Market Advancement of NiMH Batteries for Stationary Applications

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Introduction

Nickel Metal Hydride (NiMH) battery technology offers significant promise as a stationary energy storage solution; compact size, high power, long cycle life, wide operating temperature range, and unsurpassed safety.[1] These attributes have been validated in side-by-side testing with VRLA and NiCd batteries in the laboratory as well as field evaluations. Products of varying designs have begun to appear on the market ranging from small cell back-up power to substation-scale energy storage systems.

NiMH batteries first appeared on the market in the late 1980s. Small rechargeable cylindrical cells revolutionized consumer electronics by enabling the first digital cameras, cell phones and laptop computers. A decade later, advanced prismatic NiMH batteries became the enabling technology for hybrid electric vehicles. Since 1997, more than eight million hybrids equipped with NiMH batteries have been introduced to the world's roadways.[2] Development of large-format NiMH batteries is now setting the stage for power and energy savings on the electrical grid as evidenced in the recently completed Washington Metropolitan Area Transit Authority Energy Storage Demonstration Project.

NIMH Technology

A basic NiMH cell consists of a metal hydride (MH) anode and a nickel hydroxide cathode in a high conductivity aqueous potassium hydroxide electrolyte. This chemistry provides a nominal voltage of 1.2 volts per cell. While this is lower than lead-acid, NiMH is characterized by higher energy density, both gravimetric and volumetric, higher heat tolerance, and longer cycle life at deeper discharge depths making it an attractive alternative for stationary applications.[1] In addition, NiMH contains no toxic materials and is recyclable.

Telcordia GR-3168-CORE

The first stationary NiMH battery standard, Telcordia GR-3168-CORE, was published in 2012, "Generic Requirements for Nickel Metal Hydride (NiMH) Battery Systems in Telecommunications Use". Revised slightly in a 2014 re-issue, this document outlines the testing protocol for stationary NiMH batteries similar to other Telcordia GRs for different battery chemistries. Requirements are grouped by level of deployment, I – III, and cover categories of general design, safety, performance, and service life. The contents of GR-3168 are summarized in Table 1.

Criteria	Level I	Level II	Level III
General Product	❑ Quality - Product Samples ❑ Documentation and Training ❑ Physical Design ❑ Electrical Safety ❑ Bonding and Grounding ❑ Self-Heating and Surface Temperature ❑ Battery Management System • Fail-Safe Design • Reliability • Features • Physical Design/ Manufacturing • Status and Alarms • Accuracy of Measurements	❑ Reliability ❑ Quality - Failure Mode and Effect Analysis	❑ Quality - TL9000, Product Changes ❑ Documentation and Training ❑ Reliability - Fail-Safe Design
Safety	❑ Overcharge ❑ External Short Circuit ❑ External Reverse Polarity ❑ Overdischarge ❑ High-String Voltage ❑ Conducted/Radiated Emissions ❑ Lightning and AC Power Fault ❑ Handling Shock - Packaged/ Unpackaged	❑ Simulated Telecom Environmental Cycles ❑ Immersion (Flooded Conditions) (CR) ❑ Overcharge ❑ External Short Circuit ❑ External Reverse Polarity ❑ Overdischarge ❑ Conducted/Radiated Immunity ❑ System-Level ESD ❑ System-Level EFT (O) ❑ Earthquake ❑ Transportation Vibration	❑ Simulated Brush Fire (CR) ❑ Operating Altitude ❑ Overcharge ❑ External Short Circuit ❑ External Reverse Polarity ❑ Overdischarge ❑ Low-Level Vibration Resistance
Performance	❑ Float Voltage ❑ Capacity ❑ Re-charge Time ❑ End of Discharge Voltage	❑ Cycling ❑ Temperature and Humidity During Transportation and Storage ❑ Immersion (Flooded Conditions) (CR) ❑ Shelf Life and Charge Retention ❑ Particulate Contaminant and Corrosive Gas	❑ Cold Temperature Start (CR) ❑ Salt Fog Exposure ❑ Extended Outages
Service Life			❑ Service Life

