A Numerical Analysis on the Performance and Optimization of the Savonius Wind Turbine for Agricultural Use

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ABSTRACT

Given the state of the world nowadays, renewable energy is becoming more and more essential rendering wind turbine electricity quite important. Its shape and the fact that the Savonius vertical axis wind turbine runs at relatively low wind speeds with high torque values makes it suitable for practical uses such as that of an irrigation system in agriculture industry. This paper utilizes numerical research with Computational Fluid Dynamics (CFD) to investigate the performance of a vertical-axis wind turbine. The ANSYS CFD program was engaged to construct the simulations during the pre- and post-processing stages. Wind speed remained constant while the angular velocity was altered to enable analysis of the flow through the wind turbine. Because of its mechanical simplicity, the primary profile of a semicircle has remained a typical option for turbines that generate high torque based on drag force. The effects of using elliptical curves and the fluctuation in thickness along the profile chord were both examined in this study. Equivalently, an attempt to optimize the rotor's design was made. After the performance of a numerical simulation, a geometry consisting of simple circle arcs was developed, with a 10.9% improvement in the power coefficient, analogous to prior optimizations with more complicated geometries. The numerical results derived include the torque coefficient evolution throughout a full rotation as well as the distribution of vorticity magnitude at different rotor points.

Keywords-renewable energy; VAWT; Savonius; CFD; power coefficient; TSR

I. INTRODUCTION

The need to continue tackling global problems regarding climate change and resource consumption is critical in the current socioeconomic environment. Therefore, the main component of the proposed United Nations resolution to achieve zero net carbon emissions by 2050 is renewable energy. With the potential to cover 35% of the world's future energy needs, wind energy plays a significant part in the attempt to accomplish a sustainable future [1]. During the last year, new installations producing 19 GW of electricity have been established, bringing the total amount of wind energy generated in Europe to 255 GW and so reinforcing the continent's current efforts to meet its energy and climate goals. Despite appearing to be a respectable quantity, the produced wind energy amount falls short of the target to obtain up to 451 GW by 2030, necessitating an increase of more than 50% in the yearly wind energy production [2].

Agricultural industry has been continuously on an expansion mode and thus it can be assumed that the pollution created by generating the required energy can have a negative impact on the climate change crisis [3]. Consequently, renewable energy applications demonstrate a major potential in this sector. Given the growth of wind energy use over the past ten years, it is reasonable to draw the conclusion from an economic viewpoint that using a power source based on wind is similar to using a typical source based on fossil fuel from a cost-effective standpoint [4]. In this light, utilizing wind turbine technology efficiently to generate power would be ideal for decreasing carbon emissions in agriculture [5]. One operation that might be benefited by wind turbine usage is irrigation. That is, the required power for pumping can be reached by using vertical wind turbines under typical operating conditions [7]. Additionally, as the power comes straight from the shaft [6], there are no conversion losses in this situation as opposed to other systems, adding another advantageous technological aspect.

In general, Vertical-Axis Wind Turbines (VAWTs) [8] are more desirable than horizontal-axis turbines because they are functional and efficient with relatively modest design parameters and can be used on a smaller scale [9]. Their simpler operation and usage, compared to horizontal turbines, their ability to function in all wind directions and their easier maintenance make VAWTs more preferable. Taking into consideration the fact that developing countries are in a struggle to implement renewable energy due to technical and financial reasons [10], it would be appropriate to choose a small VAWT with a low level of technological complexity such as the Savonius one. In this direction, throughout the recent decades there have been some isolated instances where wind energy produced by a Savonius turbine type was used successfully in agriculture in developing countries such as Peru or Indonesia [11]. More recently there have been studies effectuated to implement wind energy sources to suitable regions in South Africa [12]. In comparison to the other VAWT types, the Savonius type performs better when it starts operating with lower wind speeds [13]. The profile section is made up of two semicircular profiles with an S-shaped appearance that are projected at an angle on the z-axis to improve the behavior of the turbulent flow. It has been shown that 180° is the ideal angle of twist for a two-bladed, single-stage Savonius [14]. This offers the fundamental benefit of technological simplicity in addition to its compact size.

