Assessment of Reliability and Performance of Microgrid Use Cases Toward Meeting the Defined Objectives

19 February 2014

Jason Stamp, Ph.D., Sandia National Laboratories

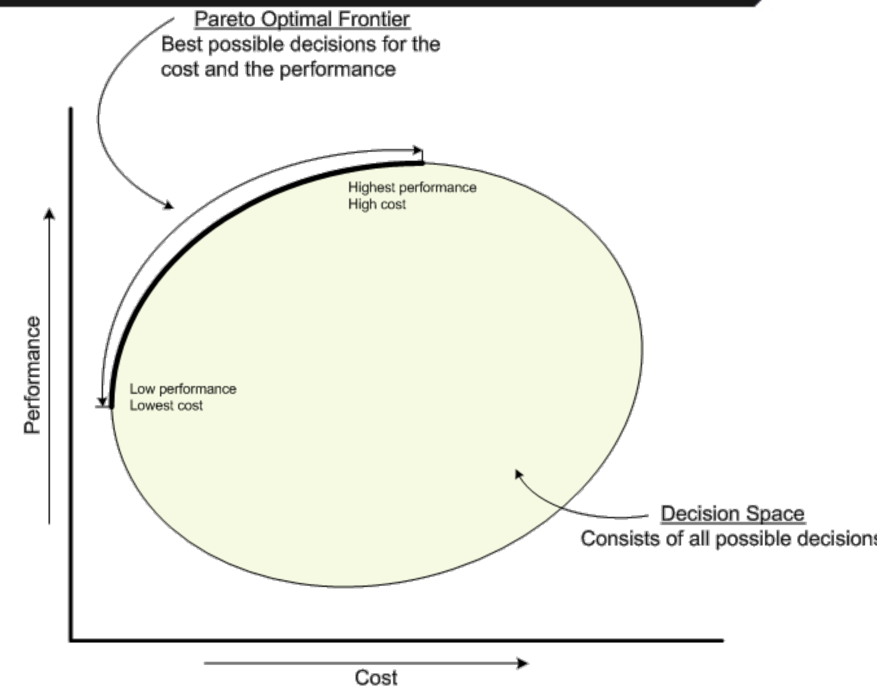
Program Manager: Dan Ton, DOE

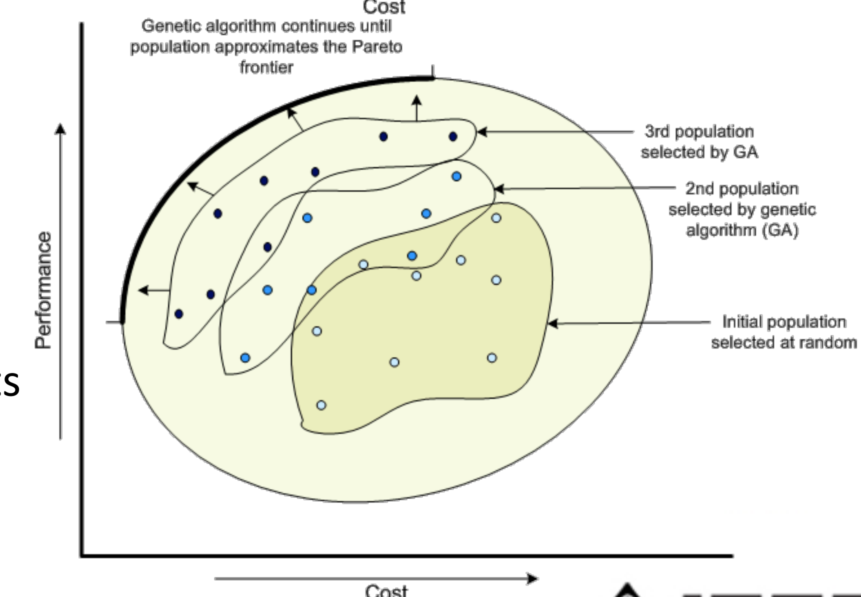
Bottom Line Up Front

- DOE microgrid targets are to develop <10 MW systems that can reduce outage time of required loads by >98% at a cost comparable to non-integrated baseline solutions (uninterrupted power supply plus diesel genset), while reducing emissions by >20% and improving system energy efficiencies by >20%, by 2020
- Sandia has developed an Energy Surety Design Methodology (ESDM) that calculates and optimizes microgrid designs to meet performance targets while islanded from the utility
- Teams from SNL, LBNL, and PNNL are integrating software capabilities to develop an integrated microgrid design toolset (MDT) that will show a way to calculate these measures of effectiveness
- The MDT is planned to be transitioned for industry use
- In CY13, the proof-of-concept integration was completed

