

A simulation investigation the performance of a small scale Elliptical Savonius wind turbine with twisting blades and sloping ends plates

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ABSTRACT

The Savonius wind rotor considered the most common categories of the vertical axis wind rotor in order to generate energy from the wind. Elliptical blades one of adopted geometry to design the Savonius turbine rotor. The development of the blade geometry is some of the most essential strategies for improving the Savonius rotor's performance. In this paper, CFD simulations were used to study the effect of geometric parameters of the small scale elliptical Savonius turbine rotor (ESTR) with inner surface wavy blades. The simulation has been implemented in a in a two configurations design models, ESTR models with twisting angle in range of (5° to 45°) and ESTR models with tilt angle of end plates (3° to 15°) with an aspect-ratio of (1) and an overlap-ratio within (0.2). The performance was assessed using torque and the power coefficient varies with the tip speed ratio. The numerical results shows that the increase in the maximum power-coefficient with increase of twist angle and tilt angle until optimum values of 30° and 12° for a twist angle and tilt angle, respectively. Although in all configuration show a good increase in power coefficient but there are a significant increasing in maximum power coefficient for ESTR model with twist angle of 30° which was 3.7% while the increasing reach to 14.55% at ESTR model with tilt angle 12° at tip speed ratio of 7. As well as, in comparison to the preceding ESTR model, these two models give a leap in power coefficients for a distinct range of tip speed ratios.

Keywords: VAWT, Savonius turbine, ESTR, Twist angle, tilt angle, Power coefficient

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1. Introduction

The growing depletion of fossil energy sources, as well as the pollution that results, necessitate the search for alternate and sustainable energy sources, which are now known as renewable energies. [1], [2],[3],[4],[5]. Wind energy, being a clean with sustainable energy sources, is one of the most important renewable energy sources that has attracted a lot of attention around the world. The most common way to capturing energy from the wind by a wind turbine for producing the power. There are many different types of wind turbines, they are, however, classified into two types: horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT)[6]. One of the simplest and common types of VAWTs is Savonius wind turbine rotor (SWTR) it was created in 1925 by Savonius the Finnish engineer [1], [7]. The Savonius rotor is a drag wind turbine whose operating based on the drag-force between the rotor blades' convex and concave surfaces as they spin around a vertical shaft. Despite the fact that the Savonius turbine produces less power than other wind turbines, it has a number of benefits, including the ability to operate in any wind direction, minimal noise, simple design, inexpensive manufacturing, installation, and maintenance costs. [6], [8].

1.1. Performance parameters of SWTR

The interested researchers have conducted many investigations the experimental with numerical tests to develop and boost the performance of the Savonius wind turbine. The researchers studies included main parameters of the blade geometry such as the geometric shape of a blade, the aspect ratio (height to rotor diameter, H/D), the overlap ratio (OR), number of blades, blade angle, and twist angle. As well as, the extra important parameters were concerned, like end plates and orientation devices [9], [10]. The aspect ratio in the 1 to 2 range (1 is better) has proven to be the best performer. Also, classic Savonius turbines with blades with overlap ratios have better starting features as compared to non-overlap blades [9], [11]. The positive horizontal and vertical positions of OR with maintained the external rotor diameter (to some extent), enhance the performance of SWTR relatively compare to other zero and negative OR positions [12]. The values of OR in range of (0.1- 0.2) has proved satisfied the best performance for elliptical SWTR, where optimum value of OR was of 0.2 [9], [13].

The SWTR to be rotate usefully, it must has at least a two blades. In this regard, the number blades effect on SWTR performance efficiency was reviewed. The coefficient of power decreases with an increase in the number of blades, more than three blades or more. In another words, the rotor with two-blades achieve a higher performance in a comparison [14] From another hands, using the orientation devices like guide vanes achieve an increase in performance of SWTR compare to that without guide vanes [15], [16], [17],[18], [19].

The twisting of blade angle is one of the important parameters effect on SWTR performance. The Savonius helical turbine without overlap ratio (OR=0) and H/D equal 1 for tow twist angle 30 and 45 have been studied by experimental and numerical tests and their effect on the aerodynamic performance. The results showed that an increase of the twist angle from 0 to 45 reduces the coefficient of maximum power (C_p) [20]. While that Tahani [21] in his study proved that the twist for Savonius blades lowers the negative torque on the return blade and increase its performance. This is also proven by El-Askary [8] through by study the performance of SWTR model with OR of 0.15 and H/D of 1 at different twisting angles ranged of (0-180). The simulation results show that the maximum of C_p rises with the growing of twist angle of optimum value up to 45, which also was achieve the most efficient performance in the numerical studies that were conducted by Lee [22] and Saad [23]. In summary, most of researchers conducted that Savonius twist-blades turbine achieve a higher performance compared to the conventional one [14], [24], [25], [26].

The end plates presence are one of the secondary parameters that must considered due to effected noticeable on the Savonius turbine performance. Premkumar T [27], in his experimental study for a helical Savonius rotor turbine with and without end plates. The study conclude that the helical Savonius rotor with end plate more efficient compare to that one without end plates. The torque of a Savonius turbine is proportional to the endplate area, as well as by using the upper and lower endplates of the Savonius rotor, the power coefficient increases significantly to 36% compared to the rotor without endplates. [28].

In this study, the focus is on the effect of geometric parameters by investigating using CFD simulation, the twisting angle (ϕ) and tilt angle (α) of end plates for the elliptical Savonius turbine rotor (ESTR) with inner surface wavy blades that submitted by Salih [9]. Accordingly, the modelling procedure is selected and validated from the reference. [9]. In addition, network and turbulence models for the computational domain were verified. Also, two modified ESTR models, the Savonius twisted-blade rotor and the tiltly endplates of the rotor, are a suggestion for improvements over the previous design of ESTER.

2. Methodology

2.1. Geometrical parameters and modeling

In the present study the main geometrical parameters, the blade shape, OR (e), and H/D was adopted from study that presented by [9] as a base model for this study. In Ref [9] there is an isometric and top view of ESTR has been shown in Figure-1. The rotor model has a two elliptical blade with wavy inner surface, also it has up and down end plates with same diameter. The dimensions of parameters design are listed in Table 1.

