Expeditionary Power Systems

SAND2017-4251PE

US Marine Corps Microgrid Design Toolkit (MDT) Project Brief

Identifying Optimal Hybrid Energy Technology Sets for Marine Corps Expeditionary Military Deployments

Sandia Team:

Nadine E. Miner, Ph.D.

John P. Eddy, Ph.D.

Christopher B. Atcitty

Rob Vander Meer

Elizabeth Lopez

Cliff Hansen

Carl J. Unis

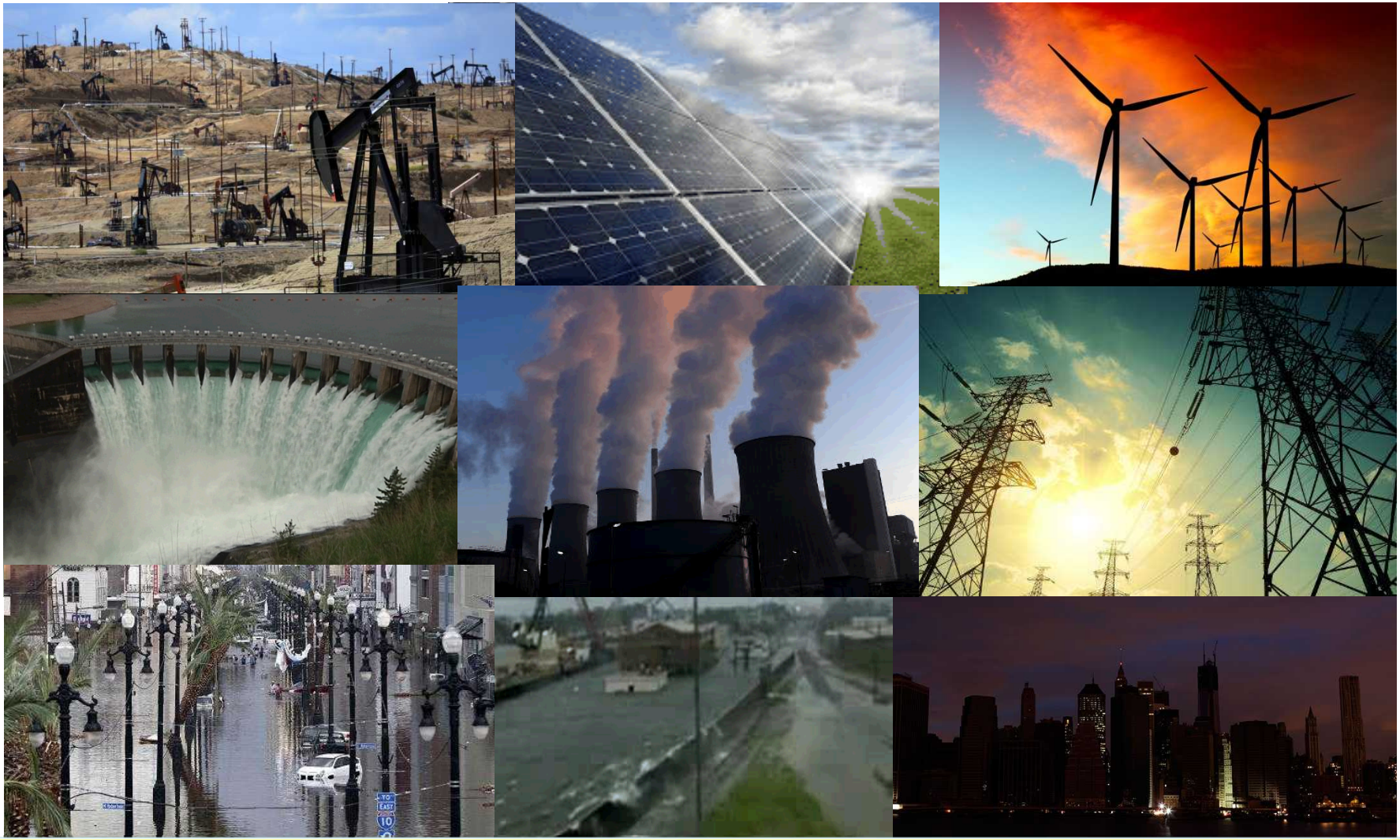
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Approved for Distribution D: Distribution authorized to the Department of Defense and U.S. DoD Contractors only (Administrative or Operational Use). Other requests shall be referred to USMC E2O, Pentagon, Washington, DC.

