POWER CURVE MEASUREMENTS OF LOCALLY MANUFACTURED SMALL WIND TURBINES

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ABSTRACT

The performance of locally manufactured small wind turbines is rarely measured, let alone with any degree of accuracy. This study is the first in a series that aim to use the international standards for power performance testing to obtain reliable measurements of the behaviour of these machines. A 1.8m diameter machine was monitored for 4 months on the Scottish peninsula, Scoraig, and a power curve produced. Peak power for the machine was found to be 267W at 13.5m/s and the rated annual energy production (on a 5m/s average wind speed site) is predicted to be 495kWh. Results are in strong agreement with wind tunnel tests performed in a separate study, up until furling begins.

NOMENCLATURE

Ø	*rotor diameter*
C_p	*power coefficient*

INTRODUCTION

Under the right conditions, the local manufacture of small wind turbines can provide a sustainable solution for rural electrification. The wind turbine designed by Hugh Piggott of Scoraig Wind Electric and described in the instructive manual, *A Wind Turbine Recipe Book* [1], is a rugged machine designed to be produced using only basic tools and techniques. The success of this manual has permitted the dissemination of the technology to the point at which over 1,000 machines have now been produced and can be found across the world in every single continent. Although estimates exist for the power and energy production of these machines, no accurate measurements of their performance has yet been made.

This research aims to measure the performance of a range of these machines, from 1.2-4m diameter (Ø) over the course of approximately 1 year. The testing is taking place in situ on the Scottish peninsula, Scoraig, Ross Shire. Described in this paper is the measurement of the first machine, a 1.8m diameter wind turbine. The turbine was monitored from 26th April to 4th September 2012 and 18,835 samples were recorded.

METHODOLOGY

The international standard for power curve testing of small wind turbines, as described in IEC-61400-12-1 [2] was used as a guide during the design of the measurement procedure to ensure the highest degree of accuracy possible given the available time and resources.

SITE SELECTION

The selected site was chosen as it is on the far Western tip of the Scoraig peninsula, with no trees nearby and therefore almost completely exposed to the wind coming directly off of the Atlantic Ocean. The house to which the turbine provides electricity is the only building nearby. As it is located 50m South-South-West at a level 10m below the base of the wind turbine tower, it was deemed to have negligible effect on the flow at hub height.

Figure 1 shows that the predominant wind direction during the monitoring period was North-Easterly, with occasional high winds also coming from the South-West. **Figure 2** shows the frequency distribution of wind speeds recorded during the test period, which had a mean of 4.97m/s.

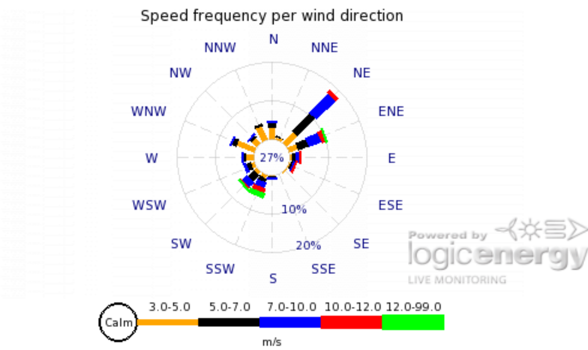

Figure 1: Wind rose for the Glasshouse test site during the measurement period. Image courtesy of Logic Energy.

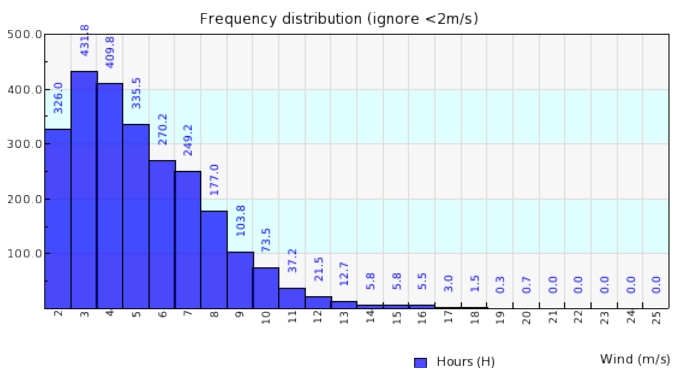

Figure 2: Wind speed frequency distribution for the Glasshouse test site during the measurement period. Image courtesy of Logic Energy.

