Research Progress on Energy Conversion Efficiency of Wind Turbine

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Abstract. Wind energy occupies an overwhelming advantage in global renewable energy. At present, as a renewable and pollution-free natural energy, wind energy is being valued by people and is expected to become the main source of electricity in Europe, Asia, and North America in the future. A wind turbine is electric power equipment that converts wind energy into mechanical power, which drives the rotor to rotate and finally outputs alternating current. The working principle of the wind generator is that the wind wheel rotates under the action of the wind and converts the kinetic energy of the wind into the mechanical energy of the wind wheel shaft. The generator rotates under the drive of the wind wheel shaft to generate electricity. This paper will focus on the structure of the active wind system, including the direction of wind direction detector, impeller controller, generator blade structure, location of different areas, and the prediction of wind speed by using artificial intelligence technology as well as the selection of batteries and the optimization of grid connection technology. Through the above aspects put forward a variety of ways to improve efficiency.

Keywords: wind energy, electricity, wind turbine.

1. Introduction

With the increasingly prominent environmental protection problems, energy supply is increasingly tight, wind power generation as a clean renewable energy power generation has been more and more welcome and attention of the world's people, at the same time, wind power is one of the most mature new energy power generation technology and the most large-scale development conditions of power generation. Therefore, in recent years, China's wind power industry has also been rapidly developed. Due to China's vast territory, long coastline, abundant wind resources, and complex terrain conditions, so the distribution of wind energy resources is not uniform. According to the Calculation of more than 900 weather stations by the Chinese Academy of Meteorological Sciences, the theoretical reserves of land wind energy resources are 3.226 billion kW, and the exploitable reserves of wind energy resources are 253 million kW, mainly concentrated in the northern regions, including Inner Mongolia, Gansu, Xinjiang, Heilongjiang, Jilin, Liaoning, Qinghai, Tibet, and Hebei provinces and regions. The coastal and island wind energy resources are rich, with an exploitable capacity of about 1 billion kW, mainly distributed in Liaoning, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, and Fujian, Guangdong, Guangxi, and Hainan provinces, cities, and districts. But the northern provinces and regions, due to flat terrain, and convenient transportation, so conducive to the construction of large wind power plants, such as the Dabancheng wind power plant in Xinjiang and Inner Mongolia Huiteng Xile wind power plant, etc.

But now, the development of wind power is still faced with these problems that need to be solved, the wind power industry lacks scientific planning, even if the wind power industry in our country is developing rapidly, but because of the lack of data due to the industry as a whole planning ambiguous problem still is very outstanding, thus appeared a patchwork of local governments and enterprises, the phenomenon of blind production. The second point is the problem of the wind power grid, wind

power grid the key problems include the forecast analysis tools, the use of the stability of the power transmission and transmission facilities construction problems, and wind power operation mainly depends on the size of the wind speed, which increases the instability and intermittent of wind, the wind not controllable will cause certain impact to wind power system security, In addition, the main accumulation area of wind energy is far away from the main consumption area, and there is a real demand for long-distance transmission, which poses a more severe challenge to wind power technology.

In this article, it will focus on the structure of an active wind system, including the direction of the wind direction detector in the system to the impeller controller, and the energy conversion efficiency and puts forward several feasible methods including the improvement of the blade structure of the generator and the location selection problem for a different region, as well as the use of artificial intelligence technology to predict and calculate the relevant data such as wind speed. Finally, the selection of battery and the optimization of grid connection technology, which is our proposed for wind power generation technology to improve the efficiency of several different methods.

2. Active upwind system and wind direction and speed measurement

2.1. Structural design of the active upwind system

The wind direction indicator includes A wind direction detector to obtain the wind direction information around the impeller; an impeller controller to adjust the angle of the impeller rotating surface; A processor connected with a wind direction detector and an impeller controller; The impeller controller uses the driving signal to adjust the rotating surface of the impeller to be perpendicular to the current real-time detected wind direction [1].

