PERFORMANCE EVALUATION OF THE NEXT GENERATION OF SMALL VERTICAL AXIS WIND TURBINE

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Summary: The use of renewable energies has been raised, over all with the big machines used in the wind farms. However, the small wind turbine market still has a big gap. The Small Vertical Axis Wind Turbine (VAWT) study aims at fill this gap, developing turbines with ranges between 200W and 500W. These characteristics permit to take advantage of the wind in regions were it has low speed, high turbulence and to be used in autonomous systems. This project will focus the prototype blades fabrication, methodology to analyze the power performance of the VAWT in lab and bench tests with generators.

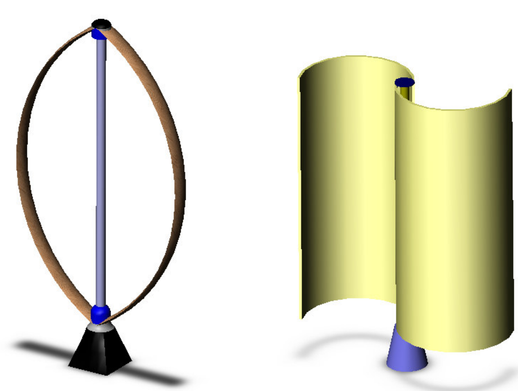
1. INTRODUCTION

Brazil is a continental dimensions country and its developing nation condition still does not satisfy all citizens' necessities of receiving electric energy in their homes. Part of the population does not have access to this resource for reasons of investment, but also because they live at difficult access places or in environment preservation areas. Allied to the technical development there is a concern with the environment aspects.
In this context, those called renewable energies, such as the wind energy, are actually attractive for the investors, from the conception to the installation of aerogenerators.

The object of this paper, the small vertical axis wind turbines (SVAWT), starts the study and development process of these new generation machines in Brazil. In the current situation of the country there is market for the small machines, beside the wind turbines uses in wind farms. The SVAWT`s to serve as an auxiliary generation source in urban areas or as an autonomous and independent way in regions far from the big centers.

The option for the vertical axis machines study and development was taken because of its characteristics which are seen as advantages to the application proposed, such as dispensing orientation systems, once they can start working in any direction of wind.

This particularity makes the operation of these machines easier in high turbulence regions, which are found in urban centers and also in rural areas with the presence of natural obstacles. The research of classical and current models of these machines is indispensable to carry out a paper like this, and it is also indispensable to mention classic models as Darrieus and Savonius. Darrieus model consists in low solidity machines, using symmetrical aerodynamic airfoils usually composing a rotor in Troposkien or Catenary shape [1]. With two or three blades, this model presents a variation that consists in a straight blades rotor named "Type H". Its characteristic is to work with wind high speed, having difficulty to start with low free wind drafts. Otherwise, Savonius model has high solidity and torque, so that it can be connected and used as an engine starter to Darrieus model.



(a) (b)

Figure 1. VAWT (a) Darrieus concept and (b) Savonius concept

Nowadays, the small machines development experiences variations of these models, looking for combinations of the main characteristics allied to aerodynamics innovations. Among the current proposals, high and low solidity machines can be found in many shapes, such as straight blades, Troposkien and helical.

The performance evaluation of small machines comprehends the aerodynamical analysis stages, prototypes designs and fabrication, laboratory tests, being stressed in this presentation the fabrication and laboratory tests stages according to the structure presented in the Fig. 2. Details of the project are presented in reference [2].

