Hybrid Power Generation for Improved Fuel Efficiency and Performance

Electrical Energy Storage Applications and Technologies (EESAT)

October 11th, 2017

Outline

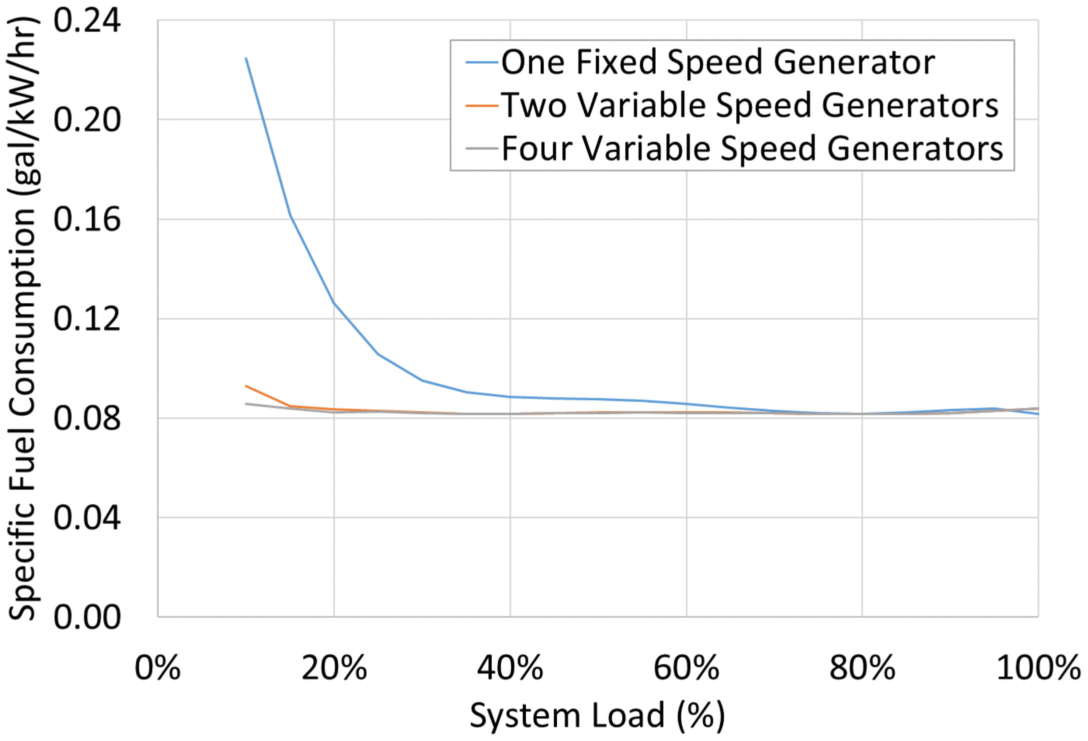
- Project Background and Introduction
- Preliminary Analyses
- Energy Storage Requirements and Technology
- Detailed Design
- Testing
- Conclusions

Project Background and Introduction

- Fuel cost is the largest single contributor to lifecycle cost in island power/prime power scenarios.
  - 1 MW unit may use 400,000+ gallons of fuel per year under typical usage.
  - $2,000,000/year in fuel alone @ $5/gallon delivered cost.
- For military applications, fuel delivery also comes with a risk of loss of life.
  - ~250 casualties in FY2007 from 6,000 fuel convoys.
- Any reduction in fuel consumption translates directly to reduction in operating cost, as well as reduction in risk of casualties in military applications.
- Conventional diesel generators have good fuel efficiency at higher loads.
  - However, specific fuel consumption increases for loads <40%.
- While it is not desired, generators may operate a significant amount of time at low load.
  - Particularly in smaller installations or for critical operations where power reliability requirements demand a significant amount of spinning reserve.
- Key project goal:
  - Significantly improve specific fuel consumption over conventional diesel generators at lower loads while maintaining efficiency similar to conventional diesel generators at higher loads.

Preliminary Analyses

- System level design and analysis was performed prior to detailed engineering to define the optimum system architecture. Four key design attributes were considered:
  1. Fixed vs. variable speed prime mover
  2. Permanent magnet vs. synchronous generator
  3. Number of engine-generator sets
  4. Energy storage
- Based on this analysis, the selected architecture contains:
  - Two 450 kW variable speed diesel engines
  - Each running a Permanent Magnet Generator
  - A minimum of 450 kW/15 kWh of energy storage
- The architecture is extensible from one to many engine-generator units and also supports renewable energy input for further fuel consumption reduction.



