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Utility Assessment Report for SPIDERS Phase 2: Ft. Carson (Rev 1.0)

January 2014

JL Barr
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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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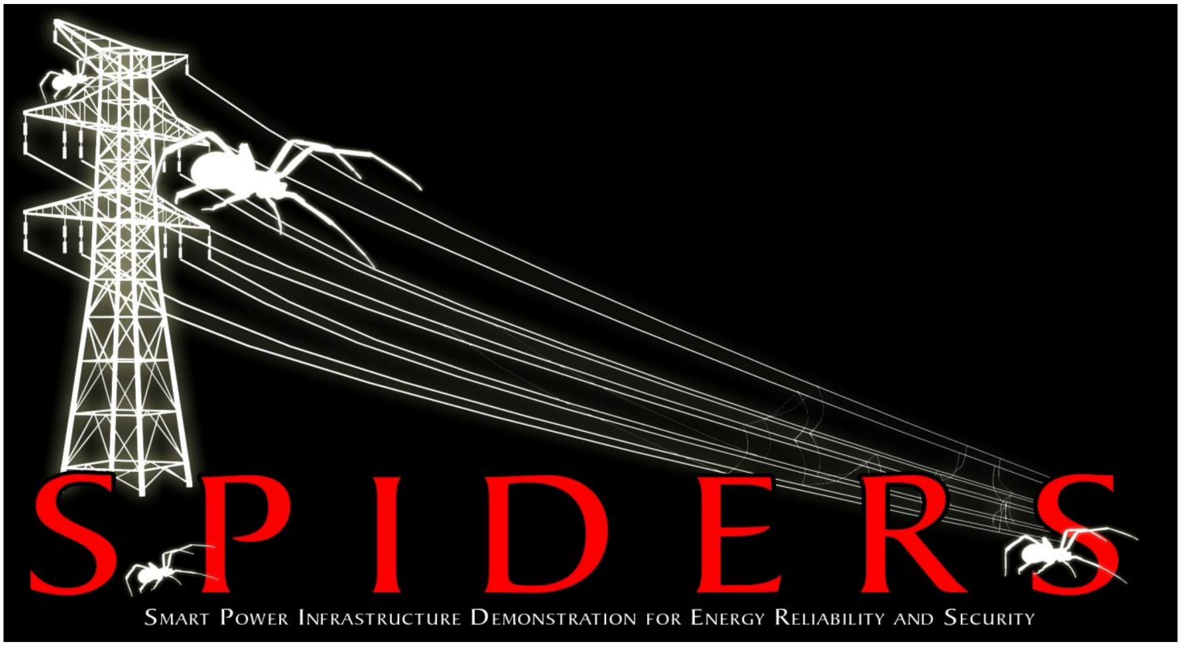

Utility Assessment Report

Phase 2 Operational Demonstration

January 2014

Summary

This document contains the Utility Assessment Report (UAR) for the Phase 2 Operational Demonstration (OD) of the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Joint Capability Technology Demonstration (JCTD). This report is not complete without the associated report addendum[1]. The UAR for Phase 2 shows that the SPIDERS system was able to meet the requirements of the Implementation Directive (ID) at Ft. Carson. During the OD, there were no interruptions to essential/uninterruptible loads. Renewable resources in the form of 500 kW of solar photovoltaic (PV) generation were integrated into the system and reduced the amount of diesel fuel consumed. Because of the integration of renewables and increased generator operating efficiencies, the essential/uninterruptible Phase 2 facilities have the potential to operate 19.3% longer with a fixed amount of fuel. The reduced consumption of diesel fuel reduced CO_2 emissions by over 2,250 lbs., approximately a 39% reduction over the traditional mode of backup operation. There were four unplanned events that occurred during the OD: PV Maintenance, a generator derating, failure to operate the SPIDERS synchronization breaker remotely, and the system exited SPIDERS during generator maintenance. Although these events were unplanned, the metrics and measures from the Phase 2 OD demonstrated that the Phase 2 SPIDERS system was a success. Despite representing a success for the metrics provided, the unplanned events present valuable lessons to be learned for the Phase 3 OD and for improving the operation of the Ft. Carson SPIDERS microgrid.

[1] "Utility Assessment Report for SPIDERS Phase 2 Addendum: Ft Carson," can be obtained by request from the JCTD Program Office Work Flow Manager (WFM), which as of January 2015 is Brandon Burke. Requests should be sent to brandon.h.burke.ctr@mail.mil.

Acronyms and Abbreviations

B&M	Burns & McDonnell
CD	Compact Disc
CO_2	Carbon Dioxide
CONOPS	Concept of Operations
COTS	Commercial Off the Shelf
CP	Casualty Procedure
CSET	Cyber Security Evaluation Tool
CSU	Colorado Springs Utilities
CVR	Conservation Voltage Reduction
DG	Diesel Generator
DHS	Department of Homeland Security
DoD	Department of Defense
DOE	Department of Energy
DPW	Department of Public Works
EMS	Energy Management System
ESM	Energy Surety Microgrids
EVSE	Electric Vehicle Supply Equipment
FCSS	Ft. Carson Support Services
FEMP	Federal Energy Management Program
GUI	Graphical User Interface
HMI	Human Machine Interface
IAP	Integrated Assessment Plan
ICS	Industrial Control System
ID	Infantry Division
IMT	Integrated Management Team
IP	Internet Protocol
IPERC	Intelligent Power & Energy Research Corporation
IT	Information Technology
JCTD	Joint Capability Technology Demonstration
kvar	Kilovolt amp reactive
kvarh	Kilovolt amp reactive hour
kW	Kilowatt
kWh	Kilowatt hour
M&O	Maintenance and Operation
MAC	Mission Assurance Category

MOE	Measure of Effectiveness
MOP	Measure of Performance
NAVFAC	Naval Facilities Engineering Command
NDA	Non-disclosure Agreement
NIST	National Institute of Standards and Technology
NO_x	Nitrogen Oxides
NTP	Network Time Protocol
OAEP	Operational Assessment Execution Plan
ODEP	Operational Demonstration Execution Plan
OD	Operational Demonstration
OE	Oversight Executive
OM	Operational Manager
OP	Operational Procedure
OS	Operating System
OTA	Operational Test Authority
OTE	Operational Test and Evaluation
PCC	Point of Common Coupling
PM-10	Particulate Matter
PNNL	Pacific Northwest National Laboratory
PRA	Probabilistic Risk Assessment
PV	Photo Voltaic
RMS	Root Mean Squared
SCADA	Supervisory Control And Data Acquisition
SOP	Standard Operating Procedure
SOx	Sulfur Oxides
SO_2	Sulfur Dioxide
SPIDERS	Smart Power Infrastructure Demonstration for Energy Reliability and Security
TD	Technical Demonstration
THD	Total Harmonic Distortion
TM	Technical Manager
TTP	Tactics Techniques and Procedures
UAR	Utility Assessment Report
UPS	Uninterruptible Power Supply
USACE	United States Army Corps of Engineers
USNORTHCOM	United States Northern Command
USPACOM	United States Pacific Command
UV	Ultraviolet
V2G	Vehicle-to-Grid

VSE	Virtual Secure Enclave
VVOWECC	Volt-Var Optimization
WECC	Western Electric Coordinating Council
WTG	Wind Turbine Generator
XFMR	Transformer
XM	Transition Manager

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1.0 Introduction

The objective of the SPIDERS JCTD is to demonstrate a cyber-secure microgrid architecture with the ability to maintain operational surety through secure, reliable, and resilient electric power generation and distribution. There are four critical requirements listed in the Implementation Directive as being necessary to demonstrate enhanced power surety for national security:

1. Protect task critical assets from loss of power due to cyber attack.
2. Integrate renewables 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 “bootprint,” and cost.

SPIDERS is a multi-year project divided into three phases, this document will focus on Phase 2. The Phase 2 SPIDERS contract was awarded to Burns and McDonnell in June of 2012 and was followed by 16 months of design, construction, and testing. For Phase 2 of the SPIDERS JCTD, the primary goal is to ensure the Essential/Uninterruptible loads at Ft. Carson have access to secure, reliable electrical power in the event of a prolonged utility power outage. It will expand previous efforts (i.e., Phase 1) by integrating significantly larger sources of renewable generation and further testing the cyber security capabilities of the system. The Ft. Carson microgrid integrates diesel generators (DGs), PV panels, and electric vehicles used as electrical energy storage to provide backup electrical power to multiple circuits containing different categories of loads for the microgrid. The categories of these loads are described in Table 1, with essential/uninterruptible and discretionary loads present in the Ft. Carson microgrid (no loads were categorized as essential/interruptible). Essential/Uninterruptible loads required power under all conditions, as they would under traditional modes of backup generation. In addition to the essential/uninterruptible loads, the Ft. Carson microgrid also incorporates several discretionary load buildings that can be energized, if sufficient resources are available. These do not require continuous power. However, if extra generation and fuel are available, they provide useful services or capabilities to operations under the microgrid conditions. The SPIDERS control system manages all of the microgrid generation sources and selects generators to optimize DGs power performance for a given load, thereby improving endurance by minimizing the amount of diesel fuel consumed.