A procedure to extract the greatest potential from a device whose movement is dependent on drag force has not yet been acknowledged by a significant group of specialists; therefore, there is a constant quest for these devices optimization based on diverse points of view [15]. One approach to solving this issue is to primarily focus on the negative torque produced and attempt to reduce it. In this regard, a few studies have used deflectors [16], barrier plates [17], or a curtain design [18], even though these may have limitations in terms of capturing all of the wind's potential energy. In addition to studying how to manipulate the flow using exterior structures, there are optimizations involving key design elements like the aforementioned aspect and overlap ratio, twist angle, and the influence that the number of stages and blades has on them [19-21]. Going into elliptical geometry, altering the blades thickness along the chord or the blade arc angle, and more recently, a blade design modeled from sand eels, can all be noted as enhancements to the section's geometry [22]. A common way in these optimization methods is to employ a genetic algorithm [23], where the inferred condition is checked using CFD during the iteration step. This process has become important and typical in experimental research concerning flow characteristics or aerodynamic analysis as an extra method of validation and a more analytical approach to streamline behavior [24].

The Savonius wind turbine flow is typically modeled as 2D flow in CFD studies, which is similar to the mid-plane flow of the rotor's turbine [25, 26]. The Savonius power performance estimation has something of an upper bound in the shape of the 2D prediction. This method is useful since it requires less computational time and resources to run the numerous CFD simulations necessary for rotor geometry optimization. In contrast to 3D analysis results [27] or even to experiments outcomes [28-29], 2D unsteady CFD simulations, typically overestimate the torque, and the peak of the torque coefficient versus tip speed ratio curve is shifted to a higher TSR.

Unsteady 2D simulations on an improved design of a traditional Savonius wind turbine were performed in this paper using the ANSYS Fluent CFD to examine the aerodynamic performance and forces acting on this type of wind turbine. Six operating points were studied for this work in order to assess the turbine flow behavior. In the future, the numerical results derived from the computational model will be validated in an experimental testing program which will be conducted in a wind tunnel.

II. METHODOLOGY

The geometry of the typical Savonius rotor has certain features when it comes to its design [30]. In order to find out the height, rotor diameter, chord of the blade and other geometric variables it is initially needed to set a core of logical concepts related to wind turbines. The principle from which the calculations begin is based on the necessary power output, where the turbine application is a good indicator to assume a certain value. Another set parameter is the power coefficient C_p which describes similarly to an efficiency factor how much power is actually harvested. According to [31] a proper value for the Savonius type is 0.15. Subsequently it is defined as:

$$C_p = \frac{P_0}{P_w} \tag{1}$$

where P_0 is the power that gets generated by the turbine and P_w the potential power of the wind [30]. They can be expressed as:

$$P_0 = T\omega \tag{2}$$

$$P_w = \frac{1}{2}\rho S V^3 \tag{3}$$

where T is the turbine torque, ω the rotational speed, ρ the air density, S the reference area (in our case, the turbine's diameter multiplied by the turbine's height), and V is the wind velocity.

Setting a constant standard value for the wind speed of 12 m/s and knowing the air density (1.22 kg/m^3), assisted the determination of the turbine swept area, and the geometric feature presented in Table I.

With the help of (2) and (3) in pursuance of improving the design-simulation process and to be able to analyze the numerical simulations results, a further formulation of C_p and with the expression for torque gets:

$$C_p = \frac{\omega R}{V} C_m \tag{4}$$

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

where C_m is the coefficient of torque and the tip speed ratio λ (TSR) is defined as above, representing the connection between the performance of a wind turbine and its aerodynamic characteristics. By having constant the radius and the wind speed, a variation of the angular velocity is needed for the power coefficient analysis. With this equation, it is possible to easily establish C_p through simulations by extracting the aerodynamic torque.

Furthermore, in order to enhance performance, an optimization study has been established. Multiple approaches are considered for this process while techniques to combine them are also under investigation. Instead of going for an implementation of a remote object in the flow and trying to manipulate the torque generation the finding of a geometry that can provide better results is examined.

As Figure 1 shows, there will be a total of 4 arcs for a blade, each with its own parameters. To remain at a stable and simple analysis of the configuration, the center of every arc is situated on the same vertical axis that contains the intersection point of the arcs and the value of the chord remains the same. For a simpler understanding the notations *x* and *y* for the horizontal and vertical distances previously discussed are used.

