SMALL WIND TURBINES GENERATORS : POWER CURVE PERFORMANCE

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Abstract. The demand of Small Wind Turbines Generators (SWTG) has been increasing significantly in the world. Nowadays, exist more than 50 manufacturers of SWTG that represents more than 125 different models. In general, they are small companies with limitations to obtain the curve characteristic of their machines. Thus, a lot of SWTG are introduced in the market without certification and respective power curve.
The present work deals about a methodology that allows to obtain the curve characteristic of SWTG. A system including a DataLogger was used and a new power transducer was projected with capable to measure the instantaneous power of the turbine for different speed of wind.The turbine was tested in laboratory with its respective blades exciting through the flow of air of an axial fan. The instantaneous power, wind speed, rotation of rotor, and temperature of operation of the SWTG were monitored and measured. The preliminary results show that with this methodology proposal is possible to obtain the curve characteristic of SWTG. In the turbine in study, the power curve obtained in laboratory was low than the power curve supplied by the manufacturer.
In the continuity of the project, a field work will be accomplished and the same system will be tested, but, of this time, in conditions of natural wind. In this stage of the work, will be use as base the norm IEC614000-12 and tests and results found in other bibliographical references.

***Keywords**. Small Wind Turbine, Power Curve, Characteristic Curve, Performance Test.*

1. Introduction

The demand of Small Wind Turbine Generators (SWTG) has been increasing significantly in the world. Nowadays there are more than 50 manufacturers that represent more than 125 different models. Turbines from 50W to 50kW are available in the market. In spite of the technological development in the last 10 years and the growth of the market of such machines there isn't a pattern for the certification and tests of these turbines. Only in 1999 NREL (National Renewable Energy Laboratory) describes the procedure for the first certification of a SWTG in United States Corbus et al. (1999) recognizing that the methodology for certification of SWTG tests is now in initial phase.

In the case of Large Wind Turbine Generators the manufacturers counts with standardization norms for the test of its machines. In Europe the norm IEC 61400-12 threats about the methodology for test of power curves of wind turbines. The RISO National Laboratory of Denmark presents in 1990 practical recommendations for wind turbine tests. In United States AWEA (American Wind Energy Association) presents in 1988 recommendations to standardize tests of wind turbines. Credential laboratories in wind energy around the world (NREL, LAUGHTER, DEWI, ECN) accomplishes the certification of large wind turbines, however, such task is not economically attractive for small wind turbines. Besides, to build small turbine's power curve we must consider the existent differences in relation to the form as the generated energy is used. For example, Large Wind Turbines works connected on the electric grid while SWTGs works with batteries storage.

In the case of SWTG the power curves are made by the manufacturers, each one following some methodology without any normalization that certifies the quality of the results. On this context we can ask, which is really the guarantee that SWTGs acquired in the market presents the performance that is indicated in its catalogue? No one, since the manufacturer doesn't present nor the methodology or the quality certification of the accomplished tests.

For more severity of the curves presented by the manufacturers, the same ones should be obtained at laboratories that present equipments and technical quality following appropriate norms. In a project financed by CNPq (Alé, 2002) the Renewable Energy Laboratory of NUTEMA - PUCRS are working in a methodology to build the power curve of a SWTG. A MSc. dissertation is in development in this research line (Peña, 2002) which should be concluded in 2003. The main results obtained until now are presented here and compared with the manufacturer's information and of consulted bibliographical references.

2. Norms for Determination of Power Curves

IEC (International Eletrotechnical Commission) works on analysis and standardization of electric and electronic projects. The IEC 61400 norm refers to Energy Generation Systems using Wind Turbines, and the part 12 (IEC 61400-12) is about the methodology for test of wind turbine's power curves. It is divided in chapters, which threats test conditions, equipments used in the tests, measure procedures, and analysis of the results. The items below comments the most important topics of the norm as well as recommendations of Fransden and Pedersen (1990), of AWEA (1988) and of Corbus et al. (1999).

· *Local of the Tests*: The tests should be done in field under natural atmospheric conditions. The norm recommend to install turbines in an open place avoiding lands with trees, buildings and other obstructions that can affect the measuring of wind speed and also the wind turbine output power. There can be used only data collected from sectors where anemometer and turbine are not affected by interferences.

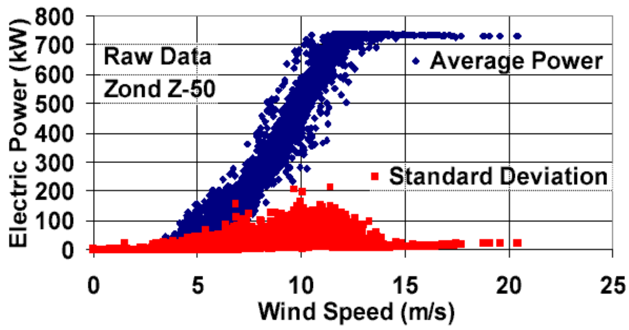
· *Electric Power*: The power transducer should measure true RMS of the active power. It should cover a band of - 50% to 200% of the nominal power of the turbine. The voltage should be maintained relatively constant during the tests. In the case of SWTG the voltage can be measured on the top of the turbine and also in batteries storage to determinate losses in the line. AWEA recommends that the power of the turbine be measured after all the losses obtaining the effective power delivered for the load. In a SWTG this happens between the load controller and the batteries. To SWTGs tests is recommended to measure the turbine performance in two voltages, both 112% and 96% of batteries nominal tension.

