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Research on Sodium-Sulfur Battery for Energy Storage System

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Abstract*:* *Sodium sulfur battery is one of the most promising candidates for energy storage applications. This paper describes the basic features of sodium sulfur battery and summarizes the recent development of sodium sulfur battery and its applications in stationary energy storage. The research work in the Shanghai Institute of Ceramics, Chinese Academy of Sciences (SICCAS) on beta-Al2O3 ceramics and the sodium sulfur battery is also introduced. This paper is focused on sodium-sulfur (NaS) batteries for energy storage applications, their position within state competitive energy storage technologies and on the modeling. At first, a brief review of state-of-the-art technologies for energy storage applications is presented. Next, the focus is paid on sodium-sulfur batteries, including their technical layouts and evaluation. It is introduced the equivalent circuit model of the battery cell. At the end, there are presented the results from simulation model which was developed in Simulink to verify the proper function*

Keywords: Sodium sulfur battery

I. INTRODUCTION

Sodium sulfur battery is one of the most promising candidates for energy storage applications developed since the 1980s [1]. The battery is composed of sodium anode, sulfur cathode and beta-Al2O3 ceramics as electrolyte and separator simultaneously. It works based on the electrochemical reaction between sodium and sulfur and the formation of sodium polysulfide and exhibits high power and energy density, temperature stability, moreover low cost because of its abundant low-cost raw materials and suitability for high volume mass production [2–4]. Great achievements have been made during the last two decades, especially under the collaboration of Tokyo Electric Power Company (TEPCO) and NGK Insulator, Ltd., (NGK). The batteries have been applied in various ways such as load leveling, emergency power supply and uninterruptible power supply. The markets covered industrial, commercial owners and wind power generating systems etc. This paper summarizes the recent development of sodium sulfur battery, especially its applications in stationary energy storage, and introduces the research work in SICCAS. Due to increasing pressure on integration of high capacities of renewable energy sources there are also stricter demands for power regulation. Energy management is increasingly important for the proper function of power grids. Energy storages can help with the compensation of power fluctuations caused by renewable energy sources or any other causes, even more they can improve the dynamics of the classic thermal and nuclear power plants. There are several technologies of energy storages. Most of them use the energy accumulation in another type of energy (mechanical, chemical, thermal, etc.). For providing high power (more than 100 MWe) there are currently available only pumped hydro storages (PHS), compressed air energy storages (CAES) and thermal energy storages (TES). PHS and CAES are limited by geographic demands, environmental impacts and gas combustion in the case of CAES. The biggest disadvantage of TES is really slow dynamics (up to hours). For the more widespread construction of high-capacity complex energy storages there is need of an additional technology which provides small (less than 10 MWe) or medium (10 - 100 MWe) power with significantly faster dynamics. The batteries are most suitable and economically viable for this application at present.

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1.1 Objective

The objective of research on Sodium Sulphur Battery for energy storage system is to develop a megawatt-level energy storage system with high energy density, large capacity, and long service life. Sodium sulphur batteries are increasingly being used to stabilize output from wind and solar power generators. The battery is a type of molten salt electrical energy storage device, named for its constituents: Sodium (Na) and Sulphur (S). The battery is formed by combining the liquid states of the negative sodium and positive sulphur electrodes. The battery has a similar energy density to lithium-ion batteries, and is fabricated from inexpensive and non-toxic materials. However, due to the high operating temperature required (usually between 300 and 350 °C), as well as the highly corrosive and reactive nature of sodium and sodium polysulfides, these batteries are primarily suited for stationary energy storage applications, rather than for use in vehicles. Despite their low cost, molten sodium-sulphur batteries suffer from safety and durability issues, such as a short cycle life of fewer than 1000 cycles on average. As a result, these batteries have not achieved significant commercial deployment.

