Research on the function orientation of pumped-storage plant in China

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Abstract. With the growth of electrical load and development of clean energy, peak regulation of power system has been paid more attention to, in which case pumped-storage plant becomes the most efficient and economical way against peak load and the ensurance of safe and stable system operation. However, the dispatch and operation mode of pumped-storage plant is a little unreasonable at present in our country, due to the insufficient acknowledge of plants’ function orientation in different regions. This paper studied the standard of classifying pumped-storage plants, by dividing the plant function into three types security oriented, peak shaving oriented and renewable energy accommodation oriented, based on the local load characteristic, structure of power supply, accommodating capability of renewable energy, nuclear energy, etc. Finally, according to the current and future development situation of five Chinese regions, the function orientation partition of pumped-storage plant is given, which has profound guiding and practical significance for pumped-storage plant dispatch and operation.

1.  Introduction
In recent years, power system regulating problem caused by growth of power load and development of clean energy has been increasingly apparent. And limited by resource endowment and no key break-through of most storage technologies, as shown in [1-2], pumped-storage plant will still be the most effective and economic tools in the present and the future to ensure operation safety and stability of power system in China.

Current pumped-storage plants in China lacks of unified rules, and each regions’ dispatching institutions about pumped-storage is pretty diverse, which leads to a big difference of actual pumped-storage utilization and its design. It’s largely due to the lack of understanding of regional pumped-storage plants’ function orientation. In fact, with the rapid energy industry development of China and the huge adjustment of energy structure, power system need to be more safe and reliable, the function orientation of pumped-storage plant has been given new meanings, which are presented in [3-5].

In this paper, standards of classifying pumped-storage plants have been studied, by dividing the plant function into three types security oriented, peak shaving oriented and renewable energy accommodation oriented, based on the local load characteristic, structure of power supply, accommodating capability of renewable energy, nuclear energy, etc.
2. Function orientation of pumped-storage plant

2.1. Overview of pumped-storage plants’ function

Pumped-storage plant has two main function characteristics. The first is to converse flexibly between power generation and power consumption, which can be used in power peak cutting and valley filling. Second is start-up quickly and response to the change of the electric load quickly, thus can be used in grid frequency control, phase control, emergency reserve and black-start, also shown in [6-9]. Overall, ordinary function of pumped-storage plants includes peak cutting and valley filling, frequency control, emergency reserve, regulating support for new energy and nuclear power, phase control, black start power supply, etc.

As shown in table 1 which are presented in [10], contrary to coal-fired and gas-fired plants, pumped-storage plant has obvious advantages on regulating ability, start-up rate, rich functions, and so on.

Table 1. Comparison of operation characteristics of different power plants.

|                                  | Pumped-storage plant | Coal-fired plant | Gas-fired plant |
|----------------------------------|----------------------|-----------------|----------------|
| Unit commitment                  |                       |                 |                |
| Regulating capacity (%)          | 200                   | 30 ~ 50         | 100            |
| Start-up rate                    |                       |                 |                |
| Start-up to full-load            | 2 ~ 3 min             | 6 ~ 8 h         | 45 min         |
| No-load to full-load             | 30 ~ 35 s             | 2 ~ 3% capacity/min | 6 ~ 8 min |
| Ramping rate (capacity/min)      | 50 ~ 100%             | 2 ~ 3%          | 12 ~ 15%       |
| Valley filling                   | ✓                     | ×               | ×              |
| Frequency control                | ✓                     | ✓               | ✓              |
| Phase control                    | ✓                     | ✓               | ✓              |
| Spinning reserve                 | ✓                     | ✓               | ✓              |
| Black start power supply         | ✓                     | ×               | ✓              |

2.2. Classification of function orientation

Although pumped-storage has various functions, however, because of regional grid differences about source structure, load characteristic, balance between power supply and demand, and the orientation of pumped-storage plants in different region cannot be the same, and should be considered respectively.

Considering the current electric power development in China, the functional requirements for the pumped-storage by power system are mainly three types security oriented, peak shaving oriented and renewable energy accommodation oriented.

