Battery Applications

Why has life gotten so complicated

Donald Karner

Electric Applications Incorporated

THE BATTERY SHOW
The Expo for Advanced Batteries
SEPTEMBER 16-18, 2014
Novi | Michigan | USA

Summary

- EAI background
- Basic energy storage economics
- Simulated battery testing and what it can provide
- Examples of simulated battery testing
- Conclusions

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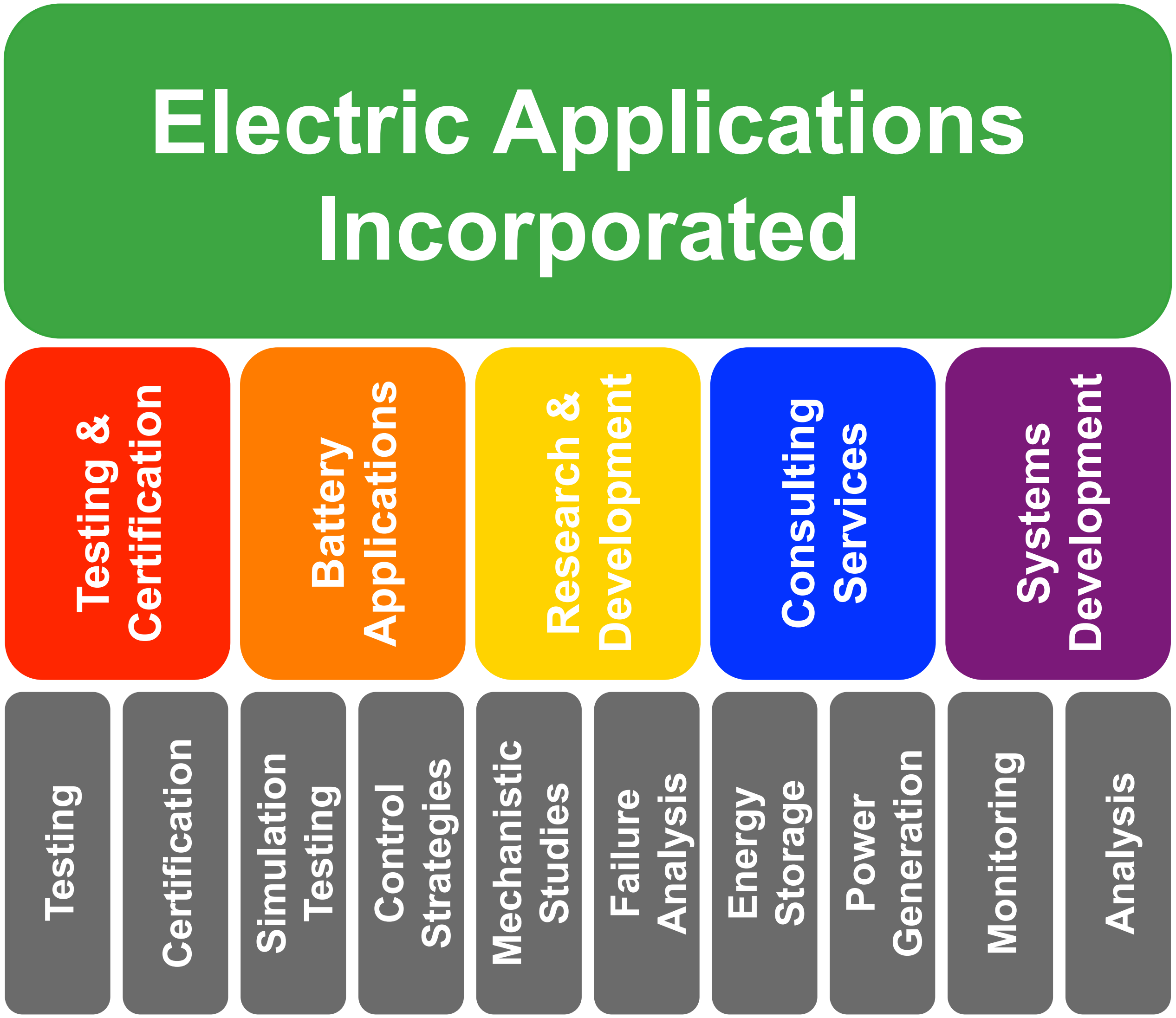

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EAI Experience

- 20 years of battery research experience
  - Research and development in Li ion, NiHM, Ni assymetric, VRLA lead-acid (gel and AGM)
  - Production experience in VRLA (gel and AGM)
  - Simulated life testing of lithium ion, NiMH, Ni assymetric,
  - Design of custom operating algorithms
  - Fast charging
- 20 years of EV experience
  - EV design and performance evaluation
  - Traction battery applications
  - Industrial battery charging systems
  - EV infrastructure

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EAI Experience

- 10 years HEV and PHEV experience
  - Fleet testing
  - Vehicle and battery pack design
  - Vehicle retrofitting
  - Charging and operation
- 15 years energy utility experience
  - Generating plant design, construction & operations
  - Transmission & distribution engineering
  - Coal gasification
  - Gas-to-liquids
  - Algae to diesel

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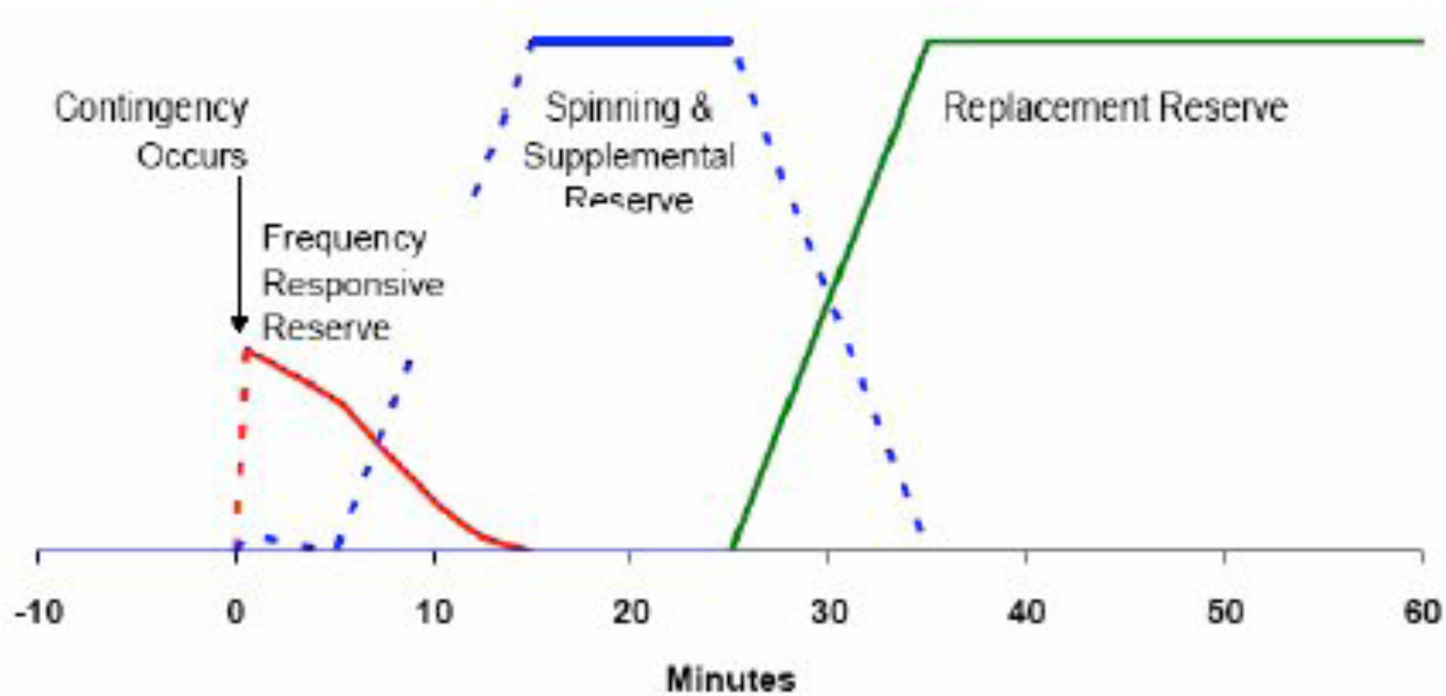
Battery Energy Economics

