LABORATORY TESTING OF SMALL WIND TURBINES

Peña, Gustavo de M.
Pontifical Catholic University of Rio Grande do Sul
NUTEMA – Renewable Energy Laboratory - Ipiranga ave, 6681. Porto Alegre, RS, Brazil
gmpena.cz@terra.com.br

Alé, Jorge A. V.
Pontifical Catholic University of Rio Grande do Sul
NUTEMA – Renewable Energy Laboratory - Ipiranga ave, 6681. Porto Alegre, RS, Brazil
villar@pucrs.br

Adegas, Fabiano D.
Pontifical Catholic University of Rio Grande do Sul
NUTEMA – Renewable Energy Laboratory - Ipiranga ave, 6681. Porto Alegre, RS, Brazil
fda@pucrs.br

Abstract. The demand of Small Wind Turbines Generators (SWTG) has been increasing significantly in the world. Nowadays, there are more than 50 manufacturers of SWTG who represent over 125 different models. In general, they are small companies with limitations to obtain the characteristic curve 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 power curve of SWTG. A system, including a data logger, was used and a new power transducer was projected with capacity of measuring the instantaneous power of the wind turbine for different wind speed. The wind turbine was tested in laboratory with its respective blades stimulated by 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 proposed methodology, it is possible to obtain the curve characteristic of SWTG. In the wind turbine studied, the power curve obtained in laboratory was lower than the power curve supplied by the manufacturer, but closer to the ones found in the bibliographical references about power curve testing. In the continuity of the project, a field work will be accomplished and the same system will be tested, but, this time, in natural wind conditions. In this stage of the work, the standard IEC614000-12 will be used as reference, as well as tests and results found in other bibliographical references.

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

1. Introduction

The power curve, or characteristic curve, of wind turbines, is a very important data base, since it makes possible the analysis of performance of the wind turbine for a determined region, according to the study of distribution of wind speed, for the estimate of the energy that might be generated. Therefore, it is of extreme importance that this curve is reliable and real.

In spite of the technological development from the past 10 years, and also the growth of the wind turbine market, nowadays, for small wind turbine generators (SWTG), there is no certificate standards or performance tests for these machines, not even standards for power curve determination. The manufacturers generally provide these data in their catalogs, however, they do not make reference to the procedures adopted to generate the power curve, especially because there are no standards, but it makes the users purchase the machine, relying on a generation of energy that might not be real.

Only in 1999, the National Renewable Energy Laboratory (NREL) described the procedure for the first certification of a SWTG in the United States, Corbus et al. (1999), recognizing that the methodology used for the certification of SWTG tests is currently in its initial stages.

Regarding to High Wind Turbine Generators (HWTG), the manufacturers take into consideration norms of standardizing for the testing of their machines. In Europe, the standard IEC 61400-12 deals with the methodology of wind turbine power performance testing. RISO (National Laboratory of Denmark) presented, in 1990, practical recommendations for wind turbine testing. In the United States, the American Wind Energy Association (AWEA) presented, in 1988, recommendations for the standardizing of wind turbine testing. Laboratories accredited on wind energy worldwide (NREL, RISO, DEWI, ECN) perform the HWTG certification, however, such task is not economically attractive when it comes to SWTG.

The International Eletrotechnical Commission (IEC) works on the study, analysis and standardizing of electric and electronic projects. Standard IEC 61400 refers to Wind Turbine Generator Systems, being that part 12 (IEC 61400-12) deals with the methodology of HWTG power performance testing. This part is subdivided into chapters, in which topics such as test conditions, test equipment, measurement procedures and the analysis of the derived results are approached.

This standard recommends a final report on the derived results, whose format must be followed according to its specifications.
In the case of SWTG, the power curves are presented by the manufacturers, each following their own methodology, without any normalization that certifies the quality of the results. Therefore, one can ask what really is the guarantee that a SWTG, purchased in the market nowadays, gives for the power curve indicated in the catalog? None for the buyer, since the manufacturers do not present the methodology, neither the certification of quality of the testing performance.

For a higher control of the data quality provided by the curves presented by the manufacturers, these curves should be obtained or certified in laboratories or entities who provide equipments of technical quality following the appropriated standards.