TECHNICAL SPECIFICATION OF WIND TURBINE

The Glasshouse wind turbine, shown in Figure 1, is a 1.8m diameter machine built to the specifications of Hugh Piggott's *A Wind Turbine Recipe Book* [1] in 2008. The relevant technical information is presented below in Table 1. The only major modification to the design of the machine is the fact that it contains two magnet rotor discs, instead of just one, as described in *A Wind Turbine Recipe Book* [1]. This is a result of a manufacturing error, in which the stator was cast too thick. As a result, flux density in the stator was too low (even when the air gap between the rotor and the stator was reduced to the minimum possible without compromising mechanical reliability) and the cut in speed of the machine would therefore have been excessively high. To rectify this problem, a second rotor disc was manufactured and installed on the other side of the stator, as is normally done for larger machines.

Blades	
Number	3
Profile	Based on Aquila
Material	Wood (Siberian Larch)
Generator	
Generator topology	Axial flux permanent magnet
Permanent magnet material	Neodymium-iron-boron (NdFeB)
Nominal voltage	12V
Rotor disc material	Steel, polyester/fiberglass composite
Stator material	Polyester
No. coils	6
No. poles	8
Resistance	0.412Ω
Tower	
Height	7.7m
Type	Tilt-up guyed
Material	Tubular steel
Electrical System	
Battery type	4x450Ah Rolls S-600 6V
Battery configuration	12V - 2 series pairs paralleled
Charge controller	Tristar 45 in diversion mode
Inverter	Studer Joker 800W

Table 1: Technical specifications of the Glasshouse wind turbine.

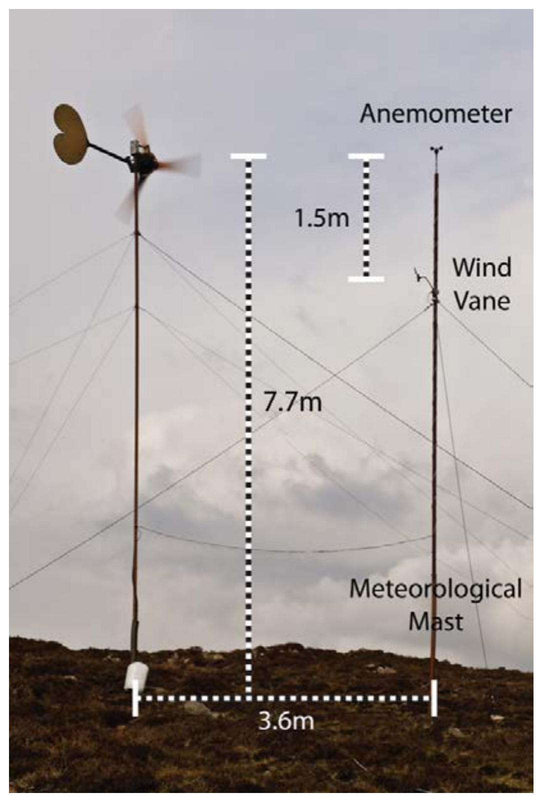

Figure 3: Photograph of the meteorological mast showing its proximity to the wind turbine.

Technical Specification of Data Logging System

The variables listed in Table 2 were measured and recorded by the Logic Energy LeNet data logger. All variables were measured at a frequency of 1Hz and averaged over a 10 minute period. The averaged data was transmitted every 10 minutes via the GSM network and stored on the Logic Energy server.

