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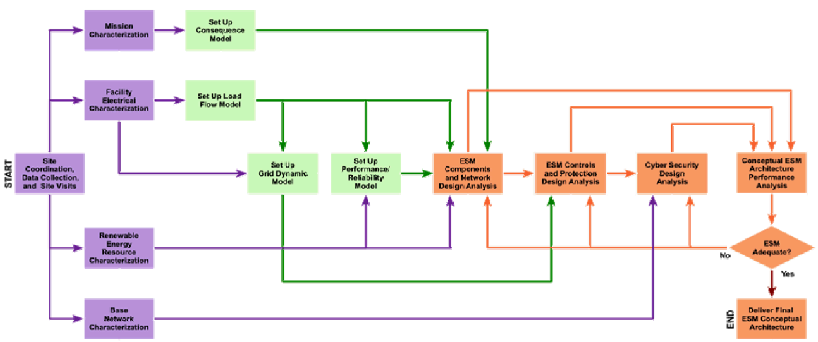

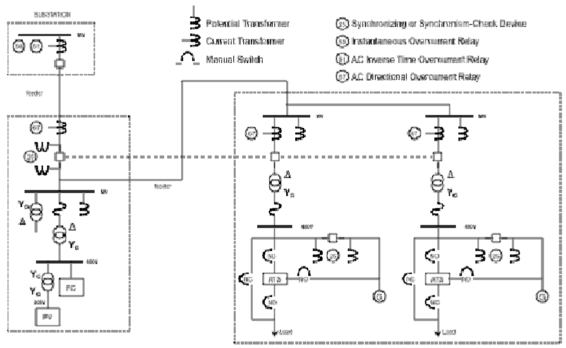

Microgrid Modeling to Support the Design Process

Jason Stamp, Ph.D.

Energy Surety Engineering and Analysis

U.S. DEPARTMENT OF ENERGY   NNSA National Nuclear Security Administration

Overview

- Background
- Requirements analysis process
- Supporting models
- Optimization analysis

Selected Energy Surety Microgrid Projects

(Funded by DOE OE, DOE FEMP, and DoD)

- 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: Smart Power Infrastructure Demonstration for Energy, Reliability, and Security

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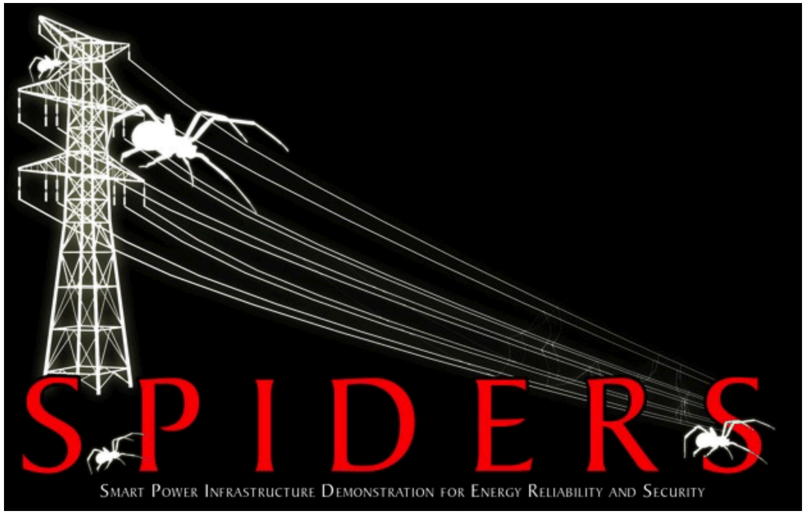
Objectives

1. **Improve reliability** for mission-critical loads by connecting generators on a microgrid using existing distribution networks.
2. **Reduce reliance on fuel** for diesel power by using renewable energy sources during outages.
3. **Increase efficiency** of generators through coordinated operation on the microgrid and less excess capacity.
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. **Reduce energy costs** during normal operations by controlling microgrid resources to lower consumption / demand charges, and also generate ancillary services revenue



Transition

Transition Plan includes smart microgrid design guides – Uniform Facilities Criteria (UFC) for Services, cyber design guides for ICS, MOAs with services and service labs. Commercial Transition Plan includes cooperation with NIST, working with industry associations (NERC, EEI, etc.)

Lifecycle Funding Summary

	FY11	FY12	FY13	Total
Total	$18,121	$8,300	$6,700	$33,121

Technical Scope

DoD, DOE, and other agencies collaborate to design and implement three separate microgrids supporting critical loads at DoD bases to reduce reliance on commercial power (which becomes less reliable with increasing threat). Each is slightly larger and more complex in scope than the previous:

- Joint Base Pearl Harbor Hickam
- Fort Carson
- Camp Smith

A key part of the project is the standardization of the design approach, contracting, installation, security, and operation of these micrograds to support future applications.

SPIDERS/ESM Load Categorization

- Tier 1 – those 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 – those 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 – those 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 Startup Operations

