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Response Analysis of Parked Spar-Type Wind Turbine Considering Blade-Pitch Mechanism Fault

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Floating offshore wind turbines experience fault conditions. For a parked wind turbine, if the pitch mechanism fails, the blades cannot be feathered to the maximum pitch set point—the blades are seized. Three parked scenarios are considered: fault with 1 seized blade, fault with 3 seized blades, and normal condition. The responses of a spar-type wind turbine are investigated under turbulent wind and irregular wave conditions. However, only the steady-state (and not the transient) response in the fault condition is estimated. In normal parked conditions, the platform-yaw is sensitive to the blade azimuth while surge and pitch are not. The blade azimuth plays a key role in the roll and yaw motion responses in the parked conditions with 1 seized blade. Fault cases under 1-y environmental conditions are compared to normal cases under 50-y environmental conditions. A fault with 1 seized blade often leads to large roll resonance and yaw motion responses with the extremes exceeding the 50-y reference values by more than 16%. The extreme main-shaft bending moments are more than twice the 50-y reference values. Fault cases with 3 seized blades cause an average rise of 38% and 23% for surge and pitch motion extremes, and more than 10% of the tower-bottom bending moments and blade-root bending moments compared to the 50-y reference of the normal operating case.

INTRODUCTION

Offshore wind energy has witnessed rapid development in recent years. The total installed capacity in 2010 reached approximately 3000 MW, some 1.5% of worldwide wind farm capacity (Burton et al., 2011). In the design of offshore wind turbines, a set of design conditions and load cases with a relevant probability of occurrence shall be considered. The load cases, which are used to verify the structural integrity of an offshore wind turbine, should include both operational and nonoperational design situations such as power production, parked and fault conditions (IEC, 2009; DNV, 2010). Despite the need for defining a possible fault case, the correlation between a likely environmental condition and a fault situation remains virtually unknown for a land-based turbine or an offshore one. Therefore, it is necessary to assume appropriate environmental conditions corresponding to the specified fault scenario in the design case analysis.

The occurrence of the faults and the severity of the end-effects are important for offshore wind turbines. The former can be quantified based on the statistics about the failures experienced by wind farms (Ribrant, 2006). The end-effects, namely the potential harm inflicted on the wind turbines, are the main topic of this paper. It was shown in the recent RELIAWIND project (Wilkinson and Hendriks, 2011) that the blade-pitch system failure contributes 21.3% to the total failure rate. Among the various forms of hydraulic pitch actuator faults, valve blockage is safety critical and leads to an inoperable pitch actuator and a fixed blade (Esbensen and Sloth, 2009). Upon the presence of such a severe fault, either the supervisory controller or the protection system will ensure an immediate shutdown (DNV/Risø, 2002). The rotor is often brought to a standing-still or idling state by aerodynamic brakes. For an offshore floating wind turbine (FWT) with the fault, the outcome is largely decided by the wave and the wind that it is subjected to for a certain period.

Simulation of an FWT considering parked and fault conditions has been limited so far. It was found that certain parked (idling) conditions can lead to instabilities involving side-to-side motion of the tower and yawing of the platform for a barge-type wind turbine (Bir and Jonkman, 2007). Platform yaw instability was documented when researchers considered the blade fault with an idling rotor (Jonkman and Buhl Jr., 2007). Karimirad and Moan (2010) compared 2 nonoperational cases for a standing-still spar-type wind turbine under a harsh environment and observed extra nacelle surge for the case with yaw fault. When an FWT rotor is brought to a complete rest, the aerodynamic excitation and damping are sensitive to the blade azimuth angle and angle of attack (AOA) relative to the inflow wind. Pitch or yaw mechanism fault may affect the AOA directly and spread the effect to the hydrodynamic loads that are related to the platform motion. Thus, it is interesting to investigate how the response is affected by the fault conditions compared to the normal parked condition.

In recent years, dynamic responses of the spar-type FWT have been examined experimentally and numerically (Nielsen, Hanson and Skaare, 2006; Utsunomiya, Sato, Matsukuma and Yago, 2009). In this paper, a catenary moored deep spar FWT is selected.

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