· *Speed of the Wind*: The speed of the wind should be measured with calibrated three cup anemometer. The uncertainty expressed as standard deviation of the anemometer should be less than 0,2m/s in the wind speed interval of 4 to 15m/s. It is recommended that the anemometer works at least two months in the field conditions before the measuring. It should be set up at ±1,0m of the cube height. The norms recommend installing a mast or tower separate from the turbine to accomplish measuring. The IEC 61400-12 recommend that the anemometer is installed between 2 to 4 diameters in front of the turbine. The American norms (AWEA) recommend placing the anemometer 1.5 to 6.0 diameters in front of the turbine. The norm specifies that only the data collected from the quadrants free from obstructions should be used to build the power curve.

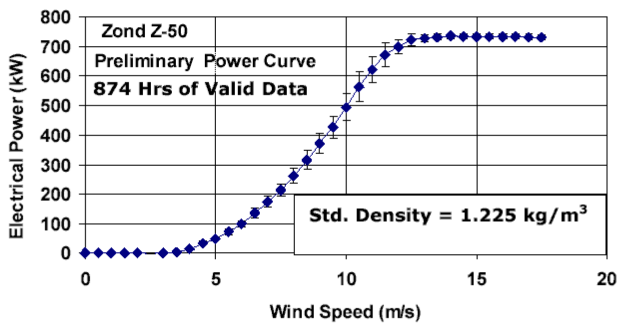
· *Direction of the wind*: Wind direction sensor should be set up in an arm moved away at least 1,0m from the mast of the anemometer. The norms recommend measuring the direction of the wind during the tests with identifying the predominant winds and the sectors where the tower makes interference to the anemometer.

· *Correction of the air density*: The power curves should be presented for standard air conditions. The temperature and atmospheric pressure should be measured to correct the air density to the standard atmospheric conditions. The sensors should be set up close of the turbine or in a meteorological mast to represent the air density in the center of the turbine rotor. The precipitation should be measured to separate the data obtained in raining periods.

· *Period of the Tests*: IEC 61400-2 Enclosure-E recommends applying tests in a period of 1500 hours of turbine energy generation and six months of operation with wind speed faster than 10m/s for 250 hours and 15m/s for 25 hours. It should reach 90% operation availability.



(a) Data without manipulation.



Source: VadensBosche et. al (2000)

(b) Data organized by bins method.

Figure 1. Example of a Wind Turbine's Power Curve.

· *Power Curve*: Between anemometer measured speed and the power supplied by the turbine exist different response times that should be considered. For its smaller inertia the anemometer responds faster than the wind turbine. This difference can make the machine performance measuring difficult by using instantaneous values instead of average values. The norms recommend that once accomplished the collection of turbine's power data, they should be organized in speed series intervals called "bins ". For example, in the speed interval of 3,0 to 3,5 m/s (bin of 0,5m/s) they gather all instantaneous power registered in this wind speed interval obtaining a medium value of the power. Such procedure is applied for all the speed intervals obtaining the power curve, as shown in Fig. (1). Recommendations of AWEA request a minimum of 60 samples for smaller bins of 12,5m/s, 20 bins samples for speeds between 12,5 to 15,6 m/s and 10 bins samples for larger speeds than 15,6m/s.

3. Field Tests to Determine SWTG Power Curves

Nowadays the information and publications that shows tests of SWTG are very limited. The manufacturers of SWTG are not accustomed to specify the adopted methodology when showing the power curve. Field procedures and tests in wind tunnel are methods that has been adopted. There is an international consensus that the best methodology to be used is to test the machine in real conditions of operation. For this reason all the international norms present a methodology that allows to obtain the power curve in field tests.

Corbus et al. (1999) describes the procedures for field tests and certification of a SWTG following IEC 61400-12. An AIR 403 turbine was tested in a tower of 14m with an anemometer placed 2.5 diameters away and another in a mast distant 15m of the turbine. During the tests the charge is controlled for the following battery voltages, 40%, 70% and 100%, with 60 hours of operation for each. For each one of the three voltages is necessary 30 minutes of data collecting for every interval of 0,5m/s (bin) of wind speed, and the data are recorded with 10 minutes average. Usually the authors describe the whole methodology. However, they are not used to show results obtained with this methodology.

At the moment the most significant results related with field tests of SWTG were accomplished by P. Gipe (2001). The author does some field tests obtaining the power curve of turbines in autonomous systems for remote applications with batteries storage. Five commercial turbines were tested: Bergey BWC 850 (850 W), Air 303, Air 403 (400W), LVM Aerogen 6F (280W) and Rutland 910-F (100W). In all tests the anemometer is installed in the same tower that sustains the turbine in an arm moved away from the tower and positioned in a lower height than the cube of the turbine. An NRG Maximum #40 anemometer were used and the author didn't measure the direction of the wind. The power is measured with a commercial transducer connected to the Nomad Data Logger from Second Wind Inc. adopting a one minute average for data collection. In the results he makes air density correction, however the temperature and atmospheric pressure are not measured. The results show that Southwest Windpower's turbines and the Bergey 850 turbine have power curves lower than the curve presented by the manufacturer. The other two ones present a similar performance to the one specified by the manufacturers. Even without following the international norms when testing the machines, the methodology is shown appropriate to compare the results to the manufacturers' ones. Bowen et al. (2002) presents the field results obtaining a power curve of a 10kW turbine with data collected in a 15 month period. The results show that the generated energy is only about 40% of the expected for the local average wind speed. Beyond the results of the power curve obtained with 10 minute averages are very inferior to the manufacturer's curve.