Table 1. Contents of Telcordia GR-3168

Varying 55°C Test

One of the most interesting tests in GR-3168 is the Battery Age Test, intended to determine the service life of a NiMH battery. Batteries are aged using an environmental cycle that averages 55°C (131°F), designed to simulate the conditions inside an outdoor cabinet from cool of the night to the highs of the day, including solar loading:

- Midnight to 9AM: 45°C (113°F)
- 9AM to noon: 45°C to 65°C (113 – 140°F)
- Noon to 9PM: 65°C (140°F)
- 9PM to midnight: 65°C – 45°C (140 – 113°F)

Using a Thermotron model S-32-8200 Environmental Test Chamber to control this thermal profile, BASF has been conducting simultaneous testing of a variety of 12V battery modules used in common stationary applications:

- 100Ah FT-type thin plate pure lead Monobloc VRLA
- 80Ah (10 cell) maintenance free NiCd telecom module
- 4Ah (10 cell) NiMH module type A (standard long life industrial)
- 4Ah (10 cell) NiMH module type B (advanced high temperature cathode)

While this may seem like a wide range of battery sizes, the objective of the test was to compare battery chemistries and construction designs in the smallest commonly deployable unit; hence 12V modules, 100Ah VRLA front terminal monoblocs and 10 x 80Ah NiCd cells, as opposed to 48V strings. 12V modules of 4Ah NiMH cells were selected since multiple strings of this cell configuration would be connected in parallel to achieve the capacity required by a given application. Charge and discharge rates were scaled proportional to each module's rated capacity.

After 30 days float on the Varying 55°C profile, batteries are cooled to 25°C, equilibrated for 24 hours, and discharged at an 8-hour rate. The results of this monthly discharge are shown below in Figure 1, presented as a percentage of the battery's rated capacity.

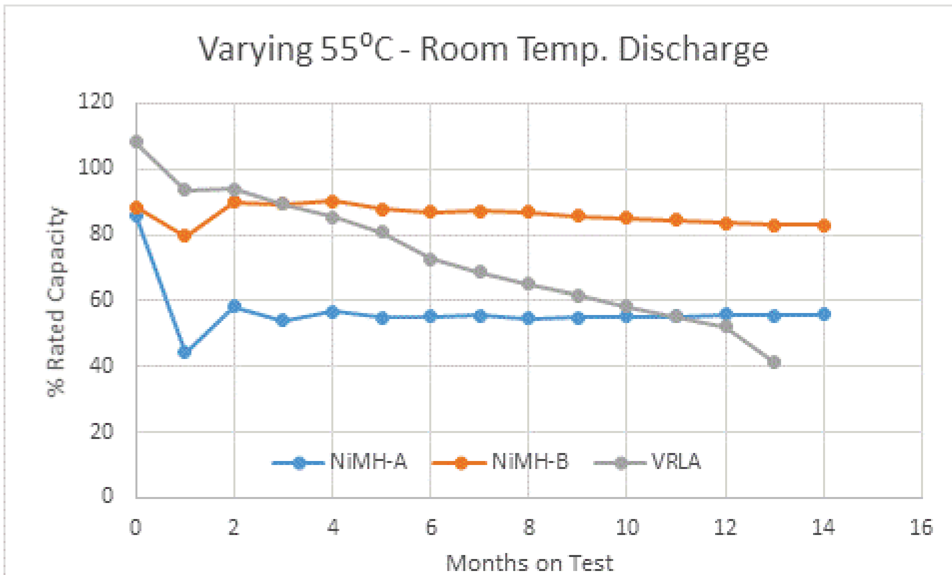


Figure 1. 8-hour discharge at RT following 30 days float on Varying 55°C profile

Specifications for the NiCd battery state the product will operate in temperatures from -20°C to +50°C (-4°F to +122°F) and tolerate -50°C to +70°C (-50°F to +158°F) for short durations[3]. Apparently, 9 hours per day at 65°C exceeded these "short duration" conditions as electrolyte leakage was observed on multiple cells and the module was removed from the test.