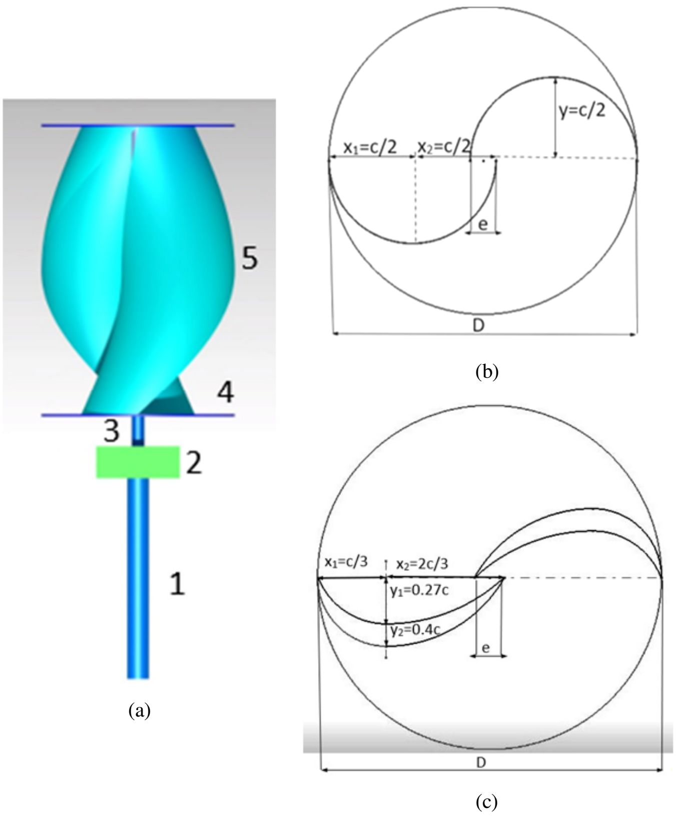


Fig. 1. Savonius 3D model, (b) baseline cross section, (c) optimized geometry cross section.

Figure 1 (a) depicts a 3D CAD model of a twist Savonius wind turbine composed of a pole (1) on which stands the permanent magnetic generator (2), which is coupled to the blades (5) and their end-plates (4) through the shaft (3).

TABLE I. GEOMETRY FEATURES OF SAVONIUS ROTOR

Parameter	Value	
	Baseline	Optimized geometry
Design Power [W]	2000	
D [m]	3	
H [m]	4.5	
c [m]	1.624	
e [m]	0.254	
x_1 [m]	0.812	0.541
x_2 [m]	0.812	1.083
y_1 [m]	0.812	0.438
y_2 [m]	0.812	0.65

As it can be noticed, for each side of the blade the *y* is equal for both arcs, so y_1 designates the upper side and y_2 the lower side. For *x*, the first type of arcs for both sides shares the same value x_1 corresponding to the first type of arc and x_2 to the second. Since the sum of x_1 and x_2 has to be the length of the chord, their ratio with the chord determines how close to the elliptical one the geometry will be. Contemplating the ratios between *x* and *y* already fixed, a distribution of a third and two thirds of the chord gives with an estimated measure of the reference angle a peak difference of seven degrees from the optimal value of 47.5°. The assessment of the optimal ratios of 0.8 for the lower side and 0.54 for the upper side requires a certain *y* value for every *x*. If by the new geometry definition, a common value of *y* for each side of the blade is established, then an uncertainty concerning to what *x* to refer when applying the certain ratios appears. For this problem a middle way solution was used, where the horizontal value for these ratios is neither x_1 nor x_2 but their average, which is the half of the chord, as shown in Figure 2 where every *x* and *y* are expressed by the length *c*. With this parameterization form, it is obvious that for the base geometry, the *x* and *y* values are all equal to the radius of a semicircle, which is equal to the half of the chord.

To check the overall flow behavior and to ensure that the numerical calculations are valid, the spatial domain must be expanded using a multiplier factor based on the rotor diameter. As shown in Figure 4, an inner domain (with the function of the rotor) and an outer domain (with the role of the stator) are specified. After being able to implement the geometry in a CAD program, the next step in the preprocessing stage is to generate the mesh (Figure 3). To achieve high quality, cell sizing criteria are employed for the interface between the inner and outer domains, as well as for the blades, with an inflation command applied to the boundary layer zone.

The cell size was related to the Reynolds number, which remained in the lower portion of the turbulent flow interval. More specifically, we set a characteristic parameter $y+$ to an essential value of 1. The cell dimension for the profile's boundary layer may be conditioned and set as the height of the first layer is 0.03 mm and for the sizing of the blades an element size of 5 mm.

To adequately analyze how the grid density can impact the results precision, three cases of number of cells (150000, 200000, and 250000 cells) have been taken into consideration. Therefore, the variation noticed between them has the order of a tenth of a percent. Moreover, given the fact that the time needed to compute the different meshes is somehow proportional to the cells number (reaching even double the time for 250000 cells compared to 150000 cells), the impact is not great enough in order to maintain the simulation efficiency regarding the computation time. A schematic overview of the entire numerical investigation procedure is shown in Figure 2.

