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TECHNOLOGICAL DEVELOPMENTS IN BATTERIES

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ABSTRACT

Batteries are an essential part of our modern lifestyle, finding application in various aspects of everyday life such as mobile devices, electric cars, renewable energy sources and many others. The technological development of batteries is continuous and fast in order to improve performance and reduce their negative impacts on the environment and society. This paper explores the technological advances of batteries through different generations and technologies, from classic lithium-ion batteries to new innovative concepts such as solid and lithium-alloy batteries. The improvement processes include improvements in the capacity, charging speed, safety and durability of the batteries, as well as the recycling of components to reduce the environmental footprint. With continued research and innovation in the field of batteries, we can expect to see significant advances in battery efficiency and sustainability, with the potential to revolutionize the way we use and store energy in the future.

KEY WORDS: Lithium-ion batteries, battery capacity, battery charging and discharging, renewable energy sources, effectiveness

1.INTRODUCTION

Energy storage batteries play a key role in modern power systems. Research and development of this technology has been increasing over the last decades. With the disappearance of fossil fuels and the growth of renewable energy sources, the need for an efficient way of storing the produced energy is constantly growing.

These batteries are a great way to store energy for later use, as they can store energy for long periods of time without losing charge. Energy storage batteries consist of several components, including a battery, a controller, and a power management system. The battery is the main component, and the controller is responsible for controlling the flow of energy from the battery cell to the energy management system. The power management system is responsible for regulating the flow of power from the battery cell to the device being powered.

Energy storage batteries are devices that convert electrical potential into chemical potential and vice versa, enabling the storage and reuse of electrical energy. This is essential in situations where the energy produced cannot be used immediately or when additional energy is needed during periods of high consumption. Battery energy storage has many advantages, including improving the stability of power grids, reducing pollution and reducing the need for heavy infrastructure development. This technology could soon enable more efficient use of renewable energy sources and environmental improvement.

To understand the challenges and significance of energy storage batteries, we need to consider the following aspects:

1. Variability of renewable energy sources: Solar and wind power are variable, meaning they are produced only when the sun or wind is available. Batteries make it possible to store excess renewable resources and use them when they are not available.
2. Improving grid efficiency: Energy storage batteries can improve the stability and efficiency of power grids, making them better able to cope with the variable nature of renewables.
3. Ability to react in crisis situations: In the event of natural disasters or other crisis situations, batteries can provide an external source of energy and help establish the energy infrastructure.
4. Sustainability and environmental protection: Batteries have the potential to reduce pollution and contribute to sustainable development by replacing fossil fuels.

In this paper, we will explore various aspects of energy storage batteries, such as battery function, types of batteries used, their advantages and challenges, as well as current advances and applications in this field.

2. BATTERY CATEGORIES

Rechargeable batteries are widespread today and have the ability to store electrical energy in a chemical. Batteries currently used in the power industry are: lead-acid batteries (Lead-acid), nickel-metal hydride (NiMH) batteries, lithium-ion batteries (Li-ion), sodium-sulfur batteries (NaS) and redox flow batteries (RFBS).

3. TECHNOLOGICAL CHARACTERISTICS AND APPLICATION IN THE REAL WORLD

3.1 Lead-acid batteries

The lead acid battery is the oldest rechargeable battery. Its use in households and industry dates back to the mid-1800s. In such a battery, the positive and negative electrodes are separately made of lead dioxide and metallic lead which are immersed in a dilute sulfuric acid electrolyte. The biggest advantage of this type of batteries is that they are energy efficient. Of course, it also has its drawbacks, such as a short service life, slow charging and low energy density. This type of battery is mainly used where profitability and reliability are key, and service life is not of great importance.



Pic. 3.1 Lead-acid battery

3.2 Nickel-metal hydride batteries (NiMH)

The NiMH battery consists of a positive electrode based on nickel oxyhydroxide, a negative electrode based on metal cadmium and an alkaline electrolyte. This battery has higher power and is environmentally friendly. However, there are also several technological problems, such as a high degree of self-discharge, limited working life and efficiency (about 65%). In addition, the fast charge and overcharge tolerance of this battery is very low. In particular, during rapid charging of the battery it is possible to generate large amounts of heat, and the accumulation of hydrogen can cause a breakdown that further leads to a reduction in capacity. Since it is small, its most common use is in easily portable devices.



