

SODIUM-METAL HALIDE BATTERIES FOR STATIONARY APPLICATIONS

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INTRODUCTION

Advanced batteries based on sodium-metal halide chemistry (“Sodium Batteries”) have been explored for use in electric vehicle applications¹ because of their high specific energy, power density, and long cyclic life. These advantages and others can also make Sodium a good choice in critical stationary applications such as uninterruptable power systems (UPS) and telecom backup systems. Currently, lead-acid batteries dominate these applications in such forms as wet cells and valve-regulated lead-acid (VRLA) batteries.

Sodium Batteries have superior power density and specific energy compared to lead-acid batteries as well as higher cyclic life at normal ambient temperature. The Sodium battery is tolerant to extreme ambient temperatures with no impact to its performance, unlike lead-acid systems, which must be derated or suffer drastically shortened lifetimes.

The Sodium battery is a ‘smart’ battery with capability for remote diagnostics and health monitoring. It includes an on-board Battery Management System (BMS) that handles thermal management, recharge/discharge functions, and float operation.

The high performance of the Sodium Battery gives it potential to do more than simply displace lead-acid in stationary applications. Its capability for sustained high-power discharge and frequent cycling make it an ideal candidate to transform battery systems in stationary applications from simple backup power systems to hybrid energy storage systems, allowing further energy savings through off-peak grid recharging and renewable power integration.

SODIUM-METAL HALIDE BATTERY BASICS

Sodium metal halide batteries were first developed in the 1970s by the Zeolite Battery Research Africa (ZEBRA) project in Pretoria, South Africa¹. During the 1980s Beta Research and Development of Derby, UK refined the cell chemistry and developed large-scale manufacturing processes. Today, Beta is part of General Electric’s Energy Storage Technology business.

ZEBRA batteries have been successfully demonstrated in electric vehicles such as the Mercedes A Class car, Vito van⁴ and the Th!nk City compact car. Vehicles powered by these batteries have logged millions of kilometers.

Sodium-metal halide battery technology has showed promise in mobile applications, for example the hybrid locomotive. Locomotives have relatively harsh duty cycles that include operation in extreme climates ranging from deserts to the coldest areas of the world, and have limited space and weight available for energy storage. This combination requires the batteries to have very high energy density, high reliability and tolerance to ambient temperature.

Sodium Batteries have demonstrated some of the highest energy densities found among commercially available battery chemistries. Its energy density, safety capabilities, and handling of highly variable ambient conditions make Sodium Batteries suitable for use with hybrid locomotives. These characteristics also make the Sodium Battery a good fit for use in stationary applications

Cell Components

Figure 1 is a representative schematic diagram of a sodium-metal halide cell. During manufacture the cathode compartment is filled with metal (Ni), salt (NaCl), other additives, and a liquid electrolyte; there is no elemental sodium involved in the manufacturing process.



Eq. 1: Cell Reaction

When the Sodium Battery is first charged sodium ions from the NaCl in the cathode travel through the liquid electrolyte and the beta-alumina ceramic solid electrolyte (BASE) separator. The BASE separator is an electrically insulative conductor of sodium ions at high temperature. When the cell is charged, the anode is filled with liquid sodium. The process is reversed during discharge, with sodium ions traveling through the BASE separator to re-form NaCl in the cathode.

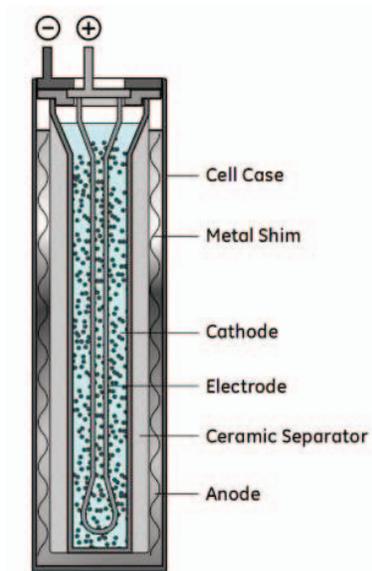


Figure 1 – Cell Schematic

Operating Characteristics

The open-circuit voltage of this cell chemistry is about 2.5V, while operating at an internal temperature in a range of approximately 250° to approximately 350°C. Depending on the application a Sodium Battery may discharge as low as about 1.7V per cell. The nominal recharge voltage is about 2.7V per cell.

