Numerical Investigations on the Startup Dynamics of S-Rotor Vertical Axis Wind Turbines

Introduction

The use of Vertical Axis Wind Turbines (VAWTs) in urban environments is on the rise due to their relatively smaller size, simpler design, lower manufacturing and maintenance costs, and above all, due to their omni-directionality. However, VAWTs are also notorious for their failure to self-start due to their higher cut-in speed and higher startup torque. At component level, there are various factors that contribute towards VAWTs' non-self-starting behaviour, such as the rotor design, blades orientation, pitch angle, blade thickness etc.

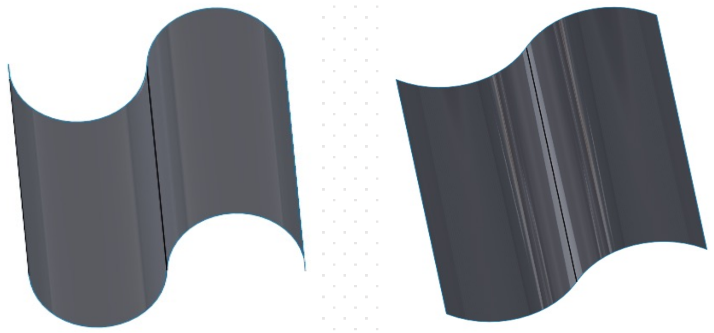
Startup of Conventional S-rotor VAWTs

Numerous studies have been carried out in order to better understand the complex startup dynamics associated with VAWTs. Most of these studies are based on numerical investigations of lift-based VAWTs. Investigations on the startup dynamics of drag-based VAWTs are severely lacking in the published literature. Based on the findings in these studies, there is a disagreement whether VAWTs can self-start or not [1,2]. In case of drag-based VAWTs, as different studies use different rotor designs [3,4], the challenge of finding a universal solution gets compounded.

Research Objectives

- To investigate the startup dynamics of a conventional S-rotor VAWT
- To modify the design of the conventional S-rotor in order to enhance its startup dynamics

Initial numerical testing of a conventional S-rotor VAWT, composed of 2 cup-shaped blades as shown in Figure 1(a), show that the VAWT fails to self-start.



(a) (b)

Figure 1. CAD model of S-rotor VAWT (a) Conventional rotor design (b) Modified rotor design

Modified S-rotor VAWT Design

Based, on the ideal flow theory, the velocity triangles on either ends of the rotor blades have been drawn for a typical radial cross-flow, as shown in Figure 2(a). This led to the derivation of a design equation for the S-rotor blades.

$$\sin(\beta_o) = \left(\frac{1}{k}\right)\left(\frac{r_2}{r_1}\right)\sin(\beta_i)$$

Here, constant k represents frictional losses over blade surface.

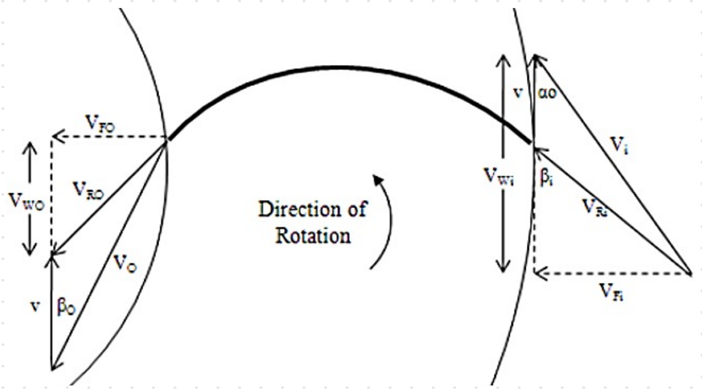


Figure 2. Blade design based on ideal flow theory

The resulting modified S-rotor VAWT is shown in Figure 1(b). For further clarity, Figure 3 presents a comparison of the geometrical features of both the conventional and modified S-rotor VAWTs.

