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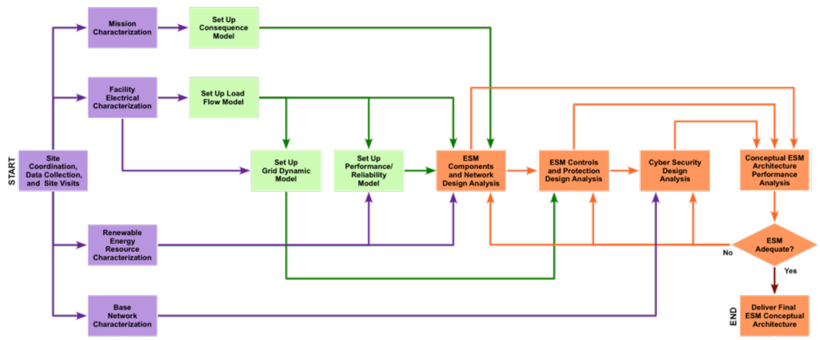

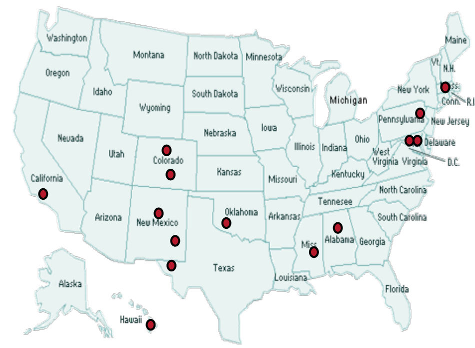

SPIDERS Phase III Design and Requirements Analysis

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Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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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

SPIDERS Microgrids Support Seven Key Value Propositions

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.

Energy Surety Microgrid: How it Works

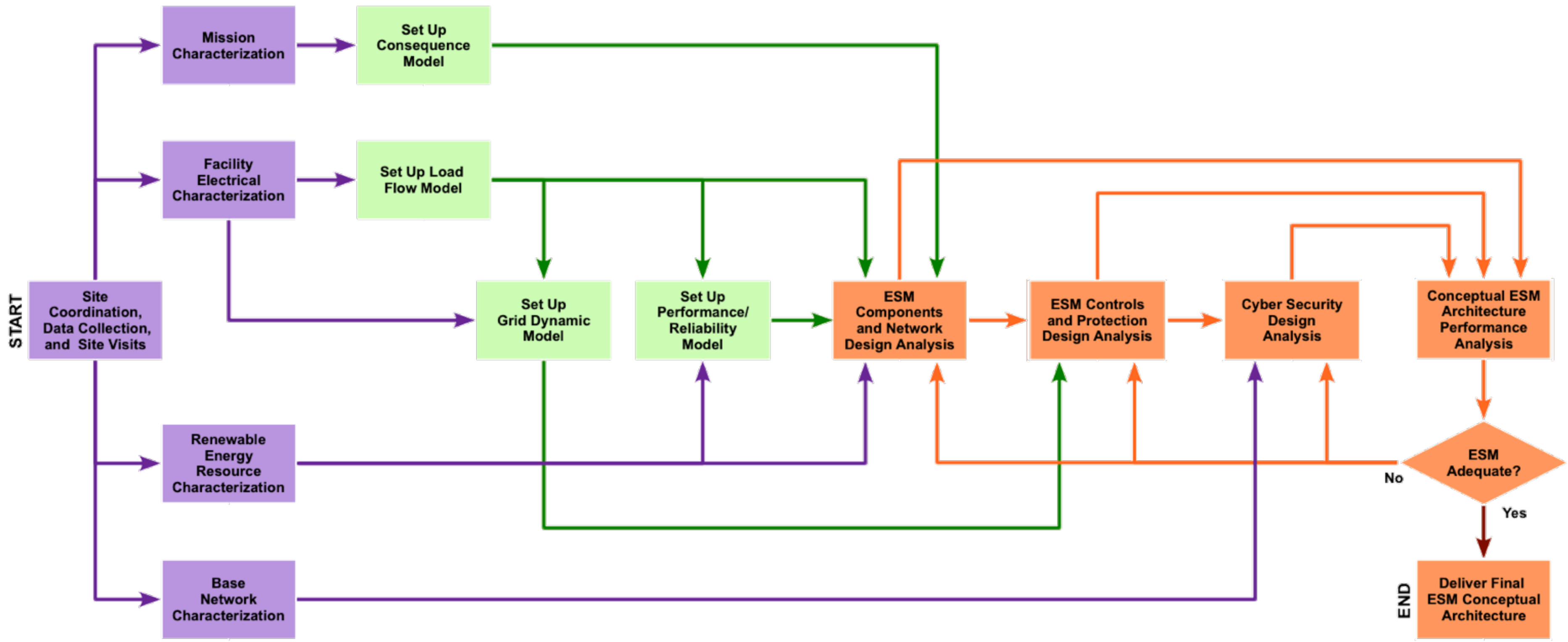
- When utility power is unexpectedly lost, normal backup operations occur (an ESM does not preclude traditional, accepted engineering practice)
- During an outage, UPS carry non-interruptible critical loads as the microgrid disconnects from the utility and the diesels start
- Architecture reconfigures 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

