Study, Design and Test of a LENZ-type Wind Turbine

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Abstract— *The current concern about reducing dependence on fossil fuels and issues about environmental conditions have guided the survey for renewable energies around the world. The present work was focused in the study, design, construction and laboratorial tests of a small-size vertical-axis wind turbine (VAWT) of Lenz-type. The wind turbine was chosen based on criteria of operation in turbulent winds and mainly due to low-cost of fabrication and possibility to use it in farms. The study was carried out in the description of wind resources in a specific area from countryside of Brazil. The Lenz turbine was designed, drawn, built and later tested in a low-speed wind tunnel. Experimental data were gathered to describe the characteristics of the prototype and to guide for further modifications to improve wind power efficiency.*

Keywords*—*Environmental, Lenz turbine, Renewable energy, Wind turbine, Wind tunnel.

I. INTRODUCTION

The wind power usage is not new in terms of human history. Wind power extraction and conversion into electric energy has increasingly evolved in the last decades, mainly after the petrol crisis in 1970s. The survey for renewable sources of energy has led to different types of mechanical designs and wind turbines of distinct shapes.

Another important aspect about wind power is the increase awareness of government and worldwide population about environmental conditions and the scarcity of fossil fuels.

In Brazil, due to the natural abundance of water resources and relatively low cost for production of electrical energy, the main energy matrix is substantially based on hydroelectric. The Brazil power generation by source in the new polices scenario could be summarized in Fig.1, according to Al-Saffar (2014).

Nevertheless, the recent water crisis which Brazil has faced in the last years (2014/2015) led to the need of diversification in the energy matrix, since the country has potential to use solar powerplants and wind power extraction by use of large field of wind turbines.

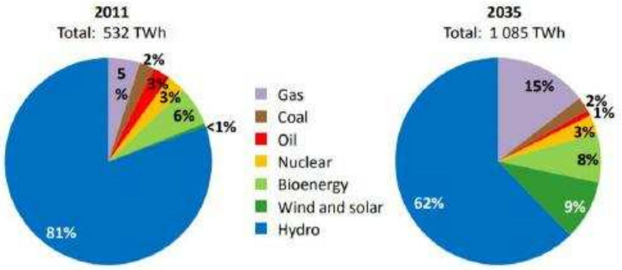

Fig. 1: Brazil power generation by source – Al-Saffar (2014).

According to Global Wind Energy Council (2016), Brazil has one of the best wind resources in the world. Also, it has been identified an expressive increase in wind energy production in Brazil in the last decade, allowing the country to be positioned among the top 10 countries that generate the most wind energy in the world – fig.2.

Fig. 2: Total installed capacity of wind energy in Brazil. Source: GWEC, 2016.

The northeast region in Brazil is where the country's largest wind potential is concentrated. For this reason, the largest number of wind turbines is installed at that location. Trade wind, large oceanic cover without obstacles and sea breezes are other important features which makes this region attractive for investment in the sector. Fig.3 illustrates the magnitude and wind distribution in Brazil's territory, according to the Brazilian Wind Energy Center (CBEE – Centro Brasileiro de Energia Eólica).

Other states like Santa Catarina and Rio Grande do Sul show potential for expanding the current wind powerplants. However, great part of Brazil of has wind velocities below 5 m/s, making difficult the power extraction at that speeds.

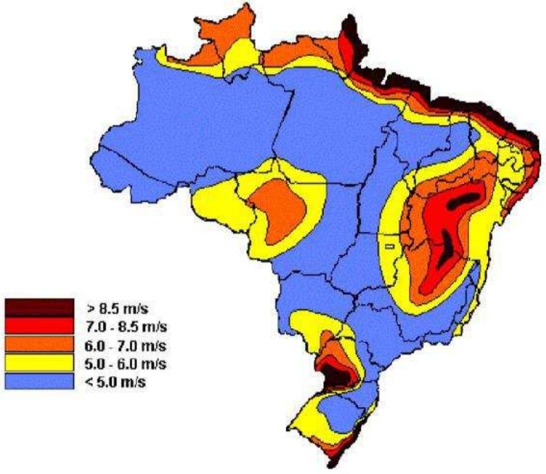

Fig. 3: Contour map for wind velocity distribution in Brazil. Source: CBEE, 2008.

