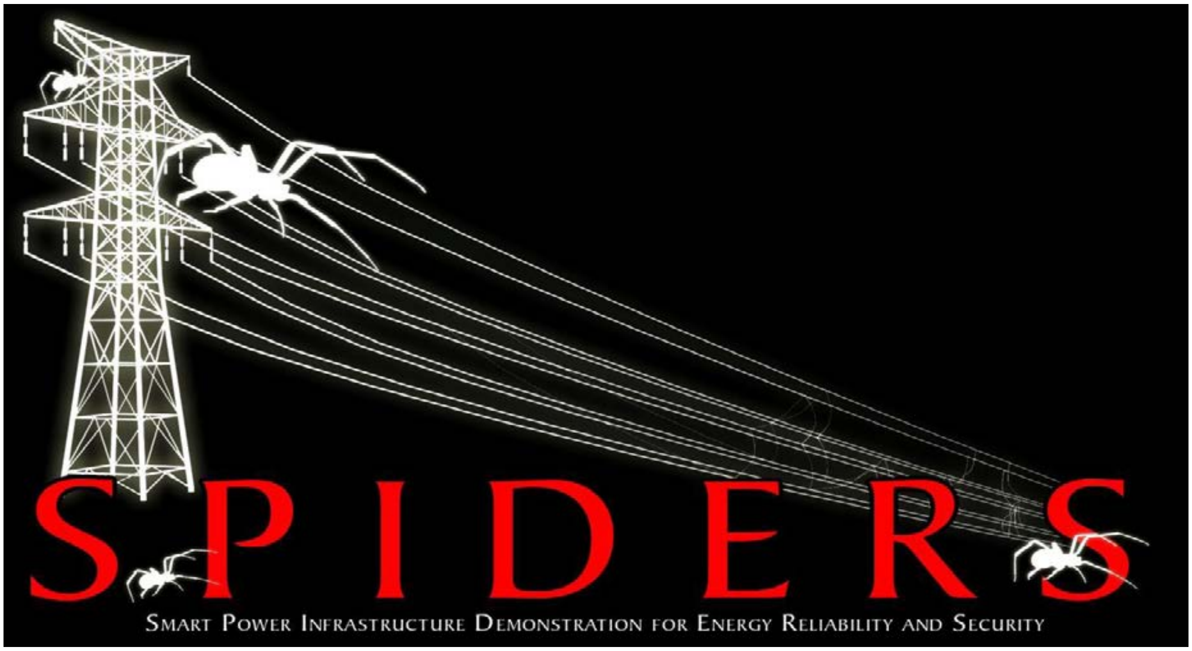

SPIDERS Phase 2 Fort Carson
Technology Transition Public Report

Joint Capability Technology Demonstration (JCTD)

Version 1.1

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SUBJECT: Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Phase 2 Fort Carson, Colorado, Technology Transition Public Report

This SPIDERS “Final Program Public Report” for Phase 2 summarizes the key outcomes generated during the second phase of the Joint Capabilities Technology Demonstration (JCTD), which was implemented at Fort Carson, Colorado, during 2013/14. The public demonstration of the technology at Fort Carson was completed in April 2014.

The SPIDERS JCTD is a 3-year, 3-phase effort to demonstrate a cyber-secure 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 inter-agency objectives and is a strong collaboration of partners, including Department of Defense (DoD), Department of Energy (DOE), Department of Homeland Security (DHS), and individual military services (Army, Marines, Navy, and Air Force). Results of the initiative are intended to help inform infrastructure investment decisions at DoD and non-DoD facilities. The SPIDERS initiative is cosponsored by the DoD and DOE, who also 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 V2G (vehicle-to-grid) energy storage and demand side management. Phase 2 increased the scale of demonstration and included energy-storage capability and demand-side management.

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 April 22, 2014 “Industry Day” presentations will be posted on the Federal Energy Management Program website. A final public report will be issued in late 2015 at the end of Phase 3.

