Outlook and application analysis of energy storage in power system with high renewable energy penetration

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Abstract. To realize low-emission and low-carbon energy production and consumption, large-scale development and utilization of renewable energy has been put into practice in China. And it has been recognized that power system of future high renewable energy shares can operate more reliably with the participation of energy storage. Considering the significant role of storage playing in the future power system, this paper focuses on the application of energy storage with high renewable energy penetration. Firstly, two application modes are given, including demand side application mode and centralized renewable energy farm application mode. Afterwards, a high renewable energy penetration scenario of northwest region in China is designed, and its production simulation with application of energy storage in 2050 has been calculated and analysed. Finally, a development path and outlook of energy storage is given.

1. Introduction
In order to realize low-emission and low-carbon energy production and consumption, in recent years, China has actively promoted the development and utilization of renewable energy and set several national goals that non-fossil energy consumption should account for 15%, 20% and 50% of the total energy consumption in 2020, 2030 and 2050 respectively [1]. Considering the intermittency and volatility of renewable energy and its power output, it has be widely acknowledged that energy storage can be used to regulate and adjust frequency, also improve the reliability of wind and solar power connecting to the grid, which are presented in the following references [2-7]. With energy storage, the power system can operate safely and reliably with high renewable energy penetration, and national goals could be made a reality.

This paper focuses on the application of energy storage in power system with high renewable energy penetration. Firstly, two application modes are given, including demand side application mode and centralized renewable energy farm application mode. Afterwards, looking forward to an energy storage applications scenario of northwest region in China, which is mainly the second application mode, and its production simulation in the year of 2050 has been calculated and analyzed. Finally, a development path and outlook of energy storage is given.

2. Application mode of energy storage
Overall, the main function of energy storage cooperated with centralized renewable energy farms is to flatten the power output of renewable energy, otherwise, energy storage equipped for distributed generation in demand side is mainly for improving power supply reliability and power quality. Although orientations of these two energy storage application modes are different, they both are
significant to ensure the healthy development of a power system, which will have a high proportion of renewable energy in the future.

2.1. Demand side application mode

In the future, demand side from the power system will have diversified energy production and consumption patterns, such as electric vehicles, energy storage, distributed power generation, micro-network and so on. In order to meet the needs of intermittent distributed generation connecting to power grid, such as distributed photovoltaic power and small-scale wind power, the installation of energy storage will improve the user’s overall energy consumption economic and efficiency. In addition, energy storage used in demand side also can enhance power quality, grid stability and power supply reliability.

![Energy storage applications and technologies](9).

In view of micro-grid’s characteristics and function of energy storage in demand side, energy storage is required to have the characteristics of big energy density and power density, fast response, etc, which has been presented in [8]. In report [9], comparison of discharge time and rated power between various energy storage types has been completed, shown in figure 1. Combined with what characteristics demand side should have and future changes in the cost of energy storage, battery, energy storage, flywheel energy storage and electronic double layer capacitor are expected to be the mainly demand side use in the future.

2.2. Centralized renewable energy farm application mode

As we all know it has various advantages of equipping energy storage in wind or solar farms, therefore, this part focuses on reasonable capacity proportion of energy storage to renewable energy farm from the perspective of Chinese national standards about renewable energy grid-connecting.

The current wind farm grid-connecting standard in China, which is GB-T-200 (Technical rule for connecting wind farm to power system), stipulates that the change of wind farm’s power output should meet the requirements of power dispatching department, and its detailed requirement of wind powered generation ramp rate limitation is as shown in table 1.

| Capacity of wind/PV farm (MW) | power ramp rate limitation per 10 min (MW) | power ramp rate limitation per 1 min (MW) |
|-----------------------------|------------------------------------------|------------------------------------------|
| <30                         | 10                                       | 3                                        |
| 30-150                      | farm capacity / 3                         | farm capacity / 10                       |
| >150                        | 50                                       | 15                                       |
The current photovoltaic power station grid-connecting standard in China, which is GB/T 19964-2012 (Technical requirements for connecting photovoltaic power station to power system), stipulates that the change of PV station’s active power and power ramp rate limitation should conform to power system requirements of safe and stable operation with solar radiation growth of interconnected PV plants.

