

NUMERICAL INVESTIGATION OF A SAVONIUS WIND TURBINE WITH DIFFERENT BLADE OVERLAP DISTANCES**Ahmet Özkan KIRLI**

Süleyman Demirel University, Faculty of Engineer and Natural Sciences, Department of Mechanical Engineering, Isparta-Türkiye (Responsible ORCID: 0009-0002-8011-4309)

Bariş GÜREL

Süleyman Demirel University, Faculty of Engineer and Natural Sciences, Department of Mechanical Engineering, Isparta-Türkiye (Responsible Author) ORCID: 0000-0002-1780-2603

Kadir ÖZDEMİR

Istanbul Health and Technology University, Faculty of Engineer and Natural Sciences, Department of Mechatronics Engineering, Istanbul-Türkiye (Responsible Author) ORCID: 0000-0001-5119-7657

Abstract

This study examines the aerodynamic efficiency of a Savonius-type vertical-axis wind turbine with various blade gap configurations at different wind speeds through numerical methods. Blade gaps of 10 mm and 20 mm were examined at constant inlet wind velocities of 3, 7, and 11 m/s using two-dimensional transient Computational Fluid Dynamics (CFD) models. The numerical studies utilised the standard $k-\epsilon$ turbulence model to minimise computational expenses, employing a time step of 0.002 seconds across a total simulation period of 15 seconds. The findings indicate that the 10 mm blade gap consistently surpasses the 20 mm arrangement across all wind speed conditions. The findings demonstrate that a diminished blade gap markedly enhances flow organisation, torque stability, and energy conversion efficiency, underscoring the promise of optimised Savonius rotor geometries for small-scale and low-wind renewable energy applications.

Keywords: Wind turbine, Savonius wind turbine, CFD analysis, wind turbine performance.

Introduction

Humanity has been compelled to use the natural resources found in the environment due to the rise in global energy consumption and the associated rise in energy costs, as well as the requirement for renewable energy sources. Wind energy is a significant resource, and extensive research has been undertaken on several wind turbine designs that transform wind energy into electrical power. Wind turbines are essential for diminishing dependency on fossil fuels, as they provide a sustainable and eco-friendly energy source (Pérez & Márquez et al., 2013)

Modern wind turbines are primarily classified into two main types: horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs). While horizontal axis wind turbines (HAWTs) achieve greater efficiency due to their horizontally aligned rotors, vertical axis wind turbines (VAWTs) are employed less often because of their lower tip-speed ratios and related operational challenges (Schubel & Crossley, 2012; Edgardo et al., 2019). Vertical-axis designs advantageously capture wind from all directions and eliminate the need for yaw systems; yet, they typically demonstrate reduced efficiency. Among vertical axis wind turbines (VAWTs), the Savonius type is characterised by simplicity and cost-effectiveness, although it exhibits a comparatively low power output. In contrast, Darrieus-type turbines provide superior aerodynamic efficiency but necessitate external support for initiation (Elibüyük & Üçgül, 2014).

Despite VAWTs seemingly trailing HAWTs in technological advancement, it has never been definitively established that HAWTs had superior aerodynamic efficiency. The principal benefit of HAWTs is their superior energy production capacity, making them the favoured choice for large-scale electricity generation (Howell et al., 2010). Vertical Axis Wind Turbines (VAWTs) have numerous advantages, including the removal of yaw control, quieter operation attributed to reduced rotational speeds, simplified blade designs that cut manufacturing expenses, and improved mechanical resilience due to their passive stall characteristics under high wind conditions. The aforementioned advantages render vertical axis wind turbines (VAWTs) worthy of

reevaluation for severe offshore environments and extensive wind energy applications (Howell et al., 2010; Zhang & Zhu et al., 2018).

Vertical-axis wind turbines are primarily categorised into four design types: Savonius, Darrieus, H-shaped, and helical turbines. Savonius turbines possess a rudimentary design, with two or more semi-cylindrical blades, and function through drag forces that rotate a vertical shaft to produce energy. Their features encompass low production costs, little maintenance needs, omnidirectional wind acceptance, functionality at low wind speeds, and strong beginning torque, rendering them appealing for urban applications. Although Savonius turbines have superior performance at low speeds and high torque, Darrieus and H-shaped turbines provide enhanced aerodynamic efficiency but experience poor startup torque. Helical-bladed configurations offer enhanced aerodynamic stability and more consistent power delivery. This diversity enables each turbine type to meet various application requirements, while hybrid designs seek to integrate the advantages of numerous configurations (Castellani & Astolfi et al., 2019).