Table 1. Load Categories on Microgrid

Microgrid Load Categories	
Load Category	Description
Essential/Uninterruptible	Loads that represent critical functions that need access to power at all times and cannot tolerate even momentary outages. These loads are normally backed up by a UPS and an emergency generator. For example: essential computer systems.
Essential/Interruptible	Loads that represent critical functions that need access to power at all times but can tolerate brief outages. These loads are normally backed up an emergency generator. For example: lighting in a room where essential functions are performed.
Discretionary	Loads that do not require access to power at all times because they do not normally represent essential functions. These loads normally do not have an emergency power system. These loads may become essential to particular missions under unusual situations. For example: gymnasiums.

The evaluation of the effectiveness of the Phase 2 of SPIDERS was determined by conducting a 74-hour OD. The OD occurred between October 21st and 24th of 2013 at Ft. Carson, CO and was conducted by the Operational Test Authority (OTA). This document contains detailed results of how SPIDERS achieved the goals of the Implementation Directive as shown by specific Measures of Performance (MOPs) and their parent Measures of Effectiveness (MOEs).

This document is organized as follows: Section 2 gives a review of the Phase 2 OD, Section 3 gives the OD results, Section 4 lists recommendations for Ft. Carson and future ODs, while Section 5 contains the concluding remarks. 1.1.1.1Appendix A contains detailed evaluations of individual MOPs. An Official Use Only addendum to this document titled "Utility Assessment Report for SPIDERS Phase 2 Addendum: Ft. Carson (Rev 1.0)" contains additional OD information.[1]

2.0 Operational Demonstration Review

Between October 21st and 24th of 2013, the OD for Phase 2 of SPIDERS was conducted at Ft. Carson, CO. The Pacific Northwest National Laboratory (PNNL) acted as the Operational Test Agent (OTA) under the Phase 2 Operational Manager (OM), U.S. Northern Command (USNORTHCOM). Staff members from PNNL were on site conducting the OD. OTA staff members were present during major events and during normal hours of operation for Department of Public Works (DPW) staff; a 24-hour presence was not maintained. An automated data collection system was in operation during the entire OD, with exception of the Diesel Generator (DG) fuel levels, which were taken manually. Collected data was periodically quality checked throughout the OD. Data was collected in accordance with the Integrated Assessment Plan (IAP), which was approved by the SPIDERS Integrated Management Team (IMT) prior to the OD [1].

[1] "Utility Assessment Report for SPIDERS Phase 2 Addendum: Ft Carson," can be obtained by request from the JCTD Program Office Work Flow Manager (WFM), which as of January 2015 is Brandon Burke. Requests should be sent to brandon.h.burke.ctr@mail.mil.

2.1 Locations on Ft. Carson

During the OD activities occurred at four primary locations: Building 1, Building 2, Building 3, and Building 4.[1]

2.1.1 Buildings 1, 2, and 3

Buildings 1, 2, and 3 contain essential/uninterruptible loads for the Phase 2 OD, as well as the 900, 1,000, and 1,250 kW DG sets.

2.1.2 Building 4

The building 4 served as the main operations location for the SPIDERS OD. When utility power is lost the backup generators on the SPIDERS microgrid automatically startup and supply their loads in the traditional backup mode. It is the operator(s) at the building 4, via the primary SPIDERS Human Machine Interface (HMI), which controls whether the system stays in normal backup mode or transitions to SPIDERS mode. Operators at Building 4 also have the ability to conduct a soft transition to SPIDERS when utility power is available; this mode was not examined during the OD, but was tested during the Technical Demonstration (TD). Access into building 4 is controlled through limited key access for authorized personnel.

2.2 Planned Events for the OD

The OD was conducted in accordance with the SPIDERS Ft. Carson Operational Demonstration Schedule; all events detailed in the operational demonstration schedule were completed during the OD. The OD was initiated through opening a distribution isolation breaker to isolate the microgrid from Colorado Springs Utility (CSU) supplied power (i.e., black start). The OD was concluded after approximately 74 hours with the return of facilities to CSU supplied power. In addition to the events planned in operational demonstration schedule, other unplanned events occurred.

2.3 Unplanned Events for the OD

During the course of the OD, there were four unplanned events. The first two events occurred before the demonstration and continued throughout the 74 hours of operation. The third occurred right at the beginning of the demonstration as the system attempted to enter SPIDERS mode. The fourth event occurred around noon of the third day of the OD.

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[1] "Utility Assessment Report for SPIDERS Phase 2 Addendum: Ft Carson," can be obtained by request from the JCTD Program Office Work Flow Manager (WFM), which as of January 2015 is Brandon Burke. Requests should be sent to brandon.h.burke.ctr@mail.mil.

2.3.1 Unplanned Event 1: Photovoltaic maintenance

Ft. Carson has a 2.0 MW PV array that was selected for use in the SPIDERS microgrid. Half of this PV array, 1.0 MW, is connected to the overall microgrid via a bypass feeder, providing service to a remote essential/uninterruptible load on the bypass. A third party owns the PV array and power is sold to Ft. Carson via a Power Purchase Agreement (PPA). As a result, full control and capacity of this array were not available to SPIDERS during the OD.

Through various agreements with the third party owner of the array, the SPIDERS project was only designed to integrate 1.0 MW of the 2.0 MW solar array into the microgrid design. However, only half of this portion of the array was functional at the time of the demonstration due to technical difficulties experienced within the PV system. As a result, only a maximum of 500kW of PV was made available to SPIDERS during the OD.

In an attempt to restore the microgrid capacity to the full 1.0 MW, third-party technicians were working on the inverters of the PV array throughout the OD. As a result, the working 500 kW array was often taken offline while work was conducted. The impact of the work was that the 500 kW portion of the array that was technically available for the OD was not always.

As a result, the renewables contributions are significantly less for the evaluation than original estimates in the 100% design document [2]. With the overall energy production from the PV array being reduced, the electric vehicles never entered charging conditions on the microgrid, preventing the effective testing of their energy storage contribution to SPIDERS mode. Had the full 1.0 MW been available, the excess solar generation would have change the results of several of the MOPs. The additional PV generation power, both in direct power provided to the grid and energy later discharged from the electric vehicles, would reduce the overall energy the DGs needed to provide. As a result, fuel use should decrease with the full 1.0 MW, which would lead to a longer runtime with existing resources, and lower environmental emissions while operating under SPIDERS.[1] An analytic estimate of what the benefits could have been if the full 1.0 MW of PV were available are not included in this document since the intent of the UAR is to presented the actual performance of SPIDERS during the OD.

2.3.2 Unplanned Event 2: Derating of 900 kW generator

During initial commissioning and testing of the SPIDERS microgrid on Ft. Carson, an issue was noted with the 900 kW generator. While the generator itself can output up to 900 kW, the circuit breaker connecting it to the circuit did not appear to support such an output. Initial testing of the SPIDERS microgrid revealed that the protection circuit breaker tripped at values slightly above 500 kW. The breaker itself appears to be failing, but was still operational below 500 kW of generator output. The integrators coordinated with Ft. Carson facilities and determined that the breaker would be flagged for

[1] For a detailed description of the operation of electric vehicles in the Ft. Carson SPIDERS microgrid the reader is directed to “Technical Report: For Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Joint Capability Technology Demonstration (JCTD), Phase 2, Fort Carson, CO”. This report can be obtained by request from the JCTD Program Office Work Flow Manager (WFM), which as of January 2015 is Brandon Burke. Requests should be sent to brandon.h.burke.ctr@mail.mil.

post-OD testing and repair. The SPIDERS deployment could continue, but the 900 kW generator would be derated to 500 kW to prevent tripping the breaker.

As a result of this condition, the 900 kW generator operated on the system as a 500 kW generator for the OD. This smaller output rating impacted the dispatching of the generator. Intervals where the 900 kW and 1,000 kW generator may have been sufficient, instead required dispatching the 1,250 kW generator in some combination with the 900 kW or 1,000 kW generators. The overall result is generators may not have been operating as efficiently as possible, especially the 900 kW generator. This impacted any generator-related metrics of the operational demonstration, such as fuel savings.