The VRLA module showed steadily decreasing capacity with each monthly test as might be expected from prolonged exposure to elevated temperature. The two NiMH modules returned relatively stable, but vastly different capacities. This will be explained further below.

Following discharge, battery modules are recharged at room temperature for 24 hours and discharged again at the 8 hour rate. While this is not part of the GR-3168 test procedure, we believe it provides a valuable capacity verification. The results are shown below in Figure 2.

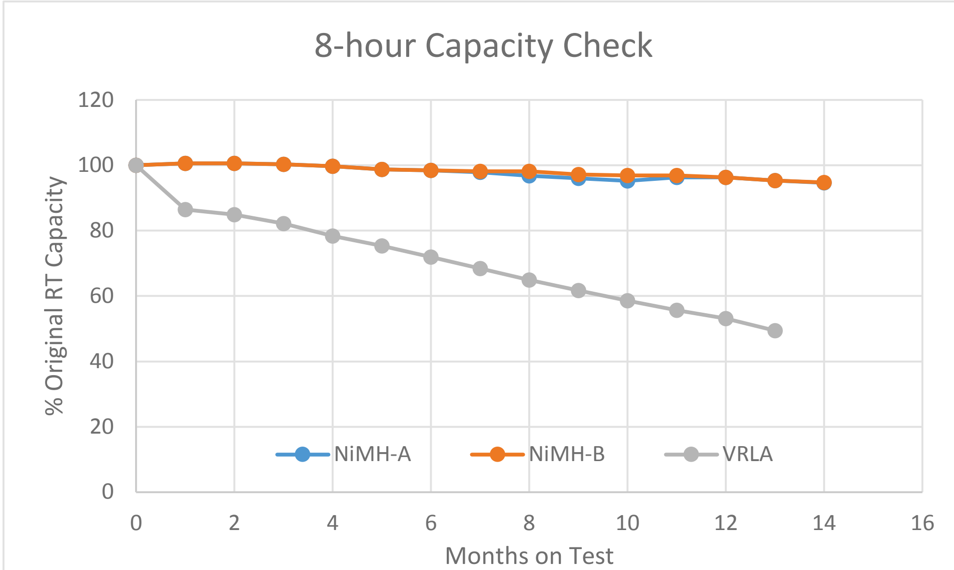


Figure 2. Capacity check following recharge at room temperature

After recharge at room temperature, VRLA results were fairly unaffected and the module was removed from test after 13 months having reached 50% of its original capacity. On the other hand, a significant change was observed for the NiMH modules where both types now showing almost identical results - nearly full capacity following recharge at room temperature after 14 months on test. Although a significant change from Figure 1, the result was not surprising as it has been documented that standard NiMH (Type A) does not charge well at temperatures higher than 50°C.[4] The Type B NiMH module used an advanced cathode material which is capable of charging fully at 65°C and, therefore, did not display the same behavior as the standard Type A NiMH module. Testing of both NiMH modules will continue.

Varying 45°C Test

While it is very impressive that NiMH continues to perform after more than one year on this high temperature profile, daily exposure to 65°C (140°F) represents an extreme condition, not likely to be experienced in the field – especially over the course of an entire year. An earlier, unpublished version of GR-3168 suggested a second, more realistic aging test, the Varying 45°C test, where all temperatures in the thermal profile were 10°C lower than the Varying 55°C test, thus; 9 hours at 55°C (131°F), 9 hours at 35°C (95°F), and 6 hours in transition between 35 and 55°C (95 and 131°F).

Similar to above, BASF has been conducting simultaneous testing of various 12V battery modules on the Varying 45°C aging test. While the same type batteries were used as in the Varying 55°C test, an additional VRLA module was also included; a 12V, 8Ah monobloc module commonly used in Fiber-To-The-Home (FTTH) equipment.

