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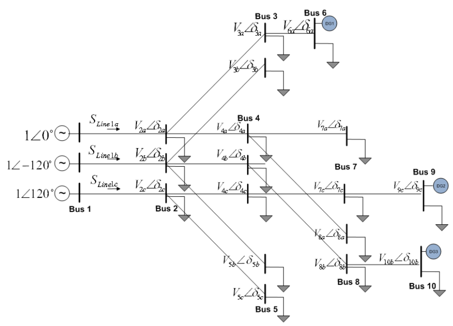

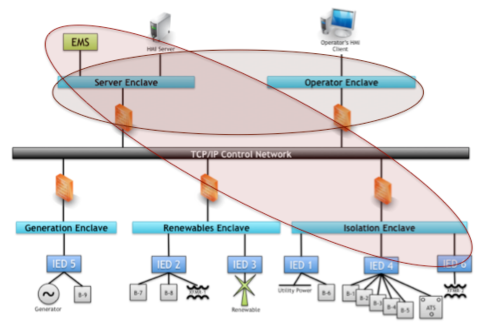

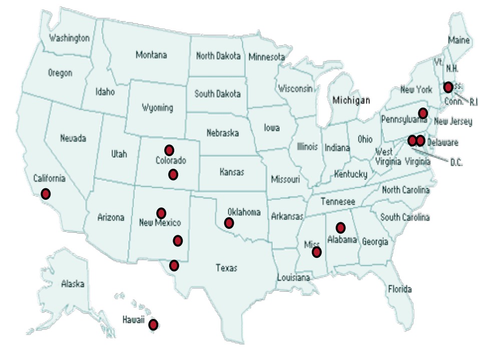

SPIDERS Project: Status and Design Analysis

Jason Stamp, Ph.D.

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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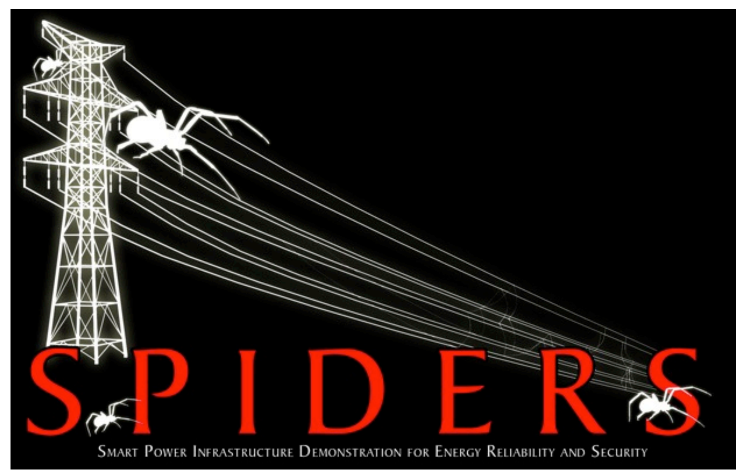
Bottom Line Up Front

- SPIDERS is building three microgrids, each with increasing capability, which will function as permanent energy systems for their sites
  - Site 1 (Joint Base Pearl Harbor Hickam) is complete
  - Site 2 (Fort Carson) is complete
  - Site 3 (Camp Smith): completed preliminary design, demo in FY15
- The project will promote adoption of microgrid technology for DoD through:
  - Design analysis methodology
  - Cyber security architecture



SPIDERS Participants

Sandia National Laboratories

PACOM, NORTHCOM, DOE, DHS

DOE National Laboratories

Military Services

Military Facilities Organizations

Local Utility Companies

States of Hawaii & Colorado

SPIDERS JCTD Overview

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PEARL HARBOR / HICKAM AFB CIRCUIT LEVEL DEMONSTRATION

- Renewables
- Storage
- Energy Management

FT CARSON MICRO-GRID

- Large Scale Renewables
- Vehicle-to-Grid
- Large scale storage
- Critical Assets
- Demonstration to tie in with COOP Exercise

CAMP SMITH ENERGY ISLAND

- Entire Installation Smart Micro-Grid
- Islanded Installation
- High Penetration of Renewables
- Demand-Side Management
- Redundant Backup Power
- Makana Pahili Hurricane Exercise

TRANSITION

- Template for DoD-wide implementation
- CONOPS
- TTPs
- Training Plans
- DoD Adds Specs to GSA Schedule
- Transition to Commercial Sector via DOE
- Transition Cyber-Security to Federal Sector and Utilities

CYBER-SECURITY

Department of Energy Support for SPIDERS

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- DOE Office of Electricity Delivery and Energy Reliability funded SPIDERS design efforts
- Based on Energy Surety Microgrid design process that has been used at many DoD sites
- DOE design analysis focuses on:
  - Energy reliability for critical missions
  - High readiness and immediately deployable technologies
  - Cyber security for the control systems

Selected Energy Surety Microgrid Projects (Funded by DOE OE, DOE FEMP, and DoD)

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- Ft. Belvoir, MD – 300 Area
  Developed eight conceptual designs; working with DoD on partial implementation.
- Maxwell AFB, AL (R&D project)
  Designed and supervising construction as an experimental microgrid.
- Ft. Devens, MA, 99th ANG
- Indian Head – Naval Surface Warfare Center, MD
- Ft. Sill, OK
  - Developed ESM design including 700-1000
  - kW landfill gas distributed generation system.
- Kirtland AFB, NM
  - Eight ESM conceptual designs are complete;
  - supporting collaborative DoD/DOE proposals
  - for further development and implementation.
- Ft. Carson, CO (SPIDERS site)
- Camp Smith, HI (SPIDERS site)
- Ft. Bliss, TX
  Multiple ESM designs are complete.
- Vandenberg AFB, CA
- West Point, NY
- Cannon AFB, NM

SPIDERS/ESM Load Categorization

- Tier C – loads / buildings that are critical to the mission; these loads usually have dedicated backup generators. Tier C_U loads are non-interruptible and will include UPS, while Tier C_I loads can endure short losses of electrical power.
- Tier P – loads / buildings that are nice to have, but that can be switched on or off the microgrid at the base commander's discretion. Some of these loads may have dedicated backup generators. Some may be designated ahead of time, while others might be promoted ad hoc (depending on their configuration).
- Tier O – loads / buildings that will not be powered during microgrid operations.
- Tier O_P – loads that are too small to merit the cost of automation (e.g. streetlights or parking lights).

Energy Surety Microgrid: How it Works

- When utility power is unexpectedly lost, normal backup operations occur (an ESM does not preclude traditional, accepted engineering practice)
- During an outage, UPS carry non-interruptible critical loads as the microgrid disconnects from the utility and the diesels start
- Architecture reconfigures the the existing medium voltage (MV) network to create a microgrid backbone
- Connections for existing diesels are changed to allow simultaneous connection to critical building loads and also the MV network (additional energy assets can be added, but an ESM does not require a new central plant)
- The diesels are synched together on the MV microgrid network, and any other additional sources (like renewable energy) are brought online
- Tier 2 loads may be served as feasible and useful

ESM reuses existing equipment to support mission energy security

SPIDERS Microgrids Support Seven Key Value Propositions

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1. **Improve reliability** for mission-critical loads by connecting generators on a microgrid using existing distribution networks.
2. **Increase endurance for backup energy during outages** by using renewable energy sources and increased efficiency of generators.
3. **Improve maintenance capabilities** by allowing for necessary downtime of diesel generators during extended outages without interruption of service, as well as enabling full-load testing of machinery grid-connected.
4. **Reduce operational risk** for energy systems through a strong cyber security for the microgrid.
5. **Enable flexible electrical energy** by adding capability to selectively energize loads during extended outages.
6. **Improve energy situational awareness** through always-sensing control system.
7. **Reduce energy costs** during normal operations by controlling microgrid resources to lower consumption / demand charges, and also generate ancillary services revenue.

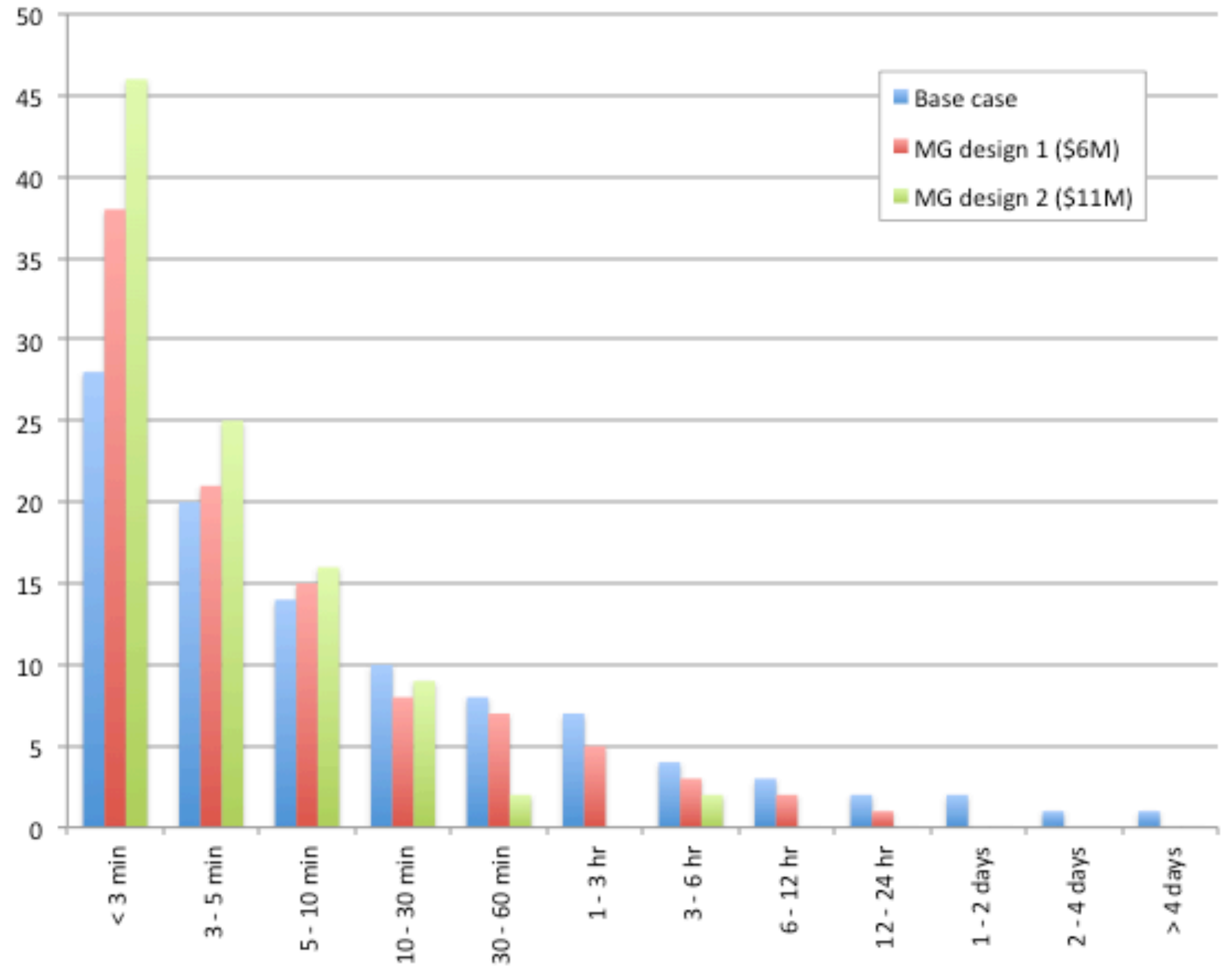
Microgrids Support Quantitative Metrics

<table>
<tr><td colspan="3" rowspan="2"></td><td colspan="3">Operating Mode</td></tr>
<tr><td>Normal</td><td>Typical Emergency</td><td>Abnormal Emergency</td></tr>
<tr><td colspan="2"></td><td>Abbreviation</td><td>N</td><td>TE</td><td>AE</td></tr>
<tr><td rowspan="3">Benefit</td><td>Technical</td><td>TC</td><td>N-TC</td><td>TE-TC</td><td>AE-TC</td></tr>
<tr><td>Financial</td><td>FN</td><td>N-FN</td><td>TE-FN</td><td>AE-FN</td></tr>
<tr><td>Environmental</td><td>EN</td><td>N-EN</td><td>TE-EN</td><td>AE-EN</td></tr>
</table>

- Normal, technical (N-TC):
  - Improved power quality if equipment from resiliency measures support it
  - Simpler backup testing through improved control and energy flexibility
- Normal, financial (N-FN):
  - Reducing energy billing costs through energy consumption management
  - Revenue from market/demand response participation or from energy contracts with utilities
- Normal, environmental (N-EN):
  - Deferred emissions from reduced consumption or improvements to utility operations
- Typical emergency, technical (TE-TC):
  - Improved reliability for critical loads: systems designed for resiliency could be used to support critical load during normal outages if there are failures in normal backup procedures or equipment

