Evaluation of the peak-shaving capability of the receiving-end power system with multi-infeed UHV

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Abstract. Peak-shaving capability mainly refers to the capability of the power system to maintain the balance between the active output and load balance in real-time. Sufficient peak-shaving capability is one of the important conditions to ensure the security and stability of the power system. The access of multi-infeed ultra-high voltage will largely weaken the peak-shaving capability of the power system and thus increase its peak-shaving pressure. This paper first introduces the characteristics of renewable energy generation such as wind generation and photovoltaic generation since a large amount of renewable energy from the sending-end system through several UHV delivery often increases the peak-shaving pressure of the receiving-end power system. On this basis, it analyses the impact of multi-infeed UHV on peak-shaving of power system. Then, an evaluation method that uses equivalent peaking capacity to measure the peak-shaving capability of the UHV receiving-end power system with multi-infeed UHV is proposed. Finally, Zhejiang Power System is used as an example to evaluate its peak-shaving regulation capability in the typical years and the typical day using the proposed method.

1. Introduction

With the continuous development and maturity of ultra-high voltage (UHV) transmission technology, power resources can be optimized across regions using long-distance transmission. As of June 2019, the cumulative line length of the UHV project in China has been 27,570 kilometers and the cumulative substation capacity has been 296.2 million kW. The world's largest and most capable UHV AC-DC hybrid power grid has been built, which provides strong physical network support to promote the rational allocation of power resources and expand the consumption capacity of renewable energy in interprovincial regions.

A large proportion of the electricity delivered by UHV comes from renewable energy sources. Renewable energy generation such as wind power generation and photovoltaic power generation has intermittent, uncontrollable and volatility characteristics. The anti-peaking characteristics of wind power and the mismatch between photovoltaic power generation output and load peak will lead to a further increase of peak-shaving pressure of power system [1,2]. Therefore, although China's UHV transmission technology has promoted the development of long-distance cross-regional transmission, and to some extent solved the problem of electricity demand in the receiving area, large-scale multi-infeed UHV also brings great difficulties to peak-shaving of the receiving-end power system. For example, as a typical UHV provincial-level receiving-end power system, the East China Power Grid...
faces huge peak-shaving pressure during the trough of grid load [3]. So sufficient peaking capacity is a prerequisite for the receiving-end power system to accept renewable energy such as wind power [4]. It is needed to study the evaluation of the peak-shaving capability of the receiving-end power system with multi-infeed UHV.

At present, for the evaluation of peak-shaving capability, domestic and foreign scholars have carried out various research and obtained many research results with reference and practical value. In [5], various peak-shaving methods of the current power system and their respective problems are introduced. In [6], Monte Carlo random sampling method is used to solve the peaking deficiency probability and expected value, to evaluate the peaking margin at different time scales. In [7], the capacity evaluation method is used in the typical operation scenario to evaluate startup mode of the conventional hydropower and thermal power, system peak-shaving capability and new energy consumption capacity in the provincial power grid. Literature [8] estimates wind power consumption space using typical daily load curves and peak-shaving capabilities of conventional power supply. In [9], the time series method is used to establish a calculation method for peak-shaving capability evaluation and unit operation optimization for the period of low load. Most of the above studies are to evaluate the peak-shaving capability of a certain power generation resource or simply measure the peaking capacity surplus of the system from the perspective of peaking capacity balance, which lacks a peak-shaving capability evaluation method for the provincial-level receiving-end power system with multi-infeed UHV.

To solve the problem mentioned above, this paper aims to provide a precise and realistic evaluation method that can evaluate the peak-shaving capability of the receiving-end power system with multi-infeed UHV at each time. This method can measure the peak-shaving capability of the power system from different time scales and provides a valuable basis for planning and dispatch of the power system. The impact of multi-infeed UHV on peak-shaving of the power system is firstly analyzed, and then an evaluation method for the peak-shaving capability of the UHV receiving-end power system with multi-infeed UHV is proposed. Finally, the peak-shaving capabilities of the Zhejiang Power System in the typical day and typical years are evaluated using the proposed method.

2. Impact of multi-infeed UHV on peak-shaving of power system

2.1. Characteristics of renewable energy generation

Due to the randomness and uncontrollability of renewable energy such as wind power and photovoltaic power generation, a large amount of renewable energy from the sending-end system through several UHV delivery often increases the peak-shaving pressure of the receiving-end system. This section mainly analyses the characteristics of wind power generation and photovoltaic power generation.

The variability of wind resources leads to uncertainty in the output of wind power. By analyzing the influence of the wind power curve on the load curve, it can be seen that wind power has an anti-peaking characteristic. The wind power anti-peaking characteristic means that the trend of wind power output is opposite to the trend of grid load curve due to the uncontrollable wind speed. The wind power output is small at the peak load stage, and it is large at the low load stage. Figure 1 shows the anti-peaking characteristic of wind power.

Since the output of photovoltaic power generation is affected by various factors such as weather conditions and solar radiation intensity, its output is a non-stationary random process. Similar to wind power, photovoltaic power is an uncontrollable power source in the power grid.

