



A review investigation of the Savonius hydrokinetic turbines: application and optimization

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Abstract

In response to the ongoing global energy crisis, there has been a growing interest among researchers and professionals in the energy sector in exploring sustainable and renewable energy alternatives. Among these, hydroelectric power holds a prominent position owing to its numerous advantages, including its broad geographical availability. Recent investigations have highlighted hydrokinetic energy as a promising substitute for conventional fossil fuel-based energy sources. Savonius turbines, a specific category of vertical-axis turbines, have shown potential when integrated into hydrokinetic energy systems for generating clean and sustainable power. However, these turbines require manual initiation and are characterized by relatively low rotational speeds, which can negatively impact overall efficiency and increase operational costs. When deployed in flowing water environments, the operational characteristics of Savonius turbines undergo significant changes, necessitating design optimization to enhance performance. As a result, extensive research efforts have been directed toward optimizing the design and performance parameters of Savonius turbines under hydrokinetic conditions. This article aims to systematically review the existing body of literature in this domain and analyze how various influential parameters contribute to the functional efficiency of these energy systems.

Keywords: Hydrokinetic Systems; Renewable Energy; Savonius Hydrokinetic Turbines; Savonius Turbine; Energy Efficiency

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1. Introduction

In recent years, the rapid expansion of industrial activity and continuous technological progress have significantly escalated global energy consumption. By 2018, global electricity demand had surged by 75%, reaching approximately 23,031 TWh, and projections indicate a further increase of 58% by the year 2040 [1]. In response to this growing demand, numerous nations are actively seeking to diversify their energy portfolios by integrating renewable sources and

implementing substantial policy shifts toward sustainable energy systems. However, achieving a complete transition from fossil fuels to renewable technologies-without impeding economic development-remains a complex and demanding endeavor. Notably, the global installed capacity of renewable energy has more than doubled over the past decade [2], reflecting significant progress in this domain. Among the various renewable technologies, hydropower constitutes the largest share, with an installed capacity of approximately 1,310 GW, representing 51% of the global total.

Wind energy follows with a capacity of 621 GW (24%), while solar energy accounts for 585 GW (23%). Other renewable sources, including geothermal and biomass, collectively contribute an estimated 104 GW, equivalent to 2% of the total installed renewable energy capacity.

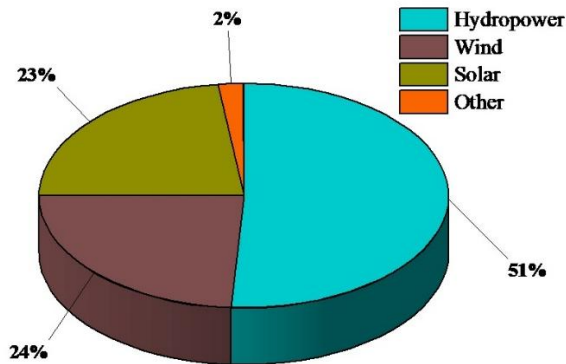


Fig. 1. Total Renewable generation capacity by energy source at the end of 2019 [3]

Given that water bodies cover more than 75% of the Earth's surface, hydropower emerges as one of the most sustainable and dependable renewable energy sources [4]. It offers greater predictability and consistency in energy output compared to other renewables. Furthermore, the carbon emissions associated with the construction of hydropower facilities are significantly lower than those of many conventional power generation systems. In contrast, the development of extensive wind or solar farms often leads to substantial alterations of the natural landscape, potentially disrupting local ecosystems and drawing resistance from nearby communities due to aesthetic and environmental concerns. Hydroelectric plants, however, are generally less susceptible to such opposition, as they can be constructed in offshore locations or integrated into existing flowing water systems, often serving multiple functions beyond electricity generation. Moreover, hydropower systems exhibit higher capacity factors relative to wind and solar technologies, indicating a more efficient utilization of installed capacity. In addition, the operational uncertainty associated with hydropower is comparatively lower, contributing to its appeal as a stable and resilient source of renewable energy [5].

