Research on optimal allocation of pumped storage and wind and photovoltaic hybrid power system

Yaofu Wu *, Zhihua Liu, Shuqing Zheng, Jingying Wan

Zhejiang Qujiang Pumped Storage Power Corporation Limited, Quzhou, China

*Corresponding author e-mail: xu_lj@hdec.com

Abstract. In recent years, Zhejiang Province has a great development of wind farm and photovoltaic station, and which has gradually embossed the safety operation margin of the grid. This paper builds a evaluation model of pumped storage and wind and photovoltaic hybrid power system, and optimize configuration research process simulation of pumped storage and wind and photovoltaic hybrid power system. Two methods with increment model and pure model of pumped storage and wind and photovoltaic hybrid power system are adopted to propose a reasonable grid-connected capacity rate and the reasonable proportion and coordinated optimized configuration ratio of pumped storage and wind and photovoltaic hybrid power system. The results show that the method effectively evaluate the influence and benefit of optimal allocation of pumped storage and wind and photovoltaic hybrid power system to Zhejiang power grid.

1. Introduction

Wind farm and photovoltaic station always play an important form of developing renewable energy, and have become an inevitable development trend with continuous expansion of both. They play the role of assisting and supplementing power supply, and they can also save energy and protect the environment. Wind energy and solar energy are gap-sex energy, restricted by natural conditions such as wind speed, light and temperature, with a strong randomness and volatility of individual wind farm and photovoltaic station, and with the large-scale grid-connected capacity of wind farm and photovoltaic station, the adverse effect of the safety and stable operation of power grid cannot be ignored. Wind energy and solar energy have unstable characteristics, but both of them have strong complementarity in time and geographical domain. A scenery complementary hybrid power system can be formed by using output characteristics of wind farm and photovoltaic station.

In recent years, the utilization rate of wind energy and solar energy and other renewable energy in Zhejiang Province has gradually improved. Most of domestic and foreign research focuses on the construction simulation, optimization configuration and control strategy of operating characteristics of individual power system such as wind, photovoltaic and energy-storage, or two energy complementary power systems such as wind and energy-storage, wind and photovoltaic, photovoltaic and energy-storage. The optimal allocation of pumped storage and wind and photovoltaic hybrid power system is still lacking in depth. Therefore, taking the characteristics of wind and photovoltaic hybrid power system and the role played by energy-storage facilities in power grid into consideration, This paper is based on the cost present value of electricity system to propose a reasonable grid-connected capacity rate and the
reasonable proportion and coordinated optimized configuration ratio of pumped storage and wind and photovoltaic hybrid power system, aims to provide reference for the adjustment of energy structure in Zhejiang Province.

2. Operating characteristic of wind and photovoltaic power system

2.1. Operating characteristic of wind farm
Zhejiang Province is a coastal province, and the wind energy resources in coastal areas are rich, especially in the development of offshore wind power. Data analysis according to the 8760 hours of wind farm in Zhejiang Province, the output of wind farm in winter of Zhejiang Province is large, and the summer is slightly small. The average annual output of wind farm accounts for about 23.4% of the installed capacity. The electricity of wind farm is mainly concentrated in the area of 0% to 50% section of the wind farm output. When the grid-connected capacity rate of wind farm is 40% to 50% of the installed capacity, the electricity of wind farm accounts for about 93.4% to 97.6% of the annual total electricity.

The abandon wind power corresponding to different valley load of the power grid is analyzed through the statistics of the actual output of wind farm corresponding to the peak and low valley load of the whole power grid, and the capacity rate of valley load is determined by combined with power system and power system guarantees. The output ration of wind farm in peak load period correspondence rate 95% in Zhejiang Province is 1.1%~1.8%. The output ration of wind farm in valley load period correspondence rate 5% in Zhejiang Province is 63%~70%, and the abandon wind power of 8 hours is 0.7%~1.2%. Combined with the development of renewable energy in Zhejiang Province and the requirements for renewable energy sources, in this paper, the grid-connected capacity tare of wind farm is 65% in valley load period.

2.2. Operating characteristic of photovoltaic station
Because the amount of solar radiation is directly related to the weather, the operating characteristic of photovoltaic station in Zhejiang Province are random, intermittent and volatility. Data analysis according to the 8760 hours of photovoltaic station Zhejiang Province, the electricity system of photovoltaic station in winter is in a low value area, and then reaches the peak in summer. The average annual output of photovoltaic station accounts for about 14.3% of the installed capacity. The electricity of photovoltaic station is mainly concentrated in the area of 0% to 60% section of the photovoltaic output. When the grid-connected capacity rate of photovoltaic station is 50% to 60% of the installed capacity, the electricity of photovoltaic station accounts for about 94.5% to 97.3% of the annual electricity system.

