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EXPERIMENTAL EVALUATION OF THE AERODYNAMIC PERFORMANCE OF TURBINES SMALL WIND CONFECTIONED IN PROTOTYPING 3D

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Abstract. *This paper presents the experimental evaluation in wind tunnel of two small wind turbines features five blades. Therefore, using 3D prototyping, two models were built on a reduced scale, which were first evaluated using Optimal Blade Betz and Optimal Blade Betz Modified. Prior to evaluating the distribution machine at speeds determined in the tunnel cross-section with the aid of a Pitot tube. With the known tunnel velocity profile, determines the static torque of the prototype with the use of a digital torquimeter coupled to the machine axis, which recorded all the readings for the speed range of 1 m/s to 9,88 m/s. Also with the torquimeter evaluates the influence of the angular position of the blades in the measured torque. Therefore, it is mobile designed in the hub, allowing vary their angle in the outflow, thereby changing the angle of attack and therefore the torque produced. Employed a photo tachometer for measuring the rotation of the model in free spin. With the data, determines the static torque curve and RPM curve as a function of incident speed. Through experimental determination of the incident velocity profile and the velocity profile in the aerodynamic wake of each turbine is evaluated the variation of the amount of movement of the flow and determined the power extracted by the rotor in free rotation. This study aims to contribute to the design of a real wind turbine informing the aerodynamic characteristics of the equipment shall be constructed with this layout. With the data analyzed to make a prediction for the prototype power curves. The experimental results demonstrate torque and power good approximation to the results obtained by evaluation by analytical element of the paddle method. The turbine constructed with Optimal Betz Blades presented static torque 17,8% higher than constructed with the Modified Blades and extracted 22% more power air outflow.*

Keywords: *Small wind turbine, wind energy, aerodynamic tunnel.*

1. INTRODUCTION

Meet the challenge for humanity is living today who seeks new ways to generate energy. Wind energy is already a reality in our country, spread primarily through wind farms consist of large wind turbines. However there is a government effort to decentralize this generation. Small wind turbines can bring a new reality to the Brazilian energy generation promoting this decentralization becoming also an outlet for water and energy crisis in the country today.

In the current market, they are commonly made available various types of small wind turbines with different designs and prices. However, doubts remain about the data reported in the catalogs of manufacturers. As these are usually very optimistic, given the fact that often make use of estimates and not real data from a device that is fully operational.

As the most informative data equipment is its power curve, an objective of this work is to experimentally determine the power curve through the torque curve of a prototype built on a reduced scale.

Another objective of this work is to contribute to the research project "Design and construction of a Small Wind generator with inherent safety," informing the aerodynamic characteristics that the actual turbine, as designed, will present.

Finally we intend to predict coefficients correlating the data with numerical simulation with the data collected in the laboratory and finally with those observed when the actual turbine up and running. These factors will enable the prediction of reliable power curves from previous data, without making the construction of a real turbine for tests.

To do so is made a general review of IEC 61400-2, ABNT NBR IEC 61400-12-1 and IEC 61400-11 also observing the provisions of Normative Resolution No. 482 establishing the general rules for the Microgeneration access and minigeneration Distributed and Clearing System of Electricity and Decree Nº 85 stipulating the Conformity Assessment Requirements for Wind Turbines - RAC.

2. METHODOLOGY

2.1 Design and prototype construction process

For design calculation of the blades was used Betz's theory, which provides equations for the calculation of the chord (C (r)) and the blade twist angle (β (r)) Eq. (1) and Eq. (2) respectively.

$$C_{(r)} = \frac{1}{n} 2\pi R \frac{8}{9C_l} \frac{1}{\lambda_D \sqrt{\lambda_D^2 \left(\frac{r}{R}\right)^2 + \frac{4}{9}}} \tag{1}$$

$$\beta_{(r)} = \arctan\left(\frac{3\,r}{2\,R}\,\lambda_D\right) + \alpha_A \tag{2}$$

Table 1 - Data Entry

Radius (R)	Diameter (D)	Area (A)	π	Mass spec. air (ρ)	Blades number (n)	Speed ratio. blade tip (λ_D)	Parties divided	Vel. Angle (Ω)	dr	$C_{P\ Betz}$	Power Máx.
0,25	0,5	0,196	3,141592654	1,225	5	3	25	120	0,01	0,593	71,27
m	m	m²	admensional	kg/m³	admensional	admensional	arbitrated	rad/s	m	admensional	W
Torque Máx.	**Power Disp. Wind (P_d)**	**$C_{P\ Real}$**	**extracted Wind Power (P_t)**	**Real Torque**	**Speed. Nominal (U_∞)**	**Coefic. Drag (C_D)**	**Coefic. Lift (C_L)**	**ε (C_L/C_D)**	**Angle of Attack (α_A)**	**r**	**Profile Airspeed.**
0,593	120,26	0,444	53,52	0,45	10	0,018	1,15	63,89	10	0,01- 0,25	NACA 0012
N.m	W	admensional	W	N.m	m/s	admensional	admensional	admensional.	°	m	

In Tab. 1 shows the data that was entered in the equations to enable the acquisition of the project values, which allowed the perfect construction of prototype blades. In the images of Fig.1 shows the prototype and some construction details. To make it possible to measure the torquimeter would be used for data acquisition, made the calculation of the forces acting on the blades in order to meet up the power and finally the torque. The torque value calculated for the 10th attack angle was 0.265 Nm. Recalling that in this particular case the torque was calculated static, ie those used Equations not considered the angular velocity or local radius.

