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Redox Flow Battery as an Energy Storage Device

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Abstract

A battery has become an indispensable device in our modern life. Whenever we talk about portable electrical energy source for various applications, battery help us in all the ways. Batteries are devices at high global demand with increasing applications day by day. To mitigate carbon footprints globally, solar and wind power, are increasingly being introduced as alternative energy sources. Such energy sources require energy storage devices for their regulated supply and offline use. Therefore, for the next-generation power system, energy storage technologies will be indispensable. Among the energy storage technologies, battery energy storage technology is considered to be most viable and reliable. In particular, a redox flow battery, which is suitable for large scale energy storage, has currently attracted the attention of global community. This paper reviews the technical development of the redox flow battery.

Keywords: Redox battery, Energy storage, Renewable Energy .

1. Introduction

To realize a low-carbon society, the introduction of renewable energies, such as solar or wind power is increasingly being promoted these days worldwide. A major challenge presented by solar and a wind power generator is their fluctuating output. If they are introduced in large numbers to the power system, problems, such as voltage rises, frequency fluctuations and surplus of the generated power, are predicted to occur. As a solution to these problems, energy storage technologies are attracting attention, amongst which energy storage batteries are expected to become indispensable for use. Various energy storage batteries are being developed and many application verification projects using such batteries are currently being promoted globally. Thus, expectations are growing for their practical use to the power system in near future. The redox flow (RF) battery, a type of energy storage battery, has been enthusiastically developed in Japan and in other countries since its principle was publicized

in the 1970s. Some such developments have been put into practical use. This paper reviews the history of the RF battery's development, along with the status of its use.

Potentially beneficial energy storage technologies include enclosed and flow batteries (e.g. intelligent vehicle- to- grid traction battery systems or stationary distributed/utility- based systems, pumped water, compressed air, thermal heating, high speed flywheels and hydrogen-based approaches. Primary outcomes of energy storage could include energy efficiency improvements (and thus a reduction in the use fossil fuel- powered utilities) and an increased use of renewable energy sources. Vanadium based redox battery is the most widely commercialized RFB used for large- scale energy storage. Because of vanadium used, it has a low environmental impact, especially when compared to traditional lead- acid batteries. Past, present and potential future RFB competitors of the all vanadium battery include iron/chromium, bromine/poly-sulphide, zinc/bromine, zinc/cerium and soluble lead-acid batteries. Many other variants of the half cells and the resultant cell chemistries are being developed internationally.

Global attention is towards renewable energy sources as an alternative energy option due to rising fossil fuel prices and concerns reducing carbon footprints. However, a major challenge for implementing renewables, such as wind and solar, on a large scale, is their inherent temporal intermittency. For continued growth of renewables, while maintaining the expected level of stability and reliability in the energy grid, significant advances are needed in the area of large-scale energy storage. Electrochemical energy storage (EES) systems have been broadly identified as promising for short-term grid leveling and for long-term energy storage. Redox Flow Batteries (RFBs) are gaining increasing levels of attention as a viable approach for grid-scale EES. RFBs differ from conventional batteries in that charge is stored in a pair of liquid-phase redox couples with disparate electrochemical potentials, unlike the solid-phase anodes and cathodes used in conventional batteries (e.g. Li ion, Ni-Cd, and Pb-acid). Thus, these liquid species can be stored in tanks of arbitrary size and flowed through separate electrode stacks to store and recover electrical energy. These properties lend well to modular, flexible designs that decouple energy density and power. RFBs also enjoy comparatively high stability due to the lack of phase changes upon cycling.