II. RESEARCH WORK AND METHODOLOGY

The research work on sodium sulfur battery in China was dated back to the 1970s, but since 1980, SICCAS has become the only Chinese institution engaged in sodium sulfur battery research. Systematic research work has been carried out on beta-Al2O3 ceramics and battery as well as module. Both β- or β″-Al2O3 ceramics were investigated. Ceramic tubes with homogenous microstructure, favorable electrical and mechanical properties were fabricated based on a double-zeta powder process as illustrated in Fig. 4. The powder process employed the respectively synthesized zeta-lithium aluminate (Li2O·5Al2O3) and zetasodium aluminate (Na2O·5Al2O3) (both at 1250 °C) as precursors for the beta-Al2O3 ceramics. In comparison with the direct mixing process applied by NGK [2], the double-zeta process made the green powders before the forming as homogeneous as possible because of the pre-dilution of the minor component lithium with alumina. The green tubes were made with the spray dried powders by an isostatic pressing forming technique at the pressure of 2.5 T cm−2 , then the tubes were sintered at 1580–1650 °C to prepare the ceramic tubes.The sodium sulfur battery works based on the electrochemical reaction between sodium and sulfur and the formation of sodium polysulfide. While discharge, the sodium metal in the anode compartment is oxidized to Na+ ions as reaction (1) described and transports across the beta-Al2O3 ceramic electrolyte membrane and combines with reduced sulfur anions formed by reaction (2) to generate sodium polysulfide NaSx in the sulfur compartment.

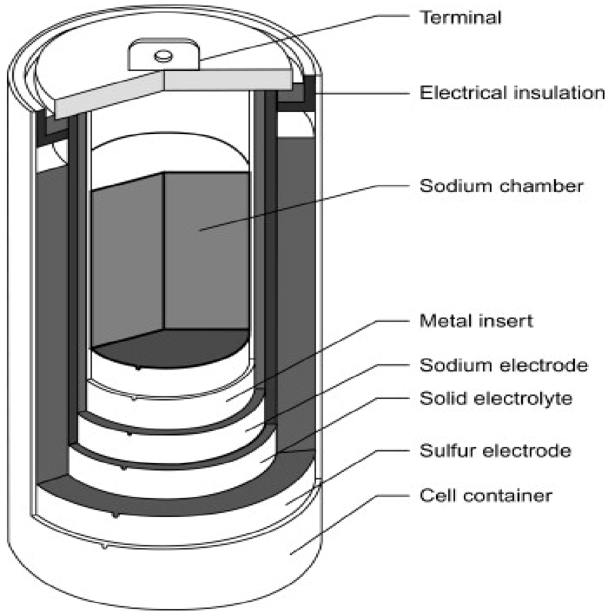

Fig. Sodium-Sulphur Battery

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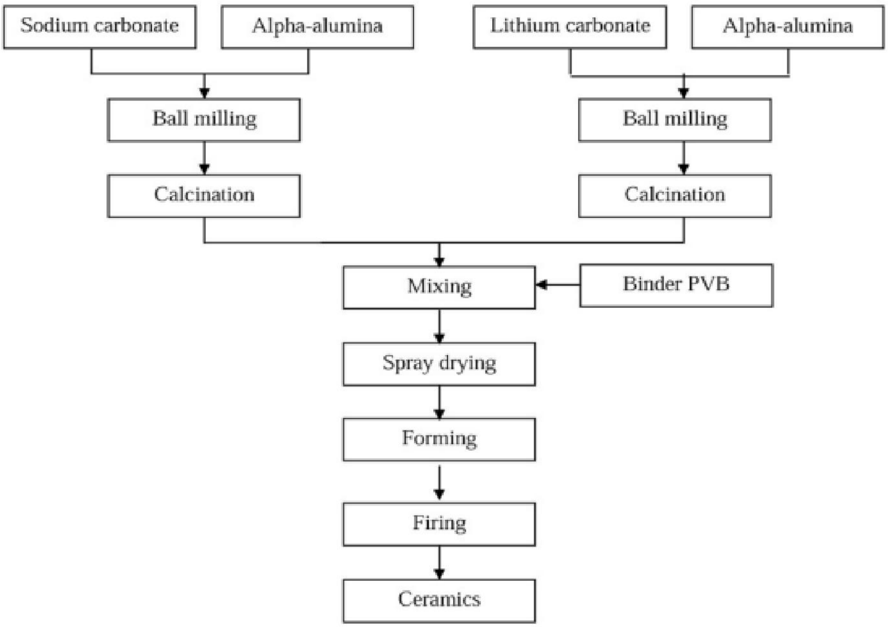

Fig. Schematic illustration of double-zeta process adopted in SICCAS.

