Performance of a Small Scale Turbine in an Urban Environment

A thesis submitted for the degree of
Master in Science
In
Energy Systems and the Environment

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September 2009

Acknowledgments

On the completion of this project, there are a number of people whom the author feels indebt for their help. First, I would like to thank to my supervisor Dr. Andrew Grant, Dr Paul Strachan and Dr. Olimpo Anaya Lara and for their time, advice, and assistance during this thesis work.

I also wish to thank the Mackintosh Environmental Architecture Research Unit (MEARU), especially to Tim Sharpe who is the representative of MEARU. I would also like to extend my thanks to a number of persons from Proven S.L., who patiently assisted me by answering my questions and providing me a view of the Proven wind turbine.

I would like to thank Professor Juanjo, and Professor Josep Clua “Duc de Montblanc”, they taught me how to study and also Dr. Rafael Pindado .

I would especially like to thank Christopher and Claire Hyland and especially Tricia and Mikel, whom without their assistance I could not write this report.

I would like to especially thank my friends, Carlos Garcia “el Russo”, Noé Perez “el Madero”, Rubén Rodriguez “Trato truco”, Paquito espejo, Daniel Visiga, Rubén Pérez “chiruka”, Lupin, David Vegas “el Vasco” and all my university friends that without their support I could not finish this degree.

Finally special regards to my mother, who died in October of 1998.

ABSTRACT

This dissertation focuses on a small scale wind turbine in an urban environment. Significant under-performance had been suspected for some time, and this was confirmed by an examination of recorded data. The aim of the project was to identify the possible causes.

The initial investigation concentrated on a detailed examination of the roof-top site of the turbine and an adjacent weather station. From this, and a mapping of tall buildings in the immediate area, an indication of the likely effects of wind direction on turbine performance was obtained. However a detailed analysis of performance data revealed no discernible directional sensitivity.

Unfortunately the data sets available covered a very limited period and it was not possible to trace the history of the turbine's performance since its installation. Recent records suggest that it is failing to reach the correct speed of rotation to produce its rated power. A number of possible causes are examined. The difficulties of monitoring and controlling wind turbines in an urban environment are discussed, and recommendations for remedial action in this particular case are made.

Table of Contents

Glossary

Symbol		**Units**
A	The area swept by the rotor blades	m^2
c	Scale parameter	
C_p	Coefficient of Power	%
D	Diameter of the turbine	m
h	Probability density function	
I	Current in ampere	A
K	Shape parameter	
M	Mass	kg
P_o	Power output	Watts
Pm	Mechanical power	Watts
V	Voltage	Volts
rpm	The speed of the rotating field	rpm
V	Wind speed	m/s
V_∞	Upstream wind velocity at the entrance on the rotor blades	m/s
V_e	Downstream wind velocity at the exit of the rotor blades	m/s
Z	Impedance in Ohm	Ω
ρ	Air density	kg/m^3

Chapter 1

1. Introduction

1.1 History

The wind has been used to generate energy for centuries. First it was used to move ships. Later the Persians invented the windmill, initially to pump water before eventually being used to grind crops. Nowadays modern windmills are called wind turbines and are used to generate electricity on a large scale. They continue to increase in size: 5 MW turbines are now in production, and machines of 10 MW are under development

Persians began to use wind to pump water around AD 634–644. The windmill was introduced to Europe by the Islamic empire and spread around in the 9th century, but it was in the last quarter of the 12th century, in northwestern Europe, in the triangle of northern France, eastern England and Flanders, where the modern (vertical or horizontal-shaft) windmills appeared. Until the industrial revolution windmills were working to grind crops and pump water but were then largely replaced by steam-powered and internal combustion machines, which in their time were more efficient [1].

The first known electricity generating windmill was a battery charging machine installed in 1887 by James Blyth in Scotland, but the first windmill for electricity production (supply) was built in the United States in 1888 [2]. In the following years, prototypes machines were constructed in many countries (some of them very large) without much success. It was not until the 1970s that turbines for electricity generation were produced in significant numbers. Denmark was the first to establish a wind turbine manufacturing industry. Because of financial incentives available in Southern California this led to the appearance of the first large scale wind farms in the 1980s.

The most important issues in the construction of a wind farm are the average speed and “the quality” of the wind. Even if the wind speed is good, turbulence produced by trees, or hills (or in cities, by buildings) could affect the energy production and introduce unsteady loads. Wind resources can be calculated by a measuring mast and consideration of topography (roughness of the terrain) and the orography (obstacles such as trees or hills). If wind conditions are right it is possible to maximize energy production (efficiency) and minimize the cost. The surrounding of the wind turbine has to be an open space (as much as possible) in the predominant wind direction. Without any obstacles or very few, the performance of the wind turbine is improved [16]. Turbulence could damage a turbine. Unsteady forces around a wind device could damage blades, hub or the mast. Turbulence also could affect the foundation and finally destroy it. In addition, in order to repair a turbine, it must be within easy access for maintenance when it is needed.

Wind turbulence is very important in cities were speed and direction may change as a result of the many impeding structures. The wind turbine efficiency drops and the power output becomes less than expected. There are also concerns over structural loads, vibration and noise; for these reasons the urban turbine is not yet well established. In cities it is difficult to find places where wind is clear and constant; even in the highest building it is possible to have turbulence, hence performance is affected.

The cost-efficiency of small wind turbines is open to question. The reality is that the turbine's design and production is very costly, hence it becomes difficult to see profit on the energy savings made by the turbine. This is not helped by possible underperformance in the urban environment.

Producing the wind turbines on a larger scale could reduce the initial costs; hence the cost-efficiency would start to become attractive. If the efficiency of the turbines were improved, their use would be more widespread. But there remain safety concerns and possible threats to animals (especially birds that could potentially fly into the spinning rotor)**.**

Nowadays, as people are more aware about possible global pollution problems and the increase of the earth's temperature, it is becoming more important to "possess" renewable energy. At present wind energy is perhaps the most feasible in the renewable energy sector, and turbines give a very visible indication of the owner's green credentials. However, researchers will need to improve the efficiency of turbines for maximum performance.

1.2 Newberry Tower Wind Turbine Project

Three years ago, the Mackintosh Environmental Architecture Research Unit (MEARU) decided to install a small scale wind turbine, Proven 2.5 kW. The diameter of the turbine is 3.5 metres with annual output expected to be in the range of 2,500-5,000 kWh. This specific turbine is designed to work in wind speeds higher than 2.5 m/s “cut in” and than <70 m/s “cut out”. The rated wind speed is 12 m/s [17].

This installation project was supervised by Dr Tim Sharpe. MEARU was interested in doing an experimental study about the feasibility of building integrated wind energy through use of a wind turbine [2]. The original idea was to integrate a number of sources of renewable energy in the urban environment and reduce the CO_2 emission.

Figure 1

Figure 2

Newberry Tower is the highest building in its area. The wind turbine was installed in 2006. During the first meeting with Dr Tim Sharpe in June 2009 he stated us that during the first six months the turbine had worked correctly and had achieved the expected energy output. However, after six months, the energy output dropped, and had never reached the theoretical output again. Available data from the time period May 2008 to June 2009 showed that the maximum power output is less than 1 kW. During normal operation this would be expected to be 2.5 kW demonstrating a serious drop in performance.

During that same meeting, Dr. Sharpe commented that he had also experienced initial problems with the inverter and later with the physical position of the turbine weather station which could have potentially affected performance. However, when these problems were resolved the turbine was still underperforming [2].

Due to this is it could be argued that it is necessary to look at other ways performance could be affected such as the position of surrounding buildings. An investigation of this is shown below through the following photographs.

The Figure 3 shows the wind turbine position. Circled in red is the Newberry Tower and the highest buildings in the area are circled in green. The Newberry Tower is still at least 3 metres higher than the other buildings [25].

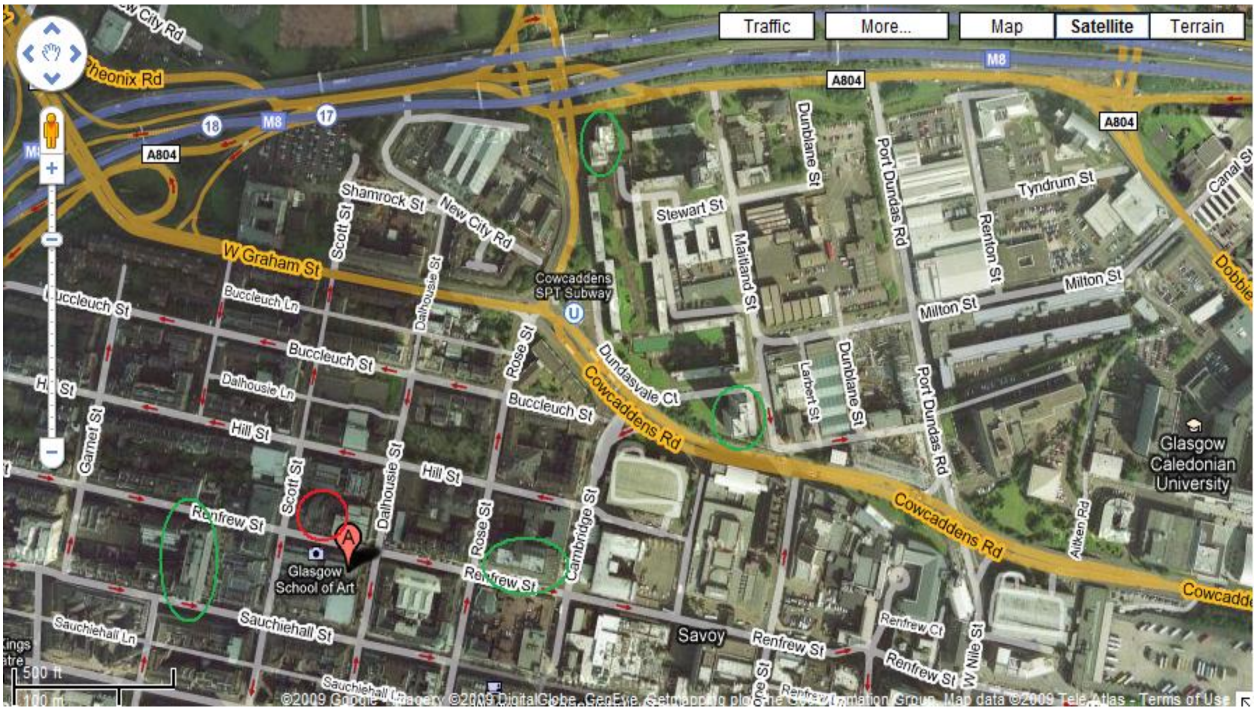


Figure 3

The following pictures are taken from the roof of Newberry Tower. In these pictures, it is possible to see surrounding buildings in the area around the Newberry Tower that could potentially affect the energy output. The picture below depicted in Figure 4 shows the buildings from North to East of Glasgow. There are two buildings circled in green that could create some turbulence in this area. These buildings are situated around 420 metres the first in the right and 450 metres the second in the left from the turbine.

Figure 4

The Figure 5 shows the buildings from East to South of Glasgow. The building circled in green is situated around 178 metres from the turbine and stands around 3 to 4 metres below the Newberry Tower.

Figure 5

The Figure 6 shows buildings from the South to the West of Glasgow. In this area there is one building which could produce turbulence. It is around 70 metres away and around 3 metres lower than Newberry Tower.

Figure 6

The Figure 7 shows buildings from Southwest to Northwest of Glasgow. It is clear from this that there are no buildings that it could affect the turbine’s performance as all are much lower.

Figure 7

The Figure 8 shows a tower which is situated on the roof of the Newberry Tower, located from Southwest to Northwest. This tower is around 11 metres away from the turbine and taller than the tower on which the wind turbine is installed. It could be argued that this could create the biggest turbulence in this area, together with the airflow coming from the bottom of the building.

Figure 8

In this plot is possible to see the roof layout. Circled in green is the opposite tower.

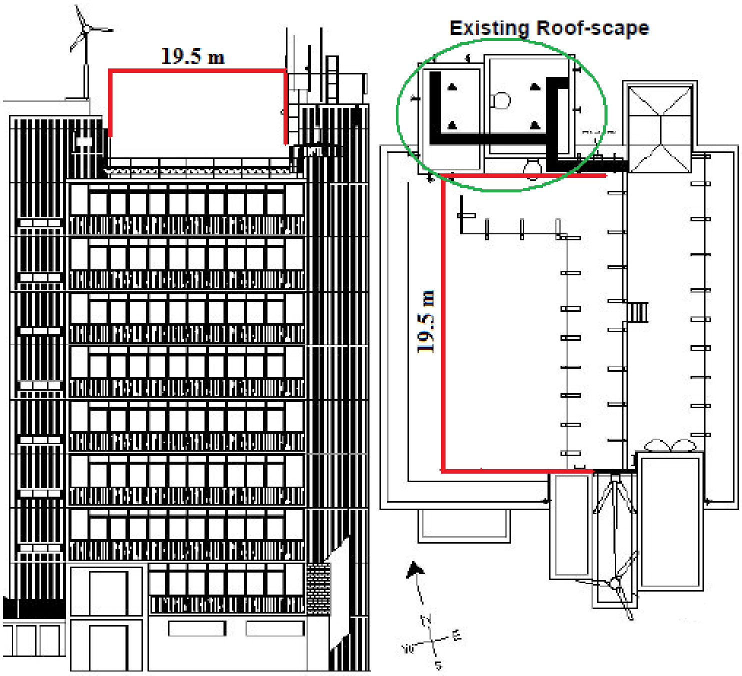


Figure 9

Chapter 2

2. Literature Review

This chapter will look at the following 2 different areas

- People who have been using wind energy through the installation of a small wind turbine. (Case study 1)
- The opinion of experts on small scale wind turbine efficiency. (Case study 2,3,4,5)

Following from this, it will review several case studies located in Europe and the USA.

2.1 Case Study 1

The first case study is Donnachadh McCarthy's Camberwell home (3 Acorns Eco-Audits). In November 2005 he installed a Stealthgen D400 which is rated at 400 Watts. During the first year, this installation had various problems. Firstly it experienced some vibration issues which were resolved when original turbine bearings were changed. Next the energy input dropped considerably and this issue was resolved when the inverter that was replaced in August 2006 [3]. This installation only produced about 30 kWh over 3 years. (Email Donnachadh McCarthy, Appendix C).

Donnachadh McCarthy's Camberwell home

Figure 10

Another example of the use of small wind turbines for energy is Ormiston Wire Ltd. This company installed a Proven 2.5 kW wind turbine in July 2003 and at the same time, also installed 120 solar photo-voltaic panels.

Ormiston Wire Ltd

Figure 11

The turbine and the PV panels produce enough electricity for the company and Ormiston Wire Ltd surplus to sell back to Ecotricity (Ecotricity is a green energy company based in Stroud, Gloucestershire, England, specializing in wind power). Unfortunately no details of the relative contribution from wind and PV have been published. This installation is one of the first industrial applications of small wind turbines in the UK [4].

A further example is Thames Valley University. In October 2004, Thames Valley University installed a pair of Proven wind turbines on top of Westel House. Both turbines could supply around 2 % of the electricity demand for Westel House per annum [5].

Twin turbines on TVU's Westel House. Figure 12

2.2 Case Study 2

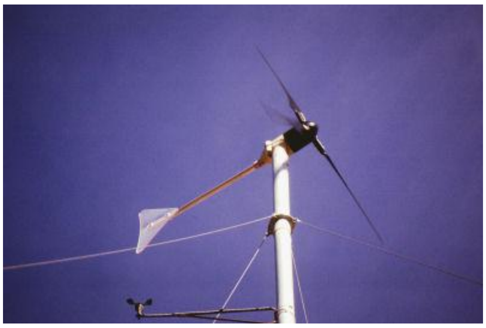
One expert in this field of turbines is Paul Gipe. Paul has written several books of this topic and has also had many other articles published. These have been translated from English to many different languages.

Paul Gipe reviewed the Spanish Survey of Small Turbine Technology project. The research was carried out by Spain's national energy centre, CIEMAT. In the town of Soria a group of people carried out some tests for stand-alone wind systems. CIEMAT's Ignacio Cruz summarized that medium-size wind turbines have higher efficiency than the small scale wind turbines for stand-alone applications. He also stated that as this is still a young technology the installation of a small scale wind turbine for stand applications have a higher cost than larger turbines. Cruz found that a small turbine’s power coefficient could not go further than 35 % when medium size could reach to 42 % [6].

Another interesting report from the Paul Gipe website is the “Whisper H40 Final Report”. Between the years 2001-2002 Paul Gipe installed a Whisper H40. This turbine’s power output was rated at 460 watts. Before he installed it, the rating changed to 900 Watts at 12.5 m/s [7].

Paul Gipe’s conclusion was that Whisper H40 is an interesting wind turbine device but it does not reach the ideal power curve performance at 900 watts.

Whisper H40’s test at Applachian State University's Beech Mountain Small Wind Research and Demonstration Facility by Brent Summerville confirmed earlier power curve tests on the H40 at the Wulf test field.



Whisper H40

Figure 13

Results shown in figure 14 suggest that 900 W output is obtainable but on many occasions the output falls well below this, giving a mean power curve at round 650 W.

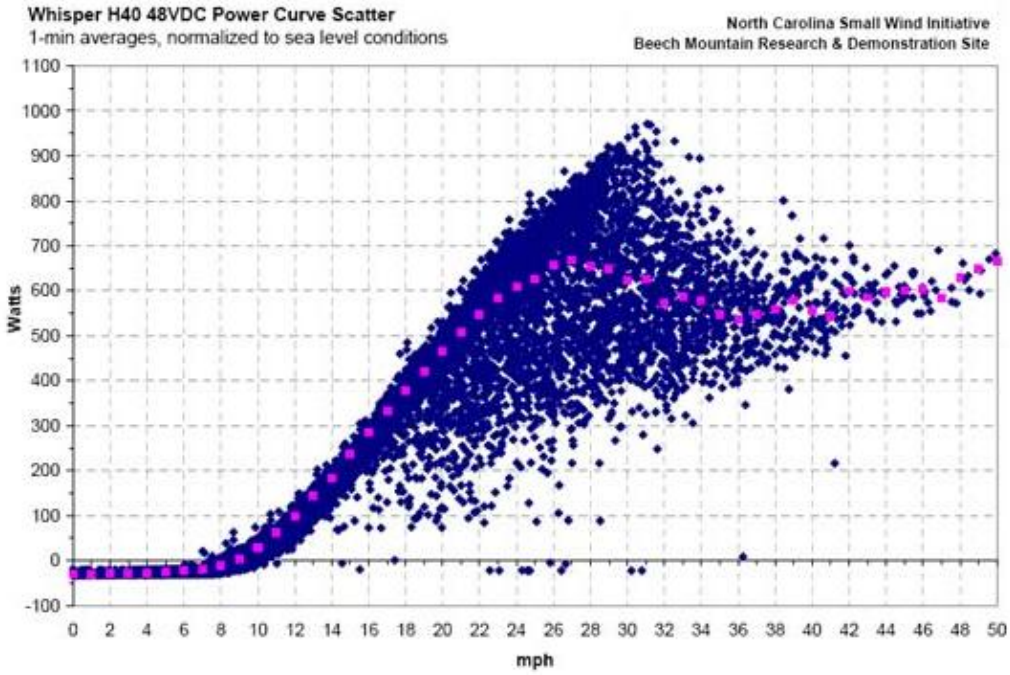


Figure 14 Source [7]

2.3 Case Study 3

This section uses examples from the NREL website which focuses on the Small Wind Turbine Applications: Current Practice in Colorado report [8]. These illustrate several cases where small wind turbine applications have worked successfully.

The first example is situated in rural Douglas County, Colorado. This region provides unusual winds. The farm has an off grid home and has installed Whisper H900 and Whisper 4500 wind turbines, and also a Solec PV panels, rated at 1.44 kW. This installation is supported by 12 kW diesel generator. Both turbines have good wind resources although there is also turbulence, but both turbines work without problems.

Whisper 900 wind turbine on hillside above. Douglas' County home

Figure 15

The second example is a situated in rural residential area of Boulder County. It has a grid connection and it installed a WPT 3 kW turbine and also a BP Solar model 590 PV panels, 8.6 kW. These turbine and solar PV panels generate an energy surplus; total power consumption is about 1000 kWh/monthly [8].

Whisper 3000 wind turbine adjacent to passive-solar home with PV panels on roof

Figure 16

The next example is situated at the same area as the first example, 0.5 miles away. This home has 3 different energy systems, an on-grid electrical system, an off-grid electrical system, and a water-pumping system [8].

Winco 450 Watts

Figure 17

This installation has a pair of Winco wind turbines of 450 Watts and an aerometer mechanical water-pumping windmill.

2.4 Case Study 4

Europe has different non-governmental organisations which inform and advise people how to make changes to their houses to save energy. In addition, this will also help with climate change by reducing Co_2 emissions. One example of this is in the Energy Saving Trust website where it is possible to find information about products or methods to reduce your reduce Co_2 emissions by recycling, install low energy light bulbs or generate your own electricity.

In this website there are different reports and documents but there is one interesting approach to the small scale wind turbine which explains the reliability of the small scale wind turbine [9]. The "Micro and Small wind turbine applications in the built environment" report by the carbon trust/ESPRC funded carbon vision project called Tarbase has a similar conclusion to the previous report [10].