2.3.3 Unplanned Event 3: Failure to operate synchronization breaker remotely

To simulate a total grid failure scenario and perform a black start, a breaker upstream of the synchronization breaker was intentionally opened. The synchronization breaker connects the microgrid components with the main distribution system during grid-connected operations. Under microgrid operations, the SPIDERS control system would intentionally open this breaker to prevent any synchronization problems when the utility power is restored, and to allow a gradual transition back to utility power.

During testing for the TD, this breaker was manually opened to initiate an outage and start testing SPIDERS. In this mode, the SPIDERS system was tested during the TD without the impact to base facilities and operations that would occur from a “black start.” However, for the OD, the utility power was disconnected at the switch upstream of the synchronization breaker. This would blackout the entire SPIDERS microgrid, which includes eliminating grid power to the synchronization breaker. The breaker has an on-site Uninterruptible Power Supply (UPS) to provide control power when grid power is unavailable, so the SPIDERS system can open it and receive remote telemetry to indicate it is open. A unique feature of the synchronization breaker is that it will draw the required power from either side of its contacts (load-side or utility-side). During all prior tests conducted by Burns and McDonnell and/or Intelligent Power and Energy Research Corporation (IPERC), at least one side always had power, so the breaker never relied on the UPS. When a switch further into the utility-supply side was opened to simulate the blackout, this breaker returned to UPS power.

During the simulated blackout initiated at 05:38 MDT on October 21st, the UPS for the synchronization breaker was unable to provide backup power[1]. This was eventually determined to be due to the battery associated with the UPS not being charged due to a poor wiring connection on the UPS. The breaker was delivered new to the integrators in this condition. As a result, the SPIDERS system was not able to verify the commands or condition of the breaker, preventing it from fully engaging the SPIDERS mode of operation. The SPIDERS HMI indicated to the operator that the microgrid was not transitioning into SPIDERS mode. Upon consult and inspection, the integrators quickly realized the problem and manually opened the breaker at 05:40 MDT. Power was restored to the utility side allowing the breaker to communicate once again, but still leaving the SPIDERS microgrid isolated from the utility system.

Without the integrators being on-site, this likely would have resulted in the system only operating in traditional modes of back-up operation. While integrator intervention was required, the system did effectively blackout in a realistic manner and refused to enter SPIDERS mode without proper verification

[1] Twenty four hour time convention is used for this report.

of isolation from utility power. This is an expected behavior and is not considered a failure, since the system transitioned in a coordinated manner to traditional operational mode.

Intervention on the part of the integrators was required to restore breaker control power, which allowed the breaker to respond to SPIDERS control and communication. Once the breaker began properly responding to SPIDERS communication, the OD resumed. The main implication is the system operated in traditional emergency mode for approximately five minutes longer than necessary; impacting the runtime, fuel use, and emissions rates a small amount. It is important to note that if the operators were the only people present at the time of this unplanned event, the system would have gone into traditional backup mode and all essential/uninterruptible load would have been served. The integrators were allowed to intervene, with the approval of the OTA, in order to continue the OD. It was determined by the OTA that allowing the integrator to intervene was of greater value for the proper assessment of SPIDERS Phase 2. The Phase 2 OM was also present and concurred with OTA assessment to proceed.

This unplanned event highlights the necessity of testing systems in the exact configuration that they are expected to run; it did not reveal any form of system vulnerability. Had the system been tested in this configuration during the TD this issues would have been identified prior to the OD. This event, combined with a similar type of event at the Phase 1 OD, should serve as a lesson learned for the Phase 3 OD that testing should be under conditions that are identical, or as close as possible, to expecting operating conditions.

2.3.4 Unplanned Event 4: SPIDERS Mode exit during generator maintenance

During the morning of October 23rd, routine fuel checks and generator maintenance checks were performed on the system. During the check of the 900 kW generator, a low oil pressure alarm was intermittently activating. Per Ft. Carson Standard Operating Procedures (SOP), the technician called in the alarm and a maintenance request was filed. The 900 kW generator had been running for nearly the entire OD, so it was not expected to automatically shut down anytime in the near future. The system operator was notified, and with assistance of the integrator, coordinated with the SPIDERS system to bring the idle 1,000 kW generator online and shutdown the 900 kW generator. The generator was locked and tagged by the system operator until maintenance could be completed.

A short time after the generator was shut down, a Ft. Carson Support Services (FCSS) maintenance technician arrived and began servicing the generator. The cause of the alarm appeared to be a very low oil level, likely caused by the significantly higher use of the 900 kW generator than usual. The maintenance technician completed his maintenance and was ready to test the generator. As part of the lockout procedure, the technician was told to coordinate with the SPIDERS operation center.

Shortly after 10:00 MDT, the technician entered the SPIDERS operation center and indicated that he was going to start the generator to perform final maintenance checks. It is unclear who he spoke to, but none of the immediate SPIDERS operators seemed aware of the visit. At approximately 10:23 MDT, the technician had returned to the generator and proceeded to begin testing the unit. Starting the unit is part of the standard maintenance procedure and requires restarting the generator, running it for a period of time, and ensuring the alarm has cleared and everything is working properly. The lock and tag mentioned earlier was still in effect and the generator was not “returning to service.”

After the technician started the generator, the co-located SPIDERS controller once again saw an active generator. At this time, the SPIDERS controller resumed control of the generator and registered that the generator was back in service. As a result, the SPIDERS control system began ramping up the 900kW generator, ramping down the 1,000 kW generator brought online earlier, and began the 1,000kW generator's countdown to cool-down and shutdown. Shortly after 10:26 MDT, the 1,000 kW generator began shutdown procedures.

Shortly before 10:30 MDT, the technician finished up the maintenance checks on the generator. He attempted to turn off the generator so the lock and tag could be removed and the generator returned to service. However, the local SPIDERS controller characterized the generator as available to the system and identified it as currently handling a significant portion of the load. Despite attempting to shut down the generator, the SPIDERS control system maintained that it was operational and continued to try and dispatch the generator.

At 10:30:03 MDT, the 900 kW generator shut down. However, the SPIDERS control system believed it was still in service and all electrical connections were maintained. As a result, the running 1,250 kW generator was not only supplying all of the load of the microgrid, but also supply the power the 900 kW generator was drawing to keep it spinning (i.e., motoring the generator). As a result of this increased load, the 1,250 kW generator load increased to 1,300 kVA and slowly settled to a value of approximately 1,280 kVA. Simultaneously, the frequency of the microgrid dropped to 56.96 Hz, where it remained for the rest of the event.

The system operated under this condition until 10:36:31 MDT (6 minutes and 29 seconds in this state). Shortly after the 900 kW generator shut down, integrators located in building 4 noticed unreasonably high power readings on the HMI. They immediately attempted to remove the 900 kW generator from service in the SPIDERS control system and bring the 1,000 kW generator back online.

At 10:36:31 MDT, the system exited SPIDERS mode. Due to limited data streams available to the OTA, it is unclear if a load change prompted this, if an under-frequency condition occurred, or if the 1,250 kW generator exceeded an overload limit. The system dropped out of SPIDERS mode and returned to traditional operations, as designed. Essential/Uninterruptible loads were maintained by their individual backup generators.

After consulting with the OTA and receiving approval, corrective actions began to try and reenter the SPIDERS mode of operation. Over approximately the next hour, attempts were made to try and get the system back into SPIDERS mode. As a result of the conditions that led to the exit from SPIDERS mode, the legacy generator governors on nearly every generator were in an error state and unresponsive to the SPIDERS control system. The integrator visited each of the three backup generators to perform a soft reset through the legacy generator interface, which was unsuccessful. A hard reset was then performed by removing the DG status signal from the legacy generator controllers, which cleared the error codes and let the generators respond to the SPIDERS control system and re-enter SPIDERS mode.

At 11:46:40 MDT, the final controller reset was complete and the system began fully responding to the SPIDERS control system again. By 12:00 MDT, the SPIDERS microgrid was fully reestablished and the OD continued for the remainder of the scheduled time.

A major conclusion of this incident is that in the event of an unknown system state or significant problem such as the one experienced during the 900 kW generator maintenance interval, SPIDERS will exit and return to traditional operations mode, as designed. Essential/Uninterruptible loads continued to be served by the individual backup generators, but all secondary loads, which would not normally have back-up generators, were without power while the operators attempted to restart the system.