AGENDA

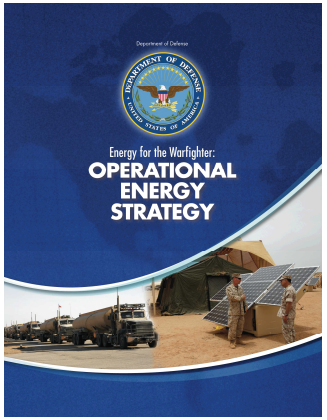
- Motivation for Microgrids
- USMC MDT Project Overview
  - Background, Objectives, MDT Improvements, Deliverables
- Introduction to the Microgrid Design Toolkit (MDT)
- Use Case Example
- Next Steps and New Opportunities for MDT
- MDT Demonstration
  - Basic Capabilities
  - Advanced Capability Demonstration
- Questions and Feedback

Motivation for Microgrids



Complex Trades to Create Energy Resilient Systems

Department of Defense (DOD)'s Operational Energy Strategy



- More fight, less fuel: reduce the demand for energy in military operations
- More options, less risk: expand and secure the supply of energy to military operations
- More capability, less cost: build energy security into the future force

Reducing Battlefield Fuel Use = Saving Lives

More Soldiers Died In Iraq Delivering Fuel than in Combat Operations

From Microgrid Concept to Design

Sandia's Microgrid Design Tool (MDT) can assist users in taking a microgrid concept to a more detailed, optimal design.

MDT is a decision support software tool for microgrid designers.

The software employs powerful search algorithms to identify and characterize the trade space of alternative design decisions in terms of user defined objectives

Once the trade space has been characterized, the software provides many views and features to help explore that trade space to extract information

MDT is an Innovative Capability

MDT has the ability to simultaneously do the following:

- Perform topology optimization
- Perform optimal asset selection
- Account for power and component reliability
- Account for dozens of user-specified metrics when performing the trade space search

As a result, MDT is able to present a user with:

- An entire trade space of information from which to draw conclusions
- Large amounts of performance information generated by the simulation for each solution set

It's the combination of these capabilities that sets MDT apart from other tools

USMC MDT PROJECT OVERVIEW

USMC-MDT Project Scope

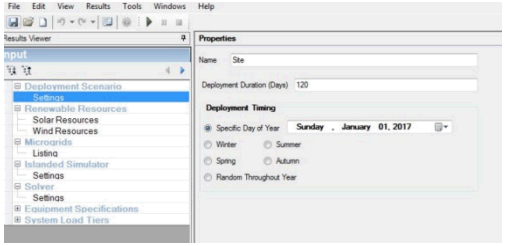
- Product Manager Expeditionary Power Systems (PdM EPS) of Marine Corps Systems Command (MARCORSYSCOM)
  - Responsible for all energy technology development, testing, systems integration and acquisitions for the Marine Corps
- Need: in-house analysis capability to help inform the USMC planning, requirements development and acquisition decision making processes about expeditionary energy technologies, including alternative energy technologies, microgrids, etc.
- Engaged Sandia National Labs to deliver an in-house USMC version of the Microgrid Design Toolkit (MDT)
  - Initial 12 month effort: POP March 2016 to February 2017
  - Follow-on support for model development, deployment/MDT-use and additional capability development: POP is TBD

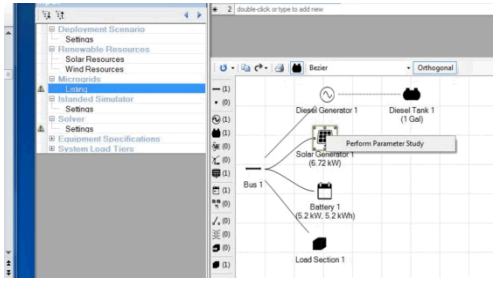
Project Goals

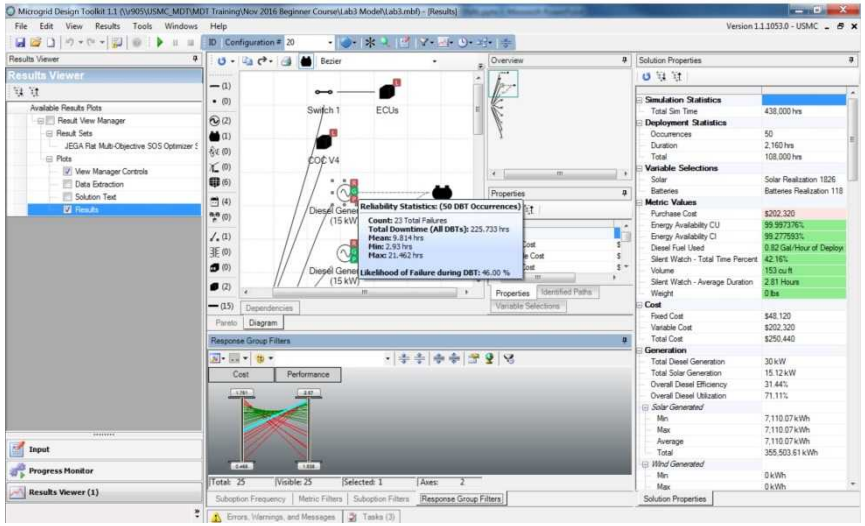
- Develop full set of custom MDT models to provide quantitative results that will answer MARCORSYSCOM EPS' key questions
  - Worked with EPS engineers to define the correct questions and identify what specific information is needed
- Leverage previous work, full scope of USMC models and information
  - Cost models, USMC HOMER models, others…
  - Sandia USMC-MDT models, MEB and MEU EDLs, Load profiles, …
- Add features to USMC-MDT as required
  - Improve user interface for novice users
  - Improve output results features
  - Improve battery modeling, cost modeling, solar modeling, load profiles
  - Parameter study capability
  - Results Roll-up– consolidate system technology counts across multiple models
  - Develop beginner and advanced training, quick start guide

