Optimizing the Use of LIDAR in Wind Farms: Minimizing the Life-Cycle Cost Impact of Yaw Error

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Summary

Yaw error lowers the efficiency and reliability of wind turbines resulting in higher maintenance costs. LIDAR devices can correct the yaw error; however, they are expensive, which creates a trade-off between their costs and benefits. In this study, a stochastic discrete-event simulation model is developed that models the operation of a wind farm. We optimize the NPV changes associated with using LIDAR devices in a wind farm to determine the optimum number of LIDAR devices and their associated turbine stay time as a function of number of turbines in the wind farm for specific turbine sizes.

Introduction

A significant contributor to the high cost of electricity production from wind farms is yaw error. Yaw error is the angle between the wind turbine's central axis and the wind flow. Yaw error reduces the energy production while putting extra cyclic loads on the turbine's components, which results in higher maintenance costs.

Inaccurate measurements of wind speed and direction result in formation of a bias in the yaw controller, which results in inaccurate measurements of yaw error known as static yaw error. Yaw error values observed in the field range from a few degrees to as much as 50°, with average values of approximately 7°.

LIDAR devices can be used to measure the wind speed and direction ahead of the turbine by sending laser beams into the air ahead of the turbine. Particles carried by the free wind flow reflect the laser beam and by analyzing the reflection, LIDAR can accurately measure the wind speed and direction. The LIDAR data is then used to correct the yaw controller bias.

In this work, we develop a model that simulates the operation of a wind farm and calculates the cash flows associated with the wind farm. We then use net present value (NPV) as a metric and by optimizing the difference in NPV for cases with and without LIDAR, we determine how many LIDAR devices a wind farm requires and how often they need to be circulated in the wind farm in order to maximize the LIDAR's value.

Model

NPV is the summary of all the operating cash flows (CF). In this case only performance, maintenance and LIDAR cost cash flows are considered,

$$NPV = \sum_{i=0}^{n} CF_i \qquad n\text{: years}$$

$$\Delta NPV = NPV_{LIDAR} - NPV_{no-LIDAR}$$

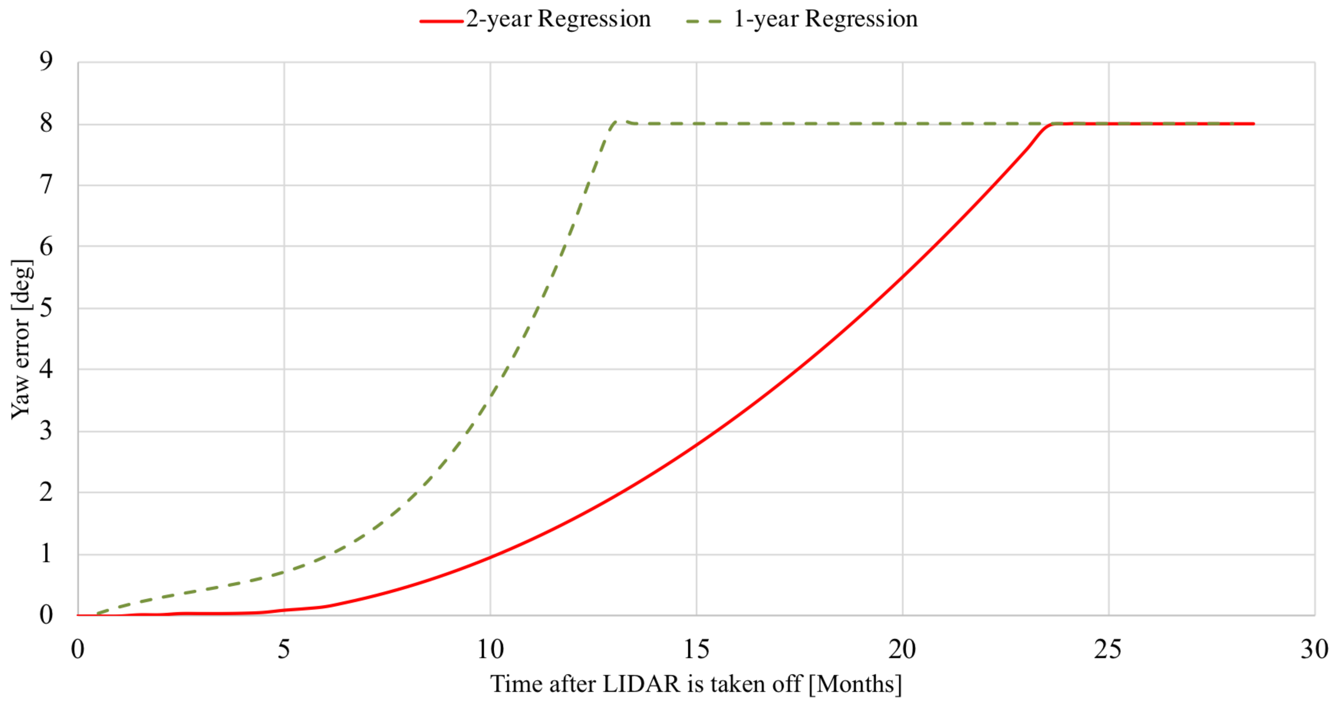
Two cases have to be considered simultaneously. A case where the turbines in the wind farm operate under yawed conditions and a case where there are one or more LIDAR systems circulating between turbines.

