Several Factors Affecting the Inspection of Wind Turbines by UAV

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Abstract: The country strongly supports the development of new energy industries, with the clean energy wind power industry developing rapidly and the market maturing, the scale of wind farms and installed capacity expanding, and the blade length increasing to 60-70m. The increased blade length and weight increase the probability of damage. the manual inspection method is time-consuming and laborious, with a high economic cost, low inspection efficiency, and high safety risks, and cannot meet the current wind turbine fast and efficient inspection requirements. This paper introduces the characteristics of the type of UAV, its working status, and mode, and proposes how to determine the best area for UAV inspection according to the factors that can cause interference to the inspection in the actual wind field, to achieve the demand for fast and efficient inspection of the blade surface and improve the accuracy of inspection. It is believed that with the development of UAV technology, UAVs will play a more important role in the field of inspection.

Keywords: Wind Turbine Blade, UAV, Wind Power Inspection

1 Introduction

Energy plays an important role in the development of today's society, and while constraining economic and social development, the use of fossil fuels has also caused environmental pollution and degradation. China's large population has a great demand for energy use, and the excessive use of fossil energy can cause a series of environmental problems [1]. Therefore, natural resources such as wind, solar, and tidal fuels have been developed.

Wind energy is an important new and renewable energy resource with good development prospects that has a positive impact on promoting new energy development, reducing pollution emissions, protecting the natural environment, and achieving energy conservation and emission reduction goals, and its development and utilization play a very important role in the sustainable social and economic development of China [2-3]. From the 1970s to the present, China's wind power industry has been able to develop rapidly and expand fiercely, and wind power generation has also been developing rapidly. China's installed wind power generation has long ranked first in the world. In 2020, the country's wind power installed 71.67 million kilowatts, of which 68.61 million kilowatts of onshore wind power and offshore wind power installed 3.06 million kilowatts. By the end of 2020, the country's wind power installed a total of 281 million kilowatts, of which 271 million kilowatts of onshore wind power and offshore wind power installed a total of about 9 million kilowatts. The wind turbine blade is one of the key components of the wind turbine, and its quality and reliability are the key factors to ensure the safe operation of the turbine [4], which directly affects the overall performance of the wind turbine. As a result, we must conduct this inspection regularly to ensure that we can process blade damage promptly [5]. The current traditional blade detection fault of the main approach is a useful telescope for long-distance observation or rope, elevator dropping way for wind turbine inspection. Traditional blade inspection has the following drawbacks: low inspection efficiency; high worker labor intensity; high altitude operation; high degree of danger; high inspection costs; long inspection time; power generation loss during downtime [6]. To cope with these problems, this paper through the comparison of conventional wind turbine blade inspection methods clearly shows that the UAV inspection method has more speed, safety, and timeliness

2 Characteristics, Classification and Selection of UAV

Unmanned Aerial Vehicle (UAV) is an unmanned aircraft operated by radio-controlled equipment and self-contained programmed control devices. It relies on aerodynamics to provide lift for the vehicle, can fly autonomously or remotely, and can carry equipment and perform missions. With the development of technology in recent years, manufacturing technology, remote sensing technology, power systems, control engineering, and artificial intelligence have also made qualitative leaps, while UAV technology is a popular research area worldwide, which is an important reason why the overall performance of UAV has been greatly improved. At present, UAV have been used in more fields, such as aerial photography, agriculture, plant protection, communication, express transportation, disaster rescue, observation of wildlife, monitoring of infectious diseases, mapping, surveying, inspection, and many other industry fields [7], and the model of UAV + industry applications will also play a greater function in the future.

Technically speaking, UAV can be classified into three types: fixed-wing UAV, helicopters, and multi-rotor UAV. Helicopter and fixed-wing UAV need to rely on the thrust generated by propellers or turbine engines to power the aircraft forward, with the main lift coming from the relative motion of the wings in the air. These two types of drones fly fast and are not easy to get started. The mechanical structure is complex, maintenance costs are high, there is no range advantage, and the fixed mechanical connections are prone to wear and tear, which can lead to reduced reliability in flight. Multi-rotor UAVs rely on the lift generated by multiple rotors to balance the gravity of the vehicle so that it can fly and control the stability and attitude of the vehicle by changing the rotational speed of each rotor. Because multi-rotor UAVs are easy to operate, can lift vertically, can hover, are highly stable, and can fly at any speed within a certain speed range, they can be used in multiple scenarios. UAV is mainly used in the wind power field as an alternative to manual labor for efficient troubleshooting of wind turbines, such as, blade cracking, blade surface shedding, deformation, nacelle towers, etc. [8] By carrying high-definition camera equipment to complete data transmission promptly, drones can reduce downtime, improve utilization rates and the quality of wind turbine inspections, reduce costs and operating safely.

