Investigate Aerodynamic Performance of a Counter-Rotating Wind Turbine

Problem Statement and Objective:

With the rising global energy demands, there is a surge in the development of innovative rotor designs. One such significant design is the counter-rotating wind turbine. The term "counter-rotating wind turbine" in this context encompasses both designs where rotors rotate in opposite directions as well as the variant where the rotors rotate in the same direction. There are pros and cons to both approaches, and this study aims to shed light not only on the aerodynamics of the more conventional counter-rotating design but also on the co-rotating configuration.

For the primary focus of this research, two blade sets are positioned on opposing ends of the turbine nacelle. The main objective is to examine the relationship of induced velocity and the thrust of both the rotors and to pinpoint the crucial parameters that significantly impact the turbine's efficiency and to understand how to model it. Key parameters such as upwind rotor loading, downwind rotor loading and rotor spacing will be systematically altered and studied to identify the configuration that yields the highest efficiency.

Research question:

- *How does the loading and induction of upwind rotor affect the downwind rotors in a counter-rotating wind turbine?*
- *Which key parameters like rotor spacing, upwind and downwind loading significantly influence the turbine's efficiency?*
- *What is the optimal configuration of these parameters to achieve maximum turbine efficiency?*
- *How does the counter-rotating wind turbine design compare with the co-rotating variant in terms of aerodynamic efficiency and power generation?*

Preliminary Literature Review:

An initial review of existing literature was conducted to gain insight into the factors influencing the aerodynamic efficiency of counter-rotating wind turbines (CRWT).

Oprina G. and Chihaia R.A [1] provided a comprehensive overview of the development of the CRWT. Their work highlighted several methodologies used to determine the parameters that influence the aerodynamic performance of a CRWT with varied blade profiles.

Sung Nam Jung and Tae-Soo No [2] delved into the aerodynamic performance utilizing the quasi-steady strip theory. They considered the near-wake behavior of the auxiliary rotor, positioned upwind of the main rotor, to analyze the turbine system's performance. This analysis was supported by wind tunnel test data from scaled model rotors. Notably, the auxiliary rotor's size was less than half of the main rotor's diameter. Their findings suggest optimal performance when the gap is maintained at around half of the auxiliary rotor's diameter.

Similarly, Sungmin Lee and Hogeon Kim [3] investigated the aerodynamic attributes of CRWT. They compared three distinct rotor configurations: a 2-bladed single rotor, a 4-bladed single rotor, and a counter-rotating rotor. The numerical methodology they employed was grounded in the vortex lattice method and cross-validated using measurements from the NREL Phase-VI rotor. To ensure a balanced comparison, the aerodynamic characteristics of a CRWT were juxtaposed with single rotors of both equal and half solidity.

Their calculations revealed that a CRWT's efficiency surpassed a single rotor of half solidity by 30%. However, it lagged by 5% compared to a single rotor of equal solidity. Furthermore, they noted that the aerodynamic benefits arising from the swirl recovery in a CRWT had minimal impact on overall turbine performance.

Proposed Methodology:

The literature reveals that previous aerodynamic performance studies predominantly focused on wind turbines with rotors mounted on either side of the nacelle or on the same side on the nacelle. And the diameters of rotor-1 and rotor-2 are not identical. However, there's limited research on turbines with the same diameter blades mounted on both sides of the nacelle. It is also observed that the literature does not provide enough study showing how the relationship between the thrust and induced velocity and the optimal distance at which the rotors are placed for a better performance. This research intends to explore the effects of the thrust (C_T) on induced velocity field using double stream tube model approach where both the sets of the blades are modelled as actuator disk and compute the loads experienced. The spacing between both rotors is varied in the range approx. 2%*d* – 20%*d* where "*d*" is the diameter of the rotor.

Initial findings will be derived using the low-fidelity double stream tube model. These results will subsequently be validated using a high-fidelity model that merges RANS (Reynolds-Averaged Navier-Stokes) with the actuator disk model. Furthermore, this study will take into account both upstream and downstream induction factors. Additionally, it will also delve into comparing the aerodynamic performance of co-rotating to counter-rotating in terms of aerodynamic efficiency and power generation.

References

[1] Oprina, G., Chihaia, R.A., El-Leathey, L.A., Nicolaie, S., Băbuțanu, C.A., & Voina, A. (2016). A review on counter-rotating wind turbines development. Journal of Sustainable Energy, 7(3), 91. National Institute for R&D in Electrical Engineering ICPE-CA, Bucharest. Email: gabriela.oprina@icpe-ca.ro

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