STRANDED ENERGY IN AN INOPERATIVE RESS

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SAE 2015 Government/Industry Meeting

January 23, 2015

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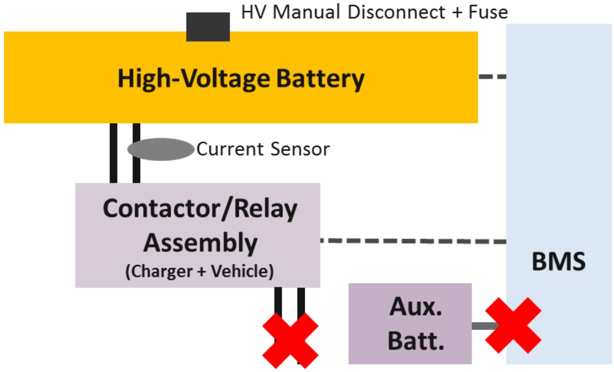
NHTSA has sponsored a 2-year research project with Argonne National Laboratory to identify, develop, and demonstrate methods for the safe management and handling of a battery in post-crash and non-operational environments.

Non-operational environments may include: service, repair, end of life disassembly, post-crash, post-fire, vehicle crash scene, vehicle tow, and vehicle storage.

Areas of Focus:

- Definition of interface connector and location
- Diagnostic interface
- Diagnostic protocol
- Standardized discharge port/terminal
- Architectural requirements

Field Discharging of a Battery…High Level Problems



Problem 1: 12V Power

- 12V cables may be cut per first-responder guide
- Contactors and BMS need 12V power to operate
- Offline system power likely necessary

Problem 2: Battery Access

- Wide variety of battery packing strategies often lead to difficult battery terminal access
- Under-hood access is possible with no other faults (need to check for isolation issues)

Volt Main Terminal Connections

(In-lab vs under vehicle)

Problem 3: Battery Diagnostics

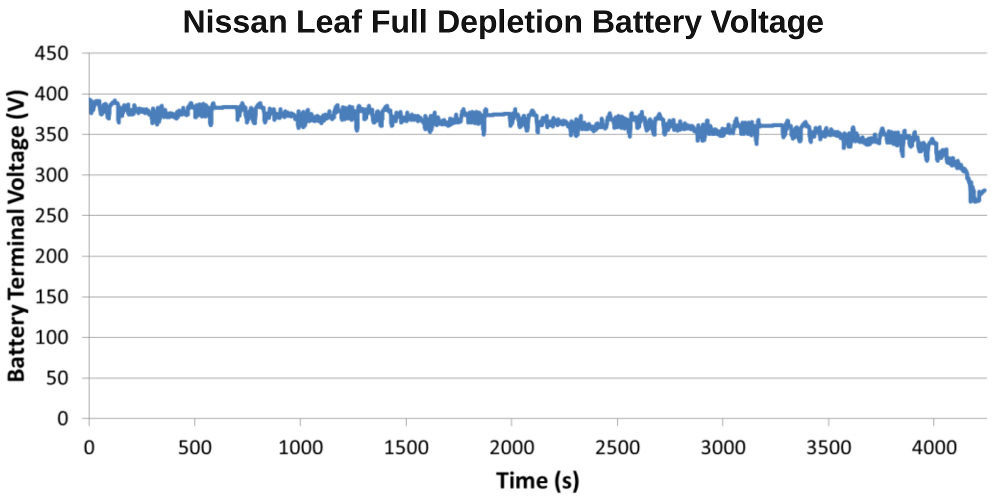
- Diagnosing the battery's condition is important prior to discharging, but depends on the availability of information
  - BMS full function
  - Cell monitoring active/No BMS
  - Cell monitoring inactive/non-existent

Toyota Prius PHEV Battery

What does Stranded Energy impact…

Two primary hazards associated battery damage are high voltage exposure and increased risk of thermal event

1. **Reduction in voltage is typically not substantial at lower energy levels**
   - Voltage does decrease, but usually remains in the realm of dangerous voltage
   - Bringing the total pack voltage to a lower level (<50V) would likely require bringing the battery to a damaging SOC level