Microgrid Design Tradeoff Analysis

- 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

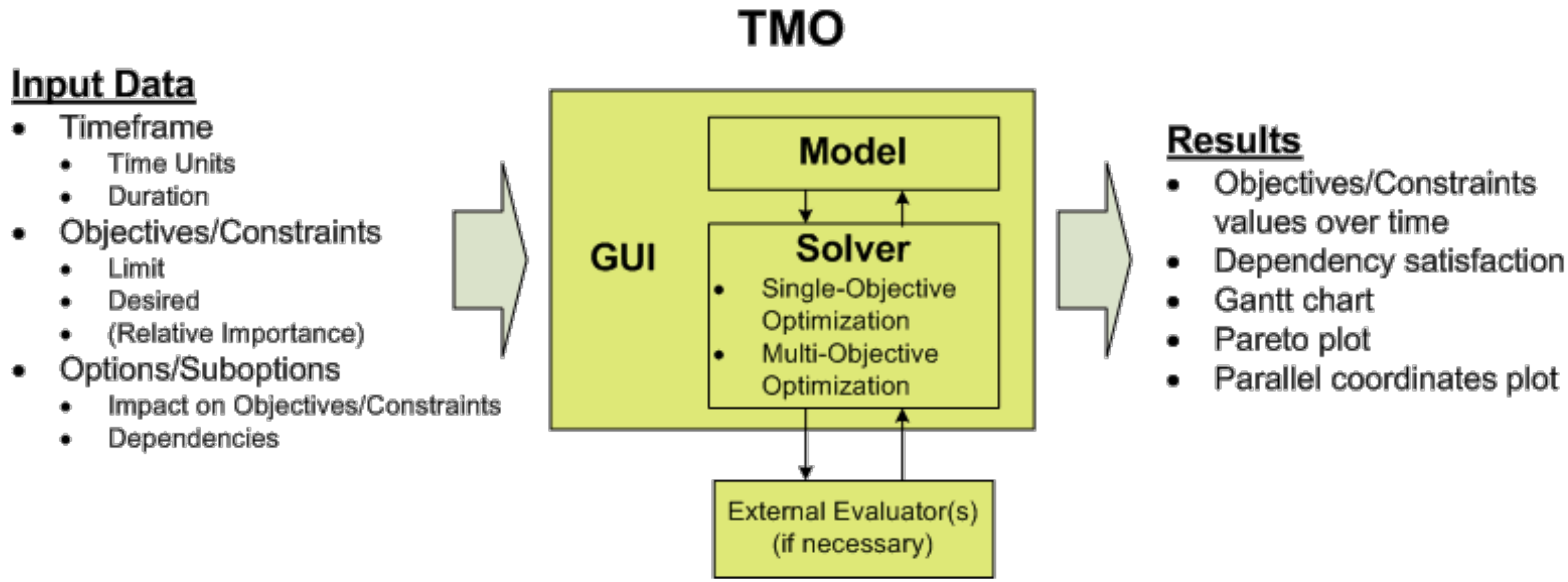




Technology Management Optimization (TMO)

- 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
- Past projects:
  - Microgrid optimization for the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS)
  - MRAP-ATV Capability Packages
  - Stryker Modernization
  - Ground Combat Vehicle (GCV) Whole Systems Trade Analysis
  - Nuclear Security Strategy Action Core Team (NSSACT)
  - Integrated Lifecycle Security (ILS)

