Overview of Energy Storage Technology Based on Distributed Energy System

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Abstract. Distributed energy is an important part of energy system. As one of the key supporting technologies of distributed energy system, energy storage technology will bring revolutionary changes to energy consumption mode, which is of great significance to China's energy transformation. At present, the development of energy storage technology in China is very rapid, but there are obvious defects and deficiencies in the practical application of various energy storage technologies. This paper discusses the development status, trends and challenges of contemporary distributed energy system, makes a detailed classification of energy storage technology, analyzes the scientific problems faced by energy storage technology, and finally gives the development suggestions of energy storage technology under distributed energy system.

1. Development status, trend and challenge of distributed energy system

1.1. Development status of distributed energy system

(1) Foreign development status

The United States is the country with the earliest development of distributed energy (1978) [1]. As of 2016, 6000 distributed energy power stations have been built. It is estimated that the total installed capacity of distributed power stations will reach 187 million kilowatts in 2020, accounting for 29% of the total installed capacity of the country. At present, it has developed into the stage of multi energy complementary distributed energy 4 [2]; Japan's distributed energy projects mainly focus on cogeneration and solar photovoltaic power generation. The installed capacity is about 36 million kilowatts, accounting for 13.4% of the total installed capacity in China. Japan plans to achieve the goal of 20% of the total power generation by 2030. The EU's distributed energy development is at the leading level in the world. Germany is expected to invest 30,000 projects by 2020, with a total installed capacity of 2.77 million kilowatts, doubling the gas-fired distributed generation capacity to 25% of the total national power generation. The United Kingdom has built more than 1000 distributed CCHP systems through a large number of incentive policies to support the development of CCHP.

(2) Domestic development status

China's distributed energy started late. By the end of 2019, China's natural gas distributed installed capacity is about 24 million kilowatts, mainly distributed in Beijing-Tianjin-Tangshan, Yangtze River Delta and Pearl River Delta Area. For example, Guangzhou University City, Shanghai Pudong Airport, Beijing Gas Group Dispatching Center Building, Shanghai Huangpu Central Hospital, etc. It is expected that by the end of 2020, the capacity of natural gas distributed generators will reach 50 million kilowatts,
doubling on the current basis. In terms of development quality, the regional distributed energy projects are mostly in the level of cogeneration, and the CCHP and multi energy complementary are not considered.

| Region                | In operation  | In construction |
|-----------------------|---------------|-----------------|
| Shanghai              | $0.90 \times 10^4$ | $1.11 \times 10^4$ |
| Beijing               | $90.41 \times 10^4$ | $91.43 \times 10^4$ |
| Guangdong Province    | $216.33 \times 10^4$ | $225.09 \times 10^4$ |
| Sichuan Province      | $10.68 \times 10^4$ | $13.20 \times 10^4$ |
| Other regions         | $152.00 \times 10^4$ | $164.50 \times 10^4$ |

1.2. Development trend of distributed energy system

(1) Energy storage will play an increasingly important role in distributed energy system.

Distributed energy system has the characteristics of intermittence, uneven distribution and large fluctuation. Energy storage system can solve the mismatch between generation power and load power, and response time of different types of power sources, enhance the schedulability of renewable energy, and improve the energy supply quality, stability and operation efficiency of distributed energy system [3]. For the lithium battery energy storage technology, reducing the cost and improving the service life is the future development direction. For the chemical energy storage device, relying on electrochemical conversion to achieve hydrogen, methane and liquid fuel from new energy power; relying on thermochemical conversion to achieve high-grade thermal energy efficient storage are two important development trends.

(2) Multi energy complementary integrated optimization

Multi energy complementary technology can effectively improve the operation efficiency of energy system and equipment utilization rate, pursue the cascade utilization of energy and improve the energy utilization efficiency. It can effectively solve the problem of energy consumption and avoid energy waste. At the same time, it can effectively drive local investment, promote the development of the industry and scientific and technological innovation. At the same time, the implementation of multi energy complementary integration optimization project is one of the main tasks of energy development in the 13th five year plan. It can be seen that the top-level design at the national level leads the development of distributed energy in the direction of multi energy complementarity [4].