Sincerely,

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Executive Summary

The objective of the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Joint Capability Technology Demonstration (JCTD) is to demonstrate a microgrid architecture that is cyber secure, reliable, and resilient. The SPIDERS JCTD demonstrates the practicality and benefits of creating microgrids within existing military infrastructure. There are key features of microgrids that provide several benefits related to both energy security and energy efficiency. The results of the JCTD will help inform infrastructure investment and decisions at Department of Defense (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 because of cyber-attack.
2. Integrate renewable and other distributed energy generation concepts 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 inter-agency objectives through strong collaboration with the operational DoD Combatant Commands program leaders (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 Management (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 [PNNL], Oak Ridge National Laboratory [ORNL], Sandia National Laboratories [SNL], National Renewable Energy Laboratory [NREL], and Idaho National Laboratory [INL]) and private sector subcontractors support the development, implementation, and evaluation of the SPIDERS microgrids.

The SPIDERS JCTD is a three-phase program that began in 2011. Phase 1 was a limited-scale demonstration of a cyber-secure microgrid at Joint Base Pearl Harbor-Hickam, Hawaii. Each subsequent phase moves to a different demonstration site and each subsequent phase demonstrates 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 demonstration at Camp Smith, Hawaii will be completed in mid-2015. The three phases of the SPIDERS JCTD include the following infrastructure:

- Phase 1 created a microgrid consisting of a single distribution feeder; two electrically isolated loads; two isolated diesel generators; and an isolated photovoltaic (PV) array.
- Phase 2, which is the basis of this report, consists of three distribution feeders; seven building loads; three diesel generators; and a 1-megawatt segment of a PV array.
- Phase 3 will utilize new and existing generation sources to form a microgrid to support loads of a complete military installation.

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

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Figures

Acronyms and Abbreviations

ATS	automatic transfer switch
CNSSI	Committee on National Security Systems Instruction
CONOPS	Concept of Operation
COTS	commercial off the shelf
DHS	Department of Homeland Security
DIACAP	DoD Information Certification and Accreditation Process
DoD	Department of Defense
DoDI	Department of Defense Instruction
DOE	Department of Energy
ERDC-CERL	Engineer Research and Development Center-Construction Engineering Research Laboratory
GUI	graphical user interface
HMI	Human Machine Interface
INL	Idaho National Laboratory
JBPHH	Joint Base Pearl Harbor Hickam
JCTD	Joint Capability Test Demonstration
kV	kilovolt
kW	kilowatt
MW	megawatt
NAVFAC	Naval Facilities Engineering Command
NDT	neutral deriving transformer
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic
SNL	Sandia National Laboratories
SCADA	supervisory control and data acquisition
SPIDERS	Smart Power Infrastructure Demonstration for Energy Reliability and Security
TARDEC	U.S. Army Tank and Automotive Research and Development Engineering Center
V2G	vehicle to grid
V	Volt

SECTION 1

Background

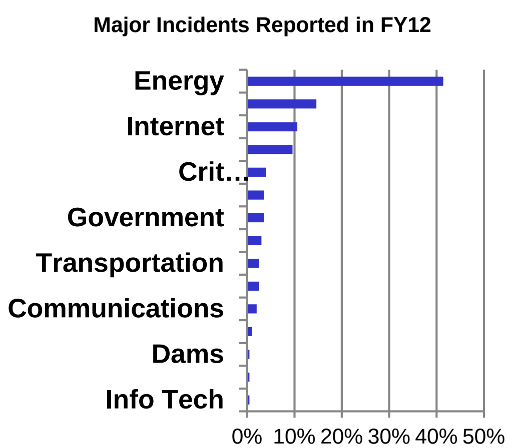
In 2008, the Defense Science Board Task Force on Department of Defense (DoD) Energy Strategy issued the report "More Fight-Less Fuel". This milestone report was produced at the direction of the Under Secretary of Defense for Acquisition, Technology, and Logistics. The Task Force concluded that the DoD 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. With respect to the cybersecurity challenge, Figures 1-1 and Figure 1-2 illustrate the trend of an increasing cybersecurity problem with respect to infrastructure.

