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Dynamical measurement system for wind turbine fatigue load

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ABSTRACT

A measurement system specially used in wind turbine fatigue load assessment is developed based on Labview platform and Control Area Network (CAN). By applying CAN bus communication technology, the system can perform data automatic acquisition, data stable transmission and data real-time monitoring. By adopting the technology of virtual instrument modular design, the system is designed to analyze the wind turbine mechanical load levels against wind and power, equivalent loads and lifetime fatigue loads, etc. Considering the effects of small load strengthening, low amplitude load damaging and multilevel load interaction, a novel fatigue lifetime prediction model is proposed to obtain more accurate and reliable prediction of blade fatigue life. With the developed measurement system, the in-field load measurements are performed and the results showed the system has satisfactory accuracy and good adaption, convenient operation, high integration, low cost and great practicality to load measurement of large wind turbine. And based on the proposed model the fatigue life of WT blade can be estimated more trustworthily and reliably.

1. Introduction

In order to meet the world ever-increasing energy needs in the presence of continuously depleting fossil-fuel reserves and stricter environmental regulations, wind energy is currently the fastest growing installed alternative-energy production technology [1]. One issue for concern for wind turbine operators is damage due to fatigue loads caused by fluctuating wind conditions [2]. Fatigue load measurement is extremely important in the wind energy generation industry because it must be demonstrated that the designed Wind Turbine (WT) can withstand the expected fatigue loads during its design service life. Hence, the dynamical load measurement on in-field WT is very necessary which helps to improve the WT design and manufacture. In many developing countries, one of the bottlenecks constraining on the development of wind energy generation industry is a lack of authoritative measurement services for WT products. The situation is very typical and particularly serious in China. After many years of rapid and booming growth, Installed capacity of wind power market in China has exceeded 80 GW, and China has been one of the largest wind farms in the world [3]. However, most of key WT components operating in Chinese wind farms are mainly designed and imported abroad. So it is necessary to develop their own measurement technologies to improve the design-manufacture ability for keeping up the high installed capacity. Concerning the WT measurement technologies, especially for fatigue load on-site measurement, China lags far behind other countries such as Germany, Denmark and Netherlands etc. for more than 30 years [4,5]. At present, a small amount of WT load measurement projects have been carried out in China, mainly by CEPRI (China Electric Power Research Institute) that still lacks the practical experiences and reliable reference data [6–8]. Although many Chinese WT developers have established their own testing centers and platforms, their measurement abilities are relatively low and limited just for their own products. Since there is no authorized WT test and certification center in China, the vast majority of WT products on the market have not been certified by the third-party organizations so that some inferior products without in-field measurement reports flood into the domestic market. Moreover, the manufactured WTs without rigorous tests and certifications have relatively weak competitiveness in the international WT market.

The status quo of China's WT industry causes the following four problems. From the viewpoint of design-manufacture, the corresponding technologies are relatively backward and some key technologies depend on the direct import. The load measurement is not only to obtain a true picture of the actual loads on components

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thus to increase confidence in the WT design but also to identify the critical and important effects that are impossible to simulate [9,10]. It enables the WT manufacture developer to more effectively improve future WT design by validating and refining the corresponding computation models, thus to develop their own core technologies with independent intellectual property rights.

From the viewpoint of data accumulation, the wind industry's youth means that the detailed WT load data for in-depth WT fatigue analysis is scarce. The WTs in the commercial operations haven't been through a complete life cycle. The service loads are random and unpredictable because of the various and harsh operation environments. Any new theory or technology about WT design and manufacture needs enough load data to do field-proving. WT dynamic load measurement is beneficial to obtain the firsthand data at different operation conditions, which might provide the valuable information to verify the new technologies in the WT industry.

From the viewpoint of maintenance, to better know the load state and running structural fatigue is a prerequisite for WT failure warning and control optimizing. Although the WT design lifetime is over 20 years, actually the WT manufacturers generally provide only 2–3 years of warranty. Since the WT usually operate long-term in varying load, harsh conditions, with the increase of running time its reliability declines and failure likelihood increases. When the WT exceed their quality guarantee period, the manufacturer would no longer provide free repair and maintenance. The related work has to be undertaken by the wind farm owner. So it is necessary to monitor the WT load conditions, thus to develop a reasonable plan or modify the maintenance plan for ensuring the rational WT operation.

