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ScienceDirect

Energy Procedia 80 (2015) 13 – 20

Energy Procedia

12th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2015

Evaluation of fatigue loads of horizontal up-scaled wind turbines

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Abstract

Wind turbines, especially for offshore applications, are continually being up-scaled on the basis that having fewer separate sites per installed MW will reduce balance of plant and O&M costs and hence may reduce cost of energy. Obviously the loads on a wind turbine increase with the size of the machine. However there is presently no generic, systematic study of how fatigue loads vary with wind turbine size. Both extreme and fatigue load evaluation is essential for the design of wind turbines. This paper however has its focus solely on fatigue loads.
The aim is to investigate the dependency of fatigue loads (lifetime damage equivalent loads are employed to calculate the fatigue loads) on wind turbine scale and subsequently to develop generic fatigue load trends with scale, ideally in the form of simple power law curves.
Seven wind turbine models were created from a reference model (Danish design) based on up-scaling with similarity. Such scaling does not accurately reflect commercial trends but is considered a best starting point to gain fundamental understanding. Fatigue loads in various design load cases (startups, power production, idling, and shutdowns) as specified in IEC standards are simulated and trend lines determined. This work is part of a much larger generic study of all the main influences on wind turbine loads.

Keywords: Fatigue ; Lifetime damage equivalent loads; Scaling

1. Introduction

The wind turbine industry aims to make wind energy as cheap as possible. This can be done by reducing energy cost by increasing the size of machine. There is a strong belief that the increasing of unit size can reduce the expenses on delivery, infrastructure, operational and maintenance cost of a single unit compared with the few

doi:10.1016/j.egypro.2015.11.401

smaller machines [1]. According to these abovementioned factors the size of a wind turbine is continuously growing to decrease the energy cost produced by wind turbines.
There are two methods of investigating the increase in instantaneous loads due to the up-scaling of wind turbines.

1. Scaling with similarity: Based on several assumptions: preserve the original tip speed ratio, geometric similarity applies to modifications, type of aerofoils and materials are unchanged within the turbine [2, 3].

2. Compare data from commercial wind turbines. There is large variety of wind turbine designs due to the diverse environment of sites. In this case the gained data is scattered [3, 4].

This paper adopts the first method, as the most secure way to understand generic trends, although at a later stage, comparisons with commercial designs will be made.

2. Theory

2.1. Type of loads

A wind turbine is a dynamic system which is subjected to continuously changeable wind direction and speed. As a result the forces on a wind turbine are constantly varying. Therefore a machine needs to resist the varying loads, which are the summation and combination of different load types such as [5]:

- Aerodynamic loads: wind shear, yaw error, turbulence
- Gravitational loads: weight of blade
- Inertial loads: rotor accelerations and decelerations
- Operational loads: braking, yaw error, blade pitch control, generator disconnection
- Impulsive loads: tower shadow

Additionally these loads categories can be divided into deterministic and stochastic part of loads. Where, the deterministic loads are repeatable loads such as: wind shear, tower shadow, gravitational loading, etc. The stochastic part of loads is random and depends on turbulence of the wind flow.

2.2. Fatigue loads

As it was mentioned before this paper focuses on the fatigue loads. The source of fatigue loads per one rotor revolution is the summation of the above mentioned loads in the previous section. Typically there are 10 million revolutions during the life span of a unit, which is usually 20 years [6, 7]. Lifetime damage equivalent loads (DELs) are employed to calculate fatigue loads in this research based on IEC standards [8]. Lifetime DELs are calculated by the combination of the ten minutes load calculation of each mean wind speed with Weibull distribution of wind speed over entire year. Figure 1 depicts the method of calculation the damage equivalent loads.

Where, Markov matrix is a result of the combination Weibull distribution and ten minutes wind simulation. It demonstrates the size and number of cycles, which are calculated by rainflow counting method from the ten minutes simulations [9, 10]. Subsequently the manipulation with equivalent loads and the number of revolutions per life design gives lifetime DELs.