The effects of yaw error on energy production can be articulated through cosine of yaw error (α),

$$P = \frac{1}{2} C_p \rho A V^3 cos^3(\alpha)$$

C_p: power coefficient
ρ: air density
A: rotor sweep area

Yaw error behavior once the LIDAR is moved to another turbine is not clear. The yaw controller can stay calibrated for a period of time, then start losing its calibration, or it can lose calibration immediately. In either case, it will eventually stabilize at some maximum yaw error value.



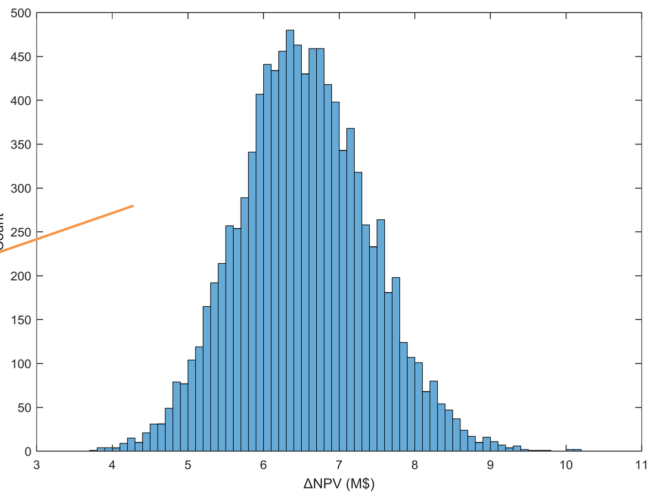
Case Study

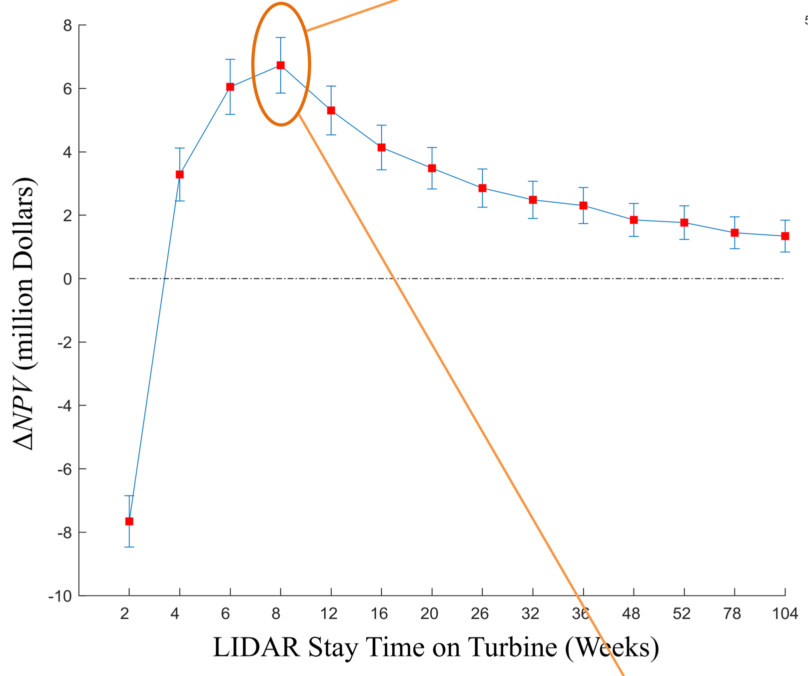
A wind farm with 4MW turbines is considered. The number of wind turbines is a variable. One or more LIDAR devices are circulate between turbines correcting the yaw errors. LIDAR stay time is a variable. A SCADA system indicates which turbine has the largest yaw error and needs the next LIDAR visit. Four components are assumed to be affected by yaw error: blades, generator, gearbox and the pitch control system. Condition-based preventative maintenance is assumed.

LIDAR devices cost $120,000 a piece with average life of 10 years (wind turbine life is 20 years). There is LIDAR maintenance every two years that costs $12,000. The energy price is assumed to be 0.144 $/kWh and a two-year yaw regression profile is assumed.