3. 1 Laboratory Tests of Wind Turbines

To characterize the power curve of wind turbines, the norms recommend that the tests are applied in field under natural atmospheric conditions. The specialized literature and international norms don't recommend tests in wind tunnel or hydraulic channels with models in scale. The present project intends to test the SWTG in two ways. One in laboratory with fan airflow and another in field in natural atmospheric conditions. A methodology developed in laboratory, at this stage of work, is shown which the machine receives an air flow through a free jet from an axial fan. In this method the speed of the air jet can be easily controlled. However, the fluid flow is very turbulent and it arrives in the plan of the turbine without uniformity. When varied the frequency of the fan's motor, an appropriate band of speeds can be had to determine the curve of the turbine. It should be pointed out that the procedure doesn't allow to obtain a uniform air flow that represents the conditions of an atmospheric or natural wind. Such type of fluid flow could be obtained in a wind tunnel. For example, the University of Technology of Delft in Holland has a wind tunnel of 2.2m of diameter by 10m of length with an axial fan of 45kW. The tunnel allows to do tests of wind turbines installed at a 2,0m distance away from the exit of the tunnel reaching 15m/s speeds. Rotors with diameter of 1,5m have been tested successfully. A posterior study will allow us to accomplish the same test, but with a more refined project using a wind tunnel with the same fan comparing the profile of speeds in the plan of the rotor to the power curve of both tests. The last stage will be the field test of the turbine.

4. Laboratory Metodology to Determine Power Curves

To determine the power curve of a SWGT a methodology was developed in laboratory in which the turbine is set in motion by the air flow of an axial fan of 10CV. The speed of the fan is regulated by a frequency inverter obtaining a band of speed from 2,0m/s to 17m/s measured in the exit section of the fan. To build the power curve of the turbine an autonomous wind system was prepared including batteries storage, a group of DC loads, and a load and voltage regulator of the batteries. To measure the requested variables, a data acquisition system was used (data logger) registering the wind speed measured with a three cup anemometer and the power of the turbine with a power transducer developed for the project. The rotation of the turbine was measured with digital tachometer. A barometer, sensor of humidity and sensor of temperature were also used for posterior correction of air density.

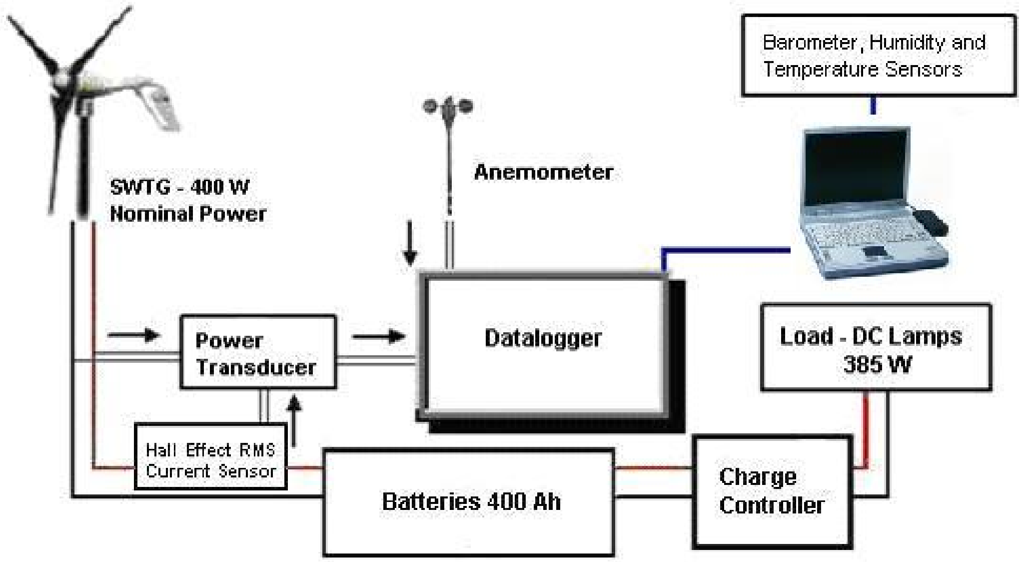


Figure 2. Test structure schematic.

4.1 Small Wind Turbine Features

In the tests a commercial turbine of Southwest Windpower model AIR403 of three blades and 1,17m of diameter with nominal power of 400W/12V to a speed of 12,5 m/s was used. The turbine doesn't have gearbox and the generator is permanent magnet type. The turbine generator produces three-phase alternate current (AC) rectified for direct current (CC) internally. The rectifier and the controller of battery charge are installed in the nacelle of the turbine. The blades of the turbine are manufactured of fiber injected carbon and molded. With superior speeds to 19 m/s the blades present an aeroelastical deformation originating stall, braking and protecting the turbine of extreme winds. The performance curve presented by the manufacturer is represented in the Fig. (3).

