Application of energy storage technology and its role in system peaking and frequency modulation

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Abstract. Photovoltaic and wind power have experienced rapid development, but they are facing problems such as the abandonment of wind and other renewable resources, and through recent years of development, energy storage technology has become a key technology, and now it has become the main way of power grid frequency modulation, it has a response. The length of time and the precise tracking characteristics have been recognized by people. This paper introduces the characteristics and applications of various energy storage technologies in peak shaving and frequency modulation for reference.

1. Background
According to the State Grid Energy Research Institute, the installed capacity of new energy will exceed that of thermal power by 2035. In 2035, the installed capacity of new energy was $1.43 \times 10^4$ GW, accounting for 17% to 38% of the total installed capacity in 2017, and the proportion of new energy to total power generation was from 7% to 23% when the generating capacity was $2.7 \times 10^7$ GW·h. Academician Zhou Xiaoxin mentioned in the consultation project "Strategic Research on China's New Generation Energy System" of the Ministry of Science of the Chinese Academy of Sciences that in 2030, Total installed capacity reached $2.689 \times 10^4$ GW, with 15% and 18% of wind power and 18% of solar power respectively, and $8.58 \times 10^7$ GW·h of annual total power generation, with 8% and 9% of wind power and solar power respectively in China. In 2050, China's total installed capacity reached $5.208 \times 10^4$ GW, with wind and solar power accounting for 27% and 41% respectively, and the annual total power generation reached $1.213 \times 10^8$ GW·h, with wind and solar power accounting for 21% and 27% respectively. With the development of renewable energy, the pressure on the power grid will be greater. On September 28, 2016, 48.36% of Australia's southern power grid was powered by new energy after 50 hours, which was triggered by extreme weather[1]. At present, the high quality FM resources are very few, and the load fluctuation of the power grid is relatively large. The deviation between the load of the power grid and the output of thermal power plants will lead to the frequency offset. With the gradual maturity of wind and solar power market in China, the supply and demand balance of power grid in a short period of time has become more serious. Inertial regulation of existing coal-fired units can not meet the requirements, while energy storage can quickly adjust frequency and peak.
2. Common energy storage categories and applications

2.1. Flywheel energy storage
The basic principle of flywheel energy storage is to use electrical energy to drive the flywheel to rotate, and convert electrical energy into mechanical energy for storage. When electric energy is needed, the stored mechanical energy is converted into electrical energy. Tsinghua University and Sinopec Zhongyuan Petroleum Engineering Co., Ltd. have developed the first MW flywheel energy storage power engineering prototype in China, which is located in Lankao County, Henan Province. The charging and discharging cycle efficiency is 86% to 88%, and the maximum power generation is 1088 kW.

Flywheel energy storage technology usually takes "hours" as the unit of storage time, and its storage capacity is relatively general. However, this kind of energy storage device has strong dynamic characteristics and can release great energy in a short time, so it is often used to quickly adjust the frequency of power system. The emergence of flywheel energy storage technology effectively compensates for the shortcomings of short-term and long-term energy storage system, so this energy storage technology can be used to compensate for the short-term change of power generation in wind power generation system.

2.2. Pumped storage
The mechanical and electrical equipment of pumped storage power station works in the motor state during the low load period, pumping the water from the lower reservoir to the upper reservoir, and working in the generator state during the peak load period. By utilizing the hydropower stored in the upper reservoir, the potential energy can be stored, and the total energy storage is proportional to the drop and volume of the reservoir.

Pumped storage power station is the most widely used energy storage technology so far. It has many advantages, such as large storage capacity, mature and reliable technology, more cycles, high energy conversion efficiency, unlimited energy storage cycle, etc. Pumped storage technology is usually used in peak shaving and centralized power generation of power system. It is affected by geographical conditions, and has a long construction period, huge initial investment. Most of the power stations can not meet the construction conditions of pumped storage power stations, so it is difficult to apply it in wind and solar power generation systems.

2.3. Ultra-capacitor energy storage
At present, electromagnetic energy storage technology mainly includes superconducting magnetic energy storage and ultra-capacitor energy storage. Superconducting magnet energy storage devices usually use superconducting material coils as medium, and use the magnetic field generated by DC current to store energy. Because superconducting magnet energy storage technology does not need to convert energy, it is dynamic and can produce very high power in very short time. However, the superconducting magnet energy storage device used in this technology has relatively short storage time and relatively small storage capacity, and is often used in power systems.

Ultra-capacitor energy storage technology is based on the theory of electrochemical double layer. The ultra-capacitor energy storage device can release huge pulse power and ensure that the power surface is always in the best state when charging. At the same time, the anisotropic ions in the surrounding electrolyte solution will be attracted by the charge, which will adhere to the electrode surface and eventually promote the formation of double charge layer. The structure of ultra-capacitor energy storage device is relatively simple, there is no toxic substance, charging time is short, and it can generate large current. Its characteristics will not be weakened by the increase of the number of charging and discharging cycles. However, in the charging process, ultra-capacitor energy storage technology has a very high demand for voltage, and the voltage of a single ultra-capacitor is relatively low, so ultra-capacitor energy storage technology is often used in short-term high-power load smoothing in the power grid, which can ensure the stability of the power supply system when the voltage is unstable[2]. In recent
years, it has been widely used in energy storage environment because of its fast charging speed, long cycle life, high energy conversion efficiency and good low temperature characteristics.

