PO.ID 112

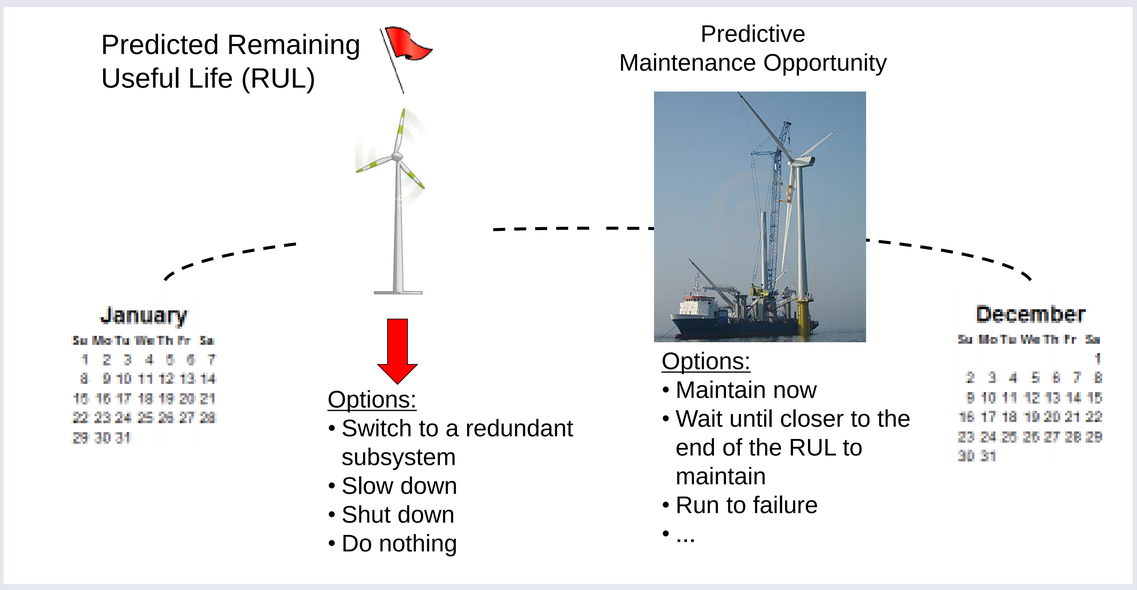
Development of a Maintenance Option Model to Optimize Offshore Wind Farm O&M

Xin Lei, Peter Sandborn, Roozbeh Bakhshi and Amir Kashani-Pour
CALCE, Department of Mechanical Engineering, University of Maryland

Abstract

The prediction and optimization of maintenance activities provides a significant opportunity for wind energy operation and maintenance (O&M) cost reduction. This paper introduces the concept of predictive maintenance options applied to offshore wind farms managed via power purchase agreements (PPAs). For a single turbine, a predictive maintenance option is created by the incorporation of Health Monitoring (HM) or Prognostics and Health Management (PHM) into subsystems such that a remaining useful life (RUL) is predicted as the subsystem's health degrades. The option is exercised when predictive maintenance is performed (based on the RUL) before subsystem or turbine failure; the option expires if predictive maintenance is not performed prior to failure. The concept has been extended to offshore wind farms managed under a PPA with multiple turbines indicating RULs. The time-history paths of cost avoidance and cumulative revenue are simulated with the inclusion of uncertainties in wind and the forecasted RULs. Using a simulation-based real options analysis (ROA) that analyzes a series of "European" style options, possible predictive maintenance opportunities after RUL predictions are analyzed, and the maintenance opportunity that maximizes the value of the predictive maintenance option can be determined.

Motivation

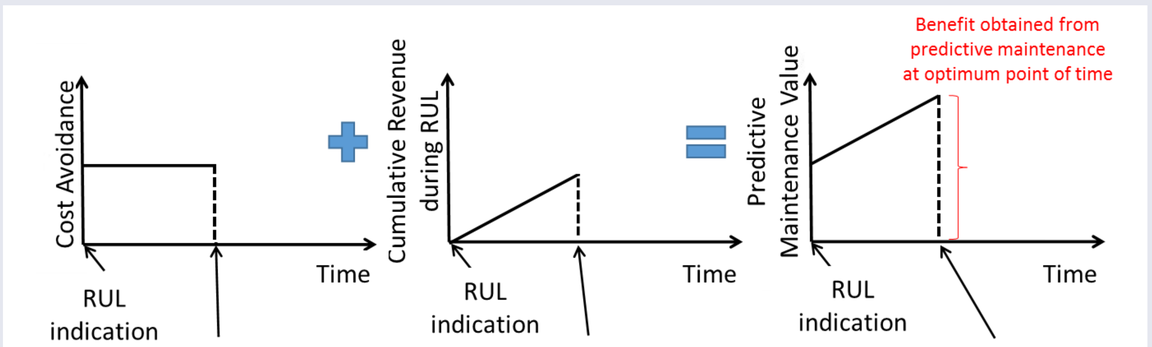


What should be done? --- If the <u>value</u> of each of the *options* could be determined, I would have a basis upon which to make a decision.

