



Review of the Recent Power Augmentation Techniques for the Savonius Wind Turbines

Open
Access

Mohanad Al-Ghriybah^{1,3,*}, Mohd Fadhli Zulkafli¹, Djamal Hissein Didane², Sofian Mohd¹

¹ Department of Aeronautical Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), Johor, Malaysia

² Department of Energy and Thermofluid Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), Johor, Malaysia

³ Department of Renewable Energy Engineering, Faculty of Engineering, Al-Isra University, Amman-Jordan

ARTICLE INFO

ABSTRACT

Article history:

Received 4 April 2019

Received in revised form 13 June 2019

Accepted 25 June 2019

Available online 15 August 2019

Savonius wind turbine appears to be attractive and promising for electric generation in urban areas and low wind speed regions. Although the advantages of the Savonius rotor such as low-cost, simplicity and reliability, it suffers from low efficiency when it compared with other vertical axis wind turbines. For this reason, numerous studies have been performed to enhance the power characteristic of this turbine. In this field, a lot of innovative augmentation techniques have been implemented to improve the rotor performance, such as deflector plates, nozzles, guide vanes, windshields, and curtain plates. This paper reviews the most recent and effective power augmentation systems for the Savonius wind rotor in order to provide the researchers with a comprehensive view of current augmentation techniques. It is found that the augmentation systems contributed to the power coefficient enhancement for the conventional and modified Savonius rotors. The proposed designs used to overcome the negative torque created on the returning blade.

Keywords:

Savonius rotor; power augmentation;
wind turbines

Copyright © 2019 PENERBIT AKADEMIA BARU - All rights reserved

1. Introduction

From the beginning of life, human societies have been based on sunlight power, whether in a direct form such as sun radiations or indirect forms such as wind and hydro energies. Nevertheless, with the progress of civilization, fossil fuels, in particular, have become the more common sources of energy until the early 1970s because of the ease of transport and processing [1]. After the 1970s, energy from renewable resources such as solar radiation, hydropower, wind and biomass energies are starting to take dominion over the energy sectors due to the depletion of the conventional fuel resources. Globalization has become a key factor in the increase of the energy demand. As the demand increase, higher supply of energy is required [2]. Due to the barriers of using conventional resources such as outdoor air quality and the other environment pollutions, in addition to the high

* Corresponding author.

E-mail address: Mohanad.alghriybah@gmail.com (Mohanad Al-Ghriybah)

price of extracting and refining fossil fuels, great efforts are made in respect of the use of renewable energy resources [3]. Wind energy is one of the most important and effective sources of sustainable energy due to its availability and simplicity. It has evolved into a booming global business. Operating costs of wind turbines fell in a dramatic way over the last decade, moving closer to those of conventional energy resources [4].

The output energy from wind turbines depends usually on the geographical location, meteorological conditions, and type of turbine [5]. Wind turbines can be classified based on their rotational axis orientation, with respect to the wind direction. In this case, there are two types of wind turbines; vertical axis wind turbine (VAWT) and horizontal axis wind turbine (HAWT) [6]. HAWT is the most widespread type of wind turbines due to their high efficiency. Nevertheless, VAWT has featured over HAWT such as lower in construction and maintenance costs, lower noise level, and independent of the wind direction [7]. They can potentially be built to a far larger size than HAWT. For instance, floating VAWT hundreds of meters in diameter where the entire vessel rotates can eliminate the need for a large and expensive bearing. These features make them convenient for small-scale applications [8]. VAWT can be further classified based on turbine rotor designs. For example, Savonius type and Darrieus type [9]. Darrieus type has higher efficiency than Savonius, but they produce high stresses over the turbine blades. However, the Savonius type has shown a better starting torque than Darrieus at low wind speed.

Savonius type VAWT is a small, cheap, and simple turbine invented in 1925 by Sigurd Savonius. Generally, this type of turbines is depending on the drag theory of operation and commonly used in low wind speed regions [10]. Savonius type is composed of two vertical half cylinders as shown in Figure 1, which produces low noise level compared to the other types of wind turbines. That's because it works at a low tip speed ratio [8]. However, it suffers from low efficiency, which is an important area to improve. For efficiency enhancement, numerical and experimental studies were carried out based upon the improvement of the Savonius wind turbine. These studies included modifications on the blade profile [11–16], rotor stages [17, 18], and number of blades [19, 20].

Beside those modifications, several studies employ the augmentation techniques that can enhance the performance of the Savonius rotor. The present review aims to compile those techniques which are used to reduce the negatives of the Savonius rotor.

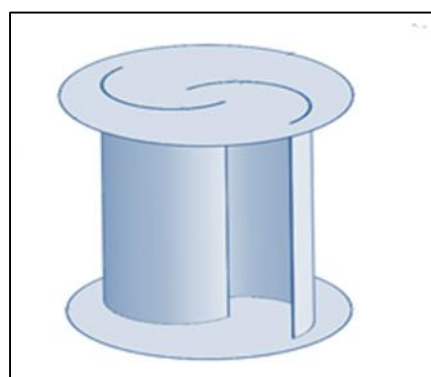


Fig. 1. Conventional Savonius rotor

2. Power Augmentation Devices

The Savonius wind rotor is not so efficient. The performance of the rotor can be enhanced by using external geometries which called “power augmenters”. Different geometries were proposed in the previous studies such as deflector plates, windshields, guide vanes, nozzles, etc. The main goal of using those geometries is to decrease the drag force of the returning blade which the wind pressure

generates a negative torque. Furthermore, the drag force will be increased on the advancing blade and the local acceleration of the blade also will be increased. These methods show a valuable result in increasing the starting characteristics of the rotor as well as the coefficient of power.

2.1 Deflector Plates

Straight or curved plates are placed in front of the returning blades in order to reduce the wind resistance. The performance of the Savonius rotor has been increased by installing a flow deflecting plate as Ogawa *et al.*, [21] reported. They performed wind tunnel experiments for a Savonius rotor with an overlap ratio of 0.2 and a deflector plate with adjustable angles as shown in Figure 2. They found that the rotor gains a 27% enhancement in terms of power coefficient when the angle of the plate adjusted to an angle of 30 degrees as shown in Figure 3. With the same procedure, a set of experiments has been performed with a two- combined deflector plates on a shape of V as shown in Figure 4, by modifying the angle between the two plates in a range between 5 and 45 degrees. The results showed that the rotor gains a 20% improvement in its power [22]. The effect of the V-shaped deflector on the performance of Counter-Rotating Savonius was also studied by Etemadeasl *et al.*, [23]. The results showed that the power coefficient increases by a percentage of 80%.

