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Evaluation of an experimental prototype in an aerodynamic tunnel with characteristics of a small wind turbine with two blades

Abstract

The experimental consideration of wind turbines in an aerodynamic tunnel is a powerful alternative to determine the performance of these equipment, both to assimilate their behavior in operation, and to identify constructive and aerodynamic aspects, aiming to convert these characteristics to the real turbine. In the understanding described in this work, the aerodynamic characteristics of the prototype were evaluated, the static torque for the different flow speeds and the power coefficient was estimated based on the concept of variation in the amplitude of movement of the drying when crossing the turbine at different speeds of the flow. The results are compared with the values achieved analytically. The research theory predicted the aerodynamic and structural event, investing numerical and experimental tools. The present work constituted the first experimental event to evaluate the aerodynamic performance of the research project. At this stage, the experimental assessment of static torque was carried out, analyzing the aerodynamic wake of the prototype and determining the RPM curves for the attached wind speeds. The perspective is that it will be possible to describe a new process to, based on the correlation coefficients, determine a curve of the amount of energy granted by a source in a reliable unit of time through simulation or prototyping before starting the survey of real module equipment.

Keywords: prototyping, wind turbine, turbine

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Introduction

Wind energy had its initial historical record in Persia, 220 BC. Initially, it was consumed in agriculture for pumping water and grinding grains through windmills. The Persian system, consisting of a vertical axis guided by drag, which depended on wood and sail cloth, had fifty percent of the sails in contact with the wind, connected to a central rotor that transmitted the rotation directly to the grain grinding mechanism.[1] This model of vertical axis mill spread throughout the Islamic world, providing its use for many centuries.

However, in the historical course of the dissemination of wind activity as an energy source, there is a lack of fossil fuels. It is known that the expected human dependence on coal, natural gas and oil may exceed the volume of world reserves. Examining the prognostic method used in 1956 by M. King Hubbert and extending his research to the world population, it is possible to estimate that the peak of oil supply on the planet will occur by 2030.

The method used by Hubbert was able to assume the peak experienced by Americans in 1971, and depended on analyzing data from past generations to estimate future achievements within the American state.[2]

Spontaneous gas consumption has increased considerably, which can be attributed to the adoption of gas as a primary source for industrial energy production. Although there was a drop in 2009, the perspective observed is that the use of gas should increase.

At current consumption rates, known volumes of common gas should last approximately 62.8 years.[3]

The supply of coal increased significantly throughout this decade, and was mainly driven by an increase in demand for activities in the developing world.

Coal is the preferred energy source due to its low cost and abundance as a natural requirement. However, ember has a great ecological importance, both in removal and use, being higher than that presented in other fossil fuels. The forecast is that in current consumption, known volumes of coal should last 119 years.[4]

The Brazilian energy disturbance triggered by the water imbalance also stands out, given that the origin currently has great subordination to hydroelectric plants.

This entire assessment leads us to a fall in favor of renewable energy sources. As a result, wind energy is taking great strides towards gaining a place at the forefront in relation to exhaustible fossil energy.

Some works developed in Brazil and around the world, which deal with the themes contained in this work, are reviewed and help in achieving some determinations and give light to various knowledge.

Currently, residential and commercial buildings have made use of small wind turbines to meet their electrical energy requirements, as this is obtained by the movement of air (wind), and an abundant source of renewable energy is found in all areas and at different intensities. According to Lehmann; Koenemann Table 1, small wind turbines are machines that have a nominal power of up to 30 KW and an engine diameter of up to 15 m. And they can also be subdivided into mini and micro – wind turbines.

Table 1 Presents the classification of wind turbines according to the power generated by each equipment

Classification	Power [kW]
Industrial wind power generation	P > 500
Large-scale wind power generation	100 < P < 500
Small-scale wind power generation	30 < P < 100
Mini-generation	1 < P < 30
Micro-generation	P < 1

Source Lehmann; Koenemann.

Therefore, we present reasons for choosing small turbines, namely:

I. The region's network is weak to accommodate large turbines. What is the situation like in remote areas, with low population density, and low consumption.

