XLVI CILAMCE
VITÓRIA - ES - BRAZIL - 2025
XLVI IBERO-LATIN AMERICAN CONGRESS ON COMPUTATIONAL METHODS IN ENGENEERING

Design and Evaluation of Savonius Wind Turbine Models in a Wind Tunnel

Anderson G. Girardi[1], Felipe P. Mariano[1], Andreia A. Nascimento[1]

[1]*Escola de Engenharias Elétrica, Mecânica e de Computação, Universidade Federal de Goiás*
Av. Esperança, s/n, Campus Samambaia, Al. Ingá, Edificio: B5 Engenharia Mecânica, CEP: 74.690-900, Goiânia, Goiás, Brasil
andersongomes@ufg.br, fpmariano@ufg.br, aanascimento@ufg.br

Abstract. To enhance understanding of the conversion of wind kinetic energy into mechanical work, this study presents the design and construction of vertical-axis Savonius wind turbine models for educational use in a wind tunnel. The work emphasizes the use of low-cost materials and a simplified manufacturing process. Two turbine models with distinct configurations were developed. The first model was constructed using PVC pipes, featuring overlapping blades, a single stage, and a defined central shaft. The second model was fabricated from acrylic, with non-overlapping blades, a two-stage configuration, and no apparent central shaft; the blades are mounted on acrylic disks, which in turn hold shaft tips that connect to either a torque measurement device or an electric generator. The two-stage design of the second model enables automatic startup of rotation, and the absence of a central shaft reduces the overall weight of the turbine, although it poses challenges for balancing. Rotational speed measurements were performed using a tachometer, while torque was measured using a custom-built static torque meter. The results include the tip speed ratio relative to wind speed and the torque coefficient, i.e., the efficiency curves of each wind turbine model. These are compared with results reported in the literature.

Keywords: Savonius Wind Turbine, Wind Tunnel, Wind Turbine Efficiency Curve.

1 Introduction

The growing focus on sustainability in the global context has driven initiatives aimed at energy transition and environmental education, especially in the framework of the United Nations Sustainable Development Goals (SDGs). Among these, SDG 7 stands out, which seeks to ensure access to clean and affordable energy, and SDG 4, which addresses the promotion of quality education. In this scenario, wind energy emerges not only as a viable and renewable alternative for electricity generation but also as an effective pedagogical tool for teaching applied sciences and engineering.

Wind turbines are devices that convert the kinetic energy of the wind into useful energy and are generally classified into two types: horizontal-axis wind turbines (HAWT) and vertical-axis wind turbines (VAWT. HAWTs are commonly employed in large-scale installations due to their high efficiency in locations with constant and unidirectional wind. VAWTs, although less efficient in absolute terms, offer important advantages such as constructive simplicity, robustness, low cost, and the ability to operate with wind from any direction, making them ideal for urban use and educational applications.

Among vertical-axis models, the Savonius turbine stands out for its efficient performance at low wind speeds, ease of manufacturing and maintenance, and practical application in experimental and academic contexts. These characteristics favor its use as a didactic resource, allowing the construction of functional prototypes with accessible materials and simple tools.

In addition to educational use, several studies have highlighted the potential of Savonius turbines for distributed energy generation, especially in regions with infrastructure restrictions. An example is the work of Menet [1], which presents the development of a complete wind generator based on the Savonius rotor, validating its efficiency and applicability in local electric generation systems.

According to the review conducted by Mohammed et al. [2], Savonius turbines combine features such as good starting performance, low noise level, and moderate angular velocity, contributing to component durability. However, the geometric arrangement of the blades strongly influences the overall system performance, directly affecting the generated torque and aerodynamic efficiency

To address these challenges, recent research has sought to improve blade geometry and explore new constructive configurations. In one such study, Bouzaher [3] analyzed the use of flexible blades capable of changing shape during rotation. This approach demonstrated significant torque gains—over 100% in certain conditions—although excessive deformation may compromise the turbine's self-starting capability.