With a project financed by the Brazilian National Counsel of Research and Development (CNPq – Alé, 2002), the NUTEMA-PUCRS Renewable Energy Laboratory has been working in a methodology to obtain the characteristic curve of the SWTG. A MS dissertation, following this research trend (Peña, 2002), is being developed, and it should be finished by the end of 2003. The main results obtained so far are presented here and compared to the information given by the manufacturer and bibliographical data consulted.

2. Developed Technology for Obtaining of SWTG Power Curve

2.1 Field Technology

There is an international consensus about the best technology to be employed, that is, it is the one which tests the machine in its real operation conditions; that is why all the international standards present a methodology which makes possible the determination of these power curves in field testing.

Currently, there is a limited number of information and publications presenting the SWTG tests. The SWTG manufacturers, when presenting the power curve, do not specify the adopted methodology. Corbus et al. (1999) describe the procedures for field testing and the certification applied to a SWTG which, in general, follows the standard IEC 61400-12. In his testing, he used a SWTG (400W), placed in a 14m high tower, with one anemometer placed by 2.5 diameters from the wind turbine, and another placed in a mast 15m away from the wind turbine. During the test, the charge is controlled for voltages corresponding to the state of charge (SOC) of the battery of approximately 40%, 70% and 100% with 60 hours of operation for each SOC voltage. For each of the three SOC voltages, it is necessary 30 minutes of data for each interval of 0.5m/s (bin) of wind speed. The data is stored each 10 minutes in average.

Generally, the authors describe all the methodology, however, they do not present the results of the power curve obtained with the methodology employed.

Until the present moment, the most significant results related to SWTG field testing have been performed by Paul Gipe (2001). The author performs a series of field tests, obtaining the wind turbine power curve, which operate in autonomous systems (application of battery storage).

Gipe has tested 5 commercial wind turbines: Bergey BWC 850 (850W), Air 303, Air 403 (400W), LVM Aerogen 6F (280W) and Ruthland 910-F(100W). In all tests, the anemometer is placed in the same tower where the SWTG is, but separated from the tower by an iron bar and placed in a height lower than the wind turbine hub. An NRG Maximum #40 anemometer was used, but the author did not measure the wind direction. The power is measured with a commercial power transducer connected to the Second Wind Inc. NOMAD data logger, adopting averages of 1 minute in the data collecting. In the results, the air density is corrected, however, without measuring the temperature and barometric pressure. The results show that the Southwest Windpower wind turbine and the Bergey 850 one present a power curve inferior to the one given by the manufacturer. The other two present a performance analogous to the one specified by the manufacturer. Even without following the international standards to test the machines, the methodology shows to be adequate in comparing the results with the ones from the manufacturers.

Bowen et al. (2002) present the field results, obtaining the power curve of a 10kW wind turbine collected in a period of 15 months. The results show that the generated energy ranged around only 40% of the expected energy for the local average wind speed. Besides, the presented results of the obtained power curve with averages of 10 minutes were much inferior than the manufacturer’s curve.

2.2. Laboratory Technology

As mentioned before, to characterize the SWTG power curve, the standards recommend that the tests must be performed in field under natural atmospheric conditions. Specialized literature and international standards do not recommend tests in wind tunnels, hydraulic channels with models in scale. However, the purpose of the present project is to test the SWTG in two kinds of tests. One in laboratory, with fan air flow, and another in field, under natural atmospheric conditions.

In this work, it is showed the methodology developed in laboratory, in which the machine receives an air flow through a free jet of an axial fan. With this method, it is possible to control the speed of the air jet easily, however, the flow is highly turbulent and reaches the wind turbine plane without uniformity. Changing the frequency of the fan motor, one can obtain the adequate range of wind speeds so to obtain the wind turbine power curve. It is important to notice that the procedure does not allow the obtention of a uniform air flow which represent the conditions of a natural or atmospheric wind. Such type of flow could be obtained in a wind tunnel.
For example, the Delft University of Technology in Holland has a wind tunnel of 2.2m of diameter by 10m length, triggered by an axial fan of 45kW, which allows the performance of test of wind turbines placed in a distance of 2m from the exit of the tunnel, reaching speeds such as 15m/s. Rotors with 1.5m of diameter have been successfully tested.

The study developed in this work might be conducted by the Delft University of Technology in Holland, with a more accurate scheme as to the use of the wind tunnel, thus generating the power curve with the data from the wind speed profile in the rotor plane and the instant power generated.