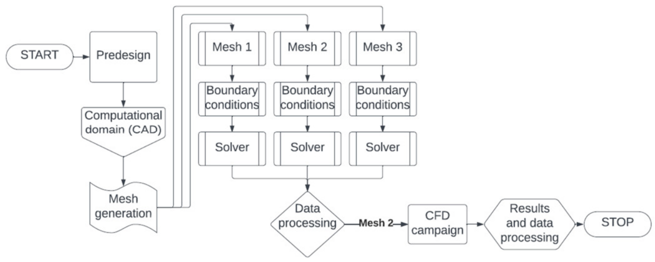


Fig. 2. Block diagram.

TABLE II. MESH STATISTICS

No.	Subdomain	No. of nodes	No. of elements	
			Tri	Quad
Mesh 1.	**Rotor**	50871	106	49603
	Stator	103718	35	102864
	TOTAL	154589	152613	
Mesh 2.	**Rotor**	51280	137	49988
	Stator	150942	22	149962
	TOTAL	202222	200109	
Mesh 3.	**Rotor**	51954	125	50664
	Stator	201544	34	200433
	TOTAL	253498	251256	

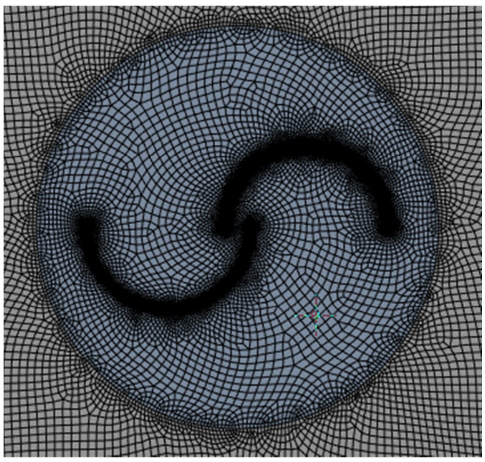


Fig. 3. Rotor's domain mesh.

It has been shown that the k-ω Shear Stress Transport (SST) turbulence model of the Savonius rotor adequately reflects the real-life phenomenon [32, 33]. Menter's model has the benefit of predicting behavior near the wall as well as away from the surface [34] by integrating the conventional models *k-ω* and *k-ϵ*. This integration is facilitated by a function that links the models by taking different values at various sections of the flow. The governing equations revolve around the kinetic energy (k) and the dissipation rate (ω). In pursuance of a converged solution, each simulation is made with a time span of ten full rotations of the rotor. In order to preserve a strong correlation between the findings and time, the numerical solution's timestep is precisely selected to allow the rotor to revolve by one angular degree during the course of one timestep. With the imposed rotor angular velocity taken into account, the necessary value for this may be calculated with ease.

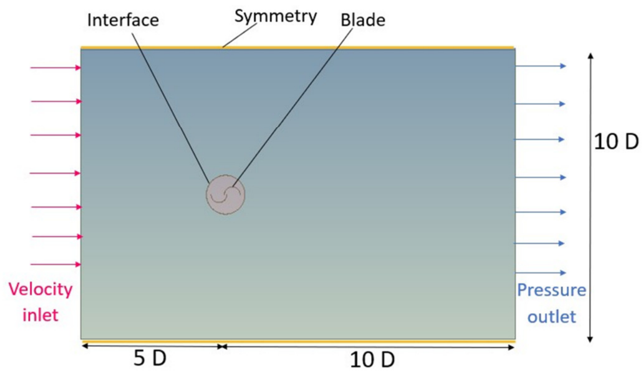


Fig. 4. Boundary conditions and outer domain features.

III. RESULTS AND DISCUSSION

A particular variation of C_m with the rotating angle θ is found after running many simulations in Ansys Fluent. Given that torque is produced during motion, both positive and negative, with the magnitude of each varying with the rotating angle, it is reasonable to assume that this type of relationship between an angle and a waveform graph—more precisely, a sine wave with two maxima and two minima with nearly equal values between them—would result. In Figure 5 the torque coefficient for both cases for the last complete 360^o revolution is represented. Vorticity magnitude is a crucial parameter in wind turbine CFD simulations that helps study and comprehend the airflow behavior around turbine blades. The local spinning of fluid particles inside a flow field is measured as vorticity. It is useful in determining the air's rotational speed as it flows through or around the blades of a wind turbine.