Microgrid Resiliency Analysis Example

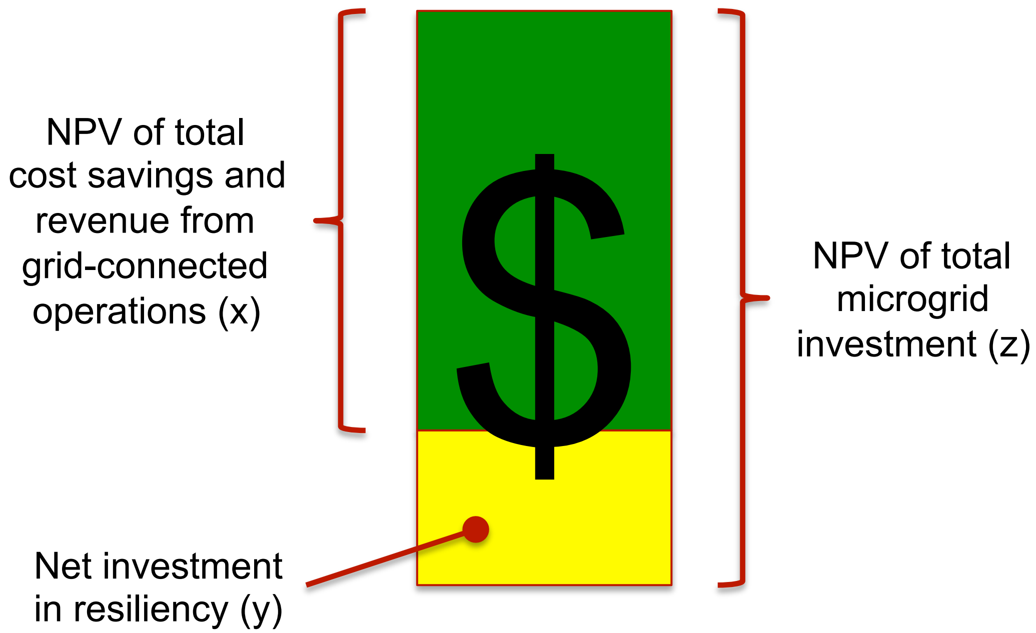
- Analysis for combination of 1/3/5/28 day outages
- Time critical load unserved, given that it happens
- Base case/MG1/MG2: 5%/0.4%/0.1% rate of critical load unserved per outage



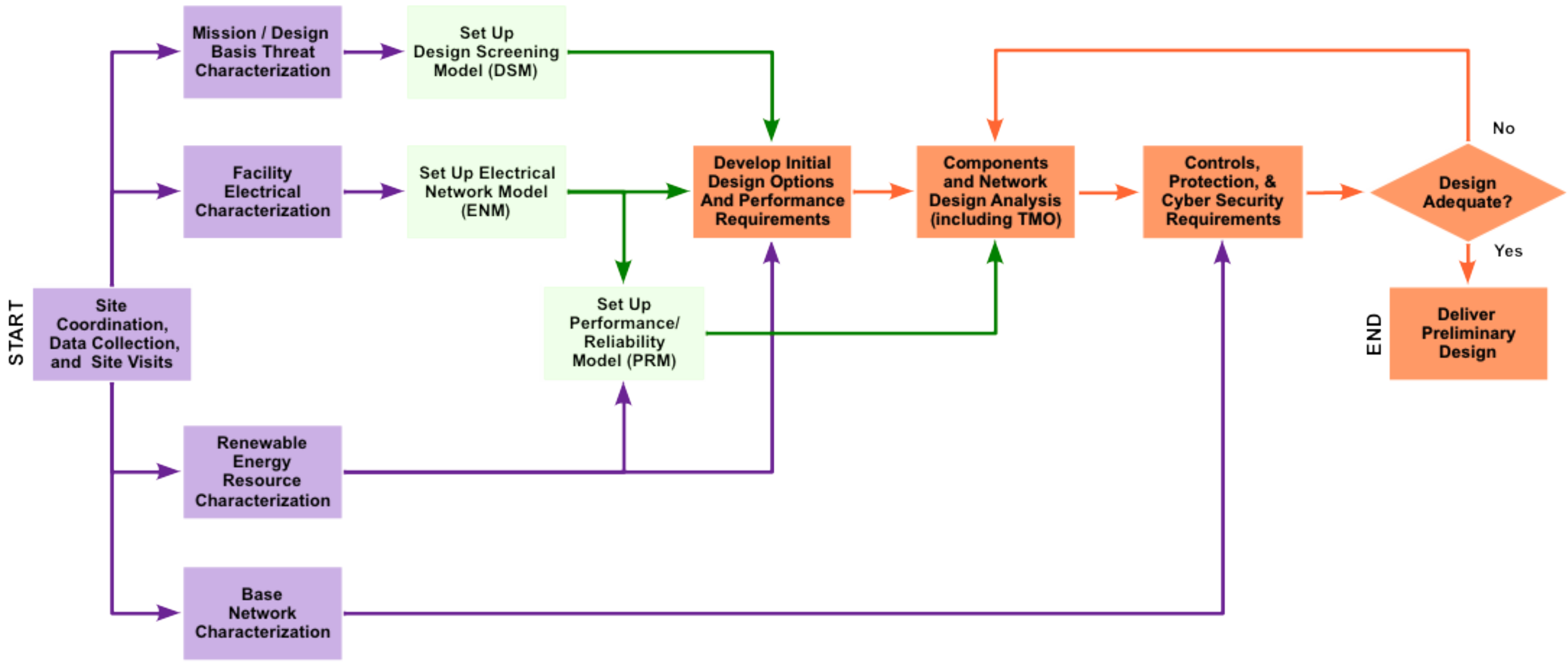
Microgrid Resiliency Analysis Example

- Here, $x + y = z$
- The benefits of resiliency improvements are difficult to think of in terms of dollars
- However, if investments are considered as shown to the right, stakeholders have a simple question:

  Are the benefits worth the investment *y*?



SPIDERS/ESM Technical Approach

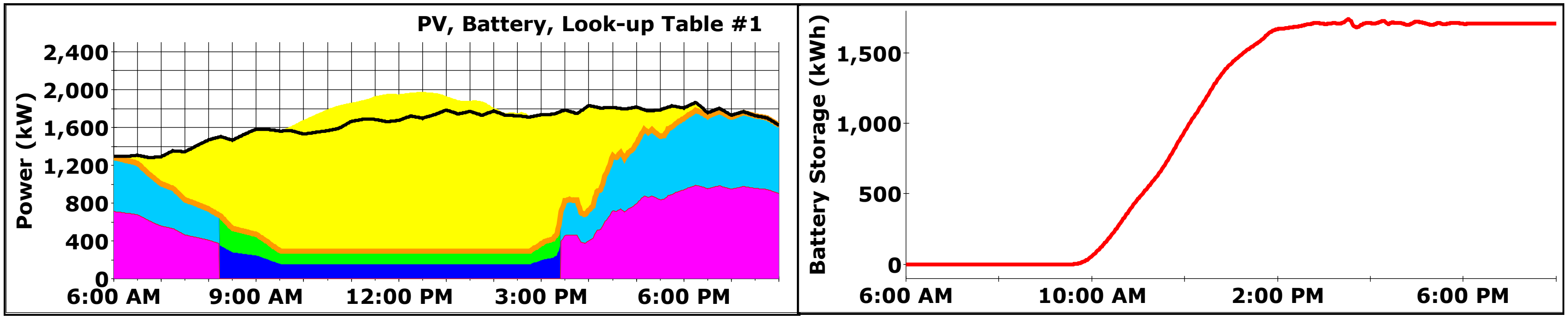


- Design Phase
  - Conceptual design – What are the microgrid requirements and what energy assets are needed?
  - Preliminary design – What are the microgrid functional requirements? How do we control and secure it?
  - Detailed design – Create a buildable construction specification, teaming with industry.
- Installation and Testing
- Operation and Transition

Design Decisions Basis

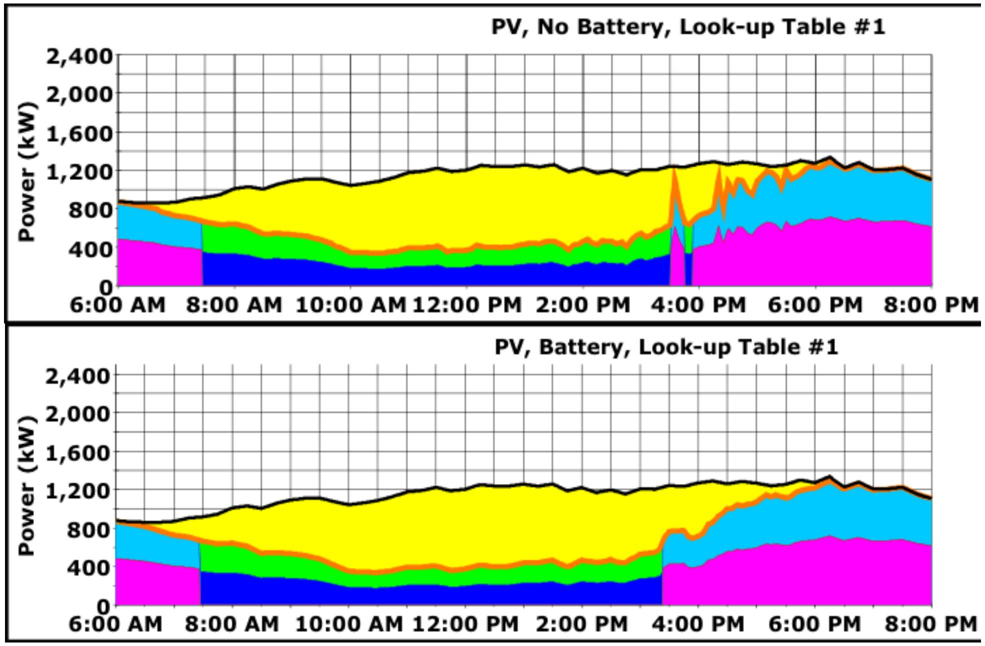
- Design Screening Model (DSM)
  - Narrow microgrid design options
  - Investigate key relationships between building load, PV generation, and diesel electrical generation
- Electrical Network Model (ENM)
  - Ensure voltage magnitudes remain close to rated values despite changes to feeder configurations
  - Determine if the feeder has adequate capacity to carry the additional new generation
- Performance/Reliability Model (PRM) using TMO (Technology Management Optimization) software
  - Used to optimally determine several design parameters for the the three SPIDERS microgrid
  - Optimally manage high-value, long-lived, highly technical equipment over the lifetime of a system

Design Screening Model (DSM)



This system has too much PV energy and would require an impractical battery.

Adding electrical storage reduces renewable energy intermittency issues. More load would reduce the PC penetration percentage.



Example DSM Results

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Islanded Microgrid Mode

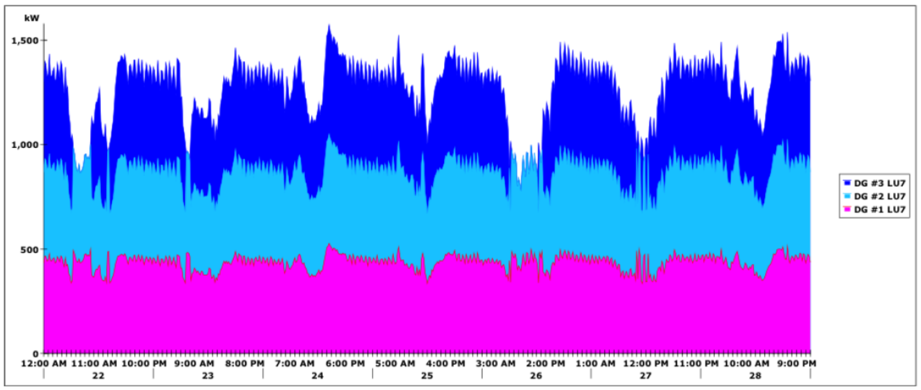


Figure D.3: Critical load support when islanded with 3x 1000 kW generators.