The operation of the system in traditional mode affected many of the metrics associated with the DGs on the system, such as decreased runtime and increased emissions. Furthermore, the PV array was not integrated during the entire traditional operation time, further reducing the amount of energy it was able to supply to the system. While the SPIDERS microgrid architecture is capable of energizing the microgrid with a generator removed for maintenance, this was not part of the Concept of Operations (CONOPS) applied to Ft. Carson. When the SPIDERS system was operated with a generator removed for maintenance during this OD, a lack of procedural understanding temporarily created increased risk for stakeholders at Ft. Carson, including operators and those located discretionary load facilities located on the microgrid. As this state of operation was outside of CONOPS, training, and anticipated SOP for Ft. Carson SPIDERS and was a by-product of decisions made to accommodate the OD (as opposed to exiting SPIDERS mode for maintenance), it will not be used to inform suitability MOPs [2, 3]. It should also be noted that because this state of operation was an artifact of actions taken to accommodate the OD, these events do not in any way represent a vulnerability of the SPIDERS system; the system is not expected to ever operate in this mode again. It should be noted that the OM was surprised to learn that removal of generators from the microgrid for maintenance was not well supported by the system or training. This event will be utilized to inform lessons learned for future ODs and will count negatively against the SPIDERS system in any assessment that allowed for maintenance while islanded.

2.4 Impact of Unplanned Events

The impact of the first three unplanned events was minor. The first unplanned event resulted in a lower solar generation capacity than expected, which may have increased the fuel efficiency of the system and further offset the emissions impacts of the DGs. Furthermore, the lower PV output meant the electric vehicles were not used to store excess solar energy during the OD, so their charging impact is not evaluated. The vehicles were able to successfully discharge their initial energy into the microgrid, but no further capabilities, such as VAR support, were exercised or evaluated in the OD.

The second unplanned event had impacts similar to the first. With the 900 kW generator derated to less than 500 kW, generators would have been dispatched in a slightly different manner than if it provided the full 900 kW output. The main impact would be attributed to intervals with the 1,000 kW and 1,250 kW generators were running. If the 900 kW generator supported a higher rating, the 1,000 kW and 900 kW generator or the 1,250 kW and 900 kW may have been the proper generator combination. This change in dispatch would likely affect the projected runtime and emissions impacts of the overall DGs.

The third unplanned event resulted in more of an impact to the test plan than the actual operation of the OD. The time between the black-start initiation and full SPIDERS restoration of all loads was longer than anticipated, but was still early enough to minimize impact to building occupants as it occurred prior to those occupants being onsite. Essential/Uninterruptible loads were carried by their generators in traditional mode for a longer duration, with the only operational impact being an increase in fuel use and emissions.

The fourth unplanned event resulted in significant impact to the OD. The incidents leading to the event highlighted several areas for improvement in the conduct of the OD. Several of the efficiency and effectiveness metrics were impacted by not only the actual unplanned event, but the increased runtime and configuration of many of the generation assets. Furthermore, without the presence of members of the integration team and given the limited duration of the OD, the system would not have been restored into SPIDERS mode and would have been left in traditional operations mode. It should be noted that during a longer outage or a true emergency, SPIDERS mode would eventually be restored through necessary maintenance and under consultation of the integration team. However, the limited duration and simulated-emergency situation of the OD meant traditional microgrid operations would have been the near-term fallback for the system. Consideration was given to terminate the OD due to the outages experienced by the discretionary load occupants, but the OTA and OM decided to complete the OD.

While the fourth unplanned event eventually resulted in SPIDERS transitioning to the traditional mode of operation (as intended), the steps leading up to this mode change are very concerning. Aside from an anomalous reading noticed by the integrators watching the HMI, there appeared to be no indication of a problem on the system. The 1,250 kW generator supplied the entire system, including motoring the 900 kW generator, for approximately five minutes, despite being slightly overloaded and in a significant under-frequency condition. It is unclear what finally caused the system to exit SPIDERS mode, but the period of operation in the single-generator state is extremely concerning for the implications it has on both system reliability and situational awareness associated with the event.

The unplanned events provided significant insight for post OD recommendations for not only normal Phase 2 operations, but also Phase 3 planning. These recommendations are included in section 4.2 of the UAR.

3.0 Operational Demonstration Results

Despite the four unplanned events, the OD for Phase 2 of SPIDERS was successful. The successful evaluation was based on the demonstrated ability of SPIDERS to support each of the four critical requirements of the Implementation Directive. The four critical requirements are:

1. Protect task critical assets from loss of power due to cyber attack.
2. Integrate renewables 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 “bootprint,” and cost.

Each of the five MOEs (Effectiveness, Efficiency, Renewables Integration, Suitability, and Cyber Security) properly supported the four critical requirements. The following subsections review what the requirements were for all MOEs, with the exception of Cyber Security, to properly support the four critical requirements of the Implementation Directive, and how the requirements were met. Details on each of these MOEs and supporting MOPs, with the exception of Cyber Security, can be found in Appendix A.[1]

3.1 MOE 1: Effectiveness

MOE 1 for the Ft. Carson SPIDERS demonstration examines the effectiveness of the SPIDERS mode of operation. In particular, the impacts on endurance and overall quality of power for the loads on the SPIDERS microgrid are examined. To achieve success for MOE 1, the SPIDERS mode of operation is required to increase the operation time of the system. This increased operation time cannot be at the expense of reliability or power quality.

Increased operation time for the fixed quantity of fuel was accomplished during the Phase 2 OD. While this is influenced directly by generator efficiency (MOE 2), this particular MOE focused on how the system was able to effectively utilize all generation assets to minimize fuel use. Dispatching the generators in a more efficient manner and adding in the 500 kW of PV generation allowed the system to operate for a longer period of time given a fixed amount of fuel. Even with identical generator efficiency, the inclusion of PV decreases the amount of energy each DG needs to produce, hence reducing its overall fuel use and extending the runtime for a fixed quantity of fuel. Due to the structure of the Phase 2 OD, with some loads being considered discretionary and of lower priority, there are multiple ways to evaluate the endurance of the SPIDERS system.

The first evaluation method is comparing the full operation of the SPIDERS microgrid with traditional operations. Traditional operations are defined as the four generator sources (60 kW, 900 kW, 1,000 kW, and 1,250 kW) all serving their individual essential/uninterruptible loads. During most of the OD, the SPIDERS mode of operation only used two generators. It should be noted that the value of MOP 1.1 indicates that the 74.8-hour OD duration only represents a 0.2 hour expected runtime increase over the expected fuel usage of traditional operations for 74.8 hours. However, this SPIDERS operation represents not only reducing the number of active generators to serve the essential/uninterruptible load, but also the addition of load that would not normally be served: the discretionary loads. Under traditional operations, the generators would have only served an estimated 67.45 MWh of essential/uninterruptible load during 74.8 hours. Under the conditions of the OD, the SPIDERS mode of operation served not only the 67.45 MWh of essential/uninterruptible load, but also 14.93 MWh of discretionary load. For the exact same quantity of fuel required to serve the 67.45 MWh of essential/uninterruptible load for 74.8 hours, the SPIDERS mode of operation could serve all 82.38 MWh of essential/uninterruptible and discretionary load on the microgrid for 75.0 hours. The 0.2-hour increase indicates that serving the entire microgrid at all load levels, the microgrid could run slightly longer than using traditional, individual backups at the essential/uninterruptible facilities for the same quantity of fuel. This is the sole method of SPIDERS operation performed during the OD. During an actual outage, Ft. Carson has the ability to manually remove discretionary loads from the SPIDERS microgrid, providing capability for increased runtime and a more direct comparison with traditional operations. This mode of operation was not utilized for the OD

[1] For a detailed account of the evaluation on MOE-5, Cyber Security, refer to, "Utility Assessment Report for SPIDERS Phase 2 Addendum: Ft Carson," which can be obtained by request from the JCTD Program Office Work Flow Manager (WFM), which as of January 2015 is Brandon Burke. Requests should be sent to brandon.h.burke.ctr@mail.mil.

due to the impact it would have for activities being performed at Ft. Carson in discretionary load facilities.

A second evaluation method extrapolates results from the data collected during the OD to explore a more direct comparison with traditional generator operations. In this situation, rather than serving all the secondary load sources, only the essential/uninterruptible buildings are brought onto the SPIDERS microgrid. It is useful to note that this includes supporting the full building load of the essential/uninterruptible resources and not just the internal partial-loading supported by traditional backup that represents the true essential/uninterruptible assets. That is, it covers only the essential/uninterruptible buildings, but may include some further additional load when compared to traditional operations. This represents an easily configurable scenario of the microgrid through feeder switch adjustments, not any significant facilities-level changes. The expected SPIDERS generator dispatch was derived from simulations based on operations of the system during the OD, but does not represent any operational mode performed during the demonstration. The significant difference in the SPIDERS generation dispatch is the ability to adjust generator loading to more efficient operating points, often resulting in the ability to shut down one or more generators on the system. Furthermore, the ability to utilize the 500 kW PV array is also included. Utilizing the simulated generator operations with only essential/uninterruptible buildings connected, the Phase 2 microgrid would be able to operate for nearly 89 hours (14.4 hours beyond the 74.6-hour traditional operation period, or 19.3%). This 14.4 hour increased operations period represents the benefits the SPIDERS mode of operation would provide to only assets normally covered under traditional operations, unlike the actual OD condition which also served discretionary loads as well. Under conditions that would require longer operation of the essential/uninterruptible resources, dropping the discretionary load provides over half a day of additional runtime over traditional, individual backup generation.