From the report "Domestic Small Scale Wind Turbine Field Trial" it could be concluded that it is necessary to improve the reliability of small scale wind turbine and the wind speed database. The database has a lack of resolution and energy predictions are not always accurate. Following from this, improvement in domestic consumers' information could increase the sale of wind turbines and reduce Co_2 emission from existing UK building stock by 50 % by 2030.

Figure 18

Figure 18 represents the introduction of small scale wind turbine in a rural environment

The conclusion of the Micro and Small Wind Turbine Applications in the Built Environment report is that micro and small scale turbines could contribute to reduce Co$_2$ emission but this area has to be developed as the methodology has a lack of information for specific turbines in different building types. There is also a lack of accuracy in databases as seen in the previous report.

2.5 Case Study 5

Universities like Strathclyde have been enrolled in different small scale wind turbine projects. In Glasgow, the Lighthouse Building had installed four ducted turbines with integrated photovoltaic spoilers [11]. Ducted turbines use the updraft of the airflow along a building site. Airflow goes up from the bottom of the building to the roof where the wind turbines are installed.

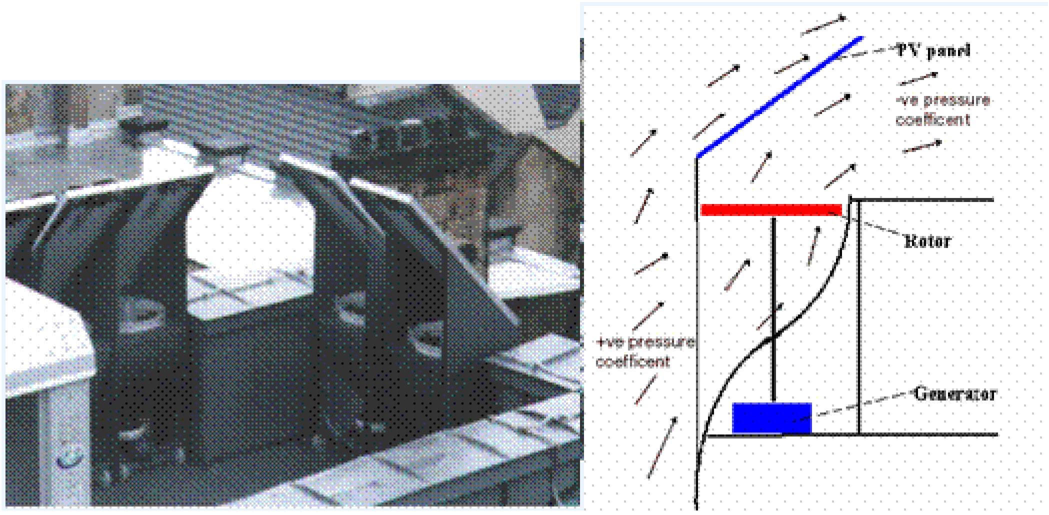


Figure 19

Ducted wind turbine installed in the Lighthouse building Glasgow

Clarke at [11] concludes that a ducted turbine helps to reduce electricity demand along with passive solar and PV panels. Winter is the only period where is clearly observed that extra energy is needed.

Chapter 3

3. Theory

3.1 Wind Fundamental Theory

A wind turbine is a rotating machine which converts the kinetic energy in wind into mechanical energy. If the mechanical energy is used directly by machinery, such as a pump or grinding stones, the machine is usually called a windmill. If the mechanical energy is then converted to electricity, the machine is called a wind generator or wind turbine [12]. A comprehensive theoretical treatment may found in [13].

- Kinetic Energy:

The kinetic energy in air of mass *“M”* moving with speed V is given by:

$$KE = \frac{1}{2} MV^2 = E \, ;$$

A is the area swept by the rotor blades given by:

$$A = \frac{\pi}{4} D^2 \, ;$$

The volumetric flow rate of air through the turbine is AV; the mass flow rate of the air in kg/s is ρAV so now

$$Pm = \frac{1}{2} (\rho AV) V^2 = \frac{1}{2} \rho AV^3 \, ;$$

Pm is the power output at the site.

- Power Extracted from the Wind:

$$Pm = \frac{1}{2}\rho A V\{V\infty^2 - Ve^2\};$$

The mass flow rate of the air through blades is, therefore, derived by multiplying the density with the average velocity, giving:

$$\text{Mass flow rate} = \rho A \frac{V\infty + Ve}{2};$$

Mechanical power extracted by the rotor, which is driving the electrical generator:

$$P_0 = \frac{1}{2}\left[\rho A \frac{V\infty + Ve}{2}\right].\left[V\infty^2 - V_e^2\right] = \frac{1}{2}\rho A V^3 \frac{\left(1+\frac{Ve}{V\infty}\right)\left[1-\left(\frac{Ve}{V\infty}\right)^2\right]}{2};$$

Where $\frac{\left(1+\frac{Ve}{V\infty}\right)\left[1-\left(\frac{Ve}{V\infty}\right)^2\right]}{2}$ is the power coefficient of the rotor;

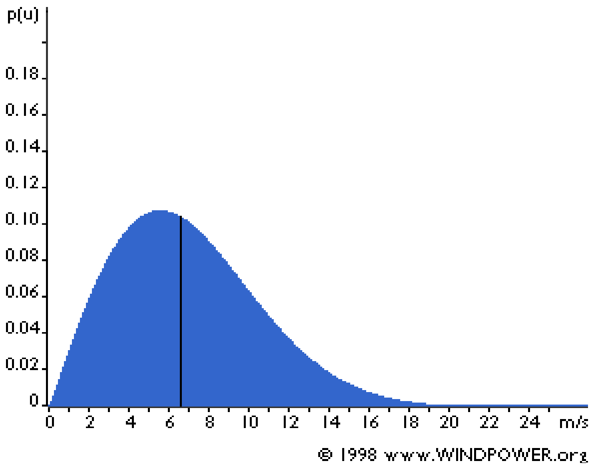
$$C_p = \frac{\left(1+\frac{Ve}{V\infty}\right)\left[1-\left(\frac{Ve}{V\infty}\right)^2\right]}{2};$$

C_p depends on the ratio of the downstream to the upstream wind speeds, which is $\left(Ve/V\infty\right)$. For an idealised turbine without losses, C_p peaks at the Betz limit (C_p = 16/27 = 0.59), and in this ideal case $\left(Ve/V\infty\right)$ is 1/3. The practical maximum value of C_p is below 0.5 [12]. Therefore;

$$P_0 = \frac{1}{2}\rho A V^3 C_P;$$

3.2 Describing Wind Variations: Weibull Distribution

The traditional method of doing this is to express the probability density of wind velocities through a Weibull Distribution. A typical site graph is shown Figure 20. The median wind speed for the site shown, indicated by the vertical line, is about 6.7 m/s. The areas under the curve are equal on each side.



(The Danish web-site from which this is taken (see copyright label) is a particularly useful source of information on wind energy)

Figure 20

The Weibull distribution is a continuous probability distribution , the probability density function of a Weibull random variable given by [13]

$$h(V) = \left(\frac{\kappa}{c}\right) * \left(\frac{v}{c}\right)^{(\kappa-1)} * e^{-\left(\frac{v}{c}\right)^{\kappa}} \quad \text{for } 0 < V < \infty;$$

Where $k > 0$ and $c > 0$

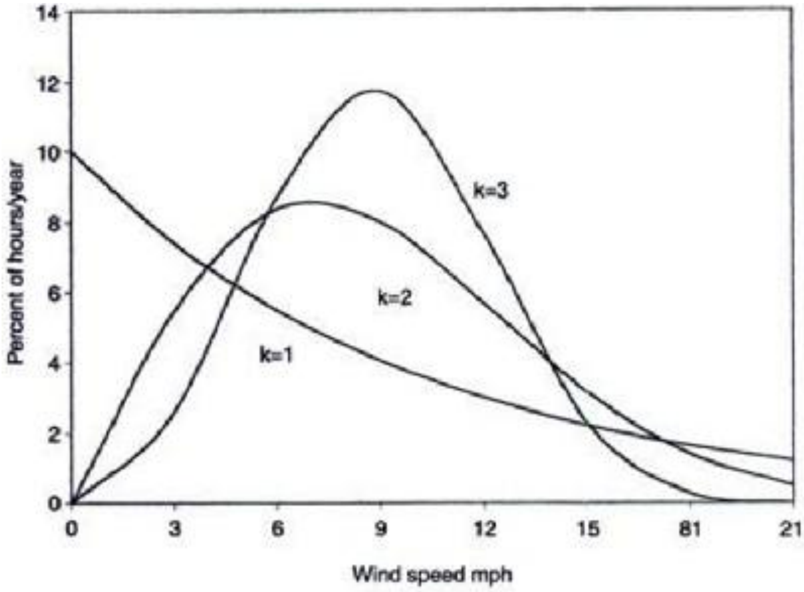
It is a complementary cumulative distribution function and a stretched exponential function. The Weibull distribution is related to a number of other probability distributions; in particular, it interpolates between the exponential distribution ($k = 1$) and the Rayleigh distribution ($k = 2$).

v is the wind speed and finally h is given by:

$$h = \frac{Fraction\_of\_time\_wind\_speed\_is\_between\_v\_and(v + \Delta v)}{\Delta v}$$

Source [13]

Figure 21 shows Weibull probability distribution.



Weibull probability function with scale parameter *c* =10 and shape parameter *k* =1, 2 and 3

Figure 21

Graph of *h* vs. *v* at various *k* Values

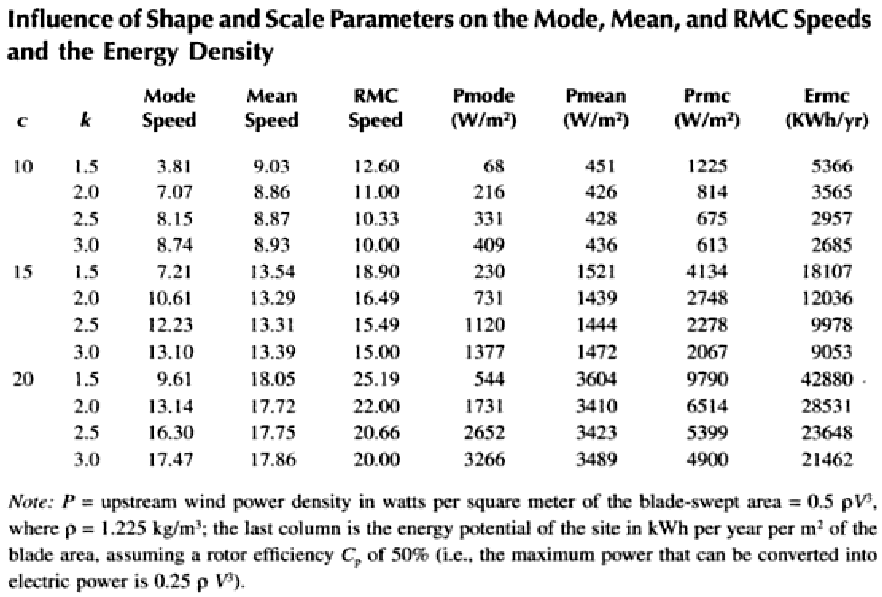
Source [14]

k = 1 designates the exponential distribution, $h = \lambda * e^{-\lambda v}$

where $\lambda = 1/c$

k = 2 makes it the Rayleigh distribution, $h = 2\lambda^2 * v * e^{-(\lambda v)^2}$

k > 3 makes it approach a normal bell-shape distribution [13].



Influence of Shape and Scale Parameters on the Mode, Mean, and RMC Speeds and the Energy Density

c	k	Mode Speed	Mean Speed	RMC Speed	Pmode (W/m²)	Pmean (W/m²)	Prmc (W/m²)	Ermc (KWh/yr)
10	1.5	3.81	9.03	12.60	68	451	1225	5366
	2.0	7.07	8.86	11.00	216	426	814	3565
	2.5	8.15	8.87	10.33	331	428	675	2957
	3.0	8.74	8.93	10.00	409	436	613	2685
15	1.5	7.21	13.54	18.90	230	1521	4134	18107
	2.0	10.61	13.29	16.49	731	1439	2748	12036
	2.5	12.23	13.31	15.49	1120	1444	2278	9978
	3.0	13.10	13.39	15.00	1377	1472	2067	9053
20	1.5	9.61	18.05	25.19	544	3604	9790	42880
	2.0	13.14	17.72	22.00	1731	3410	6514	28531
	2.5	16.30	17.75	20.66	2652	3423	5399	23648
	3.0	17.47	17.86	20.00	3266	3489	4900	21462

Note: P = upstream wind power density in watts per square meter of the blade-swept area = 0.5 ρV^3, where ρ = 1.225 kg/m³; the last column is the energy potential of the site in kWh per year per m² of the blade area, assuming a rotor efficiency C_p of 50% (i.e., the maximum power that can be converted into electric power is 0.25 ρ V^3).

Source [14]

- Energy Distribution:

If the energy distribution function is given by:

$$e = \frac{\text{kWh contribution in the year by the wind between v and } (v + \Delta v)}{\Delta v} ;$$

Then the distribution would look like the shaded curve in the Figure below for the Rayleigh equation

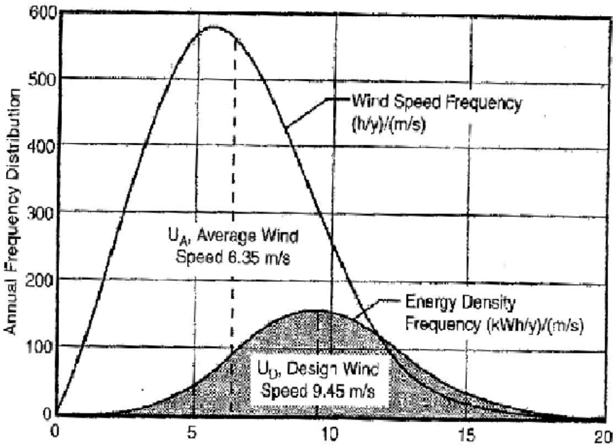


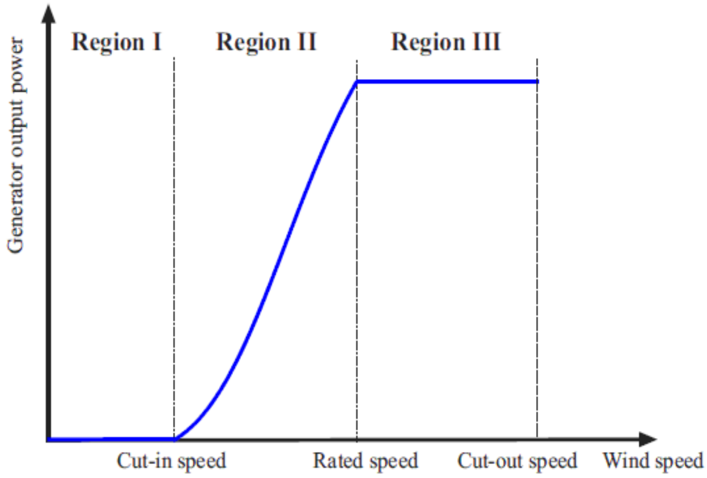
Figure 22

Wind Speed and Energy Density Frequencies for Various Wind Speeds

3.3 Wind Turbine System

Kinetic energy in different wind speeds is converted into rotational energy in the rotor. It is then transferred to a gearbox and afterwards to the generator where it directly converts the mechanical energy into electrical energy. The Proven wind turbine does not have a gearbox but many large wind turbines have one. It is necessary to convert this electrical energy to the equivalent grid values, 50 Hz or 60 Hz and constant voltage amplitude. Many turbines operate at constant rotational speed, but smaller machines are often variable speed and it then necessary (if connecting to the grid) to process the electrical output with an inverter. The inverter converts the electricity generated for different wind speeds to a constant voltage and frequency. Finally electrical energy is transferred to the grid and converted to 230 V or 400 V, 50 Hz and used by an industrial or domestic consumption [16].

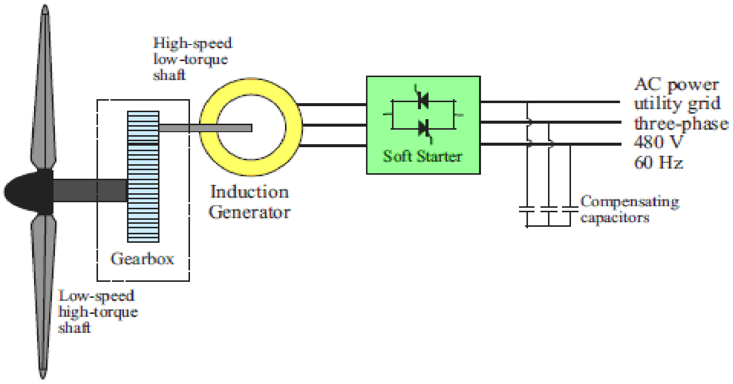
A traditional wind turbine output graph is divided in three different regions. The plot below shows the typical wind energy distribution for a wind turbine, Region I, Region II, Region III which correspond with different wind speeds.



Ideal characteristic of a wind turbine generator

Figure 23

In Region I, where wind speeds are under the cut-in, wind speeds could not move wind turbine blades and it does not produce energy. For Region II, wind speeds are between the cut-in and the rated wind speed [15], in this region power output increases sharply as wind speed increases. In Region III, wind speeds are over the rated wind speed and power output is maintained roughly constant at the rated value. This regulation of power output is achieved either though control of blade pitch angles, or though natural stalling of the flows over the blades. After Region III the wind speed exceeds the Cut-in value and the turbine must shut down for safety reason [16].



Constant-speed wind turbine configuration with a squirrel-cage induction generator that is directly coupled to the grid

Figure 24

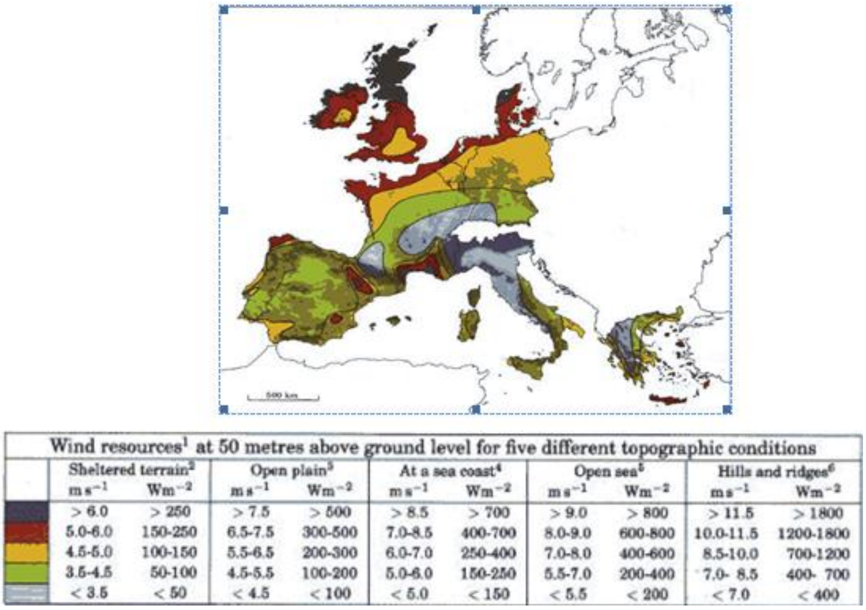
3.4 The Wind Market in Europe

In 2008 the European wind market had increased to over 8.4 GW installed energy capacity. Since 2007 it has increased by 15 % to reach a total installed energy capacity of 64,949 MW in 2008 up from 56,535 MW the previous year and it is expected to reach 240 GW by 2012 [17]. Again assuming current growth, global wind turbine production will grow by over 155 % in the same period, and has in fact now hit 20 GW production of new installations per year.

The global electricity produced by wind energy will in 2012 exceed 500 TWh (up from 200 TWh in 2007) [15]. China and United states are the countries which are developing fastest in the wind market, their superpower (or upcoming superpower) status and the increasing price of oil and other conventional energy sources having a large effect.

Europe is just being North America with 10.3 GW annual energy installations. By 2020, Europe has to generate 20 % of total energy using renewable energy. It will therefore need to generate about 35 % of its electricity from a renewable energy source, of which wind might produce 12 % [18].

The Figure 25 illustrates the wind energy resources in Europe. Notice that the UK and Ireland have the highest wind speed in Europe. In particular, Scotland which has the highest wind speed in the UK, over 6 m/s[17].



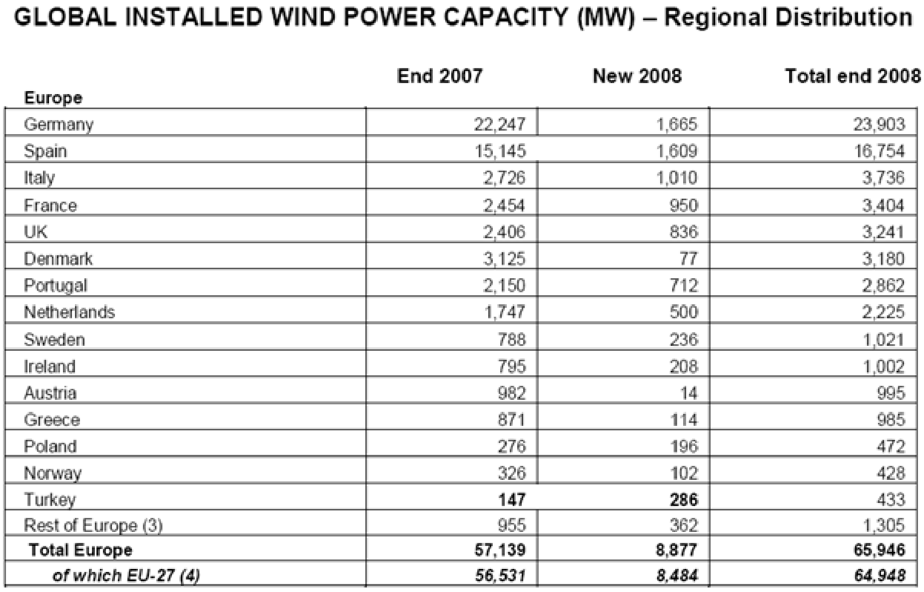
Wind resources[1] at 50 metres above ground level for five different topographic conditions

	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}
⬛	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
🟥	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
🟨	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
🟩	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
⬜	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Figure 25

Source [18]]

Table A shows the installed wind capacity in Europe. Germany has highest wind energy production, only Spain having comparable levels of activity. Other countries like Italy, France and the UK are developing large programmes to increase the use of this source.