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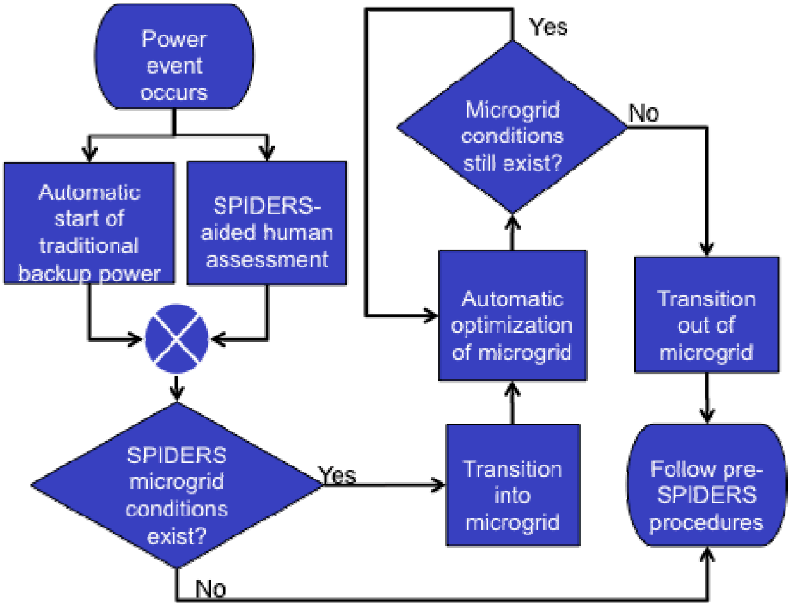
- Utility power is lost. Inverters with anti-islanding shut down.
- All emergency generators start when they sense the loss, but only power their associated Tier 1 load. Non-interruptible Tier 1 loads usually are equipped with UPS (uninterruptible power supplies) to provide 5+ minutes of backup power while the generators start.
- The microgrid EMS (energy management system) senses a power loss and opens PCC (point of common coupling) breakers after a predetermined interval, and then reconfigures MV (medium voltage) feeders (using sectionalizing breakers) to form the microgrid backbone.
- The EMS sends signals to each building to disconnect all from the microgrid (except Tier 4).
- The EMS then determines which generator will be used to energize the MV network (and supply the necessary inrush current). Afterward, all other generators will synchronize to the MV network and back feed their power by closing breakers that connect them directly to the main building service (a bypass breaker). Depending on the size and complexity of the microgrid, this may occur in stages.
- Backup emergency generators operate in parallel and are controlled by the ESM. Not all will be used – they will be dispatched for optimal fuel usage and operational reliability. Energy storage will be brought on-line.
- After a delay, inverter-based renewable energy systems will return and supply power to the microgrid.
- Tier 2 loads may be served as necessary and feasible.

SPIDERS/ESM Shutdown Operations

- Generator ATS (automatic transfer switch) bypass breakers will be opened. Running generators will supply their Tier 1 loads. No additional generators will be started; Tier 1B (interruptible) loads without a running generator will lose power briefly.
- Microgrid feeders will be returned to their original configuration.
- Breakers at PCCs will close. Tier 1 loads are immediately reconnected to the utility as their ATS senses voltage.
- Remaining Tier 2 and Tier 3 loads are reconnected via the microgrid EMS. Generators are shut down and returned to ready state.
- While connected to utility power, the EMS can dispatch generators, energy storage, etc. to support reduction of the base's utility bill (energy usage, demand charge, or power factor penalty) and participate in local grid ancillary service markets (as feasible)



