

# Analysis of source-grid-load contribution to wind power accommodation

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**Abstract.** In recent years, China's wind power is developing rapidly, but wind electricity curtailment becomes a serious problem. This paper evaluates wind power penetration limit from peak regulation, analyses relevant technical elements that impact wind power accommodation, coving the source side, the transmission side and the load side. By taking certain measures around the three aspects, for example, reducing the minimum technical output of conventional units, increasing outbound transmission capacity, or increasing the valley load, wind electricity curtailment will be effectively reduced. This paper quantitatively analyses wind power penetration limit under certain conditions and the source-grid-load contribution to wind power accommodation, and explores the important technical factors that affect wind power accommodation.

## 1. Introduction

Resource shortage, environmental pollution and climatic variation are increasingly severe. The energy development path established on the basis of traditional fossil energy will be difficult to sustain. The low-carbon, renewable clean energy system will alter traditional fossil energy system, which is the core of worldwide energy revolution. At present, China's new energy capacity ranked first in the world, especially the wind power is far ahead, but wind curtailment is very serious. In order to promote the sound development of wind power, earnestly implement the national new energy strategy policy, it is necessary to further study the reason of wind curtailment, come up with reasonable measures to promote wind power accommodation. Combined with domestic [1-3] and international research results [4-7], policies and market factors play a vital role in the development of wind power, but from a technical point of view, the source side, the transmission side and the load side are important factors affecting wind power accommodation [8-9].

## 2. Technical factors influencing the wind power accommodation

In order to adapt the wind power utilization and accommodation on a large scale, all kinds of power resources need to work in coordination. To implement large-scale wind power development and efficient utilization in our country, we need to analyze the current outstanding problems and solve the problems. About policy and market aspects, please refer to the literature [1] and literature [10]. In the technical level, the solution can be proceeded from the power side, grid side, and load side. We need to improve power supply flexibility in the power supply side, to expand the capacity of the grid side, and to implement demand management and electrical energy alternative in the load side. We need to implement a variety of measures, improving the power system absorption capacity in an all-round way, promoting wind power development better and faster.



Peaking space of the power system is the difference between the maximum output and the minimum technical output. The peaking space need to meet the requirements of peak-valley load difference. When the system contains wind power, it should also meet the peak-valley difference of wind power. From the peak regulation point of view, we can draw the following rules.

The maximum load and power transmission channel capacity decide the operating capacity of the conventional units. Specifically the maximum load plus channel delivering power, minus the output of the wind power at the peak time, determines the conventional unit-operating capacity.

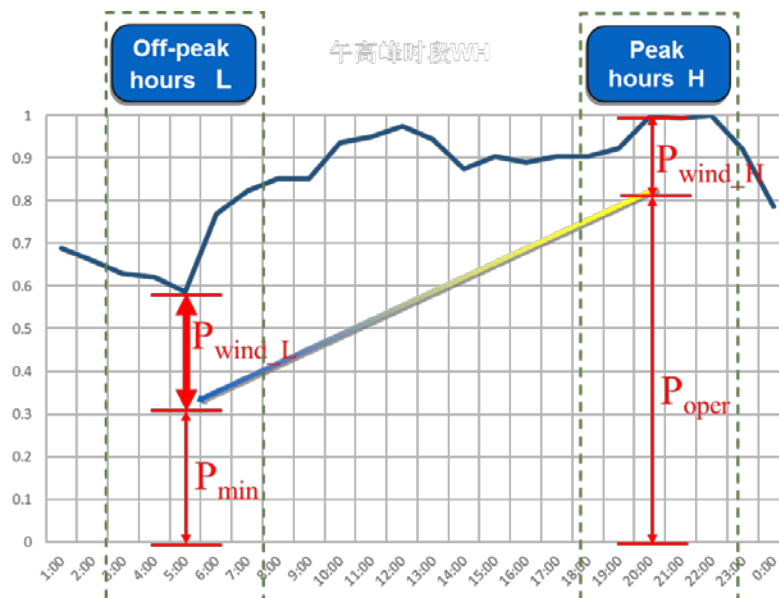
The minimum technical output of operating units decides the wind power accommodation scale. Specifically the valley load minus the minimum technical output of conventional units, determines the wind power accommodation scale.

### 3. Source-grid-load contribution

From technical perspective, the scale of wind power accommodation is governed mainly by the following factors: the capacity of operating units, the spare capacity, the maximum load, the peak-valley load, the transmission line capacity and regulating ability, and adjustable capacity of different types of units, such as heating units, nuclear power plants, hydroelectric units, thermal power, pumped storage units, captive power plant, etc.

#### 3.1. Wind power accommodation scale calculation

Figure 1 is a schematic diagram about a typical daily load curve and the corresponding wind power accommodation scale. The basic daily load curve has a noon peak, an evening peak and a valley. Noon peak usually appears at about 12:00, the evening peak appears at about 22:00 in summer and 19:00 in winter. Because in winter, the duration of sunshine is shorter than in summer, the lighting loads reach the maximum around 20:00, then the cooling loads are launched successively, so the evening peak will appear at 22:00. The difference between the two peaks is small. The valley usually appears at about 3:00~5:00.



