Research on Peak Shaving Power Source Planning for Receiving-end Grid Considering High Proportion of New Energy and Large-scale Outer Power

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Abstract: Due to the mismatch of energy production and energy demand, multiple ultra-high voltage transmission fed in the grid and reverse-peak shaving characteristics of new energy, higher requirements have been imposed on peak shaving capability of receiving-end grid with large-scale new energy. This paper investigates the planning and configuration strategy of peak shaving power source based on the characteristics of regional power source structure, the configuration strategy of peak shaving power sources, DC links and interregional peak shaving capability. Simulation results of power balance and peak shaving balance calculation from a receiving-end grid in East China demonstrate the effect of peak shaving power sources planning proposed in this paper.

1. Introduction

Ultra-high voltage (UHV) grid has solved the contradiction of mismatched energy production centers and energy demand centers in China in terms of long-distance power transmission, and met the power demand of receiving-end grid, however, weak peak shaving capability of power from outside increases the pressure and risk of peak shaving for receiving-end grid. Meanwhile, the higher environmental protection requirements accelerate the transition of receiving-end grids structure. The large-scale development of new energy such as wind power and PV power has continually raised their proportion of installed capacity in the receiving side power grids, the impact of the reverse peak shaving of new energy is gradually growing, and the operation characteristics of receiving side power grids has changed profoundly, imposing higher requirements on the peak shaving capacity of the power system in operation on the receiving-end grids.

Ref.[1]-[2] studied the peaking shaving problem of receiving-end grid based on the output characteristics of new energy and peak shaving capacity. Ref.[3]-[4] discussed it based on grid structure and feed-in short-circuit ratio. However, few literatures show the peak shaving power source planning and configuration strategy for receiving side power grids for the high proportion of new energy and large volume of outer power. Therefore, this paper will investigate the planning and configuration strategy of peak shaving power source based on the characteristics of regional power source structure, the configuration strategy of peak shaving power sources, DC links and interregional peak shaving capability. Simulation results of power balance and peak shaving balance calculation
from a receiving-end grid in East China demonstrate the effect of peak shaving power sources planning proposed in this paper.

2. Principles of peak shaving power source planning for receiving side power grids

2.1 The power source structure differences of different regions
Due to the economic development level and geographic and meteorological conditions, different regions of receiving-end grid have some differences in power source structure. Different power source structures will generate different configuration strategies for peak shaving power sources. For saving peak shaving resources and improving the peak shaving capability, special configuration for peak shaving power sources based on the characteristics of different regional power source structures of receiving-end grid is required.

2.2 The impact of DC links on grid security
Base on the existing fault through criteria under high proportion of new energy, frequency stability can be maintained in an AC grid without adopting any strategy when a single pole blocking occurs in a DC system. However, a bipolar blocking of DC system will result a large-scale power transfer in the AC system, which will threaten the safe and steady operation of the grid. Therefore, the peak shaving power sources planning should be studied based on power flow, power angle and voltage by the layout of natural gas generating set to the UHV DC system and coordinated control strategy.

2.3 The mutual supplement capacity of peak shaving power sources
Ref. [6] proposed a wind power receiving capacity evaluation system based on the standby demand capacity and peak shaving capacity restraint of the system, which had effect in the research of the connection of inflow power under the restraint of peak shaving. In a receiving-end grid with high proportion of new energy, the peak shaving is pressured is in the mode of valley load while outer power and the electricity of new energy are large. In the area with concentrated outer power links, the peak shaving sources cannot be met the requirement based on the local sources when they operate at the minimum output level for a long time. Thus, some methods, for example, different reserve proportion or channel construction of different regions should be used for improving the peak shaving mutual supplement capability for receiving-end grid.

3. Analysis of a status quo power pattern of a receiving-end grid
In a province in East China, the receiving-end grid is located in the east coastal area. In the 13th Five-Year Plan period, with the implementation of the overall energy strategy of the state, the advance of the energy production and consumption revolution and the full implementation of the air pollution prevention action plan, the outer power has played an important role in the safe power supply for grid and economic development in this province. Furthermore, large-scale new energy such as wind power and PV power have been constructed and the proportion of new energy is increasing for the requirement in the construction of green energy system.