The wind direction detector is used to monitor the wind direction and other information in real-time, and transmit the real-time monitored information to the processor. The processor further controls the impeller controller to adjust the direction of the whole impeller to make it perpendicular to the current wind direction, to improve the utilization rate of large generators for wind energy [2].

As shown in Figure 1, a wind direction detector can be used as a wind vane. At the same time, according to the research results of scientists on this wind direction monitor, the wind direction is converted into an electronic signal and sent to the signal processing module, the wind vane is collected and filtered and output to the analog-to-digital converter, and the wind vane converts the wind direction analog signal into a digital signal by the analog-to-digital converter [3]. Then it is transmitted to the processor, which receives the wind direction information, processes it, determines the wind direction, and sends the stepping motor pulse width modulation (i.e. drive signal) [4]. When the stepping motor receives the trigger signal, it will adjust the driving signal of the angle difference and direction of the impeller according to the needs of the system, and use the wind direction and other information to adjust the perpendicularity of the impeller to the wind direction.

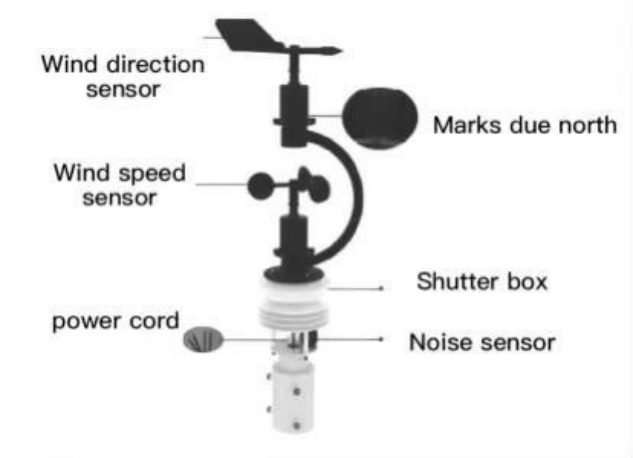


Figure 1. Wind direction detector.

As shown in Figure 2, with the access of a large number of various terminals, the current data security protection measures are difficult to effectively protect the data and data interaction process of wind turbine generators [5-6]. Now it is necessary to monitor and access control the behavior of various types of terminals, and timely and accurately realize the monitoring and identification of abnormal network access behavior such as counterfeit terminal access [7-8].

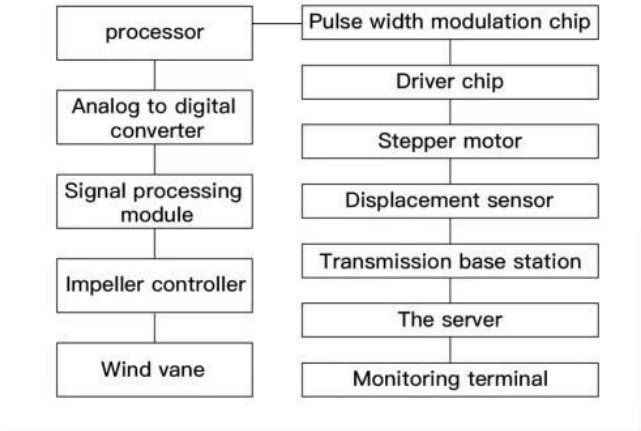


Figure 2. The hardware structure design of wind energy tracking control system.

The monitoring terminal is a storage device for video recorders and video recorder signals. A large amount of monitoring data is generated in the monitoring process. These data need to be collected, transmitted, stored, analyzed, and displayed in real-time [7]. As the Figure 3 shows:

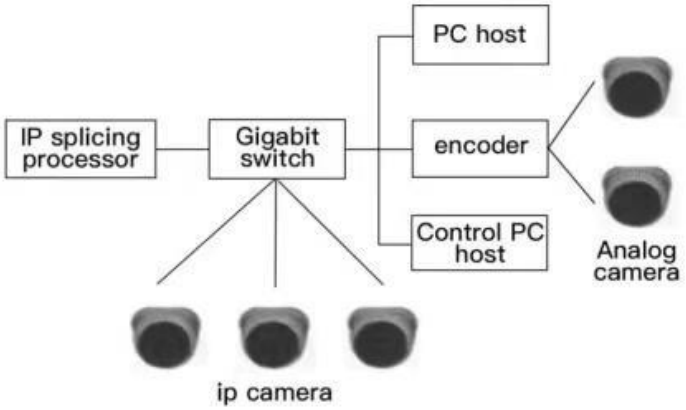


Figure 3. The monitoring terminal [1].

According to the existing research, scientists use the gradient estimation method to design the optimal torque compensator to compensate for the given torque value. According to the principle of aerodynamics, the mechanical energy F and mechanical torque Tm captured by the wind turbine of the wind power generation system can be expressed as:

$$F=\frac{1}{2}\pi\rho R^2 C_p(\alpha,\beta) \tag{1}$$

$$F=\frac{1}{2}\pi\rho R^3 \frac{\lambda_F(\alpha,\ \beta)}{\beta}V^2 \tag{2}$$

$$\beta=\frac{\omega_r R}{V} \tag{3}$$

In the above formula, ρ represents the air density; R represents the wind turbine radius of the wind power generation system; V represents the wind speed of the wind power generation system, C_p represents the power input by the wind into the wind turbine surface, represents the actual speed of the wind turbine; λ_F represents the utilization coefficient of wind energy; α Indicates the

pitch angle; β Represents the tip speed ratio. The gradient function can be constructed according to the above formula:

$$f(\omega_r) = \frac{dF(\omega_r)}{d\omega_r} \tag{4}$$

According to the wind energy tracking system based on gradient estimation explored by scientists, the rationality of this active upwind system has been verified by simulation experiments:

Table 1. Wind power generator.

Initial Wind Speed	1.6 m/s	Rated Power	1000 W
Rated Wind Speed	6 m/s	Maximum Power	1500 W
Safety Wind Speed	30 m/s	Output Voltage	220 V
Wind Turbine Radius	1.5 m	Rated Speed	300 rpm
Generator Efficiency	Greater than 75 %	Noise	Less than 60 dB
Stator Equivalent Resistance	0.85	Stator Winding Inductance	0.005
Friction Coefficient	0	Moment of Inertia	0.0008

The wind speed of the simulation experiment is within 2 s from the beginning, and the wind speed changes from 3 m/s to 10 m/s, exceeding the rated wind speed; After the 2nd s, the wind speed is stable at 10 m/s, and the wind speed curve is shown in Figure 4.

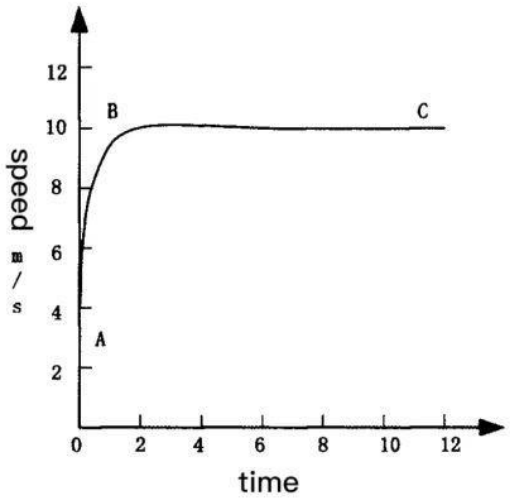


Figure 4. Wind speed curve.

It can be seen from Figure 4 that the wind speed at point a is the minimum wind speed, which is 3 M/s. at this time, the wind power generation system has just run; The wind speed at point B is 10 m/s, reaching the maximum wind speed; The wind speed at point C is 10 m/s, reaching a stable state.