MDT Capability Improvements

- User interface simplified for novice users
- Majority of specifications are from drag-drop diagram display
- Improved output displays of results including easy access to solution performance specifications
- Improved:
  - Cost modeling
  - Battery modeling
  - Results consolidation over multiple models
  - And more







MDT Improvements (cont)

- Complex Design Options
  - Allows one to define sets of coordinated decisions
  - Can be used to express “bulk” decision variables for MG design
  - Helps prevent optimizer from trying out nonsensical configurations
- Parametric Studies
  - Allows study of single grid asset or single complex design option over range of possible specifications (or realizations)
  - Results plots allow one to investigate metric trends over a set of possible MG designs (different generation sizes, topologies, etc.)
  - Can be used to extract sensitivity informatio.
- Advanced Output Features
  - Manual modification of solutions
  - Filtering on metrics and/or technologies
  - Coloring and Highlighting
  - Layout and Docking
  - Advanced saving and loading of results

USMC MDT Deliverables

- Completed USMC MDT capability – provides easy-to-use islanded microgrid design and analysis capability
- Deliver MDT on 2 Dell Laptops
- Deliver MDT on DVDs for USMC EPS use/distribution as desired
- 2 days of training 2/21 and 2/22, Day 1: Beginner, Day 2: Advanced
- 92 Baseline MEU and MEB models and corresponding load profiles
- 47 world-wide solar profile locations with USMC angle specifications
- USMC MDT Documentation
  - User's Manual
  - 10 comprehensive, hands-on instructional labs
  - Quick start guide

2-Day Training – Beginner Labs

Day 1 Beginner Training (Nadine)			
Lab #	Title / Description and notes	Mapping to User Questions	Author
Lab 1 (new)	Performance evaluation using MDT * This lab shows how to use MDT to evaluate the energy performance of a specific hybrid system to support a specified load over a defined duration. SET THIS MODEL UP FROM SCRATCH	Q3. How much fuel is required for a specific hybrid system to support a specified load profile over a defined duration?	Nadine
Lab 2 (new)	MDT Basic Use - starts with simple design options, then shows user how to do a simple design option modification within a complex design option * This lab will be based on ***Use Case example*** , section 2 where MDT finds optimal generator choice. This will break up previous Lab 1 into 2 labs. (note: Use case section 3 shows how to add failure modes -- good to include this in lab 1?)	Q1. Given known power requirements, available assets, and mission duration, what is the optimal equipment mix to minimize (a) fuel consumption, (b) volume, (c) weight, (d) other --> maximize energy availability? (This example shows how simple design options of choosing optimal generator type -- this could be used to answer Q1 correct?)	Nadine
Lab 3 (old lab 1)	Finding Optimal Solutions and Exploring Results * note: this lab was too long -- but should be reduced by adding lab 1 & 2	Q2. Given: known power requirements, and mission duration for employment of the system (MEHPS as an example), what system configuration is the (a) lightest (fewest batteries), (b) most fuel efficient configuration … Q5: constraining either system cost, weight, volume or fuel consumption, what is the optimial hybrid system configuration (system efficiencies/losses user selectable??) (setting limits and constraints, also slider GUI to constrain metrics)	Nadine
Lab 4 (old 2)	Silent Watch Lab - Impact of more decision variables - as applied to MEHPS (not unit level)		Chris
Lab 5	What is the impact of regional weather variation on hybrid performance? a. set up hybrid energy example in one location (make sure (a), (b) are addressed in lab pareto and results exploration) b. excursion: change location (right now we change location and season and that makes it hard to understand changes in results - simplify lab to only change location and understand results)	Q4. Given: known power requirements, available assets, mission duration, and mission location, what is the effect of regional weather variation on hybrid performance? How does this change over the total timespan of the operation?	Chris