ESM reuses existing equipment to support mission energy security

SPIDERS/ESM Load Categorization

- Tier 1 – loads / buildings that are critical to the mission; these loads usually have dedicated backup generators. Tier 1A loads are non-interruptible and will include UPS, while Tier 1B loads can endure short losses of electrical power.
- Tier 2 – 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 3 – loads / buildings that will not be powered during microgrid operations.
- Tier 4 – loads that are too small to merit the cost of automation (e.g. streetlights or parking lights).

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

- Systems Dynamics Modeling (SDM)
  - Narrow microgrid design options
  - Investigate key relationships between building load, PV generation, and diesel electrical generation
- Load Flow Model (LFM)
  - Ensure voltage magnitudes remain close to rated values despite changes to feeder configurations
  - Check capacity of all equipment
  - Determine if the feeder has adequate capacity to carry the additional new generation
- Dynamic Grid Model (DGM)
  - Test severity of in-rush current produced by transformers during microgrid energization
  - Cold load pickup of tier 2 loads after all tier 1 loads have been served
- Performance/Reliability Model (PRM)
  - Leverages optimization software called TMO
  - Used to optimally determine several design parameters for the Camp Smith SPIDERS microgrid
  - Optimally manage high-value, long-lived, highly technical equipment over the lifetime of a system

Systems Dynamics Modeling

- During islanding mode,
  - Two cases were considered: with and without PV.
  - Pertinent model results include duty cycles, production intervals in terms of percent of rated capacity, and fuel consumption
- For grid-tied mode with Rider M, fuel cost, fuel consumption, and current HECO rate structures were evaluated to determine total cost avoidance for Camp Smith's participation in the Rider M tariff
- PV generation was considered to reduce local demand overall during grid-tied mode; however, it did not significantly contribute during curtailment hours (1700-2100) for Rider M

Example SDM Results

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Islanded Microgrid Mode

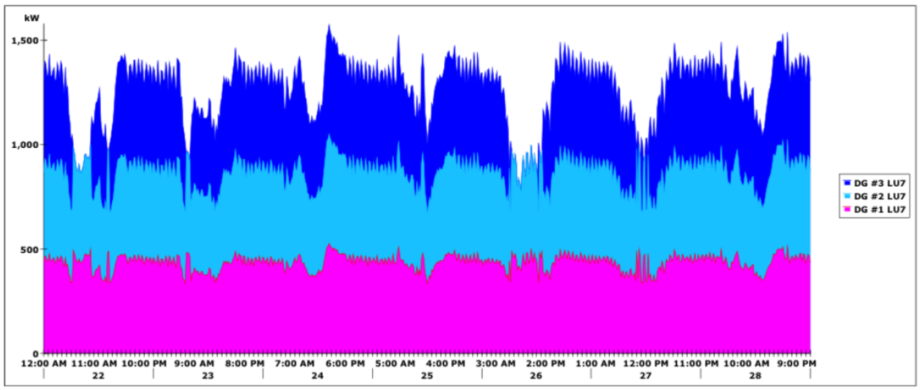


Figure D.3: Critical load support when islanded with 3x 1000 kW generators.