Savonius vertical axis wind turbines (VAWTs) have been extensively examined in both experimental and computational fluid dynamics (CFD) research owing to their capacity to produce substantial beginning torque at low wind velocities, function autonomously of wind direction, and possess a straightforward geometric configuration. A notable advantage emphasised in the literature is their capacity to initiate operation at minimal wind speeds, generally between 2 and 4 m/s (Bhutta et al., 2012). The absence of a yaw-tracking mechanism, essential for HAWTs, also decreases maintenance expenses (Carroll, 2015).

CFD analyses robustly substantiate these advantages. Altan and Atilgan (2008) investigated the flow interactions of the Savonius rotor utilising ANSYS Fluent, revealing that the turbine generates substantial torque at low wind velocities and displays more stable separation zones in comparison to Darrieus and horizontal axis wind turbine configurations. Likewise, CFD-based research conducted by Menet (2004) and Zhao & Zhang et al. (2019) has demonstrated that Savonius turbines exhibit consistent performance even in turbulent and highly variable wind conditions. The CFD results corroborate the rotor's intrinsic "self-limiting" aerodynamic characteristics, which mitigate excessive loads at high wind conditions—an effect theoretically articulated by Paraschivoiu (2002, p. 38) and substantiated by the simulations conducted by Jain et al. (2017).

Moreover, Savonius turbines produce considerably reduced noise levels owing to their minimal rotating velocities. (Islam et al., 2008) ascribe this quality to low-Reynolds-number flow dynamics, emphasising their appropriateness for small-scale renewable energy applications. Kamoji and Kedare et al. (2009) experimentally showed that Savonius rotors produce substantial torque at low wind velocities, rendering them highly efficient for pumping and small-scale energy generation.

The Savonius turbine fundamentally relies on drag forces, exhibits substantial starting torque, and is particularly well-suited for low wind-speed conditions, while also being the most straightforward of vertical-axis turbine designs. Conversely, Darrieus, H-Darrieus, and helical turbines function on lift forces, providing superior efficiency although exhibiting less startup torque and more intricate aerodynamic properties.

This project involved the design and fabrication of a Savonius wind turbine, with its performance evaluated using computational fluid dynamics (CFD) analysis. The numerical outcomes were subsequently contrasted with experimental measurements.

Materials and Methods

Geometry

The computational domain illustrated in Figure 1 was defined using dimensionless ratios of 2D in width, 1.3D in height, and 6.5D in length, with D representing the diameter of the Savonius rotor. The rotor diameter was set at 0.30 m, correlating to actual domain dimensions of roughly 0.6 m in width, 0.4 m in height, and 1.95 m in length.

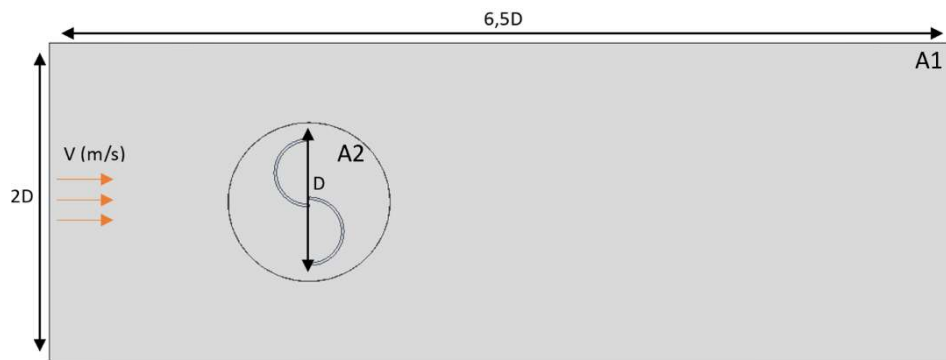


Figure 1. CFD domain

Mesh

The mesh structure was divided into two main zones: Region A1, the external domain, utilised a 5 mm element size, whilst Region A2, the internal domain, employed a refined 2 mm element size. A 2 mm transition mesh was employed between A1 and A2 to facilitate a seamless adjustment of grid density at the interface. Furthermore, inflation layers were implemented around the rotor blades to precisely record near-wall flow dynamics and enhance the resolution of boundary-layer phenomena. Figure 2 illustrates a two-dimensional numerical grid.