According to the existing wind power installed capacity, blade length, tower height and other factors on the UAV equipment to put forward several requirements.

(1) Wind resistance. Wind farms generally have high wind speeds and require the wind resistance of the UAV at about 10m/s.

(2) Free hovering. To observe different wind power, blades need to be in a different position, and the UAV needs to have a stable hovering performance.

(3) Imaging function. The UAV does not have to carry a high pixel camera, but it can not be less than 8 megapixels but also meet with fast imaging and anti-shake function.

(4) Flight height. The size of the wind turbine and the blade length is getting larger and larger, requiring the drone flight height greater than 200m

(5) Continuity. The wind farm inspection needs to ensure uninterrupted inspection of a wind turbine, and according to the efficiency of the front drone in-

spection so the drone flight length of at least 15min.

(6) Weight. Because the wind farm is located in a remote, harsh and windy environment, the UAV is required to be easily portable, mobile, and weigh no more than 20 kg [9-10].

As shown in Table 1, the three commercially available UAVs are compared in terms of their relevant performance.

On the other hand, the main way to the traditional blade detection fault is to use telescope distance observation, climbing, lift down way of wind turbine inspection, and drone blade inspection can replace the traditional inspection work efficiency is low, aerial work safety accidents, a long working time affect the economic benefits of wind farm defects, as shown in Table 2 for the characteristics of the inspection method.

Comprehensive above can be learned that multi-rotor UAV has the advantages of simple operation, no need to help run and taxi runway, no mechanical joints, good reliability, not easy to wear and tear, low maintenance costs, free hovering, etc. A combination of factors, we choose the fourth generation of the Jiang Genie series, Phantom4, which is small, fast, flexible control, simple structure, easy to operate, and light quality to meet our needs.

3 Wind Turbine Blade Damage Type

The blade is the key to the wind turbine to obtain wind energy converted into electricity, long-term rotation in the natural environment not only to resist external climatic factors but also to withstand centrifugal force, aerodynamic forces, and other forces. Wind farms are generally built in mountainous areas, deserts, near the sea, and other wild areas unattended [11], these places are accompanied by a large amount of wind energy at the same time but the harsh environment is also susceptible to typhoons, thunderstorms, ice, snow, sand and dust, and other adverse weather effects. Blades in such a working environment inevitably produce damage, for example, lightning strikes, ice cover, cracking, deformation of adhesive material, fall off, etc., affecting the normal efficiency of the blade.

Table 1 Comparison of Drone Performance

	Multi-rotor	Fixed-wing	Helicopter
Continuity	+	+++	++
Carrying Capacity	+	+++	++
Reliability	+++	+++	+
Ease of Use	+++	+	+
Serviceability	+++	+	+

Table 2 Comparison of Wind Farm Inspection Methods

Wind Turbine Blade Inspection	Routine Inspection (Ground)	Platform Inspection (Overhead)	UAV Inspection
Personnel Requirements	Two	Four	Two
Wind Speed Requirements	None	No Higher than 6m/s	Not Higher than 10m/s
Whether to Stop	Yes	Yes	Yes
Detection Efficiency	10 Units/Day	2 Units/Day	12 Min/Units
Level of Security	High	Low	High
Degree of Accuracy	Low	Low	High

3.1 Blade Cracking and Shedding

The complex production process makes the quality of the fan blades uneven. Affected by factors such as uneven glue content in the gaps between the blades or incomplete curing, the fan blades will crack at the inner bonding seams during operation, especially It is the middle area of the blade tip and the windward side of the blade, and is the most vulnerable part of the fan blade to damage and cracking. If the cracking damage of the fan blade is not discovered and dealt with in time, it will lead to the failure of the fan equipment and constitute a shutdown accident.

Wind turbines produce irregular and unpredictable blade vibration phenomena during normal operation. This long-term vibration can cause structural failure of the trailing edge of the blade, and transverse cracks produced in the blade can lead to serious accidents [12]. In the lower and middle parts of the overall blade, 90% of the cracks are fan self-vibration triggered by the blade transverse crack initial. On the ground, people are difficult to find. Due to the fan, since vibration, blade shaking, crack at each rise and shrink instantly, the external dirt takes the opportunity to enter, crack within the formation of the blade on the black horizontal lines, the ground may be found. As shown in Fig.1, because the crack within the existing dirt can not be closed, the formation of only slightly difficult to close the phenomenon, so the crack is gradually deepened and extended [13].

