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Proceeding Paper

Experimental Investigation of Two- and Three-Blade Savonius Hydrokinetic Turbine for Hydropower Applications: A Study across Various Turbine Positions from Channel Centre to Channel Wall †

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Abstract: Hydrokinetic energy has gained significant attention in recent years as a promising renewable energy source due to its low environmental impact and potential for use in remote locations. This research aims to optimize the performance of the Savonius hydrokinetic turbine, a crucial component of zero-head hydropower systems, for efficient renewable energy extraction from flowing water. Laboratory-scale experiments with two and three-blade Savonius turbines at different channel positions investigate geometric dimensions and design parameters like the power coefficient (C_P) and Torque coefficient (C_T). The experimental results are compared with previous research, confirming the superiority of the two-blade configuration, which achieved C_P and C_T at the same TSR and channel locations. Specifically, the two-blade Savonius turbine demonstrated a C_P of 0.27 and a C_T of 0.37 at TSR 0.7 and the channel's centre placement. Placing the turbine at the channel centre yields the best performance for both configurations. This study provides valuable insights for enhancing the efficiency of hydrokinetic turbines, contributing to renewable energy technology advancements, and addressing climate change and energy security challenges. The Savonius hydrokinetic turbine has the potential to be a sustainable energy source.

Keywords: coefficient of torque; coefficient of power; tip speed ratio; hydrokinetic turbine; two blade; three blade

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1. Introduction

Energy is essential for human well-being because it enables daily human activities such as agriculture, business, communications, education, healthcare, and transportation [1]. Energy is a key contributor to global economic and social development, which can be derived from both renewable and non-renewable sources. The need for renewable energy sources has increased as a result of reasons such as global energy demand, the increasing expense and unreliability of nonrenewable energy, and the negative environmental repercussions connected with consumption of nonrenewable fuels [2]. In recent years, there has been a rapid acceleration in the adoption of clean energy technologies like solar power, wind energy, hydropower, and biofuels, with a particular emphasis on renewable sources. Renewables accounted for 30% of the world's power generation in 2022, marking a significant increase from less than 20% in 2010 [3]. Solar photovoltaic, wind, hydropower, and bioenergy output experienced substantial growth, contributing significantly to the upward trend. Among these sources, hydropower has been widely acknowledged as a dependable, highly efficient, and environmentally sustainable form of energy [4]. However, conventional hydropower requires large dams, which can cause significant environmental and social impacts [5].

On the other hand, hydrokinetic energy has emerged as an economically valuable option for green energy generation. It entails harnessing the kinetic energy that is freely available in irrigation channels, small and big river-flowing areas, ocean tides, and water currents found in the ocean to generate small-scale hydropower [6]. This system offers enormous potential for producing electricity from low-velocity, low-head water utilizing hydrokinetic turbines. The kinetic energy available in the flowing water is converted into mechanical energy by these turbines. These turbines are also known as free flow or free stream turbines, and zero-head hydrokinetic turbines [7]. With its low environmental impact and potential for use in remote locations, hydrokinetic energy has gained significant interest in recent years as a promising renewable energy source [8]. Its implementation might make an important contribution to the global energy mix and aid in addressing the serious concerns of climate change and energy security [9].

Hydrokinetic energy, derived from the kinetic energy of flowing water bodies, holds significant promise as a clean and reliable renewable energy source, particularly for remote locations. Unlike traditional hydroelectric dams, it minimizes environmental disruption and offers constant power generation. Research in this field is pivotal, focusing on technology optimization, environmental impact assessment, resource evaluation, grid integration, economic viability, and regulatory frameworks, all aimed at harnessing the full potential of hydrokinetic energy for sustainable and accessible power generation in remote areas while preserving natural ecosystems.

A wide range of technical and economic issues must be considered when selecting a turbine rotor layout. These challenges become much more prominent for hydrokinetic turbines as an emerging field of energy conversion [10]. Three generic classifications are made based on the rotational axis of the turbine with respect to the water flow direction: (a) horizontal axis, (b) vertical axis, and (c) cross-flow turbines. The vertical axis Savonius turbine was designed primarily for wind energy gathering in the 1920s by Finnish engineer Sigurd Johannes Savonius. Savonius was inspired by a Flettner ship's turbine and created his concept by cutting the cylindrical turbine in half [11]. Two semi-circular buckets were connected to a turbine shaft with a small overlap, as shown in Figure 1.

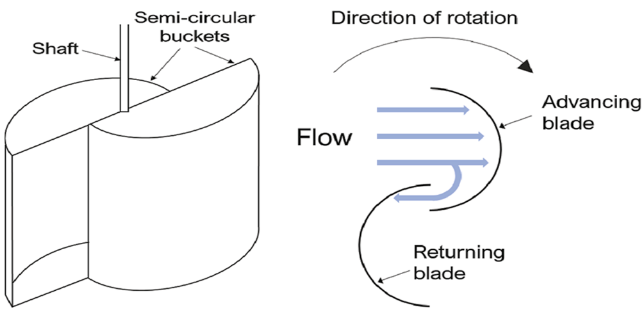


Figure 1. Initial concept of Savonius turbine [11].

