Bipolar Nickel Metal Hydride Battery Development and Testing

DOE ENERGY STORAGE SYSTEMS RESEARCH PROGRAM

ANNUAL PEER REVIEW

November 2 – 3, 2006, Washington, D.C.

James Landi jlandi@electroenergyinc.com
203-797-2699

Program Objectives and Benefits

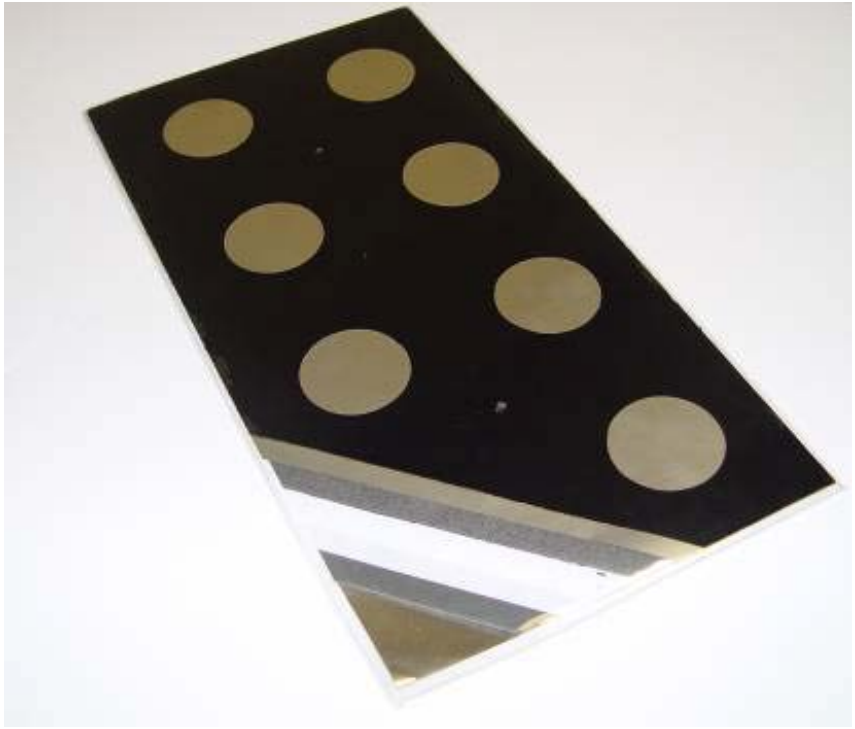
- The objective of this program is to further develop the bipolar NiMH battery design to be used in high-energy and high-power energy storage applications.
  - Build and demonstrate large-format batteries
  - Demonstrate these batteries in present and future applications

- The bipolar NiMH battery could provide the following benefits:
  - Improve efficiencies by reducing transmission peaking losses and shifting peak demands.
  - Reduce power and voltage sag to users.
  - Provide an efficient method to distribute backup energy/power for utilities to ensure uninterruptible service to their customers.
  - Increase reliability of solar and wind systems that require energy storage.

Program History

- This program commenced September 2005, and is a continuation of previous development and demonstration programs.
- Previous Accomplishments
  - Built and delivered a 600 V, 35 kWh, 20 kW Inverter battery system
    - Effort was in collaboration with First Energy
    - Testing done by EPRI Solutions in Knoxville, TN
  - Built a 500 V, 100 kVA UPS battery system, replacing ultra-capacitors
  - Built and delivered a 48 V, 50 Ah battery for a 3 kW UPS system
  - Successfully demonstrated a high power 40 kW, 350 V battery module
- Present Program Milestones
  - Market Assessment
  - Design and Performance Improvements
  - System Builds and Demonstrations

EEI's Bipolar Wafer Cell Battery Design



- Current flows perpendicular to all electrode surfaces
- Active materials are efficiently utilized, minimizing internal resistance
- Flexible form factor
- 25% higher power
- 25% less volume
- 25% lower manufacturing cost
- Environmentally friendly
- Excellent life

ELECTROENERGY

Two Bipolar NiMH Battery Types

High Energy NiMH

- Thicker/higher capacity electrodes
  - High Energy/Lower power per unit weight and volume
    - >50 Wh/kg, >140 Wh/L
    - 35 W/kg, 100 W/L – Continuous
- 12 V to >600 V systems

High Power Applications

- Thinner/lower capacity electrodes
- High power/Lower energy per unit weight and volume
  - >1 kW/kg, >2.6 kW/L - <10 second pulse
  - >30 Wh/kg, >80 Wh/L
- 12 V to >700 V systems

