# A stochastic model for opportunistic maintenance planning of offshore wind power systems

## Workshop on Optimization of Maintenance Activities Models, Methods and Applications Chalmers, Göteborg

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**On Optimal Maintenance Management for Wind Power Systems**

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Continuation of the project at Chalmers.





## Outline

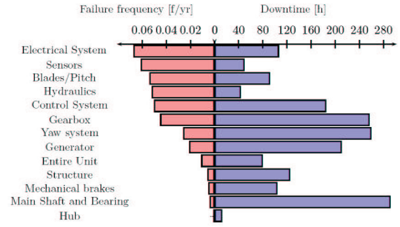


Photo: Lina Bertling





## Reliability




(Adapted from "Survey of failures in wind power systems with focus on Swedish wind power plants during 1997-2005", J. Ribrant and L.M. Bertling, IEEE Transaction on Energy Conversion, vol.22, num.1, 2007)

- Costs for the maintenance (spare part, staff, transportation, equipment)
- Costs for production losses (logistic & repair times)

Need for optimizing maintenance strategies and maintenance planning.





## Offshore wind energy

EWEA installed capacity target: 65GW in 2008 → 180GW in 2020 (Europe), incl. 1.3% offshore wind in 2008 → 20% in 2020.

Advantages of offshore wind power:
- High and steady wind
- Low visual and noise impacts

But implies:
- High initial investment costs
- High maintenance costs
  - Transportation
  - Accessibility constraints → High downtime





## Maintenance today

- Corrective maintenance (SCADA detection)
- Scheduled preventive maintenance e.g:
  - Oil sampling & analysis for the gearbox
  - *Visual inspection blades
  - Inspection of safety systems
- *Online vibration monitoring for the drive train

Some ideas for reducing maintenance costs:
- Optimized condition based maintenance decisions
- **Optimal maintenance planning with the use of opportunistic maintenance**

## Objective

Scheduled preventive maintenance is performed at fixed time period, no consideration for production and transportation costs.

Fixed time → Time window

**Objective**: To perform scheduled preventive maintenance at the lowest cost possible by taking advantage of:

- Corrective maintenance
- Low production

**Approach**: Mixed integer linear problem with one stage recourse. Improvement of a deterministic model inspired by the aircraft opportunistic model.





## Assumptions

- Wind and power production forecasts for next 6 days (with growing uncertainties)
- Statistical power production distributions for longer horizon

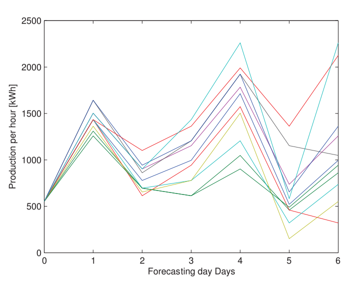
The model consists of:

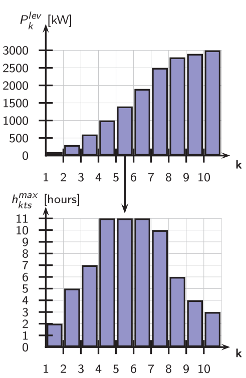
- Rolling horizon, i.e. daily re-scheduling
- 2 months horizon (today, recourse stage with short: 6 days + middle: 3 weeks + long: 1 month)
- Wind and production uncertainties → Generate scenarios





## Forecasting - Examples








## Constraints

- Perform preventive maintenance tasks in the remaining time window
- Perform corrective maintenance tasks in the short horizon
- Maximum number of working hours per day (short horizon)
- Maximum number of working hours at specific power production level (middle and long horizons)
- Maximum wind speed for accessibility





## Sets

$T_{short}$ Set of short horizon time steps
$T_{middle}$ Set of short horizon time steps
$T_{long}$ Set of long horizon time steps
$WT$ Set of wind turbines
$PM$ Set of preventive maintenance tasks
$CM \subset WT$ Set of wind turbines requiring corrective maintenance
$S$ Set of wind/production forecasting scenarios