Energy Density

The Sodium battery has one of the highest specific energies of current, commercially-available batteries. Such a high specific energy value may result in savings in floor space for utility or UPS applications. In telecom applications, Sodium batteries may enable relatively longer discharge times and/or an increase in available space within a radio base station for additional revenue-generating equipment.

Lifetime

Sodium Batteries may last thousands of cycles before requiring replacement, based on such factors as the Depth of Discharge (DoD) and power delivery rates. Replacement may be due to increases in internal resistance. Initial testing indicates potential capability of over 2000 discharges to 80% DoD. This gives an additional advantage in energy density over lead-acid, NiCd, and some other battery chemistries, which can be restricted to 50% DoD or less in order to last beyond a few hundred cycles.

Because of the solid electrode, the Sodium Battery does not self-discharge and may be capable of 15+ years of operation on float. The battery may be cooled to ambient temperature, freezing the sodium electrode and the liquid electrolyte in either a charged or uncharged state. In the frozen state the Sodium Battery may have a near indefinite shelf life.

Ambient Condition Tolerance

The nature of the Sodium Battery decouples internal or operating temperature from ambient temperature conditions, reducing or eliminating the need for de-rating in hot or cold ambient conditions. This enables systems requiring battery backup, such as telecom base stations, to move into areas of the world where hot conditions have restricted growth or required frequent battery replacement.

Because the Sodium Battery is thermally insulated, a battery backup system built for Sodium Batteries may function without coolers such as air conditioning units or thermo-electric coolers. The power required to keep the Sodium Battery at the proper internal operating temperature can be much less than the power demands of a typical battery cooling system attempting to cool a comparable battery in a traditional system. Sodium Batteries used in some high-power discharge applications may, however, require cooling. During operation, the Sodium Battery surface temperature is held at a maximum of about 10 °C above ambient.

Low Maintenance

The Sodium Battery requires relatively low maintenance, even compared to sealed gel or valve-regulated lead-acid batteries. The terminals are maintenance-free and water addition is not required. The Battery Management System automatically reports all required parameters to estimate battery health. As previously discussed, stored batteries are inert and do not require periodic float charging or protection from freezing.

Safety and Reliability

If an individual cell fails due to breakage of the solid electrolyte; the battery module itself may continue to operate at reduced capacity because the cell will fail short. In such a failure the elemental sodium in the anode will react with the salt in the cathode, rendering the cell safely inert.

GE's cell design includes features to make the cells robust against overcharging; and GE's BMS includes advanced state-of-charge monitoring to prevent accidental overcharging.

The Sodium Battery does not discharge gases, particularly not gaseous hydrogen or hydrochloric acid, in normal operation and so does not require related ventilation or venting. Further, the Sodium Battery does not contain cadmium, sulfuric acid or lead.

USE IN STATIONARY APPLICATIONS

Testing of sodium-metal halide batteries in stationary applications indicates that the battery performs well in typical backup power duty cycles. The tested Sodium batteries experienced minimal degradation and showed potential for a long operating lifetime². GE has evaluated the Sodium Battery for important stationary power market segments including telecom, UPS and power utilities.

Telecom Applications

Radio Base Stations (RBS) in the telecommunications industry may run on 24V or 48V DC power and can include batteries to ensure continuous service during a power outage. Pending FCC mandates propagated in response to Hurricane Katrina require 8-hour backup capability³. Currently, a common telecom battery cabinet provides nominal backup power for 4 hours or less. In practice, many legacy battery systems operating in the field may provide even less than the rated 4 hours due to aging and degradation. Other telecom applications include hybrid telecom towers where a base station can be powered by diesel gensets or by a renewable source such as wind or solar.⁵

The batteries currently available for use in RBS systems may be provided in sets of four series-connected 12V lead-acid batteries with capacities of up to about 150 Ah. Sets of twenty-four 2V cells of over 1000 Ah have been used in installations, and these require relatively more power and/or longer discharges. Either arrangement occupies significant floor space, especially when eight-hour discharge capability is required.

The nominal float life of lead-acid batteries used in telecom applications is from about ten to fifteen years, however this lifetime has been difficult to achieve in practice. The useful life may be dramatically reduced by frequent discharge/recharge cycling and/or exposure to high ambient temperatures. Lead-acid batteries require ventilation because of hydrogen that may be released during charging, and may be cooled with a room air conditioner or with a cabinet-mounted thermo-electric cooler (TEC).

