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# Input data used for "Integration of Degradation Processes in a Strategic Offshore Wind Farm O&M Simulation Model"

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This note describes the input data used for the NOWIcob model when carrying out the case study presented in the paper "Integration of Degradation Processes in a Strategic Offshore Wind Farm O&M Simulation Model". The NOWIcob model is developed by SINTEF Energy Research and first described in [1]. The input data format is described in detail in the user guide [3], and the modelling assumptions are described in detail in the technical documentation [2]. The weather model that is implemented in NOWIcob is described in more detail in [4]. A general description of the NOWIcob model and links to additional related publications can also be found at the web site for the NOWIcob model[1].

For the work presented in this paper, version 3.0 of the model was used, code revision dated 2016-08-11. The existing NOWIcob code was used for loose integration of the degradation model whereas a separate branch of the code base was created to test full integration. As the source code of NOWIcob is protected by SINTEF Energy Research, it is not released as supplementary material together with this paper.

The offshore wind farm scenario used for the case study is based on [5] and was also described in more detail in a restricted deliverable from the LEANWIND project (D4.2, executive summary available online[2]). Table 1 contains the values of general parameters describing the offshore wind farm scenario. More detailed description of the different parameters can be found in the documentation of the input data of the NOWIcob model [3]. The wind turbine is based on the LEANWIND 8 MW reference wind turbine described in [6].

Table 2 specifies the failure and maintenance data set that was used. It is based on the data set in [5], which in turn is based on similar data sets explained in more detail in [7] and [8]. For the blade degradation case study, the maintenance category "Minor repair" is used as the condition-based maintenance task and "Major replacement" is used for the corrective maintenance task. "Major replacement" tasks maintenance tasks require a jack-up vessel; all other maintenance tasks only require a crew transfer vessel. Before a "Major replacement" or "Major repair" task can be scheduled, a "Pre-inspection for Major replacement" has to be carried out to assess the damage and the need for spare parts. In the variant of the case study where the full data set is used, the "Major replacement" maintenance tasks in Table 2 come in addition to the "Major replacement" maintenance tasks associated with blade degradation.

[1] http://www.sintef.no/en/projects/nowicob-norwegian-offshore-wind-power-life-cycle-c/

[2] http://www.leanwind.eu/wp-content/uploads/LEANWIND_D4.2_Executive-Summary.pdf

**Table 1.** General wind farm scenario data, based on [5].

| Parameter | Value |
|---|---|
| Number of turbines | 125 |
| Wind turbine power rating | 8 MW |
| Distance to shore | 30 km |
| Inner wind farm average distance – planned (preventive maintenance tasks) | 8.0 km |
| Inner wind farm average distance – unplanned (corrective maintenance tasks) | 1.5 km |
| Hub height | 115 m |
| Lost production due to downtime electrical infrastructure | 0.0 % |
| Fuel price for vessels | 0.6 €/l |
| Working shift | 07:00–19:00 |
| Minimum working time | 3 h |

**Table 2.** Failure and maintenance data set, based on [5].

| Maintenance task | Failure rate [per turbine per year] | Active maintenance time [h] | Spare part lead time [days] | Spare part costs [€] | Logistics time [h] | Number of technicians required |
|---|---|---|---|---|---|---|
| Manual resets | 5 | 3 | 0 | 238 | 0.0 | 2 |
| Minor repair | 3 | 7.5 | 0 | 5 279 | 0.2 | 3 |
| Major repair | 0.3 | 22 | 10 | 29 320 | 0.2 | 4 |
| Major replacement | 0.11 | 34 | 60 | 400 000 | 0.0 | n/a |
| Pre-inspection (for Major repair/replacement) | n/a | 7.5 | 0 | 0 | 0.0 | 2 |
| Annual service | n/a | 64 | 0 | 0 | 0.2 | 3 |
| Blade inspections | n/a | 6 | 0 | 0 | 0.2 | 2 |

The task "Blade inspection" is added to represent the inspection strategy in the case study, and it is scheduled from the beginning of January each year. Although this inspection strategy is not realistic for offshore wind farms, it is chosen to test the impact of weather conditions on the results from loose and full integration of degradation. For the loose integration, it is represented as a predetermined preventive maintenance task. "Annual service" is a predetermined maintenance task that is scheduled to start in the beginning of April each year. For inspections and predetermined maintenance tasks, turbine downtime is only incurred during active maintenance, i.e. while technicians are working in or at the wind turbine. For all the other maintenance categories in Table 2, turbine downtime is incurred from the time that a failure occurs and until the maintenance task is complete. Completion of these maintenance tasks are given priority over the condition-based maintenance tasks, which in turn have higher priority than predetermined preventive maintenance tasks and inspections.