Results

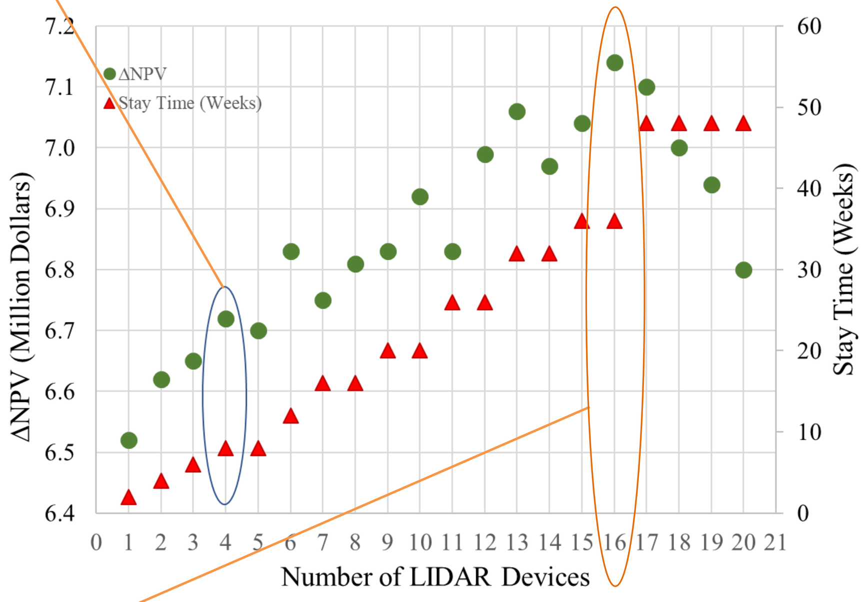
Consider a wind farm with 50 turbines with 4 LIDAR devices that have an 8 week stay time on each turbine they visit.



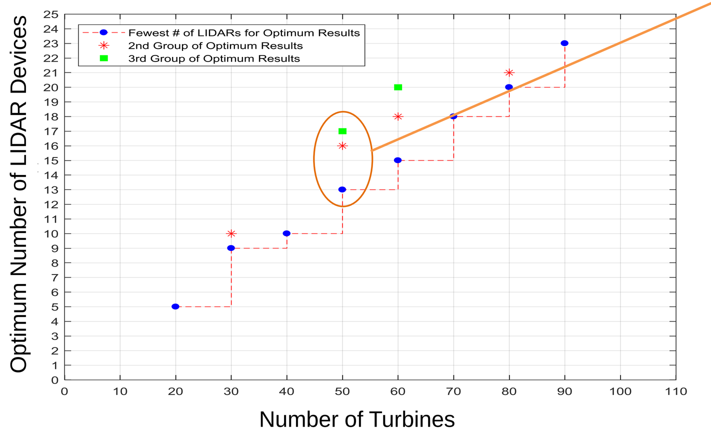


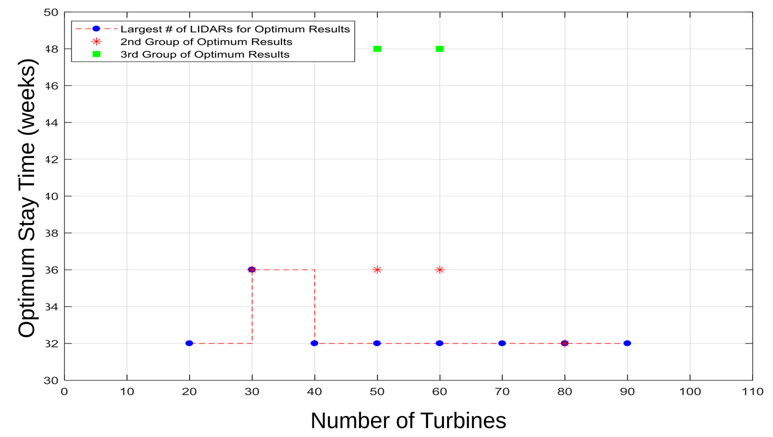
We vary the stay time to find the value that maximizes the ΔNPV. Each point corresponds to a distribution of ΔNPV for the stay time.

The process is repeated for different numbers of LIDAR devices in the wind farm. (the optimum point is not unique).



Final, we vary the number of turbines in the wind farm.





Conclusions

An optimum number of LIDAR and their stay time on a turbine can be determined for a farm of a particular size (number of turbines and turbine size). Determining the optimum usage of the LIDAR can result in significant cost avoidance. This model optimizes the business case for the adoption and use of LIDAR in wind farms.

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