2.2. Wind speed and direction measurement with ultrasonic sensor

There are many methods to suppress strong noise. Among them, array signal processing technology adapts a sensor array to receive signals, which can effectively suppress noise interference in the complex environment [5]. Scientists propose a wind speed and direction measurement method based on an ultrasonic sensor array and feature space (ESB) beamforming algorithm. The algorithm has a fast convergence speed and strong robustness. It is suitable for the measurement of wind direction and wind speed in complex scenes [6]. Figure 5 is the five-element arc superwave sensor array structure.

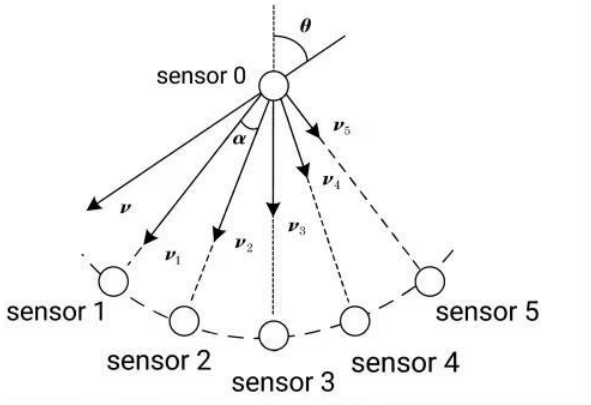


Figure 5. Five-element arc superwave sensor array structure [6].

As shown in Figures 6 and 7, the array structure is composed of one transmitting array element and five receiving array elements. The ultrasonic sensor 0 sends signals and the ultrasonic ratio sensor 1~5 receives signals to form the array model. Ultrasonic sensors 1~5 are evenly placed on the arc surface with sensor 0 as the center and radius r, and the included angle of adjacent ultrasonic receiving array elements is α. When there is no wind, the time required for transmitting an ultrasonic signal to spread to each ultrasonic receiving array element is equal. In the case of wind, the time required for transmitting an ultrasonic signal to each ultrasonic receiving array element is different, and it is different from the wind speed V and wind direction angle θ of.

According to the experimental results of wind speed and wind direction measurement of ESB beamforming algorithm by scientists at present, when the wind direction and wind speed mode change, the proposed scheme can accurately estimate the wind direction and wind speed with less error. The wind speed and wind direction measurement based on the ESB beamforming algorithm can realize the effective measurement of all-round wind direction and wind speed [5].

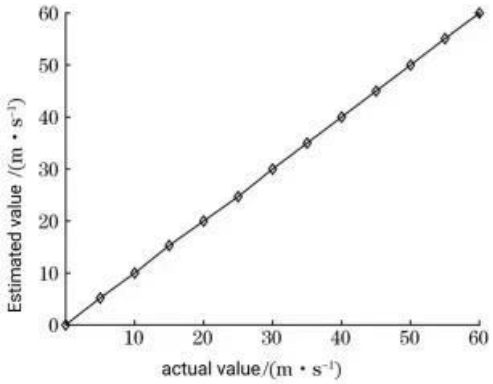


Figure 6. Estimation results when wind speed changes.

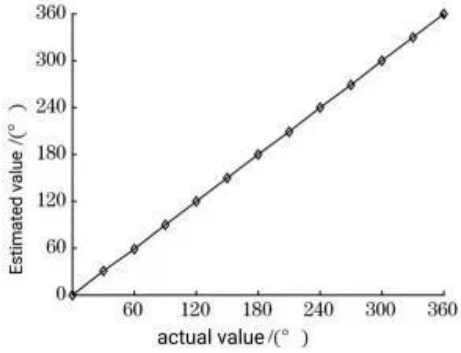


Figure 7. Estimation results when the wind direction changes.

2.3. Summary of wind direction and wind speed measurement

The gradient-based active windward system can track the wind direction in real-time, improve the windward effect of the impeller and improve the wind energy utilization of the wind turbine. Scientists are constantly improving and developing the existing active windward system. The EBS beamforming algorithm for relatively accurate measurement of wind speed and direction mentioned in this paper is reviewed. Due to its unique noise suppression ability, fast convergence speed, and strong robustness, it is suitable for various complex scenes. The two technologies can be combined to improve the reliability of the active windward system.3.