GLOBAL INSTALLED WIND POWER CAPACITY (MW) – Regional Distribution

Europe	End 2007	New 2008	Total end 2008
Germany	22,247	1,665	23,903
Spain	15,145	1,609	16,754
Italy	2,726	1,010	3,736
France	2,454	950	3,404
UK	2,406	836	3,241
Denmark	3,125	77	3,180
Portugal	2,150	712	2,862
Netherlands	1,747	500	2,225
Sweden	788	236	1,021
Ireland	795	208	1,002
Austria	982	14	995
Greece	871	114	985
Poland	276	196	472
Norway	326	102	428
Turkey	**147**	**286**	433
Rest of Europe (3)	955	362	1,305
Total Europe	**57,139**	**8,877**	**65,946**
of which EU-27 (4)	***56,531***	***8,484***	***64,948***

Table A

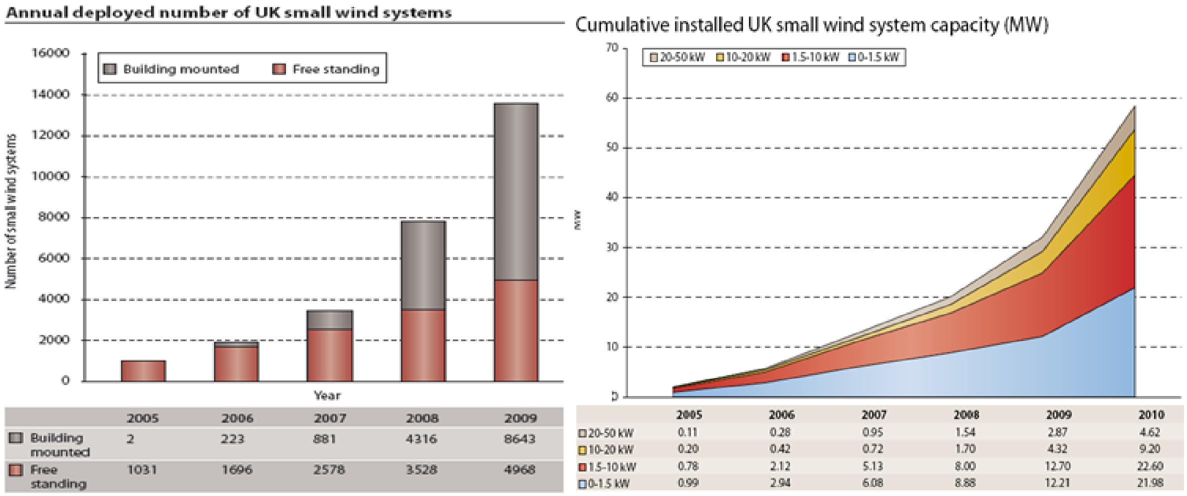
Source [19]

Scotland has increased its wind energy sector, expecting to reach 10 % of electricity from this source by 2010. It’s still uncertain if Scotland will achieve the European 20 % target by 2020. The 2010 and 2020 targets are really challenging. Spain’s renewable energy production percentage may almost pass 10 % by 2010, Germany might achieve its 2010 target but it’s really uncertain that either country will achieve 20 % by 2020. Denmark is the only country at present whose percentage output can plausibly hit the 20 % target [20].

3.5 Small Scale Wind Turbine

In the United Kingdom in the small scale wind turbine market, almost 10,000 small systems have been deployed, providing over 20 MW of installed capacity. Annual deployment has increased from 7.11 MW in 2007 to 7.24 MW in 2008 [21]. The UK is also a major exporter of small scale turbines. The principal buyer is the US, whose market grew over 78 % last year, providing more than 17.3 MW of installed capacity. This sector will increase to more than 1 GW by 2020 if there are appropriate policies allowing it to support private investors.

Figure 26 shows the growth in installed capacity of different small scale wind turbines. The annual energy production depends on the wind speed of the site and as in the big wind turbine case the character of the wind also affects how much energy a small turbine can deliver.



	2005	2006	2007	2008	2009
▨ Building mounted	2	223	881	4316	8643
🟥 Free standing	1031	1696	2578	3528	4968

	2005	2006	2007	2008	2009	2010
☐ 20-50 kW	0.11	0.28	0.95	1.54	2.87	4.62
🟨 10-20 kW	0.20	0.42	0.72	1.70	4.32	9.20
🟥 1.5-10 kW	0.78	2.12	5.13	8.00	12.70	22.60
🟦 0-1.5 kW	0.99	2.94	6.08	8.88	12.21	21.98

Figure 26

Source [22]

The small scale systems are divided in four different groups, each group is also divided by the power output that a turbine could deliver. The pie chart below shows the UK installed capacity in 2008 for the different small scale wind turbines.

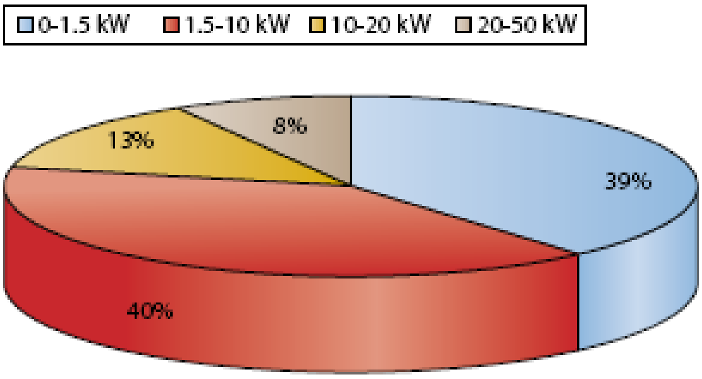


Figure 27

These urban turbines produce electricity at the location where it is installed; hence there are no transport losses. The generator transforms mechanical energy electricity just once and in addition, there is only one loss caused by conversion (AC to DC then DC to AC and finally to AC 230).

This turbine technology can be used in numerous locations, not only in urban environments but also in remote locations where the national grid connection does not extend. For example, in the Antarctica the International Polar Foundation (IPF) has installed eight 6 kW Proven turbines which will delivery annual output between 6000 to 12000 kWh depending on the site.

Due to the nature of wind energy it unfortunately prohibits it from being used as an emergency energy. It is not always available at the time it is need, but it can of course be used to charge energy stores (e.g. batteries) for energy use.

Chapter 4

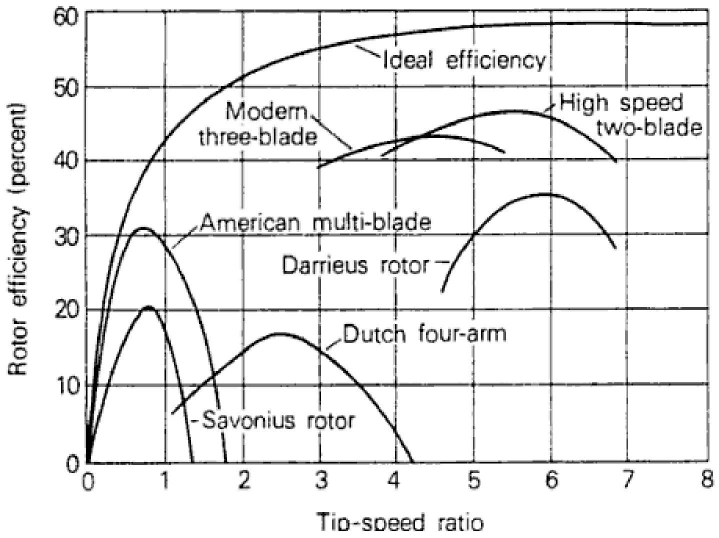
4.1 Methodology

Three years ago, the Mackintosh Environmental Architecture Research Unit (MEARU) installed a small scale wind turbine, 2.5 kW. During the first 6 months, the Proven 2.5 kW turbine went through a performance test and the power output was acceptable. After 6 months the turbine started to produce less energy and power output decreased to between 1/3 and 1/4 of the expected output (see p 11).

The turbine is controlled by a combination of (i) the inverter loading the generator, based on a 3 point voltage-power curve with load regulated by the voltage (proportional to Rpm) and (ii) the passive pitching of the blades. If there is no load on the generator because for example, the grid connection is lost or the inverter is switched off, the turbine will then spin up to its maximum offload speed for the given wind speed. The loading curve which is programmed into the inverter is one of the key things to check, in order to evaluate if a turbine is under-performing.

The physical data investigated throughout this dissertation were collected between May 2008 and June 2009 and recorded on a per minute basis. It quickly became difficult to work with this per minute data because of its quantity; hence it is dealt with in 10 minute averages. Around 1,000 data acquisitions per week were received. Therefore plotting ranges of 1,000 pieces of data it is possible to look at the turbine performance over a week. It is still necessary to use 1 minute data for certain investigation plots. A table which contains the most important parameters, Voltage, Ampere, Power or Rpm was constructed to produce calculated features such as coefficient of power, load impedance or tip speed ratio.

Modern three blade wind turbines reach a maximum Cp value in the range 0.4 to 0.45, and tip speed ratio of 4 to 5. High values of Cp are maintained over a wide range of tip speed ratio. Smaller turbines (particularly those with rotors of high solidity such as the Proven machine) would have a smaller value of maximum Cp, and would tend to operate at lower tip speed ratio.



Coefficient of power vs *V0/V* ratio [24]

Other important parameters to look at in to the spreadsheet are the current and calculated impedance, both of which would be plotted with respect to the mean $V = IZ$. Current is inversely proportional to the impedance. Plotting both parameters would allow us to clearly see if the turbine is running slow when there are higher wind speeds, high current and small impedance.

4.2 Results

4.21 Ideal Case

This type of turbine could produce an annual energy output in the range of 2,500-5,000 kWh depending on site [24]. The plot below shows Proven 2.5 kW turbine power production at different wind speeds. It demonstrates that the output peaks at a wind speed of 15 m/s producing almost 3 kW and then drops slightly, stabilizing at 17 m/s at approx 2.7 kW. Figure 28 shows ideal value for a new Proven 2.5 kW wind turbine.

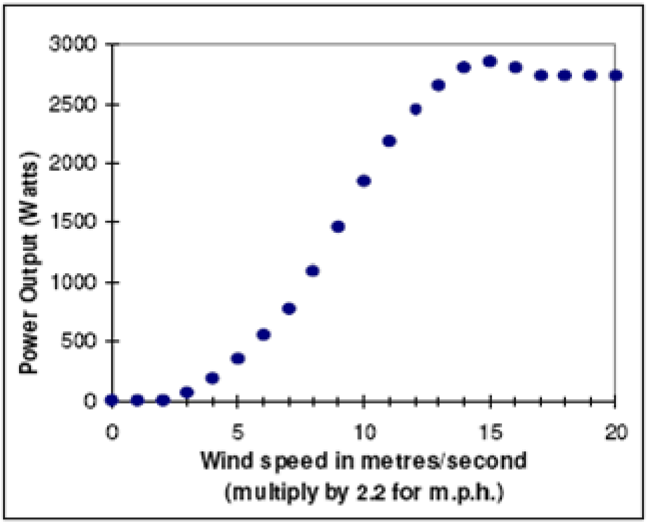


Figure 28

Figure 28 is for the latest version of the Proven 2.5 kW wind turbine and the power output reaches almost 3 kW. In comparison, Figure 29 represents the previous Proven 2.5 kW. From this it demonstrates that the power output did not go higher than 2.2 kW at 14 m/s, although the performance in wind speeds greater than this is not shown. For each wind speed there will be an optimal rpm to maximise power output, and if this is not achieved the performance will suffer.

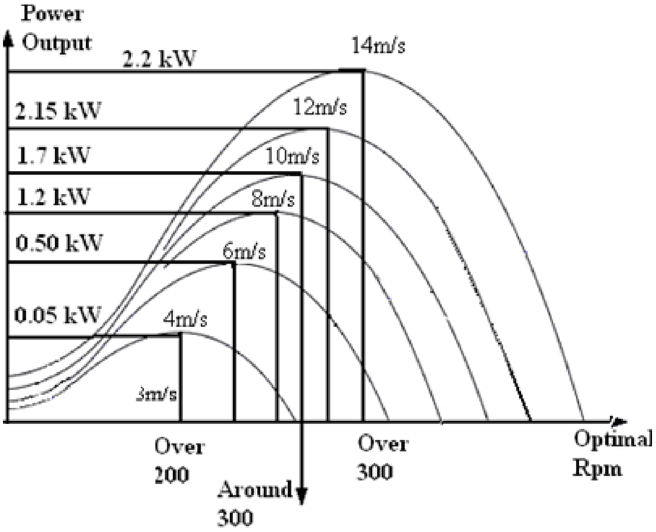


Figure 29

The turbine described in Figure 29 starts to produce energy, when wind speed reaches around 4 m/s. At this wind speed the coefficient of power is around 15 %. It continues to rise until 8 m/s when the Cp reaches a maximum around 35 % and then goes dips to under 10 %, at 25 m/s.

Figure 30 shows an ideal coefficient of power for the latest Proven 2.5 kW turbine with respect to the tip speed ratio performance. The maximum Cp is around 40 % and λ is around 3- 3.5.

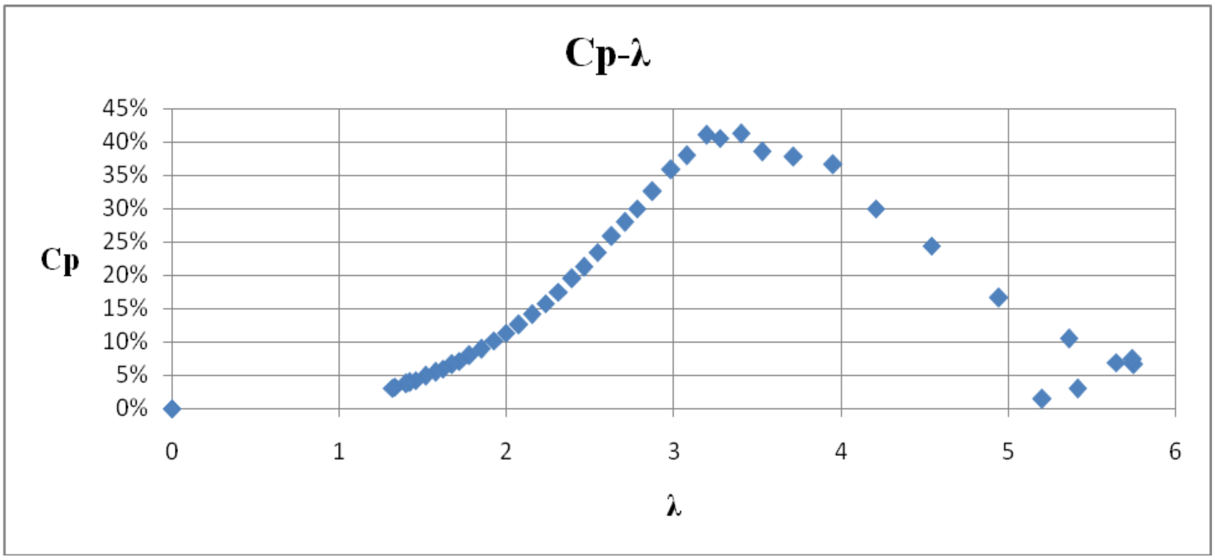


Figure 30

The turbine spins faster when wind speed increases, therefore at a higher wind speed, up to a point, rotors will spin faster. The point at which this turbine is spinning fastest is around the rated wind speed. This turbine tends to turn more slowly at wind speeds greater than the rated wind speed (see Figure 31). The highest speed is between 12-14 m/s with maximum rpm around 330. Above 14 m/s the turbine will slow down not below 300 rpm. The Proven is unusual in having deformable blades, which flex in a controlled manner in high winds. Aerodynamic behaviour is changed and there is some reduction in the rotor swept area. Details of blade behaviour are commercially sensitive.

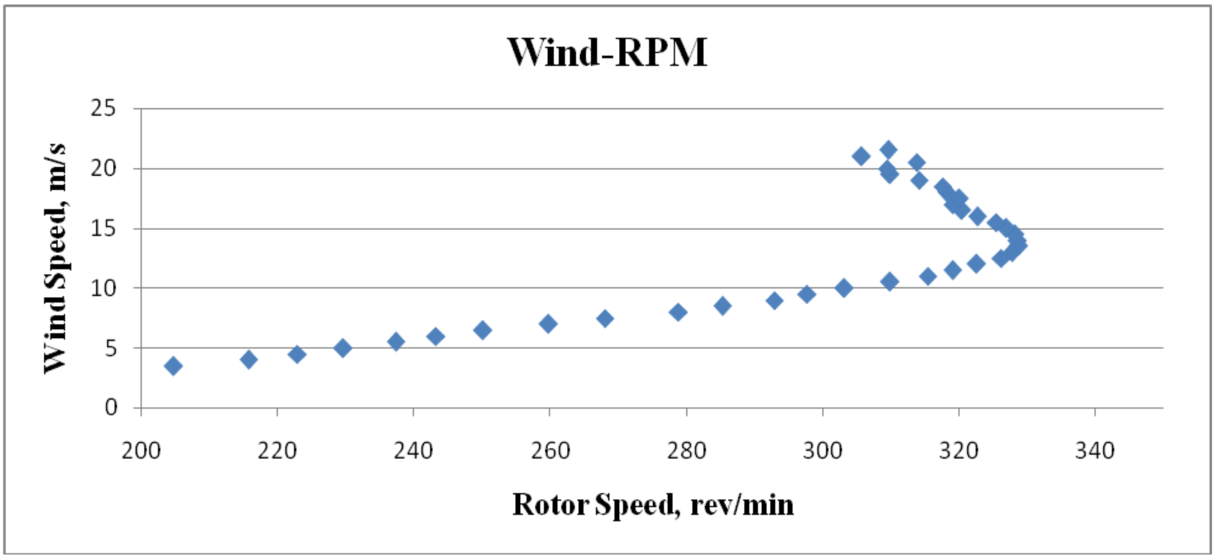


Figure 31

Similar circumstances occur with voltage. It increases until the turbine reaches rated wind speed. After it surpasses this speed it will then drop several volts mirroring the effect of the rpm described above. Output voltage is around 295 ±0.5 Volts at rated wind speed.

Wind direction may also be important. The energy output from a wind turbine may be higher in some wind directions. This could occur due to obstacles such as buildings affecting the turbine thus resulting in the power output decreasing or increasing. This raises the issue of accuracy of wind speed measurement. It is clearly impossible to measure wind speed at the exact location of the turbine. Discrepancies between measured and “true” wind speed may be substantial, especially in an urban location. Finally, power output may also be affected by changes in atmospheric air density.

4.22 Case Study

This case study is divided in six different parts.

1. Cp with respect to tip speed ratio.
2. Cp with respect to wind speed.
3. Wind speed with respect to rpm.
4. Power with respect to rpm.
5. Current and voltage and Impedance.
6. Wind direction and its effect on performance.

In plotting Cp with respect to tip speed ratio the performance of the wind turbine is going to be evaluated. Similarly it is possible to evaluate Cp with respect to wind speed. The aim is to calculate the efficiency of the wind turbine from the following graphs. From this it can be illustrated through percentages whether or not the turbine is performing as it should.

Power output with respect to rpm is one of the things that are used to evaluate the wind turbines performance. From plotting this data it can be shown that at each optimum rpm the turbine gives the appropriate power output. Any problem that occurs with the turbine power output may be resolved by studying the power versus rpm data.

Voltage, current and calculated impedance give an idea about the inverter effectiveness. The inverter is part of the control system which increases or reduces the spinning of the blades according to the optimum rpm at a particular wind speed. Following from this, it reduces or increases voltage and current when wind speed changes.

The collected data is divided in 12 different parameters which the most important parameters to this study project are: Rpm, power output, voltage, current, and bins. Wind direction was not possible to record. The wind direction was obtained from Met Office (see Appendix C). Using the data recorded parameters such as tip speed ratio or impedance were calculated.

May 2008

1. Cp with Respect to Tip Speed Ratio

As stated in the Methodology, coefficients of power plots are divided in weeks. Each plot represents seven days, hence these plots are divided in four weeks and there is an extra plot for the other 3 or 4 days.

Figure 32 represents the Coefficient of power curve with respect to λ. The maximum effciency is under 20 %. There are three points above to 20 % but these cases are when wind speed are under 4.5 m/s and power output is small, therefore these points are not reliable. λ is between 3 and 4 and maximum Cp is around 3.5. The plot below shows the first weeks turbine performance in May 2008. For more information please refer to Table 2.