- Batteries are a significant portion of the upfront energy system cost
- Batteries typically require replacement over the life of the energy system
- Cost and cycle life of batteries typically dominates the lifecycle cost of energy systems

Energy Storage Example

EAI was contracted to prepare a conceptual design and cost forecast for a one megawatt-hour utility frequency regulator (UFR) utilizing battery energy storage



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System Costs

Inverter	$172,000
Batteries	$1,350,00
Supervisory System	$409,114
System Integration	$1,797,000
TOTAL COST	$3,728,114

Battery cost is over 1/3 of total cost and is recurring

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Assuring Battery Performance

- Extensive field testing
  - Accurate
  - Time consuming
  - Not always practical/possible
  - Always expensive
- Modeling
  - First order approximation
  - No accurate life-cycle models
  - Difficult to make application specific
- Laboratory simulation
  - Practical alternative

Laboratory Simulation

- We would like testing to be fast
  - Accelerated time is definitely possible
  - Care must be taken not to invoke failure mechanisms peculiar to the time acceleration
    - Battery temperature
    - Charge efficiency
- Test cycles must be developed with care
  - Accurately represent actual application
  - Accelerate time as much as reasonable
    - Common sense
    - Testing experience

Simulating Normal Operations

- Operating cycle
  - Number of charge/discharge cycles between full charges (PSoC cycles)
  - Bottom of discharge and top of charge
    (PSoC window)
- Composition of recharge
  - Charge rate
  - Charge algorithm
  - Charge time
- Environment
  - Temperature
  - Vibration

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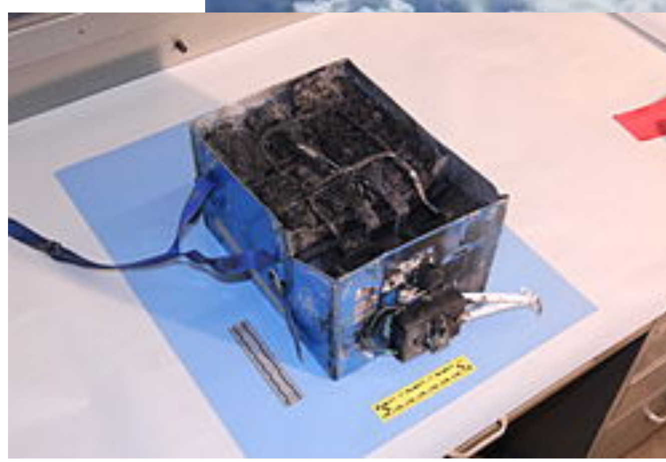
Simulating Abnormal Operations

- Electrical abuse
  - Over charge
  - Over discharge
  - Power quality
- Mechanical abuse
  - Vibration
  - Shock
  - Decompression
- Failure modes
  - Graceful
  - Dynamic



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Optimizing Operating Conditions

- Number of PSoC cycles between full charges
  - High number avoids potential overcharging
  - Periodic recharge restores battery capacity in some chemistries
- PSoC window size
  - Small windows typically extend battery life (turnovers)
  - Large window makes better use of investment
- Charge rate
  - Low charge rate extends battery life but takes more time
  - High charge rate readies battery for next cycle at the expense of charge efficiency and potential shortened life

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Optimizing Operating Conditions
(cont'd)

- High SoC window
  - For example 60% - 90% SoC
  - Power applications
  - Protects from over discharge
- Low SoC
  - For example 30% - 60% SoC
  - Assures high charge efficiency
  - Protects from over charge

Proper cycling involves compromise

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Developing Simulation Algorithms

- Preliminary algorithm selected
  - Previous experience
  - Field data logging
  - Operating objectives
- Initial cycling under a matrix of simulated conditions
  - Number of PSoC cycles
  - Size of PSoC window
  - Placement of PSoC window
  - Full recharge conditions

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Developing Simulation Algorithms
(cont'd)

- Best performing algorithm selected for expanded testing
  - Sensitivity studies
  - Abuse tests
  - Environmental condition changes
- Life-cycle testing conducted
  - One or a few algorithms
  - Algorithms may be adjusted over time
    - Based on experience with battery performance
    - Commonplace with PbA batteries
  - Warranty validation studies

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Field Validation

- Data collection system(s) installed in the field
- Data transferred to a central location for analysis
- Regular analysis and trending conducted
  - Monitor algorithm performance
  - Track battery condition
  - Detect abuse
- Validation assures successful battery operation

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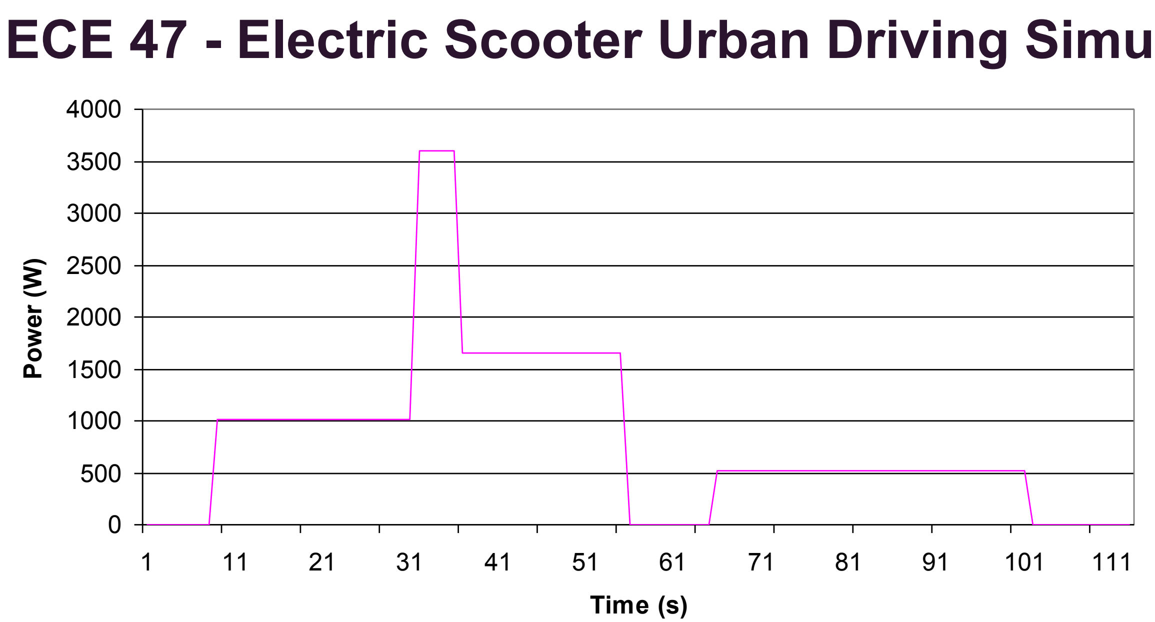
Simulation Testing at EAI

- Electric scooters
- Remote area power supplies
- Airport push-back tractors
- Airport bag tractors
- Grid energy storage
- Hybrid & plug-in hybrid electric vehicles
- Energy storage for demand reduction

Electric Scooter Test Cycle



- 0.8 km per cycle, 112 seconds in duration
- No detail on SOC/charging in Standard
- Customer wanted to know affect of fast charging on cycle life
- Developed and tested fast-charge algorithm - 60% return in 16 minutes
- 8000 km demonstrated – completed with battery at 77% of initial capacity