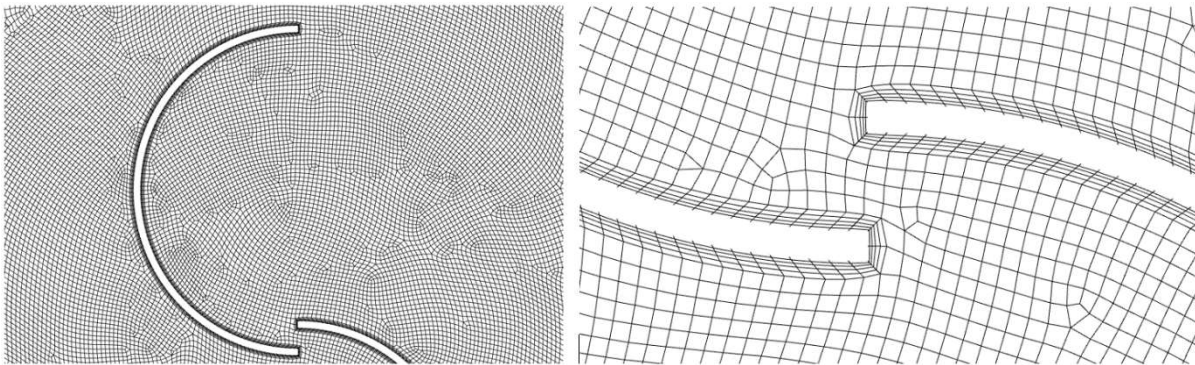


Figure 2. Mesh detail

Boundary conditions

Figure 3 illustrates that the computational domain boundaries were established with the left side functioning as a uniform velocity inlet, where wind speeds of 3.7 m/s and 11 m/s were implemented, accompanied by an air density of 1.225 kg/m³. The right boundary was designated as the pressure outlet, whilst the top, lower, and lateral surfaces—excluding the intake and outlet—were represented as no-slip solid walls. The boundary conditions, along with the chosen meshing approach, guarantee an accurate depiction of the physical flow environment around the turbine.

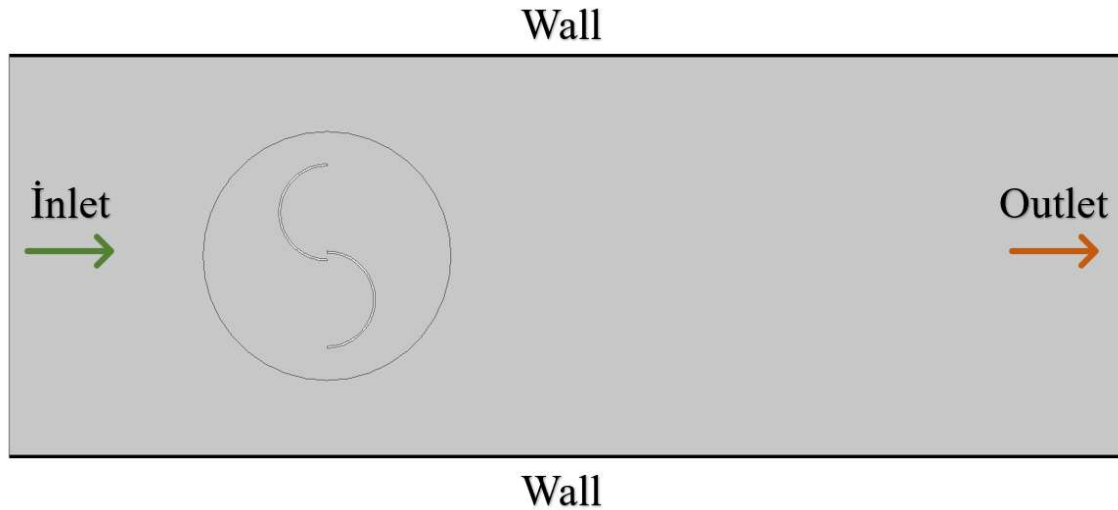


Figure 3. Boundary conditions

Solution method

Transient simulations were performed using a time step of 0.02 seconds across 7,500 iterations, equating to a total simulated physical duration of roughly 15 seconds, adequate for the rotor to attain its maximum and steady-state conditions, as illustrated in the convergence graph in Figure 4.