Other authors, such as Hosseini et al. [4] and Mu et al. [5], proposed twisting the blades into a helical shape, altering the flow along the turbine profile. Results indicated that this modification eliminates reverse torque and reduces static torque variation, improving performance during startup. Such advancements point toward a trend of developing Savonius turbines with better dynamic response and greater adaptability to variable wind conditions.

Complementing this line of investigation, Kumar et al. [6] explored various constructive strategies, such as multiple stages, deflectors, and adjustments to blade overlap ratio. Using numerical simulations and comparative analyses, the authors identified relevant gains in torque and power, reinforcing the potential of these turbines for urban applications and didactic experimentation.

Given this context, the present work introduces the development of two experimental models of vertical-axis Savonius turbines, focusing on their application in educational and laboratory environments, particularly in wind tunnels. The projects prioritize the use of low-cost materials and accessible manufacturing methods, enabling replication in academic contexts with limited resources. The models differ in geometry and structure, allowing for comparative analysis of their performance characteristics. Measurements of rotational speed, torque, and relative efficiency were conducted, and the results are discussed in light of the literature, contributing to the advancement of understanding Savonius turbine behavior on a small scale and their role in teaching sustainable technologies.

2 Material and Method

2.1 Experimental Model

This experimental study was conducted with the objective of developing and comparing two models of Savonius-type wind turbines, focusing on their didactic applicability in wind tunnels. Both models were designed with accessible and low-cost materials, allowing replication in academic environments with limited infrastructure, [7].

The first model (SV1) was built from PVC pipes cut longitudinally to form semicylindrical blades. The blades were assembled with an angular overlap of approximately 20° around a rigid metallic central shaft, Figure 1(a). This configuration resulted in a single-stage model with a visible shaft, fixed to a wooden base supported by simple bearings. All components were assembled using screws, washers, and nuts, prioritizing a robust and easily dismountable structure.



(a) SV1. (b) SV2.

Figure 1. turbine modes

The second model (SV2), shown in Figure 1(b), was developed using 3.0 mm acrylic plates laser-cut into circular shapes with an "S"-shaped central recess into which the turbine blade was fixed (these are the bases of the turbine stages. The blades were made of straight-cut acrylic, bonded to the bases with Sinteglas S-320 adhesive

between the circular plates. The upper and lower bases were made of 5.0 mm acrylic and fixed to the model using epoxy resin. Each stage was assembled without overlap between stages.

The principal parameters of Sv1 and Sv2, along with their corresponding values and units, are summarized in Tables 1 and 2. Additionally, the air density considered in this study is $\rho = 1.166$, kg/m^3

Table 1. Constants for SV1 turbine

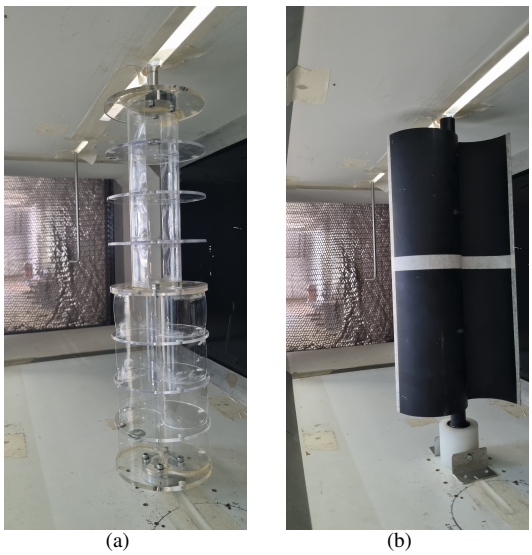
Constant	Symbol	Value
Pulley radius (m)	r	0.010
Swept area of blades (m^2)	A	0.059
Rotor radius (m)	R	0.080
Rotor diameter (m)	D	0.16
Rotor height (m)	H	0.368

Table 2. Constants for SV2 turbine

Constant	Symbol	Value
Pulley radius(m)	r	0.025
Swept area of blades (m^2)	A	0.04
Rotor radius (m)	R	0.050
Rotor diameter (m)	D	0.100
Rotor height (m)	H	0.400

At the end disks, metallic tips were attached, which were used in the torque measurement system and with a tachometer(Instrutherm TD-813). This configuration eliminated the need for a continuous central shaft, contributing to the reduction of the overall mass of the assembly, although it required greater attention to static balancing.