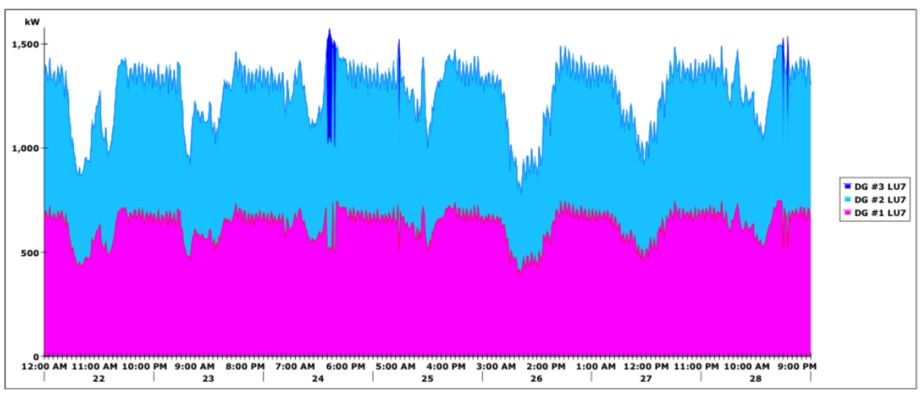
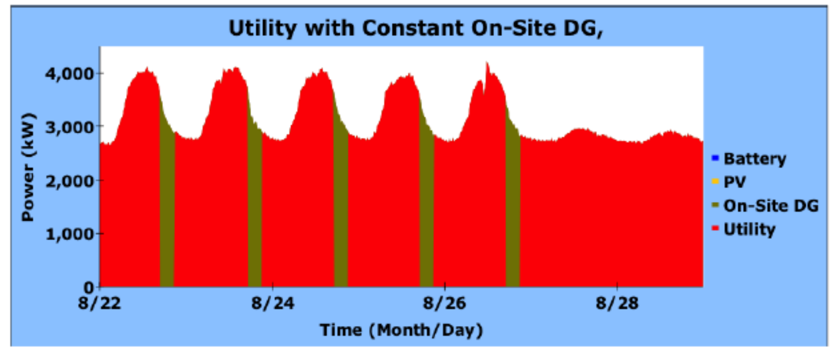
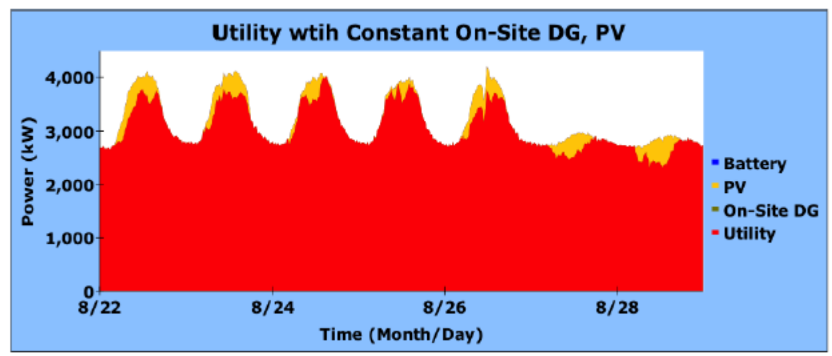


Figure D.4: Critical load support when islanded with 3x 1500 kW generators.

Grid Connected – Revenue Operation (Rider M)



