Research of rational curtailment rate and development guiding mechanism of wind power in China

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Abstract. It is not conducive to green low-carbon development to pursue very low wind power accommodation rate regardless of cost. In order to improve the efficiency of wind accommodation and realize the coordinated development of wind power and power grid, a “rational curtailment rate” of wind power should be studied and evaluated. This work proposes that the “rational curtailment rate” of wind power should be defined as a curtailment rate when the marginal wind power accommodation cost equals to the marginal wind power accommodation benefits at given level of installed wind capacity. The rational curtailment rate is related to the system peak shaving capacity and installed wind capacity. According to the rational curtailment rate, three development strategies are proposed to guide the improvement of wind power accommodation level and energy supply efficiency: First, calculate rational curtailment rate separately in every provinces, and establishing early warning standards for wind power construction differently. Second, the idea of wind power development should be adjusted to “adjust resources flexibly first”. Third, set up different wind power investment guidance for in different areas, indicated by rational curtailment rate.

1. Introduction
During the last decade, China shared the highest wind energy capacities in the world. In recent years, with the rapid wind power development in China, the problem of wind power accommodation has been paid more attention and positive response. However, in the long run, wind installation capacities will continue to grow at a high speed as the accelerated arriving of era of "fair access" of wind [1]. Under the prevailing concept of "entire amount accommodation" of wind, the growth of wind installation capacities will be restricted, which is a bad effect on the realization of high-quality energy development [2]. Therefore, it is necessary to study the index and evaluation method of “rational curtailment rate” of wind power development, in order to improve the efficiency of wind accommodation and realize the coordinated development of wind power and power grid.

It is not conducive to green low-carbon development, if the pursuit of very low wind power accommodation rate regardless of cost. At present, the whole society has made tremendous efforts and cost to achieve a low average wind power curtailment rate control target setting at 5 percent. Meanwhile, the power system operation is also facing safe and stable pressures [3]. Actively exploring the essence of rational curtailment rate is to combine low-carbon energy supply with high energy efficiency to achieve healthy, orderly and coordinated development.
2. **Concept of “Rational Curtailment Rate”**

To pursue an extremely low wind power curtailment rate will greatly increase the cost of the system peak shaving and reduce the economy of the overall energy supply system [4]. Taking a province in Northeast China as an example, in 2018, the periods that wind power output was larger than 70% of the rated power only add up to 198 hours, which only accounts for 0.6% of the theoretical total wind power generation in the whole year. In order to accommodate this part of the peak power, additional peak shaving facility investments were needed. If this part of wind power output is voluntarily curtailed and regarded as active peak shaving actions, and the saved investment was used to build new wind turbines, the annual increase wind energy generation will be 30 times of the peak curtailment energy.

From the view of the whole cost of the energy system, the curtailment rate of wind power has a “rational value” [5]. This study proposes that the “rational curtailment rate” of wind power should be defined as a curtailment rate when the marginal wind power accommodation cost equals to the marginal wind power accommodation benefits at given level of installed wind capacity. When "rational curtailment rate" is achieved, the total cost of power supply reaches the lowest level. Marginal accommodation benefits are the cost of fossil fuels which replaced by wind power generation and emission reduction benefits. Costs and benefits are measured according to the annual equivalent of the project life cycle conversion.

3. **Major factors affecting rational curtailment rate**

3.1. **The relationship between rational curtailment rate and system peak shaving capacity**

Assuming wind power install capacities scale and other system conditions are fixed, the total cost of power supply in the whole system decreases and then rises with the increase of peak shaving capacity. The rational curtailment rate is curtailment rate corresponding the lowest total cost of system power supply. Taking a province in Northeast China as an example, the relationship between thermal power flexibility renovation and wind power accommodation in 2020 is simulated and analysed [6]. When the capacity of peak shaving is low (e.g. 1.25 GW), the curtailment rate is reduced by 0.5 percentage points per 100 MW peak shaving capacity, which reduces system power supply cost 2.6 million RMB. When the new peak shaving capacity is relative high (e.g. 2.5 GW), every 100 MW increase in peak-shaving capacity can only reduce the curtailment rate by 0.25 percentage. The revenue is lower than the cost input, the total cost of power supply in the system will rise by 4.4 million RMB instead. The rational curtailment rate of the system is 5.7%, when the new peak shaving capacity is 2 GW and total cost of the system is the lowest one.

![Figure 1. The relationship between rational curtailment rate and system peak shaving capacity](image-url)
3.2. Relation between rational curtailment rate and installed wind capacities scale
When other conditions of the system remain unchanged, rational curtailment rate increases with installed wind power scale. Taking a province in Northeast China as an example, the results of simulation analysis in 2020 show that if the install capacities scale of wind power is small (e.g. 4 GW), the peak shaving resources of the system can meet the demand of wind accommodation, and the corresponding rational curtailment rate level is low (about 5%). If the install capacities scale of wind power is reached to 12 GW, the rational curtailment rate will reach to about 15%, the marginal input of peak shaving resources will increase, and the total cost of power supply will decrease and then rise with the increase of wind power install capacities. This means that for a given system, there is an optimal install capacities scale of wind power with the lowest total cost of power supply which corresponds to the rational curtailment rate.