Given the current context for the search for renewable energy sources and the high Brazilian wind potential, the current work was proposed to study, design and test a vertical-axis wind turbine (VAWT) of Lenz-type. The choice for this model was based in some characteristics as for instance, the possibility of operation in urban and rural areas, which in Brazil constitutes a market still not explored yet. Other aspects such as low-cost and reliability were also considered. After the conceptual study, the prototype was sized and 3D-designed in CAD. The wind turbine was built, and experimental tests started in a low-speed wind tunnel at different wind speeds to extract the mechanical power and electrical capability of the wind turbine prototype. All the data gathered is being used to promote further improvements in the prototype and to enhance the wind power extraction and conversion. Further steps are planned towards the fabrication of a specific generator for this VAWT.

II. VERTICAL-AXIS WIND TURBINE (VAWT)

It is well known that VAWT is a type of wind turbine where the main rotor shaft is set transverse to the wind. One of the advantages of this type of wind turbine is the location of generator and gearbox that could be placed close to the ground helping maintenance issues. Other positive aspects are related to omni-directionality, that means they do not need to track the wind, and the possibility of operating at low velocities and/or with turbulent and gusty winds. Another favorable point is the low-cost of fabrication and the capability of increasing the generated power per unit of land area, making it ideal to be installed on a wind farm in countryside of Brazil. Fig. 4 illustrates one of the VAWTs, most commonly called Darrieus-type.

It is possible to find different applications for Darrieus-type wind turbines. However, a lot of disadvantages are seen for making it available at large size. Also, its efficiency is around 30% and there are major difficulties in protecting the Darrieus turbine from extreme wind conditions and in making it self-start.

Fig. 4: Vertical-axis wind turbine – Darrieus-type. Source: Wikipedia, 2018.

Savonius-type wind turbine is another possibility. Even though they have low efficiency, they are often used because its low cost and high durability. Due to high torque on the rotating shaft, one of the applications is water pumping.

Based on Darrieus and Savonius-type wind turbine, Edwin Lenz proposed a different kind of mechanical device, combining aerodynamic lift force and drag actions in the rotor airfoils or turbine's blades – Fig.5.

Fig. 5. Example of a Lenz-type wind turbine (Lenz, Edwin).

Advantages of Lenz-type wind turbine are related to low-cost of fabrication due its simplicity, robustness, reliability, possibility of working with low speed winds, easier self-starting and possibility of higher efficiency when compared to Savonius, crediting to this design the capability to be installed in farms and houses in countryside Brazil.

III. DESIGN AND CONSTRUCTION

One of the design restriction for this Lenz-type VAWT was the size of the exit nozzle from the wind tunnel, where the turbine was tested. In this work, the size was h = 0.6 m. According to this limitation for testing the final prototype, the wind turbine height was assumed H = 0.6 m. To keep a swept area below 0.30 m^2 the wind turbine radius was determined by the following equation:

$$A = 2R \times H \qquad (1)$$

Thus, the wind turbine radius was R = 0.225 m. The aspect ratio of the VAWT could also be calculated based on radius and height, according to:

$$AR = 2R / H \qquad (2)$$

The shape of the blade was kept according to the original's Lenz vertical axis turbine recommendations, as visualized in Fig. 6, where R is the wind turbine radius, W_c is the wind turbine chord and W_w is the wind turbine width.

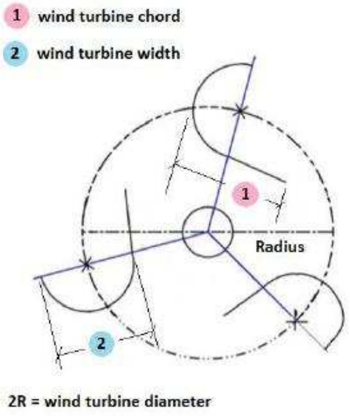

Fig. 6: Wind turbine sizing - sketch.

The final sizing of the Lenz-type VAWT gave the following shape for the 3-blades design, as illustrated in Fig. 7.

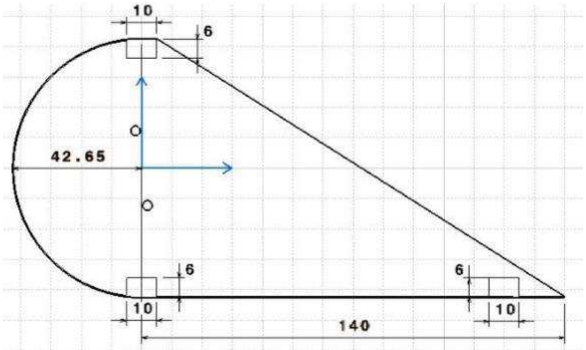

Fig. 7: Final shape of the wind turbine blade (dimensions in mm).

