid Batteries: Camp JCTD receives an energy cost credit or penalty of 0.10 percent for each 1 percent the monthly power factor deviates from 85 percent. Assuming the annual energy consumption of 23,900,000 kWh, using the microgrid system to improve power factor by 10 percent will save $35,800:

23,900,000 kWh x 10 x 0.10% x $0.15/kWh = $35,800

Solar Farm with a Microgrid: Normally a solar farm would not reduce peak demand, because variable output due to cloud cover would result in inconsistent output. A stand-alone PV system cannot guarantee 100% output every 15 minute time period. But by backing up the solar farm and guaranteeing output with batteries and further backing up the batteries with prime power, Camp JCTD could see full benefit of the solar farm peak power reduction.

500 kW x $21/kW/month x 12 months/year =$126,000

Microgrid and Curtailable Rate Schedule: The microgrid could be used to support a rate schedule modification. If the site agrees to a 2-hour curtailment of a fixed amount of power at a set time of day, the monthly demand charged to the local utility would be reduced by 40 percent of the curtailed demand. The two sets of batteries each have a capacity of 250 kWh. If half of the available energy is used to curtail the load, the savings is $12,600:

(250 kWh/2 hrs.) x 40% x $21 x 12 = $12,600.

Net result – by working in concert, the CAMP JCTD microgrid can double the cost savings of the future solar farm.

SECTION 4

4 Conclusion

The SPIDERS JCTD microgrid successfully met the stated objectives of increasing system efficiency and reliability while maintaining adequate power quality.

- The cyber-secure control system withstood “red team” attack and received a passing assessment.
- Fuel consumption and emissions were reduced as a result of integrating available renewable generation sources and optimization of generator performance by using strategies which shifted load among available generator resources to create maximum efficiency.
- Renewable energy was successfully integrated.
- The system provides mechanisms for future cost reduction.

4.1.1 Looking Forward

SPIDERS microgrids have been successfully operated at three locations. Validate the operation and control strategies and the systems designs appear sound.

The installations successfully integrated renewable energy. They also showed significant improvement in reliability and generator efficiency, a result of optimizing performance of the generators as a system. The data indicate a 30 percent fossil fuel reduction during power outages may be a reasonable expectation.

Integrating the outcomes of SPIDERS Phases 1, 2, and 3 into future DOD microgrid designs increases the value and security of microgrids at military installations.

In situations where an installation is not connected to a utility, this approach of optimizing generator efficiency and better integration of renewable energy can significantly reduce energy cost.