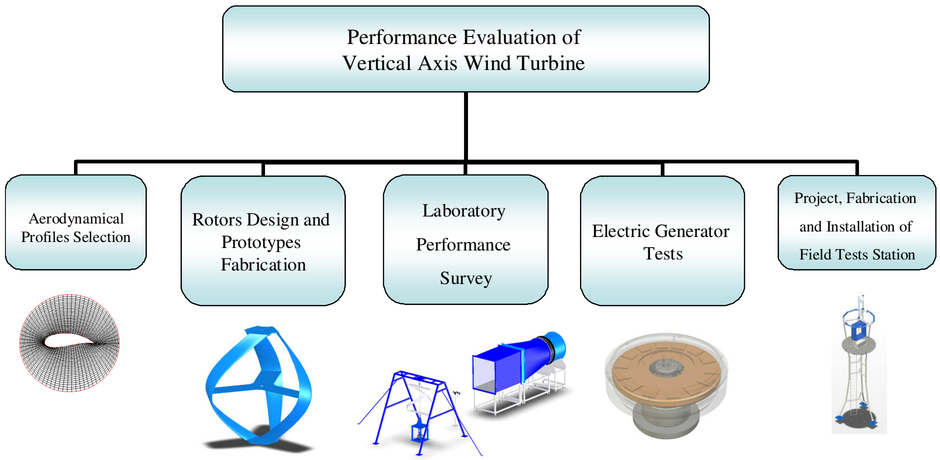


Figure 2. Structure of VAWT`s project

2. ROTORS DESIGN AND FABRICATION

Two basic geometries of VAWT`s had been used actually. A helical type and another Darrieus type of blades straight lines. The helical type of turbine has been applied in small hydroelectric turbines [3] e also in some models of wind turbines as the manufactured ones in England [4] and Nederland [5]. Examples of models Darrieus type of blades straight lines and high solidity have been currently manufactured in U.S.A. [6] and Italy [7]. This project presents the stages of manufacture and test of this type of geometries.

According to the proposed structure, the rotors design stage is preceded by the selection of aerodynamical airfoils. A qualitative analysis was made with simulations using the program PRO-TEEV [8], which was developed in the laboratory, with straight blades rotors of different airfoils through which were selected symmetrical airfoils of small thickness and anti-symmetrical airfoils of large thickness which accented camber for prototypes fabrications.

The prototypes design look for an optimized use of the kinetic energy received from the wind and it makes necessary an ideal relation between rotation and torque, with the proposal to adapt the right electric generator through the power coefficient of the machine. For doing it, helical designs using symmetrical airfoils were explored varying the solidity of the rotors. Straight blades prototypes were idealized searching, through anti-symmetrical airfoils with a certain angle of attack, rotors with efficient torque and moderated rotations.

The prototypes were made in fiberglass, what gives them an excellent finishing on its surface, low weight and balancing, making them ideal for tests stage due to the necessity of low production, reducing the costs with fabrication.

The Fig. 3 shows the design and the result of the fabrication of a high solidity helical rotor prototype with two blades using the symmetric airfoil NACA. The rotor's dimensions are 1m x 1m and the angle between blades tips is 180º.

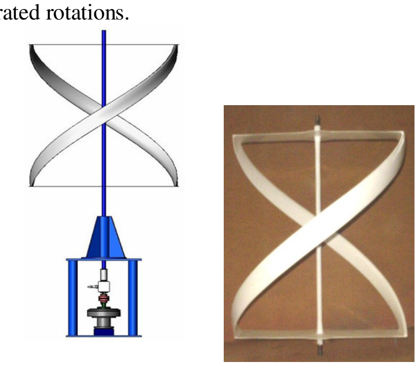


Figure 3. Design and prototype of helical rotor with 2 blades

The Fig. 4 shows the design and the result of the fabrication of a helical rotor prototype which, as the one showed before, has two blades using NACA symmetric airfoil but, because of the airfoils chord increase, from 180mm to 350mm, this rotor has high solidity.

In the same way, Fig. 5 shows a helical rotor with three blades using NACA symmetric airfoil. This rotor dimensions are 1m x 1m, with the angle between blades tips is 120°.

