



INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI  
SHORT ABSTRACT OF THESIS

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**Multi-Body Dynamic Analysis and Vibration Control of Horizontal Axis Wind Turbine**

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**SHORT ABSTRACT**

Horizontal axis wind turbines have gained prominence in the recent past as an efficient power-generating device, particularly in areas with abundant wind resources. Varying forces on turbines influence wind farm power production and efficiency in different geographical regions. These wind turbines are categorized as onshore and offshore based on their locations, with onshore being more accessible and easily connected to local power grids. However, onshore wind speeds fluctuate due to geographical features, requiring detailed analysis to ensure consistent wind availability and minimal impact on settlements and the environment. In contrast, offshore turbines are more profitable in the long run due to factors like steady wind flow, ample space for large wind farms, and less noise pollution. Yet, offshore construction, installation, and grid connection costs depend on water depth and distance from the shore. Despite offering more power than onshore turbines of similar size, offshore turbines face a harsher environment, demanding rigorous design for safe and sustained operation. Structural vibrations are significant in the marine environment due to combined wind and wave effects.

Today's multi-mega Watt wind turbines have long, slender, and flexible blades and towers, which experience significant vibration due to aerodynamic, hydrodynamic, and seismic loads. The blades are generally made of composite layups with cambered airfoil sections, which induce elastic and dynamic coupling between bending and torsional modes. In addition to these phenomena, the aerodynamic pitching moment also arises due to the offset of the blade pitch axis from the aerodynamic center. With this in mind, a complete multi-body dynamic aero-servo-elastic model of a horizontal axis wind turbine, including bending-torsion coupling in blades, is developed in Kane's framework using MATLAB. The TurbSim package from the NREL is used to simulate the three-dimensional wind field passing through the rotor plane, and the aerodynamic loads are calculated using a modified BEMT. In offshore environments, wind turbines are exposed to wave currents in addition to aerodynamic loads. These wave loads are simulated using Morison's equation, with wave time histories generated from the Pearson-Moskowitz spectrum for two-dimensional wave propagation. The response of a benchmark wind turbine is validated with FAST

and HAWC2. The model is then utilized to develop efficient control strategies designed for various turbine components depending on their location (i.e., onshore and offshore).

The effect of elastodynamic bending-torsion coupling in blades mentioned earlier is investigated thoroughly in this study. The dynamic coupling is found to be particularly detrimental at higher wind speeds than the rated value. On the other hand, elastic bending torsion coupling can have both beneficial and adverse effects on the dynamic response of the turbine depending on its direction (i.e., twist-to-feather and twist-to-stall). Hence, proper design and implementation of structural layout can enhance the aerodynamic performance of the blade. The optimal design of the composite fibre orientation of a benchmark turbine blade is presented to show its beneficial effects in load/response mitigation.

Monopile-supported offshore wind turbines are common in shallow waters, which require intricate design models to accommodate their size, power, and environmental conditions. This involves developing a detailed multi-body dynamic model by incorporating SSI as it is crucial for accurate dynamic analysis. A benchmark turbine at the North Sea is modeled using Kane's method, analyzing each soil layer and the system's dynamic response through coupled analysis. Fatigue life is assessed according to IEC 61400-3 standards using a rainflow algorithm, which accounts for both short-term stress and long-term serviceability. The study also develops the design curves for specific power ratings, ensuring structural integrity over the turbine's lifespan.

Besides monopiles, small vibrations in the tower can cause a detrimental effect on the drive-train assembly located at the nacelle. Hence, the study continued to investigate efficient control strategies for the vibration control of wind turbine towers. A wavelet-based strategy for fore-aft vibration control of onshore horizontal axis wind turbine towers is presented in this study. For this purpose, an active tuned mass damper is combined with an aero-servo-elastic turbine model in the multi-body framework. The combined system is exposed to turbulent wind and seismic ground motion to investigate the controller performance in extreme operating conditions. The optimal tuning is achieved by frequency-dependent gain scheduling via wavelet transform. Numerical studies demonstrate the advantage of the proposed gain scheduling over classical LQR. The efficiency of the proposed algorithm is verified using different flow conditions and seismic input, where the performance is compared with benchmark results.

On the contrary, spar-type floating wind turbines exposed to marine environments experience significant vibration due to hydrodynamic loads, which is more prominent under wind-wave misalignment. This unavoidable vibration can induce significant damage to sensitive electro-mechanical components, leading to downtime for maintenance. With this in view, the present study proposes a modified spar-torus combination by introducing a spring and dashpot in between to work as an isolator. First, a comprehensive mathematical model for this offshore multi-body system is developed using Kane's approach with proper aero-elastic and hydrodynamic simulation. The response of the modified spar-torus combination is demonstrated, highlighting the efficiency and advantage of the proposed vibration isolation. Different sea states and wind conditions are simulated to investigate the performance envelope of the proposed controller for spar-type floating wind turbines.

This study also investigates the use of a double-pitched rotor with two different pitch angles to address power fluctuation and rotor vibration in modern horizontal-axis wind turbines. The model of a double-pitched turbine operating in both onshore and offshore environments is developed in the multi-body dynamic framework. Three control algorithms are developed: an optimal PID, a weight-optimized LQR, and a wavelet-based LQR. Gain scheduling in these algorithms is optimized through multi-objective optimization based on rotor speed error and structural vibration. The algorithms outperform a generalized full-blade single-pitch baseline control, as demonstrated using benchmark data from a 5MW turbine. The performance of these algorithms is evaluated under various flow conditions and wind-wave misalignments, with benchmark results serving as a basis for comparison.