2. **Evidence suggests that lowering the energy level of a battery pack may reduce the risk and severity of a thermal event due to battery damage**
   - Particularly important for towing/storage/repair/secondary responders
   - Analogous to draining a fuel tank following an accident

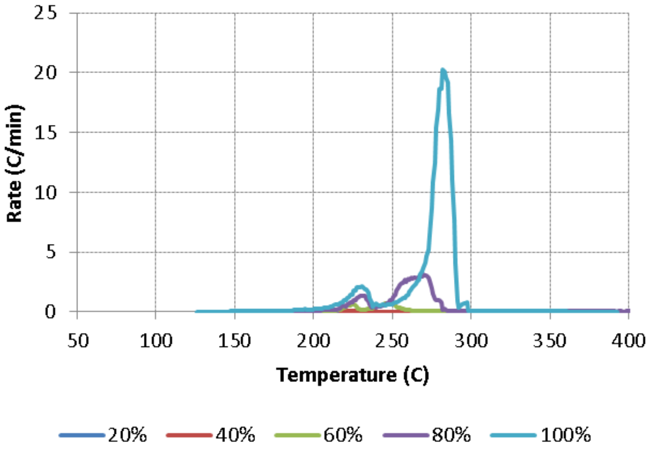
SNL Accelerating Rate Calorimetry (ARC) Testing Results

ANL funded ARC and thermal ramp testing at Sandia (PI: Josh Lamb) to assess 16 Ah LG-CPI lithium-ion pouch cells (NHTSA provided)

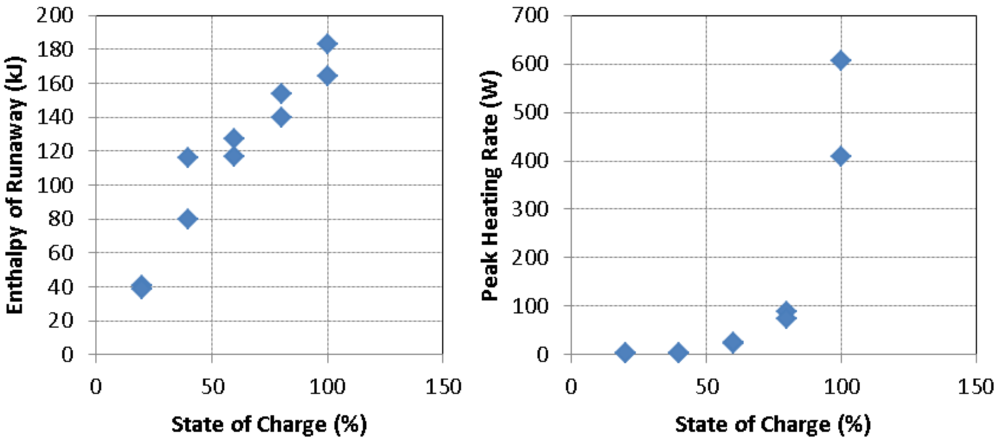
- ➢ Observe trends versus SOC for large format cells
- ➢ Support evaluation of “safer” SOC levels post incident

- **Below 60% SOC shows significantly lower heat release and 40% and lower is very small**

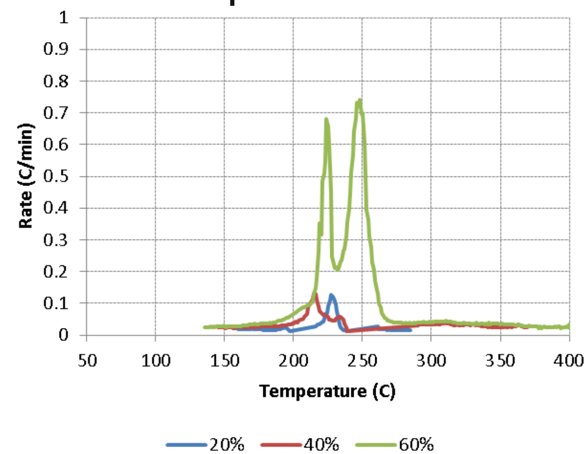
ARC Heat Release Rate vs. Temp/SOC



ARC Results vs SOC



Close-up: 20-60% SOC



In-field Battery Failure Discussion

Pack failures in the field are often a mix of several different failure modes:

Fisker Issues (from Sandy flooding) highlighted

Water Intrusion

BMS Damage and Shorting

Module Damage

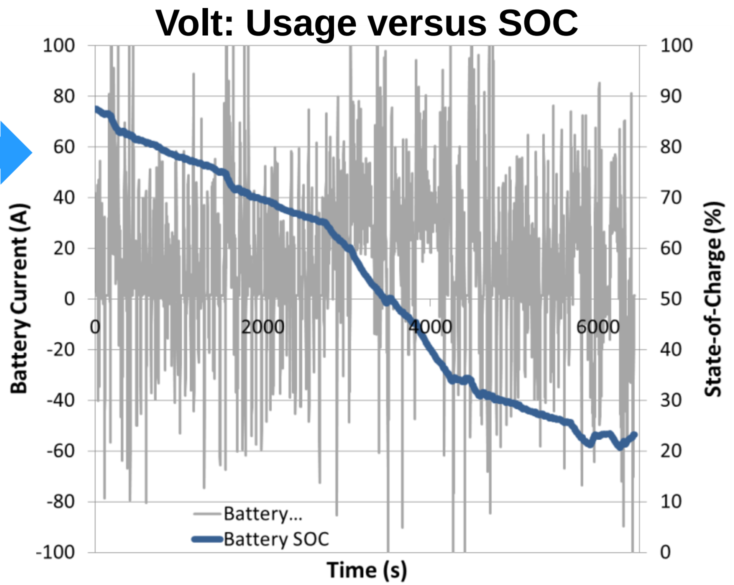
Arcing/Discharge

Cell Damage

Operational and Post- Incident Battery Diagnostics

Common operational diagnostics

- **State-of-charge (also SOE)** – Often used as gauge of remaining energy…SOC actually relates to concentration and inherent state
- **State-of-health** – Typically estimates usable life left in battery and power fade/resistance increase



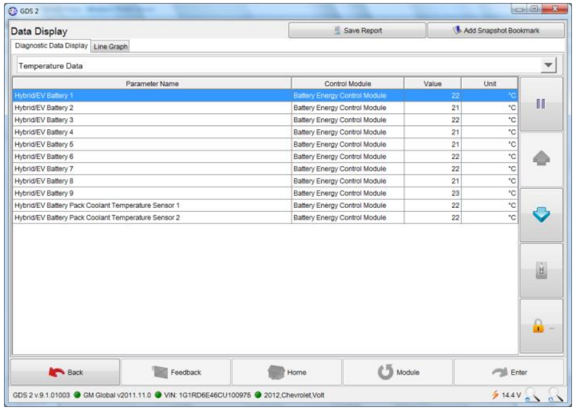
- **Cell-to-cell variation** – Typically used to inform balancing and identify faulty cells
- **Min/max cell voltage** – Used for pack management, balancing, and fault detection
- **Estimated cell resistance** - Used to detect cell faults and power capability
- **Pack temperature(s)** - Used for thermal management and fault detection
- **Isolation resistance** – Checks for electrical isolation faults between battery and vehicle ground(s)

Most major faults related to stranded energy/runaway can be detected through isolation resistance tracking and voltage probing/trending

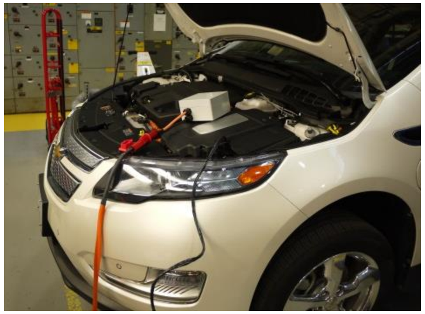
Prototype Design Directions

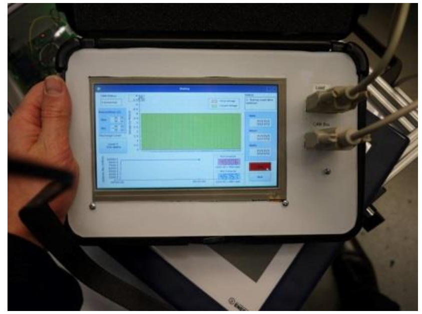
Research focused on a wide spectrum of possible solutions, but several key ideas span the work…

