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The Review of Energy Storage Technologies Selection

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Abstract

With the development of intermittent energy, the impact of intermittent energy has become increasingly serious. Energy storage technology not only can be used for peak load regulation of power grid, smooth load, improving the utility ratio of electrical equipment, and reducing the power cost, but also can be used to promote the use of renewable energy, improve the system running stability, adjust the frequency, and as a means to adjust the impact of overload in the power grid. However, the selection criteria and the diversity of technologies make choice difficult. It is particularly important to select the energy storage technology scientifically. This paper gives a broad overview of the selection of energy storage technology in several multicriteria decision making domains.

Keywords: Energy storage; Renewable; Selection of hybrid energy storage

Introduction

Nowadays, the energy storage and the electrochemical storage systems are becoming increasingly important. Energy storage systems are applied in several domains of application such as photovoltaic, telecommunication, spatial, vehicle, agricultural, etc.

Many technologies of energy storage, which are: physical energy storage, chemical energy storage and electromagnetic energy storage, will be compared in this paper according to different selection criteria in order to determine the most appropriate technology for each type of application [1].

Energy storage technology

With the development of energy storage technology, the main energy storage technology can be divided into the following categories.

According to the classification of technology, it is divided into four categories: Physical storage (such as pumped storage, compressed air energy storage, flywheel energy storage, etc.), chemical energy storage (such as sodium sulfur batteries, flow batteries, lead-acid batteries, nickel-cadmium batteries, supercapacitor, etc.), Energy Storage (superconducting magnetic energy storage, etc.) and the phase change energy storage (ice storage, etc.).

According to time division, the energy storage can be divided into short-term energy storage which the discharge time form the second level to the minute level, medium energy storage which the discharge time from a few minutes to several hours and long-term energy storage which the discharge time from hours to days.

According to the functional classification, it can be divided into two types: energy storage Energy-usage (EES) and energy storage Power-usage (PES). Energy type energy storage is characterized by high energy, which is mainly used for high energy input and output, and the power type is characterized by high specific power, which is mainly used for instantaneous high power input and output. Energy storage can discharge device relatively slow time and experience over a long period of time (such as 10 minutes to hours) and power energy storage with high discharge rate fast discharge (e.g., several seconds to several minutes).

The characteristic of energy storage technology

The storage system by compressing air operates like a gas turbine at high temperatures. CAES has a significant technical feasibility and it is considered one of the most efficient engines for converting heat into electrical power, becoming an economic attractive system for load management [2]. In CAES, the energy is stored by compressing air via electrical compressors in huge storage reservoirs that usually already exists, such as underground caverns, abandoned hard-rock mines, or natural aquifers. CAES provides low environmental impacts and has a high life cycle. On the other hand, the need of a fuel in the combustion process (usually natural gas) increases the operational costs and the greenhouse gas emissions. Pumped hydro energy storage is an energy storage system which takes as basis a conventional hydroelectric technology. PHS uses the potential energy of water, transferred by pumps (charging mode, during off-peaks) and turbines (discharge mode, during peaks) between two reservoirs located at different altitudes. PHS can be considered highly expensive in initial costs (installation), as well as require suitable sites and long lead-times for construction. The efficiency is usually limited by the efficiency of the deployed pumps and turbines. A flywheel can accumulate and store mechanical energy in kinetic form. The stored energy depends on the inertia and speed of the rotating mass (rotor). The flywheel is a rotor placed inside a vacuum to eliminate friction-loss from the air and suspended by bearings for a stabile operation. A flywheel presents high density energy, high efficiency and high life cycle. Super-Capacitors store energy by way of separating the charge onto two facing plates. They use polarized liquid layers at the interface between a conducting ionic electrolyte and a conducting electrode, increasing the capacitance. Super-Capacitors present high efficiency, high life cycle capability and low environment impact. Hydrogen is an immature technology but envisaged as a promising means of electrochemical storage attracting huge interest. Since hydrogen is not a primary energy source, its energy storage is based on an electrolyzer to split water into hydrogen and oxygen. Most aspects in the hydrogen-related technology, including generation, storage and utilization in fuel cells, still need further development.

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The selection of energy storage technology

Large-capacity, high-density, high-efficiency, low-cost and long service life of the storage energy technology is undoubtedly the most ideal, but so far there is not a kind of energy storage technology can satisfy these conditions simultaneously. Therefore, it is necessary for all storage technology choice suitable application field, namely the right selection of energy storage. Under normal circumstances, when the selection of energy storage system, the economy, security and stability, and the capacity of the energy storage system should be considered.

Zhao et al. [2] conducted independent research on the island micro-grid energy storage selection, found that pumped storage and compressed air energy storage not available for large-scale 10 MW and below sized island independent micro-grid, and the cost of Lead-acid as the only batteries for large-capacity we can accept is widely used in the island independent micro-grid energy storage.