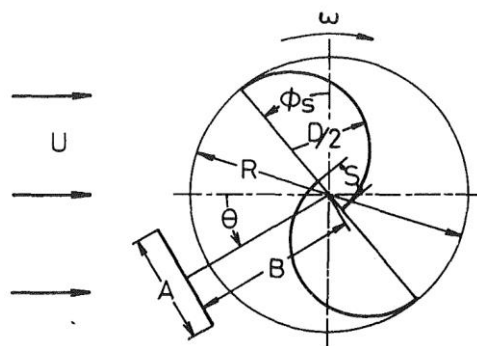


Fig. 2. Configuration of Savonius rotor and a deflecting plate [21]

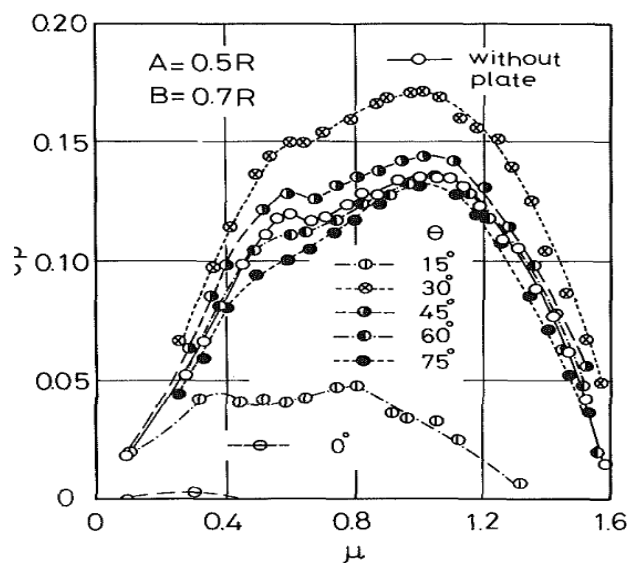


Fig. 3. Effect of the deflector angle on the power coefficient [21]

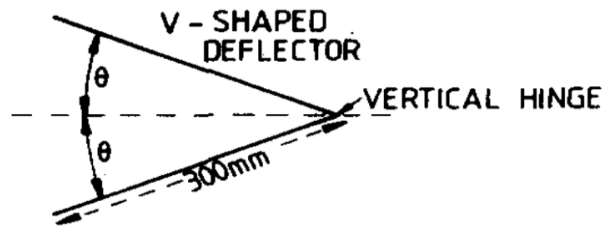


Fig. 4. V-shaped deflector [22]

In the recent past, Mohamed *et al.*, [24] carried out a numerical study on the two and three-bladed Savonius rotor with a straight plate wind deflector. They found that the self-starting capability increased for both configurations with a positive static torque at all angles. Moreover, the coefficient of power was relatively increased by 27.3% and 27.5% respectively for the two and three-bladed rotor as shown in Figure 5. With the same procedure, a numerical study on an optimized shape of the Savonius rotor with one doubly-curved deflector has been performed by He *et al.*, [25]. They conclude that the power coefficient increased by a percentage of 95% when the deflector was covered half of the returning-blade. In the same field, Youssef *et al.*, [26] proposed a novel technique by introducing a baffle on the advancing blade and a deflector on the returning blade as shown in Figure 6. The numerical results showed that the novel technique was able to double the power coefficient from 0.24 to 0.47.

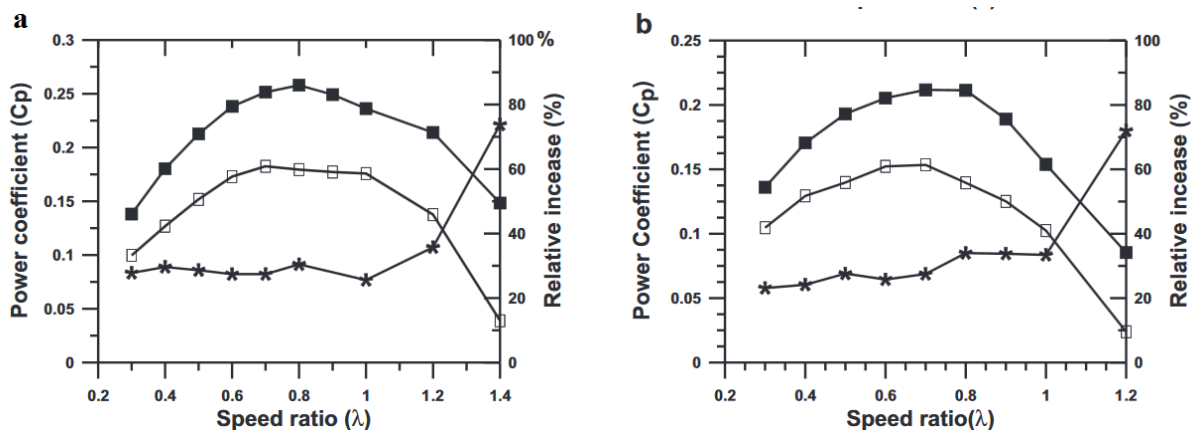


Fig. 5. Performance of the optimized configuration: a: three blades, b: two blades [24]

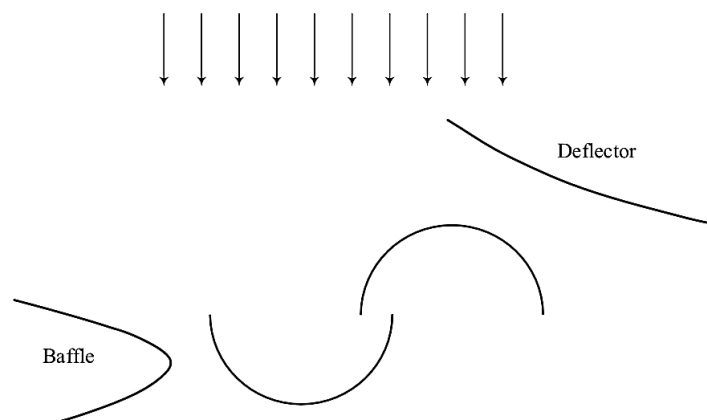


Fig. 6. The baffle/deflector system [26]

An experimental study was carried out by Golech *et al.*, [27] on the effect of the deflector plate on the performance of the multi-stage Savonius rotor. The results concluded that the deflector plate

increased the power coefficient by 42%, 31% and 17% for two stages 0 phase shift, 90 phase shift, and three-stages Savonius rotor respectively. Kailash *et al.*, [28] conducted an experimental study on the effect of two deflector plates on the performance of the Savonius wind rotor. The test was also performed to determine the optimum position of the deflector plate for various designs as shown in Figure 7. The results suggested that two deflector plates, which placed upstream to the wind flow, increase the power coefficient to 35%.

