CONSTRUCTION OF A SAVONIUS WIND TURBINE AND ITS PERFORMANCE EVALUATION

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Abstract. *This paper deals with the performance analysis of a Savonius wind turbine. The rotor was built according to key characteristics, such as number and spacing of blades, number of stages, aspect ratio, use of end plates and central shaft, as pointed by the literature. Field tests were performed at the Ipiranga Pontal beach site, in the city of Linhares, Espírito Santo. Performance was assessed through the calculation of the power calculation coefficient (Cp), which expresses the ratio of power extracted by the turbine to the total contained in the wind. The maximum Cp value obtained was 0.285, which is in agreement with computer simulations and wind tunnel experiments found in the literature.*

Keywords*: Wind Turbine. Savonius. Performance evaluation.*

1 INTRODUCTION

Despite its geographic position near the Equator, with intense winds, the share of wind energy in the Brazilian energy matrix is small in relation to other sources, according to the Brazilian National Electric Energy Agency (ANEEL, 2015).

In view of the possible water crisis and instability in fuel prices, the use of wind energy would be a preventive option to reduce dependence on traditional energy sources, reduce pollution and keep electricity price stable, especially in a country where most of the electricity production occurs from hydroelectric and thermal power plants such as Brazil.

Micro generation from wind sources is an interesting option for the use of the available potential, so the present work addresses the use of a Savonius wind turbine. This kind of turbine has simple construction, requires lower wind speeds, has a high starting torque and allows adjustments to its design depending on the application. The present work will assess the performance of an experimental Savonius rotor through field tests.

2 THEORETICAL BACKGROUND

The wind turbine is a mechanism that transforms the kinetic energy of an air flow into mechanical energy through aerodynamic forces using parallel and/or perpendicular components depending on the configuration of the rotor (Hansen, 2008).

Two of the best known types of vertical axis turbines are the Darrieus and Savonius models. In the Darrieus turbine (Fig. 1a) developed and patented by Georges Jean Marie Darrieus in 1931, wind forces act similarly as in horizontal axial turbines with high tip-speed ratios; its blades, however, have complex constructive features. The Savonius turbine (Fig. 1b), with semicircular profiled blades, was developed and patented by Sigurd Johannes Savonius (1930). Its movement starts with low wind velocities (3 m/s), which makes it suitable to be used as a starting system for Darrieus systems (Fig. 1c) (Silva, 2011; Nunes Junior, 2008). The main advantage of vertical wind turbines over the horizontal type is that there is no need to align the turbine with the wind direction, which reduces manufacturing and installation costs, making them more accessible, especially for small, micro generation systems (Silva, 2011).

The main factors that influence the performance and consequently the power supplied by a wind turbine are wind speed, rotor area (flow cross-section) and power coefficient, which depends on the rotor format (Menet, 2004). The power supplied by the wind to the turbine can be determined by equation (1):

$$\boldsymbol{P_{turbine} = C_p \frac{1}{2} \rho A V^3} \tag{1}$$

Where C_p is the power coefficient (electric power to wind power ratio), ρ is the air density, A is the rotor area and V is the wind speed. Another important parameter for rotor performance is the rotor tip-speed ratio (λ), which is the ratio of peripheral velocity (U) to wind speed (Menet, 2004).

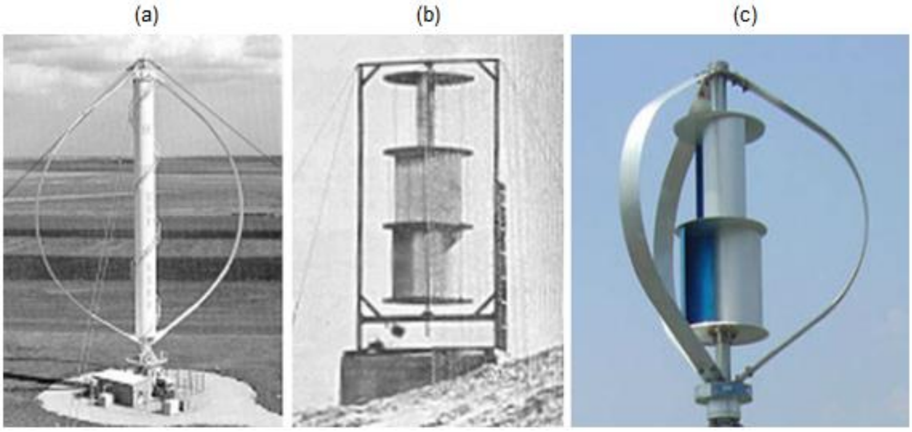

Figure 1: Examples of vertical axis wind turbines: Darrieus radial turbine (a); Savonius radial wind turbine (b); and mixed Darrieus-Savonius radial turbine (c) (Marques, 2004; Akwa 2014).