SPIDERS/ESM Technical Approach

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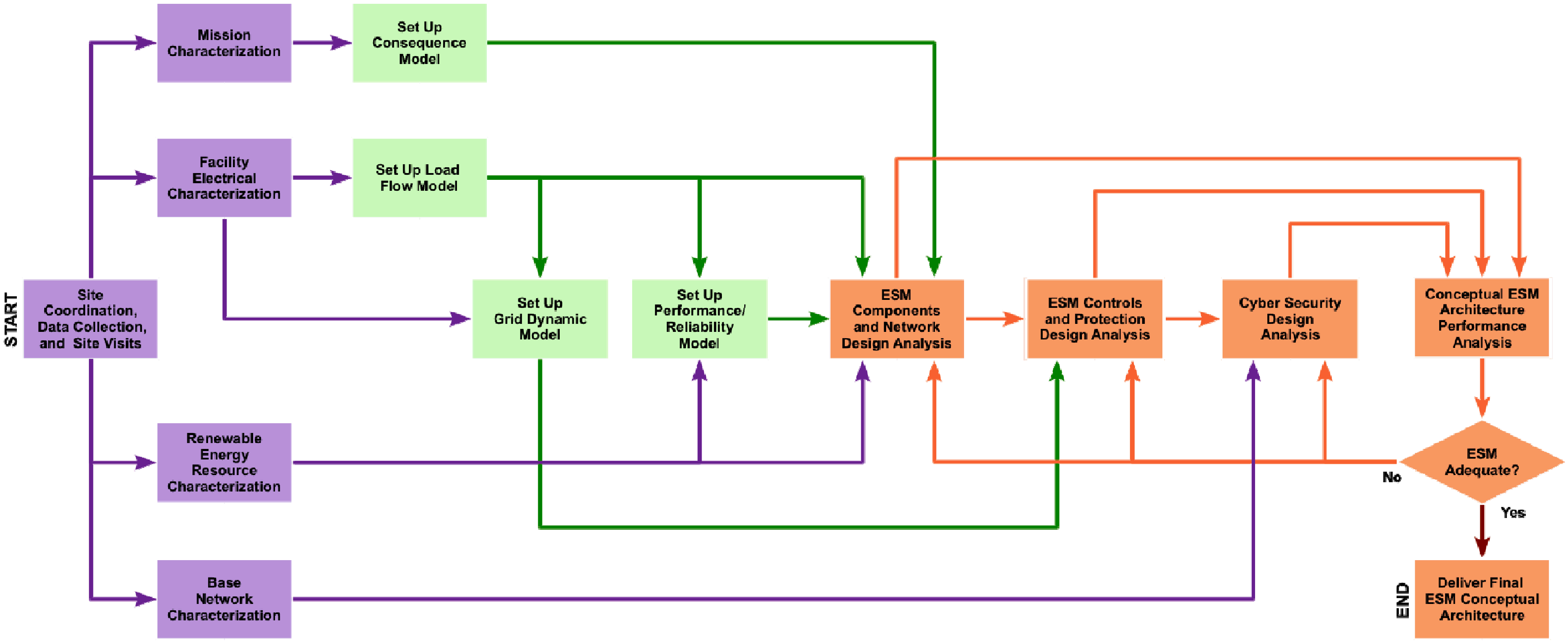
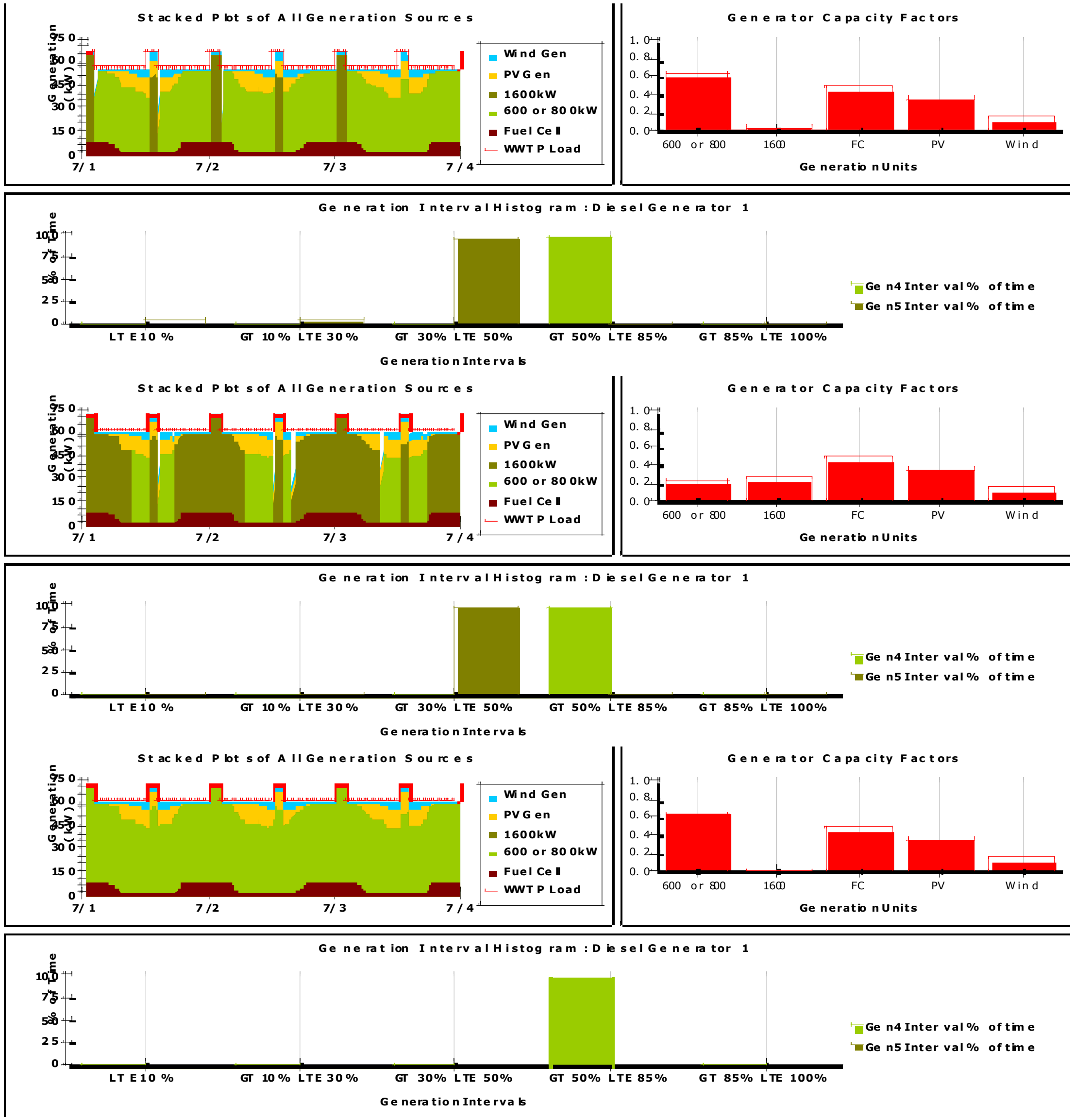


- **Design Phase**
  - **Conceptual design – What are the microgrid requirements and what energy assets are needed?**
  - **Preliminary design – What are the microgrid functional requirements? How do we control and secure it?**
  - **Detailed design – Create a buildable construction specification, teaming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

Systems Dynamics Modeling (SDM)

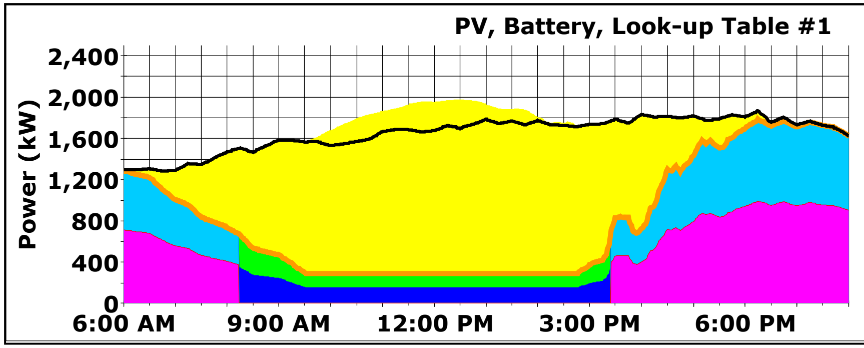


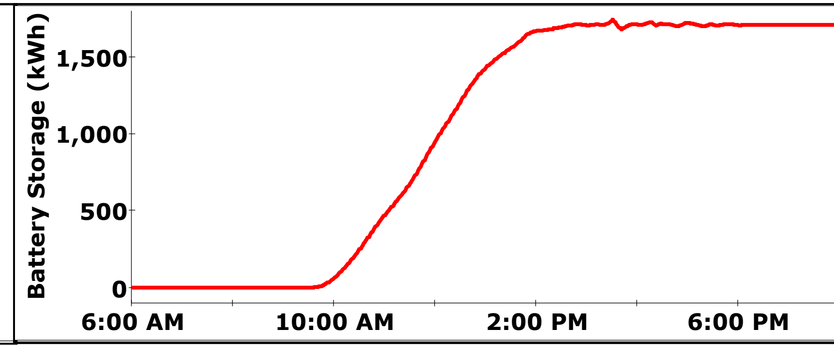
560kW load, 600kW and 1600kW diesel generator, 100kW fuel cell