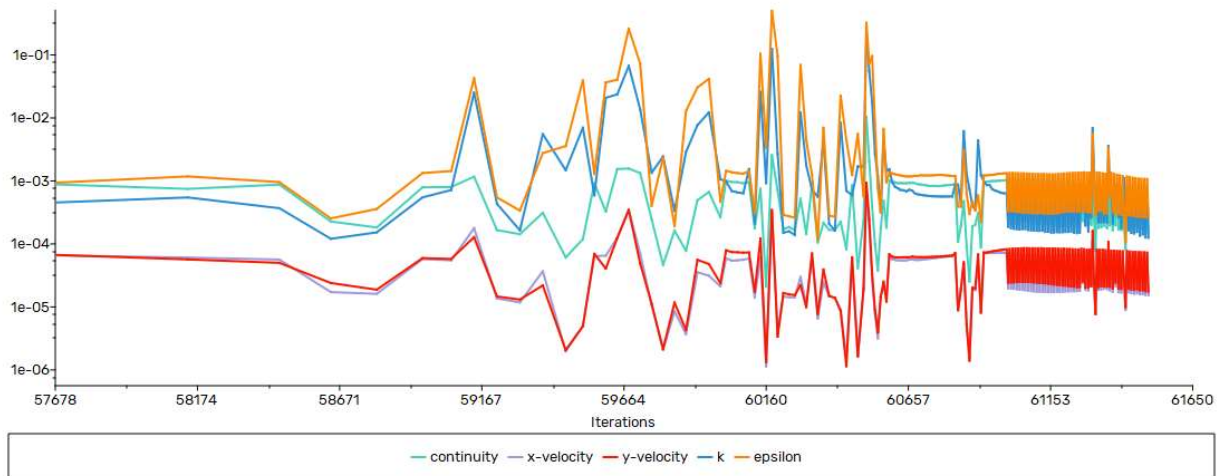


Figure 4. Convergence graph

Results

In this study, the performance of Savonius-type vertical axis wind turbines was analysed under varying blade overlaps and wind speeds, focusing on torque, power, and angular velocity (ω). **As presented in Figure 5**, the 10 mm blade overlap demonstrated superior efficiency compared to larger overlaps. This indicates that smaller openings reduce flow separation and enhance the aerodynamic performance of the turbine.

When wind speed was considered, **Figure 5 clearly shows that the turbine operates more efficiently at 11 m/s compared to 3 m/s and 7 m/s**. This finding highlights that while Savonius turbines are capable of functioning at low wind speeds, their performance becomes more stable and productive beyond a certain threshold.

Overall, the data in Figure 5 reveal that Savonius turbines optimised with smaller blade overlaps perform more effectively at medium-to-high wind speeds. This conclusion contributes to the **design optimisation of**

turbines for urban environments or regions with relatively low turbulence, where reliable energy generation is essential. Furthermore, the combined evaluation of blade overlap and wind speed parameters provides a valuable foundation for future CFD-based optimisation studies.

