Wind turbine blade failure case analysis and control measures

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Abstract. In this paper, combined with the wind farm blade failure cases, the blade failure reasons are analyzed from the aspects of blade design, material performance, manufacturing quality, transportation and hoisting, online monitoring, wind farm operation, and maintenance. In order to prevent blade operation failure, measures and suggestions based on blade selection, supplier selection, operation and maintenance management are proposed, which provide methods for blade design, manufacturing, and production maintenance.

1. Introduction
After more than 30 years of development of wind power generation in China, wind farm development, wind turbine equipment design, and manufacturing technology become mature gradually, owning to the outstanding advantages in the utilization of wind resources and the cost of electricity. Combined with the global carbon-neutral development strategy in 2060, wind power, as a green power energy, is of great significance to the improvement of the earth’s ecological balance and global energy structure [1]. Including the efficiency of wind power generation, the power grid and the whole social energy structure, the stable and good operation of wind turbines have been paid huge attention by all parties. The single unit capacity of the wind turbine is from 2MW to 12MW. To improve the ability to capture wind energy, the blades are becoming longer and longer, and the length of the newly designed blades have reached 120m. With the increase of single blade length, weight, and bearing limit, more strict requirements are needed including blade structure design, manufacturing process, production quality, and method detection [2]. In recent years, the number of wind farm accidents caused by blade failure is increasing. This paper analyzes the causes of wind turbine blade failure accidents in order to provide preventive measures for various blade failure reasons.

2. Fault overview
In March 2016, a broken blade occurred in Xiangyun, Yunnan Province (Figure 1, Figure 2). Serious destructions of a blade happened including the edge, the web, the girder and trailing edge. After analyzing the data and photos of design, manufacturing, transportation, hoisting, and other evidences, it was found that improper operation was applied during.
Figure 1. The Broken blade.

In July 2016, in Guizhou wind farm, the monitoring platform reported that the blade 1 and 2 pitch angle was large, and the blade 2 and 3 pitch angle was large (Figure 3). The operation and found a broken blade. After inspecting the fallen blade shell, many folds were found on the leading and trailing edges. It was found that there were many chordal folds in the leading edge, main beam, and trailing edge of the blade.

Figure 2. The Blade tip cracking.

In March 2020, in Shandong wind farm, the monitoring platform reported that the vibration of vibration sensor 2 of fan A1 exceeded the limit, and the signal triggered fan A1. At 15:29, after the second start-up of the unit, the under-voltage trip was reported at 15:35, and at 15:40, the maintenance personnel found that the No. 2 blades were broken (Figure 4). The damage of blade and the second section of the tower tube were founded, which may be a collision between the blade and the tower.

Examples of wind farm accidents in previous years (Table 1).

Table 1. Failure cases.

| Accident time | Local       | Failure                                                                 |
|---------------|-------------|-------------------------------------------------------------------------|
| March 2016    | Yunnan      | Blade loading and unloading violate operation requirements               |
| September 2016| Guizhou     | There were some problems in the blade, such as high resin content, fold, poor bonding thickness, lack of glue, lower tensile strength, and modulus of the main beam than the design. |
| September 2016| Yunnan      | Lightning strike                                                         |
| December 2016 | Shenzhen    | The blade was damaged during transportation, which was not following the process requirements. |
| 2017          | North China | There were many problems in the main girder and several areas of the blade, such as fold, insufficient bonding width, and so on. |
| 2017          | Northeast China | There were many manufacturing problems, such as end face fold, resin-rich, filling FRP defects with putty, and so on. |
| February 2018 | A wind farm | Trailing edge UD fold.                                                   |
| March 2020    | Shandong    | Insufficient design stiffness                                             |
| May 2020      | Henan       | The problems of lack of glue, air bubble and not installing stiffener in web bonding |
3. Failure modes
The failures of wind farm blades are mainly because of lightning strike, paint surface corrosion, crack, adhesive cracking, fracture, and so on. The common failure modes and damages of blades are shown in Table 2 [3].