FIGURE 1-1

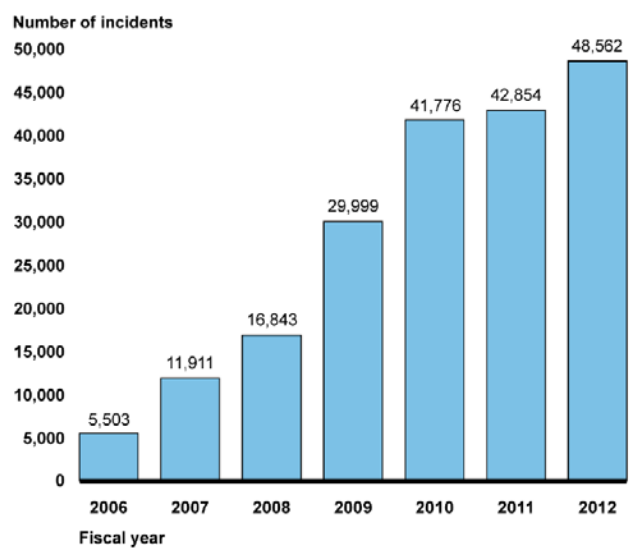
Incidents Reported in FY12 by Target



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

FIGURE 1-2

Growth of Incidents Reported 2006 - 2012



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

The JCTD is an implementation of recommendations of the Task Force, 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 clearly 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 have been provided with backup generation or uninterruptible power supplies. However, various factors are causing a need to reassess the assumption, specifically:

- Increased optimization and integration of grid operations during normal operation may create interdependency among grid operators
- A steadily increasing percentage of less consistent power sources (such as private renewable sources) are being integrated into grid systems
- Growing integration of internet-based control and data acquisition and the exponential growth in the number and sophistication of cyber threats to industrial control systems
- Reduced investment in infrastructure because of decades of deregulation

The above have left the nation’s power grid (and indirectly the military) increasingly vulnerable to either sabotage or natural disasters, potentially resulting in widespread failures.

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)

The SPIDERS JCTD explores a possible avenue for mitigating the potential effects of the military’s dependence on the Contiguous United States power grid via the creation of microgrids within the 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 one another to support independent loads. The goal of the SPIDERS JCTD is to show how this could be implemented at existing facilities with existing assets.

1.1 SPIDERS Phase 1 Summary Information

The SPIDERS Phase 1 focused on a circuit-level demonstration of cybersecurity and integrated renewable energy. SPIDERS completed a technical demonstration at Joint Base Pearl Harbor-Hickam (JBPHH) during December 3 to 7, 2012. In Phase 1 of the SPIDERS JCTD, isolated generators were integrated with a small photovoltaic (PV) array within a single distribution circuit to serve a critical load at JBPHH.

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 installation 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.)
- Fully loaded black start operation by opening 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
- Paralleling and synchronization 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
- 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