Variable	Sensor
Wind speed	NRG Max40
Wind direction	Davis Pro-D
Temperature	Zener diode
Rotational speed	AC frequency
Current	LEM-HT-200-SBD hall effect probe
Voltage	Data logger powered directly from Glasshouse battery bank

Table 2: Technical specifications of the data logging equipment.

The relative positions of the wind measurement instruments and the wind turbine are shown in Figure 3. The anemometer is located 2 rotor diameters (3.6m) from the wind turbine tower and at hub height, as required by IEC61400-12-1 [2].

Figure 4 shows the layout of the sensing equipment used to record the data. Excluding the anemometer and wind vane, all sensors were located in a waterproof housing beside the battery bank at the Glasshouse. Signals were transmitted to the data logger from the wind turbine tower (frequency) and meteorological mast (wind speed and direction) using a 12-core armoured telecom cable.

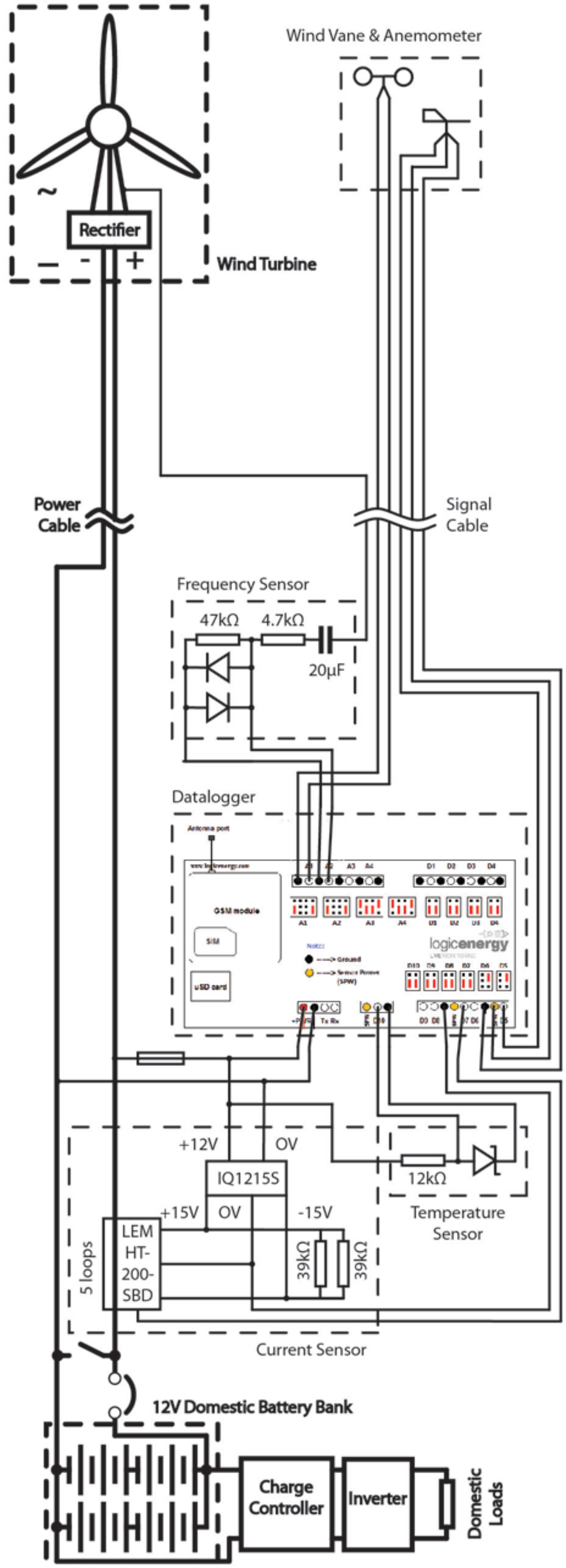

Figure 4: Wiring diagram of the data logging equipment installed on the Glasshouse wind turbine. LeNET image courtesy of Logic Energy [3].