The Savonius wind turbine is a VAWT well-known for its adaptability to many wind conditions, including low wind speeds. Utilizing the vorticity created by the wind as it passes over the bent blades is one of the fundamental ideas underlying the Savonius turbine's functioning. In the context of a Savonius wind turbine, the strength or intensity of the vortices produced by the revolving blades is referred to as the vorticity magnitude (Figure 6). In essence, the vortices are whirling masses of air created by the blade shapes. The turbine's rotational speed, the turbine's blade size and shape, and the wind speed all have an impact on the vorticity magnitude.

(a)

(b)

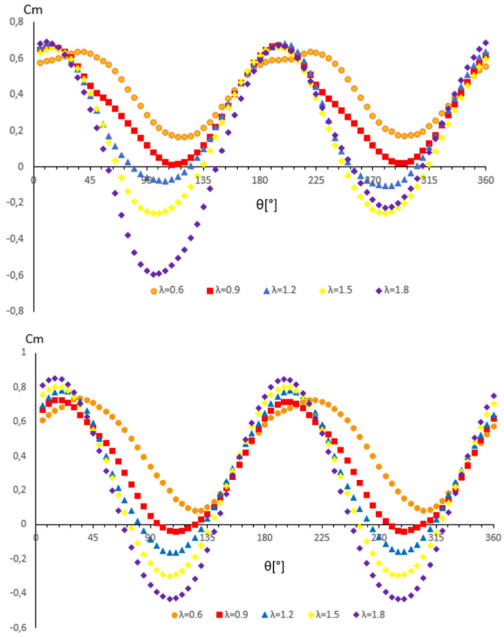
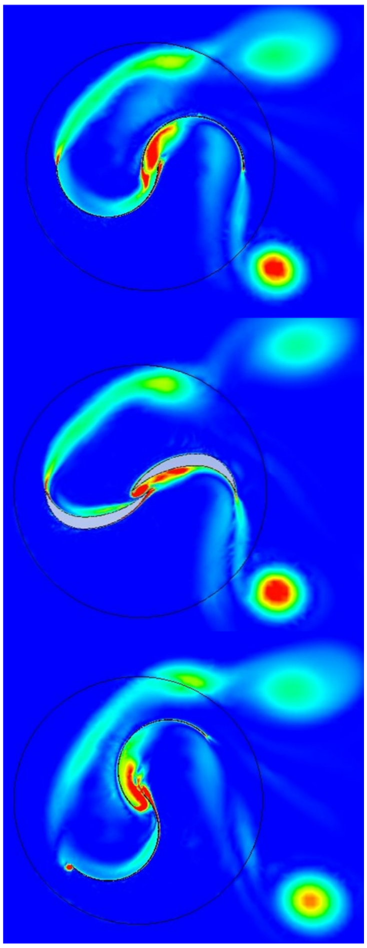


Fig. 5. The torque coefficient variation for the last complete revolution: (a) baseline, (b) optimized geometry.

(a)

(a')

(b)



(b')

(c)

(c')

(d)

(d')

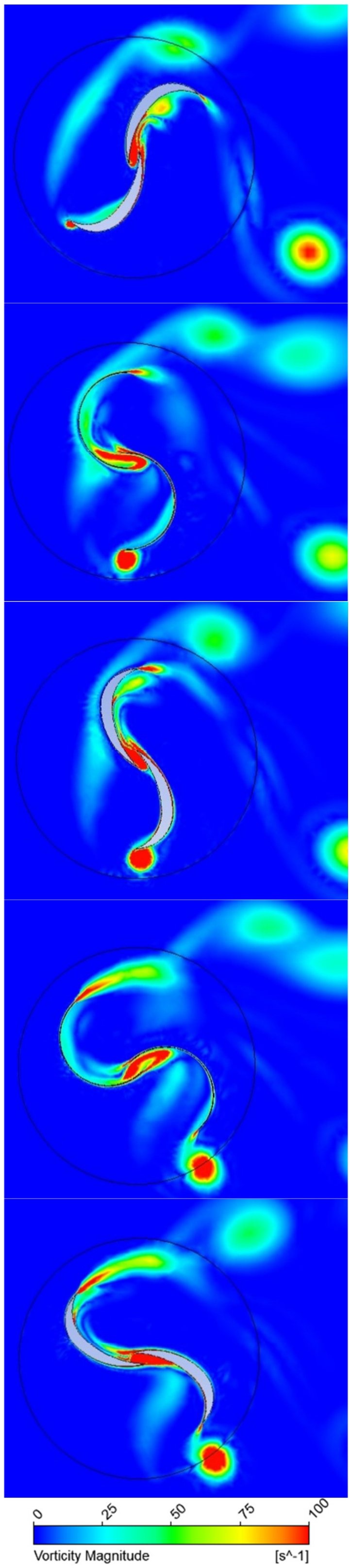


Fig. 6. Vorticity contours: case 1: (a) 0°, (b) 45°, (c) 90°, (d) 135°, case 2: (a') 0°, (b') 45°, (c') 90°, (d') 135°.

