Power Management for Heavy Tactical Vehicles

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Penn State ARL

Penn State University
Applied Research Lab

- Established by U.S. Navy in 1945
- Designated a University Affiliated Research Center (UARC) in 1988
- Largest research unit within PSU with more than 1,200 faculty and staff
- Approximately $150M in research funding in FY2008
- Role: serve as trusted agent for DoD
- Mission: Research, Tech Transfer, Education
- University Resources: College of Engineering, PA Transportation Institute, Materials Research Lab

Penn State ARL

ARL is primarily a science and technology-based laboratory with leadership in the following core competencies:

- Acoustics
- Guidance and control
- Power / energy systems
- Hydrodynamics, hydroacoustics, propulsor design
- Materials and manufacturing
- Navigation and GPS
- Communications and information
- Systems Engineering
- Graduate education

Power System "Needs" for Heavy Tactical Vehicles

- Improved reliability – power whenever it's needed
- More power available during 'normal operation' – i.e., power for air conditioning, C4ISR, CREW, IED countermeasures, lighting
- More power / longer operation during 'silent watch'
- Reliable engine starting
- Reduced logistics burden
- Lower lifecycle costs
- Simplified maintenance and diagnostics

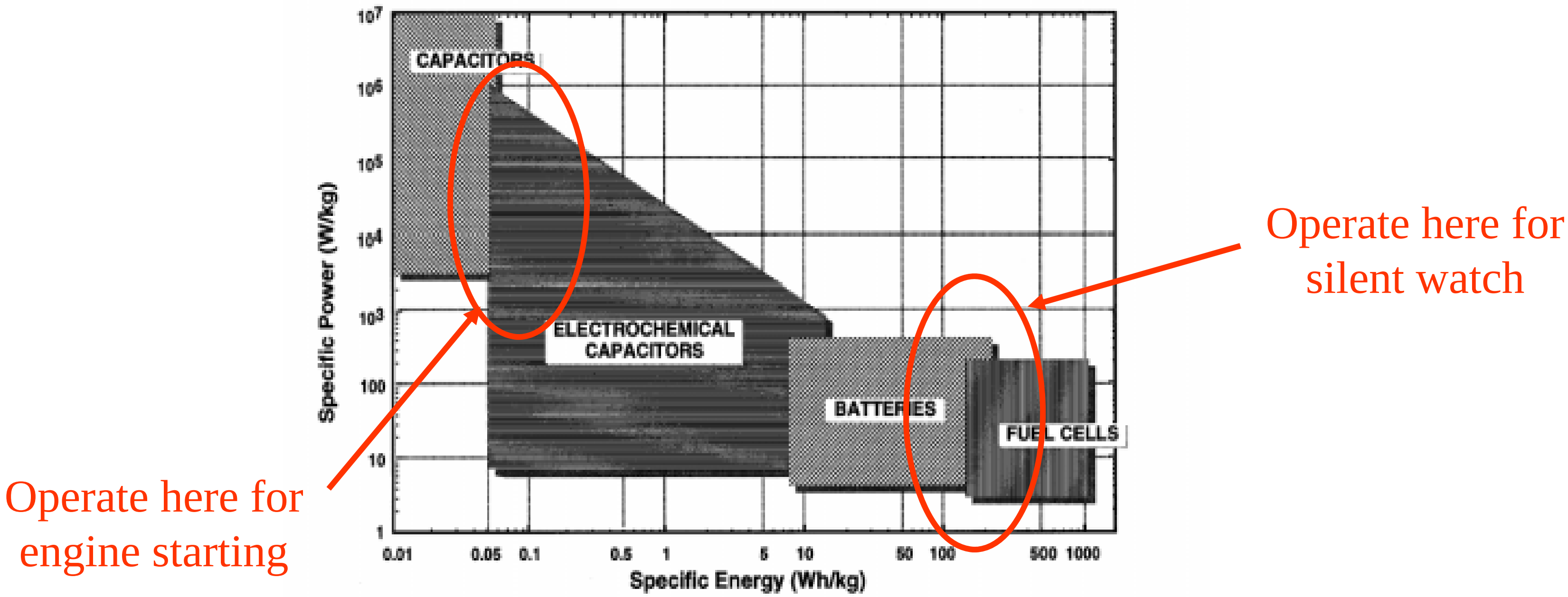
Battery graveyard in Kuwait

Primary Power Management System (PPMS)

- Common vehicle power & energy architecture
- Configurable for specific missions
- Split energy storage system
  - Ultracapacitor for vehicle starting
  - Deep cycle batteries for silent watch
- Hydraulically-driven generator for high power drive & accessory loads
- Planetary Gear Starter
- Integrated power management & control
- Integrated CBM+
- VCS monitoring and control

