Including Load Sequence Effects in the Fatigue Damage Estimation of an Offshore Wind Turbine Substructure

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ABSTRACT

Retardation is a load sequence effect, which causes a reduced fatigue crack growth rate after an overload is encountered. Retardation can be cancelled when the overload is followed by an underload. The net effect is beneficial to the fatigue lifetime of Offshore Wind Turbines (OWTs). To be able to take this into account, computationally demanding cycle-by-cycle approaches are required.

This paper presents a methodology which aims at reducing a very long variable amplitude stress signal, such that it can be used to estimate the cycle-by-cycle fatigue damage, without jeopardizing accuracy. Filtering and reduction techniques are combined, based on typical events seen in the loading pattern of an OWT, e.g. during a storm. The effectiveness of the method is shown by comparing the number of cycles and the fatigue damage estimation, before and after reducing.

KEY WORDS: Offshore Wind; Fatigue; Load Sequence; Retardation; Crack Growth.

INTRODUCTION

The fatigue lifetime of welded joints is a design driver for Offshore Wind Turbine (OWT) substructures. An important simplification in the current Linear Fatigue Estimation Method is that load sequence effects are not accounted for. One of these load sequence effects is the retardation effect, which causes a lower fatigue crack growth rate after an overload is encountered, resulting in a longer fatigue lifetime. This effect can be included into the fatigue damage estimation by using certain Fracture Mechanics approaches. These methods use a cycle-by-cycle approach, which makes the processing of long variable amplitude signals a computationally demanding task. This paper presents a methodology that aims at reducing a large variable amplitude stress signal of an OWT support structure in such a way that it can be used to estimate the fatigue damage by using these cycle-by-cycle methods, without jeopardizing accuracy.

The goal is to create an equivalent time trace which still contains all information relevant to the load sequence dependent fatigue damage estimation. This reduced signal will contain far less individual cycles.

First, a short overview is given of the current fatigue life estimation methods. The Offshore Wind Substructure design codes prescribe the Linear Fatigue Estimation Method. Alternative methods based on Fracture Mechanics are introduced. The effects and challenges of including load sequence effects are explained. Actual measurement data from an OWT is used as demonstration. Secondly, the proposed method with all required steps is presented. The method is explained with an example. To show the effectiveness of the methodology, the reduced signal is compared to the original signal.

BACKGROUND ON FATIGUE DAMAGE ESTIMATION

There are various methods to estimate the fatigue life of (offshore) structures. Here, a distinction is made between sequence dependent and sequence independent methods. First, the currently used sequence independent estimation method is explained. Next, Fracture Mechanics methods are introduced, which are sequence dependent.

Current estimation methods

The main fatigue life estimation methods used in current practice are based on offshore wind substructure standards (DNVGL, 2014; DNV, 2014; IEC, 2009). In these standards, a number of operational conditions are provided, e.g. normal operation, parked condition and fault conditions. Each load case contains a variety of combinations of environmental loading, such as wind, wave and current loading. Also the wind, wave or current directions and misalignments between them are taken into account. Due to numerous combinations of wind, wave and current loading and alignment, several hundred individual 10-minute long simulations are to be included in the fatigue assessment. Each 10-minute simulation typically contains more than one thousand stress fluctuations.