Compared to other turbine designs, the Savonius turbine offers distinct advantages, primarily its cost-effectiveness and exceptional adaptability [12]. This article aims to improve its efficiency while retaining these key attributes. The Savonius turbine stands out for its economic manufacturing, making it viable in economically challenged mountainous regions. Its ability to capture water from any direction, superior self-starting performance, reduced noise emissions, and consequent longer service life due to less wear and tear all enhance its appeal as a sustainable energy solution.

Figure 1 illustrates that the primary driving force behind the rotation of the SHKT turbine is the drag force acting between the advancing and returning blades. To increase the net driving power, one can either augment the force on the advancing blade or diminish the force on the returning blade. Due to the unidirectional water flow, the turbine self-rotates along its axis, leading to variations in the drag coefficient of both blade types, ultimately affecting the rotor's torque and resulting in cyclic fluctuations. Hydrokinetic turbines harness the kinetic energy available in free-flowing rivers, and researchers have fine-tuned various characteristics of the semicircular blades to maximize the turbine's power coefficient.

The Savonius HKT revolves around a vertical shaft, producing power depending on drag differential between its concave blade and convex blade profiles [13]. The essential geometric dimensions of a three-dimensional Savonius HKT are its height (H_T), turbine diameter (D_r), and endplate diameter (D_{ep}), as shown in Figure 2. Number of blades, Aspect ratio (AR), separation gap (SG), augmentation technique, overlap ratio (OR), varied blade profile, and number of stages are the many design characteristics of Savonius hydrokinetic turbines for performance enhancement.

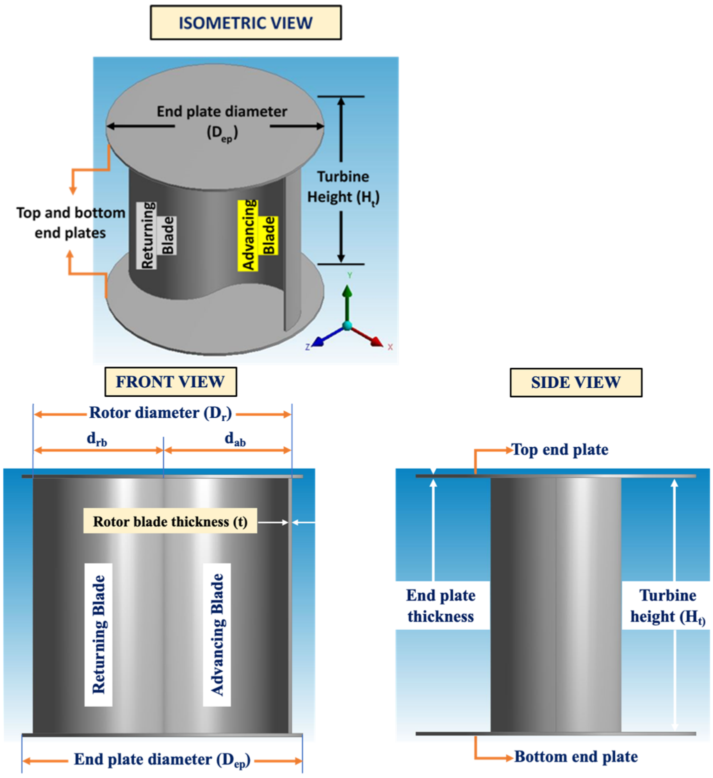


Figure 2. Three-dimensional view of geometrical terms used in Savonius HKT.

Several studies have sought to optimize the performance variables of Savonius HKT by optimizing its separation gap (SG), overlap ratio, aspect ratio, end plates, blade design, and blade numbers. Some researchers employed various augmentation approaches to reduce the negative torque on the returning blade and enhance the performance measures like C_T and C_P.

Golecha et al. [14] investigated the effect of the ideal position of the deflector plate in two-stage and three-stage modified SHKT and discovered that the maximum coefficient of performance Cp increased by 42 percent with the deflector plate for two-stage SHKT at the 0 degree position. Kumar et al. [15] performed a numerical analysis of a twisted two-blade SHKT to investigate the performance parameters C_P and C_T and discovered that a Savonius HKT with a twisted angle of 12.5 degrees yields a maximum C_P of 0.39 for a TSR 0.9 to a input water flow velocity of 2.0 metres per second.

Parag et al. [16] compared the performance parameters of two-blade and three-blade turbines with a conventional blade profile, experimentally and numerically, and discovered that the maximum C_P for a two-blade turbine of 0.28 for a TSR value of 0.84 and three-blade turbine C_P was 0.17, at TSR 0.67. Thiyagaraj et al. [17] carried out an experimental investigation to improve the coefficient of power C_P by testing 2, 3, 4, 5, and 6 blade turbines and discovered that the Savonius turbine with an 0.2 overlap provides the highest coefficient of power of 0.105 for two-blade turbines when in comparison to the remaining blade profiles.