The output of photovoltaic power generation is directly proportional to the solar illuminance. The solar radiation intensity has a unimodal characteristic in the 24-hour curve, first rising to the maximum value of the radiation, and then falling to the minimum value of the radiation. Therefore, the photovoltaic power output generally also has a unimodal characteristic at 24 hours, as shown in Figure 2.
Similar to wind power, the output of photovoltaic power generation also has an anti-peaking characteristic for the power grid. Since the grid load curve is generally bimodal, the daytime trough load is generally at noon, which is just the moment when the photovoltaic power generation output is large, so it has the anti-peaking characteristic. The photovoltaic anti-peaking characteristic has such an extreme situation: when the load is low during the daytime, the photovoltaic power output reaches the maximum; and in the peak load phase, the photovoltaic power output is low or even stops generating electricity.

2.2. Impact of multi-infeed UHV considering its characteristics
With the completion and commissioning of a large number of UHV transmission projects and the integration of a large number of new energy sources, the power supply characteristics and supply structure of the receiving-end power system have changed. The multi-infeed UHV has the characteristics of large capacity and weak controllability. Therefore, after the power grid receives the multi-infeed UHV, its reliability is reduced, the peak-shaving capability is reduced, and the frequency stability problem is highlighted [10].

The equivalent load can be obtained by removing the multi-infeed UHV in the original load. The peak-shaving pressure of the receiving-end power system depends on the peak-to-valley difference of the equivalent load after the multi-infeed UHV is removed. A comparison of the load curves before and after considering multi-infeed UHV of a typical day in Zhejiang Power Grid is shown in Figure 3.
It can be seen from the figure that if the peak-to-valley difference of the equivalent load is significantly greater than the original load, it indicates that multi-infeed UHV brings greater peak-shaving pressure to the receiving-end system. The peak-shaving performance of multi-infeed UHV will directly affect the peak shaving of the receiving-end power system. When multi-infeed UHV can follow the changing trend of the load to a certain extent, it has a positive peak-shaving effect, which can alleviate the peak-shaving pressure of the receiving-end power system. However, when the peak-shaving performance of multi-infeed UHV is worse, the peak-shaving pressure faced by the receiving-end power system is greater. Therefore, to absorb multi-infeed UHV, the receiving-power system needs to reserve more peaking capacity and peak-shaving depth to improve its peak-shaving capability.

3. Evaluation method for peak-shaving capability of UHV receiving-end power system with multi-infeed UHV

The peak-shaving capability of the power system is measured by the equivalent peaking capacity of the power system. According to the actual situation of the grid operation, the value of the load at each time is used to determine the unit output of the power system, which is expressed as

$$P_g(t) = (1 + k)P_l(t)$$

where $P_g(t)$ is the unit output of the power system at time $t$. $k$ is the rotation reserve ratio of the power system, which includes load reserve ratio and accident reserve ratio. $P_l(t)$ is the load value of the power system at time $t$.

Assume that multi-infeed UHV does not participate in peak shaving because of its characteristics, it is necessary to remove the multi-infeed UHV from the unit output calculated above as the base value of the power system’s conventional unit output which is used to measure the start-up capacity of the power system. So the maximum start-up capacity can be expressed as

$$P_{s_{max}}(t) = P_g(t) - P_{UHV}(t)$$

where $P_{s_{max}}(t)$ is the maximum start-up capacity of power system at time $t$. $P_{UHV}(t)$ is the sum of multi-infeed UHV power at time $t$.

The minimum start-up capacity of the power system can be calculated from the given minimum technical output of each unit in the system and is therefore considered a known quantity. The equivalent peaking capacity of the power system is the difference between the maximum start-up capacity and the minimum start-up capacity, which can be expressed as

$$\Delta P(t) = P_{s_{max}}(t) - P_{s_{min}}(t)$$

where $\Delta P(t)$ is the equivalent peaking capacity of power system at time $t$. $P_{s_{min}}(t)$ is the minimum start-up capacity of power system at time $t$.

4. Case study

Since the Zhejiang Power system is a typical receiving-end power system whose multi-infeed UHV capacity reached 30000 MW in 2019, this paper takes Zhejiang Power System as an example to evaluate its peak-shaving capabilities in a typical day and typical years using the evaluation method described in the previous section.

The years from 2015 to 2020 during the 13th Five Year Plan are selected as typical years of the Zhejiang Power System. The data required and calculation results of equivalent peaking capacities of the Zhejiang Power System in the typical years are shown in Table 1. The maximum values of load and multi-infeed UHV power are used to calculate the annual equivalent peaking capacities in order to consider the situation when facing large peak pressure. And the data for 2019 and 2020 are predicted values from power system planning. It can be seen from the calculation results that the equivalent peaking capacity of the Zhejiang Power System from 2015 to 2020 is basically increasing year by year.
### Table 1. Data required and calculation results of equivalent peaking capacities of Zhejiang Power System in the typical years.