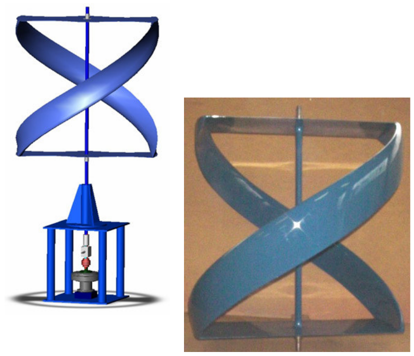


Figure 4. Design and prototype of helical rotor with 2 blades and high solidity

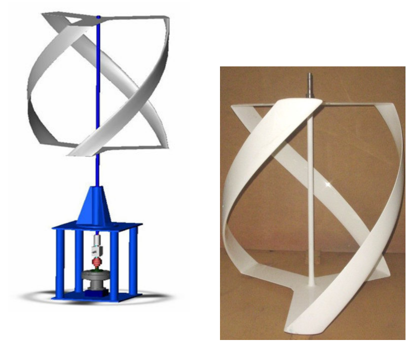


Figure 5. Design and prototype of helical rotor with 3 blades

Another model of a rotor made under a different concept uses straight blades with no symmetric airfoils and accented camber.

Between the blades, near the axis, there is a central element with a symmetric airfoil positioned in a way that accents the pressure in the blades internal surface.

This rotor is a high solidity one that is presented in the Fig. 6. Its dimensions are similar are similar to the others, but its blades chord are of 500mm.

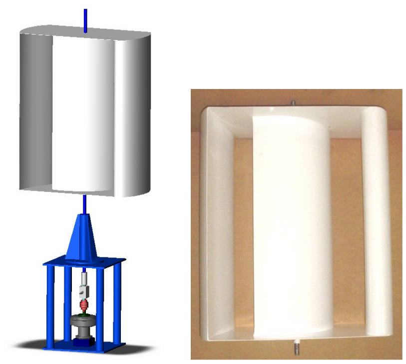


Figure 6. Design and prototype of high solidity rotor

3. LABORATORY PERFORMANCE EVALUATION

The performance evaluation of different rotors is made with prototypes tests in wind tunnel, following a methodology which permits to carry out a survey of potency and torque coefficients in relation to the tip speed ratio.

3.1 METHODOLOGY

The prototypes project and fabrication presented before have the purpose of evaluate the aerodynamic performance of rotors and obtain the power coefficient (Cp) and torque coefficient (Ct) as function of tip speed ratio (TSR), as well as torque and power for different rotation of turbines. The methodology used to carry this activity was developed at NUTEMA [9-10] and it is already use in tests with small horizontal axis wind turbines (HAWT`s).

The applied methodology consists in a system formed by a bank of batteries, a load bank DC and a load and tension controller of the batteries. An acquisition data system is used to measure the wind speed and the power of the turbine. The rotation, the temperature of the generator and the ambient temperature are also measured. The Fig. 7 shows this methodology.

