Structural Optimization and Parametric Study of Offshore Wind Turbine Jacket Substructure

Kok Hon Chew1,2, Michael Muskulus2, Daniel Zwick2, E.Y.K Ng1 and Kang Tai1
1School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore
2Department of Civil and Transport Engineering, Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT

Studies were conducted on a bottom fixed offshore wind turbine with jacket type substructure, including structural optimization and parametric studies for a newly developed three-legged jacket. The four-legged jacket adapted for the NREL 5MW reference turbine within the IEA Task 30 OC4 project was selected as the reference support structure design. Coupled aero-hydro-servo-elastic simulation was carried out in the time-domain to model the dynamic response of the turbine. Fatigue (FLS) and ultimate limit state (ULS) analyses were performed for the substructure members. By comparing against the reference model, the three-legged designs were iteratively optimized to obtain Pareto optimal designs (with lowest material consumption). Under the load cases studied, the three-legged jacket can save up to 55 per cent (LC 5.6) and 13 per cent (LC 5.7) of structural mass and is feasible as an interesting alternative to the four-legged jacket. Further analyses were carried out to evaluate both design options in terms of structural stability and vibrational frequencies. Finally, parametric studies were carried out to investigate the sensitivity of the performance of the jacket substructures with respect to different load cases, loading directionality, and wind-wave misalignment. It is concluded that wind-wave misalignment effects can be neglected, but directionality effects can lead to differences in joint fatigue lifetimes of up to 60 per cent. It is therefore important to account for these effects in the design phase.

KEY WORDS: Offshore; Wind Energy; Jacket; Support Structure; Fatigue; Optimization.

INTRODUCTION

Offshore wind energy has become a hot topic in the renewables energy industry recently despite its first introduction in 1930s, as people are looking at tapping into the richer wind resource in the offshore area which provides a good alternative green power supply to populated cities mainly at the coastal region without affecting the human habitat onshore. There is presently about 6.83 GW offshore wind capacity installed worldwide, with another 5.31 GW currently under construction and an additional 31.2 GW wind projects approved by governments1. So far Europe is the leader in this industry with a total capacity of 4.34 GW wind turbines fully connected to the grid across 10 countries (EWEA, 2012). Most of these projects are deployed in shallow-water regions, with less than 30m water depth, and a lot of research and development is on-going to study the installation at greater water depth as well as further away from shore. However, this poses greater challenges not only in the technical and practical aspects, but also in the viability of the overall technology to lower the cost of energy in the current highly competitive energy market.

The three main cost components in a typical offshore wind project life cycle are the turbine, operations and maintenance (O&M), and the support structure (Musial and Ram, 2012). The substructure cost generally increases along with the water depth, due to the complexity of the structural design and manufacturing process, as well as the additional material cost (Dolan, 2004). There is no one-type-fits-all design existing so far, as different design options may offer relative advantages over the others subject to the technological limitations at the specific site water depth, soil conditions, seabed bathymetry, environmental loadings, etc. In the UpWind European project, a number of existing and proposed support structure concepts were investigated (de Vries, 2011). In the transition-water zone, the jacket substructure concept is comparably lighter in structural mass, while exhibiting higher transparency to the wave loading, greater structural stiffness, and lower soil dependency. De Vries (2011) also presented a preliminary study of the unconventional three-legged jacket substructure model, and highlighted its potential competitive advantage in the structural mass requirement over the four-legged jacket. However, high fatigue loading is expected at the leg joints in return, and it was concluded that this needs to be studied further.

This paper studies both the four-legged and three-legged jacket support substructure for offshore wind applications. Dynamic and stability assessments on the structures were performed, subject to selected parametric case studies. Optimization was carried out for the three-legged model, while comparing the fatigue limit state (FLS) and ultimate limit state (ULS) analysis against the referenced four-legged design.

1 http://www.thewindpower.net/windfarms_offshore_en.php