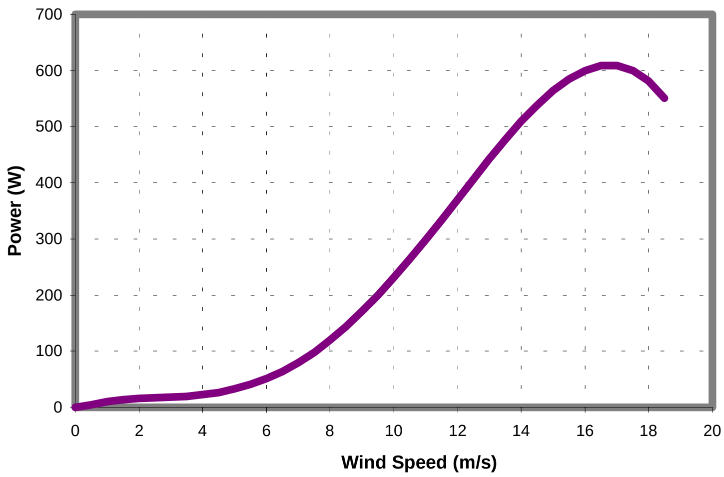


Figure 3. SWTG Air 403 e power curve presented by the manufacturer.

4.2 Power Transducer Project

To measure the power generated by the turbine, a power transducer was projected, Fig. (4) compatible with data logger used to store the wind speed data. The power transducer was adjusted in LABELO-PUCRS, credential laboratory for national and international metrology institutes, like INMETRO (Brazil) and PTB (German). The transducer curve is shown in Fig. (4).

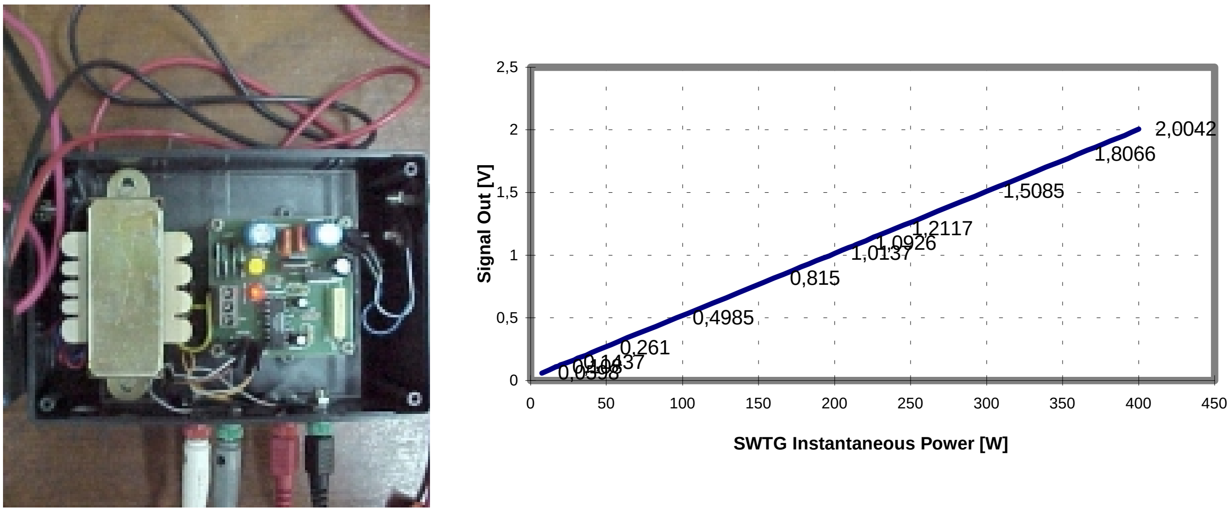


Figure 4. Power Transducer and its respective curve.

The transducer projected has a measurement uncertainty of ± 1,5%, which in output power means ± 6 W.

4.3 Air Speed Caracteristics on Turbine Plan

As shown in Fig. (5), the three cup anemometer was positioned for 1,0m moved away of the fan and the turbine distant 2,0m of the fan.

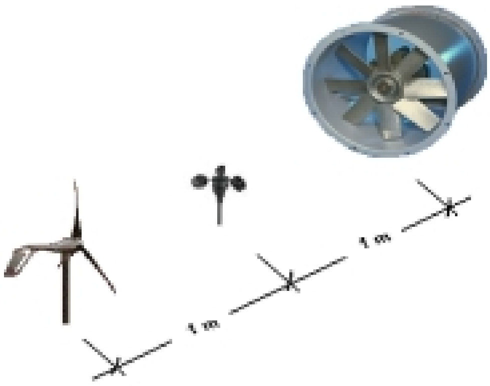


Figure 5: Scheme of separation between turbine, anemometer e axial fan.

If the experience had been done in a wind tunnel with a uniform test section, the anemometer speed would be easily correlated with the air speed in the plan of the turbine. In the present experience an axial fan of free jet was used in which the fluid flow is highly turbulent and the air speed profile in the plan of the anemometer is different from the air speed profile in the plan of the turbine. The procedure described below was done to correlate these speeds:

· The speed in the plan of the turbine was measured in a covered area for the swept area by the turbine blades 2,0m away from the fan.

· The speed of the anemometer was registered positioned at 1,0m of the fan.

· These results were related obtaining a correlation curve for posterior use in the determination of the SWTG´s power curve.