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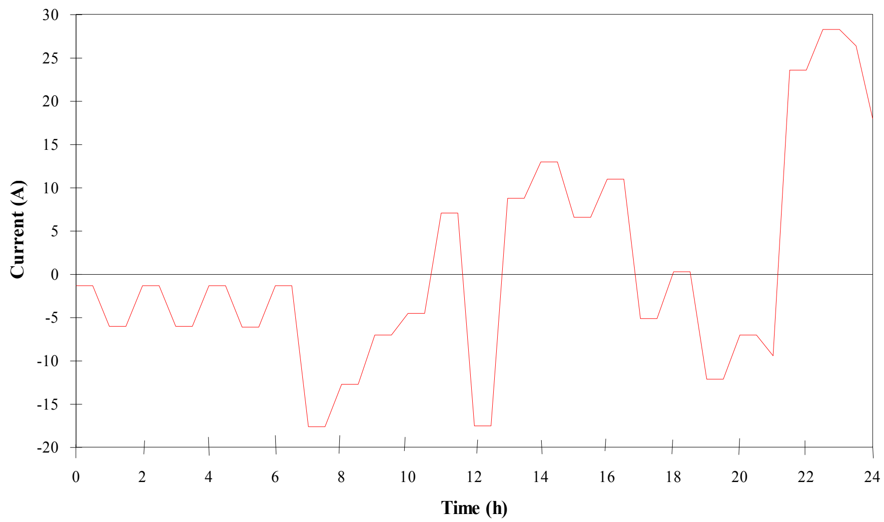
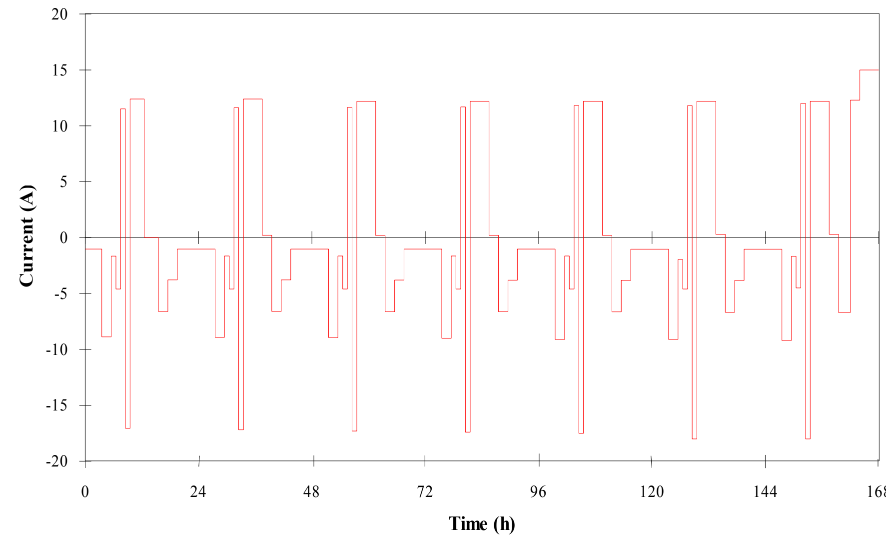
Remote Area Power Supply

PV and Diesel Power Source Optimization



Simulated 1-day RAPS profile (100-Ah battery)



Simulated 7-day RAPS profile (150-Ah battery)

- Conducted at CSIRO
- Formulated with real data
- No acceleration
- Lead-acid only
- Battery life 1 year (AGM)
- Battery life 5 years (Gel)
- Lab data verified by field use

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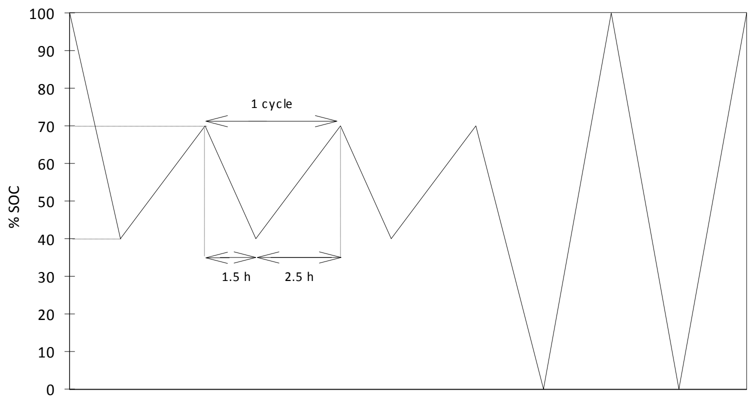
Remote Area Power Supply

PSoC (40 to 70% SoC) System Operation



- Cycle 40 to 70% SOC
- Partial-state-of-charge (PSOC)
- 52 cycles between recharges
- Battery still at 90% capacity
- PSOC performance of gel now well proven in field

Lifetime energy from gelled electrolyte battery per manufacturer (143 Ah battery)

%DoD	Cycles	Ah
10	6000	86 000
20	3200	91 500
40	1250	71 500
60	900	77 000
80	700	80 000
100	500	71 000
40-70 PSOC	5500	235 950

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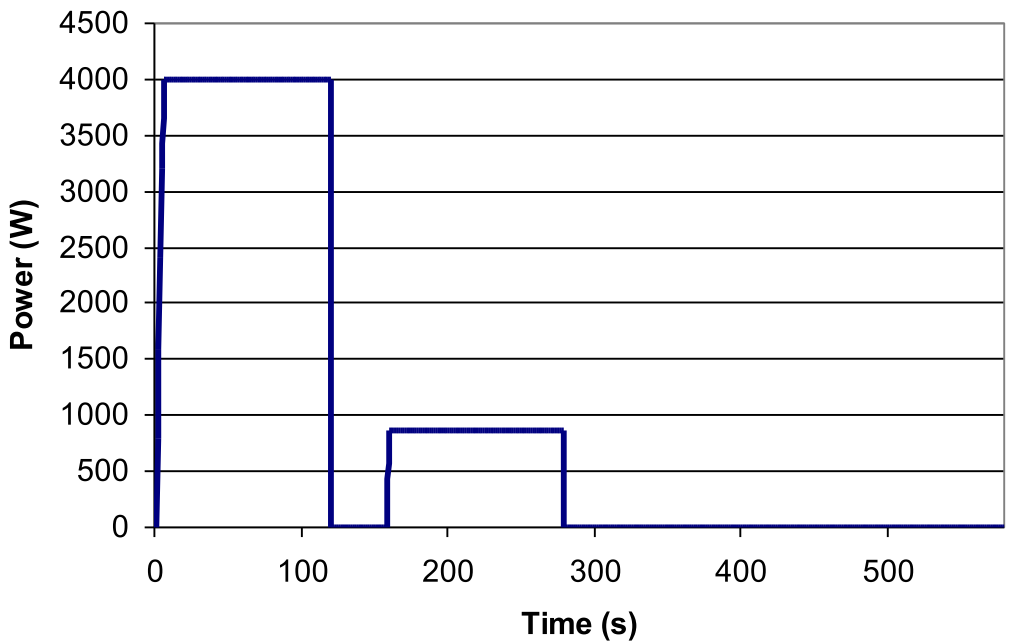
Airport Pushback Tractor

- Design, construct and test electric pushback tractor
- High power low energy PSoC application
- Flat plate gel lead-acid utilized to eliminate maintenance and provide requisite ballast

Airport Pushback Tractor



Simulated EPBT power profile (one 12-V monblock)

- **Operate batteries between 30 to 80% SOC**
- **11 PSOC cycles between full recharges**
- **Four lead-acid batteries assessed**
  - **Sonnenschein (gel)**
  - **Optima (AGM)**
  - **Vision (AGM)**
  - **NSB (AGM)**

