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Optimizing wind turbine maintenance strategies through reliability deteriorating modeling

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ABSTRACT

In contemporary wind energy systems, the optimization of maintenance strategies for wind turbines is paramount to ensure sustained performance and permanency. This study presents an innovative approach to optimize wind turbine maintenance strategies through reliability deteriorating modeling. The methodology outlined herein integrates statistical analysis, probabilistic frameworks, maximum likelihood estimation, Monte Carlo simulation, gamma process, and optimization algorithms to devise a comprehensive strategy tailored to each wind turbine's unique operational characteristics. This approach not only enhances the efficiency of maintenance operations but also minimizes downtime and operational costs.

The methodology commences by statistically analyzing the failure times of individual turbines within a wind farm, establishing the foundation for subsequent analyses. Leveraging this data, a probabilistic density function for turbine failure is derived, capturing the relationship between failure probability and time (Kim et al., 2013). Through maximum likelihood estimation, the parameters of a damage function are determined, facilitating a deeper understanding of turbine degradation over time without delving into specific damage mechanisms. Subsequently, utilizing Monte Carlo simulation, the probability density from inspection to damage is elucidated, providing insights into potential failure scenarios (Zou et al., 2021). Moreover, employing the gamma process enables the calculation of failure probability density, further refining the maintenance strategy (van Noortwijk 2009).

Integral to the methodology is the utilization of optimization algorithms, specifically the Whale Optimization Algorithm, to ascertain the optimal maintenance strategy (Mirjalili & Lewis, 2016). By iteratively refining parameters based on the insights gained from preceding analyses, the algorithm identifies the most efficient maintenance schedule

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tailored to the specific operational conditions of each turbine. This approach considers various factors such as inspection intervals, repair actions, and resource allocation, ensuring a holistic and effective maintenance plan.

The significance of this research lies in its ability to revolutionize wind turbine maintenance practices, moving away from traditional fixed-interval approaches towards a proactive, data-driven strategy. By incorporating probabilistic modeling and optimization techniques, this methodology accounts for the dynamic nature of turbine degradation and operational conditions, thereby enhancing reliability and prolonging the lifespan of wind energy systems. Furthermore, the proposed approach aligns with contemporary trends in risk-based maintenance planning, emphasizing the importance of proactive maintenance strategies in ensuring the resilience and sustainability of wind energy infrastructure (Yeter et al., 2020).

In conclusion, this abstract presents a novel methodology for optimizing wind turbine maintenance strategies through reliability deteriorating modeling. By integrating statistical analysis, probabilistic frameworks, and optimization algorithms, this approach offers a comprehensive solution to the challenges posed by turbine degradation and maintenance planning. Through empirical validation and implementation, this methodology holds the potential to revolutionize the maintenance practices within the wind energy sector, fostering greater efficiency, reliability, and sustainability.

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