The swept area plan of the turbine was divided in small areas of 10cm by 10cm in which the instantaneous speed was measured and medium speed of whole plan was obtained. Such procedure has been done for frequency band from 15Hz to 65Hz. Figure (6) shows an example of the result of the speeds field in the plan of the turbine for the frequency of 50 Hz in which the mesh represents the swept area for the turbine. The mesh was interpolated using computer tools.

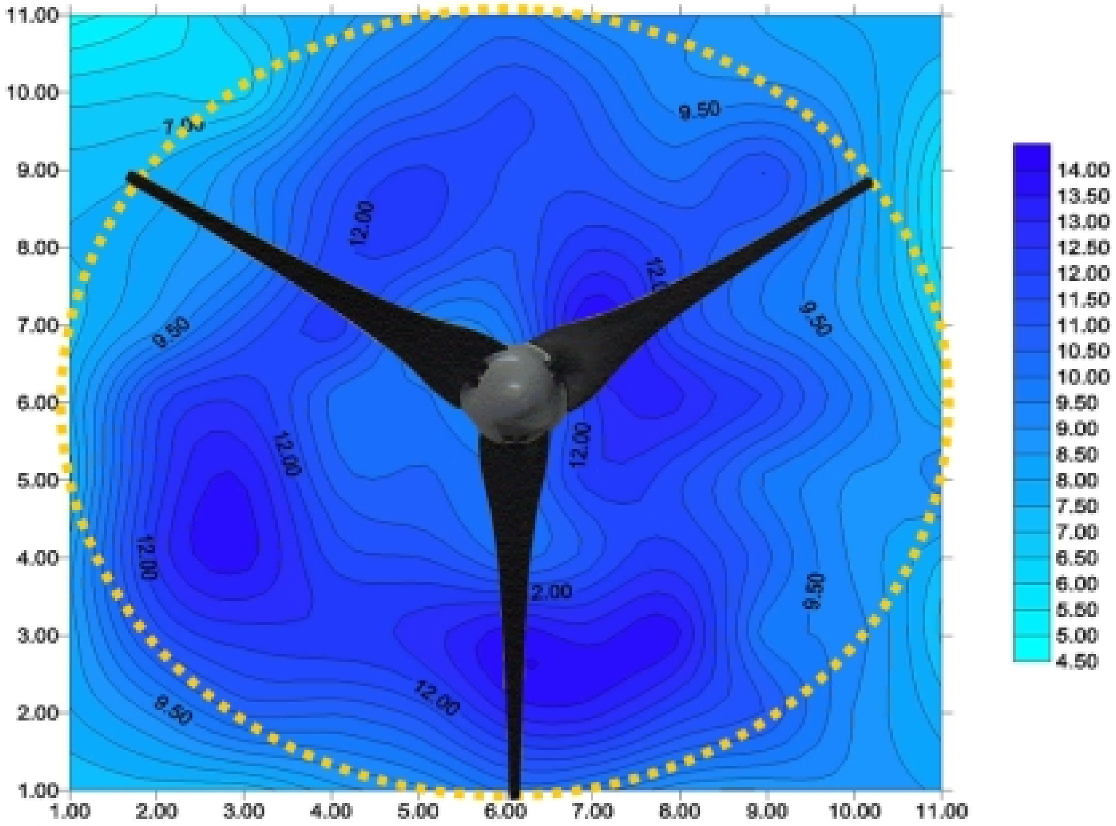


Figure 6: Air speed profile in turbine plane with inverter on 50 Hz frequency.

A correlation function among the speed of the anemometer and the speed in the swept plane for the blades of the turbine was obtained. Figure (7) illustrates this result.

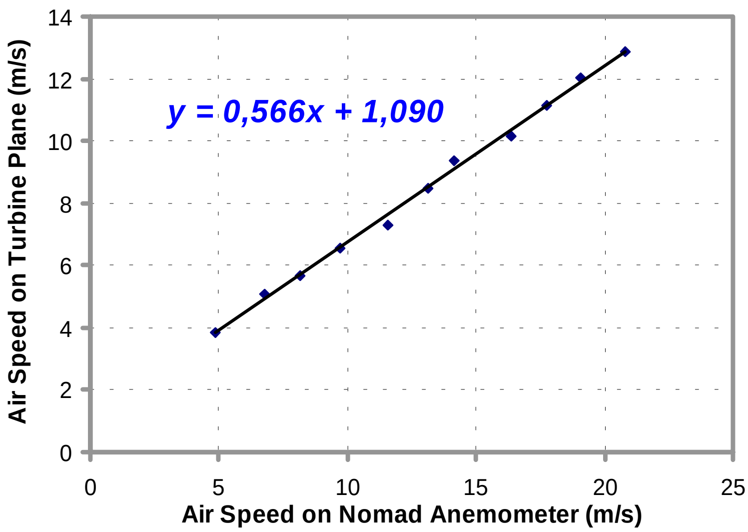


Figure 7: Curve relating air speed on anemometer and air speed on turbine plane.

4.4 Power Storage and Load Control

A batteries storage formed by four batteries 12V/100Ah connected in parallel with capacity of 400Ah was installed. For loads, lamps of 55W/12V were used totalizing 325W of load. To avoid the complete discharge of the battery during the tests a load controller was used (TRACE C-40) allowing consumption management of batteries, supporting a constant regime of 40A of current to picks of 65A. The load control flux gram is shown in Fig. (8).