2.2.1. Security oriented. It refers to the functions of emergency reserve, black start, frequency control, phase control, which can handle various emergencies appearing in the power system. And this kind of plants are mainly located in the high power reliability requirements of important economic and political centres, or the grid key hub.

2.2.2. Peak shaving oriented. This kind of plants are mainly distributed in the system of load peak and off-peak difference is big and regulating capacity is insufficient. With the rapid development of society, the proportion of residential load keeps rising, and triggers the increase of load peak and off-peak difference. Pumped-storage plant has obvious advantages in Peak cutting and valley filling, especially its unique function in filling valley, which makes it extremely useful in reducing the system load peak and off-peak difference.
2.2.3. *Renewable energy accommodation oriented.* As discussed in [11-12], this type of pumped-storage plants can cooperate with some certain power plants and provide directional operation service. As for new power plants such as wind power and solar energy, because of its natural characteristics of randomness and intermittent, its effective capacity is low and should have a certain capacity of pumped-storage plants with given proportion can be effectively improved. Besides, to keep safe operation, nuclear power has a very high requirements so should be matching capacity of pumped storage units with appropriate load, energy storage or security, otherwise cannot give full play to the function of design.

2.3. *Standards of function classification*

Considering function orientation given above, this section will introduce the standards of pumped-storage classifying shown in figure 1, based on the local load characteristic, structure of power supply, accommodating capability of renewable energy, nuclear energy, etc.

![Figure 1. Classification basis for the function orientation of pumped-storage plant.](image)

2.3.1. **Key node of grid.** It belongs to security oriented. Located in cities having high power supply reliability requirements, such as Beijing, Shanghai and other political and economic centres. Besides, if plants locate in grid key hub node, such as drop point of large-scale UHV DC, pumped-storage can be the effective means of frequency control and active power control.

2.3.2. **Load peak and off-peak difference and rate of regulating plants.** It belongs to peak-shaving oriented on the situation of large load peak and off-peak difference and low rate of regulating plants.

2.3.3. **Rate of power from other regions and its operation mode.** It belongs to peak-shaving oriented when pumped-storage located in the area accept lager rate of power from other regions.

2.3.4. **Rate of wind and PV abandon.** When area’s rate of renewable power integration is lager and the rate of power abandon is high because of lacking regulating capacity, the pumped-storage belongs to renewable energy accommodation oriented.

2.3.5. **Regulating demand of nuclear power.** If there exists nuclear power plant, and needs of regulating and security, the pumped-storage belongs to renewable energy accommodation oriented.

Function orientation of pumped-storage plants is not immutable, instead, it should be adjusted as the grid’s characteristics changing. For example, Central China has lots of runoff hydropower, in flood

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[Image 1](image)
season, pumped-storage plants mainly bear peak shaving function, and when dry season came and the need of regulating reducing, its function turned to be security oriented. Thus, in practice, function orientation of pumped-storage plant should be treated differently in different evaluation periods.

3. Regional function orientation of pumped-storage plant in China

Due to lager geographical area of China and its uneven regional social and economic development level, the load characteristics and power structure also have big difference of different regions, also shown in [13]. This section puts forward on the combination of classification basis, according to the present situation and future development trend of Chinese regional grid, which are presented in [14], and analyzed regional function orientation of pumped-storage plant in China.

3.1. North China grid

In present, the function orientation of pumped-storage plants in north china grid focuses on security and peak-shaving. North china grid mainly depends on coal-fired plants, which accounts for 78.6% of the whole capacity by the end of 2014. Its load peak and off-peak difference is almost 27% no matter in winter or summer. Because of heat supplied plants starts up more in winter, the rate of regulating capacity only gets 10~20%, which needs pumped-storage to filling the valley especially.

In the future, as the increasing incoming power flow scale and new energy bases into operation, the function orientation of pumped-storage plants in north china will focus on security and renewable energy accommodation. During the 13th five-year, as the large-scale wind bases in Hebei province and Inner Mongolia province and UHVDC project from Jalute to Qingzhou and from Shanghaimiao to Linyi building into operation, the capacity of wind power in north china will be 20 million kW and 70 million kW power will come from other regions, thus, corresponding pumped-storage should be constructed for grid security operation and wind power accommodation.