Multi energy complementary and integrated optimization are the new connotation of distributed energy development. Multi energy complementarity refers to the complementary coordination among various energy subsystems on the energy supply side. It emphasizes the complementary and mutual assistance, and changes to intelligent, flat and personalized energy utilization mode, so as to realize the local energy acquisition and consumption.

1.3. Challenges of distributed energy system in China

The development of distributed energy system is facing new challenges, which are mainly reflected in the following three aspects:

(1) In terms of technology, it will bring impact and challenge to public power grid. First of all, because the distributed energy system adopts a variety of power generation methods, the frequency difference is very large, some even in the form of direct current, such as fuel cell and solar power generation [5]. Therefore, how to solve the synchronous operation of power generation equipment is one of the challenges of distributed energy system to the traditional power system. Secondly, when the load fluctuates, the load voltage of the current distribution line can be kept within the allowable fluctuation range by adjusting the tap of on load tap changer or the input capacity of reactive power
compensator. However, when the distribution network lines are connected to the distributed energy system, this regulation method may not meet the voltage requirements of users.

(2) In terms of economy, distributed energy investment is not attractive. Because distributed energy brings social benefits, such as protecting the environment, reducing noise, saving land, saving energy, etc. The benefits in this respect are called external influences in economics, and these cost benefits cannot be fully reflected in the market, resulting in large initial investment and poor investment attraction of distributed energy system, which requires government policy support.

2. Status and classification of energy storage technology

2.1. Simplified physical model
With the rapid development of distributed energy and intelligent microgrid, various energy storage technologies have been widely concerned and applied. As of the end of December 2019, the total installed capacity of energy storage projects in operation in the world is 183.1 GW. Among them, China, as one of the three countries with the largest installed capacity (China, the United States and Japan), has attracted worldwide attention for its investment and attention to energy storage. At present, the total installed capacity of energy storage projects in China is 32.3 GW, accounting for 18% of the world, with a year-on-year increase of 3.2%. According to the form of energy storage, energy storage technology is mainly divided into thermal energy storage technology, electrochemical energy storage technology, electric energy storage technology, chemical energy storage technology and mechanical energy storage technology [7], as shown in Figure 1. At present, the thermal energy storage technology, electrochemical energy storage technology and mechanical energy storage technology are relatively mature and have achieved large-scale application, but there are still some shortcomings to be improved. The application scale of electric energy storage and chemical energy storage technology is small, but it develops rapidly.

![Figure 1. Classification of energy storage technology](image)

Different energy storage technologies have different energy storage time and power. Electrochemical energy storage technology includes not only the mature lithium battery technology and lead-acid battery technology, but also the new technologies such as flow battery and sodium sulfur battery. Among them, by the end of 2019 [6], the cumulative installed capacity of lithium-ion batteries has reached 7193 MW, accounting for 87.3% of the total installed capacity of electrochemical energy storage. However, there are still problems such as low energy density, short cycle life and poor safety, which seriously restrict the application of lithium batteries. The advantages of lead-acid batteries lie in their relatively low price, mature technology and high application share. Up to now, the installed capacity of 412 MW has been put into operation, accounting for 5% of the total installed capacity of electrochemical energy storage.
As emerging and efficient high-capacity power storage batteries, the current installed capacity of liquid flow battery and sodium sulfur battery account for 1.0% and 6.2% respectively, which have certain application prospects in large-scale distributed generation and Microgrid systems [8].

![Schematic diagram of power type and energy type energy storage](image)

**Figure 2.** Schematic diagram of power type and energy type energy storage

In addition, mechanical energy storage methods such as compressed air energy storage and flywheel energy storage also have their unique application fields. At present, some compressed air energy storage power stations (such as Huntorf CAES power station in Germany and McIntosh CAES power station in the United States) have been put into commercial operation. As a kind of energy storage method, flywheel energy storage is suitable for the field of fast frequency modulation with high starting time requirements, such as power frequency modulation, braking energy recovery of high-speed railway and subway, etc. By the end of 2019, the installed capacity of compressed air energy storage power station and flywheel energy storage power station, which have been put into operation in the world, account for about 0.2% of the total installed energy storage capacity.