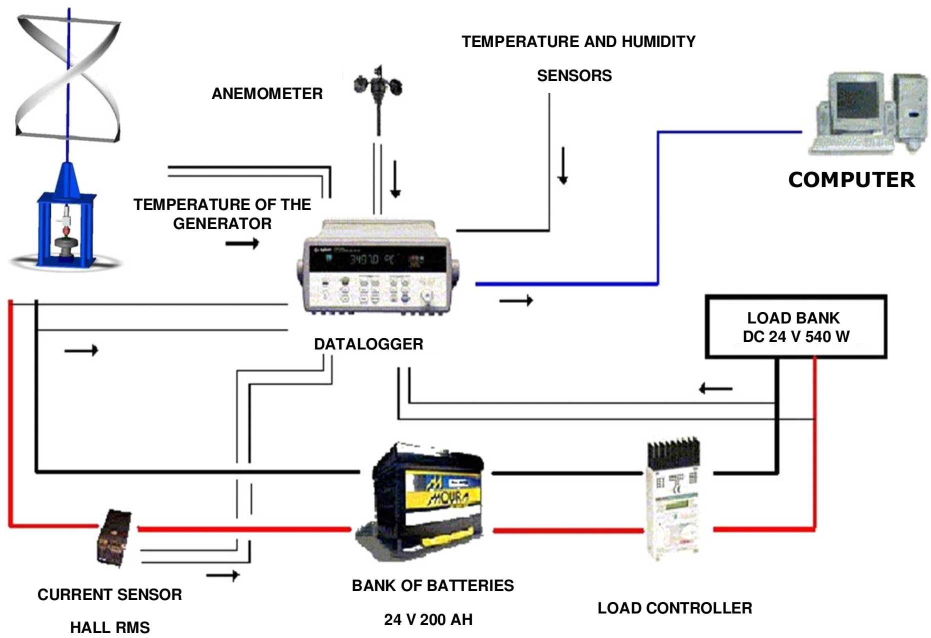


Figure 7. Methodology representation

3.2 LABORATORY TESTS STRUCTURE

To carry the laboratory tests with rotors it is necessary the confection of an structure to support the turbine counting on a mechanic and instrumentation system. A wind tunnel with modular structure and many independent sections was made using an a axial fan. The configuration adapted to the laboratory tests with VAWT`s prototypes is presented in the Fig. 8.

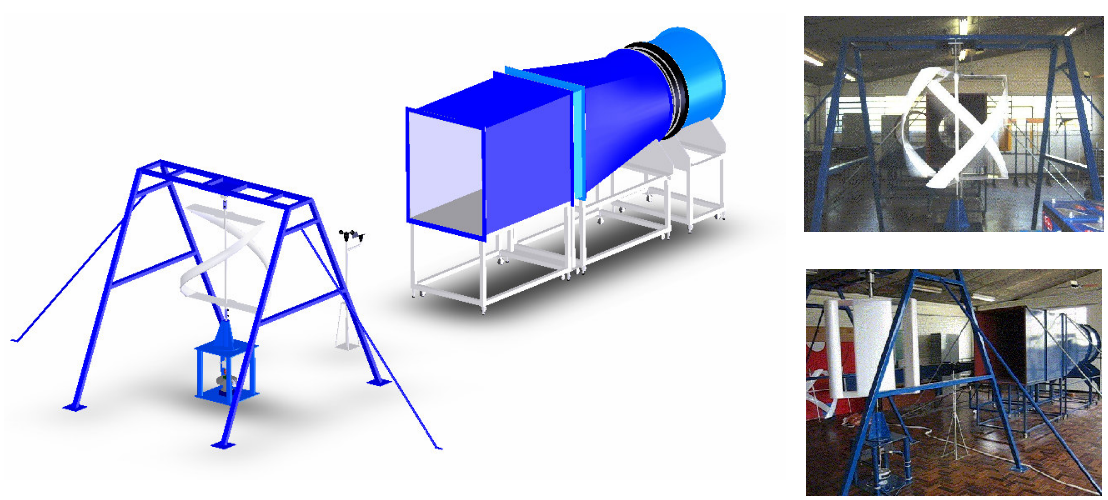


Figure 8. Laboratory tests structure

3.3 ANALYSIS OF THE RESULTS

Among the prototype models fabricated, the rotor with straight blades and high solidity was pointes out and presented the most satisfactory results. The results obtained to this VAWT were emphasized in this paper.

The results analysis was introduced through the presentation of the visualization of the flow lines in the airfoils of the rotor and of the static torque test carried.

With the airfoils positioned with angles of 0°, 45° and 90° to the stream lines, as shown in Fig. 9, we can see the influence of the central airfoil.