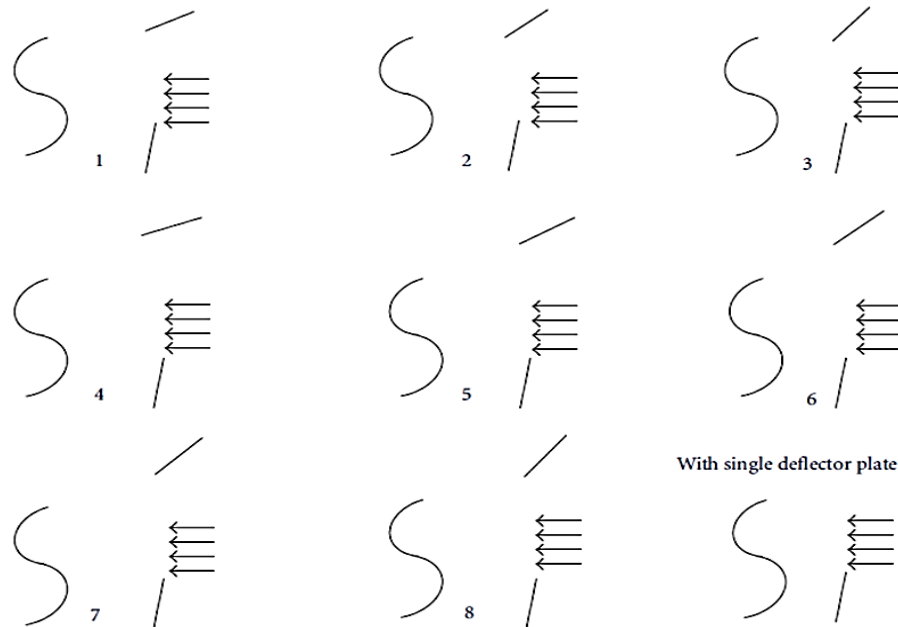


Fig. 7. Different arrangements of the two deflector plates studied by Kailash *et al.*, [28]

The effect of two deflector plates was also studied by Roy *et al.*, [29]. They performed an experimental study on a modified Bach-type Savonius rotor with deflectors as shown in Figure 8. The deflectors were positioned ahead of the advancing blade in an angular position between 0° and 30° by a step of 10° , where the angular position of the other plate was fixed at 40° . The results showed that the newly developed rotor with deflectors placed at ($\alpha = 40^\circ$, and $\beta = 10^\circ$) has shown improvement of 32.3% in terms of power coefficient.

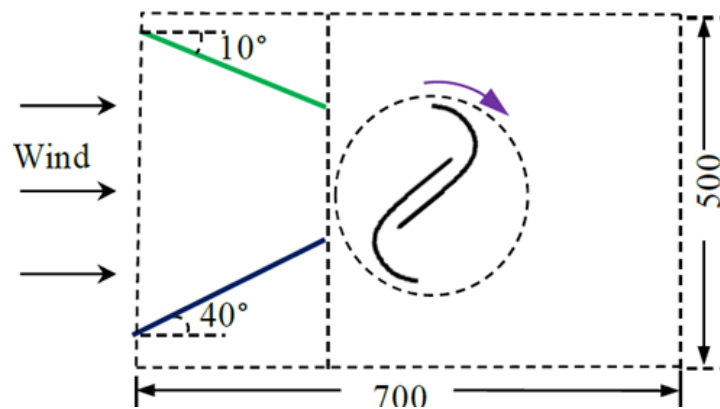


Fig. 8. New developed Savonius rotor under oriented jet [29]

Chen *et al.*, [30] studied the effect of wind deflectors on a parallel matrix system of Savonius rotors. The results showed that the performance of the system was increased by 16% when the deflector system was used. Mosbahi *et al.*, [31] proposed a novel deflector system consisting of a single straight blade with a NACA 0020 airfoil as shown in Figure 9. The new system was able to enhance the performance of the Savonius rotor by 12%.

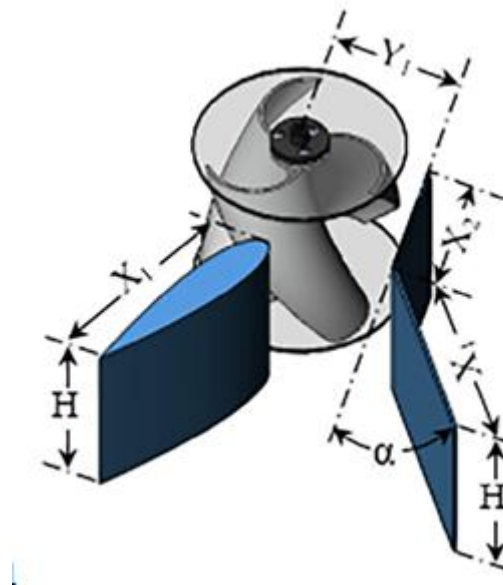


Fig. 9. Deflector system proposed by Mosbahi *et al.*, [31]

2.2 Windshields

Windshields are used as a negative torque reducer, and to increase the generated power from the Savonius wind rotor. These shields are commonly installed in front of the returning blades in order to minimize the drag force on it. Alexander and Holowina [32] conducted an experimental study in order to investigate the effect of adding end plates and windshields on the performance of the conventional Savonius rotor. They observed that the shield system increases the output power by 35.3%.

Computational CFD simulations were performed by Yonghai *et al.*, [33] on the windshield designs by introducing two parameters, i.e. Camber-X and Camber-Y (Figure 10). The results concluded that the new design of the windshield can improve the efficiency of the traditional Savonius rotor.

A different style of windshields was investigated by Emmanuel and Jun [34] by using six-blades Savonius wind rotors. The aim of their study was to explore ways which can improve the efficiency of the Savonius rotor by reducing the drag force of the returning blades. The results showed that the Savonius rotor with six-blades without shield have low efficiency, but still higher than the standard rotor. A power coefficient of 0.4 was reached by using shields.

A new passive-pitch shield was proposed by Tian *et al.*, [35]. The new system consisted of two plates that could adjust its pitch angle according to the wind trend. The performance of the Savonius rotor using the passive-pitch shield was found to be 46.32% more.