In this study, a two configurations were suggested to improve the performance of base design of ESTR, the first configuration based on make a twisting in vertical axis of rotor blade. The twist angles (ϕ) in range of (5° to 45°) by step of 5, were adopted in this study [21].Figure 2. Shows the modeling shapes of ESTR with twisted blades with the vertical axis at twist angles range of (5° to 45°). The second configuration was based on using sloping ends plates in tilt angle (α) ranged of (3° to 15°) step of 3 as shown in figure 3, all models of ESTR were modeled by SolidWorks.

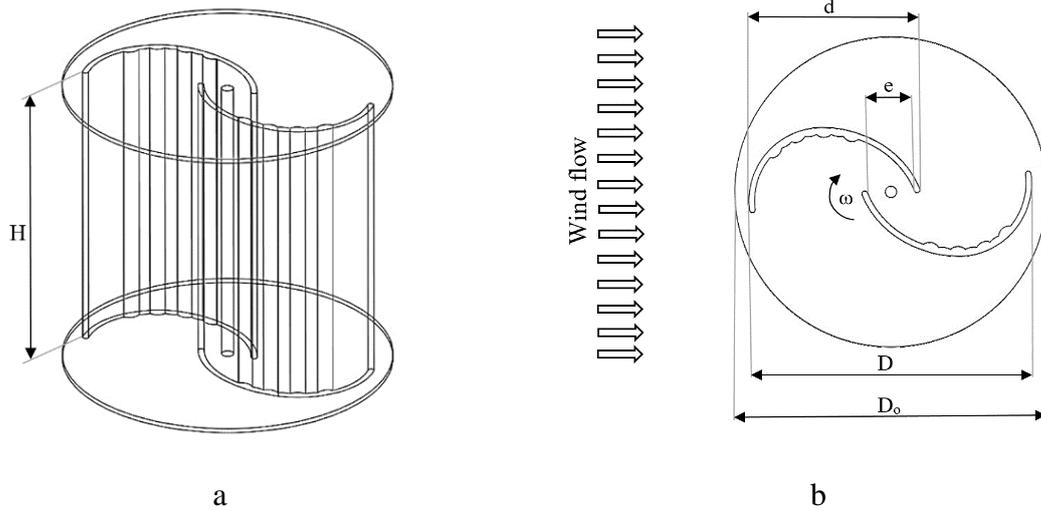


Figure 1. The schematic shape of base model of ESTR, (a) Isometric view, (b) top view

Table 1. The main geometrical parameters of ESTR according to ref. [9]

Rotor diameter (D)	200 mm
End plate diameter (D _o)	220 mm
Blade height (H)	200
Aspect Ratio (H/D)	1
Blade chord length (d)	112.5 mm
Overlap ratio (e/d)	0.2
No. of blades	2
No. of stage	1
Thickness of blade	4 mm
Thickness of end plate	3 mm
Twisting angle (φ)	0°
End plate tilt angle (α)	0°

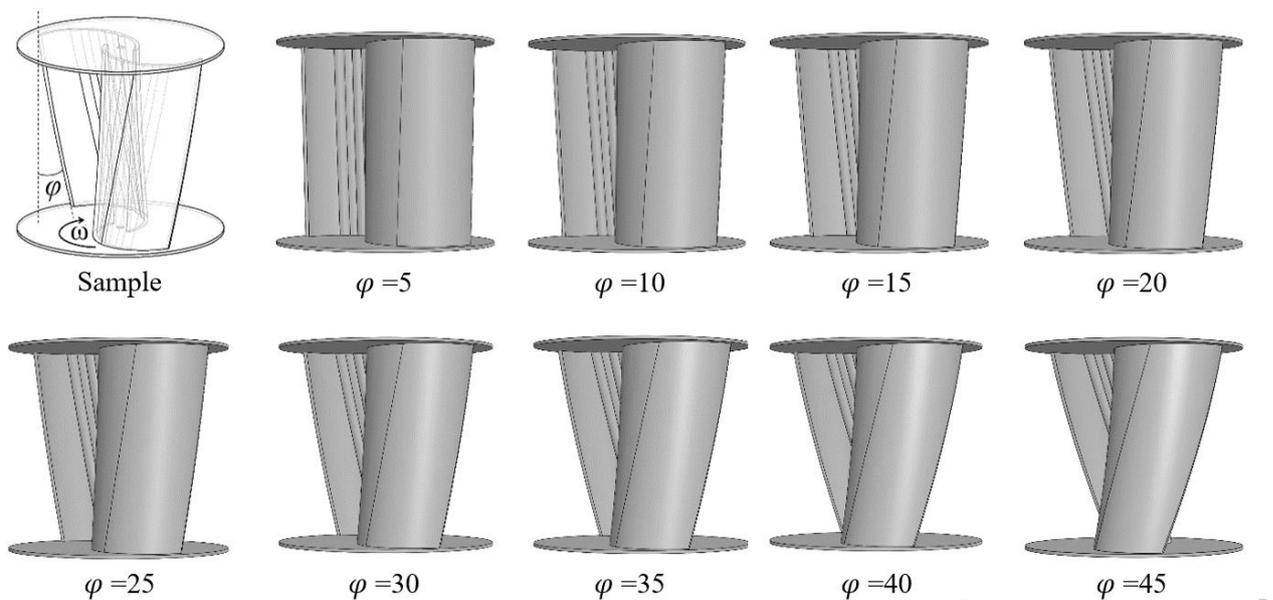


Figure 2. The modeling shapes of ESTRs with twisted blades about the vertical axis