2. Need for Energy Storage

As energy storage technology in the power system, pumped hydro energy storage is widely known. Occupying about 10% of the total power generation capacity, it functions as a load leveler; namely, it levels the power load by storing power during off-peak hours and discharging it during peak hours. Variable-speed pumped hydro energy storage with varying rotating speed of a pump, is currently in practical use. Some pumped hydro systems have a sophisticated power system stabilization function of frequency regulation or others. As other energy storage technologies, energy storage batteries, superconducting magnetic energy storage (SMES), flywheels, compressed air energy storage (CAES), and electric double-layer capacitors (EDLC) are known. They are being developed for various applications to make effective use of their individual characteristics, and some of the developments have been put into practical use.

An advantage of SMES is that they are high in energy storage efficiency and can discharge a large amount of power instantaneously, since they store electric energy as it is. They are expected to be put into practical use in the near future, as electric power companies and national projects are conducting their verification tests. This SMES, used for instantaneous voltage sag compensation, is among the world's largest. In other countries, such as the United States, SMES is already commercialized for the power system stabilization and for instantaneous voltage sag compensation. Regarding flywheel technologies, the Fusion Institute of the the Japan Atomic Energy Agency has a flywheel power generator with the world's largest energy storage capacity. The generator is used as a magnetic field coil power supply. The CAES is a technology that compresses air and stores it in an underground hollow space, and generates power in combination with a gas turbine generator where necessary. It is in practical use at some power stations in Germany and the United States. EDLC technology has a characteristic of instantaneous large output because, like capacitors, it charges and discharges electricity by absorbing and desorbing electric charge without any chemical reaction taking place. The technology is also advantageous in that it is maintenance free. Recently, EDLC products with large capacities that can be used for electric-power facilities are commercially available, and are also being used in such applications as instantaneous voltage sag compensation, absorption of regeneration energy and voltage regulators for electric railway, and natural-energy-generation output fluctuation stabilization. In comparison to all above energy storage technologies, battery energy storage technology is superior in

technical integrity and has excellent practical uses because it can be installed and distributed in as per our requirements. It is thus a highly promising technology.

3. Redox Flow Battery for Energy Storage

The word redox is a combination of, and thus stands for, reduction and oxidation. A redox battery refers to an electrochemical system that generates oxidation and reduction between two active materials, forming a redox system, on the surface of inactive electrodes (the electrodes themselves do not change). A redox flow battery has the electrolyte including these active materials in external containers, such as tanks, and charges and discharges electricity by supplying the electrolyte to the flow type cell by pumps or other means.

The battery reaction principle is simply the change in valence of the metal ions in the electrolyte, realizing a long charge/discharge cycle service life. The output section (cells) and capacity section (tanks) are independent of each other and can be optimally designed according to application needs. Maintenance is easy mainly because the same electrolyte is supplied to individual cells and therefore the state of charge (SOC) in each cell does not need to be monitored, and because heat can be controlled easily based on the flowing electrolyte. Since the SOC can be easily monitored by measuring the potential of the electrolyte, the SOC can be monitored continually during operation. The electrolyte is stored in the positive and negative tanks separately, so that no self-discharge occurs during stand-by and stoppage, except in the cell section. RF batteries are useful to absorb irregular, short cycle output fluctuations, such as in natural energy generation, because they have the characteristic of instantaneous response in an order of milliseconds and can charge and discharge at an output rate a few times larger than the designed rating for a short period of time. The electrolyte is friendly to the environment, because it scarcely changes during normal operation except for changes in ion valance, and it can be used virtually permanently and reused. Along with many advantages of RF batteries, it has certain limitations such as, an RF battery uses metal ions dissolved in a solution as its active material with limited solubility. Size of the battery tank should be necessarily large as compare to other storage batteries. Additional pumping power is required to circulate electrolyte. Shunt-current losses may occur through electrolyte.