Energy Storage Requirements

- The requirements for the energy storage system were set based on two transient response scenarios:
  1. Engine speed and load change from idle/no load to max speed/max load.
  2. Bringing one engine-generator online due to load increase.

Scenario 1:

450 kW (max engine power) for 10 seconds – 1.25 kWh

Scenario 2:

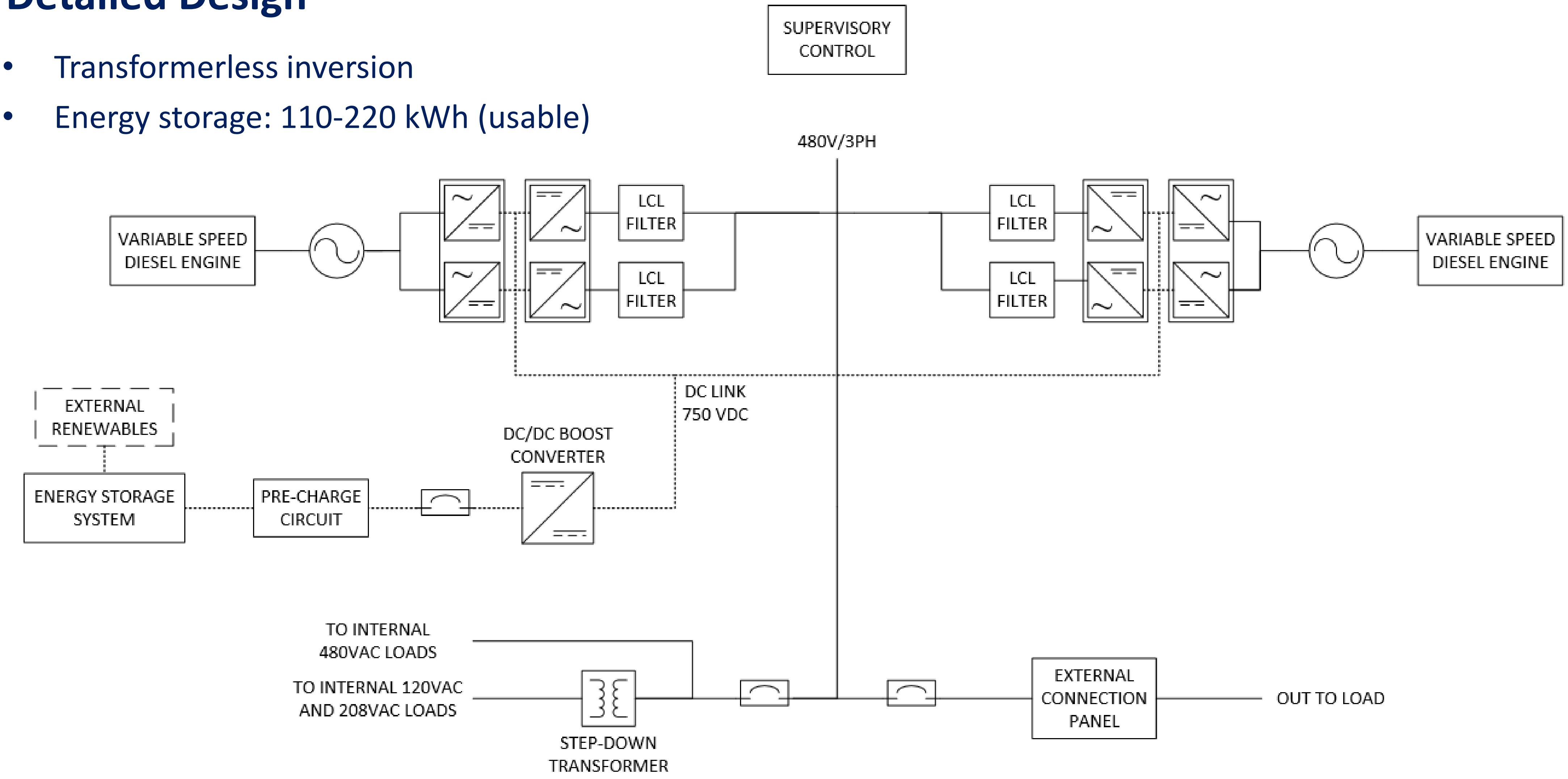
450 kW (max engine power) for 30 to 120 seconds – 3.75 kWh to 15 kWh

Energy Storage Technology

- Ultracapacitors were determined to not economically feasible for the energy level required.
- Lithium chemistries were deemed most suitable. These must be sized for power, resulting in excess energy capacity for these scenarios.
  - This can provide other benefits, such as “silent hours” operation.
- Three chemistries were considered:
  - Lithium Titanate (LTO)
  - Lithium Nickel Manganese Cobalt Oxide (NMC)
  - Lithium Iron Phosphate (LiFePO4)
- LTO was eliminated due to the high cost premium compared to the others.
- Lithium NMC and Lithium Iron Phosphate have similar performance characteristics at similar costs.
  - LiFePO4 was selected for this application based on commercial factors.