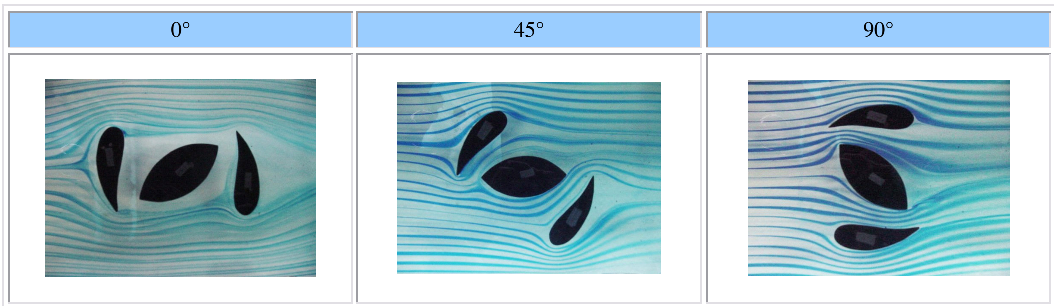
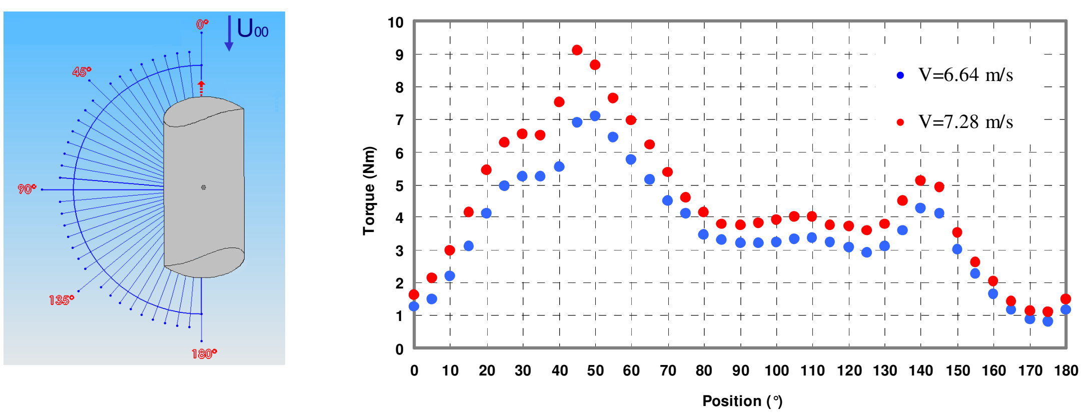


Figure 9. Visualization in hydrodynamic canal

The Fig.10(a) shows the variation in the turbine position to carry out the static torque test, which consist in keep the turbine totally braked up in front of the wind tunnel, measuring the torque in the rotor axis, to 5° step in a total variation of 180°. The results of this test are presented in the graphic of Fig. 10(b).



(a) (b)

Figure 10. Results of static torque test

In Figs. 11 and 12, the characteristic curves of potency coefficient and torque coefficient are presented because of the tip speed ratio (TSR) to the rotor of high solidity. The results were obtained through the application of the methodology presented in the item 3.1.