4. History of the development of RF batteries

Full-scale development of the batteries started in the 1970s. The principle of the RF battery system was presented by L. H. Thaller of the National Aeronautics and Space Administration (NASA) of the United States in 1974. NASA mainly conducted research on the Fe/Cr system, discontinuing it in 1984 with the publication of the Final Report. At the same time in Japan, the Electro-technical Lab was conducting basic research, and the development of the Fe/Cr system made progress as a project of the New Energy and Industrial Technology Development Organization (NEDO). In about 1985, in Australia, the University of New South Wales (UNSW) proceeded to develop the V system. Concerning the practical use of RF batteries, electric power companies and manufacturers in Japan jointly conducted research with enthusiasm, and in about 2001, the V system was partially put into practical use. Since then, global concerns are shown towards redox batteries as useful and efficient energy storage devices.

5. Latest developments

Recently, because smart-grid technologies are becoming increasingly popular worldwide with the introduction of renewable energy in great amounts, energy storage batteries are expected to play a more important role. Hence, the development of energy storage batteries is being promoted globally. RF batteries are no exception. They are attracting public attention as large-capacity storage batteries, and their development is being promoted worldwide. The main system of their development is the Vanadium based RFB system. The redox flow battery (RFB) is one of the most promising systems for large scale electrochemical energy storage applications. The development of redox-active materials is an essential part of RFB research. Commercial RFBs utilize redox-active inorganic ions, which have several issues such as expensive and toxic active materials. Also, crossover of redox species, and high cost of the ion exchange membrane are the concerns about RF batteries. The incorporation of redox-active polymeric materials is an intriguing solution because low-cost polymeric redox-active materials and size-exclusion porous membranes formed by polymers could be applied to replace expensive inorganic redox-active materials and ion exchange membranes, respectively. The development of polymer-based redox-active materials in RFB application has advanced rapidly in the past few years. Three major categories based on materials are the aqueous redox-active polymers, the non-aqueous redox-active polymers and oligomers, and polymer suspension systems. Synthetic strategy of polymeric redox-active materials and their

properties such as redox potential and solubility in electrolyte reports the performance of recent polymer based RFB cells, including cycling stability, cell voltage, and implementation of size-exclusion porous membranes.

6. Conclusions

RF batteries are becoming popular among the options available for energy storage particularly in case of renewable energy such as solar and wind energy sources. In Japan, most RF batteries that have been put into use at the sites of consumers comprise several hundreds of kilowatts class. Relatively small systems of a few kilowatts to several tens of kilowatts have been commonly used for independent power supplies worldwide. In the near future, such applications as smoothing of a larger scale wind power output fluctuations or secondary control in the power system are expected. In consideration of these applications, larger capacity RF batteries will be necessary. Though such storage devices must be safe, reliable, durable and cost efficient at a level equivalent to conventional power systems.

Currently, the most developed RFB technology is the vanadium redox-flow battery (VRB), which has been demonstrated on the MW scale. However, scaling up of the technology for broad market penetration is significantly hindered by the relatively high cost, low energy density and narrow operating temperature. The low energy density and narrow operating temperature window besides the relatively high cost of the vanadium redox-flow battery (VRB) severely hinder its commercial deployment. Herein, in conjunction with low-concentration $\text{VO}_2^+/\text{VO}_2$ + catholyte, we introduce a redox targeting-based VRB (RT-VRB) system in which a Prussian blue analogue (PBA), $(\text{VO})_6[\text{Fe}(\text{CN})_6]_3$, is employed as a capacity booster to address the above issues. This provides ample room to broaden the operating temperature window of a RT-VRB relative to a conventional VRB. The theoretical volumetric capacity of the PBA could reach more than 3 times that of VRB.

It has also been reported that, by tuning the pH of the electrolyte, the battery voltage can be effectively enhanced, finally leading to an increase in energy density. With this strategy, an all-aqueous alkaline Zn-I₂ RFB achieving a high-energy-density and anode potential enhancement as compare to the conventional counterparts. This became the highest energy density for an all-aqueous redox flow battery obtained to date. We expect that further development of the RF battery, including system up and improvement of cell materials, will be promoted along with various verification tests by end-users, and that the RF battery will play an important role in the power system in near future.

7. References

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