ELECTROENERGY

Electro Energy's Market Assessment of High Power and High Energy Storage

- EEI is conducting an ongoing market assessment to identify opportunities and pilot demonstrations for the bipolar batteries
- Three market segments identified as prime candidates for bipolar battery applications
  - Electric Utilities
  - Critical Infrastructure Service Providers
  - Multi-Tenant Buildings
- Energy storage solutions have two significant hurdles to overcome:
  - Education: Understanding the benefits associated with batteries
  - Investment: The economics of battery technology remains a barrier

ELECTROENERGY

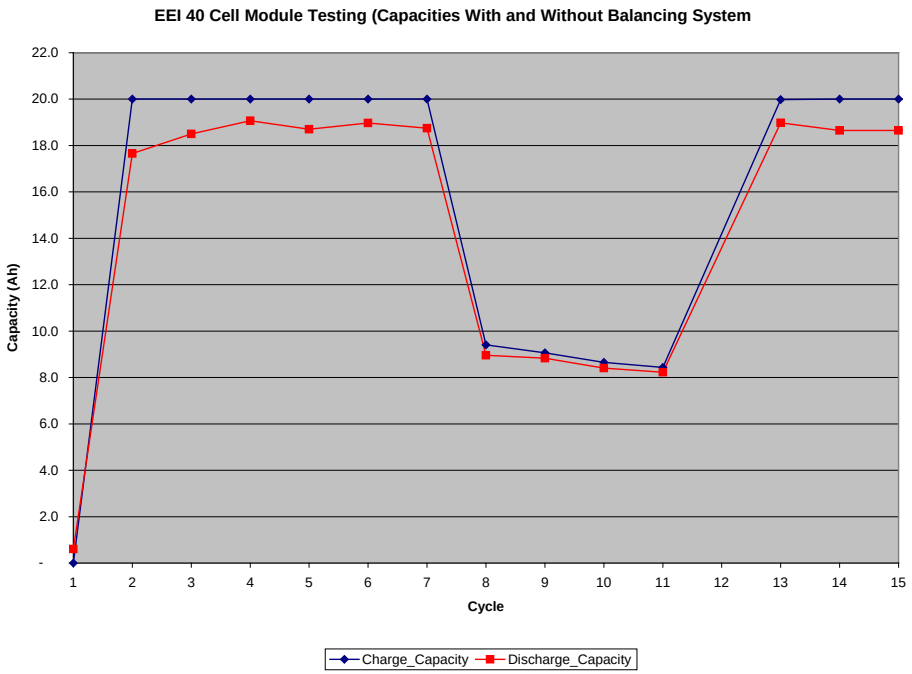
Design Improvements

- Optimized negative-to-positive ratio resulting in improved performance and increased cycle life.
- Improved electrode production processes
  - Established a continuous nickel foam based production process for energy cells
  - Developed in-house capability to produce hydride electrodes for energy cells
  - Developed a thin coating process for nickel and hydride electrodes for power cells
- Implemented an automatic electrolyte filling process
- Developed and implemented a sealed stack formation process
- Investigated alternate materials leading to cost reductions

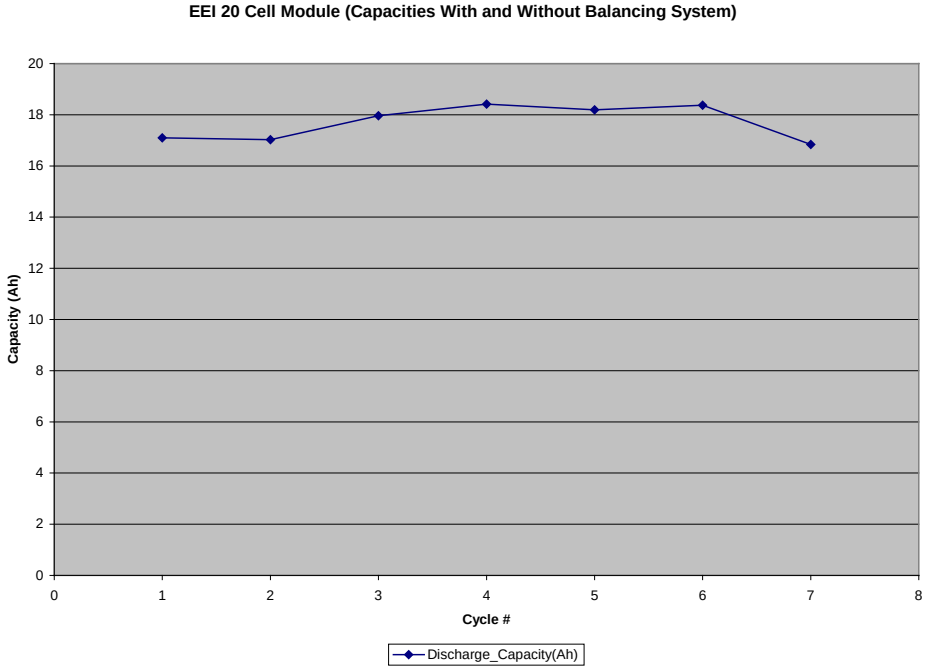
Cell Balancing System

- EEI has been utilizing a commercial cell balancing system to balance every 5, 10, 15, 20, or 30 cells in battery systems
- Results in improved capacity, reduced heat, and increased efficiency