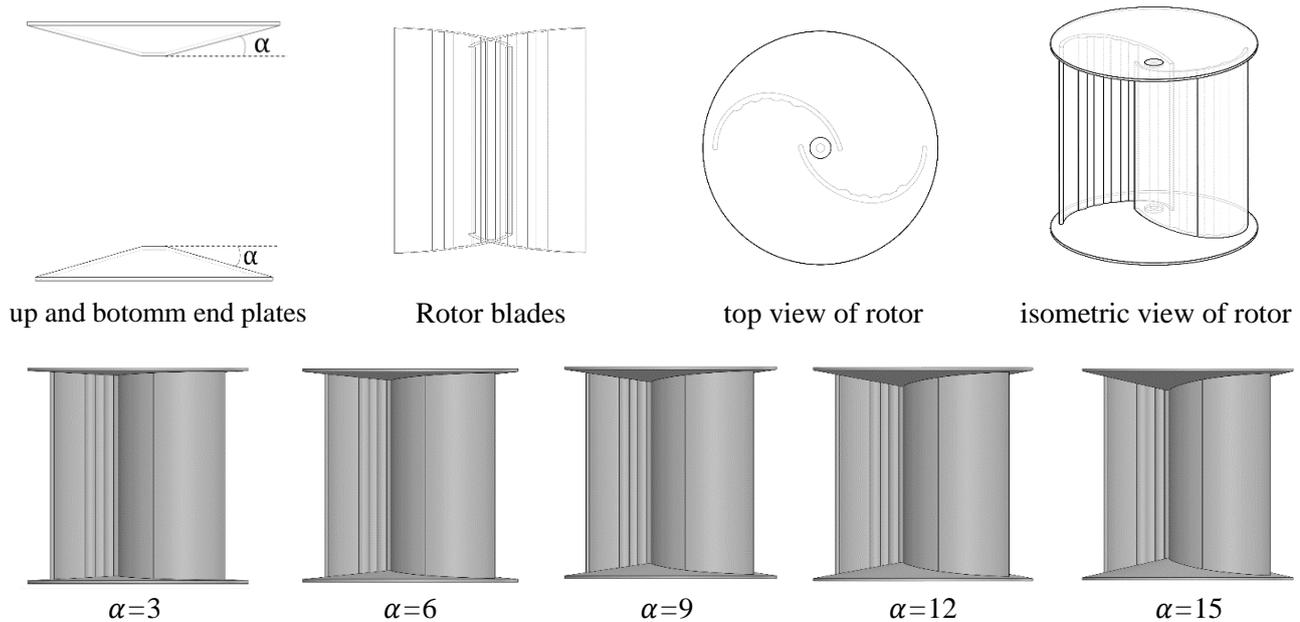


Figure 3. The modeling shapes of ESTRs with sloping ends plates

2.2. Domains of computation and boundary conditions

CFD was used to investigate the performance of ESTR model. The 3D computational domain for the model ESTR was adopted according to dimensions of previous study by [9]. In the current study, a high level of precision in flow investigation was required, for the entire geometries of the ESTR model, a 3D domain was created using CFX. As shown in Figure 4, the domain of a 3D CFD model has been created out up of two parts: a static domain and a rotary domain. The domain of stationary denotes a virtual model of a wind tunnel test section in dimensions of 400 mm *400 mm *1200 mm, The rotating domain, on the other hand, has a cylindrical shape and is placed in the middle of a stationary domain. It has rotor blades that revolve at the same angular speed as the rotary domain. The frozen rotor with specified pitch change is used as the interface of model between the rotary and stationary domains [29]. ANSYS 18.1 was used to simulate a transient blade row with a second order high resolution technique. The flow was assumed to be isothermal, with air as the working fluid and a reference pressure of 1 atm at default turbulence intensity [29]. In the stationary domain, the tunnel walls are symmetric, the entrance flow velocity is fixed at a particular value, and a zero relative static pressure is assumed at the outlet. The rotor blade's boundary condition is defined as a smooth part (wall), and the rotating exposure is set to the specified rotational speed. (SST k- ω) is a proven turbulence model that provides a very excellent prediction of outcome [21], [30]. The residual convergence criterion target is set to 10^{-4} .

2.3. Mesh and grid independent test

To avoid numerical diffusion, ANSYS CFX requires a high-quality mesh. The mesh quality metrics were taken into consideration to quantify the quality. The mesh type was Tetrahedron with default growth rate for stationary and 1.1 for rotary, where the mesh density was higher along the rotor blades' wall and interface. As indicated in Table 2, an independence test was performed to assess mesh quality in terms of skewness and orthogonal quality. The trial No. 1 was adopted for the mesh due to get up a less of skewness and higher orthogonal quality [31]. Figure 5 depicts the mesh on both the rotational and stationary domains.

Table 2. The statistic grid independence for ESTR model

Trial No.	Stationary domain		Rotating domain		skewness	Orthogonal quality
	Element No.	Nodes No.	Element No.	Nodes No.		
1	97356	18870	2757439	630182	0.78	0.998
2	194725	37101	5563588	1271496	0.789	0.993
3	389845	72575	11466554	2620553	0.799	0.992
4	782099	145270	22990441	5254209	0.8	0.993
5	1578014	288552	47820117	10928755	0.798	0.995