2-Day Training – Advanced Labs

Day 2 Advanced Training (JOHN)			
Lab 6	Creating complex design options - start from existing lab that only has simple design options (starting from same model as lab 2) - adding redundant connectivity to some asset	Q7. Given known deployment scenarios such as mission duration, location, power demand profile, volume, weight and power reliability constraints, what is the optimal system to satisfy the requirement. Optimal would be defined as (select one) fuel efficiency, lightest, or smallest volume.	Chris
Lab 7	Parametric Study Capability (based on Lab 3 model)	Q8. How is the Hybrid system performance affected by (a) reduced batter capacity – perhaps 80% of new (b) reduce solar performance – 60% of new. The answer to this question would help Project Officers	Elizabeth
Lab 8 (instructional)	Advance Control Options 1 – Islanded simulator settings 2 – Solver settings 3 - Results viewer toolbar 4 - Grid settings and refueling settings 5 - Spinning Reserve 6 - Reliability (Intrinsic and Locational) 7 - Hard limits 8 - Filtering of Input Grids 9 - Errors, Warning and Messages		John
Lab 9 (instructional)	How to Manually Modify operation of modeled MEHPS (refer back to model used in Lab 3)	Q9. Given a specific hybrid system configuration, what is the effect on system performance from a change to the system's control logic ? Example: changing the battery charge dispatch logic to shut off the generator at 95% SOC vice 90% or start the generator at 20% SOC vice 10% . In context of single MEHPS system w/specific load profile	John
Lab 10 (instructional)	Advanced Output Features: 1 - How to manually modify solutions 2 - Metric Filters 3 - Technology Filters 4 - Highlighting		John

INTRODUCTION TO MDT

Microgrid Design Toolkit (MDT) Description

MDT is a decision support software tool for microgrid designers

The software employs powerful search algorithms to identify and characterize the trade space of alternative design decisions in terms of user defined objectives

Once the trade space has been characterized, the software provides many views and features to help explore that trade space to extract information

MDT is an Innovative Capability

MDT has the ability to simultaneously do the following:

- Perform topology optimization
- Perform optimal asset selection
- Account for power and component reliability
- Account for dozens of user-specified metrics when performing the trade space search

As a result, MDT is able to present a user with:

- An entire trade space of information from which to draw conclusions
- Large amounts of performance information generated by the simulation for each solution set

It's the combination of these capabilities that sets MDT apart from other tools

Sandia MDT Capability

- MDT can provide energy performance, parametric and optimization analyses for power technology insertions, including hybrids, that assist in portfolio mix decisions
  - Helps answer questions such as: What is the right mix of microgrid assets for the best DCS kit? What is optimal amount of energy storage on a microgrid?
  - Employs an optimization algorithm (genetic algorithm) to identify the most efficient technology sets from the large set of potential solutions (e.g., $>10^{50}$ possible solutions)
  - Provides insights about **type of technologies** (e.g. battery storage size, PV type) that best satisfies a unit's power demands taking into account reliability, location and seasons
  - Provides insights into **quantity of each technology** required
  - Combined results over dozens of models helps decision makers determine **optimal portfolio of energy technologies**

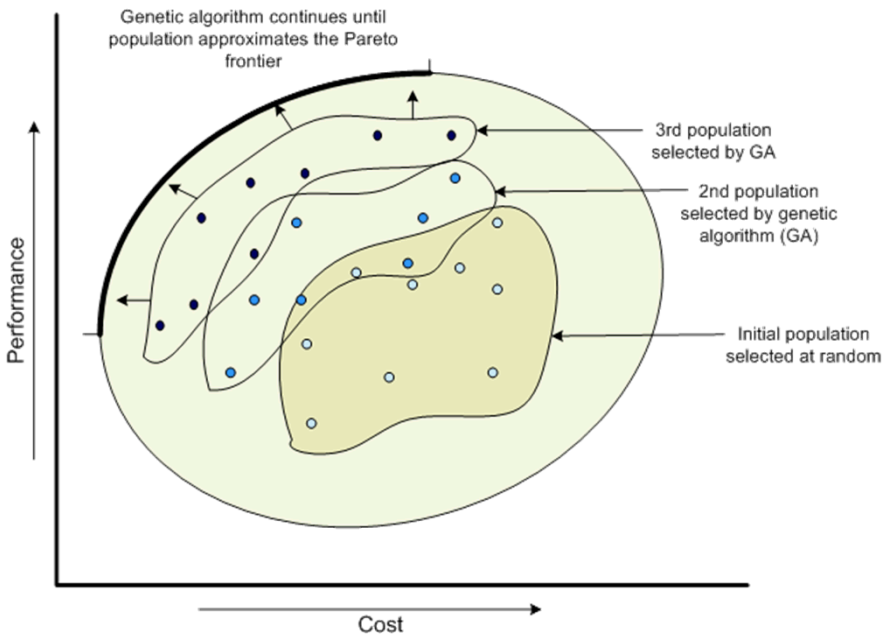
Sandia MDT Capability

Using the USMC-MDT, one can:

- Effectively search very large design spaces for efficient alternatives
- Investigate the simultaneous impacts of several design decisions
- Have defensible, quantitative evidence for decisions
- Gain a quantitative understanding of the trade-off relationships between design objectives (cost and performance for example) and alternate technical design decisions
- Gain an understanding of impacts of requirements on technology sets
- Perform what-if analysis to assist with requirements definitions, design decisions, etc.
- Perform hypothesis testing by manually generating solutions and comparing to the solutions found by the MDT

