International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 16, No. 1, March 2025, pp. 555~563
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v16.i1.pp555-563

Experimental study on the use of Savonius combined blade rotors as wind turbines and hydrokinetic turbines

Arifin Sanusi[1], Jahirwan Ut Jasron[1], Sudirman Syam[2]
[1]Department of Mechanical Engineering, Faculty of Science and Engineering, Universitas Nusa Cendana, Kupang, Indonesia
[2]Department of Electrical Engineering, Faculty of Science and Engineering, Universitas Nusa Cendana, Kupang, Indonesia

Article Info

Article history:

Received Sep 24, 2024
Revised Nov 11, 2024
Accepted Dec 9, 2024

Keywords:

Blade combined
Hydrokinetic
Renewable energy
Rotor Savonius
Wind turbine

ABSTRACT

Renewable energy development is increasingly important to anticipate the limited use of fossil energy and its impact on the environment. The Savonius turbine is a vertical axis turbine that can utilize flow from all directions with simple construction, so it has the potential to be developed as a wind turbine and hydrokinetic to generate electricity. This paper aims to conduct an experimental studied the same Savonius combined blade rotor as a wind turbine used in a wind tunnel and a hydrokinetic turbine in an irrigation channel. The experimental results show that the Savonius turbine can function well as a wind and hydrokinetic turbine. The Savonius combined blade turbine improves the performance of conventional Savonius blade turbines, including its use as a hydrokinetic turbine, which is affected by flow velocity. The performance of the Savonius turbine is indicated by the power coefficient Cp and torque coefficient (Ct) values based on the fluid flow velocity. At the same wind speed (4 m/s), the combined blades can increase the performance Cp by up to 11% compared to conventional blades. The use of the same combined blades tested as a hydrokinetic turbine resulted in an increase in Cp and a decrease in Ct with an increase in tip speed ratio (TSR).

Corresponding Author:

Arifin Sanusi
Department of Mechanical Engineering, Faculty of Science and Engineering, Universitas Nusa Cendana
St. Adisucipto Penfui, Kupang, NTT 85228, Indonesia
Email: arifin@staf.undana.ac.id

1. INTRODUCTION

The need for energy, especially electrical energy, has become critical in line with the increasing population and rapid technological developments. Alternative energy sources, like renewable and ecologically friendly energy sources, are being developed to meet the growing demand for electrical energy. This is because conventional energy sources, like coal and oil, are becoming scarcer and cause more pollution. Renewable energy sources widely available in every region are wind and water, which do not cause environmental pollution and can be converted into electrical energy using wind turbines and hydrokinetic turbines connected to generators. One of the best and most popular forms of renewable energy is wind energy, which has been shown to help lower air pollution and slow global warming [1]. Savonius turbines are commonly used as wind energy generators. This turbine has a simple construction and can utilize wind from all directions using the drag principle. The performance of the Savonius rotor is influenced by flow, geometric parameters, and operational conditions so changes will give different results [2]. Technically, several factors, such as geometrical and operating state characteristics, affect the Savonius turbine's performance [3]. The Savonius turbine performance can be increased by employing extra equipment in the turbine rotor assembly. It has been demonstrated that the performance of Savonius turbines can be enhanced by employing a curtain, and Savonius turbines can be enhanced by adding more equipment to the turbine rotor assembly [4]. On the other hand, wind turbine construction will become more difficult as more equipment is added [5]. Researchers have examined and modified the rotor and blade of conventional Savonius turbines using various methods to improve turbine efficiency. In areas with medium to high wind speeds, conventional Savonius blade turbines operate more effectively. Meanwhile, areas with low wind speeds are suitable for the use of elliptical Savonius blade turbines [6]. Compared to conventional blades, Savonius rotor wind turbines modified with blade combinations show improved performance [7], [8]. Along with other changes and advancements to enhance the Savonius wind turbine's performance, the installation of end plates at the end of the vertical turbine affects turbine performance [9].

Water flows in open channels are one of the renewable energy sources that can be developed because they are found in many remote areas and have not been reached by the electricity network. Hydrokinetic and wind turbines work on the same operating principles except over varying speed ranges [10]. The mass of kinetic energy of water as a result of its movement is called hydrokinetic energy. Water flow with a low head can generate power using hydrokinetic turbine technology [11]. Fluid density, turbine rotor cross-sectional area, and flow speed are the variables that influence a turbine's power [12].

The Savonius hydrokinetic turbine is one type of vertical-axis turbine that can produce electricity as water flows through canals and rivers [13]. The mass of the hydrokinetic energy depends on its velocity fluid [14] he estimated fluid density in a hydrokinetic turbine running at a rated velocity of 2-3 m/s is 1.223 kg/m^3 for wind and 1,000 kg/m^3 for water, respectively [15]. It is possible to use the modified Savonius hydrokinetic turbine in rural settings with water velocity ranging from 0.3 to 0.8 meters per second [16].