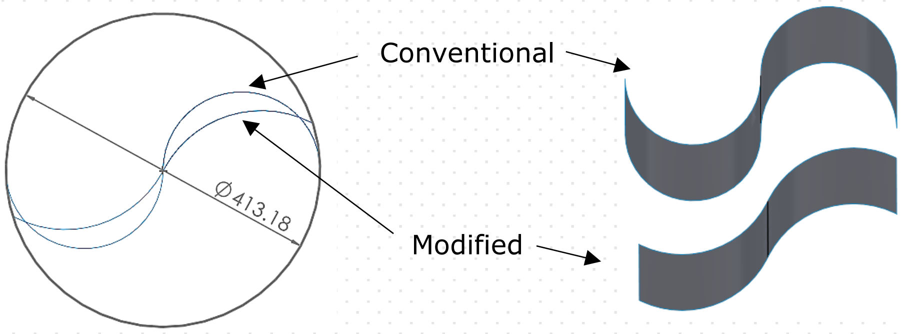


Figure 3. Conventional vs Modified S-rotor

Startup of Modified S-rotor VAWT

Flow induced rotation of the S-rotor VAWTs has been numerically modelled using advanced Computational Fluid Dynamics (CFD) based techniques. 1DOF model for rotation of the blades and Dynamic Meshing for Fluid-Structure Interaction have been used. The results obtain clearly show that with the design modification, the S-rotor did start to rotate, as shown in Figure 4. It can be seen that starting from rest, the modified S-rotor VAWT picks up speed until it reaches its peak rotational velocity of ~600rpm.

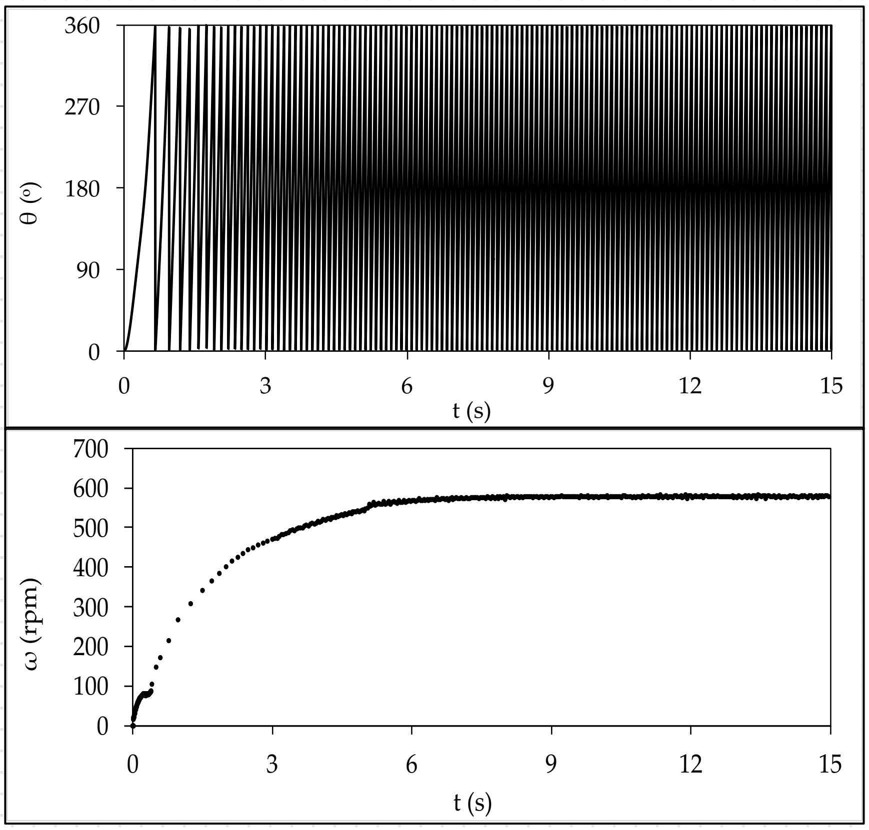


Figure 4. Startup of modified S-rotor VAWT

Conclusions

The primary conclusion of this study is that although conventional S-rotors are unable to self-start, with appropriate design modifications, they can be made to self-start. The startup of the modified S-rotor shows a gradual increase in its rotational speed until the maximum speed is achieved.

References

[1] Hill, N; Dominy, R; Ingram, G; Dominy, J (2008) Darrieus turbines: The physics of self-starting. Proceedings of the IMechE, Part A: Journal of Power and Energy, 223, 21-29.

[2] Untaroiu, A; Wood, HG; Allaire, PE; Ribando, RJ (2011) Investigation of Self-Starting Capability of Vertical Axis Wind Turbines Using a CFD Approach. Journal of Solar Energy, 133, 041010.

[3] Tigabu, MT; Khalid, MSU; Wood, D; Admasu, BT (2022) Some effects of turbine inertia on the starting performance of vertical-axis hydrokinetic turbine. Ocean Engineering, 252, 111143.

[4] Svendsen, HG; Merz, KO (2013) Control System for Start-up and Shut-down of a Floating Vertical Axis Wind Turbine. Energy Procedia, 35, 33-42.

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