Energy extraction from water resources is primarily achieved through two distinct methodologies. The first involves conventional large-scale hydroelectric systems, which rely on the construction of dams or reservoirs to generate energy by exploiting differences in hydraulic head. This method transforms the potential energy of stored water into electricity through controlled water flow and turbine operation. The second

approach, known as hydrokinetic technology, harnesses the kinetic energy of naturally flowing water—such as rivers, tidal currents, or ocean streams—by directly driving turbine blades. The mechanical energy generated is then converted into electrical energy via transmission mechanisms. Compared to traditional hydroelectric systems, hydrokinetic turbines generally present a lower environmental footprint, as they do not require extensive civil infrastructure or significant alteration of aquatic ecosystems. Moreover, unlike other renewable sources, hydrokinetic systems demand relatively minimal land use for installation. These advantages have garnered growing interest among energy researchers worldwide, promoting the development and deployment of hydrokinetic technologies [6].

Hydrokinetic energy represents a promising resource with significant potential to contribute to the global electricity supply, with estimates suggesting that approximately 800 TWh of recoverable hydrokinetic flow capacity is available annually on a worldwide scale. Despite this potential, one of the primary limitations of hydrokinetic turbine systems lies in their relatively low energy conversion efficiency. To address this issue, numerous optimization studies have been undertaken, focusing on improving turbine design and performance. Among the various turbine configurations, the Savonius turbine has emerged as a particularly suitable candidate for harnessing energy from low-velocity water flows. Its simplicity, cost-effectiveness, and operational reliability make it advantageous in such conditions compared to other turbine types. A key aspect of performance enhancement in Savonius turbines involves modifications to their geometric features, which directly influence their hydrodynamic behavior and energy output. Accordingly, this paper aims to review and synthesize existing research on the design optimization of Savonius hydrokinetic turbines, with particular emphasis on the parameters that significantly affect their performance [7].

2. Hydrokinetic Systems

Hydrokinetic energy conversion systems have a wide range of potential applications, particularly in regions with consistent water flow. Existing technologies in this domain are primarily derived from wind turbine designs, which are generally categorized based on the orientation of their rotational axis. The two main types are horizontal-axis and vertical-axis turbines. The distinction lies in the alignment of the turbine's rotational axis

relative to the direction of flow. The Savonius turbine, a type of vertical-axis wind turbine (VAWT), is characterized by its relatively low rotational speed and high torque output, making it well-suited for low-flow environments. Its robust and simple design contributes to ease of fabrication and maintenance. Key features of the Savonius turbine include:

- Lower efficiency due to power from drag.
- The Savonius wind turbine is larger than the Darius at the same power.
- Due to its high torque, it is suitable for applications such as pumping water from a well.
- The Savonius vertical wind turbine must be started non-automatically.
- Its slow speed reduces productivity and increases costs [8].

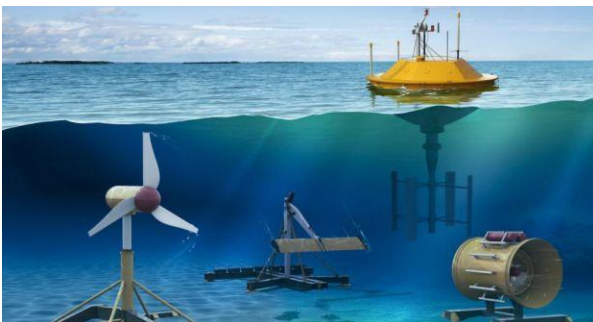


Fig. 2. Hydrokinetic and marine energy

All hydrokinetic turbines described above consist of rotor blades affixed to a central structure that transmits mechanical energy to a gearbox and generator system for electricity production. These turbines are generally classified based on the orientation of their rotational axis relative to the water surface. Axial-flow turbines have a rotor shaft aligned parallel to the direction of water flow, enabling efficient energy extraction in high-velocity conditions. In contrast, vertical-axis turbines feature a rotor shaft perpendicular to the water surface, while in-plane (or horizontal cross-flow) turbines have their rotor axis positioned horizontally but perpendicular to the flow direction. The selection of an appropriate turbine type is contingent upon several site-specific factors, including flow velocity, water depth, and operational requirements. Axial-flow turbines, which function similarly to propeller blades, employ either fixed or variable pitch blades and rely primarily on lift forces to generate rotation. These turbines are particularly well-suited for environments characterized by high stream velocities (typically exceeding 2 m/s) and