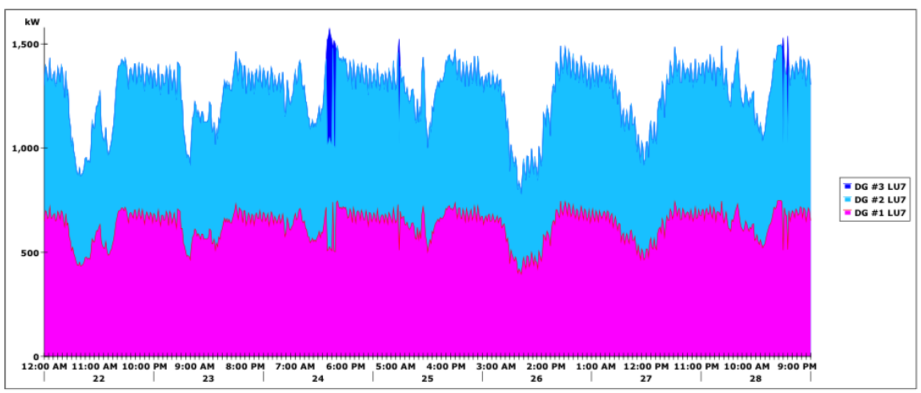
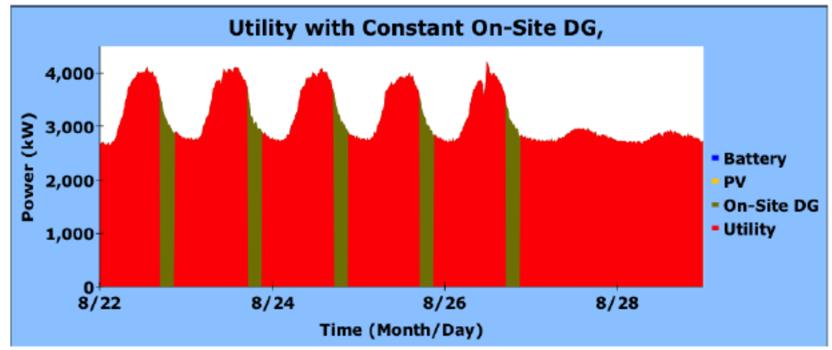
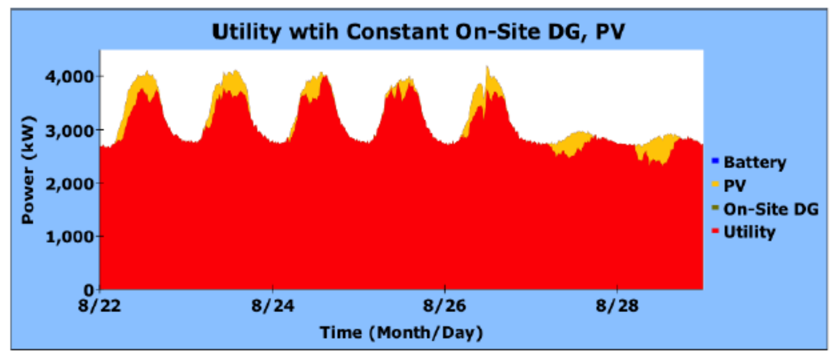


Figure D.4: Critical load support when islanded with 3x 1500 kW generators.

Grid Connected – Revenue Operation



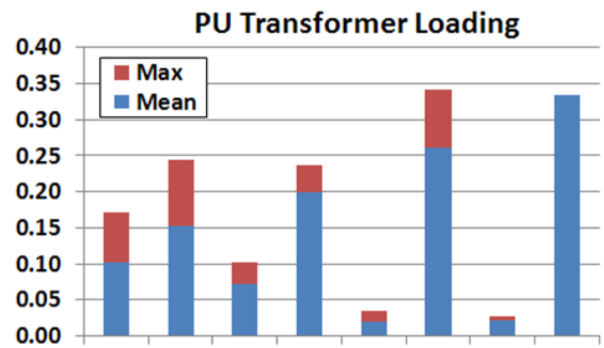
(a) Rider M curtailment hours over 1 week.

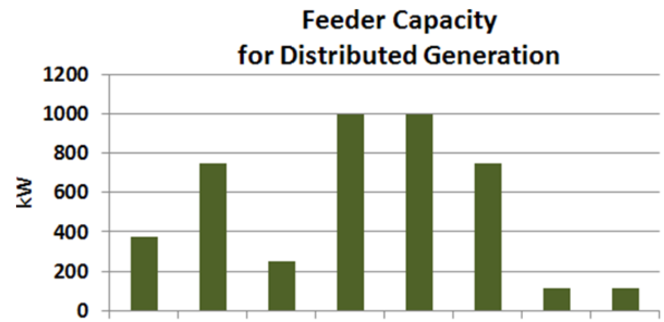


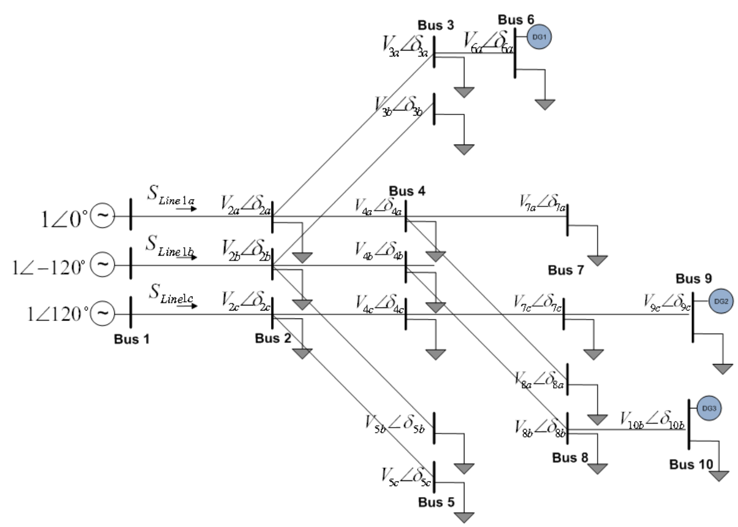
(b) Solar contribution over the same week.

Electrical Network Model (ENM)

- Voltage and flow analysis
- Development of a notional microgrid one line diagram
  - Determination of switching to form the microgrid MV backbone
  - Designation of PCCs
  - Low voltage switches are preferred to medium voltage switches to bring Tier 1 and 2 buildings onto, and take Tier 3 buildings off, the microgrid
  - LV switching allows Tier 3 loads to be upgraded later to Tier 2
  - Some Tier 3 loads removed more cost-effectively by disconnecting an entire lateral, but these later can not be easily upgraded later to Tier 2 loads







Example one line diagram

Technology Management Optimization (TMO)

- Sandia software that computes planning roadmaps
- Tradeoffs are treated objectively and defensibly
- Solves user-defined problems: timeframe, objectives/ constraints, options/suboptions are all user-defined
- Optimizes over time (including time-based resource constraints, e.g. growth in demand, load-leveling of costs, etc.) using genetic algorithm solver
- Single-objective and multi-objective optimization
- Incorporates an external interface for linking to other programs; for microgrids, a Monte Carlo simulation of system performance
- Past projects:
  - Analysis for the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) project
  - MRAP-ATV Capability Packages
  - Stryker Modernization
  - Ground Combat Vehicle (GCV) Systems Trade Analysis
  - Nuclear Security Strategy Action Core Team (NSSACT)
  - Integrated Lifecycle Security (ILS)

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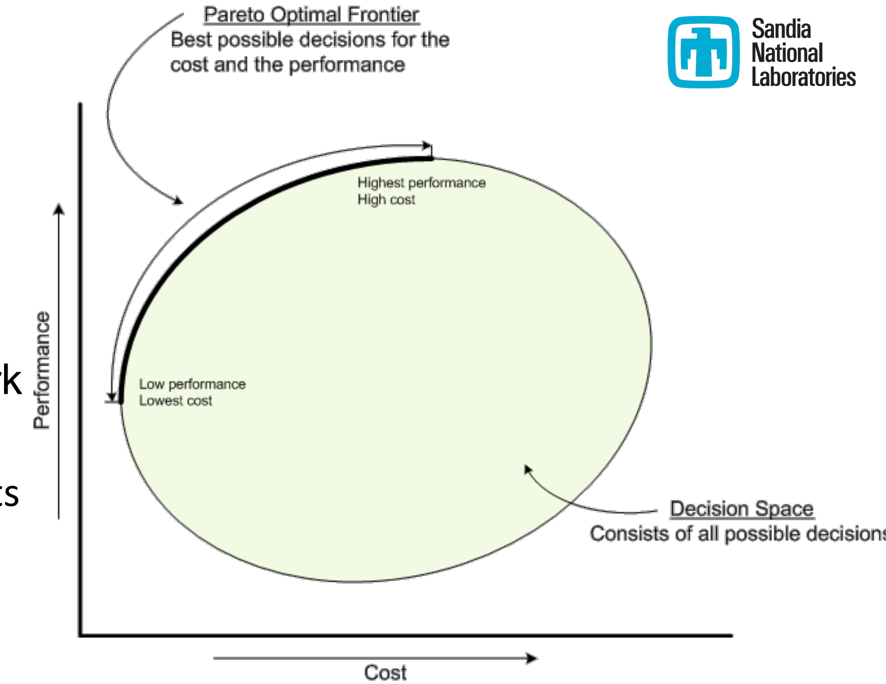
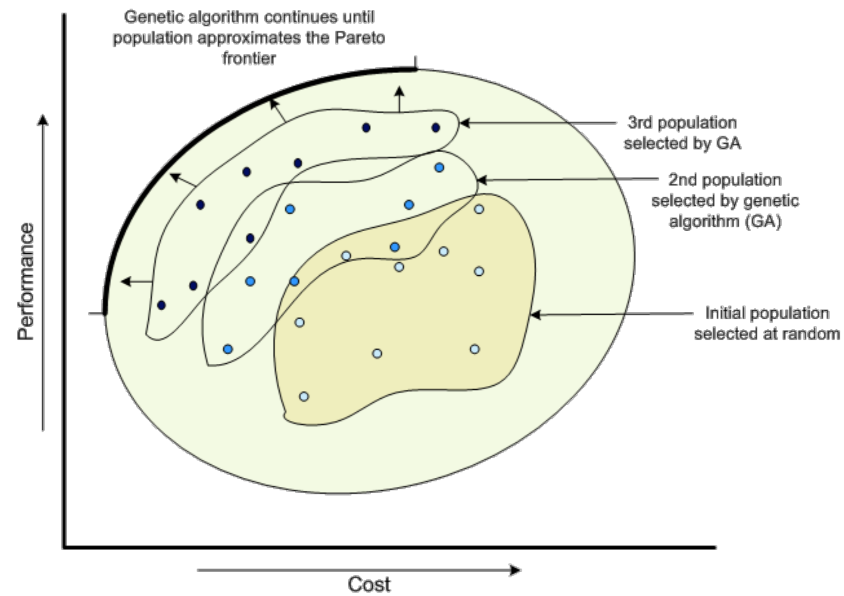
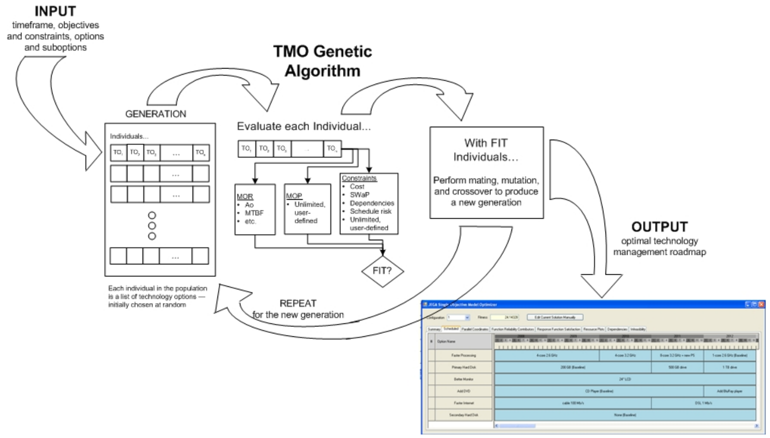
TMO Microgrid Design Tradeoff Analysis