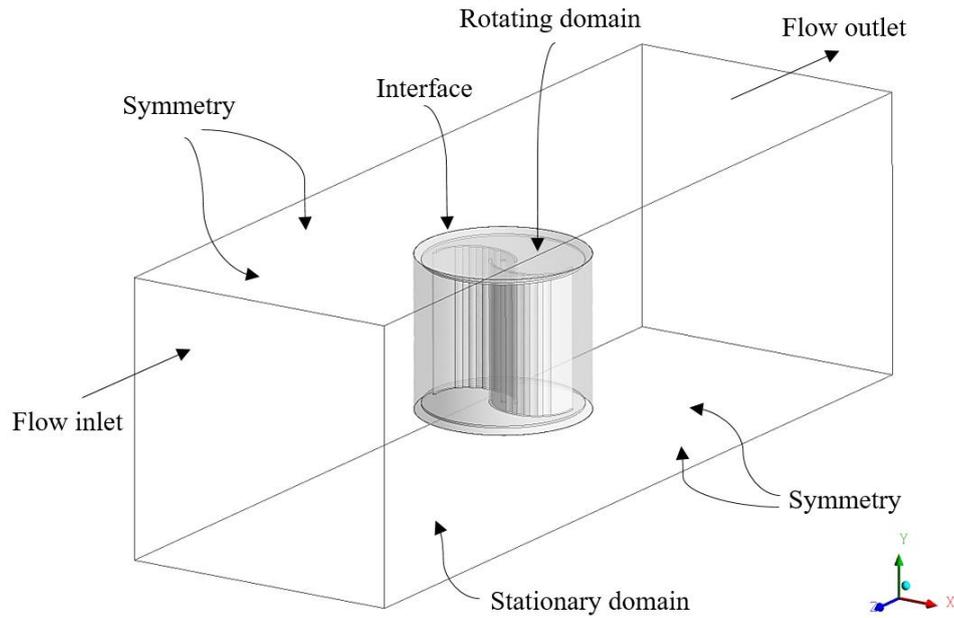


Figure 4. The computational domain of ESTR model

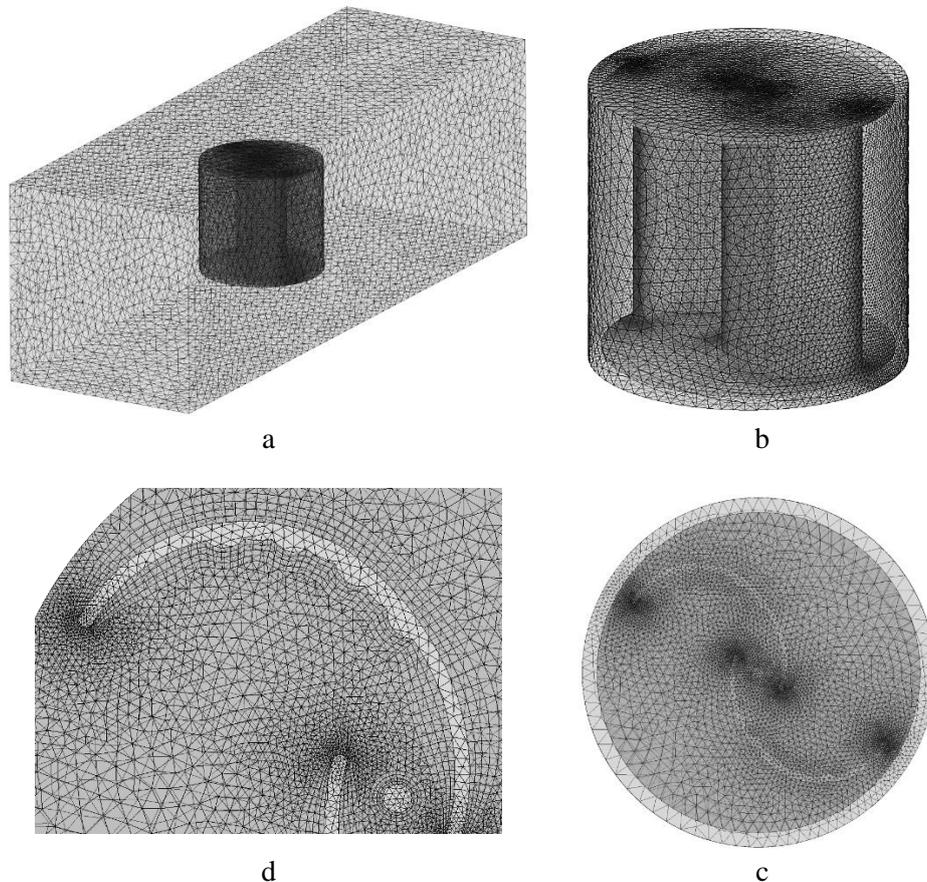


Figure 5. Mesh of ESTR model, (a) all domains, and (b) Rotating domain, (c) View from the top of the revolving domain, (d) mesh refinement near the blade from above

2.4. Calculating performance

As a result, ESTR's the power Coefficient (C_P) is a measure of performance that is defined as: (C_P). In general, the performance of VAWTs and other types of wind turbines is evaluated by comparing the energy output by the rotary to wind energy available. Wind power is one of resources of mechanical power to operate a Savonius wind rotor which the angular velocity (ω) multiplied by the turbine torque (T). As a result, the performance of the ESTR is represented by the power-coefficients (C_P):

$$C_P = \frac{P_{turbine}}{P_{wind}} = \frac{T\omega}{0.5 \rho A V_{\infty}^3} \quad (1)$$

The most popular way to see the power coefficient is to plot its value as various with tip- speed ratio (λ), which is defined by the equation as:

$$\lambda = \frac{\omega R}{V_{\infty}} \quad (2)$$

Furthermore, the torque coefficients (C_T) can be used to investigate ESTR performance. As a result, (C_T) as various of C_P was found to be:

$$C_T = \frac{\text{Actual torque}}{\text{Theoretical torque}} = \frac{T}{0.5 \rho A R V_{\infty}^2} = \frac{C_P}{\lambda} \quad (3)$$

Where A is ESTR swept area equal to HD, ρ is air velocity, R is rotor radius, and V_{∞} is air velocity. The varying tip speed ratio (from 0.1 to 1.4) for an ESTR with a wind speed of 6 m/s were calculated using the CFD, and the related anticipated coefficient of power as compared to experimental data and simulation studies of ref. [9] the purpose of validating the modelling approach used into this investigation. Figure 6 shows that the proposed modeling approach agrees well with experimental results and can thus be used for modeling and inquiry.

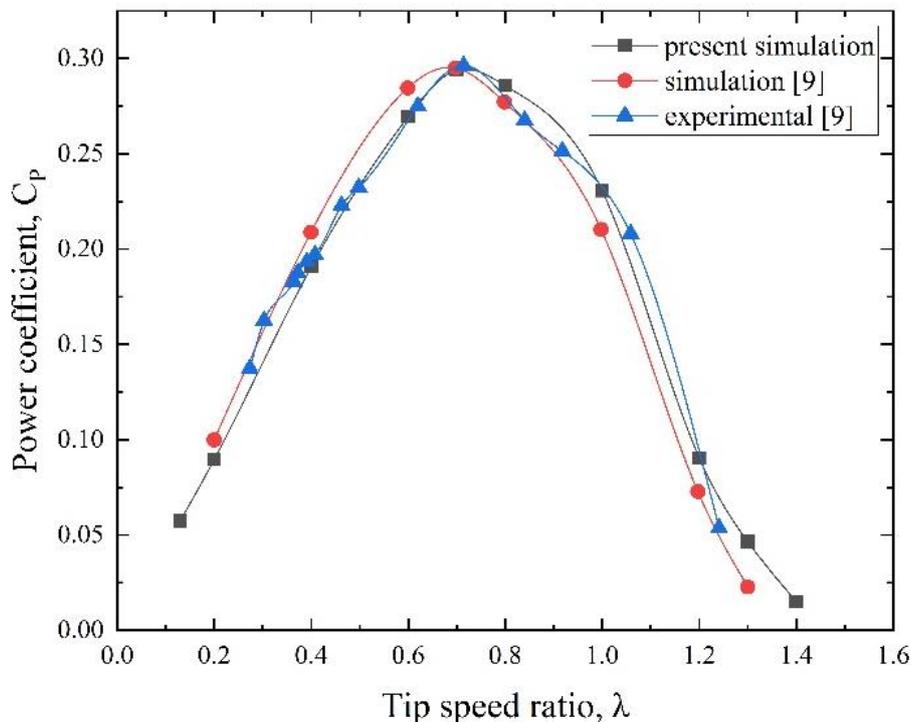


Figure 6. Verification curves of present simulation model with the experimental and simulation models of previous study

3. Results and discussions

The findings of the current ESTRs' design and modeling will be reviewed and compared with prior studies based on the specified assessment modeling approach [9]. The simulation results are presented in terms of power and torque-coefficients. The design process began with a simple ESTR model as the base design, and geometrical alterations were performed to improve the power coefficient.

