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
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

![Graph showing specific energy and specific power for different energy storage systems](image)
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 vs. FTTS Requirements

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Runtime (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6TMF</td>
<td>3.00</td>
</tr>
<tr>
<td>Hawker Armasafe</td>
<td>3.00</td>
</tr>
<tr>
<td>Trojan J150</td>
<td>9.00</td>
</tr>
<tr>
<td>Cobasys NiMHax 9500</td>
<td>9.00</td>
</tr>
</tbody>
</table>

FTTS Objective: 9.00 hours
FTTS Threshold: 6.00 hours

Silent watch runtime estimates based on 60A loading @ 24VDC, with battery pack of equivalent size/weight to that of (4) 6TMF batteries.
Lifecycle costs based on 25 year vehicle lifetime with two high intensity conflicts and 6000 charge/discharge cycles.
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

Cycle Life for 100% DoD

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°F ~ 6KJ
• Energy stored in ESMA 28V Ultracap ~ 120KJ
• Energy stored in Hawker Armasafe 4-pack ~ 17,300KJ
• An engine crank @ 50°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

- **ULTRACAP**
- **STARTER**
- **START**
- **SW2**
- **DC/DC Converter 40A, 28V**
- **External Charge Input**
- **Power Management Module**
- **Battery V, I, T Ultracap V, I, T Ignition Sense**
- **J1939/CAN**
- **SW1**
- **NATO Slave**
- **28VDC Power Distribution**
- **DC/AC Inverter**
- **120VAC/60Hz Power Distribution**
- **+ DEEP CYCLE BATTERIES**
- **ALTERNATOR**
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)

engine @ idle (700rpm)
• 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

engine @ idle (700rpm)
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 - Fuel level
- Engine oil level - Fuel filter condition
- Transmission oil level - Air filter condition
- Coolant sensor level - Tire pressure monitoring
- Hydraulic system - 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

- 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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