Pic.3.2 Nickel-metal hydride batteries (NiMH)

3.3 Lithium-ion batteries (Li-ion)

The Li-ion battery is an advanced battery originally developed by Sony in the early 1990s. During charging these batteries are switched on and off from the positive and negative electrodes respectively. Unlike other batteries, Li-ion has the advantage of high energy density (which occurs due to the high output voltage), high efficiency, long service life and they are environmentally friendly. The working life of the battery is of great importance for grid use and also affects the economic durability of energy storage. The modernity of the technology and standard production of the Li-ion battery are also important because they determine the complexity of management and maintenance. Li-ion batteries play an important role in frequency distribution and regulation.

Lithium-ion batteries are most widely used in electric vehicle batteries (eg, the Tesla Model S); for home energy storage and utility services. The Tesla Gigafactory plans an annual lithium-ion battery production capacity of 35 GWh and anticipates a reduction in the price of the lithium-ion battery pack by more than 30%. It is clear that the lithium-ion battery is among the most promising electric energy storage technologies, and its installed capacity is well poised to increase.



Pic.3.3 Lithium-ion batteries (Li-ion)

3.4 Sodium-sulfur batteries (NaS)

The NaS battery was originally produced by the Ford Motor Company to power early model electric cars in the 1960s. Since 2002, this type of battery has been commercialized and is gradually becoming the most recognized on the market. Unlike the batteries described earlier, NaS batteries are composed of a molten sulfur cathode, a molten sodium cathode, and a solid aluminum oxide-ceramic electrolyte. Charging and discharging must be done at temperatures higher than 300°C, such that sulfur and sodium are in a molten state. External heating is required to initiate charging and discharging, but is usually not necessary since internal heating can be achieved by electrochemical reactions. The potential of these batteries comes from the ability to provide high energy density (150-240 Wh/kg), high efficiency (70%-90%) and long life (2500-4000 cycles). Essentially, by being able to operate at high temperatures these batteries are used in hot, harsh environments.

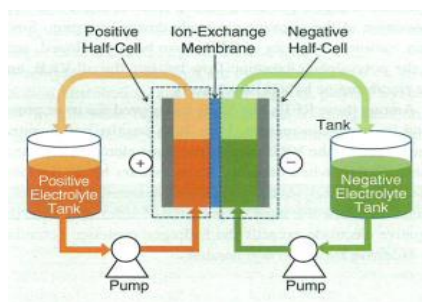
During this decade, NaS batteries play an important role in the power system and renewable energy generation. Even in spite of their popularity, we have to be very careful in their application because pure sodium is dangerous and can burn suddenly on contact with air and moisture.



Pic. 3.4 Sodium-sulfur batteries (NaS)

3.5 Redox flow batteries (RFB)

As shown in Figure 3.5, a redox flow battery (RFB) is a type of energy storage device that consists of separate power and energy modules. The power module provides energy conversion between chemical and electrical energy. The interior usually consists of multiple cells to meet energy needs, each with positive and negative half-cells separated by an ion exchange membrane.



Pic. 3.5 Schematic view of an RFB battery

Energy conversion occurs when liquid electrolytes are pumped from reservoirs into cells, where an electrochemical reaction occurs at the electrodes. The ion exchange membrane prevents electrolytes from mixing and transports charged ions to form an internal pathway between the positive and negative half-cells. Compared to other rechargeable batteries (eg lead-acid and lithium-ion), commercial redox flow batteries (RFBs) currently have a lower energy density. However, they exhibit several distinct advantages.

The power and energy capacity of flow batteries (RFBs) are completely independent of each other. RFB electrode agents provide only an electrochemically active surface for redox reaction and only liquid phase reaction during space/discharge, RFB chemistry has a long lifetime. For example, the Vanadium redox battery has been proven to last more than 200,000 and more than ten years in demonstration projects in large and Europe, much more. Flow batteries have good transient behavior, with very fast response. Switching times between different and discharges are often less than 0.02 seconds. It is therefore well suited to balancing many variable renewable energy sources.