A third evaluation is a slight variation of the second. Rather than utilizing SPIDERS to serve the essential/uninterruptible buildings, SPIDERS will only serve the essential/uninterruptible assets of the system. The load served is identical to traditional emergency backup operations, but the 500 kW PV array and the generator dispatch methods of the SPIDERS system are available. This evaluation provides a direct comparison of traditional and SPIDERS modes of operation with identical load served. However, configuring the SPIDERS microgrid in this fashion would require manipulations beyond normal feeder switchgear, and may require configuration changes within the essential/uninterruptible buildings. As with the previous method, this portion of the evaluation was carried out completely in simulation with assumptions observed during the OD. Under this condition, the operation time of the microgrid is extended to 91.4 hours (16.8 hours beyond the 74.6 hour traditional operation period). Under conditions where maximal fuel efficiency was required, operating the microgrid in this manner will extend the fuel supply by roughly 23%.

As discussed in the previous paragraphs, the Ft. Carson SPIDERS OD had loads divided into essential/uninterruptible and discretionary categories. Compared to traditional, individual backup generators, the SPIDERS microgrid allowed all of the discretionary loads to remain energized. Under the full SPIDERS microgrid of the OD, the system supported nearly 795 kW of additional peak load and provided 14.93 MWh of discretionary load energy that would not have been provided in traditional operations. Leveraging the addition of the PV generation and more efficient dispatching of existing resources, this demonstrates the ability of the SPIDERS system to operate the Ft. Carson microgrid in a more effective manner, keeping less-critical resources online during the blackout.

Note that this initial effectiveness measure, the additional runtime under the SPIDERS mode of operation, would be directly impacted if the full 1.0 MW of PV generation were available during the OD. Once the inverter repairs are complete, the additional 500 kW of solar generation in the system is expected to provide more “fuel-free” energy into the system during daylight hours, as well as charge the electric vehicles as energy storage. This stored photovoltaic generation may defer a larger generator start (e.g., prevent the 1,000 kW from needing to be run if the 900 kW were only exceeded for a minute), or just simply be discharged back into the microgrid on a scheduled interval. Both the immediately available energy (direct PV) and deferred energy (stored in the electric vehicles) would further reduce fuel consumption by the DGs. This decreased fuel use would allow the system to run even longer on the same quantity of fuel traditional operations would have required. While it is unknown exactly how much it would extend the runtime, the additional 500 kW of solar would increase this effectiveness metric beyond the values demonstrated in the OD.

Another metric developed and outlined in the IAP for evaluating the effectiveness of the SPIDERS microgrid is the reliability of the system. One metric is the amount of time an additional generator was available to the system. If any generator failed on the system or required maintenance, the SPIDERS system would remove the generator from service and rely on the remaining two to serve the required load. During the Phase 2 OD, one generator was available in standby for approximately 71 hours of the OD, demonstrating increased operational reliability.

Despite the increased capability for reliability, it is useful to mention the generator outage event outlined in Section 2.3.4. When the 900 kW generator was removed from service for maintenance, the SPIDERS system operated exactly as intended. The remaining two SPIDERS-connected generators served the load, representing an increased reliability. However, due to the events described in Section 2.3.4, the system exited SPIDERS mode and returned to traditional backup operations. Reliability equivalent to traditional operations was maintained throughout this event. However, this represents an overall decrease in reliability of the system (in regards to total load supported). Only discretionary loads experienced the outage, but would not have been energized under traditional mode. Any additional operations are considered “increased reliability” for the system, but could have been higher without the impacts of the unplanned event. Despite maintaining traditional reliability, the nature of the failure and the transition to traditional operations had significant potential to decrease the reliability of even the essential/uninterruptible resources (i.e., if the 900 kW, 1,000 kW, or 1,250 kW generators became non-operational in a more severe manner than observed in the OD, even their traditional operations load served would be impacted negatively). Such a generation-loss scenario would be true during traditional operations as well, but this problem was made more apparent during the SPIDERS OD.

Another reliability-based metric associated with effectiveness is greater testing of the microgrid assets during and leading up to the OD. With the inclusion of discretionary loads and generally loading individual generators at higher levels, limitations on the operating conditions were discovered. The example mentioned in Section 2.3.2, the 900 kW generator, was found to have an issue with its circuit breaker, effectively limiting it to less than 500 kW of output. Without the deployment of SPIDERS or running the generator at a higher loading than traditional operations, this limitation may not have been discovered until it had either failed completely, or a higher demand was requested during traditional operations. Discoveries like this help highlight the effectiveness of the SPIDERS mode of operation, both in utilizing resources to a greater potential and discovering issues associated with operating them beyond the levels of traditional backup operations.

The final aspect of effectiveness is the overall power quality of the electrical system during the SPIDERS mode of operation. With the exception of frequency, nearly all of the electrical characteristics remained within acceptable limits during the OD. Although not directly an MOP, voltage levels were regulated with smaller deviations from nominal during the SPIDERS operations. While no voltage violations were recorded during the OD, or during grid-connected operations the week before. Voltage levels observed during the SPIDERS microgrid operations did not vary as much as the prior week, but no violations were observed in either data interval. Microgrid operations appeared to regulate the voltage to a tighter band, but voltage regulation during grid-connected periods was well within acceptable limits.

The only power quality metric to exhibit violations was the electrical frequency of the microgrid. During the event described in Section 2.3.4, the frequency dropped to below 57 Hz for over 5 minutes. Under Western Electricity Coordinating Council (WECC) guidelines, which govern the transmission system where Ft. Carson is located, any excursion below 57 Hz is supposed to result in an immediate trip of the resource [3]. However, the SPIDERS microgrid attempted to ride through this low frequency condition. While not explicitly governed by WECC standards while operating as a microgrid, these frequency limits represent bands selected to prevent equipment damage or abnormal operation in under or over frequency conditions and were chosen as the criteria for evaluating frequency in the IAP. While the excursion observed during the OD is not known to have caused any equipment damage, it still highlights a couple detriments to the effectiveness of the Ft. Carson SPIDERS deployment. It should also be clear this is a setting inside the generator itself and not a direct SPIDERS setting – it was merely expressed by the SPIDERS OD.

The first implication of the frequency excursion is that the SPIDERS microgrid would maintain this lower quality of power service, which may be harmful to devices on the system. While the microgrid remained operational for over five minutes in this state, no visible fluctuations are present to indicate it was attempting to reconcile the issue. It is unclear if any action could have been taken by the system to improve the frequency, but no indications of such a condition appeared to be present on the SPIDERS HMI during the actual OD. That is, there was no visible notification that this frequency condition may be outside an acceptable range of operation. If the IAP-selected frequency bands are more restrictive than expected or acceptable frequency ranges on the microgrid, this may explain the lack of an HMI-based indicator.

The greater implication of the frequency excursion is associated with the underlying cause of the deviation. Based on observations during the OD and the data collected from the system, it appears the 1,250 kW generator was not only serving the entire microgrid, but was also powering the 900 kW generator (effectively converting the generator into a large motor). The 1,250 kW generator was slightly overloaded, and it is suspected an overload alarm is what eventually caused the exit out of SPIDERS mode (no information on what directly caused the final “failure” was recorded). However, the greater implication comes from the 900 kW generator’s operation during this time.

It is assumed that back feeding into generators would be a possibility that should be protected against, especially in a microgrid operation that had the potential to have more solar generation than load (if all 1.0 MW of solar were eventually able to integrate into the microgrid). Since the final trip did not appear to be associated with the back feeding of the 900 kW generator, this indicates such protection was not in place. The resulting frequency excursion represents a power quality issue in the OD, but this implication influences the overall reliability of the system. There may be further potential for back feeding of a generator to occur through situations different from the OD (additional renewable generation, or other equipment failures). While the PV generation did go to zero at the time of the incident, it is unclear if this was the SPIDERS system removing it as a potential over-generation source or some exogenous event. Local-level protections against such occurrences may be needed to effectively operate the SPIDERS microgrid in situations with a high level of renewable generation available.

Overall, the SPIDERS operational mode of the Ft. Carson microgrid shows positive impacts to the evaluated effectiveness metrics. The system successfully extended the effective runtime of the essential/uninterruptible assets, and included all of the discretionary assets. With the exception of the incident noted in Section 2.3.4, power quality was maintained at similar levels to the normal grid connection.