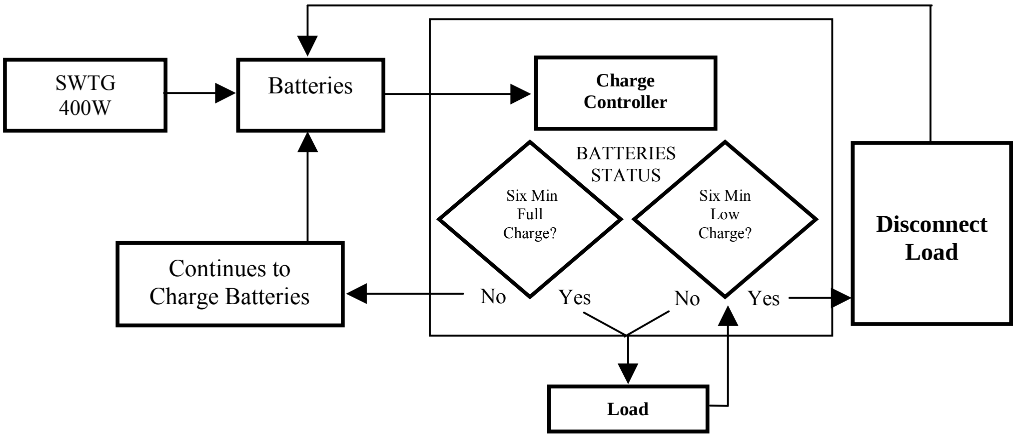


Figure 8: Flux gram showing load control.

4.5 Procedure for Data Acquisition

A commercial data logger from Second Wind Inc. model Nomad, shown in Fig. (9), was used to collect data. It has analog and digital entrances for monitoring such variables as speed and direction of the wind as well as temperature. This data logger allows to obtain samples of data every second and medium values of these data in intervals of 1min, 5min, 10min, 15 min, 30min and other larger intervals. Besides it allows organizing the data in bins making the power curve graphic an easy task. To measure the air speed a three cup anemometer of NRG Inc. model Maximum #40 was used. The power is measured with RMS Hall Effect current sensor and using the projected power transducer. The choice for a RMS sensor is due to the rectified current isn't pure DC itself. The anemometer was installed in a digital terminal, and the power transductor installed in an analog terminal of band 0 - 2,5 V. The data logger was configured for data collection of one in one minute with calculation of average, maximum, minimum and deviation for the wind speed and power generation following the recommendation of IEC 64100-12. The air temperature and atmospheric pressure data allowed to do the correction of power curve for the conditions of standard air density (1,225 kg/m3). To carry though the tests, the rotation of the fan was modified varying the frequency of the inverter of one in one Hz during 10 minutes obtaining a band of air speed in the plan of the turbine from 2,0 to 15m/s. The power output band acquired in the tests was from 0 to 410 W. The total time of tests was approximately eight hours. The rotation of the turbine was also measured with digital tachometer correlating this information with the power results.

Figure 9: Detail of bench test showing data logger and power transducer.

According to the power of the turbine, monitored by the Data Logger, the load had been increased to maintain constant the consumption of the batteries in the whole test. For example, if turbine was generating 110 W, two lamps were turned on, so the load was also 110 W. This way the turbine control system doesn't brake the turbine to protect batteries storage, so the SWTG generates the possible power for an air speed. The load controller was connected during all process, in case an intervention in the voltage of the batteries was necessary. After the end of the tests data had been transferred for a PC through serial port and formatted in electronic datasheet using the method of the bins. The power data related with air speed in the plan of the turbine allowed to determine the power curve of the turbine. Figure (10) shows a picture taken during laboratory tests.

Figure 10: Test in laboratory of a 400W SWTG.

5. Results

The power curve results obtained from the described methodology is shown on Fig. (11) and Fig. (12), and it is compared with the manufacturer's curve and also with the results obtained by P. Gipe (2000). The obtained results are closer the obtained by P. Gipe than the curve presented by the manufacturer. Recent tests accomplished by P. Gipe (2003) with other models of Southwest Windpower reveal that new turbine models present lower performance than the manufacturer expected. The relation between power output and rpm is shown in Fig. (13).