2.4. Battery energy storage

2.4.1. Principle and composition of battery energy storage. As a kind of electrochemical energy storage, battery energy storage has been widely used in energy storage system in recent years. Battery energy storage technology mainly realizes charging and discharging through redox reaction of positive and negative electrodes of batteries. The energy storage device of this technology is generally composed of controller, battery and DC/AC inverters. At present, the highest application rate in power generation system is battery energy storage device. From the point of view of chemicals used, battery energy storage device mainly includes lead-acid battery energy storage device, lithium-ion battery energy storage device and sodium sulfur battery energy storage device.

2.4.2. Characteristic of battery energy storage. Lead-acid batteries were used to build large-capacity energy storage system to connect to the power grid. As an application of peak shifting and valley filling, it was first started in the 1980s. However, lead-acid batteries have shorter cycle life (the average cycle life is 500-1500 cycles) and shorter service life at high temperature, lower energy density and power density (30-50 Wh/kg, 75-300 W/kg), and environmental pollution exists in the manufacturing process, and gradually withdraw from the energy storage system[3]. With the improvement of performance and safety of lithium-ion batteries and the reduction of cost, the application of lithium-ion batteries in power systems has attracted much attention due to their high energy density, no memory effect, no pollution, small self-discharge and long cycle life. The energy conversion efficiency and investment cost of several batteries are shown in Table 1.

| Year | Technology type                  | Planned service/year | PCE /%  | Investment/ (yuan•KW⁻¹) |
|------|----------------------------------|----------------------|---------|------------------------|
| 2013 | Lead acid battery                | 5                    | 70~85   | 1500                   |
|      | Li-ion battery                   | 5                    | 90~95   | 6000                   |
|      | All vanadium redox flow battery  | > 10                 | 75~85   | 4500                   |
| 2015 | Lead acid battery                | 5~8                  | 70~85   | 1300                   |
|      | Li-ion battery                   | 5~8                  | 90~95   | 3000                   |
|      | All vanadium redox flow battery  | > 10                 | 75~85   | 3900                   |
| 2020 | Lead acid battery                | 5~8                  | 70~85   | 600                    |
|      | Li-ion battery                   | 5~8                  | 90~95   | 1500                   |
|      | All vanadium redox flow battery  | > 10                 | 75~85   | 3000                   |

2.4.3. Application of battery energy storage. In 2013, Anhui 215.6 kWp photovoltaic + 2.16 MWh lithium iron phosphate battery project adopted advanced energy management system and unattended full intelligent control to ensure the stability of power consumption. In 2014, the QINGUANG Storage Power Station in Arital, Tibet, China, 1 MW Box Inverter Room Lithium Battery Project provided reliable power supply for Gangrenboqi to Shenshan District in Tibet. In 2014, the 1.8MW optical storage independent micro-grid project of Xinjiang Corps adopted lithium batteries to solve the basic living electricity consumption of farmers and herdsmen and frontier guards in power-free areas, which brought
about the local economic development [5]. In 2018, the technological progress and cost reduction of lithium-ion batteries will touch the turning point of commercial application for the first time with a cycle life of 5000 cycles and a system cost of 1.5 yuan/W·h. The next step is likely to achieve the goals of more than 15,000 cycles, energy efficiency of more than 90%, system cost of less than 1.0 yuan/W·h and power cost of less than 0.2 yuan. With the decreasing cost of integrated energy storage system and the release of policy documents such as Guidelines on Promoting Energy Storage Technology and Industry Development, under the guidance of peak-valley price difference of power grid, distributed energy storage on user side, which is dominated by electrochemical energy storage, has developed rapidly.

2.5. Thermal storage

2.5.1. Forms and characteristics of thermal storage technology. 90% of the global energy budget is based on heat conversion, transportation and storage. In recent years, large-scale heat storage has been paid more and more attention. According to the form of thermal storage, it can be divided into sensible thermal storage, latent thermal storage and chemical thermal storage. Sensible thermal storage has low price, simple structure and mature technology, but its energy storage density is low, its volume is large, and its temperature output fluctuates greatly, which has been commercialized; latent thermal storage has high energy density, small volume and stable temperature output, but it is still in the stage of research and development in the field of high temperature technology, which is close to commercialization; chemical thermal storage has high energy storage density, long energy storage cycle, but poor stability and high difficulty in scale. Most chemical reactions with high energy storage density are dangerous and are still in the stage of technical research.