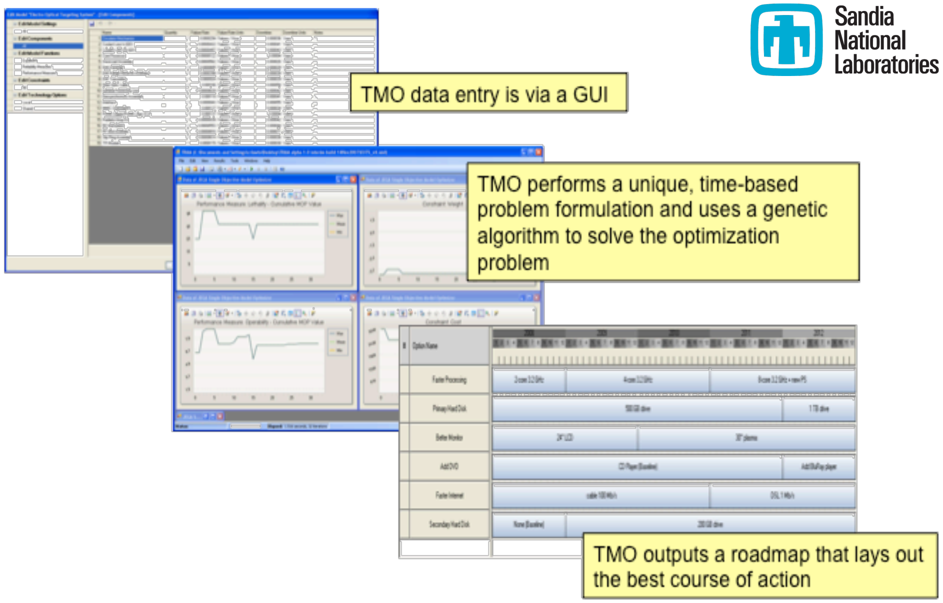
- Nonlinear – integer – dynamic (does not require assumptions about linearity)
- Constraints include some elasticity, and work toward goals while respecting limits
- Multi-objective optimization: site-specific targets and limits for all performance metrics and constraints
  - Revenue and environmental performance while grid-connected
  - Critical load reliability (and longevity)
  - Non-critical but potentially still important loads (priority load service)
  - Environmental and budgetary constraints
- Design variables can include equipment and also operating modes
  - Environmental & budgetary constraints
  - Building selection & microgrid reach
  - Dependencies between selections

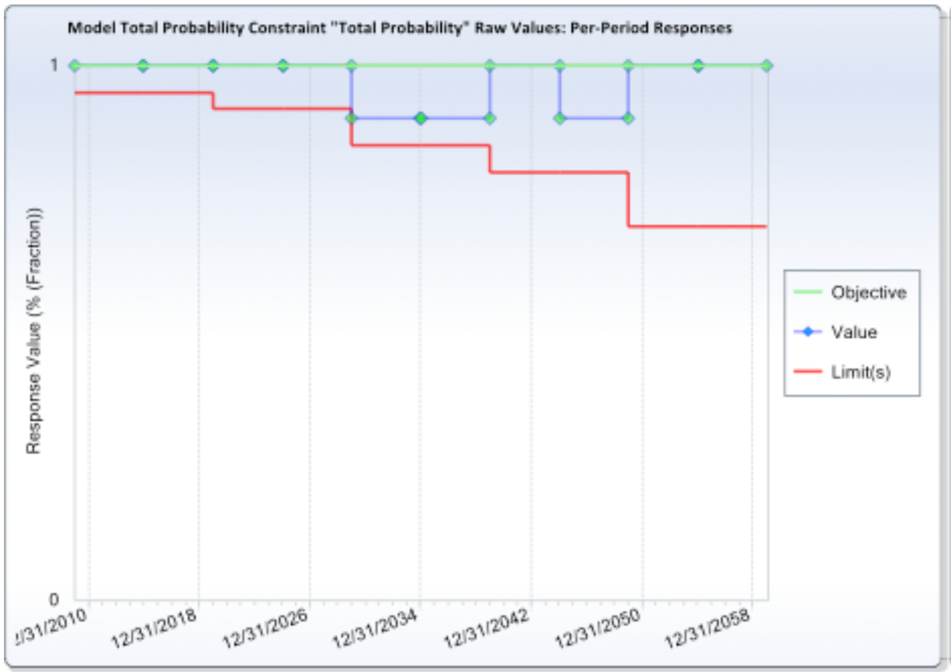


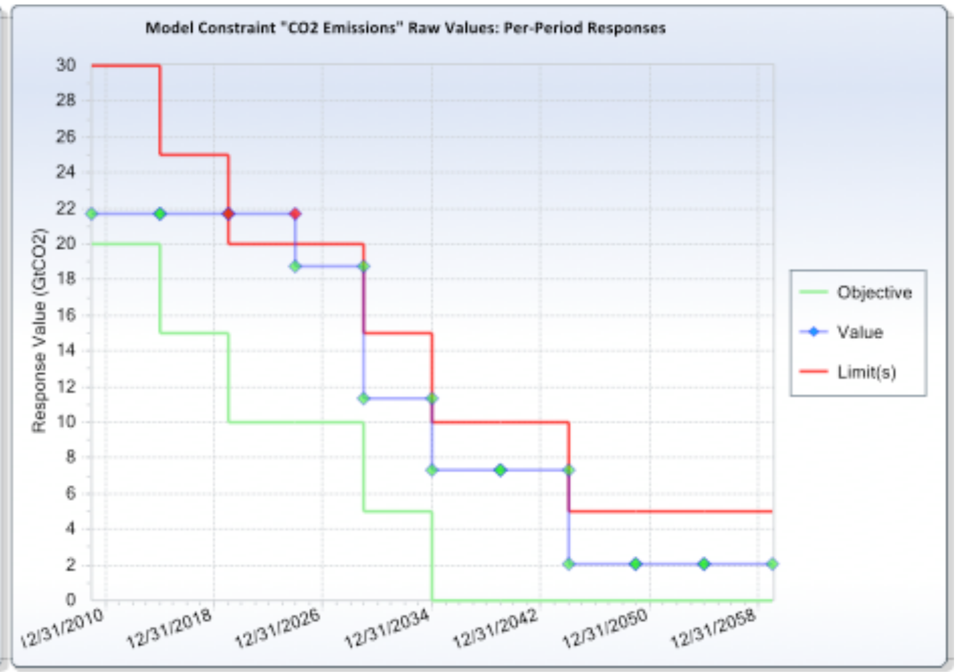


TMO Interface And Structure





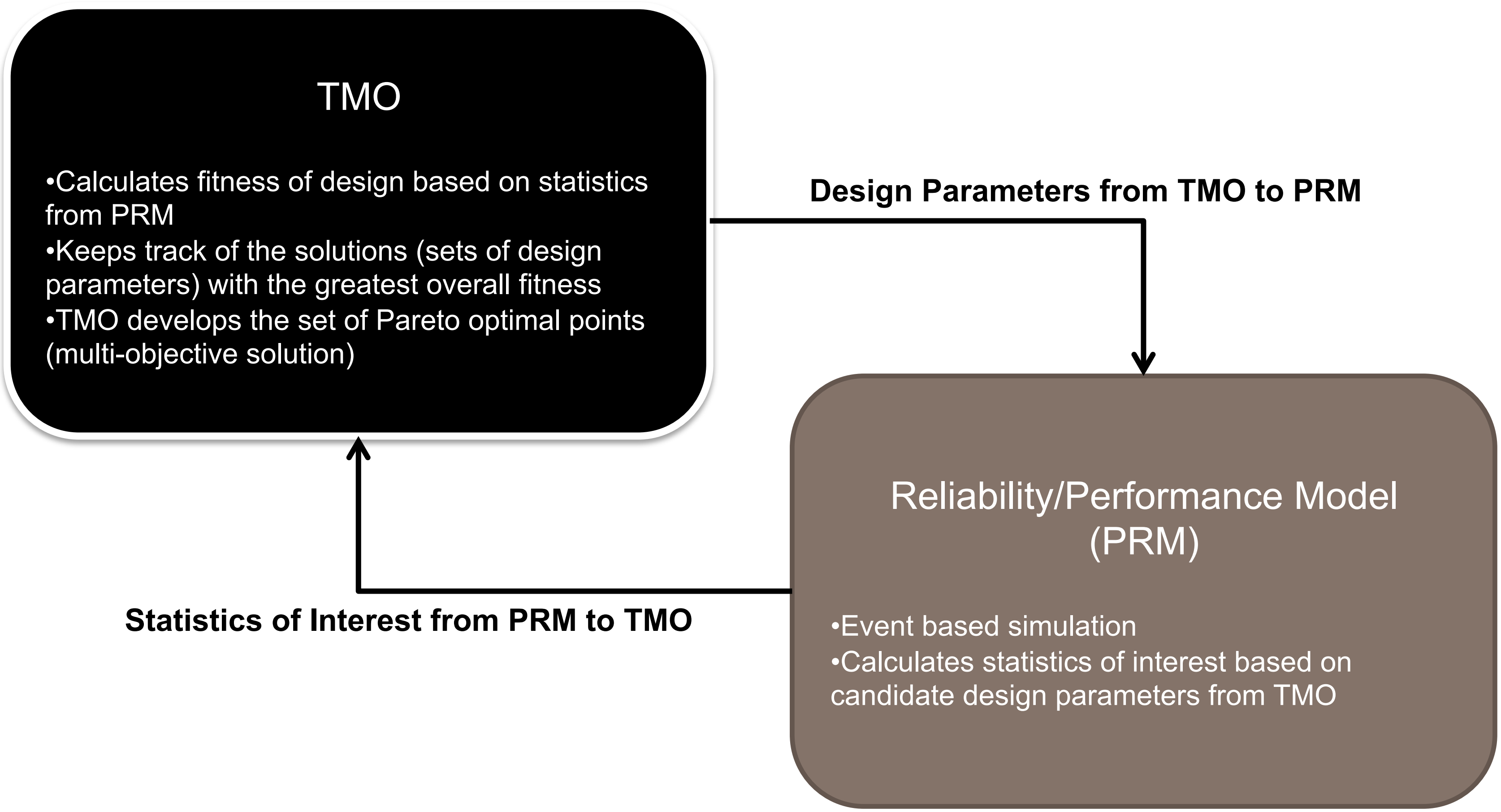




Performance/Reliability Model (PRM)

- The purpose of the PRM is to statistically quantify the behavior of a candidate microgrid design in terms of performance and reliability
- This information is used by TMO to tune the design according to the design options in order to maximize performance and reliability while minimizing cost
- PRM operation:
  - Samples utility outages according to a distribution (e.g. at a rate of ~4/year) for thousands of years
  - Microgrid is simulated during each outage and statistics are collected
  - Uses an event-driven simulation for better calculation efficiency
  - Once the standard error of the mean (SEM) of the primary statistic is below the desired threshold, the simulation stops and returns the analysis
- Required Information:
  - Electrical layout, including transmission/distribution line data
  - MTTF and MTTR for grid elements, transmission lines, other relevant equipment
  - Generator efficiency curves and other data
  - Load profiles (both critical and priority)
  - PV and wind profiles, etc.