|          | 2015  | 2016  | 2017  | 2018  | 2019  | 2020  |
|----------|-------|-------|-------|-------|-------|-------|
| Load (MW)| 5850  | 6548  | 6982  | 7141  | 7464  | 8030  |
| Unit output (MW)| 6435 | 7203  | 7680  | 7855  | 8210  | 8833  |
| Multi-infeed UHV power (MW)| 2240 | 2255  | 2731  | 3011  | 3014  | 3014  |
| Minimum start-up capacity (MW)| 1814 | 1732  | 1725  | 1968  | 2100  | 2196  |
| Equivalent peaking capacity (MW)| 2381 | 3216  | 3224  | 2876  | 3096  | 3623  |

### Table 2. Data required for calculating equivalent peaking capacities of Zhejiang Power System in the typical day.

| Load (MW) | Unit output (MW) | Multi-infeed UHV power (MW) | Minimum start-up capacity (MW) | Time (h) |
|-----------|------------------|-----------------------------|--------------------------------|----------|
| 38533.2   | 42386.52         | 15222.1                     | 21076                          | 0        |
| 37117.5   | 40829.25         | 13661.8                     | 21076                          | 1        |
| 35845.3   | 39429.83         | 13284.2                     | 21076                          | 2        |
| 35048.3   | 38533.13         | 13449.3                     | 21076                          | 3        |
| 34595.1   | 38054.61         | 13375.1                     | 21076                          | 4        |
| 35294.1   | 38823.51         | 13443.8                     | 21076                          | 5        |
| 37282.2   | 41010.42         | 14387.4                     | 21076                          | 6        |
| 40114     | 44125.4          | 15399.2                     | 21076                          | 7        |
| 45249.6   | 49774.56         | 17809.1                     | 21076                          | 8        |
| 46638.6   | 51302.46         | 18405.9                     | 21076                          | 9        |
| 48169.4   | 52986.34         | 18856.7                     | 21076                          | 10       |
| 45786.4   | 50365.04         | 17692.6                     | 21076                          | 11       |
| 41785     | 45963.5          | 16576.4                     | 21076                          | 12       |
| 46126     | 50738.6          | 16821.6                     | 21076                          | 13       |
| 47920.4   | 52712.44         | 18285.3                     | 21076                          | 14       |
| 48018.1   | 52819.91         | 18082.3                     | 21076                          | 15       |
| 48792.3   | 53671.53         | 18559.2                     | 21076                          | 16       |
| 47358.1   | 52093.91         | 18296.8                     | 21076                          | 17       |
| 44231.4   | 48654.54         | 17268.2                     | 21076                          | 18       |
| 43229.9   | 47552.89         | 17209.2                     | 21076                          | 19       |
| 44147.5   | 48562.25         | 17273.9                     | 21076                          | 20       |
| 43882.2   | 48270.42         | 16974.8                     | 21076                          | 21       |
| 44139.6   | 48553.56         | 16254.7                     | 21076                          | 22       |
| 42464.2   | 46710.62         | 14062.4                     | 21076                          | 23       |
| 39478.9   | 43426.79         | 13710                       | 21076                          | 24       |

One day in the flood season is selected as a typical day of Zhejiang Power System when its peak-shaving pressure is large. On June 24, 2018, due to the upstream water supply, the Jinshuisan Power Plant applied for 4 units overnight, and the Wuxijiang Power Plant applied for 1 large unit and 3 small units overnight, and the Zhejiang Power System's negative reserve was tight. The data required for
calculating equivalent peaking capacities of Zhejiang Power System in the typical day are shown in Table 2.

Figure 4 shows the curve of calculated equivalent peaking capacities in the typical day of the Zhejiang Power System and the curve of original peaking capacities which doesn’t consider multi-infeed UHV. Obviously, there is a big difference between the two curves and equivalent peaking capacities are more realistic and precise as the impact of multi-infeed UHV is considered. According to the obtained equivalent peaking capacities, suggestions can be given to improve the peak-shaving capability of the Zhejiang Power System. For example, more flexible generation such as gas power generation should be applied when the equivalent peaking capacity is small.

![Figure 4. Comparison between equivalent peaking capacities and original peaking capacities.](image)

5. Conclusions
Multi-infeed UHV with a large proportion of renewable energy increases peak-shaving pressure of the receiving-end power system, which makes peak-shaving capability’s evaluation an important task for the power system. The existing evaluation methods are to evaluate the peak-shaving capability of a certain power generation resource or simply measure the peaking capacity surplus of the system from the perspective of peaking capacity balance, which lacks a peak-shaving capability evaluation method for the provincial-level receiving-end power system with multi-infeed UHV. This paper analyses the impact of multi-infeed UHV on the receiving-end power system by comparing the peak-to-valley differences between original load and equivalent load. Then an evaluation method is proposed which uses equivalent peaking capacity to evaluate the peak-shaving capability of the receiving-end power system. Equivalent peaking capacities in a typical day and typical years of Zhejiang Power System are calculated in the case, and comparison between equivalent peaking capacities and original peaking capacities is given which verifies the effectiveness and practicality of the proposed method. As the sufficient peak-shaving capability is one of the important conditions to ensure the security and stability of the power system, the method proposed in this paper can provide a valuable basis for planning and dispatch of the power system and thus avoid the situation that the peaking margin is insufficient, which will bring practical and economic benefits to the operation of the power system.

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