Despite the overall effectiveness success, the implications associated with the under-frequency event require considerations in future deployments. The under-frequency values themselves represent a lower power quality to the system, and overall asset-protection may not be sufficient to maintain effective reliability of the essential/uninterruptible generation assets.

3.2 MOE 2: Efficiency

MOE 2 of the Ft. Carson SPIDERS demonstration evaluates the overall efficiency of the SPIDERS mode of operation. With the pooled generation resources and more effective dispatch of said resources, generators are expected to operate more efficiently. To meet success for MOE 2, generators should be running less and produce fewer emissions than traditional operations. Furthermore, system losses are expected to be an insignificant portion of the overall energy provided to the microgrid.

The primary indication of efficiency is the amount of energy produced per gallon of fuel utilized. Operating the generators at a higher efficiency point results in less fuel used to produce the same amount of energy, and shutting down unneeded generators removes the fuel cost of idling those generators. By sharing the generation resources on the microgrid, the system operated at an average efficiency of 19.1% higher than that of traditional operation. It is useful to note that this increase in efficiency is a result of optimal utilization of existing generation. The result is significantly less fuel required for the system, which influenced the longer runtime indicated in MOP 1.1.1.

It is worth pointing out that MOP 1.1.1 is also heavily influenced by PV generation offsetting what ordinarily would have been diesel generation, hence the separation of efficiency and effectiveness. Additional PV generation on the system would increase MOP 1.1.1 (runtime), but it is not clear how it would affect this fuel efficiency MOP. The additional 500 kW PV array could change the generator dispatching, which could result in higher or lower fuel efficiency. If a larger generator was shut down due to the additional PV, the smaller generators may be operating at a more efficient point and require less fuel per unit energy. However, if no generator dispatch changes occurred, the additional PV could push the generators to lower operating points, requiring a little more fuel per unit energy. Insufficient data exists from the OD to determine the impact to generator efficiency if the full 1.0 MW of PV generation was made available.

By sharing the generation resources, one generator was often shut down and sitting idle on the system. In the standby state, this generator is no longer contributing to the fuel use or emissions rate of the system. When averaged across the four generators that would ordinarily be running during traditional operations, the average generator was running for 34 hours less under the SPIDERS operational mode.

This average is based on only four generators and should not be interpreted literally. Individual generators varied significantly in this average. For example, the 60 kW generator was off for nearly the entire OD, but the 900 kW was active for nearly the entire OD (aside from the maintenance interval and event). If only these two generators were averaged, it could indicate the "average reduced runtime" would be roughly half the OD interval (since one generator was off and the other was on, the total generator runtime divided by two would be half the OD interval). When averaged with the two other generators that were running roughly 50% of the time, the average will be heavily influenced by the 60 kW and 900 kW outliers. The 34-hour "average reduced runtime" is obviously not the exact operating case. However, it does indicate significantly less total runtime from all four generators compared to traditional operations. This indicates an overall improvement in the efficiency of the system.

Reduced fuel usage and more efficient operating points directly influence the emissions from the generators as well. All raw quantities of emissions (estimated direct emissions) were noticeably reduced under the SPIDERS mode of operation. Using the data available, it is estimated that the SPIDERS OD produced over 2200 mass-pounds less carbon dioxide than traditional operations. It is worth mentioning that this savings occurred while the microgrid was technically serving more load than traditional operations as well, via the inclusion of discretionary load buildings.

Another method for highlighting the efficiency of the SPIDERS operational mode is in emissions-intensity readings. Rather than being the pure mass of the substance emitted, it is normalized against the power to provide an emission rate per unit energy. With more efficient operating points and an overall decrease in emissions by the system, these intensity values represent a greater efficiency directly. The carbon dioxide intensity calculated for the traditional operations is an average of 310.6 mass-pounds of carbon dioxide per kilowatt hour. Under SPIDERS operations, this number is reduced to an average of 157.1 mass-pounds of carbon-dioxide per kilowatt hour. This is almost half the carbon emissions rate of the traditional operation mode, again while serving additional load.

While the overall SPIDERS mode increased efficiency of the generators, there are some additional losses associated with interconnecting the buildings. Traditional operation had the individual generators attached directly to the loads they were serving. Under SPIDERS, the existing distribution network is used to share these resources across all of the buildings of the microgrid. This results in a higher amount of losses on the microgrid under SPIDERS, especially associated with the bypass feeder that goes to the PV array and the essential/uninterruptible building located near it. However, even with this longer distribution run, the higher voltage kept losses to a minimum. No direct measurements are available and even calculated estimates of losses are less than 100 Watt-hours for the entire OD. Given this configuration enabled the 60 kW generator to shut down and allowed the import of the 500 kW PV array, these losses are miniscule in the overall system load. Efficiency technically decreased when associated with losses, but its inclusion of the PV and removing another smaller, less efficient generator greatly increased the overall efficiency of the system.

Operating the Ft. Carson microgrid in SPIDERS mode showed significant increases to the overall efficiency of the system. Overall fuel use was decreased through greater fuel efficiency and decreased generator operating times, resulting in lower environmental emissions by the system. All of this was accomplished while serving more load than the traditional mode of operations would usually provide. While it is unclear how the efficiency of DGs would be affected if the full 1.0 MW of PV generation were made available, decreased fuel consumption is expected, and therefore emissions are expected to be even lower than the values calculated from the OD.

3.3 MOE 3: Renewables Integration

MOE 3 of the Phase 2 SPIDERS OD quantifies how much of an influence the renewable generation sources contributed to the overall system. The Ft. Carson PV array is sized at 2.0 MW and 1.0 MW is electrically available to the SPIDERS microgrid, but as mentioned in Section 2.3.1, only 500 kW of that array was available during the OD. To achieve success for the renewables integration MOP, this 500 kW array should be offsetting a portion of the energy supplied by the DGs, resulting in less emissions and fuel usage.

Despite the significantly reduced capability and intermittency of the PV array, significant contributions were still made to the overall system energy during the SPIDERS OD. The PV array provided over 7% of the total energy used by the microgrid during the OD. During one peak load time, the PV array provided 19.03% of the power required. It is useful to note that the OD took place shortly after the Autumnal equinox. Therefore, the values from the OD can be viewed as slightly conservative estimates for annual contributions of the PV array on the system (higher energy output is expected in summer months and lower during winter months).

Overall, the PV array was successfully integrated into the Ft. Carson SPIDERS microgrid. Additional capacity would have offset the diesel generation impacts even further, both directly and through potential stored energy in the electric vehicles. However, even the single, 500 kW section of the array provided a large portion of the energy and helped increase the overall runtime of the system during SPIDERS operations.

3.4 MOE 4: Suitability

The Phase 2 OD demonstrated that the system satisfied the MOPs and criteria associated with success for MOE 4, Suitability. The assessment team's evaluation on suitability indicates that the SPIDERS system can be embedded in ongoing base operations.

This conclusion is informed by the evaluation of the Suitability related MOPs which indicate, among other things, the following:

- The training and training materials were of a satisfactory quality and complete.
- There was an appropriate effort for the identification and establishment of safety procedures.
- Operations of essential/uninterruptible facilities were minimally impacted through the addition of SPIDERS, indicating the unobtrusiveness of SPIDERS to the personnel at those locations.[1]
- The situational awareness afforded by the SPIDERS HMI was appropriate for operating the system.
- The intuitiveness of the HMI and manner in which users interacted with the HMI was also effective.

[1] When the system was operated with a generator removed for maintenance during this OD, a lack of procedural understanding temporarily created increased risk for the Ft. Carson stakeholders. As this state of operation was outside of CONOPS, training, and anticipated SOP for Ft. Carson SPIDERS and was a by-product of decisions made to accommodate the OD, it will not be used to inform suitability MOPs [4]. However, the event will be utilized to inform lessons learned for future ODs and would count negatively against the SPIDERS system in any assessment that allowed for maintenance while islanded.

Feedback from trainees on training was primarily positive. Feedback from others observing training indicated that trainees were not as engaged as desired. From interviews, this lack of engagement was partially attributed to the proximity of the U.S. government shut down to the training sessions. It was explained that the trainees had a backlog of work and the SPIDERS training may have not been seen as a priority.

The generator maintenance event, detailed in Section 2.3.4, was a serious shortcoming of the OD. This event and specifically the decision to maintain the SPIDERS microgrid while performing maintenance on a generator without the corresponding training of SPIDERS operators or the maintenance team for this operation had serious consequences for the operation of the SPIDERS system as it took over an hour to return the system back to SPIDERS operation. Returning the system to SPIDERS mode would not have been possible during the OD by the Ft. Carson SPIDERS user base. It was only through the expertise of the integrators and knowledge they gleaned through the SPIDERS Phase 1 (Joint Base Pearl Harbor Hickam) demonstration on the need to perform a unique reset procedure on the generators in lieu of restarting all of the generators that it was possible to re-engage SPIDERS.