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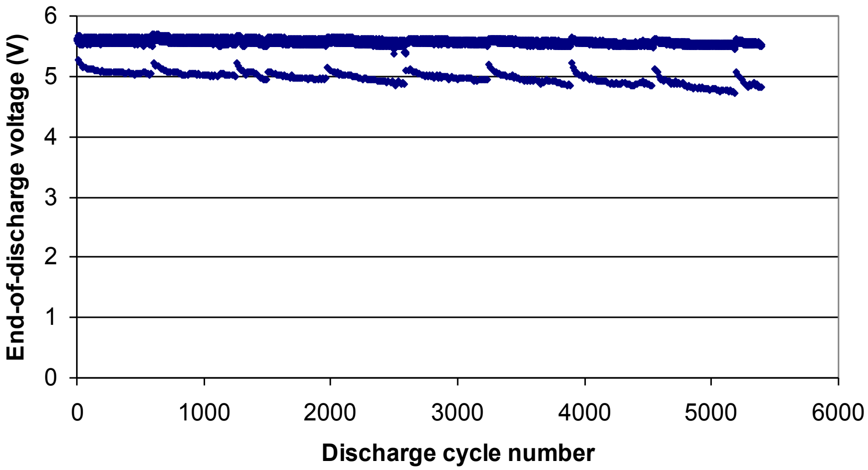
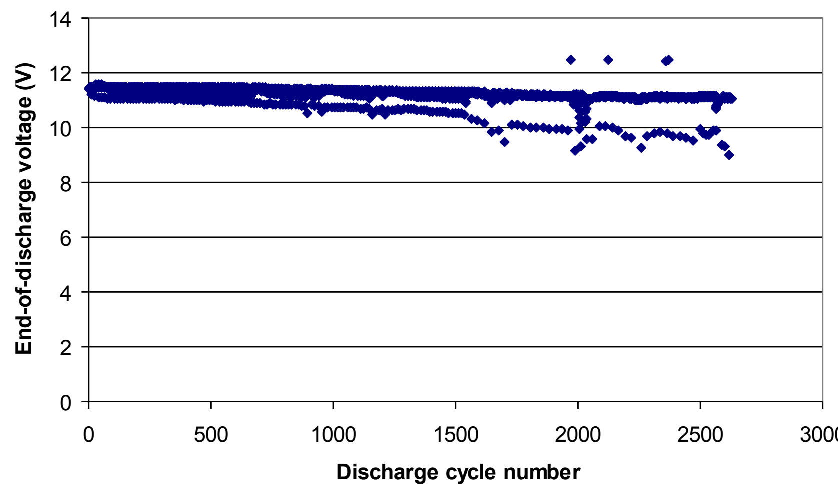
Airport Pushback Tractor



Gel EODV during simulated EPBT duty



AGM EODV during simulated EPBT duty.

- Gel performed 5500 passes through simulated profile (2 years field service)
- Still at 90% initial capacity
- Predict four years of field service
- Both Gel and AGM exceed expectations and are cost effective

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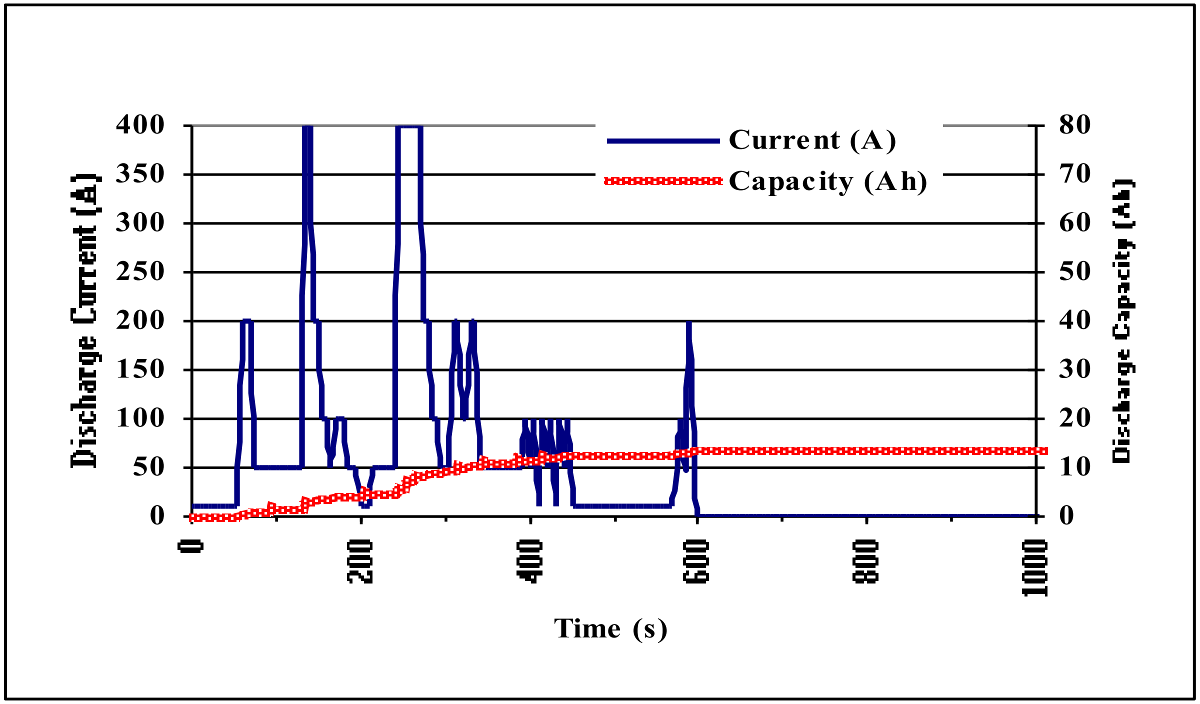
Airport Bag Tractor



discharge component for luggage tugs

- 6 PSOC cycles between 30 to 80% SOC (recharge time 30 min)
- Each PSOC cycle provides 10-15 operations
- Hence, 60-90 operations per full recharge
- Full recharge 4-6 h
- Three gelled-electrolyte lead-acid batteries evaluated

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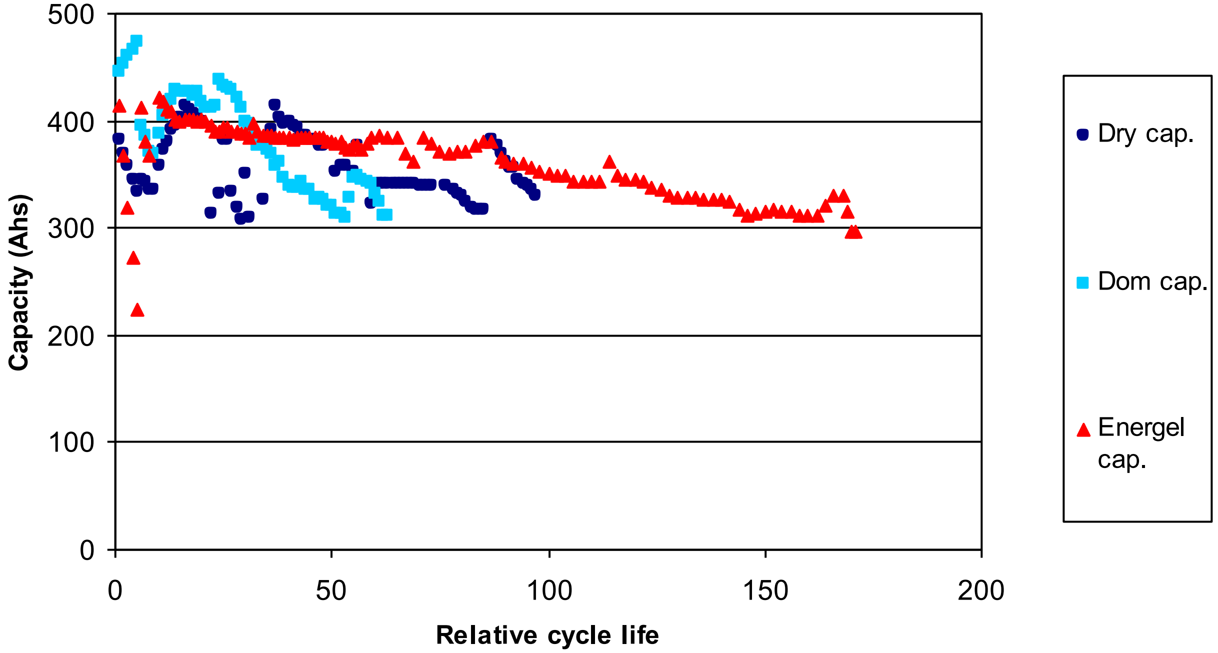
Airport Bag Tractor



- **Relative purchase price**
  - **Energel $120 Dryfit$162 Dominator $110**
  - **Energel gave 1,030 days of operation (13,500 operations)**
  - **Cost per operation can be calculated**