After chosen and purchased the torquimeter has gone up for the 3D printing process. At this stage it was dedicated 80 hours to printer tests and the resulting pieces and 120 hours for prototyping turbine. An advanced study of 3D printing and also meet up the properties of the filaments used as raw material was required, as well as the most suitable printer settings so that it had the best pieces in the shortest time possible. If Before starting printing parts (Fig.1a) noted the need to divide up the shovel in 3 equal portions every 75 mm, z since the printer was a maximum dimension of 100 mm, and each blade was 225 mm long. Thus, each prototype needed 17 parts PLA (Polylactic acid derived from corn or sugarcane) to be built. In a second shaft and bearings ABEC 7, the results can be seen in Fig.1b and Fig.1c.

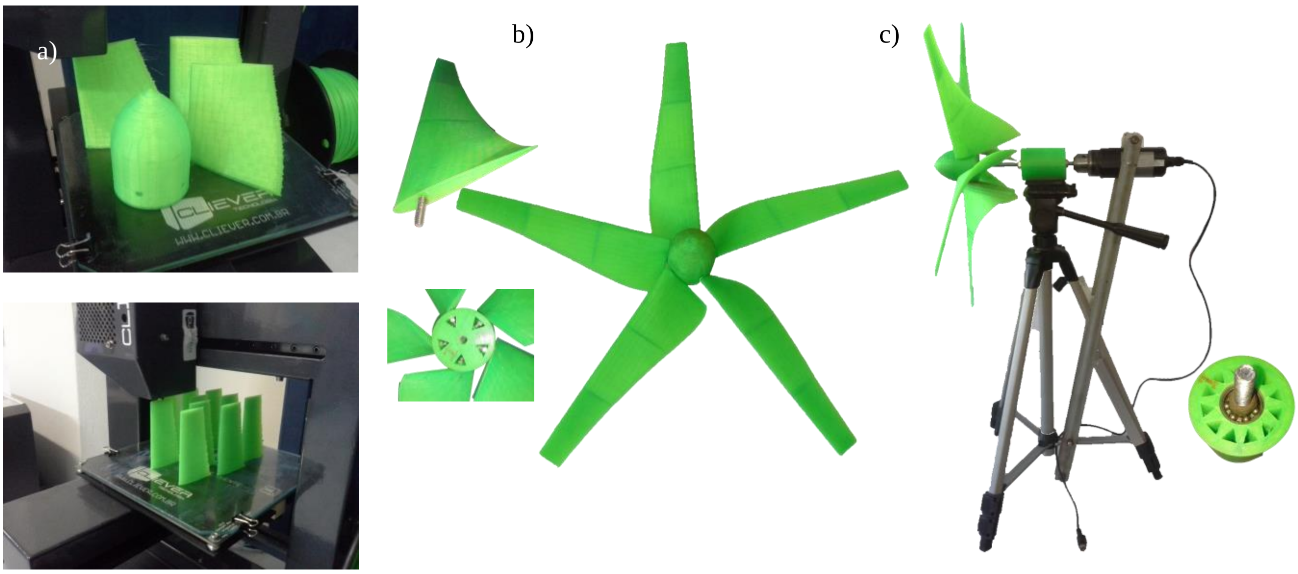


Figure 1 - a) Printing of parts; b) Details of the socket of the blades; c) Installation and detailing the prototype shaft

2.2 By determining the velocity profile of the aerodynamic tunnel

Before exposing the turbine to the flow of square section channel tunnel (1m x 1m), the velocity profile was defined for the frequencies of 20 Hz to 50 Hz (Fig.2). To do so provided are two Pitot tubes connected to an inclined pressure gauge (MI) and other electronic (ME) who were the readings of flow speeds. The Pitot connected to the MI was the reference and its position was kept constant in return the ME had their positions variable vertical and horizontally, forming a mesh points. The readings of the stitches were later placed in a specific software and graphically set speed profile. The readings showed little speed variation and the profile was almost constant near the channel walls and somewhat blunt the closer the center tunnel.