Microgrid Design Tool (MDT) Optimization

- Genetic Algorithm based optimization
- Constraints include some elasticity, and work toward goals while respecting limits
- Truly multi-objective optimization: site-specific targets and limits for all performance metrics and constraints
  - Critical load reliability (longevity)
  - Non-critical loads (service)
  - Environmental and budgetary constraints
- Design variables can include equipment selections and also operating modes
  - Environmental and budgetary constraints
  - Microgrid building selection and perimeter
  - Dependencies between selections



Microgrid Design Toolkit (MDT)

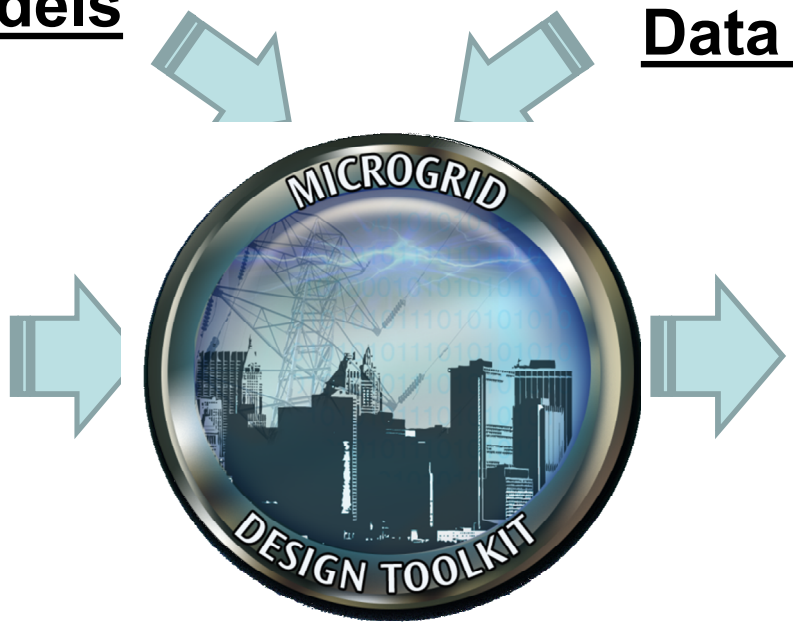
Optimization Modeling For Gaining Technology Insertion Insights

Sandia-developed Microgrid Design Toolkit (MDT) characterizes the trade-space and provides what-if analysis of design choices to provide quantitative insights to decision makers for Hybrid Energy Solutions

Baseline Models

Equipment Data Base

Technology Options and User Inputs



MDT Results

ITERATIONS to Refine Results

Microgrid Design Toolkit (MDT)

Optimization Modeling For Gaining Technology Insertion Insights

Sandia-developed Microgrid Design Toolkit (MDT) characterizes the trade-space and provides what-if analysis of design choices to provide quantitative insights to decision makers for hybrid energy solutions

Baseline Models

- Equipment deployed creates demand
- Or demand (load) models
- Or custom load models

Equipment Data Base

- Energy demand/production
- Usage specification
- Reliability information

Technology Options and User Inputs

- Identify energy producers and technology insertion options
- Select location and season (solar and/or wind profile)
- Reliability/maintenance data
- Select user mode
  - Performance analysis
  - Parametric study
  - Optimization