Although hydrokinetic energy technology is relatively new compared to other hydroelectric power generation technologies, the potential kinetic energy of river water flow based on the dispersion of water velocity compared to river flow shows a more significant value [15]. Hydrokinetic turbines work similarly to wind turbines but generate more electricity because water has a higher density than air at the same speed [17]. Free-flow turbines require large flow openings to collect as much water mass as possible at low speeds and pressures, which is the main difference between these turbines and high-head turbines [18].

Hydrokinetic turbine power generation is mainly intended for rural use in locations far from the existing electricity grid. The characteristics of the Savonius hydrokinetic turbine are better than those of conventional hydro turbines due to its self-starting nature at lower flow rates [19]. Vertical turbines, such as the Savonius turbine, are cheaper than horizontal-axis hydro turbines and require less maintenance when used for small-scale power generation [20]. The Savonius hydrokinetic turbine presents a viable and sustainable option for obtaining energy from river flows for isolated communities. It can operate at limited and shallow water flows [3]. The kinetic energy of flowing water is transformed into mechanical energy by hydrokinetic turbines, which power a generator to create electrical energy.

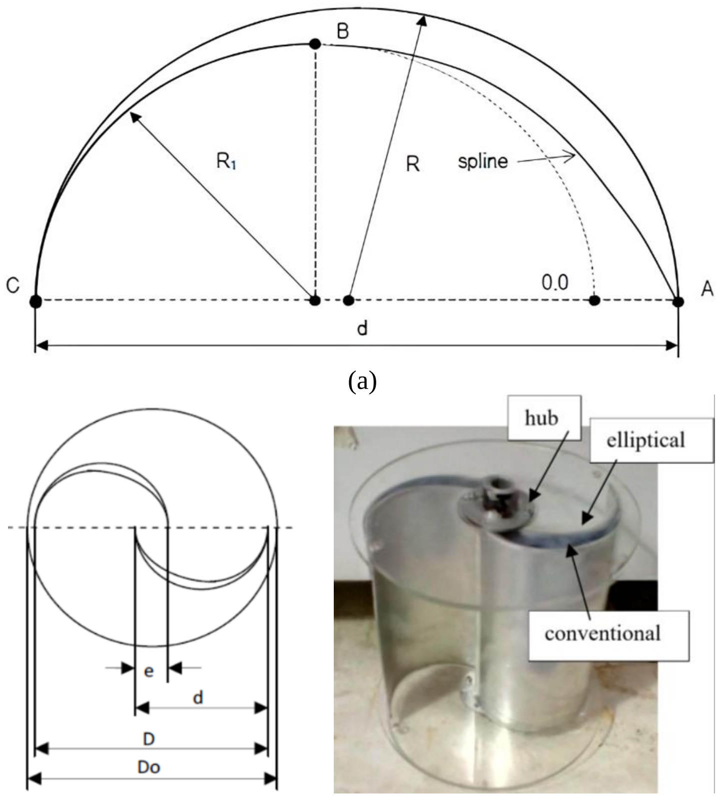
Hydrokinetic systems have emerged as a reliable technology in the field of renewable energy in recent years [19]. One of the newest technologies to capture energy from moving water is the hydrokinetic turbine [14]. However, a literature review reveals a need for more experimental research on river hydrokinetic turbine footprints [21]. Differences in density and flow velocity for wind and hydrokinetic turbines will cause differences in the resulting performance, even though they use the same turbine. Likewise, Savonius turbines with different blades will also provide different performance values [8]. Therefore, a study is needed to analyze how the same Savonius turbine rotor performs experimentally applied as a wind turbine and hydrokinetic turbine. The results of the development of a conventional Savonius blade turbine rotor into a combination blade are analyzed before being used as a hydrokinetic turbine rotor in irrigation channels with different airflow velocities.

2. METHOD

2.1. Rotor turbine configurations

The Savonius combined blade turbine is used as an energy-driving turbine, which will be tested experimentally using wind energy and hydrokinetic, a development of the conventional Savonius blade model to increase turbine efficiency [7]. he principle of the Savonius turbine is that the thrust of the blades on the concave side (advancing blade) is greater than the torque on the convex side (returning blade) so that it causes a rotating motion (rotation) in the turbine rotor. Increasing the distance from the center of rotation on the concave side of the advancing blade will increase positive torque while decreasing the distance from the center of rotation on the convex side of the returning blade will decrease negative rotor torque. The distance of the force capture point from the center of rotation can be increased by using an elliptical blade model on the concave side. The drag capture point is closer to the center of rotation on the convex side using the traditional (semicircular) model than the elliptical model. Using different blade models between the concave side using an elliptical model and the convex side using a conventional model, the combined blade model will provide a more significant difference in moment compared to the same model based on the force capture point towards the center of rotation. The Savonius turbine rotor used in the experimental test was made in the form of a 200 mm diameter prototype, using overlap and end plates based on the rotor diameter size using a combined blade rotor, as shown in Figure 1.