Severely Unbalanced Pack Shows 100% Capacity Increase



Typical Pack Shows Greater than 5% Capacity Increase



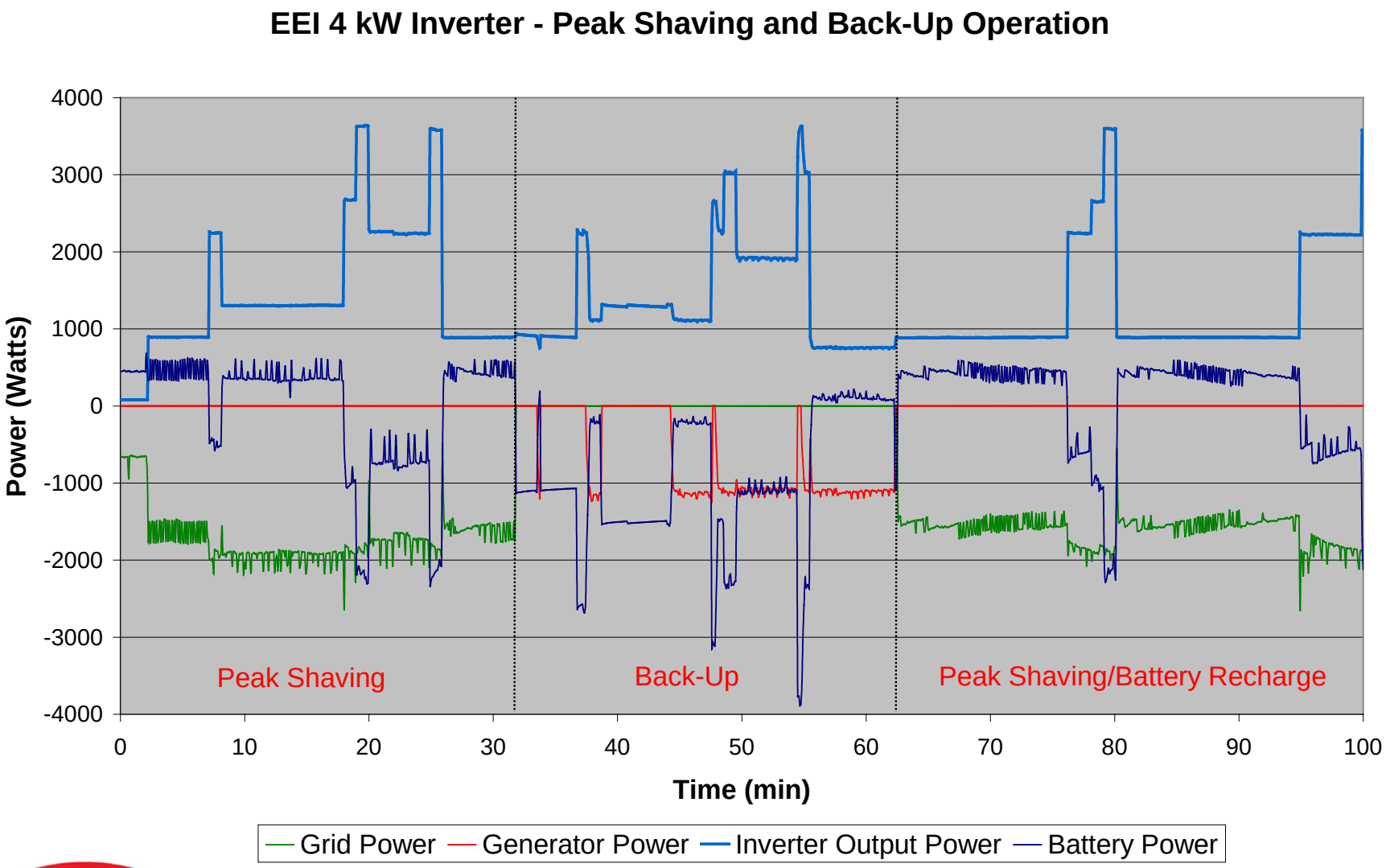
ELECTROENERGY

EEI 4 kW Inverter Peak Shaving/Back-Up System

- 4 kW Inverter
- 1.5 kW Generator
- 3 – 1 kWh Batteries (Each 48 V, 20 Ah)