Vimal et al. [18] studied the influence of the aspect ratio and overlap ratio on the performance of a SHKT in a labscale setup channel with a water depth of 270 mm and discovered a maximum C_P for an aspect ratio less than 0.6 and overlap ratio 0.11, increasing until the aspect ratio reaches 1.8. Shashikumar et al. [19] conducted a combined experimental investigation and numerical analysis on five V-shaped semi-circular turbine blade configurations to evaluate $C_{p\ max}$. The optimal rotor blade profile V4 demonstrated a $C_{p\ max}$ of 0.22 at a TSR of 0.87 which is 19.3% greater than the conventional blade profile due to its lower negative torque.

According to the previously cited literature review, the installation geometrical parameters influence for SHKT was discussed by a few authors, and all of the investigations were conducted in the straight and middle of the channel. Researchers used various methodologies to improve the power extracted from the water using SHKT. There is no literature available on the installation of the turbine at different geometrical locations starting from the middle of the channel to the side wall of the channel for two- and three-bladed Savonius hydrokinetic turbines. Therefore, an experimental setup has been created for this investigation, and it will be introduced and explored in the following section.

2. Materials and Methods/Methodology

In a laboratory-scale experimental setup, the focus is on optimizing the performance of two- and three-blade Savonius hydrokinetic turbines positioned at various locations within a controlled channel. This setup aims to assess and enhance the efficiency of these turbines in capturing the kinetic energy of flowing water. The experiment involves the utilization of a closed-loop channel with regulated water flow, along with measurement instruments like a tachometer, torque measurement devices, flow meters, and pressure sensors to collect critical data. Through careful experimentation, data analysis, and performance parameter calculations, including (C_P) and (C_T), the present study aims to determine the most effective turbine configurations and placements within the channel. Ultimately, the present work serves as a vital step in advancing the utilization of Savonius turbines for hydrokinetic energy generation, providing valuable insights for optimizing their performance in real-world applications, particularly in regions with varying water flow conditions.

Golecha et al. [14] conducted an experimental study in an open channel with a cross-sectional area of the channel 730 mm $\times$ 330 mm to analyze the effect of the deflector plate on parameters like C_T and C_P for modified SHKT. In the current study, experiments were carried out in water re-circulating multipurpose hydraulic flume having a channel cross-sectional area of 215 mm $\times$ 350 mm using a model on a smaller scale of Golecha et al. Scaled-down Savonius HKT dimensions are calculated and written in Table 1. The geometrical dimensions of the two- and three-bladed SHKT employed in this study have the same blade diameters and aspect ratio, with the only difference being the number of blades, as shown in Table 2.

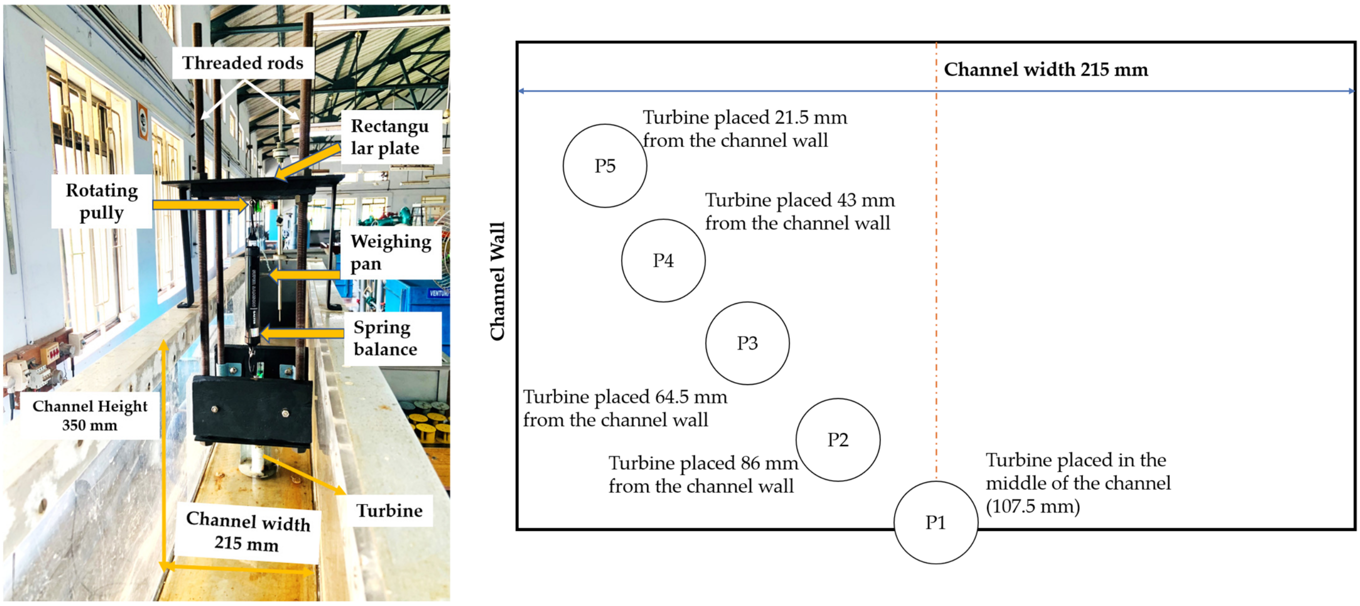
Figure 3a displays the experimental test rig that was used to calculate performance characteristics such as coefficient of torque (CT) and coefficient of power (CP) by monitoring the applied load and rotor shaft speed. It is composed of four threaded rods that serve as a supporting framework and a rectangular plate bolted to the threaded rod at a fixed distance from the structure's bottom. A semicircular-shaped rotor blade with end plates constructed of a galvanized iron sheet of 1 mm thickness is secured to the circular plate using flange bearings, along with a stainless steel shaft of 12 mm diameter. With nylon thread wrapped around the rotor shaft, a rope break dynamometer for loading is also attached to the supporting structure. A spring balance (Salter, 2.5-g precision) is attached to one end of a nylon string that runs through a revolving pulley and connects to a weighing pan on the right side of the construction. Finally, to execute the experiment, the entire experimental test setup is placed on a multipurpose tilting flume. The current study investigated the performance parameters of two and three bladed Savonius hydrokinetic turbines at five different locations, beginning in the middle of the channel, as illustrated in Figure 3b.