According to Betz law, the maximum theoretical value of C_p is 0.59 but actual values are around 0.32 (Saha, Thoyla and Maity, 2008; Akwa, 2014). The power coefficient for the Savonius turbine is given by equation (2) (Menet, 2004), where ω is the turbine angular velocity, *V* is the wind velocity and *R* is the rotor radius.

$$\boldsymbol{C_p = f(\lambda) = -0,36560 * \left(\frac{\omega R}{V}\right)^2 + 0,6505 * \left(\frac{\omega R}{V}\right)} \quad (2)$$

Despite its simple construction, various parameters influence the performance of the Savonius rotor, as shown in Fig. 2, such as the aspect ratio, number of blades, number of stages, end plates, and blades position in relation to the turbine axis. As pointed by Akwa (2010) the influence of these features have been extensively studied by the literature, with some findings presented here.

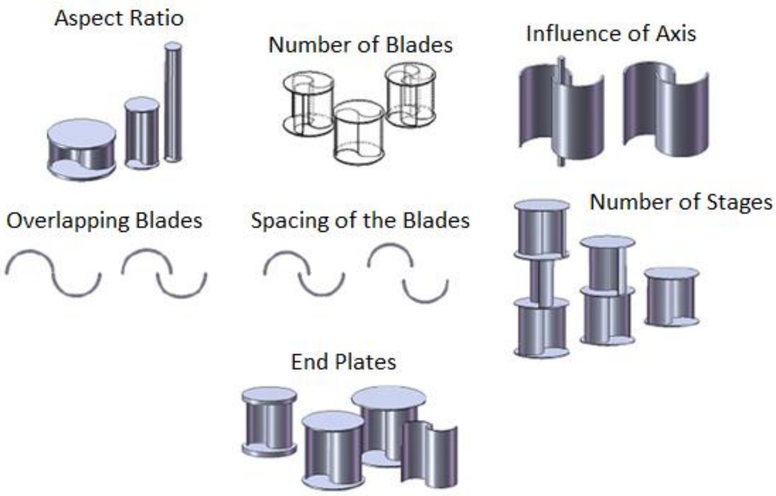

Figure 2: Construction features for Savonius rotors. (Adapted from Akwa, 2010).

For electric power generation, an aspect ratio (which is the ratio of the impeller height to its diameter) around 4 is preferred, as it allows for higher angular speeds (Menet, 2004; Vance, 1973).

The use of end plates enhance the performance of the wind generator, allowing for higher values of Cp, as shown in Fig. 3, where rotors with and without end plates are compared. These accessories prevent the air from escaping through the upper and lower ends of the rotor blades. Fujisawa (1992) and Menet (2004) recommend end plates with a diameter 10% higher than the rotor.