The Sodium Battery internal temperature is relatively decoupled from ambient temperature. In a typical telecom industry duty cycle the Sodium Battery does not require any cooling. This eliminates the need for cooling equipment and can give the operator additional flexibility and space for equipment.

Figure 2 compares lead-acid batteries to Sodium Batteries for an exemplary telecom RBS installation. In this example, the RBS equipment load is 2 kW. The cooling load for the lead-acid batteries (typically 100-200W depending on ambient temperature) is not included, and the batteries are permitted to discharge up to 80% DoD. The batteries are sized to support an 8-hour discharge

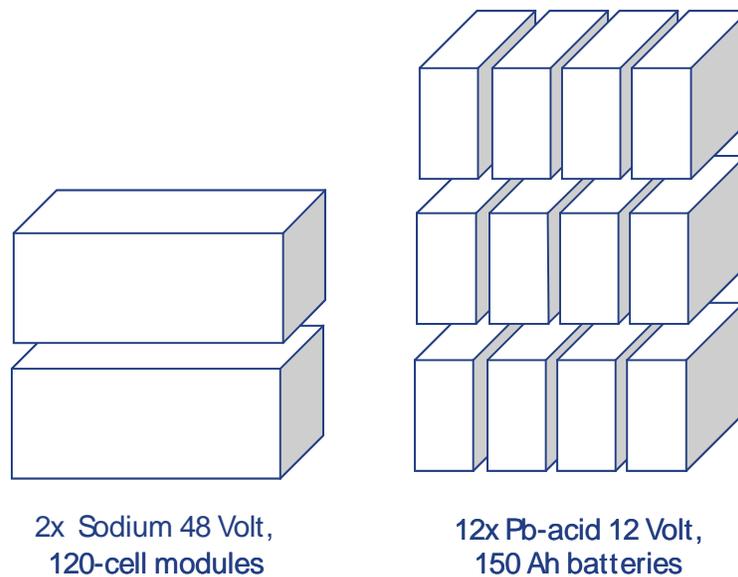


Figure 2 – Telecom Cabinet Battery Comparison

| | Lead-Acid | Sodium Metal Halide |
|--------------------|---------------------|---------------------|
| RBS Power Draw | 2000W | 2000W |
| DC Voltage | 48V | 48V |
| Discharge Time | 8 Hours | 8 Hours |
| Required Capacity | 333Ah | 333Ah |
| Battery Voltage | 12V | 48V |
| Batteries Required | 12 (3 strings of 4) | 2 |
| Total Weight | 700 kg | 240kg |
| Approx. Volume | 300 liters | 150 liters |
| Life | ~200 cycles | > 2500 cycles |

Table 2: Telecom RBS Comparison

At twice the volume and nearly three times the weight, the lead-acid batteries would require a separate battery cabinet to provide enough energy for an eight-hour discharge; the Sodium Battery would occupy two shelves in a 23-inch standard RBS cabinet.

It should be noted that while the two batteries were compared on the basis of equivalent depth of discharge (DoD), 80%, lead-acid batteries are often limited to 50% DoD to conserve life.