According to the standards mentioned above, the capacity proportions of energy storage to centralized wind power and PV stations can be set as 10% and 20% respectively in the future. According to the study shown in [9], reasonable continuous discharge time of energy storage cooperated with renewable energy should be few hours, and 4 hours are recommended in the field of power system regulating. According to the characteristics of energy storage applications shown in figure 1, CAES and L/A batteries kinds of storage will have greater development potential cooperating with centralized renewable energy stations.

3. Application case study of energy storage in power system with high renewable energy penetration

Due to the lack of site resources of pumped hydro storage in northwest China, the pumping storage’s capacity of less than 100 gigawatts has been expected in year of 2050 in the northwest. Considering there will be rapid development and high penetration of renewable energy connecting to the power grid in northwest China, therefore, it is deeply necessary to equip other kind of energy storage to cooperate with northwestern renewable energy, such as compressed air storage, electrochemical energy storage, etc.

Based on a high renewable energy penetration scenario of northwest China [reference in press [10]] which power supply structure is shown in figure 2, the function of energy storage to promote renewable energy consumption has been studied in this section by setting different proportions of energy storage. In particular, we choose CAES in this study, and the cost of CAES used IEA’s research results which has been presented in [11] as shown in figure 3.
The power system production simulation of this analysis needs to be over long-periodic, one year, and the software application named GridView developed by ABB Inc is used. In this period, start-up mode of coal power stations will be optimized, that is, with the equipment of energy storage, less starting up of coal power and more accommodation of renewable energy will happen. Results of typical day’s production simulation in 2050 with or without storage are shown in figure 4 and figure 5 respectively. Especially, the capacity proportions of energy storage to wind power and PV is set to be 10% and 20% respectively in figure 3 according to the conclusions above.

**Figure 4.** Power system production simulation of typical day in 2050 with storage.

**Figure 5.** Power system production simulation of typical day in 2050 without storage.
As we can see, energy storage plays a role of power load peak shifting in a day. And because of large-scale development of wind power and solar power, the net power load has been different with the original power load of peak-valley characteristics. To meet the real-time balance of power supply and demand, energy storage will choose the most difficult regulating time, that is the time when wind and PV abandon the most and which is about 10:00~13:00 in figure 4, to pump and accommodate renewable energy as much as possible. In addition, there are energy limitation of storage, which is continuous charge and discharge time generally lower than 4 hours, thus, storage has already been charged fully after 13:00, after that, even there’re a lot of renewable energy abandonment, the storage has no ability to pump.

Figure 6 presents the influence on renewable energy accommodation of various storage capacity, and results shows that 10% of capacity ratio of storage to wind and PV power will be enough to improve the accommodation of renewable energy.

![Figure 6. Influence on renewable energy accommodation of various storage capacity.](image)

| 2020 | 2030 | 2050 |
|------|------|------|
| • mainly dominated by PSH | • breakthrough of new technology | • new technology become dominated in large-scale energy storage |
| • CAES, FW, Na-S and EDLC come into the demonstration and commercial application stage | • substantial decline of cost | • popularization of electric vehicles |
| | • Li-ion and VR become mainstream of large-scale commercial applications | • widely used in residential and commercial fields and create innovative power system business |
| | • CAES and L/A begin to be applied to large-scale renewable energy farms | |

4. Development path and outlook of energy storage

Development path of energy storage from 2020 to 2050 is shown in table 2. In the future, energy storage development will have two characteristics. Firstly, gradually developed storage technology will support non-fossil energy to be dominant power supply. With the significant decrease of cost of renewable energy technology, the proportion of renewable power generation will continue to rise, and energy storage should be cooperated to flat renewable energy’s fluctuation. Secondly, with the popularization and application of distributed energy system by use of multi-energy complement mode, such as wind power, DG PV and small storage, distributed generation will become an important power supply part.
5. Conclusions
After the application analysis of energy storage in power system with high renewable energy penetration, we found that energy storage has significant effects on renewable energy accommodation in the future high renewable energy penetration scenario, just like power system of northwest China in 2050. Moreover, in our case of northwest China in 2050, results shows that 10% of capacity ratio of storage to wind and PV power will be enough to keep reasonable curtailment of renewable energy, and it’s in correspondence with the ratios from our study of Chinese standards, which suggests that the capacity proportions of energy storage to centralized wind power and PV stations to be 10% and 20% respectively. To outlook the development path of future energy storage, breakthrough of new storage technology and large-scale application in both centralized renewable energy stations and distributed energy systems are expected.

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