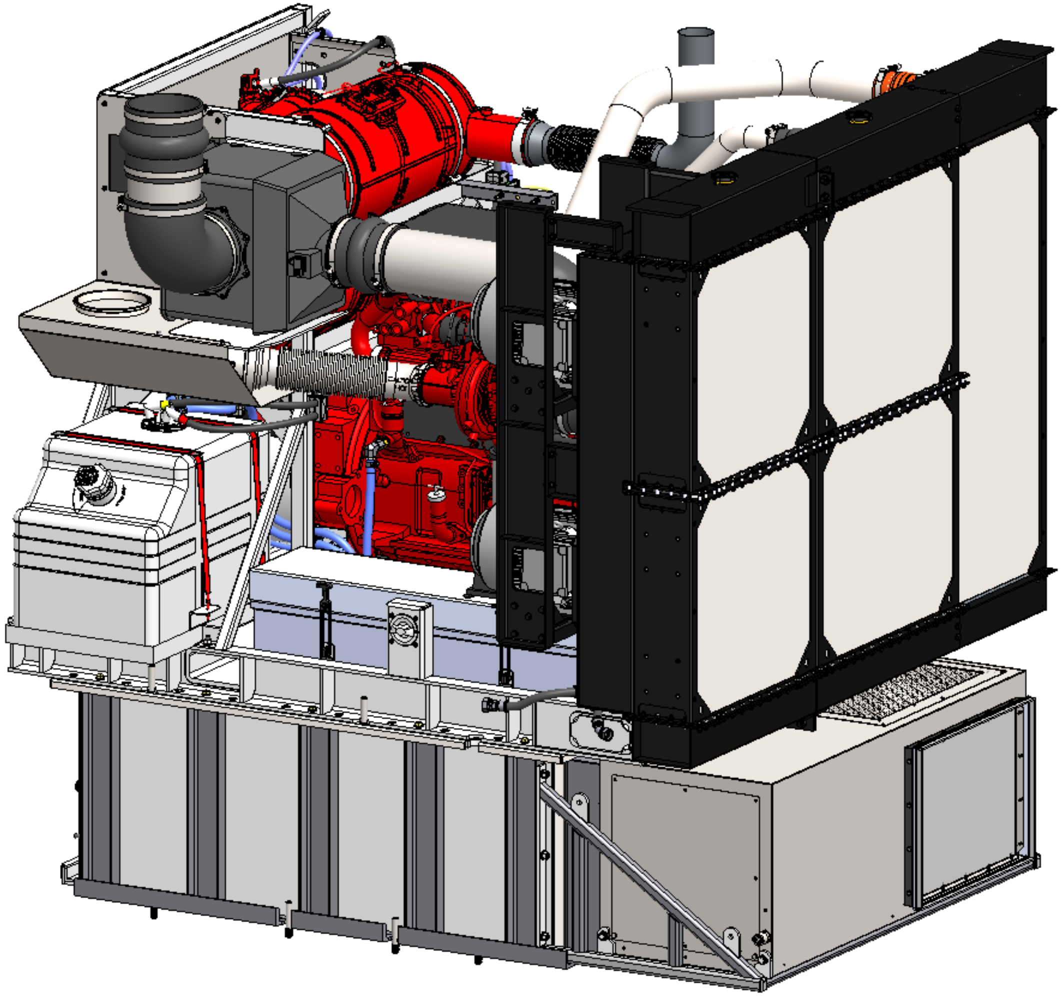
Detailed Design

- Transformerless inversion
- Energy storage: 110-220 kWh (usable)