615kW load, 600kW and 1600kW diesel generator, 100kW fuel cell

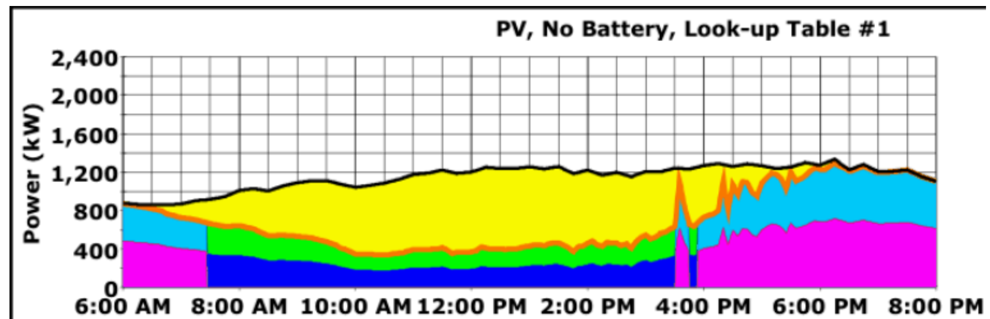
615kW load, 800kW and 1600kW diesel generator, 100kW fuel

Systems Dynamics Modeling (SDM)

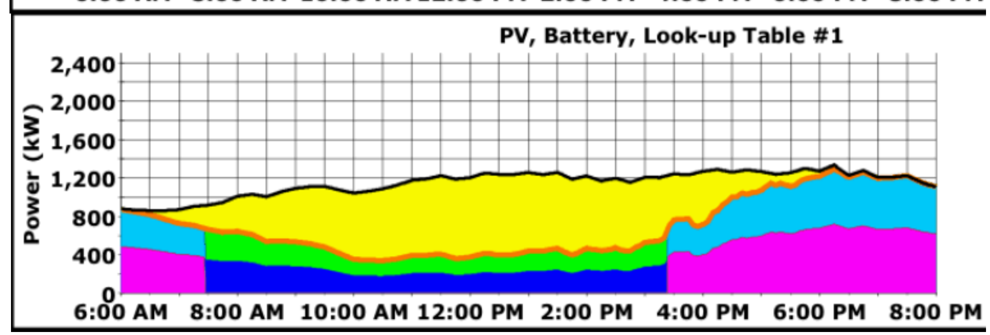




This system has too much PV energy and would require an impractical battery.

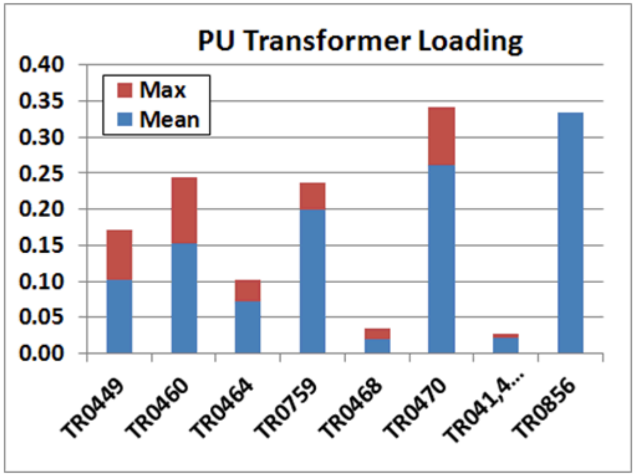


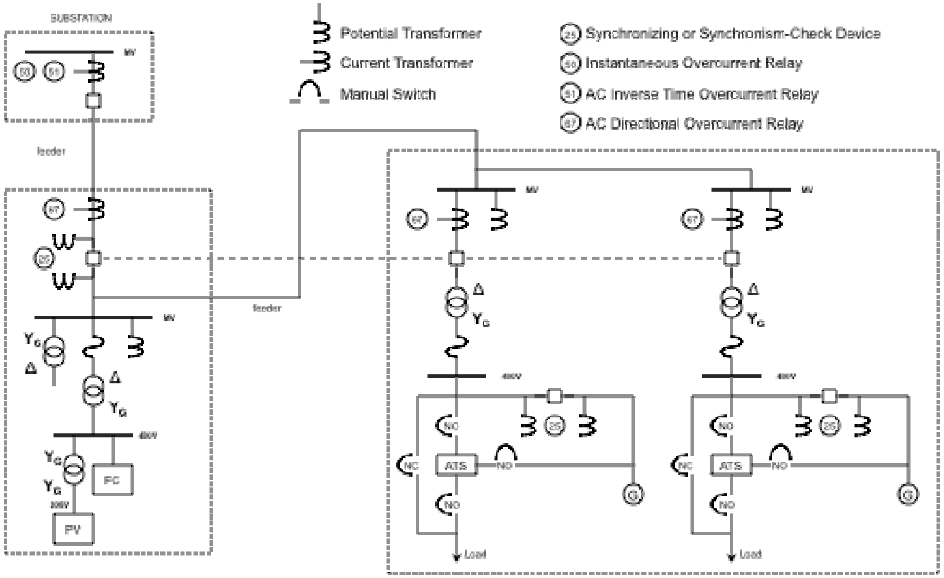
Adding electrical storage reduces renewable energy intermittency issues. Also, more load would reduce the PV penetration percentage.