3. Research on energy conversion of wind turbine

3.1 Basic structure

The principle of the wind turbine is to convert wind energy into mechanical energy. Wind turbine usually consists of the wind turbine blade, low-speed shaft, high-speed shaft, anemometer, tower, generator, and hydraulic system. Among them, the wind wheel is a device that converts wind energy into a machine, which can change the direction of the wind wheel according to the change of wind direction to maximize the use of wind energy. The tower is the support connecting and supporting the wind turbine and generator, and its height depends on the surrounding terrain and the size of the wind turbine to ensure the regular operation of the wind turbine [8]. From Betz law, we know that there is a limit to the maximum utilization of wind energy, and the coefficient of this limit is called the Bates limit. The value of this limit is 0.593. At present, the Institute can make the utilization rate of wind energy closer to this figure.

3.2 Influencing factors of wind energy conversion

There are many factors affecting the wind energy conversion rate. The lift generated by the air passing through the blade airfoil will directly affect the wind energy conversion efficiency. According to the structure and bearing capacity of the wind turbine, the installation of blade tip or blade root extension and appropriate extension of blade length can also significantly improve the power generation capacity of the wind turbine [9]. However, among many blade parameters, the airfoil is the most important. The selection of an airfoil model is essential to the efficiency of wind turbines. The airfoil selection should try to make the lift drag ratio close to the maximum value so that the lift drag ratio curve is affected by the number of blades or tip speed ratio λ The more minor the impact, to ensure the maximization of blade efficiency [10]. In the late 1930s, the United States did systematic scientific research on airfoils and proposed the famous NACA four-digit airfoil family and five-digit airfoil family. From the number of the four-digit airfoil, we can directly see some characteristic geometric parameters of airfoil: camber, maximum camber position, and thickness [11]. This systematic research has laid a foundation for the later research of wind turbine blades.

3.3 Wind turbine blade structure and cost

Modern small wind turbine blades are mostly solid structures, while large wind turbine blades adopt the structural form of “section steel main beam + skin shell + filler” [12]. On the theoretical basis of aerodynamics and theoretical mechanics, we pursue the minimization of blade weight under the same conditions, further seek the maximization of wide blade area, and enhance the wind catching ability of blades, to improve the utilization efficiency of wind energy. The typical materials of wind turbine blades worldwide include glass fiber reinforced plastic (GFRP), carbon fiber reinforced plastic (CFRP), wood and cloth skin materials, etc. The tensile modulus of CFRP is 2 ~ 3 times that of GFRP. Large blades reinforced with CF can give full play to its high elasticity and lightweight advantages. However, whether the large amount of CFRP can be used on fan blades depends on the price of CF. The performance of CFRP is much better than that of GFRP, and no matter whether the blade or the whole wind turbine is undoubtedly lighter, the price is also higher. Therefore, an in-depth

research is being carried out on the aspects of raw materials, process technology, and quality control to reduce the cost of CFRP. Therefore, the hardware optimization of fan power generation capacity considers the feasibility of the scheme and considers the total cost of fan operation.

3.4 Influence of different regions

Due to its strong region, a wind storage turbine needs to be installed in an open place with the wind all year round. Large-scale wind turbines are generally installed in inaccessible places. If you want to maximize the utilization of wind energy. Then we need to explore the impact of different regions on wind turbines. Temperature, altitude, and humidity affect air density and viscosity, thus affecting the conversion rate of wind energy.

The formula of kinetic energy in wind is: $P = 1 / 2\rho AV3$

The formula of actual output power of wind turbine: $P = 1 / 2\rho AC_pV3$

(P is wind power output, V is wind speed ρ Is the air density, a is the blade swept area, C_p is the power coefficient)

Ideal gas equation of state: $PM = start$

(P is the gas pressure, M is the molar mass of the gas, and z is the compressibility coefficient of air under the conditions of P and t.)