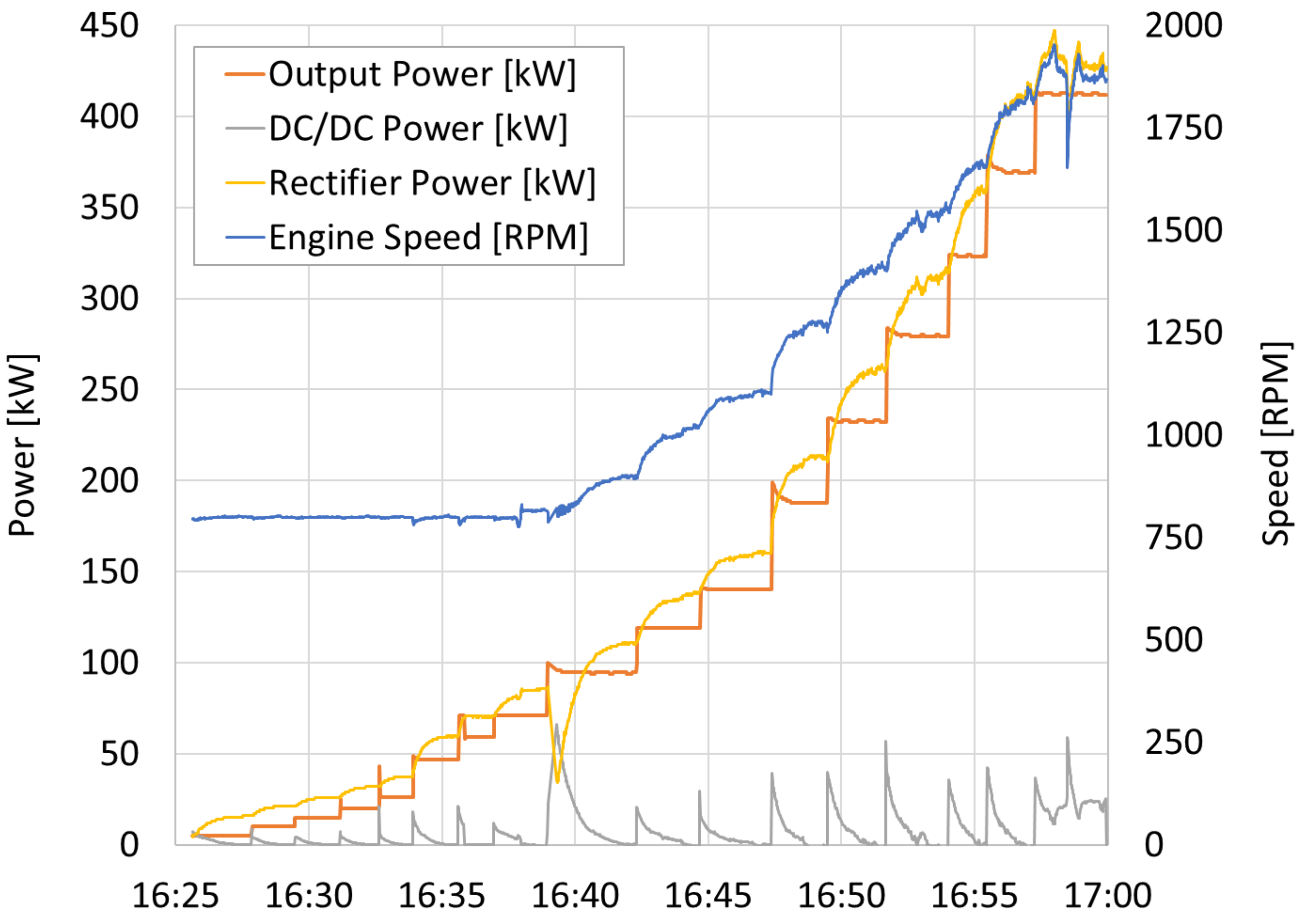
Detailed Design

- Power Module contains:
  - One Tier 4 Final 450kW variable speed diesel engine and Permanent Magnet Generator
  - One Energy Storage Module
  - Related subsystems (e.g. cooling)
- Designed for regular/minor service to be performed in situ.
- Entire module can be removed from structure for major overhauls.