Results of this ongoing testing are summarized in Figure 3. Following an initial jump in capacity for the 8Ah FTTH battery, both it and the larger VRLA module have shown roughly the same rate of capacity loss (~5% per month) with each discharge. Capacity of the NiCd battery is also decreasing steadily, but at a slower rate, ~2-3% per month. Both NiMh modules are holding steady, showing very little, if any reduction from their initial discharge capacity after 11 months at elevated temperature.

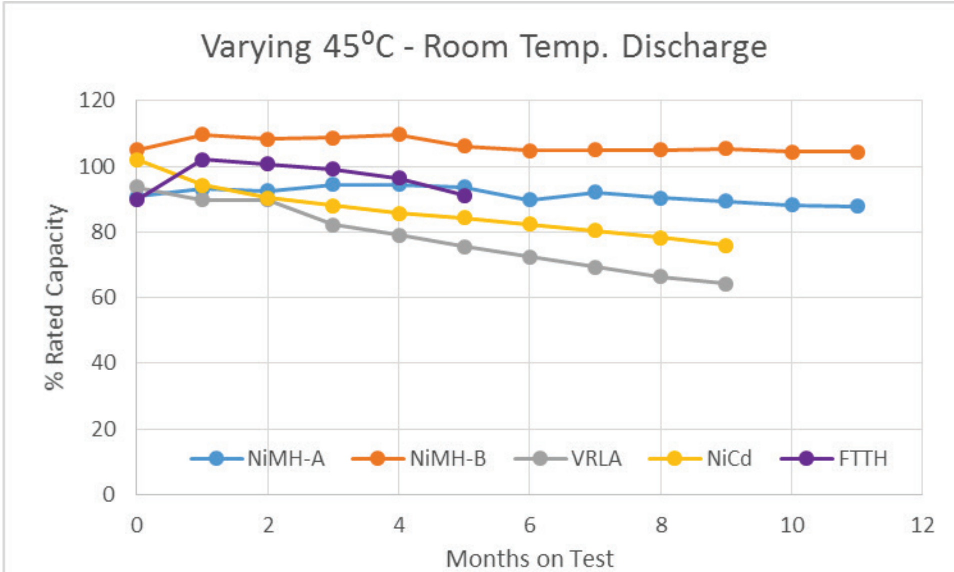


Figure 3. 8-hour discharge at RT following 30 days float on Varying 45°C profile

Following discharge, batteries are recharged at room temperature and subsequently discharged at the 8 hour rate. The results of this capacity check are summarized in Figure 4. Similar to the results in Figure 2, the standard NiMH battery (NiMH-A) recovers to full capacity following recharge at room temperature. Testing of all modules on the Varying45°C test will continue for the foreseeable future.