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

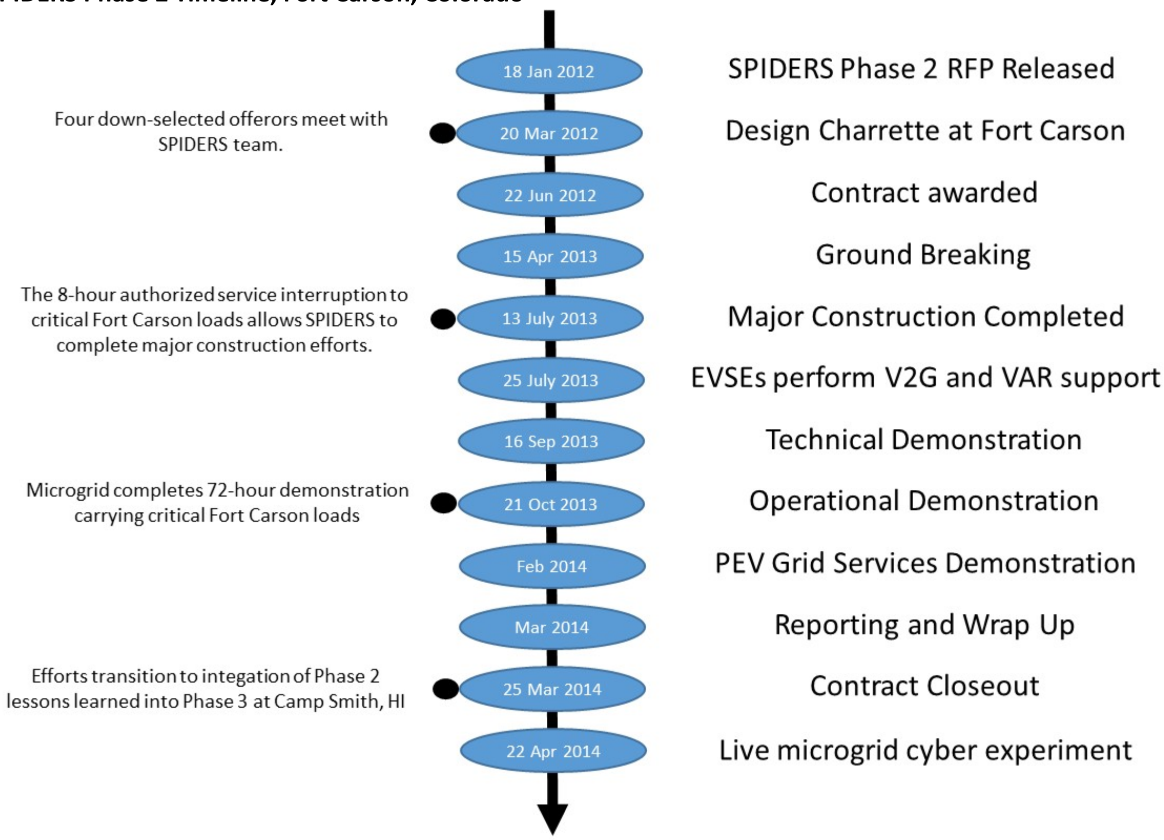
SECTION 2

SPIDERS Phase 2 at Fort Carson, Colorado

DOE led the preliminary design for SPIDERS based on their decade of experience with microgrids. A cross organizational Technical Management Team was responsible for making decisions and providing guidance as the preliminary design moved to a site-specific functional design. Burns & McDonnell developed the detailed design for SPIDERS Phase 2. Burns & McDonnell also performed infrastructure improvements, implementation of the SPIDERS microgrid solution, and system commissioning, testing, training, and reporting. The timeline for the Fort Carson activities is illustrated on Figure 2-1.

FIGURE 2-1

SPIDERS Phase 2 Timeline, Fort Carson, Colorado



2.1 SPIDERS Phase 2 Microgrid Primary Components

2.1.1 Building Classification

The Fort Carson SPIDERS microgrid demonstration focused on a cluster of seven buildings. The selected buildings represented a variety of categories with respect to critical operations. The following Fort Carson buildings were included in the SPIDERS demonstration:

- **Microgrid Essential** - Those building loads that have a backup generator and are required to support the microgrid as designed. At Fort Carson, this included three buildings, each with a generator. Prior to SPIDERS, backup emergency generators lacked redundancy; after SPIDERS the three generators provide N+1 capability to carry the entire microgrid load under normal conditions.
- **Microgrid Supported** – These building loads 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. A prime example of this would be facilities with only renewable generation assets (PV, electric vehicle supply equipment, and similar). The building design at Fort Carson did not integrate all of the available generators as defined in the preliminary design because they were not necessary to reliably support the load. One building fell into this category.
- **Microgrid Discretionary** – These buildings have the capacity to be connected to the microgrid, but the building can 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. At Fort Carson, three buildings fit in this category.
- **Non-microgrid** – These buildings are outside the microgrid boundary.

The Fort Carson demonstration included buildings and loads from the three microgrid designations listed above.

The existing high voltage distribution system was used for connecting loads. Generators were directly connected to the medium voltage side of building transformers using bypass breakers. Automatic synchronizers permit parallel operation of generators or utility. Microgrid boundary isolation switches were added between the microgrid substations. Two segmentation switches were also added to allow for segmenting the microgrid into three distinct sections to energize the microgrid gradually to maintain stability in the system.

2.1.2 PV Renewable Resource

Fort Carson has an existing 2-MW PV solar array, of which 1 MW was connected to the microgrid (at the time of demonstration, 500-kilowatt [kW] was temporarily out of service, thus only 500 kW contributed to the microgrid). The existing PV array was connected by a third 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. This is a required safety feature because the renewable energy resource could backfeed grid elements on the circuit. Formation of the microgrid allows the safe reintroduction of renewable energy during a grid failure. This is done by disconnecting the microgrid from the primary grid prior to reconnecting the renewable resource. Careful management of the microgrid generators and loads protects the renewable resource from overload.

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.

2.1.3 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-directionally charging 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 ERDC-CERL). 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 voltage support to the microgrid through reactive power injection.

Boulder Electric truck

2.1.4 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 to 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 significant reconfiguration of existing systems. Unless pointed out, most observers would not notice the difference before and after the microgrid conversion.

