Optimization under probabilistic constraints of complex structures: application to the anchoring of floating offshore wind turbines

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Ph.D. expected duration: 2015-2018

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Abstract:

Renewable energy is energy that is generated from natural processes, that are continuously replenished, through adapted devices. In particular, the wind turbine technology can be used to generate large amounts of electricity in wind farms both onshore and offshore. Recent research and developments have been focused on the offshore floating wind turbine solution that offers an increased energy productivity among others advantages. However, the effort to move further from the sea coast to deep water areas requires floating platforms and additional constraints through higher material demands.

Therefore a key component participating in the reliability of the structure is the anchoring system which must verify some international standards (see [6]) and accounts for a significant part of the floating support cost (see [4]). Hence the mooring system design optimization under reliability constraints have a meaningful importance.

The reliability of the system is mainly characterized by its resistance against fatigue. In materials science, fatigue is the weakening of a material caused by the progressive and localized structural damages that occur when the material is subjected to cyclic loading. Fatigue analysis focuses on the nominal stress required to cause a failure after a given number of cycles (see [4], [3] and [1]).

Formally, let x be the vector of design parameters characterizing the mooring system, let ξ be a random vector modeling the uncertainty involved in the accumulated damage and let X_{LT} be a stationary random process that describes the random characteristics of the marine environment (waves and wind). Considering the ergodicity assumption for X_{LT} and the accumulative nature of the damage, the total damage g over a time interval $[0, T]$ can be calculated as follows:

$$g(x, \xi) = \int_0^T G\left(x, \xi, X_{\mathrm{LT}}(t)\right) dt \simeq T\, \mathbb{E}_{X_{\mathrm{LT}}}\left[G\left(x, \xi, X_{\mathrm{LT}}\right)\right] \tag{1}$$

Here $G(x, \xi, X_{\mathrm{LT}})$ is the damage suffered by the mooring lines for a given sea state.

Reliability-wise, the design of the mooring system must avoid a failure of the anchoring lines which is translated by g being above a given threshold $s_1 = 1$. Moreover, the geometry of the mooring lines requires that the angle β between the vertical of the floating platform and the mooring line at top extremity to be larger than $s_2 = 10$. Also the physics of the materials require that the tension T in the mooring lines is non-negative.

The problem of designing the anchoring system can be stated as the search for an optimal design x minimizing manufacture, maintenance and installation costs $c(x)$, while satisfying probabilistic

constraints (of threshold exceedance type), with a confidence probability level p_i, $i \in \{1,2,3\}$, specified by the stakeholders:

$$\begin{aligned}
\min_x \quad & c(x) \\
\text{s.t.} \quad & \mathbb{P}_\xi \left(g(x,\xi) - s_1 > 0 \right) < p_1 \\
& \mathbb{P}_\xi \left(\beta(x,\xi) - s_2 > 0 \right) < p_2 \\
& \mathbb{P}_\xi \left(T(x,\xi) > 0 \right) < p_3
\end{aligned} \tag{2}$$

Functions G, β and T are available as the outputs of a simulator for global analysis of moorings, called *DeepLines*, developed by Principia and IFP Energies nouvelles. DeepLines is a very time-consuming numerical simulator based on finite elements methods.

Problem 2 requires the estimation of probabilities of failure in which three different black-box functions appear. Before applying adequate optimization techniques for solving Problem 2, an efficient method to compute probability constraints must be used. Since each simulation is expensive, this puts a limit on the total number of simulation and classical Monte Carlo method must be avoided. The idea to deal with this problem is to construct a metamodel using Kriging methodology based on the available runs, and then use this model as a replacement for the expensive simulator. The so called importance sampling estimation techniques for a smart selection of experiments, from which the Gaussian process predictors will be build and the probabilities estimated, are recommended. State-of-the-art reliability methods propose a **S**tepwise **U**ncertainty **R**eduction strategy for estimation of the probability of failure. To deal with this problem, we rely on META-IS techniques where an estimation of the optimal density is proposed([2]). In order to reduce the total number of calls to DeepLines, we propose to mix the three optimal densities for each probability and sample according to a single density that minimizes the variances of all estimators at the same time. The optimal density will be presented along with numerical results.

References

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Short biography – [Ivana Aleksovska; Univeristy Paris 7, Paris; IFPEN, Rueil-Malmaison]
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