From the viewpoint of certification, the measurements and certifications of China's WTs mostly are done by the test institution abroad at huge cost, which is not beneficial to China's wind industry development. In addition, to meet the WT export requirement, the measured fatigue load should meet the requirements or specifications developed by the organizations, such as IEC (International Electro technical Commission), Germany GL, DEWT (German Wind Energy Institute), Risoe (Denmark National Laboratory), DNV (Det Norske Veritas Classification Society Denmark) [11–14]. Therefore, it is a good choice to establish an accurate, authoritative and reliable load measurement system for the thorough evaluation and WT certification.

Since the dynamic load measurement of WT is a complex task involving the detailed knowledges of operation conditions, stress distribution, load levels and material properties etc., the measurement system needs to meet the following four requirements.

(1) The measurement system is preferably less-expensive. Although there exist some accurate WT load measurement systems abroad, the cost associated with conducting WT load measurements is a main economic factor hindering their direct applications into the wind site. Owing to the budget constraints on the WT developers, it is necessary to develop a low-cost alternative to the expensive one.
(2) The measurement system preferably provides better ways to visualize the load measurement procedure, thus to enhance the measurer's ability in the load data analyzing. Furthermore it is better to be easy-operating for the wind farm workers without the specialized knowledge of WT load.
(3) The system should provide the operations predetermined in the recognized standards such as IEC standard, GL standard, and guarantee the measurement of high quality with uniform interpretations of standards and recommendations, so that the measurement results can be accepted and certificated in the international wind power industry.
(4) The system is preferably easy for installation or disassembly of different type WT in different wind site so that the measurement results would be exchanged and shared. When the configurations of the measurement set-ups are changed, the system software is desired to quickly adapt the measurement equipments for new type WT under new wind farm conditions.

All of the status quo, problems and requirements in aggregate motivate the science of WT dynamic load measurement. It is very necessary to design a low-cost, high-efficiency, easy-operation, universal and practical WT load dynamic measurement system. In view of the WT complex load conditions and oscillatory load sequences, a new prediction model is proposed by taking into account strengthening effects, small load damage and inertial damage. Moreover, the experimental results are provided to verify its accuracy and reliability in the fatigue life assessment of WT blade. Whether it is from theoretical research or practical application, it is undeniable that the work about WT load measurement has a profound scientific meaning.

Based on the most popular WT load measurement standard IEC 61400-13, the paper provides a specialized measurement system of in-field WT dynamic load which particularly is suitable to apply in the small wind farms. All these individual equipments have been integrated into an organic whole based on Labview virtual instrument software architecture, and the new prediction model is proposed to evaluate the fatigue life of WT blade based on the measured load data. The paper is organized as follows: Section 2 is devotes to a brief introduction of the whole architecture of the dynamic measurement system. Section 3 describes its hardware configuration mainly including key sensors location and information communication. Section 4 elaborates the software structure and main function modules including data acquisition, data validation and correction, capture matrix establishment, load analysis and fatigue life prediction. In Section5 the field experiments are provided to validate the performance of this measurement system and the proposed model.

2. Structure of measurement system

Because of the excitation of random wind, the WT usually experiences complex dynamic load conditions, which make its accurate load measurement more challenging. The WT load dynamic measurement involves collecting both a comprehensive statistical database and a set of time series, which define the behavior of the WT in the main external conditions and the operational situations [11]. The external conditions have stochastic characteristics and the operational conditions depend on the WT configurations that must be specified for each particular case. So the measurement system is very specialized for the in-field running WT with the functions of multi-channel data acquisition, stable data transmission and flexible data processing.

The designed system structure is shown in Fig. 1. The measurement system consists of four data acquisition units including tower bottom unit, nacelle unit, hub unit and met-mast unit. All the datasets from the four acquisition units are aggregated to the local host Personal Computer (PC) in the tower base, and then transferred to the remote terminal server via the wireless network. The acquisition units contain 40 data channels including 14 channels recording the load signals, 5 channels recording the corresponding meteorological parameters, 5 channels recording the operational parameters and other transmission channels or reserved channels. The measured load quantities include blade flap-wise and lead–lag bending moments, tower top bending moment and tower top torsion, tower base bending moment,