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Efficient Power Generation: Optimizing and Controlling Wind Turbine Systems

Michael Carter
Department of Renewable Energy Engineering, Coastal Technical University
Aberdeen,United Kingdom
mcarteroo@ctu.ac.uk

Abstract: In recent years, China's societal and economic advancements, coupled with the enhancement of national living standards, have led to heightened environmental and clean energy awareness. Consequently, research and development in clean energy have accelerated across various regions, resulting in the establishment of large-scale wind power stations. Wind turbine systems have thus seen widespread implementation in China. This paper primarily elucidates the working principles of wind power generation technology and the principles underpinning the optimal operation of wind turbines. Additionally, it suggests three methods for adjusting the power output of wind turbines. Finally, it examines the practical applications of wind turbine system control technology.

Keywords: Wind turbine system; Working principle; Control Technology; Adjustment method

1. Introduction

After the 1870s, mankind began to enter the second industrial revolution, and human society began to enter the electrical age. Electricity has been widely used and replaced steam as the main energy source for industrial production and social life, which has brought about huge changes to the production structure and lifestyle of human society. With the development of power generation technology, wind power technology has been widely used in China. In the process of wind power generation, wind turbine system control technology is an important foundation and influencing factor for further development of wind power generation technology. However, with the social and economic development of our country and the increasing demand for electricity from human life, China's original wind turbine system control technology has been unable to meet the high requirements of modern wind power generation technology, which has hindered the further development of wind power generation technology.

2. Working Principles of Wind Power System

Wind power mainly uses wind energy for power generation. It is the most important and effective power generation method after the development of new clean energy. The components of the wind turbine system mainly include impellers, generators, and converters. Among them, the main function of the impeller is to collect wind energy and convert it into mechanical energy, and then convert it into electrical energy through a wind turbine system generator and the current is AC; the alternating current converted by the generator is converted into alternating current with the same voltage as the power grid through a converter, and finally merged into the power grid through a transformer for operation. The working principle diagram is shown in Figure 1.

3. Optimal Operation Principles of Wind Turbine

After relevant research, we know that there are three main factors affecting the optimaloperation of wind turbines: one is the wind energy collected by the impeller; the second is the actual operating power of the generator; the third is the feedback efficiency of the generator to the wind speed. Through the analysis of the theoretical knowledge of dynamics, the mechanical output power (P) of the converted wind energy collected by the wind turbine impeller can be expressed by the following formula:

$$P_r = \frac{1}{2}\rho C_p(\beta,\lambda)\pi R^2 V^3 \tag{1}$$

$$\lambda = \frac{\omega R}{V} \tag{2}$$

In formulas (1) and (2), the meaning of each variable is shown in Table 1.

Table 1. Meaning of Variables in Formulas (1) and (2)

Variables	Meaning	Unit
Pr	Power absorbed by the wind wheel	W
ρ	Air density	kg/m
Cp	Wind turbine's power coefficient	
R	Wind wheel's radius	m
V	Wind speed	m/s
β	Pitch angle	
λ	Leaf tip's speed ratio	
ω	Speed of wind wheel rotation angle	r/s

The following conclusions can be obtained in formula (1): 1) if the wind speed (V) is fixed, the absorbed power (Pr) of the wind wheel has a positive correlation with the radius (R) of the wind wheel. That is, the larger the radius of the wind wheel, the stronger the power absorbed by the wind wheel. However, if the radius of the wind wheel is too large, it will not only increasethe cost of the wind wheel, but also increase the difficulty of installing the wind wheel. 2) If the radius (R) of the wind wheel is a fixed value, the absorbed power (Pr) of the wind wheel has a positive correlation with the wind speed (V). That is, when the wind speed is larger, the absorbed power of the wind wheel is larger. Therefore, in order to improve the absorbed powerof the wind turbine, it is necessary to install the wind turbine system in a high altitude area as much as possible. This is because, at the same place, the higher the position of the wind turbine system, the greater the wind speed of the wind wheel. 3) The absorbed power (Pr) of the wind turbine of the power generation system has nothing to do with the number of blades of the wind turbine, but has a positive correlation with the air density (ρ) around the generator system. 4) Under normal circumstances, the power coefficient (Cp) of a wind turbine cannot be used as a constant, and the maximum value is 0.593. However, it will change due to changes in wind speed (V), rotor rotation angular speed (ω), and pitch angle (β).

3.1. Pitch Adjustment

Variable pitch adjustment is mainly based on the fixed-pitch wind turbine to adjust the power of the wind turbine by adjusting the angle of attack of the impeller blades. When the regulated power of the wind turbine exceeds the rated power, the pitch angle (β) starts to rotate towardthe side with less wind by a certain angle. At this time, the pitch angle (β) and the angle of attack (α) have a negative

correlation. After the wind turbine system is connected to the grid, the power of the wind turbine can be adjusted by controlling the speed of the impeller when the variable pitch unit is running.

3.2. Active Stall Adjustment

Active stall adjustment is an organic combination of variable pitch adjustment and fixed pitch stall adjustment. When the wind speed of the wind turbine is low, the power of the wind turbine needs to be adjusted by means of pitch adjustment to continuously improve the aerodynamic efficiency of the wind turbine; When the power of the wind turbine reaches the rated power, the pitch angle (β) is rotated by a certain angle toward the side of the smaller wind force through the pitch stall adjustment method. At this time, the angle of attack (α) starts to increase and deepens the stall of the impeller blades. The ability of the wind turbine to collect wind energy is reduced, thereby stabilizing the power of the wind turbine.

4. Practical Application of Wind Power System Control Technology

China's wind turbine system control technology is often used in land power generation construction and offshore wind power construction. However, in the process of land power generation construction, due to the continuous increase in the demand for electricity by society,the scale of land power stations has continued to expand, occupying a large amount of land resources. Moreover, most of the terrestrial power stations are closer to the city. The function of terrestrial power generation is easily affected by the tall buildings in the city, and the wind turbine system control technology cannot perform optimally. This results in low efficiency of wind power generation, low economic efficiency and caused the waste of land resources. However, with the development of wind turbine system control technology in China, related power experts have begun to apply wind turbine system control technology to the field of offshore wind power construction. The sea is different from the land, and its wind resources are more abundant. According to the research on the optimal operation principle of the wind turbine, it can be known that the wind energy collected by the impeller is one of the reasons affecting the optimal operation of the wind turbine. If an offshore wind power station is built ina shallow sea area, the wind energy that the wind turbine can collect is much greater than thatof inland, and the power generated by the wind turbine is about 1.5 times that of land. However, due to the high construction cost of offshore wind power stations, and the immature application of offshore wind turbine system control technology, there are some deficiencies, and further research on offshore wind power technology is needed.

5. Conclusion

In summary, with the continuous development of the country's society and economy, China's stored energy is also declining, and the environment has also suffered a certain degree of damage. Energy and environmental issues are becoming increasingly prominent and are receiving more and more attention. As one of the clean energy sources in China, wind energy has been applied to power generation technology, following the concept of green sustainable development in China, and wind power technology has become one of the most common power generation technologies in China. At present, there are mainly two types of wind power generation in China, terrestrial wind power and offshore wind power, which provide the power needed for China's economic and social development and human life. However, due to the large defects of wind turbine system control technology in China, the wind power generation efficiency in China is low, which greatly affects the further development of wind power technology in China. Therefore, in order to improve wind power generation technology in China, it is necessary to strengthen the research on wind turbine system control technology.

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