Load Flow Model (LFM)

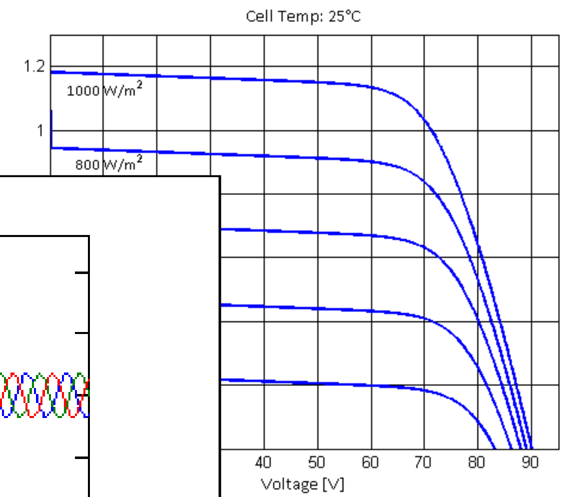
- Voltage and flow analysis
- Development of a notional microgrid one line diagram
  - Determination of switching to form the microgrid MV backbone
  - Designation of PCCs
  - Low voltage switches are preferred to medium voltage switches to bring Tier 1 and 2 buildings onto, and take Tier 3 buildings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

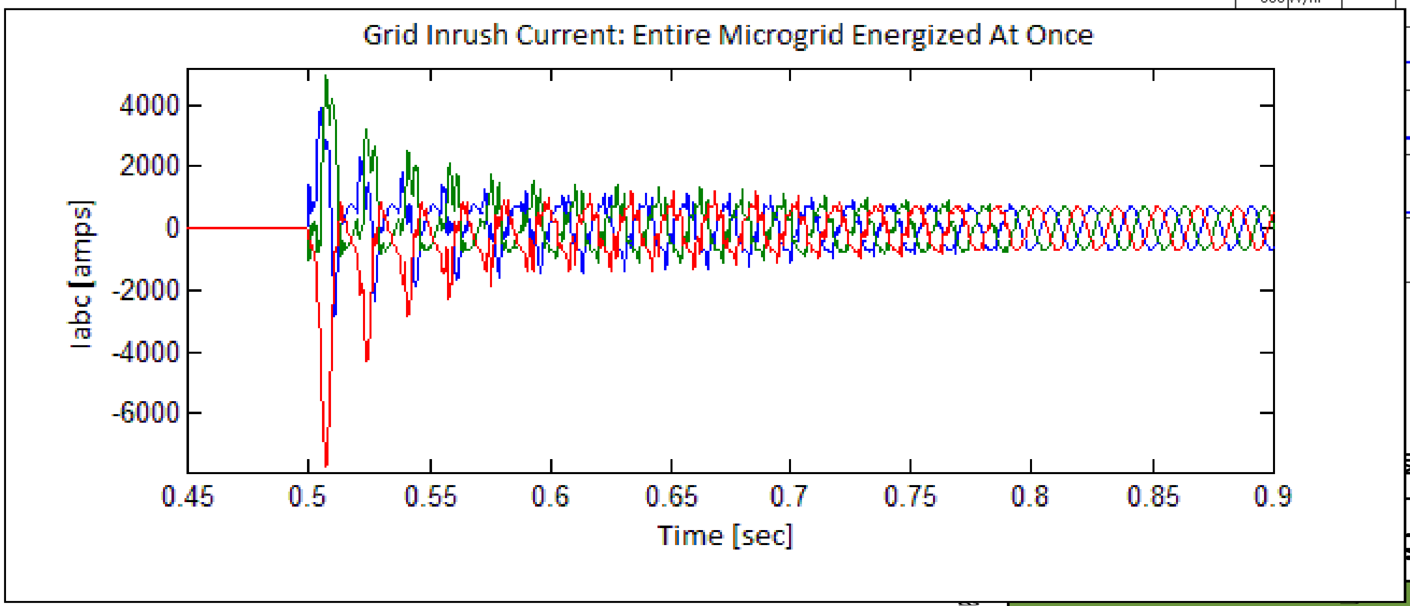


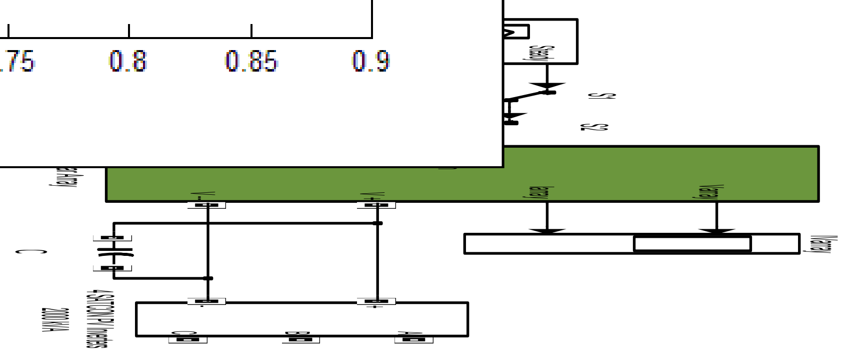


Dynamic Grid Model (DGM)

