

# The Power Grid Development with Distributed Wind Plant Growth Based on Coordination Analysis

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**Abstract.** the wind plant capacity developed continuously since 2009. However, the wind plant type changed quietly, those preformed in the unit capacity increased from 1MW to 5MW, the wind farm located from onshore wind power to offshore wind power, and the large-scale distributed wind plant transformed into small-scale distributed one. Recently, the distributed wind plant was growing rapidly for policy guidance, which has a great influence on the power grid operation because of the change of the power supply layout. How to analyze the influence is an important matter to power system development. The analyzed results will decide the trends of the distributed wind plant in future. Therefore, the coordination analysis of distribute wind plant growth is crucial to those developments. In this paper, the reasonable distributed generation scale arrangement was discussed based on the difference measures.

## 1. Introduction

Due to the global climate warming become more and more crucial, the worldwide eventually factored the carbon emission into ecological environment. The percentage of fossil-fired energy decreased for the 21st century due to renewable energy explosive growth [1]. As report by IEA, In 2016, total combustible fuel plants accounted for 60.8% of total OECD (Organization for Economic Co-operation and Development) gross electricity production (made up of 57.8% from fossil-fuel-fired plants and 3.2% from biofuels, waste, etc. plants), nuclear plants 18.0%, hydroelectric plants 12.9%, and geothermal, solar, wind, tide and other plants at 8.2%. One reason why production fell was lower demand of China in 2016. Those decreased around 320 million tons. The most important factor of why demand fell in China was lower consumption of electricity generation, though China still uses half the world's coal. Alongside the decrease of fossil-fired generation, 2016 also saw the continued increase of renewable generation across the OECD and in countries like China. In the OECD, renewables generation grew by 3.8% to account for 23.8% of all electricity generated, its highest share to date. The growth was largely driven by wind and solar WIND, which saw annual average growth rates of 21% and 43% between 2000 and 2016. The share of non-hydro renewable electricity in total OECD electricity production increased from 1.8% in 1990 to 10.9% in 2016. These technologies grew much faster than any other power source between 1990 and 2016. In 2017, the wind plant capacity was 539.5GW in the world. There was 188.4GW in China. In 2017, 19.7GW wind plant was installed. According to NEAC (National Energy Administration of China)'s distributed wind power planning, the distributed wind power was defined as the plant must access to grid below 35 kV, but the generated power is not allowed to boost into the higher voltage grid. And those would be supported significantly by simplifying review and approval procedures and allowing market transaction in local



power grid [2]. Moreover, several provinces had published their distributed wind power development planning, which is shown in Table.1. 20.6 GW wind plant has been arranged from 2018 to 2020.

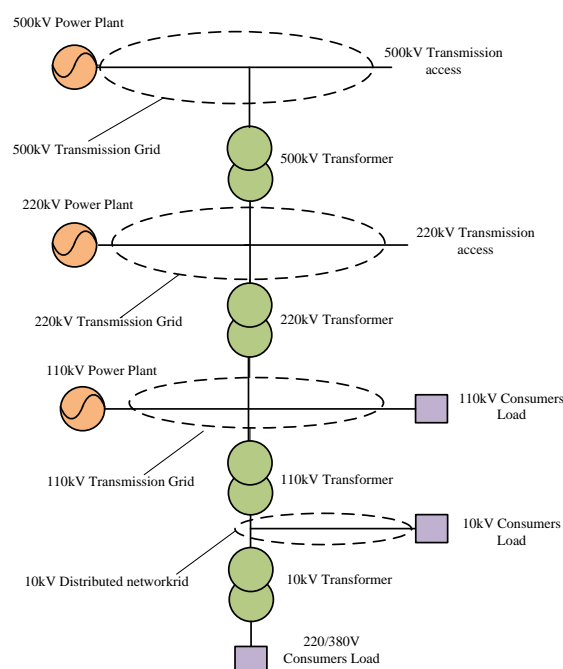
**Table 1.** Planning capacity of distributed wind plant from 2018 to 2020

Province	Planning capacity (GW)
Hebei	4.3
Shanxi	1
Henan	2.1
Guangdong	0.45
Shanxi	1.25
Guangxi	5
Anhui	4.5
Guizhou	2
Total*	20.6

\* Because other provinces haven't published the development planning, the whole capacity cannot census completely; the total in table represents the amount of 8 provinces.