2.2 Objectives and Outcomes

The SPIDERS Fort Carson project had the following objectives:

- Improve reliability for mission-critical loads by connecting generators on a microgrid using existing distribution networks.
- Reduce reliance on fuel for diesel power by using renewable energy sources during outages.
- Increase efficiency of generators through coordinated operation on the microgrid and reduction of excess capacity.
- Reduce operational risk for energy systems through strong cybersecurity for the microgrid.
- Enable flexible electrical energy through the use of building microgrid architectures that can selectively energize/de-energize loads and sources during extended outages.
- Demonstrate potential vehicle-to-microgrid and vehicle-to-grid values via methods such as peak shaving.

Smith Electric military truck

The following was accomplished during the Technical Demonstration to show that the JCTD objectives were met by the Fort Carson microgrid:

- The existing diesel generation assets were optimized to minimize fuel consumption during a grid outage by the integration of the renewable energy sources (solar).
- The critical load was 100 percent served and provided with a greater redundancy in power sources than the previous infrastructure afforded. During operation, existing diesel generators could be better managed when connected to the microgrid. Some generators could be powered down, which allowed operating generators to function at peak performance, thus reducing fuel consumption. (When generators operate at partial load they are less efficient because energy losses, such as friction, become more significant.)
- The core facilities in the microgrid islanded and reconnected seamlessly.

Typical of transfer switch

- Power quality was maintained to accommodate sensitive loads.
- Cybersecurity measures, exceeding emerging standards, were implemented to demonstrate a resilient architecture resistant to external attack.
- Electric vehicles were integrated into the system to improve power factor and stability.

2.3 Project Approach

Since 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 requirement has been extended to include the ability to completely revert back to non-SPIDERS operation by turning off SPIDERS mode on the graphical user interface (GUI). Turning off SPIDERS mode on the GUI prevents the supervisory controller from making decisions or implementing control actions. Thus, the installation of the 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 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 the traditional, automatic transfer switch based control system to be the default mode for compliance with Life Safety Codes and if the SPIDERS control system fails for any reason.

The SPIDERS Fort Carson microgrid solution is based on the following concepts:

- Use of medium voltage switching for microgrid segmentation and building isolation to minimize disruption to current buildings during construction and testing
- Use of medium voltage bypass breakers near existing generator automatic transfer switches (ATSs) to minimize disruption of the existing generators (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 diesel generators to carry the complete load should PV and vehicle batteries trip off line
- Integration of Government-furnished electric vehicles for both backup power system support as well as for grid services during normal utility connection
- Integration of a new high voltage breaker in new switchgear to enable a seamless transition between microgrid and utility-tied operation