As discussed in literature, Gohil and Patel (2014), 3 blades are most preferred and most applicable for wind turbine rotors. A few troubles are related to the use of 2 blades, which are noisier when compared to designs with 3 or more blades, imbalance of the wind turbine that could lead to rattle, difficult to self-start and discontinuous spin, among others.

The pitch-angle for the blade was kept closest to 9° according to the recommendations from the Lenz's design. Table 1 summarizes the prototype's design parameters for the Lenz-type wind turbine built in this work.

Table.1: Summary of VAWT's design parameters.

Parameters	Current Value
Aspect ratio	0.75
Diameter	450 mm
Height	600 mm
Wing width	85.3 mm
Wing chord	182.65 mm
Frontal area	0.27 m^2
Pitch angle	~ 9°

Fig. 8 illustrates the final prototype CAD's design and photo of the Lenz-type VAWT, to be tested. The entire cost of fabrication for the prototype of this small-size wind turbine was around $90,00 (ninety American dollars) and took not more than a week for being completely assembled.

Fig. 8: 3D-drawing and photo of the Lenz-type VAWT.

IV. EXPERIMENTAL TESTS

The experiments were carried out with the use of a 60 x 60 cm^2 wind tunnel (WT) at the Experimental Aerodynamics Research Center (CPAERO) from Federal University of Uberlandia, Brazil, shown in Fig. 9. Flow momentum was generated by a rotor of 12 blades driven by a 25 hp electrical engine. The maximum air speed in the tunnel test section is approximately 30 m/s with minimal blockage.

Fig. 9: Lenz-type turbine under tests.

As the wind turbine was designed to not exceed 60 cm in height, it was placed at 1 chord-length from the wind tunnel test section exit, as demonstrated in Fig. 9. Wind tunnel power-up conditions were set for velocities of 5, 6, 7, 8, 9, 10, 10.8 and 11.7 m/s with different resistive loads (R_c) applied in the electrical system as 14.7, 12, 9, 6 and 3 Ω (ohms), making the total test matrix with 40 points.

To evaluate the shaft mechanical power, it was necessary to use a DC generator and a resistive load, as sketched on Fig. 10. The DC generator was energized, and the resistive loads were applied in the circuit as seen below:

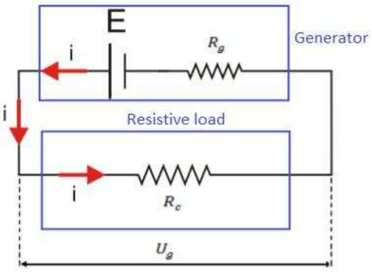

Fig. 10: VAWT's electrical circuit sketch.

The experimental evaluation was carried out by setting the wind tunnel speed measured by a Pitot-tube installed in the test-section. Confirmation for the averaged flow velocity was assured at the WT nozzle exit by a portable digital anemometer. With the flow velocity adjusted, the Lenz-type self-started and was kept steady for a while. After the stabilization of the system, the resistive load was then adjusted, according to the test-matrix. The wind turbine revolutions per minute (rpm) started to decrease and stabilized again. Then, the rpm was measured by a digital tachometer in the main shaft of the VAWT. A mean of three measurements were taken for the main shaft's rpm and this value was assumed to be the correct output. Figure 11, illustrates the electrical system, mainly the rheostats used to adjust the resistances in the circuit.

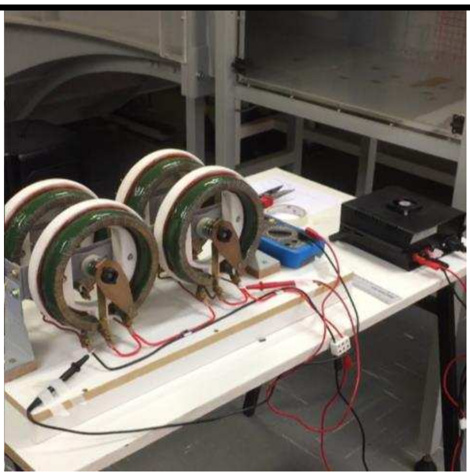

Fig. 11: Lenz-type turbine under electrical tests.

