Chance constraint optimization of a complex system: application to the fatigue design of a floating offshore wind turbine mooring system

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Abstract:

Floating offshore wind turbines enable to install high power turbines with favorable wind conditions. Their economic feasibility requires an optimization of the additional cost due to the floater equipments. In this talk, we propose a strategy to find a design of a Floating Wind Turbine mooring system that satisfies reliable fatigue limit states with minimization of the material cost. An application to a modified version of the semi-submersible NREL case study of [1] is presented. In accordance with industrial design rules, the mooring system must limit the floater movement to ensure the turbine production, avoid compression in the mooring lines and withstand the damage caused by fatigue. The resulting three constraints inherit the random characteristic of the marine conditions, the material properties, and the installation configuration.

Therefore, we deal with an optimization problem with a deterministic cost function and probabilistic constraints with high confidence levels (the failure probabilities must be less than 10^{-4}). The cost function is simple and fast to evaluate. The main difficulty of this type of problem lies in the estimation of the constraints at each loop of the optimization algorithm. They are expressed as threshold exceedance probabilities of maxima and integrals of temporal random processes over long periods of time. To calculate the failure probabilities, a naive approach such as the Monte Carlo method requires an impracticable number of evaluations of a time consuming simulator. To reduce the computational burden we propose a two-step methodology that takes into account the nature of the constraints to solve the problem in a reasonable time.

First, limit theorems on the integrals and maxima of processes [2, 3] allow us to reformulate the constraints into time-independent and faster to evaluate ones. Hence, at the end of the first step of the methodology, a new equivalent and easier to solve optimization problem is obtained.

However, the Monte Carlo approach is still too greedy to estimate the reformulated constraints. Over the last decades, many approaches have been developed to solve optimization problem with failure constraints among which methods based on adaptive kriging (AK) strategy [4, 5, 6]. These methods rely on building a kriging model of the performance functions and enrich this metamodel with a learning criterion. Nevertheless, all these methods require constraints expressed as probabilities and our reformulation approach provides constraints expressed in the form of expectations. We have, therefore, introduced and studied a new AK method called AK-ECO which stands for "Adaptive Kriging method for Expectation Constraint Optimization".

The second step of the methodology consists in solving the reformulated problem with AK-ECO. For each constraint, a metamodel is built in the augmented space which spans the design space and the space of the environmental variables. Then the AK-ECO procedure consists in carrying out cycles of optimization in which a first phase of local enrichment of the metamodels is performed,

followed by a resolution of the reformulated problem using sampling on the refined metamodels. The enrichments are made using a new learning function adapted to the reformulated constraints.

This methodology has been applied with success to an academic example and to the industrial case and performs much better than state-of-the-art algorithms.

References

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Short biography – I obtained a Master's Degree from University of Paris-Saclay in modeling and numerical simulation. I am currently a third year PhD student. This thesis, funded by IFP Énergies Nouvelles, focuses on a Reliability-Based Design Optimization problem applied to the design of an offshore wind turbine.