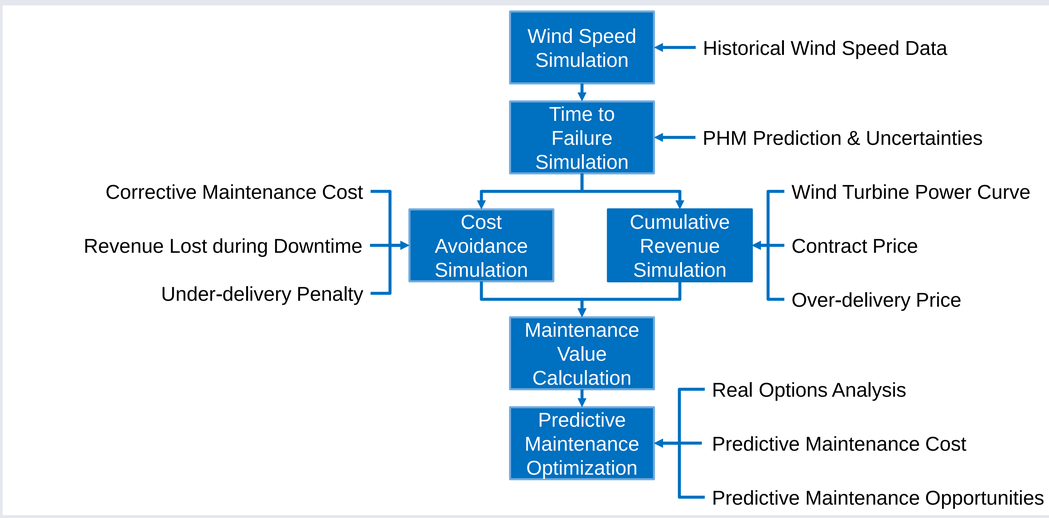
Predictive Maintenance Options

The real options created by Health Monitoring (HM) or Prognostics and Health Management (PHM):

- Buying the option = paying to add HM or PHM into wind turbine subsystems
- Exercising the option = performing predictive maintenance prior to failure
- Exercise price = predictive maintenance cost
- Value returned by the option = cost avoidance and cumulative revenue during the RUL
- Letting the option expire = do nothing and run the turbine to failure



Predictive Maintenance Options



Value Paths Simulation

Wind turbine: Vestas V112-3.0 MW Offshore

Wind speed simulation

- 2003 to 2012 buoy data fit with a Weibull Distribution
- Monte Carlo simulation to get buoy height wind speed paths
- Power Law to transfer buoy height wind speed to hub height

Power Purchase Agreement (PPA) modeling

- Wind farm energy delivery annual target
- Contract price applies before annual target is met
- Over-delivery price applies after annual target is met
- Under-delivery penalty will occur if annual target is not met

Time to Failure (TTF)

- Represents how RUL is used up for the subsystem with RUL prediction (assuming turbine fails thereafter)
- Uncertainties in RUL prediction and wind included

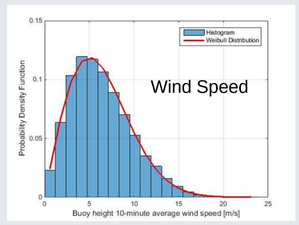
Cost Avoidance (CA)

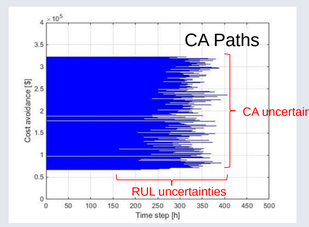
- Maintenance cost (parts, service, labor, etc.) avoidance
- Revenue lost avoidance
- Under-delivery penalty avoidance

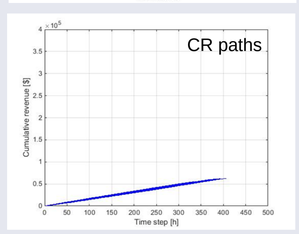
Cumulative Revenue (CR)

