IOXUS
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The Case for Sodium - Sulfur Batteries and Ultracapacitors

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Introduction

When dealing in the field of exotic, high energy batteries, sodium sulfur batteries need to be understood. Batteries with the highest theoretical energy and power densities use anodes of alkali metals such as sodium, lithium, and potassium, which are the most reactive metals. Sodium sulfur reactants have an operating temperature of 300º C, with a potential energy density output of more than 400Wh/kg, or 200Wh/lb. Their charge/ discharge efficiency is in the range of 86-92%. Compare this to about 30 Wh/kg for a lead acid battery. Current costs for sodium sulfur, also called NaS batteries, are around $400/kWh. The high operating temperature along with the highly corrosive nature of the sodium polysulfide allows this technology to only be used in stationary applications, such as grid energy storage.

Basic sodium sulfur battery operation

Sodium sulfur batteries are made up of many cells. Each cell is typically made in a tall, cylindrical configuration. The entire cell is enclosed by a steel casing that is protected, usually by chromium and molybdenum, from corrosion on the inside. This outside container serves as the positive electrode, while the liquid sodium serves as the negative electrode. The container is sealed at the top with an airtight alumina lid. An essential part of the cell is the presence of a BASE (beta- alumina sodium ion exchange) membrane, which selectively conducts Na^+. The cell becomes more economical with increasing size. In commercial applications, the cells are arranged in blocks for better conservation of heat and are encased in a vacuum-insulated box.

During the discharge phase, molten sodium at the core serves as the anode, meaning that the Na donates electrons to the external circuit. The sodium is separated by a beta-alumina solid electrolyte (BASE) cylinder from the container of sulfur, which is fabricated from an inert metal serving as the cathode. The sulfur is absorbed in a carbon sponge. BASE is a good conductor of sodium ions, but a poor conductor of electrons, so it avoids self-discharge. When sodium gives off an electron, the Na^+ ion migrates to the sulfur container. The electron drives an electric current through the molten sodium to the contact, through the electrical load and back to the sulfur container. Here, another electron reacts with sulfur to form S_n^{2-}; sodium polysulfide .The discharge process can be represented as follows:

$$2\ Na + 4\ S \rightarrow Na_2S_4\ E_{cell} \sim 2\ V$$

As the cell discharges, the sodium level drops. During the charging phase, the process reverses. Once running, the heat produced by charging and discharging cycles is sufficient to maintain operating temperatures and typically no external source is required. Pure sodium presents a hazard because it spontaneously burns/explodes in contact with water, so the system must be protected from moisture. In modern NaS cells, sealing techniques make fires unlikely, although there have been cell leaks.

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NaS battery energy storage applications

Since 1983, TEPCO (Tokyo Electric Power Co.) / NGK (NGK Insulators Ltd.) have become the primary drivers behind the development of the NaS battery because all of its components (Sodium, Sulphur, Ceramics) can be abundantly found in Japan. First large-scale prototype field testing took place from 1993 and 1996, using 3 x 2MW, 6.6kV battery banks. Based on this trial, improved battery modules were made commercially available in 2000. The performance was as follows:

- Capacity : 25 - 250 kW per bank
- Efficiency of 87%
- Lifetime of 2,500 cycles (at 100% DOD - depth of discharge), or 4,500 cycles (at 80% DOD)

As of 2008, sodium-sulfur batteries are only manufactured by one group, the NGK/TEPCO consortium, which is producing 90MW of storage capacity each year. The General Electric Company (GE) announced plans to establish an NaS battery manufacturing facility in Schenectady, NY, in 2009.

There is currently a demonstration project using NGK Insulators' NAS battery at Japan Wind Development Co.'s Miura Wind Park in Japan.

Japan Wind Development has opened a 51 MW wind farm that incorporates a 34 MW sodium sulfur battery system at Futamata in Aomori Prefecture in May 2008.

There are already 165MW of installed capacity base in Japan alone as of 2007, and NGK has just announced plans to expand its NAS factory output from 90MW a year to 150MW a year.

Xcel Energy has announced that it will be testing a wind farm energy storage battery based on 20-50kW sodium-sulfur batteries from NGK Insulators Ltd of Japan. The 80 ton, 2 semi-trailer sized battery is expected to have 7.2MW-hours of capacity at a charge and discharge rate of 1MW.

NaS batteries can be deployed to support the electric grid. Under some market conditions, NaS batteries provide value via energy arbitrage (charging battery when electricity is abundant/cheap and discharging into the grid when electricity is more valuable) and voltage regulation. NaS are a possible energy storage technology to support renewable energy generation, specifically wind farms and solar generation plants. In the case of a wind farm, the battery would store energy during times of high wind but low power demand. This stored energy could then be discharged from the batteries during peak load periods. In addition to this power shifting, it is likely that NaS batteries could be used throughout the day to assist in stabilizing the power output of wind farms during wind fluctuations. These types of batteries present an option for energy storage in locations where other storage options are not feasible due to location or terrain constraints.

NaS cell voltages

Operating discharge voltages for NaS batteries are lower than those for lead acid batteries. On a 5 hour discharge rate the NaS battery would start at around 1.9V per cell and finish at around 1.4V per cell, with a mean voltage of about 1.7V per cell compared to lead acid, with a 2.0, 1.7, and 1.9 volts per cell.

