Fatigue Calculation of Offshore Jacket Structural For Monitoring

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Abstract. Based on the IEC 61400-3 offshore wind turbine (OWT) design guidelines. The NREL 5MW wind turbine with Taiwan domestic jacket support structure in 18 meters water depth was selected to perform the fatigue strength calculation for the support structure. Commercial software Bladed and SACS are used to perform the required structural responses and fatigue strength calculations. The stress concentration factors (SCF) and S-N curves for the stress calculations of tubular joints are adopted based on the recommendation of DNV GL guidelines. The magnitude of the stress variation range and the corresponding number of counts are obtained by the rainflow counting algorithm. Finally under the assumption of Palmgren-Miner linear cumulative damage rule, the cumulative damage of the structure component can be calculated and then the fatigue life can be estimated. The numerical evaluation results can also be available for the further reference on the determination of sensor locations for the structural monitor system.

1. Introduction
Due to the focus on the issues of environmental protection and warming, the exploitation of renewable energy become more and more important for all the nations in the world. The application of wind energy is one of the favourable way for renewable energy utilization. In general, the designed service life of offshore wind farm is about 20 to 25 years, where both the maintenance and performance of the wind farm should be taken into account. Thus, it is necessary to assess structural fatigue life during the design stage. In this paper, the NREL 5MW wind turbine with Taiwan domestic jacket support structure in 18 meters water depth was selected to perform the required analysis. Where the software Bladed is used to calculate the aerodynamics load of wind turbine and then the marine structure software SASC is adopted to calculate the responses of support structure.

According to the IEC61400-3 design standard specification, there are several design load conditions should be taken into account during the design stage. Such as DLC-1(Power Production), DLC-2(Power Production plus occurrence of fault), DLC-3(Start up), DLC-4(Normal shut down), DLC-5(Emergency shut down), DLC-6(Parked), DLC-7(Parked and fault conditions) and DLC-8(Transport assembly maintenance and repair), etc. The purpose of this paper is to evaluate the fatigue life of the support structure. Therefore, only the design load condition of the DLC1.2 combined probability distribution is chosen for the analysis.

Sea bed condition and environmental data of an offshore site near Taiwan Strait are selected as boundary and load conditions for the analysis. In this paper, the time domain loads are calculated under the specified weather conditions by using the software "Bladed", and then the local stresses are obtained by using the marine structural analysis software "SACS". The magnitude of the stress variation range and
the corresponding number of counts are obtained by the Rainflow counting algorithm. Finally, the cumulative fatigue damage local joints are evaluated by fitting the appropriate SN curve and the Palmgren-Miner’s rule. And then the fatigue life of the support structure can be evaluated.

2. Wind turbine system

2.1. Wind turbine

The NREL 5MW turbine design[1] is chosen for this paper, include the material, tower and blade structural design together with generator itself show in the Table 1. The bottom diameter of the tower is 5 m with thickness of 0.038 m, while the top diameter connecting to nacelle is 3.12 m with thickness of 0.03 m. The basic dimension, component mass and rotor speed are shown in the Table 2.

2.2. Support structure

In general, all dead loads must be included in the design with nominal densities of the materials chosen. For loads/structures not covered by the load cases stated in this design basis, or DNV-OS-J101 [2], the environmental loads must be determined based on a return period of 50 years. Fatigue design of the jacket foundation is made as per [2] and DNVGL-RP-0005[3]. A typical jacket foundation arrangement and its main dimension are illustrated in Figure 1.

| Table 1. Main dimension of the wind turbine |
|--------------------------------------------|
| Rated power(MW)                          | 5   |
| Rotor, Hub diameter(m)                    | 126.3 |
| Hub height(m)                             | 90  |
| Cut-in, Rated, Cut-Out wind speed(m/s)    | 3, 11.4, 25 |
| Cut-In, Rated Rotor speed(rpm)            | 6.9, 12.1 |
| RNA mass(t)                               | 350 |
| Tower mass(t)                             | 347 |
| Transition piece(t)                       | 666 |
| Jacket support structure(t)               | 462 |

| Table 2. Material properties              |
|--------------------------------------------|
| Young’s modulus (GPa)                     | 210 |
| Shear modulus (GPa)                       | 81  |
| Density (kg/m³)                           | 7850 |

2.3. Natural frequency

The offshore wind turbine encounters cyclical loads of wind, wave and rotor for full operation life. In the design stage, the natural frequency of the overall structure including wind turbine and jacket foundation should be checked to avoid the resonance with the wind and wave as well as the vibration caused by the rotation of the rotor.

