PO.045

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

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Abstract

Light Detection and Ranging (LIDAR) systems are used for wind speed and direction measurements. By using LIDAR, static yaw error (the angle between wind direction and rotor central axis) can be minimized. Minimizing the yaw error will result in extra energy production from wind turbines. Also, the presence of yaw error puts extra cyclic loadings on several turbine components, which increases the damage accumulation and subsequently results in earlier than expected failures. As a result, correcting the yaw error will extend the life of turbine components and avoids maintenance (O&M) costs. However, LIDAR devices are expensive and a detailed analysis and return on investment (ROI) model of the cost benefits is required to make an optimum business case.

Objectives

There is a critical tradeoff between the costs and benefits of using LIDAR. Understanding this tradeoff requires:

- Modeling the connection between static yaw error and reliability
- Modeling the connection between static yaw error and revenue generation
- Developing an O&M model that forecasts the maintenance costs as a function of static yaw error
- Creating a stochastic cost-avoidance based return on investment (ROI) model
- Optimizing the usage policy for the LIDAR

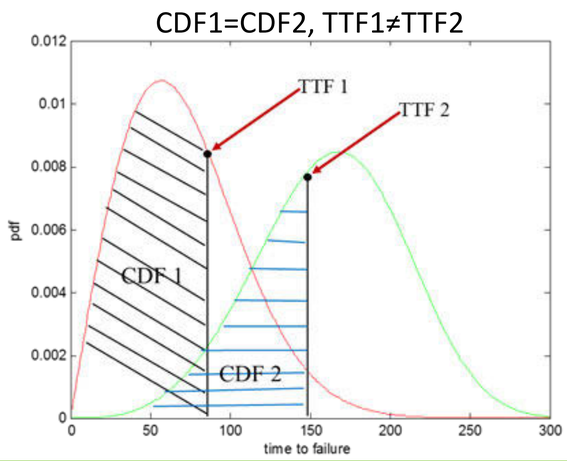
Methods

- The ROI model developed here is a stochastic discrete-event simulator where events (failures and maintenance) are probabilistic and the state of the system (operational or stopped) only changes at discrete points in time
- The ROI calculation is for the support life of the wind farm
- The ROI model includes both revenue generation and the O&M costs of the wind farm

$$\text{ROI} = \frac{(C_{O\&M_{No-LIDAR}} - C_{O\&M_{LIDAR}}) + (R_{LIDAR} - R_{No-LIDAR}) - I}{I}$$

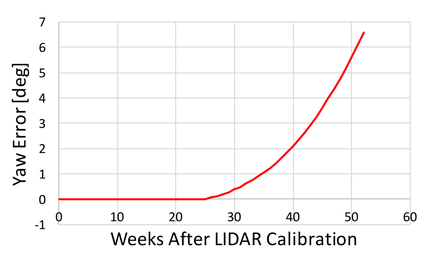
I = Investment
R = Revenue
$C_{O\&M}$ = O&M Cost

- In order to calculate the ROI, a case with LIDAR has to be compared to a case with no LIDAR
- The two cases have to share identical timeline conditions
  - For energy production, the identical condition is the same wind speeds
  - For maintenance costs where LIDAR affects the reliability distributions, the identical condition is the cumulative distribution function of the failure events



Yaw Error Correction

- LIDAR stays on a turbine for a period of approximately two weeks, collects data that will be used for control sensor calibration, then it is moved to the next turbine.
- It is expected that the control sensor remains calibrated and the turbine operates at the minimum yaw for a period of 6 months, then the sensor starts losing calibration and the yaw regresses back to an uncorrected value.



Case Study

Consider an offshore wind farm consisting of 50 wind turbines

- 5 components in a turbine (blades, gearbox, generator, pitch control and electronics). Reliability (time to failure distributions) taken from Spinato et al. [1]
- Maintenance is replacement only and the parts are as good as new

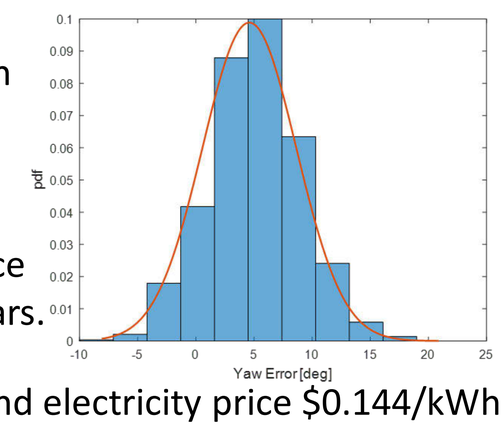
Component	Cost ($) [3]	Downtime (days) [4]
Blade	200,000	7
Gearbox	300,000	5
Generator	150,000	3
Pitch Control	50,000	2
Electronics	10,000	3

- Reliability of all the components except the electronics are affected by the yaw error with the relation [2]:

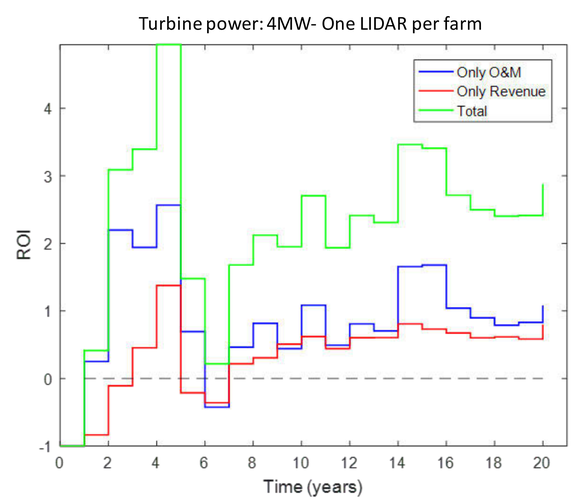
$$N(\alpha) = 0.0139\alpha^3 - 0.1553\alpha^2 + 3.7151\alpha + 0.0733$$

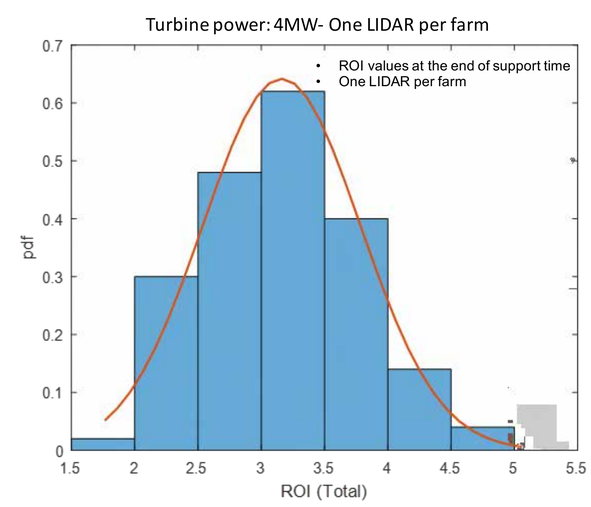
N is the number of cycles to failure representing 63.2% unreliability, which is the same as Weibull scale parameter (α is the yaw error)

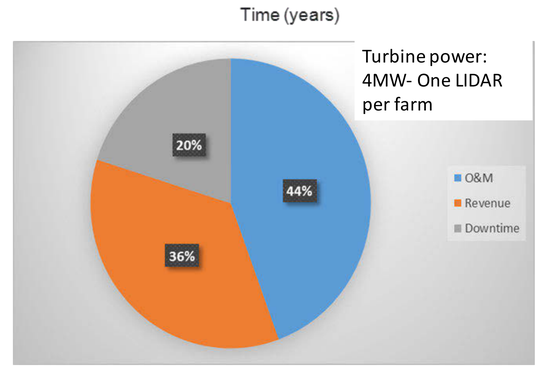
- Values of yaw error are sampled from a probability distribution. This distribution was generated using the empirical yaw error values reported by LIDAR manufacturers and farm owners
- LIDAR cost is $120,000 with maintenance costs of $12,000 required every two years. LIDAR's average life is 5 years
- Discount rate assumed to be 7%/year and electricity price $0.144/kWh



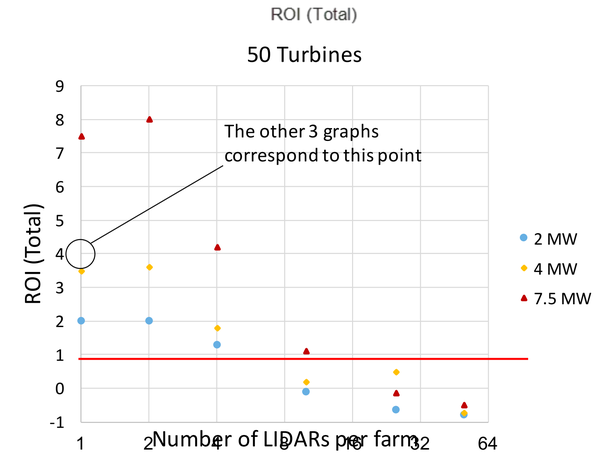
Results







Total cost benefits = dollar value of O&M cost avoidance + extra revenue + revenue loss cost avoidance due to downtime



Conclusions

- ROI is a function of the turbine size, higher ROI values are achieved for larger turbines.
- An optimal number of LIDARs to use in a wind farm can be found. The optimal number depends on the capacity of the turbines.
- Predicting the behavior of yaw error after the LIDAR is taken down is an important variable, which needs further investigation.
- At this point, maintenance is assumed to be replacement, in future work repair events could be added as well.

References

1. F. Spinato, et al., "Reliability of Wind Turbine Subassemblies," IET Renewable Power Generation, 2009.
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3. J. Nilsson et al., "Maintenance Management of Wind Power Systems Using Condition Monitoring Systems -Life Cycle Cost Analysis for Two Case Studies," IEEE Trans on Energy Conversion, 2007.
4. "Windstats Newsletter." Haymarket Media Group.