Bipolar Nickel Metal Hydride High Power and Energy Storage Batteries for Utility Applications[1]

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Abstract
Under programs with the Department of Energy and Sandia National Laboratories, Electro Energy, Inc. (EEI) has developed high-power and high-energy bipolar nickel metal hydride batteries to meet the broad requirements of energy storage for utility applications. Presently available rechargeable batteries generally fall short of the required mix of characteristics necessary to meet the performance requirements of these systems while still remaining economically competitive. Capacitors and ultra-capacitors have significant power but do not have the necessary energy storage capability. EEI's unique bipolar design based on flat wafer cells has resulted in higher power and energy densities for the nickel-metal hydride chemistry. This design approach results in reduced weight and costs, and increased performance, over other competing energy storage devices. These advantages make the EEI design a logical choice for customer side power quality and peak shaving applications, as well as wind, solar, and other electric utility energy storage, power and automotive applications.

The implementation of this battery design would provide the following benefits: 1) improved efficiency by reducing the peak generation demands and shifting these demands to more efficient load generating equipment for night-time battery charging, (2) reduced power and voltage sag to users, coupled with reliable backup power, (3) an efficient method to distribute energy/power backup for utilities to ensure uninterruptible high quality power to their customers, (4) increased reliability of continuous solar and wind systems that require energy storage, (5) power assist for fuel cells used for electric generation, and (6) reduced volume and cost batteries for automotive applications. EEI is developing and demonstrating technology for 500V/100kVA and 50V/3kW inverter systems, high-power 350V and 42V applications, and high energy 600V/40kWh/20kW UPS systems and pluggable hybrid power systems.

Introduction
Rechargeable batteries with long life and low cost play a significant role in the energy efficiency, environmentally friendly field by reducing electricity cost and pollution. A rechargeable battery can function as an energy reservoir, carry electrical energy for portable applications, or provide peaking energy when a demand for electrical power exceeds primary generating capabilities. Available rechargeable batteries generally fall short of the required mix of characteristics necessary to make these systems competitive with alternative approaches with regard to performance and economics. Capacitors and Ultra-capacitors have significant power but do not have the necessary energy storage capability. Therefore, the driving consideration for the viability of such systems is the availability of an advanced rechargeable battery that has a mix of characteristics superior to existing batteries or alternative energy systems presently available.

Electro Energy, Inc. (EEI) has developed a unique, advanced design, high power, high energy, long life, clean, safe, and low cost bipolar nickel-metal hydride battery to be used in a broad range of applications. EEI's wafer cell bipolar Ni-MH battery technology provides considerable performance advantages over conventional and advanced lead-acid and other battery systems, and delivers superior energy density and cost advantages over conventional Ni-MH and nickel-cadmium battery designs. BP Ni-MH batteries are approximately one half the weight and size and have three times the life of the best commercially available Pb-acid battery.

Figure 1 shows a schematic cutaway of the EEI bipolar cell and Figure 2 shows the schematic of the bipolar battery design concept. Individual flat wafer cells are constructed with contact faces, one positive electrode, a separator, and one negative electrode. The contact faces serve to contain the cell and make contact with the positive and negative electrodes. These contact faces are sealed around the perimeter of the cell to contain the potassium hydroxide electrolyte. To fabricate multi-cell batteries, identical cells are stacked, one on top of another, so that the positive face of one cell makes contact with the negative face of the adjacent cell, resulting

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in a series connection of the cells. To complete a full battery, current collecting contact sheets are placed on the end cells to serve as the positive and negative terminals of the battery and the entire stack is held in compression in an outer battery housing. By fabricating each individual wafer cell as a self-contained unit and sealing the perimeter of each cell, the design overcomes the historic problem of attempting to seal the edge of the multiple cells in a stack. The unit cells can be leak tested, electrically tested, and replaced if necessary to ensure the reliability of a full battery. The EEI battery design has several advantages as summarized in Table 1.