DATA PROCESSING

To remove erroneous data recorded when the anemometer is in the wake of the wind turbine, all data from the sector 298.5-19.5º was removed (as recommended by IEC61400-12-1 [2] and illustrated in Figure 5), leaving a total of 13,438 samples. However, in contrary to the requirements of the standard, data from when the wind turbine was downstream of the anemometer was not excluded as it can clearly be seen in Figure 6 that the profile of the anemometer and meteorological mast are very small compared to that of the wind turbine. Data from times when either the wind turbine or the met mast was downstream of the house was also not removed. As shown in both Figure 5 and Figure 6, not only is it 50m away, but it is also 10m downhill from the turbine and was therefore also deemed to have a negligible effect on turbine performance. This assumption was confirmed by the agreement of the data obtained from this sector with that from other wind directions.

As described in IEC61400-12-1 [2], power values were normalised using the air temperature recorded by the Zener diode. Unfortunately as the Zener diode was located inside the waterproof housing on the South side of the Glasshouse, it would have been particularly vulnerable to falsely high readings.

0.5m/s bins were used to produce the final power curve, as described in IEC61400-12-1 [2] .

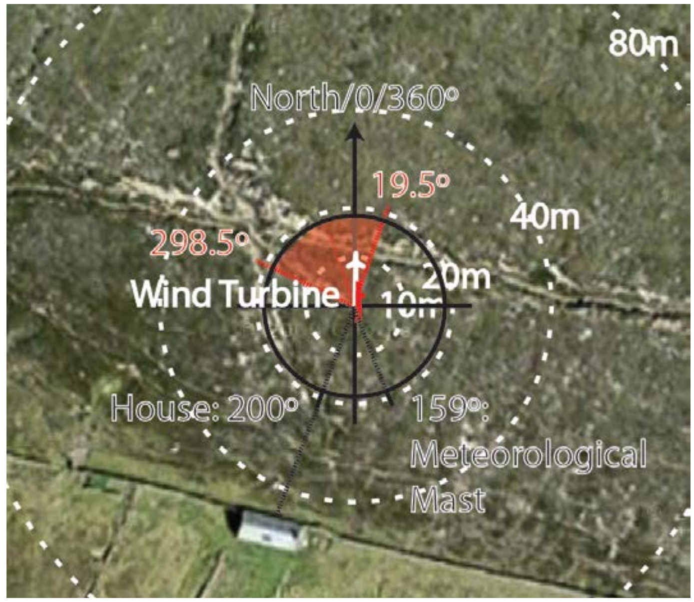

Figure 5: Satellite photograph of the site showing radial contours of distance from wind turbine (white) and the excluded sector when the meteorological mast is downstream of the wind turbine (red). Image courtesy of Google Maps.