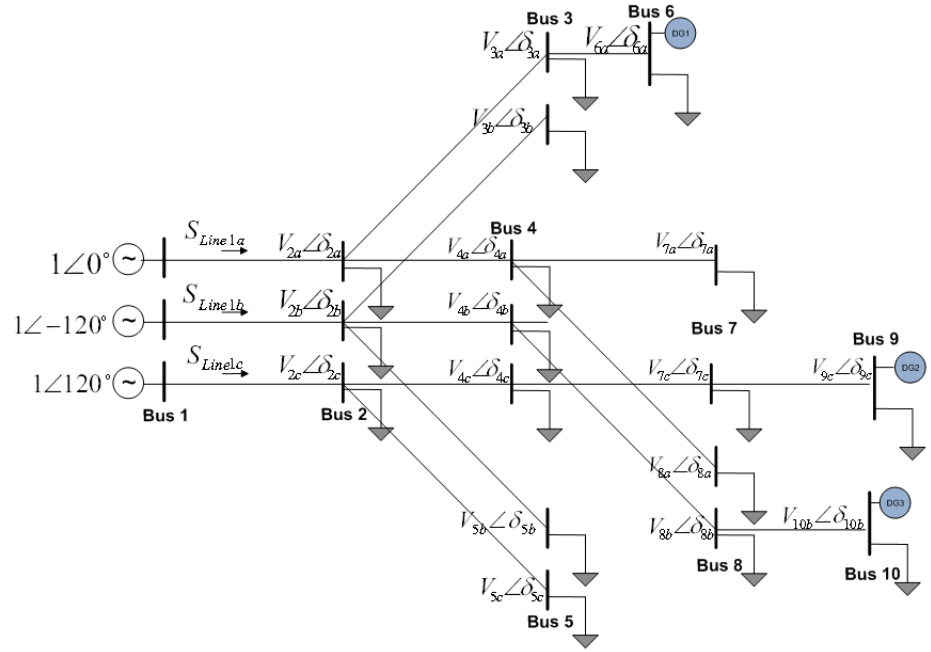
(a) Rider M curtailment hours over 1 week.



(b) Solar contribution over the same week.

Load Flow Model (LFM)

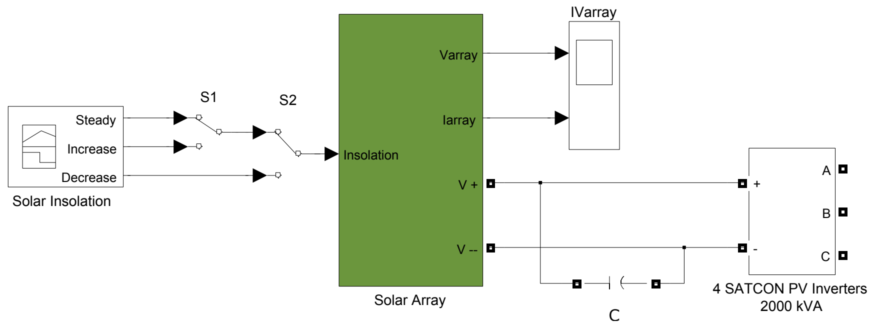
- Voltage and flow analysis
- Development of a notional microgrid one line diagram
  - Determination of switching to form the microgrid MV backbone
  - Designation of PCCs
  - Low voltage switches are preferred to medium voltage switches to bring Tier 1 and 2 buildings onto, and take Tier 3 buildings off, the microgrid

