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Ultracapacitor/Battery Hybrid Designs: Where Are We?

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Objectives

- Better understand ultracapacitors: what they are, how they work, and recent advances in new designs and capabilities
- Discuss potential applications in traditional energy storage applications for ultracapacitors
- Comparison of ultracapacitor and battery characteristics, performance, pro’s/con’s
- Introduce the concept of ultracapacitor/battery hybrid systems, aimed at maximizing & combining the best performance features of each
- Review Mesa/Ioxus Test Data & Results

Challenges For Old School Battery Guys

- **Capacitor people talk funny**
  - Farads, joules & coloumbs vs. AH
  - Power delivery vs. energy storage
  - Don't care about cycling, temperature, or depth of discharge
- **Needed to create a 'Rosetta Stone' so we could communicate**
- **Bode & Vinyl not much help**; IEEE 485 not designed to address this combination of technology; not a lot of information describing how ultracapacitors and batteries work together in stationary applications

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Comparison of Batteries & Ultracaps

- Batteries can store a lot of energy, but are limited in terms of power density
- Batteries can support long-term, steady state discharges, but can't respond well to momentary, high rate power demands
- Ultracaps have the opposite characteristics: limited in terms of total energy storage (compared to batteries), but with very high power density relative to size
- Ultracaps differ from traditional capacitors in their utilization of nanoscale electric double layers, giving them orders of magnitude greater energy storage capabilities

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Ultracaps

- 500,000 to 1 Million cycles
- Fairly impervious to temperature (-40°C to 65°C)
- Charge/Discharge at least 100 times faster than batteries
- Extremely broad voltage window – 0V to 2.7V (Doesn't care about total discharge to 0)
- No chemical reactions during charge/discharge
- Very predictable in terms of SOH (state of health), DOD (depth of discharge), therefore making it easy to predict EOL (end of life)
- Maybe its role is expanding beyond just power delivery applications (load leveling, peak shaving, power factor correction); might be a future role in **energy storage**

Batteries & Ultracaps: Review

- Lead acid battery ideally suited for long-term, steady power discharge
- Ultracaps ideally suited for very high rate, momentary loads, and can recharge as quickly as charge current is available
- Is there a role in the relative near future for ultracaps in traditional energy storage applications?
- Is there a way to combine the optimal performance characteristics of each technology into a single, higher performance hybrid system?

Traditional Stationary Energy Storage Application: Utility Sub-Station/Power Generation

- Typical utility load has two distinct & different functions:
  - Long-duration back-up for relatively low power ‘base’ loads (2-15 Amps common)
  - Providing high peak current for momentary & tripping loads like switchgear, circuit switchers, or circuit breakers (300 – 400 Amp momentary loads common)
- This high rate momentary load significantly impacts overall battery system size.
- IEEE485 sizing guidelines aimed at handling coup de fouet
- Lead acid batteries can’t respond quickly to these high rate loads; requires a much larger battery to handle these momentary loads.

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A Tale of Two Cities: IEEE 485 Sizing Profiles For Two Load Scenarios

Scenario 1: Fossil Fuel Generating Plant

- Fig. 1. Load profile reveals high momentary inrush at beginning (1548 Amps) & end (468 Amps) . Using a traditional lead Acid Battery only, the IEEE 485 sizing calculations call for a 2500AH lead acid flat plate battery
- Fig. 2. Assuming an ultracapacitor to handle these momentary loads, the new IEEE485 load calculations call for a 1630AH lead acid flat plate battery.
- Adding an ultracap cuts the battery size by almost 40%

A Tale of Two Cities: IEEE 485 Sizing Profiles For Two Load Scenarios

Scenario 2: Utility Sub-Station

- Fig. 3. Load profile reveals high momentary inrush at beginning & end of 400 Amps; IEEE 485 sizing calculations call for a 800 AH lead acid tubular plate battery
- Fig. 4. Assuming an ultracapacitor to handle these momentary loads, the new IEEE485 load calculations call for a 50 AH lead acid tubular plate battery….a very significant reduction in recommended battery size.
- These two scenarios suggest that there are significant opportunities to reduce battery system size with the use of ultra capacitors in battery systems to handle high momentary loads.