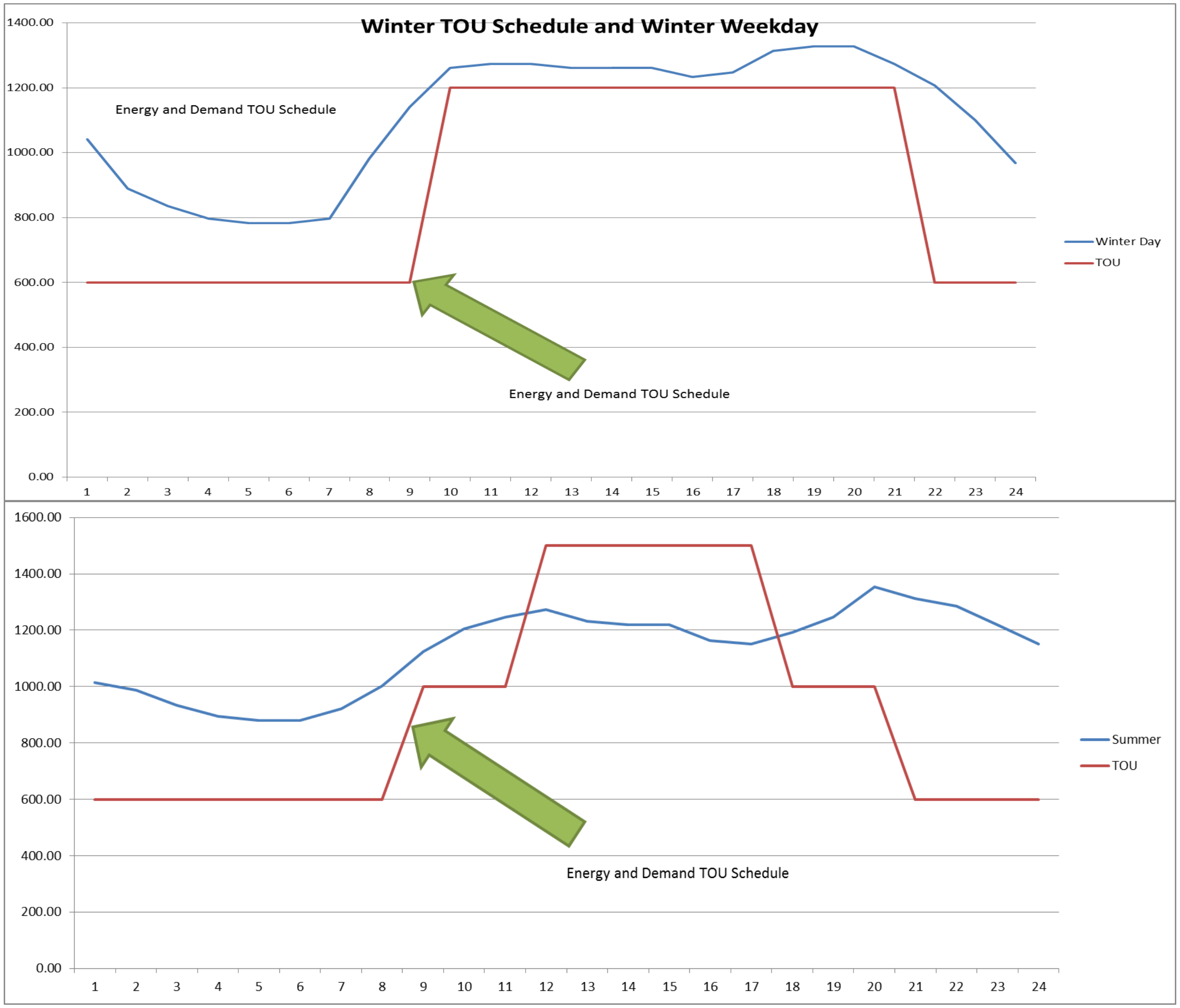
Optimizing Microgrid Design Performance



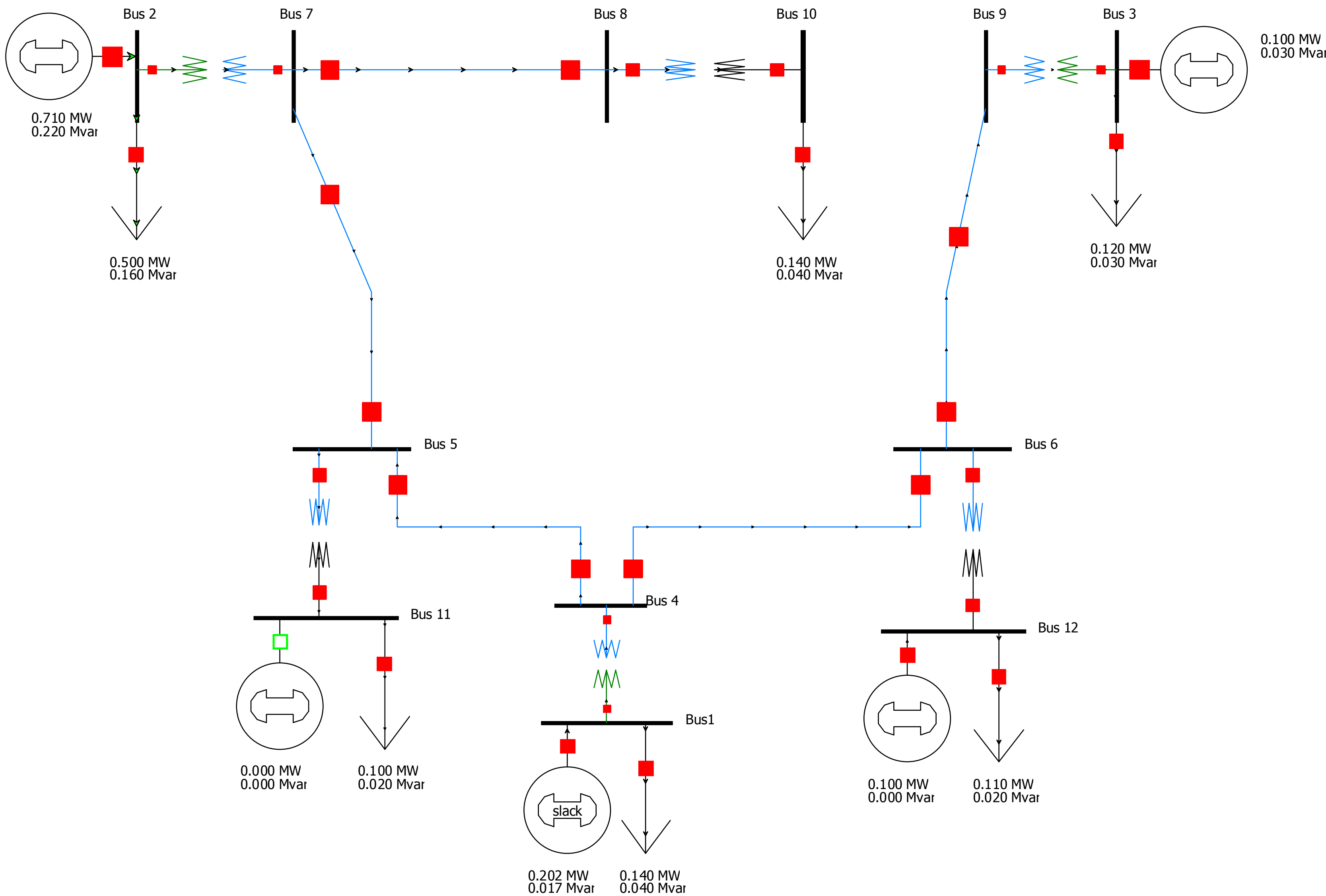
Example Microgrid Design Process

- Project characterization:
  - Requirements and constraints
    - Operational requirements
    - Site environmental restrictions
    - Timeframe
  - Design basis threat (DBT): events that are key for the design analysis
    - Utility outage and duration
    - Cyber and/or physical threat; enemy actions
    - Weather and natural disasters
- Data requirements:
  - Load patterns
  - RE characterization
  - Existing systems:
    - Electrical networks
    - Fuel storage and supply
  - Financial characteristics
    - Tariff
    - Riders and potential contractual options
    - Markets
- DSM concepts for improvement:
  - Architectures (Multiple or single microgrid? Leave some buildings isolated?)
  - Equipment (Re-use which existing generation? Add new ones? Renewable energy: How much? More spinning reserve or storage is needed?)
  - Operations (Is there an optimal usage pattern for energy resources?)
  - Footprint (Which buildings are on the microgrid(s)? Which feeders? Add new lines?)
  - Economics (Which riders to add?)
- Metrics:
  - Periods:
    - Grid-connected
    - Typical emergency
    - DBT (abnormal emergency)
  - Types:
    - Technical
    - Financial
    - Environmental
  - Weights, thresholds, and targets
- Analysis and refinement

Example TOU Rate: Winter Day versus Summer Day



Example: Test System Diagram



Example: Design Asset Choices and Costs

PV Power (kW)	Diesel Power (kW)	Battery Power (kW)	Battery Run Time (h)
0	0	0	0.666666667
100	100	100	1
200	200	200	4
500	500	500	
1000	1000	1000	
2000	2000	2000	

PV Price ($/W)	Diesel Price ($/W)	Battery Price ($/Wh)	Payback Time (y)
1.5	0.3	0.13	5

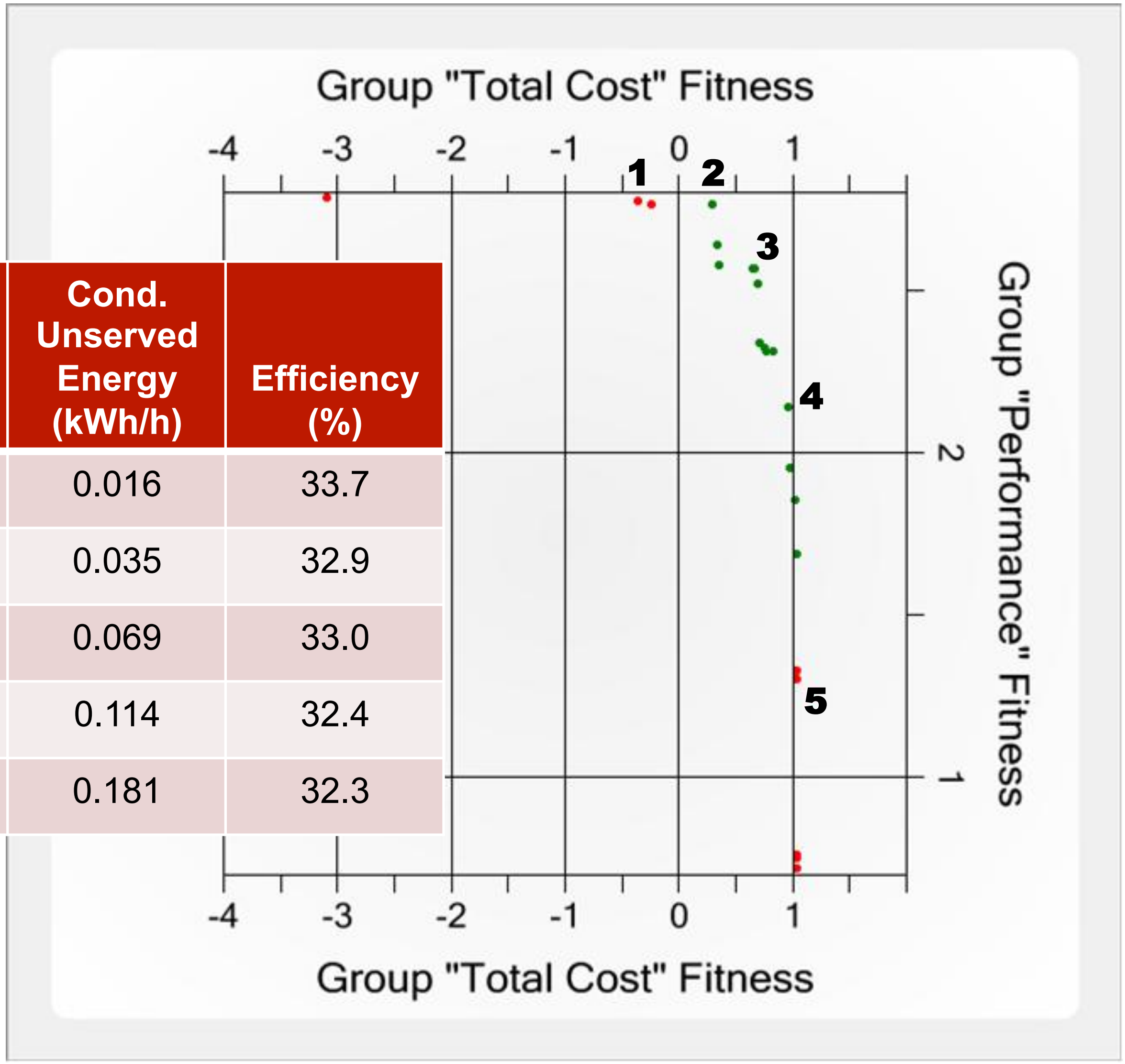
- Energy storage at bus 11 (output if generation is low or charge if excess generation is available)
- Diesel generation at buses 1, 2, 3
- PV at bus 12

Example:
TMO Objective Functions for the Test Case

		Threshold (poor) Value	Desired (good) Value
Metric	**Goal**	**Limit**	**Objective**
Total Cost	Minimize	$1,200,000	$900,000
CO_2 Emissions / year	Minimize	4,400,000 kg	3,000,000 kg
Conditional Unserved Energy (Critical Load Not Served per Islanded Interval when Unserved Load Occurs)	Minimize	10 kWh/h	0 kWh/h
Average Generator Efficiency Per Outage	Maximize	30%	37%