3. Proposed Technology

In order to obtain the power curve from a SWTG, a special methodology was developed, performed in laboratory, in which the wind turbine is triggered by an air flow coming from a 7,35kW axial fan. The fan speed is regulated by a frequency inversor, acquiring an average speed range of 2m/s to 17m/s by the exit of the fan. In order to obtain the wind turbine curve, it was prepared an autonomous wind system, including battery storage, DC load, and a charge and battery voltage regulator. In order to measure the variable required, it was used a data acquisition system (data logger), recording the wind speed measured by a three-cup anemometer and the wind turbine power with a power transducer developed exclusively for this project.

The rotation of the wind turbine was measured with a digital tachometer. A barometer, an humidity sensor and a temperature sensor were also used for posterior correction of the air density. The Fig. (1) shows the test structure schematics.

![Test Structure Schematics](image)

In tests, it was used a Southwest Windpower commercial wind turbine, model AIR 403 of three blades and 1.17m of diameter with nominal power of 400W/12V to a speed of 12.5m/s. The wind turbine does not have a gearbox and the generator is a permanent-magnet type. The wind turbine generator produces three-phase alternate current (AC) internally rectified for direct current (CC). The wind turbine blades are manufactured in fiber injected and molded carbon. With speeds higher than 19m/s, the blade presents an aeroelastical deformation originating stall, breaking and protecting the wind turbine from extreme wind speeds (Stall Control).

In order to measure the power generated by the wind turbine, it was projected a power transducer, Fig. (3), compatible with the same data logger used to store the wind speed data. The power transducer employs a RMS hall effect current sensor in order to help measure the power generated. This equipment was adjusted at LABELO-PUCRS, a laboratory accredited by national and international metrology institutes, such as INMETRO (Brazil) and PTB (Germany). The power transducer projected has a measurement accuracy of ±1.5%, which, in terms of power output, corresponds to ±6W. The power transducer response curve is also shown on Fig. (2).
A battery storage was installed, formed by four 12V/100Ah batteries connected in parallel with a capacity of 400Ah. For the load, there were used four 55W/12V lamps, summing up to 325W of load. To avoid the complete discharge of the battery during the tests, it was used a load controller (TRACE C-40), making possible the management of the battery load consume, bearing a constant regime of a 40A current up to peaks of 65A. The load control scheme is presented on Fig. (3).

In order to perform the acquisition of data, it was used a Second Wind commercial data logger, model Nomad, which has many terminals for the monitoring of variables such as wind speed and direction, as well as temperature, humidity, pressure and so on.

Data logger allows you to obtain samples of data each second and average values from these data in intervals of 1min, 10min, 15min, 30min and other higher intervals. Besides, data logger allows you to organize the data in bins, with the possibility of making graphics of the power curve easily. In order to measure the wind speed, it is used a NRG three-cup anemometer, model Maximum #40. This wind speed measured by the anemometer was related to the actual speed that reaches the wind turbine plane, as described in 3.1. The anemometer was placed in a counter terminal, and the power transducer placed in an analogical terminal of 0-2.5V range. Data logger was configured for the collecting of data every one minute with average calculations of wind speed, maximum, minimum, average and standard deviation calculations of the power generated, according to the recommendations of standard IEC 64100-12. The recording of the air temperature, humidity and atmospheric pressure made possible to correct the power curve for the standard air density conditions (1.225 kg/m³). In order to perform the tests, the rotation of the fan was manually controlled, increasing the inversor frequency in one Hz each 10 minutes, with which it was obtained an average speed range on the wind turbine plane of 2 to 15m/s. The rotation of the wind turbine was also measured by a digital tachometer, relating this information to the power results.

According to the wind turbine power monitored by data logger, the load was increased little by little, so to keep the battery consume constant along the tests. The load controller was connected during the whole process, in case it was
necessary to intervene in the battery voltage control. After the end of the test, the data was transferred to a PC through serial port and formatted in an Excel table, resorting to the bins method. This way, the power data related to the wind speed on the wind turbine plane were obtained, and they allowed the acquiring of the wind turbine power curve. Fig. (4) shows a photograph taken during the laboratory tests.

Figure 4. Test in Laboratory of a Southwest Windpower wind turbine (AIR 403).