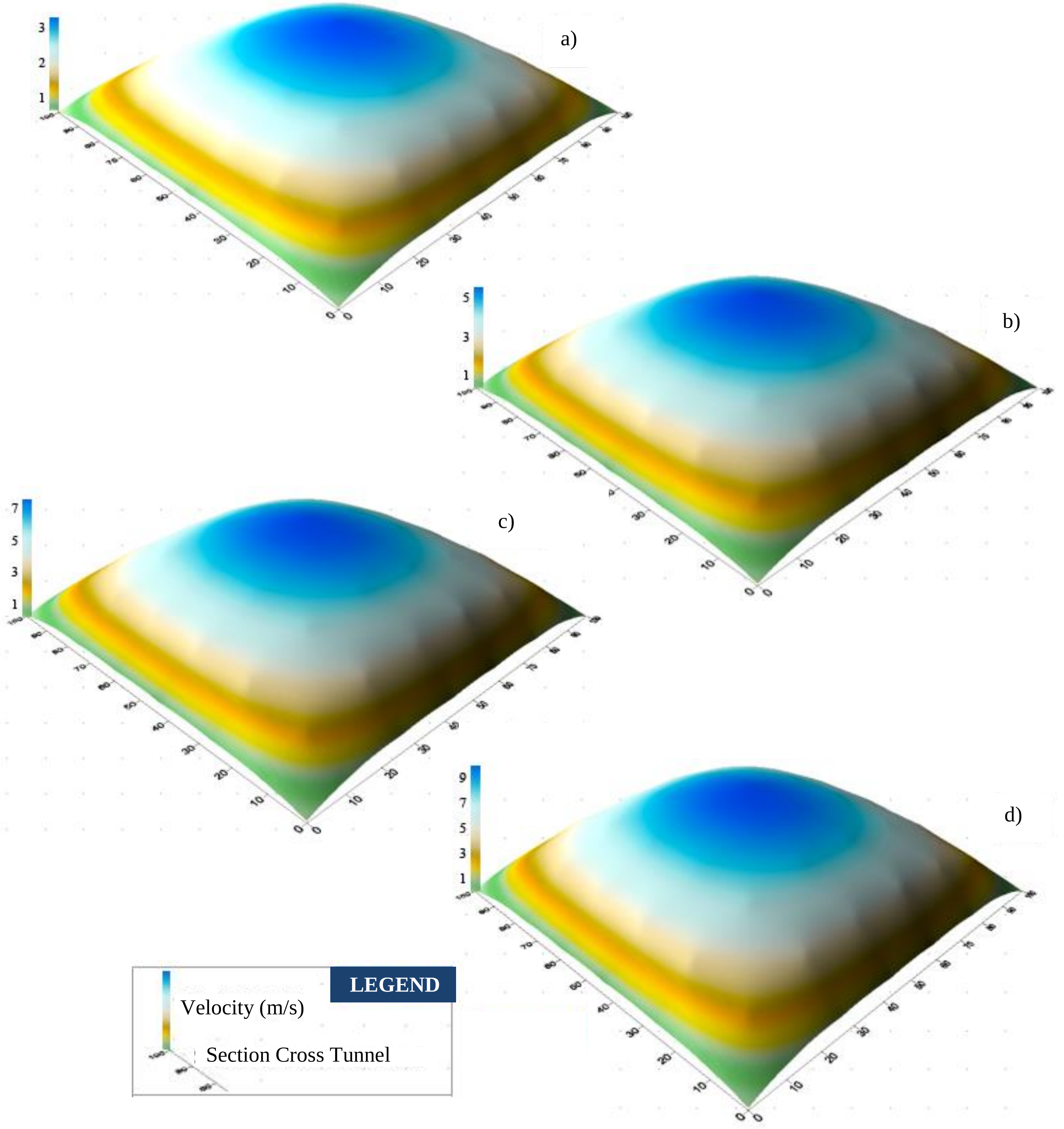


Figure 2 - Velocity profile of tunnel aerodynamic: a) 20 Hz; b) 30 Hz; c) 40 Hz; d) 50 Hz

Knowing the velocity profile is the prototype mounted inside the tunnel and measured torque, revolutions per minute and it was determined experimentally the wake of the turbine based on the theory of Betz, the graphical representation is displayed in Fig. 3