Split Energy Storage System Design Benefits

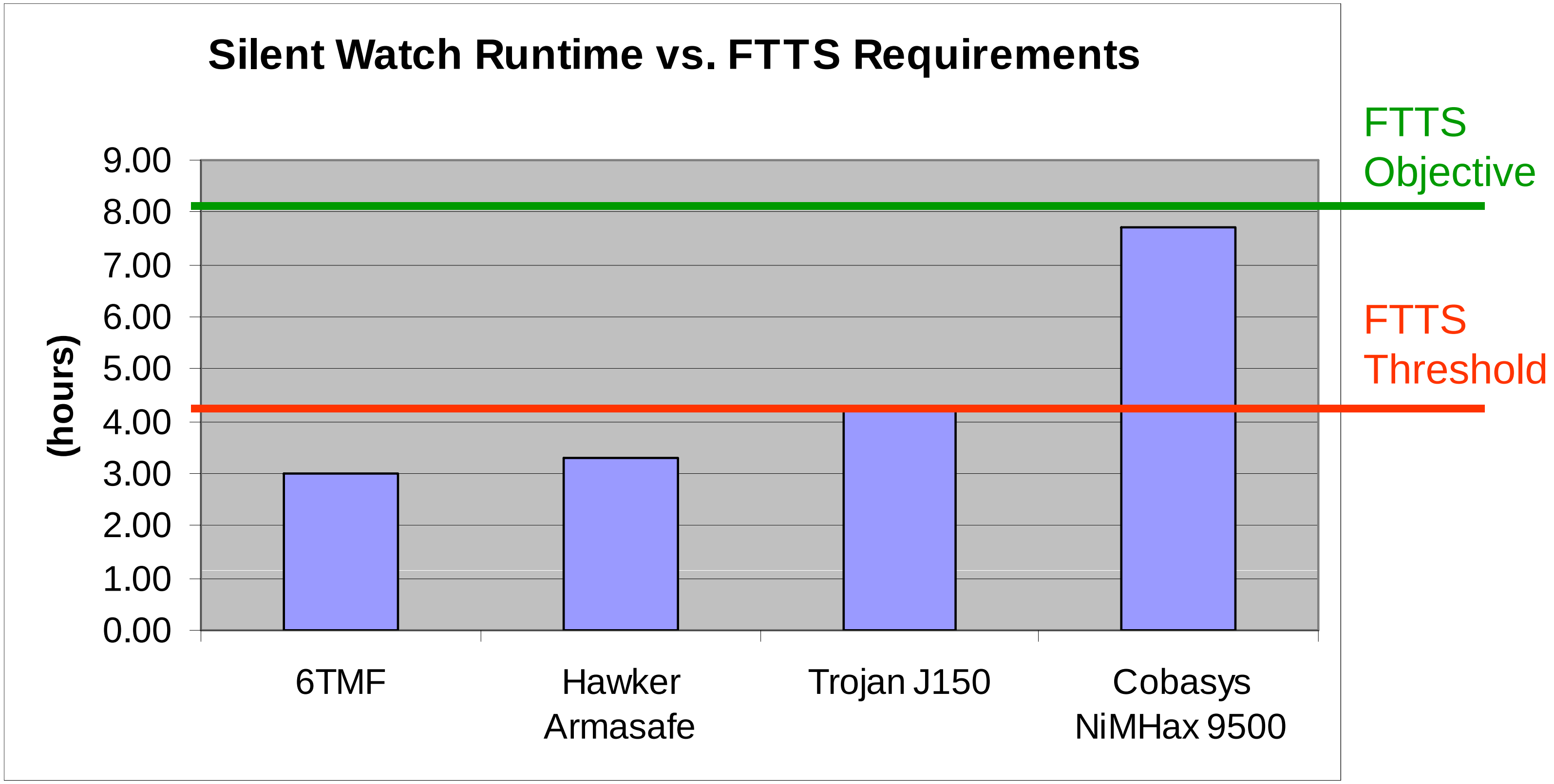
- Separate the two different power requirements
  - High power for engine starting (more CCAs)
  - High energy for silent watch (deep cycle application)
- No battery exists that can be optimized for both functions
  - Use appropriate technology for each requirement



Split Energy Storage System Design Benefits

- Utilize ultracapacitors for engine starting
  - Ultracaps rated for 100K's of cycles
  - More reliable starting than batteries (even w/ battery monitoring)
- Use the appropriate battery technology for specific silent watch requirements
  - One vehicle configuration regardless of battery chemistry
  - Lead acid => inexpensive, sufficient energy for most missions
  - Li Ion, NiMH => for missions that require longer or higher power silent watch
  - Could integrate fuel cells as they become available in future

Energy Storage for Silent Watch



Silent watch runtime estimates based on 60A loading @ 24VDC, with battery pack of equivalent size/weight to that of (4) 6TMF batteries

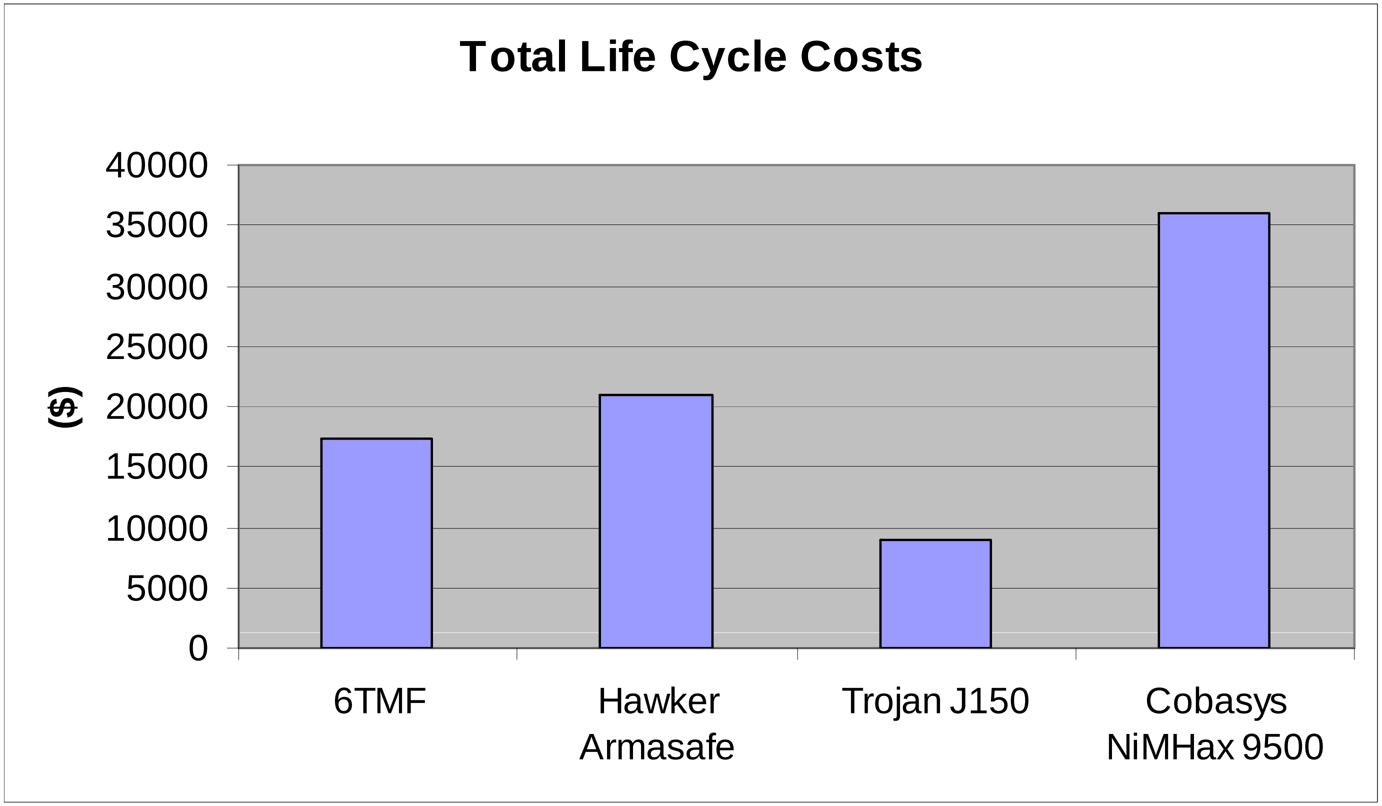
6TMF

Hawker Armasafe

Trojan Lead Acid Deep Cycle Battery

CobaSys NiMHax 9500

Energy Storage for Silent Watch



Lifecycle costs based on 25 year vehicle lifetime with two high intensity conflicts and 6000 charge/discharge cycles.