significant water depths, often greater than 2,000 meters. Under such conditions, axial-flow turbines are capable of achieving higher starting torque, reduced oscillatory behavior, and superior energy conversion efficiency. Cross-flow turbines are better adapted to moderate flow velocities and can facilitate energy generation in locations with less extreme hydraulic conditions. However, a major drawback of this turbine type is the pronounced fluctuation in torque output, which can adversely affect performance stability. In-plane turbines, inspired by traditional water wheel mechanisms, primarily operate using drag force. While mechanically simple, they generally exhibit lower efficiency compared to vertical-axis configurations. The Darrieus turbine, a well-known vertical-axis turbine, remains one of the most prominent examples within this category [8].

The Savonius turbine, originally developed in 1922, was initially utilized primarily as a wind energy device. However, in recent decades, its application has expanded considerably, with growing interest in its potential for hydrokinetic energy extraction. A notable advantage of the Savonius turbine is its ability to generate power irrespective of the fluid flow direction, eliminating the need for orientation mechanisms. Additionally, this turbine design is not constrained by water depth, enabling deployment in wide and shallow waterways where other turbine types may be less effective. In contrast, the first large-scale marine hydrokinetic turbine to be deployed was an axial-flow system known as Seaflow, with a rated capacity of approximately 300 kilowatts [9]. This installation marked a significant milestone in the practical application of hydrokinetic technology for electricity generation in marine environments.

Recent research efforts have increasingly focused on optimizing the geometric design of hydrokinetic turbine blades to enhance performance. Lu et al. [10] employed genetic algorithms to optimize the blade geometry of Savonius-type hydrokinetic turbines, demonstrating the effectiveness of evolutionary techniques in improving aerodynamic characteristics. Similarly, Lee et al. [11] investigated blade designs across various turbine configurations, noting that although vertical-axis turbines benefit from simpler construction, their high starting torque requirements often prevent automatic self-starting, posing a significant operational challenge. In another study, Mohammadi et al. [12] explored the optimal design of a hydrokinetic turbine tailored for low-velocity water flows in the Golden Gate Strait.

This research utilized a hybrid optimization approach combining particle swarm optimization with aerodynamic analysis via XFOIL. The optimization process involved refining hydrofoil sections at multiple spanwise locations—specifically at 0.4, 1.2, 2.4, 3.4, and 4.4 meters from the hub. Employing the Harp_Opt tool, which is grounded in Blade Element Momentum (BEM) theory, the study successfully determined the optimal distributions of chord length and twist angle along the blade span to maximize energy capture. Rourke et al. [13] conducted an assessment of the feasibility of deploying hydrokinetic turbines in Ireland, concluding that the majority of potential sites exhibit flow velocities below 2 m/s. Such conditions are particularly conducive to the deployment of vertical-axis cross-flow turbines, which are well-suited to operate efficiently in low-velocity environments. In a related study, Guney [14] highlighted that the mechanical components of vertical-axis cross-flow turbines—namely the transmission, generator, and gearbox—can be positioned above the water surface. This configuration offers significant advantages by simplifying both installation procedures and routine maintenance activities, thereby enhancing operational accessibility and reducing downtime. Zhou et al. [15] examined the prospects of hydrokinetic turbines deployed at a commercial scale, suggesting that axial-flow turbines will play a pivotal role in future large-scale megawatt projects. Presently, significant research and development efforts in hydrokinetic energy are concentrated in the United States and Europe, largely due to the favorable oceanic and tidal current conditions in these regions that provide suitable flow velocities for turbine installation. Conversely, in locations characterized by low flow velocities and limited hydraulic head, vertical-axis turbines present a more viable solution. Despite their potential, vertical-axis turbines require further study and optimization to enhance their efficiency and operational reliability. Continued research is essential to fully realize their application potential in such environments.