The sharply development of distributed wind plant produced a profound influence to power grid, which is not same as the centralized wind generation. Since the centralized one construction and operation, the power interconnection systems for above 110kV grade had been design details, and the impact of power station to power system had been analyzed clearly. But the distributed wind plant was connected into 35kV or 10kV, the power interconnection system was oversimplified, the impact of distributed electricity generation does not discuss specialized, this question would be analyzed based on simulation calculation.

## 2. Power grid operation mode

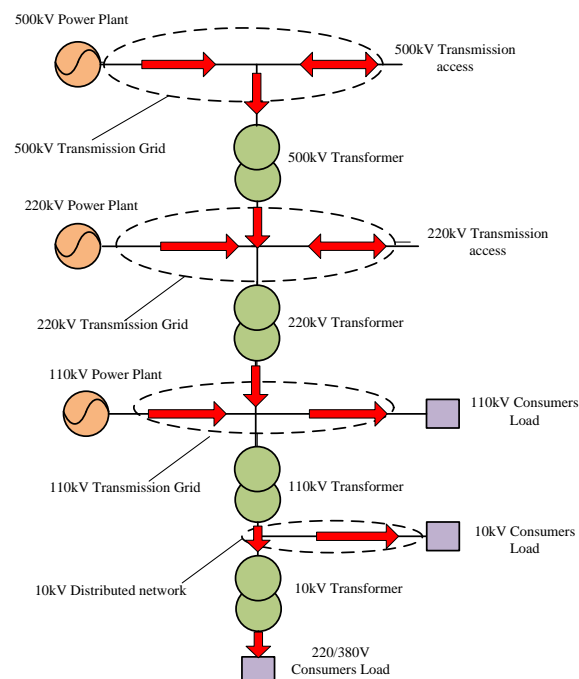


**Figure 1.** The hierarchical structure of 500/220/110/10/0.38 (0.22) kV series power grid.

To analyse the impact of the distributed wind plant, the normal operation mode should be analyzed firstly. The power transmission structure had been analysed to reflect the transferring characteristics from power plant to consumer [3]-[4]. In China, the 220kV power grid was the backbone network in 1981, and then, 500kV power grid were established as main network in following 30 years, 500 kV power grid covered provinces or regions. Nowadays, the 1000kV UHV power grid and  $\pm 800$ kV UHVDC project were successes, 7 UHV projects and 7 UHVDC projects were put into operation, and 2 UHV projects and 5 UHVDC projects were under construction. Synchronous UHV power grid will cover the East, North and Middle China in 2020 [5]-[6]. Therefore, the power grid is made up of different voltage grades. The hierarchical structure for 500/220/110/35/10 kV power grid was described as Figure.1.

### 2.1. Traditional power grid operation

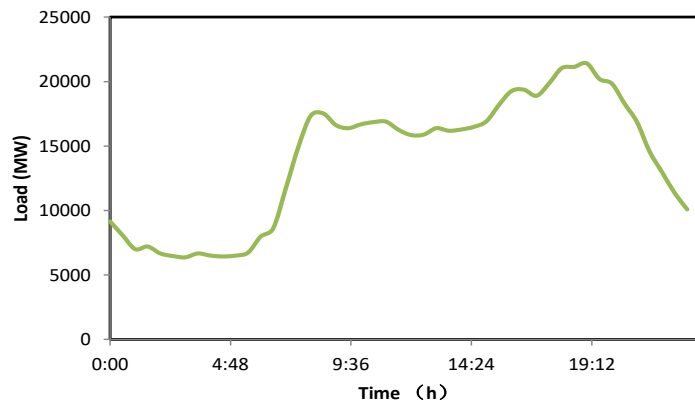
The traditional electric energy was thermal power and hydropower in China. The installed capacity of each generation exceeds 20MW almost, which coupled with high voltage level. Generally, the interconnect grade was above 220kV. However, the loads were mostly connected to a low voltage grade, such as 35kV, 10kV or lower one. In the circumstances, the power flow usually transfers from high voltage to low voltage at the hierarchical structure. The large power plants generate electrical energy, which are transmitted to high voltage grade. A part of the electrical energy is transmitted to load center of power system, and then that is transferred to low voltage grade by transformers. Another part of electrical energy is transmitted to other power grid by transmission access. Correspondingly, the electrical energy might be transmitted into this power grid from other one. The power flow in hierarchical structure power grid is shown in Figure.2. The lower voltage grades accept the electricity purely throughout the year.



