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Fatigue of Dynamic Power Cables Applied in Offshore Wind Farms

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Abstract

The goal of this master thesis was to estimate the fatigue life of a dynamic power cable applied in offshore wind farms, as well as get an insight in how friction mechanisms in the copper conductors affect the fatigue life. This was done by global analyses in SIMA RIFLEX where the whole cable was modeled and local analyses in BFLEX where only the upper part of the cable was modeled with a bend stiffener included. Rainflow counting was used to count the cycles, and a mathematical model developed by [3] was used to calculate the fatigue life for the two layers of the conductors. The main analyses estimate the fatigue life of the dynamic power cable to be 640.28 years, with layer 2 as the design layer. Further sensitivity studies show that the contact between the conductors and contact between the layers within the conductors play a significant role in the fatigue life, and should be included in analyses in the future.

Introduction

As offshore wind installations are moving into deeper waters, floating support structures are the most plausible solutions. A lot of research has been done on estimating the fatigue life for flexible risers and umbilicals in the oil and gas industry, but this is not the case for dynamic power cables applied in offshore wind farms. A conductor usually consists of several conductors with layers of copper wires in each conductor. The wires are stranded helically around a core wire, and this causes contact both between the layer and within each layer, making the conductor vulnerable to several fatigue mechanisms, [3]. [2] explains that neither the fatigue properties, nor the methods to establish SN-data of copper conductors are established by the cable or offshore industry. Lifes50+ is a project financed by the Horizon2020 program where the goal is to develop cost-effective floating solutions for 10MW wind turbines, [1]. One of the designs in the project is the OO-Star developed by Dr. Techn. Olav Olsen shown in Figure 1. This was considered an appropriate case study to investigate the lifetime of dynamic power cables further.

Figure 1: Illustration of OO-Star, the case study used in this project

Main Objectives

The objective of this master thesis is to estimate the lifetime of a dynamic power cable applied in offshore wind farms and get an insight into the contact mechanisms in the conductors affecting the fatigue life. The project is an extension and continuation of a preliminary study executed in the fall of 2018.

The main objectives of this study are:

1. Perform a literature study and acquire the necessary theoretical background on all topics relevant for the master thesis, including but not limited to global and local analyses, offshore wind turbines, cable technology, and fatigue.
2. Choose and establish a case scenario regarding wind turbine floater design, location, environmental conditions, cable design, and SN-fatigue data
3. Create a global model in SIMA RIFLEX and determine cable configuration.
4. Create a local model in Bflex
5. Perform global and local analyses and process the results to estimate the fatigue life of the dynamic power cable.
6. Conduct a sensitivity study to investigate the friction mechanism in the conductor.

Modelling Methodology

Global Model

The global model was modeled in SIMA RIFLEX and consisted of the whole dynamic power cable. It was attached to the sea bed, and a point on the free surface behaving like the floating wind turbine due to provided transfer functions from Dr. tech. Olav Olsen. The cable has a lazy wave configuration achieved by adding a buoy section to the middle of the cable. The global model could have 3 possible positions and corresponding wind conditions: Near, Neutral and Far. The modeling conditions for the cable were that the curvature in the cable could not exceed 1.3675 $1/m$, and no compression in the cable. The final configuration was found through an iterative process.

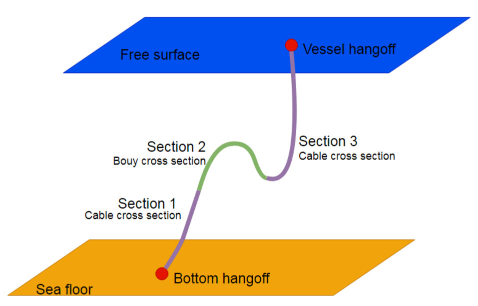

Figure 2: Illustration of global model

Local Model

The local model was created in BFLEX, and consisted of a cable, a bend stiffener and a stiffened pipe. The local model only consisted of the top part of the cable, as it is assumed that the most severe fatigue damage will occur at the vessel hang off. The cable cross section had several layers as can be seen in Figure 3 with the following components: (A)Center tube, (B)Conductos, (C)Sheath layer 1, (D)Armouring layer 1, (E)Tape layer, (F)Armouring layer 2, (G)Outer sheath. A,C,E and G are modelled with the straight BFLEX elements HSHEAR363 while B,D and F are modelled with the helical BFLEX elements HSHEAR353. HCONT464 was used to model the contact between the different layers and HCONT454 was used for the contact between the helical conductors.