6TMF

Hawker Armasafe

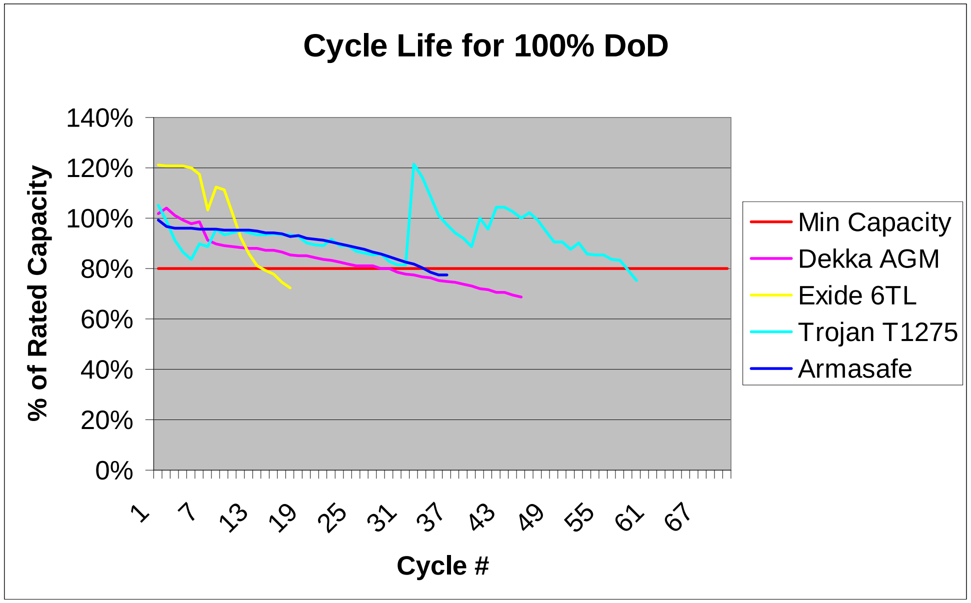
Trojan Lead Acid Deep Cycle Battery

CobaSys NiMHax 9500

Deep Cycle Battery Testing

Battery test station

- 4 electronic load banks and power supplies
- LabVIEW software-controlled
- Run 4 independent load profiles simultaneously
- Equipped with a freezer and high temp chamber for testing at environmental extremes

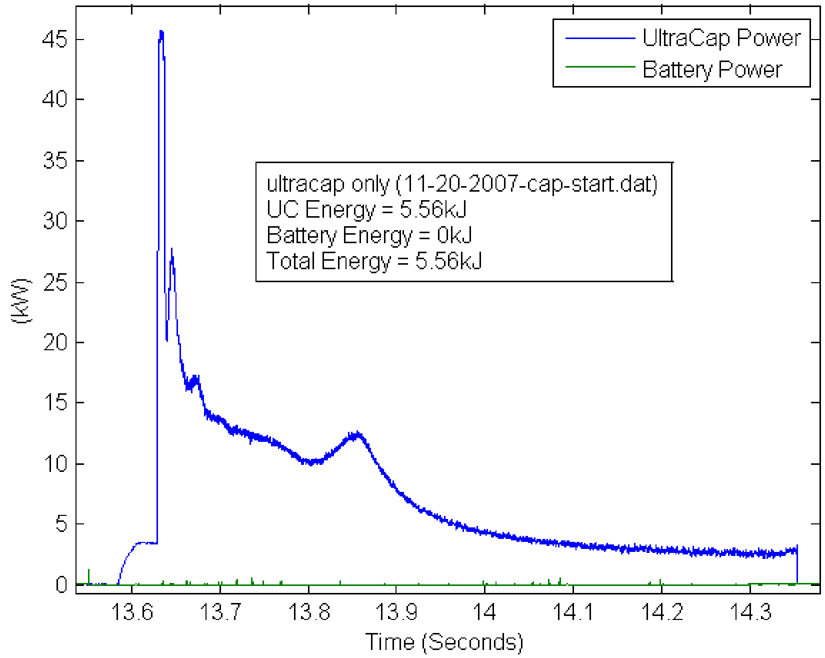


Purpose

- Test and characterize silent watch run-time under different operating conditions
- Characterize battery lifetime (lifecycle costs) based on operating cycles

Currently cycling 6T-style flooded lead acid batteries from Axion Power

Energy Storage for Engine Starting



ESMA 28V Ultracap (provided by KBI)

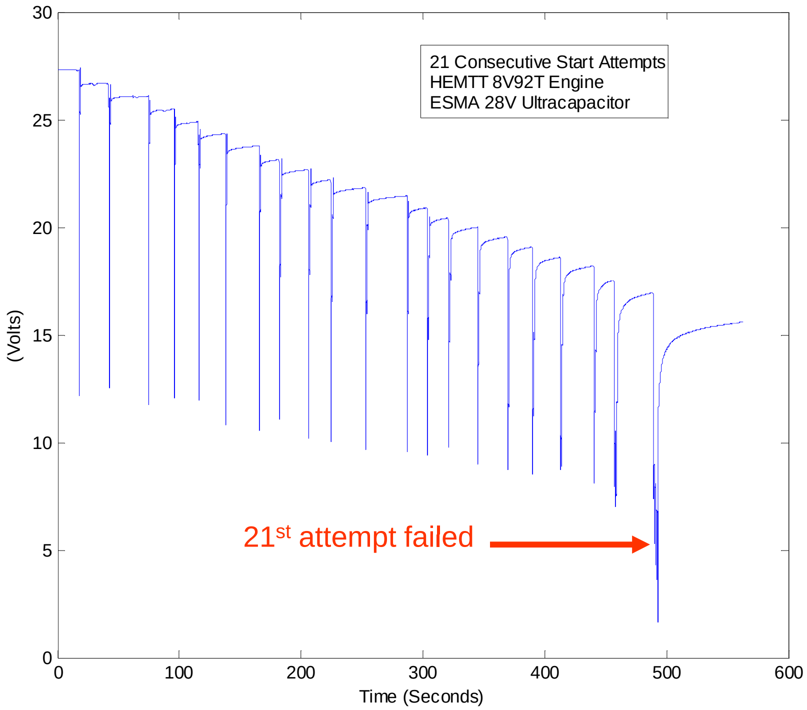
- Peak power plotted comparable or better than that of four 6T lead acid batteries
- Less affected by low temp's (compared to batteries)
- Easy to accurately measure ultracap SOC
- Ability to recharge rapidly