Observations of both situational awareness of electrical components and unobtrusive operations (negating the generator outage event's impact on suitability MOPs) revealed that the SPIDERS system worked well for SPIDERS operators and the generator maintenance team. The DPW operators had no problem understanding exactly what the state of each SPIDERS component was or what each component's expected future state would be while switching modes. The DPW staff also showed comfort with moving through SPIDERS modes in the HMI. The FCSS staff were comfortable logging into the system, inspecting generator state and inspecting alarm state. With regard to unobtrusive operations, no additional actions were required from facility personnel for the SPIDERS implementation. From observation of DPW actions and HMI interactions it was clear that SPIDERS operation was well integrated into the larger SOP. There was communication between all involved parties (e.g., field electricians, Facilities, DPW, and FCSS) and decision makers prior to any state change of SPIDERS. This was exemplified during the generator outage event when DPW informed decision makers of the situation and were given exact conditions under which SPIDERS system would return facilities to the grid connected condition. Finally, DPW users desired an additional layer of security, beyond what is currently provided, through additional warnings and locks on cabinets and switches associated with SPIDERS breakers.

In conclusion, SPIDERS operations met the requirements of MOE 4, and MOE 4 is considered successful.

3.5 MOE 5: Cyber Security

The overall Cyber Security MOE received a passing assessment; however, not all of the individual MOPs for Cyber Security passed. As with any cyber-based system, this evaluation is a snapshot in time, only reflecting known information about design, isolation and appropriate stewardship and therefore does not account for future changes in design. Minor changes to system configuration or process/procedures, for example, will alter future assessment findings.

"Utility Assessment Report for SPIDERS Phase 2 Addendum: Ft Carson," contains a detailed account of the evaluation on MOE-5, Cyber Security, and can be obtained by request from the JCTD

Program Office Work Flow Manager (WFM), which as of January 2015 is Brandon Burke. Requests should be sent to brandon.h.burke.ctr@mail.mil.

4.0 Recommendations for Future ODs and Ft. Carson

Based on the events of the Phase 2 OD, the OTA team compiled a list of recommendations for the future Phase 3 ODs, as well as post OD recommendations for Ft. Carson.

4.1 For future ODs

The recommendations within this subsection are directed towards the SPIDERS team, and future OTA efforts, in particular.

- Clearly articulate roles and responsibilities for the OD. This will clearly define the circumstances and modes in which operators interact with the SPIDERS technical manager and contractors during the OD.
- Develop simple generator maintenance functionality available through the SPIDERS HMI.
- Enable and utilize scenario based training (e.g., generator maintenance while microgrid is still activated).
- Articulate the need for training from supervisors to those being trained and test operator proficiency post-training.
- If possible, test system in the TD exactly as it is to be operated during the OD.
- For a detailed account of lessons learned as related to cyber security, refer to "Utility Assessment Report for SPIDERS Phase 2 Addendum: Ft Carson". This report can be obtained by request from the JCTD Program Office Work Flow Manager (WFM), which as of January 2015 is Brandon Burke. Requests should be sent to brandon.h.burke.ctr@mail.mil.

4.2 For Ft. Carson

The specific recommendations for Ft. Carson are as follows:

In cooperation with IPERC, upgrade HMI software modification that will allow for a simple mechanism for removing/returning a single generator from/to the microgrid for maintenance.

A SPIDERS simulator co-located with the operational HMI would be useful so that decisions could be thought through and exercised prior to committing to those actions on the operational system. This recommendation is out of scope for the SPIDERS contract at Ft. Carson, and if adopted, Ft. Carson would need to procure a simulator outside of the SPIDERS JCTD effort.

Additional warnings and protective controls (e.g., both cabinet and switch locks) are desirable for all SPIDERS breakers. This will give another layer of security to field electricians.

Incorporate second bank of PV into SPIDERS once inverter repair is complete. This will yield up to 1MW of PV available to Ft. Carson while in SPIDERS mode. Testing the SPIDERS mode of operation with the full 1 MW of PV and electric vehicle storage capability is suggested to insure SPIDERS is able to properly manage these additional resources that were not tested during the formal OD.

Low fuel alarms may be revisited in order to keep the generators on line for longer periods between refueling. The generators at Ft. Carson had low fuel alarms set relatively high (approx. 40% fuel remaining) which, when tripped, would trigger an action in the SPIDERS control system to select and bring online the next most appropriate generator and automatically offload the low-fuel alarmed generator.

Ensure consistent maintenance log entries between FCSS staff maintaining generators and refueling team.

5.0 Concluding Comments

The Implementation Directive states that the objectives of the SPIDERS JCTD is to demonstrate a cyber-secure microgrid architecture with the ability to maintain operational surety through secure, reliable, and resilient electric power generation and distribution. The Phase 2 OD showed that these objectives were achieved. The four critical requirements listed in the Implementation Directive as being necessary to demonstrate enhanced power surety for national security were met. The four requirements were:

1. Protect task critical assets from loss of power due to cyber attack.
2. Integrate renewables 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 “bootprint,” and cost.

The five MOEs were rated as successful in this UAR. Based on the IAP procedure, this indicates an overall rating of “successful” for the Phase 2 OD.

6.0 References

Integrated Assessment Plan Template and Operational Demonstration for SPIDERS Phase 2: Ft. Carson, Pacific Northwest National Laboratory, PNNL-22733, September, 2013.

SPIDERS Ft. Carson 100% Submittal, Burns and McDonnell and IPERC Solutions, March, 2013.

WECC Coordinated Off-Nominal Frequency Load Shedding and Restoration plan, Western Electricity Coordinating Council, April 28, 2010.

SPIDERS Ft. Carson Concept of Operation, SPIDERS Operational Management

Appendix A

Complete List of MOP Values

Appendix A

Complete List of MOP Values

This appendix contains the values for each of the relevant MOPs listed in the IAP for the second phase OD of SPIDERS. The following tables provide three sets of values for the MOPs, by MOE. The "Normal" value is for the traditional mode of backup operation, the "SPIDERS" mode is as operated during the OD, and "Δ Value" is the difference between the first two. In general, positive "Δ Value" results indicate an improvement SPIDERS operation had on the system, while negative "Δ Value" results indicate degradation in performance.

Table 2. MOPs for MOE 1.1

MOE 1.1 - Sustained Operations				
MOP	MOP Name	Normal	SPIDERS	Δ Value
MOP 1.1.1	Increased Runtime	74.6 hours	74.8 hours	0.2 hours
MOP 1.1.2	Increased Time	100.0%	100.3%	0.3%
MOP 1.1.3a	Increased Essential/Uninterruptible Asset Runtime	74.6 hours	91.4 hours	16.8 hours
MOP 1.1.3b	Increased Essential/Uninterruptible Bldg. Runtime	74.6 hours	89.0 hours	14.4 hours
MOP 1.1.4a	Increased Essential/Uninterruptible Asset Time	100.0%	122.5%	22.5%
MOP 1.1.4b	Increased Essential/Uninterruptible Bldg. Time	100.0%	119.3%	19.3%

Note: MOP 1.1.3 and 1.1.4 represent simulated values based on observations of the OD. Only MOP 1.1.1 and MOP 1.1.2 are quantities from the explicit operation

Table 3. MOPs for MOE 1.2

MOE 1.2 - Additional Load Served				
MOP	MOP Name	Normal	SPIDERS	Δ Value
MOP 1.2.1	Additional Peak Load Served	0.0 kW	794.7 kW	794.7 kW
MOP 1.2.2	Additional Energy Supplied	0.0 kWh	14.93 MWh	14.93 MWh

Table 4. MOPs for MOE 1.3

MOE 1.3 - Reliability				
MOP	MOP Name	Normal	SPIDERS	Δ Value
MOP 1.3.1	Additional Generation Resource Availability	0 hours	70.7 hours	70.7 hours
MOP 1.3.2	Effective Asset Testing	Qualitative		