Fig.1 Blade Cracking

The surface shedding of fan blades usually occurs on the windward side of the blade, the leading edge of the blade, the trailing edge of the blade, etc. Because these positions are eroded by wind and sand for a long time and washed by heavy rain, the outer layer of the blade is used to protect the internal composite material and fiber cloth. The gel coat is easily damaged. The fiber cloth inside the blade leaks, and defects such as cracks, wear and surface peeling are prone to occur. The fan blades are cracked on the scene, as shown in Fig.2, and the cracking is in the longitudinal mouth opening form.

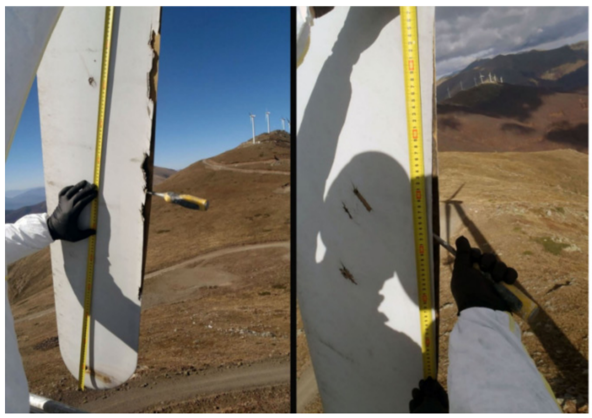

Fig.2 Fan Blade Cracking and Shedding

3.2 Lightning Damage

In recent years, with the propeller blade manufacturing process improvements and new materials being used, lightning strikes have become the main reason for blade damage. Suffering from lightning in the wind turbine, blade damage accounted for about 20% of the total. For wind farms established in mountainous areas and near the sea, the terrain is complex and there are more thunderstorm days, and the blade damage phenomenon caused by lightning strikes should be given full attention [14].

The blade is the most vulnerable component of wind turbines to direct lightning strikes, and it is also one of the most expensive components of wind turbines. Around the world every year about 1% to 2% of the operating wind turbine blade suffered lightning strikes, most lightning strikes only damage the blade tip part, a small number of lightning strikes will damage the whole blade [15], To make effective use of wind energy, wind turbines are usually installed in higher areas, with blades the highest of the fans the parts are vulnerable to lightning. When lightning strikes the fan blade, the energy released by it makes the temperature of the internal structure of the blade rise sharply, causing the composite material on the blade surface to burn, and causing varying degrees of damage to the blade surface. The blades subjected to lightning damage at the site are shown in Fig.3.

Fig.3 Blade Lightning Strike Damage

3.3 Ice on Wind Turbine Blades

The ice cover of fan blades is closely related to the latitude and longitude of the wind field. The higher the latitude is, the more severe the ice is. The icing on the blade has a great impact on the safe operation of the fan, which is one of the key difficulties to be overcome in the field of wind power. When the wind location is too cold, the higher the humidity in the air, the more likely it is to ice the rotating blade edges high in the air. In more serious cases, the entire blade can be covered with ice once the unit is shut down. When the blade is covered by ice, the mass of the blade will increase, and the aerodynamic resistance of the blade side will intensify, thus causing the blade imbalance. Moreover, the output power of the unit will be reduced and the vibration of the unit itself will be intensified. It leads to high fatigue load, increases blade bending moment and reduces blade service life. A more serious situation is the occurrence of the extreme loads mentioned above. An example of ice accretion on a turbine blade is presented in Fig.4.

Fig.4 Ice Accretion on a Turbine Blade

4 UAV Inspection Blade Best Area to Determine

In the actual wind farm inspection, many factors will cause certain interferences to the inspection. Airflow and wind speed may cause collisions between the wind turbine blades and the UAV, and light at some angles may also affect the UAV imaging effect, resulting in slow and unclear imaging results [16-17]. The ambient temperature can affect the performance of the UAV battery, which in turn affects the range of the UAV, and the position of the blades is also a direct factor affecting the UAV inspection. To solve the problem of the change of airflow and wind speed bringing about the occurrence of UAV and blade collision accidents and to ensure that the imaging effect of imaging equipment is not affected by light, this paper gives a method to ensure that the UAV and blade being inspected surface are in the best area by adjusting the cabin position.

The size of the wind direction and wind speed changes are force majeure factors in the wind farm, so in the inspection, we have to ensure that the position of the blade and the UAV will not collide due to the violent change of the wind direction and wind speed. As a result, the UAV in the inspection process should remain downwind of the detection blade, as shown in Fig.5.

