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Influence of Wind Induced Fatigue Damage in the Reliability of Wind Turbines

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Abstract : Steel tubular towers serving as support structures for large wind turbines are subject to several hundred million stress cycles arising from the turbulent nature of the wind. This causes high-cycle fatigue which can govern tower design. The practice of maintaining the support structure after wind turbines reach its typical 20-year design life have become common, but without quantifying the changes in the reliability on the tower. There are several studies on this topic, but most of them are based on the S-N curve approach using the Miner's rule damage summation method, the de-facto standard in the wind industry. However, the qualitative nature of Miner's method makes desirable the use of fracture mechanics to measure the effects of fatigue in the capacity curve of the structure, which is important in order to evaluate the integrity and reliability of these towers. Temporal and spatially varying wind speed time histories are simulated based on power spectral density and coherence functions. Simulations are then applied to a SAP2000 finite element model and step-by-step analysis is used to obtain the stress time histories for a range of representative wind speeds expected during service conditions of the wind turbine. Rainflow method is then used to obtain cycle and stress range information of each of these time histories and a statistical analysis is performed to obtain the distribution parameters of each variable. Monte Carlo simulation is used here to evaluate crack growth over time in the tower base using the Paris-Erdogan equation. A nonlinear static pushover analysis to assess the capacity curve of the structure after a number of years is performed. The capacity curves are then used to evaluate the changes in reliability of a steel tower located in Oaxaca, Mexico, where wind energy facilities are expected to grow in the near future. Results show that fatigue on the tower base can have significant effects on the structural capacity of the wind turbine, especially after the 20-year design life when the crack growth curve starts behaving exponentially.

Keywords : crack growth, fatigue, Monte Carlo simulation, structural reliability, wind turbines
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