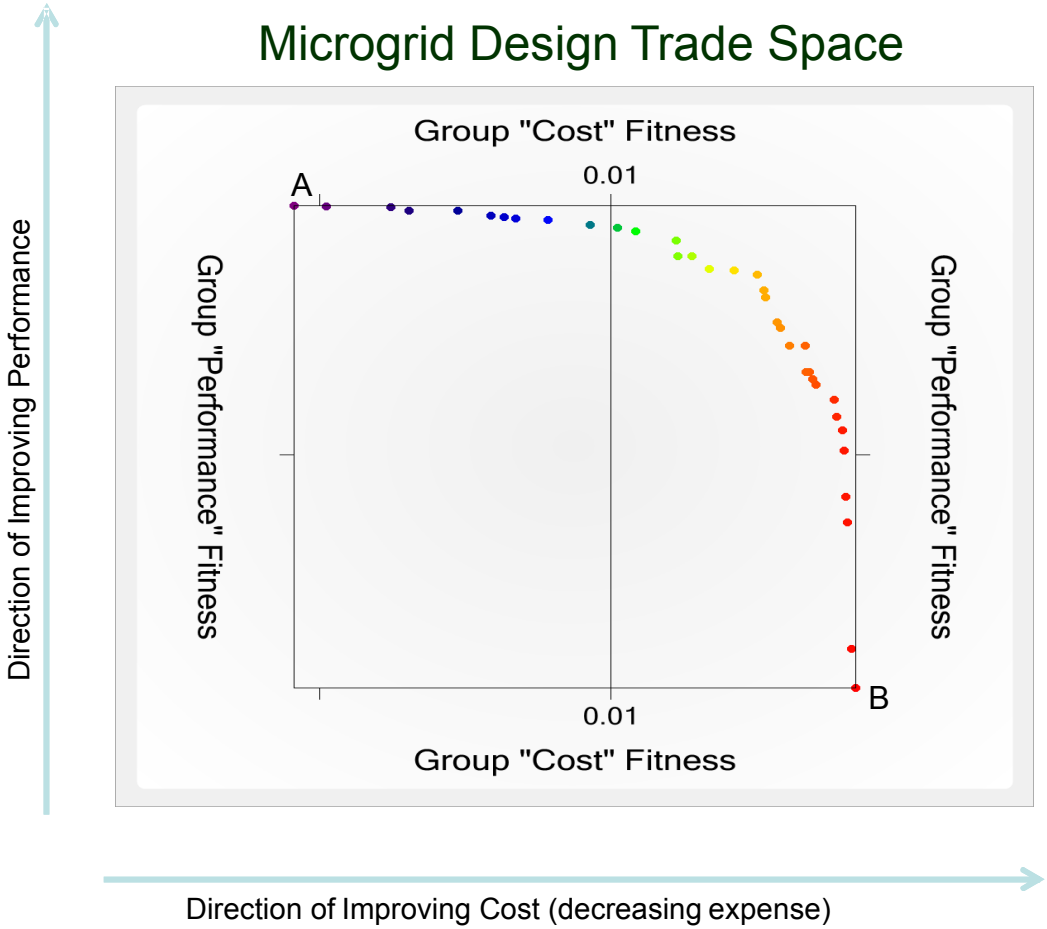
ITERATIONS to Refine Results

MDT Results

- Energy performance
  - Energy availability, cost, fuel used, volume, silent watch, gen utilization
- Parametric sweep results
- Optimal and feasible solution sets
  - Generator types/counts
  - PV type/amount
  - Battery type/quantity

Microgrid Design Toolkit (MDT) Provides Pareto of Feasible Solutions

Microgrid Design Trade Space



Each point represents a feasible, unique microgrid design that meets objectives

Point “A”: highest cost, highest performing
Point “B”: lowest cost, lowest performing

Given any point on the chart, no improvement in cost can be made without corresponding decrease in performance and visa versa

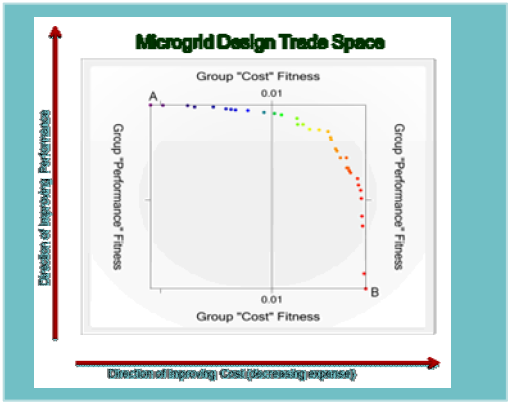
This chart shows two user-defined objective dimensions, cost and performance. MDT supports up to 5 dimensions

Objective dimensions made up of user selected metrics

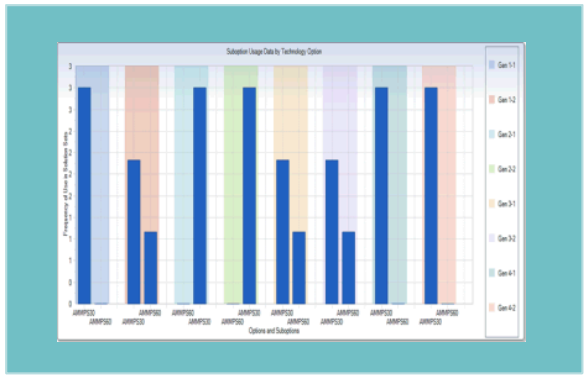
Additional MDT output results views help users investigate the complete solution set.

MDT produces set of feasible solutions that represent efficient trade-offs amongst design objectives and requirements

More on MDT Optimization Results and Impacts



Type of technologies (e.g. solar size and efficiency, size and type of battery storage, microgrids) that best satisfy the defined power demand and conditions



Quantity of technologies (e.g. # solar panels, amount of battery storage) that best meet the deployment power demands

Combined Results → Help to inform decision makers about optimal energy portfolios

Use Case Pareto of Feasible Results

- All solutions shown in Pareto frontier; filter to show feasible solutions
- Examine progression of solutions with 10kW AMMPS generator
  - Starts with best "Cost" fitness solution, then adding technology to increase performance