3.2. East China grid

In present, the function orientation of pumped-storage plants in east china grid is peak shaving oriented. East china grid has large load with peak and off-peak difference being 20 million kW, and the grid mainly depends on coal-fired plants, which accounts for 65% of the whole capacity by the end of 2014. East China grid has lots of pressure of regulating, and its existed pumped-storage plants play big role.

To cope with the increasing incoming power flow scale and rising rate of nuclear power, function orientation of pumped-storage plants in north china will be regulating oriented. The ratio of power come from other regions will be over 30% after 2020, and pumped-storage will be the vital plants to provide active power supply.

3.3. Central China grid

In present, the function orientation of pumped-storage plants in central china grid is peak shaving oriented. Central China power grid is the largest hydropower installed capacity, the highest proportion of power grid in 2014, hydropower installed capacity of 130 million kW, the proportion of 46%. The research and practice show that the proper development of pumped-storage plants in the grid with the ratio of the main power of the runoff type hydropower has the comprehensive benefits such as improving the operating condition of the thermal power unit, reducing the running cost of the whole network and rationally utilizing the seasonal electric energy of hydropower. Such as Hubei, Hunan, Henan have different proportions of hydropower, but with the ability to adjust and more than a small proportion of hydropower stations, the dry season can be used for water and electricity peaking, loss of regulation of hydropower during flood season, to use water peak, it can only force to take abandoned water peaking mode. In this kind of power grid, with the pumped storage power station, it can absorb the basic charge in the flood season and convert it into the peak charge, so as to reduce or avoid flooding in the flood season, improve the economic efficiency and improve the hydropower flood season operation condition, of the operating conditions.
The future of central pumped storage power station is mainly located in the support by the end of power to ensure safe and stable operation of power grid. With the Jiuquan-Xiangtan and northern Shaanxi-Wuhan and other UHVDC projects completed, the central China region by the proportion of power into the province by the proportion of electricity will rise to about 20%, part of the delivery of the power flow of 60 million kW, the channel is mainly distributed by transmission and distribution, and it has anti-peaking characteristics. The pumped storage power station in the district will undertake the task of supporting the power supply and regulating the peak of the power network.

3.4. Northeast grid
In present, the function orientation of pumped-storage plants in northeast grid is renewable energy accommodation oriented. Same as the north china grid and east china grid, northeast grid mainly depends on coal-fired plants, and what makes things worse is heat supplied plants accounting for the very great proportion, which will lead to low regulating capacity in winter, and when the wind power blows will makes it even worse.

It will still be renewable energy accommodation oriented to pumped-storage plants in northeast grid in the future. As new wind power bases going into operation in Gansu province, Qinghai province and Ningxia province, more regulating pressure will appear in northeast grid, therefore, more pumped-storage plants should be built to prevent serious wind abandon.

3.5. Northwest grid
Pumped-storage plant hasn’t been put into operation in northwest yet, and the planning plants should be oriented to renewable energy accommodation. In northwest grid, hydropower accounts for 17% of the whole capacity, on the other hand, its load peak and off-peak difference was only 20%. However, without regard to the rapid development of renewable power, it turns to be well in grid regulating. According to the national planning, the wind capacity of northwest grid by 2020 will be nearly 50 million kilowatt, which accounts for about 35% of the northwest peak load, and will put pressure on grid regulating. At present, power abandon caused by lack of regulating capacity occurred in Gansu province and Xinjiang province, it will be even harder when the proportion of wind and PV get higher in the future. Thus, to build pumped-storage plants in these areas have become very necessary.

4. Conclusion
Based on the domestic and foreign development experience and the reality of China, this paper puts forward the method of pumped-storage plant’s function orientation, and classifies into three types security oriented, peak shaving oriented and renewable energy accommodation oriented. Then, combined with the current and 13th five year plan development in China, five regions’ pumped-storage plant’s function are given, including North China, East China, Central China, Northeast and Northwest. The research has profound guiding and practical significance for pumped-storage plant dispatch and operation.

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