The rotor speed ranges between 6.9 and 12.1 rpm. The speed can be converted to times per second, from 0.115 Hz to 0.202 Hz. For a three-blades wind turbine, the corresponding exciting frequency range is fall between 0.345 and 0.606 Hz, which can be converted to times per second, from 0.115 to 0.202 Hz. With three blade mounted on the wind turbine, the affecting frequency range is also triple, from 0.345 to 0.606 Hz. The wave and wind frequency distribution are respectively analysis by JONSWAP and Kaimal spectrum. All possible affecting frequencies are sorted in Figure 2. The only remained safe range, in which the natural frequency shall be designed, is between 0.233 and 0.25 Hz. Figure 3. Wind turbine mode shapes shows the calculated first and second side-to-side and fore-to-aft modes respectively.
3. Metocean

3.1. Foundation position
The environmental data comes from National Oceanic and Atmospheric Administration (NOAA). Dominant wind direction is north-northeast, 22.5 degrees clockwise rotation, for around six years at Taiwan Strait in Figure 4. Jacket foundation installation position In summer, the wind direction is not fixed and the average speed is relatively low except for typhoon. Prevailing wave direction is north-northwest.

3.2. Wind data
The wind data is given in Table 3 Wind speed versus wind direction, As for Wind plot show in Figure 5. (a) wind speed distribution, (b) wind rose map
3.2.1. Wave Condition

Wind versus wave is presented in the following as scatter diagrams for selected wind speed intervals with the distribution of significant wave height and wave peak period given as hours per year in average for the period 2010-01-01 to 2016-12-31 in the Table 4. Wave scatter diagram. The wave directions and misalignment are given in Figure 6. Wave Direction joint Probability Table

4. Fatigue assessment

Offshore wind turbines are exposed to turbine excitation, wind and wave loads varying in time throughout their lifetime [4]. It leads to constantly varying in time stresses and making the support structure prone to fatigue. In general, fatigue damage accumulation at welded tubular joints can be estimated using the calculated local hot spot stresses. First, stress concentration factors (SCF) and S-N
curve for the tubular joint can be obtained according to the recommendation of the guidelines of DNV GL RP C203 [5]. and the hot spot stresses can then be calculated in time-domain. Then the magnitude of the stress variation range and the corresponding number of counts are obtained by using the rainflow counting algorithm as shown in Figure 7. Rainflow Counting. Finally, the cumulative fatigue damage ratio can be calculated by using the Palmgren-Miner rule as shown in Figure 8. Fatigue assessment according to Palmgren-Miner rule. Fatigue assessment according to Palmgren-Miner rule, and the fatigue life can then be estimated based on the calculated cumulative damage ratio.

![Figure 7. Rainflow Counting](image)

![Figure 8. Fatigue assessment according to Palmgren-Miner rule](image)

4.1. Fatigue result

Table 5. Fatigue damage life shows part of the calculated results. The analysis results show that the calculated fatigue life is more than 20 years generally for most of the joints. and the calculated fatigue life is relatively shorter while structure members are located near the pile position, it is suspected that it is caused by the large force acting on those structure members near the soil.

| Joint | Member | Damage ratio | Damage life |
|-------|--------|--------------|-------------|
| 57    | 57 – 61| 0.29         | 79          |
|       | 57 – 16| 0.91         | 22          |
| 58    | 58 – 1 | 0.48         | 40          |
|       | 58 – 62| 0.16         | 121         |
| 59    | 59 – 63| 0.47         | 41          |
|       | 59 – 11| 0.15         | 125         |
| 60    | 60 – 6 | 0.3          | 58          |
|       | 60 - 64| 0.95         | 21          |
5. Conclusion
In this paper, a NREL 5MW wind turbine with Taiwan domestic jacket support structure is selected as an example to perform the fatigue strength calculation for the support structure. Commercial software Bladed and SACS are used to perform the required structural responses and fatigue strength calculations. The calculated results show that the estimated fatigue life for most of the joints of supporting structure members are expected to be more than the required designed service of 20 years. And it is expected that the numerical evaluation results can also be available for the further reference on the determination of sensor locations for the structural monitor system.

6. References
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