2.5.2. Application of thermal storage technology. The most typical application of thermal storage technology is to use heat storage equipment such as thermal storage tanks to peak load regulation, promote the absorption of renewable energy, at the same time, ensure people's livelihood heating, break the constraints of the operation mode of thermal power unit "fixing electricity by heat" on the peak shaving capacity of the system. At the same time, a photo thermal power station can be built, which can directly drive the steam turbine to generate electricity through the heat collecting system, and can also store part of the heat through the heat storage system to realize continuous power supply at night. According to the calculation of China Academy of Engineering, the installed potential of photo thermal power generation in China is $1.6 \times 10^5$ GW, with an annual generating capacity of $4.2 \times 10^8$ GW·h. According to China Renewable Energy Development Roadmap 2050 issued by China Renewable Energy Society, photo thermal power generation in 2020 will be able to bear peak load regulation and intermediate power load, and after 2025-2030, it will be able to bear basic load, and realize parity of access to the Internet.

3. Application of hybrid energy storage

3.1. New energy storage power station

In 2016, a large-scale hybrid energy storage demonstration project was built at Beizhen wind farm in Liaoning Province. The wind turbine assembly unit has a capacity of 99MW. The hybrid energy storage system consists of 5MW×2h lithium iron phosphate battery, 2MW×2h full vanadium flow battery and 1MW×2min supercapacitor.

The energy system can output active power and reactive power to the power grid according to the dispatching instructions, and assist the safe and stable operation of the power grid. In addition to replacing the SVG that the wind farm must configure, it can also realize the rapid regulation of active power, which solves the problem of extremely high voltage in the surrounding power grid at night when the wind power is high, and restrains it to a certain extent. Voltage sag caused by short circuit fault of power grid is analyzed. Among them, lithium batteries and liquid flow batteries are mainly used for
steady-state energy regulation, while supercapacitors are mainly used for high-frequency fluctuation suppression and responding to grid voltage regulation requirements.

3.2. Improve the integrated power quality
Port shore power mainly uses peak non-linear impact load, and the utilization ratio of power supply and distribution network is low; a large number of power electronic devices such as frequency converters bring serious harmonic pollution; impact loads such as aerial crane and gantry crane often cause voltage sag, sag, fluctuation and flicker. In view of this universal problem, a hybrid energy storage demonstration project of 4MW×2h lithium iron phosphate battery and 1MW×15s supercapacitor is planned to be completed in mid-2019[6].

4. The role of energy storage in peak-shaving and frequency-modulation of the system
The capacity of peak shaving is not enough, frequent switches of large thermal power units will result in waste of resources, loss and insecurity, insufficient installed capacity of pumped storage power plants, and the future development of smart grid requires more renewable energy access. The ability of power grid to accept access depends on the structure of power system, especially peak shaving capacity. In the "Three North" area, wind and solar energy resources are abundant. Under the advocacy of the state to vigorously promote the absorption of new energy, the rate of wind abandonment is still relatively high. The application of energy storage technology can promote the absorption of new energy and alleviate the pressure of peak shaving of the system. In the winter heating period, the application of heat storage technology achieves thermoelectric decoupling, breaks the traditional operation mode of thermal power unit "fixing electricity by heat", and the power generation enterprises can also get considerable benefits by participating in peak shaving.

The main power of primary frequency modulation in China's power grid is large thermal power units, which lack of high-quality frequency modulation power supply with good response speed and energy-saving ability. Because of its excellent fast power output and precise tracking ability, energy storage has a "small and large" leverage effect compared with traditional thermal power or hydropower units. Many scholars have studied the leverage effect of frequency modulation capability of energy storage. Literature [7] assumes that the climbing rate of thermal power units is 4% per minute, and that the energy storage and frequency modulation capability of 20MW batteries is equivalent to 187.5MW thermal power units, the former is about 9 times more efficient than the latter. In document [8], it is assumed that the energy storage capacity of 25 MW batteries with 3% rated power per minute is equal to that of 83.3MW coal-fired units, and the difference is 3.3 times; Literature [9] points out that the same frequency modulation capability of coal-fired units is the same. Under the same capacity and unit regulating power, the efficiency of battery energy storage without FM dead zone is more than 25 times higher than that of traditional power supply. Literature [10] states that the effect of energy storage and FM in American electricity market is 1.7 times that of hydropower units, 2.5 times that of gas units and 20 times that of coal-fired units.

5. Conclusion
As a new energy service product, energy storage is a high-quality and reliable millisecond control response resource. It can provide active and reactive power dual support, peak regulation and frequency regulation, emergency response to standby accidents and other services for power grid. In order to alleviate the power supply pressure during the summer peak period and improve the local absorption level of renewable energy, peak-shaving and valley-filling capacity, local power supply capacity and flexible regulation capacity of power grid, energy storage will be widely used in China in the future. This paper introduces the relevant information about energy storage and the role of energy storage in peak shaving and frequency modulation of the system, hoping to bring some inspiration to relevant practitioners and promote the progress of China's electric power industry.
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