| Failure modes                      | The damage position                                      | Performance status                      |
|-----------------------------------|----------------------------------------------------------|----------------------------------------|
| Blade fracture                    | Leaf root, leaf middle                                   | Fold fracture                          |
| Adhesive cracking                 | Front and rear edge bonding area, web bonding            | The bonding area appears to be separated|
| Lightning damage                  | Leaf-blade surface                                       | The fiberglass appears black            |
| Paint surface damage              | Surface crack, surface corrosion, leading-edge protection corrosion or peeling, etc | Cracks, surface corrosion, peeling of paint or protective film |
| The crack                          | Root, trailing edge spoke beam, near the main beam, trailing edge bonding area | FRP splitting                          |
| Transport and hoisting damage     | Lifting point location, blade tip, leading-edge          | Paint wear, fiberglass lamination       |
| Improper operation and maintenance damage | The regional                                             | Fracture, cracking, paint peeling, etc |

4. The reasons of failure
The operating environment of the wind farm is complex. Due to internal force or external force, the blades would appear a variety of failure damage in operation. There are many reasons for failure damage, such as blade fracture, adhesive cracking, shell bulge, pit, and bulge, etc. The damage may be caused by a single factor or the superposition of multiple factors, which can be seen as uncontrollable or controllable external uncontrollable factors and controllable factors [4]. The factors (e.g. wind and sand, water vapor, rainstorms, hail, lightning) can’t be influenced or overcame by manpower. A comprehensive and objective analysis of human controllable factors has practical value for evaluating wind. There are several human controllable factors which would result in blade damage and failure.

4.1. Design defects
The fabricated blade root, main beam, and trailing edge auxiliary beam of 60M-80M long blade just reached the minimum standard. If the working loading exceeded the design limit, it would bring about blade bonding cracks and shell delamination. Besides, short distance between blade or tower tube would also result in blade failure. Since 2019, due to the impact of the national policy on wind power integration, the single unit bidding price has decreased [5], but the blade has become longer and longer as well as increasing cost. To reduce the weight and cost of the blade, blade manufacturers have developed a variety of lightweight blade profiles, such as reducing the number of layers of root and main beam, cancelling some reinforced layers, and so on. The decrease of blade layer thickness leads to the decrease of strength and failure in operation.

4.2. Material properties
The main materials for manufacturing blades are carbon, resin, structural adhesive, paint, etc. The material properties of resin and structural adhesive have a great impact on the operation quality and safety of the blade. With the increasing supply capacity of domestic blade manufacturers, the updating and promoting speed of domestic materials is also faster and faster. To reduce the cost and obtain more profit margin, the blades of other wind power projects are made by domestic materials, except for the blades of some offshore wind power projects which are made by imported materials. In recent years, FRP cracks caused by domestic resin and structural glue are becoming more and more common, which affects the service life of blades.
4.3. Quality control issues
Although the preparation process is automated, the blades are still hand-made products, lacking a unified production standard. More importantly, due to the uncertain methods of controlling quality, visual inspection methods are still used which would result in inescapable problems like cracks, micro delamination, deep folds, whitening, etc. The inefficient methods applied in producing process and inspection process would bring about defects leading to damage and failure of blade.

4.4. Transportation and lifting problems
Although more wind farms have been built, the number of specialized persons for transportation and installation of the equipment are still insufficient. All kinds of damage would occur in transportation not mention the improper operation. To avoid the responsibility and the maintenance cost, the transportation and wind farm hoisting personnel usually deal with the problem privately. If the occurred damages in transporting or hoisting process were not handled in time, more serious failure of equipment would happen.