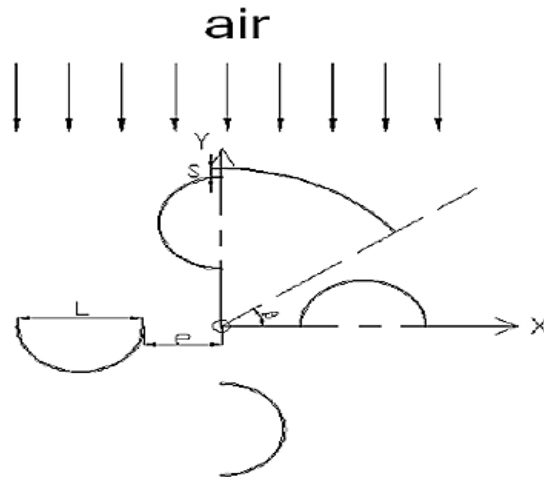


Fig. 10. Savonius rotor with windshield [33]

2.3 Curtain Plates

Curtain plates are a set of plates which fixed in front of the wind turbine in order to prevent the negative torque on the convex side of the rotor. Altan and Atilgan [36–38], proposed a novel design consisting of two plates. The top point of the first plate and the bottom point of the second plate are fixed as shown in Figure 11, while the other sides of the plates are designed as adjustable for any required angle. Experiments with various angles were performed in a wind tunnel. The results showed an improvement in the extracted power by 16% when a curtain with ($\alpha = 45$ degrees and $\beta = 15$ degrees) was used. A curtain with three plates was proposed by El-Askary *et al.*, [39]. They performed a numerical investigation on three new designs based on Altan and Atilgan [38] design by fixed the upper plate at angle to 15 degrees as shown in Figure 12. The idea behind the extra plate is to direct the wind to the concave side on the other surface of the same blade, reducing the negative torque while enhancing the positive torque created. The numerical results showed that design (c) gave a maximum C_p of around 0.52. which increased by around 62% compared to conventional rotor. However, it was noticed that a strong vortex shedding generated around the new designs which may generate a high noise.

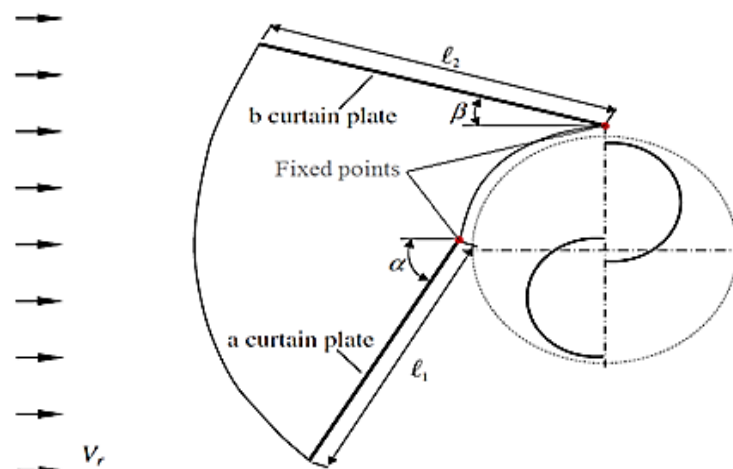


Fig. 11. Design of the curtain arrangement placed in front of the Savonius wind rotor [36]

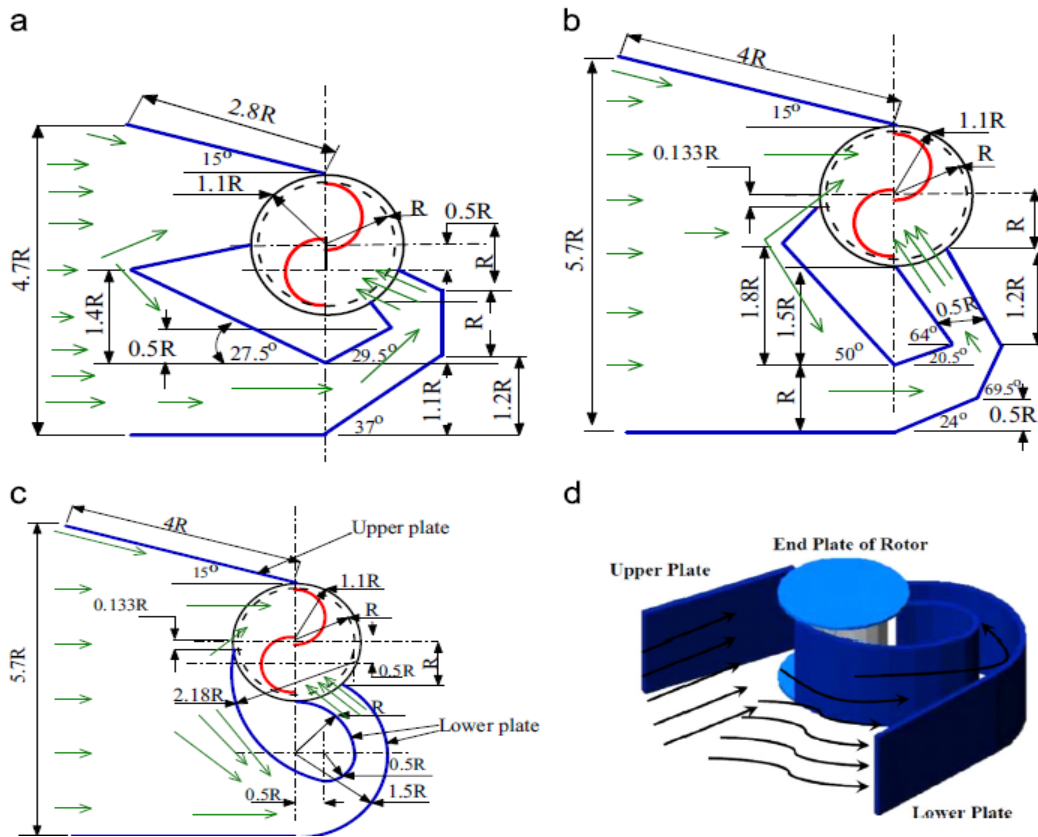


Fig. 12. Three different designs to control the wind direction proposed by El-Askary *et al.*, [39]

In the same field, Tartuferi *et al.*, [40] redesigned the two plate curtain system to make it dependent on the wind direction as shown in Figure 13. The new proposed design consists of two aerodynamic appendages, partially enclosing the Savonius rotor. The first part is the lower conveyor which is lying alongside the blade with the concave side, whereas, the second part is adjusted to the returning blade with the convex side. The function of this system is to reduce the dynamic pressure on the returning blade which caused by the incoming flow. Both parts were joined to hinges which made the system self-align relative to the direction of the incoming flow. The results showed a 20% improvement in the extracted power. The effect of the curtain width was also studied by Yowono *et al.*, [41] using a single curtain. They found that the relative size of the curtain (width of the curtain/diameter of the Savonius turbine) can affect the performance of the rotor.