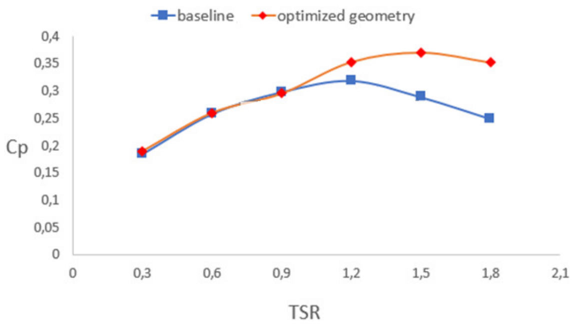


Fig. 7. Power coefficient variation.

A power coefficient (Figure 8) study is also necessary to determine how productive and suitable the model recommended for its application is. A data set of C_p and a dependence on TSR may be visualized with the help of an averaged torque coefficient and the established value of TSR for each numerical calculation. The final TSR range was set to be 0.6–1.8 in order to emphasize the nominal situations for each geometry (1.2 for the base and 1.5 for the new optimized design). These cases are emphasized when the highest values of C_p are obtained (0.319 for the base and 0.371 for the optimized design).

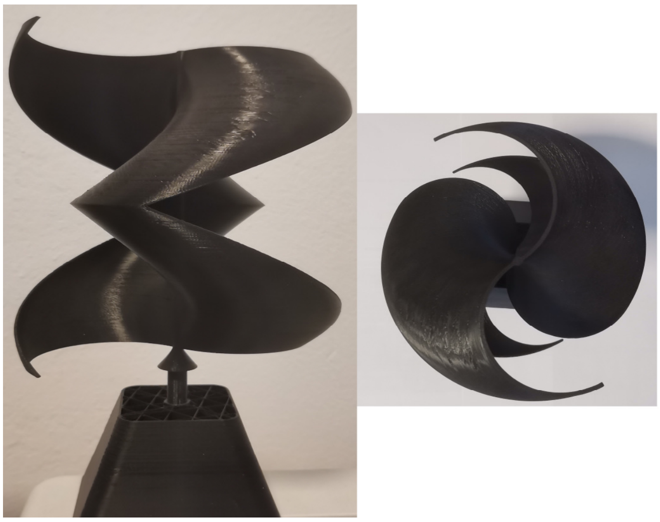


Fig. 8. 3D PLA print of the Savonius model.

IV. CONCLUSIONS

Given the dynamic nature of energy, the Savonius wind turbine has favorable traits for agricultural applications and meets the necessary performance benchmarks. By implementing a design that responds to the necessary operating conditions and by utilizing numerical simulations to observe the flow behavior, this might be examined. Moreover, this research delves deeper into the 2D optimization procedures. It thus creates a new geometry that more succinctly combines two previously proven techniques, yielding a notable improvement of 10.9% in comparison to the baseline geometry's nominal case and 28.48% in comparison to the optimized geometry's nominal case. In this sense, the next measures which will be taken to enhance and catch up to the other wind turbines' performance are straightforward.

Regarding future work, in an effort to capture the flow behavior, the beginning process for various wind speed values will be numerically investigated in both 2D and 3D. Future work will also include an experimental testing campaign which will be conducted in a wind tunnel on smaller models (Figure 8). The final models will be produced using 3D printing technology.

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REFERENCES

[1] *Future of Wind: Deployment, Investment, Technology, Grid Integration and Socio-Economic Aspects*. Abu Dhabi, United Arab Emirates: IRENA, 2019.

[2] "Wind energy in Europe: 2022 Statistics and the outlook for 2023-2027," *WindEurope*. https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2022-statistics-and-the-outlook-for-2023-2027.

[3] F. N. Tubiello *et al.*, "The Contribution of Agriculture, Forestry and other Land Use activities to Global Warming, 1990–2012," *Global Change Biology*, vol. 21, no. 7, pp. 2655–2660, 2015, https://doi.org/10.1111/gcb.12865.

[4] *Renewable Power Generation Costs in 2017*. Abu Dhabi, United Arab Emirates: IRENA, 2018.