According to the literature, when the temperature changes in the range of 10 ~ 40 ℃, the air density decreases by about 3%, and the power generation decreases by about 1.7% for every 10 ℃ increase in temperature. Within a certain altitude range, the power generation decreases with the increase of altitude. When the altitude changes in the range of 0 ~ 4000m, the air density decreases by about 7% and the power generation decreases by 3% ~ 5% for every 500m increase in altitude. Under certain pressure and temperature, the power generation decreases with the increase of humidity. Compared with the power generation under dry air, the power generation decreases by 0.06% for every 20% increase in humidity [13]. Therefore, it can be concluded that with the increase in temperature and altitude, the air density gradually decreases, resulting in the reduction of wind turbine efficiency, resulting in the reduction of power generation. The increase in air humidity also leads to a reduction in power generation. (the curve influence of temperature on power and the curve influence of altitude on power are shown in the figure below.)

From this research result, we can see that the wind turbine is suitable to be installed in plain areas with low temperatures, such as the northeast plain and North China Plain in China. It can fully improve the efficiency of the wind turbine.

4. Research on energy conversion of wind turbine

The energy storage part is an important part of the wind power generator. Batteries play an important role in storing electric energy and stabilizing voltage in DC power supply system [14]. Maintenance-free lead-acid batteries are mainly used in the energy storage structure of large wind turbines in practical application. The performance of these batteries is suitable for long-term small current charging and discharging and their service life is generally long. The battery capacity is configured as follows. Whether it is reasonable or not directly affects each technical and economic index of wind power generation. With a small capacity option, the excess electricity generated in windy conditions cannot be adequately stored. If the capacity is too large, investment will be increased; Second, the battery may be under charge for a long time, which will affect the efficiency and service life of the battery [15]. Therefore, the capacity of an energy storage battery needs to be determined [16] by balancing reliability and cost of use. In addition, the intermittent discharge mode of the wind turbine energy storage battery can cause low voltage ride-through and other faults in the integrated grid system. Solving the problem of wind power low-voltage ride-through and becoming the power grid fault recovery is the technical parochial of large-scale use of wind power [17]. Therefore, optimizing grid-connected technology can effectively save energy and reduce

consumption, improve wind power market efficiency, and provide good technical guarantee for the development of clean energy such as wind power.

4.1 Design of battery capacity

As it can better reflect the actual work of battery in practical engineering, both IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications, IEEE Std 485-2010 and DL/T 5044 Technical Specifications for DC System Design in Electric Power Engineering, recommend the"Step Calculation Method"for calculating battery capacity [18]. The table of capacity conversion factors given by the battery manufacturer and the time/ampere meter for different discharge termination voltages are the basic data for calculating the battery capacity using the “step calculation method”.

The step calculation method of battery capacity shall be calculated according to the following formula:

First stage calculation capacity

$$C_{c1} = K_k \frac{I_1}{K_c} \tag{5}$$

Second stage calculation capacity

$$C_{c2} = K_k[\frac{1}{K_{c1}} I_1 + \frac{1}{K_{c2}}(I_2 - I_1)] \tag{6}$$

Calculation capacity in stage *n*

$$C_{cn} = K_k[\frac{1}{K_{c1}} I_1 + \frac{1}{K_{c2}}(I_2 - I_1) + \cdots \frac{1}{K_{cn}}(I_n - I_{n-1})] \tag{7}$$

Random load calculation capacity

$$C_r = \frac{I_r}{K_{cr}} \tag{8}$$

Superposition Cr on the largest stage of Cc1-Ccn, and then compare with Cc1, the larger is the calculated capacity of the battery.

