Opportunistic Maintenance for Offshore Wind Farms

Petros Papadopoulos, David W. Coit, Ahmed A. Ezzat
Department of Industrial & Systems Engineering, Rutgers University

Introduction

- Wind energy is set to supply 35% of the nation’s electricity by 2050. As of 2019, this percentage stands at 7.3%.
- Operations & Maintenance (O&M) costs are a major contributor to wind’s cost of energy, and hence, its economic outlook (-30% of total wind energy cost).
- The O&M costs are even higher for offshore wind due to:
  1. Limited accessibility (i.e. dozens of miles off the shores).
  2. High production losses (i.e. 12MW turbines).
  3. Safety considerations (i.e. harsh wind & wave conditions).
- The industrial practice for O&M planning is mostly reactive, while most research studies are agnostic to offshore settings.
- We propose an offshore-specific opportunistic maintenance scheduling strategy based on mixed integer linear programming (MILP) which minimizes the total maintenance costs by:
  1. Grouping maintenance tasks whenever possible.
  2. Scheduling maintenances during low-wind periods.
  3. Considering site accessibility and safety considerations.

An Insight to the Mathematical Model

- The time framework is split into two horizons:
  1. Short-term horizon (STH): hourly intervals $t = 1, ..., 24h$ ahead
  2. Long-term horizon (LTH): daily intervals $d = 2, ..., 15d$ ahead
- Profits are combined into a single objective function:

$$
\text{max} \quad S + \sum_d l^d \\
\text{Short-term profit} + \text{Long-term profit}
$$

- Short-term profits (for the day-ahead planning):

$$
S = \sum_t \left[ (R_{\text{pt}}^t - K_{\text{m}}^t - \Phi n_{x}^t - \psi \tau m_{x}^t + n_{d}^t) - \Xi v - Qq \right]
$$

- Long-term profits (for long-term planning):

$$
l^d = \sum (R_{\text{pt}}^d - K_{\text{m}}^d - \Phi n_{x}^d - \psi \tau m_{x}^d + n_{d}^d) - \Xi v^d
$$

- Other constraints include:
  - Crew access.
  - Turbine availability & power output.
  - Maintenance actions.
  - Residual life estimates (RLEs).

Case Study

- Assume 10 turbines with 5 MW capacity per turbine.
- Wind speed and wave height is obtained via NYSERDA’s deployed Buys at a potential wind farm site off New York.
- Power data is obtained from an operational wind farm in the US, as a fraction of the nominal capacity of the wind turbine.
- Wind and RLE forecasts are assumed to be available.
- Wind power curves are estimated using the method of bins to calculate the power output as a function of wind speed.

- Crew access on offshore wind turbines is performed with crew transport vessels (CTVs); access is restricted when:
  1. Wave height (Average) > 1.5 m (for a medium-sized CTV).
  2. Wind speed (Average) > 15 m/s (for the turbine’s nacelle).

Results

- The optimization is performed using GAMS on a standard laptop by IBM’s CPLEX solver; the average solution time < 30 sec for an optimality gap < 0.1%.
- Our opportunistic model is solved for 80 different weather profiles, and compared to 3 other strategies:
  1. Non-opportunistic: no accessibility, no vessel dispatch costs.
  2. Time-based: maintenance performed at or near the RLE.
  3. Reactive: corrective maintenance only.

Conclusions & Contribution

- From the comparison, it seems that our model yields the best result in all scenarios.
- The model presented is efficient both cost-wise and computation-wise.
- Study highlights the importance of employing our opportunistic strategy, compared to other popular strategies followed in the literature and practice of offshore wind energy.

Contact

Petros Papadopoulos
Email: petros.papadopoulos@rutgers.edu
Phone: (732) 470 4579

References

- For a full list of references please contact: petros.papadopoulos@rutgers.edu