Table 1. The geometrical values of SHKT and scaled down channel dimensions are represented.

Sl. No.	Parameters	Author [14]	Present Work
1	Rotor diameter (D_r) in mm	245	72
2	Aspect Ratio	0.7	1
3	Endplate Diameter (D_{ep}) in mm	269.5	79.2
4	Turbine Height (H_T) in mm	170	51
5	Channel width in mm	730	215
6	Channel height in mm	330	350

Table 2. The geometrical dimensions of the two and three-blade modified Savonius hydrokinetic turbines used in the experiment.

Sl. No.	Parameters	Two Blades	Three Blades
1	Rotor diameter (D_r) in mm	72	72
2	Number of blades	2	3
3	Endplate Diameter (D_{ep}) in mm	79.2	79.2
4	Turbine Height (H_T) in mm	72	72
5	Aspect ratio	1	1
6	Channel width in mm	730	215
7	Channel height in mm	330	350
8	Channel length in mm	4750	4750



(**a**) (**b**)

Figure 3. (**a**) Experimental test rig installed in hydraulic multipurpose tilting flume. (**b**) Various places where the two- and three-bladed Savonius hydrokinetic turbines were installed to test performance characteristics such as C_T and C_P.

Performance Parameters

The TSR, C_P and C_T, of SHKT are expressed using the below equations. To compute these parameters, the water flow velocity in the channel and turbine shaft rotational speed N to be computed.

$$\textbf{Coefficient of Torque } (C_T) = \frac{T_{Rotor}}{T_{Available}} = \frac{T_{Rator}}{\left(\frac{1}{2}\rho_w A_r V_w^2\right)\frac{D_r}{2}} \tag{1}$$

where A_r = area of the rotor blade in mm^2, D_r = Diameter of the turbine in mm, V_w = Velocity of the water in $\frac{m^2}{Sec}$, ρ_w = Density of water in $\frac{kg}{m^3}$,

$$\textbf{Rotor Torque } T_{Rotor} = (W_L - S_{SB})g(R_{shaft} + R_{Rope}) \tag{2}$$

where W_L = Load acting on the shaft in gms, S_{SB} = Spring balance value in gms, R_{shaft} = Radius of the shaft in mm, R_{Rope} = Radius of the rope in mm,

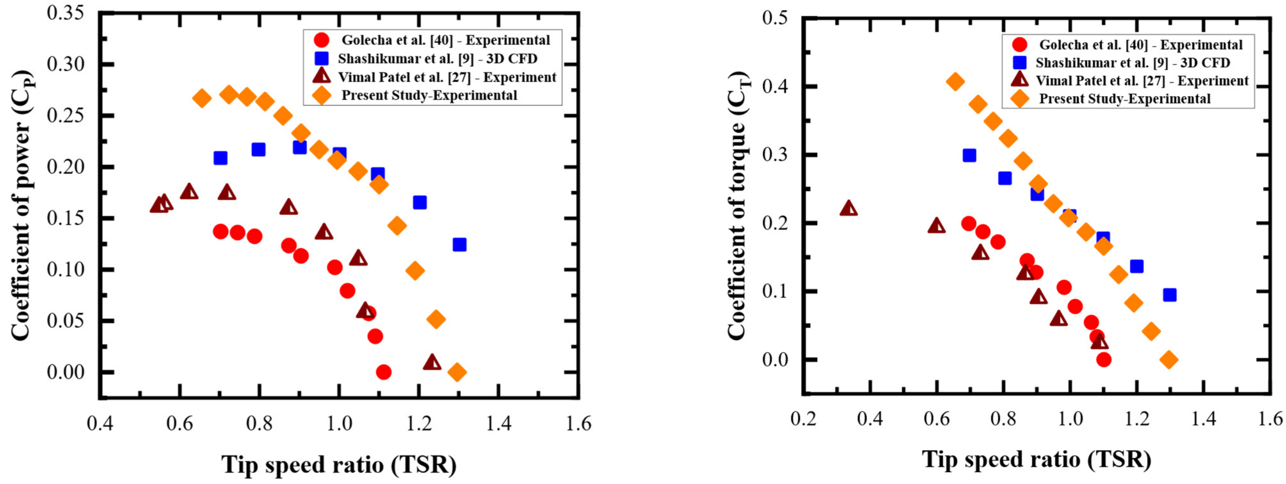
$$\textbf{Coefficient of Power } C_P = \frac{P_{Rotor}}{P_{Available}} = \frac{(T_{Rotor} \times \omega)}{\left(\frac{1}{2}\rho_w A_r V_w^3\right)} \tag{3}$$