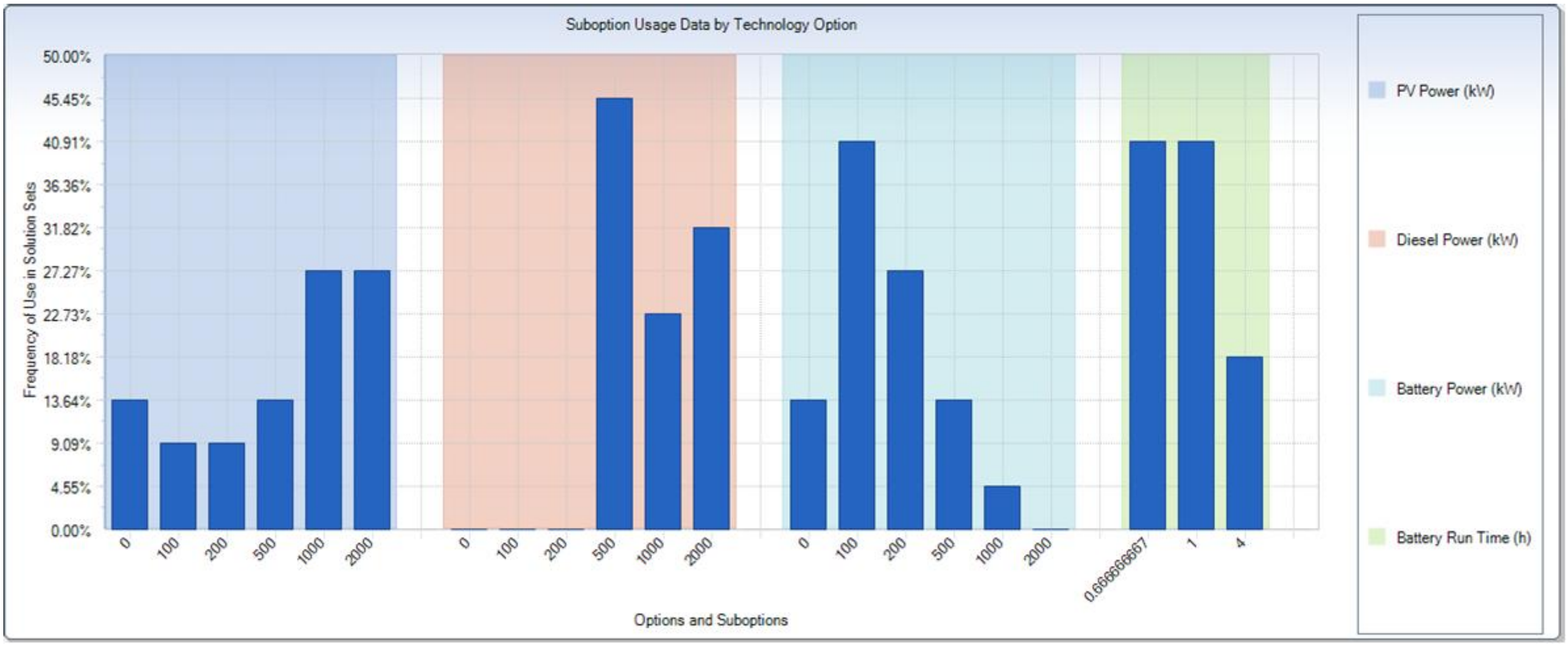
Example: Analysis Results

Point	Cost ($k)	CO2 emissions (10^6 kg/yr)	Cond. Unserved Energy (kWh/h)	Efficiency (%)
1	1296.6	2.62	0.016	33.7
2	1014.4	3.55	0.035	32.9
3	921.1	4.05	0.069	33.0
4	889.5	4.35	0.114	32.4
5	865.9	4.56	0.181	32.3



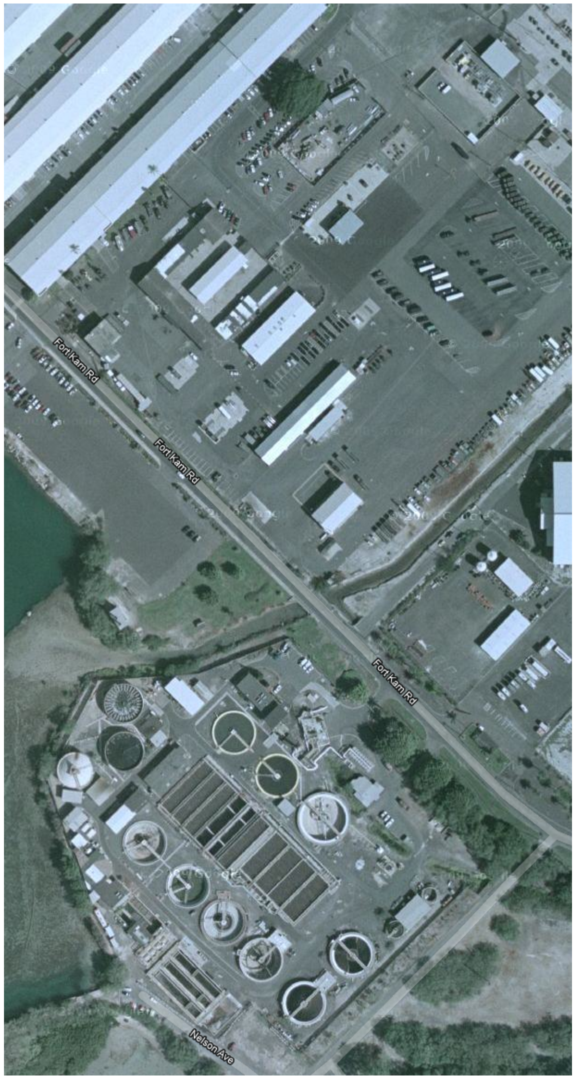
Example: Analysis Results

- This chart shows the frequency of each design choice on the Pareto frontier
- Helps understand solution patters; as an example, the design should very likely include 500kW or more of diesel generation and 1000kW or less of battery



Phase 1: Hickam AFB Status

- 100% design complete, contracting by USACE
- Single feeder microgrid (all load is Tier 1, two diesel engines, photovoltaics, & energy storage)
- Sandia and DOE labs developed the preliminary design and worked with USACE, the integrator, and their subcontractors
- Operational demonstration in January 2013
- Results show that:
  - Systems operates as intended
  - Site personnel can manage the microgrid

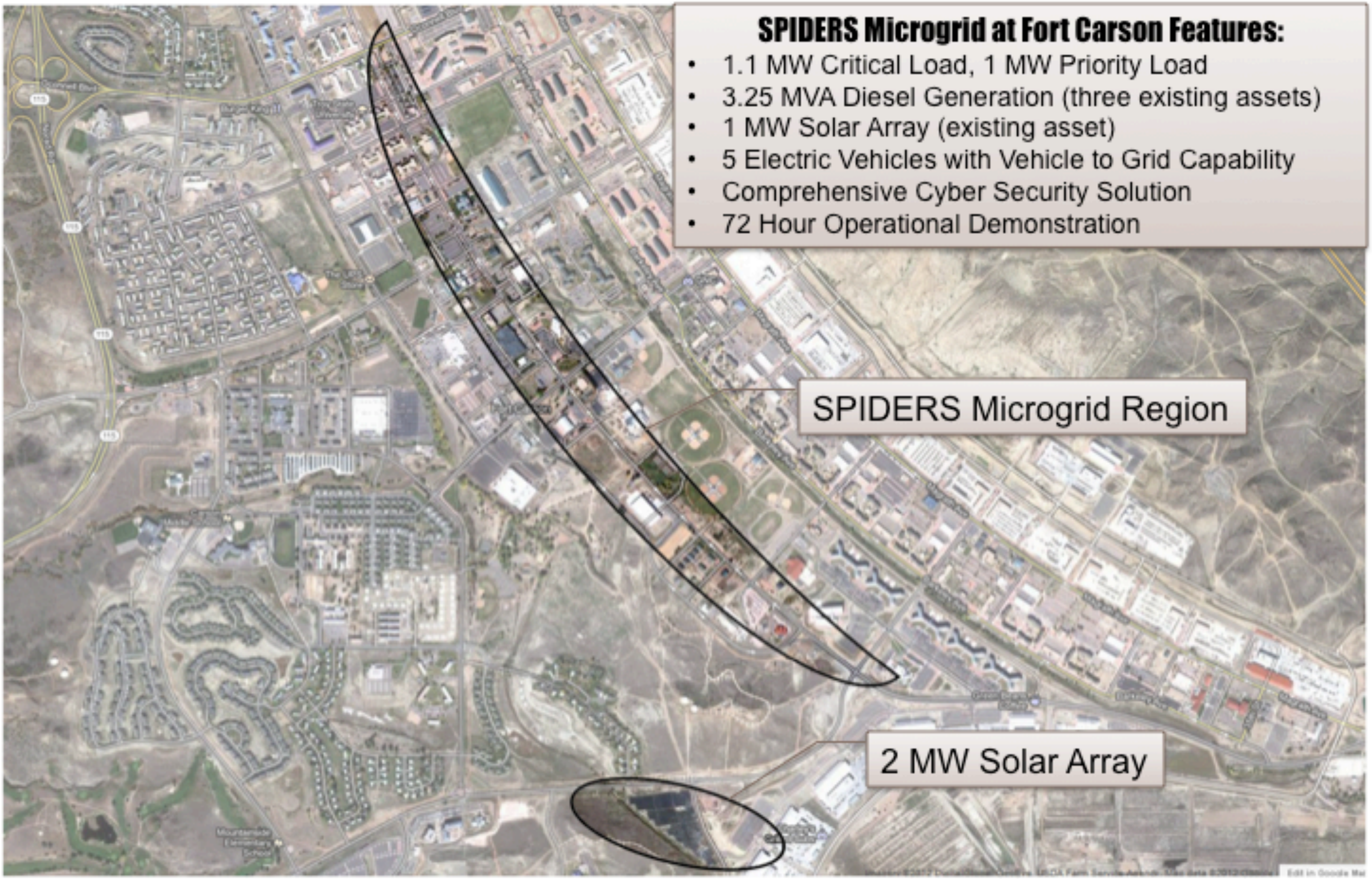


Performance/Reliability Model (PRM)

- Case 1: smaller microgrid
- Key improvement is to critical load reliability
- Constrained optimal solution selections are based off of SDM analysis

Metric of Interest	600kW Optimal	800kW Optimal	1600kW Suboptimal	1600kW Optimal	Base Case	Objective	Limit	Units
Variable Cost	**1,176,000**	**960,000**	**549,000**	**610,000**	**0.0**	**1,200,000**	**1,500,000**	dollars
Mean generator efficiency	**36.7**	**36.2**	**31.6**	**31.6**	**30.7**	**37**	**30**	percent
Average diesel deferred	**855**	**631**	**584**	**583**	**0**	**600**	**300**	gals/outage
Percent of time CLNS > 0	**0.25**	**0.25**	**0.50**	**0.25**	**9.8**	**0**	**1**	percent
Mean CLNS (when CLNS > 0)	**115**	**132**	**104**	**137**	**202**	**0**	**400**	kWh/outage
Fitness	**4.849**	**4.786**	**4.19**	**4.33**	**-118.4**	**N/A**	**N/A**	(unitless)
Primary diesel	600kw	800kW	1600kW	1600kW	N/A	N/A	N/A	N/A
Secondary diesel	1600kW	1600kW	600kw	600kw	N/A	N/A	N/A	N/A
Average CO2 deferred	9.49	7.01	6.48	6.48	0.0	N/A	N/A	tons/outage
Mean CLNS (all simulations)	0.29	0.33	0.52	0.34	19.8	N/A	N/A	kWh/outage
Average starts (primary)	0.978	0.978	0.988	0.988	0.988	N/A	N/A	starts/outage
Average starts (secondary)	0.048	0.048	0.048	0.048	0.988	N/A	N/A	starts/outage
PEM fuel cell size	160	100	100	90	0	N/A	N/A	kW
Additional hydrogen storage	0	0	0	0	0	N/A	N/A	kg

Phase 2: Fort Carson



Phase 2: Fort Carson Status

- Preliminary design report complete
- Recommendations for:
  - MV and LV topology
  - Renewable energy (PV)
  - Storage size and application
  - V2G for PEVs
- Design charrettes (intensive period of design activity) were held at Fort Carson in March 2012
  - Briefed on DOE design
  - Questions were fielded and documented
- Includes Tier C, P, and O loads (Hickam was Tier C only)
- Final integrator selected
- Requirement for seamless planned transition was successfully added; 100% design is complete
- Construction is complete
- Operational demo in October 2013

The SPIDERS Microgrid at Fort Carson

- 1 MW solar and 3.25 MVA diesel backup generation
  - No modifications to PV inverters
  - Proof-of-concept at JBPHH with 150kW PV array
  - Maximum output prediction and metering manage PV integration
- 5 electric vehicles with V2G capability
  - Provide some stabilization to microgrid
  - Developmental converter/aggregator interfaces with microgrid control system
  - Intended to provide demand response, peak shaving, and ancillary services in wholesale market
  - Active VAR injection from charging stations promises rapid payback