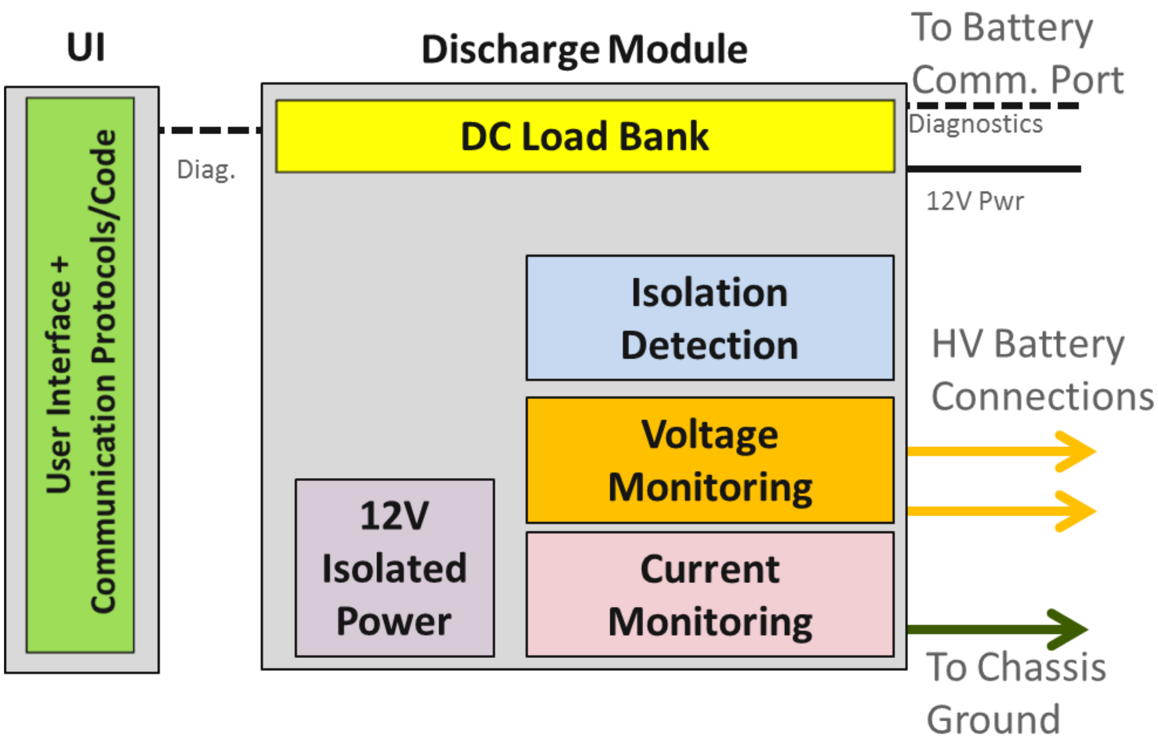
- Work within the existing (and successful) safety protocols
- Leverage existing vehicle hardware whenever possible
- Avoid introducing additional failure modes
- Focus on tool modularity to accommodate a range of issue severity



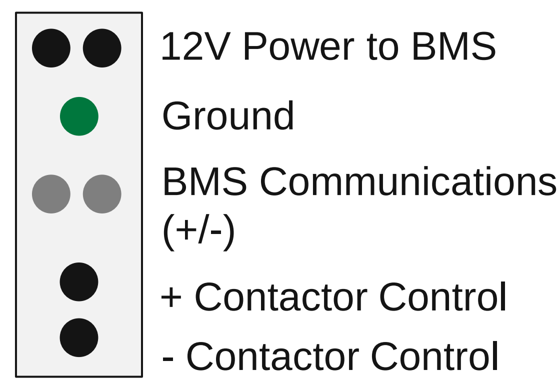
Modular Discharge/Diagnostic Tool Overview







Recommended Battery Interface Port



Discharge Tool Diagnostic Screen