where ω = Angular Velocity $\frac{Rad}{Sec}$,

$$\textbf{Tip Speed Ratio } TSR = \frac{\omega D_r}{2V_w} \tag{4}$$

3. Results

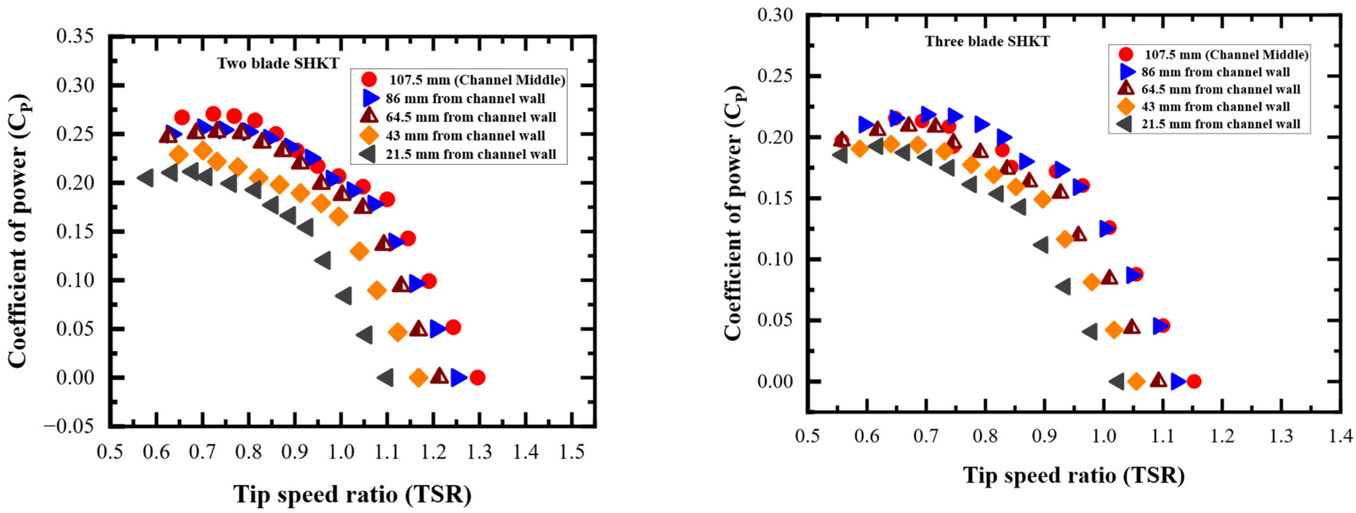
The placement of two and three-bladed SHKT with aspect ratios (AR) of 1.0 and 72 mm diameter in five different positions in a multipurpose hydraulic tilting flume facility water channel with an inlet water flow velocity (V_w) of 0.5 m/s was studied. C_P and C_T in relation to TSR are calculated experimentally using a rope type dynamometer test rig. The experimental results of the two-blade Savonius hydrokinetic turbine are compared to those of previously published turbines. Figure 4a depicts comparative plots of Cp variations with respect to TSR. The two-bladed Savonius turbines located in the middle of the channel results were used in this study, and the comparison shows that the experimental results obtained in this study follow the same pattern as previous researchers. For the current study of two-bladed SHKT with an aspect ratio of 1.0 and rotor diameter of 72 mm, the value of C_P is 0.26 for TSR 0.7, according to Shashikumar et al.'s [20] 3D CFD numerical reading. Golecha et al.'s [14] experimental values for the coefficient of power C_P are 0.14 in comparison to a TSR value of 0.7. Vimal Patel et al. [18] shows the C_P as 0.17 for the TSR value 0.7, indicating that the current work follows the same trend as previous researchers. Figure 4b shows a comparison graph for the coefficient of torque Ct with respect to TSR for a previous researcher's numerical and experiential work as well as current work. The 3D CFD work of Shashikumar et al. [20] gives the value of C_T 0.29 for TSR 0.7, the experimental work of Golecha at al. [14] provides the value of the coefficient of torque C_T 0.19 for TSR 0.7. Vimal Patel et al. [18] shows values of C_T 0.17 for TSR 0.7 and presents experimental work for two-blade SHKT and shows the value of C_T 0.35 for TSR 0.7. Figure 4b clearly depicts that the current experimental work follows the same trend as previous research in both experimental and numerical investigations.



(**a**) (**b**)

Figure 4. (**a**) Comparison of the C_P vs. TSR for the current experimental study with previous authors. (**b**) Comparison of the C_T vs. TSR for the current experimental work with previous studies.