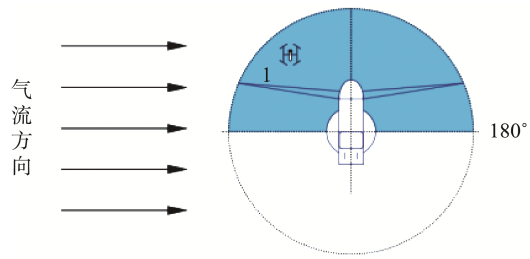

Fig.5 Drone Inspection Area under Airflow

When the UAV inspects the surface of blade 1, the nacelle head when located in the shadow area, the UAV is in the wind turbine downwind of the position. The UAV can inspect in Fig.3 in the range of 180°. When there is a sudden increase in wind speed and airflow, the drone will be blown away from the blade inspection range, where it can effectively avoid colliding with each other and the blade, while the nacelle head tries not to adjust to other directions, otherwise, there will be the risk of the UAV hitting the blade.

4.1 Determine the Best Inspection Area by Airflow, Wind Speed and Light

To effectively obtain the blade surface picture information, using the equipment carried by the UAV to detect the blade surface, needs to take into account that light may have a certain impact on the imaging effect. When in the sun for inspection, first of all, we should pay attention to not backlight image, and secondly, to obtain clear image information, the UAV lens optical axis should be kept perpendicular to the blade surface to be inspected, as far as possible to make the imaging equipment lens axis and the angle between the light presented best between±60°[18], as shown in Fig.6.When inspecting the windward side of the blade and the leading edge, then by adjusting the position of the nacelle so that it is located in the shaded range in the figure, which can ensure that under the influence of light, the blade to be detected on the surface is located in a better detection position. The inspection area can get a clearer image to find the fault, and the UAV can achieve the best inspection effect.

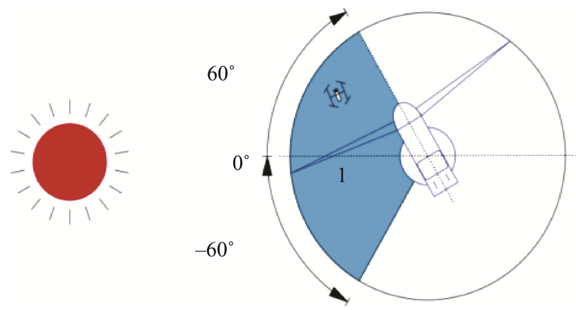

Fig.6 Inspection Area of the UAV in the Light

When considering the following factors, such as wind direction, airflow, light, wind speed, etc., on the impact of the UAV inspection imaging effect [19], we take the inspection blade 1 leading edge as an example and adjust the nacelle to the shaded area in the area shown in Fig.7. The blade's airflow direction is approximately parallel. The UAV lens is also perpendicular to the blade's surface to be detected so that the light and blade's airflow direction in a vertical state can be in the wind speed, airflow, light, and other factors. To achieve the best inspection effect, inspection blade 1 on the windward side, leeward side, and trailing edge can also adjust the nacelle head to determine the inspection area. According to the above method, when inspecting each surface of the blade by adjusting the nacelle range, we can determine the best area of the UAV inspection blade range.

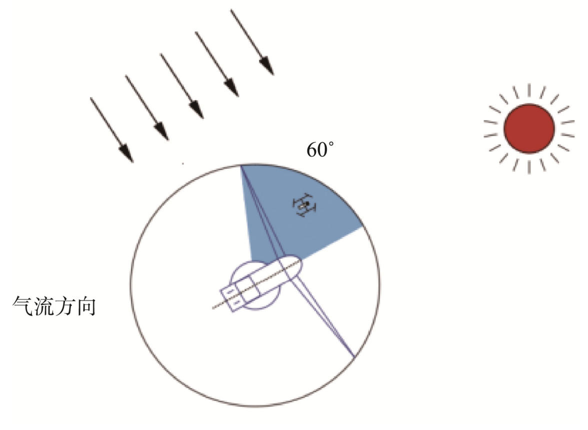

Fig.7 Inspection Area of the UAV in the Airflow and Light

4.2 Determine the Best Inspection Area by Blade Position

When using the drone to blade inspection, the impeller needs to be fixed to prevent the blade from suddenly rotating leading to a collision accident with the drone. Although the imaging equipment carried by the drone also has a certain adjustment ability but the adjustment range is limited, in order to be able to achieve the best inspection imaging effect, the drone lens axis should still maintain a vertical state with the blade detection surface.