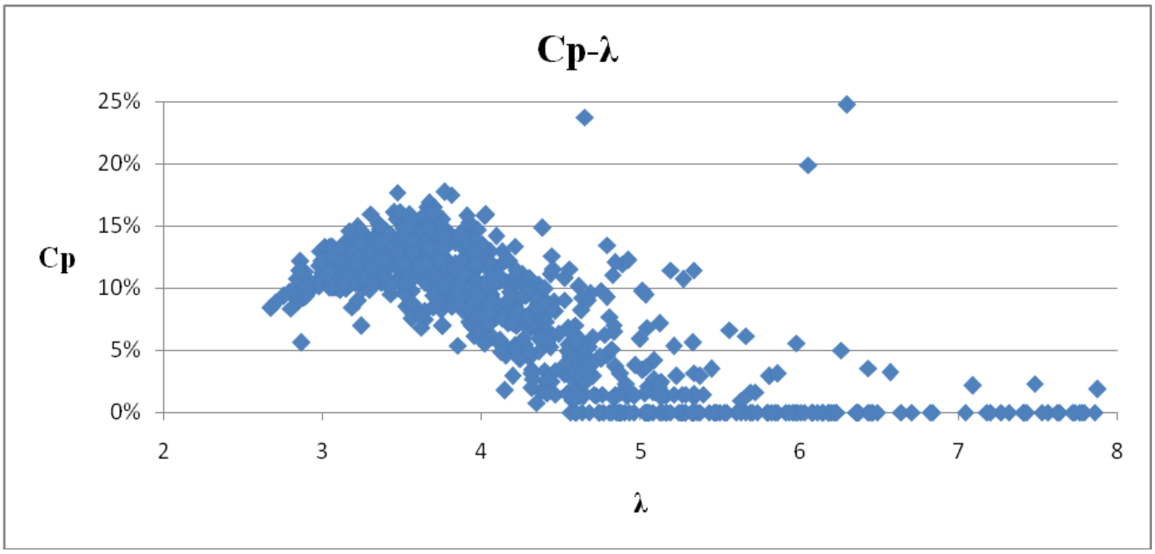


Figure 32

From Figure 33, from the wind third week of May 2008, it can be clearly seen that the same circumstances have occurred as in the previous plot. The turbine continued to underperform, Cp did not reach 20 % and λ potimum was still between 3 and 4.

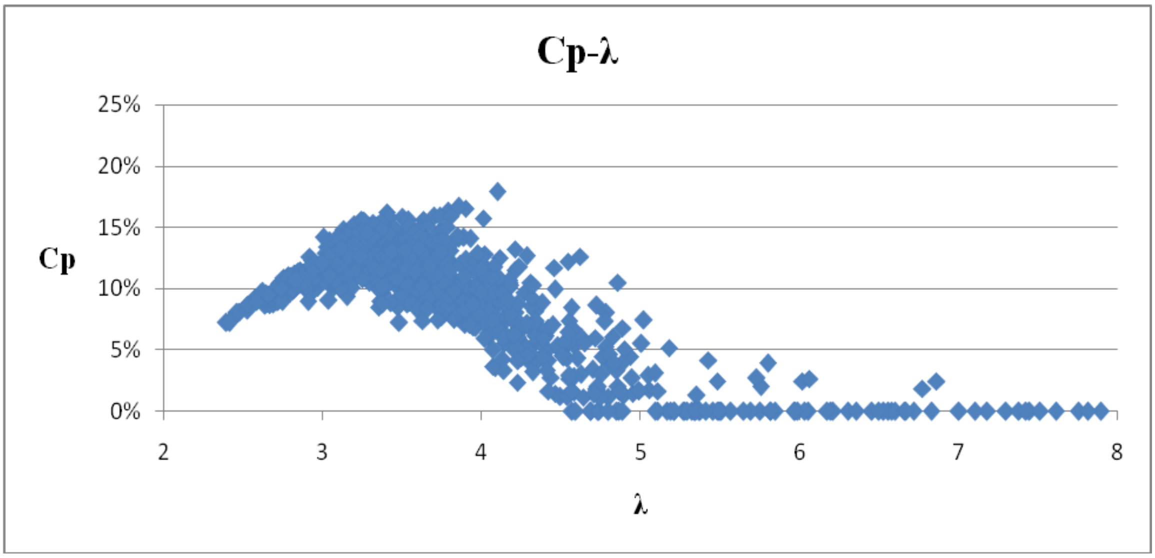


Figure 33

For more information please refer to Table 1

2. Cp with Respect to Wind Speed

This part shows Cp evolution with respect to wind speeds during the first week of May 2008. The graph shows a maximum Cp at between 5 to 7 m/s and the correct increase and decrease in Cp evolution. These circumstances are similar to the ideal case where Cp reaches a maximum percentage of around 7 m/s, but of course the peak values are far from too low.

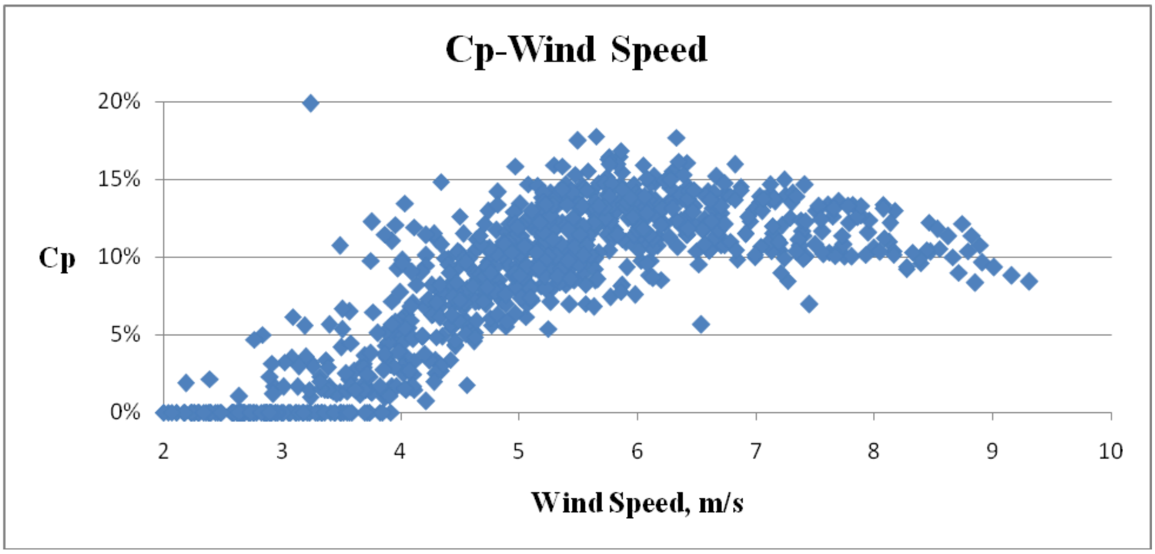


Figure 34

The third weeks graph (Figure 35) shows the same characteristics as the previous one in Figure 34. Here it demonstrates that the downward trend of Cp at high wind speeds continues beyod 10 m/s.

For more information please refer to Table 1

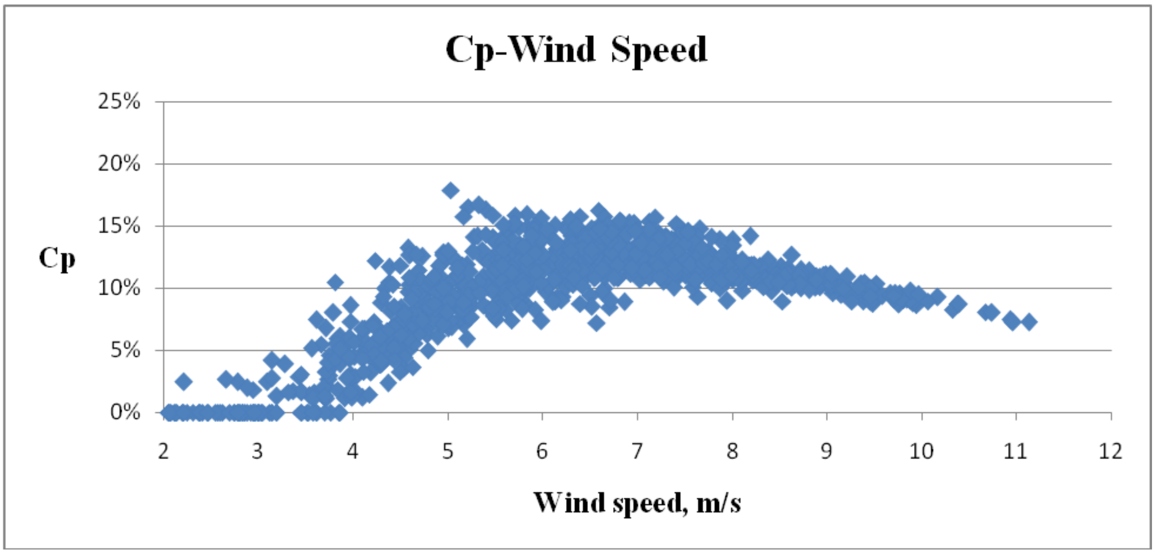


Figure 35

3. Wind Speeds with Respect to Rpm

To find clearer results, wind speed and rpm have been plotted without using an average 10 minutes such as had been used for the other plots. Instead it has been plotted minute by minute. It is more interesting to look at exact wind speeds rather than an average, particularity considering higher wind speeds. Using this method it could possibly highlight any unusual behaviour.

In the following graphs plots are 3 days data acquisition, hence to show a month there are 10 plots.

During May 2008, there were 51 times that wind speeds were 12 m/s or higher. Hence during these 51 times, the energy output should have gone up to 2.2 kW. However, in reality the maximum energy output was 0.7 kW. Nevertheless, it to be taken into consideration that in an ideal case, with higher wind speeds of over 14 m/s all parameters (setback rpm, voltage and current) tend to drop in value.

Figure 36 shows a correct rpm evolution with a steady rise as in normal ideal circumstances. In an ideal case the rpm should be over 300 at around 10m/s however, in reality the rpm at 10 m/s did not go further than 285 rpm.

This difference between the real and ideal rpm should cause a drop in the expected energy output of around 0.5 kW. However, in this case the energy output dropped to 0.4 kW, thus showing a difference in energy output of 1.1 kW between what was expected and the reality.

In order to extract power from the turbine at low wind speeds, it is necessary to let the rotor spin before will be possible to create power otherwise it would stall and stop. Therefore graphs below show rotor speeds movement before 4 m/s [24].

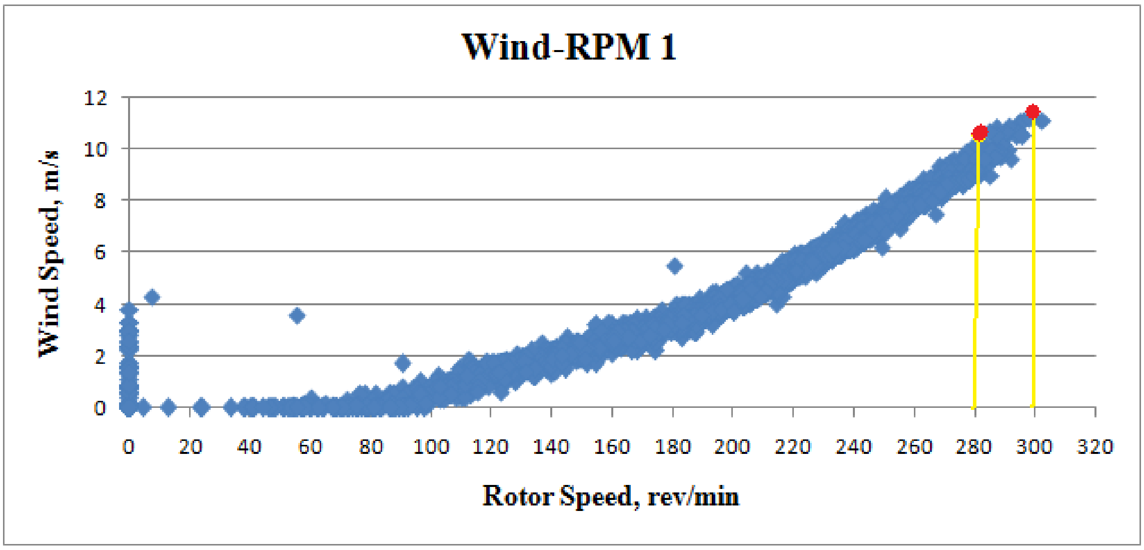


Figure 36

In Figure 37 the 2 points highlighted in red illustrate 280 and 300 rpm. The first red point is around 10 m/s and second is almost 12 m/s. Extracted from ideal case rpm at both points rpm should be over 300 rpm at 10 m/s and over 320 rpm at 12 m/s. However in this case they both have between 20 and 30 less rpm and the turbine spin is between 5 to 10 % less.

Due to the decreased rpm stated above the it should therefore result in the spin turbine producing less energy. Even so, surprising given the the above data the power output produced was much less than 50 %. It would have been expected that at 10 m/s power output should be around 1.8 kW.

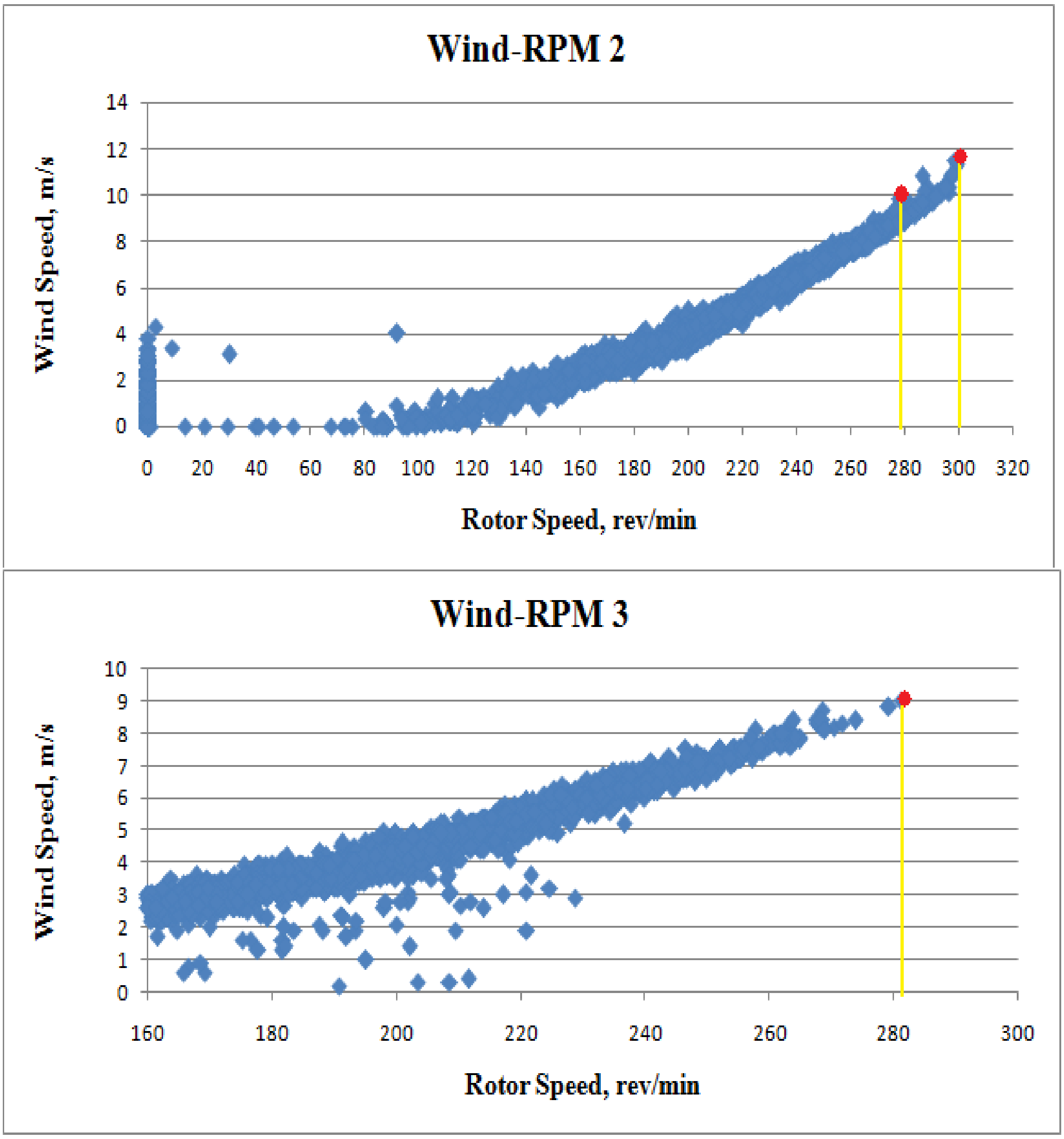


Figure 37

Figure 38 shows a steady increase of rpm until it reached 303 rpm at 12 m/s.

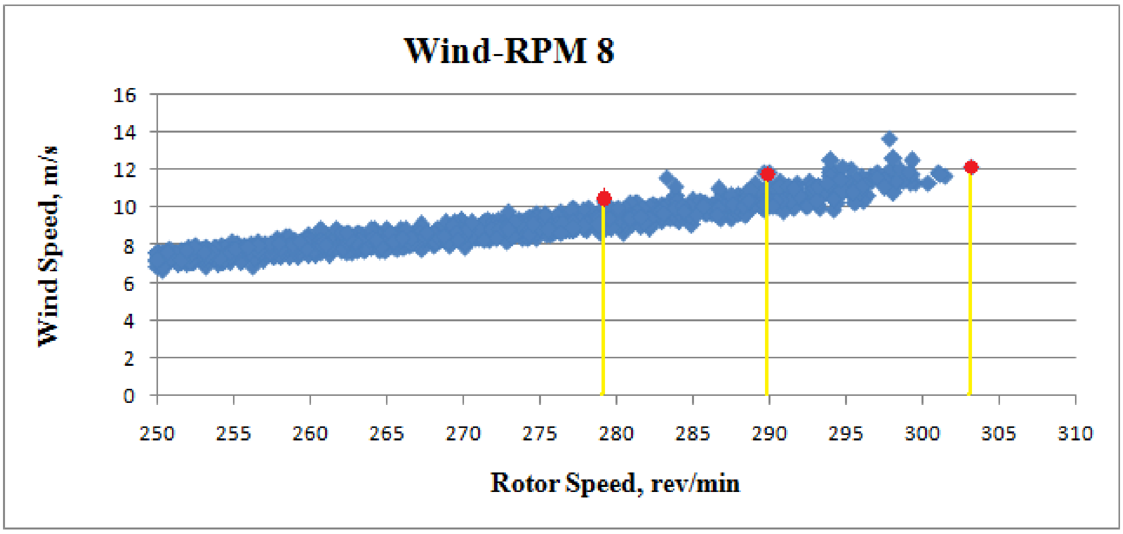


Figure 38

Figure 39 shows similar characteristics to the previous plots. At the end of the rpm evolution, the wind speed went up to 14 m/s and speed fell back to 298 rpm.

It is interesting to see that at the end of the rpm evolution, there were blue points between 11.3 and 12.7m/s where the rotor speed went beyond 300 rpm. This small increased in the rpm did not have any representation in the power output which remained stable at between 0.5 and 0.7 kW. However, it had a small representation in parameters such as voltage, current and impedance. See more information in Table 1, in Appendix A.

Table 1 shows different parameters at 302 rpm.

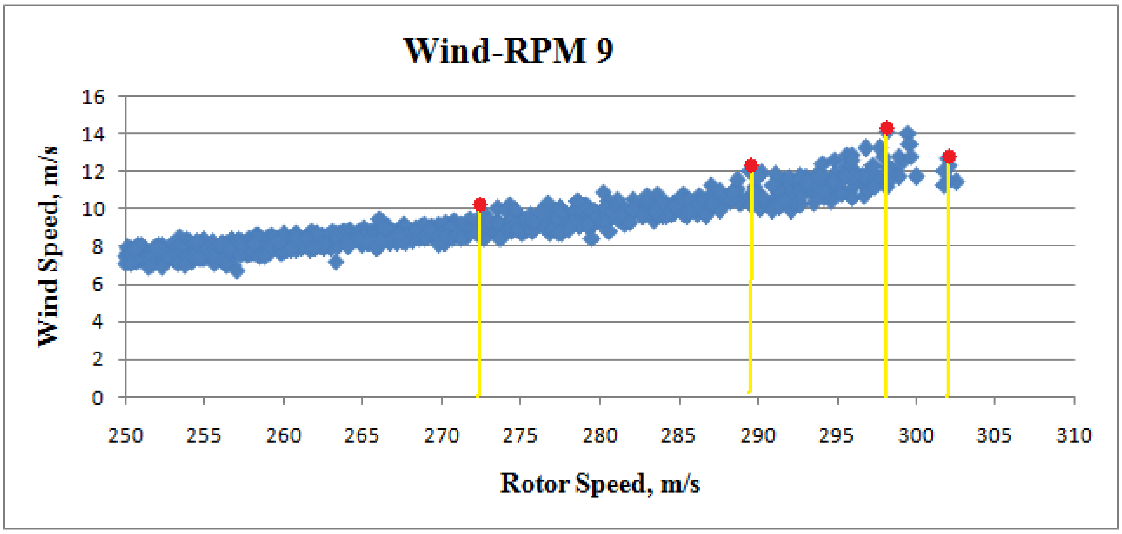


Figure 39

4. Power with Respect to Rpm

In this part of the case study, the graphs are plotted minute by minute and the now graphs have now changed to represent an average 10 minutes.