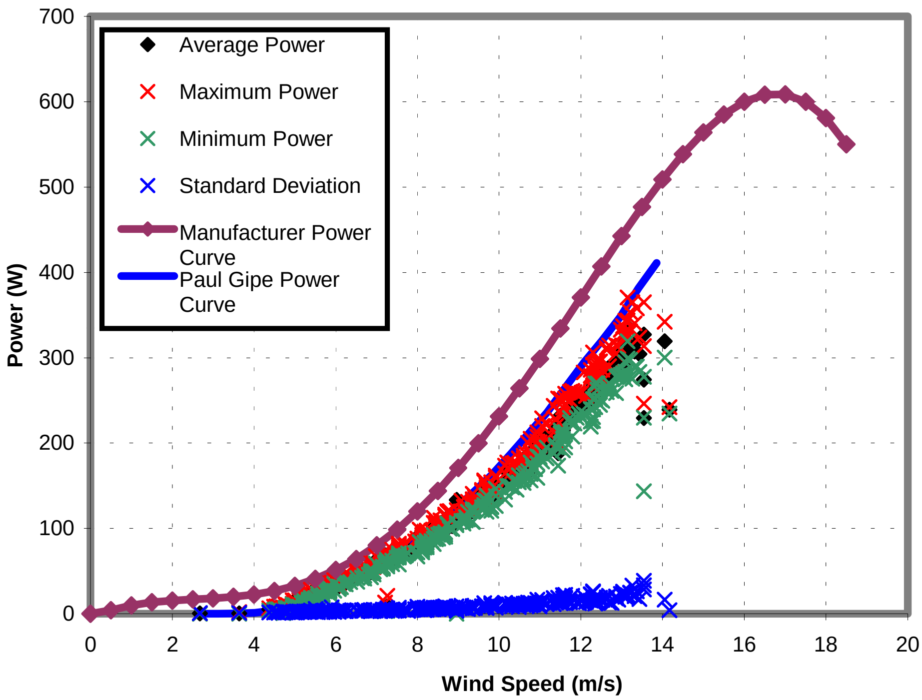


Figure 11: All power variables collected.

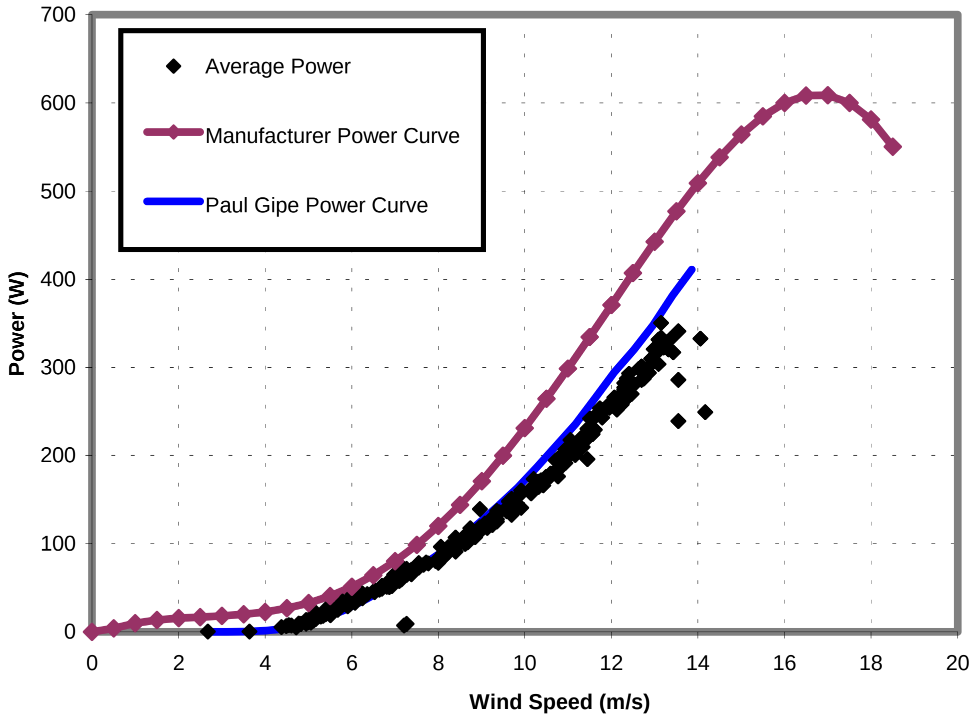


Figure 12: Comparison between average power collected and two other power curves.

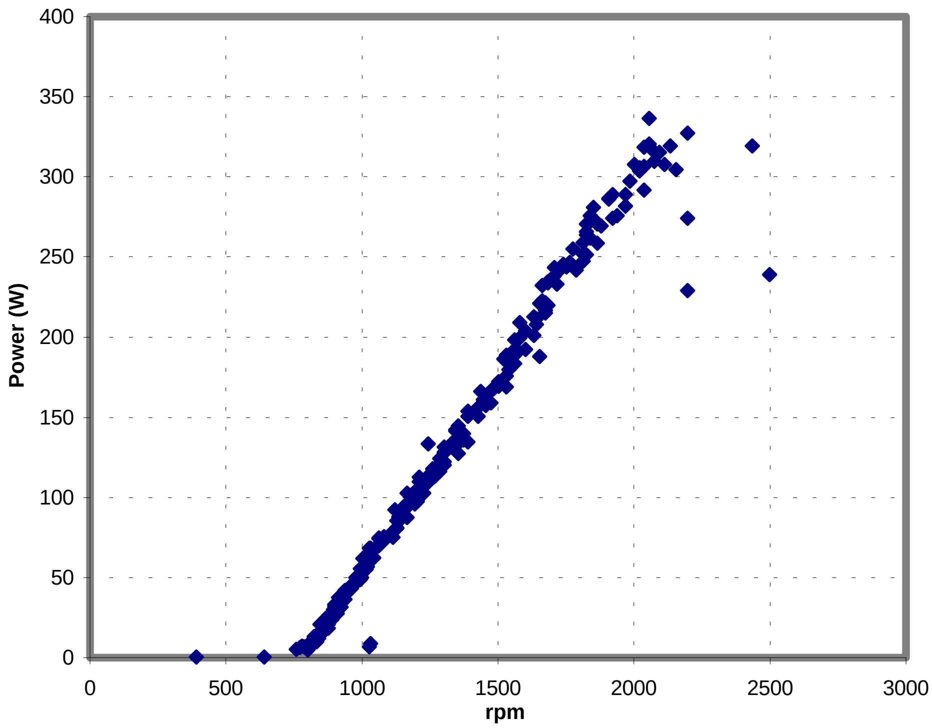


Figure 13: Data relation between power and rotation.