In the formula: - Reliability coefficient, take 1.40;

C_{c1}-C_{cn} -Calculated capacity of each stage at 10 h discharge rate of battery (A.h);

I_1-I_n-Load current (A) of each stage;

K_{c1}-capacity conversion factor (1/h) for all discharge time in each calculation stage;

K_{c2}- Capacity conversion factor of discharge time except step 1 (1/h) in each calculation stage;

K_{cn}- capacity conversion factor (1/h) of the last step discharge time in each calculation stage;

C_r- random load calculation capacity (A.h);

I_r- Random Load Current (A);

K_c- capacity conversion factor of initial (1 min) shock load (1/h);

K_{cr}- Capacity conversion factor (1/h) for random (5 s) shock loads.

4.2 Optimization of wind turbine grid connection technology

The basic structure of wind photovoltaic origin system is shown in the Figure 8 [19]. The electric energy generated by photovoltaic and fan is connected to DC bus and then connected to power grid or supply load through inversion and boost. The energy storage system is also connected to the DC bus [20].

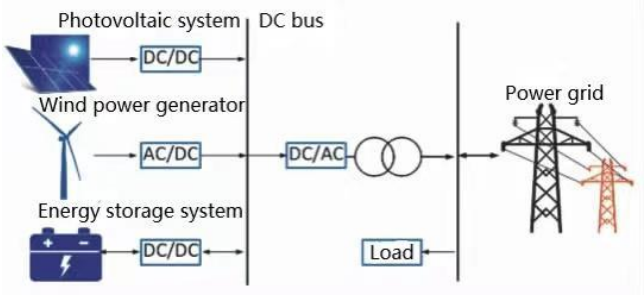


Figure 8. The basic structure of wind photovoltaic origin system.

With the increase of capacity of wind turbine assemblies, when the power grid fails and voltage drops, wind turbines that do not have low voltage ride-through capability or have insufficient low voltage ride-through capability will exit the power grid for self-protection. If a large number of wind turbines exit the power grid, the voltage of the power grid will continue to drop, resulting in paralysis of the power supply grid. In the process of wind energy storage itself, there will be relatively many factors of instability, which will have a direct impact on power grid dispatching after the actual grid connection, and will also bring certain restrictions on the normal use of residents.

In order to better avoid the degradation of power quality caused by wind power grid connection, it is necessary to take specific measures to control power quality. However, the main method nowadays is to suppress harmonics. Specifically, by adding static reactive power compensation equipment to the system, and then effectively track reactive power according to whether there is a change in reactive power as a judgment standard. Such a method not only has high accuracy, but also has fast reaction speed. In addition, by adding static reactive power compensation equipment, the voltage stability can also be effectively controlled [21].

5. Improvement of wind turbine energy conversion

5.1 Improve energy conversion efficiency by optimizing fan blades

5.1.1 Optimization of vortex generator.

The vortex generator is a spoiler which is vertically arranged on the surface of wind turbine blade with a fixed mounting Angle.Through the interaction with the incoming flow [22], the wing tip vortex generated by the laminar boundary layer to achieve transition to turbulent boundary layer, achieve the purpose of lifting and reducing drag to improve the lift-drag ratio and power generation efficiency.Blade vortex generator is mainly used to disturb the fluid on one side of the suction surface. When fluid separation occurs on the suction surface, the speed at the suction surface position is increased [23]. As the speed increases, the pressure on the suction surface decreases, the pressure difference between the two sides ΔP increases, and the force on the blade surface increases, resulting in the increase of the total amount of work and power.When the vortex generator is installed at the blade root design with large Angle of attack, high gust or turbulence intensity and dirt on the blade surface, its power enhancement advantage is obvious [24].

5.1.2 Optimization design of spoiler.

The blade spoiler actively changes the shape of the fan blade, mainly to make up for the design defect caused by the small overall output of the blade root area.After installing the spoiler, the flow rate of the suction surface has a higher rise, the pressure of the suction surface decreases, the flow rate of the pressure surface decreases, the pressure on the pressure surface increases, the pressure difference on the blade surface increases, the force on the blade surface increases, the work increases, and the power increases [25]. After adding the spoiler, the pressure on the pressure surface increases, while the pressure on the suction surface decreases. Finally, due to the effect of pressure difference, the lift coefficient changes, and the lift coefficient and lift-drag ratio increase.The increase of lift coefficient caused by the spoiler does not divide regions, that is, it causes the increase of lift

coefficient in all operating sections, greatly increases the force on the local section, and increases the power generation [26].