The combined blade shown in Figure 1. was constructed using an ellipse model, described by Kacprzak *et al.* [22] as a concave side, and a standard blade model, described by Kamoji *et al.* [23] as a convex side of a semicircle with a radius of R = 57.5 mm. Both models were selected because they have the exact dimensions, especially the curved lines connecting the x-axis coordinate points (Figure 1(a)), namely A (- 15 mm; 0), B (50 mm; 50 mm), and C (- 100 mm; 0). The line connecting points A and B is a spline, and the line connecting points B and C is a quarter-circle line with a R1 = 50 mm radius. From these points, the comb. Once the diameter is known, the other rotor dimensions (Figure 1(b)) are determined based on the best ratio value from previous research as in Table 1. The rotor prototype is made of aluminum plate, and the end plate is made of acrylic with a thickness of 5 mm, without using a shaft in the middle. The shaft is placed on the endplate using hubs at the top and bottom to support the rotor Figure 1(c).



(b) (c)

Figure 1. Blade combined: (a) coordinate points, (b) rotor dimensions, and (c) prototype rotor

Table 1. Dimensions of the prototype rotor blade combined

Parameters	Relationship	Value
Height of rotor (H)	Aspect ratio (H/D) = 1	200 mm
Endplate diameter (Do)	Endplate ratio (Do/D) = 1.1	220 mm
Overlap distance (e)	Overlap ratio (e/D) = 0.15	30 mm
Chord blade distance (d)	Chord blade combined (D + e)/2	115 mm

2.2. Experimental setup

The experiment began with the preparation of the test equipment device. The experimental setup was carried out by installing a Savonius turbine rotor prototype in a wind tunnel for testing as a wind turbine. In contrast, for testing as a hydrokinetic turbine, the same rotor prototype was installed in an irrigation channel. A two-blade turbine rotor prototype Figure 1(c) was installed on the test frame, a 15 mm diameter shaft outside the blade was used as a support, and a pulley mount was used for torque measurement. The rotor shaft is supported by an axial bearing at the bottom and a radial bearing at the top. The diameters of the pulley and rope are 30 mm and 3 mm, respectively, and a spring balance is used as a load indicator.

The wind turbine experiment used an open jet-type wind tunnel with a cross-sectional area of 300 x 300 mm (Figure 2) with a wind speed set at four m/s using an anemometer Lutron AM4206. To see the performance of the rotor blade combined, a conventional rotor blade prototype with the exact dimensions was also tested in a wind tunnel as a comparison. Meanwhile, the hydrokinetic turbine testing was carried out directly on the irrigation channel with a surface area of 0.5 m (Figure 3) using a combination rotor blade prototype at irrigation airflow speeds of 2.4 m/s and 2.5 m/s respectively, measured using Flowatch FL-03 with an accuracy of 5%. After all the preparations and experimental setups were completed, testing was done by measuring the maximum turbine rotor rotation (n_{max}). The next stage is to provide a load (F), which is the difference between the ballast load (F1) and the spring balance (F2), to reduce the rotation every 50 rpm until it stops rotating (n=0) or reaches the maximum load. The bearings are lubricated with multipurpose oil at the beginning of data collection so that friction does not occur, which can reduce measurement accuracy, and measurement of the load (F1 and F2) is carried out at each constant rotation with a reduction of 50 rpm using a model-type tachometer (KW06-563) which has an accuracy of ± (0.05% + 1 digit).