TMO Overview

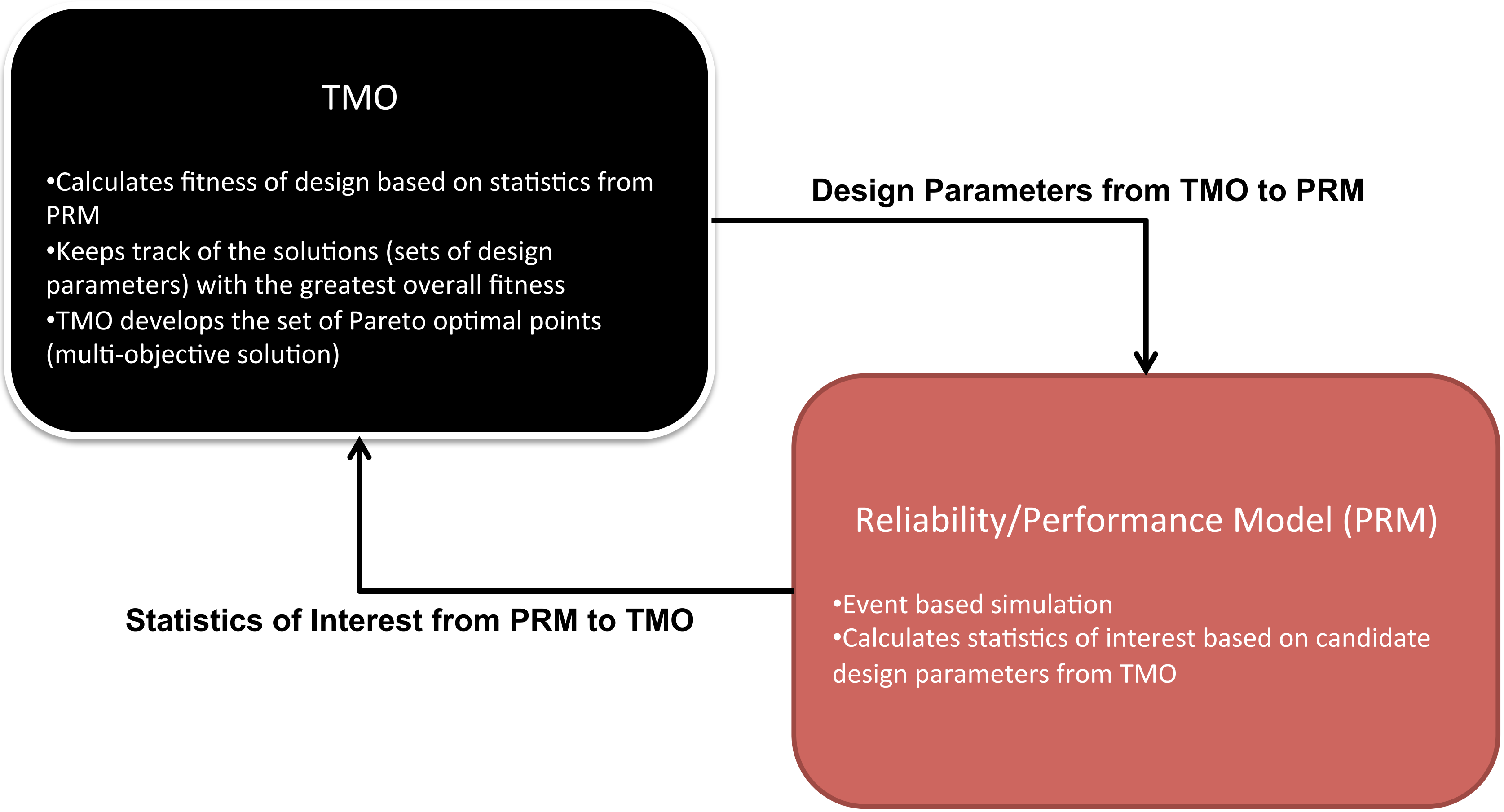


- A GUI controls TMO input, execution, and output displays
- Optimizes over time (including time-based resource constraints)
- Single-objective and multi-objective optimization
- User-defined objectives and constraints, including scheduling risk
- Includes dependencies between options—both “requires” and “obviates”
- TMO incorporates an external interface for linking to other programs; for microgrids, a MC simulation of system performance

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.

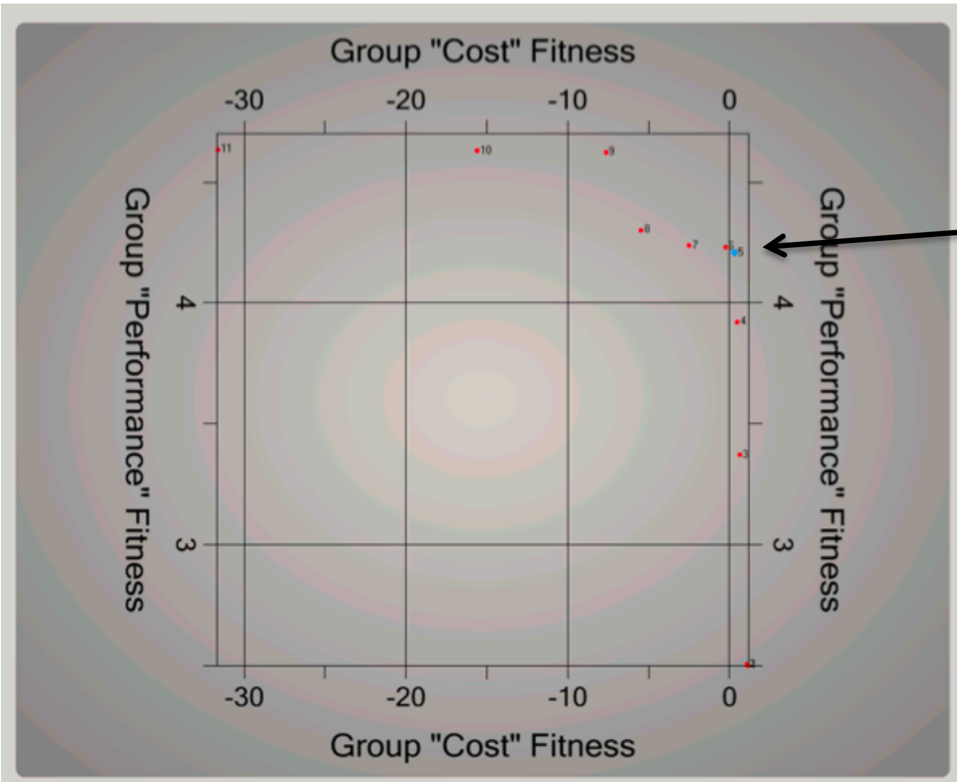
Optimizing Microgrid Design Performance



SPIDERS TMO/PRM

- Options:
  - Which Tier 1 / Tier 2 buildings? Which feeders? Add new LV/MV?
  - Re-use which existing diesels? Add new ones?
    - Re-use cost depends on LV configuration, age, etc.
    - Add emergency diesels, low-emissions diesels, or natural gas units
  - Renewable energy: How much PV? How much spinning reserve or storage is needed? How does this affect budget or fuel consumption?
  - Is there an optimal usage pattern for energy resources?
- 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 and the percentage of outages that results in some Tier 1B load not served (excluding the time during 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 problems)
  - Diesel consumption: renewable energy and storage systems defer diesel
  - The average diesel generator efficiency achieved over all utility outages
  - The capability of supporting Tier 2 loads over extended outages (Tier 2 Load Served); note that it will increase the fuel consumption rate)
  - Carbon generation deferred: lower the carbon “bootprint” of the base

Performance/Reliability Model (PRM)



Fitness	Tier 1	Tier 2	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.