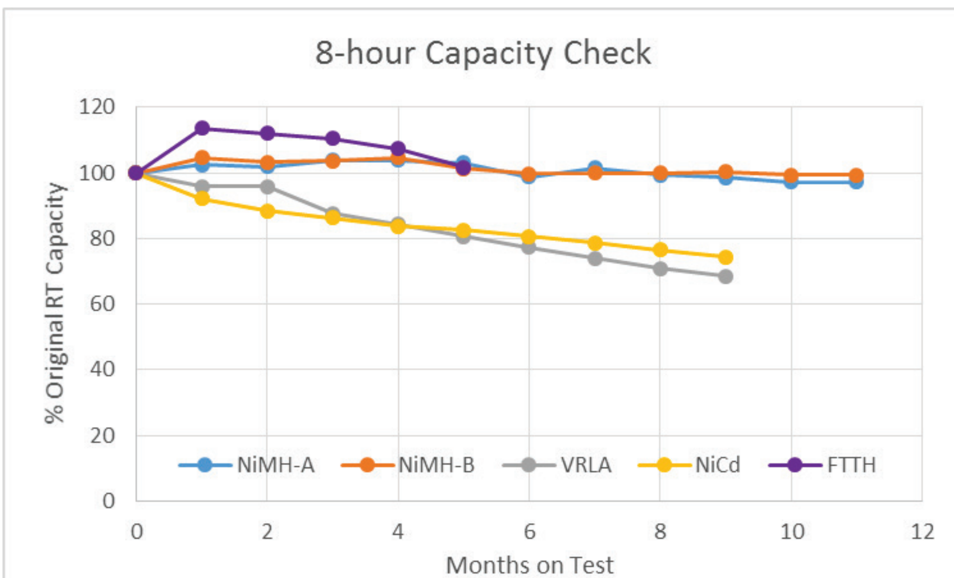


Figure 4. Capacity check following recharge at room temperature

Recent advances in commercialization

Product #1: Small Cell power system

When a major supplier of DC power systems set out to develop an innovative power solution for outdoor small cells, they conceptualized a low-cost system with limited battery reserve, sufficient to power almost 90 percent of AC interruptions, but far smaller than traditional telecom back-up systems. Since outdoor small cells are typically deployed on utility poles, street lights or sides of buildings, other key requirements also needed to be considered; aesthetics, space, weight, operating temperature range, deployment in harsh environments, safety, mounting flexibility, and minimum maintenance. Based on the high power density of NiMH cells, they chose a low-profile solution using an integrated battery with on-board battery management electronics. The resulting product, shown in Figure 5, weighs less than 25 pounds and occupies less than ½ cubic feet in volume, with the capability to power loads up to 600W at ambient temperatures ranging from -40 to +55^{o}C.[5]

Figure 5. 600W Small Cell Power System (left) and its integrated battery module with NiMH cells and BMS (right).
(Photos courtesy Alpha Technologies Ltd. and FDK)

The NiMH battery module shown in Figure 5 weighs only 7 pounds excluding the supporting metal chassis. An equivalent VRLA solution would weigh more than 3 times as much and would occupy more than twice the space. While some might argue that certain Li-ion batteries might provide similar power and energy with slightly less weight, the decision for NiMH was made based on its long history of safe, reliable performance in other demanding applications.[6]

Product #2: Battery Power Systems (BPS) using large-format NiMH cells

In contrast to the small cylindrical cells used in the product above, another BASF licensee has introduced a product using large-format prismatic NiMH cells. At 5400Wh (36V, 150Ah) this product dwarfs all other commercially available NiMH batteries. This battery uses a unique bi-polar construction design to achieve high power and rapid charge/discharge capability. Figure 6 illustrates this unique bi-polar construction, while Figure 7 shows the high rate charge/discharge capability it can achieve.