## Decision variables I

$$nx_{ij} = \begin{cases} 1 & \text{if preventive maintenance task } j \text{ in wind turbine } i \text{ is performed the present day} \\ 0 & \text{otherwise,} \end{cases}$$
$$i \in WT,\ j \in PM$$

$$ny_i = \begin{cases} 1 & \text{if corrective maintenance task in wind turbine } i \text{ is performed the present day} \\ 0 & \text{otherwise,} \end{cases}$$
$$i \in CM$$

## Decision variables II - Recourse stage

$$x_{ijts} = \begin{cases} 1 & \text{if preventive maintenance task } j \text{ in wind turbine } i \text{ is performed at step } t \text{ for scenario } s \\ 0 & \text{otherwise,} \end{cases}$$

$i \in WT,\ j \in PM,\ t \in T_{short} \cup T_{middle} \cup T_{long},\ s \in S$

$$y_{its} = \begin{cases} 1 & \text{if corrective maintenance task in wind turbine } i \text{ is performed at step } t \text{ for scenario } s \\ 0 & \text{otherwise,} \end{cases}$$

$i \in CM,\ t \in T_{short},\ s \in S.$





## Auxiliary variables I

$$nz = \begin{cases} 1 & \text{if the wind park is visited the present day} \\ 0 & \text{otherwise,} \end{cases}$$

$$nv_i = \begin{cases} 1 & \text{if the WT } i \text{ is visited the present day} \\ 0 & \text{otherwise,} \end{cases}$$

$i \in WT$

$ne$ Supplementary maintenance hours for the present day





## Auxiliary variables II - Recourse stage

$$z_{ts} = \begin{cases} 1 & \text{if the wind park is visited at step } t \text{ for scenario } s \\ 0 & \text{otherwise,} \end{cases}$$

$t \in T_{short},\ s \in S$

$$v_{its} = \begin{cases} 1 & \text{if the WT } i \text{ is visited at step } t \text{ for scenario } s \\ 0 & \text{otherwise,} \end{cases}$$

$i \in WT,\ t \in T_{short},\ s \in S$

$e_{ts}$ Supplementary maintenance hours at time step $t$, $t \in T_{short}, s \in S$

$h_{tks}$ Maintenance hours used at production level $k$ at step $t$ for scenario $s$, $t \in T_{middle} \cup T_{long},\ k \in \{1, ..., L\},\ s \in S$





## Objective function

$$\min \overbrace{nz \cdot C_{tr}}^{\text{Transport cost}} + \overbrace{ne \cdot C_{pen}}^{\text{Penalty work hours}} + \Big[\overbrace{\sum_{i \in CM} ny_i \cdot P_1^{CM}}^{\text{CM loss costs}} + \overbrace{\sum_{ij} nx_{ij} \cdot \tau_j^{PM} \cdot P_1}^{\text{PM loss costs}}\Big] \cdot C_{el}$$

$$+ \frac{1}{N_s} \sum_{s \in S} \Bigg[ \overbrace{\sum_{t \in T_{short}} \Big[ z_{ts} \cdot C_{tr} + e_{ts} \cdot C_{pen} + \Big[ \sum_{i \in CM} y_{its} \cdot P_{ts}^{CM} + \sum_{ij} x_{ijts} \cdot \tau_j^{PM} \cdot P_{ts} \Big] \cdot C_{el} \Big]}^{\text{Short horizon PM loss and transport costs}}$$

$$+ \overbrace{\sum_{t \in T_{middle} \cup T_{long}} \Big[ \sum_k h_{tks} \cdot (P_k^{lev} \cdot C_{el} + \frac{C_{tr}}{h - 2 \cdot \tau_w}) \Big]}^{\text{Middle/Long horizon PM loss and transport costs}} \Bigg]$$