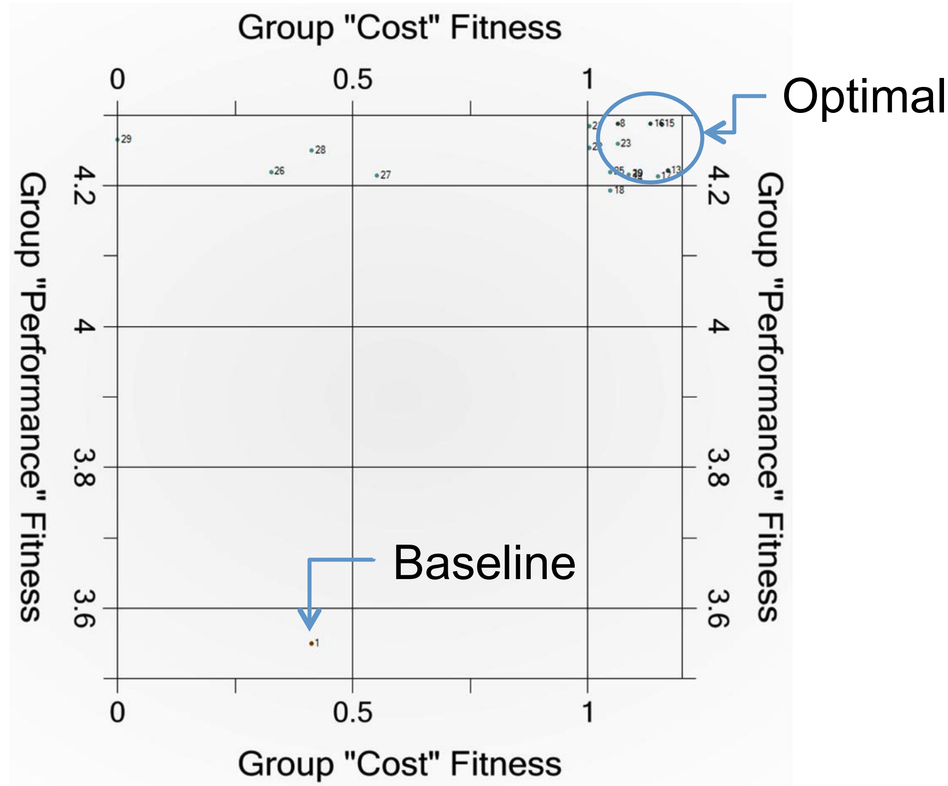
With no Tier 2 load served, the microgrid fuel consumption is approximately 79.6 gal/hr.

