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Abstract. Energy storage is one of the main problems bothering the power system. The present research situation of energy storage is outlined. The working principles, development process and technical features of pumped storage, compressed air energy storage, flywheel energy storage, electromagnetic energy storage and chemical energy storage are described in detail. The application prospect of energy storage is proposed.

1. Introduction

Smart Grid is an important carrier of low-carbon development in China, which is the future direction of the grid and related to national energy security and sustainable development of energy. Different with the traditional large centralized power grid model, there are not only conventional power plants, but also introduced a number of new energy power generation in the Smart Grid generation side. Smart grid allows the use of new energy sources account for the energy needs of 30% or more [1]. These new energy sources including wind, solar, ocean energy and resource potential is great, which can be sustainable use and have played an important role in meeting energy needs, environmental protection, and economic development. But they are affected by geography, season, day and night etc, there is random, intermittent, and low stability in its power generation, which is prone to lead the frequency bias and voltage fluctuations. Therefore, wind power in China Inner Mongolia, Jilin, Jiuquan and other places sometimes will be limited to the grid, and some even have to shut down. If these problems could not be solved, the popularization of new energy sources will be limited. The energy storage technology can solve the bottleneck of the new energy access to the grid.

Energy storage technology use chemical or physical methods to store electrical energy, and the energy can be converted into electrical energy to release when needed. It can solve the random, intermittent, volatility caused by voltage, frequency and phase changes as wind power and solar power, to achieve the smooth output of new energy power generation, so that the new energy power can be delivered to the grid stable and reliable. Meanwhile, the energy storage technology can be used to the "load shifting" and power quality improvement of the power grid. Energy storage technology is one of the core technologies of the construction of smart grid, through storage power stations all over the grid, smart power grid can be more energy efficient scheduling. Used of appropriate large-scale energy storage devices, can delay and reduce the equipment investment used to transmission, transformation and distribution, and improve the utilization and power supply reliability of existing power equipment, so that the power grid truly to become "smart.".

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2. Development status and outlook of Energy storage technology

Energy storage technologies mainly include mechanical energy storage, magnetic energy storage and chemical storage.

2.1. Mechanical energy storage

Mechanical energy storage is divided into pumped storage, compressed air energy storage, flywheel energy storage etc..

2.1.1. Pumped storage. Its working principle is pumping water from the downstream reservoir to the upstream reservoir in the trough power load, to store the electrical energy into gravitational potential energy of water, and releasing upstream reservoir water to generate electricity in the peak power load (shown in Figure 1). It is the most sophisticated and widely used energy storage methods in power system technology. The main application areas not only include pumped-storage peak load shifting, FM, PM, emergency backup systems and provide reserve capacity, but also can improve operating efficiency of thermal power plants and nuclear power generation side. Pumped storage power station can respond quickly within minutes when the grid load sudden change, which is unmatched by other power plants [2],if connected with wind power, solar power and other to form small power supply network, it can also be used in remote areas or isolated islands [3]. Meanwhile, the pumped storage power station can reasonably design the reservoir capacity according to how much electrical energy stored. In the current cases of large-scale development and construction of wind, solar and nuclear power, pumped storage power station, as a safe and reliable operation of power grid, become an integral part of the grid. However, the pumping energy storage greatly subject to geographical location, ecological environment and construction period (generally 4-5 years) and other aspects, for example, Huitengxile grassland, one of the largest wind power bases in Inner Mongolia, for lack of water, pumped storage power station is difficult to build, only to online wind power and thermal power in accordance with ratio of 1:2.Constructions of pumped storage power station are late in China, northern China had built two small Pumped Storage stations in post-South and Miyun in 1968 and 1973. However, during the 40 years, China's pumped storage accumulated a wealth of experience and technology, although the total installed capacity is not great, but the size of a single power station has been forefront in the world, for example, the Guangzhou Pumped Storage Power Station is the world's largest pumped storage of installed capacity. Pumped Storage is the future direction of high water head, high rotational speed, large capacity.

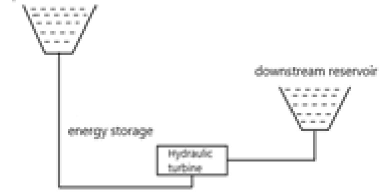

Figure 1. Schematic diagram of pumped storage.