Figure 1: EEI's Cell Schematic Cut-Away

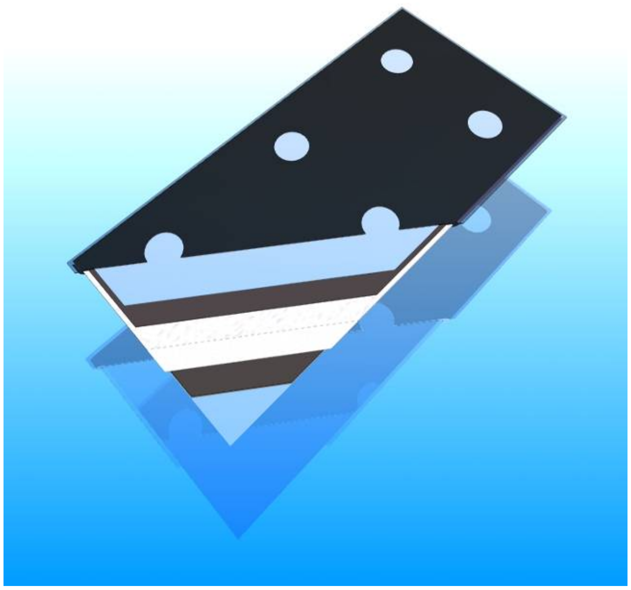


Figure 2: Bipolar Battery Design Schematic

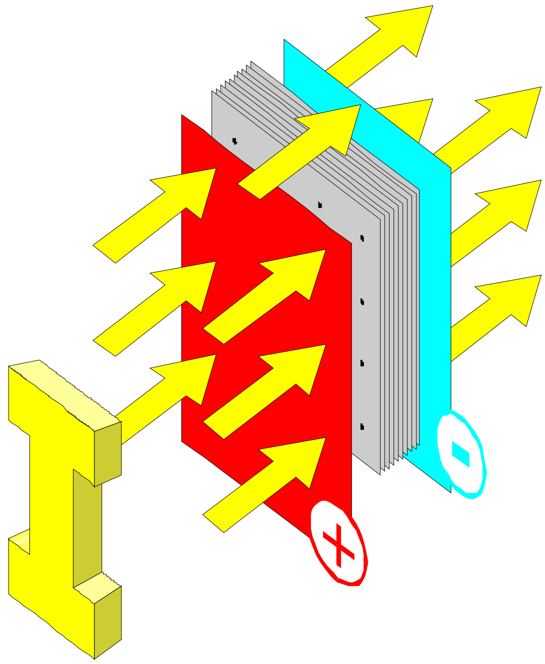


Table 1: Advantages of EEI Nickel Hydride Wafer Bipolar Design

Each cell individually sealed	Improved energy and power density
No external cell terminals or tabs	No separate cell-to-cell current collectors
Adaptable to heat transfer fins placed in stack	Scaleable to large area, capacity, high voltage
Compatible with coated or plastic bonded electrodes	Excellent thermal conductivity due to metal foils – adaptable to heat transfer fins placed in stack
Reduced battery impedance	Minimized path for current flow
Automated flexible manufacturing	Lower cost

EEI has been pursuing a number of applications utilizing this design concept. The concept is very flexible, enabling batteries to be configured with varying electrode thicknesses, electrode areas, and number of cells in series, thus fulfilling applications ranging from high energy to high power. EEI is developing and demonstrating technology for high-power NiMH systems in the range of 500V/100kVA and 50V/3kW inverter systems and 350V and 42V applications. EEI has also developed and demonstrated high energy systems up to the 600V/35kWh/20kW UPS battery system, as well as pluggable hybrid electric vehicle batteries [1-2].

High-Power Bipolar Batteries

Through efforts with the DOE, PNGV, and commercial organizations, EEI has been developing high voltage high power bipolar batteries for the past several years. A thin cell with a capacity of 6 Ah and an active electrode area of 6” by 12” has been identified as a baseline product. This cell has high power and low energy per unit weight and volume, and was designed specifically for low impedance and high rate capability. It has a typical weight of 170 grams and delivers 42 Wh/kg and 122 Wh/l of energy and greater than 1kW/kg and 2.7kW/l of 10 second pulse power at the cell level. The bipolar design facilitates the building of high voltage, high power systems, in small packages, thus greatly increasing battery power density. Identical cells are stacked with end contacts and held in compression with ribbed end plates and a battery housing to fabricate batteries.