II. There is less fluctuation in the electricity generated in a park made up of small turbines, as fluctuations occur at random and tend to cancel each other out.

III. The large cost of using large cranes and the consequent construction of reinforced roads to carry turbine components means that small turbines are more economical in certain areas.

IV. Several small machines undo the risk in case of a temporary failure.

V. Aesthetic considerations can sometimes dictate the use of small machines. However, larger turbines have a lower rotational speed, meaning that a large machine does not attract as much attention as several smaller ones that have a higher rotational speed.

Several technologies offered today come from international houses not specifically developed for use in Brazil.

To carry out the research, the study of aerodynamics and structural is expected, using numerical and experimental tools, including one of the most valuable in experimental aerodynamics, the wind channel.

The respective work consisted of the first experimental stage of approximate calculation of the aerodynamic performance of the research arrangement, presenting the experimental evaluation in an aerodynamic channel with properties of a small wind turbine with two blades. For this, 3D prototyping was used. A small-scale paradigm was constructed. With the aid of a Pitot tube, the distribution of displacements was carried out in the cross section of the channel, prior to the beginning of the machine evaluation. Knowing the speed profile of the tunnel, the static torque was defined using a torque meter, recording the data achieved for the appropriate speed ranges according to the table.

Temperament was evaluated in the new angular positions of the blades by measuring torque. To this end, they were designed movable in the hub, which gave rise to various angulations in conjunction with the flow, thus transporting the angle of goods and, consequently, the torque produced. The rotation of the original in free rotation was measured using a tachometer.

With the values found, the static torque zigzag and the RPM zigzag relative to the incident speed were established. With the participation of the experimental determination of the incident velocity trace and the velocity trace in the aerodynamic wake of the prototype, the alternation of flow movement was evaluated and the energy extracted in free rotation was stipulated.

The best distributions between chord size and slope side in each order could be acquired with the design parameters, which included the evaluated wind performance, blade forest, peak speed rate and angle of attack.

Experimental methodology

Description of the experiment

To calculate the sizing of the wind turbine blades, the blade element theory was used as a basis, assuming the optimal Betz power coefficient (CpBetz). The index that indicates the power coefficient depends on the relationship between the speeds, that is, V_3/V_1. For a speed ratio $V_3/V_1 = 1/3$ the degree of power is maximum, known as the Betz power coefficient (CpBetz = 16/27 = 0.593). It can be expressed directly as a function of the ratio of speeds before (V1) and after (V3) in the turbine.[5]

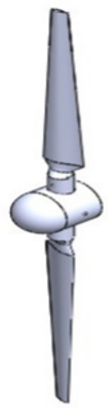
$$CpBetz = 1/2[1 - (V_3/V_1)^2][1 + V_3/V_1].$$

With all the variables known, the prototype manufacturing process began. With chord measurements, angles and knowing the aerodynamic profile, the prototype was designed in 3D CAD software, 3D printing technology called Fused Filament Fabrication (FFF) was used. Plastic filament type PLA (Lactic Plastic) was used as printing material.

The execution was done layer by layer, using very thin plastic threads that, through repetitions, build the objects.[6] For correct printing, a 3D file was generated in CAD Software recognized by Cliever Lab Software (Pro) and saved in STL format.

The pieces are 40 mm in diameter and the Hub is designed to, together with the 250 mm of each blade, form a set of 540 mm.

The blades were assembled with the hub using 2 2 mm screws that were inserted into the blades (1 cm). The hub was connected to the axle via a threaded bar.



In this threaded bar, the following were inserted in this order: a nut, a shaft fitting piece and another nut with a pressure washer completing the entire shaft assembly, as shown in illustrative Figure 1–5 below.

Figure 1 Set.

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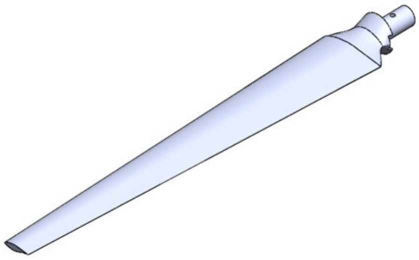

Figure 2 Shovel.