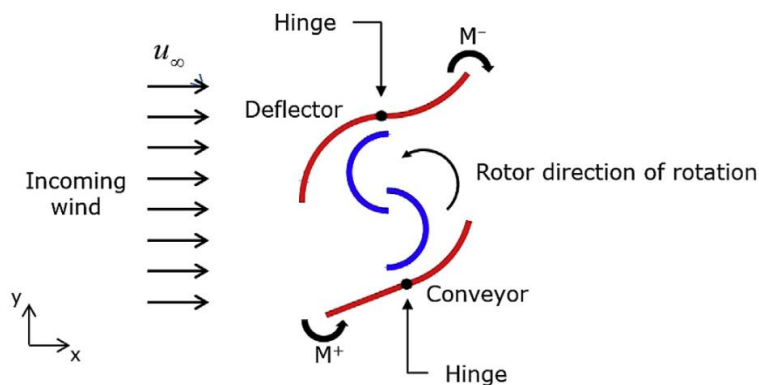


Fig. 13. Sketch of the new conveyor deflector curtain system, self-orienting relative to the wind direction [40]

2.4 Guide Vanes

Guide vanes are one of the additional devices. Their function is to direct the upstream wind onto the advancing blade and prevent the wind from flowing onto the returning blade resulting in reducing the negative torque on the rotor [42]. Different styles and designs were proposed in the previous studies with different applications. In order to improve the performance of the Savonius rotor, Tang *et al.*, [43] designed a novel type of Guide vane with six plates as shown in Figure 14. The new design is supposed to improve the coefficient of power by increasing the wind speed on the advancing blade and, reducing the wind resistance on the returning blade by adjusting the wind direction. The numerical simulation of the novel design showed more than 50% improvement in terms of power compared to the conventional Savonius. Sun *et al.*, [44] conducted also a numerical simulation for the guide vane with six blades, but with a different plate shape as shown in Figure 15. The results showed that the new design contributes to reducing the negative torque hence increasing the efficiency. Tjahjana *et al.*, [45] tested the Savonius rotor at various slope angles of the guide vane system. They found that the optimum slope angle is to be 60° .

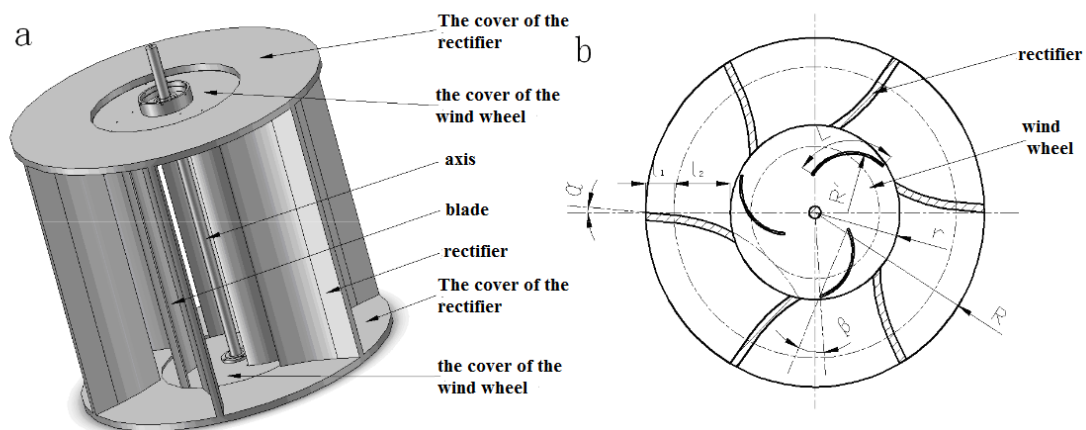


Fig. 14. Guide vane proposed by Tong *et al.*, [43]

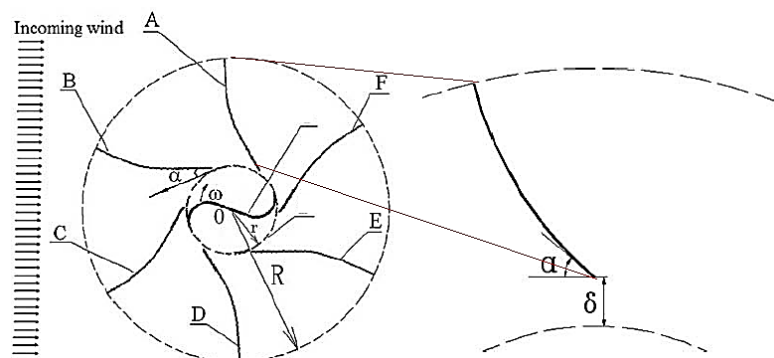


Fig. 15. A cross-sectional view of the power augmented vertical axis wind turbine [44]

Salem *et al.*, [46] tested a three blade Savonius rotor instead of two blades in order to study the effect of guide vane on the rotor. They proposed four designs of guide vanes as shown in Figure 16. The experimental results showed that the guide vanes affects the performance of the rotor by increasing the coefficient of power up to 65.89% compared to the rotor without guide vane when they used basic design plus 45° .

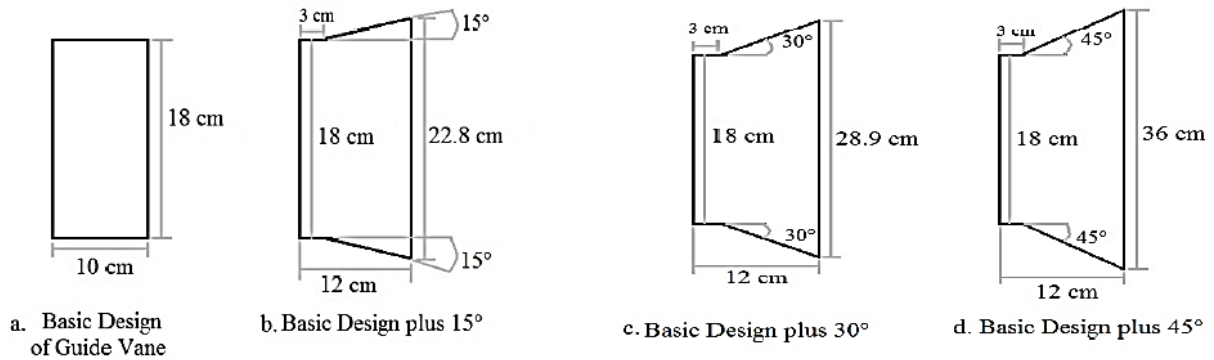


Fig. 16. Models of various guide vane design [46]

2.5 Nozzles

The main idea behind the use of nozzle is to enlarge the wind speed before it hits the rotor blades and so reduce the negative torque of the rotor. The convergent nozzle was used by Shikha *et al.*, [47] in order to investigate its effect on the two, four and six-blade rotor. They proposed a different dimension of the design, the main design is shown in Figure 17. The nozzle concentrator is positioned at the upwind and comprises of two straight plates to direct the wind flow to the rotor surface. The results showed that the performance was affected by two main factors; the number of blades and the nozzle dimensions. The six-bladed rotor was the most efficient with 55 cm long nozzles.