2.3 By determining experimentally the real wake of the turbine through the theories of Betz

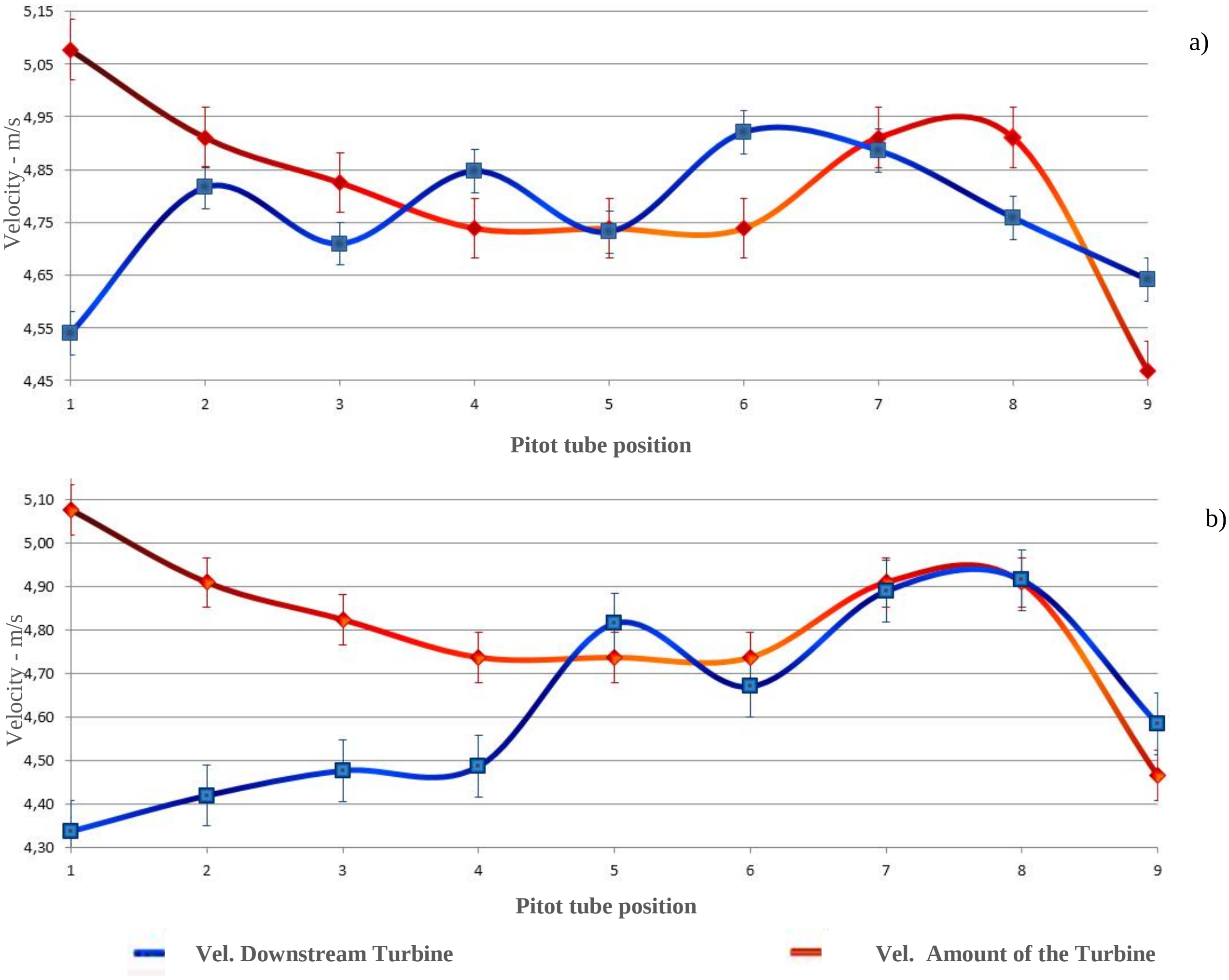


Figure 3 - Aerodynamic wake for: a) Modified Optimal Betz Turbine; b) Turbine Betz Optimal

To determine the aerodynamic wake graphically defined in Fig.3 used two Pitot tubes positioned before and after the turbine. With this set up the input speed and output speed. Armed with this, it obtained numerical speed retained by the turbine and then then calculated the power coefficient (C_P) for the two prototypes. Introducing the 30 Hz 37.6% for turbine optimal Betz and 28.6% for turbine optimal Betz modified.

2.4 Determining the static torque curve, RPM curve and the numerical power curve

To facilitate understanding, the torque curve (Fig.4) and RPM curve (Fig.5) was experimentally determined, while the power curve in Fig.6 displayed results section was determined by calculation, that is, a forecast of what is expected for this Phase II work.

For the determination of the static torque tunnel speed was increased and the fixed shaft torque wrench reading the prototype was made. Already, the revolutions per minute were determined by a digital tachometer photo appointed to the prototype free spin. Any torque for reading and for reading the RPM was used the two types of blades by varying its position (P1, P2 and P3). Since P1 is the rope twist angle 1 calculated in the project, this is, 20,20º. P2 angle was determined using the value P1 added 15 and used to P3-P2 is added 15. Thus, for presentation purposes, we will, 20º, 35º and 50º. With the readings in the hands-defined torque curve for the two types of blades provided for this work positioned at three different angles.

To set up the power curve numerically we used the data stipulated in Tab.1 varying only the design rated speed according to the speed variation from 1 to 9,88 m/s provided through the tunnel velocity profile and paying attention treated to the fact that the channel obstructed by the fan showed a 12.5% decrease speed for optimal turbine Betz and 14.3% for the Modified. Thus was obtained the power curves illustrated in Fig.6. The decreased speeds not reached the rated speed of 10 m/s was required to make an extrapolation of the speed thereby obtaining the power curves of Fig. 7.

