Abstract

Vertical Axis Wind Turbines (VAWTs) offer several advantages over their horizontal counterparts (HAWTs), particularly in urban environments and turbulent wind conditions, due to their portability, omnidirectional wind acceptance, and compact design. While VAWTs exhibit relatively lower efficiency in low-turbulence, steady wind environments, they tend to outperform HAWTs under highly turbulent and directionally varying conditions. However, widespread adoption of VAWTs is hindered by their inherent limitations, including poor self-starting capabilities, intermittent positive torque generation, and lower energy conversion efficiency. To address these challenges and improve energy extraction, the present research explores augmentation techniques aimed at optimizing the aerodynamic performance of VAWTs. These methods include innovative modifications to inlet flow paths, blade geometry optimization, and advanced structural enhancements such as ducting and cowling systems, all intended to reduce negative torque and enhance wind inflow velocity.

Among the key parameters influencing VAWT performance, the selection of a suitable blade profile plays a pivotal role. This study reports a detailed two-dimensional transient CFD simulation of a Darrieus type lift based turbine using the NACA0017 airfoil which has chosen due to its promising starting torque characteristics. The Unsteady Reynolds-Averaged Navier–Stokes (URANS) equations were solved with SST $k-\omega$ turbulence modeling to assess turbine behavior across varying inlet wind speeds. The performance of NACA0017 was compared with the widely studied NACA0015 profile, with specific focus on instantaneous net torque coefficients across a range of tip speed ratios (TSRs). Results indicate that NACA0017 delivers comparable power coefficients, reaching values of 0.21, 0.23, and 0.25 at inlet wind velocities of 3 m/s, 4 m/s, and 5 m/s respectively, thereby validating its viability for enhanced turbine design.

To further improve the performance of VAWTs, the concept of duct augmentation was explored. This technique leverages a strategically designed duct to accelerate the incoming airflow and reduce wake effects, resulting in greater energy capture. A two-dimensional numerical investigation was carried out on a ducted VAWT with NACA0017 blades and compared against its bare blade counterpart. The analysis encompassed key performance indicators such as coefficient of power (C_P), torque ripple factor, wake velocity deficit, turbulent intensity, and vorticity distribution. The results reveal a significant enhancement in turbine efficiency with duct augmentation: the C_P increases nearly fivefold (ranging from 0.5 to 0.7) at a TSR of 3.5 for inlet velocities between 3 and 4 m/s. Additionally, the torque ripple was found to be minimized at this

TSR, indicating a smoother and more stable torque output under ducted conditions.

Extending the analysis into three dimensions, a comprehensive CFD simulation was conducted for a VAWT equipped with NACA0017 blades and augmented with flat plate deflector. The URANS SST $k-\omega$ model was used to resolve turbulent flow characteristics. At both 4 m/s and 5 m/s, the deflector-equipped turbine achieved higher power coefficients, peaking at 0.28 and 0.29, respectively compared to the bare rotor. Flow visualization using the Q-criterion indicated more organized vortex structures and reduced aerodynamic losses with the deflector, especially at the optimal TSR of 2.5.

Beyond the technical enhancements, this work also addresses the broader question of sustainability in wind energy systems. Despite their promise as a clean energy source, VAWTs and wind power in general, must be evaluated holistically in terms of economic viability, environmental impact, and societal acceptance. A literature based sustaiinability assessment was performed, highlighting key performance indicators such as greenhouse gas emissions, water usage, and ecosystem impact. While wind energy offers considerable advantages over conventional fossil based systems, challenges remain in areas such as waste management, biodiversity disruption, and community integration. The study emphasizes the need for a balanced and comprehensive approach to evaluating the long-term sustainability of wind energy technologies.

In conclusion, this thesis presents a multifaceted investigation into the aerodynamic optimization and sustainability evaluation of VAWTs. Through computational modeling, augmentation strategies, and holistic impact assessments, the research contributes to the development of more efficient and environmentally responsible wind energy systems suitable for modern decentralized power generation.