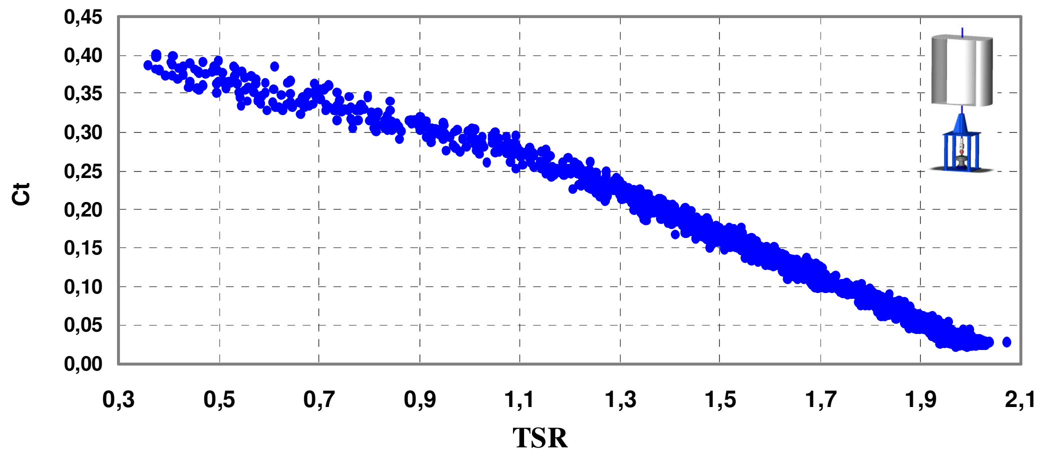


Figure 11. Curve of Ct versus TSR for the high solidity rotor

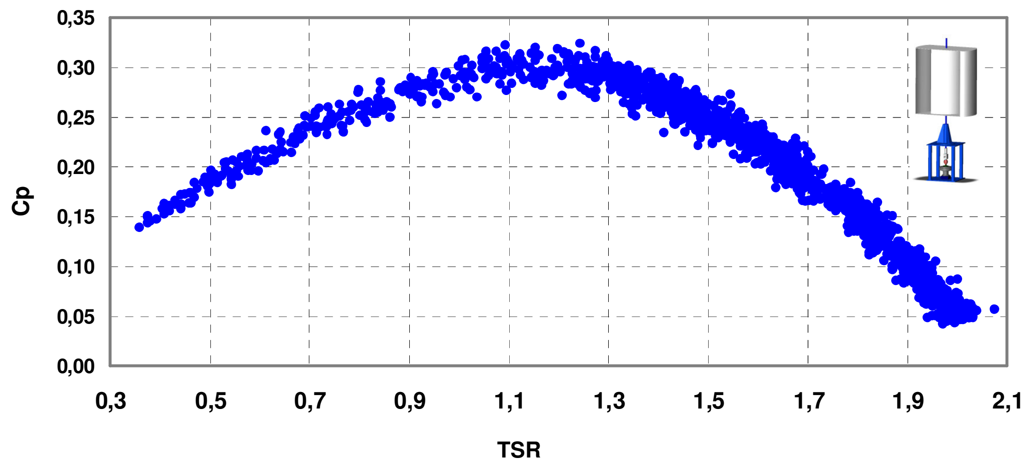


Figure 12. Curve of Cp versus TSR for the high solidity rotor

The relation between the maximum Cp and the Ct verified to the same TSR characterize this machine for its good performance in moderated rotations, which reduces mechanic problems, specially those related to the system vibration.

4. ELECTRIC GENERATOR TESTS

Preliminary tests with permanent magnet synchronous generator, PMG, in a specific bench permit the survey of characteristic curves, making possible the electric rotor and generator set optimization.

The first electric generators tested were equipments projected to horizontal axis wind turbines, which were fabricated and commercialized in Brazil. The results showed the necessity of a new generators project with the purpose to reach maximum performance in VAWT`s. With PRO-GIP, a computer program created at NUTEMA, which makes the relation between the performances equations by turbines and electric generators, the generator name E200W – 200 was fabricated. To this generator the results of bench tests are showed [13].

In the testing bench the electric generator is connected to a torque transducer and set in motion by an electric motor which has its rotation controlled by a frequency inverter. An outline of the methodology used is presented in Fig. 13.