2.1.2. Compressed air energy storage. Its working principle is pumping water from the downstream reservoir to the upstream reservoir in the trough power load, to store the electrical energy into gravitational potential energy of water, and releasing upstream reservoir water to generate electricity in the peak power load (shown in Figure 1). It is the most sophisticated and widely used energy storage methods in power system technology. The main application areas not only include pumped-storage peak load shifting, FM, PM, emergency backup systems and provide reserve capacity, but also can improve operating efficiency of thermal power plants and nuclear power generation side. Pumped storage power station can respond quickly within minutes when the grid load sudden change, which is unmatched by other power plants [2],if connected with wind power, solar power and other to form small power supply network, it can also be used in remote areas or isolated islands [3]. Meanwhile, the pumped storage power station can reasonably design the reservoir capacity according to how much electrical energy stored. In the current cases of large-scale development and construction of wind, solar and nuclear power, pumped storage power station, as a safe and reliable operation of power grid, become an integral part of the grid. However, the pumping energy storage greatly subject to geographical location, ecological environment and construction period (generally 4-5 years) and other aspects, for example, Huitengxile grassland, one of the largest wind power bases in Inner Mongolia, for lack of water, pumped storage power station is difficult to build, only to online wind power and thermal power in accordance with ratio of 1:2.Constructions of pumped storage power station are late in China, northern China had built two small Pumped Storage stations in post-South and Miyun in 1968 and 1973. However, during the 40 years, China's pumped storage accumulated a wealth of experience and technology, although the total installed capacity is not great, but the size of a single power station has been forefront in the world, for example, the Guangzhou Pumped Storage Power Station is the world's largest pumped storage of installed capacity. Pumped Storage is the future direction of high water head, high rotational speed, large capacity.

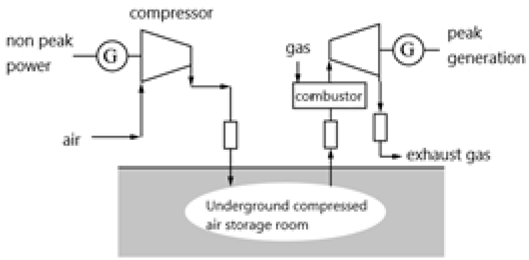

Figure 2. Schematic diagram of compressed air energy storage.

2.1.3. Flywheel energy storage. Flywheel energy storage devices include: flywheel, motor, power electronics and control system, as shown in Figure 3. The principle is that when the flywheel system stores energy, turning the electrical energy into flywheel kinetic energy of rotation through electric motor. When needing power supply, turn the flywheel kinetic energy into electricity through a generator, then exporting to the external load. To reduce operating losses, improve the speed of the flywheel and efficiency of flywheel energy storage device, bearing of flywheel energy storage device generally use non-contact magnetic bearing technology [4]. And seal the motor and flywheel in a vacuum container to reduce the windage. Generators and electric motors typically use a motor to achieve, through the bearing directly connecting to the flywheel. While system is in standby mode, the device can run with minimal loss.

In 2003, Fuji Electric installed a 200 kW flywheel energy storage system in Japan Dogo Island island, used to reduce the output volatility of the three 600 kW wind turbines, combined with the existing diesel generators to form an island grid, which effectively stabilize the grid frequency. Most of our flywheel energy storage technology is still in the laboratory stage. In 2004, Beijing University of Aeronautics successfully developed the first station avionic use external rotor magnetic energy storage flywheel in the domestic with the support of the "863" project and In May 2005, they successfully developed the first station of rotor magnetic energy storage flywheel. Flywheel energy storage has storage density, high efficiency, long life, instantaneous power, fast response, low maintenance costs, environmental pollution, deep discharge, without geographical restrictions etc, which can solve the randomness and volatility problems of new energy power generation, to achieve smooth output of new energy power generation, effectively regulating the voltage, frequency and phase change caused by new energy power generation [5]. The drawbacks of flywheel energy storage are that its discharge time is short, which can only discharge tens of seconds to minutes and its equipment costs is high, replacement parts is expensive. Flywheel energy storage is developing forward to high-speed, high-temperature superconducting flywheel.

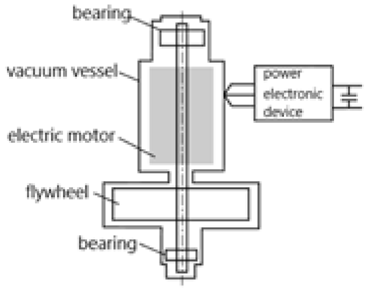

Figure 3. Schematic diagram of flywheel energy storage

2.2. Electromagnetic energy storage

2.2.1. Capacitor energy storage (super capacitor). Super capacitor consists of two porous electrodes, separator and electrolytes, as shown in Figure 4.

