Case Study on Scale Optimization of Pump-storage Variable Speed Units Based on Power System Operation Simulation

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Abstract. Pumped-Storage Hydro (PSH) power units, especially variable speed units, have great roles in guaranteeing power system operation safety, stability and efficiency. As the investment cost of pumped-storage variable speed unit is higher than fixed speed unit, it is necessary to study its optimal scale. This paper used a scale optimization model for variable speed units based on power system security constrained unit combination model, which can demonstrate the most economic scale of variable speed units in all new pumped-storage power units under a given power supply planning. And then, calculation examples of multi-category regions in China were done, which shows that in a given power plan, demand on pumped storage variable speed units in the peak shaving and valley filling category region is the highest, followed by safety guarantee category, and demand on pumped storage variable speed units in feed end areas in proportioned new energy absorption category is relatively low.

1. Introduction
Along with the rapid development of new energy and interconnected power grid in China, operation characteristics of the grid have changed significantly, grid regulation capacity and disturbance resistance have decreased, and the stability form of power systems has become more complicated. Before the formation of more advanced power system suitable for new energy access at high proportion in the future, regulation power supply such as pumped-storage unit is required to ensure the safe and stable operation power system.

In recent years, pumped storage variable speed unit technology has developed quickly, showing relatively outstanding advantages on operation [1-4]. Japan is the country with most pumped storage variable speed units applied. It has totally more than 10 power stations and 17 units; except Japan, the application of variable speed units mainly concentrates in Germany. Our country has commenced variable speed unit projects such as Feng-Ning Phase II Pumped-storage Power Station and so on, which have important significance on ensuring safe and stable operation of grid, as well as promotion of new energy absorption and so on. The study on pumped storage variable speed units in China focuses on the variable speed unit technology and its excellent characteristics, with less emphasis on optimal allocation of variable speed units in power systems.

Since pumped storage variable speed unit performs far better than constant speed unit in ensuring safe and stable operation of the system, the more variable speed units applied in the power system, the better effect on maintaining stable frequency, conducting active and inactive power control, improving
generation efficiency and so on. Therefore, without economic limits, the optimal proportion scheme shall be to build pumped storage variable speed units completely. However, cost of variable speed unit is higher than that of constant speed one. How to optimize the optimum capacity proportion between newly built constant speed units and variable speed units will be the emphasis of this paper.

2. Model of capacity proportion optimization of pumped storage variable speed unit
Reasonable capacity proportion aims at optimal comprehensive benefit [5]. The establishment of a model of pumped storage variable speed unit in stochastic production simulation can give the optimal proportion of variable speed/constant speed pumped storage in a certain area. First of all, aiming at the optimal comprehensive benefit, the model of pumped storage variable speed unit in stochastic production simulation is established; then, based on the scenario analysis and comparison method, a reasonable and comprehensive evaluation model for the operation benefit of pumped storage variable speed units in each region is established by using the stochastic production simulation software, and quantitative empirical analysis is carried out to give scientific and reasonable capacity allocation proportion of pumped storage variable speed units for each region.

![Figure 1. Capacity proportion optimization process of pumped storage variable speed units based on the scenario analysis method](image)

In particular, the capacity proportion of pumped storage variable speed units defined in this study indicates the proportion of newly-built variable speed units in all newly-built pumped storage units under a given power supply planning scheme. Refer to reference documents for specific model.

3. Parameter setting
A reasonable and comprehensive evaluation model for the operation benefit of pumped storage variable speed units in each region is established by using the stochastic production simulation software, and quantitative empirical analysis is carried out to give scientific and reasonable capacity allocation proportion of pumped storage variable speed units for each region under the existing 2030 Power Planning Scheme. Wherein, according to the document classification, case study is conducted in North China in safety guarantee category, East China in peak shaving and valley filling category and Northwest China in proportioned new energy absorption category respectively.

A 7-node national production simulation model is established according to the division of operation zones of State Grid. Since the newly built pumped storage power station will affect the system operation in each year during its life cycle, the model operation simulation period is selected to be 2016-2030.
Referring to the research results of State Grid Energy Research Institute for power supply development scenarios in each region in 2030, it is expected that the total installed capacity in the whole country in 2030 will reach up to 2.5 billion kW as shown in Table 1. Refer to the following table for the overall and regional distribution of installed power supply. Same with the above mentioned functional location and zoning, the regional scheme and cross-region transmission scale of the national grid is as shown in Figure 2. Other parameters’ setting can also be found in [5].

Table 1. Overall Installation of Power Supply of China in 2030 (10,000 kW)

| Power Supply Type   | 2016  | 2020  | 2030          |
|---------------------|-------|-------|---------------|
|                     |       |       | China  | North China | East China | Northwest China |
| Hydro               | 30391 | 34270 | 38192  | 214        | 2049        | 4771            |
| Pumped storage      | 2669  | 3504  | 7190   | 1757       | 2861        | 500             |
| Coal                | 97953 | 109543| 119091 | 21747      | 20930       | 21690           |
| Gas                 | 7537  | 11140 | 17140  | 4934       | 9292        | 1554            |
| Nuclear             | 3363  | 5820  | 8330   | 1150       | 1520        | 4713            |
| Wind                | 15673 | 22338 | 34237  | 9360       | 2960        | 13707           |
| Solar               | 7804  | 13709 | 27606  | 9957       | 3042        | 16756           |
| Biomass and others  | 1253  | 1777  | 2741   | 850        | 1110        | 478             |

4. Case analysis

4.1 Case for reasonable capacity proportion in safety guarantee category regions
North China is selected as the study object for the safety guarantee category. The overall installed power supply in North China in 2030 is as shown in Table 1, in which 13.3 million kW of pumped storage power station will be put into operation after 2020.