3. RESULTS

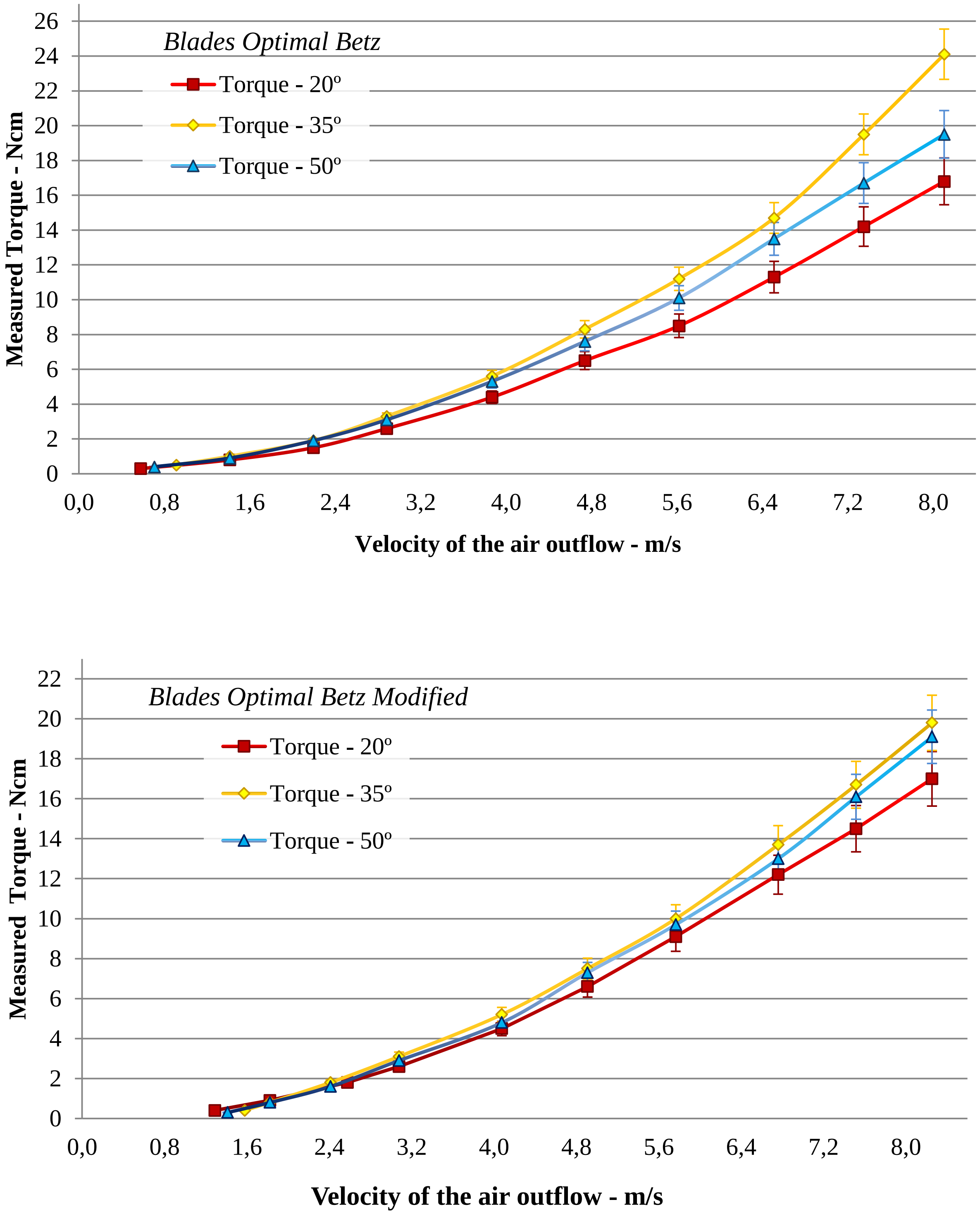
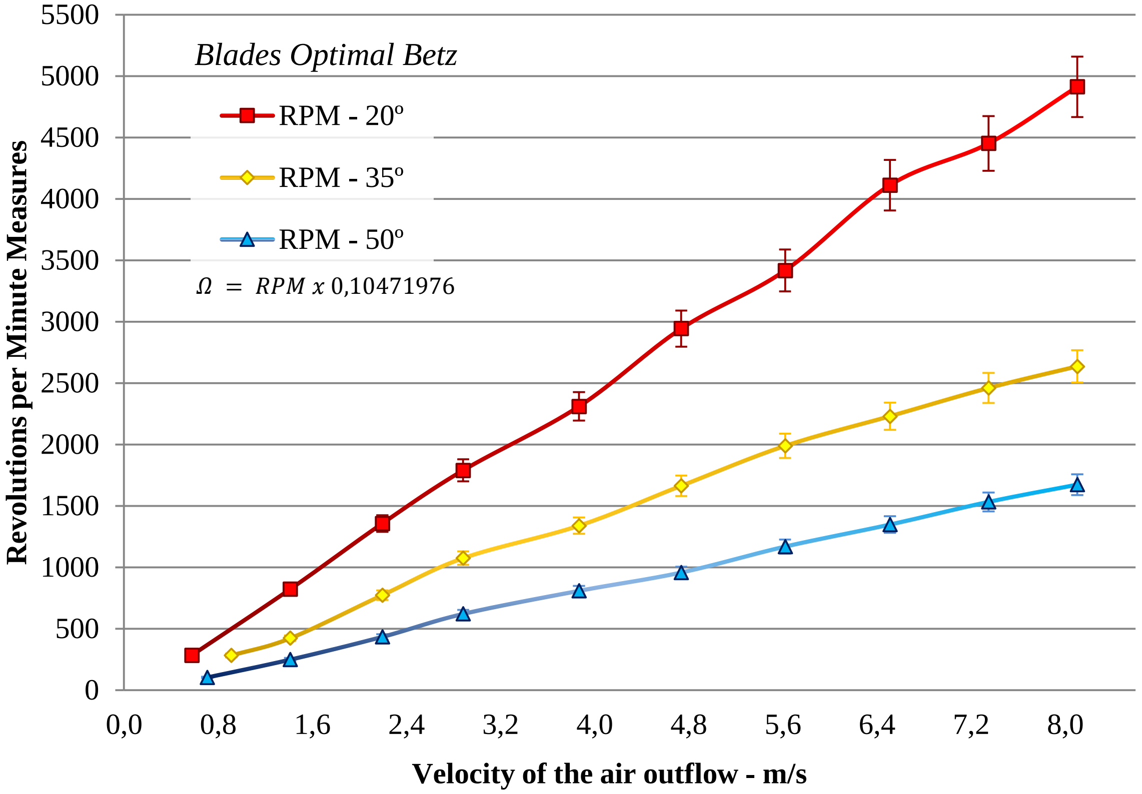