The operating characteristic of photovoltaic station in Zhejiang province are shown as follows: the output of photovoltaic station in sunny appeal to a sinusoidal half wave, as the irradiance increases smoothly in the morning, the peak is reached between 12: 00 to 14: 00, and then declines smoothly. In the case of cloudy weather, it will be obviously fluctuated by the cloud. The maximum load of Zhejiang power grid mainly occurred at 11:00 am and 4:00 pm, and the photovoltaic station in Zhejiang Province is mainly distributed, and all the performance of photovoltaic occurs during the day, which is the same with the peak load of Zhejiang power system.

The relationship of the grid-connected capacity rate and electricity system of wind and photovoltaic hybrid power system and operating characteristic are conducive to the reasonable design of wind and photovoltaic grid-connected capacity rate and reduce the peak load regulation difficulty of power grid and cut down the investment of supporting facilities.

2.3. Complementary operating characteristic of wind and photovoltaic
The daily average output of wind farm in Zhejiang Province basically show the state of "high in morning and evening, low in noon", the output reaches to the maximum value about in 0: 00~4: 00 and 19: 00~23:
0 of the day, and then the output falls to the valley about in 7:00~15:00. The output of wind farm is high especially in November to April.

The daily average output of photovoltaic station in Zhejiang Province basically show the state of "high in noon, nothing in morning and evening", and which is look like parabolic line type. There is a small output in 5:00~6:00, then gradually increases with the strengthening of the light, then reaches to the maximum value in 11:00~13:00, after 13:00, the output gradually decreases. After 19:00, the output of photovoltaic station is basically reduced to 0. The output of photovoltaic station is high especially in July to October.

The relationship curve of complementary grid-connected capacity rate of wind and photovoltaic hybrid power system and the cumulative electricity system in Zhejiang Province can be seen in Figure 1. As you can see in the figure 1, if only take wind farm into account, the grid-connected capacity of wind farm is considered as 55%~60% of the installed capacity, then the grid-connected electricity of wind farm is accounts for 96.4%~97.3% of the total electricity; if only take photovoltaic station into account, the grid-connected capacity of photovoltaic station is considered as 55%~60% of the installed capacity, then the grid-connected electricity of photovoltaic station is accounts for 93.7%~94.6% of the total electricity; if take the wind and photovoltaic hybrid power system into account both, the grid-connected capacity of wind and photovoltaic hybrid power system is considered as 55%~60% of the installed capacity, then the grid-connected electricity of wind and photovoltaic hybrid power system is accounts for 99.4%~99.7% of the total electricity.

It illustrates that the wind and photovoltaic hybrid power system have a great complementary action. When the wind farm and photovoltaic station are collected to a hybrid power system and then connect to power grid, the measure can reduce the integral output fluctuation, and the measure can reduce the unfavourable influences to the power grid, and the measure can improve the operating factor of generating capacity and the electricity of wind and photovoltaic hybrid power system.

Figure 1. The relationship curve of complementary grid-connected capacity rate of wind and photovoltaic hybrid power system and the cumulative electricity system

3. Optimal allocation of pumped storage and wind and photovoltaic hybrid power system and the cumulative electricity system

3.1. Evaluative model
First, the extension of power supply planning in Zhejiang power grid is researched, and the rational allocation of pumped storage and wind and photovoltaic hybrid power system is optimal. Based on this, Zhejiang Province has added some scenery power station capacity, and the research needs to be added, and the reduction of scenery capacity and increased savings capacity can be considered to be a reasonable operation of the power grid to ensure the coordination of pumped storage and wind and
photovoltaic hybrid power system. The optimal allocation of pumped storage and wind and photovoltaic hybrid power system increment evaluative model is built on this basis. To avoid other factors, according to the operating characteristic of pumped storage and wind and photovoltaic hybrid power system, the optimal allocation of pumped storage and wind and photovoltaic hybrid power system pure evaluation model is built to analyze the coordination operations under different scenery distribution conditions.

3.2. Simulation result analysis

It is known from the simulation of increment model of pumped storage and wind and photovoltaic hybrid power system that when the proportion of wind farm and pumped storage power station is 3 to 3.4:1, the cost present value of power grid system in calculation interval is in a low-value range, and the increment part of photovoltaic station won't increase the dissolve burden of Zhejiang power grid system, so it can be seen from the point of view of satisfying the supply demand of capacity and electricity of Zhejiang power system, no additional energy-storage facilities is needed in Zhejiang power grid system.