4.5. Operation and maintenance management
In the operation and maintenance of wind farms, more attention had paid on the generator, gearbox, and other equipment, but less attention is paid to blade operation and maintenance. Due to the lack of professional inspectors, careless staff, and insufficient funds in preventive maintenance and detection equipment, the blade fault of the wind turbine can't be found and handled in time. If the little defects expanded, serious accidents and economic losses may be brought about.

4.6. Lack of online monitoring
Since 2019, the monitoring of blade operation status has attracted huge attention and an online monitoring function is required for newly built wind farms. However, the changes of vibration frequency and amplitude caused by blade damage could not be found in time for wind farms built before 2019.

5. Preventive measure
5.1. Choose the right blade type
As the whole machine suppliers had begun to design and develop blades, personalized blade design and higher fan matching are the new trend. In the early plans of constructing wind farms, the meteorological wind conditions and wind measurement data should be fully collected, the ultimate load and strength of blades should be predicted, and the range of strength and stiffness of blades should be preliminarily determined. Accurate blade selection can reduce the waste of resources and save the cost of wind farm construction.

5.2 Supplier inspection before bidding
Before project bidding, the quality management system of blade suppliers should be investigated based on the aspects of blade raw material quality, process management, design technology, consistency of process implementation, production management, quality control, defect standard setting, product certification, etc. The best wind turbine blade manufacturer could be selected after evaluating investigation results.

5.3 Optimization of blade profile design
In recent years, the speed of blade development and replacement is fast, the operation time of the new blade is not long, and the operation effect has not been fully verified. The blade supplier shall collect and pay attention to the operation condition of the new blade profile, analyse the fault problems, and optimize the blade structure or aerodynamic design in time.

5.4 Process optimization for material properties
The main materials used in blade fabrication, especially resins and structural adhesives, are important for
the best performance. The effect of filling and bonding issue is generally low when the ambient temperature and humidity are close to the material usage specifications, showing a benign trend in terms of quality stability and production efficiency. At present, most wind turbine blade supplier workshops in China can’t achieve a constant temperature and humidity environment. To reduce filling defects in the production process, resin flow rate and wetting change during the filling process need to be tracked in time. When an abnormal situation occurs, it is necessary to deal with the problem according to environmental conditions and personnel skills.

5.5 Improve process quality control
For the hand-made industry, personnel management should be strengthened on the basis of designing, optimizing processes, and formulating specifications [6]. Reduce wrinkles, resin Starvation and other defects by reducing personnel turnover and professional skills training. At the same time, efficient quality management regulations should be established according to the number of molds, staffs, inspection frequency, inspection report process, confirmation process of sequence, etc.

5.6 Focus on transport and hoisting
Blade transportation and hoisting is an important task for safe and reliable operation of a wind turbine. Enterprises with qualification and blade transportation and hoisting capacity should be selected to undertake blade transportation. The vehicle body positioning device shall be installed on the transport vehicle so that the staffs in wind farm can know the transport progress at any time. After the blades arrive at the wind farm, they shall be inspected by professional personnel to ensure any potential quality problems before hoisting. The hoisting of the wind turbine should be carried out in accordance with the instructions.

5.7 Improve the management system of wind farm
The management system and technical standards for blade inspection, blade maintenance, and damage tracking should be established. The blade is inspected frequently by professional personnel, and the damage is repaired according to the results of online condition control, condition inspection, and detection to reduce the damage diffusion or blade failure.

6. Conclusion
The blade is the component of a wind turbine to convert mechanical energy into electrical energy. Reasonable blade design, stable manufacturing quality, and detection method are very important for the safe operation of the wind farm. Due to the various failure causes and reasons of wind turbine blades, it is necessary to pay attention to the blade quality from the design, manufacturing, transportation, monitoring, operation and maintenance management, and other factors. At the same time, it is necessary to apply the online monitoring technology in real-time to monitor the operation status of wind turbine blades. The tiny defects found in the initial stage should be repaired in time and the failure prediction should be carried out for the stable operation and sustainable benefit of the wind farm.

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