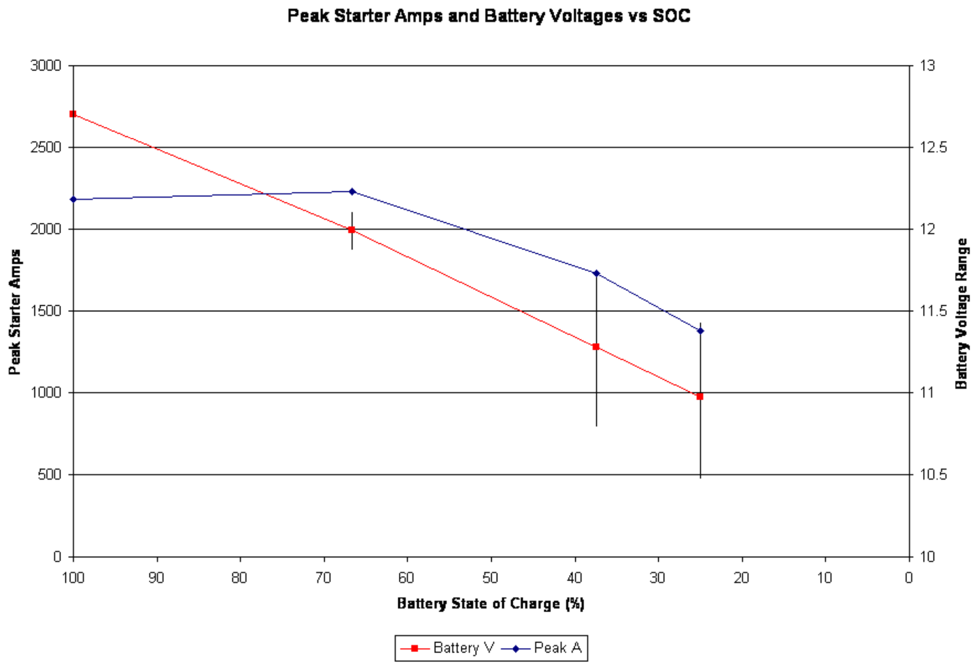
Energy for Engine Start … some numbers

- Energy required to crank 8V92T @ 50^{o}F ~ 6KJ
- Energy stored in ESMA 28V Ultracap ~ 120KJ
- Energy stored in Hawker Armasafe 4-pack ~ 17,300KJ
- An engine crank @ 50^{o}F requires:
  - 5.0% of total energy in ESMA ultracap
  - 0.035% of the total energy in Hawker 4-pack

- **Question:** If stored energy is > 6KJ, will vehicle start?
- **Answer:** Yes, if sufficient power can be delivered

Energy for Engine Start





Ultracapacitor

- ESMA Cap ~ 120KJ
- Energy to start ~ 6KJ
- Per energy calcs, should get ~ 20 starts

Batteries

- Battery's ability to deliver power decreases with SOC
- Also affected by age/health

Energy for Engine Start

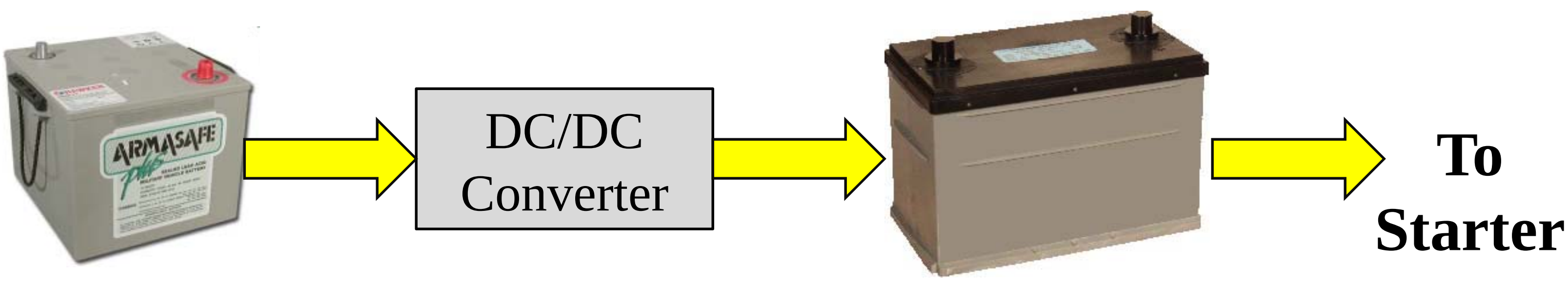
Battery SOC vs. Power

• Battery's ability to deliver power is reduced as SOC falls, and as batteries age

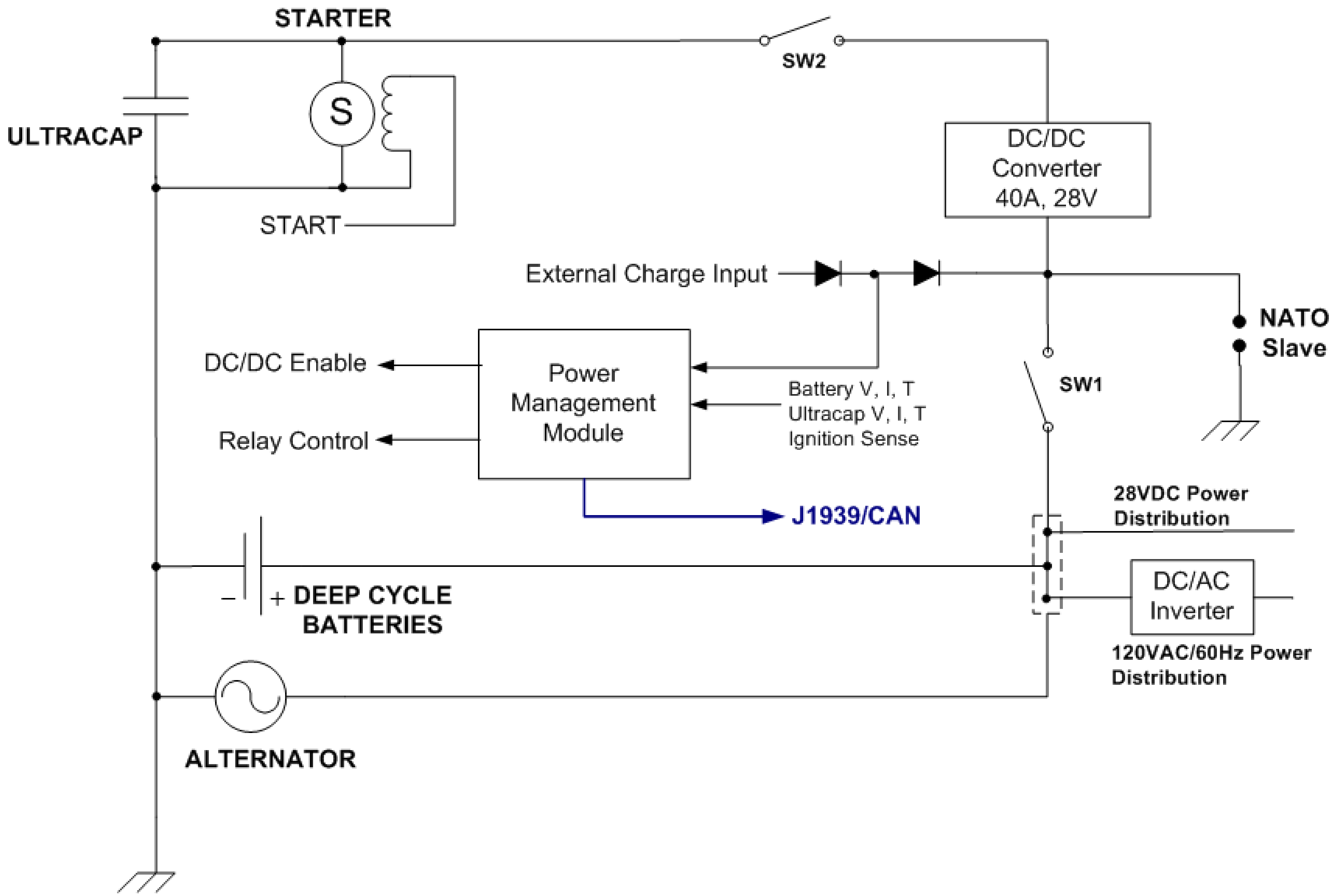
• Below 25% SOC may not be able to crank engine