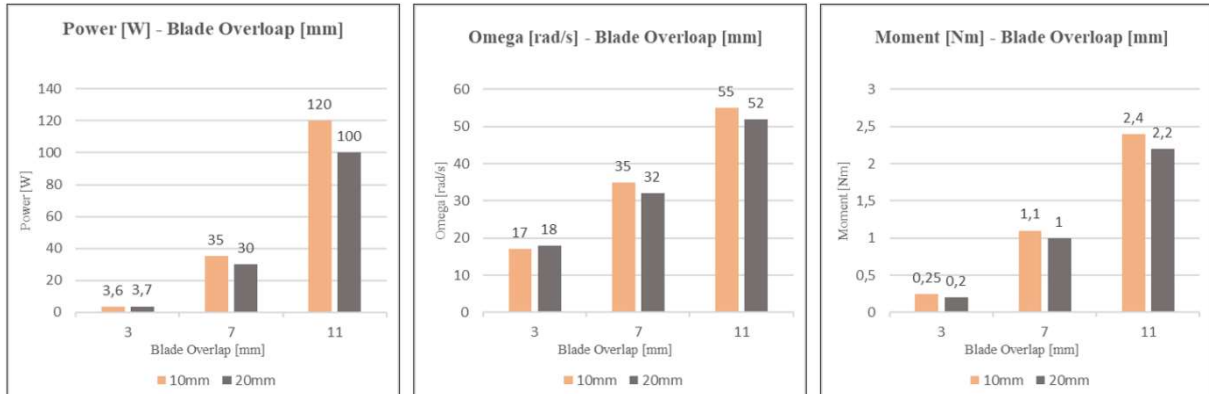


Figure 5. Power, omega, and moment results for blade overlap

The flow behaviour of the Savonius-type vertical axis wind turbine under a constant wind speed of 3 m/s with different blade overlaps (10 mm and 20 mm) was examined in Figures 6 and 7.

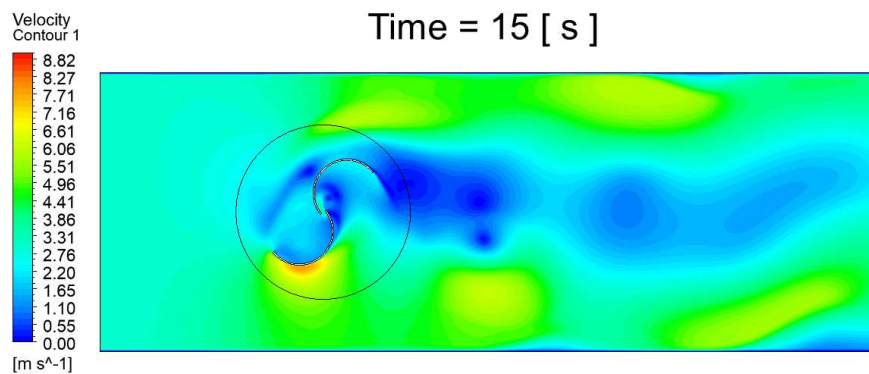


Figure 6. 10mm Overlap – 3m/s Wind Speed

At a 10 mm overlap, the flow was observed to enter the turbine in a more controlled and directed manner. The velocity contours revealed more balanced vortex structures and distinct velocity gradients around the turbine. This indicates that even at low wind speeds, the turbine is capable of generating rotational momentum, providing an advantage in terms of starting torque.

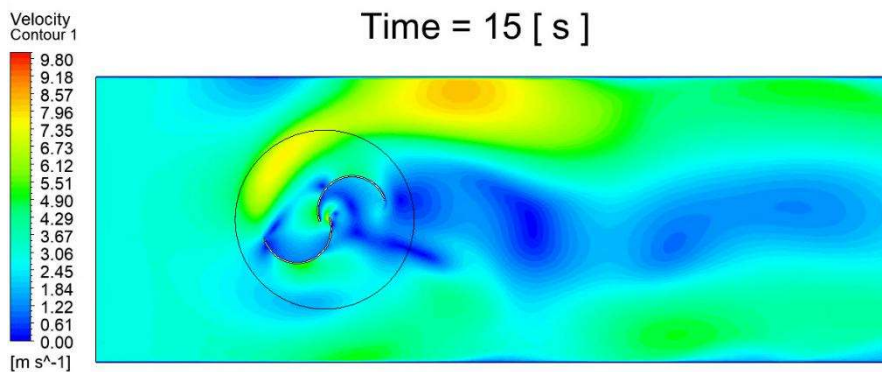


Figure 7. 20mm Overlap – 3m/s Wind Speed

At a 20 mm overlap, however, the flow was distributed more diffusely and irregularly around the turbine. Spiral vortices were more pronounced but carried energy less efficiently. The wider overlap increased flow separation, making stable operation at low wind speeds more difficult. This comparison demonstrates that narrower blade overlaps are more advantageous for turbine performance at low wind speeds. In particular, the 10 mm overlap offers a more efficient solution in terms of starting torque and rotational capability at low speeds, whereas the 20 mm overlap leads to energy losses under such conditions.