UPS Applications

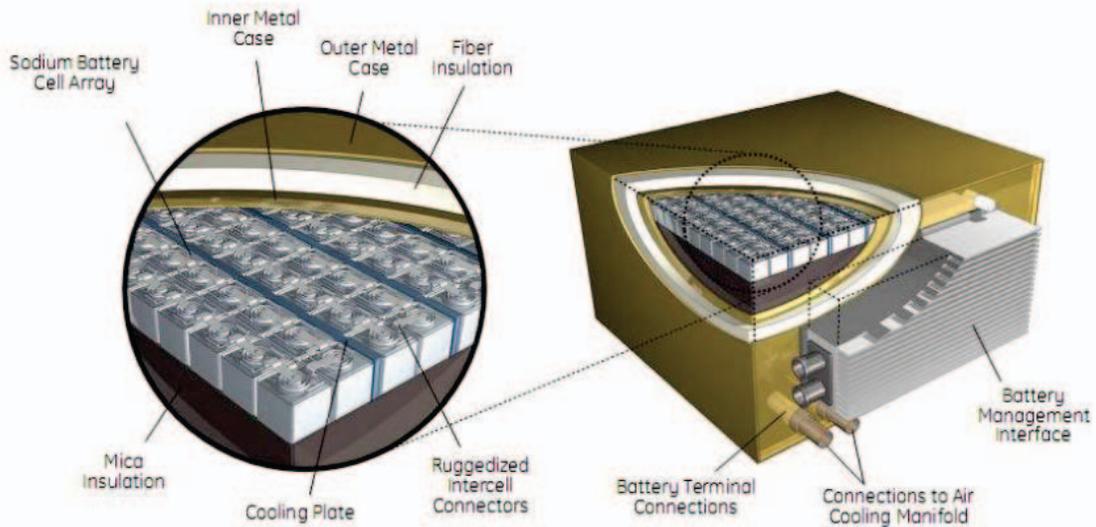


Figure 3: 540V NaMx battery for UPS applications

Two major segments of the Uninterruptable Power Source (UPS) market exist: battery-only systems with up to 15 minutes of backup power (enabling safe shutdown to prevent loss of data), and battery-generator systems where the battery provides up to 15 seconds of bridging power to ensure constant power while the generator starts. Similar to the telecom example, a Sodium battery set used for UPS applications will save significant floor space, weight and cooling loads over equivalent capacity lead-acid systems.

The onboard Battery Management System included with Sodium Batteries is an advantage in UPS applications because individual batteries can be continually and remotely monitored and can be replaced as needed when they approach end-of-life. The GE team has analyzed the utility outage profile for the last decade in North America. Based on the profile, a predicted life for Sodium Batteries in North American applications would be 20 years.

Long Discharge Applications : Utilities and Hybrid Energy Storage Systems

While sodium-metal halide batteries can perform in power backup applications as well or better than traditional lead-acid solutions, their high energy density makes them particularly well suited for applications where the equipment routinely runs on DC battery power. The prime energy source may be a diesel generator or a renewable energy source, which stores energy in the battery similar to the way a hybrid vehicle operates. An important parameter for such an application is a high ratio of discharge time to recharge time. A battery-based energy storage system may also be used in utility and smart grid concepts, where a battery system for a building or block or residences may be applied to avoid using grid power at peak demand times.

In much of the emerging world, for example parts of Africa and India, the power grid is unreliable or nonexistent. In these areas, there is a growing market for cell phone service but no power infrastructure to support it. Frequently, diesel generators are used to power the equipment, but these require constant refueling, frequent maintenance, and pose a noise problem in populated areas. Long-discharge batteries can minimize generator run time; a larger, more efficient generator can be installed at low incremental cost and operated with the battery in constant discharge/recharge mode.

Available lead-acid battery technology has achieved limited deployment with these hybrid systems because of the inherent low energy density, high maintenance requirements, short life in cyclic operation and sensitivity to ambient temperature conditions. Sodium Batteries can be sited in remote locations and experience daily long cycles while maintaining cyclic life, and the BMS allows remote monitoring and diagnostics to ensure high uptime without on-site maintenance. The energy density advantage of Sodium Batteries is especially important for hybrid energy storage applications, which may need up to 24 hours of discharge capability. This advantage will be felt both in footprint and in reduction of transportation costs to remote sites due to lower weight and space.

“Smart” Battery Services

The on-board BMS manages temperature and ensures that the battery cannot be discharged or recharged in thermal situations that could damage it. It monitors current, voltage, state-of charge and other parameters that can be valuable for an operator or a supplier working under a contractual service agreement (CSA). Service-focused RM&D (Remote Monitoring and Diagnostics) capabilities may be included in the battery management system for little incremental cost. Stationary battery operators and suppliers are just beginning to explore the value of battery RM&D business cases.

SUMMARY

Sodium-metal halide batteries have advantages in available energy density, longevity, safety, and temperature capability that make them well suited for stationary applications such as telecom backup, UPS systems, and hybrid energy applications. Their ability to function in relatively high ambient temperature enables growth in emerging-world markets that have been previously limited by the short lifetimes of lead-acid batteries in similar conditions. The long history of Sodium Batteries in vehicle applications has resulted in a manufacturing infrastructure ready to ramp up and serve the needs of the stationary market.

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