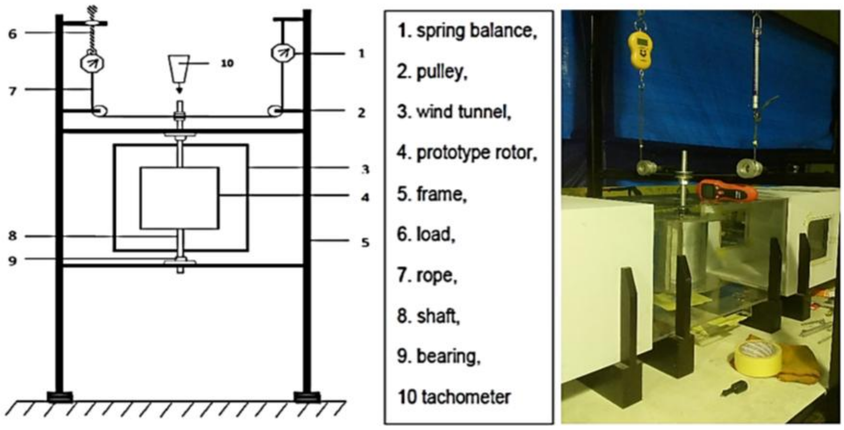


Figure 2. The experimental apparatus wind tunnel

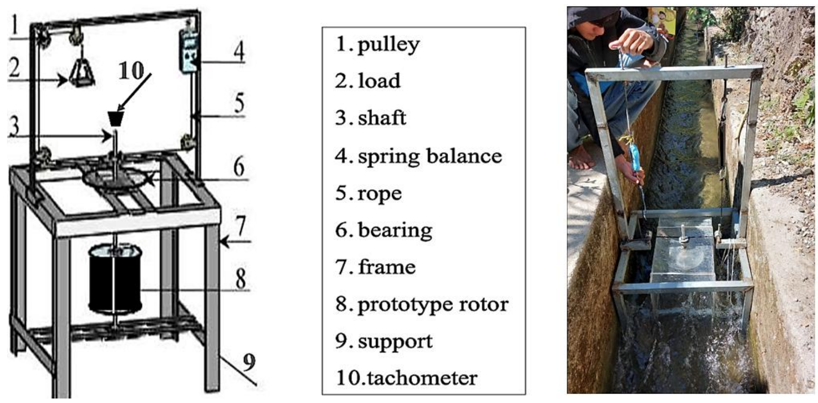


Figure 3. The experimental apparatus irrigation canal

Experimental studies on the use of Savonius combined blade rotors as wind turbines and hydrokinetic turbines were carried out in the same manner including procedures as in Figure 4. In general, the research procedure is carried out as in Figure 4. The analysis of the turbine torque at each rotation using (1).

$$T_T = \frac{(F_1 - F_2)(R_{pulley} + r_{rope})g}{1000} \quad (1)$$

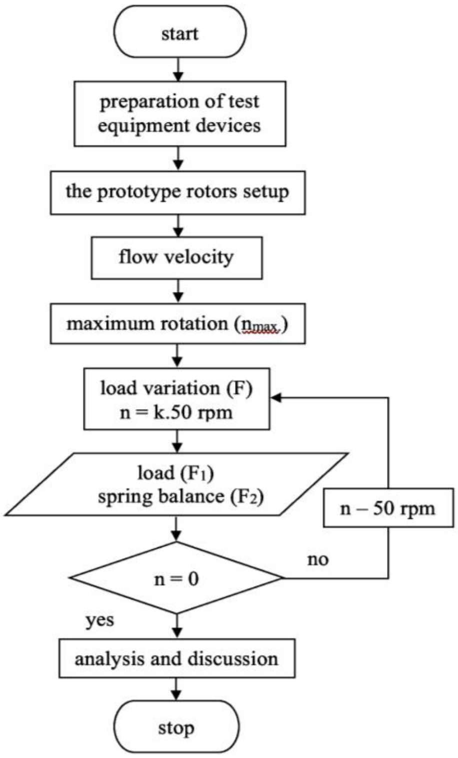


Figure 4. A flowchart for research

From the analysis of turbine torque based on the research results, the next step is to analyze turbine power using (2)-(5). Power turbine power using (2).

$$P_T = T_T\left(\frac{2\pi n}{60}\right) \quad (2)$$

The actual power and torque produced by a rotor can be decided by the coefficient power and the coefficient torque. The coefficient of power is as (3).

$$C_p = \frac{2P_T}{\rho_a A_T V^3} \quad (3)$$

The coefficient of torque is as (4).

$$C_t = \frac{2T_T}{\rho_a A_T V^2 R} \quad (4)$$

The tip speed ratio (TSR) is the ratio of the rotor tip velocity to the flow velocity. Tip speed ratio as in (5).

$$TSR(\lambda) = \frac{\omega.R}{V} \quad (5)$$

3. RESULTS AND DISCUSSION

3.1. Results

Experimental results show that the use of a Savonius turbine blade combined rotor can be used as a turbine to generate wind energy and hydrokinetic energy. The Cp and Ct against the TSR are represented graphically to show the results as in Figure 5. Figure 5 displays the Savonius wind turbine's experimental findings with combination and conventional blades at a wind speed of 4 m/s, and the use of a combined blade rotor as a hydrokinetic turbine in irrigation flows with different speeds. The Cp, when used as a hydrokinetic turbine, produces the same tendency as a wind turbine, but there are visible differences in value due to differences in fluid velocity and density. The maximum value of the Cp occurs at a lower TSR when using a Savonius turbine as a hydrokinetic turbine.

The hydrokinetic Savonius turbine is greatly influenced by the water flow velocity. A velocity difference of 0.1 m/s will cause the TSR tendency to increase along with the increase in flow velocity, as shown in Figure 6. As with Cp, the trend of Ct between wind turbine and hydrokinetic turbine is the same, flow velocity affects it. Ct is better with lower TSR as shown in Figure 7.