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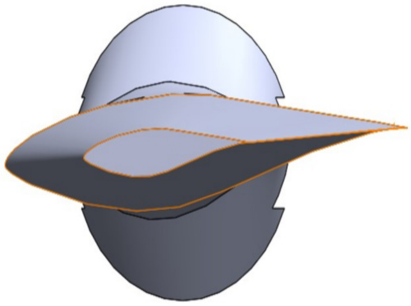

Figure 3 Top view.

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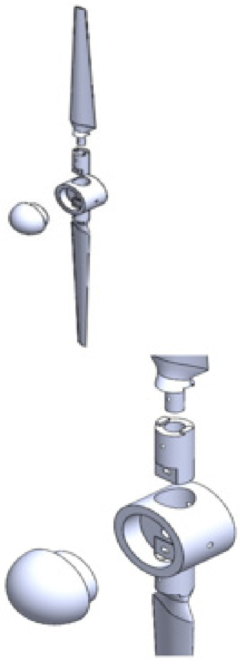

Figure 4 Expanded view of the set.

Source Author

Figure 5 Wind tunnel automation.

Source FT, UNB.

The aerodynamic tunnel, Figure 5, used was the "Darcy Ribeiro" tunnel on the Asa Norte campus of the UNB Faculty of Technology Laboratory.

In Betz's theory, three speeds are considered to analyze the available power of a turbine. In order to determine these speeds, an experiment was set up with two Pitot tubes that measured the speed upstream and downstream of the turbine (Figure 6).

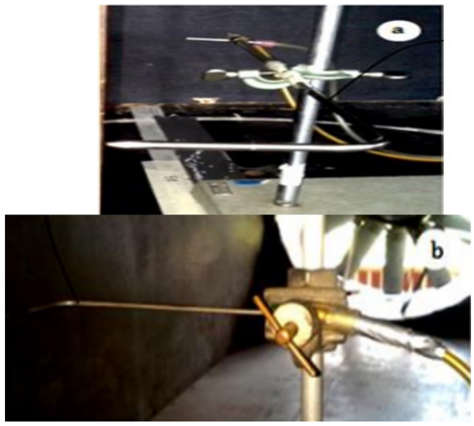

Figure 6 a) Pitot tube 1, b) Pitot tube 2.

Source UFRGS

To experimentally determine the Static Torque, a digital torque meter was used. To this end, some design calculations were necessary, in order to size the correct equipment for the task in question.

Once the speed profile of the tunnel was known, the static torque of the prototype was defined using a digital torque meter coupled to the equipment shaft, which recorded all readings for the speed ranges of 1m/sec. up to 9.88 m/sec. Also with the aid of the torque meter (Figure 7), the influence of the angular position of the blades on the measured torque was evaluated.

To determine the revolutions per minute (RPM) of the prototype, a digital tachometer was used (Figure 8). This device shoots a laser that reflects on the rotating surface and records the measurement using photo electronic means, used to measure the number of revolutions per minute (RPM) of a given engine. To calculate the number of rotations around the shaft contour, the RPM frequency unit is multiplied by a thousand.

Figure 7 Digital torque meter used.

Source LUTRON TQ-8800

Figure 8 Digital tachometer used.

Source Instrutemp measuring instruments.

The turbine was unfastened from the torque meter in order to allow it to rotate freely after starting the tunnel exhaust fan. Using the values obtained, convert from RPM to Rad/sec, obtaining the angular velocity for each frequency.

Results and discussion

Standardization: The standards do not yet prescribe a clear methodology for developing wind turbine tests in the wind tunnel, however, there are some recommendations for carrying out field tests.

Prototyping: Prototyping, presented in this work, proved capable of generating profiles with a high degree of fidelity, which enables a safe analysis of the data obtained.