2.1 Comparison of Battery Technologies for Energy Storage

Li-ion batteries:

The most deployed type of battery at present. It has high energy density (200 - 500 Wh/l) and power density (1 500 - 2 500 W/l), due to this fact are Li-ion batteries very suitable for small handheld devices. [2] Their deployment is not very convenient for energy storages applications. Despite high cycle efficiency (90 - 97%) and relatively low capital costs (400 - 3 800 USD/kWh) in comparison to competitive energy storage systems (ESS) technologies, their number of operation cycles is quite low (around 1 500 cycles) and there are limitations due to the full use of rated capacity. Charging battery below 20% and above 80% of rated capacity leads to the significant decrease in usable capacity and battery lifetime. Moreover, it is very sensitive for the ambient temperature and it needs additional electronics to manage the charging and discharging. [3]

Vanadium-redox flow batteries:

Currently the most promising new battery technology for energy storages. It contains two separate tanks with the anolyte and the catholyte and the ion-selective membrane for ion changes. It has a very long lifetime (up to 20 000 cycles), moreover, the lifetime is restricted mainly by lifetime of the ion exchange membrane which can be simply replaced. Moreover, it is almost trouble-free and cheap (150 - 1 000 USD/kWh). Despite this, it has low energy density (16 - 35 Wh/l) and power density (2 W/l) which restrict the usage for some applications. [2, 3].

Sodium-sulfur batteries:

A very suitable battery technology for energy storages manufactured and highly deployed in the Japan. It uses molten sodium and sulfur as electrodes and solid beta alumina as electrolyte. Due to maintaining electrodes in liquid state the working temperature of the battery is 300 - 350 °C which leads to lower efficiency of the cycle (75 - 90%). Despite this, it has higher number of operation cycles (around 2 500) than Li-ion, no rated capacity limitations and may give pulse power up to five times higher than rated power. Energy density (150 - 400 Wh/l) is comparable to Li-ion but power density is quite lower (140 - 180 W/l). Capital costs (300 - 500 USD/kWh) are between Li-ion and VRB. [2, 3].