The tests were carried out in an open-circuit wind tunnel, Fig. 3(a), item 1, with a rectangular test section measuring 0.46m $\times$ 0.46m $\times$ 1.20m and controllable airflow speeds of 3.0 m/s, 4.0 m/s, 5.0 m/s, 6.0 m/s, and 7.0 m/s. Due to the simple and fragile construction of the turbines, the experiments were restricted to safe operating conditions, with the wind tunnel's minimum reliable speed of 3.0 m/s preventing measurements below this threshold. The experimental trials were performed individually for each model, which was positioned at the center of the test section, with the turbine axis arranged perpendicular to the airflow direction, as shown in Fig. 2.



(a) (b)

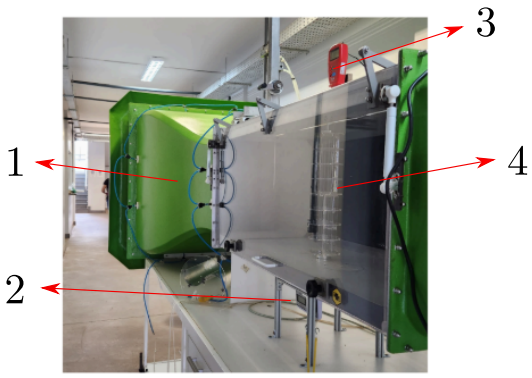
Figure 2. Savonius Turbines used in experimentals (a) SV1 and (b) SV2 models.

The rotational speed measurements for the models were taken using a digital tachometer, Fig. 3(a), item 3) positioned at the upper end of the turbine shaft. To determine torque, a static torque meter was developed based on the principle of the Prony brake, [8], Fig. 3(b).

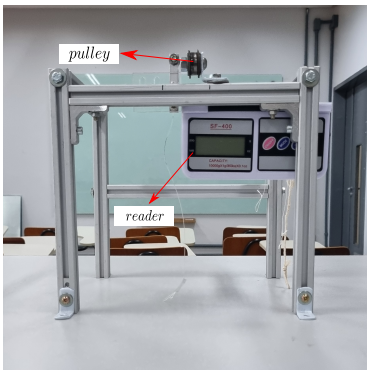
2.2 Mathematical Model

To analyze the performance of the developed Savonius turbine models, eq. (1) - eq. (3) were applied. eq. (1) allows for the calculation of the blade tip speed ratio (λ):

$$\lambda = \frac{R \cdot \omega}{V} \tag{1}$$



(a) (1) Wind tunnel, (2) Torque meter, (3) Tachometer, (4) Turbine model



(b) Torque meter.

Figure 3. Experimental bench

where ω is the angular velocity (rad/s) and V is the wind speed (m/s).

The torque coefficient can be obtained from eq. (2):

$$C_T = \frac{T}{\frac{1}{2}\rho A R V^2} \tag{2}$$

where T represents the generated torque (N·m) and V is the wind speed (m/s). These parameters enable comparative analysis between the models in terms of mechanical performance and relative efficiency.

The power coefficient C_p, eq. (3), is obtained from the ratio between the mechanical power P_{mec} extracted by the turbine and the wind's kinetic power P_{wind}

$$C_P = \frac{P_{mec}}{P_{wind}} = \frac{T\omega}{\frac{1}{2}\rho A V^3} \tag{3}$$

3 Results and Discussion

This section presents and analyzes the results obtained from the wind tunnel tests carried out with the two Savonius turbine models (SV1 and SV2. The experimental data include measurements of rotational speed, torque, and wind speed, from which the power coefficient C_P and the torque coefficient C_T were calculated as functions of the tip speed ratio λ.