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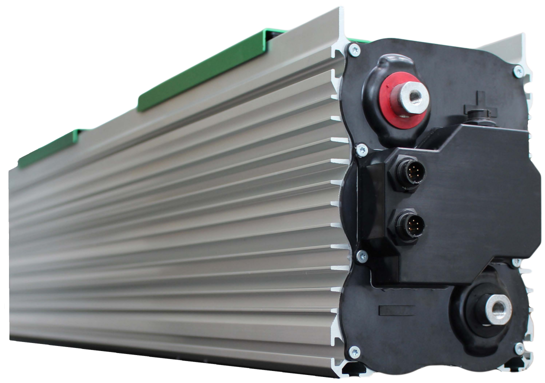
Ultracapacitors – NaS battery assistance

Given the very similar voltage range for ultracapacitors as NAS battery cells, packs of ultracapacitors could easily be integrated alongside an NAS battery system to provide additional energy storage backup capability. The ultracapacitor packs would also easily be able to provide the low system output impedance that would be necessary to interface to the synchronous grid tie inverter, distribution transformer and switchgear of many modern wind farm and solar grid tie systems.



There are two operating modes for ultracapacitors when used with NaS batteries. The first is to keep the ultracapacitors in either an uncharged state, and the second is to use the ultracapacitors in a charged state, depending on the type of load. Given that most applications are energy storage and ride through applications, only the second will be discussed here. Service life is not a factor for ultracapacitors because of the high number of charge – discharge cycles that are possible (> 500k cycles).

The second mode of operation, with an ultracapacitor power array, or ultracapacitor packs floating, means that either passive balancing or active balancing of each ultracapacitor cell must be happening in real time. With today's power electronics technology, this is not a problem, and cells can be individually balanced, in real time, to whatever voltage band is necessary without one balancing circuit affecting the other.

Ultracapacitors help NaS service life

Long service life of the NaS batteries is necessary to achieve a good economic benefit. With the threat of moisture being so important, regular NaS battery servicing is necessary, as well as individual cell inspection to ensure long term operation. Battery servicing has to include the very important work of replacement of those cells that show any sign of leakage, so that failed cells can be replaced with new ones. During this time, ultracapacitor arrays can take the critical load off of the NaS battery pack to allow for servicing.

Ultracapacitors buffer load guarantee requirements

An NaS battery, no matter what its energy density is, still suffers from the situation that it may see an abrupt increase in load, even when the battery is not at 100% state of charge. Statistical analysis of NaS battery reliability reveals that meeting specific abrupt load demands is more difficult when the state of charge of the battery is reduced. Because ultracapacitors possess, by several orders of magnitude, higher specific power than batteries, they can be used as an almost seamless buffer to enhance the servicing of NaS battery arrays. Floating ultracapacitor arrays can be connected and disconnected if needed, with minimum change in voltage, and minimum generation of electromagnetic interference, since ultracapacitor arrays can be matched to active, real time NaS battery array voltage before connection or disconnection.

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The preferred combination

The NaS battery has the ability to deliver long term power, but also has the drawback of high temperature operation, coupled with the need for periodic maintenance and inspection to make sure that any leaky cells are detected, and replaced promptly. The NaS battery is kind of like the "weight lifter" of the group. The ultracapacitors can provide short to medium times of large amounts of compatible power like the NaS battery, and have the advantage of flexibility and ease of handling with virtually no maintenance. Thus, the ultracapacitor arrays are kind of like the "sprinter of the group." The two together make the perfect power combo team - each doing their own function to help meet the overall power needs – short term and long term.

Ultracapacitors increase overall system energy time

The use of ultracapacitors in conjunction with lead acid batteries for locomotive starting has shown an increase in cranking time by more than a factor of 2 times. While providing grid backup is not exactly the same application, a very favorable increase in the power available-time curve is also expected with the use of ultracapacitors in conjunction with NaS batteries.

Conclusion

When comparing the use of ultrcapacitors with NaS battery arrays, we can come to the following conclusions:

- The ultracapacitors can take upon themselves, all of the power functions, except for extended time operation, and this is actually only dependent on the ultracapacitor system size.
- Ultracapacitor power arrays, in conjunction with the NaS batteries, can deal with any abrupt or unusual system power demand, up to or exceeding the power demand capability of the NaS battery array alone.
- State of charge of the NaS battery array does not affect the characteristics of the ultracapacitor energy delivery capability.
- Due to buffering by the ultracapacitor array, the NaS battery array is not subjected to large current loading, which makes its operating conditions, under all conditions of line and load more moderate.
- When combined with ultracapacitors and given specific NaS battery system sizes based on load requirements in the past, the size of the specific NaS battery system can be reduced and still supply the required short term to moderate term power. Ultracapacitors can offer hundreds of thousands of charge-discharge cycles. Since the depth of discharge of the NaS battery array is reduced, this represents an increase in the service life of the NaS battery array. If NaS battery/ultracapacitor maintenance and repair expenses follow the trend of lead acid battery/ultracapacitor combination trends, then users can expect to see their costs cut approximately in half.
- Ultracapacitor are not only compact, but also are sealed, and maintenance free. This means that they can be installed in almost inaccessible places.