Figure 4 - Torque curve



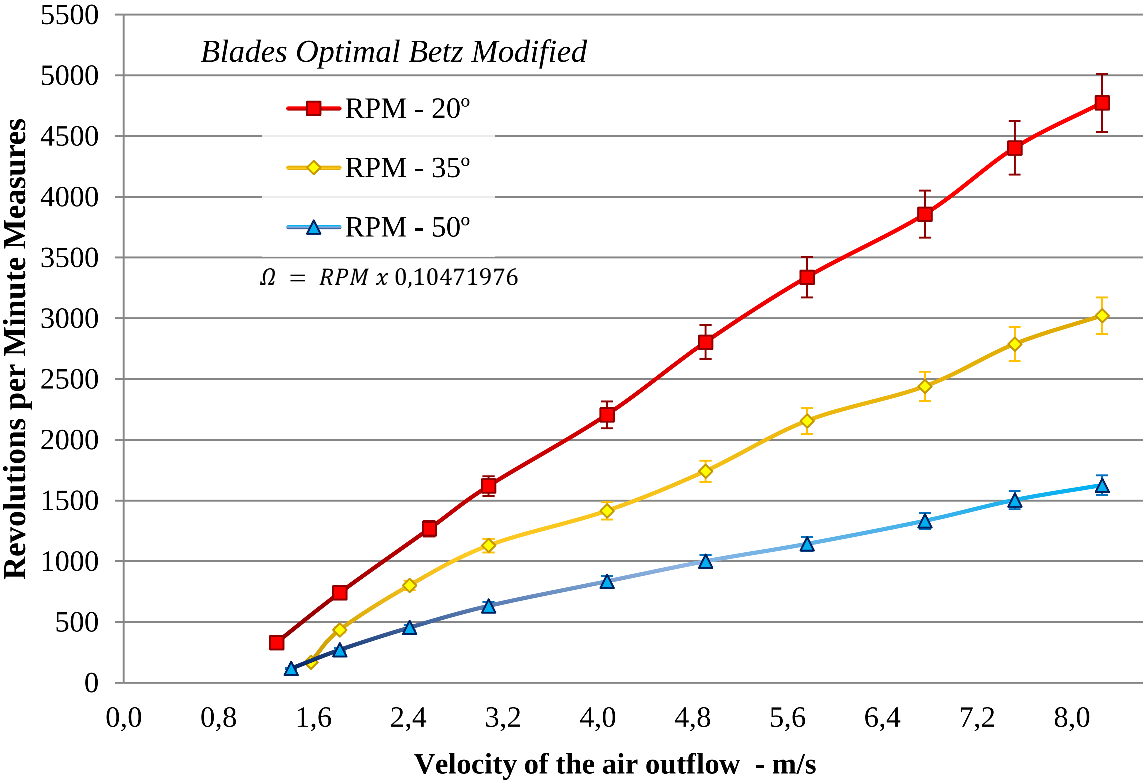


Figure 5 – RPM curve

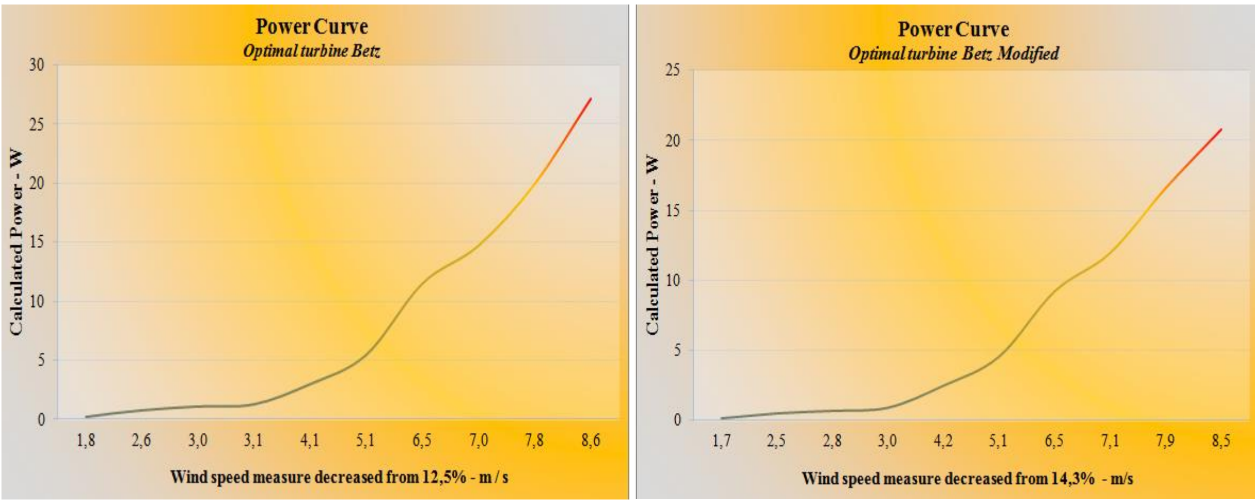


Figura 6 - Calculated power curve

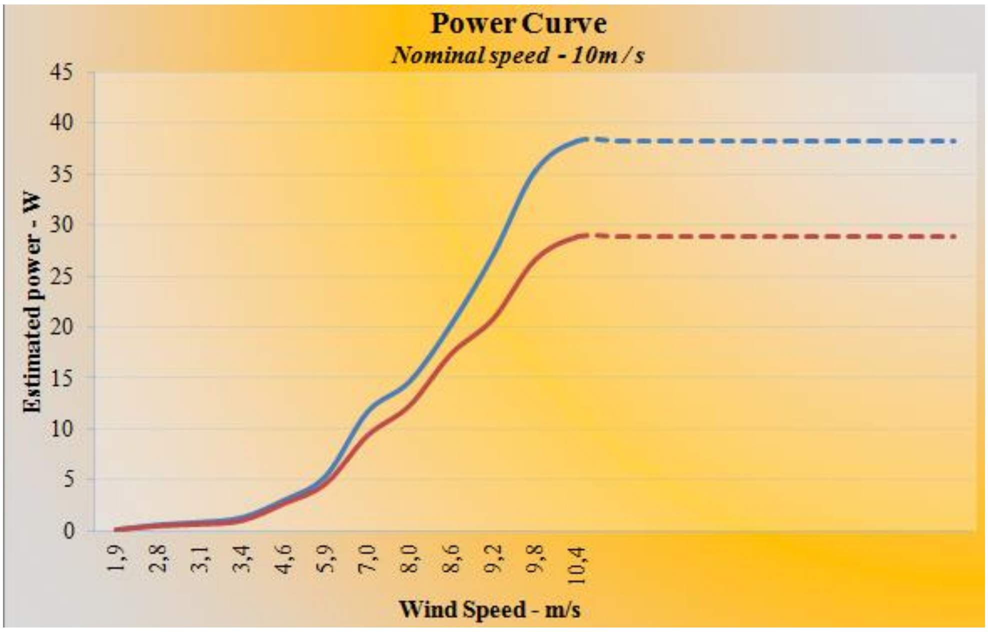


Figura 7 - Estimated power curve

4. CONCLUSIONS

The Small Wind Turbine market in Brazil is gradual and ascending development. But the data informed consumers do not always go along with this development. The aerodynamic characteristics and performance of a wind machine must follow the described by the rules to provide greater accuracy and credibility in the reported data. This standardization of testing brings benefits that can leverage the expansion and spread of this technology.

The data collected experimentally, aimed at making the information available to researchers and businesses. So before you draw one of a turbine income profile, get up a forecast of power generation and error reporting, without the investment in the construction and testing of a real machine.

Through experimental analysis of aerodynamic wake estimate a power coefficient ($C_{P\ Prototip}$) 35% to 28.6% and TOB for TOBM.

Analyzing the power curves of these models tested in P1-20,20º, the TOB extracts 22% more power flow than TOBM.

The experimental results demonstrate torque and power good approximation to the results obtained by evaluation by analytical element of the blade method. Since the static torque calculated was 9.1% higher than measured.

It is noted that experimental results in the best torque blade position is P2-35,20º, and in this position the turbine blades constructed of Great Betz static torque has 17.8% greater than with the blades Modified constructed.

The starting speed and angular velocity analysis shows better performance on tests is the TOB in P1-20,20º, giving the match with wind speed measured 0.58 m / performing 514.49 rad / s (4930 RPM) at 50 Hz.

For optimum relationship between angular velocity and static torque must construct a TOB with positioning of the blades and between P1-20,20º P2-35,20º. It can estimate that this new positioning is of 34.