4. Development Guiding for Wind Power Based on Rational Curtailment Rate
From the past practice of wind power development in China, the lack of coordinated planning of wind power and flexible regulation of resources has led to the rapid development of wind power projects. Once the phenomenon of curtailment occurs, remediation will be carried out, and the “high-curtailment rate” area will be “one size fits all” for limit the growth of installed wind power capacity. These have led to a large number of curtailment energy, high cost of consumption and severe public pressure, which is not conducive to the healthy development of the wind power industry [7]. In the past two years, with the joint efforts of all parties, the level of wind power accommodation in China has greatly improved. In 2017 and 2018, the average rate of wind curtailment has dropped to 12% and 7% respectively. As installed wind power capacity growth momentum is still very strong in the future. It is necessary to focus on the following development strategies according to the index of rational curtailment rate, so as to guide the simultaneous improvement of wind power accommodation level and energy supply efficiency.

4.1. Strategy 1: Calculate rational curtailment rate separately in every provinces, and establishing early warning standards for wind power construction differently.
The early warning standard for wind power construction should be set separately according to the rational curtailment rate which calculated by each province. For areas where actual accommodation rate is lower than rational curtailment rate, it is not suitable to be classified as a red early warning area. For example, Xinjiang should allow moderate increase in the installed capacity of wind power; for areas where actual curtailment rate higher than the rational curtailment rate, it should limit the growth of installed capacity and strengthen the flexible adjustment of resources in the power system.
Taking Xinjiang Province and Qinghai Province as examples, according to the 2018 wind power grid-connected operation data released by the Energy Bureau [8], the theoretical utilization hours of wind power in Xinjiang were 2500 hours per year, while that in Qinghai were only 1700 hours. For the same investment scale, even if the curtailment rate was 30%, the annual wind power generation in Xinjiang is still higher than that in Qinghai, and the marginal income of Xinjiang under the high curtailment rate is still higher. It can be seen that due to the different conditions of wind power resources and power systems in different regions, rational curtailment rate is quite different, and the current power balance is still mainly carried out in each provinces. Therefore, at the current stage, on the basis of considering the inter-provincial power trading arrangements, it is still advisable to adopt the rational curtailment rate standard for each province and to make rolling adjustments.

4.2. Strategy 2: The idea of wind power development should be adjusted to “adjust resources flexibly first”

National and each regional energy authorities should establish a flexible coordination mechanism for resource regulation and wind power development, which change the previous development mechanism of remediation after serious energy curtailment, and planning and approval of new flexible resource regulation with planning and approval of new wind power projects.

Specifically, when the curtailment rate of wind power in a region is less than the "rational curtailment rate", new wind turbines should be given priority to satisfy the growth of power demand; when the curtailment rate exceeds the "rational curtailment rate", the flexible regulation ability of the system should be given priority, and the growth rate of wind power installation should be restricted. As shown in Figure 3, the new growth power generation capacity of wind turbines is high, which is conducive to reducing the total cost of the power system. This is due to the fact that the cost of power generation without curtailment power is lower than the average cost of power generation in China's current power system, when the wind power is added into the subsidy or when it is connected to the grid at a fair price. Taking a province in Northeast China as an example, simulated measurement of the 2020 situation, if 1 GW wind power is added, it is necessary to complete the 1.25 GW of thermal power generation transformation at the same time, in order to achieve a rational curtailment rate and achieve the best overall system power supply efficiency.

4.3. Strategy 3: Set up different wind power investment guidance for in different areas, indicated by rational curtailment rate

From the perspective of enterprise investment, when making decision on wind power investment, it usually only considers its own benefits. If the return rate of wind power investment (after taking into account subsidies) is higher than expected, there will be investment motivation, and it does not consider the peak shaving cost of new power system after project access. This has led to the rapid growth of wind power in many areas with good wind resources, which has made it difficult to accommodation.

Therefore, the guiding mode of wind power development should be changed to implement differential incentives for wind power projects and impose differential peak shaving obligations on them. Considering the total cost of power supply and the return on investment of power generation enterprises, a quadrant map of differentiated investment guidance of wind power is formed with the coordinate axes of system economy and enterprise return, as shown in Figure 3.

For the area in the first quadrant, the curtailment rate is lower than the rational curtailment rate. At the same time, the return on investment of wind power plants is higher than the expected return rate of enterprises, which is conducive to improving the economy of the whole system and guaranteeing the returns of investors. It should actively encourage and priority development (such as Shandong and Xinjiang Province). For the area located in the second quadrant, the return on investment of wind power plants is relatively high, but it will bring great cost of accommodation, which will reduce the economy of the whole power system, it should increase the intensity of subsidy retreat; for projects that have been on the grid at a fair price, it should prioritize the responsibility of accommodation and
peaking according to system conditions or construction of peak shaving facilities such as energy storage according to the system conditions. For the area located in the third quadrant, the new wind power station is not beneficial to the power system and investors. The development of this system should focus on the construction of other power sources, power grids and peak shaving capacity. For the area located in the fourth quadrant, the peak shaving ability of the system is strong, and the new wind power station is conducive to improving the overall economy of the system, but the income of investors is poor, the subsidy should be increased to attract wind power investors.

5. Relevant Recommendations
Firstly, the early warning mechanism of wind power investment based on “rational curtailment rate” should be established by provinces and regions as units, and different standards should be set for each province and adjusted year by year.
Secondly, promoting the adjustment of wind power development thinking as “flexible regulation of resources first” to guide the future planning and formulation of wind power and flexible regulation of resources development.
Finally, promote the change of the “one-size-fits-all” management and restrictive mechanism in areas to the differentiated guidance mechanism with high curtailment rate, and promote the rational distribution of wind power development.

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