3. Savonius Hydrokinetic Turbine

The Savonius vertical-axis turbine, originally developed by Sigurd Johannes Savonius, was designed to generate electricity from wind energy. Its design is inspired by the Flettner rotor used on Flettner ships, which features a cylindrical rotor divided into two halves. In the Savonius turbine, these two semicylindrical blades are positioned

laterally and mounted on a vertical shaft, maintaining a slight overlap between them to enhance aerodynamic performance, as illustrated in Fig. 3.

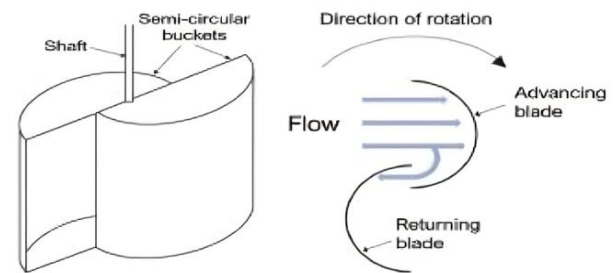


Fig. 3. Savonius hydrokinetic turbine [16]

Savonius conducted extensive experimental investigations, testing 30 different turbine configurations both in wind tunnel settings and in open-air environments to identify the most efficient geometry. His optimized model achieved efficiencies of 32% in controlled wind tunnel tests and 37% under natural airflow conditions [17]. Subsequently, Bach's 1931 study introduced a novel modification by eliminating the overlap between turbine blades and arranging them in an S-shaped configuration. This design achieved a reported maximum efficiency of 24% [18].

Elbatran et al. [19] performed a numerical investigation into the performance enhancement of Savonius hydrokinetic turbines through the incorporation of various duct nozzle designs. The study evaluated six different nozzle configurations, aiming to shield the returning blade and thereby mitigate the reversing torque that typically reduces turbine efficiency. The results demonstrated a significant improvement, with the ducted nozzle turbine achieving a maximum power coefficient increase of 78% relative to the conventional, non-ducted rotor.

Kailash et al. [20] investigated the impact of deflector plates on the performance of modified Savonius hydrokinetic turbines. The study involved experimental testing of two-stage and three-stage modified Savonius rotors to assess the influence of deflector plates positioned optimally. Results indicated that the maximum power coefficient improved by 42% for the two-stage rotor with a 0° phase shift, by 31% for the two-stage rotor with a 90° phase shift, and by 17% for the three-stage rotor, respectively, when equipped with the deflector plate.

Saleh et al. [21] conducted a comparative study examining the power performance of a conventional Savonius turbine augmented with various deflector configurations under both wind and water flow conditions. The investigation

involved experimental testing in a wind tunnel and a water channel to assess the influence of fluid medium on turbine performance. The results indicated that, for turbines equipped with deflectors and operating at equivalent Reynolds numbers, the type of fluid-air or water-did not significantly affect the power output. Consequently, wind tunnel experiments can serve as reliable proxies for evaluating the power performance of Savonius turbines in hydrokinetic applications, provided that the flow dynamics between the two fluids are comparable.

Ebrahimpour et al. [22] conducted a numerical investigation of the Savonius vertical-axis wind turbine, focusing on the influence of the overlap parameter in both horizontal and vertical directions on turbine performance. The study also examined the aspect ratio to evaluate how variations in turbine height and diameter affect overall efficiency. The findings revealed that optimizing the overlap and gap ratios effectively directs fluid flow from the leading blade to the concave surface of the trailing blade, thereby reducing negative torque generation and enhancing the turbine's performance.