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

Design Optimization: Camp Smith

- Pareto chart →
- Energy 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

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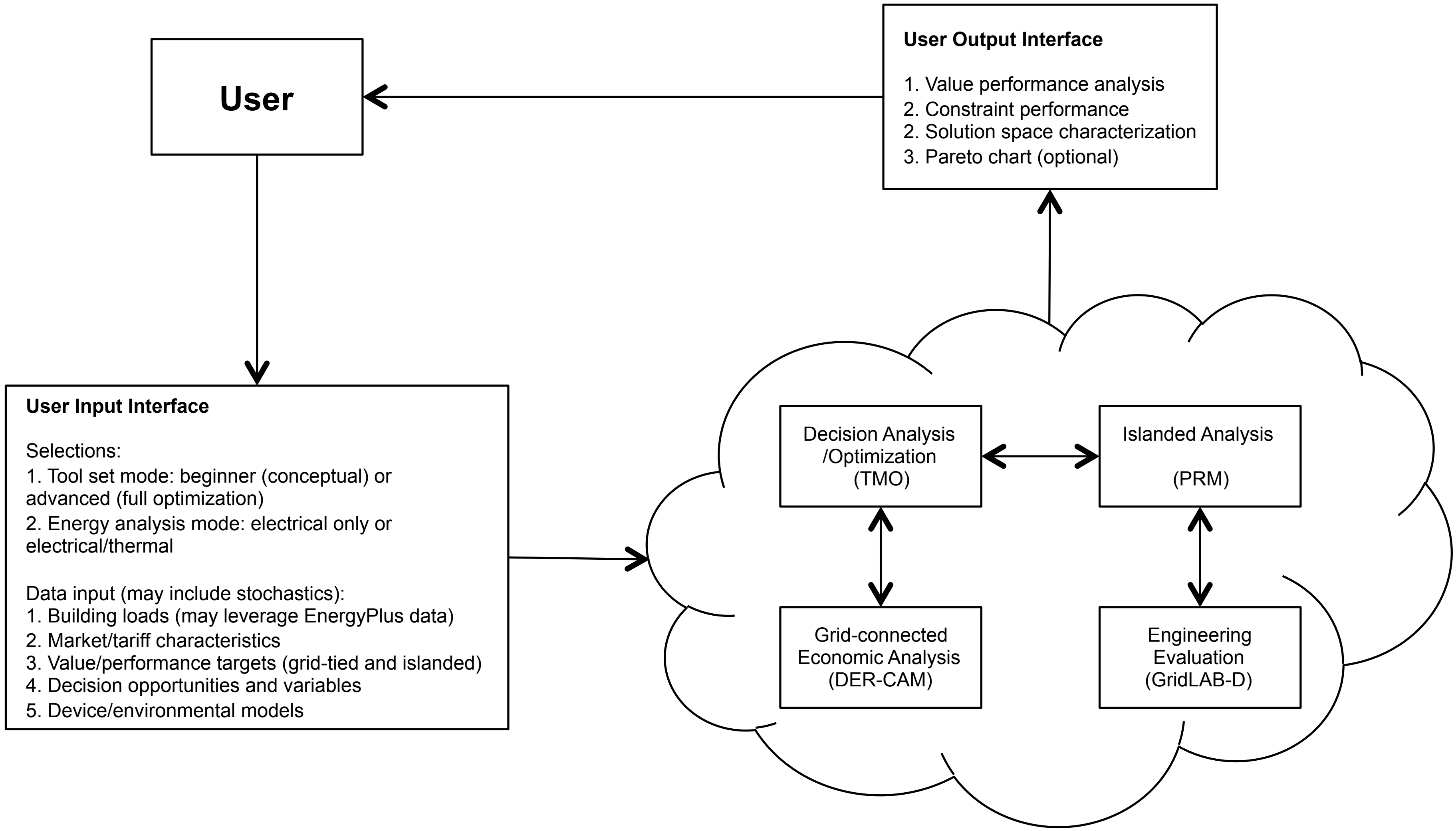
Goals for the MDT R&D

- Meet industry-identified need for standardized tool sets and approaches
- Leverage existing DOE software capabilities:
  - DER-CAM
    - LBNL
    - DER valuation during grid-connected conditions
  - GridLAB-D
    - PNNL
    - Distribution system engineering analysis
  - TMO – Technology Management Optimization
    - SNL
    - Decision support analysis/optimization for design
  - PRM – Performance/Reliability Model
    - SNL
    - Performance analysis islanded operations

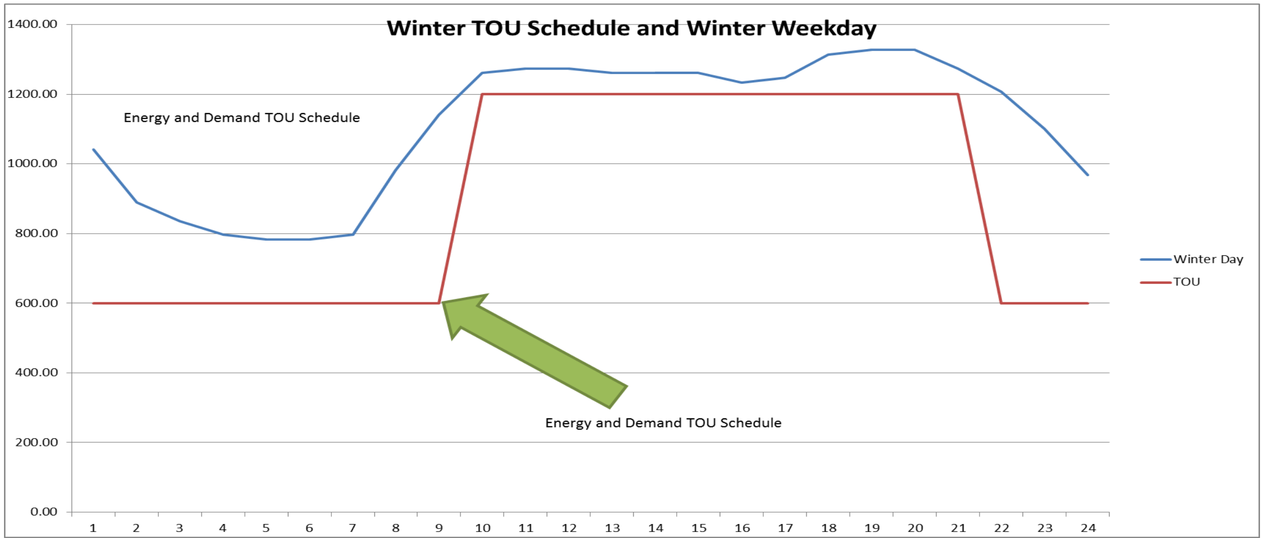
Microgrid Design Toolset (MDT) Architecture