Compared with electrochemical and mechanical energy storage technology, thermal energy storage technology has longer service life and lower cost. In distributed energy system, rich energy is stored in the form of thermal energy, which is more secure and reliable than electric energy storage, and has the potential of promotion. The International Energy Agency (IEA) pointed out [9] that at present, thermal energy is the largest form of terminal energy consumption, and heating energy consumption for household, industrial or other purposes accounts for 50% of the total energy consumption. Therefore, thermal energy storage plays an important role in the future distributed energy system and even in the field of social energy utilization.

3. **Key technologies of energy storage technology in distributed energy system**

3.1. *Multi scale dynamic response of thermal storage system under real time load*

Due to the randomness of user load and the intermittence of new energy, distributed energy load has strong variability and dynamics, which makes the heat storage system always operate under dynamic variable working conditions [10]. However, the power response of distributed energy system is usually millisecond transient response, and the thermal response of thermal storage system is usually minute level delay response. Different order of time constant makes the dynamic response characteristics of heat storage system more complex under distributed energy real-time load. One of the feasible solutions to this problem is to establish a multi scale dynamic response model of thermal storage system coupled...
with distributed energy, and analyze the multi scale dynamic response characteristics of heat storage system under distributed energy.

3.2. Converter control strategy
Energy storage converter, also known as power conversion system (PCS), is the executive equipment of power regulation in energy storage unit. Under the deployment of monitoring and dispatching system, effective and safe management of power storage and discharge is implemented. At present, the commonly used converter control strategies include PQ control, VF control, Droop control, etc.

(1) PQ control
PQ control refers to constant active and reactive power control, which controls the output active power and reactive power of energy storage converter equal to its reference power. PQ control is the most commonly used control mode of new energy grid connection, which can only be used in the grid connection mode of energy storage system. Its control principle diagram is shown in Figure 3.

![Figure 3. PQ control diagram](image)

It can be seen from the diagram that PQ control can stabilize active and reactive power output in the range of frequency and voltage variation ($f_{\min} \leq f \leq f_{\max}, U_{\min} \leq U \leq U_{\max}$).

(2) VF control
VF control means that the energy storage converter maintains the output voltage and frequency unchanged; the output active power and reactive power are determined by the load, and its control principle is shown in Figure 4. No matter how the output active power and reactive power change, the VF controlled energy storage converter automatically adjusts the operation curve to meet the random load change and keep the voltage frequency constant.

![Figure 4. VF control diagram](image)

(3) Droop control
Droop control is a kind of current sharing control mode of parallel inverters without interconnection line. The droop control converter model can be simplified as AC power supply as shown in Figure 5.
When the output impedance of PCS is mainly inductive, the output active power is approximately proportional to the phase angle difference, and the reactive power is approximately proportional to the amplitude difference of voltage. Therefore, the active power and reactive power output by the inverter can be adjusted by adjusting the phase and amplitude of the converter output voltage.

Droop control can not only work in the case of independent load, but also in the case of multiple parallel machines. In the construction of microgrid, droop control mode can be used to establish the voltage and frequency of microgrid. In the case of no upper control, the inverter can distribute the load of the system according to the local setting parameters; in the case of upper control, the inverter operates according to the parameters set by the upper controller, and it can also select whether to adjust frequency according to its own situation.

4. Conclusion
Energy storage technology plays an important role in distributed energy system. It should be demand-oriented and develop energy storage system according to different load application scenarios and actual needs of related fields. In terms of technology research, it is necessary to study the whole industry chain technology from the research and preparation of energy storage materials, device design and manufacturing to system integration. In the aspect of industry promotion, it is necessary to improve the electricity market-oriented trading mechanism, peak and valley price policy, guide energy storage policy subsidies, and formulate energy storage network standards. As one of the most active countries in the research and development of energy storage technology, China will be more in-depth in tackling the existing key technology research and development as well as the core problems that have not yet been solved. More advanced and comprehensive energy storage technologies are bound to emerge.

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