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System safety analysis of large wind turbines

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ABSTRACT

Wind turbines are a proven source of clean energy with wind power energy harvesting technologies supplying about 3% of global electricity consumption. Consequently, the requirements and expectations of wind turbines keep increasing. However, due to the harsh operation environment of wind turbines, modern large wind turbines are subjected to different sort of failures. Thus, safety engineering is a critical issue for making wind energy competitive to conventional sources and achieving the desirable renewable targets. Researches in the safety engineering of wind turbines have gained dramatically increasing attention. Accordingly, this paper reviews the main basic research types and methods and their corresponding applications in system safety analysis, aiming to let more experts know the current research status and also provide guidance for relevant researches.

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1. Introduction

Wind energy has been the fastest-growing renewable energy source in the world for some time. At the end of 2013, the global total wind energy capacity had grown to approximately 318 GW, which is enough to cover about 3% of the world's electricity demand [1]. The wind turbine total installed capacity 1996–2013 of global is shown in Fig. 1.

However, due to the harsh environment, modern large wind turbines are subjected to different sort of failures, such as main bearings, gearboxes, and generators [2]. Moreover, traffic inconvenience and downtime loss will make huge impacts on the cost of energy [3]. Thus the rapid development of wind power industry requires higher performance and reliability for equipments. If the reliable operation cannot be ensured, the actual utilization of wind turbines will decrease and operation and maintenance (O&M) costs will increase, both of which would greatly reduce the economic benefit of wind power [4].

Thus, safety engineering is a critical issue for making wind energy competitive to conventional sources and achieving the desirable renewable targets. Researches in the safety engineering of wind turbines have gained dramatically increasing attention. According to the relevant literature review, there are three major analysis types for safety engineering, i.e. failure analysis, reliability engineering and risk assessment. So this paper reviews the main basic research methods in the safety engineering of wind turbines, aiming to let more experts know the current research status and also provide guidance for researchers. Since small wind turbines have similar operating environment and principle to large wind turbines, the findings herein applicable to large wind turbines may also serve as references for small wind turbines.

This paper is structured as follows: to clearly describe the application of analysis methods, key components of wind turbines are classified in Section 2. In Section 3 the analysis types in the safety engineering are reviewed-failure analysis, reliability analysis and risk assessment. As each type of analysis requires basic analysis data, in Section 4 the basic methods are reviewed-simulation-based methodologies and condition monitoring and fault diagnosis. In Section 5, based on the analysis types and basic methods, the current research status are reviewed and summarized. The economic benefits from safety analysis are given in Section 6. Conclusions are provided in Section 7.

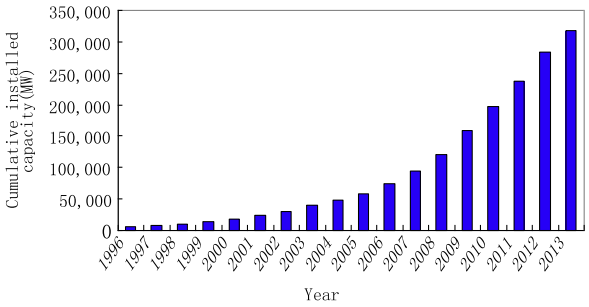

Fig. 1. Global cumulative installed wind capacity 1996–2013 [5].

2. Components

Wind turbines are designed to exploit the wind energy. The electricity can be used for a single building or connected to the grid [6]. The wind energy drives the rotor, which connected to the generator to create electricity through drivetrain. Wind turbines are mounted on towers to capture the most energy. The major components are shown in Fig. 2, which can be divided into four categories:

(1) Rotor components: including the blades for converting wind energy to low speed rotational energy.
(2) Drivetrain components: most likely a gearbox (e.g. planetary gearbox), adjustable-speed drive or continuously variable transmission component for converting the low speed incoming rotation to high speed rotation suitable for generating electricity.
(3) Generator components: including the generator and control electronics.
(4) Structural support components: including the tower and yaw mechanism.

3. Analysis type

According to the relevant literature review, there are three major analysis types for safety engineering (i.e. failure analysis, reliability engineering and risk assessment). Failure analysis focuses on the cause of a failure; reliability analysis aims at quantifying the probability of failure due to uncertainties in the design, manufacturing; risk analysis combines this information with the consequences of failure in view of optimal decision making. Among the three types of analysis, risk assessment is the most comprehensive way to deal with safety problems of wind turbines.

3.1. Failure analysis

Failure analysis is the process of collecting and analyzing data to determine the cause of a failure. It is an important discipline in many branches of manufacturing industry, where it is a vital tool used in the development of new products and for the improvement of existing products [7]. Since the 19th century, product failures have been objects of systematic and scientific analyses

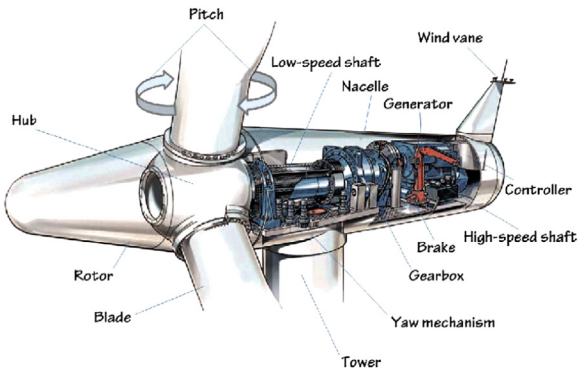

Fig. 2. Major WT components [6].