**Figure 2.** The traditional power flow in hierarchical structure power grid.

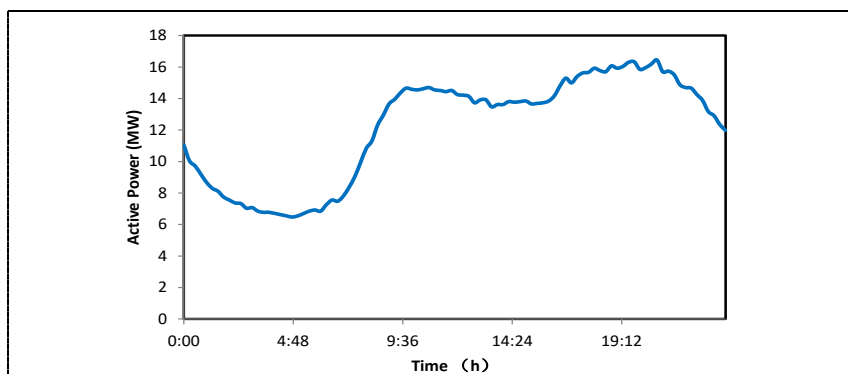
### 2.2. Power system load characteristics

The most of load was connected in lower voltage grade, such as 110kV, 10kV and 0.22 kV. The daily load curve of the province A was collected on primary equipment, which is shown as Figure 3. The load curves of 110kV transformer substations have two load peaks in a day, one peak appears at 8:45, and another peak appears at 18:45. The peak load of province A was 20540 MW.

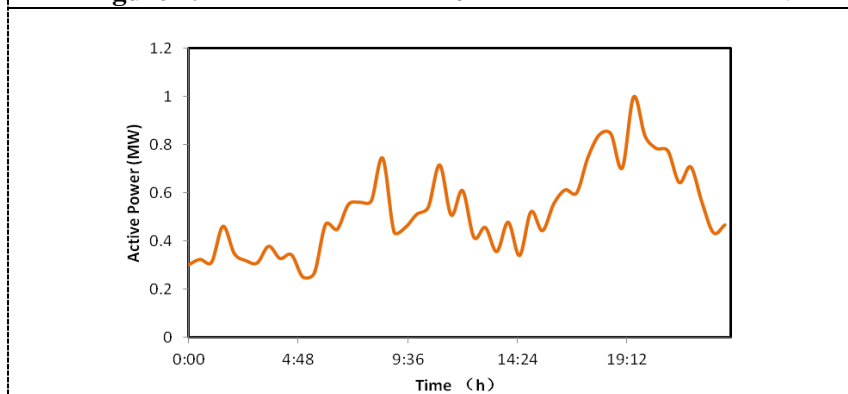


**Figure 3.** The load curves of Provincial A grid.

The typical daily load curve of different voltage grade is shown in Figure 4 – Figure 5, which collected on transformer or transmission line. From Figure 4, the load a curve of 110kV transformer substations is be similar to provincial grid one. From Figure 5, the load curve of 10kV transformer substations fluctuated persistently.



**Figure 4.** the load curves of 110kV transformer substations.

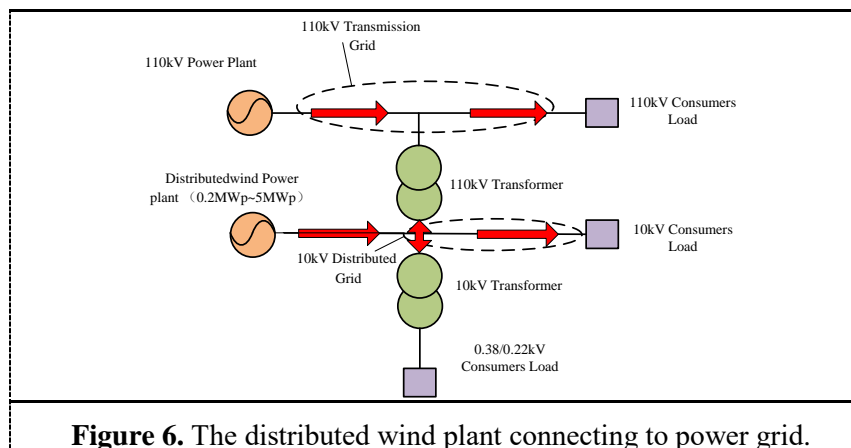


**Figure 5.** The load curve of 10kV transformer substations.

### 3. Distributed wind plant

#### 3.1. Interconnection of the distributed wind power generation

What level grid to which the distributed wind plant connected is depended on the scale of installed capacity and the native power grid structure.