Fort Carson Design Analysis

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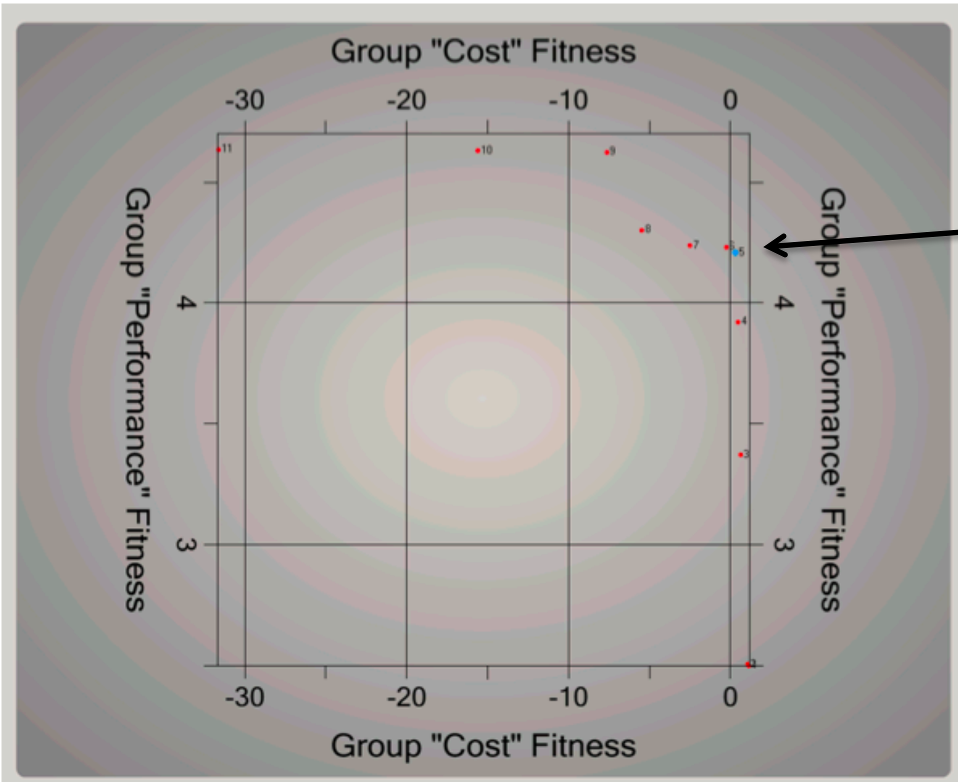


Fitness	Tier C	Tier P	Fossil Generation	PV	Battery/ PHEV
Perform-ance = 4.231	Budget allows buildings A-E and H, not F-G	Include all designated (buildings W, X, Y, Z)	Use diesels in buildings A, C, D, and H, but not B or E	PV = 1MW (out of 0, 1, or 2)	Size = 750kW / 250kWh
Cost: $1.3M	(Reason: incremental MV cost too high)	Can serve additional non-designated = 1000kW	No added fossil generation (diesel or NG)	(contract-ual limit-ations)	Use: smooth RE & defer diesel switching

This graph presents the Pareto optimal set of solutions for the Ft. Carson microgrid.

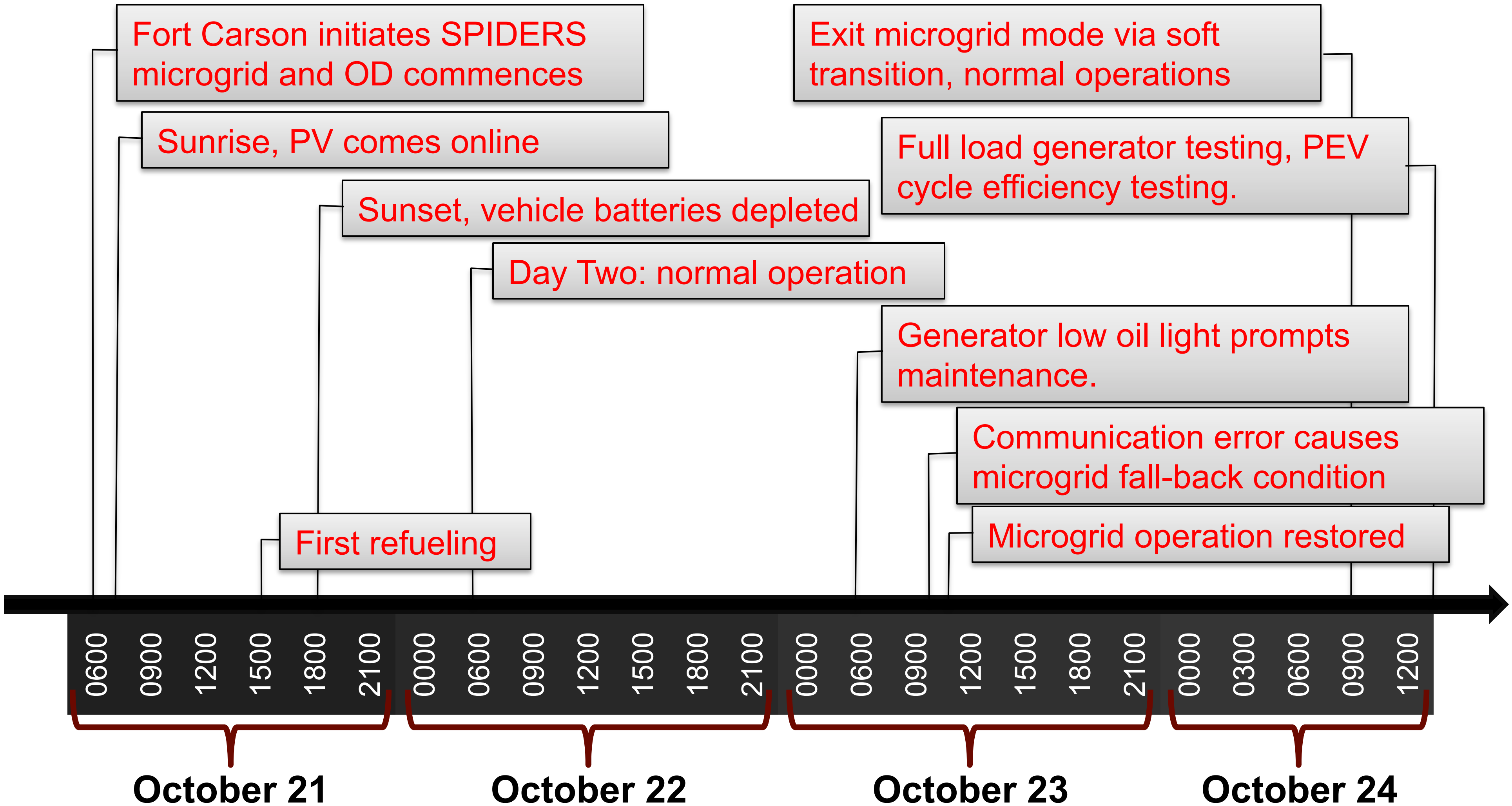
With no Tier P load served, the microgrid fuel consumption is approximately 79.6 gal/hr.

Option	Performance Fitness	Battery Size (kW/ kWH)	% of time CLNS >0	PLS (kWh/hr of outage	Diesel Redispatch Avoidance	Avg. Diesel Efficiency	Non-Designated Tier 2 Load (kW)	Incremental Cost ($US)	Avg. Diesel Used (gal/hr of outage)
Base Case	N/A	0/0	14.333	N/A	N/A	0.2817	0	300,000	102.34
4	3.921	500/250	0.0232	602.38	0.0592/hr	0.3603	400	1,185,938	109.58
5	4.207	750/250	0.0465	1078.37	0.0875/hr	0.3669	1000	1,279,125	142.24
6	4.231	1000/250	0.0232	1078.36	0.0879/hr	0.3670	1000	1,372,313	142.24

Phase 2 Operational Demonstration

- Completed successfully with all microgrid resources online
  - 1 MW of solar connect, 500 kW functional
  - 4 electric vehicles connected: 1 Boulder EV, 3 Smith EVs
  - 5 EVSEs providing VAR injection (voltage support)
- Generator maintenance conducted during microgrid operation revealed important operational process lessons
  - A human communication error between microgrid operators and maintenance personnel caused a "learning curve" outage on 23 October
  - SPIDERS team identified a software adjustment that eliminates potential for the same error in the future

Phase 2 Operational Demonstration



SPIDERS Phase 2 Challenges

- Solar array 3rd party ownership
  - Efforts between USACE, Burns and McDonnell, and Morgan Stanley to have a site access agreement in place did not conclude in time for integration of all 2 MW
  - The resulting integration includes 1 MW of solar in a single segment, which could reduce its utilization when the microgrid is islanded
  - Future DoD PPAs should include language to accommodate integration with microgrids or other energy systems
- Information system ownership
  - SPIDERS could not identify an information system owner for DIACAP
  - System ownership should be considered at higher levels for emerging cyber-physical systems
  - For the demonstration, SPIDERS will operate under an IATT

Slide courtesy of Melanie Johnson, USACE/CERL

Phase 3: Camp Smith

- Microgrid covers the entire installation – capable of serving all loads during outages
- Prior microgrid report from DOE FEMP funding
- Camp Smith includes some older infrastructure which presents challenges
- Include revenue generation/cost avoidance from the microgrid (example analysis at right)
- Demonstration planned for 2015

Demand Charge	Energy Charge	Onsite Energy Cost	Total Utility Bill	Total Average Costs
(Nominal kW)	(Utility MWh)	(Site MWh)		(Savings)
$84,760	$519,786	$0	$604,946	$604,946
4036	2227	0		0
$44,988	$487,028	$37,513	$532,416	$569,929
2,142	2087	140		$35,017
$44,988	$487,028	$37,513	$532,416	$569,929
2,142	2087	140		$35,017
$57,588	$503,257	$18,928	$561,245	$580,173
2,742	2156	71		$24,773

Key Camp Smith Microgrid Design Decisions

Recommendation	Decision
Electrical energy storage	None
Revenue operation (grid-connected)	Rider M curtailment using Tier 4I diesels
Existing diesels used for SPIDERS	Use three existing units totaling 2.5 MW (since scaled down to two existing units totaling 2.0 MW)
Seamless transition into microgrid	Only for planned transfers
Tier 4I diesel sizing	3x 1500kW, Tier 4I, low acoustics
New plant siting	Will build new plant at Camp Smith
New plant voltage	11.5kV
New plant feeder connections	Connect some existing units with new feeder
Feeders in the system's Tier 1 backbone	Utilize existing feeders
Focus for base MV improvements	MV stations: upgrade three existing stations
Include PV from the fitness center	Yes (disconnect building Tier 2 load via LV)
Tier 2 load management	Via segregation and automation at MV level

TMO-PRM: Smith

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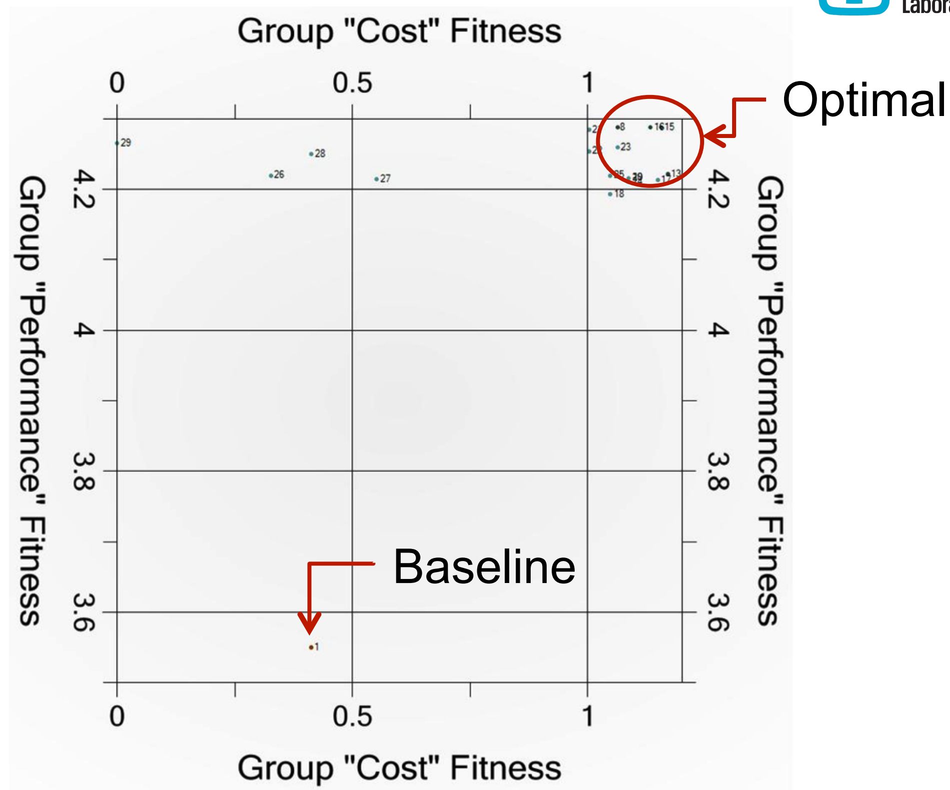
- Pareto chart →
- Availability:

Baseline	Tier 1A	0.995805
	Tier 1B	0.995341
	Tier 2	0.000000
With Tier 2	Tier 1A	0.999861
	Tier 1B	0.999844
	Tier 2	0.999808
Without Tier 2	Tier 1A	0.999998
	Tier 1B	0.999976
	Tier 2	0.000000