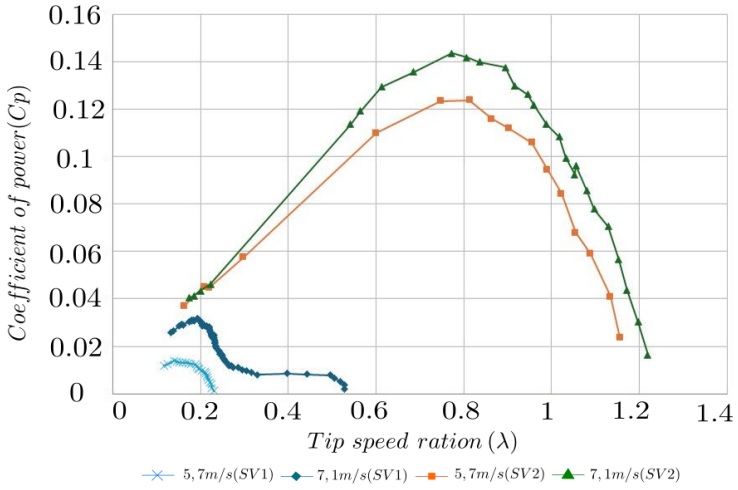


Figure 4. Power coefficient.

Figure 4 shows the significant differences between the SV1 and SV2 Savonius turbines. SV1 presented maximum C_P values close to 0.03 for a wind speed of 7.1 m/s and about 0.025 for 5.7 m/s, with the peak occurring at low tip speed ratio values, i.e., $\lambda \approx 0.15$ - 0.25. This behavior is characteristic of high-drag rotors. In contrast, SV2 achieved considerably superior performance, reaching a maximum C_P of approximately 0.145 at 7.1 m/s and 0.123 at 5.7 m/s, with the peak occurring at $\lambda \approx 0.8$, closer to the expected range for optimized Savonius turbines. These results indicate that the two-stage design and absence of a central shaft in SV2 improve aerodynamic efficiency and energy conversion.

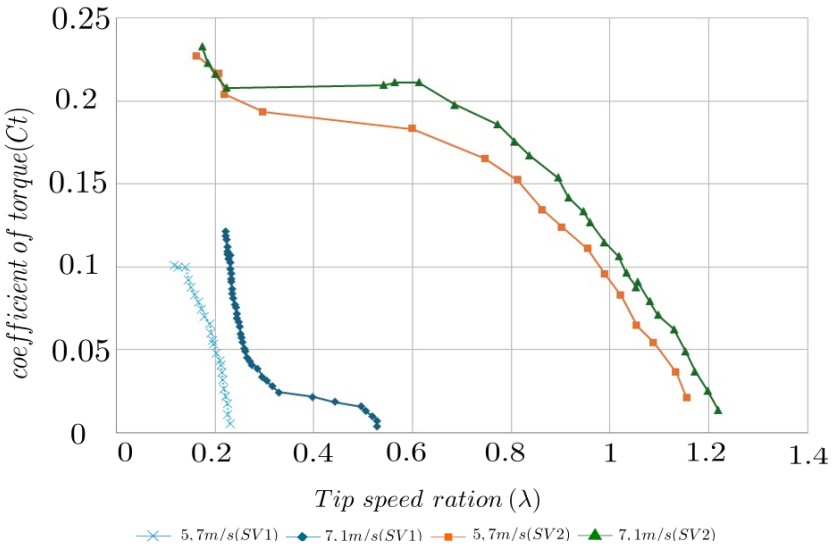


Figure 5. Torque coefficient

Figure 5 shows that SV2 has higher initial torque coefficient values, reaching about 0.23 at 5.1 m/s and 0.225 at 7.1 m/s, remaining relatively constant up to $\lambda \approx 0.5$, which provides good startup and stable acceleration. In contrast, SV1 shows lower maximum torque values, between 0.10–0.11, with a sharp drop just after $\lambda \approx 0.15$. This demonstrates its difficulty in maintaining force as rotation speed increases.