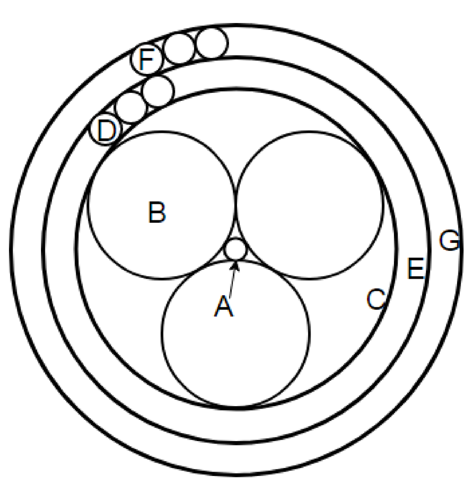

Figure 3: Illustration of cable cross section

Figure 4: Illustration of local model

Analyses Methodology

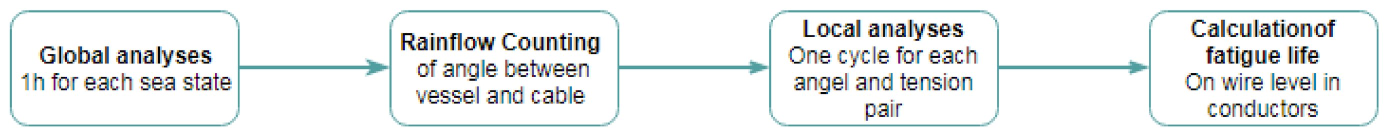

Figure 5: Flow chart for analyses algorithm

Global Analyses

The global analyses were performed by running all sea states in the scatter diagram for the chosen location West of Barra, Scotland for one hour each. The time series of the angle was calculated by the dot product of the vessel vector and upper element in the cable. Rainflow counting was used to count cycles in each angle range, and the number of cycles in each angle range was scaled to account for occurrence in a whole year according to the scatter diagram. The angle ranges were rearranged and merged into 15 classes that caused approximately the same damage each. It was decided that the angle would be the master over the tension, and as a conservative simplification it was decided that max tension occurred at a max angle, min tension occurred at min angle and corresponding tension to each angle was found through linear interpolation.

Local Analyses

The input for the local analyses were the 15 combinations of dynamic angle and tension from the global analyses. Each case was run for one cycle each. A mathematical model developed by [3] (See Eq.1) was used to calculate the stress range in each layer of the conductor and this was used with an appropriate SN-diagram to calculate fatigue life. The effect of including contact between conductors, and between layers in the conductors were also investigated.

$$\Delta\sigma = (\Delta\sigma_f + \Delta\sigma_T) \cdot SCF + \Delta\sigma_{nc} \qquad (1)$$

where $\Delta\sigma$ is the total stress range, $\Delta\sigma_f$ is the stress range due to contact between layers in the conductors, $\Delta\sigma_T$ is the stress range from dynamic tension, SCF is the stress concentration factor and $\Delta\sigma_{nc}$ is the stress range from normal curvature of the wire.

Results

Analysis	Fatigue life[yrs]	Design layer
Main analysis	640.28	2
No cond. contact	4011.16	2
No layer contact	1657.03	3

Table 1: Results

Table 1 shows the main findings. The fatigue life of the dynamic power cable is substantially longer than normal service life for any power cable. Excluding the effects of contact between the conductors and contact between layers increases the fatigue life dramatically. Fatigue is most severe in layer 2 for all analyses except when friction between layers is not included.

Conclusion

The conclusion of this study was is that the fatigue life of a dynamic power cable applied in offshore wind farms is 640.28 years with a conservative approach for this specific case study. The effect of contact between conductors, and contact between layers of wires in the conductor have a large impact on the fatigue life, and should be included in the future.

Further Work

Suggestions for further work include: Analyzing other support structure designs and locations in the Lifes50+ project, making the global model more complex by including displacement in several directions and wind, running the same analyses with double armoring, and investigating the possibilities of generalizing the process to easily analyze other case studies.

References

[1] Horizon 2020. What is horizon 2020? Accessed 10.10.2018.

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[3] Fachri P. Nasution, Svein Sævik, and Stig Berge. Experimental and finite element analysis of fatigue strength for 300 mm2 copper power conductor. *Marine Structures*, 39:225–254, 2014.

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