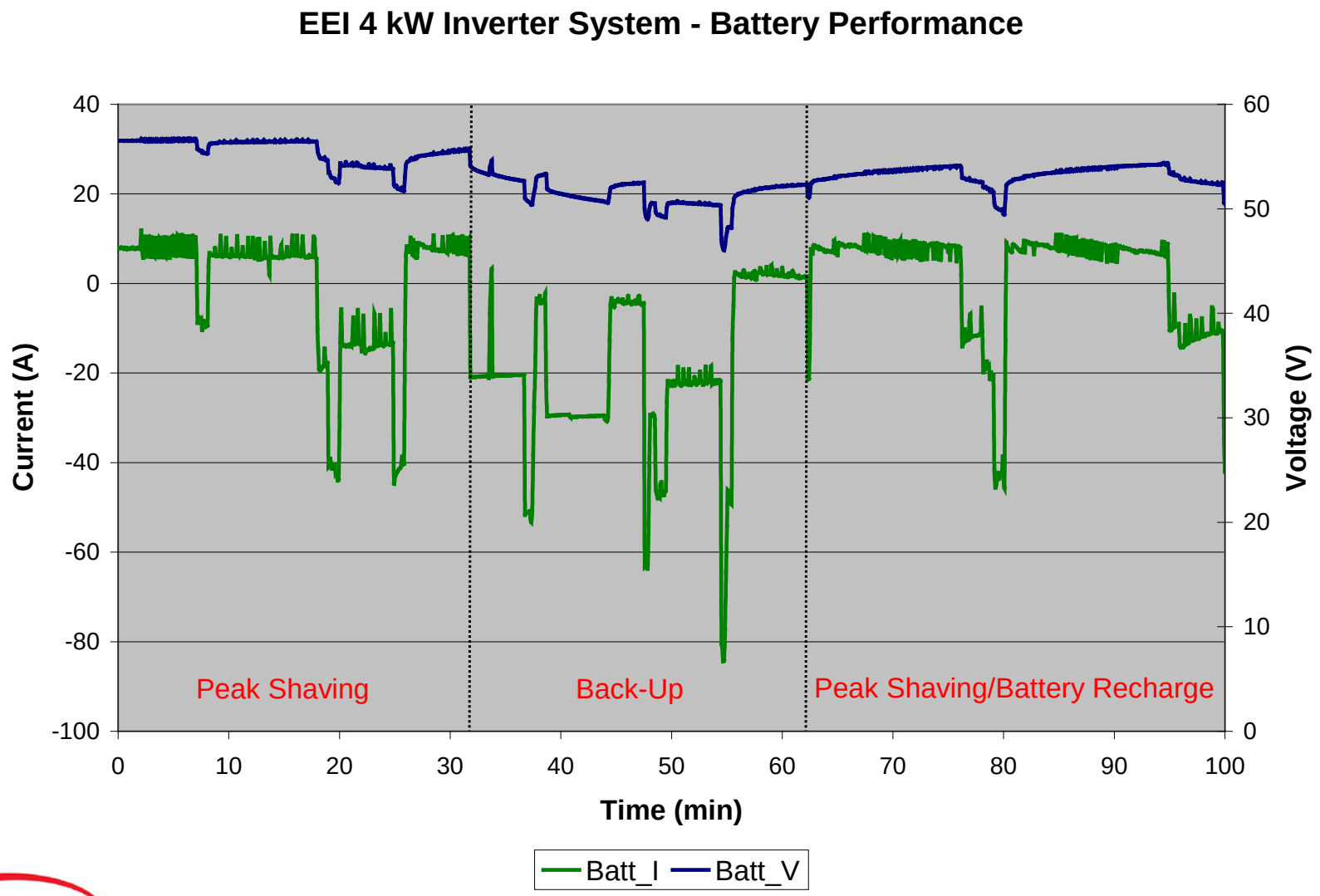
ELECTROENERGY

EEI 4 kW Inverter Peak Shaving/Back-Up System



ELECTROENERGY

EEI 4 kW Inverter Battery Performance



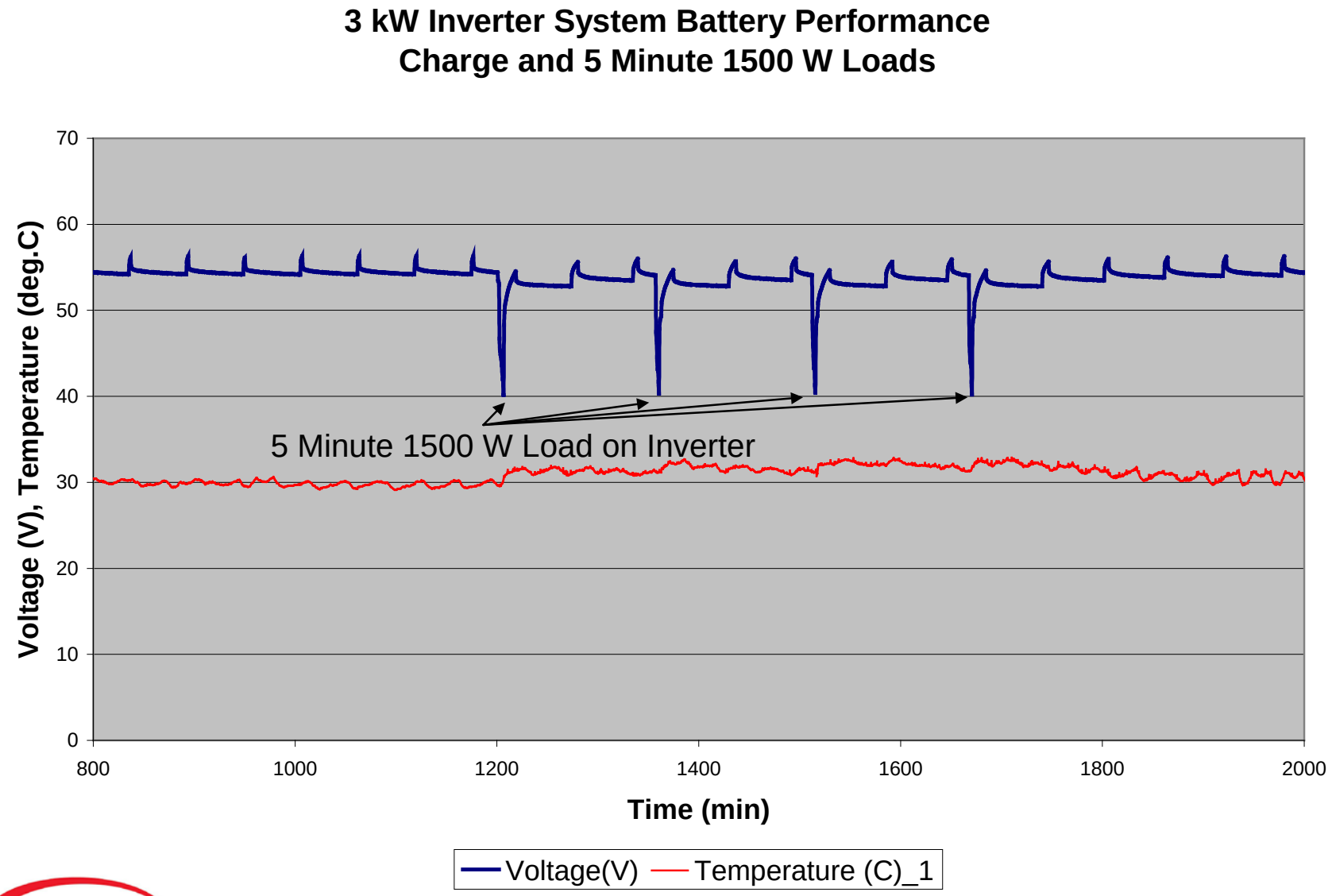
ELECTROENERGY

3 kW UPS System

- 3 kW UPS System
- 1 kWh Battery (48 V, 20 Ah)

ELECTROENERGY

3 kW UPS System – Battery Data



ELECTROENERGY

100 kVA/ 500 V High Power UPS System

Module Design

- Five 39-Cell Stacks in Series
- 5 Ah, 250 V
- 6.62” x 15” x 11.5”, 100 lbs

Complete System:

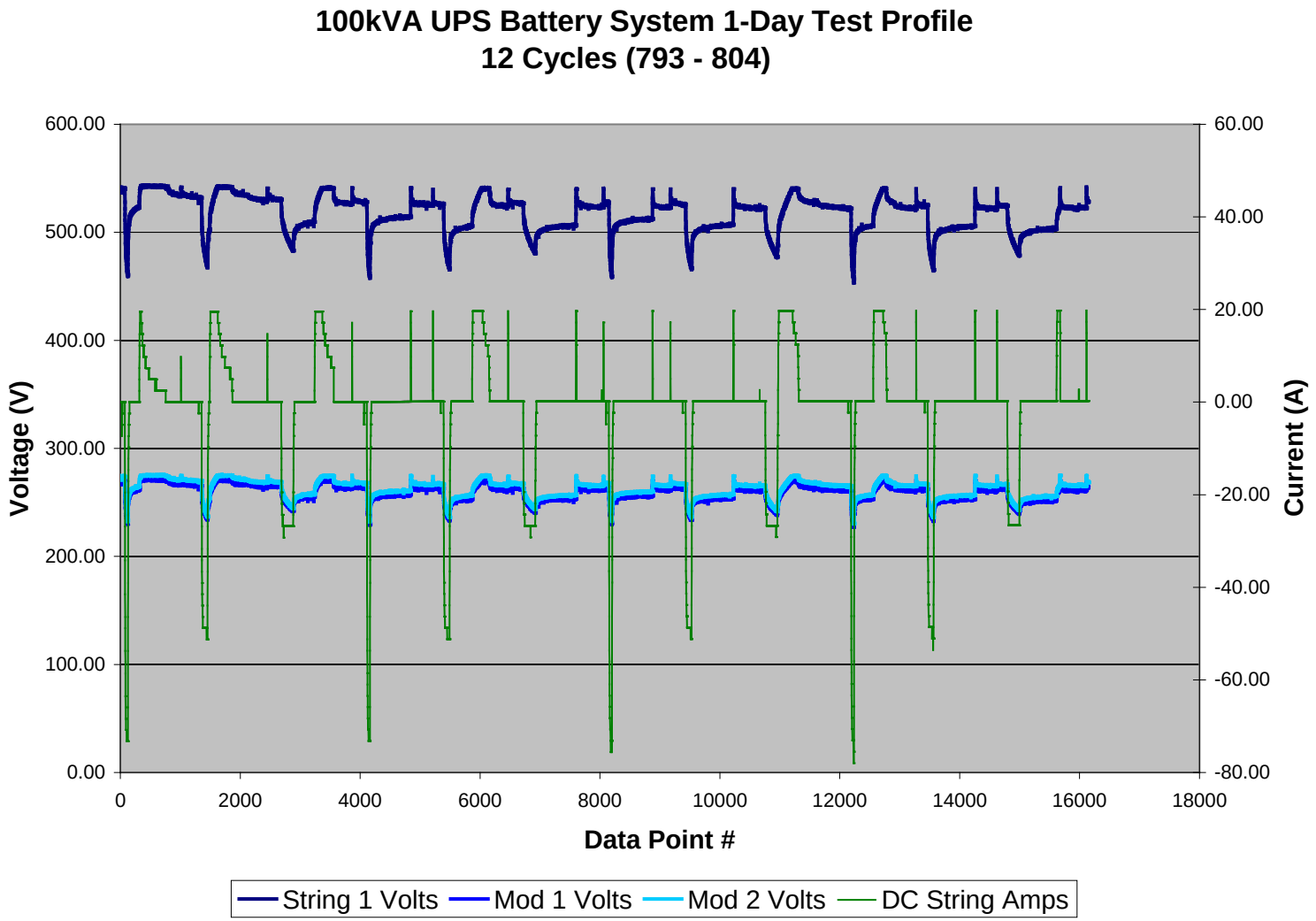
- 2 Parallel Strings of 2 Modules Series
- 5 kWh, 100 kVA
- 10 Ah, 500 V