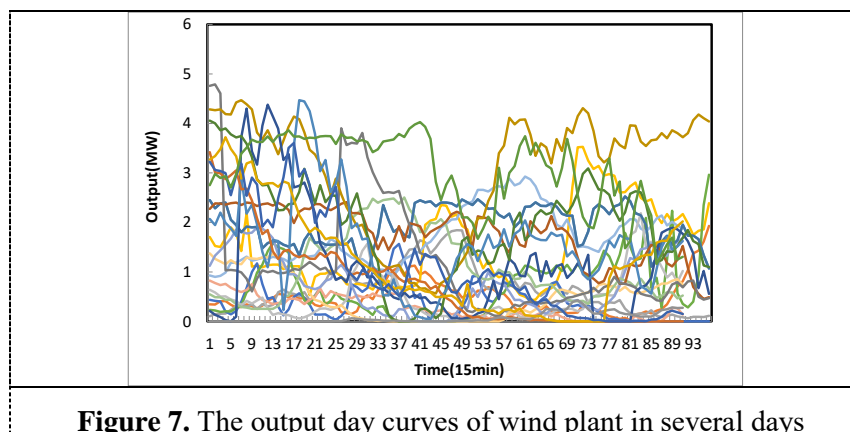


**Figure 6.** The distributed wind plant connecting to power grid.

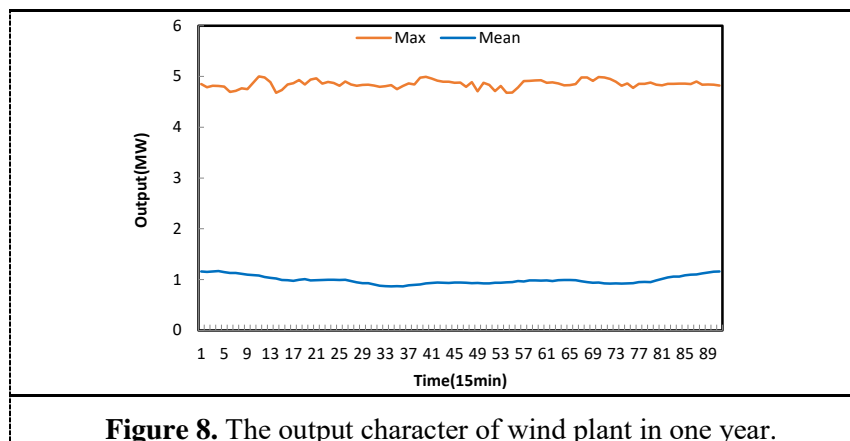
Generally speaking, the power plant which installed capacity exceeded 0.2 MWp is proposed to connect into power grid with 10 kV. The power station whose installed capacity exceeded 5 MWp is proposed to connect into power grid with 110 kV. Therefore, there are three connection modes, and those are shown in Figure 6.

### 3.2. Output curves of wind plant generation

The output power of wind plant was affected by many influencing factors. The wind speed was the most critical factor to output power because it is the energy source of wind generation. The output day curves of a 5 MW plant station were shown in Figure 7, the generated power fluctuated greatly in a day. In order to describe the output character of wind power, the raw data of wind plant output should be deal with though statistical methods. In this way, the typical character of wind plant was shown in Figure.8, the max represented the maximum output value at 15 minutes in whole year; the mean represented the average output.in the year. The max output power was able to cover any condition in a year, although the output power curves at different wind speed condition had great variability. Therefore, the max output power characteristics were used to analyze the impact to power grid.



**Figure 7.** The output day curves of wind plant in several days



**Figure 8.** The output character of wind plant in one year.

#### 4. Impact analysis

In Figure 6, the interconnect position of wind plant is described. With the distributed wind plant development, the output power from wind generation increase correspondingly, and the power flow in distributed power grid has changed for new power pumped into. At the same time, the load characteristics are variation for power generated at daytime. Furthermore, the coordination evaluation about the distribution grid is needed to be adjusted. In this section, the impact of distributed wind generation is analyzed as following.

##### 4.1. Load flow analysis

With the wind electricity generation connected into power grid, the output power is absorbed by local grid firstly. Meanwhile, the electricity supplies from higher voltage grid decreased, which are counteracted local load by output power of wind plant. The load power of transformer which the lower voltage system contain distributed wind station is equal to actual load subtract the output, as in

$$L_T(t) = L_A(t) - P_s(t) \quad (1)$$

In which,  $L_T$  is load power of transformer which the lower voltage system contained distributed wind station,  $L_A$  is actual load of the system,  $P_s$  is the max output of the distributed wind plant,  $t$  is the time in a day.