- But battery pack still has much energy remaining

• **Solution:** use batteries to charge ultracap using DC/DC converter, ultracap delivers power needed to start vehicle



PPMS Architecture

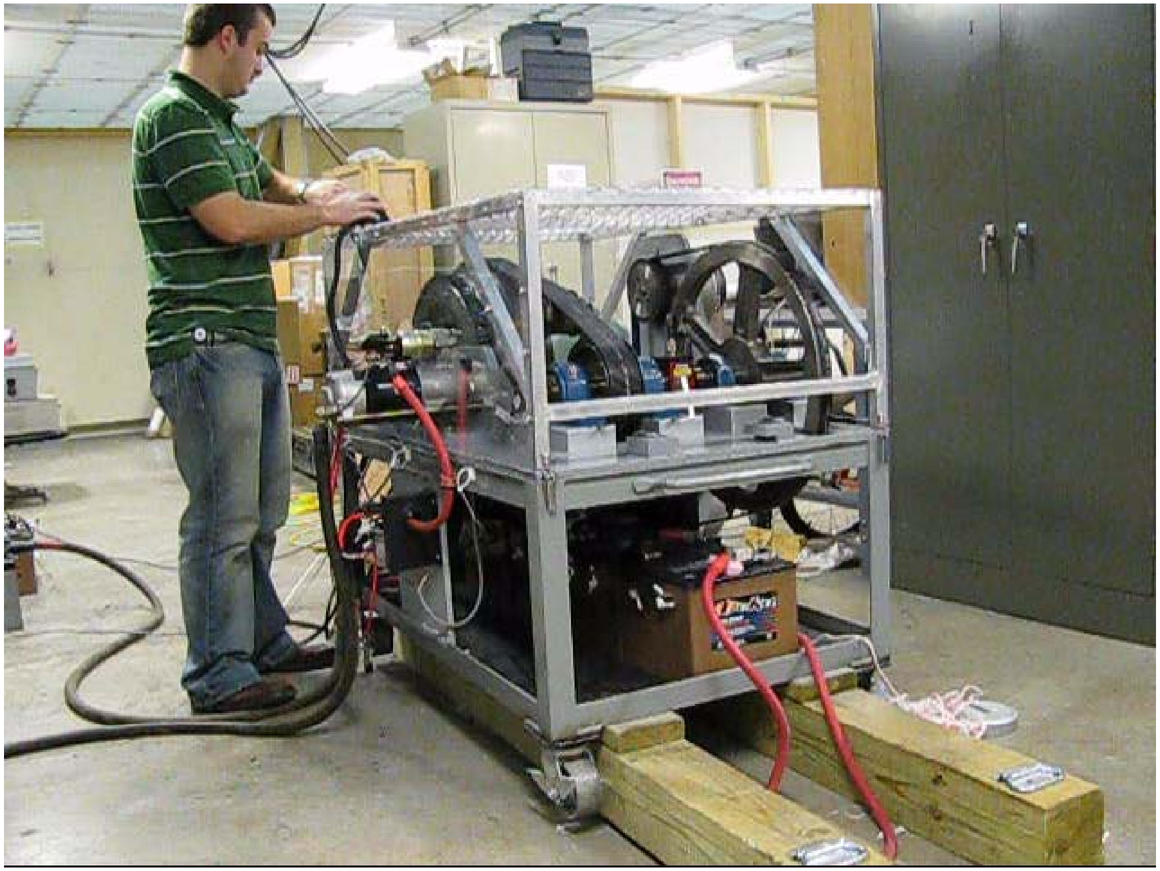


HILTEC Test Bench

Hardware-in-the-Loop Test & Evaluation Center

Purpose: simulate engine starting under a wide range of conditions in order to evaluate performance of engine starters and energy storage devices