This difference suggests that SV2 has a greater ability to overcome initial inertia and operate efficiently over a wider range of rotational speeds, whereas SV1 is more limited, especially under lower wind intensity conditions.

4 Conclusion

The results obtained in this study highlight marked differences in the performance of the two experimental Savonius turbine models evaluated. The SV2 model, built in acrylic, with a two-stage configuration, non-overlapping blades, and no central shaft, showed higher power and torque coefficients compared to the SV1 model, built in PVC, with a single stage, overlapping blades, and a defined central shaft.

SV2 reached maximum C_P values of approximately 0.145 and initialC_T values around 0.23, demonstrating better wind energy utilization, more efficient startup, and stable operation over a wider tip speed ratio range.

In contrast, SV1 presented lower coefficients, with a C_P peak below 0.03 and a rapid torque drop for $\lambda > 0.20$, indicating limitations in energy conversion and in sustaining motion under higher rotational conditions. These differences were attributed to constructive characteristics, which directly influence aerodynamics, moment of inertia, and mechanical losses of each model.

This work achieved its goal of developing low-cost, easy-to-manufacture prototypes suitable for use in educational and laboratory environments. In addition, to enabling replication in academic contexts with limited resources, the models allowed comparative analysis of geometries and configurations, contributing to the understanding of small-scale Savonius turbine behavior and reinforcing their potential as didactic tools for teaching sustainable technologies.

Acknowledgements. The authors express their gratitude to Eletrobras, the Research and Technological Development Program (P&D) of ANEEL, the Center of Excellence in Hydrogen and Sustainable Energy Technologies (CEHTES), for institutional support and FAPEG and FUNAPE for financial support, which made this work possi-

ble.

Authorship statement. The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work, and that all material that has been herein included as part of the present paper is either the property (and authorship) of the authors, or has the permission of the owners to be included here.

References

[1] J.-L. Menet. A double-step savonius rotor for local production of electricity: a design study. *Renewable Energy*, vol. 29, n. 11, pp. 1843–1862, 2004.
[2] I. Mohammed, S. Shaaban, Z. Abdulhadi, and J. Hassan. Performance of a savonius vertical axis wind turbine installed on a forward facing step. *Canadian Journal of Mechanical Engineering*, 2023.
[3] M. T. Bouzaher. Effect of flexible blades on the savonius wind turbine performance. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 44, pp. 16, 2022.
[4] M. Hosseini, A. Kianifar, M. A. Jokar, F. Aliyari, M. Chamani, and S. M. Ghasemi. Enhancing the starting characteristics of a savonius wind turbine by modifying the shape of the blades. *Energies*, vol. 15, n. 18, pp. 6661, 2022.
[5] Z. Mu, G. Tong, Z. Xiao, Q. Deng, F. Feng, Y. Li, and G. Van Arne. Study on aerodynamic characteristics of a savonius wind turbine with a modified blade. *Energies*, vol. 15, n. 18, pp. 6661, 2022.
[6] M. Kumar, R. Singh, and D. Mehta. Investigation of performance enhancements of savonius wind turbines through additional designs. *Processes*, vol. 11, n. 5, pp. 1473, 2023.
[7] J. B. Barlow, W. H. R. Jr., and A. Pope. *Low speed wind tunnel testing*. John Wiley & Sons, New York, 3 edition, 1999.
[8] S. Gudmundsson. Chapter 7 - selecting the powerplant. In S. Gudmundsson, ed, *General Aviation Aircraft Design (Second Edition)*, pp. 197–255. Butterworth-Heinemann, second edition edition, 2022.