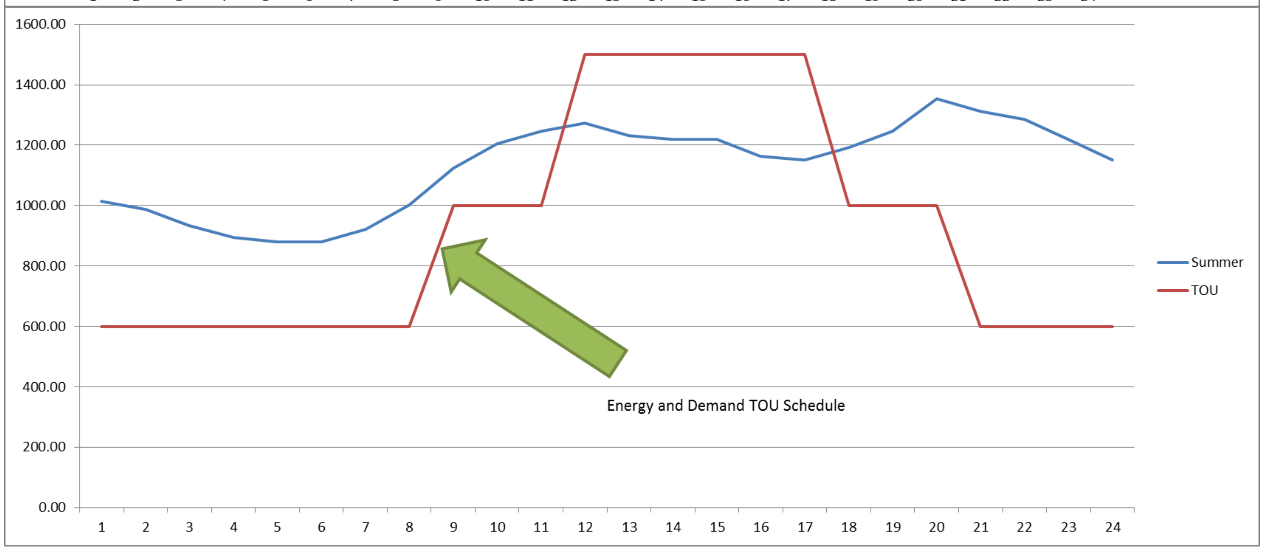


Test Analysis for Microgrid Use Case

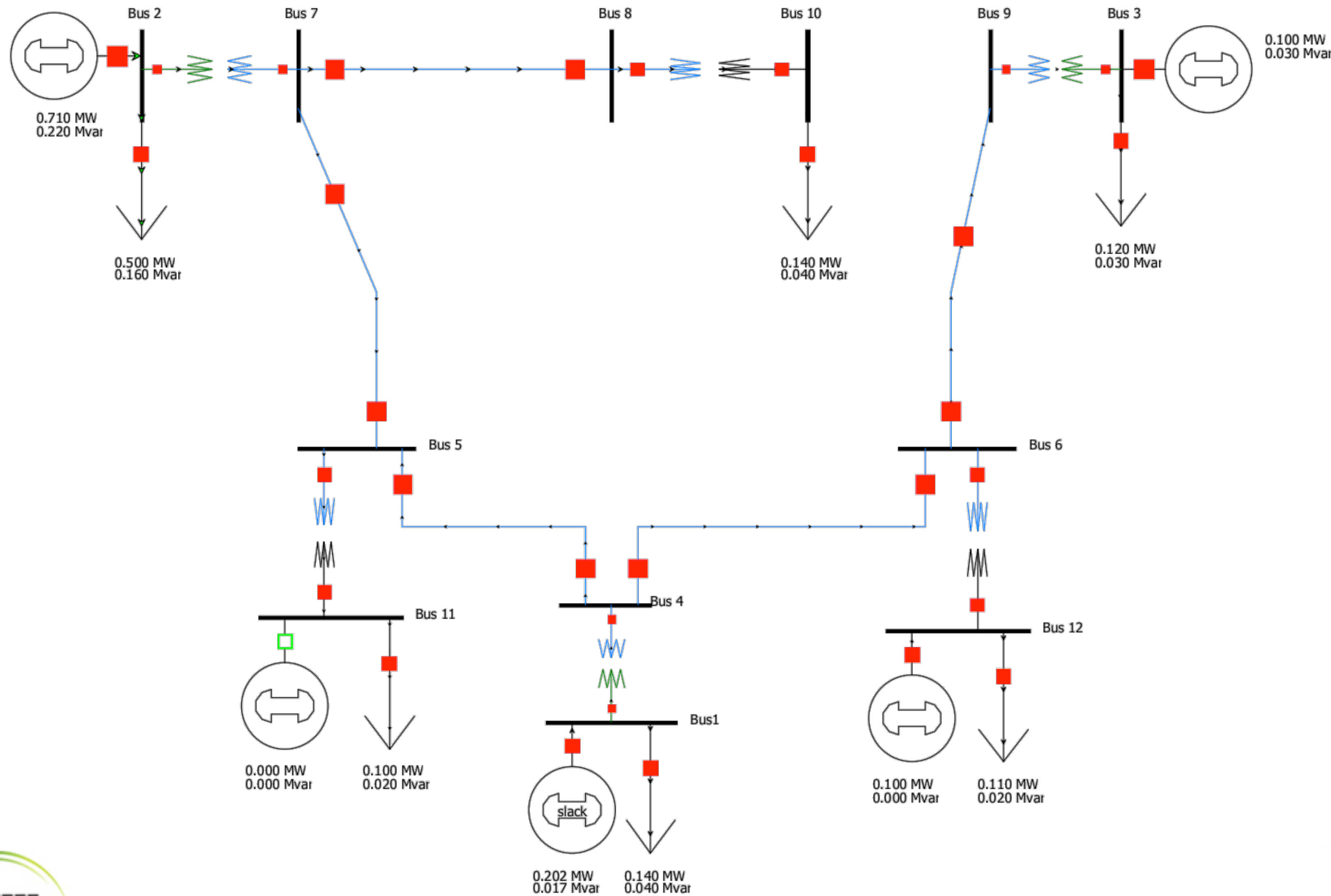
- The test system from the business case was expanded from a single bus to multiple buses to allow for a better reliability calculation by PRM
- IEEE 9-bus system was used with critical load at buses 1-3 and priority load at buses 5, 6, and 10; line 9-10 was removed to emulate a radial system
- Load scaling factors were borrowed from RTS-96 although the average load was still 1MW – 8760 MW annually)
- Three generators (instead of one) for more choices in the decision space
- PG&E Tariff E-19 – Medium Commercial demand metered TOU service (Energy and Demand TOU)
  - Summer: Peak/Partial-Peak/Off-Peak
  - Winter: Partial-Peak/Off-Peak
- Solar data based upon San Francisco, CA
- Region-based hourly marginal CO2 emissions