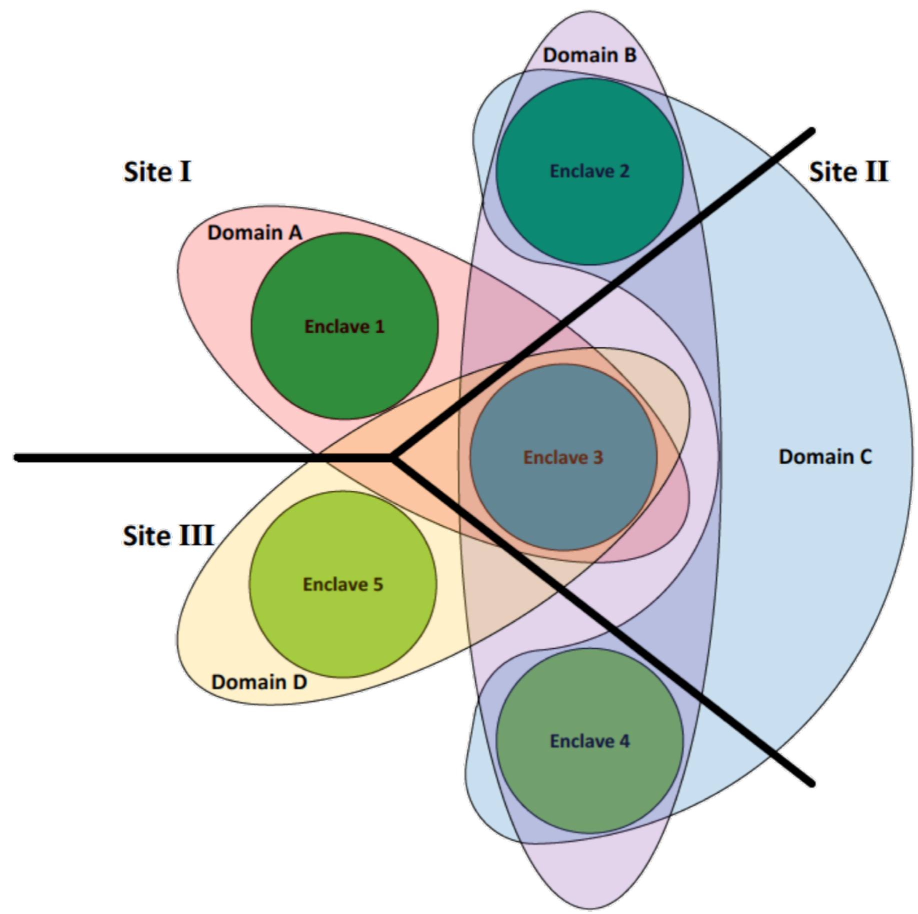


- Performance:

Option	Variable Cost	Avg. Diesel Consumption (gal/hr)	Avg. Gen Efficiency	Average Tier 1 A Not Served (Tier 1 A Outages) (kWh/h of outage)	% of Outages where Tier 1 A Not Served > 0	Average Tier 1 B Not Served, (Tier 1 B Outages) (kWh/h of outage)	% of Outages (Post-startup) where Tier 1 B Not Served > 0	Tier 2 Load Served (kWh/h of outage)
Base Case	$0	75.25	0.318	49.25	0.04167	37.83	0.05984	0.0
Option 6 (Highest fitness Solution w/Tier 2)	$1.1M	111.58	0.367	17.95	0.00378	16.60	0.00392	1275.0
Option 13 (Highest fitness Solution w/o Tier 2)	$1.1M	56.34	0.348	0.68	0.00109	1.57	0.00045	0.0

Cyber Security Architecture

- Microgrid Cyber Security Reference Architecture
  - All DoD Instruction 8500.2
  - Mission assurance category II (MAC II) and confidentiality level sensitive.
  - Complies with the requirements of the DoD Information Assurance Certification and Accreditation Process (DIACAP)
  - NISTIR 7628, Guidelines for Smart Grid Cyber Security
- In addition to DoD IA controls, additional rigor will be applied to protecting data-in-motion and data-at-rest, along with ensuring such additional rigor does not impede the operational data exchange requirements of the SPIDERS microgrid



Cyber Security: Enclaves/Functional Domains

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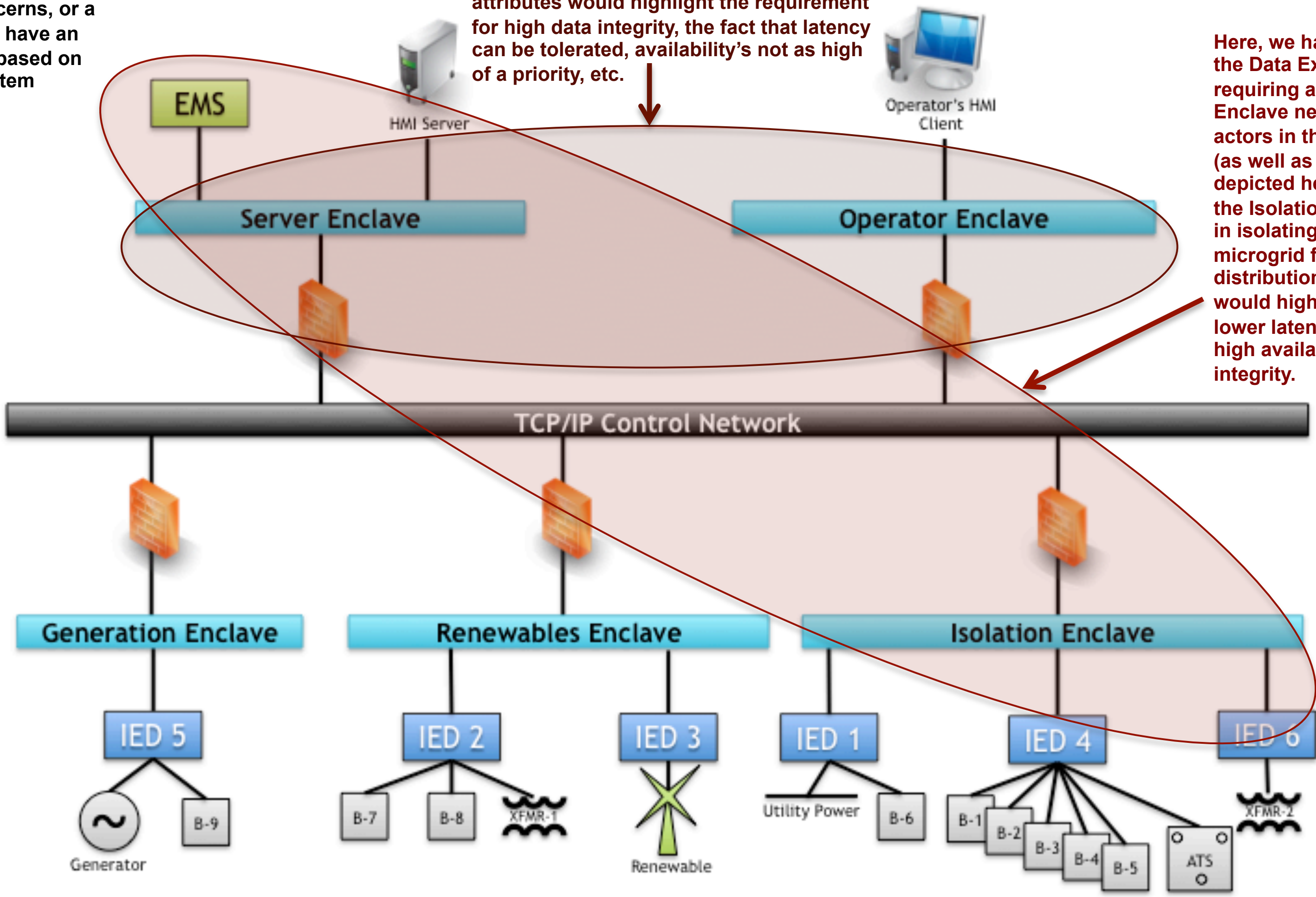
Enclaves can be defined and implemented based on multiple criteria, such as location, function, security concerns, or a combination. Here, we have an example of enclaving based on power and control system device usage types.

Data exchange attributes define how actors need to communicate with one another to support control system functions. This communication can be intra- or inter-enclave.

Functional domains help to identify inter-enclave communication requirements and define how the inter-enclave communication will be supported and secured based on the data exchange attributes.

Here, we have an example of the Data Exchange Attributes requiring actors in the Operator Enclave only needing to talk to actors in the Server Enclave. The attributes would highlight the requirement for high data integrity, the fact that latency can be tolerated, availability's not as high of a priority, etc.

Here, we have an example of the Data Exchange Attributes requiring actors in the Server Enclave needing to talk to actors in the Isolation Enclave (as well as other enclaves – not depicted here). Since actors in the Isolation Enclave play a role in isolating the SPIDERS microgrid from the regular distribution grid, the attributes would highlight the need for lower latency requirements, high availability, and high data integrity.



Once the Enclaves and Functional Domains are defined and decorated with exchange attributes as exampled above, they can be used to drive the actual implementation of the control system network. As an example, the definition of each enclave above dictates where firewalls needed to be deployed within the network to logically separate control system actors. The definition and decoration of each domain with exchange attributes dictates how quality of service should be configured for each enclave and between enclaves, which ports need to be opened in which firewalls, for which communication channels authentication and encryption needs to be utilized, etc.

Cyber Security: Status

- Version 1 cyber security reference architecture is complete
- Initial testing is complete
  - Tested using Sandia Sceptre (formerly VCSE) hybrid modeling/ simulation environment
  - Scoring was based on data characterization
- Phase II testing is ongoing

Domain	Physical	Emulated	Simulated
Control	PLC, SCADA, relays, historian…	Virtual SCADA server; Soft PLC; VMWare ESXi, virtual historian…	RTU model, relay model, simulated ladder logic…
Network	Cables, firewalls, routers, NIDS…	DynaMIPS (CISCO router); QEMU…	OPNET (SITL), routing model, wireless channel model…
Power Grid	(1)	N/A	Solar/wind models, SimPowerSystems, load flow software…

Exchange Type		AGMC	AGMC	SCADA	SCADA	PROREL	PROREL	MCM	MCM	CSCM	CSA
		Read-only	Control	Read-only	Control	Scheme X	Scheme Y	Read-only	Configuration	Configuration	Read-only
Data Type		Breaker position readings, VT/CT measurements, transformer measurements, charge readings, MW/MVAR readings	Switch/Breaker control, transformer tap adjustments, charge adjustments, MW/MVAR adjustments	Breaker position readings, VT/CT measurements, transformer measurements, charge readings, MW/MVAR readings	Switch/Breaker control, transformer tap adjustments, charge adjustments, MW/MVAR adjustments	Pilot control	Permissive transfer trip signal	Fault data, relay configuration, RTU configuration, renewables data and configuration, load data and configuration	Relay configuration, RTU configuration, renewables configuration, load configuration	ACL Rules IDS Rules Certificates Key management Logging configuration	Access log messages ACL counts Traffic anomaly detections SNMP blocks, Etc.
Data Volume		10s/100s of bytes	Bytes	10s/100s of bytes	Bytes	Bytes	Bytes	Kilobytes/ Megabytes	Kilobytes	Kilobytes	Kilobytes/ Megabytes
Reach											
	Interval	Seconds	Seconds	Seconds	Seconds	Milliseconds	Milliseconds	Minutes/Hours	Minutes/Hours	Minutes/Hours	Seconds
	Method	Multicast	Unicast	Multicast	Unicast	All	All	Multicast	Unicast	Unicast	Unicast
	Priority	Medium	Medium	Low	Medium	High	High	Low	Low	Low	High
Latency		Medium	Low	High	Low	Low	Low	High	High	High	Medium
Reliability		Important	Critical	Informative	Critical	Critical	Critical	Informative	Important	Important	Critical
Security											
	Confidentiality	Low	Medium	Low	Medium	High	High	Low	High	High	Medium
	Integrity	High	High	Medium	High	High	High	High	High	High	High
	Availability	Medium	High	Low	High	High	High	Low	Medium	Medium	High

Table 5: Example Data Exchange Requirements

Future SPIDERS Activities

- Smith construction, testing, and transition
- Cyber security (funding permitting)
  - Enhance reference architecture and reference implementation
  - Additional testing and analysis
  - Add security awareness/configuration and engineering configuration domains
  - Coordinate with more automation security standards
  - Investigate stronger platform security requirements
- Transition activities
  - Cyber security report
  - Design analysis report

Conclusions

- The proposed microgrid design requirements and recommendations analysis includes three phases:
  - Conceptual
  - Preliminary
  - Detailed
- Supported by four modeling activities:
  - Systems dynamics modeling (SDM)
  - Load flow models (LFM)
  - Dynamic grid models (DGM)
  - Performance – reliability modeling (PRM) enabled by TMO
- The program includes a strong cyber security foundation
- Coordination between the myriad agencies and personnel is strong (including integrators and vendors)

Discussion

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