During first week of May 2008 (Figure 40), power output did not go further than 0.5 kW. The circumstances are also similar in Figure 41. For the third week of May 2008, if these Figures had plotted with minute by minute data the power output could have reached 0.7 kW.

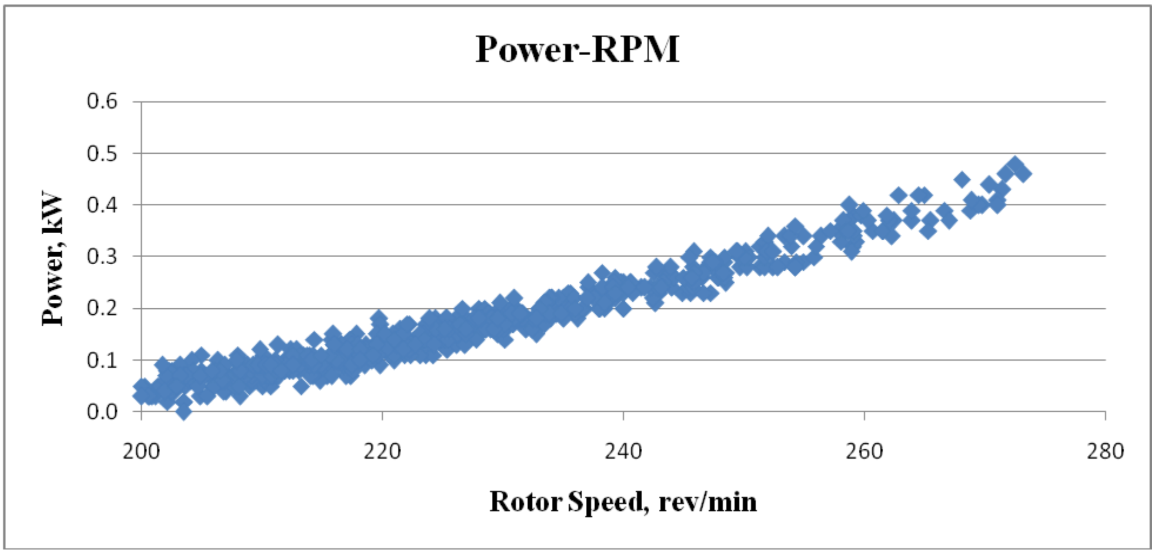


Figure 40

The highest rotor speed obtanined was 270 rpm. In the ideal case at 270 rpm power output is over 1 kW. Thus there is a deficit of 0.5 kW in output.

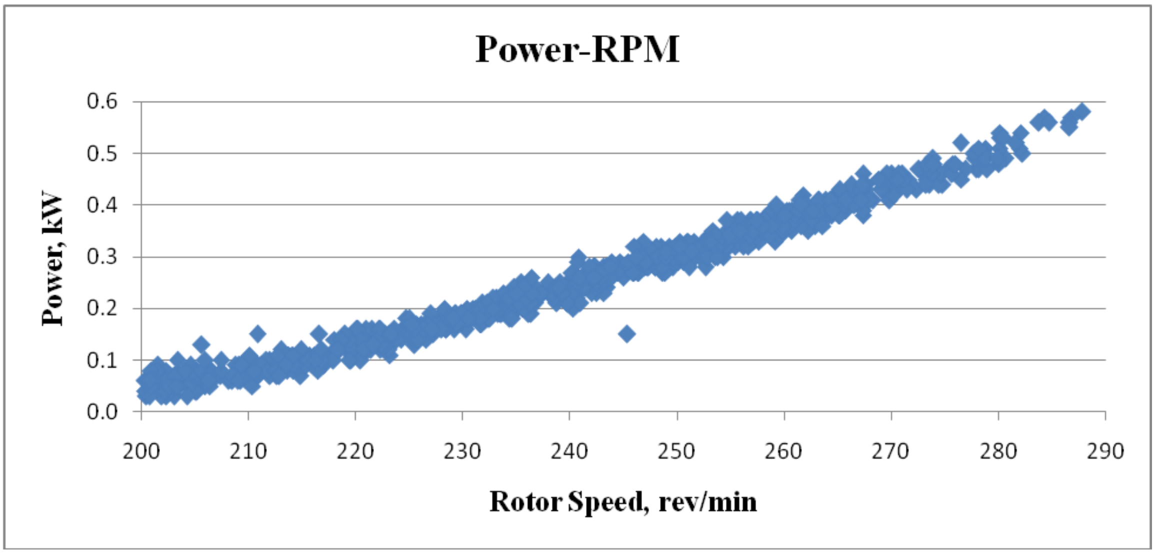


Figure 41

5. Voltage, Current and Impedance

This section shows how wind speed affects the voltage produced and further how the current is affected by wind speed. Figure 42 shows a steady increase in the voltage from 220 V to 240 V. In an ideal case, the voltage should be around 300 V at 10 m/s but in this case study conducted during May 2008 the voltage did not even reach to 270 V.

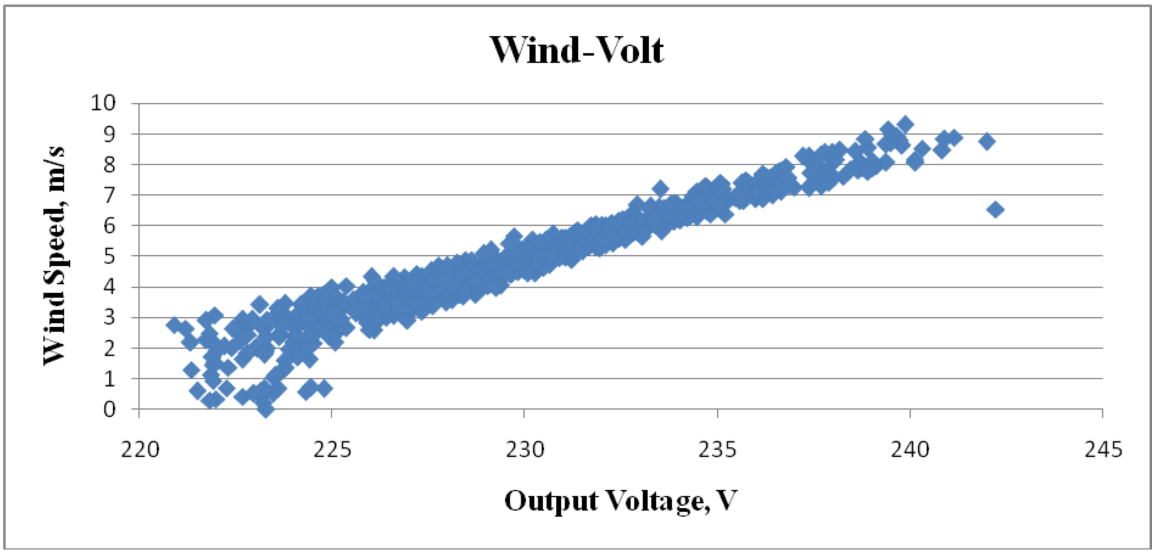


Figure 42

Figure 43 shows the third week of May 2008. Even though Figure 43 shows a windier week than Figure 42, the voltage did not increase further than 245 V. In the cases depicted in Figure 42 and 43, when the wind speed increases from 9.5 m/s (Figure 42) to 11.7 m/s (Figure 43), the voltage increases by around 5 volts.

Table 2 shows turbine performance at 10 m/s. Voltage oscillated between 242.7 and 244.6, for the same wind speed, when an ideal case should be stable with small oscillation, no more than 0.5 V.

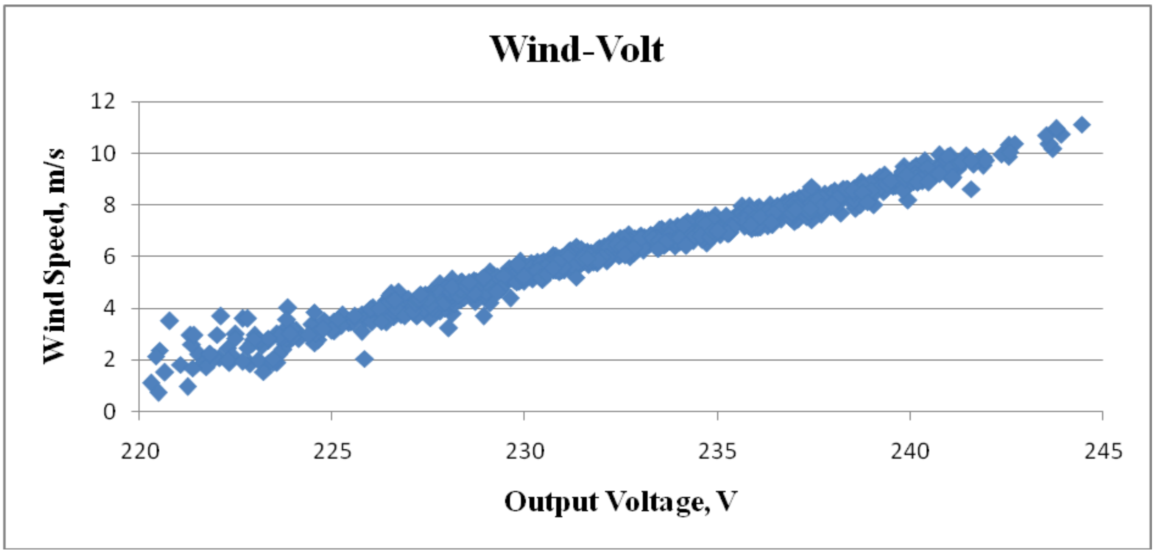


Figure 43

During the first week of May 2008 the same circumstances occurred with the current. It increased slightly but it was well below the expected level.

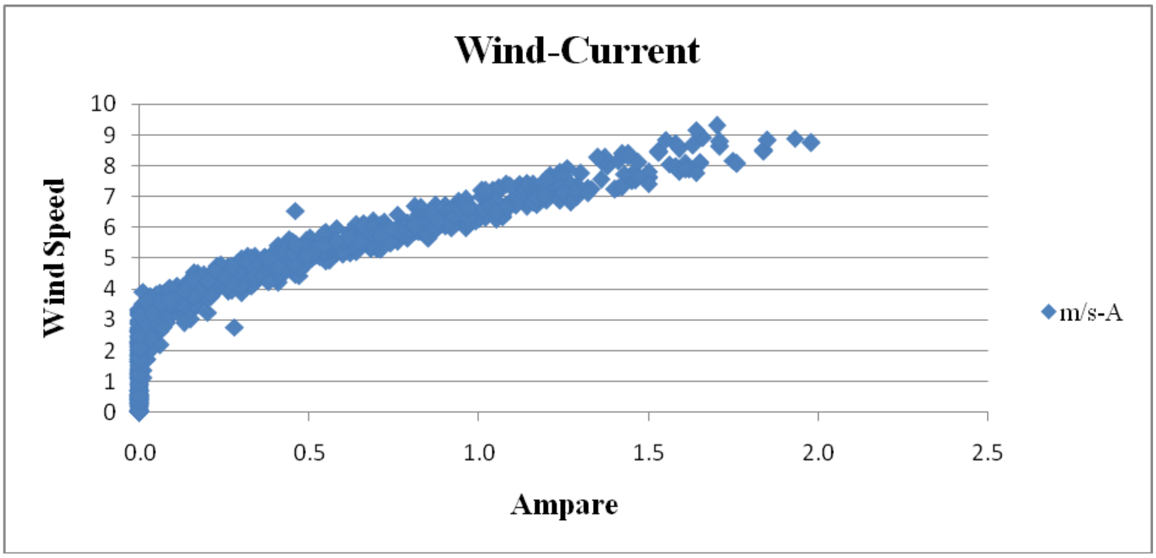


Figure 44

Figure 45 shows impedance performance with respect to voltage. When impedance was increased, the turbine could spin faster a higher voltage. Figures 45 and 46 show decreases in impedance down to almost 100 Ω at the highest voltage.

For a given wind speed, there is clearly an optimum vales of impedance which will maximise the electrical power output. Because impedance affects rotor speed (and hence λ and Cp), there is a complex relationship between control and rotor aerodynamics which is fundamental to the overall performance of the system. For more information please refer to Table 4, Appendix A.

Reference Data		**Voltage**	**Amp**	**Ω**	**Power kW**	**Wind**	**Cp**	**Rpm**
08/05/2008	14:56:16	245.2	2.4	102.17	0.6	10.5	0.09	293.6
08/05/2008	16:50:19	247.3	2.6	95.12	0.6	11.1	0.07	302.3
23/05/2008	20:54:21	246.3	2.7	91.22	0.7	11	0.09	297.7
25/05/2008	14:18:35	245.7	2.6	94.50	0.6	12.5	0.05	299.3
26/05/2008	14:18:19	246	2.7	91.11	0.6	11.8	0.06	299.3
27/05/2008	17:35:09	244.7	2.5	97.88	0.6	11	0.08	291.3
27/05/2008	20:55:14	246.7	2.7	91.37	0.7	11.7	0.07	295.5

Figures 45 and 46 show the measured impedance evolution. When voltage was increased to 240 V the impedance decreased to reach values of around 100 Ω but at low voltages, impedance values showed a surprising amount of scatter. For more information please refer to Table 2,3, Appendix A.

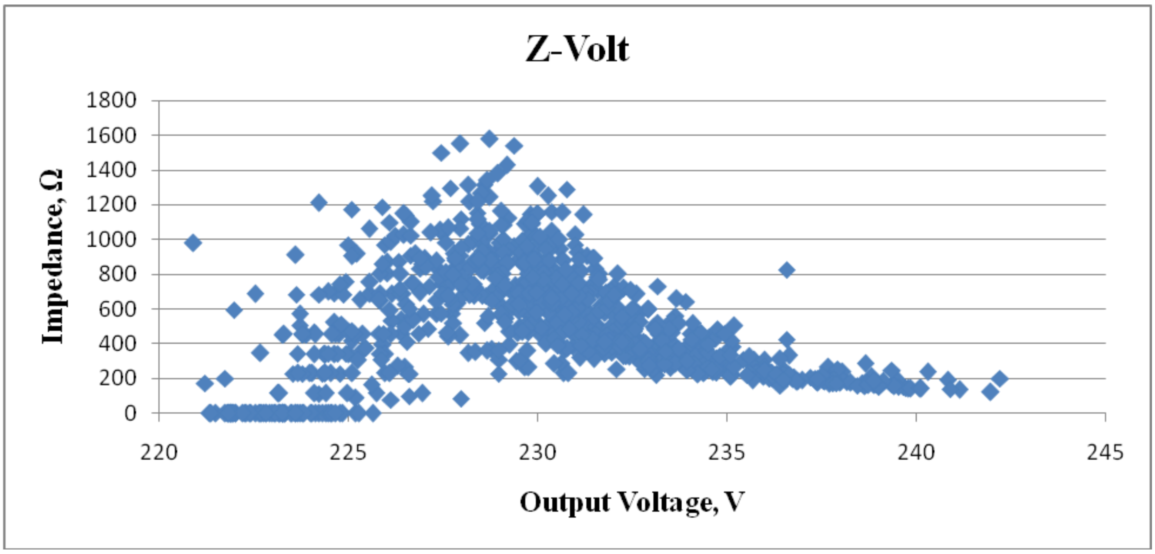


Figure 45

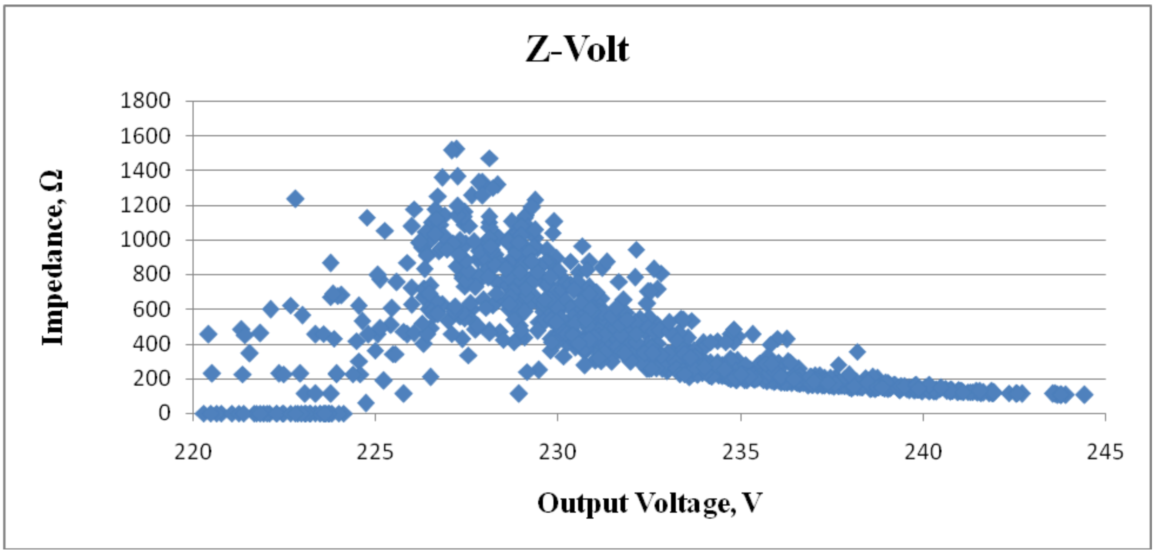


Figure 46

<u>May 2009</u>

1. Cp with Respect to Tip Speed Ratio

The coefficient of power figures for May 2009 showed similar characteristics to May 2008. The maximum Cp was not higher than 20 % and the tip speed ratio was around 3.5.

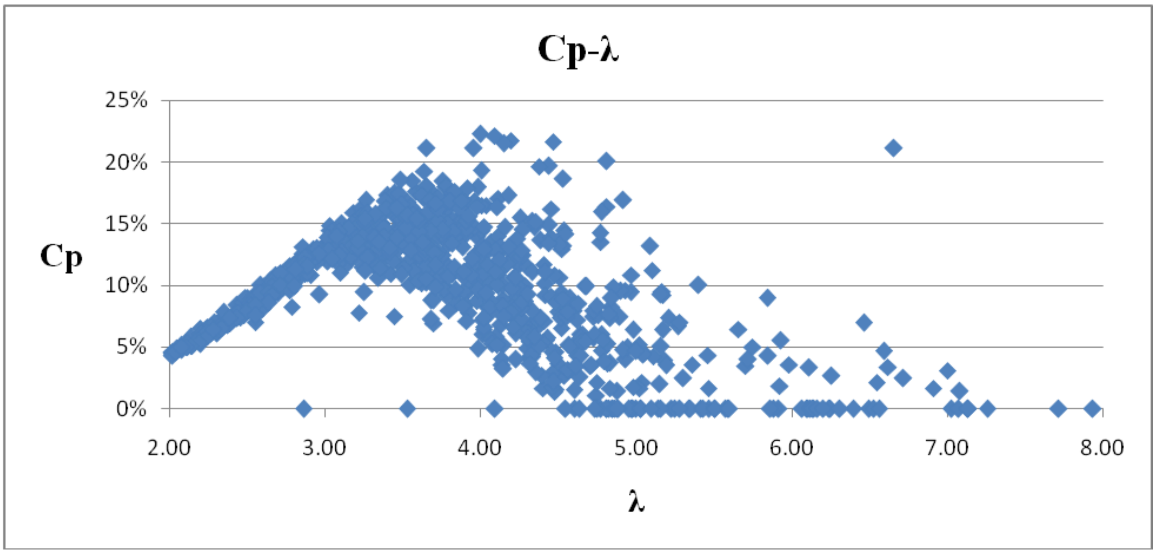


Figure 47

Figure 48 has similar characteristics to previous graphs, Figures 32 and 33. Cp was around 15 % and occurred around the ideal value of λ which is between 3 and 4. Here there were a significant number of points with higher Cp values (though all below 25 %) recorded at low wind speeds.

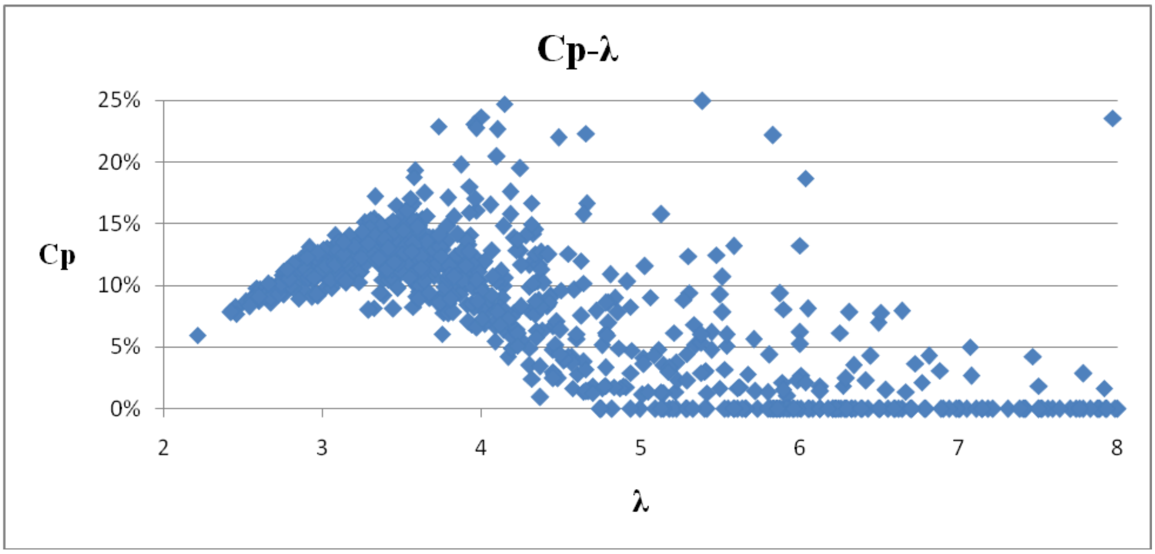


Figure 48

Comparing these two figures (47 & 48), it did not appear that there were any big differences between them. Cp and λ values were similar to the results found in 2008. If problems with the power output were caused by mechanical issues they should have become worse by 2009 and power output should have decreased accordingly.