[5] F. D. Scheaua, "Wind energy conversion within agricultural farm using vertical axis turbines of optimized SAVONIUS type," *IOP Conference Series: Earth and Environmental Science*, vol. 635, no. 1, Jan. 2021, Art. no. 012015, https://doi.org/10.1088/1755-1315/635/1/012015.

[6] I. Ushiyama and T. Pruwadi, "Development of a Simplified Wind-Powered Water Pumping System in Indonesia," *Wind Engineering*, vol. 16, no. 1, pp. 1–9, 1992.

[7] M. D'Ambrosio and M. Medaglia, "Vertical Axis Wind Turbines: History, Technology and Applications," M. S. thesis, Halmstad i Högskolan, 2010.

[8] I. Malael and V. Dragan, "Numerical and Experimental Efficiency Evaluation of a Counter-Rotating Vertical Axis Wind Turbine," *Engineering, Technology & Applied Science Research*, vol. 8, no. 4, pp. 3282–3286, Aug. 2018, https://doi.org/10.48084/etasr.2231.

[9] M. F. Basar, A. M. Norazizi, I. Mustaffa, C. T. Colin, S. N. S. Mirin, and Z. Jano, "Investigation on the Performance of a Portable Power Generation System with a Low-Cost Vertical Axis Wind Turbine," *Engineering, Technology & Applied Science Research*, vol. 11, no. 6, pp. 7809–7813, Dec. 2021, https://doi.org/10.48084/etasr.4454.

[10] I. Ushiyama and H. Nagai, "Optimum Design Configurations and Performance of Savonius Rotors," *Wind Engineering*, vol. 12, no. 1, pp. 59–75, 1988.

[11] I. Ushiyama, Y. Nakajo, Y. Nemoto, and T. Dei, "Technical Assistance to developing Countries Through Appropriate Technology," in *4th International Conference on Mechanical Engineering*, Dhaka, Bangladesh, Dec. 2001, pp. 39–51.

[12] T. S. Sithole, L. Snyman, V. R. Veeredhi, and T. Sithebe, "Implementation and Evaluation of a Low Speed and Self-Regulating Small Wind Turbine for Urban Areas in South Africa," *Engineering, Technology & Applied Science Research*, vol. 13, no. 2, pp. 10553–10558, Apr. 2023, https://doi.org/10.48084/etasr.5697.

[13] F. D. Scheaua, "Comparative Numerical Analysis on Vertical Wind Turbine Rotor Pattern of Bach and Benesh Type," *Energies*, vol. 13, no. 9, Jan. 2020, Art. no. 2311, https://doi.org/10.3390/en13092311.

[14] S. Roy and U. K. Saha, "Review on the numerical investigations into the design and development of Savonius wind rotors," *Renewable and*

Sustainable Energy Reviews, vol. 24, pp. 73–83, Aug. 2013, https://doi.org/10.1016/j.rser.2013.03.060.

[15] S. Fanel Dorel, G. Adrian Mihai, and D. Nicusor, "Review of Specific Performance Parameters of Vertical Wind Turbine Rotors Based on the SAVONIUS Type," *Energies*, vol. 14, no. 7, Jan. 2021, Art. no. 1962, https://doi.org/10.3390/en14071962.

[16] E. Kerikous and D. Thevenin, "Optimal shape and position of a thick deflector plate in front of a hydraulic Savonius turbine," *Energy*, vol. 189, Dec. 2019, Art. no. 116157, https://doi.org/10.1016/j.energy.2019.116157.

[17] M. H. Mohamed, G. Janiga, E. Pap, and D. Thevenin, "Optimization of Savonius turbines using an obstacle shielding the returning blade," *Renewable Energy*, vol. 35, no. 11, pp. 2618–2626, Nov. 2010, https://doi.org/10.1016/j.renene.2010.04.007.

[18] B. D. Altan and M. Atılgan, "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, Apr. 2010, https://doi.org/10.1016/j.renene.2009.08.025.

[19] S. Torres, A. Marulanda, M. F. Montoya, and C. Hernandez, "Geometric design optimization of a Savonius wind turbine," *Energy Conversion and Management*, vol. 262, Jun. 2022, Art. no. 115679, https://doi.org/10.1016/j.enconman.2022.115679.

[20] C. M. Chan, H. L. Bai, and D. Q. He, "Blade shape optimization of the Savonius wind turbine using a genetic algorithm," *Applied Energy*, vol. 213, pp. 148–157, Mar. 2018, https://doi.org/10.1016/j.apenergy.2018.01.029.