2 10kW AMMPS gens + 4 cases Adv solar + 6 batt packs

4 Cases Advanced solar + 6 batt packs + gen

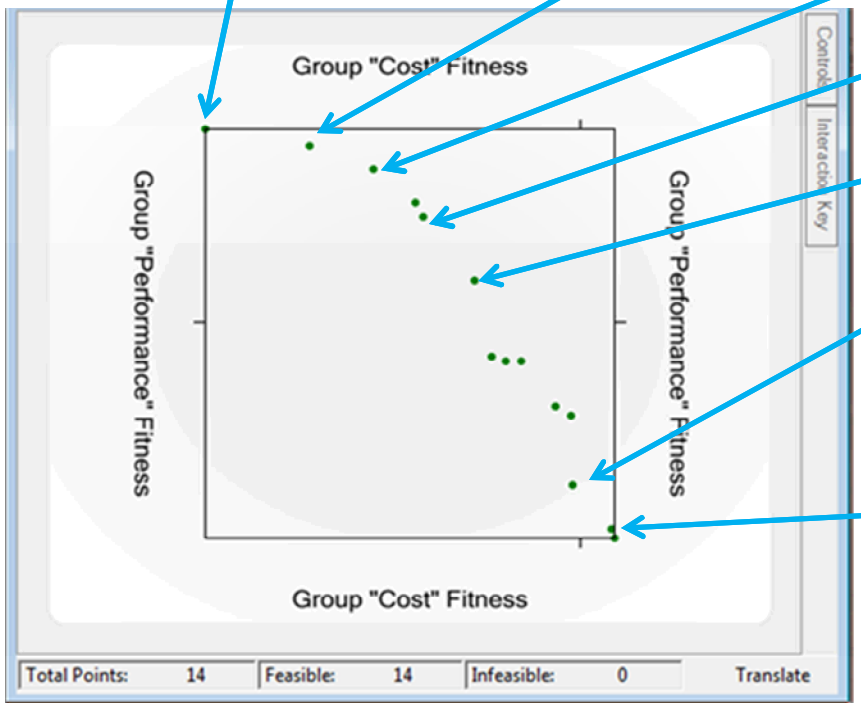
4 Cases Con solar + 6 batt packs + gen

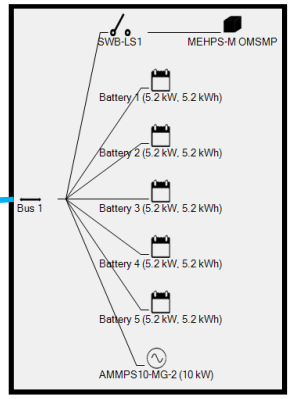
3 Cases Con solar + 6 batt packs + gen

2 Cases Conventional solar + 6 Batt 4-packs + Gen

6 Battery 4-packs + Gen

Higher Performance





1 10kW AMMPS Gen, +5 Battery 4-packs

Key Findings of MDT Results

- Baseline case gives high energy availability but with different fuel consumption and generator utilization because of seasonal load profiles
  - Fuel: 648 gallons in Spring/Fall, 1490 gallons in Summer, and 1824 gallons in Winter
  - Average Generator Utilization: 20% in Spring/Fall, 50% in Summer, and 57% in Winter
  - Redundant 10kW gens gives at least 99.99% energy availability in each case
- Adding MEHPS reduces fuel consumption with large reductions for spring/fall and more modest reductions for summer and winter
- Silent watch (SW) requirement observations
  - MEHPS-M most often needs more than 31.2kWh (6 * 5.2kWh) of battery storage to meet the 3 hour silent watch continuous requirement
  - SW varies with season and equivalent of at least 20 GREENS batteries required in summer and winter to meet SW
- Most solutions utilize one generator microgrided to hybrids. 2 gen solutions provide slight energy avail improvement, but at a higher cost

MDT quantifies how microgriding generators with hybrids ↓fuel use, ↓ generator counts, ↓ costs while ↑energy availability and ↑generator utilization

