ABSTRACT

Robust Design Optimization (RDO) to support structure of offshore wind turbines which decreases the cost and its variations considering uncertainties is discussed in this study. Firstly, an approximate model utilized with Design of Experiment (DOE) is introduced to replace the time consuming computational dynamic response analysis of FE model for saving the computational cost. Then, a Deterministic Optimization (DO) without considering the uncertainties is induced for comparison. The results provide the feasibility and efficiency of the whole framework of RDO method, which can be a reference for the design of other offshore supporting structures.

KEY WORDS: Robust design optimization; uncertainty; approximate model; design of experiment; reliability analysis

INTRODUCTION

The supporting structure is the main body of an integrated offshore wind turbine. It takes the majority of the total weight and bears various kinds of loads from the complex marine environment. With fast development of modern ocean engineering structures, the generating capacity and quantity of offshore wind turbines are growing continuously. To keep up with the pace of construction of larger wind farms to deeper waters, supporting structures will encounter a major contradiction. On the one hand, minimization of the structure weight is an effective way for economical demands as smaller size of the components can save cost in manufacturing, transportation and installation processes. On the other hand, safety of the structure needs to be guaranteed to avoid catastrophic accidents and extremely huge maintenance expenses. And increasing the size of the structure is a commonly used method. Thus, design optimization for supporting structure of offshore wind turbine is proposed here to gain the cheapest cost plan without losing a specific safety requirement.

As optimization theory develops, the Robust Design Optimization (RDO) method is more practical than the traditional Deterministic Optimization (DO) method. DO method does not consider the uncertain factors in the system design, in the manufacturing process, in the service time and in the aging process (Doltsinis and Kang, 2003). These uncertain factors will result in two main negative effects. Firstly, they will lead to the deviations of structural responses, which may exceed the limit state of stress. When it happens, the structure will be damaged or even destroyed during its lifecycle. Secondly, they will lead to the deviations of structural weight, which may exceed the budget cost. This will greatly influence the field of offshore wind turbine, for more weight means more transportation and installation fees, which commonly account for 10 percent of the total cost. Whereas, RDO method can solve the problems mentioned above. Above all, it adds the uncertainties in constraint functions to ensure the structural safety with a high reliability. Then, the solutions and performance results of robust design optimization remain relatively unchanged when exposed to uncertain conditions (Hans-Georg Beyer and Sendhoff, 2007).

Besides of the economic and safety challenges, the supporting structure of offshore wind turbine also faces its technical challenges. One of them is that the response analysis of the Finite Element (FE) model is too time-consuming. The irregular and fast changing loads (winds, waves, currents and so on) which supporting structure bears require long time intervals (about 1 hour) to simulate sufficiently accurate results during one response analysis in time domain. What is more, this analysis will be called tens of thousands of times as iteration steps during the optimization process. Thus, in order to simplify these costly computational response analyses, approximate model is introduced in this study to replace FE model but without losing the accuracy.

Modern ocean engineering is paying more and more attention to the supporting structure of offshore wind turbine in recent years. Above all, dynamic analysis with FE model of the structure in time domain is necessary to gain accurate responses, due to the tall flexible tower, highly nonlinear loads and complex interactions between components. Manenti and Petirmi (2010) built a FE model of a monopole-type supporting structure for offshore wind turbine. They used this model to study the dynamic behaviors with coupled winds and waves. Meanwhile, by using coupled aero-hydro-servo-elastic simulation to model the dynamic responses, Chew et al. (2013) optimized a bottom fixed offshore wind turbine with jacket type substructure. And they finally saved up to 55 percent of the structural mass. But these Deterministic Optimization researches did not take uncertainties into consideration. Then, Yang HZ et al. (2011) made the reliability analysis for steel catenary risers considering uncertain factors, and they used the metamodel including Kriging model in dynamic optimization process to save the computational iterative cost. Furthermore, Lu et al. (2013) presented an integrated optimization framework using Reliability Based Design Optimization (RBDO) method with a three tripod type supporting structure of offshore wind turbine. And they compared the advantages of RBDO method with DO method. Recently, RDO method is gradually aroused concerns in marine and ocean engineering area. Doltsinis, Kang and Cheng (2003) stated a robust design of 25-bar space truss structure as a two-criteria optimization and they solved the