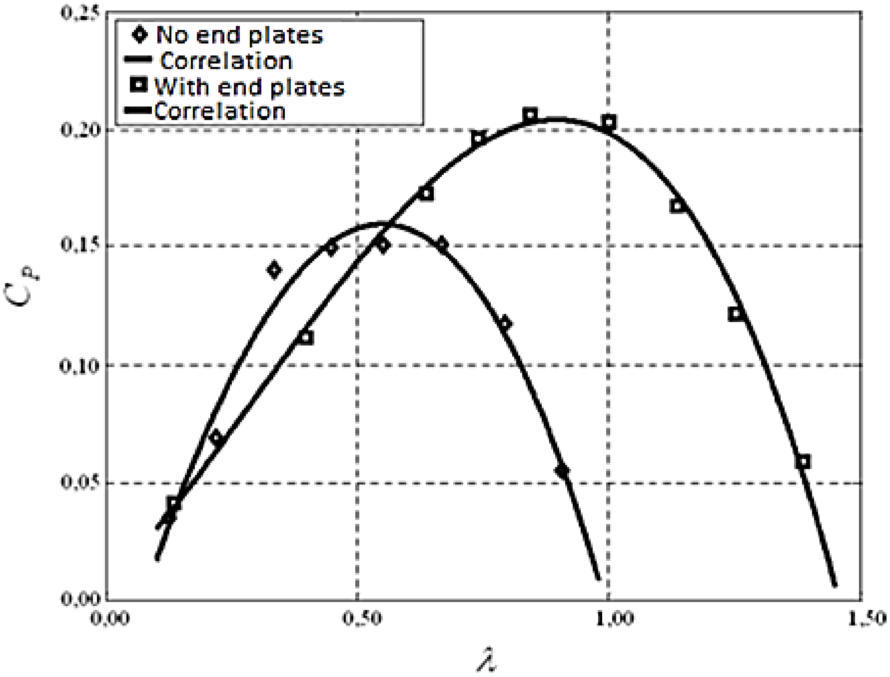

Figure 3: Influence of end plates on the rotor performance: power coefficient (Cp) as a function of tip-speed ratio (λ) for rotors with and without end plates. (Adapted from Akwa, 2010)

The literature either recommends that the blades be assembled with no gap near the axis line or with an overlap, with higher values of Cp obtained with an overlap ratio (ratio of blades gap to rotor diameter) between 15 and 30% (Fujisawa 1992, Saha, 2008). This gap allows for an air flow between the blades, reducing drag. However, when a central shaft is used for stiffness reasons, the value of Cp might be compromised (Kamoji, 2009).

According to the tests made by Saha, Thoyla and Maity (2008) (Fig. 4), the number of stages on a Savonius turbine has a direct influence on its performance, with the combination of two stages and two blades allowing for higher Cp values. Two-stage rotors developed a more constant torque curve compared to single stage models, and three or more rotors presented lower performance due to higher inertia. Similarly, rotors with two blades had better performance than rotors with three blades – which produced higher turbulence levels and lower angular velocities.

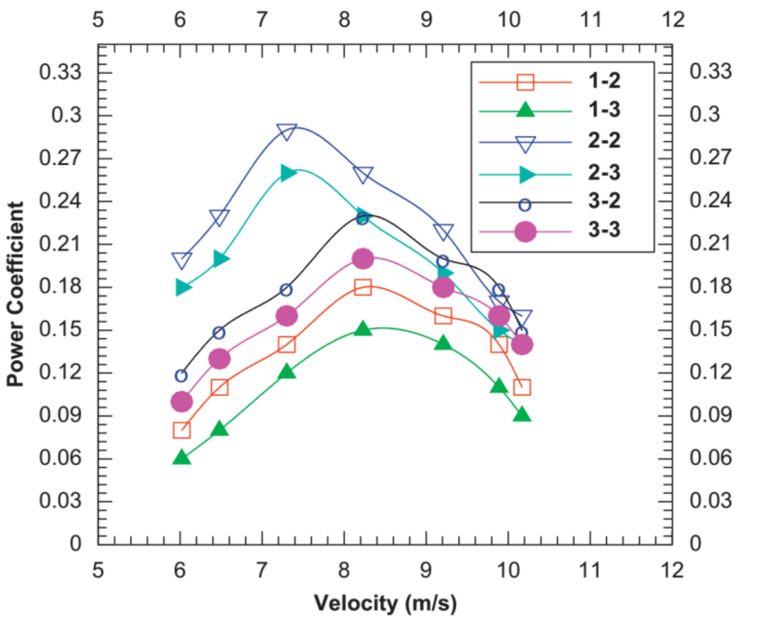

Figure 4: Variation of power coefficient with free stream wind velocity for different semicircular Savonius rotors, where *1-2* refers to 1 stage, 2 blades; *1-3* to one stage, three blades; *2-2* to two stages, two blades, *2-3* to two stages, three blades; *3-2* to three stages, two blades; *3-3* to three stages, tree blades. (Adapted from Saha, Thoyla and Maity, 2008)

3 METHODOLOGY

As the purpose of the present work is to assess the performance of an experimental Savonius rotor through field tests, the first step was the definition of the construction characteristics of the turbine. Aspect ratio, blades overlap, the use of end plates and number of stages were defined following to the literature recomendations presented in section 2. The chosen configuration was a two-stage, two semi-circular blades assembly, with endplates and no central shaft.

The intended power generation was set at 20 W, and from Equation 1, the projected area of the blades was calculated for a given wind velocity, air density and power coefficient. The diameter of the rotor was calculated by Eq. 3 (Fujisawa, 1992; Menet, 2004; Kamoji, 2009):

$$\boldsymbol{d} = \sqrt{\frac{\boldsymbol{Rotor\ area}}{\mathbf{13{,}69}}} \tag{3}$$

The turbine prototype was coupled to a mounting structure and was subjected to field tests in Ipiranga Pontal district, located in the city of Linhares, state of Espirito Santo, Brazil. Rotor frequency and wind speed were measured via an Assize AS 528 speedometer and a Lutron AM-4202 anemometer. In order to avoid the influence of variable wind speeds on turbine performance measurements (Mojola, 1985), 111 measurements were taken in June 8, 2015, between 14:30 and 18:00 h, period of the day where the highest wind speeds are observed (Silva, 2009).