**Figure 1.** A typical daily load curve and the corresponding wind power accommodation scale  
 Calculation of wind power accommodation scale will use the following parameters [11-14].

#### The load side:

$P_{load}^H$  : The maximum load, generally accrued in the evening.

$P_{load}^L$  : The valley load.

$\Delta P_{load}$  : The peak-valley load difference.  $\Delta P_{load} = P_{load}^H - P_{load}^L$ .

**Power grid side:**

$P_{trans}$  : Delivery power by transmission lines at peak load hours. It is usually the capacity of transmission lines.

$P_{trans}^L$  : Delivery power by transmission lines at valley load hours.

$\Delta C_{trans}$  : The peak-valley difference rate of power transmission.  $\Delta C_{trans} = (P_{trans} - P_{trans}^L) / P_{trans}$ .

**Power supply side:**

$P_{spare}$  : The spare capacity of the system.

$P_{oper}$  : Capacity of conventional operating units.

$P_{force}$  : The forced output of the units which are operating but not adjustable.

$C_{tec}$  : The minimum technical output coefficient of conventional operating units.

**Wind power side:**

$C_{wind}^H$  : Wind power usable coefficient at peak load hours.

$C_{wind}^L$  : Wind power usable coefficient at valley load hours.

$\Delta C_{wind}$  : The wind power difference between peak and valley coefficients.  $\Delta C_{wind} = C_{wind}^H - C_{wind}^L$ .

On the basis of above parameters, we can deduce the accommodation scale of wind power<sup>[15]</sup>. Assume some wind turbines already exist in the system, so the surplus peaking space at valley load hours is:

$$P_{adjust} = (P_{load}^L + P_{trans}) - [(P_{oper} - P_{force}) \times C_{tec} + P_{force} + P_{wind}^L] \quad (1)$$

If we increase the wind power capacity, the surplus peaking space at valley load hours will gradually decrease. When the space almost reduce to zero, the corresponding wind power capacity is the maximum scale.

Hypothesis  $P_{adjust} = 0$ , on account of  $P_{oper} = P_{load}^H + P_{trans} - P_{wind}^H + P_{spare}$ , and bring these two parameters into equation(1), we can come to the wind power accommodation scale:

$$S_{wind} = \frac{(P_{load}^H + P_{trans} + P_{spare} - P_{force}) \times (1 - C_{tec}) - (\Delta P_{load} + P_{trans} \times \Delta C_{trans} + P_{spare})}{C_{wind}^H \times (1 - C_{tec}) - \Delta C_{wind}} \quad (2)$$

From a technical point of view, many factors will affect the scale of wind power accommodation. The fluctuation of related technical parameters, including source, network, and load, will impact on wind power accommodation scale.

### 3.2. Source-grid-load Contribution to Wind Power accommodation scale

Through calculating partial derivative of equation (2), we can get the influence degree of source-grid-load parameters to wind power accommodation. The power supply side bringing down the minimum technical output, the grid side adding transmission channels, and the load side increasing the valley load, three measures can effectively promote wind power consumption. The influence degrees are in formulas (3)-(5).

$$\frac{\partial S_{wind}}{\partial P_{tec}} = \frac{\partial S_{wind}}{\partial C_{tec}} \times \frac{\partial C_{tec}}{\partial P_{tec}} = \frac{(-P_{trans} \times \Delta C_{trans} - P_{spare} - \Delta P_{load}) \times C_{wind}^H + (P_{load}^H + P_{trans} + P_{spare} - P_{force}) \times \Delta C_{wind}}{[C_{wind}^H \times (1 - C_{tec}) - \Delta C_{wind}]^2 \times P_{oper}} \quad (3)$$

$$\frac{\partial S_{wind}}{\partial P_{trans}} = \frac{1 - C_{tec} - \Delta C_{trans}}{C_{wind}^H \times (1 - C_{tec}) - \Delta C_{wind}} \quad (4)$$

$$\frac{\partial S_{wind}}{\partial P_{load}^L} = \frac{1}{C_{wind}^H \times (1 - C_{tec}) - \Delta C_{wind}} \quad (5)$$

Generally,  $C_{wind}^H < C_{wind}^L$ ,  $\Delta C_{wind} < 0$ , so  $C_{wind}^H \times (1 - C_{tec}) - \Delta C_{wind} > 0$ , we can estimate  $\frac{\partial S_{wind}}{\partial P_{tec}} < 0$ ,  $\frac{\partial S_{wind}}{\partial P_{load}^L} > 0$ . Therefore, the lower the minimum technical output of conventional units is, the larger the wind power accommodation scale will be. And the bigger the valley load is, the larger the wind power accommodation scale will be.

To grid side, the influence of raising the transmission capacity to wind power accommodation is indeterminate. On one hand, raising the transmission capacity can increase the consumption range of wind power, which is in favour of the wind power accommodation. On the other hand, raising the transmission capacity is equal to increasing the peak load, which will lead to increasing of operating capacity of conventional units and accompanying increasing of the minimum technical output, which is against wind power accommodation. According to formula (4), if  $C_{tec} + \Delta C_{trans} < 1$ , then

$\frac{\partial S_{wind}}{\partial P_{trans}} > 0$ . So if the transmission capacity is raised, we can reduce the peak-valley difference rate of

the transmission lines to meet  $C_{tec} + \Delta C_{trans} < 1$ , then the raised transmission lines will promote wind power accommodation.