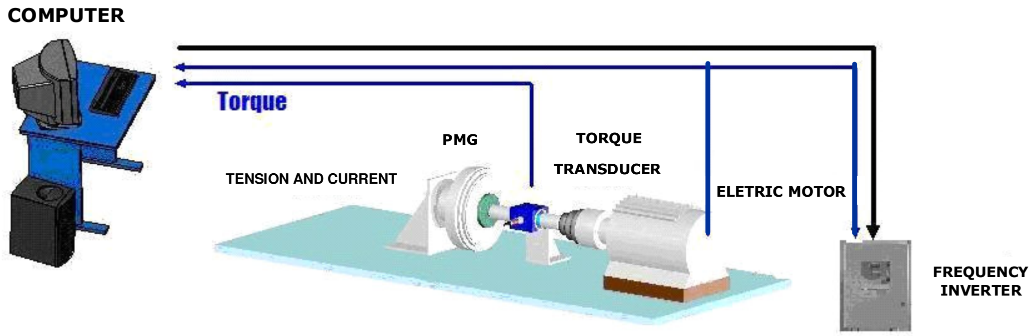


Figure 13. General outline of the generators testing bench

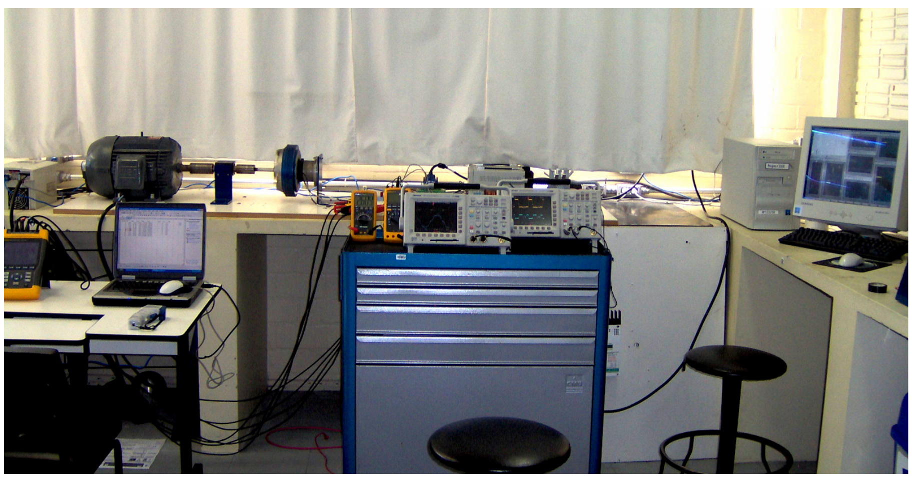


Figure 14. Testing bench

Fig. 15 shows the electric generator fabricated to the high solidity turbine model. The main data about this equipment are specified on Tab.1.

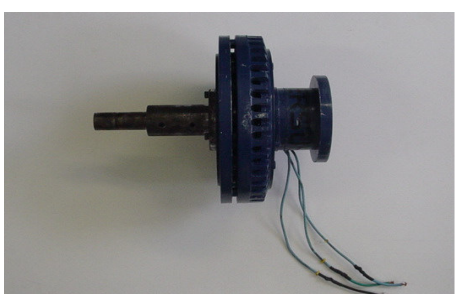


Figure 15. Electric generator E 200W -200

Tabela 1. Characteristics of the generator E 200W

Technical Specifications	
Nominal power	200W
Nominal rotation	200 RPM
Nominal tension	12 V
Number of poles	16
Number of phases	3

To the electric generator presented, the results obtained are expressed by the potency and torque curves with bank of batteries.

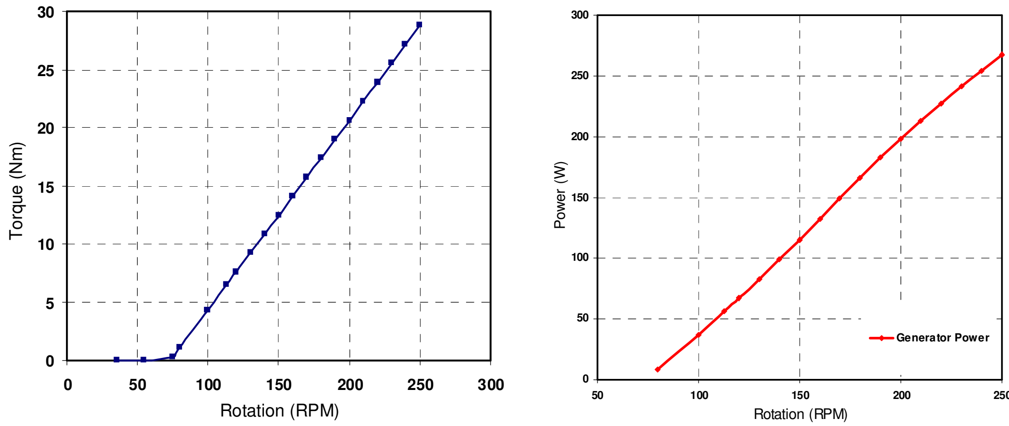


Figure 16. (a) Potency curves with bank of batteries and (b) torque curves with bank of batteries

5. STRUCTURES OF FIELD TESTS

The project and fabrication of a structure to field tests have the objective to obtain results that can be compared to the ones obtains in laboratory, expressing a real condition of use to these machines.