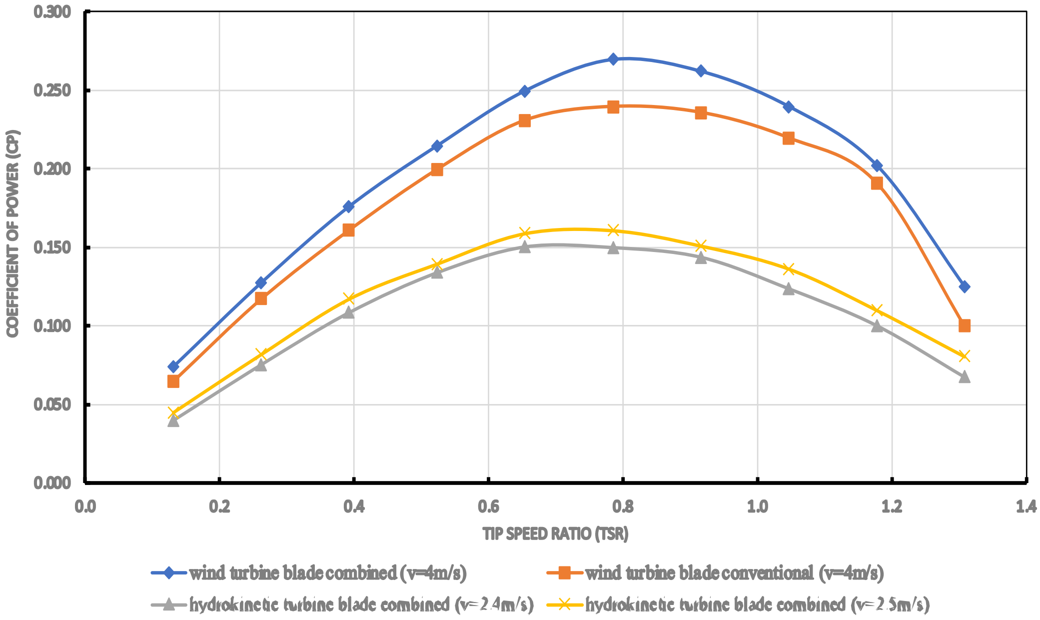


Figure 5. Comparison Cp vs TSR

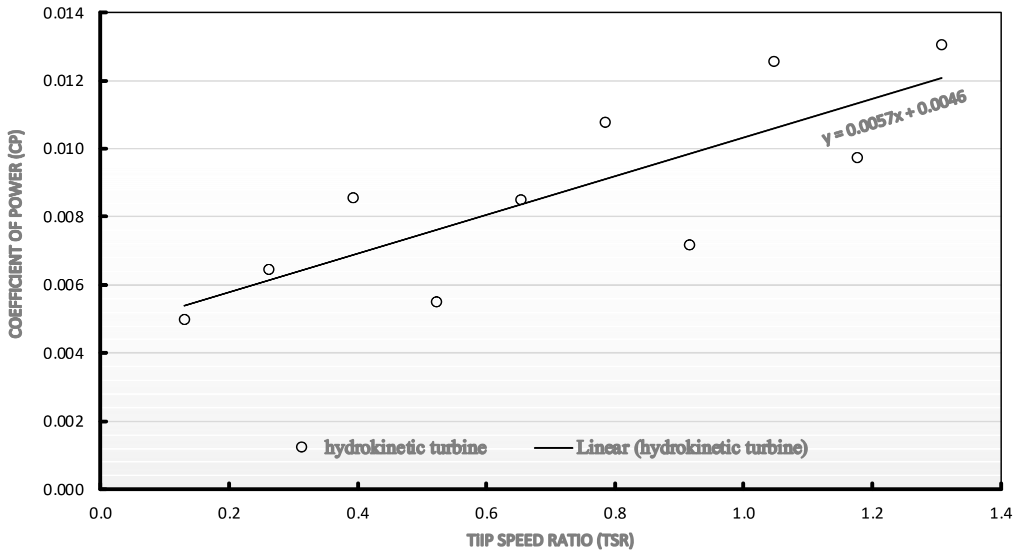


Figure 6. The Cp for each increase in velocity 0.1 m/s vs TSR

3.2. Discussion

In this experiment, two things were done, namely: 1) Modification of the Savonius rotor blade model; and 2) The modified blade model (combined blade) was applied as a hydrokinetic turbine in the irrigation water flow, as in Figures 5 and 7. The conventional Savonius rotor blade (half circle) modification is a combination blade model between a conventional blade on the convex side and an elliptical model on the concave side as a wind turbine, which was tested using a wind tunnel. In contrast, applying the combined blade rotor as a hydrokinetic turbine was tested directly on the irrigation water flow.