Table 1. The cost present value of Zhejiang power grid system (Wind- pumped storage hybrid power station)

| Project | Total capacity of Wind-photovoltaic | Capacity of wind | Capacity of photovoltaic | Capacity of pumped storage | Ratio of Wind -pumped storage | Coal consumption | Cost present value |
|---------|------------------------------------|-----------------|--------------------------|----------------------------|-------------------------------|----------------|------------------|
| Option 1 | 53400 | 13400 | 40000 | 16000 | / | 5973 | 9684 |
| 1 | 21733 | 41667 | 18780 | 3:1 | 4915 | 9089 |
| 2 | 21400 | 42000 | 18580 | 3.1:1 | 4932 | 9098 |
| 3 | 20900 | 42500 | 18500 | 3:1 | 4956 | 9112 |
| 4 | 20067 | 43333 | 18150 | 3.1:1 | 4998 | 9136 |
| Option 2 | 63400 | 18400 | 45000 | 17610 | 3.1:1 | 5075 | 9182 |
| 5 | 16733 | 46667 | 17070 | 3.1:1 | 5154 | 9228 |
| 6 | 15900 | 47500 | 16730 | 3.4:1 | 5195 | 9252 |
| 7 | 15400 | 48000 | 16590 | 3.4:1 | 5219 | 9266 |
| 8 | 15067 | 48333 | 16490 | 3.4:1 | 5236 | 9276 |

Table 2. The cost present value of Zhejiang power grid system (photovoltaic- pumped storage hybrid power station)

| Project | Total capacity of Wind-photovoltaic | Capacity of wind | Capacity of photovoltaic | Capacity of pumped storage | Ratio of photovoltaic- pumped storage | Coal consumption | Cost present value |
|---------|------------------------------------|-----------------|--------------------------|----------------------------|-------------------------------|----------------|------------------|
| Option 1 | 53400 | 13400 | 40000 | 16000 | - | 5973 | 9684 |
| Option 2 | 63400 | 13400 | 50000 | 16000 | N:0 | 5637 | 11223 |
| Option 3 | 73400 | 13400 | 60000 | 16000 | N:0 | 5134 | 13564 |

It is known from the simulation of pure model of pumped storage and wind and photovoltaic hybrid power system that when the proportion of wind farm and pumped storage power station is about 3:1, the cost present value of power grid system in calculation interval is in a low-value range, and when the proportion of photovoltaic station and pumped storage power station is about 5:1 to 7:1, the cost present value of power grid system in calculation interval is in a low-value range.
By analyzing the results of two methods with increment model and pure model of pumped storage and wind and photovoltaic hybrid power system, it is recommended that the reasonable proportion of wind farm and pumped storage power station in Zhejiang Province is about 3:1, and for small-scale photovoltaic station, there is no additional energy-storage facilities is needed to be specially equipped in Zhejiang power grid system, and for large-scale photovoltaic station, it is recommended that the reasonable proportion of photovoltaic station and pumped storage power station in Zhejiang Province is about 5:1 to 7:1.

Figure 2. The cost present value of Zhejiang power grid system (Wind- pumped storage hybrid power station)

Figure 3. The cost present value of power grid system (photovoltaic- pumped storage hybrid power station)
Figure 4. The cost present value of Zhejiang power grid system
(Wind-photovoltaic- pumped storage hybrid power station)

4. Conclusion
The evaluative model of optimal allocation of pumped storage and wind and photovoltaic hybrid power system is built with the goal of optimizing the cost present value of Zhejiang power grid system, the complementary operating characteristic of wind and photovoltaic and the optimum proportion and coordinated operation conditions in Zhejiang Province are investigated. The investigation indicates that by the way of controlling reasonable grid-connected capacity rate and recommended proportion of pumped storage and wind and photovoltaic hybrid power system, the dissolve ability of renewable energy in Zhejiang Province can be promoted, and it can promote the safe and stable and economic operation of electric power system.

References
[1] Lingjun Xu, Na Zhong, Da Sang, Gang Li, Xiaohu Zhang. "Study on Operation of hybrid Wind-PV-ES power system In East China", IOP Conference Series: Earth and Environmental Science, 2020.
[2] Duan Cong, Ma Shiyi, Wu Jun, Li Fuqiang, Hu Yuou. "Study on Peak Shaving Strategy of Pumped Storage Power Station Combined with Wind and Photovoltaic Power Generation", 2017 International Conference on Computer Systems, Electronics and Control (ICCSEC), 2017.
[3] Yongzhi Yan, Yudian Liu. Strong solid scroll optimization and real time control of wind-optical reservoir System [J]. Journal of Electrician Technology, 2014,29 (8).
[4] Hongde Tang, Jiabao Guo, Wenli Chen. Wind-scale combined power generation technology and its engineering application [J]. Power and Energy, 2011(1): 61-63.
[5] Liquan Zhang. Development status and prospects of renewable energy power generation[J]. Power Business, 2008,23 (1): 29-32.
[6] Guowei Cai, Zei Kong, Chao Pan etc. Modeling and grid control strategy of wind-mounted combined power generation system [J]. 2011 (5): 196.203.
[7] Fang Xie. Analysis of new energy joint power generation management strategies [J]. Urban Construction Theory Research (EG Sub-version), 2013 (4).
[8] Zhiyi Li, Kai Yan, Wei Zhang, etc. Analysis of large scale wind and light storage in smart grid environment [J]. Power supply technology application, 2013, 4: 140.