Jeon et al. [23] examined the influence of end plates with varying shapes and sizes on the performance of Savonius spiral wind turbines. The study emphasized the installation of end plates on both sides of the blades to inhibit lateral fluid flow after impact, thereby increasing flow concentration on the concave surfaces due to elevated pressure, which in turn generated greater positive torque. Additionally, prior research has explored the use of turbines stacked with a 90° phase shift to mitigate significant torque fluctuations and enhance the self-starting capability of Savonius turbines. These investigations identified the two-stage turbine configuration as achieving optimal performance [24]. Furthermore, the implementation of deflector and booster plates upstream of the turbine was found to reduce the negative torque produced on the returning blades, contributing to improved overall efficiency [25].

4. Important Parameters on Savonius Turbine Efficiency

As noted above, Savonius turbines have been extensively studied for wind energy harvesting long before their application in hydrokinetic systems, resulting in numerous optimization studies within the wind energy domain. However, due to the distinct fluid properties of air and water, it is essential to conduct dedicated investigations specific to Savonius hydrokinetic turbines. A

fundamental distinction between these two environments lies in the driving forces behind the flows: water movement is predominantly governed by gravitational forces, whereas wind flow is primarily driven by pressure gradients [26]. In the study conducted by Vallis et al. [27], an open channel flow was examined, revealing that hydrostatic pressure increases progressively in the vertical direction due to downstream movement within the system. This pressure magnitude corresponds to the weight and density of the water column at any given point. Supporting these findings, Bai et al. [28] demonstrated that turbines operating in flowing water experience these pressure variations along the blade height, resulting in different sections of the blade being subjected to varying hydrostatic pressures. Such variations significantly influence the flow patterns around the turbine. Additionally, in contrast to wind flow, water flow features a well-defined free surface. Consequently, turbines operating in shallow water depths can alter the free surface characteristics, thereby affecting the overall flow depth and velocity distribution around the turbine. These changes ultimately impact turbine performance.

Wang et al. [29] highlighted that the flow dynamics are significantly influenced by the pronounced differences in viscosity and density between air and water. Additionally, wind flow direction exhibits considerable variability and lower predictability, frequently undergoing rapid changes. In contrast, water flows relevant to hydroelectric power generation tend to be unidirectional and highly predictable, owing to the consistent nature of most hydrokinetic energy sources.

Sarma et al. [30] examined the performance of a three-blade Savonius turbine operating under both wind and water flow conditions, maintaining equivalent input power levels across three different flow velocities. For the hydrokinetic case, water speeds of 0.30 m/s, 0.65 m/s, and 0.90 m/s were employed, while the corresponding wind speeds were set at 2.82 m/s, 6.13 m/s, and 8.46 m/s. These velocities were selected to ensure that the input power values-0.61 W, 6.2 W, and 16.45 W-remained consistent for both media. The results indicated that the maximum power extracted by the Savonius turbine in water was 1.61 times greater than that obtained in wind. Similarly, Talukdar et al. [31] investigated the efficiency of two-blade Savonius turbines in both wind and hydrokinetic applications at an input power of 15.9 W. Their findings revealed that the maximum

pressure coefficient for the hydrokinetic turbine was 0.29, representing a 20% increase compared to the 0.25 coefficient observed for the wind turbine.

5. Research Background: Savonius Hydrokinetic Turbine Optimization

This section of the study reviews both experimental and numerical investigations related to Savonius hydrokinetic turbines, with a focus on how variations in geometric parameters—such as aspect ratio, overlap ratio, gap ratio, and blade count—affect power output. Thochi et al. [32] introduced an innovative blade optimization method employing Bézier curves. In this approach, each blade was divided into two sections and optimized independently to simultaneously enhance the pressure differential and inlet velocity. The findings demonstrated that blades designed using this technique outperformed conventional semicircular blades, yielding an efficiency improvement of 16.7%.

In a subsequent study, Thochi et al. [33] employed an artificial neural network (ANN) to optimize the semicircular blade profile of a Savonius hydrokinetic turbine. The analysis revealed that an aspect ratio in the range of 1.4 to 2.0 and an overlap ratio between 0.15 and 0.2 resulted in improved turbine performance. The study further demonstrated that ANN serves as an efficient and accurate tool for blade optimization, significantly reducing the computational time required for design iterations. The optimized blade configuration achieved an 8% increase in efficiency compared to conventional semicircular blades.