The high-power bipolar design is ideal for such applications as high rate UPS/Inverter systems, load management, power quality, and peak shaving, in addition to hybrid electric vehicles and other automotive requirements. EEI has built, tested and delivered up to 700V systems, with pulse power capabilities greater than 70kW, for advanced military applications, 500V/100kVA and 50V/3kW inverter systems and 350V and 42V applications.

An example of such a battery is a 350V, 6 Ah module (rated at 5 Ah), shown in Figure 3. Two of these modules are connected in series for a 700V, high-power military application. The overall volume of the battery is 23 l, and the weight is 55 kg. The battery contains 255 of EEI’s high-power 6 Ah wafer cells in series. Figure 4 shows a 42 V, 6 Ah high-power module for use in automotive applications. The overall volume of this battery is 4.4 l, with a weight of 10 kg. It is comprised of 35 6 Ah cells in series.

Figure 3: 350 V, 6 Ah Battery Module.

Figure 4: 42 V, 6Ah Automotive Battery

Figure 5 displays a nominal 38 kW, 10 second discharge pulse on the 350 V module after it was charged to 100% SOC. Note that the current was not constant throughout the discharge – a resistive load was used. The power density at this operating point is approximately (305 V) (125 A) / 23 l, or 1.66 kW/l. The specific power is calculated as (305 V) (125 A) / 55 kg, or 0.69 kW/kg.

One calculates the battery resistance from the data presented in Figure 5 as (358 V – 318 V) / 128 A = 0.312 ohms (0.0012 ohms / cell). From a purely ohmic perspective, it is known that the maximum power point of a battery will occur at a battery voltage of OCV / 2. In our case, this would be at 358 V / 2 = 179 V. The expected power would be $V^2 / R = (179\ V)^2 / 0.312 = 102.7$ kW, and the specific power is 1.86 kW / kg. However, these figures apply only in the limit of a vanishingly small discharge time (probably 0.1 seconds or less). Therefore these power estimates are a probable upper bound on the delivered power capability of this battery [2].

Figure 6 is a 22 kW pulse discharge for 60 seconds, on the 350 V module. Here with an average current of 77A, we see a minimum voltage of 297 V, or 1.16 V per cell.

It should be emphasized that figures such as power density and specific energy are very dependent on the specific operating point chosen. Parameters such as temperature, battery SOC, discharge current, and discharge time can have a marked influence on power density measurements.