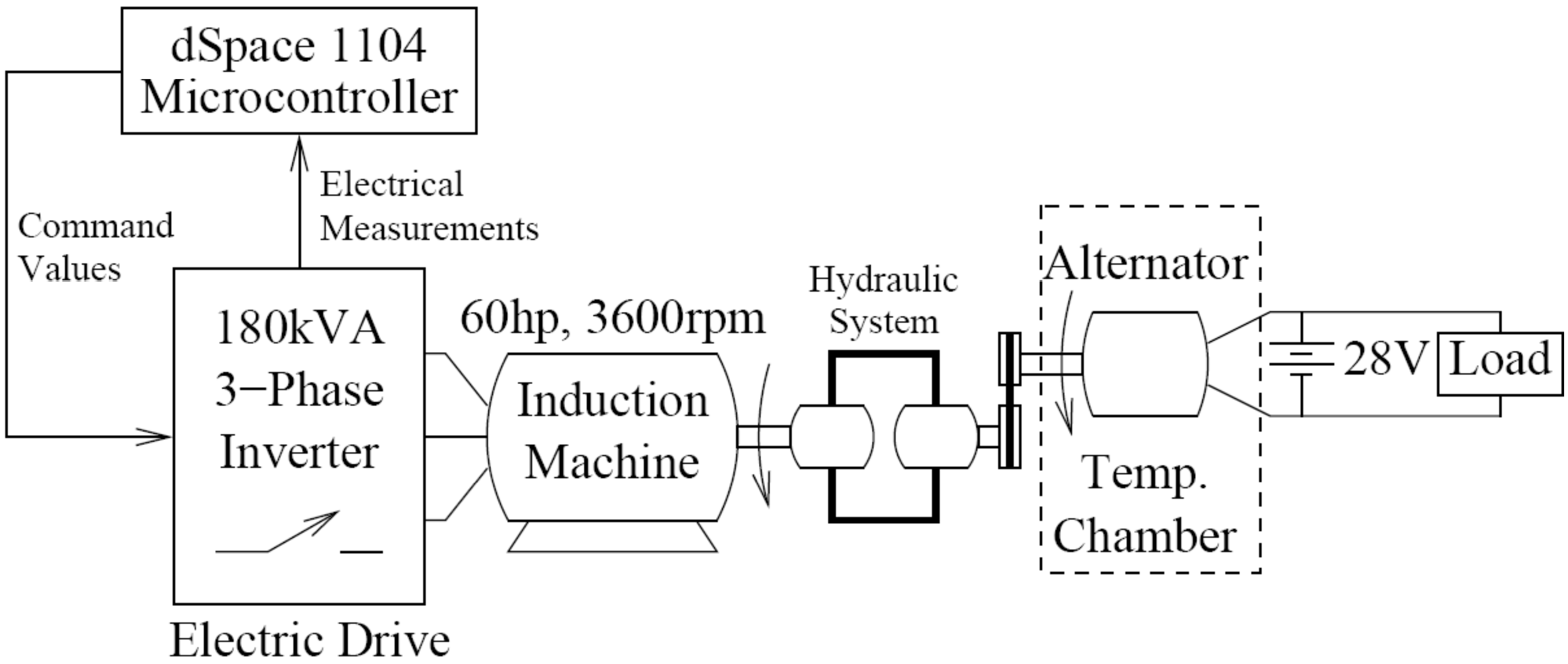
- Electric motors for assist/oppose torque
- Matlab Simulink models can be used to emulate different size engines



Hydraulic Power Generation

- Concept: install hydraulically-driven generator on vehicle for supplying high power loads
  - In place of large belt-driven alternators
- Benefits:
  - Alternator output is temp dependent, performance spec'd at 72F, but typically degrades at higher temps
  - Hydraulics allow flexibility of placement, can move alternator out of engine compartment
  - Not tied to engine speed (taken off PTO)
  - Low cost APU capability
  - Reliable operation, minimal maintenance required

Alternator Testbed



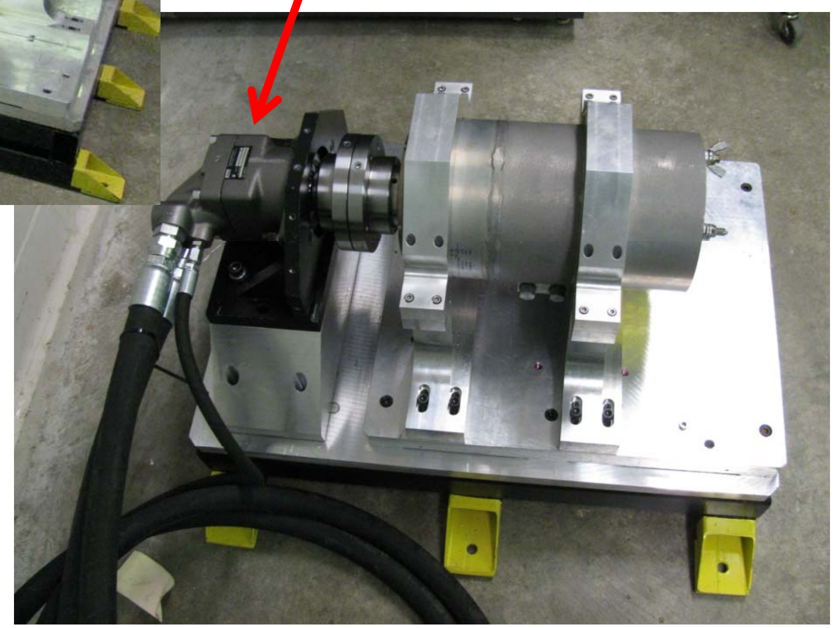
Purpose:

- Test alternators for performance vs speed, temperature

Alternator Testbed

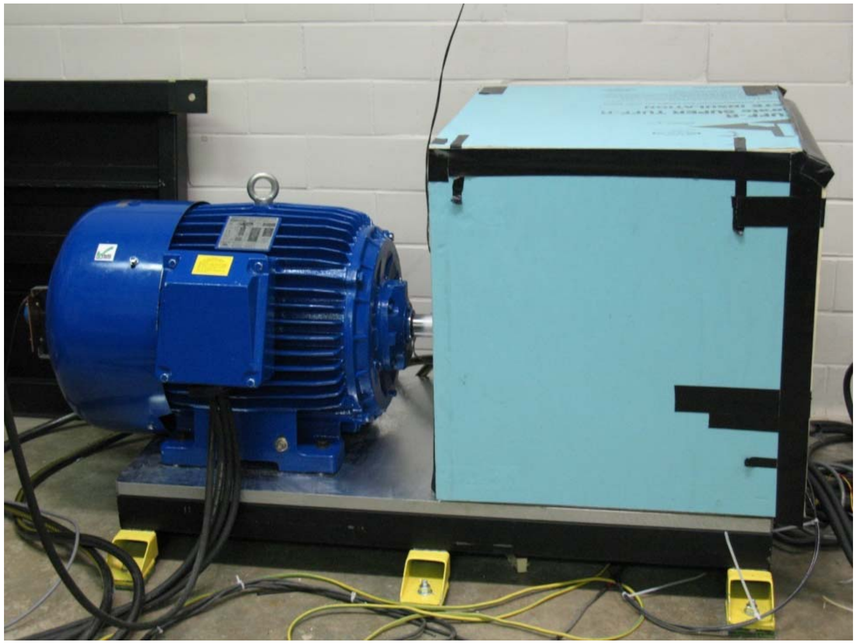
- 10 gallon reservoir
- Air-cooled heat exchanger with ¼ hp motor

Parker F11-019-HU-SV-T Hydraulic Motor
- 30kW mechanical power @ 8000rpm in spec'd system