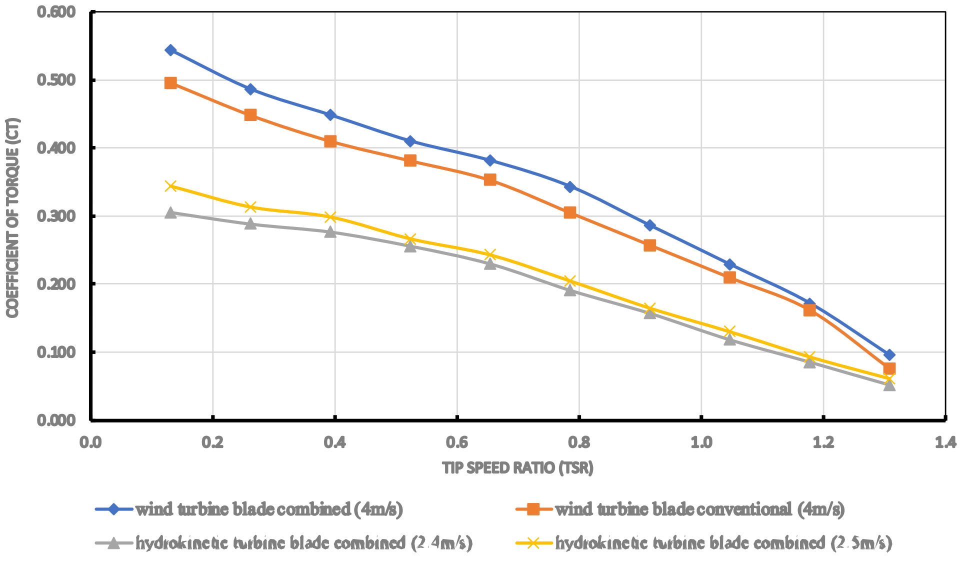


Figure 7. Comparison Ct vs TSR

The amount of power that the turbine extracts from the incoming water flow is described by Cp. In contrast, Ct allows the turbine to generate power [11]. The results of testing through a wind tunnel as a wind turbine with the same speed showed an increase in the performance of the combined blade turbine compared to the conventional blade by 11% at TSR 0.79. This increase is because the combination blade has an increased force point on the concave side so that it provides a better thrust moment compared to the force point on the convex side so that the difference in the moment of force that occurs between the joyous moment and the negative moment increases [4]. Another thing that affects the performance improvement is that the rotor is not attached to the axis in the middle of the rotor so that it does not block the fluid flow through the overlap so that it helps the force pushing the concave side of the return blade and reduces the inertia force of the turbine. Inertia force affects turbine performance, while additional inertia force can reduce turbine performance [24].

The combined blade rotors tested as a wind turbine show increased performance and are applied as a hydrokinetic turbine by utilizing water flow in open channels or irrigation. Efforts to improve turbine performance are carried out by modifying the blade shape because the performance of the modified Savonius hydrokinetic rotor depends on the blade shape factor [25]. The Savonius rotor is a combined blade model that uses dimensions based on the rotor diameter with parameters selected from the results of the Savonius turbine journal review (Table 1), which is expected to also perform better as a hydrokinetic turbine. This rotor is applied and tested as a hydrokinetic turbine using the same method for irrigation flow.

The application of the Savonius turbine as a hydrokinetic turbine can function well and produce performance that can be used as a source of electrical energy. The performance results of the Savonius combined blade rotor as a hydrokinetic turbine are determined by the water flow velocity, although it has a greater density. The irrigation water flow velocity is limited even though the water density value is greater than the air density [15]. The Cp and Ct results of the Savonius turbine as a hydrokinetic turbine are still lower when compared to using the Savonius turbine as a wind turbine and depend on the TSR. However, the potential of the Savonius rotor as a hydrokinetic turbine needs to be developed because the irrigation water flow velocity tends to be constant according to the available discharge and is suitable for energy development in remote areas with abundant river flow and irrigation in rural areas. The hydrokinetic Savonius turbine system has the potential to be applied to provide a sustainable and cheap energy supply in remote areas [3].

According to Figures 6 and 7, the hydrokinetic Savonius turbine shows a significant increase in Cp performance and increasing water flow velocity and a decrease in (Ct) with increase tip speed ratio (TSR). At the same time, the Ct value tends to increase with increasing load (decreasing TSR), as the results of hydrokinetic research using the horizontal axis Savonius turbine [26]. Reduction in rotor rotation which affects TSR due to the provision of a load to test the Ct value produced by the turbine. Hydrokinetic power generation depends on water flow, directly related to the amount of water entering and leaving the river. Turbine efficiency will decrease if the water flow rate is reduced [27]. So, using hydrokinetic turbines in the future is essential by making efforts to increase the water flow rate in irrigation is widely available in rural areas.

4. CONCLUSION

After conducting experiments regarding using a Savonius combined blade turbine as a wind turbine and hydrokinetic turbine, it can be developed as a renewable energy generator based on the results of its performance analysis. The performance of the combined blade wind turbine can increase the Cp by 11% compared to conventional blades and the maximum (Cpmax) at TSR = 0.79. The use of a combined Savonius blade turbine as a hydrokinetic turbine is limited by the water flow speed, even though the water density value is higher. The results of the analysis of the difference in water speed in the test show an increase in the Cp value of the turbine with a tendency to follow an increase in the TSR. The speed of water flow in irrigation canals is more constant according to the available water discharge, so the development of hydrokinetic turbines can be used as an energy generator in rural areas.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Laboratory of Mechanical Engineering and the funding University of Nusa Cendana Kupang Indonesia.

