

SHAPE OPTIMIZATION OF INTEGRATED WIND TURBINE TOWERS AND ITS CONNECTIONS

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Abstract

Wind turbine towers are typically built from tubular steel sections joined by prestressed bolted flange connections. They are subjected to wind pressure on the tower wall, aerodynamic loads transferred from the blades through the nacelle, offshore wave loads, and gravitational loads from self-weight and the rotor-nacelle assembly. Designing and validating these towers requires multiple analyses, including stress, deflection, vibration/resonance, buckling, and fatigue. In conventional tower optimization, bolted connections are often modeled with limited detail, even though they can open or slip and their bolts and flanges can fail by yielding under extreme events or by fatigue under cyclic loading. This work proposes a connection model that replaces discrete bolts with an equivalent continuous, uniform representation, enabling efficient integrated optimization of both the full tower and its connections. The approach is embedded in a finite element model that captures all required load cases. Flange interaction is represented with shared nodes, an assumption valid only when opening and sliding are prevented; therefore, opening and sliding constraints are imposed for each connection. The optimization minimizes the tower material cost with the design variables describing tower segments, flanges, and bolts. An explicit geometry parameterization on a reference domain enables smooth morphing between design configurations while preserving mesh validity. Residual equations are written explicitly in terms of design variables, enabling symbolic differentiation and adjoint-based sensitivity analysis. Stress and fatigue constraints are enforced locally at each connection, while deflection, resonance, and buckling constraints are enforced globally as emergent responses of the assembled tower. To evaluate local constraints accurately, a sub-modeling approach is used to recover high-fidelity local stresses at each connection from the global tower response. The implemented optimization procedure is demonstrated on simple tower with transition pieces towards the nacelle and foundation.