3.1. ESTR design configurations

As mentioned, two geometrical ESTR configurations were suggested, ESTR with twisted blades and ESTR with tilt end plates. In these modelling investigation, the values of TSR and wind speed were 7 and 6 m/s, respectively for all the suggested geometries were adopted. Because blade twist can minimize negative torque to some extent [21], the relationship variation between maximum power coefficients and twist angles (ϕ) are presented in figure 7. It is possible to see that the greatest power-coefficient ($C_{p,max}$) increases as twist angle increase until reached to optimum $C_{p,max}$ at ϕ of 30° . Also, it noted that $C_{p,max}$ decreases for ESTRs geometries with greater than 30° twist angle and even compare previous ESTR (without twisted).

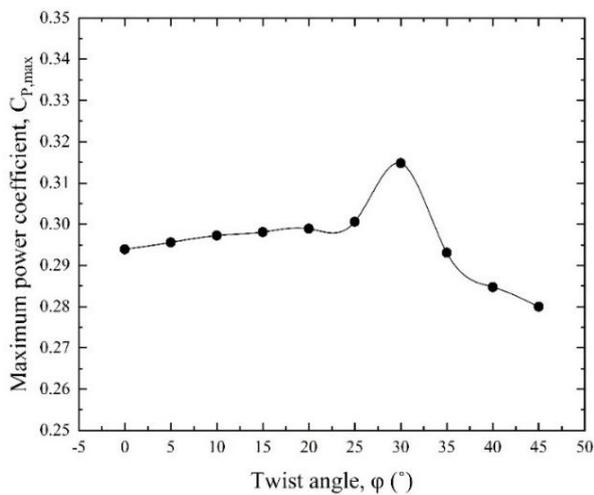


Figure 7. The relationship variation of blade twist angle on the maximum power-coefficient of ESTR

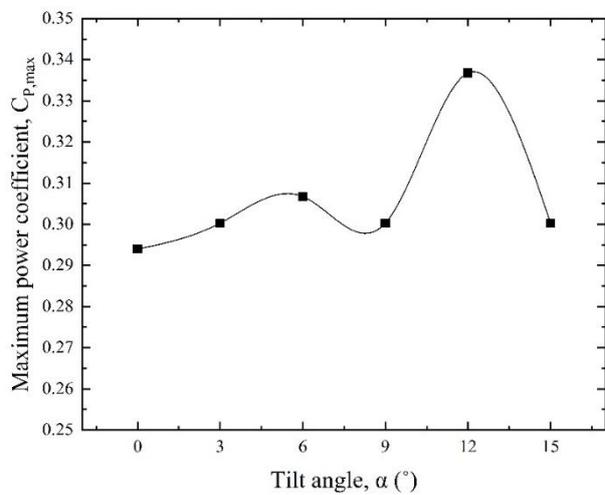


Figure 8. The relationship variation of end plates tilt angle on the maximum power-coefficient of ESTR

The second novel configuration that suggested in this study, applying a sloping ends plates instead of normal end plates. Figure 8, show effect of tilt angle for end plates on maximum power coefficient of ESTR. It was observe that increasing the performance of ESTR with increase of end plates tilt angle where the optimum value of $C_{p,max}$ recorded is 0.337 at tilt angle of 12° . The reason for this may be due to the increase in the surface contacting the flow, which in turn generates additional forces involved in increasing the positive torque on the concave blades and decreasing it on the convex blades.

3.2. Torque and power coefficients of ESTR models

The most significant parameters to evaluate the performance of the Savonius wind turbine are the power coefficients and torque coefficients. The values of C_p for the best ESTR presented configurations, ESTR at twist angle of 30° and ESTR at tilt angle of 12° were plotted as various of the tip speed ratios as shown in figure 9 and figure 10, respectively. As can be seen from plots, both configurations have C_p higher than previous ESTR with for all ranges of tip speed ratio. In addition, Figure 11 show the a comparison of the two presented configurations with the previous ESTR model, It was noticed observed that C_p values increase with increase of ESTR angular velocity until reach to $C_{p,max}$ at tip speed ratio of 7 which recorded of 0.305 at twist angle of 30° while it reach to 0.337 at tilt angle of 12° . The power coefficient decrease after tip speed ratio of 7 due to flowing air across the faster rotor where gave less chance for air to catch the blades which leads to decrease the torque on the blade hence less power produced. So, Figure 12 show the Comparison of torque-coefficient as a function of tip-speed ratio for presented and previous ESTR models.

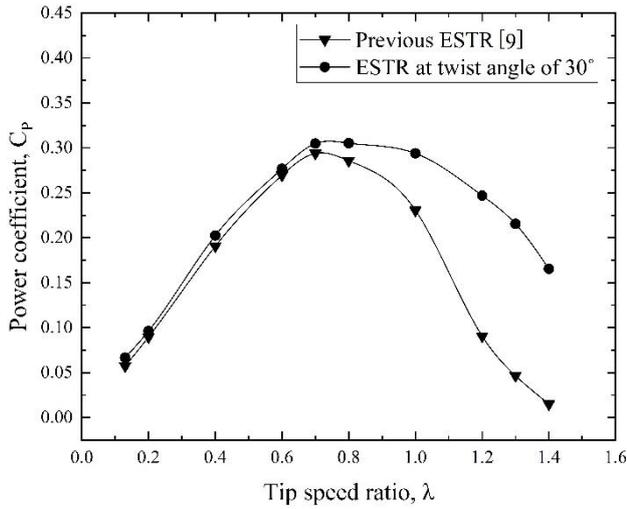


Figure 9. Relationship variation at the coefficient of power with (λ) for previous ESTR and ESTR at twist angle of 30°