2. Cp with Respect to Wind Speed

Figure 49 shows the first week of May 2009. The maximum Cp is between 5-7 m/s. It had similar Cp characteristics to May 2008. It increased and decreased at similar wind speeds.

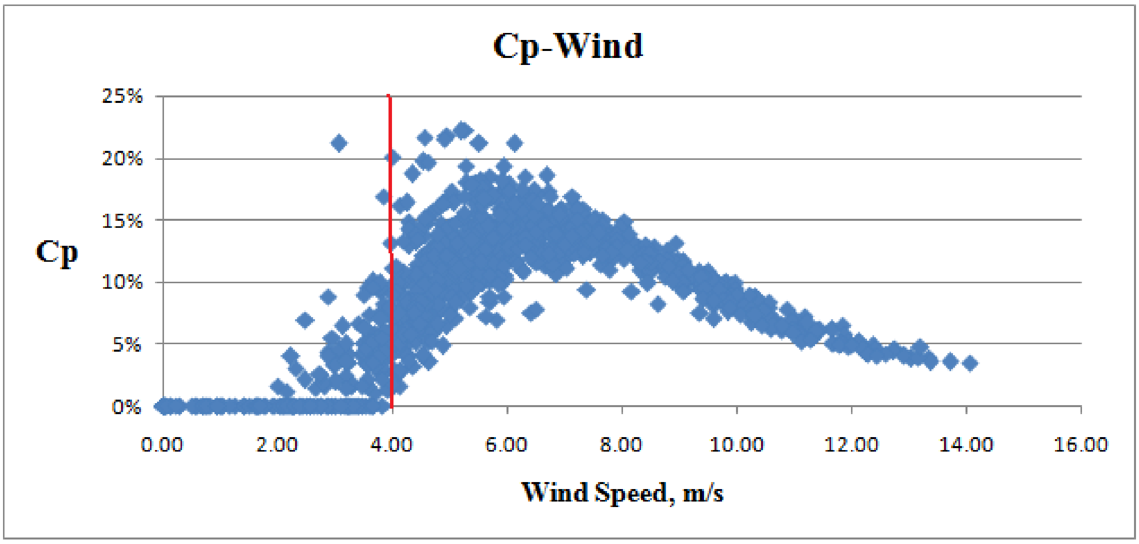


Figure 49

Figure 50 shows the third week in May 2009. It had similar characteristics to previous Figures. Cp increased to 17 % at around 6 m/s wind speed. More scatter is observed than in Figure 49.

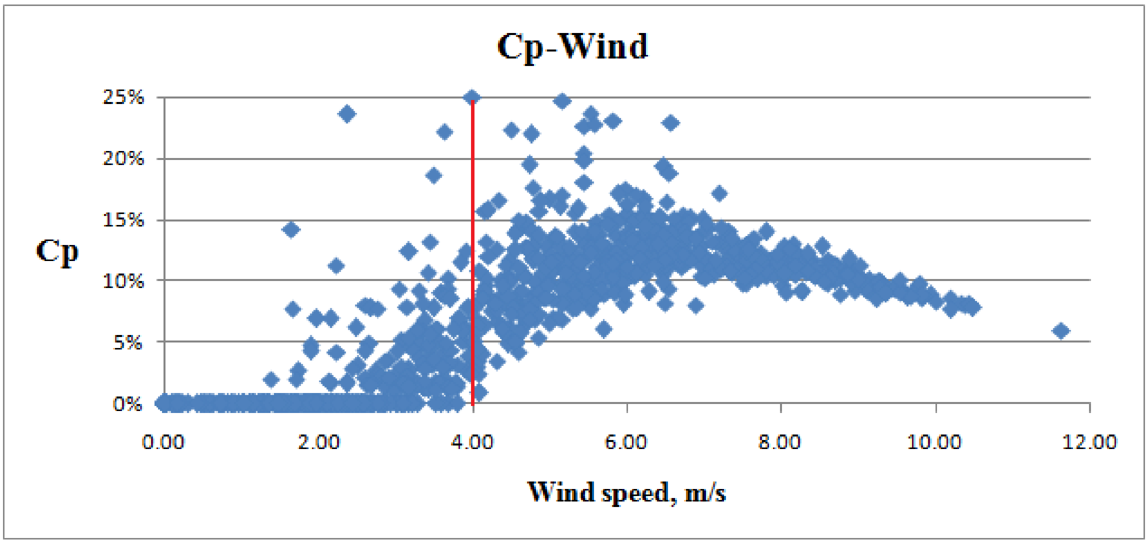


Figure 50

These Figures (49&50) demonstrate similar results and they do not appear to have any issues which could indicate possible malfunction. Again, however these figures showed problems with data at low wind speeds.

Tables A and B show real data values in the region between 0 m/s to 4.5 m/s. Table A highlights wind speed below 4.3 m/s which did not produce energy and Table B highlights wind speeds below 4.3 m/s when the turbine produced 0.1 kW.

Table A

May 2009

Reference Data		Voltage	Amp	Ω	Power kW	Wind	Cp	Rpm
01/05/2009	09:20:55	227.8	0.1	2278	0.0	4	0.0	188.9
01/05/2009	09:36:56	222.3	0.0	0.00	0.0	3.6	0.0	179.9
02/05/2009	00:12:22	226.6	0.1	2266	0.0	3.7	0.0	183.6
02/05/2009	04:05:29	228.4	0.1	2284	0.0	3.9	0.0	193.9
10/05/2009	20:05:47	243	0.0	0.00	0.0	3.9	0.0	197.9
17/05/2009	11:23:37	230.4	0.1	2304	0.0	4.2	0.0	202
20/05/2009	08:02:42	231.8	0.2	1159	0.0	4.4	0.0	207.7
25/05/2009	09:33:23	228.1	0.1	2281	0.0	4.1	0.0	197.6
27/05/2009	16:24:03	225.1	0.2	1125	0.0	4.3	0.0	194.4
Average		**229.27**	**0.1**	**-------**	**0.0**	**4.01**	**0**	**193.98**

Clearly the resolution of power data logging, at the very large increment of 0.1 kW, is going to produce some spurious results, as can be seen.

Table B

May 2009

Reference Data		Voltage	Amp	Ω	Power kW	Wind	Cp	Rpm
01/05/2009	06:09:49	226.2	0.2	1131	0.1	3.9	0.29	192.9
01/05/2009	06:11:49	228.4	0.3	761	0.1	3.5	0.40	202.4
01/05/2009	07:50:52	228.3	0.2	1141	0.0	4.4	0.00	200.7
01/05/2009	12:49:01	221.8	0.3	739	0.1	3.8	0.31	175.9
09/05/2009	14:12:52	228	0.4	570	0.1	4	0.27	203.8
09/05/2009	14:34:53	228.9	0.2	1144	0.1	3.7	0.34	200.2
09/05/2009	14:54:53	227.8	0.2	1139	0.1	3.6	0.36	184
09/05/2009	15:22:54	228.8	0.4	572	0.1	4.2	0.23	201
09/05/2009	17:04:57	228.7	0.3	762	0.1	4.2	0.23	198.8
10/05/2009	20:54:48	228.1	0.2	1140	0.1	4.3	0.21	204.1
16/05/2009	10:51:52	228.9	0.3	763	0.1	3.3	0.47	201.7
16/05/2009	12:14:54	230.6	0.4	576	0.1	3	0.63	214.7
16/05/2009	12:34:55	227.6	0.3	758	0.1	3.9	0.29	196.1
20/05/2009	17:04:58	226.4	0.2	1132	0.1	3.6	0.36	194.3
21/05/2009	12:29:34	227.2	0.3	757	0.1	4.1	0.25	203.6
21/05/2009	16:18:40	227.2	0.4	568	0.1	3.9	0.29	203.4
26/05/2009	03:54:57	228.5	0.2	1142	0.1	3.7	0.34	204.3
Average		**227.55**	**0.275**	**----**	**0.094**	**3.88**	**0.29**	**197.95**

3. Wind Speed with Respect to Rpm.

Section 3 had similar results to the same section in May 2008, (figures 36 to 39). In May 2009, there were wind speeds at 12 m/s or higher 735 times. Therefore in May 2009 it is possible to consider that it was a better month for energy production than in May 2008. However, from looking at the results in Table 5, it is seen that there were equal power output values in both years.

Figure 51 shows a fairly steady rpm evolution (even though rotor speed was well below the ideal values).

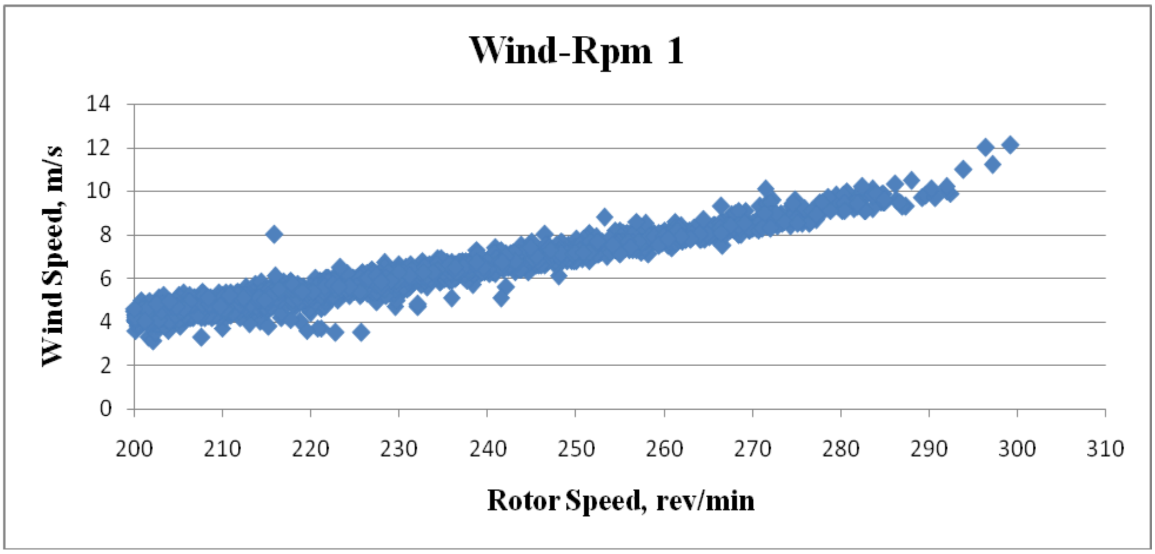


Figure 51

Figure 52 shows the third week in May 2009. In this graph it that there are higher wind speeds between 10 and 16 m/s (circled in black). The straight line (in lilac) represents the ideal rpm evolution. Values of rotor speed should continue to rise until the rated wind speed of 14 m/s. After this at higher wind speeds, the rotor speed should fall slightly. It seems that this speed reduction started early at around 8 m/s and around 255 rpm but on most occasions the rotor speed rose further, peaking at around 290 rpm. In comparison, in 2008 the setback started at 10 m/s and rpm was around 270 rpm.

Despite the difference between both years this did not greatly affect the power output. It was stable a maximum values between 0.5 to 0.7 kW.

For more information refer to Table 5, Appendix A.

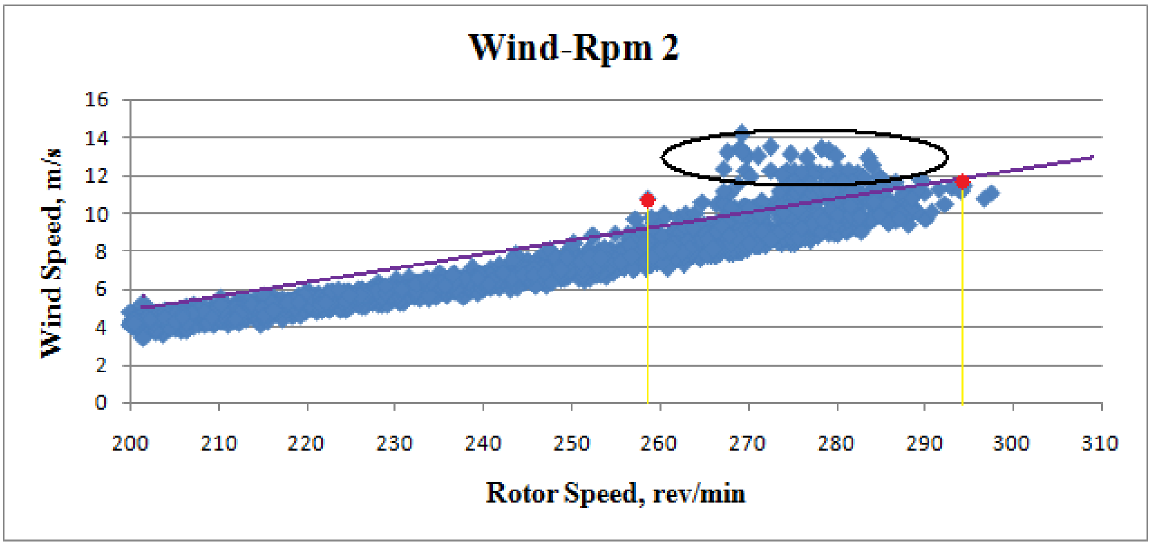


Figure 52

Figure 53 shows similar characteristics to the previous Figure. Some speed reduction started at around 9 m/s and 250 rpm. Again a maximum rotor speed around 290 rpm was observed.

From carrying out a comparison of Figure 37 and 51 with Figure 52 and 53, the first two did not show any setback and at 12 m/s reached 300 rpm with no problems. However, the second set of figures (52 & 53) showed reduced speeds around 8 m/s and 250 rpm. Although rotor speed then continued to increase, it did not reach 300 rpm as in Figures 37 and 51 did, but was slower by 20 to 30 rpm.

Although in the Figures 37 and 51 there was not any obvious rotor speed deficit, turbine performance had similar results to those in Figures 52 and 53. The power which remained limited at a maximum value of 0.7 kW

Comparing Table 2 and Table 5, results were similar in 2008 and 2009. These tables showed the performance at 10 m/s, wind speed where power output was between 0.5 to 0.7 kW. In 2009, load impedance appeared to be lower than in 2008, 91.11 Ω at 291.5 rpm, but the maximum power output remained at a maximum of 0.7 kW. For more information refer to Table 2,C, Appendix A.

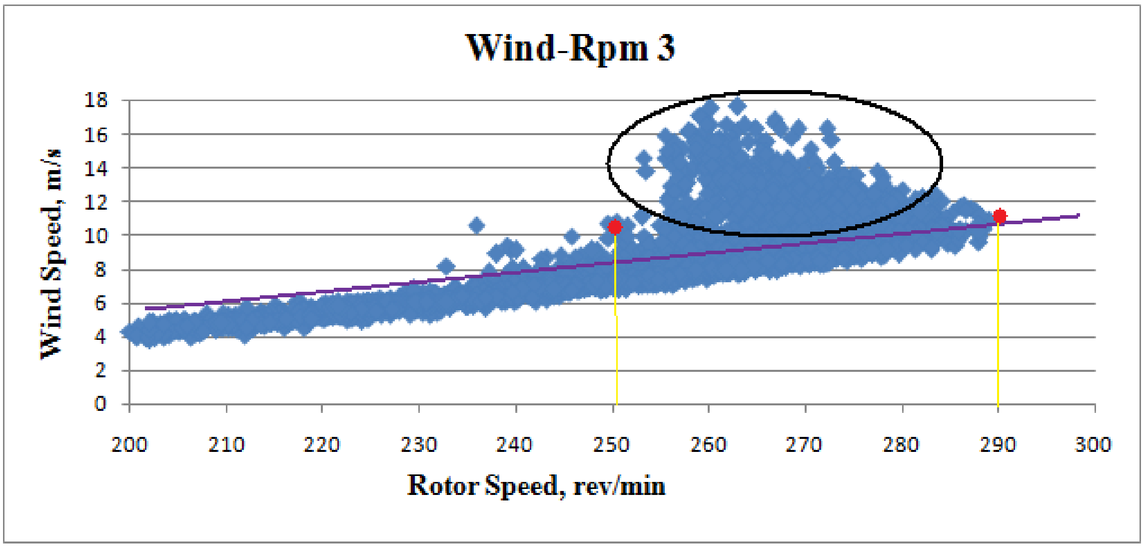


Figure 53

Table C

May 2009

Reference Data		Voltage	Amp	Ω	Power kW	Wind	Cp	Rpm
01/05/2009	17:53:10	242.7	2.3	105.52	0.5	10	0.08	280.7
03/05/2009	14:31:31	246.1	2.7	91.15	0.7	10	0.12	292.1
04/05/2009	07:56:03	238.8	1.8	132.67	0.4	10	0.07	260.4
05/05/2009	13:35:57	244.8	2.6	94.15	0.6	10	0.10	287.2
05/05/2009	17:42:05	238.8	1.8	132.67	0.4	10	0.07	262.8
06/05/2009	15:49:45	243.5	2.4	101.46	0.6	10	0.10	283.2
06/05/2009	17:07:47	239.3	1.8	132.94	0.4	10	0.07	265.9
07/05/2009	07:02:12	242.4	2.3	105.39	0.5	10	0.08	277.5
07/05/2009	14:19:26	243.8	2.4	101.58	0.6	10	0.10	286.1
14/05/2009	16:52:35	241.9	2	120.95	0.5	10	0.08	277.3
15/05/2009	05:01:58	245.3	2.5	98.12	0.6	10	0.10	284.3
15/05/2009	14:53:15	240.1	1.8	133.39	0.4	10	0.07	265.9
16/05/2009	19:58:08	239.4	1.8	133.00	0.4	10	0.07	265.6
18/05/2009	16:20:30	241	2	120.50	0.5	10	0.08	274.7
20/05/2009	13:54:52	242.6	2.3	105.48	0.5	10	0.08	282.1
23/05/2009	19:24:14	245.2	2.5	98.08	0.6	10	0.10	288.9
26/05/2009	11:18:10	241.8	2.2	109.91	0.5	10	0.08	275
27/05/2009	03:39:40	242.4	2.3	105.39	0.5	10	0.08	277.9

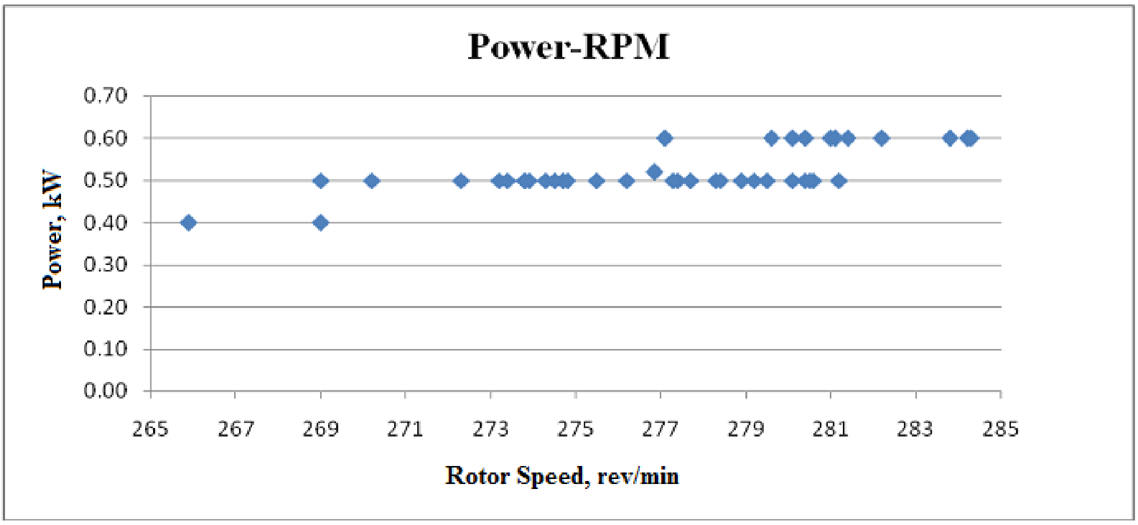


Figure 54

Table C shows real values in the wind speed region at 10 m/s and it demonstrates that with the same wind speed the turbine rotate at different rpm and the wind turbine produced different power outputs. The rpm ranges vary between 265 and 285, rotor speed, rev/min.

Figure 55 shows a setback between 10 to 11 m/s and then the turbine seems to stabilize at 12 m/s, with rpm around 280, in Table 7; it is possible to see the different performance parameters. Even though the turbine was not recording the ideal values it seems that it was working in a consistent manner.

In the ideal case, voltage should increase by around 0.3 V between these wind speeds (10 to 11 m/s). In Table 7 it shows that with the same wind speed values the voltage change by 5 volts. For more information refer to Table 7, Appendix A.

