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Wind Turbine Contingency Control Through Generator De-rating

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SUMMARY

Maximizing turbine up-time and reducing maintenance costs are key technology drivers for wind turbine operators. Components within wind turbines are subject to considerable stresses due to unpredictable environmental conditions resulting from rapidly changing local dynamics. In that context, systems health management has the aim to assess the state-of-health of components within a wind turbine, to estimate remaining life, and to aid in autonomous decision-making to minimize damage to the turbine. Advanced contingency control is one way to enable autonomous decision-making by providing the mechanism to enable safe and efficient turbine operation. The work reported herein explores the integration of condition monitoring of wind turbines with contingency control to balance the trade-offs between maintaining system health and energy capture. The contingency control involves de-rating the generator operating point to achieve reduced loads on the wind turbine. Results are demonstrated using a high fidelity simulator of a utility-scale wind turbine.

1. MOTIVATION

The integration of system health monitoring of wind turbines with controls has the potential for significant payoff when applied to individual wind turbines and even more so when applied to large wind farms or wind parks. Contractual obligations to deliver power and the long lead time to replace a damaged turbine, requires wind farm operators to have contingency plans to manage the risk that one or more turbines will suffer damage between scheduled maintenance intervals. If a turbine suffers damage such as a blade delamination, it is crucial to be able to quickly detect the presence of damage. Next, the proper response needs to be determined. The easiest solution would be to shut a damaged turbine down, but that leads to lost output and, potentially, additional costs for the operator due to unscheduled maintenance, amongst others. Unscheduled maintenance is a considerable cost driver for wind turbines since wind turbines are often times in remote locations and using a crane or other means to access the blades tends to be expensive. Alternatively, if the degree of damage is known and if the damage mechanisms are understood, the turbine could potentially continue to operate safely (until an orderly maintenance can be performed), albeit at a reduced capacity for some period of time without the danger of catastrophic failure.

A decision making component and optimization algorithm that incorporates wind forecasts, historical data, contractual power output requirements, and maintenance schedules could be integrated with the health monitoring and controls. Such a system could allow the damaged turbine using contingency control and generator de-rating to mitigate structural loads to generate power under favorable wind conditions when the wind farm power requirements are the highest. The turbine health would be monitored to assess the damage and remaining useful life of the component, to ensure that, if the damage accelerated in an unexpected manner, the operating conditions would be further restricted. This includes a decision point where the turbine could no longer be operated.

2. PAPER OVERVIEW

This study uses a nonlinear high-fidelity simulation of the 2-bladed Controls Advanced Research Turbine (CART2), an upwind, active-yaw, variable-speed horizontal axis wind turbine (HAWT) located at the National Renewable Energy Laboratory's (NREL) National Wind Technology Center (NWTC) in Golden, Colorado. The CART2 has been modeled using the Fatigue, Aerodynamics, Structures, and Turbulence Codes (FAST), a well-accepted simulation environment for HAWTs (Jonkman & Buhl, 2005). The FAST code is a comprehensive aeroelastic simulator capable of predicting both the extreme loads and the fatigue loads of two- and three-bladed horizontal axis wind turbines. A baseline torque controller operates to command the generator torque setting and a baseline pitch controller operates to command the blade pitch (Wright et al., 2006).

Previous studies by the authors explored the response of a utility scale wind turbine to blade damage (Frost, et al., 2012-2013). The FAST simulation of the CART2 allows configuration of blade properties at distributed stations along the blade span, thereby enabling the properties to be modified to simulate blade damage. The study assumed that blade damage can be represented by a decrease in the spanwise and edgewise stiffness at a blade station and be reflected in corresponding changes in strain gauge data. Blade damage represented by local changes in stiffness includes cracks and delaminations (Nelson et al., 2011). Studies of the CART2 simulator were performed by the authors to investigate effects of changes in stiffness in the blades and to identify a possible feature for damage detection. This was then used to inform a contingency controller that would mitigate loads on the turbine blades under certain operating conditions.

De-rating the generator means that the rated value of the generator speed set by the wind turbine manufacturer is reduced. When de-rating the generator, the value becomes the result of Eq. (1).

$$T_{R3} = T_m \times R \tag{1}$$

where T_{R3} is the generator torque (N.m) in region 3, T_m is the generator torque (N.m) set by the manufacturer and R is the rating coefficient between 0 (0% rated) and 1 (100% rated). To keep the laws governing region 2 and 2.5 operation consistent when de-rating, the speed set-point must also changed. The new set-point is calculated using Eq. (2).

$$V_{sp} = \frac{T_{R3} - k_{\tau 2.5}}{k_{S2.5}} + BSS + \Delta_{S3} \tag{2}$$

where V_{Sp} is the generator speed set-point in rpm, BSS is the Beginning Slope Speed in rpm (i.e., the speed at which the generator switch from region 2 to region 2.5), $k_{s2.5}$ is the coefficient of the slope in region 2.5, $k_{\tau 2.5}$ is the torque value (N.m) at the BSS speed, and Δ_{S3} is a constant speed value (rpm) shifting the set-point to strive to keep the speed in region 3.

Simulations are run with de-rated generator values to see the effects on the blade root moments. Results of this study show that the damage equivalent loads of the blades decrease when the generator is de-rated. The de-rating of the turbine results in the blades being collectively pitched at a lower wind speed. This has the effect of reducing the flapwise aerodynamic loads on the blade and hence the flapwise blade root bending moments. De-rating the generator has a stronger impact on the damage-equivalent loads of the flapwise root moments. This can be explained by the fact that flapwise forces are mainly due to aerodynamic loads whereas edgewise forces are mainly due to gravity. It was also shown that de-rating the controller has a positive impact on the reduction of the mean and the extreme moments in the root of the blade.

The study reported in this paper will address additional turbine structural loads that are impacted by generator de-rating and investigate power output under generator de-rating.

References

Frost, S.A., Goebel, K., & Obrecht, L., "Integrating Structural Health Management with Contingency Control for Wind Turbines," *International Journal of Prognostics and Health Management, A Special Issue on Wind Turbine PHM*, ISSN 2153-2648, 2013 009.

Frost, S.A., Goebel, K., Trinh, K.V., Balas, M.J., & Frost, A.M. (Mar. 2011), Integrating Systems Health Management with Adaptive Controls for a Utility-scale Wind Turbine, *Proceedings AIAA Infotech@Aerospace Conference,* St. Louis, MO.

Jonkman, J.M. & Buhl, M.L. (Aug. 2005), FAST user's guide, National Renewable Energy Laboratory, NREL/EL-500-38230, Golden, Colorado.

Nelson, J.W., Cairns, D.S., & Riddle, T.W. (Jan. 2011), Manufacturing Defects Common to Composite Wind Turbine Blades: Effects of Defects, P*roceedings AIAA Aerospace Science Meeting, Wind Energy Symposium,* Orlando, FL.

Wright, A.D., Balas, M.J. & Fingersh, L.J. (2006), Testing state-space controls for the controls advanced research turbine, *Transactions of the ASME. Journal of Solar Energy Engineering*; 128(4): 506-515.