As measurement procedure for the electrical system, first the voltage in the generator was gathered to calculate the electric output power (P_g). After, by measuring the electric armor resistance (R_g) the dissipated electric power (P_d) could be calculated. At the end, the mechanical power of the prototype shaft (P_m) is equal to the electric input power (P_e) that is the sum of the electric output power and the dissipated electric power (P_d):

$$P_m = P_e = P_d + P_g \qquad (3)$$

The mechanical efficiency of the wind power (η_m) is given by the relationship between the available mechanical power in the shaft and the wind potential (P_w) for each wind tunnel speed.

$$\eta_m = P_m / P_w \qquad (4)$$

For this specific design the maximum power of wind energy has been estimated from the equation:

$$\text{Power}_{max} = (0.5929) \times (1/2)\, \rho\, A\, V^3 \qquad (5)$$

where the factor 0.5929 is the maximum power that can be extracted from any kind of wind turbine, according to the Betz theory. For a mean and local wind velocity of 6 m/s the maximum power of wind energy calculated was:

$$\text{Power}_{max} = 21.18\ \mathit{Watt} \qquad (6)$$

V. RESULTS

From the data gathered for the different wind tunnel velocities, the mechanical power as a function of resistive loads and revolution per minute (rpm) could be evaluated. Fig 12 illustrates the surface 3D-plot showing the data.

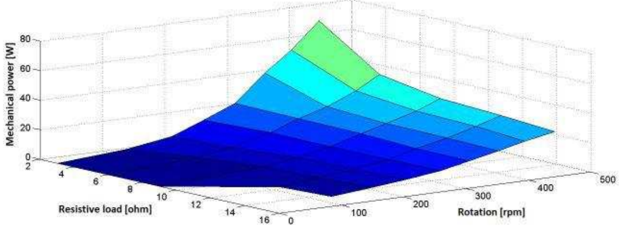

Fig. 12: Surface 3D-plot of mechanical power as a function of resistive load and revolution per minute.

The results in Fig. 12 show the increase in the mechanical power as the wind turbine rotation is augmented while the resistive load is decreased. The peak in the mechanical power close to 73 Watts was reached when the revolution was 420 rpm and the resistive load equal to 3 Ω. At this point, the mechanical efficiency (η_m) reached the maximum value of approximately 28%.

The 2D-plot for the mechanical power as a function of shaft rotation is presented in Fig. 13, for the different resistive loads employed in this work. As expected, for a given shaft rotation, the mechanical power is decreasing as the resistive load is augmented.

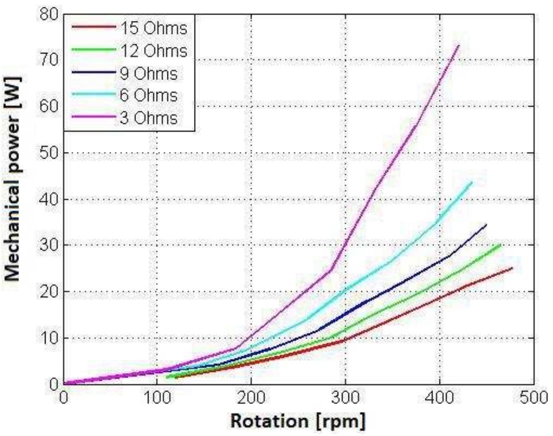

Fig. 13: Mechanical power as a function revolution per minute at different resistive loads.

Fig. 14 presents the variation of mechanical power as a function of the shaft rotation for different wind speeds tested in the wind tunnel. The results were consistent with the theory as the power is proportional to the cube of wind speed.

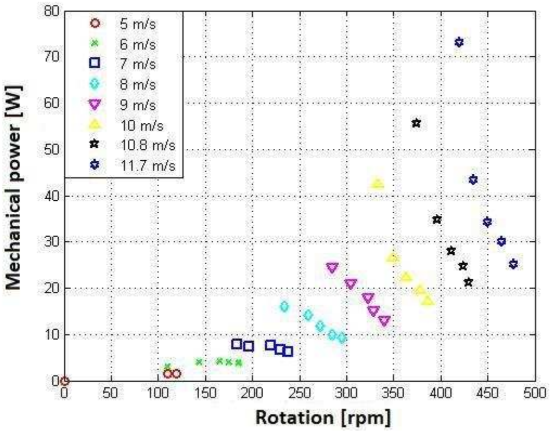

Fig. 14: Mechanical power as a function revolution per minute at different wind speeds.