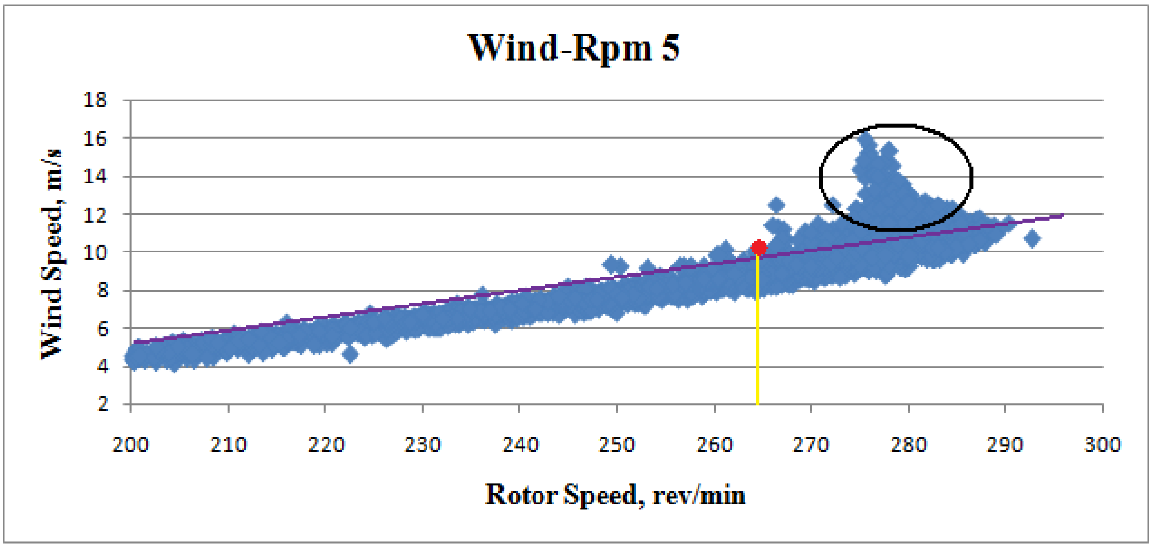


Figure 55

Figures 55 and 56 had similar performances. Figure 55 showed a reasonable rpm evolution until12 m/s, with speed limitation clear in the range 12 to 16 m/s. Figure 56 covers a smaller range of wind speeds and speed limitation was less evident. In both cases rotor speeds did not exceed 290 rpm. Even though in May 2009 wind speeds increased to over 16 m/s, power output continued to remain at values between 0.3 to 0.7 kW.

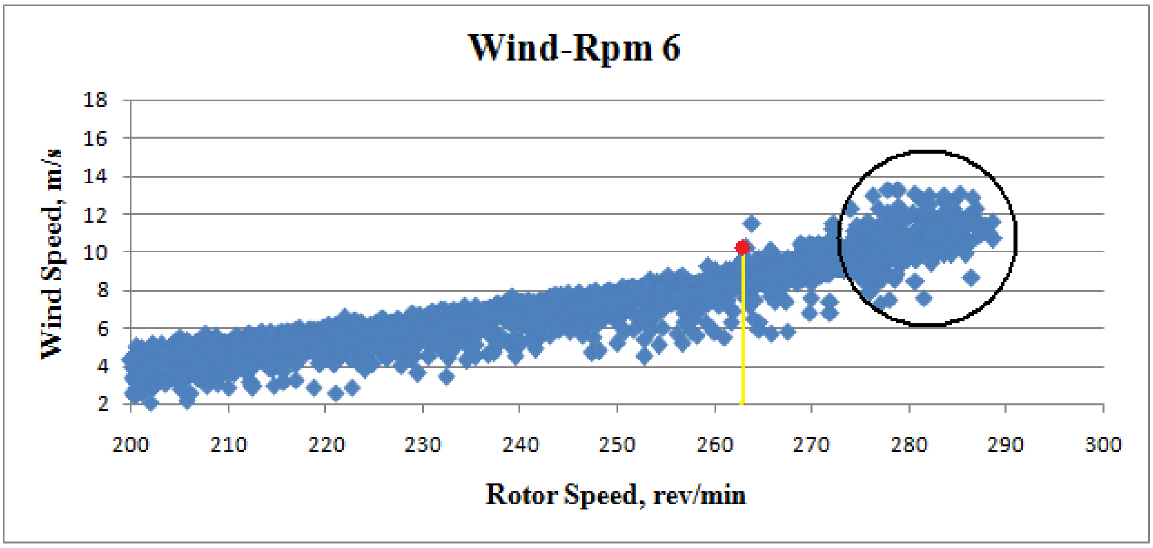


Figure 56

4. Power with Respect to Rpm

Figure 56 shows a normal rotor speed operation from 180 to 280 rev/min. During this month there were higher wind speeds but rotor speed had similar performance and power output reached the same maximum value of 0.7 kW.

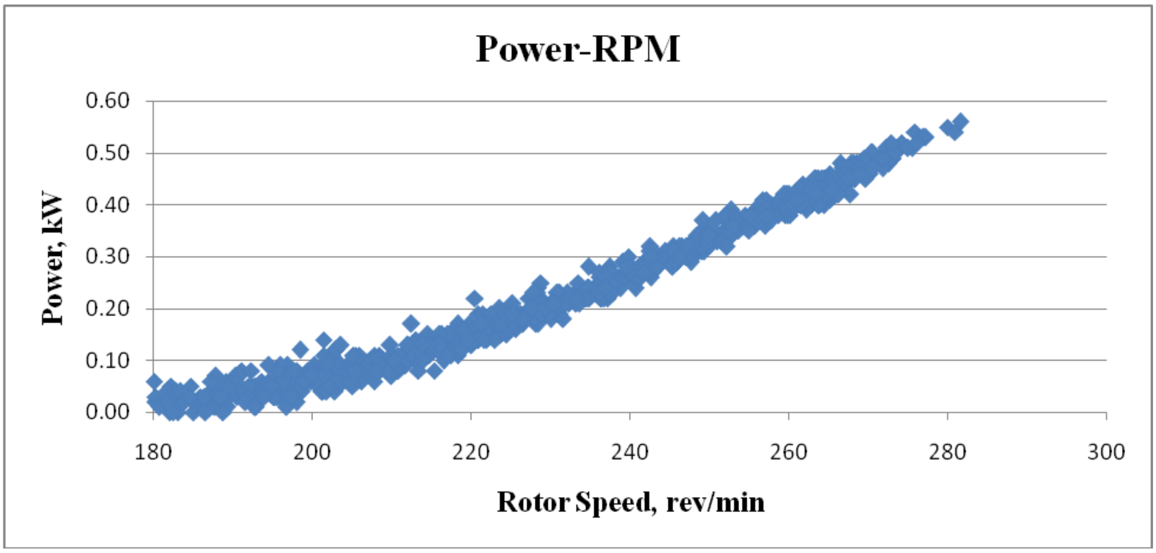


Figure 57

Figure 58 shows broadly similar performance to Figures 40 and 41. However, in the Figure 41 it seems that the rotor speed reached 290 rpm. Throughout 2008, the maximum power output was not higher than 0.7 kW. The values in Figure 58 were measured at a similar time period to those in Figure 52, when the wind speed reached a maximum of 14 m/s. In Figure 58, the maximum power output observed is around 0.55 kW. A similar condition occurred in Figure 53 when the wind speed was over 16 m/s and the power output obtained remained under 0.7 kW. More information can be found in Table 2.

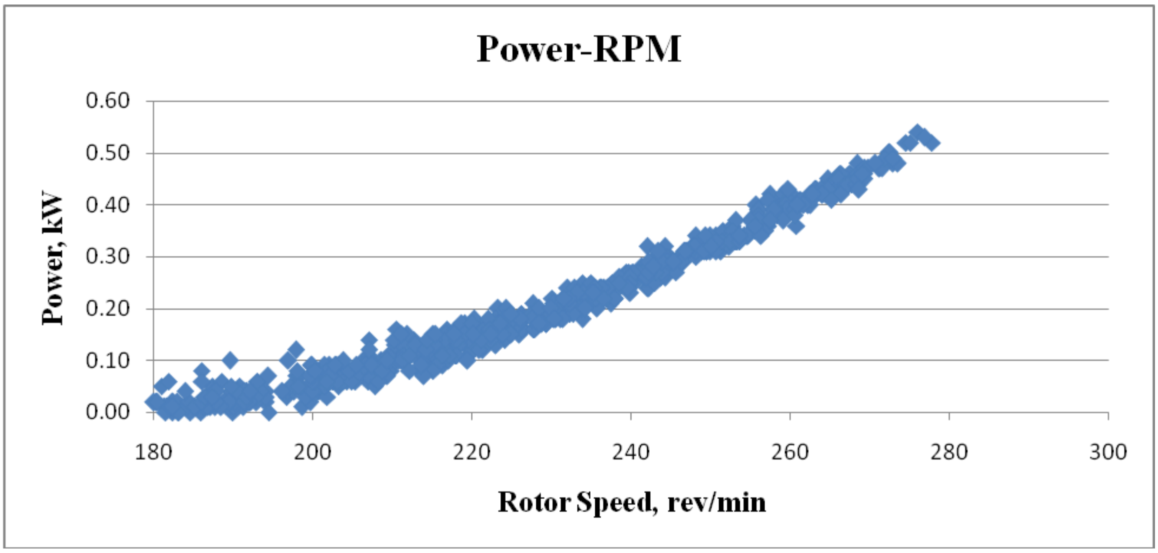


Figure 58

5. Voltage, Current and Impedance

In the ideal case the voltage at 8 m/s should be around 280 volts, so there is a major discrepancy here.

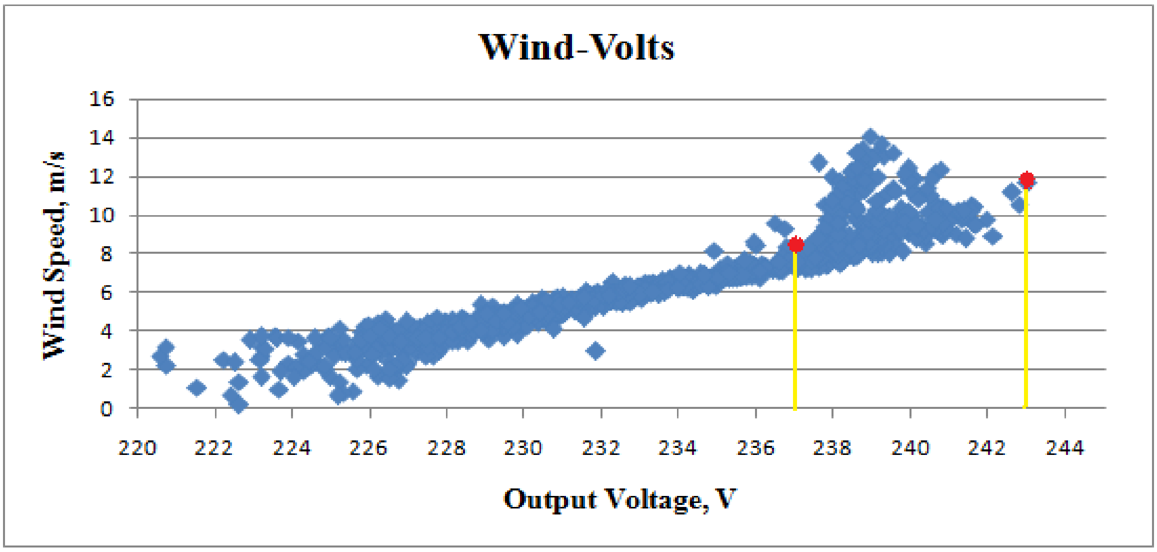


Figure 59

In the second week of May 2009, the data in Figure 59 showed a steady voltage evolution without some of the discrepancies seen in previous data. Here it seems that around 10 m/s the voltage setback started. again, the voltage performance was below ideal values.

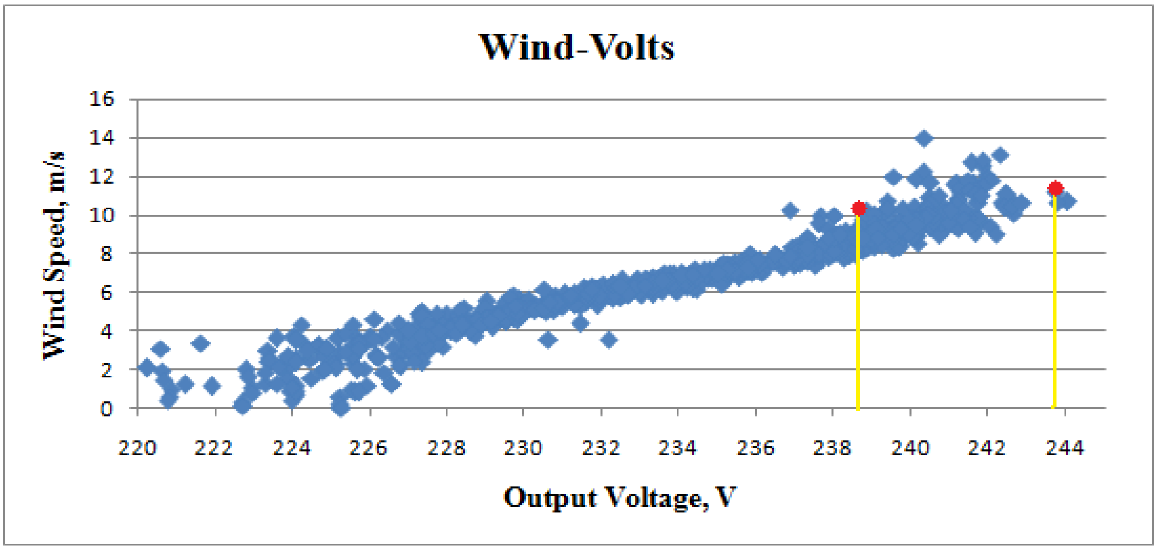


Figure 60

A similar pattern occurred with current during the first week of May 2009. In Figure 60 is shown a steady increase until current reached 1.5 A. Then similar to the voltage in Figure 58 the current started to setback began to show scatter, becoming limited to about 1.8 A at high wind speeds.

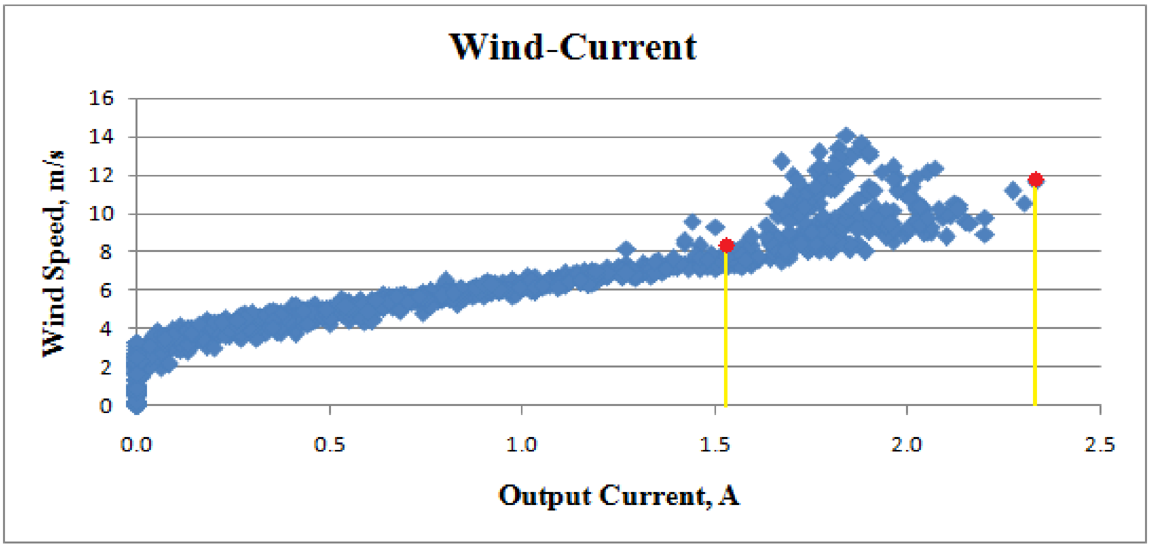


Figure 61

Figure 61 showed a more normal current evolution, but well below the ideal values.

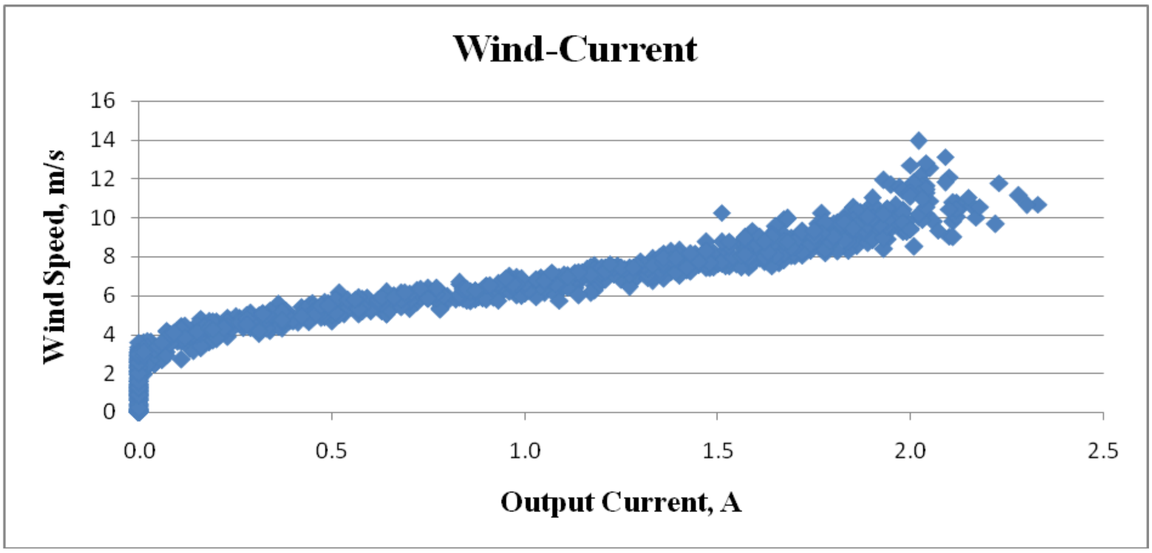


Figure 62

Figure 62 showed the trends for impedance, which were very similar to those in May 2008.

Looking at Table 5, impedance at the same wind speed had different values, this difference producing a variety of power output.

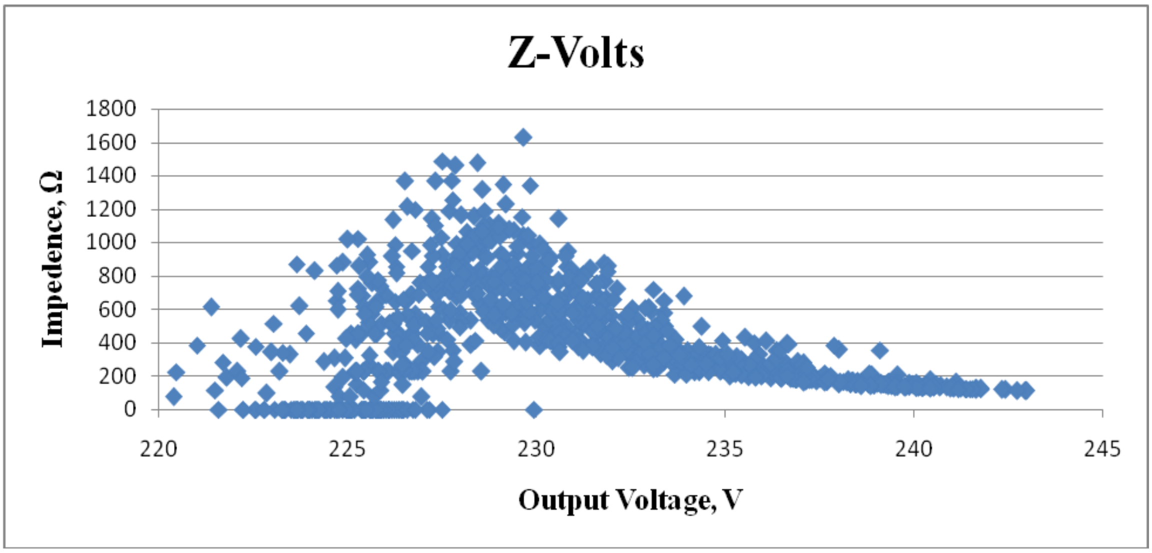


Figure 63

6. Wind Direction and its Effect on Performance

From a weather station situated in Glasgow, Met Office supplied a spreadsheet with daily wind direction from January 2009 to June 2009. It was not possible to obtain wind directions from 2008. See more information Appendix D.

The most common wind direction was from SW to SSE, as shown in the plot below.

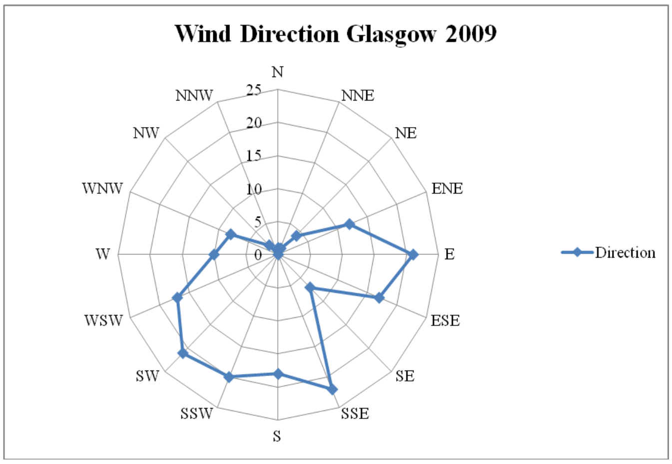


Figure 64

During the winter 2009, January to March, Figure 64 shows the predominant wind direction was SSW to SW, SSW to SW. During this period were more than 2000 times where 10 minutes average wind speeds were 12 m/s or higher but turbine power output remained at maximum value of 0.7 kW.