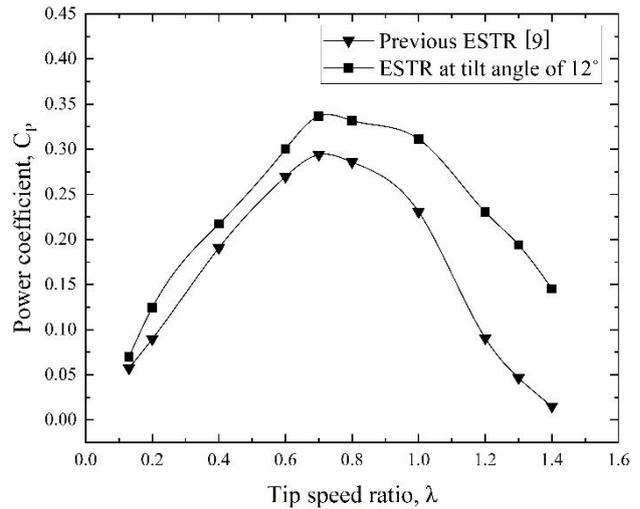


Figure 10. Relationship variation at the coefficient of power with (λ) for previous ESTR and ESTR at tilt angle of 12°

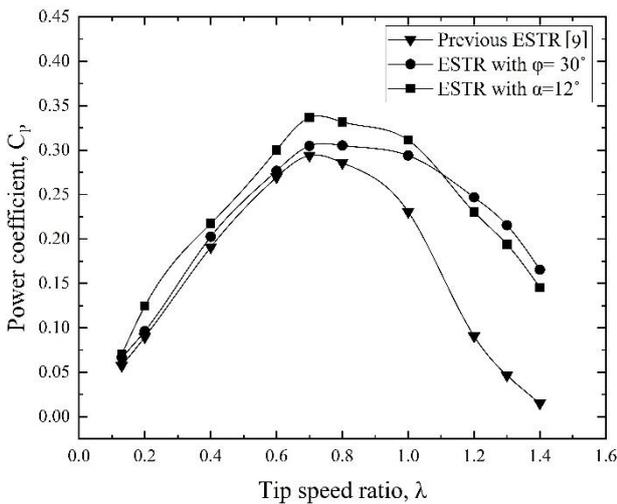


Figure 11. Comparison the power-coefficient with tip-speed ratio (λ) for models of, previous ESTR, ESTR with $\phi=30^\circ$, and ESTR with $\alpha=12^\circ$.

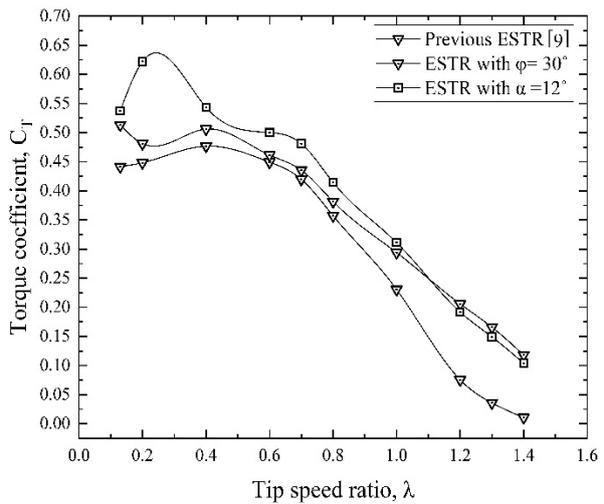


Figure 12. Comparison the torque coefficient with (λ) for models of, previous ESTR, ESTR with $\phi=30^\circ$, and ESTR with $\alpha=12^\circ$.

3.1. Flow visualization around ESTR models

The CFD simulation gives you a clear picture of the pressure and velocity distribution of presented ESTR models and gave easily to predict flow behavior in order to compare with previous ESTR. Figure 13 show the pressure distribution on the sectional and along the rotor blades for all ESTR models. It has been observed that a little increase in the pressure on ESTR models compare to previous one due to blade geometry developed for ESTR with $\phi=30^\circ$ and increase of mass flow on blades of ESTR with $\alpha=12^\circ$ which produced from decrease the pressure behind rotor blades, hence more air flow through ESTR, as showing in figure 14 that show velocity contours with wind speed of 6 m/s for the three models.