## Constraints I

Force the CM and PM task to be performed in the short horizon:

$$ny_i + \sum_{t \in T_{short}} y_{its} = 1, \qquad i \in CM,\ s \in S$$

$$nx_{ij} + \sum_{t=1}^{w_{ij0}} x_{ijts} = 1, \qquad i \in WT,\ j \in PM,\ s \in S.$$

Wind park and wind turbine access constraints:

$$nz \geq nv_i, \qquad i \in WT,$$

$$nv_i \geq nx_{ij}, \qquad i \in WT,\ j \in PM,$$

$$nv_i \geq ny_i, \qquad i \in WT.$$





## Constraints II

Working hours constraints:

$$\sum_{ij} nx_{ij} \cdot \tau_j^{PM} + \sum_i ny_i \cdot \tau_i^{CM} + nv_i \cdot \tau_w \leq h + ne,$$

$$\sum_{ij} x_{ijts} \cdot [\tau_j^{PM} + \tau_w/2] = \sum_{tk} h_{tks}, \qquad t \in T_{middle} \cup T_{long}$$

$$h_{tks} \leq h_{tks}^{max}, \qquad t \in T_{middle} \cup T_{long}, k \in \{1, ..., L\}.$$

Accessibility constraints:

$$nz \cdot w_1 \leq V_{lim}.$$

## Example

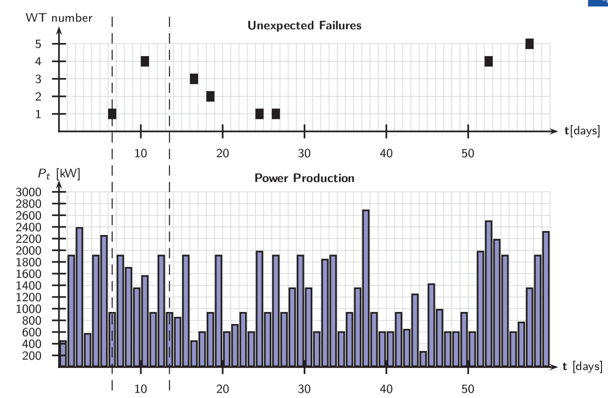
- Five 3 MW wind turbines, 60 days scenario
- Yearly service maintenance 2 days per wind turbine
  → 4 PM tasks of 3/4 h within 10, 20, 30 and 50 days
- Model with 10 forecasting scenarios

- The model has been implemented in GAMS with CoinCbc.





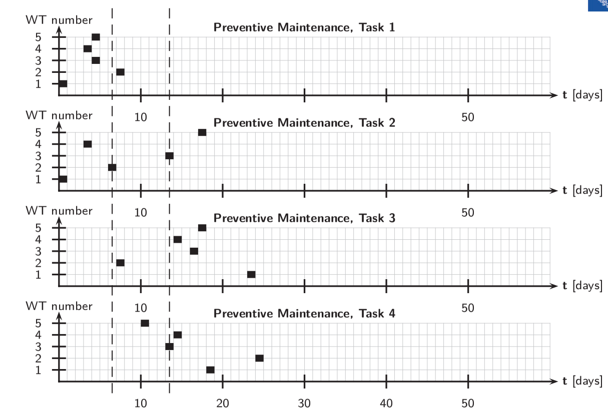
## Scenario








## Solution








## Results

- Scheduled preventive maintenance is always performed at low wind speed or failure occasions.

- Costs with opportunistic maintenance: 15172 €
- Costs for a fixed time period: 22342 €

  → Transportation and production losses costs reduced by 7170 €, 32% cost reduction
  → On a 25 years lifetime ≈ 180000 €





## Conclusion

- A stochastic opportunistic maintenance optimization model to take advantage of corrective maintenance and low production to minimize costs for performing service maintenance.

  It provides the maintenance manager with maintenance tasks to be performed each day.

- A case study will be done at Lillgrund wind power system, South of Sweden
- Possible improvements: hours steps for the first day, failure scenarios
- Application to major maintenance





Thank you for your attention!

Questions?