Table 3 and Table 4 show data for the vessels used to carry out O&M at the offshore wind farm. For the wind farm scenario that was assumed for the case study, the vessel fleet consisted of one Standard Crew Transfer Vessel and two Advanced Crew Transfer Vessels. Whenever the maintenance task requires a crew transfer vessel, either of these types of crew transfer vessels can be used, and the NOWIcob model chooses which vessel to use. It is assumed for this case study that the number of technicians available at the O&M base is not a restriction. Technician cost is not explicitly included in the O&M cost. The operation of the crew transfer vessels is limited to a 12-hour working shift, whereas the jack-up vessel operates 24 hours a day while carrying out maintenance tasks. For fix-on-failure charter of jack-up vessels, the charter duration is 10 days, the mobilisation time is 30 days, and the mobilisation cost is 840 000 €.

**Table 3.** Vessel data, based on [5].

| Vessel | Vessel speed [knots] | Technician space | Day rate [€] | Fuel consumption travelling [l/hour] | Fuel consumption stationary [l/hour] |
|---|---|---|---|---|---|
| Standard Crew Transfer Vessel | 22 | 12 | 3400 | 350 | 50 |
| Advanced Crew Transfer Vessel | 35 | 12 | 6200 | 500 | 50 |
| Jack-up vessel | 12 | n/a | 140 000 | n/a | n/a |

**Table 4.** Vessel operational phases data, based on [5].

| Vessel | Operational phase | Duration | Wave height limit [m] | Wind speed limit [m/s] |
|---|---|---|---|---|
| Standard Crew Transfer Vessel | Approach / docking | 5 min | 1.5 | n/a |
| Standard Crew Transfer Vessel | Technician transfer | 2 min /person | 1.5 | n/a |
| Advanced Crew Transfer Vessel | Approach / docking | 15 min | 2.0 | n/a |
| Advanced Crew Transfer Vessel | Technician transfer | 6 min /person | 2.0 | n/a |
| Jack-up vessel | Positioning / jacking up | 6 h | 1.8 | n/a |
| Jack-up vessel | Lifting / repair / replacement | 24 h | n/a | 11 |
| Jack-up vessel | Jacking down | 4 h | 1.8 | n/a |

Table 5 specifies the weather data sets that were used for the case study. The West Gabbard data set is only available for use within the LEANWIND project and cannot be released. On the other hand, FINO1 and Heimdal data sets are made available as supplementary material (S3 and S4, respectively). Note that the FINO1 data set can only be used in agreement with Bundesamt für Seeschifffahrt und Hydrographie [9]. The format for the weather data sets is described in Ch. 4.1 of [3]. In the Markov chain weather model [4], a wind speed resolution of 1 m/s and a wave height resolution of 0.1 m was used.

**Table 5.** Weather data sets.

| Name | Time period | Mean significant wave height | Location | Source | Comments |
|---|---|---|---|---|---|
| West Gabbard | Jan 2001 – Dec 2010 (time resolution 1 h) | 1.10 m | (N 51° 98' E 2° 08') | University of Edinburgh | Hindcast data set restricted to use in the LEANWIND project. Wind speeds at 110 m a.s.l. (extrapolated from 100 m using power law with wind shear exponent 0.14). |
| FINO1 (S3) | Jan 2004 – Dec 2012 (time resolution 1 h) | 1.48 m | FINO1 met mast, adjacent to the Alpha Ventus wind farm (N 54° 00' E 6° 35') | FINO database (http://fino.bsh.de/) [9] | Preprocessed by Iain Dinwoodie, Strathclyde University. (Gaps filled using cubic spline interpolation.) |
| Heimdal (S4) | Jun 2004 – Jun 2009 (time resolution 20 min) | 2.21 m | Heimdal platform in the Norwegian North Sea | Norwegian Meteorological Institute (http://www.eklima.no/) [10] | |

## References

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