For the power supply area connected with distributed wind plant, the power of wind plant is forbidden to up-step to high voltage since the definition proposed by NEAC, therefore, the coordination analysis have to obey those. Generally speaking, the distributed wind plant installed capacity should match to the local load level synchronously. For achieve the target, the distributed wind plant is required developing in order. So that, several ways can be adopted to arrange more capacity wind plant in some area. Frist, the storage equipment which installed in distributed voltage ranking is main measure to improve the capacity by move the electricity from peak to the valley, however, this ways request to build energy storage power stations and .need investment. Second, it is possible to raise the lowest load in a distributed grid by enlarging the supply district. Similarly, this measure requires constructing the new project to connect other grids. But there was spare line between two supply-areas in modern power grid commonly, and the cost will be declined distinctly.

##### 4.2. Experimental analysis

A distributed wind farm was arranged to in Zhuzhou city in Hunan Province. The area of wind farm with average wind speed of 5.6m/s is about 30 km<sup>2</sup>, and the wind energy content arrived 8.9MW, the whole distributed wind generation was planned to develop by 2020. However, the maximum and minimum load of the 110kV transformer which is used to access to power was 8.3MW and 4.4MW respectively in 2017. To 2020, those were forecasted to 9.3MW and 5.4MW according to a particular demand analysis. The acceptance of wind power was 5.4MW without any measures. Therefore, the 8MW wind generated power was impossible to develop for the distributed wind plant defined.

In order to accomplish the target of distributed wind capacity development, the cost of two measures mentioned in above section was analyzed through calculation; moreover, the combinatorial cost was optimized based on adopting two measures. The storage equipment adapt to battery technology that

the average price is 16 RMB/W, the cost of enlarging supply area depended on the peripheral network conditions, the connect principles included security, impedance matching and priority to construct project with lower cost. And the cost of the rest of wind power was shown in table. 2, which represented that additional investment would be 41million RMB to increase the wind capacity from 5.4MW to 8.9MW, the supererogatory project included 1MW capacity storage equipment and 2.5MW capacity from enlarging supply area.

**Table 2.** The cost of different arranged wind capacity with different measures by 2020

Capacity	Cost-optimized combination(million RMB)	Installing storage equipment(million RMB)	Enlarging supply area(million RMB)
0.5MW	1.5	8.0	1.5
1MW	5.40	16.0	5.4
1.5MW	14.0	24.0	12.0
2MW	18.0	32.0	18.0
2.5MW	25.0	40.0	25.0
3MW	33.0*	48.0	34.0
3.5MW	41.0*	56.0	48.0

## 5. Discussions

The operation and flow direction of distribution network was effect seriously by the distributed wind plant [7]. The network structure become complexity because of the control of communication facilities increased in some sense. The distribution network changes to active electric network with the distributed generation appearing [8]. The native load is supplied by local wind plant handy [9]-[10]. Those reduced the transmission demand from higher voltage grade to lower one. That will reduce the loss in power transmission. Moreover, the power flow in midday might change the direction top. As a result, the construction and investment of distribution network should take into account the transmission demand of network, which is not allowed power boosting. The traditional invest experience which is fully meet the demand of local might be not applicable. The investment about satisfy power supply should be cautious in distributed Wind plant fast-growing regions, the invest direction must pay close attention to absorption and delivery of the wind power.

The most important impact of distributed wind generation to power system is the load charities. A certain scale wind generation capacity will decrease that difference peak valley, which is good for power system operation. However, the capacity of wind generation keeps growing, the load character become worse, and the difference peak valley increase directly because of the randomly output character. The constructed scale of wind generation in a system should be planned based on valley load and some measures contained storage equipment and enlarging supply area, the cost can be adopted to meet the excess wind power capacity. It is noteworthy that the coordination among power grid. To reduce the transmission loss, the wind generations could not concentrate on a grid, which designed as distributed system. Those avoid the wind power transmits far away from wind generations concentration area to load area. The investment and planning of power station should arrange balanced in different area.

## 6. Conclusion

The power grid operation mode was proposed to analyze influence of the fast-grown distributed wind plant. The output character of wind electricity generation and load curve was investigated. The measures included the storage technology and enlarging supply area to increase installed wind capacity were studied, and the cost of those was analyzed based on project investment. The reasonable combination scheme was obtained according to the optimized model. Those could provide a reference to how much cost under different additional wind capacity.

## 7. References



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