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Probabilistic Fatigue Methodology and Wind Turbine Reliability

by

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ABSTRACT

Wind turbines subjected to highly irregular loadings due to wind, gravity, and gyroscopic effects are especially vulnerable to fatigue damage. The objective of this study is to develop and illustrate methods for the probabilistic analysis and design of fatigue-sensitive wind turbine components. A computer program (CYCLES) that estimates fatigue reliability of structural and mechanical components has been developed. A FORM/SORM analysis is used to compute failure probabilities and importance factors of the random variables. The limit state equation includes uncertainty in environmental loading, gross structural response, and local fatigue properties. Several techniques are shown to better study fatigue loads data. Common one-parameter models, such as the Rayleigh and exponential models are shown to produce dramatically different estimates of load distributions and fatigue damage. Improved fits may be achieved with the two-parameter Weibull model. High b values require better modeling of relatively large stress ranges; this is effectively done by matching at least two moments (Weibull) and better by matching still higher moments. For this purpose, a new, four-moment "generalized Weibull" model is introduced. Load and resistance factor design (LRFD) methodology for design against fatigue is proposed and demonstrated using data from two horizontal-axis wind turbines. To estimate fatigue damage, wind turbine blade loads have been represented by their first three statistical moments across a range of wind conditions. Based on the moments PI.. .P3, new "quadratic Weibull" load distribution models are introduced. The fatigue reliability is found to be notably affected by the choice of load distribution model.

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