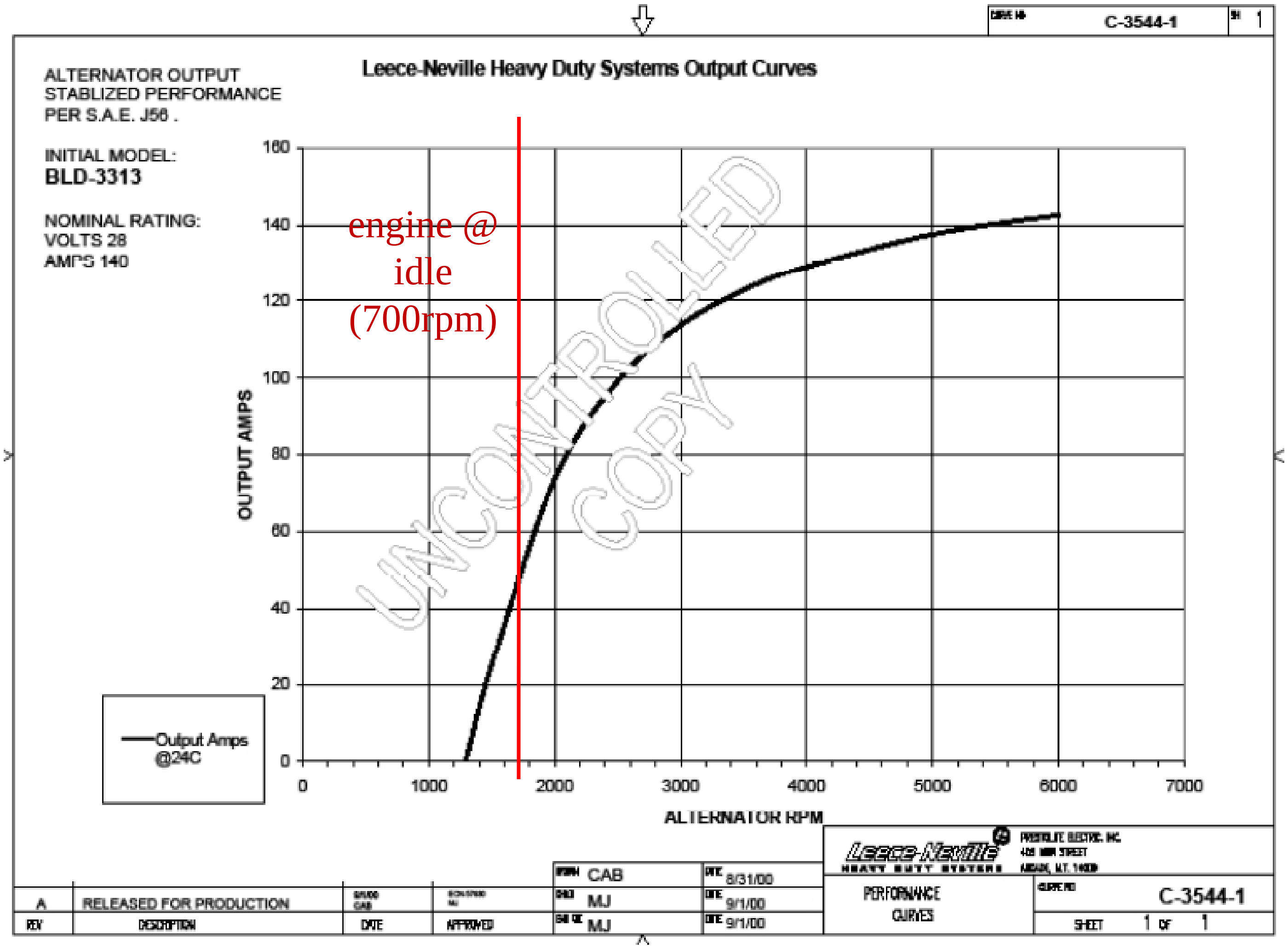
Eaton 70360 Hydraulic Pump
- Manually-Controlled Displacement
- 48kW continuous hydraulic power @ 3600rpm

Alternator Direct Drive Testing

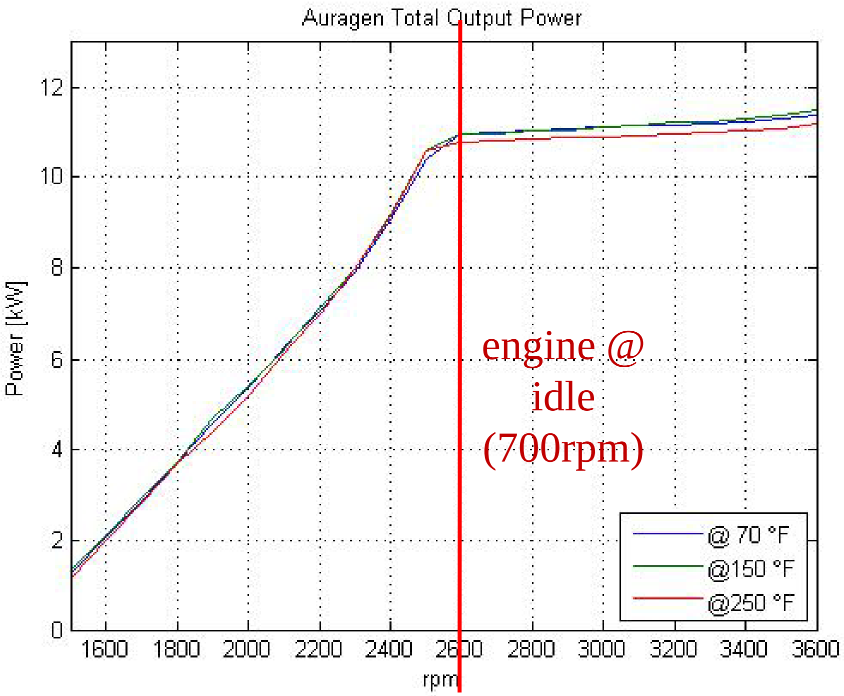


- Conducted prior to hydraulics implementation
- Alternator enclosed in heat chamber (70-250F)
- 400A DC load banks
- **Alternators tested:** Prestolite SF252, AuraGen TANGEN G8500YC, EMP Power 450
- **Yet to be tested:** Prestolite C-3544-1 (baseline), Niehoff 1602-1

Prestolite C-3544-1
140 amps (per spec)