A total of 13.3 million kW of pumped storage units will be newly built. Assuming a capacity of 300,000 kW or 350,000 kW, a total of about 40 pumped storage units will be added.

According to the production simulation analysis, with the capacity proportion of pumped storage variable speed units newly built in North China being about 50%, the operation benefit of the system will be the optimal. When the capacity of pumped storage variable speed units is gradually increased, it shows obvious peak shaving and valley filling effects. The demand for peak shaving of the system is reduced; the utilization rate of conventional units such as thermal power ones is increased; the power generation and coal consumption are both reduced; the fuel cost and variable operation cost are obviously reduced; and the effect of offsetting the increase in investment brought about by the increase in the capacity proportion of variable speed units is significant. When the capacity proportion of pumped storage variable speed units exceeds 50%, the space for peak shaving and valley filling of pumped storage is obviously reduced, and the reduction of the system operation cost is gradually
slowed down, causing less and less obvious effect on offsetting the increase in investment brought by the increase in the capacity proportion of variable speed units. As shown in Fig. 3, in the scenario completely equipped with variable speed units, the operation benefit is reduced to a negative value.

Figure 3. Operation benefit of each scenarios in North China in 2030

4.2 Case for reasonable capacity proportion in peak shaving and valley filling category regions

East China is selected as the study object for the peak shaving and valley filling category. The overall installed power supply in East China in 2030 is as shown in Table 1, in which 15 million kW of pumped storage power station will be put into operation after 2016.

A total of 15 million kW of pumped storage units will be newly built. Assuming a capacity of 300,000 kW or 350,000 kW, a total of about 45 pumped storage units will be added.

Figure 4. Operation benefit of each scenarios in East China in 2030

According to the production simulation analysis, with the capacity proportion of pumped storage variable speed units newly built in East China being about 70%, the operation benefit of the system will be the optimal. The load peak-valley difference in East China is large, and the demand for peak shaving of pumped storage units is also prominent. Compared with North China, when the capacity of pumped storage variable speed units is gradually increased, it shows obvious peak shaving and valley filling effects. The demand for peak shaving of the system is reduced; the utilization rate of conventional units such as thermal power units is increased; the power generation and coal consumption are both reduced; the fuel cost and variable operation cost are obviously reduced; and the
effect of offsetting the increase in investment brought about by the increase in the capacity proportion of variable speed units is significant. When the capacity proportion of pumped storage variable speed units exceeds 70%, the space for peak shaving and valley filling of pumped storage is obviously reduced, and the reduction of the system operation cost is gradually slowed down, causing less and less obvious effect on offsetting the increase in investment brought by the increase in the capacity proportion of variable speed units.

4.3 Case for reasonable capacity proportion in matching new energy absorption category regions

Northwest China is selected as the study object for the proportioned new energy absorption category. The overall installed power supply in Northwest China in 2030 is as shown in Table 1, in which 5 million kW of pumped storage power station will be put into operation after 2016.

A total of 5 million kW of pumped storage units will be newly built. Assuming a capacity of 300,000 kW or 350,000 kW, a total of about 15 pumped storage units will be added.

According to the production simulation analysis, with the capacity proportion of pumped storage variable speed units newly built in Northwest China being about 40%, the operation benefit of the system will be the optimal. The load peak-valley difference in Northwest China is relatively small and the load is relatively stable, so there is little demand for peak shaving and valley filling by using pumped storage power stations; in addition, after 2020, With the gradual improvement of the electricity market, more flexible and diversified pricing mechanisms, as well as the operation and launching of trans-provincial and cross-region UHV lines, the problem of new energy absorption in the Northwest China has mainly been solved (the energy abandonment rate will fall below 7% in 2020 and below 5% in 2030). Pumped storage units mainly deal with the problem of insufficient system capacity caused by the uncertainty of short-term new energy output.

As shown in the above figure, along with the increase of capacity proportion of pumped storage variable speed units, the investment of newly built pumped storage power station increases proportionally. When the capacity proportion of pumped storage variable speed units increases from 0, since it improves the new energy absorption and reduces the energy abandonment rate, new energies with zero marginal cost replaces part of the fossil energy electricity, causing the reduction of fuel cost and O&M cost, thus the operation expenses of the system is reduced significantly. Thereafter, when the energy abandonment rate of new energy reaches nearly zero and the capacity proportion of pumped storage variable speed units rises again, the "negative" benefit of pumping loss of pumped storage gradually exceeds the "positive" benefit accumulated in improving the absorption of new energy. The specific manifestation is that starting from the medium proportion scenario, the reduction of system operation cost brought by pumped storage variable speed units starts to decline.
5. Conclusion

With the comprehensive consideration on the investment and operation cost, a model of capacity proportion optimization of pumped storage variable speed units based on scenario analysis method is established, and case study is carried out. Aiming at the optimal comprehensive benefit and based on the scenario analysis and comparison method, a reasonable and comprehensive evaluation model for the operation benefit of pumped storage variable speed units in each region is established by using the stochastic production simulation software. The case shows that in a given planning scheme, the demand on pumped storage variable speed units in the peak shaving and valley filling category region is the highest, followed by safety guarantee category. The demand on pumped storage variable speed units in feed end areas in proportioned new energy absorption category is relatively low.

With the consideration on advantages of pumped storage variable speed units, it is suggested that relevant study is enhanced, independent technological innovations in China is promoted and standardization design works of power stations are conducted, thus to reduce investment cost of variable speed units. Aiming at the power development plan in different regions, more defined regional multi-node model shall be established, the study on the capacity proportion optimization of pumped storage variable speed units shall be deepened and the communication with relevant departments shall be enhanced, thus to promote the implementation of the planning scheme.

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