4 RESULTS AND DISCUSSIONS

The rotor projected area was 0.92 m², based on the intended power output. The blades are the main components of the turbine structure. All dimensions were referenced to the blade diameter. The projected area would require a blade diameter of 0.259 m, but a value of 0.25 m was adopted. Blades overlap followed Fujisawa (1992) and rotor diameter is 462.5 mm. Rotor height is 1850 mm, corresponding to four times the rotor diameter (Menet, 2004). Endplate diameter is 10% higher than the blades diameter, 508.75 mm. The number of stages is 2, with 2 blades (Saha, Thoyla and Maity, 2008). The height of the blades is half the rotor height. Both rotor extremities are connected to two SAE 1020 steel rods by roller bearings. The rods are attached to a wood stand. The use of a central shaft was avoided, as it would lower C_p, compromising rotor performance (Kamoji, 2009), so the endplates also served as a structural reinforcement. Figure 3a shows a schematic diagram of the turbine and Fig. 3b shows the assembled turbine, already mounted for testing. Table 1 lists the material used for the rotor construction.

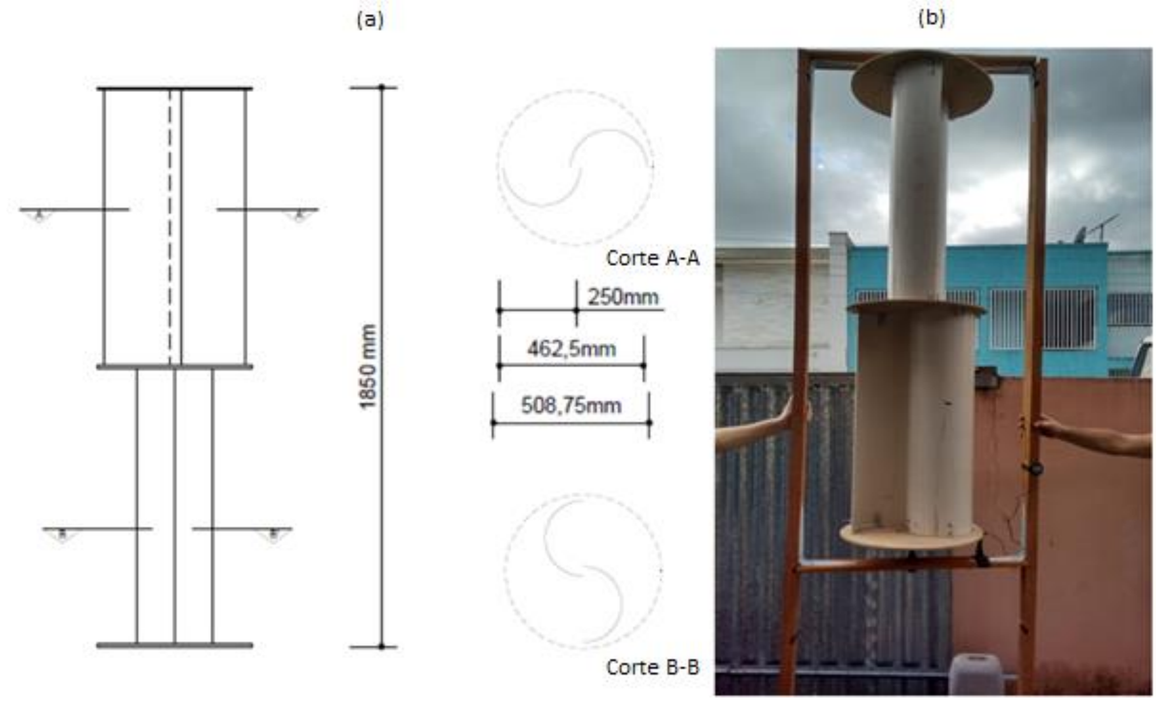

Figure 3: (a) rotor schematic; (b) assembled rotor.

Table 1: Components used for the rotor construction.