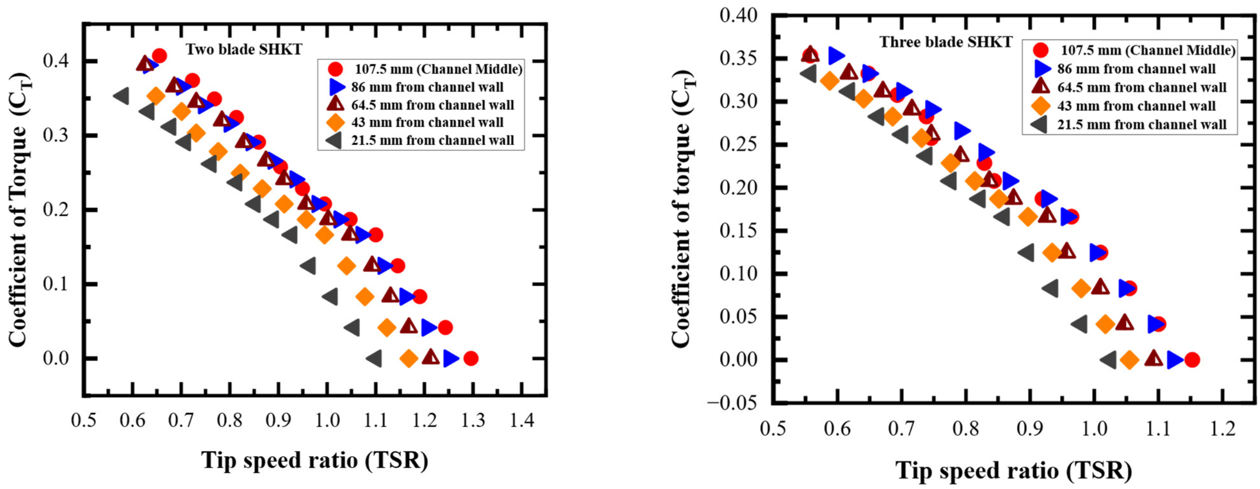
The present experimental work of two-blade Savonius hydrokinetic turbine at different channel positions, ranging from the channel wall to the middle reveal that the coefficient of power (C_P) increases from 0.2 at the channel wall to 0.27 at the middle of the channel, maintaining for tip speed ratio of 0.7, as depicted in Figure 5a. Similarly, for a three-blade Savonius turbine, the C_P rises from 0.18 at the channel wall to 0.21 at the middle for the same tip speed ratio of 0.7, as illustrated in Figure 5b. Notably, placing the turbine at the centre of the channel yields the highest C_P for both two- and three-blade Savonius turbines, offering valuable insights to optimize their efficiency.



(**a**) (**b**)

Figure 5. (**a**) C_P vs. TSR of two blade SHKT at different positions in the channel. (**b**) C_P vs. TSR for three-blade SHKT at different positions in the channel.

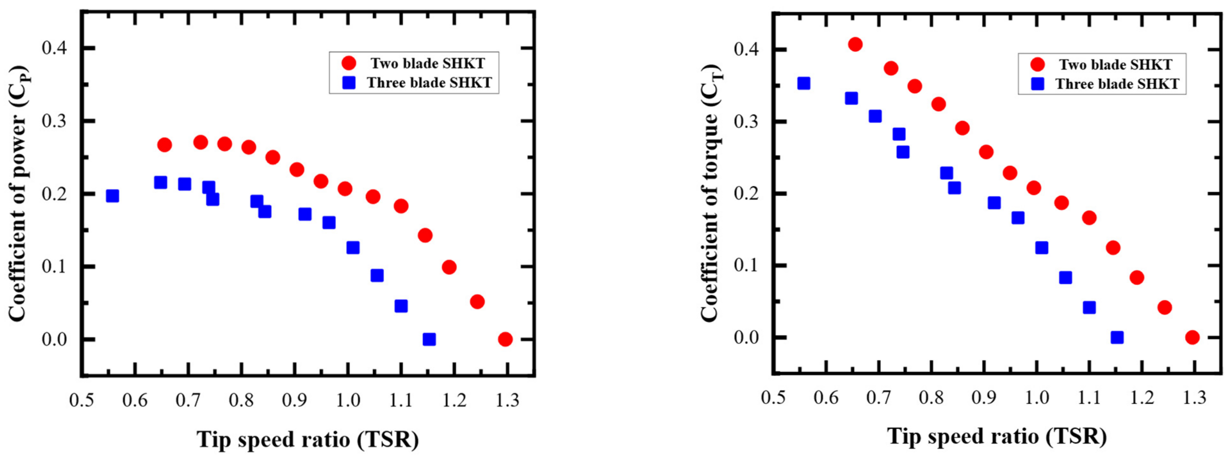
Figure 6a presents the results for a two-blade Savonius hydrokinetic turbine, indicating that the coefficient of torque (C_T) at the middle placement of the turbine reaches 0.37 at TSR 0.7. Conversely, when the turbine is positioned at the channel wall, the C_T decreases to 0.29 for the same TSR of 0.7. Similarly, Figure 6b showcases the outcomes for a three-blade Savonius hydrokinetic turbine, where the C_T at the middle placement is recorded at 0.30 for a TSR of 0.7. On the other hand, at the channel wall, the C_T reduces to 0.26 for the same TSR of 0.7. Notably, these findings reveal that for both two- and three-blade Savonius turbines, the C_T is higher when the turbine is positioned at the channel middle, highlighting the significance of this placement for optimizing torque performance.



