Surrogate Modelling For Fatigue Damage of Wind-Turbine Blades Using Polynomial Chaos Expansions And Non-Negative Matrix Factorization

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Abstract

A computational approach for the estimation of fatigue degradation of composite wind turbine blades by means of time domain aero-servo-elastic simulations is proposed. Wind turbine blades are subjected throughout their lifetime to highly stochastic loading. Fatigue damage of the composite reinforcement of the wind turbine blades has been identified early on in the wind turbine design practice as a factor driving design. A simple fatigue accumulation model is utilized for the spar cap reinforcement of a wind-turbine blade. Non-Negative Matrix Factorization (**NMF**) for the damage accumulation random field is used for dimensionality reduction. An approximate computationally efficient model, relying on Polynomial Chaos Expansion (**PCE**) of the damage state with respect to probabilistically modelled mean wind and turbulence intensity is derived. The framework is exemplified in a case-study of a 1.5MW wind turbine.

Keywords: Composite fatigue; long term fatigue assessment; fatigue degradation; Wind Turbine; thin walled composite beam; Aero-elastic simulation; Gram-Schmidt PCE; NMF.

1 Introduction

In the last few decades, wind energy is gaining ground as an attractive alternative to fossil fuels [1]. Due to the potential of increasing share of energy demand, covered by horizontal axis wind turbines (HAWT), the prediction of their long term structural behaviour becomes an important industry relevant consideration. Reliable long-term structural integrity estimation of wind turbines is imperative for the confident representation of the inescapable uncertainties with respect to the operating life-time of the turbines [2].

In this work we will demonstrate how uncertainty quantification techniques, namely a variation of the well-established Polynomial Chaos Expansion (**PCE**) [3] technique and a dimensionality reduction technique, the Non-Negative Matrix Factorization (**NMF**) [4,5], may be employed to achieve reliable assessment of the stochastic long-term degradation of composite blades due to fatigue.

In short, the components of the fatigue analysis process are the following:

1) N_{MC} number of horizontal axis wind turbine aero-elastic simulations with appropriately sampled wind conditions are performed. IEC 64100-1 [6] standards are used in the present study. Blade time-dependent resultants are sampled at N_t time-instants at as many cross-sections as possible.
2) The fatigue damage accumulation of the structural components according to any suited model is estimated. A critical discussion, based on sound mechanics of materials considerations, on the choice of fatigue models is briefly included in the introduction of [7]. Evaluation of time-dependent material stresses is needed. In this work, a 2D FE representation is used

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