According to the analysis of the velocity profile of the aerodynamic tunnel is understood that improvements in aerodynamic channel may result in a more constant flow at all points.

The experiments presented in this work, in addition to the efforts of other researchers and employees contribute to the design of a real wind turbine, the data obtained experimentally should be observed when confronted with the real turbine up and running. Thus, one can develop coefficients correlating the power curve raised experimentally in the laboratory with that is displayed when the machine is actually built. Thus, this correlation will bring more reliability when it comes to design yourself a small wind turbine, for before the turbine building, it will be possible to predict with an acceptable degree of accuracy how much equipment will generate energy. Added to that, the fact of certification bring greater reliability at the time of sizing and therefore as soon built a wind equipment is of paramount importance to have reliable power curves that do not generate sub or super dimensioning and it just is achieved taking into account the above the certification standards.

5. REFERENCES

ADINELSA. Administración de Infraestructura Eléctrica S.A**.** Disponível em: < http:// www.adinelsa.com.pe/Default.aspx>. Acesso em: 7 de maio 2014.

AIRFOIL TOOLS. Disponível em: < http://airfoiltools.com/polar/details?polar=xf-n0012-il-1000000-n5>. Acesso: em 18 de junho 2014.

Atlas do Potencial Eólico Brasileiro, pag.44, Brasília, 2001.

Audierne, E., Elizondo, J., Bergami L., Ibarra H., Probst, O., *Analysis of the Furling Behavior of Small Wind Turbines*. Applied Energy, 2010, Vol. 87, pp. 2278-2292.

AWEA. *AWEA Small Wind Global Market Study 2010*. American Wind Energy Association, 2010.

Balat, M., *A Review of Modern Wind Turbine Technology*. Energy Sources, Part A, 31:1561–1572, 2009.

BRASIL. Agência Nacional de Energia Elétrica - ANEEL. Resolução normativa nº 482, de 17 de abril de 2012.Estabelece as condições gerais para o acesso de microgeração e minigeração distribuída aos sistemas de distribuição de energia elétrica, o sistema de compensação de energia elétrica, e dá outras providências.*Diário Oficial da União*, Brasília, DF, 19 de abr. 2012. Seção 1, v.149, n.176, p.53.

Burton, T., Sharp, D., Jenkins, N., and Bossanyi, E.. *Wind Energy Handbook*. John Wiley & Sons Ltd, Toronto, 2001.

CBEE. Centro Brasileiro de Energia Eólica**.** Disponível em: < http://www.cresesb.cepel. br/principal.php >. Acesso em: 6 de maio 2014.

CEPEL. Centro de Pesquisa em Energia Elétrica. Disponível em: < http://www.cepel. br/> . Acesso em: 6 de maio 2014.

CHESF- Companhia Hidro Elétrica do São Francisco. *Fontes Energéticas Brasileiras, Inventário / Tecnologia***.** Energia Eólica. v.1 De cata-ventos a aerogeradores: o uso do vento. Rio de Janeiro, 1987.

CLIEVER. Disponível em: <http://www.cliever.com.br/> Acesso em: 15 de fevereiro 2015.

COMPOSITESWORLD. *The Markets Renewable Energy*. Disponível em: <http://www. compositesworld.com/articles/the-markets-renewable-energy-2012>. Acesso em: 19 de Abril 2014.

de Almeida, P., Silva P. **The peak of oil production - Timings and market recognition**, Energy Policy, v. 37, ed. 4, pp 1267-1276, 2009.

DEWI. German Wind Energy Institute. Disponível em: < http://www.dewi.de/dewi/ index.php>. Acesso em: 9 de maio 2014.

Eisenman, Harry J III. *Charles F. Brush: Pioneer Innovator in Electrical Technology*. Ph.D. Dissertação. Institute of Technology, Cleveland, Ohio, 1967.

Energy Information Administration *International Energy Outlook 2013*. With Projections to 2040. Disponível em: <http://www.eia.gov/forecasts/ieo/pdf/0484(2013) .pdf>. Acesso em: 15 de abril 2014.

IEC 61400-1: Wind Turbines - Part 1: Design Requirements 3ª Edição, 2005.

IEC 61400-2: Wind Turbines - Part 2: Design requirements for small wind turbines. 2ª Edição, 2006.

Manwell, J.F., McGowan, J.G., Rogers, A.L. *Wind Energy Explained: Theory, Design and Application*. Wiley, Chichester, New York, 2002.

WINDSAVE. BETTER GENERATION GROUP LTDA. Disponível em: <http://www.bet tergeneration.co.uk/wind-turbine-reviews/windsave-ws1200-wind-turbine.html>. Acesso em: 16 de maio 2014**.**

WPP. Wind Power Program**.** Disponível em: < http://www.wind-power-program.com/>. Acesso em: 11 de maio 2014.

WWEA. World Wind Energy Association**.** Disponível em: <http://www.wwindea.org/home/index.php?option=com_content&task=view&id=345&Itemid=43>. Acesso em: 17 de abril 2014.