Robust cell-level control of large battery packs

**Approach and Vision**

- Achieve cost-effective dynamic cell-level control and diagnostics
- Drive cells to non-conservative physical limits and homogeneous end-of-life
- Improve energy/power utilization, lifetime, reliability, safety

**Today’s Battery System**

- Passive cell balancing slow, wastes energy
- Cell rate-capability voltage-limited with conservative safety margins
- Energy limited by lowest performing cell in pack. Cell inhomogeneity worsens with age
- Uncertain battery state

**Proposed Battery System**

- Efficient, fast differential cell-power processing
- Electrochemical MPC reduces conservative limits and extends low temperature cell rate-capability
- All energy of disparate cells is available. Cell inhomogeneity decreases with age
- Improved knowledge of battery electrochemical state

**System Architecture**

- Low-cost isolated bypass DC/DC converter modules connect each cell to the vehicle 12 V bus
- Cell balancing is achieved by differentially supplying current demanded by the 12 V bus
- Packaging and wiring is simplified with parallel connection to 12 V bus and single digital communication line for all data
- Reduce (or eliminate) 12 V battery

**Battery Cell**

- Capacity: 25 Ah
- Series Resistance: ~ 1 mΩ

**Bypass Converter**

- Power Rating: 30 W
- Peak Efficiency: 93%

**Electrochemical Model-Predictive Control**

- Improve lithium ion battery performance with model predictive control (MPC) using physics-based electrochemical models to achieve battery performance closer to theoretical limits
- Generate simple yet highly accurate reduced-order cell models amenable to fast computation
- Identify internal physical and electrochemical parameters via experimentation to populate models

**Experimental Validation and Program Status**

**Battery Pack Integration with Bypass Converters**

- Pack level results with heterogeneous cell control

**Completed (Years 1 – 2)**

- Hardware development and pack level integration
- Heterogeneous cell control algorithm development and integration with hardware
- Initial electrochemical model parameter identification and MPC simulation

**Year 3 Plan**

- Launch new Partner Program to provide industry feedback
- Validate heterogeneous cell control through long term pack aging
- Further develop electrochemical MPC and perform cell-level hardware validation
- Develop cost-constrained control algorithms and hardware
- Demonstrate combined heterogeneous cell control and MPC at the pack level

**Cost-Benefit Analysis and Life-Prognostic Modeling**

**Problem:** Packs with well-matched cells may grow to 10% capacity imbalance over 10 years (model prediction)

**Solution:** Cost neutral active balancing system. Displaces HV-12V DC-DC

- Benefit – Utilization: Active balancing allows full utilization of cell energy
- Benefit – Lifetime: Removing limitation of weakest cell can extend life
  - 20% for PHEV
  - 40%-80%* for BEV75 (*passively cooled pack)
  - 35% for grid applications and automotive 2nd use
- Benefit – Pack thermal design: Eliminates the need for expensive thermal management that tightly controls cell-to-cell temperature differences
- Benefit – Performance: Heterogeneous cell control and electrochemical MPC co-optimize power delivery and lifetime

**Validation:** 12 month pack aging test with A/B comparison of passive/active balancing hardware employing heterogeneous cell control