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



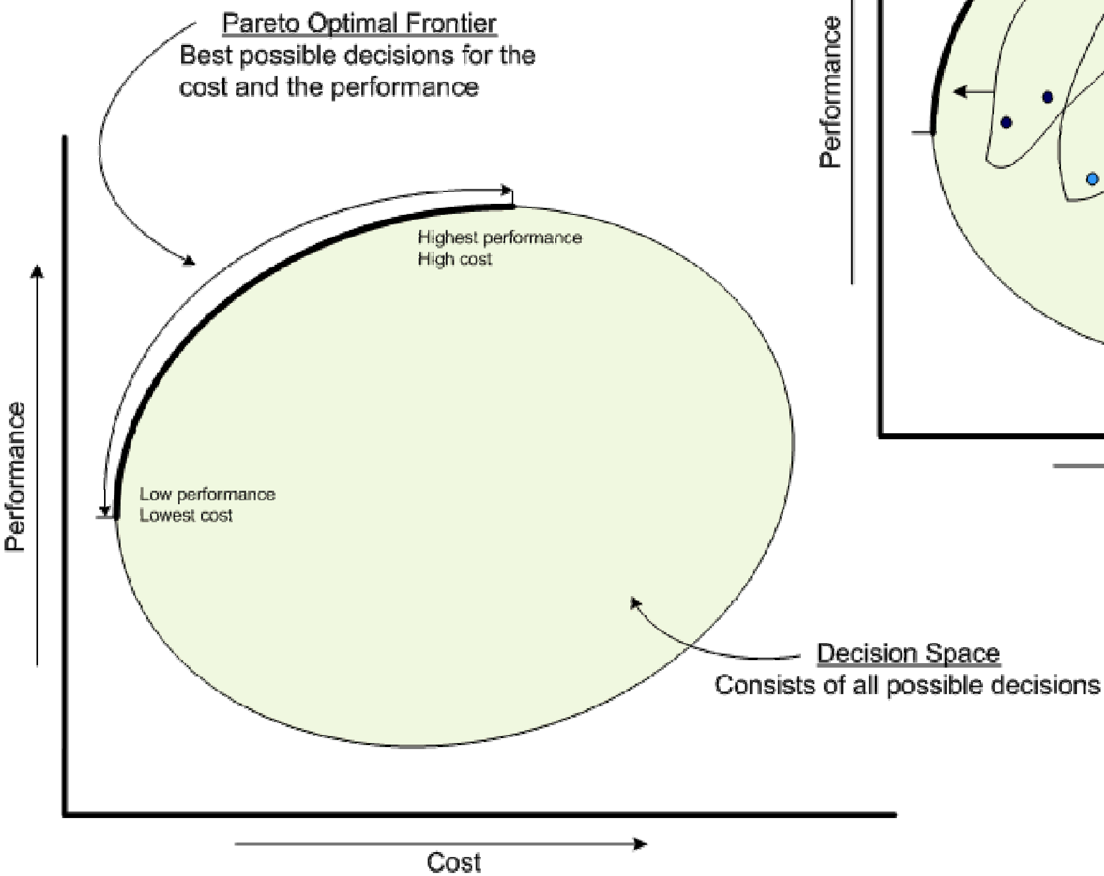


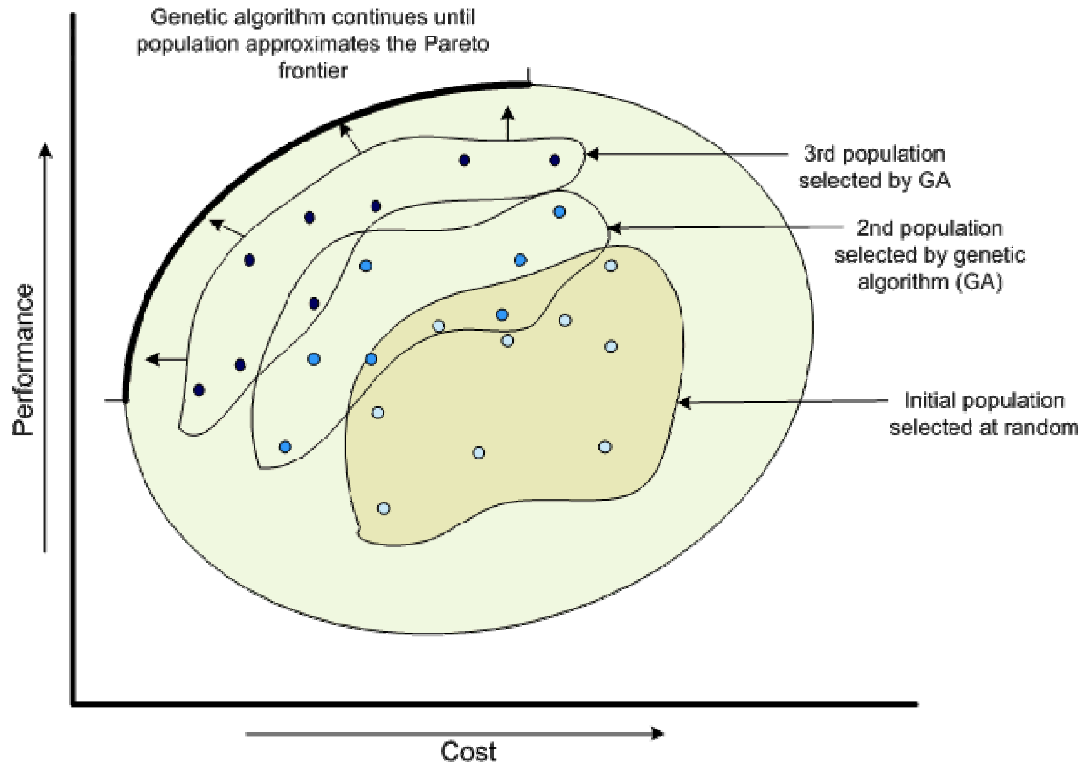


TMO Overview

- TMO is a Windows® application that produces optimal planning roadmaps
  - Technology management / insertion
  - Trade studies
  - Decision support
- TMO can be used to address energy-related problems
  - Technology management of energy systems (microgrids!)
  - Energy policy and investment questions (examples following)
- Optimization
  - 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