[21] E. Antar and M. Elkhoury, "Casing optimization of a Savonius wind turbine," *Energy Reports*, vol. 6, pp. 184–189, Feb. 2020, https://doi.org/10.1016/j.egyr.2019.08.040.

[22] Z. Zhao, Y. Zheng, X. Xu, W. Liu, and G. Hu, "Research on the improvement of the performance of savonius rotor based on numerical study," in *International Conference on Sustainable Power Generation and Supply*, Nanjing, China, Apr. 2009, pp. 1–6, https://doi.org/10.1109/SUPERGEN.2009.5348197.

[23] A. Guediri and S. Touil, "Modeling and Comparison of Fuzzy-PI and Genetic Control Algorithms for Active and Reactive Power Flow between the Stator (DFIG) and the Grid," *Engineering, Technology & Applied Science Research*, vol. 12, no. 3, pp. 8640–8645, Jun. 2022, https://doi.org/10.48084/etasr.4905.

[24] S. Meri Al Absi, A. Hasan Jabbar, S. Oudah Mezan, B. Ahmed Al-Rawi, and S. Thajeel Al_Attabi, "An experimental test of the performance enhancement of a Savonius turbine by modifying the inner surface of a blade," *Materials Today: Proceedings*, vol. 42, pp. 2233–2240, Jan. 2021, https://doi.org/10.1016/j.matpr.2020.12.309.

[25] S. ed-Din Fertahi *et al.*, "CFD performance enhancement of a low cut-in speed current Vertical Tidal Turbine through the nested hybridization of Savonius and Darrieus," *Energy Conversion and Management*, vol. 169, pp. 266–278, Aug. 2018, https://doi.org/10.1016/j.enconman.2018.05.027.

[26] O. Yaakob, Y. Ahmed, and M. Ismail, "Validation Study for Savonius Vertical Axis Marine Current Turbine Using CFD Simulation," in *6th Asia-Pacific Workshop on Marine Hydrodynamics*, Johor Bahru, Malaysia, Sep. 2012, pp. 327–332.

[27] D. M. Prabowoputra, A. R. Prabowo, S. Hadi, and J. M. Sohn, "Assessment of turbine stages and blade numbers on modified 3D Savonius hydrokinetic turbine performance using CFD analysis," *Multidiscipline Modeling in Materials and Structures*, vol. 17, no. 1, pp. 253–272, Jan. 2020, https://doi.org/10.1108/MMMS-12-2019-0224.

[28] F. Wenehenubun, A. Saputra, and H. Sutanto, "An Experimental Study on the Performance of Savonius Wind Turbines Related With The Number Of Blades," *Energy Procedia*, vol. 68, pp. 297–304, Apr. 2015, https://doi.org/10.1016/j.egypro.2015.03.259.

[29] R. Ricci, R. Romagnoli, S. Montelpare, and D. Vitali, "Experimental study on a Savonius wind rotor for street lighting systems," *Applied Energy*, vol. 161, pp. 143–152, Jan. 2016, https://doi.org/10.1016/j.apenergy.2015.10.012.

[30] B. D. Altan, M. Atilgan, and A. Ozdamar, "An experimental study on improvement of a Savonius rotor performance with curtaining," *Experimental Thermal and Fluid Science*, vol. 32, no. 8, pp. 1673–1678, Sep. 2008, https://doi.org/10.1016/j.expthermflusci.2008.06.006.

[31] J. V. Akwa, H. A. Vielmo, and A. P. Petry, "A review on the performance of Savonius wind turbines," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 5, pp. 3054–3064, Jun. 2012, https://doi.org/10.1016/j.rser.2012.02.056.

[32] A. Al-Faruk and A. Sharifian, "Flow Field and Performance Study of Vertical Axis Savonius Type SST Wind Turbine," *Energy Procedia*, vol. 110, pp. 235–242, Mar. 2017, https://doi.org/10.1016/j.egypro.2017.03.133.

[33] C. M. Shashikumar, V. Hindasageri, and V. Madav, "CFD investigation of unsteady three-dimensional savonius hydrokinetic turbine in irrigation channel with varying positions for hydro power application," *AIP Conference Proceedings*, vol. 2316, no. 1, Feb. 2021, Art. no. 030028, https://doi.org/10.1063/5.0036472.

[34] F. R. Menter, "Review of the shear-stress transport turbulence model experience from an industrial perspective," *International Journal of Computational Fluid Dynamics*, vol. 23, no. 4, pp. 305–316, Jan. 2009, https://doi.org/10.1080/10618560902773387.

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