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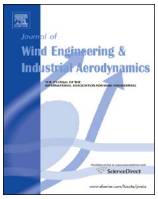

Fatigue loads of iced turbines: Two case studies

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ABSTRACT

The cold climate wind energy market is expanding rapidly due to its excellent wind resources but a lot of uncertainty exists in understanding the fatigue loads of iced turbine under normal power production operation. Two measurement campaigns were analysed on two climatically different sites (Canada and Sweden) to locate and quantify the severity of ice induced fatigue loads on commercially available turbines. Both campaigns showed similar results: icing causes production losses and slight to moderate increases tower base side-to-side fatigue loads. Individual blades and other main components did not show increased wear and tear during iced turbine operation compared to non-iced power production. These results can be used to formulate new design load cases for turbines that intend to operate in cold and icing climates.

1. Introduction

Cold Climate (CC) in wind energy is defined as weather conditions of atmospheric icing and low ambient temperatures which expose wind turbines to conditions outside their normal design limits (IEA, 2011). Areas with CC conditions are becoming more and more attractive because of high wind speeds, increased air density due to low temperatures, low population density, and in many European countries, more easily exploitable inland areas are already in use. It has been estimated that by 2013, 69 GW (24% of global wind energy capacity) were installed in CC areas and another 50 GW are expected to be installed between 2014 and 2017 (20% of global forecast) indicating a substantial market share of all global onshore wind turbine installations (Navigant Research, 2013). Thus, CC can be considered as one of the largest, non-standard climates, in wind energy today. CC weather conditions bring extra challenges to wind energy projects in terms of decrease in energy production and possibly decrease of wind turbine mechanical lifetime, which all contribute to the economy and profitability of wind farm projects (Wallenius and Lehtomäki, 2015).

Ice accretion on wind turbine blades is one of the main challenges for turbines in CC. Ice accretion is mainly caused by super cooled liquid water (in-cloud or meteorological icing) or freezing rain (Rogers and Yau, 1989) freezing instantaneously upon impact on the leading edge of the blade airfoil. A 3 MW turbine with a tower height of 100 m and rotor diameter of 120 m will have a tip height of 160 m above ground level. Such a turbine will have a substantially higher risk of being exposed to low-level cloud base height (CBH) at sub-zero temperatures than older turbines with tip heights below 100 m (Lehtomäki and Peltola, 2014). Therefore in-cloud icing induced challenges for wind turbines are likely to increase in the future if no preventive measures, such as blade ice protection systems, are taken.

Most of the research in CC wind energy is focused on lowering the economic uncertainties resulting from production losses due to icing on turbine blades as they are most eminent and the negative impacts on power production are seen instantaneously. Ice typically builds-up on the leading edge of an airfoil causing aerodynamic penalties in terms of decreased lift and increased drag coefficients (Gray and von Glahn, 1958; Bragg, 1982; Dalili et al., 2009; Addy, 2000; Jasisnki, 1997; Hochart, 2008; Homola, 2011). In the past, ice induced production losses on small to medium size wind turbines (≤ 600 kW in rated power) were reported in late 1990's (Tammelin, 1998; Tammelin and Kimura, 1998; Marjaniemi and Peltola, 1998; Jasinski et al., 1997;

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Marjaniemi et al., 2000) with production losses ranging from 10% to 20% of Annual Energy Production (AEP) in moderate to severe icing climates. From year 2000 onward, more ice induced production loss analyses are reported for individual sites in Austria, Switzerland, Canada and Sweden (Dalili et al., 2009; Westerhellweg and Mönnich, 2010; Haaland, 2011; Homola, 2011; Hellström, 2013) with production losses ranging from 5% to 25% of AEP. First efforts to map production losses due to icing for larger geographical areas based only on turbine production data have been performed in Canada (LaCroix, 2013) and Sweden (Beckford, 2015). Results from Canada concluded that an average AEP loss of 6.6% is caused by icing amounting to 100 million Canadian dollars' worth of annual losses. Results from Swedish wind farms show a clear correlation between production losses with site elevation above sea level, ranging from almost no losses in south of Sweden at sea level to 16% AEP losses at 800 m above sea level in Northern Swedish regions.

In addition to AEP losses, icing can cause aerodynamic and ice mass imbalances. These imbalances are potentially harmful regarding turbine component lifetime. Imbalances are caused by an ongoing process of ice accretion and ice shedding unevenly distributed over the rotor (Rissanen and Uski, 2005). This imbalanced iced rotor has been shown to result in large fatigue loads on the tower for a 200 kW turbine (Antikainen and Kauranen, 2000). A simple load case for iced turbines was developed and validated in (Tammelin, 1998) by applying aerodynamics penalties to the airfoil lift and drag coefficients and adding an ice mass distribution to the blades. Updated recommendations for design load calculations for iced turbine operation were proposed and partly validated on a 600 kW turbine in (Tammelin et al., 2005) by applying mass and aerodynamic imbalances to the rotor. Rotor mass and aerodynamic imbalances were investigated using simulations of 1.5 MW (Mayr et al., 2006), 2 MW (Frohboese and Anders, 2009) and 3 MW (Steiniger et al., 2015) turbines, concluding that ice mass imbalances resulted in large fatigue loading for the tower base and nacelle hub and that aerodynamic imbalances were found of less importance.

