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Towards a risk-based decision support for offshore wind turbine installation and operation & maintenance

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Abstract

Costs of operation & maintenance, assembly, transport and installation of offshore wind turbines contribute significantly to the total cost of offshore wind farm. These operations are mostly carried out by specific ships that have to be hired for the operational phase and for duration of installation process, respectively. Duration, and therefore ship hiring costs is, among others, driven by waiting time for weather windows for weather-sensitive operations. Today, state of the art decision making criteria for weather-sensitive operations are restrictions to the significant wave height and the average wind velocity at reference height. However, actual limitations are physical, related to response of equipment used e.g. crane wire tension, rotor assembly motions while lifting, etc. Transition from weather condition limits to limits on physical equipment response in decision making would improve weather window predictions, potentially reducing cost of offshore wind energy. This paper presents a novel approach to weather window estimation using ensemble weather forecasts and statistical analysis of simulated installation equipment response.

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Keywords: decision support, offshore, wind turbine, marine operations, installation, risk, probability, weather window.

1. Introduction

Cost of transport and installation of offshore wind turbines and foundations contributes to 15-20% [1] of total wind farm capital expenditure, furthermore, operation and maintenance activities typically contribute to 25-30% of the total Levelized Cost of Energy of an offshore wind farm. All these activities have one common limiting factor – limited access to an offshore location due to ever-changing met-ocean conditions. The high importance of met-ocean conditions offshore is usually a consequence of high weather sensitivity of the equipment and vessels used for transportation, installation or operation & maintenance activities.

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Typically, accessibility to a certain offshore location is expressed in terms of weather windows, during which operations can be performed, and waiting times for such weather windows. The state-of-the-art in weather window estimation today is limited to use of simple met-ocean parameters, such as wind speed at reference height and significant wave height. However, the limitations are inherently physical - related to response of equipment and vessels used for offshore operations, e.g. maximum lifting capacity of crane cables, allowable motions and accelerations of lifted components, etc. Computer software can be used to simulate responses of installation equipment under given met-ocean conditions and statistical methods can be applied to assess the probabilities of extreme response occurrence.

Moreover, weather forecasts used to predict accessibility to an offshore location are not precise. Uncertainties related to weather forecasting have an impact on the quality of accessibility predictions. The state-of-the-art way of addressing these uncertainties when predicting weather windows, is limited to simply scaling down the met-ocean condition limits by the use of an *"alpha-factor"* [2], thus making the limits more conservative. However, multi-ensemble forecasts capture the forecasting uncertainties quite well and can be used within the proposed new approach. It should be noted that use of ensemble forecasts is mentioned in [2] as an alternative to tabulated *alpha-factors*, but the procedure is not explicitly described. Also, some marine operations can be highly sensitive to incoming wave period. Current practice does not have clearly defined ways of taking wave periods or uncertainties, related to wave period forecasting, into consideration when estimating weather windows. Both are considered when using computer simulations, since ensemble forecasts of wave period is always used as part of met-ocean state description.

This paper looks into possible improvements on weather window predictions by using actual physical limits of transportation, lifting and other relevant installation equipment and proposes a new approach of assessing the effect of forecasting uncertainties on weather window predictions. This is done by statistically analyzing equipment response time series and estimating probabilities of responses exceeding certain critical limits. Furthermore, multi-ensemble weather forecasts are used to quantify the impact of forecasting uncertainties on the predicted weather windows.

"Proof of concept" of the proposed methodology is demonstrated by a case study of offshore wind turbine installation. It should be noted that the methodology is very general and field of application is relatively wide. The proposed methodology can be applied to any offshore operation, given that reasonable limits on equipment responses can be established and responses can be quantified.

Nomenclature

ECMWF	European Centre for Medium-Range Weather Forecasts
POT	Peak-Over-Threshold analysis
$F_{local}(r \le R_{ac(i)})$	Local cumulative distribution function of extreme equipment response
$E\,[n_p]$	Expected number response of peaks (extremes) per realization of forecasted ensemble sea state
$R_{ac(i)}$	Specific (*i*-th) acceptance criterion
$P_{non-exc,ens(j)}$	Cumulative distribution function of extreme equipment response, adjusted for number of peaks, when (*j*-th) weather forecast ensemble member is considered
$f(R \mid \mu_{LN}, \sigma_{LN})$	Probability density function of acceptance criterion, with μ_{LN}, σ_{LN} parameters.
$R, \Delta R$	Range of acceptance criteria used for acceptance criterion distribution
$P_{F,ac(i),ens(j)}$	Probability of failure when a specific (*i*-th) acceptance criterion is exceeded and one (*j*-th) weather forecast ensemble member is considered
N_{ac}	Number of acceptance criteria for a given operation and number of
N_{ens}	Number of ensemble members in a weather forecast
$P_{F,ac(i)}$	Probability of failure when a specific (*i*-th) acceptance criterion is exceeded
$P_{F,Op}$	Probability of failure of the whole operation