Design and analysis of helical vertical axis offshore wind turbine

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Abstract

Helical-bladed vertical axis wind turbines offer distinct advantages over straight-bladed designs, particularly in reducing torque fluctuations on the blades (1, 2). This study presents the design and optimization of a medium-scale helical-bladed turbine for offshore environments. One of the key challenges in composite applications is the design of bolted joints, which are critical for structural stability and strength (3). As part of this study, we firstly design a bespoke connection system to attach helical blades to composite struts using a system of T-bolts. Extensive finite element analyses are performed to optimize the connection design to ensure its ability to transmit the high aerodynamic and centrifugal blade forces generated during operational conditions. Potential failure modes, including bearing failure, net-tension failure, shear-out failure, fastener pull-through, and bolt failure, were systematically evaluated using cohesive zone modelling. The design was optimized to achieve a high degree of safety and reliability.
A modal analysis was conducted to identify the turbine's natural frequencies, which, along with other considerations such as weight and deflection, informed decisions on geometry and number of struts. Due to the dominance of centrifugal forces over aerodynamic loads under operating conditions (4), various strut designs were explored to reduce radial deflection. Parametric finite element studies were used to identify optimal design parameters (blade and strut dimensions and composite lay-up configurations) based on competition between weight reduction and deflection reduction.

To validate computational findings, two experimental tests were performed. Firstly, a prototype of the strut-blade connection was fabricated and tested to failure. The measured failure load under radial and circumferential loading was compared to finite element predictions, and experimentally observed mechanisms of failure were compared to finite element predictions of composite delamination and crack propagation. Secondly, a full-scale blade was tested under the application of two-point loading that was computed to approximately replicate operating conditions. Measured blade deflections and blade and strut strain tensors were compared to finite element predictions, further validating the efficacy of the turbine design.

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In summary, this research addresses the challenge of developing efficient helical-bladed turbines through the development of finite element models and experimental testing systems for bespoke bolted joint design, and optimization of blade and strut geometry and composite material configuration.

References

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