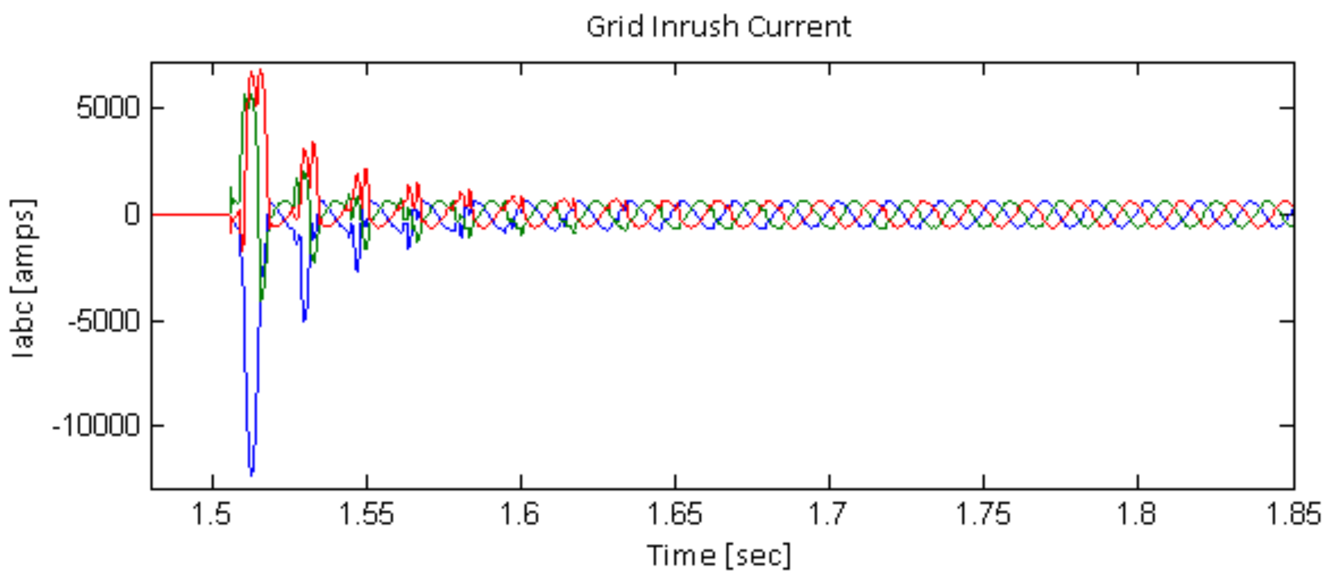


Example one line diagram

Dynamic Grid Model (DGM)

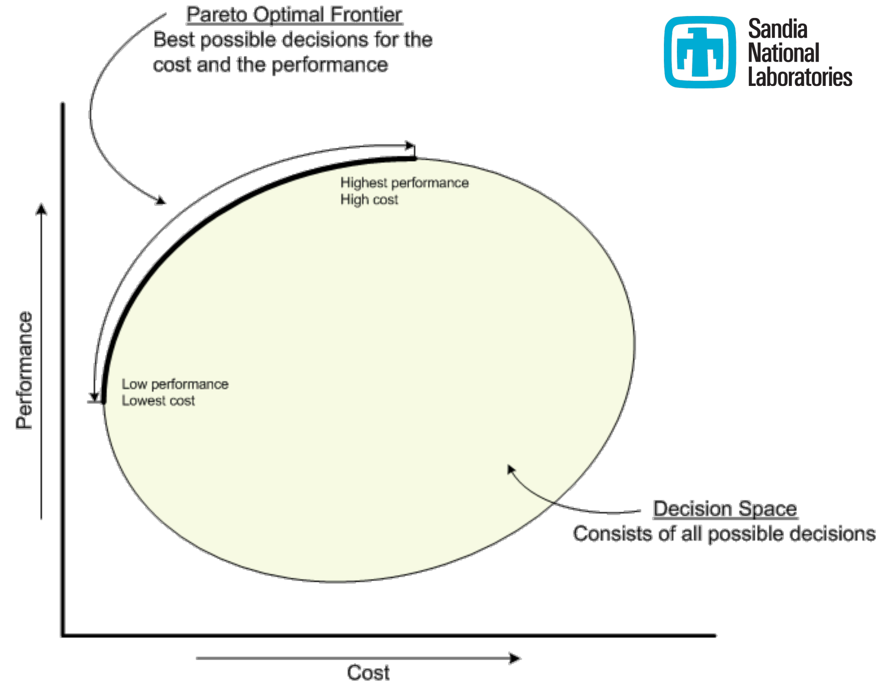
- Analysis to determine potential problematic microgrid behavior
- Power quality, voltage sags, frequency regulation, etc.
- Transformer inrush, cold load pickup for Tier 2 might be a big issue