Overall Sodium-sulfur (NaS), lithium-ion, and flow batteries are currently the main battery technologies used in large-scale energy storage.

4. BATTERY MANAGEMENT

Despite significant advances in battery chemistry and materials, effective and reliable battery management systems (BMSs) are still needed for condition monitoring, charge/discharge regulation, thermal control, cell balancing, health prognostication, and safety protection. large-scale battery energy storage. The absence of such systems is most likely the reason for the conservative use of batteries. Without proper battery management systems, catastrophic hazards and premature failure, such as thermal breakdown, can occur due to poor electrical and thermal operation and maintenance practices. The main functions of battery management systems (BMSs) include the following: Data acquisition, Condition assessment, Charge/discharge control, Cell balancing, Thermal management, Safety protection.

The key technologies to enable these functions in battery management systems (BMS) are dedicated to battery modeling, estimation of states of charge, power and endurance (SOC/SOP/SOH), cell balancing, charge control and diagnostics. defects. Since the internal states of batteries are generally inaccessible through current in situ sensing techniques, models have been established in order to mimic their dynamics and duplicate a real battery. Then, based on such models, the state/parameter behavior of the battery can be probed and manipulated with sophisticated estimation and control approaches.

4.1 Battery modeling

Mathematical modeling of battery dynamics is fundamental and is also an effective tool for advanced battery management. Related work can be categorized into three types: white-box, black-box, and gray-box models. White-box models are developed from first principles and accurately capture the internal dynamics of batteries such as ion diffusion, intercalation kinetics, and electrical potentials. A diagram between a gray box model (also known as an equivalent circuit model) that approximates the internal dynamics of a battery with some voltage sources, resistors, and capacitors. These models are relatively easy to implement, but suffer from a lack of physically meaningful parameters and insights. As a result, it is difficult to impose precise constraints that achieve safe and optimal operations with algorithms based on gray/black models.

4.2 SOC/SOP/SOH estimation

The state of charge (SOC) is an indicator of the available charge stored in the battery. Accurate state of charge (SOC) measurement is necessary not only for charge/discharge safety and battery durability, but also for system-level energy management in a smart grid.

State of Endurance (SOH) is related to the battery's aging status and remaining life. This information is critical to extend battery life.

The state of power (SOP) indicates the maximum charge and discharge power that a battery can sustain instantaneously or over a time horizon of interest. None of these conditions are directly

measurable using current sensors, leading to the emergence of different estimation algorithms. The sophistication of the condition estimation algorithm largely depends on the battery model used.

4.3 Cell balancing

For a battery pack consisting of a large number of battery cells, although all of the same type and specification, there may be cell variants that increase with battery usage. As for voltage equalization, passive and active solutions with energy dissipation and non-dissipation, respectively, are being developed. A passive scheme consumes the additional capacity of individual cells through external circuits, while an active scheme transfers energy from one "rich" cell to another "poor" cell. Temperature equalization requires advanced battery thermal management, featuring high-fidelity characterization of heat generation and transfer, package structure optimization, and efficient thermal controls, e.g., hybrid air/liquid/heat pipe cooling.

4.4 Charging control

Battery charging must be handled carefully to guarantee acceptance of a charge within a specified charge duration while meeting safety requirements. Typically, different batteries have different charging strategies. For example, the constant current/constant voltage protocol is often applied to lithium-ion batteries. New backfill methods consider multiple objectives to search for pareto optimal solutions.

4.5 Fault diagnosis

Functional safety is critical in large-scale battery storage. Electrical, thermal and electrochemical faults should therefore be diagnosed, isolated and identified through advanced hardware and software redundancy approaches. More sophisticated algorithms are needed to improve the robustness of fault diagnosis against modeling perturbations and uncertainties.