Transverse velocity profile in the aerodynamic tunnel test section: (Figure 9)

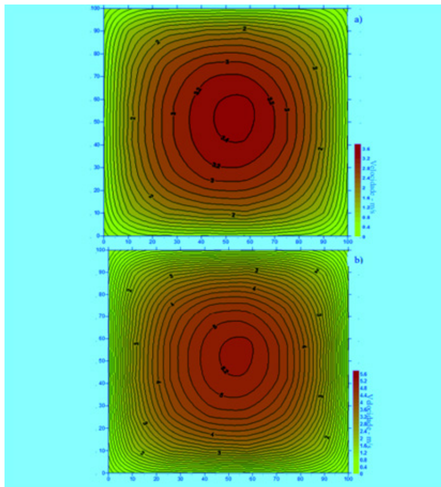

Figure 9 a) Speed determined for a frequency of 20 Hz, b) Speed determined for the frequency of 30 Hz.

Source the Author

Static torque: The static mechanical torque (TwE) estimated using the equation dTWE = ndur is 9.1% greater than that determined experimentally, showing the degree of reliability that the numerical results achieved (Figure 10).

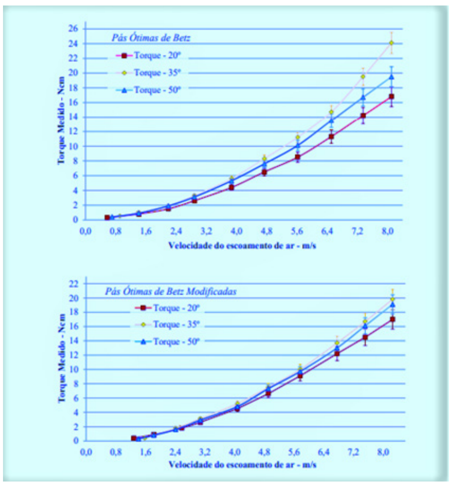

Figure 10 Experimental static torque for different blade positions.

Source the Author

Angular velocity: Once the results were available, the average data observed was entered into specific software. The graphs show the revolutions per minute observed in relation to the air flow speed (Figure 11).

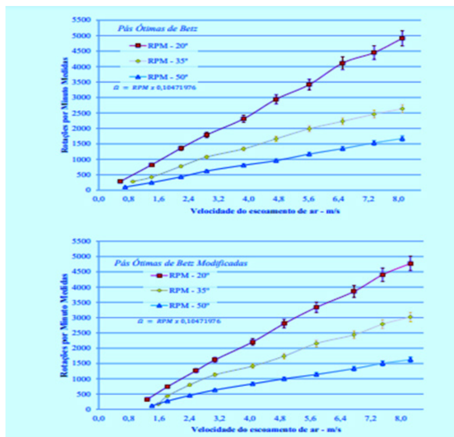

Figure 11 Experimental revolutions per minute for different blade positions.

Source the Author

Power curve: When analyzing the extracted power, calculated for that type of turbine, it was found that the TOB (Optimal Betz Turbine) extracts 22.2% more power from the air flow than the TOBM (Modified Optimal Betz Turbine), (Figure 12).

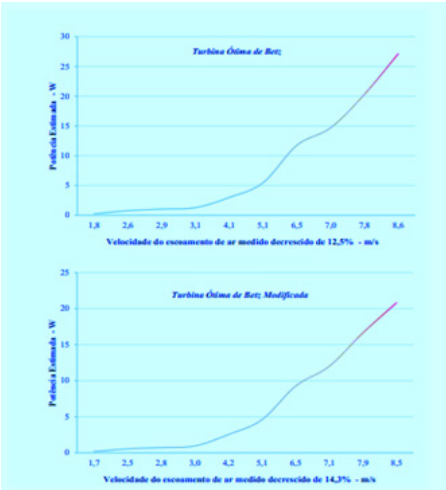

Figure 12 Estimated power curve for different blade positions.

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Aerodynamic treadmill: The aerodynamic wake predicted by Betz was very close to the real wake of the experimentally observed prototype, Figure 13, 14.

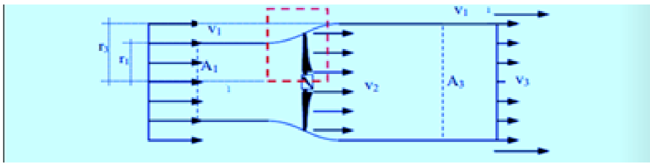

Figure 13 Highlighted area for graphic construction of the aerodynamic wake of the prototypes according to air flow through an ideal BETZ turbine.