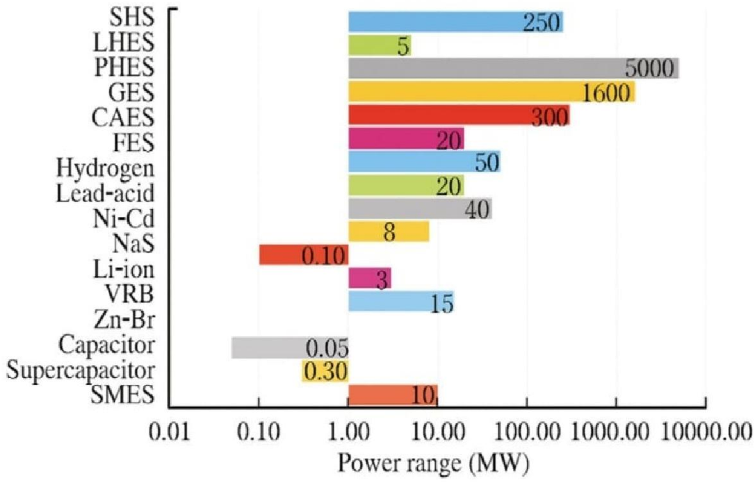

Fig. Comparison of power range for all the energy storage systems

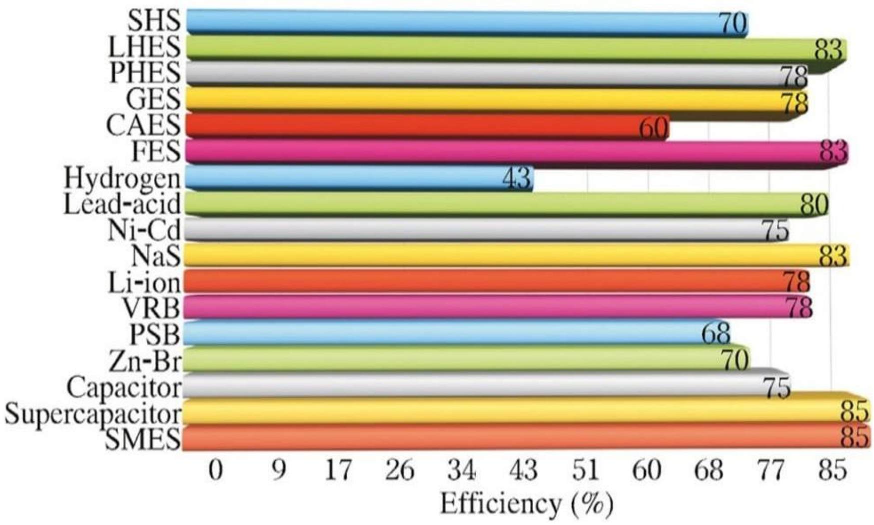

Fig. Comparison of efficiency for all the energy storage systems

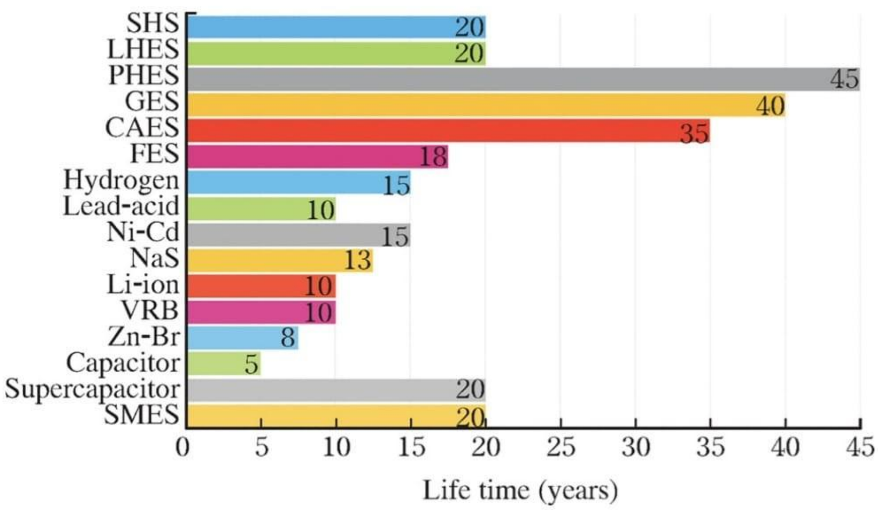

Fig. Comparison of lifetime for all the energy storage systems

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2.2 Advantages of Sodium Sulphur Batteries :-

Long duration

NAS battery is a large-capacity, long-duration storage battery suitable for daily load leveling and time shifting of wind and solar generation.

Long life expectancy

NAS battery has a calendar life of 15 years and a full charge/discharge durability of 4500 cycles.Since the active materials of the NAS battery are in molten states, there are no transition between solid and liquid due to charge and discharge, and there is no side reaction, so long life can be expected.

Tolerance for cold and high temperature environment

NAS battery, which operates at 300–340-degree C. in a thermal enclosure, satisfies optimal operating conditions without air conditioning in cold and hot areas.

Safety

The safety of batteries is attracting attention. NAS batteries have been designed with safety as a top priority and have been improved and assured by field experience.

2.3 Disadvantages of sodium sulfur batteries

Operational cost:

The increased operational cost of sodium sulfur batteries is due to the high temperature (350°C) required to liquefy sodium.

Production capacity:

Unlike Li-ion batteries, sodium sulfur batteries are not yet established in the market. Currently, NGK is the only recognized manufacturer of sodium sulfur batteries in commercial volumes.

Safety:

As the sodium sulfur batteries operate at very high temperatures, the safety risk makes them less suitable for BTM applications. Moreover, the sodium battery is highly dangerous if the liquid sodium comes into contact with water in the atmosphere.

Temperature:

Sodium- Sulphur battery needs to be operated above 300-degree celsius.

2.4 Applications of sodium sulfur batteries include:

Behind the meter (BTM) applications (including backup power and peak shaving)

In front of the meter (FTM) applications (including flex ramping and renewable shifting)

Off-grid or remote applications (including backup power in data centers and self-consumption from distributed renewable generation in islands, military areas, and remote areas)

Sodium sulfur batteries are mostly used for backup power, load leveling, and renewable energy stabilization applications.

For instance, the NaS battery system can be used as an emergency power supply during momentary voltage drops and power outages.

III. CONCLUSION

At first, a brief review of state-of-the-art technologies for energy storage applications is presented. Next, the focus is paid on sodium-sulfur batteries, including their technical layouts and evaluation. It is introduced the equivalent circuit model of the battery cell. At the end, there are presented the results from simulation model which was developed in

Simulink to verify the proper function. NaS batteries are one of the promising technologies for high-power and high-capacity chemical energy storage applications with the benefits of reduced space requirements and high lifetime even with demangingussage especially when compared to Li-ion batteries. It has been presented the simplified equivalent simulation model including the performance in Simulink environment. The presented simplified model can be employed in the more complex simulation models of the whole energy storage layout, including power electronics and energy management. The function of the model was succesfully tested and the load and the current source can be simply replaced or modified when needed.

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