Mesa/Ioxus Tests: Ultracap/Battery Hybrid System

Putting It to the Test

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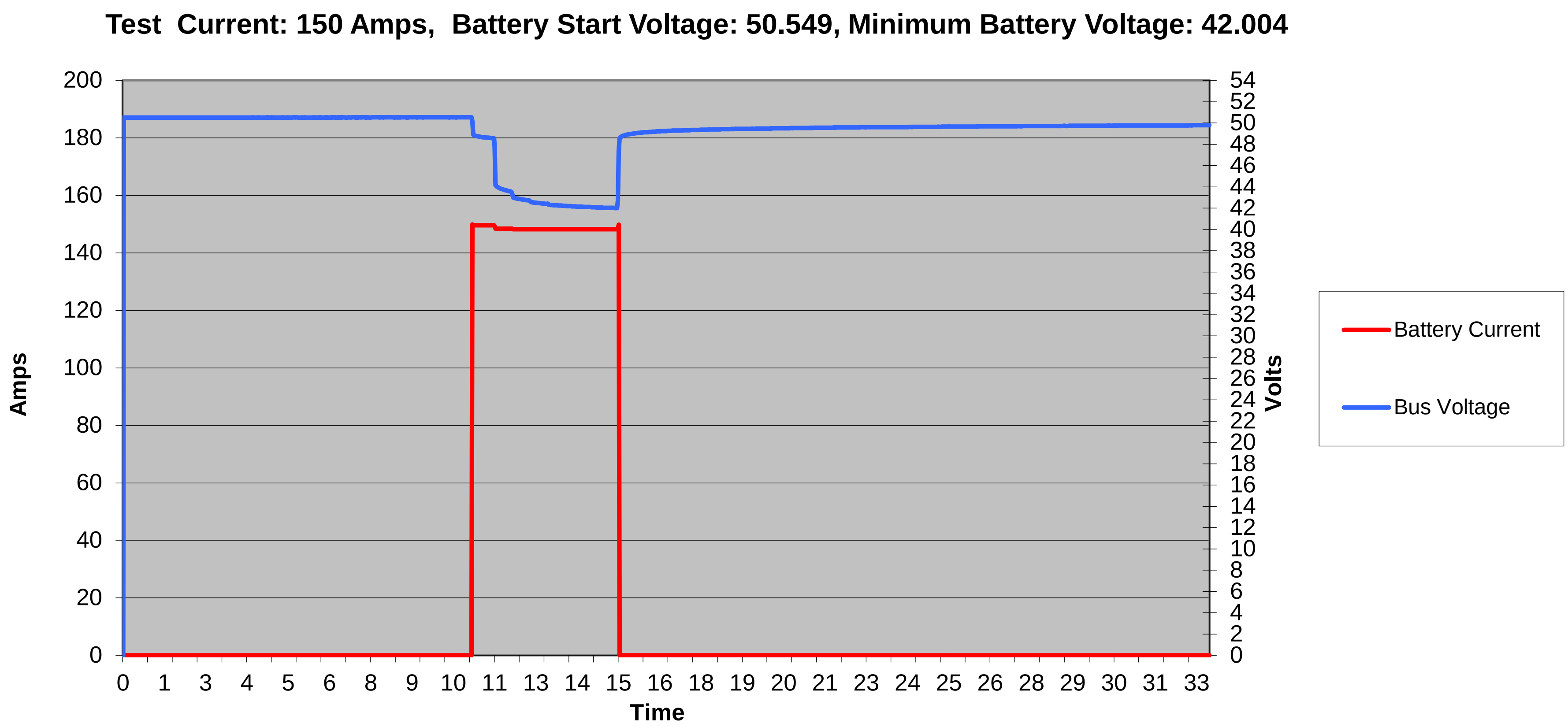
Test Setup

- 24 cell lead selenium, tubular plate, flooded battery
- Configured in parallel with 20 cells of 2000F Ioxus ultracapacitors (done to create a 100F capacitor bank)
- Alber Model 2N load bank w/ BCT 128 Data Logger
- Used load profile from Fig 3: 400 A momentary load up front, 10A continuous, and 400A at end
- Test intended to capture contributions of both the ultracap and the battery, working together as a hybrid system
- BCT not designed for data capture of momentary loads, so a high speed data logger was added, enabling data capture of fast transient loads (40 shots/second)

Battery Performance Alone: Momentary Loads

Battery alone can support approx. 150 A for short durations (2-3 seconds), while maintaining minimum required bus voltage