The power grid of this province is mainly divided into parts in the north and south of Yangtze River. Due to load and power distributions, the characteristic of power transmission sections is mainly power flowing from the north to the South [7]. This power transmission sections is mainly restricted by the power transmission capacity of the cross-river power channels. With the slowdown of load growth in the north to the Yangtze River, the increased UHV AC and DC links and the construction of the MW class wind power base in the north, the power transmission pressure is increasing on the key sections of the power transmission channel to transmit power from the north to the south [8].

In 2017, the maximum load of North River is about 39% of the maximum load of the province. However, installed capacity of whole sources in the area is 52% of the whole province, and installed capacity of new energy is only 21%. The power structure is as shown in Fig. 1. Similarly, the maximum load of South River is about 61% of the maximum load of the province. However, installed
capacity of whole sources in the area is 48% of the whole province, and installed capacity of new energy is only 4%. The power structure is as shown in Fig. 2.

Fig. 1 Power source international schematic diagram in the north area

Fig. 2 Power source international schematic diagram in the south area

From Fig. 3 we can see that, the outer power makes up 17% percentage of the province’s maximum load. It will increase to 35% in 2025. Furthermore, as shown in Fig. 4, the outer power is more constructed in South River than it in North. The outer power in the North is 35% of the province, and with the increasing of the DC power from Shanxi province and Inner Mongolia province, the proportion will be 47% at 2025. The number is closed to the proportion of South River area.

Fig. 3 Proportion of outer power in that area’s maximum load

Fig. 4 Growth trend of outer power in that area

From Fig. 4 one can see that the interconnected UHV AC and UHV DC is the main way of the UHV grids in the receiving-end grid. The percentage of outer power is increasing. For ensuring power supply and meeting the demand of outer power consumption, peak shaving capacity should be improved in this area. However, the differences of economic development and geographic conditions cause differences in the power source structures of the south and north areas. For increasing the peak
shaving capacity of receiving-end grid, it is necessary to make a differential configuration of peak shaving power source according to the power structure features of different areas in the receiving-end grid.

4. Power balance and peak shaving balance analysis

4.1 Power balance calculation by areas
The principle of power balance calculation is shown in the following: firstly, the reserve ratio of load is not considered; secondly, the outer DC links sources are considered as local sources, and the AC links are not considered. From Fig. 5 we can see that there is power supply shortage in this receiving-end grid. The load of North River area is low, thus, the source in North River area is enough. However, the load of South River area is high, and power shortage is large.

![Fig. 5 Power balance result of the whole province](image)

4.2 Peak shaving balance calculation by areas
In the area’s power balance analysis, the transmission power “from north to south” is considered as the outer power of the two areas, and the general power transmission and maximum power transmission capacity of the channel from the north to south are considered for calculating mutual supplement of peak shaving capacity of the two areas.

Based on the load characteristics, the peak shaving planning principle of this receiving-end area is as follows: the minimum load rate is 0.7, the positive spinning reserve is 4% load and negative spinning reserve is -2%, a spinning reserve of the operating sources is 6%; the reverse peak shaving coefficient of wind power is 50%; the nuclear power, PV and outer power are not considered in peak shaving; the power shortage of the province is supplied by natural gas generating set.

The area’s peak shaving balance result for this receiving-end grid is as shown in Fig. 6. It is known from the power balance result by section 3.1. Under the average reserved power source backup for areas both to the south and north of Yangtze River, at 2025, the total power surplus in the eight municipalities to the north of Yangtze River will be 3500MW, the surplus power will be transmitted to the south via the cross-river transmission channel. There is a 8600MW shortage of peak shaving in the north of Yangtze River after taking into full account the maximum peak shaving capacity of the river-cross sections. Power supply is shortage in the five municipalities in the South. on the basis of supplementing 10000MW power with gas turbines to meet power balance. The South River area can offer 6309MW for North River area peak shaving via cross-river channels. Meanwhile, there is a 1700MW power shortage for peak shaving in the area to the south of Yangtze River.
4.3 Analysis of power balance and peak shaving balance