The structure is approximately 9m height and allows the exchange of rotors and electric generators, what gives it configurations versatility adjusted to the tests.

The electric generator is located under the rotor, directly connected to it a vibration reducer. It is protected of the weather by a fiberglass capsule.

Wind direction and speed sensors are installed above the rotor tests section.

Figure 17. Design of the structure and structure installed in field

Another structure model to these field tests is presented in Fig. 18 and this compact version aims the application in urban areas, on its own tower or on buildings. It is a simplified version of the tower presented in Fig. 17, using the same way to install the rotors.

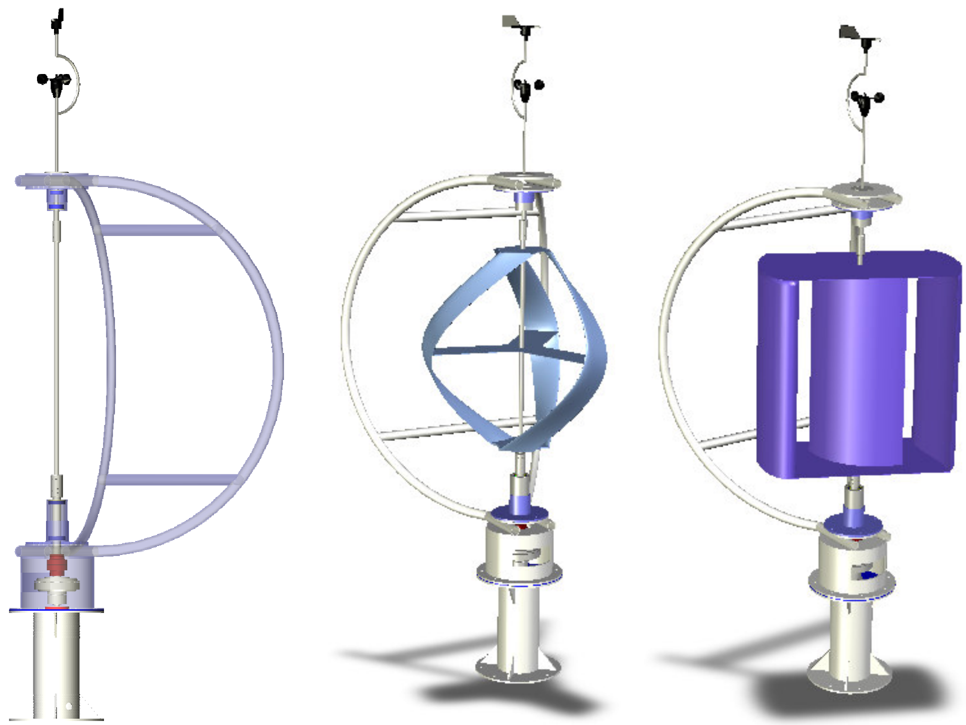


Figure 18. Visualization of the compact version for field tests and demonstration

6. CONCLUSIONS

The structure in which the project was based firstly aimed to study of traditional and modern machines, permitting a selection of models for fabrication.

The results of prototypes fabrication were satisfactory about the fidelity to the drafts and to material used, especially about weight and finishing.

Tests in wind tunnel permit to obtain information of the model prototype, such as power coefficient, torque coefficient as function of TSR. With these information, tests with high solidity models, to which were presented the main results obtained in laboratory were emphasized.

In function of the qualities techniques, permanent magnet generators were used, due to the high energetic concentration of the magnets, the brushes absence and the largest number of magnets that can be placed. The necessity of a study on the electric generators area ended up creating the PRO-GIP program, used in the project of permanent magnets generators.

Finally, the structures to field tests presented are installed in the south coast of Brazil, where tests with VAWT`s can happen in open field.

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