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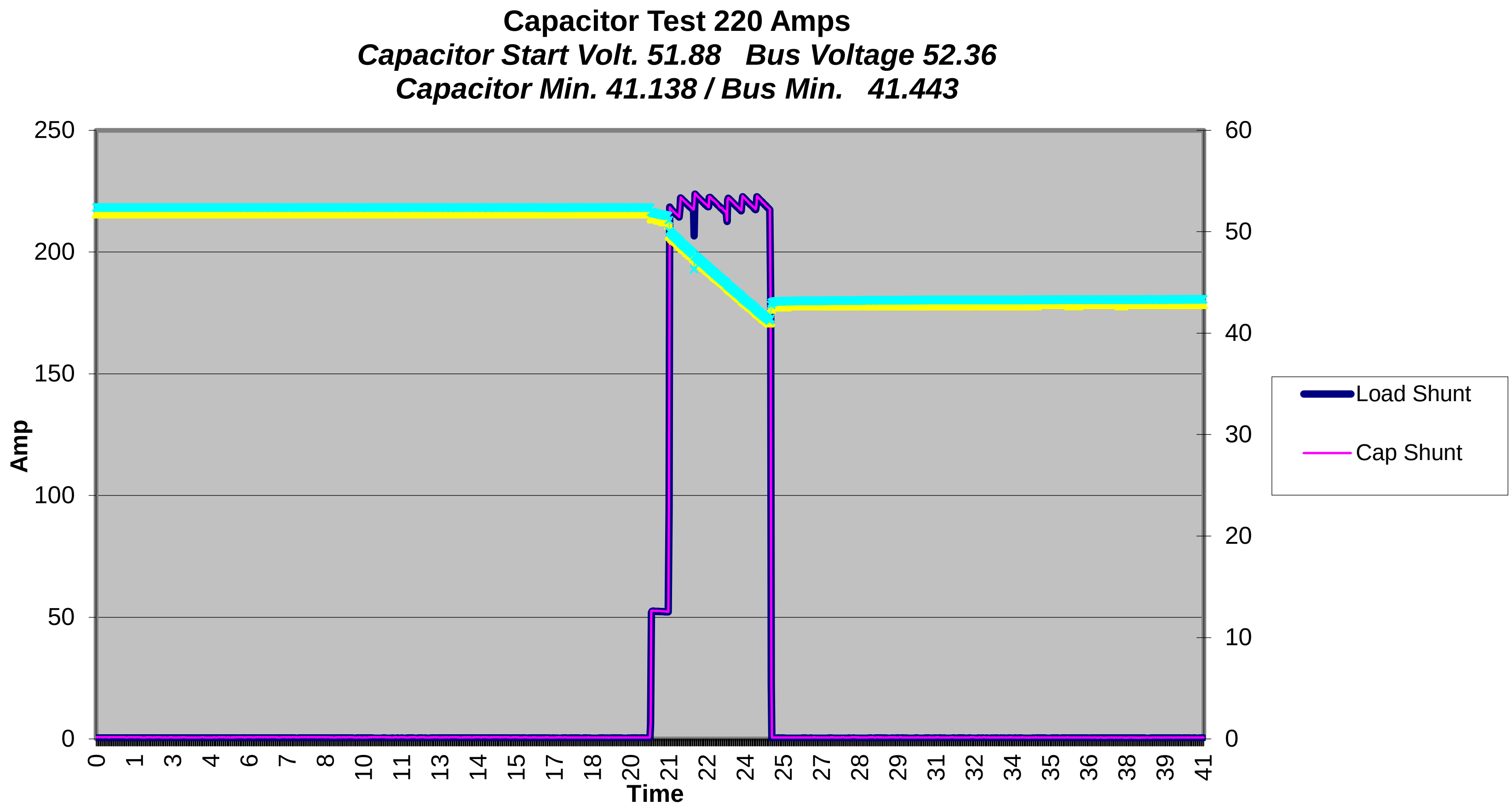
UltraCap Performance Alone: Momentary Loads

Ultracap handled 220A for 4 seconds (would have handled 400+A if we could create 1 second surge w/ resistive load)