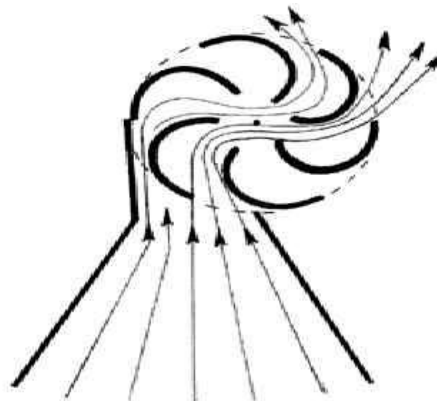


Fig. 17. A six-bladed rotor with a convergent nozzle [47]

Elbatran *et al.*, [48] proposed six novel systems of ducted nozzle to increase the rotor efficiency. The schematic diagram of the main design is shown in Figure 18. The numerical results showed that the new designs contributed to increase the velocity, increase the pressure difference to allow more flow to pass through the turbine, reduce the negative torque of the returning blade and finally enhance the extracted power.

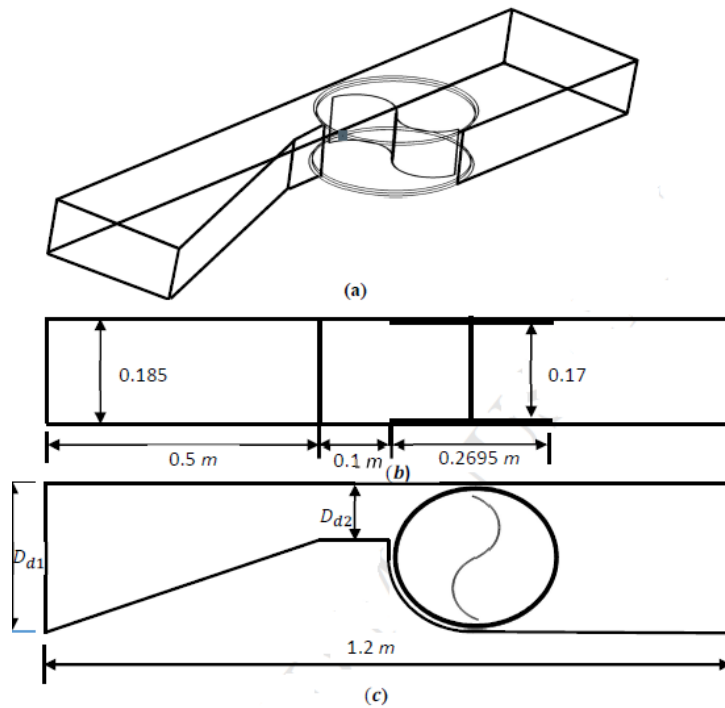


Fig. 18. Schematic diagram of special duct configuration surrounding Savonius runner: (a) isometric (b) side view (c) top view [48]

Another design was proposed by Mohammadi *et al.*, [49] as shown in Figure 19. The results showed a full agreement with Elbatran *et al.*, [48] outcomes. The extracted power was three times more than the conventional rotor without nozzle.

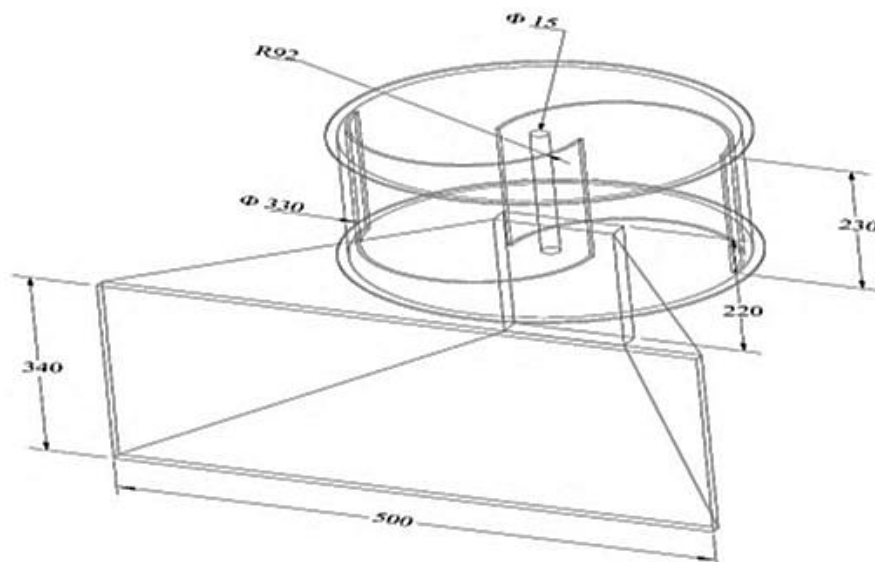


Fig. 19. Nozzle and Savonius rotor [49]

3. Conclusions

Vertical axis wind turbines are a valuable source for small-scale electricity production. Low efficiency, negative static torque, and self-starting problems are the main negatives of the Savonius wind rotor. Power augmentation devices showed an effective solution to overcome those negatives.

This review makes an endeavor to analyze the effect of power devices on the Savonius wind rotor. The main findings are below.

- i. The external power devices aimed to increase the power, static torque, and improve self-starting capability.
- ii. The efficiency of the Savonius wind rotor is low due to the negative static torque on the returning blade. The external devices overcome this negative torque by controlling the wind direction in a way that prevents the air from hitting the convex side of the returning blade which improved the efficiency of the rotor.
- iii. The combination of the number of blades and the dimension of the external device can affect the performance of the rotor. Rotors with six blades performed better than two and four blades when the same dimension of the nozzle was used.
- iv. Two-stage rotor with null phase shift performed better than the same rotor with phase shift and better than the three-stage rotor when a deflector blade was used.
- v. The main drawback of power augmentation devices was that the Savonius rotor becomes highly dependent on the wind direction. Moreover, the design became more complex.
- vi. Most of the studies are performed to investigate the effect of the deflector plates on the aerodynamics of the Savonius rotor. This has left potential scope to investigate the generated noise when such techniques were used.