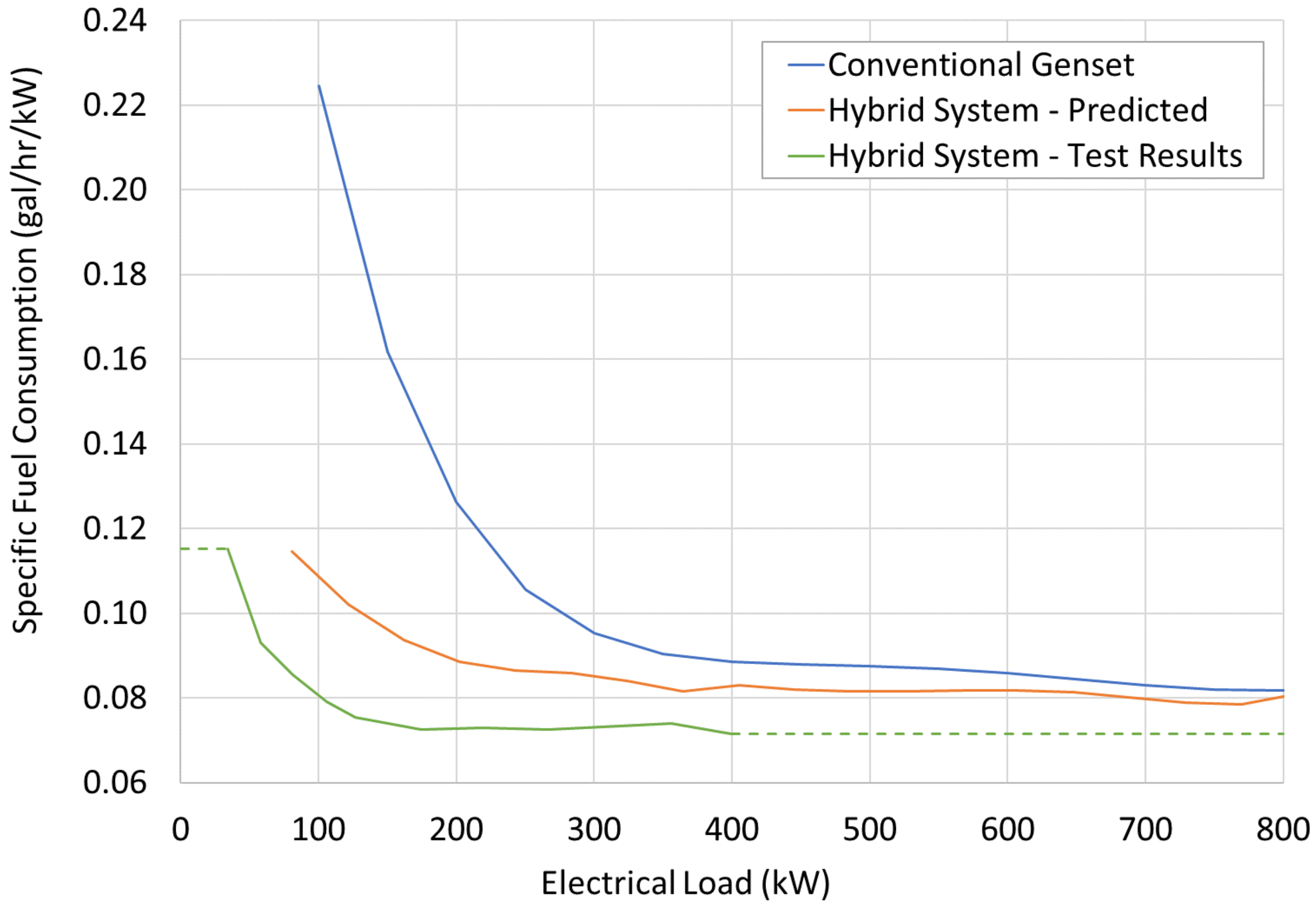
Testing

- A number of test have been performed to determine performance of the system.
- On right are results from a power ramp up to full load.
- Energy storage provides load response.
- Variable speed engine responds on a slower timescale.
- Engine speed vs. load operating line is configured to optimize fuel efficiency.



Testing

- Fuel consumption was measured during testing and results were very encouraging.
- >60% reduction in fuel consumption at 100 kW.
- >40% reduction in fuel consumption at 200 kW.
- Results exceed preliminary estimates, primarily due to:
    - Lower engine BSFC than originally estimated
    - Lower parasitic internal loads than originally estimated
    - Higher PMG efficiency than originally estimated



Conclusions

- The key project goal has been achieved with this hybrid power generation architecture:
  - "Significantly improve specific fuel consumption over conventional diesel generators at lower loads…"
    - ✓ Successfully demonstrated
  - "…while maintaining efficiency similar to conventional diesel generators at higher loads."
    - ✓ Successfully demonstrated
- Under typical prime power usage, this is anticipated to provide a 35% overall reduction in fuel consumption, reducing yearly fuel cost from $2,000,000 to $1,300,000 per year @ $5/gallon delivered cost.
- There is further testing to be performed, particularly:
  - Testing with two or more engine-generators
  - Endurance testing
  - Cold/hot weather testing