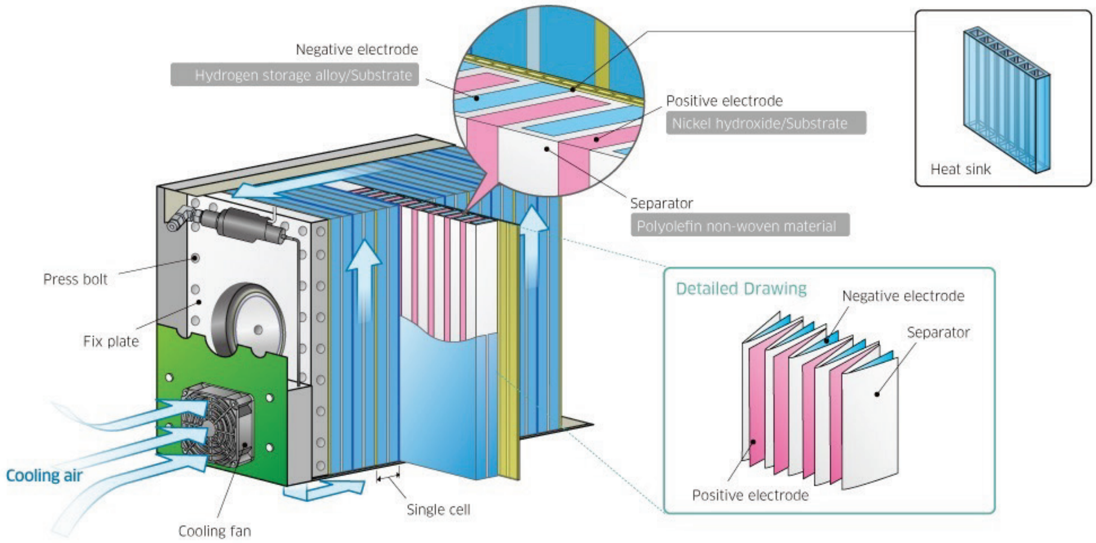


Figure 6. Bi-polar cell design/construction (Courtesy Kawasaki Heavy Industries)

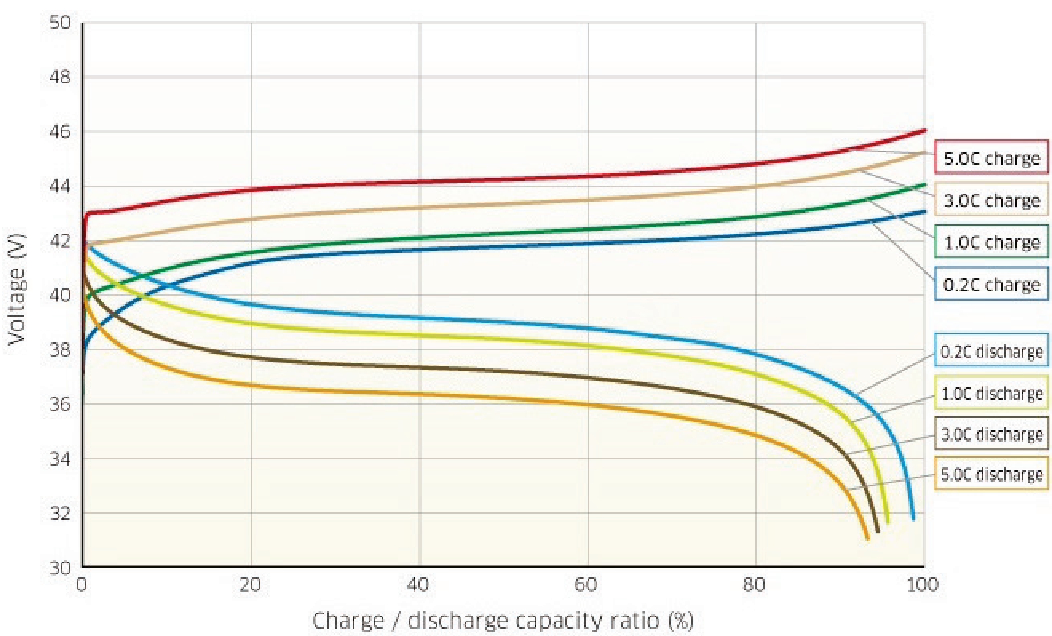


Figure 7. High-rate charge and discharge capability. (5.0C equals 750Amps)

Since 2010, numerous NiMH BPS systems ranging in size from 200 to 550kWh have been installed throughout Japan primarily in track-side railway applications where regenerative braking energy from a stopping train can be captured for reuse. Results of ongoing use of these battery systems on the Tokyo Monorail, Osaka and Sapporo subways, and numerous other regional rail lines has shown reduced energy usage, lower peak power consumption, improved line voltage stabilization and overall energy cost savings. Additional benefits include substation back-up and emergency power to move trains between stations.