Sadeqkhani et al. [34] investigated the performance of Savonius hydrokinetic turbines through advanced computational modeling techniques. The study utilized a range of predictive methods—including CatBoost, Artificial Neural Networks (ANN), Random Forests (RF), Multivariate Adaptive Regression Splines (MARS), Adaptive Neuro-Fuzzy Inference System (ANFIS), and several hybrid models such as ANFIS combined with Genetic Algorithm (ANFIS-GA), Slime Mold Algorithm (ANFIS-SMA), and Marine Predators Algorithm (ANFIS-MPA)—alongside Linear Regression (LR) to estimate the turbine's power coefficient. The analysis identified the aspect ratio as the most influential design parameter affecting turbine performance. Among the evaluated methods, CatBoost demonstrated superior predictive capability when multiple input variables were

considered, making it a highly suitable tool for performance forecasting of Savonius hydrokinetic turbines.

Hashem et al. [35] conducted a metamodeling-based parametric optimization study on Savonius hydrokinetic turbines, focusing specifically on the influence of overlap and gap ratios—key parameters that define the spacing between the turbine blades. Through comprehensive analysis, the study determined that the optimal configuration corresponds to an overlap ratio of 0.2085 and a gap ratio of 0.0057. These findings provide valuable insights for enhancing the aerodynamic performance and overall efficiency of Savonius hydrokinetic turbines.

Kumar et al. [36] conducted a computational fluid dynamics (CFD) analysis to evaluate the performance of a Savonius hydrokinetic turbine equipped with twisted blades. The study examined turbine behavior under water flow velocities ranging from 0.5 m/s to 2 m/s, focusing on the influence of helix angle and Reynolds number on rotor efficiency. Among the various configurations tested, rotors with helix angles between 0° and 25° exhibited superior performance. Notably, the turbine achieved its highest power coefficient of 0.39 at a helix angle of 12.5° under a flow velocity of 2 m/s, indicating this configuration as the most effective within the tested range.

In a numerical investigation of a two-blade helical Savonius turbine, Alexander et al. [37] reported the maximum power coefficient at an aspect ratio of 4.8. Similarly, Zhao et al. [38], through experimental analysis, identified an optimal aspect ratio of 4.6 corresponding to peak performance. Complementing these findings, Mahmoud et al. [39] demonstrated numerically that the power coefficient increases with a higher aspect ratio. Conversely, an experimental study by Kamoji et al. [40] indicated that an aspect ratio of 0.8 yielded the highest power output under the tested conditions, suggesting that optimal ratios may vary based on blade configuration and flow regime. Regarding the overlap ratio, Mahmoud et al. [39] observed that eliminating blade overlap (i.e., an overlap ratio of zero) maximized efficiency. In contrast, Fujisawa [41] identified an optimal overlap ratio of 0.15 for achieving the highest power coefficient, highlighting the sensitivity of turbine performance to geometric parameters.

Mohammad et al. [42] proposed an optimized geometry for the Savonius turbine aimed at enhancing its power coefficient and refining key performance-related parameters. The optimization

process incorporated six independent design variables to systematically evaluate their impact on turbine efficiency. Following the optimization, the study reported a substantial improvement in performance, with the power coefficient increasing by approximately 40% relative to that of a conventional Savonius turbine design.

Wahyudi et al. [43] conducted a numerical simulation to analyze the flow behavior and pressure distribution in and around the rotor of a Savonius hydrokinetic turbine. The study employed a two-dimensional representation of the rotor geometry. The resulting pressure contour plots revealed a distinct pressure drop from the upstream to the downstream side of the rotor, signifying energy extraction by the turbine. This pressure gradient, observed across the concave and convex surfaces of the rotor blades, generates the torque necessary to drive rotational motion and sustain turbine operation.