(**a**) (**b**)

Figure 6. (**a**) C_T vs. TSR of two blade SHKT at different positions in the channel. (**b**) C_T vs. TSR of three blade SHKT at various positions in the channel.

In order to improve the performance of SHKT, this study found compelling evidence supporting the two-blade Savonius hydrokinetic turbine (SHKT) over its three-blade SHKT. At a TSR of 0.7, the two-blade SHKT gives a higher C_P and C_T of 0.27 and 0.37, respectively, as shown in Figure 7a. The three-blade SHKT gives lower C_P and C_T values of 0.21 and 0.30, respectively, at the same TSR as shown in Figure 7b. Notably, the advantage of the two-blade layout is most apparent when the turbine is strategically located in the channel's centre. These findings highlight the two-blade SHKT's undeniable superiority for harnessing greater power and torque, paving the way for more efficient and sustainable energy extraction from water flows.



(**a**) (**b**)

Figure 7. (**a**) Comparison of C_P vs. TSR of two and three blade SHKT at turbine position in the middle of the channel. (**b**) Comparison of C_T vs. TSR of two- and three-blade SHKT at turbine position in the middle of the channel.

This study's practical implications are noteworthy for optimizing hydrokinetic turbine efficiency, especially in low-velocity conditions, where the superiority of the two-blade configuration, particularly when placed at the channel centre, highlights potential design improvements. This informs ideal turbine placement strategies, aiding project planners and developers in maximizing power and torque generation while minimizing environmental impact. Moreover, it promotes climate-resilient energy generation and facilitates energy access in remote areas, addressing energy security and climate change challenges, ultimately contributing to a cleaner, more sustainable energy landscape.

4. Discussion

This research study investigated the performance of two and three-bladed SHKT in a multipurpose hydraulic tilting flume with varying channel positions. The experimental results were compared with previously published studies, both numerically and experimentally, to validate the findings. The comparison of C_P and C_T with respect to TSR revealed that the experimental results of the two-blade SHKT in this study followed similar trends as previous researchers' work of Shashikumar et al. [20] and Golecha et al. [14]. The C_P values increased from 0.2 at the channel wall to 0.27 at the middle of the channel, while the Ct values rose from 0.29 to 0.37 for a TSR of 0.7. Similarly, for the three-blade SHKT, Cp increased from 0.18 to 0.21, and Ct increased from 0.26 to 0.30 at the same TSR and channel positions.

In the present study, a critical comparison was drawn between the two-blade and three-blade configurations of Savonius hydrokinetic turbines, with a particular focus on efficiency. The results unequivocally demonstrated the superiority of the two-blade design in several key aspects. Notably, the two-blade configuration consistently outperformed its three-blade counterpart in terms of efficiency, showcasing higher power coefficients (C_P) and torque coefficients (C_T) across the various positions tested within the channel. This heightened efficiency can be attributed to the reduced drag and improved aerodynamic characteristics inherent to the two-blade design. These findings underscore the distinct advantages of the two-blade configuration, positioning it as a more efficient and promising choice for hydrokinetic energy generation in practical applications, particularly in locations with fluctuating water flow dynamics.

Placing the two-blade Savonius hydrokinetic turbine in the middle of the channel emerges with significantly higher coefficients of power (C_P) and torque (C_T) at this strategic placement, underscoring the turbine's unmatched efficiency in harnessing the kinetic energy of flowing water. This efficiency not only amplifies energy generation but also minimizes the environmental footprint of hydrokinetic energy projects by optimizing resource utilization. In doing so, it reduces our reliance on fossil fuels, mitigates greenhouse gas emissions, and advances the transition towards clean and renewable energy sources. Such sustainable practices not only help combat climate change but also bolster energy security by diversifying the energy mix and reducing vulnerability to supply disruptions.

5. Conclusions

The experimental investigation was carried out on Savonius hydrokinetic turbine using a laboratory-scale experimental setup of two- and three-blade Savonius turbines placed at different channel positions, ranging from the channel centre to its wall to enhance the essential parameters like C_P and C_T with respect to TSR. Previous research was used to validate the experimental investigation, emphasizing the superiority of the two-blade arrangement. Based on the results obtained, it was found that the Savonius HKT with two blades performs better than the one with three blades. This is evident from the higher values of C_P and C_T achieved by the former at the same tip speed ratio (TSR) and channel locations. Specifically, when placed in the centre of the channel and operating at TSR 0.7, the two-bladed turbine displayed a C_P of 0.27 and a C_T of 0.37.

The present work is useful for improving the efficiency of hydrokinetic turbines, which can lead to an increase in the generation of hydropower under low-velocity conditions.

The overall performance of SHKT systems is improved by placing the two-blade SHKT in the middle of a small irrigation channel. This will contribute to the advancement of efforts toward sustainable energy solutions while also addressing the important issues of climate change and energy security.