Figure 5: 350 V – 38 kW, 10s Pulse Discharge

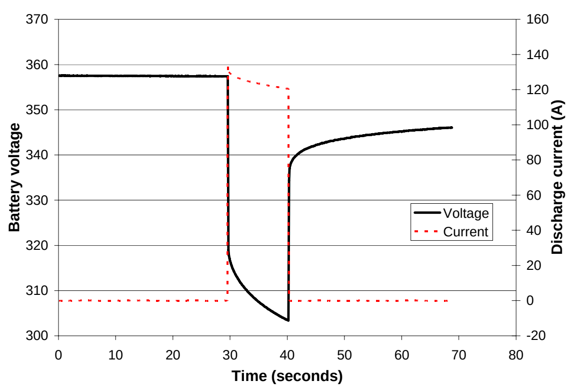


Figure 6: 350 V - 23 kW, 60s Pulse Discharge

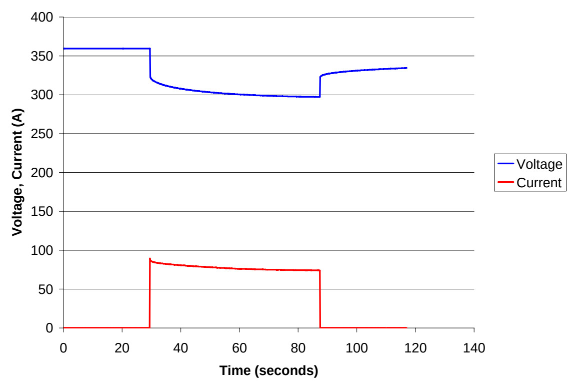
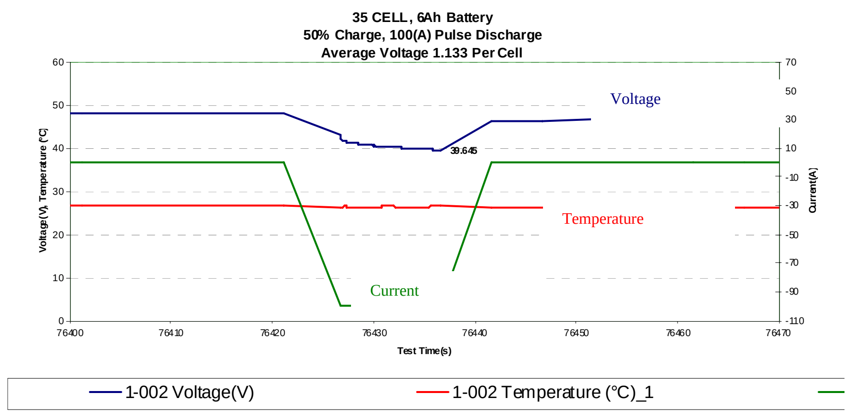


Figure 7 shows a 100A 10 second pulse on the 42V, 6Ah battery module, at 50% state-of-charge. The minimum voltage drops to 39.65 V, or 1.13 V per cell.

Figure 7: 42V, 6Ah 100A 10 Second Pulse Discharge



High Energy Bipolar Batteries

Through efforts with the DOE, EPRI Solutions, and other commercial organizations, EEI has also been developing high voltage, high energy bipolar batteries. As compared to the previously discussed high-power cells, a thicker cell with a capacity of 20 Ah and an active electrode area of 6" by 12" has been identified as a baseline product. This cell has high energy and low power per unit weight and volume, and was designed specifically for applications requiring sustained energy at lower powers. It has a typical weight of 379 grams and delivers 65 Wh/kg and 200 Wh/l of energy at the cell level. As with the power cell, the bipolar design facilitates the building of high voltage systems, in reduced sized packages.

The high-energy bipolar design is ideal for such applications as high energy UPS systems, wind, solar, and other electric utility energy storage, as well as pluggable hybrid electric vehicle batteries. EEI has built, tested and delivered up to 600V/35kWh/20kW UPS systems and 220V, 35Ah pluggable hybrid battery systems.

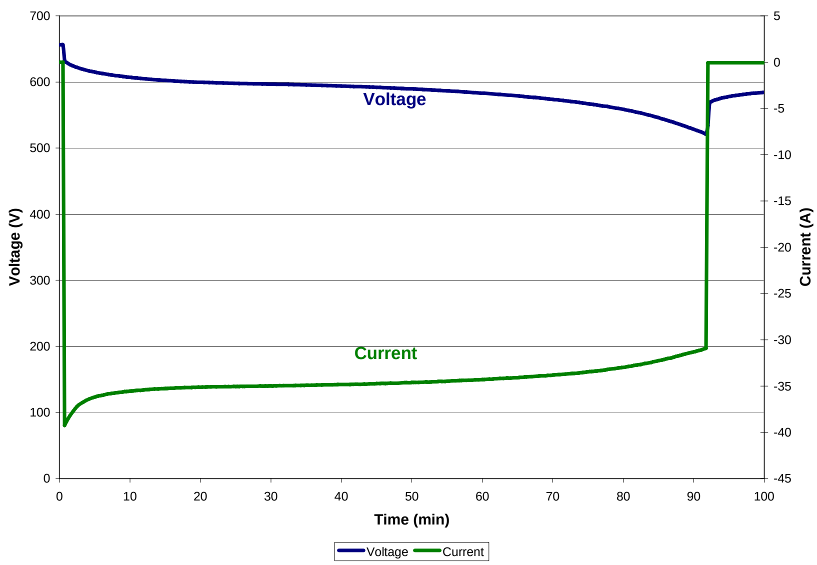
EEI's most significant high-energy system built to date is a 600V, 35kWh UPS battery system, capable of delivering up to 2 hours of power at 20kW, and is shown in Figures 8 and 9. It is comprised of 1,920 cells, housed 16 150V, 20Ah battery modules connected in a four parallel strings of four modules in series. The total system weights 3,200 lbs, including charging, controls and cooling capabilities.