Zhaobin et al. [3] compared the advantages and disadvantages of magnetic flywheel energy storage UPS, super capacitor energy storage UPS and battery UPS, and the two general methods presented in the selection of storage devices: the discharge current method and estimation method. The discharge current method selects the corresponding battery according to the maximum discharge current I of the battery. The estimation method is based on the capacity of the storage battery to choose the storage battery.

Enke and Liangjin [4] pointed out that, in the system regulation, often using compressed air energy storage, compressed air energy storage has the advantages of low cost, long service life and high safety factor. However, due to the limitation of terrain and air stored needs to be compressed under suitable underground mine or lava cave. Pumped storage is similar with the compressed air, but restricted to the terrain and the longer construction cycle. In frequency regulation, high power load, smooth transmission and distribution grid voltage support and power compensation, can use the flywheel, super capacitor and superconducting magnetic energy storage. These three energy storage technologies with high efficiency and long cycle life, fast response, clean and relatively simple maintain features, but the energy ratio is low, belongs to the low-power type of expensive storage. These three energy storage technologies can be used to short-time and high-power fast discharge. Battery energy storage system can provide active and reactive support to the system, so it is very important for the control of complex power system. The life of Lead-acid battery is shortened at high temperatures, it has a lower energy ratio and power ratio, and there are certain environmental pollution, but the low cost, reliability, and mature technology features make lead-acid batteries widely used in uninterruptible power supplies, power quality and frequency control.

Nickel cadmium battery is similar to lead-acid battery, but it has the serious heavy metal contamination. The efficiency of Li-ion is higher and has the high energy ratio and power ratio, which is friendly to the environments, but the cost is high, so it is difficult to be applied in power system in the near future. Emerging chemical energy storage battery such as fluid flow and sodium sulfur battery is currently the most suitable for large-scale development of electric power chemical energy storage technology. Vanadium Redox Flow Battery have long cycle life (more than 12,000), high energy conversion efficiency, siting and design flexibility, safety and environmental protection features, but has the low energy ratio and power ratio. Therefore, it is suitable for the selection of renewable energy storage, peak shaving and emergency power supply.

Sodium sulfur batteries have high energy storage efficiency (about 89%) and high-density energy characteristics, about three to four times the size of lead-acid battery, can be used for power quality and load regulation of peak load shifting, it is the typical type of the energy and power energy storage type. In remote areas with a high penetration of renewable energy, power grid weaker, it is better to choose a mature storage technology; for make full use of renewable energy and delay the investment of the construction of the strong power grid, we should choose the most advanced energy storage technology. Jilei et al. [5] combined the characteristics of the operating conditions with the wind and photovoltaic power generation, analyzes the wind and photovoltaic storage system that how to scientificly select the type of lead-acid batteries. Battery life of lead-acid batteries and early failure problem is the main obstacle hinder the promotion of the photovoltaic and wind power system. After analyzing the working conditions, found that gel battery has better deep discharge recovery features, low current discharge performance and the charge rate is higher than 20% 30%. Gel battery at high ambient temperatures have a longer service life, virtually can eliminates internal electrolyte stratification. From the economic analysis of the full life cycle, the advantage of gel batteries in photovoltaic and wind power generation system is more obvious. Ammar et al. [6] studied the difficult of photovoltaic battery applications selection.

Using the analytic hierarchy process (AHP), with size, cost, efficiency and life span, self-discharge rate and environment factors as the guidelines, discussing seven different battery (lead-acid batteries, nickel cadmium battery, nickel metal hydride batteries, nickel zinc battery, nickel metal hydride batteries, lithium ion battery, super capacitor), and the optimal portfolio battery selection is given under different criterion. Williamson et al. [7] studied the selection of hybrid electric vehicle energy storage device. And the performances of lead-acid, lithium-ion, nickel-cadmium, nickel-metal hydride, and nickel-zinc batteries, as well as ultra-capacitors are investigated. The nickel-metal hydride, lead-acid and the ultra-capacitor technologies demonstrate best results in terms of fuel economy and percentage drive train efficiency. On the other hand, the nickel-zinc and lithium-ion batteries show much promise, but still demand a great deal of research and development work, before they become a viable option for HEV applications. Zhu et al. [8] studied the factors of choosing a distributed generation energy storage technology, first of all, energy storage devices need to meet the demand of power regulation. Secondly, the power range decides the capacity of energy storage system. Finally, cost is another key factor when selecting the energy storage technology.

