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Testing, inspecting and monitoring technologies for wind turbine blades: A survey

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ABSTRACT

Renewable wind energy is one of the most efficient and effective ways to deal with global warming and energy crisis. Recently, wind energy has grown at an impressive rate in entire world. As we know, the blades are the most important components of wind turbine. In order to increase the energy conversion efficiency, the size of wind turbine blades becomes more and more big which blade diameter ranges from about 20 m to about 100 m or even. However, wind turbine blades are facing increasingly harsh and complexity service environment. It is necessary to testing, inspecting and monitoring of wind turbine blades in order to guarantee the service safety of wind turbine blades. This paper surveys the testing, inspecting and monitoring technologies for wind turbine blades, including mechanical property testing, non-destructive testing/inspecting, full-scale testing, structural health monitoring and condition monitoring. And then, the development trends and some suggestions of testing, inspecting and monitoring technologies for wind turbine blades are discussed.

Contents

1. Introduction

With the increasing negative effects of fossil energy on the environment, such as global warming and crisis of energy availability, have forced many countries to develop environmentally friendly alternatives including solar, wind and solar-hydrogen energies that are renewable to sustain the increasing energy demand. Wind energy, the world's fastest growing energy source, is a clean and renewable source of energy. Now more and more countries had paid more attention to wind energy especially in Europe, the United States and more recently in China and other nations [1,2].

Most wind turbines, both large and small, have the same basic parts: blades, shafts, gears, generator, and a cable (some turbines do not have gearboxes). These components work together to convert the wind energy into electricity. As we know wind turbines capture the

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most energy depended on their propeller-like blades. So, the blades are the most important critical parts of wind turbine. And the manufacturing cost of wind turbine blade is about 15–20% of wind turbine production cost. In order to increase the energy conversion efficiency, the size of wind turbine blades becomes more and more large which blade diameter ranges from about 20 m to about 100 m or even [3]. However, gradually bigger blades are facing harsh and complexity service environment which have brought an amount of service safety problems. The blades can be damaged by moisture absorption, sleet, ultraviolet irradiation, atmospheric corrosion, fatigue, wind gusts or lightening strikes and so on. Furthermore, wind turbine blade failure is very costly because it can damage other blades, the wind turbine itself, and other wind turbines located in neighbor [4]. So, it is important to detect the damage before the blade fails catastrophically which could destroy the entire wind turbine. The efficient testing, inspecting and monitoring procedures should extend wind turbine life and reduce failure possibility. Furthermore, it is also necessary to perform continuous structural health monitoring of wind turbine blades, in order to estimate level of critical damage at an initial stage before collapsing and to perform detailed inspecting and testing with elimination of the broken-down components.

To keep the wind turbine blades in continuous operation, testing, inspecting, and monitoring technologies of the wind turbines blades, including mechanical property testing, non-destructive testing/inspecting, structural health monitoring, full-scale testing and so on, become more and more important for reliability of wind turbine system and are widely applied to guarantee the service safety of wind turbine blades.

The main object of this paper is to provide a survey of the current testing, inspecting and monitoring techniques for wind turbines blades, based on published evidence. This paper is organized as following. In Section 2, current states of wind turbine blades are be depicted, in Section 3, we discussed the mechanical property testing technologies of wind turbine blades, in Section 4, full-scale testing technologies have also been introduced, non-destructive testing technologies are be reviewed and discussed. Structural health monitoring and condition monitoring for wind turbine blades follow in Section 6. Section 7 presents the new trend of testing, inspecting, and monitoring technologies of wind turbine blades. And finally, the Section 8 is our conclusions.

2. Current states of wind turbine blades

The high demand for green energy is causing a rapid increase in renewable energy. In this regard, the utilization of renewable energy resources, such as solar, geothermal, and wind energy, appears to be one of the most efficient and effective ways in dealing with environment pollution and energy crisis. Recently, wind power as the most promising and mature renewable energy has grown at an impressive rate in the entire world. Birger T. Madsen, from BTM Consult ApS (Rinkøbing, Denmark), forecasted that cumulative installed capacity will reach nearly 1,000 GW by 2020. That capacity, he contended, will enable wind power to provide 7–8% of the world's electricity demand by 2020 [4].

Wind turbines are machines that turn wind energy into mechanical energy, which is then used to produce electricity. Generally, wind turbine includes three blades. This configuration is more efficient because it can spin the rotor at higher speeds in lower wind. Three blade designs are also easier to balance. Wind turbine blades are very similar in function to glider wings. Both are designed for maximum lift and efficiency with minimum drag. So, the ability of energy capture of wind turbine system can be decided by blades. And, it included two key issues: structure and materials.

On the one hand, the structure of wind turbine blades has the characteristics of curved surface, multi-layered, variable thickness and big size. And the blades size is one of the most important problems of structure design in wind turbine blades. In order to obtain a greater efficiency of energy capture, within the past few years there has been a dramatic increase in the size and power output of wind turbines, from a rated power of 50 kW in the late 1970s to the multi-megawatt power plants of today. The world's largest wind turbine is now the Enercon (E-126). This turbine has a rotor diameter of 126 m (413 feet), formerly rated at 7 MW [5]. The big change of rotor diameter can be displayed in Fig. 1. It is anticipated that wind turbines with a rated power output in the range of 8–10 MW and a rotor diameter from 180–200 m will be developed and installed within the next 10–15 years [6]. However, an increase in rotor diameter is accompanied by a corresponding increase in the load levels experienced by the blades, input shaft, gearbox and generator, as well as by the tower and nacelle. It can significantly affect the service safety of wind turbine blades.

On the other hand, blades materials significantly affect the performance and properties of blades, such as blade weight, damage mechanism, and fatigue life and so on. Wind turbine blades are made from anisotropic materials, which are usually made in polymer matrix composites materials, in a combination of monolithic (single skin) and sandwich composites [7]. Present day designs are mainly based on glass fiber-reinforced composites (GFRP), but for very large blades carbon fiber-reinforced composites are being used increasingly to reduce the weight. The sandwich structures can be considered as a special type of composite laminate and have gained widespread acceptance as an excellent way to obtain extremely lightweight components and structures with very high bending stiffness, high strength, and high buckling resistance. These materials were processed by

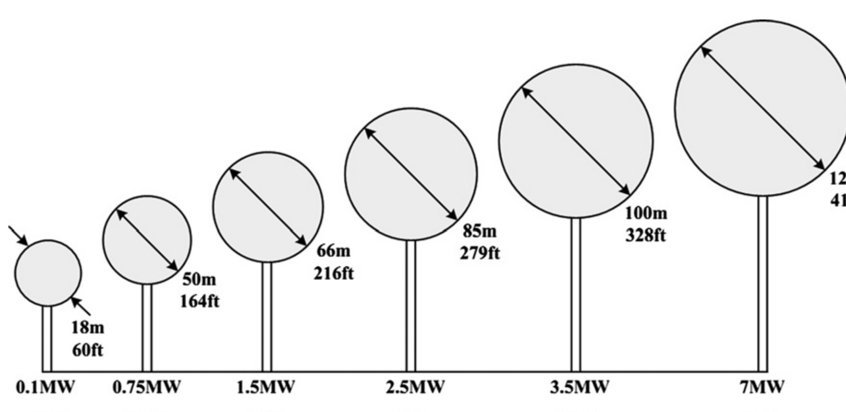

Fig. 1. The change of wind turbine blades.