Birjandi et al. [44] investigated the performance of hydrokinetic turbines by experimentally evaluating a vertical-axis turbine at varying water levels within a water tunnel. The results demonstrated that, for a fully submerged turbine, the power coefficient increased as the water level decreased. In contrast, when the turbine was only partially submerged, a reduction in water level led to a decline in the power coefficient, accompanied by noticeable flow separation on the blade surfaces. These findings suggest that lowering the water level enhances turbine performance under fully submerged conditions, primarily due to free-surface effects. The observed trends are consistent with predictions derived from one-dimensional actuator-disc flow theory.

Carvajal et al. [45] conducted a comprehensive study to examine the influence of various geometric parameters on the performance of a Savonius-type vertical-axis wind turbine. The research analyzed how variations in four key geometric parameters affect the power coefficient (C_p) and torque coefficient (C_t). Specifically, the study evaluated the impact of aspect ratio, twist angle, overlap ratio, number of blades, and number of stages on turbine efficiency. The findings indicated that an aspect ratio in the range of 4 to 6 yields optimal results, producing the highest values for both $C_{p_{ax}}$ and $C_{t_{ax}}$.

Shanegowda et al. [16] investigated the impact of turbine positioning within a channel-ranging from the center to the wall-on the power coefficient of Savonius hydrokinetic turbines with two and three blades. The study aimed to optimize the

performance of Savonius turbines as key components in zero-head hydropower systems for effective renewable energy extraction from flowing water. Experimental results demonstrated the superior performance of the three-blade configuration, which consistently achieved higher power (C_p) and torque (C_t) coefficients at comparable tip speed ratios (TSR) and channel positions. Specifically, the two-blade turbine attained a C_p of 0.27 and a C_t of 0.37 at a TSR of 0.7 when positioned at the channel center. Moreover, positioning the turbine at the center of the channel was found to maximize performance for both blade configurations.

Acid et al. [46] performed a comprehensive numerical analysis to assess the operational efficiency of wave energy converters incorporating Savonius rotor technology. Employing computational fluid dynamics (CFD) methodologies, their investigation focused on the influence of various blade geometries on the performance of a dual Savonius rotor system intended for harnessing wave energy. To accurately replicate incident wave phenomena, the computational framework integrated a piston-type wave generator within the simulation domain. Additionally, a fully three-dimensional numerical wave tank was constructed to model an oscillating water column (OWC) apparatus equipped with a three-bladed Savonius rotor, enabling the evaluation of hydrodynamic energy conversion efficiency. The findings confirmed that the developed numerical models proficiently represent the fluid flow behavior both inside the OWC chamber and through the turbine, thereby substantiating their effectiveness for detailed analysis of wave energy conversion mechanisms.

6. Summary and Discussion

Energy constitutes a fundamental requirement for human civilization, underpinning a wide array of essential activities including agriculture, commerce, communication, education, healthcare, and transportation. The escalating global energy crisis has intensified the search for sustainable alternatives to conventional fossil fuels, prompting increased interest in renewable energy technologies. Among these, hydrokinetic energy has emerged as a particularly promising candidate, owing to its minimal environmental footprint and its suitability for deployment in isolated or off-grid regions.

The Savonius turbine is an energy conversion apparatus that exploits the differential drag forces

generated between its concave and convex blades to transform fluid flow into mechanical power. Its application within hydrokinetic systems is widely regarded as a critical area of utilization in renewable energy technologies. This study presents a review of existing research efforts aimed at optimizing the performance and efficiency of Savonius turbines for such applications.