In this paper iced turbine loads from site measurements of modern, multi megawatt wind turbines were analysed. Two different wind turbines on two different locations were equipped with multiple load measurement sensors and the iced turbine structural loads for iced and non-iced situations were compared. The objectives were to (i) identify main turbine components that are mostly affected by iced turbine operation in terms of fatigue loads and (ii) evaluate main component lifetime changes due to iced turbine operation compared to non-iced operation.

In Section 2 the used datasets and methods for the two case studies are presented. In Section 3 the results of the case studies are presented followed by the conclusions and discussion in Section 4.

2. Datasets and method

Two different datasets were used from two different wind farms: one dataset from Canada (CAN) and one from Sweden (SWE). All turbine data is presented in 10 min aggregate time intervals. For both sites, component structural loads were measured with strain gages (50 Hz acquisition frequency). Short-term fatigue loads for each 10 min time interval were analysed with damage equivalent load (DEL) methodology via Rainflow counting at 1 Hz equivalent frequency. Fig. 1 shows the coordinate systems used for CAN and SWE datasets for component loads.

2.1. CAN dataset

The CAN dataset turbine is owned and operated by research institute TechnoCetre Éolien and the wind farm is located at Site Nordique Expérimental en Éolien CORUS (SNEEC) windfarm in Gaspé, Quebéc, Canada consisting of two wind turbines. The CAN dataset turbine is a Senvion MM92 2 MW turbine with a hub height of 80 m and rotor diameter of 92 m. The load measurement campaign was performed between December 2011 and May 2012. Component loads were measured for blade root (Mxb, Myb), tower top (Mxk, Myk) and tower base (Mxf, Myf) according to the coordinate systems given in Fig. 1. In addition to the load measurements, SCADA data of turbine output power, wind speed and nacelle yaw direction were available. For ice detection, a nacelle mounted pair of heated/unheated cup anemometers was used. Hub height heated anemometer wind speed was available from a met mast 500 m from the turbine.

2.2. SWE dataset

The SWE dataset turbine is located in a windfarm in Northern Sweden. The SWE dataset turbine was a Nordex N100 2.5 MW turbine with a hub height of 100 m and rotor diameter of 100 m. The load measurement campaign was performed between February 2013 and May 2013. Component loads were measured for blade root (Mxb, Myb), rotor main bearing (Mxn, Myn, Mzn), tower top (Mxk, Myk) and tower base (Mxf, Myf) according to the coordinate system of Fig. 1. Standard SCADA data of output power, wind speed and nacelle yaw direction was available. For ice detection, the SWE dataset had a camera mounted on the blade root pointing at the blade tip and the camera pictures had been visually analysed to identify the location and severity of ice on the blade. Hub height heated anemometer wind speed was available from a met mast 1000 m from the turbine.

All available sensor signals used in CAN and SWE datasets are summarized in Table 1.

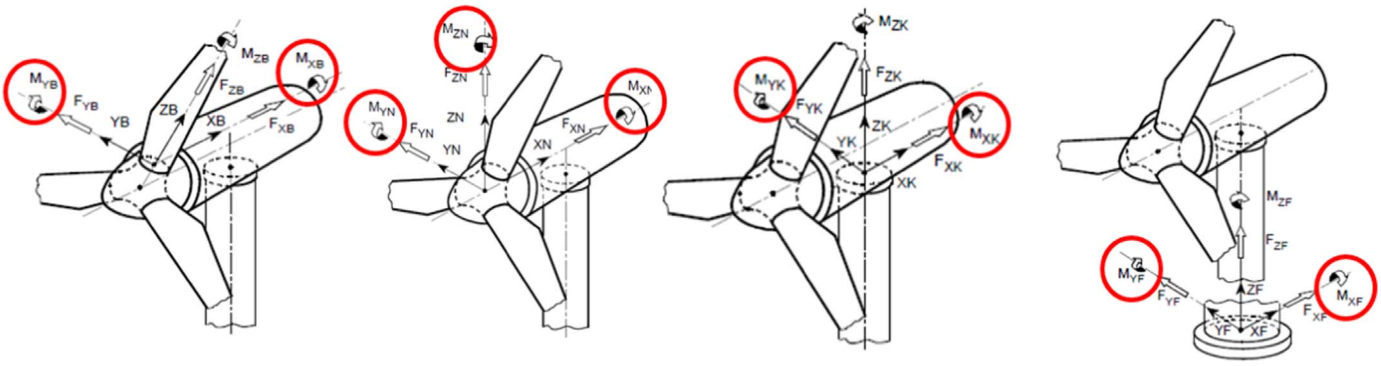

Fig. 1. Mechanical load measurement coordinate system of test turbines and in red circles, the used signals for analyses in GL coordinate system for blade root, main bearing, tower top and tower base (Lloyd, 2010). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)