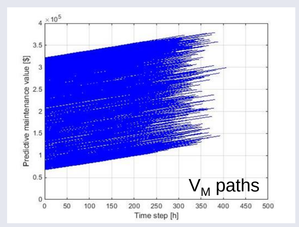
- Revenue earned and accumulated during RUL

Maintenance value: V_M=CA+CR





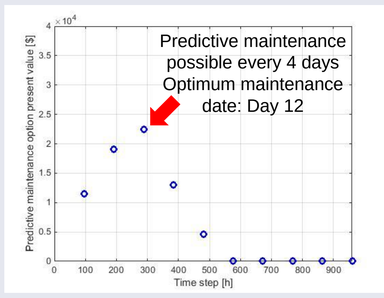


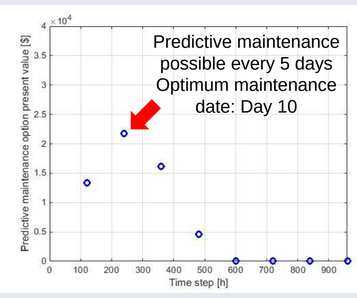


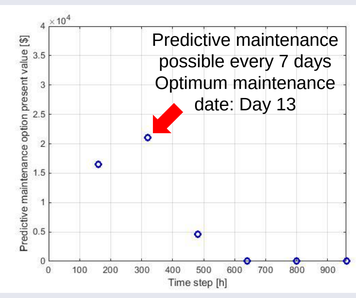
Results

<u>Maintenance Option Valuation (single turbine, single RUL):</u>

- Predictive maintenance can only be performed on specific dates
- This makes the option a sequence of "European" style options
- Given a fixed maintenance opportunity date, European Real Option Analysis (ROA) is performed to obtain the present option value
- The analysis is repeated for different maintenance opportunity dates to determine the optimum maintenance date

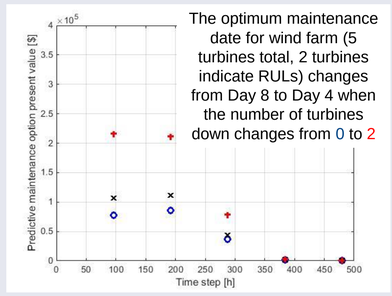


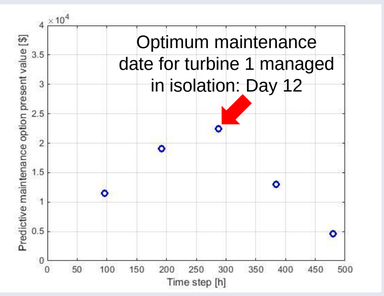


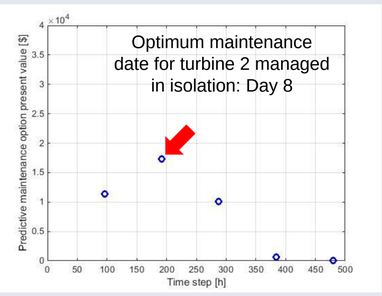


<u>Maintenance Option Valuation (multiple turbines, multiple RULs):</u>

- Multiple turbines in a farm may have RULs during the same period of time
- There may also be turbines that are not operating for other reasons
- Simulated based ROA on multiple turbines:
  - Add value paths of each turbine with RULs together
  - Do ROA on the combined value paths
  - Maintenance cost avoidances for all turbines with RULs summed
  - Exercising the option = performing predictive maintenance on all turbines with RULs on same date
  - Exercise price = sum of predictive maintenance costs for all turbines with RULs
  - Value returned by the option = sum of cost avoidances (CA) and cumulative revenues (CR) up to the first turbine failure of all turbines with RULs
  - Letting the option expire = do noting till the first turbine failure happens
- Incorporating an Availability-based PPA
  - The value of the energy produced by turbines with RULs varies depending on the states of the other turbines in the farm
  - The total energy delivery from all turbines must be calculated for under-delivery penalty avoidance
  - The total revenue of all turbines must be calculated for revenue lost avoidance







Conclusions

The goal of the analysis described in this paper is to find the optimum maintenance schedule for wind farms that are subject to a PPA that may include variable rates and penalties. Uncertainties in wind and the accuracy of the RULs forecasted by PHM are included. The predictive maintenance options approach demonstrates that the optimum maintenance plan for the turbines in a farm subject to a PPA is not the same as the optimum maintenance plan for individual turbines managed in isolation.

OFFSHORE 2015 COPENHAGEN ORGANISED BY EWEA

EWEA Offshore 2015 – Copenhagen – 10-12 March 2015