A key consideration highlighted in the literature is the distinction between the working fluids used in conventional Savonius turbines and those in hydrokinetic applications. While traditional turbines typically operate in air, hydrokinetic variants function within water, a fluid with markedly different physical properties. This fundamental difference significantly influences the parameters governing power generation, necessitating that optimization efforts be specifically tailored to the hydrokinetic context. Drawing upon the optimization studies reviewed herein, it is evident that the critical factors affecting the enhancement of these systems include:

- Overlap ratio
- Aspect ratio
- Gap ratio
- Geometrical characteristic

The aforementioned parameters exert a direct influence on both the power coefficient and torque generation of the system, thereby impacting the overall performance and efficiency of Savonius-based hydrokinetic converters. Based on the comprehensive analysis of the studies examined in this review, the following conclusions can be drawn:

With respect to the influence of the aspect ratio, the existing body of research remains relatively limited. Nonetheless, the available studies consistently indicate a positive correlation between increased aspect ratio and enhanced turbine performance. Specifically, system efficiency tends to improve markedly as the aspect ratio rises. It is also important to recognize that variations in water depth affect pressure conditions, thereby positioning the aspect ratio as a critical parameter in characterizing flow dynamics within hydrokinetic applications.

Concerning the overlap ratio and gap ratio, the reviewed literature uniformly acknowledges their substantial and favorable influence on the performance coefficient of Savonius turbines. This improvement is primarily attributed to the reduction in blade resistance, which promotes more effective overlapping of the blades. Furthermore, an optimal overlap ratio within the range of 0.15 to 0.30 has been identified as most conducive to enhancing turbine efficiency.

The key geometric parameters influencing turbine performance can be summarized as follows:

- Number of blades
- Blade orientation
- Blade shape

The reviewed studies indicate that increasing the number of blades in a Savonius hydrokinetic turbine generally enhances its performance. This improvement is attributed to the intensified turbulence generated around the blades as their quantity rises, which in turn influences the overall aerodynamic behavior and energy conversion efficiency of the system.

Regarding blade orientation, the majority of studies indicate that twisted blades are advantageous due to their significant reduction of torque fluctuations. This improvement arises because the twisted geometry effectively increases the torque arm length, thereby generating a greater net positive torque and enhancing energy extraction from the flow. Additionally, considerable research efforts have focused on modifying blade shapes to optimize turbine efficiency and output. Among these variations, concave blade profiles have consistently demonstrated superior performance.

7. Future Perspectives and Challenges

As the global demand for clean and renewable energy continues to grow, hydrokinetic systems utilizing Savonius turbines present a viable and environmentally friendly solution. However, several critical challenges must be addressed to facilitate their broader implementation and commercial viability. One of the primary limitations is the relatively low efficiency of Savonius turbines compared to other hydrokinetic devices. This calls for continued research in advanced design modifications, including hybrid blade configurations, adaptive geometry, and real-time control mechanisms, to improve energy conversion efficiency. Additionally, the performance of Savonius turbines is highly sensitive to site-specific hydrodynamic conditions, making universal optimization difficult. Developing adaptable and modular turbine systems that can be tuned to varying flow environments remains a key research direction. Furthermore, long-term reliability and durability in harsh aquatic environments pose challenges related to material selection, corrosion resistance, and maintenance strategies.

From a practical standpoint, large-scale deployment also involves socioeconomic and

regulatory hurdles. Future efforts must therefore incorporate interdisciplinary approaches combining fluid mechanics, materials science, environmental studies, and policy planning. Advanced computational modeling, coupled with experimental validation and field testing, will play a pivotal role in bridging the gap between laboratory performance and real-world application. Overall, while Savonius turbines hold significant promise in the context of sustainable hydrokinetic energy, realizing their full potential will require overcoming technical, environmental, and logistical barriers through innovative, collaborative, and scalable solutions.

8. Conclusions

The potential of the Savonius turbine for hydrokinetic energy extraction has been extensively evaluated across numerous studies focusing on the various parameters that impact its performance. Based on a comprehensive review of the literature, several significant observations emerge regarding the optimization strategies discussed.

The findings indicate that optimizing Savonius hydrokinetic turbines by carefully considering fluid flow characteristics substantially enhances their output and overall performance. Key parameters influencing these improvements include flow dynamics, blade geometry, aspect ratio, and gap ratio, among others. In conclusion, achieving superior turbine performance necessitates identifying and applying optimal parameter values, which can be effectively determined through comprehensive analysis of the existing literature.

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