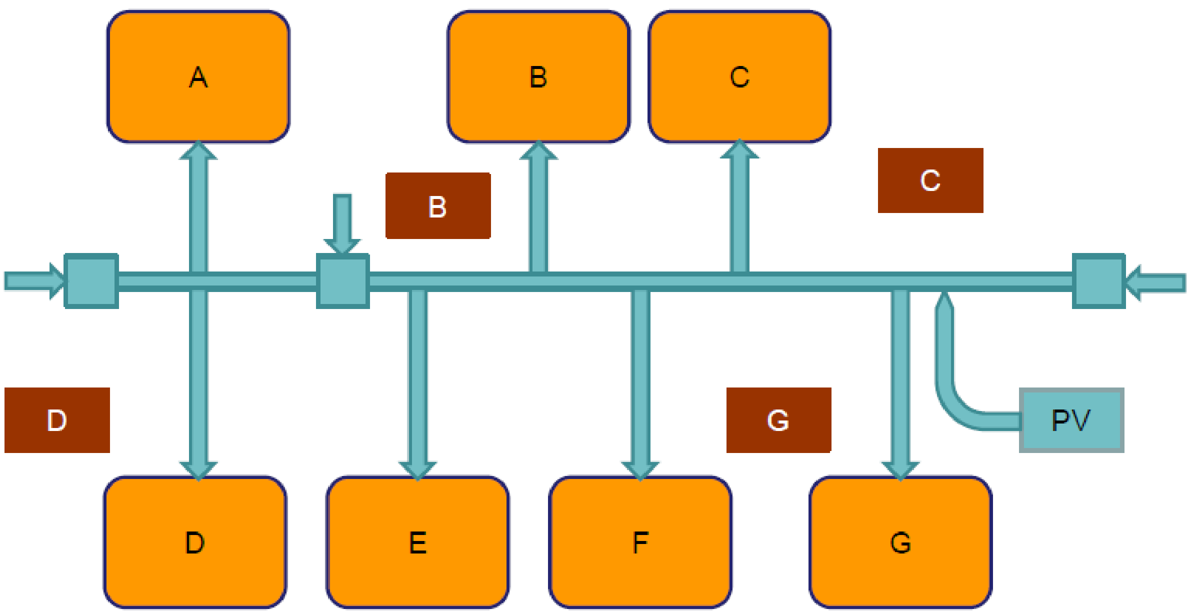
SECTION 3
Concept of Operation

Microgrid Electrical System Overview

The first principle of the SPIDERS microgrid Concept of Operation (CONOPS) is designed to "Do No Harm". Upon a power-failure event each building or load supplied with traditional backup power generation responds as originally designed. Once installation utility operators decide conditions are appropriate to island from the utility (either automatically upon loss of utility or when manually initiated) the system will initiate sequences that safely and stably "Build the Microgrid".

Below is a notional microgrid conceptually similar to Fort Carson. The basic design of the notional microgrid in normal microgrid activation is shown in Figure 3-1.

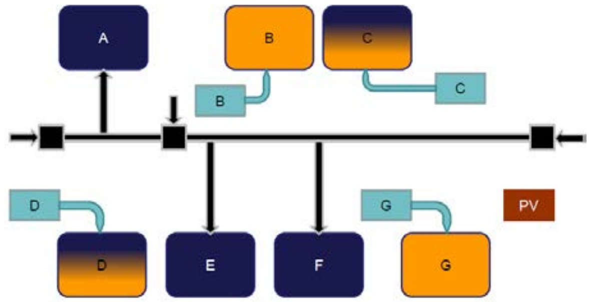
FIGURE 3-1
Notional Microgrid in Normal Mode



The system consists of the following:

- Seven loads labeled "A" to "G" (shown as large orange boxes)
- Four emergency generators associated with individual loads (shown as small rectangles B, C, D, and G)
- A renewable energy source (labeled PV)
- Three automated isolation/ segmenting switches (shown with arrows depicting direction of power feed)

1. Upon loss of power, the system responds in its traditional ATS-based manner, wherein all four backup generators within the microgrid boundary start and serve their dedicated loads via the automatic transfer switches at the individual buildings. The PV array supplies no power since its inverters shut off because of the lack of a grid reference. As a result, all or part of the loads in Buildings B, C, D, and G are restored with power and Buildings A, E, and F go "black" with no power. This mode is essentially an "autonomous" response of the electrical system and is the same operation of the system prior to SPIDERS being implemented at Fort Carson. There is no overarching control directing the equipment, but the SPIDERS control system is constantly monitoring and recording the operation of the components of the system to determine whether the conditions allow for microgrid operation.



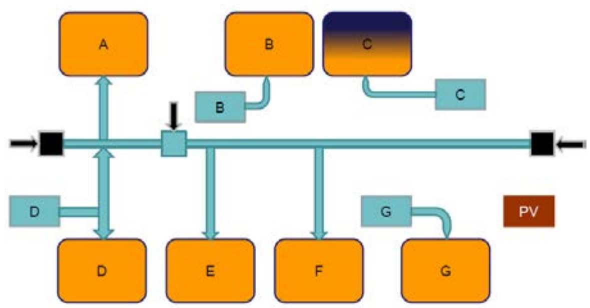
Initial autonomous response to utility failure, Buildings A, E, and F go "black", while generators provide Buildings B, C, D, and G with power

2. After an initial assessment of the causes of the utility outage and expected duration, the responsible system operator can opt to activate the SPIDERS microgrid mode of operation. The transition is initiated via an HMI to the SPIDERS control system. This operator-initiated process is necessary when the microgrid control system is in manual start mode.

3. Upon microgrid activation, the system performs a final check of the overall health of the system before entering SPIDERS mode. This includes verifying that the microgrid switches and breakers are in the correct positions, all of the controllers are actively communicating with each other, and sufficient diesel generation is online and operating properly. Assuming the system is ready, the following sequence is carried out:

    a. The system opens the high voltage boundary and segmentation switches and breaker to isolate the microgrid and the SPIDERS control system closes a switch to engage a NDT and connect it to the microgrid to provide a ground reference for the system.