3.1 Characterizing the Wind Speed on the Wind Turbine Plane

The methodology employed to generate the power curve proposed that the power data were related to the wind speed that actually gets to the wind turbine, and not the one that the anemometer measures. For so, it was necessary to co-relate the wind speed on the wind turbine plane to the wind speed measured by the anemometer. The procedure employed was the following, illustrated on Fig. (5):

The wind speed on the wind turbine plane was measured in an area covered by the area swept by the wind turbine blades, 2m away from the fan;

The wind speed of the three-cup anemometer placed 1m away from the fan was recorded;

These results were related, obtaining a correlation curve for posterior usage in acquiring of wind turbine power curve.

Figure 5. Layout of Laboratory Test Power Curve

The area plane swept by the wind turbine blades was divided into small areas of 10cm², in which it was measured the instant wind speed and determined its average. Such procedure was performed for a frequency range of 15Hz to 65 Hz. Figure (6) shows the result of the wind speed field on the wind turbine for a frequency of 50Hz, in which the mesh that represents the area swept by the wind turbine was interpolated, using a computer tool.
It is important to underline that if the experience had been performed in a wind tunnel with uniform test section, the anemometer speed would be easily related to the wind speed on the wind turbine plane. In the current experience, it was used a free-jet axial fan, in which the flow is highly turbulent, being that the profile of wind speeds on the anemometer plane is different from the wind speed on the wind turbine plane. This way, it was obtained a correlation function between the wind speed measured by the three-cup anemometer and the wind speed on the plane swept by the wind turbine blades, Fig. (7).

Figure 7. Curve correlating wind speed on anemometer and wind speed on turbine plane.

4. Results

According to the methodology described, the results of the wind turbine power curve were obtained and compared to the manufacturer’s curve, shown on Fig. 8 to Fig. 10, and also with the results obtained by bibliographical references (P. Gipe). Figure 11 shows a graphic of “Power x rpm”.

It is observed that the results obtained are closer from those obtained by P. Gipe than the ones presented by the manufacturer. Recent tests performed by P. Gipe with other models from Southwest Windpower show that the new wind turbines present a performance much inferior to those expected by the manufacturer.
Figure 8. Laboratory Test Results.

Figure 9. Average power values compared to Manufacturer and Paul Gipe Power Curves.
5. Conclusion

The results show that, with the methodology proposed in laboratory, it is possible to obtain the characteristic curve of the SWTG. The power transducer developed showed efficiency and may be easily handled to obtain the curve from other wind turbines.

The power curve obtained in laboratory shows to be inferior to the one provided by the manufacturer’s catalog, however it shows to be closer to the one obtained in field by P. Gipe (2001) with the same model of wind turbine.

In spite of the difficulty of monitoring, evaluating and quantification of the results of the studies of SWTG performance, this science is evolving into visible improvements. The lack of standardizing for SWTG performance and certification tests has stimulated the research, obtaining results such as the ones presented here.

The specialized literature and international standards do not recommend the performance of laboratory tests, however, those performed so far with the present methodology gave encouraging results when compared with field measurement of the bibliographical references consulted. Only employing the methodology to other SWTG and comparing it to field tests one will obtain more conclusive answers about the validity or not of the proposed method.
The main advantage of the method is that the tests are performed in a short period of time, with environmental factors laboratory-controlled. A posterior study will serve to perform tests using a wind tunnel triggered by the same axial fan, thus comparing the profile of wind speeds on the rotor plane and its influence on the determination of the power curve. The automation of the frequency control in the fan is a job that is being developed and will result in a diminishing of time and making the data collecting easier. The use of a calibrated anemometer is also recommended in the standards and it must be incorporated in the following measurements. It must be performed an analysis of accuracy for the instruments and equipment used. Nowadays, the wind turbine is being tested in field, adopting the standard IEC 61400-12. It is hoped that these results might be compared to those obtained in laboratory and thus validate or question the procedure adopted in laboratory.

Systems using SWTG present a growing market, being important for those who buy these machines to rely on the expectation of energy generation provided by the manufacturers. It has been observed that in the current frame, it is not possible to rely on this, being necessary that the manufacturers present with more scientific rigidity the results of their machines and adopt a standard for the determination of such curves that may be verified in field under the foreseen conditions. The present trend of work has the objective of relying on a methodology that might be used for the checking and testing of national and imported SWTG, assuring the user of the quality of the equipment purchased and the energy he will actually rely on.

6. Bibliographic References


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