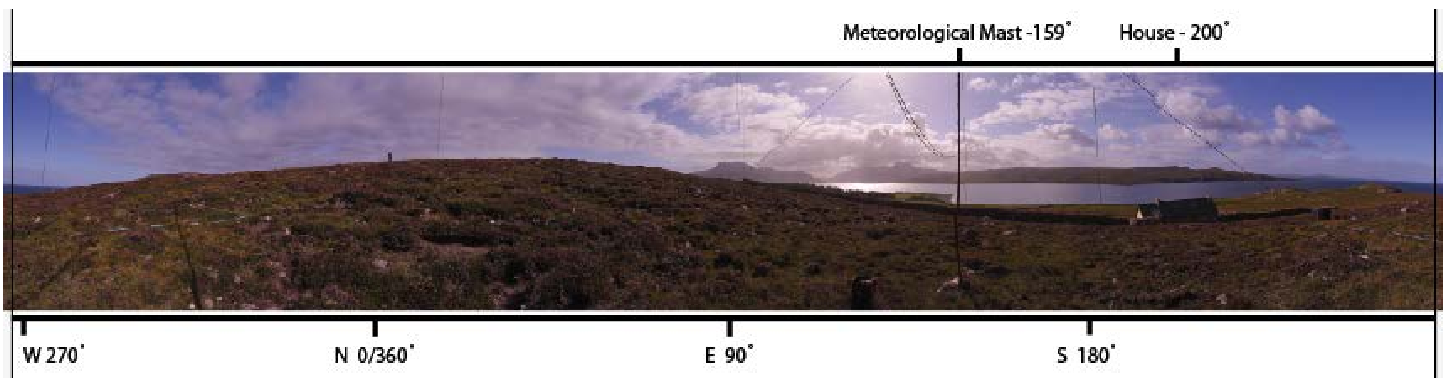

Figure 6: 360° panoramic photograph of test site relating locations of potentially significant obstacles to flow onto the wind turbine.

RESULTS

The power curve shown in Figure 7 was produced from the measured dataset, showing a peak power of 267W at 13.5m/s. This is significantly lower than the design value of 350W [1].

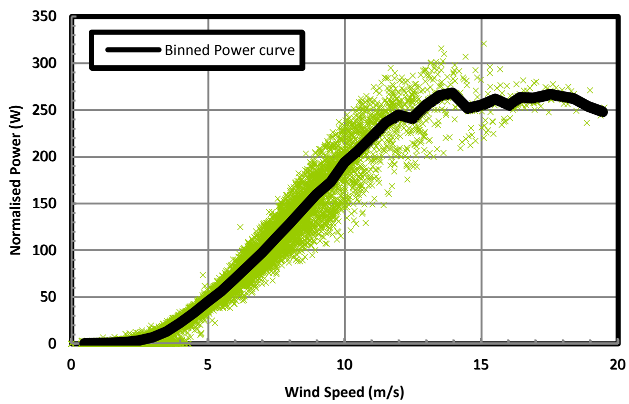

Figure 7: Scatter plot of all data (after removing samples taken when anemometer in wake of turbine) with binned power curve.

Figure 8 shows the predicted Annual Energy Production (AEP) of this wind turbine on sites with various annual mean wind speeds. Again, measured values are significantly lower than those quoted in *A Wind Turbine Recipe Book* [1].

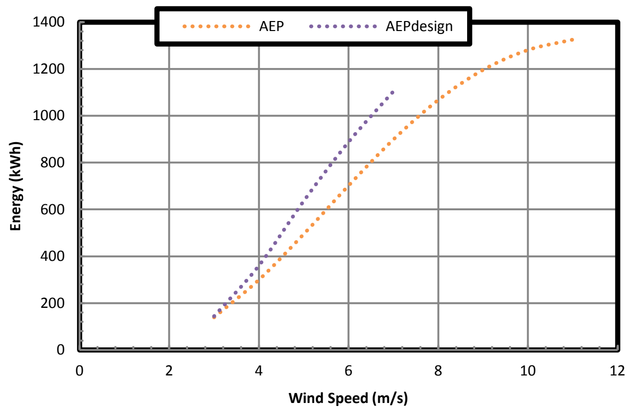

Figure 8: Comparison of the measured Annual Energy Production (AEP) with the deign values, as stated in *A Wind Turbine Recipe Book* [1]

Figure 9 partly explains why the latter part of the curve appears rougher than the former: fewer instances of high winds mean that the data in this region is less reliable, even though it exceeds the minimum number of data points to be included in the curve, just 3 [2]. In addition to this, the wind turbine uses a furling mechanism for overspeed protection in high winds. Wind turbines rarely reach steady state when furling as the balance between aerodynamic and gravitational forces is constantly shifting.