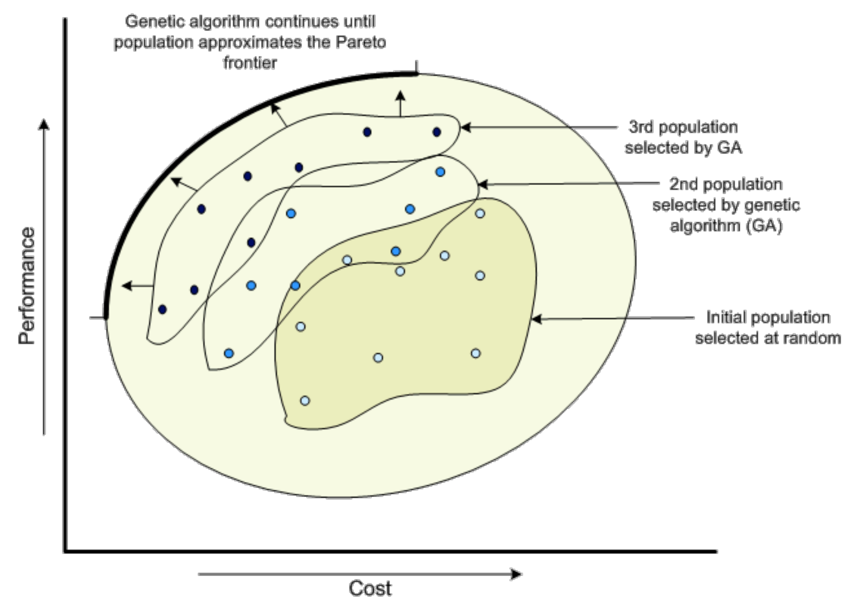




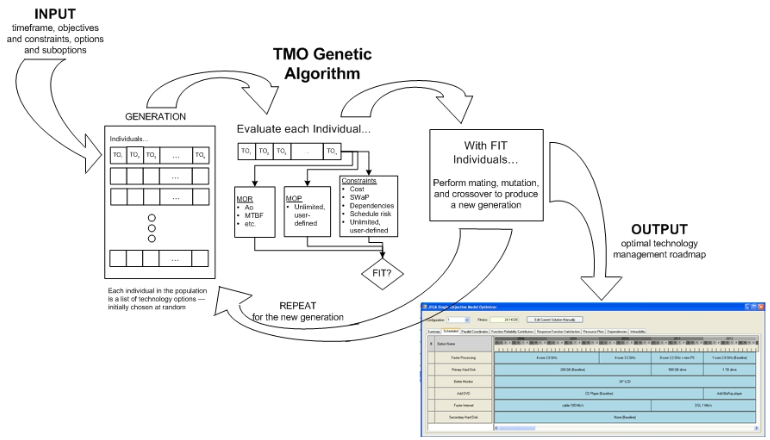
Design Requirements Optimization

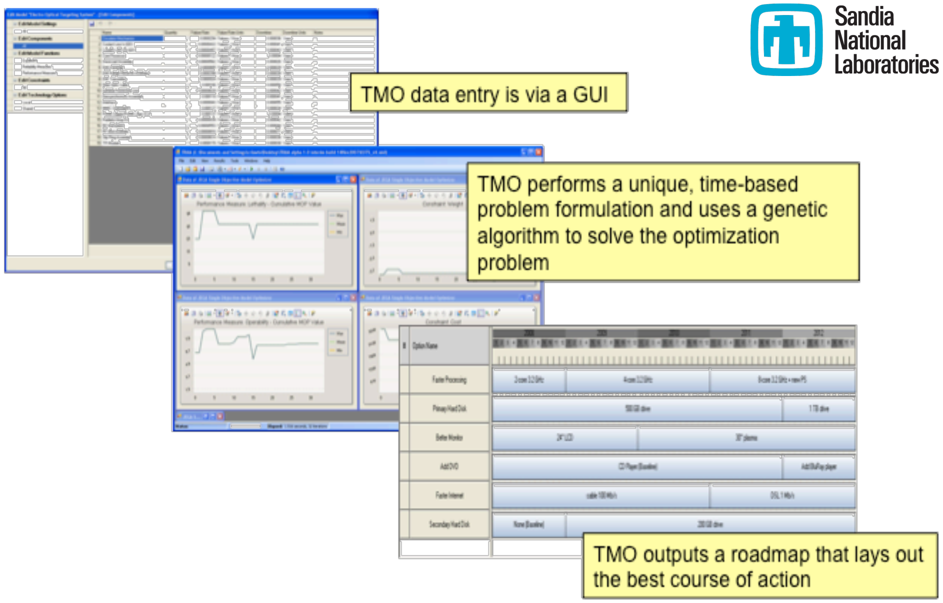
- Performance/Reliability Model (PRM) leverages optimization software called TMO
- Nonlinear – integer – dynamic
- Evaluations calculate expected values and distributions for metrics using sequential Monte-Carlo
- Based on genetic algorithms
- Constraints include some elasticity, and work toward goals while respecting limits