6. Conclusions

The results show that with the proposal laboratory methodology is possible to determine the characteristic curve of SWTG. The developed power transducer had been shown efficient and it can be used easily to obtain the curve of another turbines.

The power curve obtained in laboratory is shown inferior that the curve supplied by the manufacturer's catalog. However it is shown close of the obtained in field with the same turbine model for P. Gipe [2001].

The specialized literature and international norms don't recommend to do tests in laboratory. However, the tests up to now accomplished with the present methodology in laboratory allowed encouraging results when compared with measurements in field of the consulted bibliographical references. Only applying the methodology to other small turbines and comparing with tests in field we can have more conclusive answers on the validity or not of the proposed method. The main advantage of the method is that the tests are accomplished in reduced period of time with environmental factors controlled in laboratory. A latter study will allow to do tests using a wind tunnel with the same fan, in other to compare the air speed profile in the rotor plan and its influences in the determination of power curve. The automation of frequency control in the fan is a work that is in development and will allow to reduce the time and to make data collection easier. The use of a calibrated anemometer is also recommended in the norms and it should be incorporated in the next measurements. It should also be made an analysis of instruments and equipments errors. Now the turbine is being tested in field according to the norm IEC 61400-12. We hope to compare such results with laboratory ones and use this to validate or to question the procedure adopted in laboratory.

In spite of the difficulty of the monitoring task, evaluation and quantification of SWTGs performance results, this science is walking for visible improvements. The standardization lack for performance tests and certification has been stimulating the research obtaining results as presented here.

Systems using SWTG presents a market in expansion, being important for who buys these machines to confidence in the expectation of energy generation supplied by the manufacturers. We have been observing that in the current context it is not possible to enjoy of this confidence, being necessary that the manufacturers present with scientific methods the results of its machines and adopt standardization for the determination of this curves that reflects their behaviors in field conditions. The present work line objectifies to count with a methodology that it can be used for verification and test of national and imported SWTG, giving larger safety to the costumer about the quality of the acquired equipment and the power and energy effectively it will be able to count on.

7. Bibliographic References

Standard IEC 61400-12, International Electrotechnical Commission (IEC), “Wind Turbine Generator Systems Part 12 – Wind Turbines Power Performance Testing: Wind Turbine”. 88/66 CDV, January 2002.

Alé J.A. “Levantamento de Curvas Caracteristicas de Turbinas Eólicas de Pequeno Porte”. Projeto CNPq, Process 478039/01-8. 2002.

Peña G.M. “Instalação, Monitoramento e Análise de Performance de Sistema Eólico Autônomo de Pequeno Porte” Msc thesis (To be concluded in 2003).

Gipe P. “The Need for a International Small Wind Turbine Test Center.”, 2002, www.chelseagreen.com/Wind/Articles/NeedTest.htm

VandenBosche, J., McCoy, T., Rhoads, H., McNiff, B., Smith, B., “Power Performance Testing Activities in the DOE-EPRI Turbine Verification Program”. WindPower 2000 Proceddings, AWEA, Palm Spring, CA May 2000.

Corbus D.; Link. H.; Butterfield, S.; Stork, C.; Newcomb, C.; Sasseen T. “Certification Testing for Small Wind Turbines” NREL/CP-500-27062. Burlington, Verm. October, 1999.

Curvers A., Petersen T. F. “Recommendations for a European Wind Turbine Standard on Performance Determination” ECN–217 July 1989.

AWEA. “Standard Performance Testing of Wind Energy Conversion Systems”. 1.1 – 1988.

Gipe, P. “Testing the Power Curves of Small Wind Turbines”, WindStats Newsletter, Vol.13, nº3, 2000.

[0]RISO “Power Performance Testing – Recommended Practices for Wind Turbine Testing and Evaluation”. 2nd Ed; Denmark, 1990.

Fransden S. Pedersen B.M. “Recommended Practices for Wind Turbine Testing: Power Performance Testing”. (1990). Executive Committee of the International Energy Agency Programme for Research and Development on Wind Energy Conversions Systems.

Bowen A.J, Zakay N., Ives R.L., “The Fiel Performance of a Remote 10kW Wind Turbine., Renewable Energy, 2002, (article in press). www.elseiver.com.

Wilmot N.A., Pryor T.L., Spooner E., Brix B. “Overview of The testing and Standards Project within ACRE and Testing Protocol used for a new 5 kW Wind Turbine Demostration”. www.science.murdoch.edu.au.

Gipe P. AirX Fails Power Curve Test, 2003. www.homepages.enterprice.net/hugh0piggott/gipe/

7 Acknoledgements

We’d like to thanks CNPq for sponsorship of this research as well as Capes for the Msc. scholarship that allowed to do the activities described on this work. Thanks to our colleague Msc. Engineer Julio César Marques Lima for helping us in technical details on power transducer. We’d also like to thanks Engineer João Miguel Lac Roehe from LABELO for helping us on the power transducer test.