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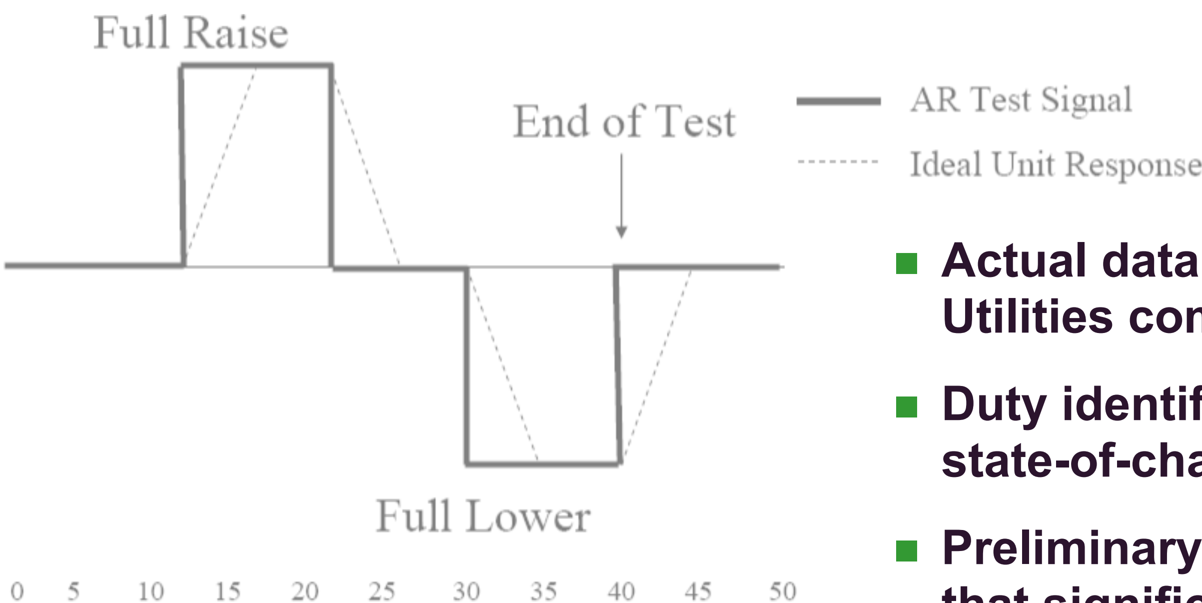
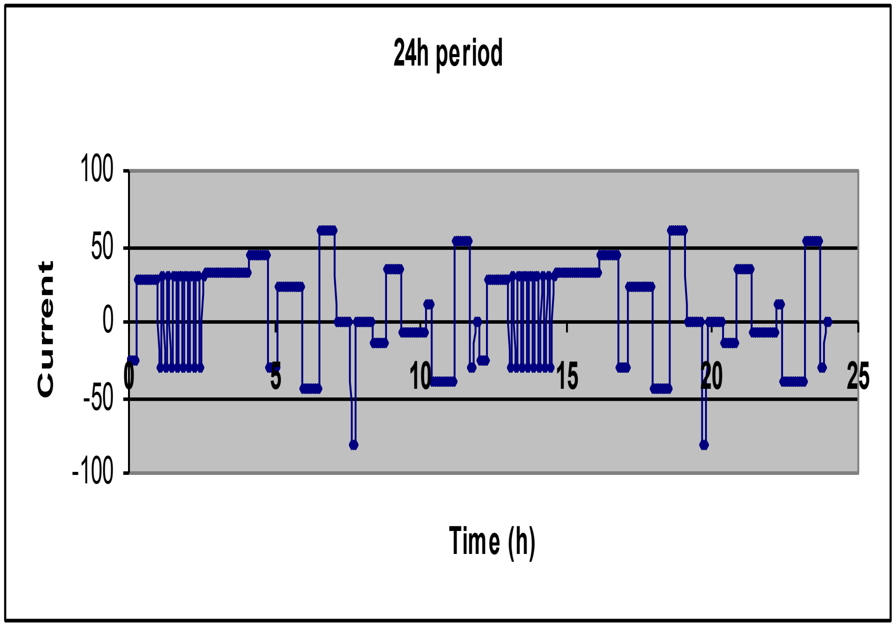
Grid Energy Storage



- Actual data obtained from Utilities company in Arizona.
- Duty identified requires partial-state-of-charge (PSOC)
- Preliminary analysis suggests that significant savings are possible if battery longevity is suitable.

Grid Energy Storage

- 30 to 80% SOC operating window
- SOC adjustment every 24 h
- EODV limit = 10.5 V
- Average current ~ C/1.5
- Weekly conditioning charge



24-h Utility Cycle

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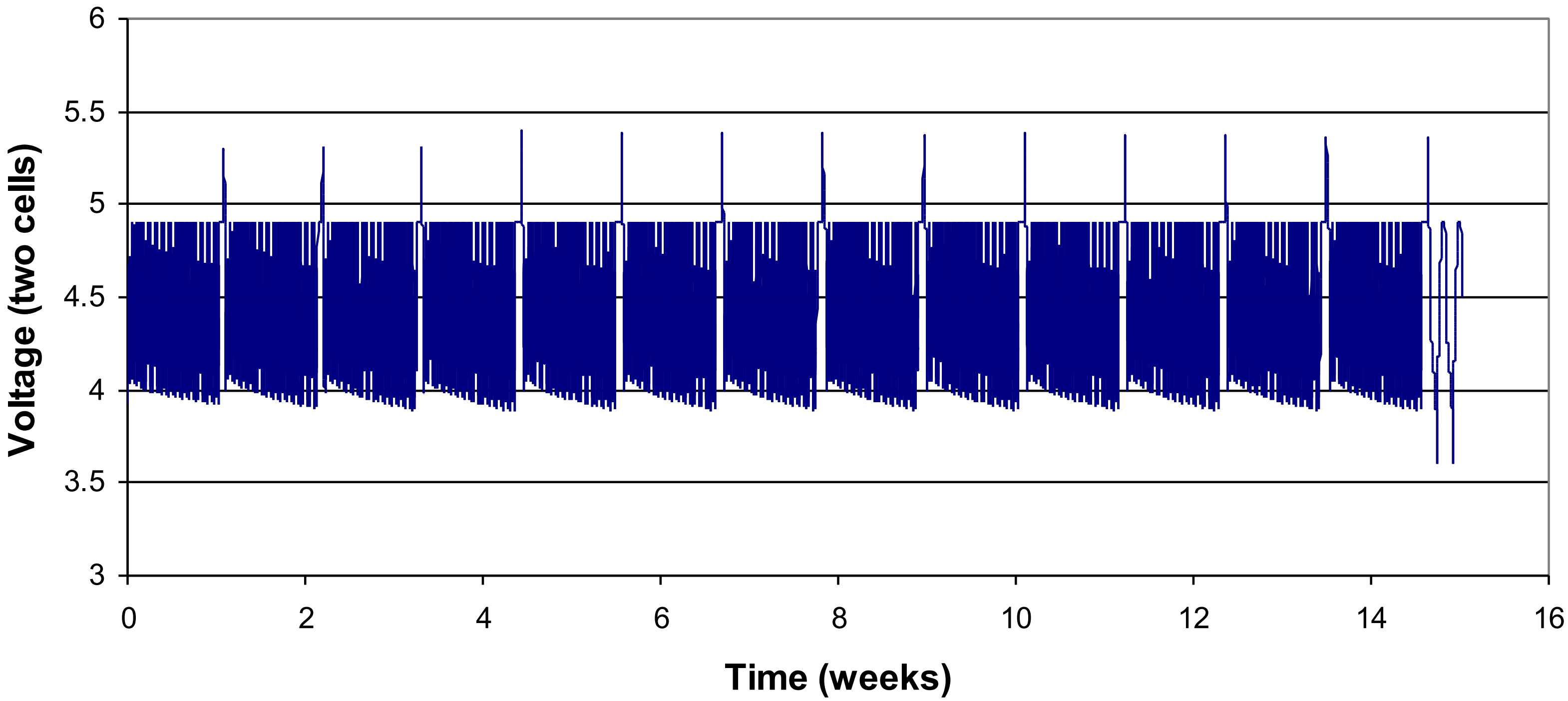
Grid Energy Storage



Performance of prototype gel battery under simulated utilities duty

Grid Energy Storage

Battery type	Equivalent 100% capacity turn overs	Lifetime cost-effectiveness
AGM 1	350	Very poor
AGM2	230	Very poor
Gel 1	2200	Marginal
Gel 2	2450	Marginal

Lifetime cost of batteries too expensive for system to be economic

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Honda Civic HEV Retrofit

- Develop a low cost HEV replacement battery
- Laboratory testing
  - Develop simulated profile
  - Test batteries in varying conditions
    (PSoC window, temperature, conditioning)
- Field testing
  - Retrofit Honda Civic using lab developed control parameters
  - Operate on road for 150,000 miles