From the results of power balance and peak shaving balance one can see that although there is no power shortage in the North area, there is a large shortage in peak shaving. This is caused by the structure of power source. The random intermittent disturbance of wind power output will obviously increase the risk of power unbalance in the system during steep rise or fall of loads [9]. The reverse peak shaving characteristic of wind power increases the peak to valley difference of equivalent load, and the regulating units should improve the response capability.

In the south area, there is a large power shortage, but the shortage of peak shaving is relatively small. The reason of that is the new energy power is low among the whole power sources in the South area. In the meanwhile, the proportion of natural gas generating set for peak shaving is higher than North area. Thus, the peak shaving power sources in the south area should be satisfied the requirement of peak shaving during high load period.

Simultaneously, the peak shaving capacity of an area is mainly reflected in the power transfer capacity of the cross-river section.

5. Deployment example and coordinated operation

A receiving-end grid with high proportion of new energy and large scale outer power in East China is taken to test the peak shaving power source planning and configuration strategy.

The power system analysis software (PSD-V2009) developed by the China Electric Power Research Institute is used in this section.

1) Differentiated configuration strategy for peak shaving power sources

From the former analysis we can know that there is power balance surplus and peak shaving gap in the north area. This is caused by the structure of power source. The reverse peak shaving characteristic of wind power increases the peak to valley difference of equivalent load, and the regulating units should improve the response capability. The peak shaving power source configuration strategy is suggested that to arrange stored energy (grid side and load side) and pumped storage. Then co-gen gas turbines, distributed natural gas generating set and other power sources can be constructed to meet the supply demand and peak shaving balance demand.

In the south area there is both power supply shortage and some peak shaving gap. The reason of that is the new energy power is low among the whole power sources in the South area and higher proportion of peak shaving gas turbines compared with that in the north. Therefore, the peak shaving power sources in the south area should be satisfied the demand of power balance and “peak leveling” in the peak load period. In the south area, we try to use peak shaving natural gas generating set, and then assisted with co-gen gas Turbines, distributed gas Turbines and stored energy to satisfy heat supply demand and peak shaving balance demand.

2) Match DC links to arrange peak shaving gas turbines

In receiving-end grid, the safe and steady operation margin of the grid is low with the constructure
of UHV DC power. The system power, power angle and voltage will be affected when a bipolar blocking fault occurs. Based on a bipolar blocking fault, the power flow, angle and voltage stabilization are calculated under two cases, with or without 2000MW natural gas generating set to MD station.

From Fig. 7 and Fig. 8 we can see that the power flow from 500kV transformer substation MD to Shuangyu is 4162MW when a bipolar blocking occurs in a UHV DC transmission. The power flow can be reduced to 3446MW when 2000MW natural gas generating set are arranged around the DC link. Line thermal stability problem is solved by this way.

![Fig. 7 Power flow diagram of bipolar blocking of UHV DC incoming power without arranging gas turbine](image1)

![Fig. 8 Power flow diagram of bipolar blocking of UHV DC incoming power with gas turbines arranged](image2)

From Fig. 9 one can see that, the oscillation of angle and voltage with natural gas generating set are lower than it without natural gas generating set under a bipolar blocking fault. Thus, the arrangement of natural gas generating set will have some effect in improving the stability of the power angle of the grid.

![Fig. 9 Effect of arrangement of gas turbines on the stability of power angle of the system](image3)

Fig. 10 shows that the voltage curve of the conversion bus during a bipolar blocking of UHV DC outer power. The voltage surge with natural gas generating set is higher than it without natural gas generating set under a bipolar blocking fault. During the fault recovery period, The bus voltage with natural gas generating set is higher than it without natural gas generating set. The main reason of that natural gas generating set is a reactive power. It worsens the problem of voltage surge by the ac filter. Natural gas generating set can offer reactive power during the fault recovery period.