TMO and Pareto Optimality





TMO Structure

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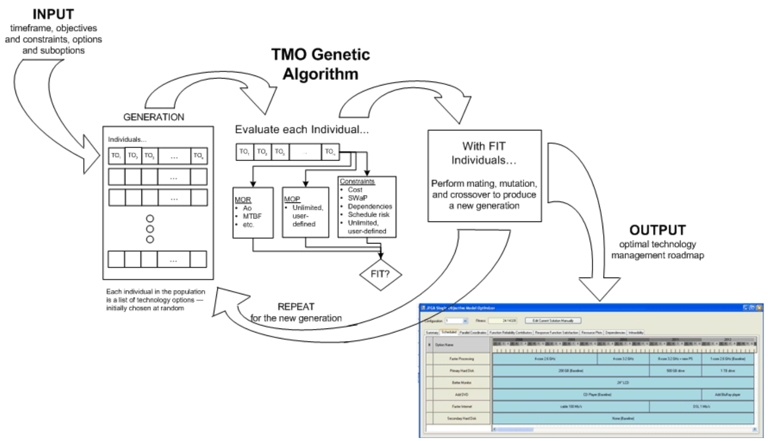
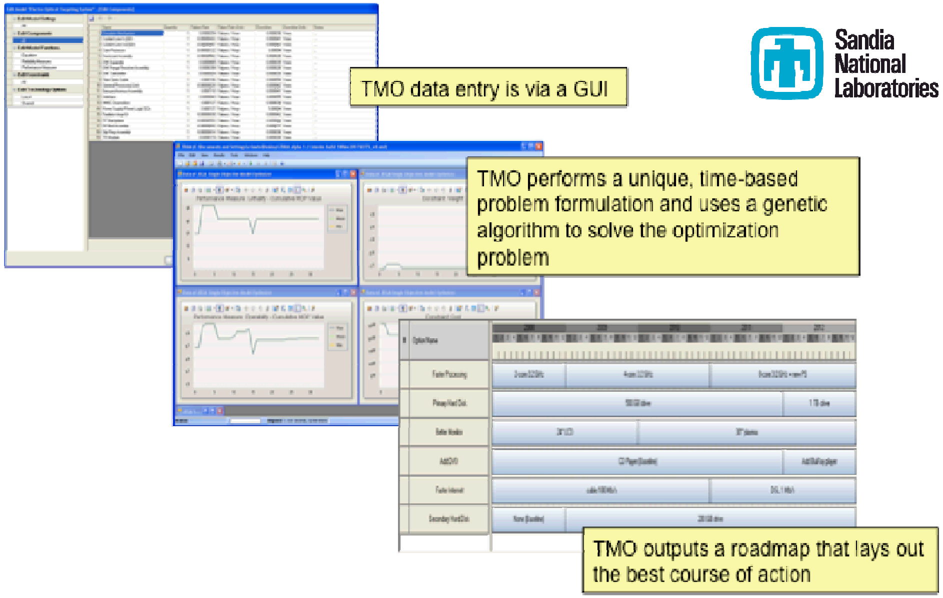
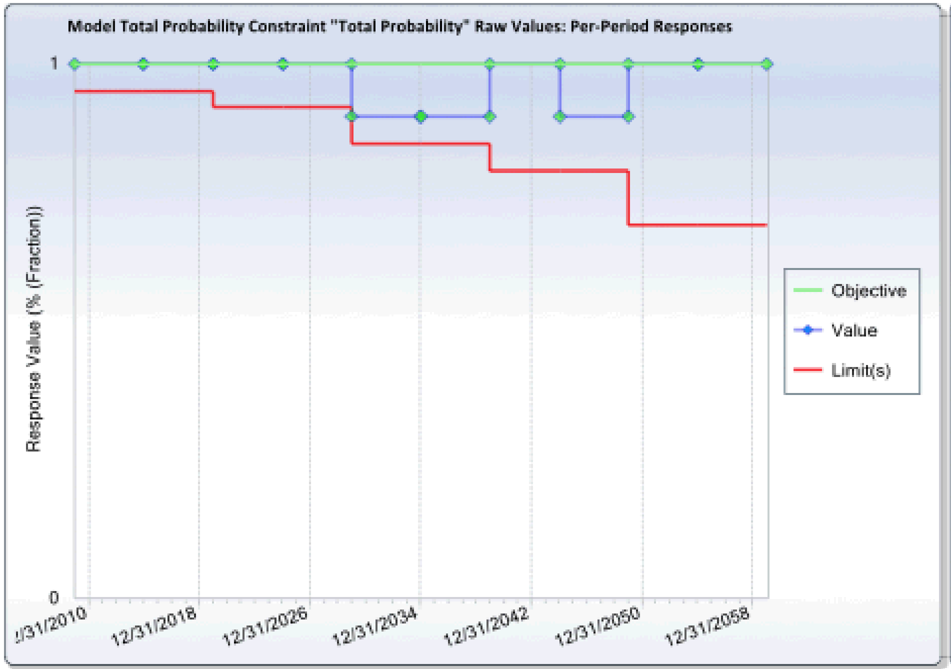
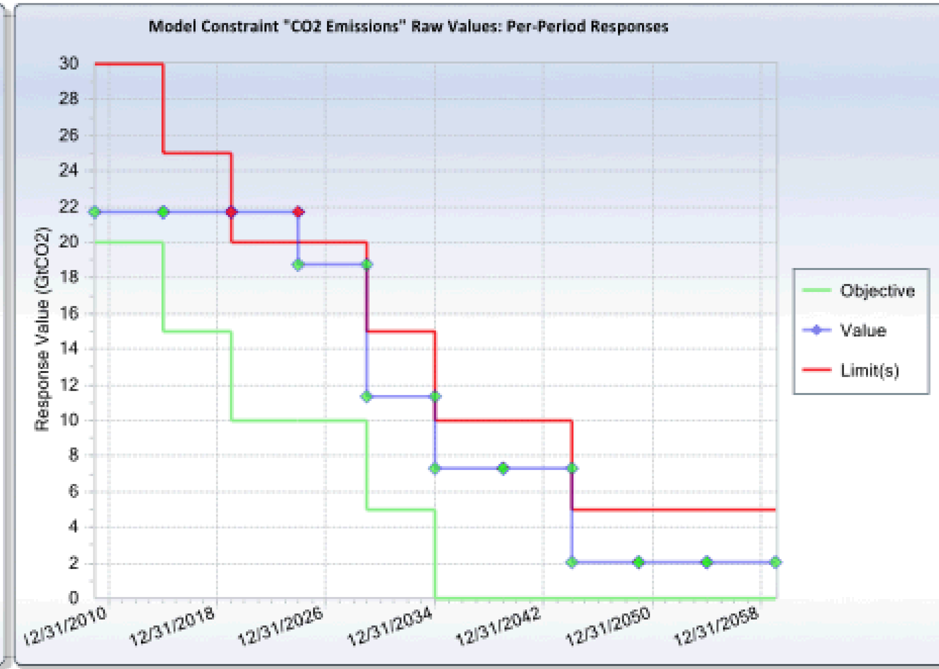
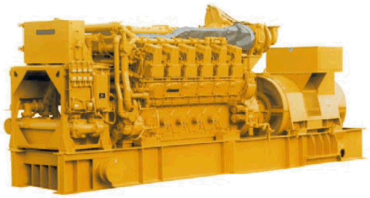