In my opinion, if you want to improve the efficiency of wind turbines in terms of energy conversion, optimization of hardware facilities is the easiest way to achieve. Firstly, the nature of wind power generation is that wind power drives the blades to rotate and ultimately outputs ac power. So how to make full use of the wind is the direction we should pay attention to most.

5.2 Improve energy conversion efficiency by using artificial intelligence technology

5.2.1 Application of UAV in intelligent inspection.

The main characteristics of UAV technology in wind power generation are strong wind resistance and long endurance. Intelligent technology can help UAV to realize intelligent inspection. During the inspection process, the operator can control the UAV more conveniently, take intelligent and all-round photos of the specific inspection area, and monitor the stable operation of the wind power generation system in real time, so as to ensure the efficient and orderly operation of the wind power generation unit at all times.After the inspection, the UAV can automatically process the pictures and videos collected during the inspection and send them to ground controllers. By comparing the inspection data with the actual power generation situation, technicians can make an accurate judgment on the operation of the current wind power generation system units. Compared with traditional manual inspection, intelligent UAV has higher inspection quality and efficiency, lower inspection cost and higher accuracy, which can improve the actual benefits of wind power generation.

5.2.2 Application of artificial intelligence technology in wind power prediction.

After the application of artificial intelligence technology, the power prediction methods commonly used in the wind power industry mainly include statistical prediction and physical prediction, among which physical prediction is the most common.Physical prediction is mainly analyze the generating area weather forecast information, calculate the wind direction, wind speed and other important reference information, and compare the above information and wind turbines weeks surround the actual difference, patients with a variety of information construct analysis model, and then through the big data technology of artificial intelligence technology to carry out scientific computing, to wind electric power make accurate predictions. The statistical prediction method is based on the mathematical statistical method. It carefully compares the historical power generation and actual power generation of the power generation system, establishes an analysis model based on a large number of historical data, and makes an accurate prediction of the future wind power through the analysis of artificial intelligence big data technology. This method has the advantages of large amount of data, intelligence and automation, and can accurately find the mapping relationship between data in massive data, and the prediction accuracy of wind power is higher.

6. Conclusions

From the current situation, there is still a lot of room for improvement of wind turbines, it summarize the following four aspects in this study.

(1) The design of the active windward system can not only improve the efficiency of the wind generator, but also give full play to the value of wind power in the clean energy system. At the same time, the cooperation with various wind direction and speed detection systems greatly improves the reliability and accuracy of the active windward system.

(2) In the structure of the wind turbine, it have a deep understanding of the basic structure of the wind turbine, and finally from the aspect of the wind turbine wing shape in-depth study, to improve the efficiency of the wind turbine. It also analyzes the optimal materials and prices to create the most cost-effective wind turbine. At the same time, according to the influence of different altitude, temperature, air density and other aspects to find the most suitable area for building wind turbines, to ensure the highest efficiency of wind turbines.

(3) In addition to the improvement of fan structure, the selection of different battery types and optimization of grid-connected technology can also improve the overall efficiency of wind energy utilization, at the same time, improve the stability of the system and optimize the use of users. Low voltage ride-through is still the biggest threat to the stability of wind power system, and there is still room for improvement in fan itself and grid-connected strategy.

(4) Improving the efficiency of wind turbines in terms of energy conversion is the final aspect of our research. It lists the purpose of improving efficiency by upgrading the blade system and achieving the maximum efficiency of wind energy conversion by predicting and calculating the environment through artificial intelligence. In our opinion, the development of wind energy is the general trend, after all, the one-time energy like fossil energy always has the risk of energy crisis. Wind power happens to be the cleanest and the one we've been working on the longest.

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