![Fig. 10 Voltage curve of the conversion bus during a bipolar blocking of UHV DC outer power](image4)
From the above analysis we can see that it is suggested to reasonably arrange peak shaving gas turbines around the DC links for solving the problems of thermal stability, transient stability, voltage stability and frequency stability when a DC blocking occurs. During the fault through period, reactive power should be controlled to alleviate the stability problem caused by dc fault

3) Unit operation modes with different standby ratio

The peak shaving mutual supplement capacity of different regions is an important method to balance the peak shaving gap caused by the different power source structures in the south and north areas to the Yangtze River. The area peak shaving capacity of this receiving-end grid is mainly reflected in the power flow transfer capacity on the transmission section from the north to the south. For exerting the peak shaving capacity of area link channels, the reserve natural gas generating set in the North area can be increased and that in the South area should be lower, and then to increase the operation capacity of peak shaving natural gas generating set in the South area.

With 6% spinning reserve in the whole province, the spinning reserve in the south area will be lowered to 3.2% when the spinning reserve of the north area is increased to 10%. The peak shaving balance results with different unit reserve ratios are as shown in Fig. 11. From the results one can see that, with 10% reserve for the north area and 3.2% for the south area, the peak shaving gap of the north area will be decreased to 6020MW at 2025.

6. Conclusion

This paper investigates the planning and configuration strategy of peak shaving power source based on the characteristics of regional power source structure, the configuration strategy of peak shaving power sources, DC links and interregional peak shaving capability:

(1) For raising peak shaving capacity, the peak shaving power sources should be configured by taking the power source different structure and characteristics of different areas in the receiving-end grid into account. 

![Fig. 10 Effect of arrangement of gas turbines on the stability of power angle of the system](image1)

![Fig. 11 Peak shaving gap in the north area in a province in East China](image2)
(2) Under a single-polar or bipolar DC blocking fault, the natural gas generating set arranged based on the UHVDC links can supported power flow, power angle and voltage and improve the performance on fault through.

(3) Mutual supplement capacity for peak shaving can be improved by adopting different reserve ratio of different areas and strengthening the construction of key section power transmission capacity. This way can also reduce the peak shaving pressure in the valley load mode when the power generated from outside and new energy is high.

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Reference
[1] Key issues in large scale hydropower consumption and peak regulation and dispatching and progress in this research
[2] Lu Siyu, Wang Tong, et al. Analysis of the effect of the characteristics of transmitting power from the west to east in the grid in South China on the new energy consumption capacity of receiving side power grid [J]. Power Construction, 2015, 36 (10): 53-59
[3] Yang Lin, Ge Yi, et al. Research on key influential factors of the scale of receiving side power grid consuming inflow power [J]. Jiangsu Electrical Machinery Engineering, 2016, 35 (3): 21-28.
[4] Li Zhaowei, Zhai Haibao, et al. Evaluation on the DC receiving capacity of the large receiving grid in East China [J]. Power System Automation, 2016, 40 (16): 147-152.
[5] Guideline for safety and stability of large scale power system [S]. Beijing: China Power Publishing House, 2001.
[6] Sun Rongfu, Zhang Tao and Liang Ji. Evaluation of grid capacity to receive wind power and application [J]. Power System Automation, 2011, 35 (4): 70-76.
[7] General report on the planning and research of power transmission grid development in Jiangsu 2019-2023 (2025) [R]. Economic and Technological Research Institute of State Grid Jiangsu Provincial Electric Power Company. 2016.05.
[8] Zhang Qian, Xi Weimin, Huang Junhui, et al. Empirical analysis of probabilistic power flow of Yangtze River crossing section of Jiangsu grid taking into account the system operation modes [J]. Power System Protection and Control, 2013, 41 (1): 47-52.
[9] Liu Jin, Yu Jilai and LiuChao. Intelligent optimization dispatching strategy for spinning reserve for the intermittent disturbance of wind power [J]. China Electrical Engineering Journal, 2013, 33 (1): 163-170.