Performance/Reliability Model (PRM)



- Options:
  - Which Tier 1 / Tier 2 buildings can we afford?
  - Microgrid MV/LV options
  - Fossil generation:
    - Reuse which existing units (cost varies for integration depending on LV configuration, age, etc.)
    - Add emergency diesels, low-emissions diesels, or natural gas units
  - Renewable energy: PV at 0, 1, or 2MW
  - Storage:
    - PHEV or stationary, variety of sizes, need energy/power ratings
    - Use cases: Smooth RE, small energy shift (to optimize diesel), large energy shift

- Metrics:
  - Critical load not served – all must have sufficient energy to ensure critical missions
  - Diesel consumption: renewable energy and storage systems defer diesel consumption during utility grid failures when diesel backup generation is needed
  - Carbon generation deferred: the renewables help lower the carbon “bootprint” of the base during microgrid operations
  - Priority load support: during extended outages
  - Keep penetration of renewable energy to a manageable level

Performance/Reliability Model (PRM)

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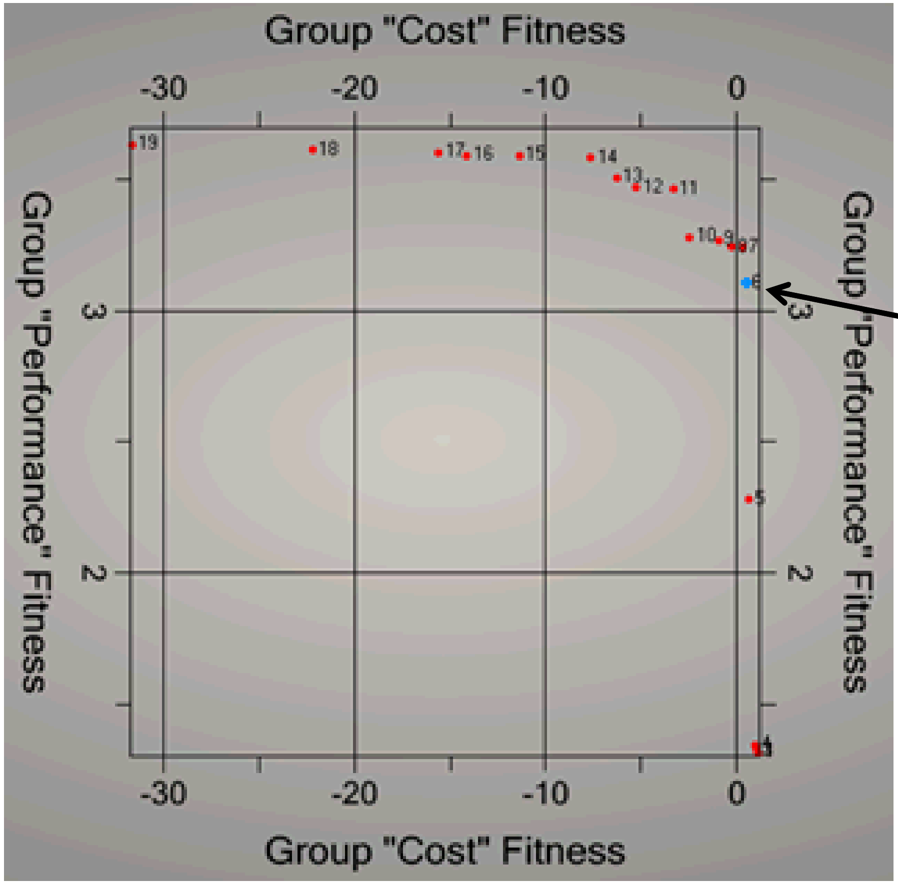
- Case 1: smaller microgrid
- Key improvement is to critical load reliability
- Constrained optimal solution selections are based off of SDM analysis

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

Performance/Reliability Model (PRM)



Fitness	Tier 1	Tier 2	Fossil Generation	PV	Battery/PH EV
Perform-ance = 3.106	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 = 500kW / 250kWh
Cost: $1.186M	(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

Case 2 (larger microgrid): This model presents several options – the optimal was chosen and tweaked to provide the most reliable system for the best cost.

Option	Perform-ance Fitness	Battery Size (kW/kWH)	% of time CLNS > 0	PLS (kWh/hr of outage	Diesel Redispatch Avoidance	Avg. Diesel Efficiency	Non-Desig-nated Tier 2 Load (kW)	Incremental Cost ($US)	Avg. Diesel Used (gal / hr of outage)
Base Case	N/A	0/0	14.121	N/A	N/A	0.3014	0	300,000	356.66
5	2.919	250/250	0.1500	591.8	0.0382/hr	0.3611	400	1,092,750	412.19
6	3.106	500/250	0.1484	1067.8	0.0788/hr	0.3664	1000	1,185,938	447.46
7	3.243	750/250	0.1484	1067.8	0.0846/hr	0.3667	1000	1,279,125	445.60

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) supported by TMO

Discussion

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