References

- [1] Herring, H. "Godfrey Boyle (ed.), Renewable Energy: Power for a Sustainable Future." *ENVIRONMENTAL POLITICS* 8 (1999): 347-347.
- [2] Muhammad Adil Khattak, Tuan Mohamad Hakimi Tuan Yahya, Muhammad Wazif Mohd Sallehuddin, Muhammad Izzuan Mohd Ghazali, Nur Awal Abdullah, Nur Athirah Nordin, Nur Ainida Mohd Mohsein Dzakurnain, Suhail Kazi. "Global Energy Security and Eastern Europe: A Review." *Journal of Advanced Research Design* 45 (2018): 19-42.
- [3] Yazid, AW Muhammad, CS Nor Azwadi, S. Mohamed Salim, and S. Mansor. "Preliminary Study on the Wind Flow and Pollutant Dispersion in an Idealized Street Canyon." *Journal of Advanced Research Design* 1 (2014): 1-17.
- [4] IRENA. 2017. "RENEWABLE POWER: SHARPLY FALLING GENERATION COSTS." https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Nov/IRENA_Sharp_falling_costs_2017.pdf.
- [5] Mohamed, Abdel-Aziz Farouk Abdel-Aziz. "Hybrid Nanocrystal Photovoltaic/Wind Turbine Power Generation System in Buildings." *Journal of Advanced Research in Materials Science* 40 (2018): 8-19.
- [6] Didane, Djamal Hissein, Nurhayati Rosly, Mohd Fadhli Zulkafli, and Syariful Syafiq Shamsudin. "Numerical investigation of a novel contra-rotating vertical axis wind turbine." *Sustainable Energy Technologies and Assessments* 31 (2019): 43-53.
- [7] Akwa, João Vicente, Gilmar Alves da Silva Júnior, and Adriane Prisco Petry. "Discussion on the verification of the overlap ratio influence on performance coefficients of a Savonius wind rotor using computational fluid dynamics." *Renewable Energy* 38, no. 1 (2012): 141-149.
- [8] Jang, Hyeonmu, Insu Paek, Seungjoo Kim, and Deockjin Jeong. "Performance Prediction and Validation of a Small-Capacity Twisted Savonius Wind Turbine." *Energies* 12, no. 9 (2019): 1721.
- [9] Bhutta, Muhammad Mahmood Aslam, Nasir Hayat, Ahmed Uzair Farooq, Zain Ali, Sh Rehan Jamil, and Zahid Hussain. "Vertical axis wind turbine—A review of various configurations and design techniques." *Renewable and Sustainable Energy Reviews* 16, no. 4 (2012): 1926-1939.
- [10] Zemamou, M., M. Aggour, and A. Toumi. "Review of savonius wind turbine design and performance." *Energy Procedia* 141 (2017): 383-388.
- [11] Shigetomi, Akinari, Yuichi Murai, Yuji Tasaka, and Yasushi Takeda. "Interactive flow field around two Savonius turbines." *Renewable energy* 36, no. 2 (2011): 536-545.
- [12] Lee, Jae-Hoon, Young-Tae Lee, and Hee-Chang Lim. "Effect of twist angle on the performance of Savonius wind turbine." *Renewable Energy* 89 (2016): 231-244.
- [13] Tian, Wenlong, Zhaoyong Mao, Baoshou Zhang, and Yanjun Li. "Shape optimization of a Savonius wind rotor with different convex and concave sides." *Renewable energy* 117 (2018): 287-299.
- [14] Chan, Chun Man, H. L. Bai, and D. Q. He. "Blade shape optimization of the Savonius wind turbine using a genetic algorithm." *Applied energy* 213 (2018): 148-157.