5. FUTURE PROSPECTS

All battery technology is evolving and advancing. However, their rate of development differs significantly. Compared to lead-acid batteries, Nickel-Metal Hydride (NiMH) and Sodium-Sulfur (NaS), Lithium-Ion and flow-through batteries (RFBS) are increasingly used due to significant performance improvements and cost reductions driven by high technological demand, and the incredible growth of the market. As data from Navigant Research shows, the Lithium-ion battery is well positioned to be the dominant battery storage technology with the most increased installed capacity in the future.

5.1 Lead-acid batteries

Advanced lead-acid batteries are new technology. An interesting design is inspired by the advantages of a traditional lead-acid battery and an ultra capacitor, the so-called ultra battery. It is

synthesized by introducing the negative electrode of an ultracapacitor, composed of activated carbon, into a standard lead-acid battery.

5.2 Lithium-ion batteries (Li-ion)

Compared with other types of batteries, lithium-ion batteries have the advantages of high energy density, high efficiency, long cycle life and environmental friendliness. Installed lithium-ion battery capacity is predicted to increase rapidly, so it is expected to become the dominant battery storage technology in the future. Future emphasis of such development could focus on how to reduce battery cost and extend battery life. It is still a daunting challenge to rationally design and integrate lithium-ion battery systems for sufficiently stable and efficient use.

5.3 Sodium-sulfur batteries (NaS)

The sodium-sulfur (NaS) battery, as a mature technology, has not experienced significant cost reductions in recent years. Development of the low-temperature fused sodium ion battery is actively underway. The lower operating temperature allows the use of a polymer outer shell instead of expensive steels such as cesium, and can be an effective way to offset costs.

5.4 Redox flow batteries (RFB)

Redox flow batteries (RFBs) have rapidly growing market opportunities as an electricity storage device for smart grids due to its ability to balance alternating renewables, control power quality, and achieve load balancing. However, redox flow batteries (RFBS) must prove their cost competitiveness for wider market penetration. From the point of view of technology, membrane materials until now have been subject to premature degradation and contamination, they are also very expensive. To address the energy density and cost limitations, more research efforts are needed to achieve fundamental breakthroughs in key materials, especially electrodes and membranes.

5.5 Hybrid energy storage

A single energy storage technology may be inadequate to meet the requirements of certain applications. Therefore, it is desirable to develop hybrid energy storage systems (HESS) consisting of two or more energy storage devices with complementary characteristics. These systems may combine different battery technologies or integrate a supercapacitor battery, fuel cells, flywheel and/or superconducting magnetic device. Typically, when a battery is used to smooth out low frequency fluctuations, another high power density medium can be combined to smooth out the high frequency fluctuations. This class of storage is now a pilot project, in the city of Aachen, Germany, where a 5-MW Li-ion and lead-acid hybrid capacity became operational in 2015 to provide testing, demonstration, power frequency, balancing. Another battery storage system consisting of a 2 MWh Li-ion battery and a 1 MWh VRB is also connected to a wind farm in Braderup, Germany.

5.6 Battery management

The continued expansion and advancements in information and communication technologies, the development of powerful cloud computing capabilities, and the growing Internet of things will greatly improve and even transform the concept of battery management, such as modeling and controlling thousands of cells in battery storage. on a large scale it will become easier. The generated commands can then be transmitted to each local battery storage station via high-speed, two-way communication. In such a battery management system the accuracy, resilience, reliability and security of battery monitoring and management can be determined simultaneously.

6. CONCLUSION

Over the years, technological advances in the field of batteries have changed the way we use and store energy. Lithium-ion batteries have become an essential part of our daily lives, enabling better mobility and efficiency in various aspects of our lives. They are used in mobile phones, laptops, electric vehicles and renewable energy sources.

Over time, the needs to improve battery technologies are increasing. Intensive research and innovation lead to stronger, more economical, safe and sustainable batteries. Solid-state batteries and lithium-hydrogen sulfide batteries are just some of the advanced concepts that promise revolutionary changes in the field of energy and energy storage. With each new advance, batteries become a stronger tool to deal with modern challenges such as the replacement of fuels, the increase in the number of electric vehicles and the stronger integration of renewable energy sources.

In essence, batteries are the most important components of our energy and environmental awareness and are expected to continue to innovate and improve in the future. Their technological development is necessary for the sustainable and efficient use of energy in our modern world.

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