REFERENCES

[1] M. Zadehbagheri, T. Sutikno, and R. Ildarabadi, “Using Y-source network as a connector between turbine and network in the structure of variable speed wind turbine,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 12, no. 3, p. 1644, Sep. 2021, doi: 10.11591/ijpeds.v12.i3.pp1644-1658.

[2] A. J. Vicente, V. H. Antonio, and P. A. Prisco, “A review on the performance of Savonius wind turbines,” *Renewable and Sustainable Energy Reviews*, 2012.

[3] M. Badrul Salleh, N. M. Kamaruddin, and Z. Mohamed-Kassim, “Savonius hydrokinetic turbines for a sustainable river-based energy extraction: A review of the technology and potential applications in Malaysia,” *Sustainable Energy Technologies and Assessments*, vol. 36, 2019, doi: 10.1016/j.seta.2019.100554.

[4] B. D. Altan and M. Atilgan, “The use of a curtain design to increase the performance level of a Savonius wind rotors,” *Renewable Energy*, vol. 35, no. 4, pp. 821–829, 2010, doi: 10.1016/j.renene.2009.08.025.

[5] K. K. Sharma, R. Gupta, and A. Biswas, “Performance measurement of a two-stage two-bladed savonius rotor,” *International Journal of Renewable Energy Research*, vol. 4, no. 1, pp. 115–121, 2014.

[6] S. Kurniati, S. Syam, and A. Sanusi, “Numerical investigation and improvement of the aerodynamic performance of a modified elliptical-bladed Savonius-style wind turbine,” *AIMS Energy*, vol. 11, no. 6, pp. 1211–1230, 2023, doi: 10.3934/ENERGY.2023055.

[7] A. Sanusi, S. Soeparman, S. Wahyudi, and L. Yuliati, “Experimental study of combined blade savonius wind turbine,” *International Journal of Renewable Energy Research*, vol. 6, no. 2, pp. 615–619, 2016, doi: 10.20508/ijrer.v6i2.3455.g6826.

[8] A. Sanusi, S. Soeparman, S. Wahyudi, and L. Yuliati, “Performance analysis of a combined blade savonius wind turbines,” *International Journal of Fluid Machinery and Systems*, vol. 10, no. 1, pp. 54–62, 2017, doi: 10.5293/IJFMS.2017.10.1.054.

[9] S. Yamada, T. Tamura, and S. Mochizuki, “Effects of end plates on performance of a small straight-bladed vertical axis wind turbine,” *Journal of Fluid Science and Technology*, vol. 12, no. 2, 2017, doi: 10.1299/jfst.2017jfst0019.

[10] J. Thiyagaraj, I. Rahamathullah, and P. S. Prabu, “Experimental investigations on the performance characteristics of a modified four bladed Savonius hydro-kinetic turbine,” *International Journal of Renewable Energy Research*, vol. 6, no. 4, pp. 1530–1536, 2016, doi: 10.20508/ijrer.v6i4.4798.g6943.

[11] P. K. Talukdar, A. Sardar, V. Kulkarni, and U. K. Saha, “Parametric analysis of model Savonius hydrokinetic turbines through experimental and computational investigations,” *Energy Conversion and Management*, vol. 158, pp. 36–49, 2018, doi: 10.1016/j.enconman.2017.12.011.

[12] D. A. A. Osman, N. Rosmin, N. S. Hasan, B. Ishak, A. H. Mustaamal Jamal, and M. Marzuki, “Savonius wind turbine performances on wind concentrator,” *International Journal of Power Electronics and Drive Systems*, vol. 8, no. 1, pp. 376–383, 2017, doi: 10.11591/ijpeds.v8i1.pp376-383.

[13] M. S. Khani, Y. Shahsavani, M. Mehraein, and O. Kisi, “Performance evaluation of the savonius hydrokinetic turbine using soft computing techniques,” *Renewable Energy*, vol. 215, 2023, doi: 10.1016/j.renene.2023.118906.

[14] A. Kumar and R. P. Saini, “Performance parameters of Savonius type hydrokinetic turbine - A Review,” *Renewable and Sustainable Energy Reviews*, vol. 64, pp. 289–310, 2016, doi: 10.1016/j.rser.2016.06.005.

[15] M. I. Yuce and A. Muratoglu, “Hydrokinetic energy conversion systems: A technology status review,” *Renewable and Sustainable Energy Reviews*, vol. 43, pp. 72–82, 2015, doi: 10.1016/j.rser.2014.10.037.

[16] A. Z. Anthony and S. Roy, “Performance analysis of a modified Savonius hydrokinetic turbine blade for rural application,” in *IOP Conference Series: Materials Science and Engineering*, 2020, doi: 10.1088/1757-899X/943/1/012034.

[17] N. K. Sarma, A. Biswas, and R. D. Misra, “Experimental and computational evaluation of Savonius hydrokinetic turbine for low velocity condition with comparison to Savonius wind turbine at the same input power,” *Energy Conversion and Management*, vol. 83, pp. 88–98, 2014, doi: 10.1016/j.enconman.2014.03.070.