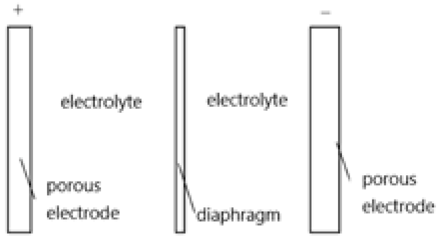

Figure 4. Schematic diagram of capacitor energy storage

According to electrochemical double-layer theory, on the electrode surface of the ideal state of the polarization at the time of charge, the charge will attract the opposite sex ions around in the electrolyte solution, making them attaching to the electrode surface to form a electric double layer, to constitute a double-layer capacitance. Due to the use carbon or other high surface area materials as the electrode, and the distance between the electrodes is very small, so the stored energy is higher, 100 to 1000 times the traditional electrolytic capacitors [6]. Super capacitor is energy storage device, lies between traditional capacitor and battery, between generally used for discharge of high-power short time energy storage systems, such as mobile communications devices and to accelerate the use of electric cars. At the power system application part, it is mainly used power quality improvement. Currently most of the commercial super capacitors are lower than 100 kW or less than 10s of discharge time, thus we commonly use modules in series to improve the output voltage.

Capacitor energy storage was put forward by Becker from General Electric Company of America in 1957 [7]. In 1968, Double Layer Electrochemical Capacitor was first successfully developed by U.S. Standard Oil [8]. Then from 1975 to 1981, B. E. Conway from Canada and U.S. Contimental Grob Inc jointly developed Mixed Oxide Electrochemical Capacitor. In our country, Super Capacitors have been studied since 1990s, and at present, companies manufacturing Super Capacitors include Tianjin Lishen Co., Shanghai Aowei Technology Development Co., Beijing Supreme Power Systems Co., ext. The products are mainly used in civilian situations such as auxiliary power supply of electric vehicle, UPS system, crane, and so on [9]. The electric bus No.11 of Shanghai, which use Super Capacitor as energy, has been running for 4 years. Now China is the only country to put Super Capacitor Bus into volume production, and the technology was independently developed by our country. There are no electric charges penetrating electrode interface when charge and discharge in Super Capacitor. The electric charges only make static movement. As a result, the charge and discharge speed (it can be recharged to 60~80% rated capacity in 30 to 40 seconds) is far greater than that of traditional chemical battery. Besides, Super Capacitor has very little limit on charge-discharge times (more than 100) and largest discharge quantity. Its working temperature is 40~50℃ and the mean lifetime can be more than 25 years. However, lower energy storage density than traditional chemical batteries as well as short discharge period become its major disadvantages. The main future development of Super Capacitor will be oriented to electric cars and to make it smooth for load of short time and large power in electric power system, and to improve the level of power supply in the situation of voltage dip and transient interference.

2.2.2. Superconducting magnetic energy storage. The coil of superconducting magnetic energy storage (SMES) system is made from superconductor. The power grid supplies electric power through converter for excitation, forming magnetic field in the coils and then energy power is stored. The stored energy will be transmitted to the power grid through inverter when the power supply is in need (as shown in Figure 5). The energy power can be stored for a long term with no attenuation because superconducting coil almost has no loss. SMES has the advantage of high speed responsibility (within 100 ms), high conversion efficiency, high capacity, etc. High-capacity energy change with electric power system in real time and power compensation can be realized. Then low frequency power oscillation can be reduced or even eliminate and the active and reactive power can be Regulated, which have a huge impact on improving the electricity quality as well as enhancing the dynamic stability of power grid [11-12]. The disadvantage is the need of refrigerating system, making the whole system more complex. A micro SMES device (1~10 MJ) from IGC CO. and AMSC CO. of U.S. has been commercialized.

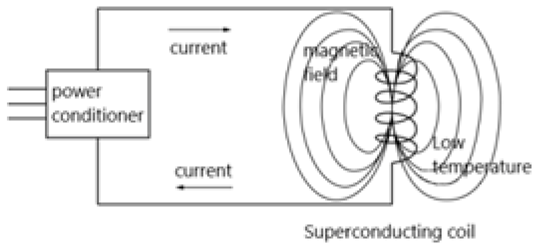

Figure 5. Sketch map of superconducting magnetic energy storage

In late 1970s, a 30 MJ superconducting magnetic energy storage device was developed in U.S.. It was mounted on a 500 KV transmission line along the west coast to eliminate 0.35 Hz low frequency oscillation and to improve the transmission efficiency. It had received satisfactory effects, but the energy storage device failed to run continuously because the cryogenic system couldn't meet the requirement and broke down. Now 1~5 MJ SEMS of low temperature has been made into products and 100 MJ SEMS system has been put into operation in in HV Transmission Networks. SEMS technology of 5 GWh has passed the feasibility study and technical certification. SEMS starts to take effect on maintaining the frequency stability of power systems, improving the transmission capacity and power quality of users.