Actual Testing System

- 1 Strings of 2 Modules in Series
- 2.5 kWh, 50 kVA
- 5 Ah, 500 V

ELECTROENERGY

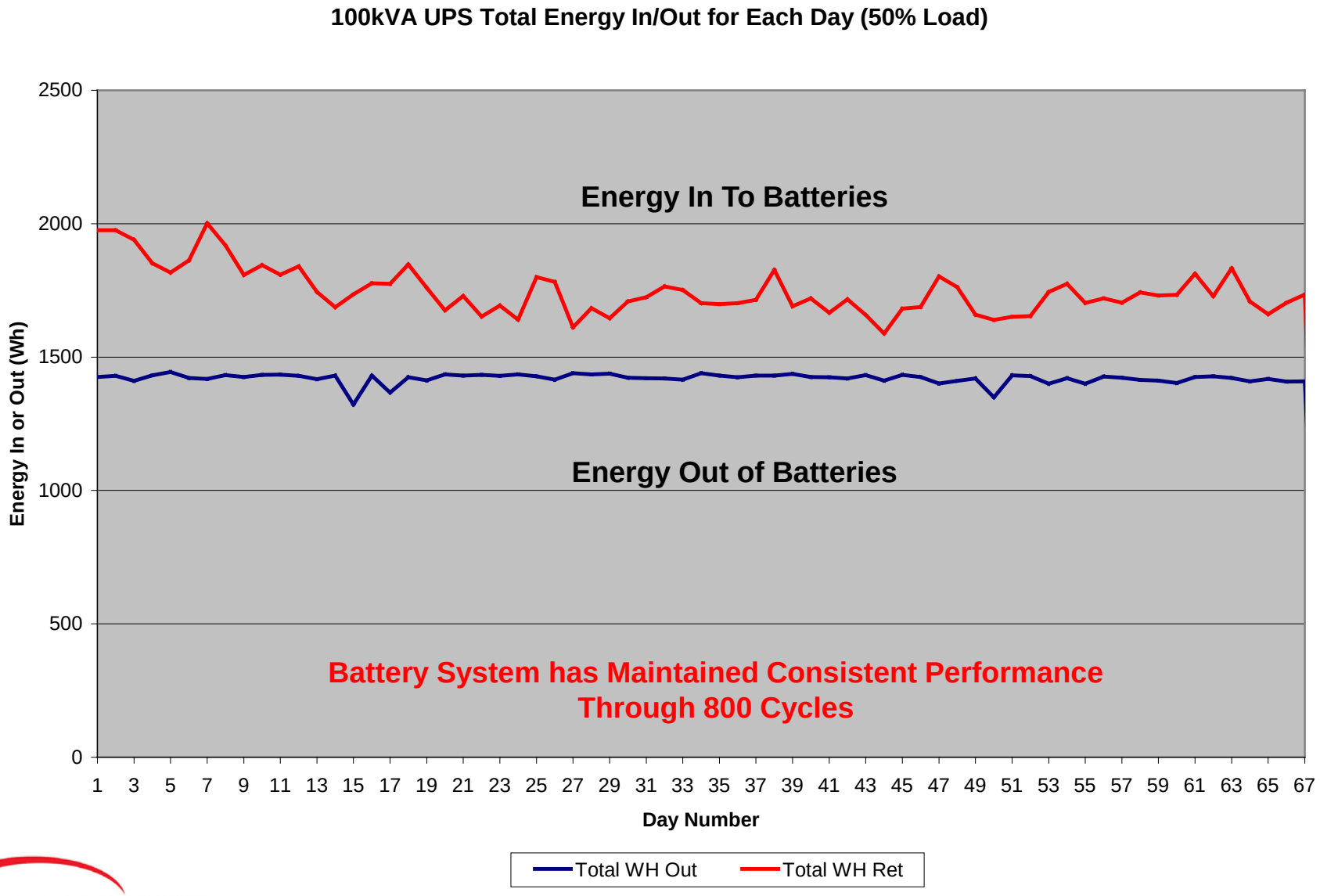
100 kVA UPS Battery 1-Day Test Profile (50% Load) Cycles 793-804



ELECTROENERGY

Battery System has Maintained Consistent Performance Through 800 Cycles

100 kVA UPS Battery Daily Energy In and Out (50% Load), at 800 Cycles



ELECTROENERGY

Plug-In Hybrid Electric Prius With Electro Energy's Bipolar Nickel Metal Hydride Battery