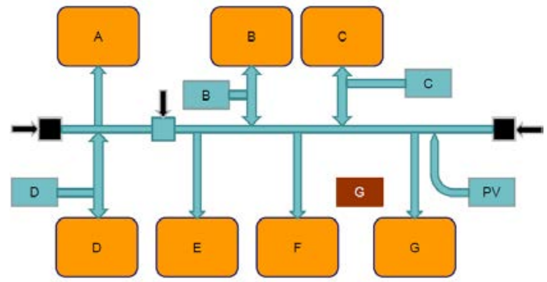
    b. The SPIDERS breaker on the largest available microgrid generator (generator at Building D in the example) will close to allow parallel power supply to the load and the building transformer to energize the first segment of the microgrid. Once the first segment is energized and stable, the control system will then close the sectionalizing switches on additional available microgrid-connected generators and additional loads to energize all loads that are not powered by their own building generator (Buildings A, E, and F).



Microgrid condition after first formation step

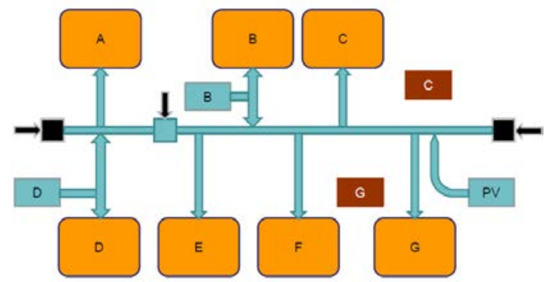
    c. At this point, the SPIDERS control system will have synchronized all generators and all intended loads will be served. Generators connected to buildings but not contributing to the microgrid (generator at Building G) will automatically shut down as if utility power was restored.

d. The control system will then monitor the load on the microgrid to determine the ability for incorporation of the PV system. The PV system will be engaged and provide as much power to the grid as conditions allow. The generators will reduce output such that the total generation matches the total load. At this point, the control system will determine if one or more operating generators can be shut off to further optimize efficiency while maintaining adequate spinning reserve.



Microgrid fully formed but not optimized

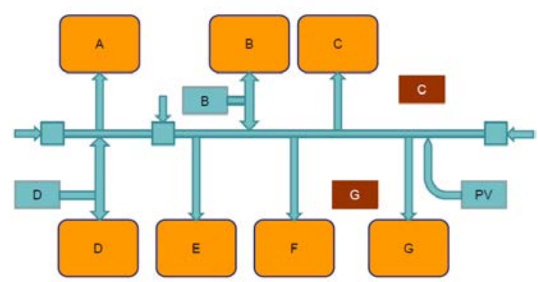
e. The process described above takes approximately 10 minutes from the time of operator-initiation until the microgrid is fully formed and stable, and then another 5 to 10 minutes for the PV inverters to re-engage; thus, generator optimization does not begin for approximately 20 minutes after initial activation of the microgrid.



Generators optimized

f. When available, the electric vehicles are utilized as a variable load to absorb excess PV generation or supply power to the microgrid. During periods where the microgrid's loads are not sufficient to keep the PV penetration to an acceptable level, the electric vehicles will be commanded to absorb the excess power. During periods of lower PV output, the vehicles will be commanded to discharge their stored energy to the microgrid. This ensures that the PV power is utilized to serve the loads to the greatest extent possible and minimizes fuel consumption.

g. Once the utility sources have returned to stable operation, the system can either automatically or at the direction of the operator be returned to grid-tied operation. The system will be commanded to synchronize across the new high voltage breaker. This will cause each operating generator's control system to match frequency and voltage with that of the utility. As soon as they are aligned for a set amount of time (typically a few cycles), the breaker will be closed. At this point, the system will be connected in parallel to the utility, and the generators will be soft unloaded, the ATS breakers tripped, and the generators cooled down.