Honda Civic HEV Retrofit

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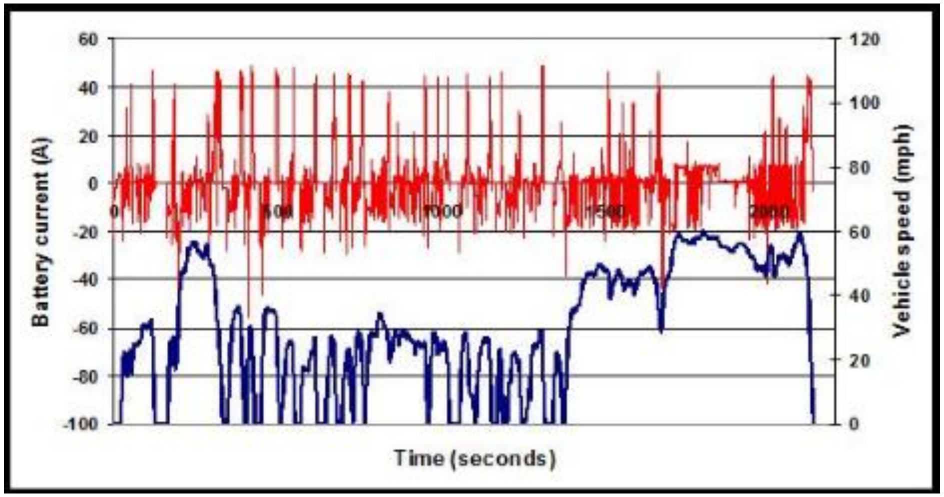
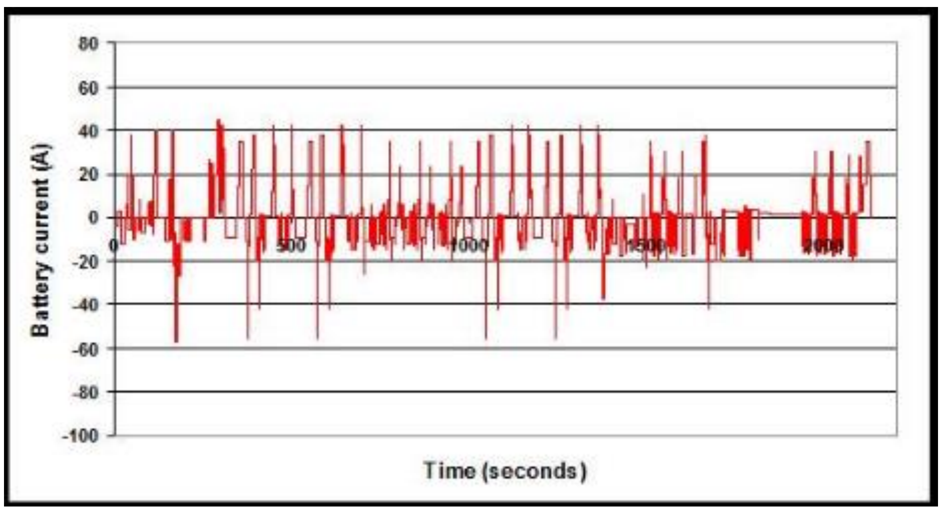
Honda Civic HEV Retrofit



Battery pack current/ vehicle speed logged during operation on the dynamometer



Battery pack current comprising the simulated profile

- **17.7 miles**
- **29 mph average**

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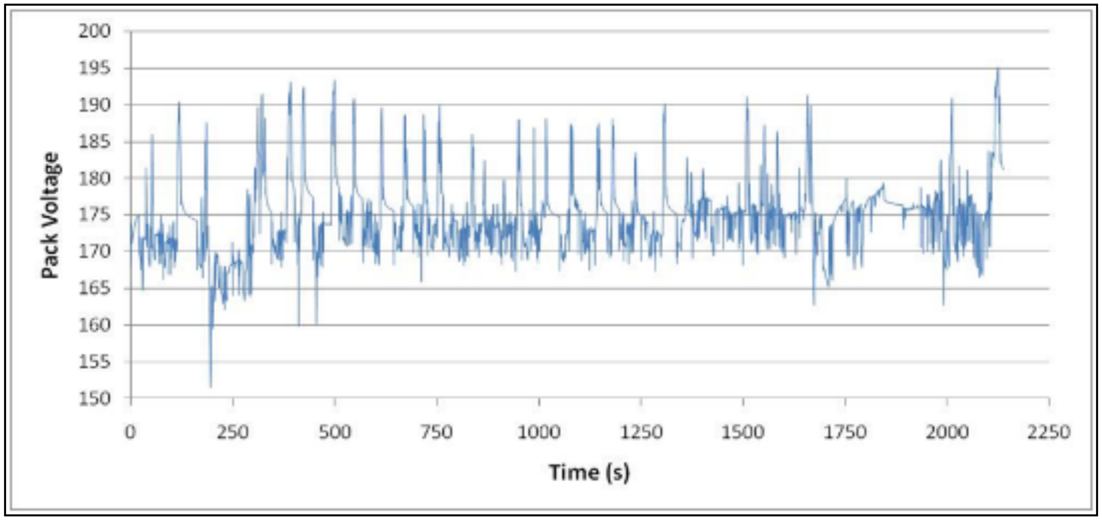
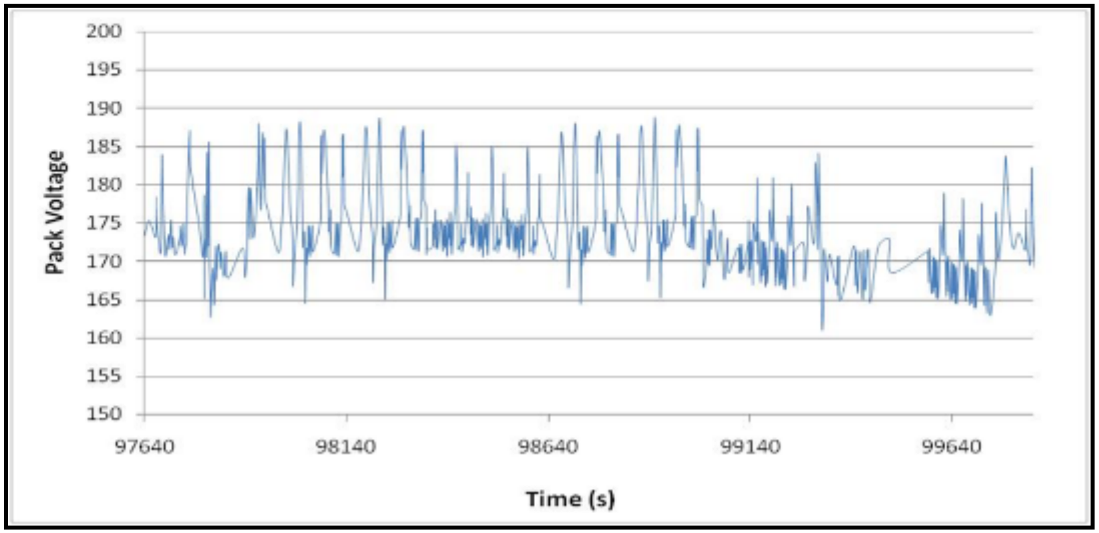
Honda Civic HEV Retrofit



Voltage of complete Civic NiMH battery pack in car on dyno



Voltage of complete Civic NiMH battery pack in lab operating on simulated profile