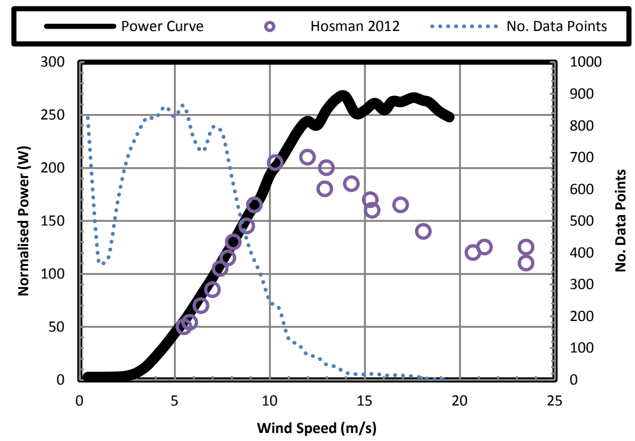

Figure 9: Relationship between the number of data points and the reliability of the measured data.

Figure 9 also shows the results obtained by Hosman [3] in the TU Delft Open Jet Facility Wind Tunnel on an identical 1.8m locally manufactured wind turbine. It is clear to see that up to 10 m/s the two sets of data are virtually identical. However, as the furling tail begins to regulate the power output, then the results begin to differ. The machine tested in the wind tunnel has a much more severe furling action, quickly cutting off power in higher winds. Although this will protect the machine, it will sacrifice energy yield.

Figure 10 illustrates the power coefficient, C_p, achieved by the wind turbine at various wind speeds, with a peak C_p of 0.25 at 4m/s. Again, the agreement with Hosman's wind tunnel data [3] is remarkable until the furling action begins around 10 m/s.

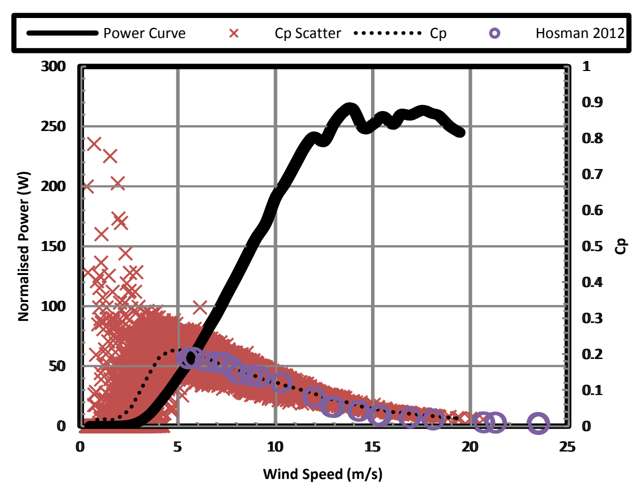

Figure 10: Scatter plot of power coefficient, C_p, using all data (after removing samples taken when anemometer in wake of turbine) with binned power curve.

CONCLUSION

The performance of the 1.8m wind turbine located at the Glasshouse on Scoraig was monitored over a 4 month period and a power curve produced. Peak power was found to be 267W at 13.5m/s and the annual energy production on a site with an annual mean wind speed of 5m/s is predicted to be 495kWh. Although there were some minor deviations from the international standards used as a guide during the testing procedure, the experimental results showed little scatter after filtering out data from when the anemometer was in the wake of the turbine and were therefore assumed to be valid. The results of this study are backed up by findings from a similar wind tunnel study, although the behavior of the furling system does vary significantly between the two machines.

ACKNOWLEDGEMENTS

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1. Piggott, H., *A Wind Turbine Recipe Book*2009, Scoraig, Scotland: Scoraig Wind Electric.
2. IEC, *Wind Turbines*, in *Part 12-1: Power Performance Measurements of Electricity Producing Wind Turbines*2005.
3. Hosman, N., *Performance Analysis and Improvement of a Small Locally Produced Wind Turbine for Developing Countries*, in *Faculty of Aerospace Engineering*2012, TU Delft.