Microgrid is synchronized with grid and seamlessly returned to utility connected

A feature of this particular microgrid is the ability to seamlessly transition from grid-tied to islanded operation. This feature may be used to prevent the buildings within the microgrid from experiencing an anticipated power outage. For example, if a fire was approaching or if the utility was experiencing a loss of generation on a heavily loaded day, the operators would command the system to enter SPIDERS mode despite the presence of utility power. The control system would then close the breaker on the grounding transformer and command the generators to start and synchronize to the utility source. Once connected, the generators would be ramped up to match the load of the microgrid, and the breaker would be tripped. As before, the system would be in the full microgrid mode of operation and would begin to optimize the generation assets to match the load. Since the utility source was never lost, the transfer switches never moved, and the load within the core of the microgrid never lost power. This feature, combined with the seamless transition back to grid-tied operation, allows the load to be unaffected by any anticipated outages.

An additional capability of this system is the ability to load test the generators without interrupting the loads. Normally, the generators are tested using the test switches on the automatic transfer switches. Although this is the simplest method of testing the generators, it has two major drawbacks. First, the test forces a momentary power outage on the equipment served by any transfer switches which have open transitions between sources. Secondly, the test is limited to only the load on the transfer switch at the time of the test. Thus, the generator may not experience a significant load during its routine testing if performed outside of peak load times.

SPIDERS load testing of the generators utilizes the automatic synchronizers on the ATS breakers enabling the generators to connect in parallel to the utility grid. Once connected, the operator is able to manually command any kilowatt output for each of the generators. Thus, the generators can be dynamically tested at any load and any power factor. While connected to the grid in this manner, the work being done by the generator is actually reducing the power consumption of the Post as measured at the utility meter. Thus, this generator test mode could also be used to achieve load curtailment (when operated within requirements of existing air permits) and at a much higher level of curtailment than the typical ATS test mode.

3.1 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 distribution 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 system “islands” and detaches from the grid.

3.1.1 Microgrid Control

As discussed in Section 2.3, this project was designed to minimize cost and retain functioning existing infrastructure. The cyber-secure microgrid control system was therefore designed to “lay over top” of the existing electrical and control systems. Individual control systems for the microgrid components (for example, generator controls for speed and voltage, individual breaker trip units, and automatic transfer switches) were present prior to the start of the project start. However, these components did not have all the components to send and receive information so they could 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. Among other capabilities, these upgrades allowed the generators to operate in parallel with each other and with the grid. There was also a dedicated control network between the various switches that allowed for isolation of the microgrid from the rest of Fort Carson grid.

The SPIDERS control system used COTS control elements. Control system design support and master controllers were provided by IPERC. These component controllers were overlaid with a master controller to provide microgrid supervision, management, and cybersecurity. The component level control 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
Courtesy IPERC

Unlike traditional centralized supervisory control and data acquisition (SCADA) systems, the SPIDERS supervisory controller is 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.

3.1.2 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

The Fort Carson microgrid was designed to meet the security guidelines listed above

The system has conducted risk management assessments to include the following:

- DHS Cybersecurity Evaluation Tool (CSET)
- JCTD Red Team Attacks and component penetration testing
- DoD Information Certification and Accreditation Process (DIACAP)
- Independent code reviews

3.2 Conclusion

The SPIDERS JCTD Phase 2 microgrid successfully met the stated objectives of increasing system efficiency and reliability while maintaining adequate power quality.

- The cyber-secure control system 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
- Microgrid supported and microgrid discretionary buildings were supported without the addition of additional generation
- Electric vehicles were fully integrated into the microgrid and demonstrated their availability to harden the system operation and improve performance

3.2.1 Looking Forward

SPIDERS microgrids have been successfully operated at two locations. Both demonstrations performed successfully indicating the operation and control strategy and systems design appears to be sound.

Both 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 from these two locations indicate a 30 percent fossil fuel reduction during power outages may be a reasonable expectation.

Integrating the outcomes of both SPIDERS Phase 1 and Phase 2 into future DoD microgrid designs increases the value and security of microgrids at military installations. Systems that could directly utilize this approach are segments or even complete distribution systems with underutilized generators where the total load can be served by the combined output of fewer, more efficiently loaded generators. In addition, any generator which has a peak demand of less than 40 percent of its rated capacity would benefit from the installation of a SPIDERS breaker to allow it to parallel to the grid for testing – even without providing any of the additional controls to permit the creation of a microgrid with the generator. This is because of the greatly improved testing, which is possible with the generator in parallel to the utility.