2.3. Chemical energy storage

Chemical energy storage includes conventional batteries such as lead acid battery, nickel-cadmium battery and lithium-ion battery. New-type batteries such as sodium-sulphur battery and flow battery are also included.

2.3.1. Lead acid battery. Lead acid battery was a secondary battery invented by Plante in 1859. Its low price and usage credibility made it applied in power plant and power grid long ago, and the battery played an important role in maintaining the security and stability of the power system. But lead acid battery has disadvantages such as low energy store density, short lifetime and small number of charge cycles, which prevent it to be used in wind power and photovoltaic power on a large scale.

2.3.2. Ni-based battery. Ni-based battery (such as nickel-cadmium battery, nickel hydrogen battery) has high efficiency and long lifetime, but it has memory effect. The storage capacity reduces as the charging time increases. Besides, it has heavy metal pollution.

2.3.3. Lithium-ion battery. Lithium-ion battery has high specific energy density and large number of charge cycles. But due to the effect of technology and environment temperature, the system index always fails to achieve the level of monomer. Lithium-ion battery is used in portable equipment and electric cars at present. For security reason, the mainly used battery in electric cars is phosphatic iron lithium battery.

2.3.4. Sodium-sulphur battery. Sodium-sulphur battery is a device to convert chemical energy into electric energy directly. Sodium is used as anode and sulphur as cathode. Beta-alumina ceramic worked as both a diaphragm and electrolyte. At a certain temperature (300~350℃), sodium ions permeate the electrolyte diaphragm and have a reversible reaction with sulphur, causing the release and storage of energy.

2.3.5. Flow battery. Flow battery is a new device for electric power storage and high-efficiency conversion. The anolyte and catholyte are stored and in different containers and recycle in respective container. Flow battery can be divided into systems as all vanadium, vanadium-bromine, zinc-bromine according to the different electrolytes that anode and cathode used. All vanadium flow battery has relatively mature technology and is most demonstrated and used among these batteries. All vanadium redox flow battery store and release electric power by mutual conversion of vanadium ion of different valences. It is the only battery that is constitute of the same element, which in theory, prevent the cross contamination cause by the mutual penetration of various types of active substances between anode and cathode. A certain number of batteries installed in series can output rated current and voltage.

3. Comparations on different parameters of various energy storage technology

Due to the different discharging time for different energy storage technology under rated power, energy storage way should be choose appropriately when applied to different power grid. When it is applied to power quality improving, power grid frequency stabilization and UPS, batteries with quick response and short discharging time should be chose, such as super capacitors and flywheel energy storage. When it is applied to power supply continuity, cushion or reserved power source, short energy storage should be chose which can discharge for several seconds to several minutes. When it is applied to cut a peak to fill cereal in power grid or grid-connected energy storage of wind and solar power, large-scale storage way which also has small self-discharge should be chose, including water pumped storage and air compression storage. In the limited geographical conditions, sodium-sulphur battery and flow battery can be chose. Without doubt, the construction of a commercial energy storage station must take its investment into account. Lead acid battery is relatively cheap, which is one reason to make it long-lasting. However, lithium ion battery is prevented to be used in large scale because of the high price.

References are cited in the text just by square brackets [1]. Two or more references at a time may be put in one set of brackets [3, 4]. The references are to be numbered in the order in which they are cited in the text and are to be listed at the end of the contribution under heading references, see our example below.

4. Conclusion

Each energy storage technology has its own advantages and disadvantages, and they can be applied in different nodes of smart grid according to its charge-discharge properties and dimensions degrees.

The smart grid is required to provide electricity that meets the need of 21st century, to be appropriate to all batteries and power storage and be available to market transaction. It is also required to optimize grid assets, improve the operation efficiency and to be self-healing, interactive and secure. All the above requires the reservation source to immediately activate when the power shortage of the grid appears in a short time. Super capacitors and flying wheel energy storage technology would be the first choice for a short interval because they respond quickly and discharge on High large current. If the power shortage is still exist after a cushion of a short period, reservation power sources which can offer a longer charge can be started to achieve an uninterruption power. These sources include water pumped-storage and air compression energy storage. Green new energies such as wind and solar power need a smooth situation, which need energy storage of large scale to ensure the stability of power conveying to the power grid. Then flow battery and sodium-sulphur battery become the best choices. Because of the appropriate energy storage technology, the power grid really gets the "smart" technical feature of informationized, digitized, automated and interactive.

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