Component	Material used for construction
Blades	PVC Pipe
End Plates	MDF
Shafts	Steel SAE 1020
Plain Bearings	Flanged Cast Iron
Bearings	Shielded
Gussets	Precast Furnishings
Fixing Structure	Wood

The turbine prototype was coupled to a mounting structure and underwent field tests in the Ipiranga Pontal district, located in Linhares, Espirito Santo State, Brazil. The rotor was placed on the beach, where it was possible to measure different wind speeds. Rotor speed and wind speed were measured simultaneously.

Figure 4 shows the variation of (C_p) with wind speed, obtained with measured data and Eq. 2. The highest values of C_p were obtained with wind speeds between 6 and 7 m/s, where C_p remained almost constant. Maximum C_p was 0.285. Results shows a similar trend when compared to results from Saha, Thoyla and Maity (2008) – in his study, a similar turbine (2 stages, 2 blades) attained a maximum C_p of 0.29, for a wind speed of 7.3 m/s. Rogowski and Maroński (2015) performed a computer fluid dynamics (CFD) simulation of a two-stage Savonius turbine without central shaft and compared the results to wind tunnel measurements, with maximum values of C_p of 0.25 and 0.245, respectively.

As no central shaft was used, some imbalance was observed in the center of the turbine, which might have affected performance results, though the stiffness of the whole assembly was guaranteed by the endplates. Wenehenubun et al (2015) performed a computer fluid dynamics (CFD) simulation of a two-stage Savonius turbine with a central shaft and found maximum a C_p of less than 0.03, which validates the configuration used in the present work.

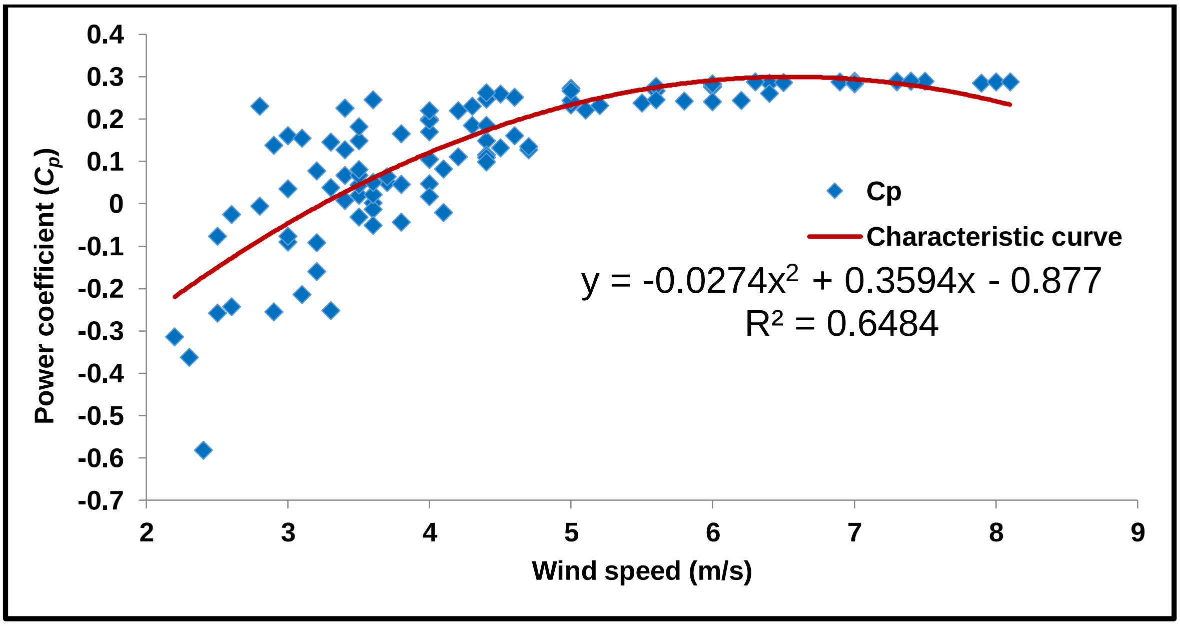

Figure 4: Power coefficient characteristic curve of the proposed turbine, related to wind speed.

5 CONCLUSION

The present work assessed the performance of a Savonius wind turbine. Specific turbine building characteristics were chosen according to the literature. Field tests were performed and results were compared to results found in the literature. The maximum measured value of C_p was 0.285, wich is similar to field tests results from Saha, Thoyla and Maity (2008) for the same turbine configuration. Results also agreed to CFD simulations and wind tunnel tests by Rogowski and Maroński (2015). Results indicate that the proposed turbine design might be a suitable alternative for electricity generation, although more research is necessary to augment the stiffness of the assembly, especially in the center of the turbine. Further research will include testing the turbine with an electricity generator.

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