The Optimization and Return on Investment Modeling for Implementation of LIDAR Systems on Offshore Wind Turbines

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1. Introduction

Concerned by climate change, the exponential growth in carbon dioxide emission production, and geopolitical concerns with fossil fuels, many nations have looked to alternative sources of energy. Offshore wind is a source of interest due to the availability of wind resources and fewer issues from local populations. The potential of offshore wind production in the United States is about 17,000 TWh of energy however, there are efficiency challenges in harvesting the wind kinetic energy. One of these challenges is the accurate measurement of wind direction. The angle between the wind direction and the wind turbine`s rotor in the horizontal plane is called yaw error. The yaw error could be as high as 20 degrees with values around 7 degrees being common. Conventional wind direction detecting methods do not give an accurate reading of the wind direction. Technologies such as light detection and ranging (LIDAR) have been successful in reducing the error to values as low as 1 degree.

2. Approach

We have created a stochastic cost model that simulates the production and O&M costs of offshore wind turbines with and without LIDAR. This model is consisted of two modules, performance and reliability. The first module simulates the power production of offshore wind farms using wind speed data for a New Jersey offshore site in the United States. The second module simulates the degradation of wind turbine assemblies (caused by yaw error) and their subsequent repair and replacement events.

3. Abstract

One of the efficiency challenges of wind turbines is yaw error. Convectional measurement systems do not give an accurate reading for the speed and direction of wind. As a result there is always an inherent error for each turbine. The presence of yaw error reduces the available kinetic energy from a turbine. This reduction for large offshore wind turbines can result in significant revenue loss. However, this is only the performance aspect. Yaw error also creates extra loads on the components of the wind turbine such as blades and the gearbox. This extra loading results in extra stresses, which results in extra damage. This damage over time will result in faster degradation and subsequently earlier than expected failure of components, i.e., reduced reliability. Considering the high costs of components and accessibility challenges of offshore sites for maintenance, reliability impact is an undesired outcome of yaw error.

In this work, we have developed a stochastic cost model that is capable of calculating the return on investment (ROI) for implementation of LIDAR systems on wind turbines. Two modules, which work concurrently, simulate the energy production and O&M costs of a wind farm over its life cycle (e.g., 20 years). The performance module uses a probability distribution for wind speeds generated from the offshore site`s time series data. Unique Weibull distributions are used for each month of year to generate the wind speeds. This module incorporates the effects of yaw errors on the energy production for different

amounts of yaw error. At the same time, this module gives the ideal maintenance opportunity windows based on the weather conditions.

The second module models reliability and predicts the repair and replacement of the wind turbines. This module incorporates corrective and predictive (PHM based) maintenance strategies for O&M. This module uses Weibull reliability distributions for each component to predict the time to failure.

4. Conclusion

The performance module calculate the generated revenue of a wind farm while the reliability module calculates the O&M costs in cases where there is no LIDAR (large constant yaw errors) and cases where LIDAR is used in the wind farm (smaller yaw errors that change over time). We use these values to calculate the ROI for various LIDAR implementations. The implementations include cases where there are one or multiple LIDAR systems in the farm and their circulation frequency among the turbines is varied.

This work will provide wind farm owners and operators quantitative insight on benefits of LIDAR applications in their wind farms.

5. Learning objectives

- Effects of using LIDAR to reduce yaw error on revenue generation of a wind farm
- Effects of using LIDAR to reduce yaw error on the O&M costs of a wind farm
- Determining the ROI for implementing LIDAR
- Optimizing the policy for the use of LIDAR in a wind farm based on ROI