Module Configuration

60 cells, 15 Ah, 73 V, 1.1 kWh

60 lbs

Battery System

Two parallel strings of three modules in series

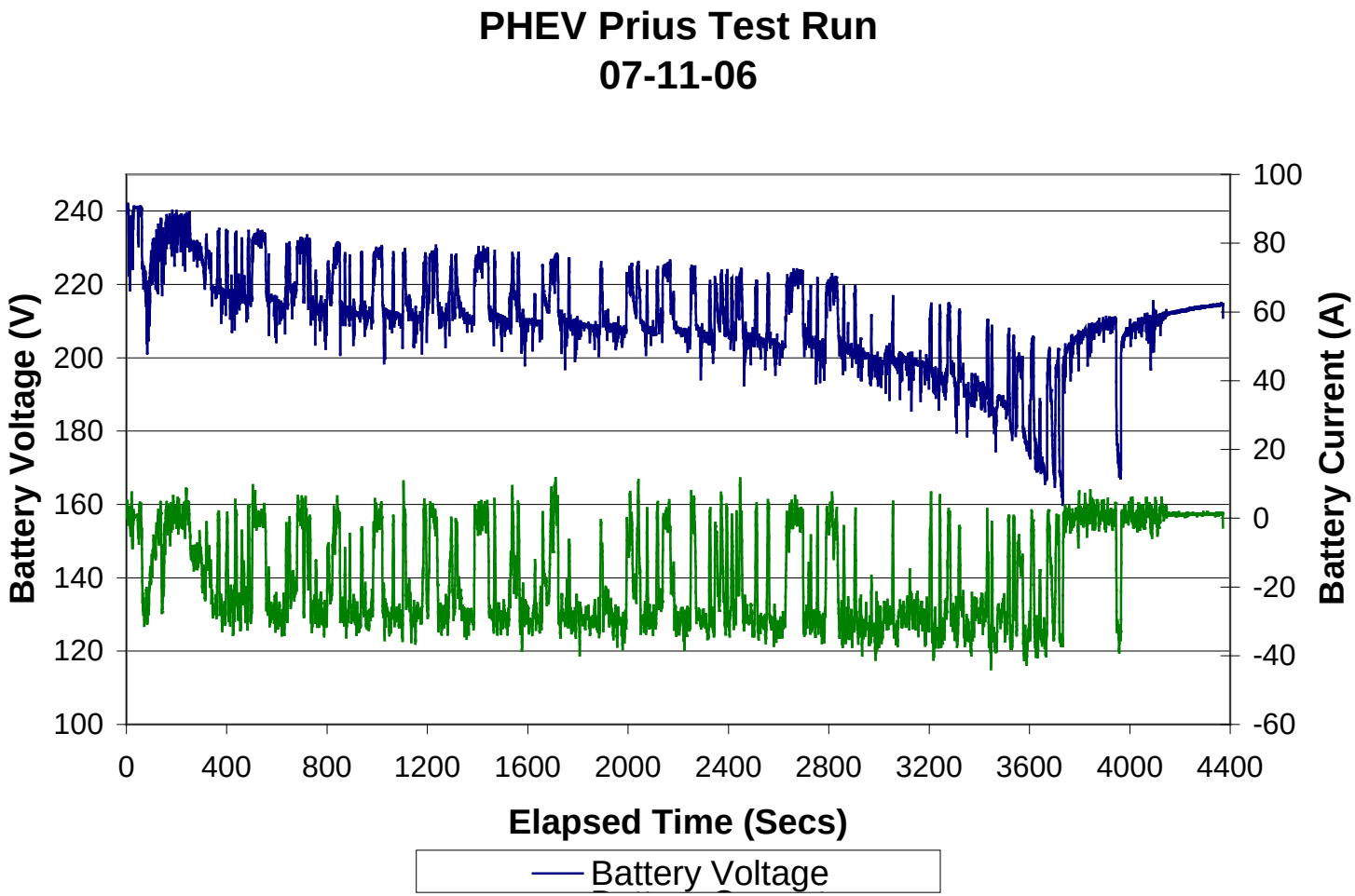
21.25" x 39.00" x 8.00", <400 lbs

All electric range: 20-22 miles

ELECTROENERGY

Plug-In HEV - 19.7 Mile Drive (All-Electric)

PHEV Battery Discharge Profile - Parallel with HEV Battery



21.3Ah, 4.5kWh removed – 0.92Miles/Ah, 4.38Miles/kWh)

ELECTROENERGY

Summary and Conclusions

- Bipolar cell design was optimized
- Module and battery performance was improved through cell/stack balancing
- Bipolar cell production processes were developed for volume manufacturing
- High-voltage modules/systems were tested, achieving multiple cycles
- The bipolar NiMH batteries were demonstrated in multiple applications

Continued and Future Efforts

- Manufacturing Process Development

- Bipolar Battery Module Optimization
  - 144 V, 6 Ah High Power Modules
  - 75 V, 20 Ah Energy Modules
  - 110 V, 15 Ah Energy Modules

- Battery Systems Pilot and Demonstration

Company Developments

- April 2006, acquired assets of battery facility in Gainesville, Florida area formerly owned by Energizer
  - Leased 200,000 Ft^2 of manufacturing space
  - Simultaneous with acquisition raised working capital to be used for:
    - Equipment up-grades
    - New Equipment
- Gainesville acquisition will accelerate commercialization and growth plans:
  - High volume electrode manufacturing for Li-Ion and Ni based products
  - Highly automated capabilities for 18650 Li-Ion cells – 30m/yr
  - Equipment can be adapted for bipolar battery manufacturing
  - High volume commercialization of bipolar Ni-MH batteries
  - Leverage bipolar expertise developed for Ni-MH into Lithium-Ion batteries
- Gainesville facility provides EEI with necessary manufacturing assets to become a leading supplier of specialty rechargeable batteries in North America

ELECTROENERGY

Acknowledgements

Electro Energy, Inc. has received funding for this effort from the Department of Energy.

In particular EEI would like to thank Dr. Imre Gyuk of The Department of Energy

Nancy Clark and David Ingersoll of Sandia National Laboratories for Program Management

ELECTROENERGY