Barnas et al. [9] studied the selection of energy storage technology under the TOU pricing conditions in the comprehensive consideration of energy storage technologies, capacity, and charge-discharge timetable. Using linear optimization method for battery selection, They found that the most cost-effective battery is lithium ion battery, mainly because of the lithium ion battery with high efficiency and 11-year project life cycle is the highest benefit. The best choice is not necessarily the cheapest, it is the measure of cycle life, efficiency and cost. In the field of transportation, energy storage components as the buffer between electric cars and public power grid, it is important to choose the right energy storage technology [10]. This paper analyzes the energy storage choice of the electric vehicle charging station. Firstly, the buffer discharge time need to be considered. Secondly, fully charge/discharge cycles will have direct impact on the life of the buffer. Finally, energy and power factor can also affect the energy storage type selection of intermediate buffer. Wenxing and Lu [11] studied the selection of micro-grid energy storage, studies show that the lithium-ion battery energy density and most efficient combined cycle storage batteries, is one of the main direction of future development of energy storage technology, the car battery areas favored. Solitary grid power systems and renewable energy systems in hybrid technology, based on lead-acid batteries and super capacitors composite battery energy storage technology has been widely used. Bo et al. [12] introduced the project of energy storage type selection at east Fushan Island. Pumped storage and compressed air energy storage as the representative of the mechanical energy storage are not available to less than megawatt energy storage system. Further considering the limitation of geographical environment on the island, the two energy storage methods are not applicable. The superconducting magnetic energy storage and super capacitor energy storage in Electromagnetic field energy storage all belong to power energy storage, unable to meet the requirements of energy storage system capacity at east fushan island. The technology of Sodium sulfur batteries and flow battery technology is currently only skilled mastered by Japanese NGK and the economic cost is very high. After a comprehensive analysis, we found that lead-acid batteries and lithium iron phosphate is the preferred choice of East Fukuyama Island project energy storage system, but the cost of lithium iron phosphate is about five times the price of lead-acid batteries. Considering a one-time investment costs, operation and maintenance costs and replacement costs, the final choice based on renewable energy applications is improved VRLA battery. Barin et al. [13] simply introduces analytic hierarchy process (AHP) in the energy storage type selection, sometimes can't get the results. It combines analytic hierarchy process (AHP) and fuzzy logic for energy storage technology selection, and the selection method is reliable. Chengshan et al. [14] according to the response characteristics of ESS (Energy Storage System) charge and discharge time, the ESS divided into power type and energy type. Former is represented by the super capacitor, flywheel ESS, with fast response, long life, small volume and is suitable for compensating short-term power fluctuations. The latter is represented by battery, has the characteristics of large capacity, slow response, and id suitable for compensation long power fluctuations. The document analysis the sample data of renewable energy power output through the spectrum analysis based on discrete Fourier transform. Based on the results of spectrum analysis, the corresponding frequency of the main volatile components of power output can be determined, in order to determine the required time scale of compensation power of ESS. When the major fluctuation component is the low-frequency component, you can select the energy type ESS. When the main component fluctuation is high frequency, the power type ESS can be selected. When the main volatile components are both high frequency and low frequency, you must select two types ESS and constitute a hybrid ESS patterns at the same time. Swierczynski et al. [15] pointed out that PSB, ZnBr and thermal energy storage technology because of immature technology and the life of PSB and ZnBr is very short, so they are seldom used in the megawatt energy storage. Li-ion was found to meet best practice standards under the premise of the cost of a priority document. By analyzing a variety of lithium ion battery, they think LFP ($LiFePO_4$/C) and LTO ($LiMO_2$/$Li_4Ti_5O_{12}$) as the best choice, although the cycle cost of LTO is higher than LFP, but has a longer cycle life. Albu et al. [16] analyzed the characteristics of different storage methods, based on the properties of different storage needs to choose a different energy storage technologies. Different types of storage characteristics are compared to generate the different weighting coefficient, the user ultimately selecte the different types of storage according to weighting coefficients.

Conclusion and Prospect

It can be predicted that the future power grid will be presented with a situation of energy storage, and the largest proportion of clean energy, fossil energy is used as auxiliary. The rational allocation of the load control system, and complemented by high-performance power electronic devices, flexible transmission, distributed power supply, demand response, efficient control of the new clean energy development model systems and other advanced technologies.

However, it is only dependent on the accuracy of the renewable energy prediction and the improvement of the control level, cannot achieve the comprehensive and efficient use of the energy. With the combination of distributed generation and energy storage technology, the system can greatly improve the energy utilization, improve the stability, reliability and economy of the system. Therefore, it is necessary to speed up the development of energy storage technology. In summary, the correct selection of intermittent energy storage is critical to large-scale use of renewable energy. In practical application, we must be based on the actual application requirements, the correct choice of storage type, in conjunction with the use of different energy storage technologies, give full play to the advantages of various energy storage technologies to complement each other. Thereby increasing the energy storage system flexible and technical and economic. Future multivariate mixed energy storage system (power type and an energy storage system) and its complementary selection of optimal control of energy storage will become an important research direction. Lithium iron phosphate battery and supercapacitor has become the direction of micro-grid energy storage development, and we should develop more advanced energy storage technologies. Secondary batteries (lead acid, lithium ion, nickel-cadmium batteries, etc.), high cost and short life cycles, and pollution of the environment, in order to reduce the impact of these deficiencies, it is necessary to develop battery recycling technology.

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