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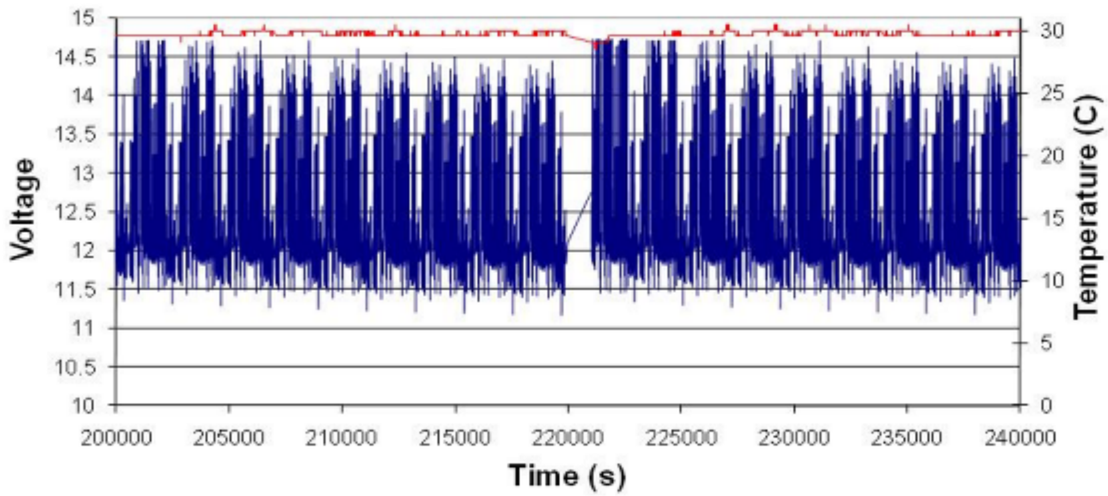
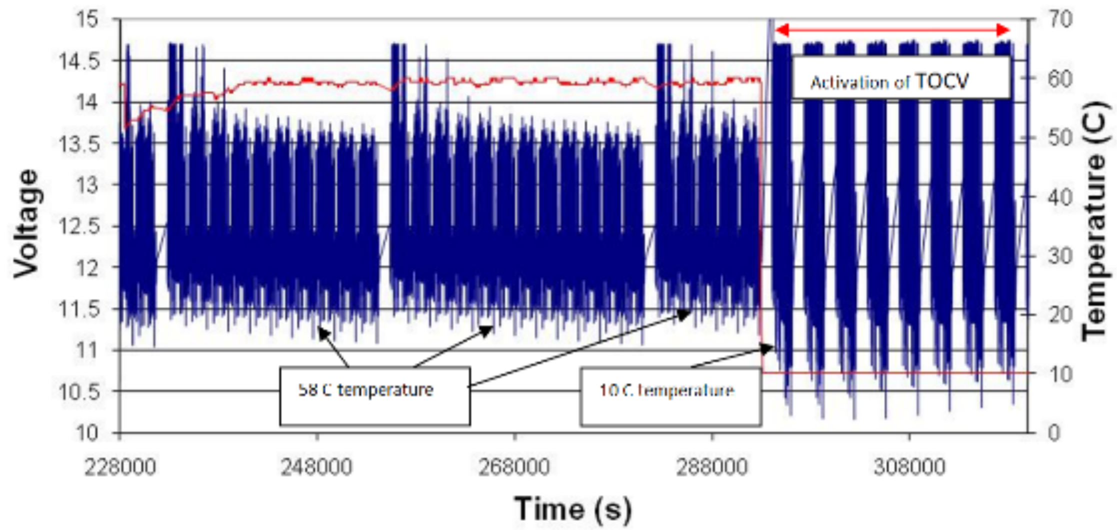
Honda HEV Civic Retrofit



Typical voltage of battery in lab at battery temperature of 30°C (43 - 53% SOC window)



Typical voltage of ultrabattery in lab at battery Temperature of 54 ˚C and 10 ˚C (43 - 53% SOC window)

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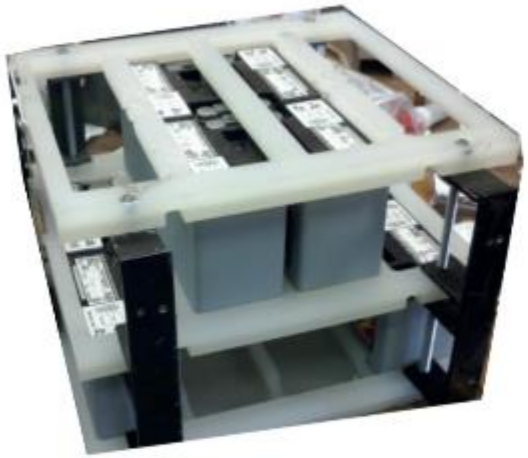
Honda Civic HEV Retrofit



Control parameters developed from lab simulation operated on road for 150,000 miles with battery retaining 95% of initial capacity

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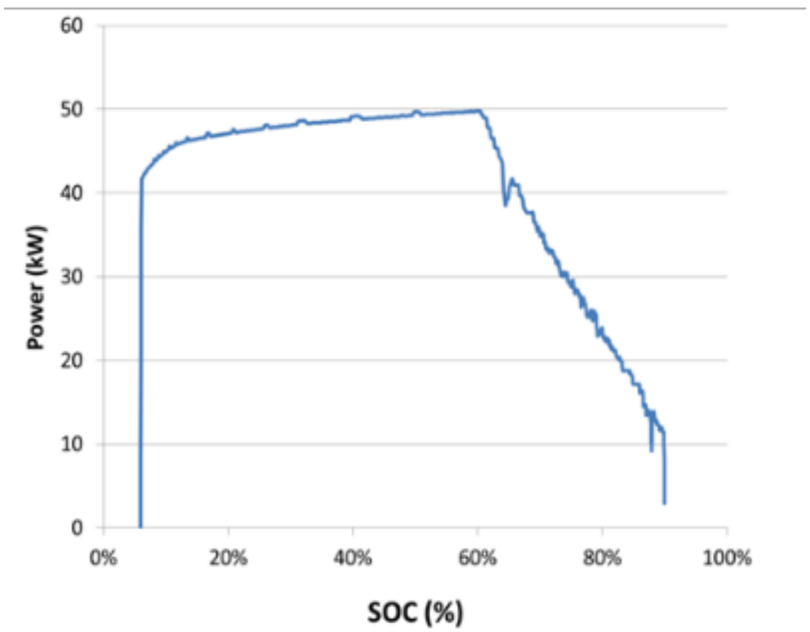
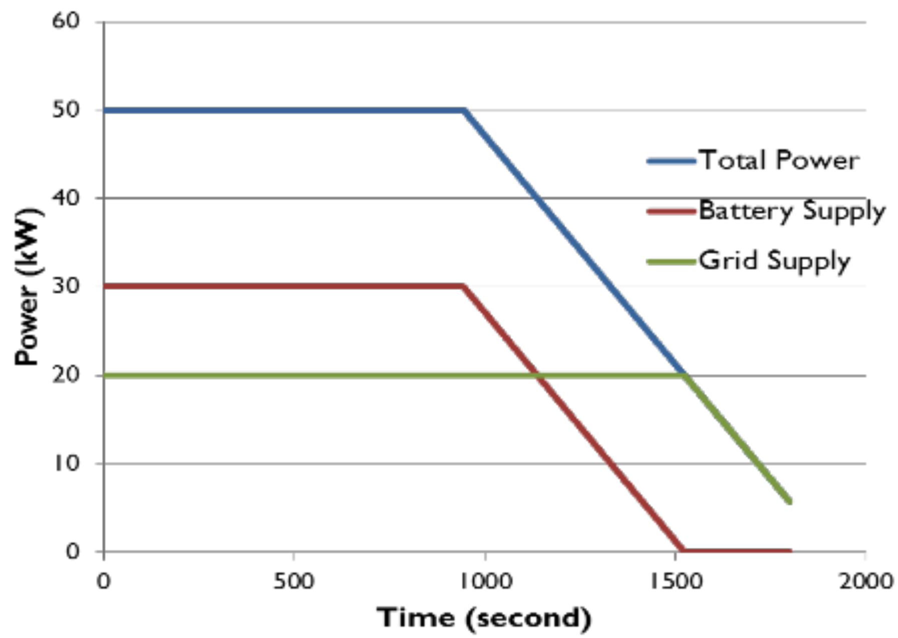
Fast Charge Demand Reduction

- Evaluate lifetime of batteries under simulated demand reduction operating conditions
- Develop algorithm
- Determine cycle life of different batteries
  - Lithium
  - Second-use NiMH
  - Advanced lead-acid