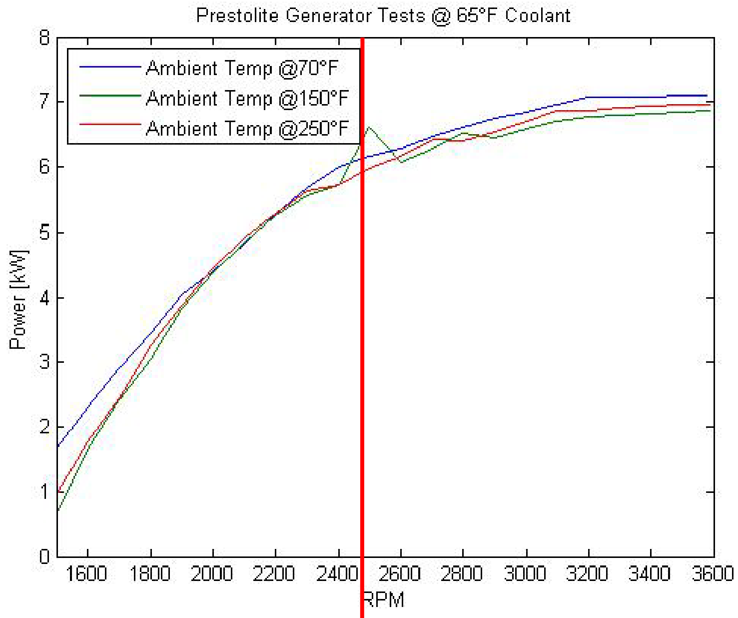


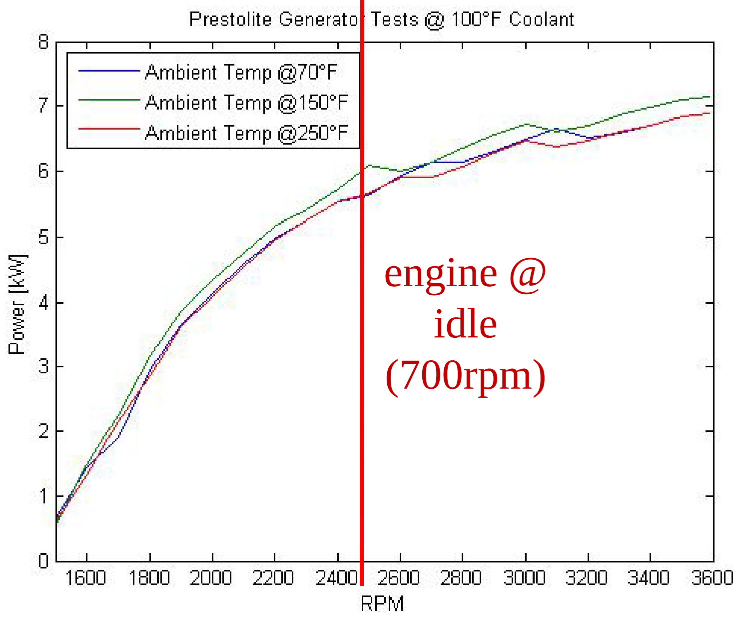
AuraGen TANGEN G8500YC



- Dual 8500W alternators with inverter charger system
- 500A @ 28VDC, 2x33A @ 240VAC
- Curve to right is DC power only
- Little degradation in power output at high temps

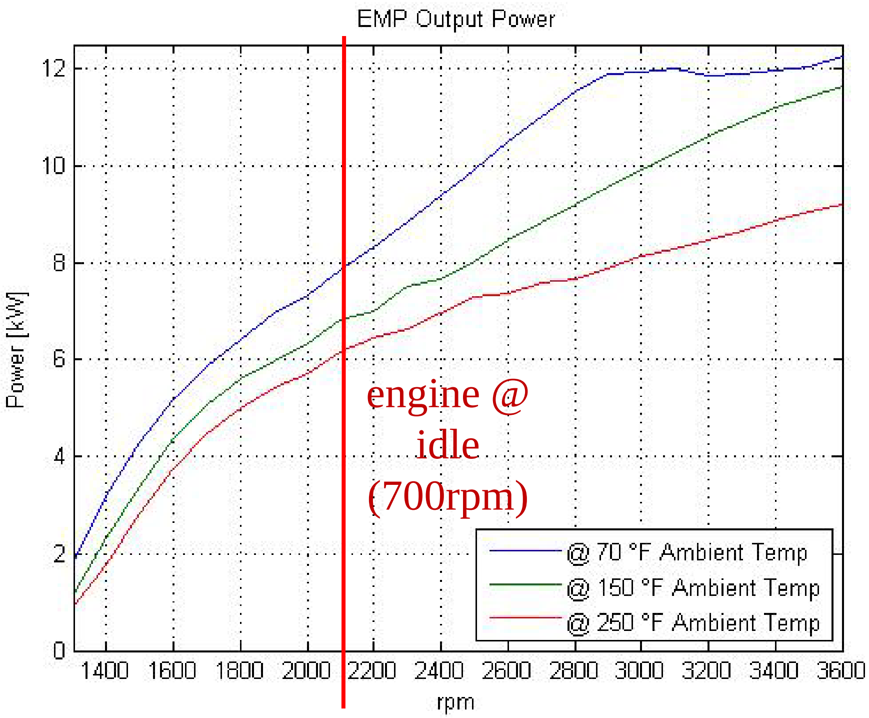
Prestolite SF252





- 300A @ 28VDC
- Brushless, water-cooled AC generator, integrated rectification
- Need to test at 212F coolant temp

EMP Power 450



- 450A @ 28VDC
- Brushless, air-cooled alternator

CBM and On-Vehicle Sensor Integration

CBM applied to existing vehicle data sources

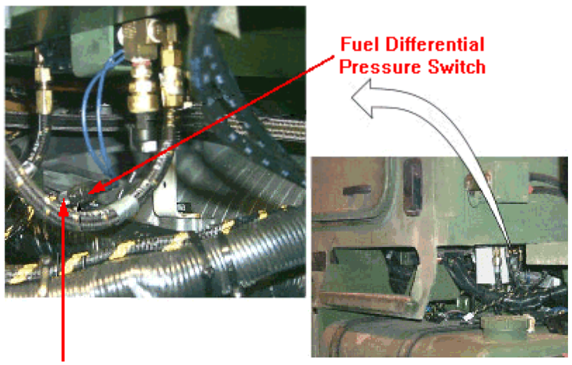
- Open data sources: J1939, J1708
- Proprietary data sources: ADM diagnostic messages, ADM operational parameters

CBM applied to new sensors

- Engine oil condition analysis
- Engine oil level
- Transmission oil level
- Coolant sensor level
- Hydraulic system
- Fuel level
- Fuel filter condition
- Air filter condition
- Tire pressure monitoring
- Brake wear monitoring

CBM applied to power system components

- Alternator V, I, T
- Battery V, I, T, SOC, SOH
- Ultracap V, I, T, SOC



Vehicle Control System

Hardware agnostic

- Software developed using Microsoft XNA Game Studio
- VCS tied to vehicle CANbus backbone
- Control of PPMS, display system operational parameters, display CBM updates, etc

Conclusions

- Penn State modeling /evaluation capabilities:
  - Hardware-in-the-Loop for simulated engine starting
  - Battery Test Station for cycle life & performance evaluation
  - Alternator Test Station for power vs. speed, temperature characterization
- PPMS and CBM+ solutions being implemented on HEMTT A2 Wrecker
- Technologies available today can provide a means to meet present day power demands
- System architecture will allow for rapid implementation of future technology improvements

Questions / Comments

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