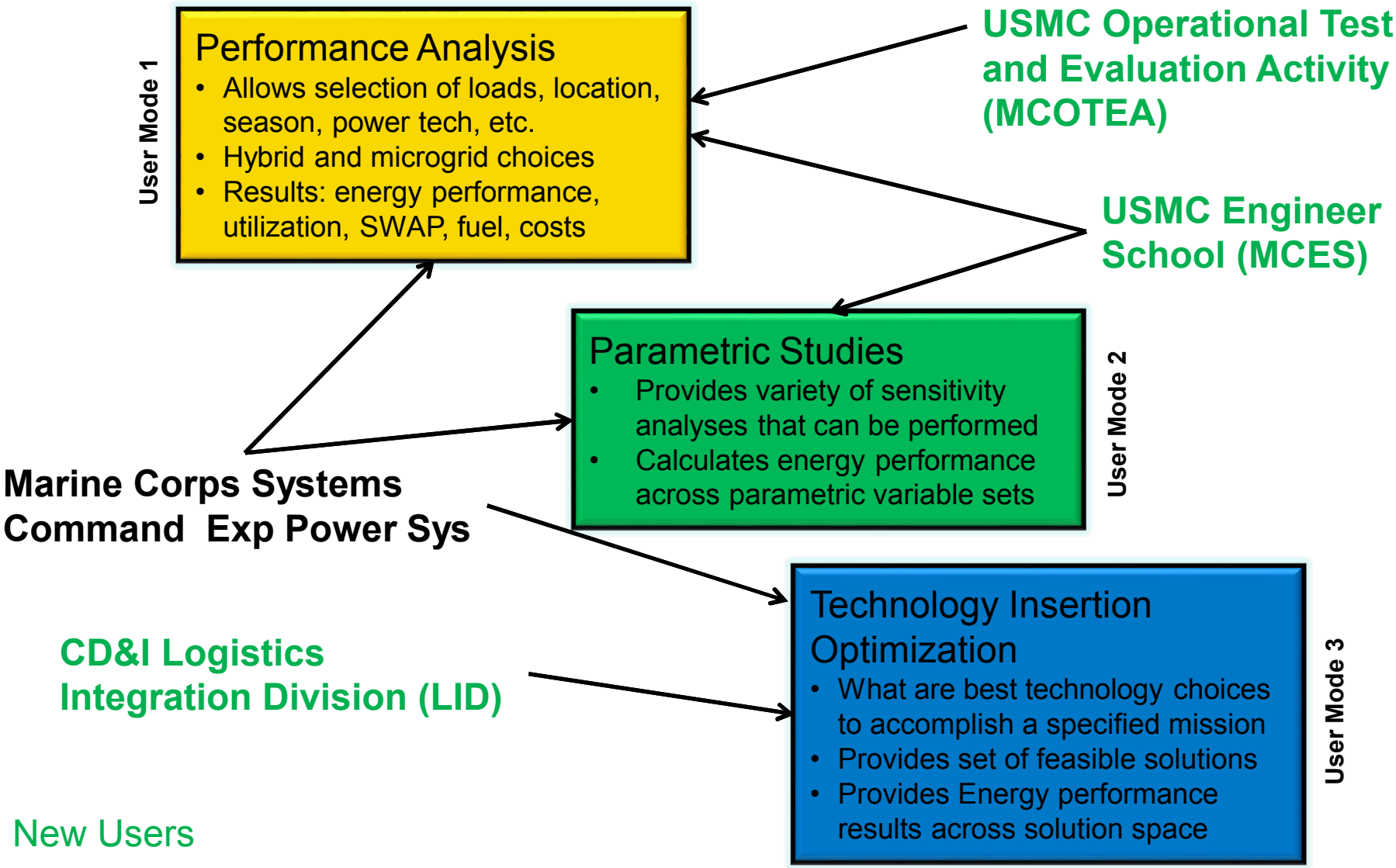
Discussion

- MDT assists with energy technology selection and technology roadmap insights based on loads, requirements, location, weather and requirements
- In the “optimization mode”, MDT produces a Pareto frontier of tech configurations which can be examined to obtain solutions that best fulfill constraints
  - Insights are limited if only a small set of “ideal” solutions are examined
  - Note: MDT also has a “performance evaluation” mode where energy performance of one solution is evaluated
- In this way, MDT helps characterize the trade-space and can assist with requirements definitions and acquisition decisions

Demonstration of Advanced features

NEXT STEPS AND NEW OPPORTUNITIES FOR MDT

Several USMC Divisions Have Interest in Using USMC-MDT Capability



New Users

High Potential for New/Expanded DOD/DOE Use of MDT

- DoD Army Environment, Energy Security, Sustainability (E2S2)
  - Brief/training demo to be given to S&T Coordinator
- Navy Program Manager Fuel, Power, Water
  - Attended Nov. USMC MDT training, on-going discussions re: Navy use of MDT
- DOE/Office of Electricity, Dan Ton
  - Resilient city/community energy program for domestic and international use
  - MDT will be a key element of the robust and repeatable methodology to be developed, in conjunction with the Energy Surety Design Methodology (ESDM)
  - Pilot (high probability): MDT designs for NOLA and Norfolk (already assessed w/ESDM)
- DOD/OSD Operational Energy and Installation Energy offices want to have a DoD deployable capability for resilient mobile and fixed installations of which MDT will be a key component
- DOD-DOE High Potential for New Collaboration under the MOU
  - In conjunction with other national lab partners (PNNL, INL, NREL), MDT will be part of an overall capability development effort being proposed to enhance national energy security through resilient microgrid designs and the use of renewable energy

Spectrum of Potential Uses for MDT

Small Power

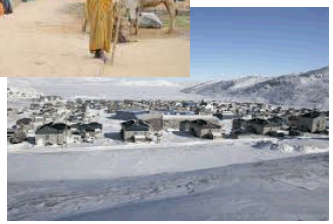
Big Power

Soldier as a microgrid

UAVs as microgrids

Gliders as microgrids 24-hrs Aloft – Navy proposal

Military Bases



Village power

City Power

Towards 100% Clean Resilient US Energy