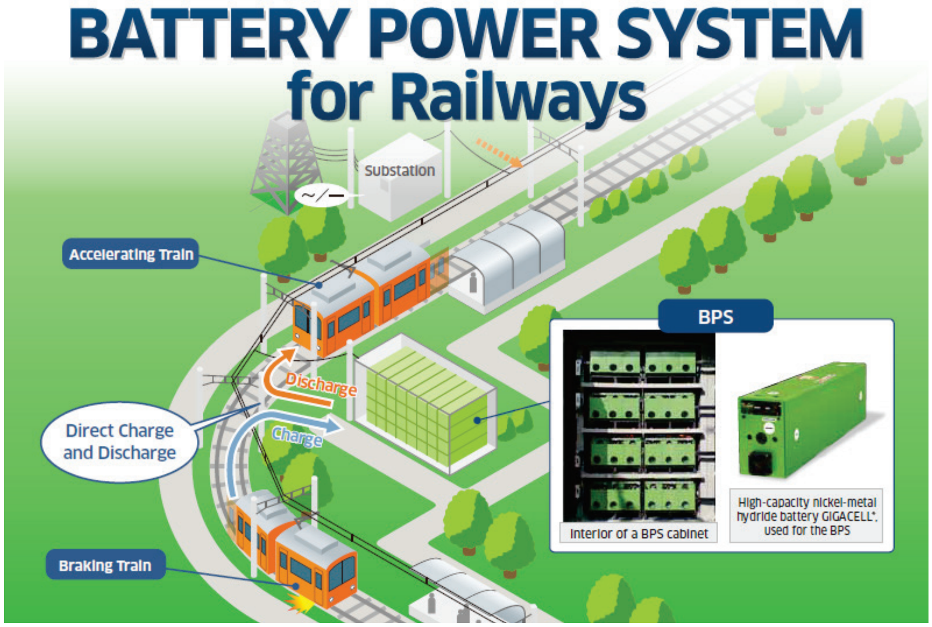


Figure 8. Illustration of a wayside railroad BPS installation.
(Courtesy Kawasaki Heavy Industries)

WMATA Energy Storage Demonstration Project

Closer to home, an installation of particular interest is the Washington Metropolitan Area Transit Authority Energy Storage Demonstration Project where a 2MW / 400kWh NiMH Battery Power System (BPS) was installed at the West Falls Church substation near the West Falls Church station on the Orange line of the Washington DC Metrorail system in 2013.

Figure 9. 400kWh BPS installation at West Falls Church substation

The DC Metrorail system is the 2nd busiest subway system in the US, carrying 720,000 passengers daily. The system serves 91 stations on 6 lines covering more than 117 miles of track. Trains are powered by 100 traction-power substations through a 700Vdc third-rail distribution system. The traction-power system consumes 500GWh annually; enough to power 45,450 homes.

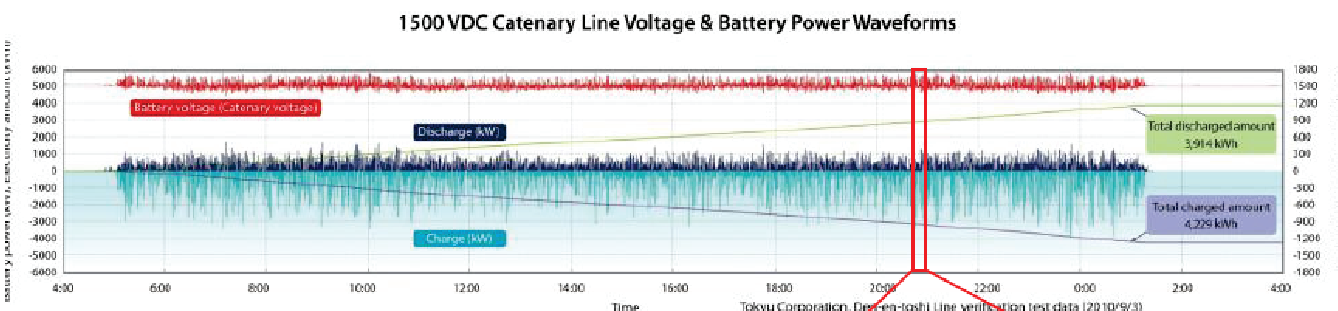
The BPS installed at West Falls Church consists of 4 parallel units, each comprised of 19 5kWh modules. Figure 9 shows the installation of these units along with air conditioning and ancillary equipment.