To illustrate the mechanical power generated by the wind turbine, the output electric power of the generator and the maximum wind potential were represented in Fig. 15. It is possible to verify that the wind turbine reached 75 Watts of mechanical power while the electric generator gave around 13 Watts of useful electrical power. This low value for the electrical power was attributed mainly due the nature of the electric generator utilized in this experiment which was designed for operation at higher shaft rotation. In this case, it is believed that most of the energy produced was internally dissipated.

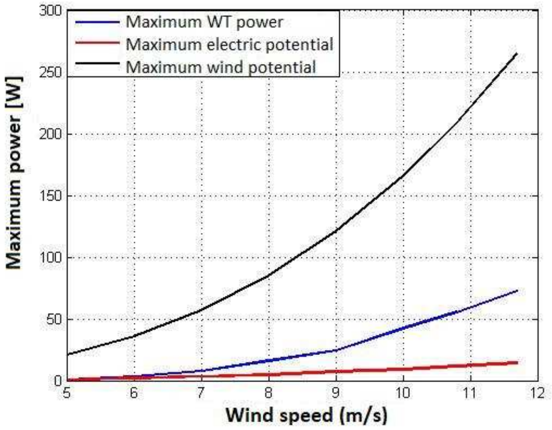

Fig. 15: Mechanical power as a function revolution per minute at different wind speeds.

The mechanical power coefficient as function of the wind speed is presented in Fig. 16 for different electric loads tested. For loads below 15 Ω the maximum power coefficient was around 9 m/s (peak value) decreasing afterwards. One of the reasons for this decaying in the power coefficient maybe attributed to the loss in aerodynamic efficiency due to the interaction of the blades and the wind flow. For safety reasons no tests were carried out for speeds above 12 m/s.

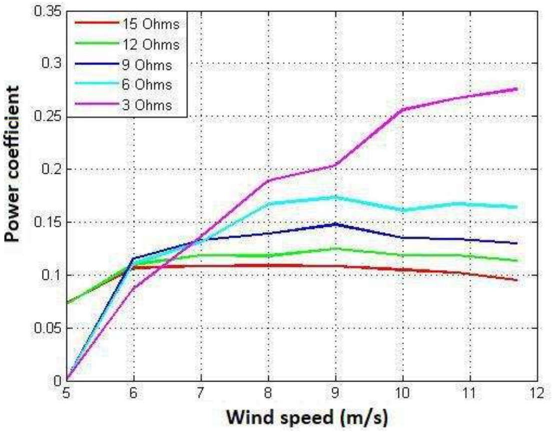

Fig. 16: Power coefficient as a function of wind speeds at different resistive loads.

For wind tunnel speeds below 5 m/s and with resistive loads of 3, 6 and 9 Ω the wind turbine was not self-started. Without resistive loads the wind turbine self-started at 4.5 m/s.

At least two important drawbacks of this design should be mentioned herein, which are attributed to the quality of bearings used and the power of the generator used for qualifying the electrical system. It is believed that the conjunction of these two factors had decreased significantly the power coefficient for values close to 27%. Other works in literature have listed values of order 30 – 40%. Thus, this point out towards further improvements in the current wind turbine.

VI. CONCLUSION

In this work a conceptual study on Lenz-type wind turbines (VAWT) was carried out. After, the design and construction of a small-size vertical-axis wind turbine was accomplished. The Lenz-type wind turbine was considered due to its low cost, durability and averaged efficiency when compared to others VAWT's like Darrieus and Savonious-type. With a very low-cost, below $100,00 (US American dollars), the VAWT was completely assembled very quickly, once the design was finished. Laboratorial tests, by using a wind tunnel, have shown important results for the mechanical power and power coefficient for the wind turbine. The mechanical power with a resistive load of 3Ω reached around 73 Watts and the functioning of the wind turbine was quite safe up to wind velocities around 11 m/s. Despite some losses in the bearings and in the electrical generator, the Lenz-type wind turbine showed potential for use in areas with low winds in countryside of Brazil, such as farms or even in small urban centers.

ACKNOWLEDGEMENTS

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