Thesis proposal

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Reliability-based design optimization (RBDO) of a floating offshore wind turbine for the ultimate limit state.

Supervision

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Duration: 3 years

Localisation: IFPEN Rueil-Malmaison, Direction Sciences et Technologies du Numérique

Requirements: master's degree in applied mathematics with background in statistics, less than 27 years old at start

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Context and motivations

The development of offshore wind turbines is an important element of the international energy transition policy. Although production costs have fallen sharply in this sector in recent years, its growth requires further progress. This is particularly the case for floating wind power, which allows turbines to be installed in more favorable wind conditions. Significant gains can be made in design by using numerical models and optimization tools that take into account reliability constraints as well as different sources of uncertainty (environmental, model and turbine real structure). The difficulty explaining the unavailability of these methods in industrial projects is that this optimization is constrained by small annual failure probabilities, of the order of 10^{-4}, which imply too many simulations. The representativeness of the wave and wind scenarios seen by the structure also implies the management of a large number of cases, of the order of thousand.

Background

In [Cousin et al, 2021] and [Cousin et al, 2022] we proposed a new reliability optimization method applied to the design of anchor lines under structural fatigue-based reliability constraints. This method exploits the stationary and Gaussian nature of the floater motions and tension in the anchor lines, assuming that a linearized frequency-domain calculation gives an acceptable approximation for this fatigue limit state. It was thus possible to reformulate the reliability constrained optimization problem

with the extreme value theory to eliminate the time dependence on threshold overshoot constraints, and using the law of large numbers for the fatigue stress. We then proposed an active kriging approach adapted to this formulation which allows to obtain a good estimation of the solution with a considerably reduced number of calls to the simulator compared to known approaches in the literature (e.g. PMA, RIA, see [Cousin et al, 2021]). While this result is very promising for an application in the industrial setting, it has only been designed for a very simplified discretization of the environmental uncertainty.
Moreover, using linearized frequency domain computation does not allow the dedicated multi-physics software available (DeeplinesWindTM) to take into account the influence of aerodynamic loading with turbine operation, nor to apply this method to reliability norms with respect to extreme environmental conditions.

Proposed approach

We propose to take up the challenge of redefining a reliable optimization approach able to deal with the described non-linear effects and non-stationary extreme environmental conditions. The envisaged method would still consist in exploiting the extreme value theory [Leadbetter 1983] but in a non-Gaussian framework [Azaïs 2008]. We also wish to reduce the computational cost as much as possible by using adaptive and multi-fidelity meta-models: the full code acting as a high-fidelity model and the linearized code as a low-fidelity model) [Le Gratiet 2013, Perdikaris 2017]. To further the efficiency, dimension reduction methods for functional data will be investigated [Tian 2013]. Another challenge will be the implementation of an approach which is accurate enough in the tail distribution of joint probability for wind and wave. This accuracy is required to get a statistical description of the extreme limit states when computing the targeted low failure probability. The deployment of the strategy will first be conducted on a toy example which will have the form of a linear oscillator forced by a locally stationary process (the linearized oscillator taking the place of a low fidelity model).

References

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