Under normal circumstances, which can be seen from the formulas, the impact from the power grid side to wind power accommodation is less than the extent of the impact from the load side. Note that this analysis is based on the planning level.

Hypothesis  $Q_{wind} = \left| \frac{\partial S_{wind}}{\partial P_{tec}} \right| + \left| \frac{\partial S_{wind}}{\partial P_{trans}} \right| + \left| \frac{\partial S_{wind}}{\partial P_{load}^L} \right|$ , the contribution of power supply, grid and load

side to wind power accommodation, are shown in formulas (6) ~ (8).

$$Q_{tec} = \left| \frac{\partial S_{wind}}{\partial P_{tec}} \right| / Q_{wind} \quad (6)$$

$$Q_{trans} = \left| \frac{\partial S_{wind}}{\partial P_{trans}} \right| / Q_{wind} \quad (7)$$

$$Q_{load}^L = \left| \frac{\partial S_{wind}}{\partial P_{load}^L} \right| / Q_{wind} \quad (8)$$

#### 4. Examples

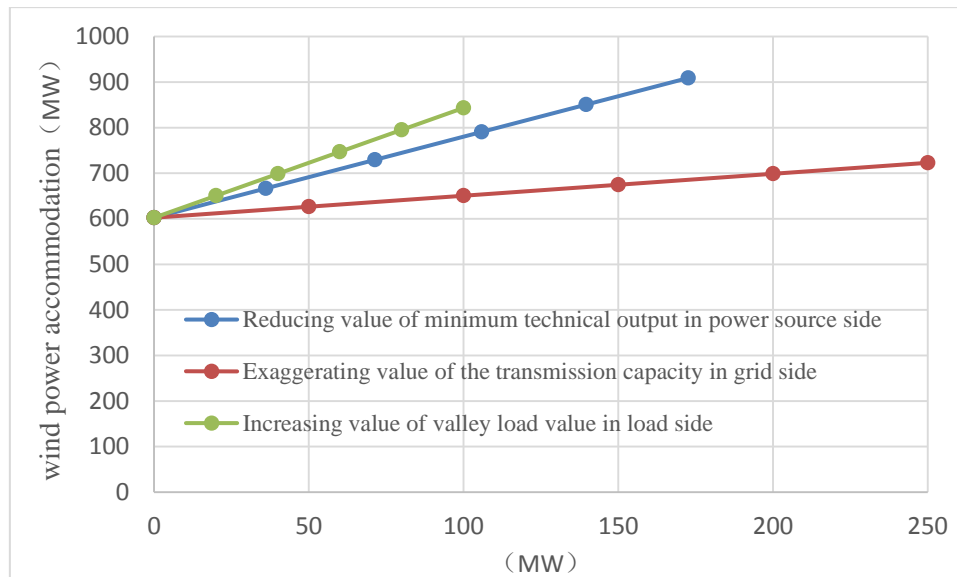
Take a typical regional power grid for example, in which the peak load is 888.9MW, and the valley load is 731.7MW. The differences ratio between peak and valley load is 17.7%. In addition, the grid has one power delivering channel, the peak transmission power is 500MW, and the valley transmission power is 350MW. The spinning reserve account for 7% of the maximum load. The force output is about 70 MW. The average minimum technical output of conventional power units is 50%. The simultaneous rate of wind power output in the peak and valley load time are respectively 0.25 and 0.53.

According to formula (2), the maximum wind power accommodation capacity is 600MW. Moreover, based on the proposed method, the contribution degrees of source-grid-load side to wind power consumption could be calculated and shown in the following table.

Table.1 Source-grid-load contribution degree to wind power accommodation

	Contribution degree to wind power accommodation
Reducing minimum technical output in power source side	43.5%
Exaggerating the transmission capacity in grid side	7.4%
Increasing valley load value in load side	49.1%

From table.1, it can be found that demand side has the maximum contribution to wind power accommodation, power supply side takes the second place, and power grid has less impact, which are also shown in figure 2.



**Figure 2.** Influence degree of source-grid-load side to wind power accommodation

Based on the three curves, the following conclusions could be figured out. If the valley load increases 100 MW, more 241MW wind power can be consumed. If the average minimum technical output ration reduces to 40%, equal to 173MW, about 307MW extra wind power will be utilized. If the capacity of the transmission line increases 250MW, the scale of wind power consumption will increase 121MW.

## 5. Conclusion

As a result, this paper has proposed that by improving the operation flexibility in power source side, enlarging the interconnected scale in power grid side and adopting demand management in demand side will guarantee the high efficient utilization of wind power. It is also important that the above mentioned three measures will play key roles in wind power consumption with different contribution degrees. Finally, the corresponding improvement and construction of three types of measures need to be based on local condition. In order to reduce the wind power curtailment, multidimensional works should be put in practice.

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