Table 5. MOPs for MOE 1.4

MOE 1.4 - Power Quality				
MOP	MOP Name	Normal	SPIDERS	Δ Value
MOP 1.4.1	Total Harmonic Distortion Violations	0 seconds	0 seconds	0 seconds
MOP 1.4.2	System Frequency Violations	0 seconds	392 seconds	-392 seconds
MOP 1.4.3	System Power Factor Violations	0 seconds	0 seconds	0 seconds
MOP 1.4.4	Diesel Generator 1 Steady State Voltage Violations	0 seconds	0 seconds	0 seconds
MOP 1.4.5	Diesel Generator 2 Steady State Voltage Violations	0 seconds	0 seconds	0 seconds
MOP 1.4.6	Diesel Generator 3 Steady State Voltage Violations	0 seconds	0 seconds	0 seconds
MOP 1.4.7	EVSE Steady State Voltage Violations	0 seconds	0 seconds	0 seconds
MOP 1.4.8	Diesel Generator 1 Voltage Imbalance Violations	0 seconds	0 seconds	0 seconds
MOP 1.4.9	Diesel Generator 2 Voltage Imbalance Violations	0 seconds	0 seconds	0 seconds
MOP 1.4.10	Diesel Generator 3 Voltage Imbalance Violations	0 seconds	0 seconds	0 seconds
MOP 1.4.11	EVSE Voltage Imbalance Violations	0 seconds	0 seconds	0 seconds

Table 6. MOPs for MOE 2.1

MOE 2.1 - System Efficiency				
MOP	MOP Name	Normal	SPIDERS	Δ Value
MOP 2.1.1	DG Increase Efficiency	100.0%*	119.1%	19.1%
MOP 2.1.2	DG Reduced Runtime	74.6 Hours	40.6 Hours	34 Hours
MOP 2.1.3	DG Reduced Total CO_2	5817.5 Lbm	3566.8 Lbm	2250.7 Lbm
MOP 2.1.4	DG Average CO_2 Intensity	310.6 Lbm/kWh	157.1 Lbm/kWh	153.5 Lbm/kWh
MOP 2.1.5	DG Reduced Total NO_x	51.1 Lbm	44.9 Lbm	6.2 Lbm
MOP 2.1.6	DG Average NO_x Intensity	2.73 Lbm/kWh	1.97 Lbm/kWh	0.76 Lbm/kWh
MOP 2.1.7	DG Reduced Total SO_x	7.4 Lbm	3.9 Lbm	3.5 Lbm
MOP 2.1.8	DGAverage SO_x Intensity	0.39 Lbm/kWh	0.17 Lbm/kWh	0.22 Lbm/kWh
MOP 2.1.9	DG Reduced Total PM-10	2.2 Lbm	0.5 Lbm	1.7 Lbm
MOP 2.1.10	DG Average PM-10 Intensity	0.12 Lbm/kWh	0.02 Lbm/kWh	0.10 Lbm/kWh
MOP 2.1.11	System Real Losses	0.0 kWh	0.016 kWh	-0.016 kWh
MOP 2.1.12	System Reactive Losses	0.0 kVarh	0.012 kVarh	-0.012 kVarh
MOP 2.1.13	System Real Losses	0.0%	0.0%	0.0%
MOP 2.1.14	System Reactive Losses	0.0%	0.0%	0.0%

*Note: Traditional kWh/gallon was arbitrarily set to an efficiency of 100%. All SPIDERS-based efficiency calculations were normalized against this value.

Table 7. MOPs for MOE 3.1

MOE 3.1 - PV Penetration Level				
MOP	MOP Name	Normal	SPIDERS	Δ Value
MOP 3.1.1	Percent of Nameplate Value	0%	16.10%	16.10%
MOP 3.1.2	Percent of Peak Load	0%	19.03%	19.03%
MOP 3.1.3	Percent of Energy Supplied	0%	7.30%	7.30%
MOP 3.1.4	Capacity Factor	0%	16.10%	16.10%

Table 8. MOPs for MOE 4.1

MOE 4.1 – Training Requirements and Material		
MOP	MOP Name	Details
MOP 4.1.1	User Training Needs Identified	Successful
	User training needs were identified through mapping the integrators expert knowledge of system operation to operator roles. The integrator identified and made training available to all SPIDERS stakeholders and operators.	
MOP 4.1.2	Training Material Developed	Successful
	The manual is organized, thorough, and generally well-conceived. The manual uses figures and pictures of the system throughout to aid the operator in orienting themselves to the system and better comprehend the information in the manual. The simulator was also praised by trainees as being realistic and useful. The simulator was made available to the trainees prior to the OD, however trainees did not take full advantage of the simulator opportunity at that time. It was expressed by some trainees (post-OD) that more simulator experience prior to the OD would have been beneficial. There were several gaps identified- 1) There are several figure references in the training manual which are inaccurate. These errors have been shared with the integrator and are anticipated to be fully corrected. 2) The CONOPS and training material did not encompass generator maintenance while in SPIDERS mode- which was indicated as desirable by end-users after the OD.	

Table 9. MOPs for MOE 4.2

MOE 4.2 – Safety		
MOP	MOP Name	Details
MOP 4.2.1	Establishment of Safety Procedures	Successful
	SPIDERS specific safety procedures and associated warning and cautions were established and identified in training and operator manuals.	
MOP 4.2.2	Procedures for Operational Modes	Successful
	From observation of DPW actions and HMI interactions it was clear that SPIDERS operation was well integrated into the larger SOP. There was communication between all involved parties (e.g. field electricians, Facilities, DPW, and FCSS) and decision makers prior to any state change of SPIDERS. This was exemplified during the generator outage event when DPW informed decision makers of the situation and were given exact conditions under which SPIDERS system would return facilities to the grid connected condition.	

Table 10. MOPs for MOE 4.3

MOE 4.3 – Human Factors		
MOP	MOP Name	Details
MOP 4.3.1	Unobtrusive Operation	Successful

	While SPIDERS was operated within Ft. Carson's CONOPS for the system it proved to be unobtrusive and aided field technicians in diagnosing generator state (e.g. low fuel).	
MOP 4.3.2	Situational Awareness at DPW	Successful
	During the OD both operators and supervisors were consistently monitoring the HMI examining the state of the system. The primary focus of the operators was to determine the state of the system with respect to fuel and generator state. The HMI detailed the state of the system by showing current mode of operation, lines energized, breakers state, renewable production, and generator alerts. Through the HMI it was possible to quickly determine system and component state associated with unplanned events (Section 2.3.3, 2.3.4).	
MOP 4.3.3	HMI Interactions	Successful
	Operators could access and initiate all of the modes of operations for SPIDERS through the HMI.	
MOP 4.3.4	Decision Support	Successful
	Operators are informed of error states in the HMI and can initiate appropriate actions by consulting the operations manual with respect to any specific error code. Without vendor support, often the appropriate action for microgrid maintenance or repair is to exit from SPIDERS mode prior taking any additional action. This approach was confirmed in DPW interviews and matches training procedures.	

Table 11. MOPs for MOE 4.4

MOE 4.4 – Maintainability		
MOP	MOP Name	Details
MOP 4.4.1	User Access	Successful
	All of the SPIDERS physical components can be accessed by DPW and FCSS personnel, basic SPIDERS control and operation were available for all operators through unique user names and passwords, and higher level access was available to a SPIDERS administrator. All of the operators and administrators of the system were identified and trained as detailed in MOP 4.1.	
MOP 4.4.2	System Update Procedures	Successful
	It was determined that SPIDERS system administrator would update the system as per direction of chief information officer. Any SPIDERS software updates will be delivered from IPERC to DPW on a Compact Disc (CD) which can be loaded into any SPIDERS HMI. Details for updating the system with this CD are well documented in the operations manual (Section 13).	
MOP 4.4.3	Component Availability	Successful
	Replacement SPIDERS controllers are available from IPERC. All other SPIDERS related components are available from corresponding vendor.	

Table 12. MOPs for MOE 4.5

MOE 4.5 – Manpower Supportability		
MOP	MOP Name	Details
MOP 4.5.1	Post OD Operations	Successful
	From post-OD interviews with operators and supervisors felt that the incorporation of SPIDERS into base operations would be useful and welcomed. Additionally they saw significant utility in the reliability and redundancy associated with SPIDERS. Finally, the ability to more effectively test generators by placing them under load was articulated.	

Table 13. MOPs for MOE 5.1

MOE 5: Cyber Security
MOE 5.1: CSET Evaluation
MOP Values for the CSET Evaluation can be found in "Utility Assessment Report for SPIDERS Phase 2 Addendum: Ft Carson". This report can be obtained by request from the JCTD Program Office Work Flow Manager (WFM), which as of January 2015 is Brandon Burke. Requests should be sent to brandon.h.burke.ctr@mail.mil.

Table 14. MOPs for MOE 5.2

MOE 5.2: Static Code Evaluation
MOP Values for the Static Code Evaluation can be found in "Utility Assessment Report for SPIDERS Phase 2 Addendum: Ft Carson". This report can be obtained by request from the JCTD Program Office Work Flow Manager (WFM), which as of January 2015 is Brandon Burke. Requests should be sent to brandon.h.burke.ctr@mail.mil.

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