In this paper, the inspection effect is compared when the blades are in the following typical positions. When the blade position is in Fig.8 (a), the UAV can easily inspect the surface of blade 1 and the front and rear edges of blade 2 and 3, but when inspecting the windward or leeward side of blade 2 and 3, the UAV is needed to fly between the blades, and there is a visual blind spot. When the blade position in Fig.8 (b), can complete the blade 1 and blade 2 front, rear edge and blade 3 windward surface, leeward surface, front edge of the inspection, but because of space problems UAV has a blind spot can not complete the blade 1, 2 windward, leeward surface and blade 3 rear edge of the inspection. When the blade position in Fig.8 (c), inspection of the three blades will have a different degree of blindness inspection process is more complex. If the complete inspection blade surface also needs to turn the rest of the blade to the vertical position and to adjust a nacelle to the leeward side of the position.

Through the actual inspection is known or when the blade position is showed in Fig.8 (a), the UAV in order to detect the blade steps less, more efficient, and better quality of the image data obtained.

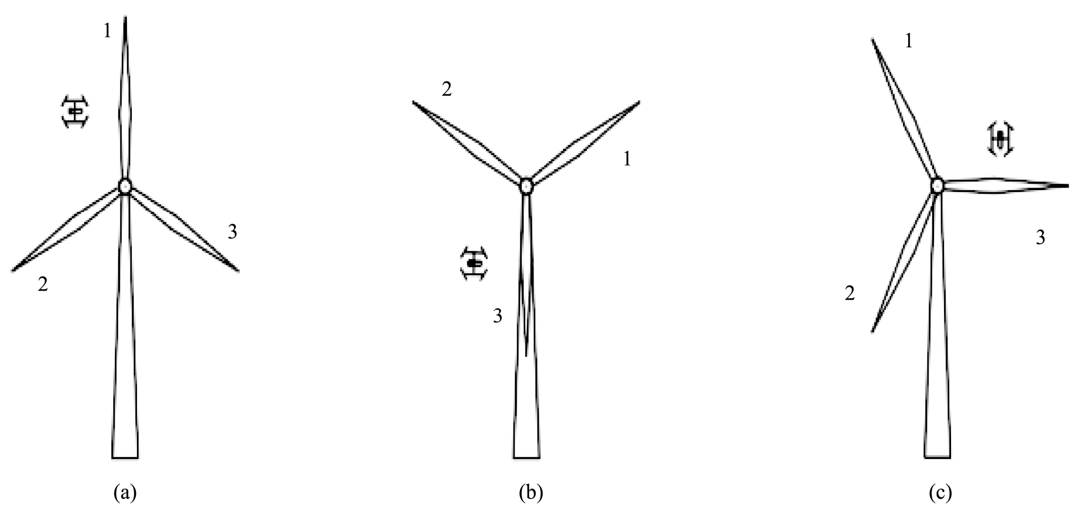

Fig.8 Typical Position of the Wind Turbine Blade

5 Application Case

Located in Wuxue City, Hubei Province, the Wuxue Runxiang 50 MW wind power generation project in Wuxue City, Hubei Province, uses UAV to detect the wind turbine blades. Each operation inspects for 25 minutes, with 8-10 units operating per day. The inspection efficiency is 5 times higher than the traditional method, and millimeter-level high-precision picture collection can be realized. After the inspection, the following problems were found: open cracking of the front edge, damaged fiber layer surface, sand eye and wind damage of the front edge, surface paint loss, longitudinal crack of the shell surface, corrosion of the glass fiber layer of the front edge, etc. In view of these problems, the autonomous detection system has carried out periodic inspection and repair, and achieved satisfactory results. In addition, Zhongneng has carried out the pilot application of wind turbine blade UAV testing in Qilinshan Wind Farm, and successfully realized the blade testing of 6 units and achieved good results.

6 Conclusion

UAV in wind power blade inspection application can effectively make up for the use of telescope observation can not achieve the degree of refinement, to make up for the shortage of manual inspection, reduce the possibility of safety accidents. The drone inspection can improve the efficiency and accuracy of the inspection blade, quickly find the blade surface defects, significantly reduce the wind turbine downtime, reduce the power loss caused by downtime. The use of drone inspection technology in wind power inspection also improves the operation management level of wind farms. The demand for clean energy is gradually increasing, and the installed capacity of wind turbines is also steadily increasing every year, making wind power inspection an important issue, with the expansion of the wind power market in the field of future UAV technology will be an important means of wind turbine inspection.

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