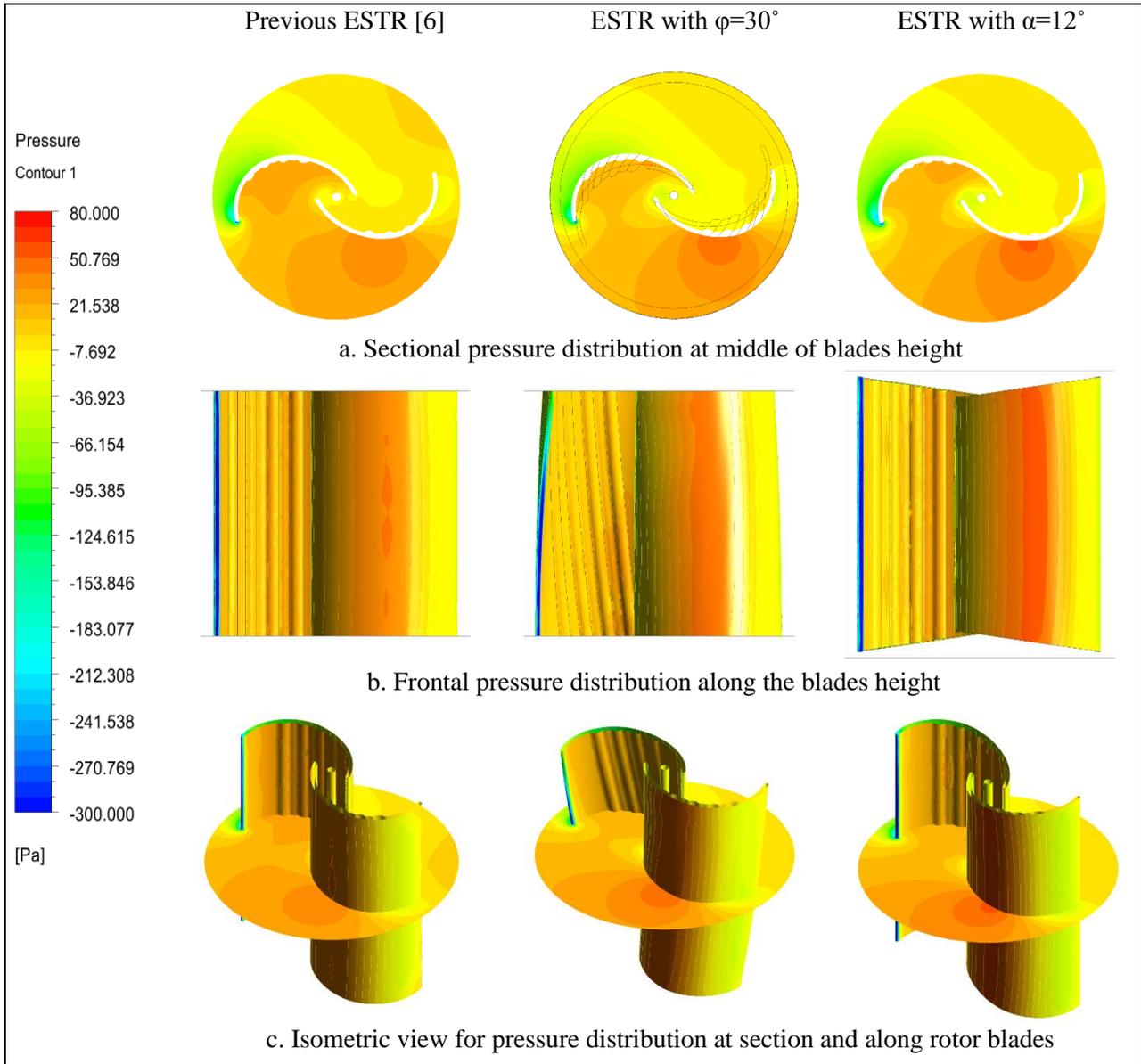


Figure 13. Pressure contours with wind speed of 6 m/s - Previous ESTR, ESTR with $\varphi=30^\circ$, and ESTR with $\alpha=12^\circ$

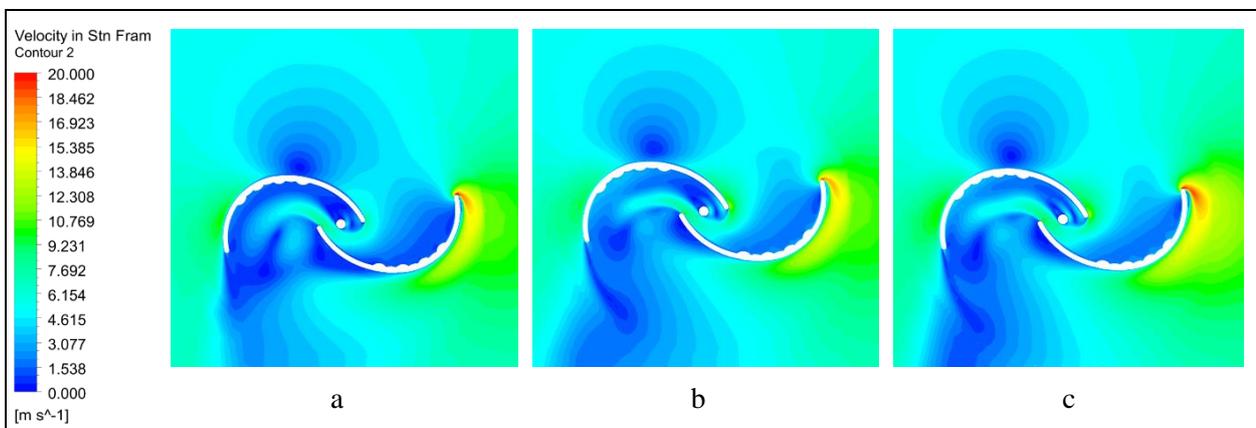


Figure 14. Velocity contours with wind speed of 6 m/s - (a) Previous ESTR, (b) ESTR with $\varphi=30^\circ$, and (c) ESTR with $\alpha=12^\circ$

4. Conclusion

In this study, a small scale elliptical Savonius wind turbine with inner surface wavy blades (ESTR) has been presented in a two configurations models, ESTR models with twist angle and ESTR models with tilt angle with a different range angles for both configurations. The performance of ESTR models were investigate by virtual computational domain using CFD of torque and the power coefficient varies with the tip speed ratio. The results show an increase in the power coefficients of present ESTR models compare to previous one. The models of ESTR with twist angle of 30° and ESTR with tilt angle of 12° have been showing a highest power coefficient. Although in all configurations show a good increase in power coefficient but there are a significant increasing in maximum power coefficient for ESTR model with $\phi=30^\circ$ which was 3.7% while the increasing reach to 14.55% at ESTR model with $\alpha=12^\circ$ at tip-speed ratio of 7. As well as, these two models provide a jump in power-coefficient for a tip-speed ratio variable values compare to previous model of ESTR.