Author Contributions: Conceptualization, S.T.G.; methodology, S.T.G. and S.C.M.; validation, S.T.G. and S.C.M.; formal analysis, S.T.G. and S.C.M.; investigation, S.T.G. and S.C.M.; resources, S.T.G.; data curation, S.T.G. and V.M.; writing—original draft preparation, S.T.G. and S.C.M.; writing—review and editing, S.T.G. and S.C.M.; supervision, V.M. and V.G. All authors have read and agreed to the published version of the manuscript.

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References

1. Yadav, P.K.; Kumar, A.; Jaiswal, S. A critical review of technologies for harnessing the power from flowing water using a hydrokinetic turbine to fulfill the energy need. *Energy Rep.* **2023**, *9*, 2102–2117. [CrossRef]
2. International Energy Agency. World Energy Outlook 2022- Roadmap to Net Zero Emissions. 2022. Available online: https://www.iea.org/reports/world-energy-outlook-2022 (accessed on 13 June 2023).
3. International Energy Agency. Renewables 2022- Analysis and Forecast to 2027. 2022. Available online: https://www.iea.org/reports/renewables-2022 (accessed on 13 June 2023).
4. International Energy Agency. Energy Technology Perspectives 2023. 2023. Available online: https://www.iea.org/reports/energy-technology-perspectives-2023 (accessed on 14 June 2023).
5. Ansar, A.; Flyvbjerg, B.; Budzier, A.; Lunn, D. Should we build more large dams? The actual costs of hydropower megaproject development. *Energy Policy* **2014**, *69*, 43–56. [CrossRef]
6. Saini, G.; Saini, R.P. A review on technology, configurations, and performance of cross-flow hydrokinetic turbines. *Int. J. Energy Res.* **2019**, *43*, 6639–6679. [CrossRef]
7. Güney, M.; Kaygusuz, K. Hydrokinetic energy conversion systems: A technology status review. *Renew. Sustain. Energy Rev.* **2010**, *14*, 2996–3004. [CrossRef]
8. Kumar, D.; Sarkar, S. A review on the technology, performance, design optimization, reliability, techno-economics and environmental impacts of hydrokinetic energy conversion systems. *Renew. Sustain. Energy Rev.* **2016**, *58*, 796–813. [CrossRef]
9. International Energy Agency. Net Zero by 2050—A Roadmap for the Global Energy Sector. 2021. Available online: https://www.iea.org/reports/net-zero-by-2050 (accessed on 14 June 2023).
10. Khan, M.; Bhuyan, G.; Iqbal, M.; Quaicoe, J. Hydrokinetic energy conversion systems and assessment of horizontal and vertical axis turbines for river and tidal applications: A technology status review. *Appl. Energy* **2009**, *86*, 1823–1835. [CrossRef]
11. Maldar, N.R.; Ng, C.Y.; Oguz, E. A review of the optimization studies for Savonius turbine considering hydrokinetic applications. *Energy Convers. Manag.* **2020**, *226*, 113495. [CrossRef]
12. Guo, F.; Song, B.; Mao, Z.; Tian, W. Experimental and numerical validation of the influence on Savonius turbine caused by rear deflector. *Energy* **2020**, *196*, 117132. [CrossRef]
13. Al-Gburi, K.A.H.; Alnaimi, F.B.I.; Al-Quraishi, B.A.; Tan, E.S.; Maseer, M.M. A comparative study review: The performance of Savonius-type rotors. *Mater Today Proc.* **2022**, *57*, 343–349. [CrossRef]
14. Golecha, K.; Eldho, T.; Prabhu, S. Influence of the deflector plate on the performance of modified Savonius water turbine. *Appl. Energy* **2011**, *88*, 3207–3217. [CrossRef]
15. Kumar, A.; Saini, R. Performance analysis of a single stage modified Savonius hydrokinetic turbine having twisted blades. *Renew. Energy* **2017**, *113*, 461–478. [CrossRef]
16. Talukdar, P.K.; Sardar, A.; Kulkarni, V.; Saha, U.K. Parametric analysis of model Savonius hydrokinetic turbines through experimental and computational investigations. *Energy Convers. Manag.* **2018**, *158*, 36–49. [CrossRef]
17. Thiyagaraj, J.; Rahamathullah, I.; Anbuchezhiyan, G.; Barathiraja, R.; Ponshanmugakumar, A. Influence of blade numbers, overlap ratio and modified blades on performance characteristics of the savonius hydro-kinetic turbine. *Mater. Today Proc.* **2020**, *46*, 4047–4053. [CrossRef]
18. Patel, V.; Bhat, G.; Eldho, T.I.; Prabhu, S.V. Influence of overlap ratio and aspect ratio on the performance of Savonius hydrokinetic turbine. *Int. J. Energy Res.* **2016**, *41*, 829–844. [CrossRef]

19. Shashikumar, H.R.; Hindasageri, V.; Madav, V. Experimental and numerical investigation of novel V-shaped rotor for hydropower utilization. *Ocean Eng.* **2021**, *224*, 108689. [CrossRef]
20. Shashikumar, C.M.; Vijaykumar, H.; Vasudeva, M. Numerical investigation of conventional and tapered Savonius hydrokinetic turbines for low-velocity hydropower application in an irrigation channel. *Sustain. Energy Technol. Assess.* **2021**, *43*, 100871. [CrossRef]