[18] A. N. Gorban’, A. M. Gorlov, and V. M. Silantyev, “Limits of the turbine efficiency for free fluid flow,” *Journal of Energy Resources Technology, Transactions of the ASME*, vol. 123, no. 4, pp. 311–317, 2001, doi: 10.1115/1.1414137.

[19] A. Dewan, S. S. Tomar, A. K. Bishnoi, and T. P. Singh, “Computational fluid dynamics and turbulence modelling in various blades of Savonius turbines for wind and hydro energy: Progress and perspectives,” *Ocean Engineering*, vol. 283, 2023, doi: 10.1016/j.oceaneng.2023.115168.

[20] K. Golecha, T. I. Eldho, and S. V. Prabhu, “Influence of the deflector plate on the performance of modified Savonius water turbine,” *Applied Energy*, vol. 88, no. 9, pp. 3207–3217, 2011, doi: 10.1016/j.apenergy.2011.03.025.

[21] V. G. Nago *et al.*, “A literature review on wake dissipation length of hydrokinetic turbines as a guide for turbine array configuration,” *Ocean Engineering*, vol. 259, 2022, doi: 10.1016/j.oceaneng.2022.111863.

[22] K. Kacprzak, G. Liskiewicz, and K. Sobczak, “Numerical investigation of conventional and modified Savonius wind turbines,” *Renewable Energy*, vol. 60, pp. 578–585, 2013, doi: 10.1016/j.renene.2013.06.009.

[23] M. A. Kamoji, S. B. Kedare, and S. V. Prabhu, "Experimental investigations on single stage modified Savonius rotor," *Applied Energy*, vol. 86, no. 7–8, pp. 1064–1073, 2009, doi: 10.1016/j.apenergy.2008.09.019.
[24] U. K. Saha, S. Thotla, and D. Maity, "Optimum design configuration of Savonius rotor through wind tunnel experiments," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 96, no. 8–9, pp. 1359–1375, 2008, doi: 10.1016/j.jweia.2008.03.005.
[25] Y. Zhang, C. Kang, Y. Ji, and Q. Li, "Experimental and numerical investigation of flow patterns and performance of a modified Savonius hydrokinetic rotor," *Renewable Energy*, vol. 141, pp. 1067–1079, 2019, doi: 10.1016/j.renene.2019.04.071.
[26] C. Buana, J. Tangko, M. R. Djalal, Lewi, Ardaniah, and N. Al Mukhtaram, "Design and performance test of series underwater Savonius rotors with horizontal axis," *International Journal of Applied Power Engineering*, vol. 12, no. 4, pp. 399–407, 2023, doi: 10.11591/ijape.v12.i4.pp399-407.
[27] V. Katutsi, M. Kaddu, A. G. Migisha, M. E. Rubanda, and M. S. Adaramola, "Overview of hydropower resources and development in Uganda," *AIMS Energy*, vol. 9, no. 6, pp. 1299–1320, 2021, doi: 10.3934/ENERGY.2021060.

BIOGRAPHIES OF AUTHORS

Arifin Sanusi is a lecturer at the Department of Mechanical Engineering, Faculty of Science and Engineering, Nusa Cendana University (UNDANA), Kupang, Indonesia. He earned his Ir., M.T. from Hasanuddin University in 1992, 2003, and his Dr. from Mechanical Engineering, Brawijaya University in 2017. He has been an Associate Lecturer at UNDANA, Kupang, Indonesia since 2020. He currently serves as the secretary of the Undana Business Management Agency (BPU-Undana). His research areas include energy conversion, energy conversion engineering, wind turbines, hydrokinetics, and renewable energy. He can be contacted at email: arifin@staf.undana.ac.id.

Jahirwan Ut Jasron has been a lecturer in the Department of Mechanical Engineering, Faculty of Science and Engineering, Nusa Cendana University (UNDANA) since 2000. He earned his S.T. degree in mechanical engineering and M.T. degree in mechanical engineering, both from Hasanuddin University Makassar, in 1996 and 2007 respectively; and Dr. degree in Mechanical Engineering, Brawijaya University in 2021. He works as the coordinator of the Mechanical Engineering Study Program, the Faculty of Science and Engineering Undana. His research interests include energy conversion, renewable energy, and ocean waves. He can be contacted at email: jahirwan.jasron@staf.undana.ac.id.

Sudirman Syam is a lecturer at the Electrical Engineering, Faculty of Science and Engineering, Nusa Cendana University (UNDANA), Kupang, Indonesia. From 2013 to 2018, he got the Ph.D. degree in Mechanical Engineering at Brawijaya University in 2018. He became an associate professor in 2019, and a full professor of electrical machines and drives in 2023. His current research interests include power electronics and its applications such as in wind turbines, PV systems, reliability, harmonics, and adjustable speed drives. He can be contacted at email: sudirman_s@staf.undana.ac.id.