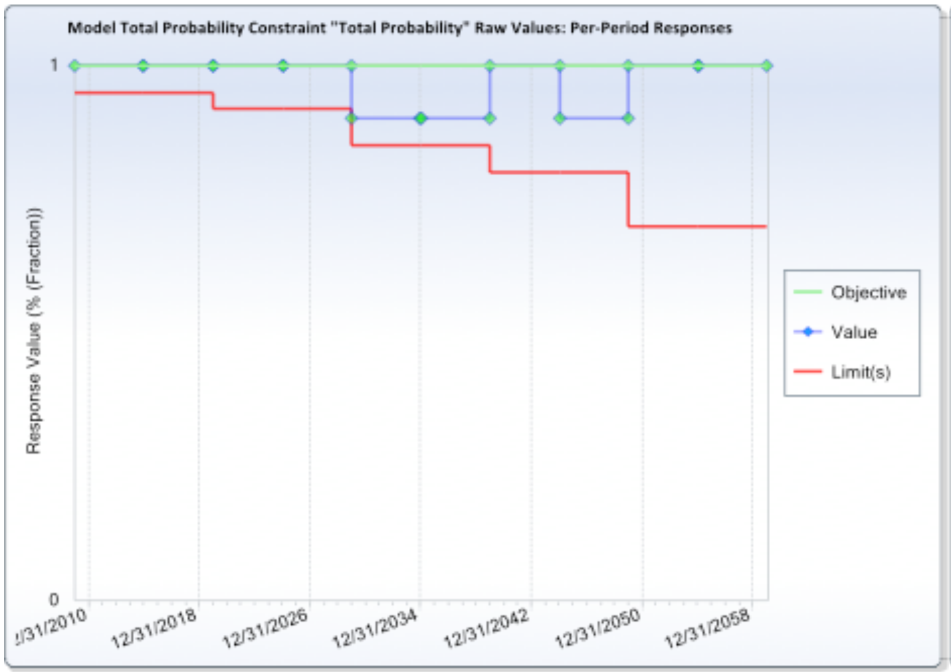


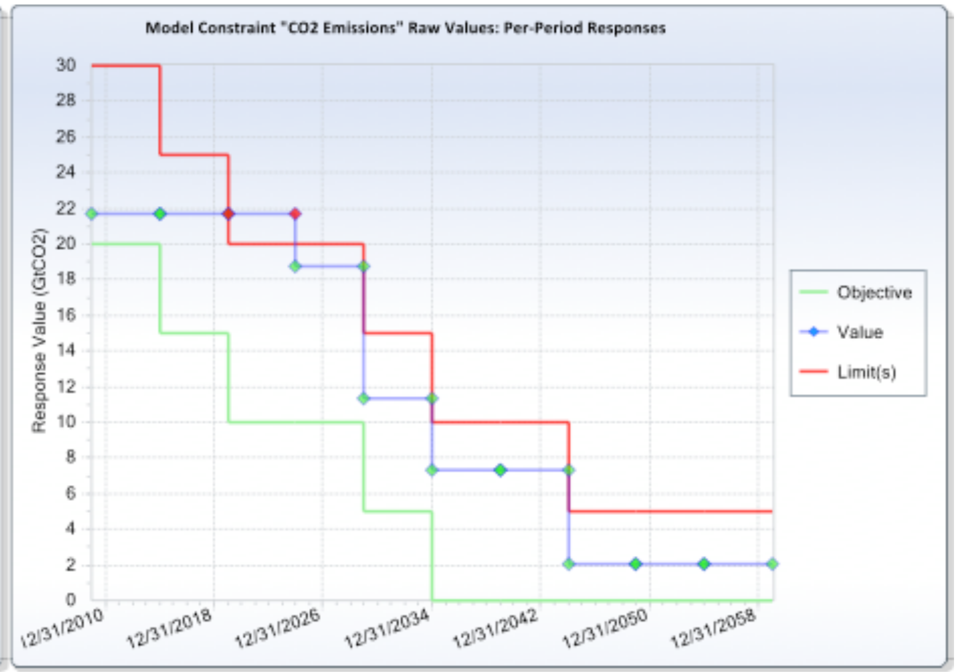


Optimization Interface And Structure









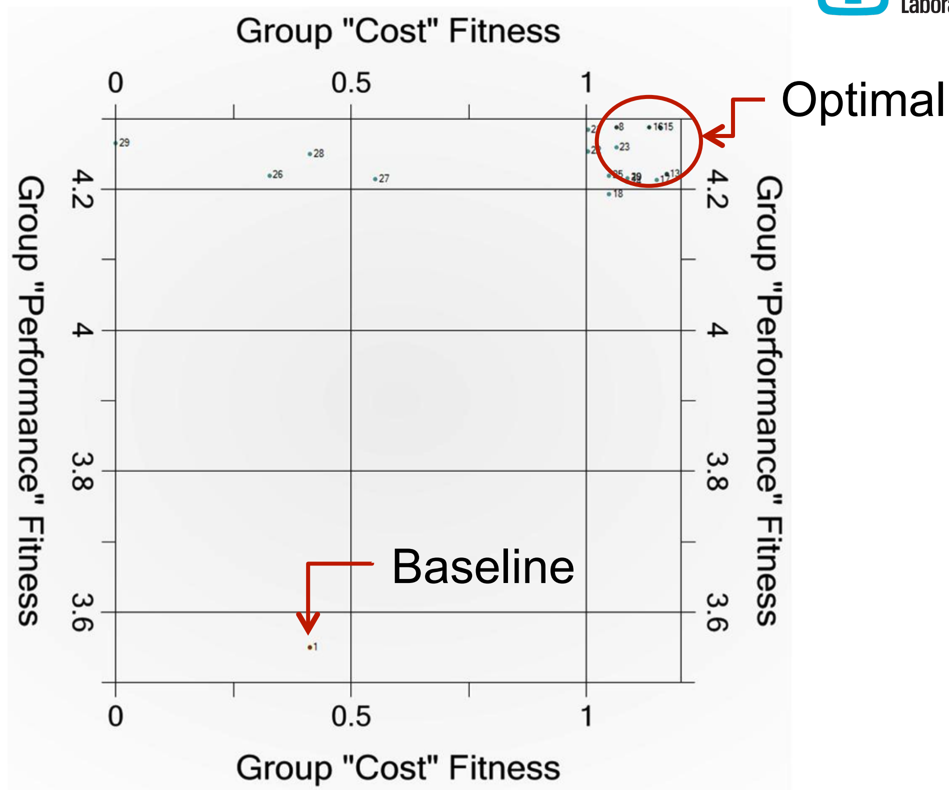
SPIDERS Performance/Reliability Modeling (PRM) Using TMO

- Options:
  - The number of diesel generators to be included as part of a new SPIDERS Power Plant (PP)
  - The size of the diesel generators to be included as part of a new SPIDERS PP
  - Whether to add an additional path from a new SPIDERS PP to the Main Station R
  - Whether to automate removal of Tier 2 load at the new fitness facility
- Metrics:
  - The capital cost of equipment installed (over and above all of the equipment that is required regardless of the PRM design choices)
  - The percentage of outages that results in some Tier 1A load not served
  - The percentage of outages that results in some Tier 1B load not served (excluding the time during microgrid startup)
  - The average Tier 1A and Tier 1B over those utility outages for which Tier 1A and Tier 1B was greater than 0 in kWh (which provides a measure of the magnitude of the problems during the times when problems occur)
  - The average amount of diesel used
  - The average diesel generator efficiency achieved over all utility outages
  - The capability of supporting Tier 2 loads over extended outages (Tier 2 Load Served)

Performance/Reliability Model (PRM)

- 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

Phase 3: Camp Smith Planning

- 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 (estimates at right)

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

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

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Discussion

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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 1000kW, Tier 4I, low acoustics
New plant siting	Will build new plant at Camp Smith
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

Bottom Line Up Front

- SPIDERS is building three microgrids, each with increasing capability, which will function as permanent energy systems for their sites
- The project will promote adoption of microgrid technology for DoD through:
  - Design and requirements methodology
  - Cyber security architecture