- [15] Alom, Nur, and Ujjwal K. Saha. "Performance evaluation of vent-augmented elliptical-bladed savonius rotors by numerical simulation and wind tunnel experiments." *Energy* 152 (2018): 277-290.
- [16] Al-Ghriybah, Mohanad, Hüseyin Çamur, Mohd Fadhli Zulkafli, Muhammad Abid Khan, Youssef Kassem, and Engin Esenel. "Study of Multiple Half Blades Effect on the Performance of Savonius Rotor: Experimental Study and Artificial Neural Network (ANN) Model." *Indian Journal of Science and Technology* 11, no. 38 (2018): 1–12.
- [17] Frikha, Sobhi, Zied Driss, Emna Ayadi, Zied Masmoudi, and Mohamed Salah Abid. "Numerical and Experimental Characterization of Multi-Stage Savonius Rotors." *Energy* 114 (2016): 382–404.
- [18] Mahmoud, N. H., A. A. El-Haroun, E. Wahba, and M. H. Nasef. "An experimental study on improvement of Savonius rotor performance." *Alexandria Engineering Journal* 51, no. 1 (2012): 19-25.
- [19] Ahmed, Wasi Uddin, Md Junayed Hasan Zahed, Md Azimur Rahman, and Mohammad Mamun. "Numerical study of two and three bladed savonius wind turbine." In *2nd International Conference on Green Energy and Technology*, (2014): 36-40. IEEE, 2014.
- [20] Bhayo, B. A., H. H. Al-Kayiem, and N. Z. Yahaya. "Performance investigation of the S-Rotors." In *IOP Conference Series: Materials Science and Engineering* 100, no. 1 (2015): 012043.
- [21] Ogawa, T., H. Yoshida, and Y. Yokota. "Development of rotational speed control systems for a Savonius-type wind turbine." *Journal of fluids engineering* 111, no. 1 (1989): 53-58.
- [22] Shaughnessy, B. M., and S. D. Probert. "Partially-blocked Savonius rotor." *Applied Energy* 43, no. 4 (1992): 239-249.
- [23] Etemadeasl, Vahid, Rasool Esmaelnajad, Farzad F. Dizaji, and Babak Farzaneh. "A novel configuration for improving the aerodynamic performance of Savonius rotors." *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy* (2018): 0957650918818968.
- [24] Mohamed, M. H., G. Janiga, E. Pap, and D. Thévenin. "Optimization of Savonius turbines using an obstacle shielding the returning blade." *Renewable Energy* 35, no. 11 (2010): 2618-2626.
- [25] He, D. Q., H. L. Bai, C. M. Chan, and K. M. Li. "Performance-based Optimizations on Savonius-type Vertical-axis Wind Turbines using Genetic Algorithm." *Energy Procedia* 158 (2019): 643-648.
- [26] Youssef, Khaled M., Ahmed M. El Kholy, Ashraf M. Hamed, Nabil A. Mahmoud, Ahmed M. El Baz, and Tamer A. Mohamed. "An innovative augmentation technique of savonius wind turbine performance." *Wind Engineering* (2019): 0309524X19849860.
- [27] Golecha, Kailash, T. I. Eldho, and S. V. Prabhu. "Influence of the deflector plate on the performance of modified Savonius water turbine." *Applied Energy* 88, no. 9 (2011): 3207-3217.
- [28] Kailash, Golecha, T. I. Eldho, and S. V. Prabhu. "Performance study of modified Savonius water turbine with two deflector plates." *International Journal of Rotating Machinery* 2012 (2012): 1-12
- [29] Roy, Sukanta, Prasenjit Mukherjee, and Ujjwal K. Saha. "Aerodynamic performance evaluation of a novel Savonius-style wind turbine under an oriented jet." In *ASME 2014 Gas Turbine India Conference*, pp. V001T08A001-V001T08A001. American Society of Mechanical Engineers, 2014.
- [30] Chen, Chang-An, Tien-Yang Huang, and Chiun-Hsun Chen. "Novel plant development of a parallel matrix system of Savonius wind rotors with wind deflector." *Journal of Renewable and Sustainable Energy* 7, no. 1 (2015): 013135.
- [31] Mosbahi, Mabrouk, Ahmed Ayadi, Youssef Chouaibi, Zied Driss, and Tullio Tucciarelli. "Performance study of a Helical Savonius hydrokinetic turbine with a new deflector system design." *Energy Conversion and Management* 194 (2019): 55-74.
- [32] Alexander, A. J., and B. P. Holownia. "Wind tunnel tests on a Savonius rotor." *Journal of Wind Engineering and Industrial Aerodynamics* 3, no. 4 (1978): 343-351.
- [33] Hu Yonghai, Tong Zhengmin, and Wang Shanshan. "A new type of VAWT and blade optimization." In *International Technology and Innovation Conference* (2009): 14-14.
- [34] Emmanuel, Binyet, and Wang Jun. "Numerical Study of a Six-Bladed Savonius Wind Turbine." *Journal of Solar Energy Engineering* 133, no. 4 (2011): 044503.
- [35] Tian, Wenlong, Zhaoyong Mao, and Hao Ding. "Numerical study of a passive-pitch shield for the efficiency improvement of vertical axis wind turbines." *Energy conversion and management* 183 (2019): 732-745.
- [36] Altan, Burcin Deda, and Mehmet Atilgan. "An experimental and numerical study on the improvement of the performance of Savonius wind rotor." *Energy Conversion and Management* 49, no. 12 (2008): 3425-3432.
- [37] Altan, Burçin Deda, Mehmet Atilgan, and Aydoğın Özdamar. "An experimental study on improvement of a Savonius rotor performance with curtaining." *Experimental thermal and fluid science* 32, no. 8 (2008): 1673-1678.
- [38] Altan, Burçin Deda, and Mehmet Atilgan. "The use of a curtain design to increase the performance level of a Savonius wind rotors." *Renewable Energy* 35, no. 4 (2010): 821-829.
- [39] El-Askary, W. A., M. H. Nasef, A. A. Abdel-Hamid, and H. E. Gad. "Harvesting wind energy for improving performance of Savonius rotor." *Journal of Wind Engineering and Industrial Aerodynamics* 139 (2015): 8-15.

- [40] Tartuferi, Mariano, Valerio D'Alessandro, Sergio Montelpare, and Renato Ricci. "Enhancement of Savonius wind rotor aerodynamic performance: a computational study of new blade shapes and curtain systems." *Energy* 79 (2015): 371-384.
- [41] Yuwono, Triyogi, Abdul Latip, Nabila Prastiya Putri, Mukhamad Ubaidillah, Erik Noer Mazhilna, Citro Ariyanto, Ulfah Andaryani, Anas Fauzi, Wawan Aries Widodo, and Bambang Arip Dwiyantoro. "The effect of width of single curtain on the performance of Savonius wind turbine." In *AIP Conference Proceedings* 1983, no. 1 (2018): 020023.
- [42] Kalluvila, Jinshah BS, and B. Sreejith. "Numerical and experimental study on a modified Savonius rotor with guide blades." *International journal of green energy* 15, no. 12 (2018): 744-757.
- [43] Tang, Zhi Peng, Ying Xue Yao, Liang Zhou, and Q. Yao. "Optimal Design of A New Type of Savonius Rotor Using Simulation Analysis." In *Key Engineering Materials* 499 (2012): 120-125. Trans Tech Publications, 2012.
- [44] Sun, Xiaojing, Ziyin Cao, Yueqing Zhuang, Diangui Huang, and Yang Cao. "Numerical modeling and optimization of a power augmented S-type vertical axis wind turbine." *International Journal of Green Energy* 15, no. 1 (2018): 13-19.
- [45] Tjahjana, Dominicus Danardono Dwi Prija, Syamsul Hadi, Yoga Arob Wicaksono, Diniar Mungil Kurniawati, Fahrudin, Ilham Satrio Utomo, Sukmaji Indro Cahyono, and Ari Prasetyo. "Study on Performance Improvement of the Savonius Wind Turbine for Urban Power System with Omni-Directional Guide Vane (ODGV)." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 55, no. 1 (2019): 126-135.
- [46] Ahmad, Elsadic Salim. "A Study of the Influence of Guide Vane Design to Increase Savonius Wind Turbine Performance." *Modern Applied Science* 9, no. 11 (2015): 222.
- [47] Shikha, T. S. Bhatti, and D. P. Kothari. "Vertical Axis Wind Rotor with Concentration by Convergent Nozzles." *Wind Engineering* 27, no. 6 (2003): 555-959.
- [48] Elbatran, A. H., Yasser M. Ahmed, and Ahmed S. Shehata. "Performance study of ducted nozzle Savonius water turbine, comparison with conventional Savonius turbine." *Energy* 134 (2017): 566-584.
- [49] Mohammadi, M., R. Mohammadi, A. Ramadan, and M. H. Mohamed. "Numerical investigation of performance refinement of a drag wind rotor using flow augmentation and momentum exchange optimization." *Energy* 158 (2018): 592-606.