The flow behaviour of the Savonius-type vertical axis wind turbine under a constant wind speed of 7 m/s with different blade overlaps (10 mm and 20 mm) was examined in Figures 8 and 9.

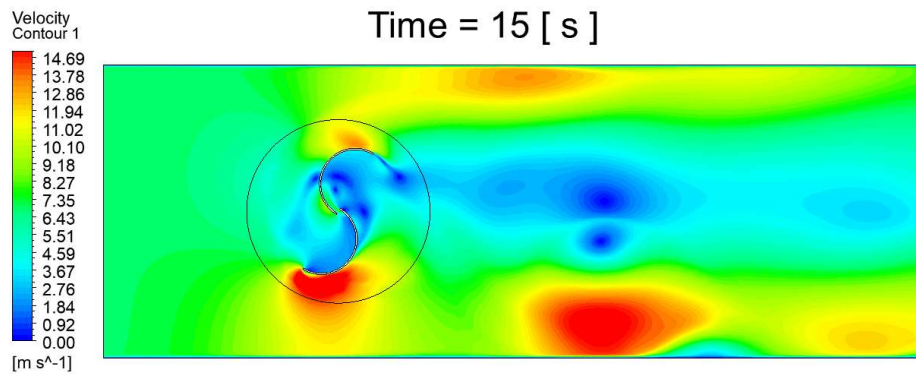


Figure 8. 10mm Overlap – 7m/s Wind Speed

At a 10 mm overlap, the flow was observed to enter the turbine in a more controlled and directed manner. The velocity contours revealed more balanced vortex structures and distinct velocity gradients around the turbine. This indicates that at medium wind speeds, the turbine can generate rotational momentum more efficiently and deliver a stable power output.

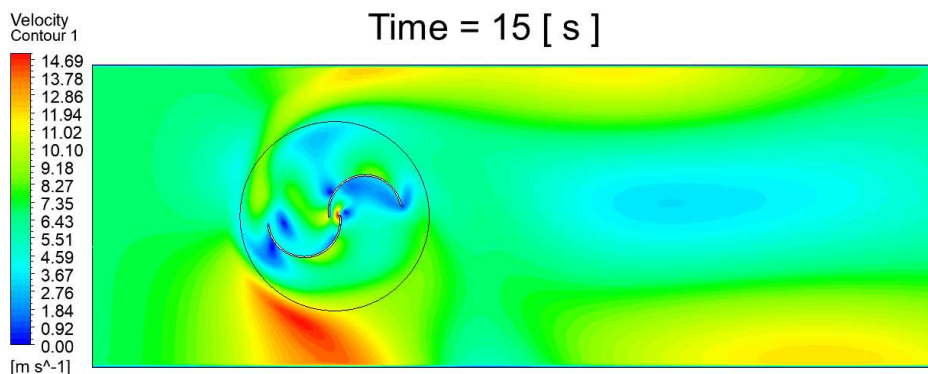


Figure 9. 20mm Overlap – 7m/s Wind Speed

At a 20 mm overlap, however, the flow was distributed more diffusely and irregularly around the turbine. Spiral vortices were more pronounced but carried energy less efficiently. The wider overlap increased flow separation, making the transition to stable operation more difficult and leading to higher torque fluctuations.

This comparison demonstrates that narrower blade overlaps are more advantageous for turbine performance at medium wind speeds. In particular, the 10 mm overlap provides a more efficient solution in terms of flow organisation and energy conversion, while the 20 mm overlap tends to cause energy losses and stability issues under low-to-medium speed conditions.

The flow behaviour of the Savonius-type vertical axis wind turbine under a constant wind speed of 7 m/s with different blade overlaps (10 mm and 20 mm) was examined in Figures 10 and 11.