The results of the 2-year study were overwhelmingly favorable as reported by the US DOT Federal Transit Administration last year:[7]

- Up to 15.4% energy savings
- Up to 12.5% peak power reduction
- 75.5V average line stabilization
- In a blackout, the fully charged BPS can move 19 fully loaded trains more than ½ mile each

As WMATA, like other metropolitan transit authorities, deals with increasing ridership by adding larger trains and increasing schedule frequency, NiMH battery power systems can help offset the associated increased power demand and energy cost.

NiMH in Renewable Energy Applications



BPS capacity	400kWh
Cycles per day (1 charge & 1 discharge= 1 cycle)	Approximately 4,000 cycles
Maximum charge power	Over 3,200kW (8C)

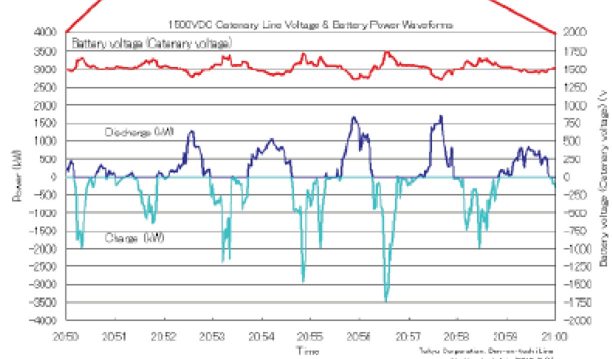


Figure 10. Single day charge/discharge profile for a wayside railroad BPS installation

As illustrated in Figure 10, a review of a typical railway installation shows that the battery experiences some 4000 charge/discharge cycles daily, similar to what might be experienced in wind or PV firming applications. Several demonstration programs are currently underway with Japanese utility companies to validate performance of the NiMH BPS system in grid-tied renewable energy installations. The longest running system is a 102kWh battery installed in 2010 to balance the output of a Kansai Electric Power Company 10MW solar plant near Osaka.

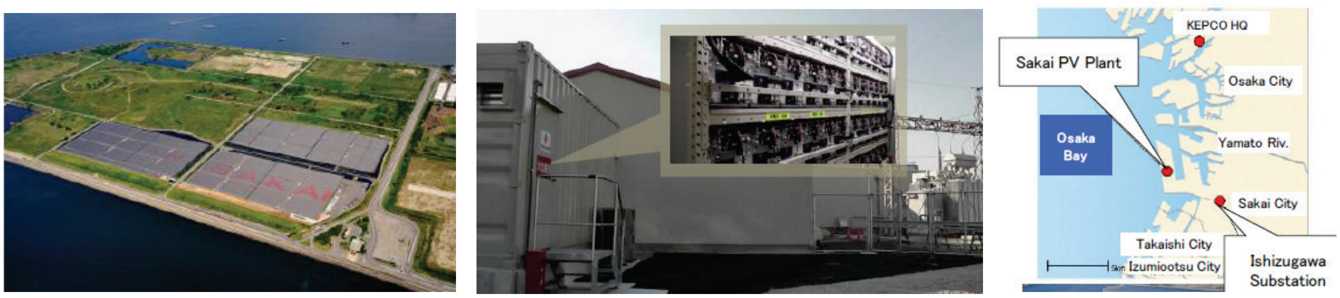


Figure 11. Solar farm and NiMH BPS near Osaka, Japan

Conclusion

Nickel metal hydride battery technology offers numerous benefits as an advanced alternative to VRLA in stationary applications.

- Proven safety and reliability in over 8 million hybrid electric vehicles
- High power and energy density
- Superior high-temperature performance and operating life
- High cycle life

While small stationary NiMH battery products have begun to appear on the market, an innovative bi-polar module is opening the door for substation-scale energy storage applications.

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