Figure 8: 600 V/35 kWh UPS Battery System Modules Exposed

Figure 9: 600 V/35 kWh UPS Battery System Closed System

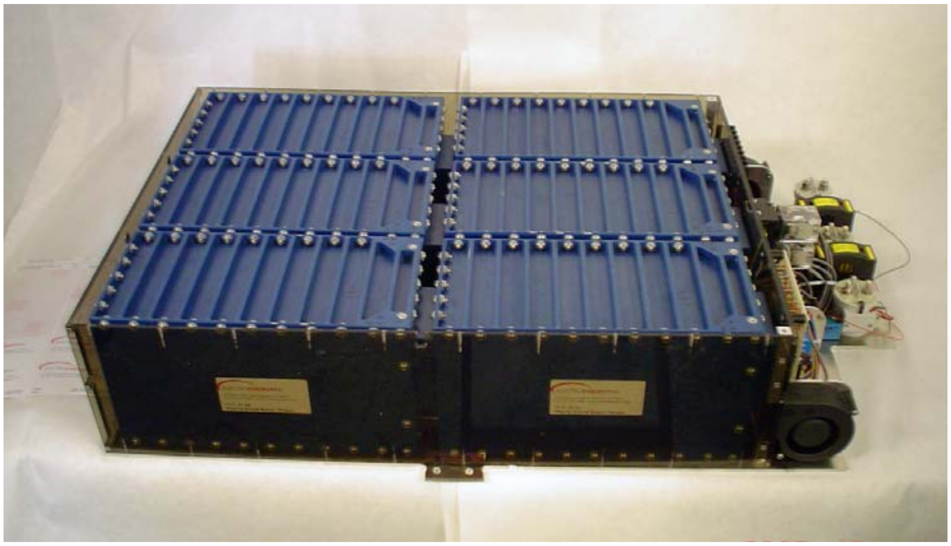
A continuous, nominal 20 kW discharge on the entire 600V system is shown in Figure 10. At this power level, the system delivers 33 kWh of energy.

Figure 10: 600 V/35 kWh/20 kW System, 20 kW Discharge – 33 kWh Out



The high-energy battery design is also very applicable to building batteries used to power pluggable-hybrid electric vehicles. Under this concept, a current hybrid vehicle is equipped with larger batteries, which could be externally charged while the vehicle is parked. This gives drivers the ability to run entirely on electric power at highway speeds for 20+ miles. For long trips, the battery never runs down -- its gasoline engine provides the usual unlimited range. EEI has built a 220V, 35Ah plug-in hybrid electric vehicle battery system, shown in Figure 11. It is comprised of six 72 V, 20 Ah modules connected in two parallel strings of three modules in series. This battery would serve as the all electric energy source, as well as the peak power source during normal HEV mode [3].

Figure 11: 220 V, 35 Ah Pluggable Hybrid Electric Vehicle Battery System



Conclusions

The bipolar NiMH battery design has considerable flexibility to be customized for energy and power applications of varying voltage and capacity. The high-power design is capable of both accepting and supplying very high power density pulses, which could be used in a variety of utility and commercial power applications. EEI has demonstrated that a high-voltage, high-capacity system can be built and successfully operated and controlled, using the high-energy bipolar NiMH battery design. The attractive weight, volume, life and cost of the EEI bipolar design should make it a viable battery for many energy storage applications.

References

[1] M. Klein, M. Eskra, R. Plivelich and P. Ralston, *Bipolar Nickel Metal Hydride Battery*.

[2] M. Eskra, M. Klein, R. Plivelich, *Pulse Power 350V Nickel Metal Hydride Battery*,

[3] *CalCars,The California Cars Initiative*, www.calcars.org

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