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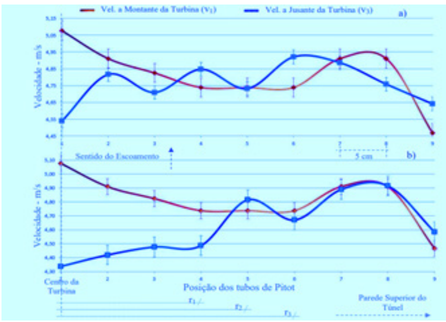

Figure 14 Comparison between the aerodynamic wake built by: a) Modified Betz optimal turbine, b)Optimal Betz turbine frequency 30 Hz.

Source the Author

Performance curve: The performance curve was analyzed in accordance with NBR IEC 61400-12-1,[7] whose objective is to provide a uniform method that allows consistency, precision and reproducibility in the measurement and subsequent evaluation of the performance of wind turbines.

The standard in question was designed with the expectation of being used by manufacturers, buyers, operators and designers of wind turbines. As such, it enables guidance in measurement, investigation and generation of operation test data for wind turbines. It must be used by all parties involved to ensure that there is continuous and operational innovation of wind turbines and that it is carried out in a consistent and precise environment and with a focus on environmental aspects.

The Standard in question also presents a measurement procedure, reporting conducts aimed at providing accurate information. In contrast, those using the standard must be aware of the differences that arise over large variations in wind shear and turbulence, and of the enumerated criteria for data selection.

A relevant factor in power performance evaluations is the measurement of wind acceleration. Therefore, the NBR prescribes the use of cup anemometers to calculate wind speed. This instrument was followed in order to be suitable for this type of test. Even in appropriate tunnels, calibration procedures were respected.

Designer for the original real configuration: The work briefly presented modeling and computational testing of the structure of a blade, made of synthetic plastic resin, for a small wind turbine. The 3D molding took into account aerodynamic aspects to enhance the conversion of kinetic wind activity into electrical activity.

Loads were attributed due to the ventilation action on the blade. To bring the tests closer to reality, data were collected regarding wind currents in the places where the wind turbine was located.

Considering the results found, based on this study, it is possible to contribute to improving the design of small wind turbine blades. Virtual testing of structures, as well as those of aerodynamic profiles carried out using computing, have become tools of great importance when it comes to designing aerodynamic equipment.

Conclusion

The area of small wind turbines in Brazil is gradually and sharply expanding. However, the data communicated to would-be consumers does not always follow this development. The aerodynamic description and development of a wind machine must be in line with the relevant standards, aiming to provide greater accuracy and credibility in relation to the data provided.

The data collected experimentally aimed to make the knowledge available to researchers and companies, so that before outlining a power profile of a turbine, a prediction of energy emergence and error logs can be achieved, without starting the construction and attempts of a real machine.

The 3D prototyping used when carrying out this study enabled the formation of profiles with a high degree of structural and aerodynamic dedication, which provides reliability of the data obtained. By experimentally observing the aerodynamic wake of a small-scale specimen tested in an aerodynamic tunnel and carried out by 3D prototyping, an expressivity coefficient- CpBetz, of 35 percent for TOB and 28.6 percent for TOBM was estimated.

A study by Akwa,[8] which talks about the aerodynamic analysis of Savonius wind turbines using insightful computational fluids and principles from Verdum, 2013, which indicates designs for wind turbines, with inherent safety, for urban use, were considered, through other things, to decide the type of machine to be tested.

In the exhibition by Acunha,[9] one can observe the analysis of the development of a narrow-sized wind turbine, carried out in the field, in which the necessary equipment for the determinations and development of the exams are mentioned and, therefore, to become aware of some equipment needed for testing.

Therefore, the decentralization of electrical energy foreseen through the use of small wind turbines could be an economically and ecologically viable solution for the coming decades, justifying the present study.

Thus, it becomes possible to describe a new method to, based on correlation coefficients, indicate and determine a reliable power curvature through simulation or prototyping before starting to manufacture a piece of graded equipment real.

Acknowledgments

None.

Conflicts of interest

The authors declare that there is no conflict of interest.

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