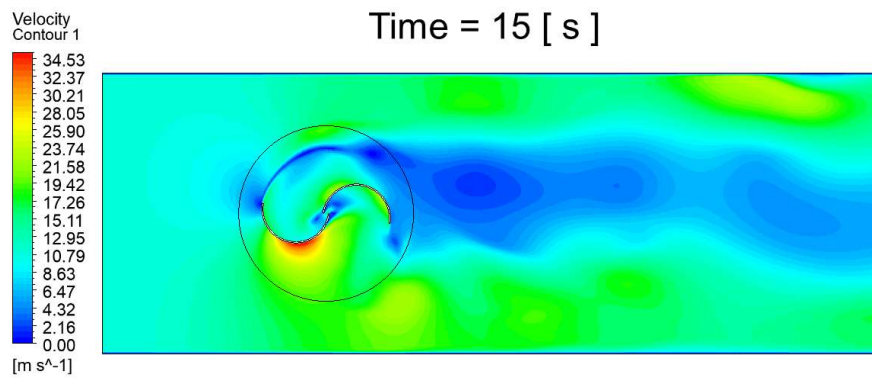


Figure 10. 10mm Overlap – 11m/s Wind Speed

At a 10 mm overlap, the flow was observed to enter the turbine in a more controlled and directed manner. The velocity contours revealed more balanced vortex structures and distinct velocity gradients around the turbine. This indicates that at medium-to-high wind speeds, the turbine can generate rotational momentum more efficiently and deliver a stable power output.

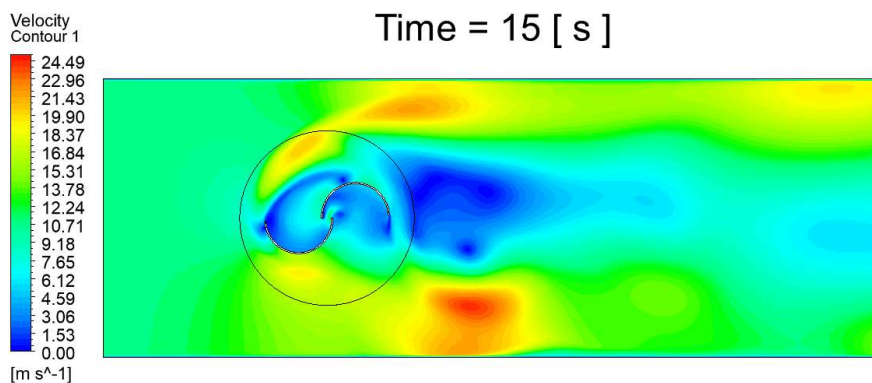


Figure 11. 20mm Overlap – 11m/s Wind Speed

At a 20 mm overlap, however, the flow was distributed more diffusely and irregularly around the turbine. Spiral vortices were more pronounced but carried energy less efficiently. The wider overlap increased flow separation, making the transition to stable operation more difficult and leading to higher torque fluctuations.

This comparison demonstrates that narrower blade overlaps are more advantageous for turbine performance at higher wind speeds. In particular, the 10 mm overlap provides a more efficient solution in terms of flow organisation and energy conversion, while the 20 mm overlap tends to cause energy losses and stability issues under such conditions.

In the Savonius-type vertical axis wind turbine, blade gaps of 10 mm and 20 mm were compared under constant wind speeds of 3, 7, and 11 m/s. At 3 m/s, the 10 mm gap allowed a more controlled inflow and provided an advantage in starting torque, while the 20 mm gap resulted in more diffuse flow and reduced efficiency. At 7 m/s, the 10 mm gap produced a more compact wake and coherent vortex structures, leading to stable power generation, whereas the 20 mm gap increased torque fluctuations and energy losses. At 11 m/s, the 10 mm gap ensured efficient flow organisation, momentum transfer, and stable power output, while the 20 mm gap caused wider separation regions and stability issues. Overall, across all wind speed regimes, the 10 mm blade gap is the most ideal configuration, offering superior performance in terms of flow organisation, torque stability, and energy conversion efficiency.

Conclusion and Recommendations

The numerical and experimental evaluation of the Savonius wind turbine, with variable blade overlap distances, has revealed that overlap distance considerably influences the turbine's performance throughout

diverse wind speed circumstances. Simulations conducted with the k- ϵ turbulence model over a 15-second transient duration demonstrated a strong connection with experimental results, exhibiting an average variation of roughly 15%. This confirms the precision and dependability of the utilised CFD technology. Particular overlap configurations produced enhanced torque and efficiency, especially at reduced wind speeds, underscoring the appropriateness of Savonius turbines for urban and low-wind settings. The results highlight the promise of refined Savonius designs in small-scale renewable energy applications and establish a basis for future research focused on improving vertical-axis wind turbine efficiency by geometric modifications.

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