TOU Rate: Winter Day versus Summer Day





Test System Diagram



TMO Asset Decision 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

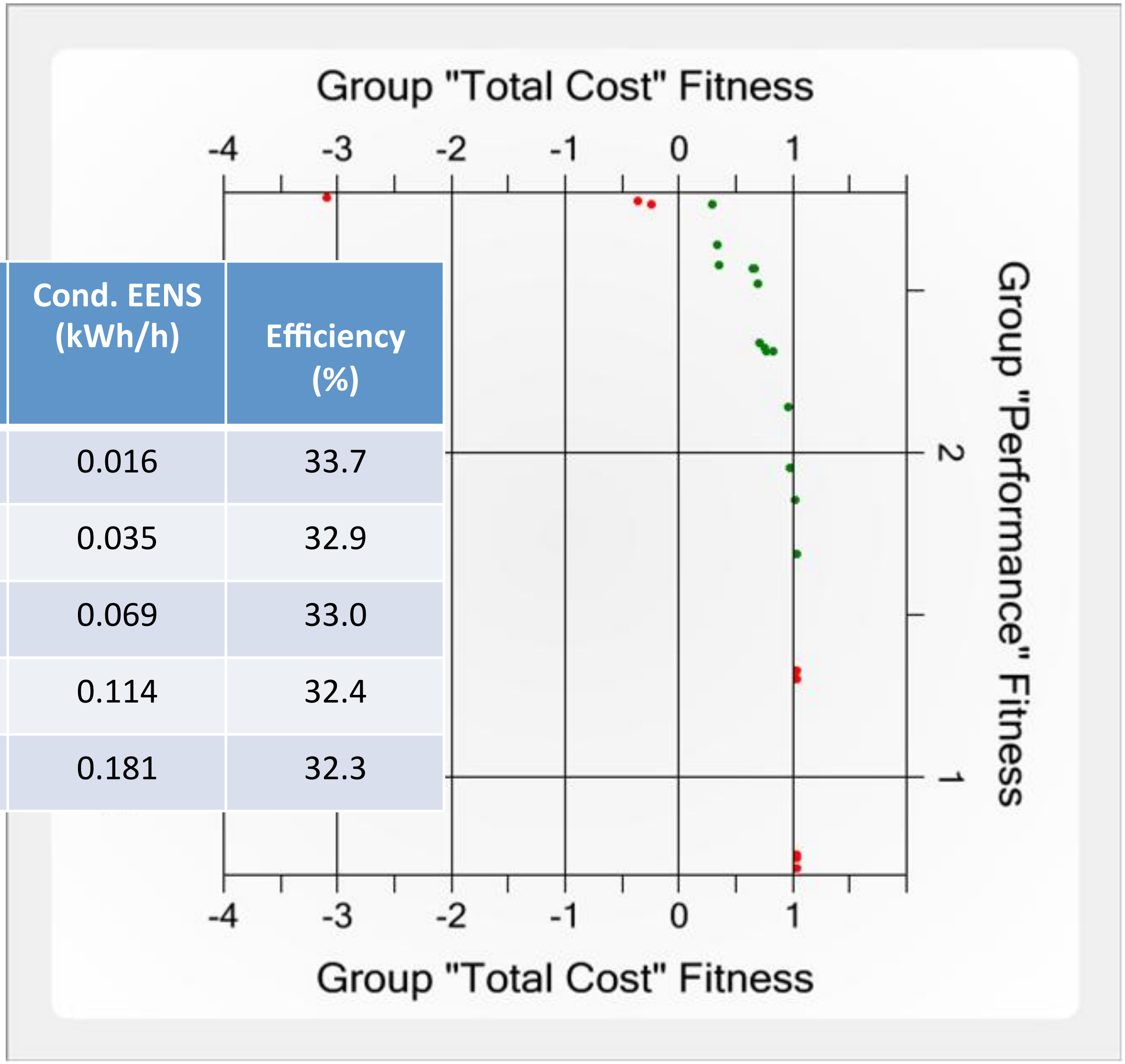
- Energy storage at bus 11 (output if generation is low or charge if excess generation is available)
- Diesel generation at buses 1-3
- PV at bus 12