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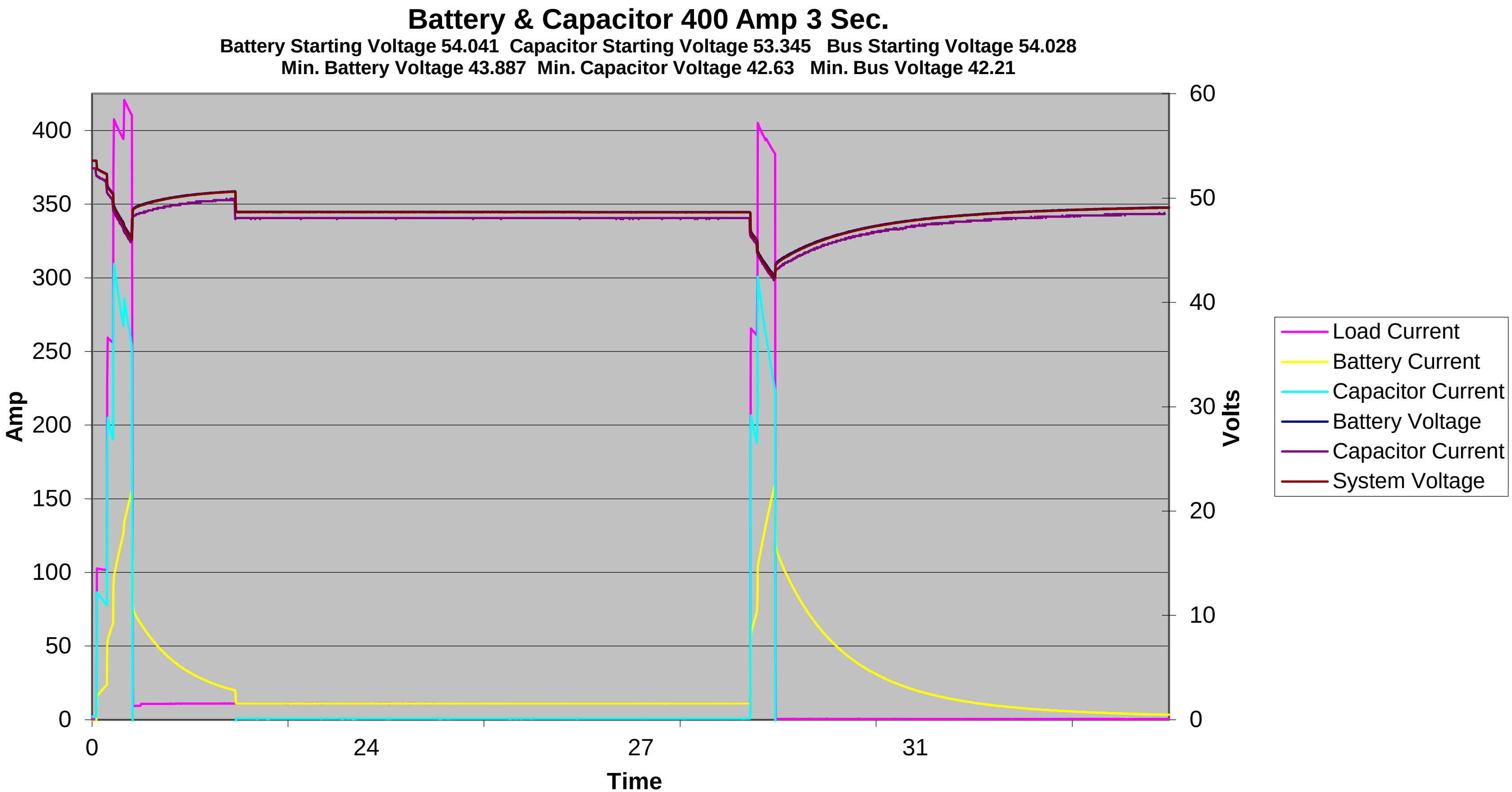
Hybrid Performance: Momentary Loads

30 minute load profile w/ 400A momentary loads at beginning & end. Supports max. surge of 440A for 3 seconds, with a 100AH battery & 100F cap, maintained system voltage. <u>System Worked, and is scalable</u>.



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Observations & Implications

- **Initial system cost:** For some of the load scenarios we tested, there are significant initial cost savings possible thru reduction in battery sizing
- **Footprint:** Potential for better utilization of critical space through smaller system size & weight.
- **Installed Cost:** Potential reductions in logistics, handling, and installation costs of back-up systems.
- **Long-Term System Performance & Reliability:** Ultracaps have a long cycle life, no maintenance, very high performance, and would add to overall system reliability.

Something To Think About

- Ultracaps currently store about 10% of the energy compared to comparably sized battery
- Research being done at places like MIT and Ioxus aimed at increasing this energy storage to **25%** in the near term future
- Has the potential to be a disruptive technology in the power industry