References

- [1] K. HoeWong, W. TongChong, N. LianaSukiman, S. ChewPoh, Yui-Chuin Shiah, and Chin-TsanWang, "Performance enhancements on vertical axis wind turbines using flow augmentation systems: A review," *Renew. Sustain. Energy Rev.*, vol. 73, pp. 904–921, 2017.
- [2] Kumail Abdulkareem Hadi Al-Gburi , Firas Basim Ismail Alnaimi , Balasem A. Al-quraishi c , Ee Sann Tan , Muayad M. Maseer , "A comparative study review: The performance of Savonius-type rotors," *Materials Today: Proceedings (Elsevier)*, In Press, Available online 30 September 2021.
- [3] Djamal Hissein Didane, et al "Development and Performance Investigation of a Unique Dual-rotor Savonius-type Counter-rotating Wind Turbine" *International Journal of Integrated Engineering*, vol. 13, no. 6. pp. 89–98, 2021.
- [4] Rino Andias, Sofian Mohd, Fadhli Zulkafli, Djamal Hissein Didane "Simulation Study of Wind Turbine System for Electric Powered Vehicle " *International Journal of Integrated Engineering*, vol. 12, no. 3. pp. 76–81, 2020.
- [5] G.Y. Sim, M.A.M. Ariff, H.H. Goh, S. N. Ramli, S.Y. Sim, S.K. Chien "The Impact of the Guide Vane on the BIWT System for the Distributed Wind Generation in the Urban Area " *International Journal of Integrated Engineering*, vol. 13, no. 3. pp. 42–52, 2021.
- [6] A. Rezaeiha, H. Montazeri, and B. Blocken, "Towards optimal aerodynamic design of vertical axis wind turbines: Impact of solidity and number of blades," *Energy*, vol. 165, pp. 1129–1148, 2018.
- [7] I. Ushiyama and H. NAGAI, "Optimum design configurations and performance of Savonius rotors," *Wind Eng.*, vol. 12, no. 1, pp. 59–75, 1988.
- [8] W. A. El-Askary, A. S. Saad, A. M. AbdelSalam, and I. M. Sakr, "Investigating the performance of a twisted modified Savonius rotor," *J. Wind Eng. Ind. Aerodyn.*, vol. 182, no. August, pp. 344–355, 2018.
- [9] S. M. A. RIDHA, "Experimental And Simulation Analysis For Performance Enhancement Of Elliptical Savonius Wind Turbine By Modifying Blade Shapes," *Universiti Tun Hussein Onn Malaysia Status*, 2019.
- [10] J. VicenteAkwa, H. AntonioVielmo, and A. PriscoPetry, "A review on the performance of Savonius wind turbines," *Renew. Sustain. Energy Rev.*, vol. 16, no. 5, pp. 3054–3064, 2012.
- [11] M.H.Nasef, W.A.El-Askary, A.A.AbdEL-hamid, and H.E.Gad, "Evaluation of Savonius rotor performance: Static and dynamic studies," *J. Wind Eng. Ind. Aerodyn.*, vol. 123, no. Part A, pp. 1–11, 2013.
- [12] M. Ebrahimpour, R. Shafaghat, R. Alamian, and M. S. Shadloo, "Numerical investigation of the Savonius vertical axis wind turbine and evaluation of the effect of the overlap parameter in both horizontal and vertical directions on its performance," *Symmetry (Basel)*, vol. 11, no. 6, 2019.
- [13] S. M. AR, H. B. S. B, M. N. Nemah, B. A. Al-Quraishi, and N. Z. B. Asmuin, "Performance Evaluation Of Savonius Wind Turbine Based On A New Design Of Blade Shape," *Int. J. Mech. Eng. Technol.*, vol. 10, no. 01, pp. 837–846, 2019.
- [14] U. K. Saha, S. Thotla, and D. Maity, "Optimum design configuration of Savonius rotor through wind tunnel experiments," *J. Wind Eng. Ind. Aerodyn.*, vol. 96, no. 8–9, pp. 1359–1375, 2008.
- [15] A. Grönman, J. Backman, M. Hansen-Haug, M. Laaksonen, M. Alkki, and P. Aura, "Experimental and numerical analysis of vaned wind turbine performance and flow phenomena," *Energy*, vol. 159, pp. 827–841, 2018.

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- [16] M. Mosbahi, A. Ayadi, Y. Chouaibi, Z. Driss, and T. Tucciarelli, "Performance study of a Helical Savonius hydrokinetic turbine with a new deflector system design," *Energy Convers. Manag.*, vol. 194, no. April, pp. 55–74, 2019.
- [17] M. S. Alli and S. Jayavel, "Numerical study on performance of savonius-type vertical-axis wind turbine, with and without omnidirectional guide vane," *Lect. Notes Mech. Eng.*, pp. 449–455, 2019.
- [18] T. Yuwono, G. Sakti, F. Nur Aulia, and A. Chandra Wijaya, "Improving the performance of Savonius wind turbine by installation of a circular cylinder upstream of returning turbine blade: Improving the Performance of Savonius Wind Turbine," *Alexandria Eng. J.*, vol. 59, no. 6, pp. 4923–4932, 2020.
- [19] J. B. S. Kalluvila and B. Sreejith, "Numerical and experimental study on a modified Savonius rotor with guide blades," *Int. J. Green Energy*, vol. 15, no. 12, pp. 744–757, 2018.
- [20] M. Anbarsooz, "Aerodynamic performance of helical Savonius wind rotors with 30° and 45° twist angles: Experimental and numerical studies," *Proc. Inst. Mech. Eng. Part A J. Power Energy*, vol. 230, no. 6, pp. 523–534, 2016.
- [21] M. Tahani, A. Rabbani, A. Kasaeian, M. Mehrpooya, and M. Mirhosseini, "Design and numerical investigation of Savonius wind turbine with discharge flow directing capability," *Energy*, vol. 130, pp. 327–338, 2017.
- [22] J. H. Lee, Y. T. Lee, and H. C. Lim, "Effect of twist angle on the performance of Savonius wind turbine," *Renew. Energy*, vol. 89, pp. 231–244, 2016.
- [23] A. S. Saad, I. I. El-Sharkawy, S. Ookawara, and M. Ahmed, "Performance enhancement of twisted-bladed Savonius vertical axis wind turbines," *Energy Convers. Manag.*, vol. 209, no. December 2019, p. 112673, 2020.
- [24] U. K. Saha and M. J. Rajkumar, "On the performance analysis of Savonius rotor with twisted blades," *Renew. Energy*, vol. 31, no. 11, pp. 1776–1788, 2006.
- [25] A. Kumar and R. P. Saini, "Performance analysis of a single stage modified Savonius hydrokinetic turbine having twisted blades," *Renew. Energy*, vol. 113, pp. 461–478, 2017.
- [26] A. Damak, Z. Driss, and M. S. Abid, "Experimental investigation of helical Savonius rotor with a twist of 180°," *Renew. Energy*, vol. 52, pp. 136–142, 2013.
- [27] T. Micha Premkumar, S. Sivamani, E. Kirthees, V. Hariram, and T. Mohan, "Data set on the experimental investigations of a helical Savonius style VAWT with and without end plates," *Data Br.*, vol. 19, pp. 1925–1932, 2018.
- [28] K. S. Jeon, J. I. Jeong, J. K. Pan, and K. W. Ryu, "Effects of end plates with various shapes and sizes on helical Savonius wind turbines," *Renew. Energy*, vol. 79, no. 1, pp. 167–176, 2015.
- [29] B. Kosasih and H. Saleh Hudin, "Influence of inflow turbulence intensity on the performance of bare and diffuser-augmented micro wind turbine model," *Renew. Energy*, vol. 87, pp. 154–167, 2016.
- [30] F. R. Menter, "Two-equation eddy-viscosity turbulence models for engineering applications," *AIAA J.*, vol. 32, no. 8, pp. 1598–1605, 2008.
- [31] M. Ozen, "Mesh Metric Spectrum Quality," *Ozen Engineering, California*. [Online]. Available: https://www.ozeninc.com/wp-content/uploads/2014/11/MESHING_WORKSHOP_2014.pdf.