TMO Objective Functions for the Test Case

		Threshold (poor) Value	Desired (good) Value
Metric	**Goal**	**Limit**	**Objective**
Total Cost / year	Minimize	$1,200,000	$900,000
CO2 Emissions / year	Minimize	4,400,000 kg	3,000,000 kg
Tier 1 Load Not Served during 1 Outages	Minimize	10 kWh	0 kWh
Average Generator Efficiency Per Outage	Maximize	30%	37%

Results from Use Case Analysis

Point	Cost ($k)	CO2 emissions (tons/yr)	Cond. EENS (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



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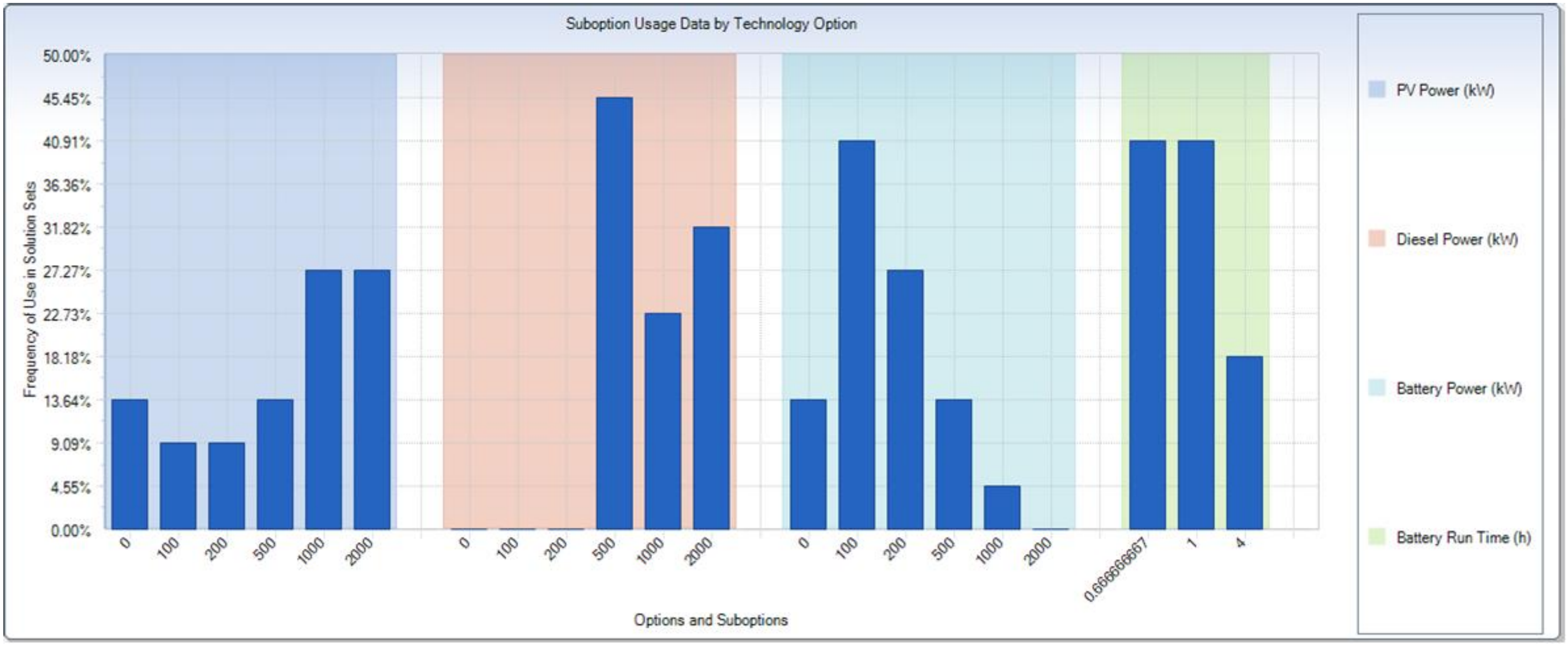

DISCUSSION

Jason E. Stamp, Ph.D.
Distinguished Member of the Technical Staff
Sandia National Laboratories
PO Box 5800, Albuquerque, New Mexico 87185-1108
505-284-6797, jestamp@sandia.gov