Fast Charge Demand Reduction



SOC of Nissan Leaf battery during fast-charge



Power required for fast charge of Nissan Leaf

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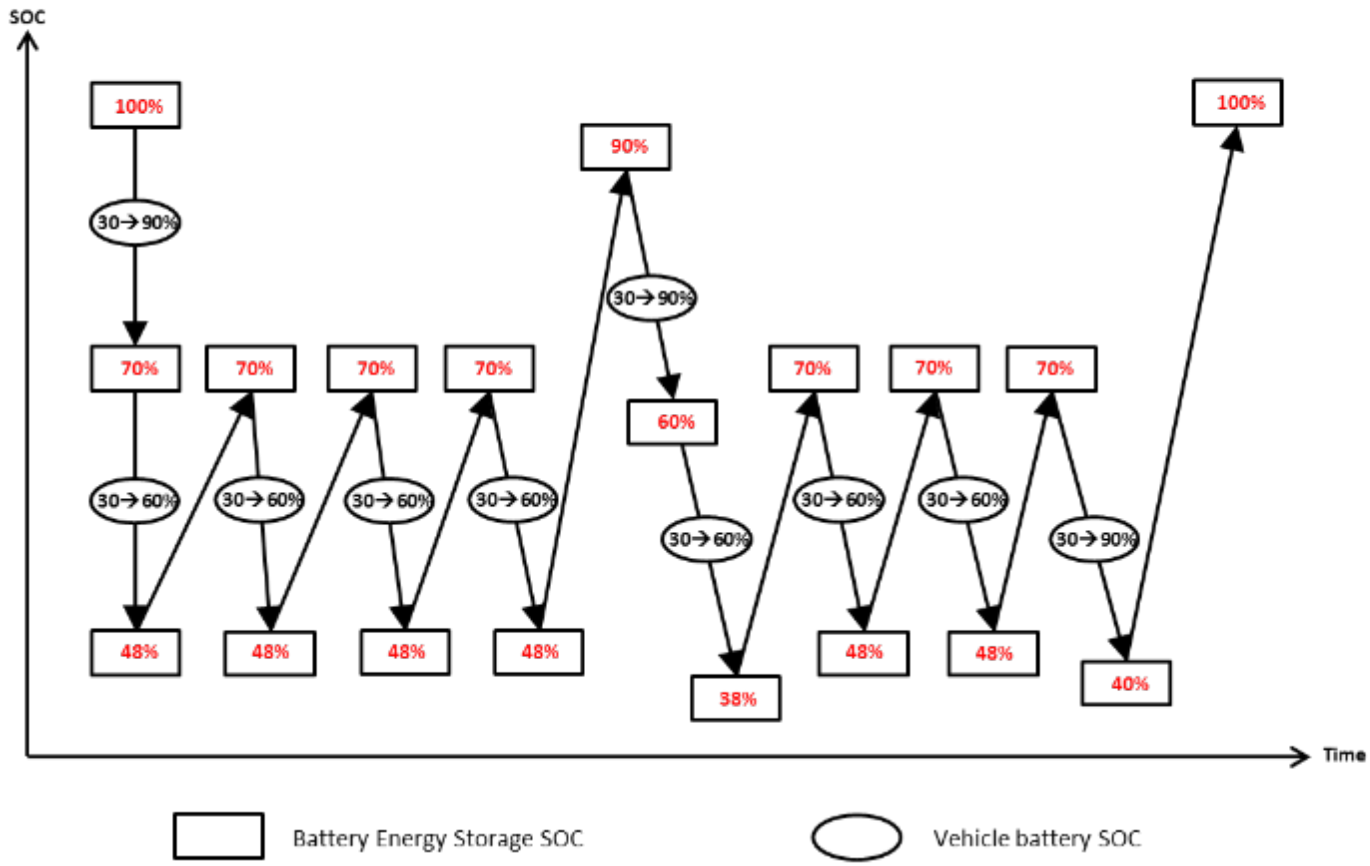
Fast Charge Demand Reduction



SOC During One Day of Demand Reduction Duty

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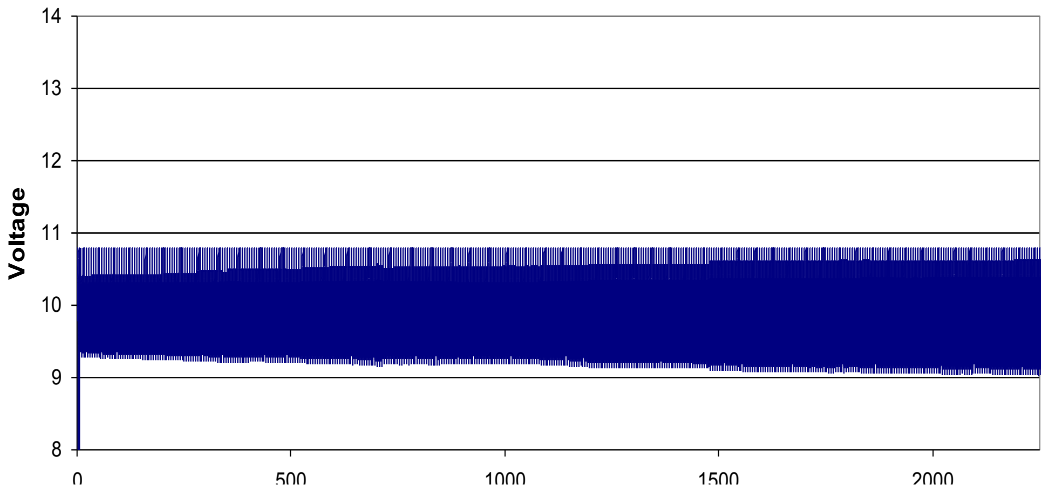
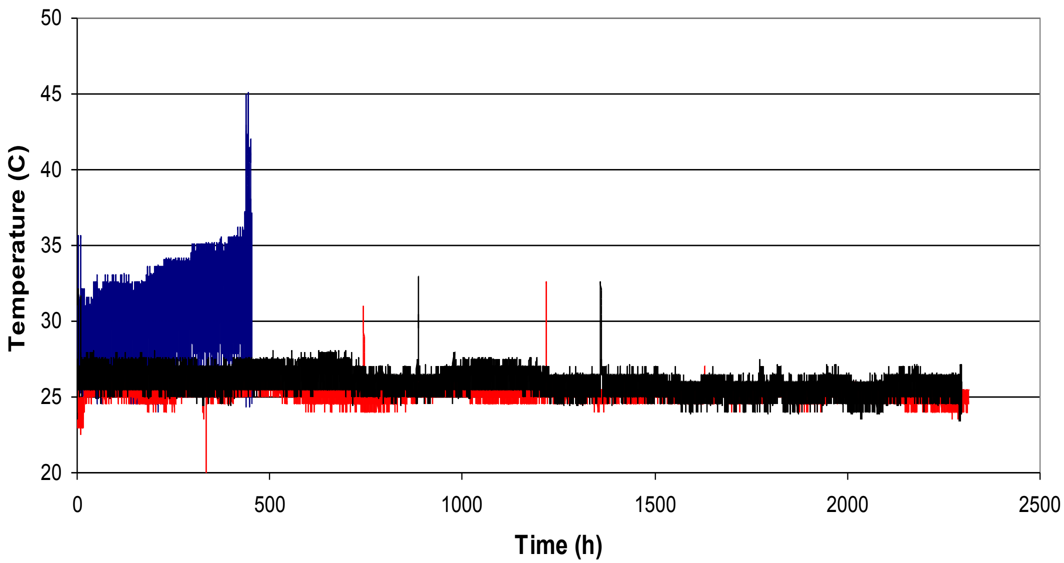


Voltage of lithium battery operating under simulated GSB profile



Temperature of thee lithium batteries operating under simulated GSB profile

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Fast Charge Demand Reduction

- Lithium batteries
  - Performance varied from poor to excellent
  - Life significantly reduced at 45˚C
- Second use NiMHx batteries
  - Excellent performance at 25˚C
  - Similar life to best lithium after 170,000 simulated miles of HEV duty

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Why Life Has Gotten Complicated

- High energy density batteries don't die gracefully
- All batteries are expensive
- Experience with advanced batteries is thin
- Customer expectations are high and getting higher
- Batteries system "invisibility" is increasing

You can't turn back the clock to when batteries were simple, but laboratory simulation can help you cope with complexity

For More Information

Visit us in Booth #B1644

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