In the wind energy production there is an important difference between seasons but in this case study power output was not affect by wind direction. The data sets were carefully examined to find cases where wind speeds were similar but directions were not, but no systematic trends could be found. The consistent under-performance of the turbine may of course have been obscuring these effects.

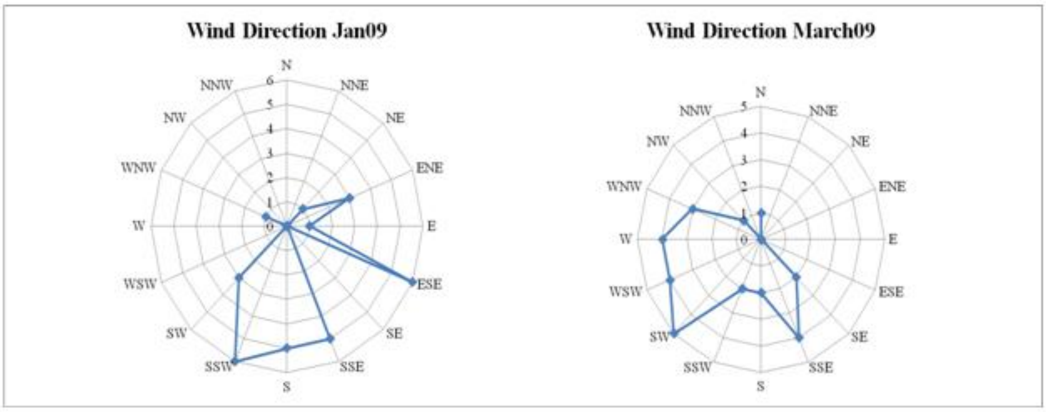


Figure 65

During the spring, April to June 2009, wind speeds were weaker than in winter, with only 250 times that wind speeds were at 12 m/s or higher. In January and April the most common wind direction was E to SSE.

In contrast in May 2009 that wind direction changed to SW to S. During May 2009 wind speeds were more than 700 times above 12 m/s. The Figure 65 shows different months during the summer 2009.

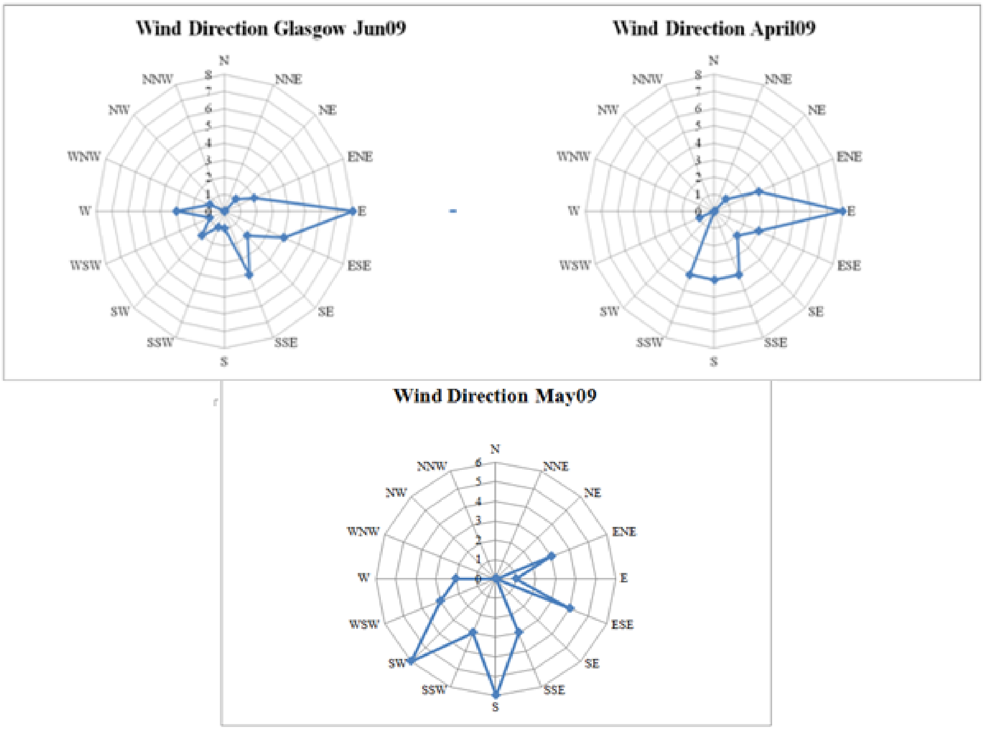


Figure 66

Chapter 5

Discussion

This chapter discusses the results obtained from the data analysis presented in the previous chapter. After a brief look at the history of the project the discussion examines the effects of air flow, wind direction and turbulence in the turbine area. It then considers the performance data and operation of the control system, and discusses mechanical aspects of the operation of the Proven turbine.

The turbine was installed in June 2006 and was reported to be working correctly. But it was also reported that six months after installation, Proven re-calibrated the inverter settings. Subsequently it appeared that power output was lower than expected, but whether this was a direct and immediate consequence of changes made to the inverter is not clear. Unfortunately there are no detailed records of data during this important period, and the only information is based on the records of the project leader at MEARU, Dr. Sharpe. But it seems that the turbine has been under-performing for most of its working life.

The only detailed performance data sets available covered periods in 2008 and 2009, but as reported in Chapter 4, they contained gaps and the precision of data recording was not ideal: for example power output was logged only to the nearest 0.1 kW. This made performance assessment rather difficult, as the maximum power recorded at any time was only 0.7 kW.

The low power output could be explained by the following three operational reasons:

- Air flow and turbulence around the roof affecting the normal wind turbine operation.
- Incorrect performance of the control system – parameter settings.
- Deterioration of the shape of the blades.

Wind direction is an important factor in the operation of turbines. Most large turbines have an up-wind rotor configuration and require to be turned mechanically to face the wind. Misalignment needs to be corrected at frequent intervals. But the Proven turbine is a down-wind machine, where the rotor is free to turn on its tower and is self-aligning. So errors in direction and consequent loss of performance should not happen.

This is true for horizontal velocities, but when a turbine is near the roof of a building there may be vertical velocities as well. The wind will travel up the face of the building and curve over the roof. Depending on where the turbine is located, the wind direction through the rotor may be well away from the horizontal and this will affect performance. So too will turbulence: the wind over the roof of a building is likely to be extremely turbulent, causing unsteady loads, vibration and fluctuations in power output.

Wind direction will have an influence on power output, because flow conditions around the turbine are likely to be different for differing wind directions. This is because of the shape of the building, its orientation and the positioning of the turbine. There is also the possible effect of nearby tall buildings on the quality of the wind flow.

Wind direction provided from the Met Office, during 2009, shows that the preferential wind direction is coming from the SW-SSE sector. For more information see p. 64.

An attempt was made to analyse the data sets, to see if turbine performance was affected by wind direction on the site. To facilitate this, the wind directions were divided into four different quadrants. The first quadrant is N to E, the second quadrant is E to S, the third quadrant is S to W and finally the fourth quadrant is W to N. Pictures of the buildings are located in the Introduction Chapter.

On the roof of the building there is one tower, which is taller than the tower where the turbine is installed. This tower is in the region W to N. Within the first quadrant there are also two tall buildings around 450 m away. The tower is shown in Figure 8 and the position of the buildings with respect to the tower where the turbine is located is shown in Figure 4.

If the wind is coming from the first quadrant, turbulence produced by the wind turbine go directly to the weather station and consequently the measurement and recording of the parameter values used to control the turbine might not be adequate.

Within the second quadrant there is one building shown in Figure 5. It is located around 180 metres away from the turbine and it is lower. Turbulence created by this building might affect the power output.

In the third quadrant, there is the Centre for Contemporary Arts; it is located at the bottom of Garnethill and is a smaller building than the Newberry Tower. Turbulence produced by this building might seriously affect the power output of the turbine.

Within the fourth quadrant, there are no remote buildings that would affect the wind speed, but the tower belonging to the Newberry Tower building is of course in this sector.

Dr. Sharpe has given his opinion that the original weather station was inappropriately located and wind speeds were not accurately recorded. This is reflected in the discrepancies between the power output and the wind speed values in the data obtained during 2007 (see Appendix F). The weather station has subsequently been relocated, but the process used in choosing the new site is not clear; certainly Dr. Sharpe disclosed also that there has not been any CFD simulation done. Hence, there is a possibility that the weather station is still not optimally located. For more information please refer to p.65, Wind Direction and its effect on Performance and Appendix E.

Parameters such as voltage or rpm have an expected value imposed by the turbine producer Proven for each wind speed. These provided a reference when studying the recorded performance data from the site.

At low wind speeds the turbine seems to be performing reasonably well. Proven turbines spin freely in light winds and the electrical load is not connected until a certain speed is reached. This is normally around 4 m/s. For a building-mounted turbine, cut-in might be irregular as a result of turbulence. Discrepancies between wind speeds at the weather station and at the rotor might also have a significant effect. The data sets suggest that power outputs were close to design specifications, although lack of precision was a problem (power stepping between 0.0 and 0.1 kW). Tip speed ratios were also reasonable, between 3 and 3.5.

Of course these wind speeds do not produce a large amount of power and it is the range around rated wind speed which is of more interest. Here it is clear that the rotor speed is not responding as it should. According to the manufacturer the rotor speed should increase steadily up to a wind speed of about 14 m/s, then reducing slightly in stronger winds to limit power output (the blades also deform in a controlled way, as discussed later).

But from the data sets, it is clear that the rotor rpm reaches a peak at much lower wind speeds, as low as 9 m/s in some cases. So the performance beyond that point is badly affected. The general evolution of the performance data shows the correct general trends, but the values are wrong. Table C on p.53 shows changes in all the wind turbine parameters, at the same wind speed of 10 m/s. It will be seen that different values of rpm are recorded for the same wind speed. When the rpm differ, the Cp, the power output, the voltage, the current and impedance also differ. Therefore, the control system seems to be responding to changes in rpm, although the overall performance of the turbine is not as it should be.

The reduction in rpm at higher wind speeds followed the pattern expected from the design specifications, although it occurred much earlier than it should. However it was not very consistent in behaviour (a lot of scatter was observed between the various data sets). Perhaps this is to be expected given the turbulent nature of the site. Before the point of maximum rpm, the rotor is not turning as fast as specified; the rate of acceleration as wind speed increases is too slow.

This behaviour points to some deficiency in the control system. Unfortunately the control algorithms could not be provided, so it is only possible to speculate. It seems clear that the electrical loading imposed on the generator is not appropriate, in the present configuration.

The wind speed recorded at the weather station is used in the control process, although as already stated the details are unknown. Because of its cubic relationship to power output, wind speed is of course a critical parameter in turbine performance. In a roof-top installation this might be a problem, because of the irregular flow patterns discussed earlier. The measured and actual wind speeds are unlikely to correspond exactly, and the relationship between them is likely to vary with wind direction and as a result of turbulence. It would be helpful (but probably extremely difficult) to eliminate wind speed as a control parameter for roof-top turbines. Perhaps a system could be devised which steadily varies electrical load until a maximum power point is found. Because of the unsteady nature of wind energy, it would require well-designed time-averaging algorithms to avoid incorrect behaviour.

The Proven turbine is fitted with hinged blades which respond to a combination of centrifugal and bending loads in a controlled way. This enables the turbine to limit power output in strong winds and to survive in storms. With any moving parts, some deterioration might be expected over a period of time. Proven turbines have been used for many years and the hinged blade system has proved to be reliable, but a roof-top installation with its highly turbulent operating environment might cause problems.

During this three months’ project, there were two visits to the roof-top site on Newberry Tower. On both days the wind turbine was working in around 10 m/s wind speed, see Appendix B. The turbine appeared to be spinning slowly for 10 m/s but the motion was normal, no abrupt movements were noticed. No specific investigations have been done in this area. Therefore there is no evidence that might suggest that the turbine has blade problems and that the centrifugal effects which produce the blade movements are not working correctly.

Conclusion

The reason why the turbine underperforms is not clear and cannot be assigned to a particular component. To clarify this would require a systematic investigation. A series of adjustments to the turbine and system should be carried out, such as changing the settings of the inverter, changing the inverter itself or replacing the turbine blades. After each modification, data should be collected and compared with previously taken measurements to discard suspected but not founded reasons of underperformance.

During the visual monitoring, no abrupt movements were observed for the mast or the turbine blades. Therefore, it is likely that power output loss is not due to mechanical damage, such as broken blades or Zebedee hinges. But progressive weakening or other deterioration cannot be ruled out.

From the combination of the smooth rotating of the blades and the low power output values (never higher than 0.7 kW), the inverter must be suspect. It could be damaged or malfunctioning and should be examined as the first step in the investigative process.

Due to the positions of the turbine and the weather station, the effects of flow deflection and turbulence must be a matter for concern. The fact that the roof area where the turbine is located is small and the presence of many obstacles mean that the air flow will be very irregular and its pattern will change with the wind direction. The use of measured wind velocity as a control parameter then becomes a problem, which will affect all urban wind installations to some extent. Ideally a system could be utilised which does not depend on accurate measurement and correlation of wind speeds.

Future work

In the following, we propose various things in order to clarify issues and improve the performance of the turbine.

As stated above, the control of the turbine depends on information captured by the weather station. CFD simulation could be used to recreate the weather station and turbine environment and examine the correlation between wind velocities for a range of flow directions. It may be possible to arrive at an optimum location for the weather station in this way. However, case must be taken to model the approaching air flow with sufficient accuracy.

A way of reducing the turbulence and misdirected flow affecting the turbine would be to increase the length of the mast supporting it. However this would increase the bending load on the mast, and may also cause vibration. The turbine manufacturer may be able to advise on the maximum length which is advisable.

In the longer term, it might be useful to look at a range of alternative control strategies to optimise performance of roof-top mounted wind turbines. However, this would require to be carried out in conjunction with the manufacturer.

CFD Programme

To understand turbulence in this area it is recommended to use a CFD simulation programme which could create turbulence at the roof by simulating the turbine and the surrounding tower. It could also be interesting to generate a visual smoke on the roof, which could produce the real turbulence evolution around the turbine and the surroundings.

Weather Stations

It could be interesting to install some weather stations around appropriate positions in Glasgow city centre which would allow research to be undertaken into the wind directions and speeds throughout the city and the most advantageous positions for turbines to be identified.

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Appendix A

Tables below show different parameters from the wind turbine. In red colour is highlight the maximum and minimum rpm and in yellow colour is highlight maximum and minimum voltage.

May 2008

- Table 1

Reference Data		**Voltage**	**Amp**	**Ω**	**Power kW**	**Wind**	**Cp**	**Rpm**
27/05/2008	07:26:50	248.7	3	82.90	0.7	11.3	0.08	301.8
27/05/2008	09:11:54	248.3	2.9	85.62	0.7	11.4	0.08	302.5
27/05/2008	11:34:57	248	2.9	85.52	0.7	11.5	0.08	302
27/05/2008	12:27:59	247.9	2.9	85.48	0.7	12	0.07	301.8
27/05/2008	12:40:00	247.9	2.9	85.48	0.7	12.3	0.06	302.1
27/05/2008	14:52:04	247.7	2.8	88.46	0.7	12.7	0.06	302

- Table 2: Figure 32

Reference Data		**Voltage**	**Amp**	**Ω**	**Power kW**	**Wind**	**Cp**	**Rpm**
08/05/2008	15:41:17	243.7	2.2	110.77	0.5	10	0.08	288.5
08/05/2008	16:00:18	244.3	2.3	106.22	0.6	10	0.10	291
08/05/2008	16:24:18	243.6	2.1	116.00	0.5	10	0.08	286.7
08/05/2008	16:55:19	244	2.2	110.91	0.5	10	0.08	288.6
08/05/2008	17:11:20	242.7	2.1	115.57	0.5	10	0.08	284.2
08/05/2008	17:12:20	243.4	2.2	110.64	0.5	10	0.08	286.8
08/05/2008	20:01:25	243.6	2.2	110.73	0.5	10	0.08	285.7
Average		**243.6**	**2.2**	**111.55**	**0.512**	**10**	**0.087**	**287.36**

- Table 3

Reference Data		Voltage	Amp	Ω	Power kW	Wind	Cp	Rpm
08/05/2008	15:41:17	243.7	2.2	110.77	0.5	10	0.08	288.5
11/05/2008	17:41:31	245.2	2.4	102.17	0.6	10	0.10	291.1
12/05/2008	18:45:16	246.1	2.5	98.44	0.6	10	0.10	293.3
22/05/2008	17:49:31	243.1	2.3	105.70	0.5	10	0.08	285.5
23/05/2008	20:31:20	244.5	2.5	97.80	0.6	10	0.10	289.8
25/05/2008	17:36:41	243.1	2.3	105.70	0.6	10	0.10	288.3
25/05/2008	14:00:35	241.6	2.1	115.05	0.5	10	0.08	282
26/05/2008	17:33:25	242.3	2.2	110.14	0.5	10	0.08	283.1
27/05/2008	21:34:16	244	2.4	101.67	0.6	10	0.10	286
Average		**243.73**	**2.32**	**105.27**	**0.56**	**10**	**0.09**	**287.51**

- Table 4

Reference Data		Voltage	Amp	Ω	Power kW	Wind	Cp	Rpm
08/05/2008	14:56:16	245.2	2.4	102.17	0.6	10.5	0.09	293.6
08/05/2008	16:50:19	247.3	2.6	95.12	0.6	11.1	0.07	302.3
11/05/2008	13:50:24	237	1.5	158	0.3	7.6	0.12	258.2
12/05/2008	10:39:02	239.6	1.8	133.11	0.4	8.2	0.12	265.5
14/05/2008	12:40:33	235	1.2	195.83	0.3	7.5	0.12	246.5
14/05/2008	12:51:33	231.9	0.5	577	0.1	5.8	0.09	222.7
17/05/2008	00:01:21	234.4	1.3	180.31	0.3	6.8	0.16	247
17/05/2008	04:13:28	236.2	1.5	157.47	0.3	7.4	0.13	251.7
23/05/2008	20:54:21	246.3	2.7	91.22	0.7	11	0.09	297.7
23/05/2008	21:06:21	243.6	2.4	101.50	0.6	9.7	0.11	286
24/05/2008	02:12:30	233	1	233	0.2	7	0.10	238.9
25/05/2008	12:30:33	244.5	2.5	97.80	0.6	11	0.08	293

25/05/2008	14:04:35	245.4	2.6	94.38	0.6	13.7	0.04	297.8
25/05/2008	14:18:35	245.7	2.6	94.50	0.6	12.5	0.05	299.3
26/05/2008	03:23:00	230.8	0.8	288.50	0.2	6.1	0.15	228.6
26/05/2008	14:18:19	246	2.7	91.11	0.6	11.8	0.06	299.3
27/05/2008	00:33:38	238.4	1.7	140.24	0.4	8.2	0.12	259.3
27/05/2008	07:01:49	243	2.3	105.65	0.6	9.5	0.12	280.4
27/05/2008	17:35:09	244.7	2.5	97.88	0.6	11	0.08	291.3
27/05/2008	20:55:14	246.7	2.7	91.37	0.7	11.7	0.07	295.5

May 2009

- Table 5

Reference Data		**Voltage**	**Amp**	**Ω**	**Power kW**	**Wind**	**Cp**	**Rpm**	
03/05/2009	12:15:28	246.1	2.7	91.15	0.7	10	0.12	292.1	W-WNW
04/05/2009	07:53:03	245.7	2.7	91.00	0.7	11.1	0.09	288.6	WNW-NW
04/05/2009	09:17:06	244.1	2.5	97.64	0.6	12.9	0.05	283.7	
04/05/2009	09:40:06	246	2.7	91.11	0.7	11.3	0.08	291.5	
04/05/2009	12:03:11	239.7	1.9	126.2	0.5	13.4	0.04	269.1	
05/05/2009	13:29:57	246.1	2.7	91.15	0.7	10.5	0.10	292.3	WSW-W
05/05/2009	13:34:57	241.9	2.2	109.95	0.5	10.1	0.08	276.3	
05/05/2009	13:35:57	244.8	2.6	94.15	0.6	10	0.10	287.2	
05/05/2009	14:12:58	241.4	2.1	114.95	0.5	12.3	0.05	274.4	
06/05/2009	13:35:41	243	2.3	105.65	0.5	12.7	0.04	280.1	SW-WSW
06/05/2009	17:58:49	238.7	1.8	132.61	0.4	11.4	0.05	264.6	
06/05/2009	18:03:49	238.7	1.8	132.61	0.4	12.9	0.03	264.9	
06/05/2009	18:11:49	243.3	2.3	105.78	0.6	11.2	0.07	283.3	
Average		**243**	**2.3**	**106.5**	**0.6**	**11.5**	**0.1**	**280.6**	

- Table 6

Reference Data		Voltage	Amp	Ω	Power kW	Wind	Cp	Rpm	
03/05/2009	14:31:31	246.1	2.7	91.15	0.7	10	0.12	292.1	
04/05/2009	07:56:03	238.8	1.8	132.67	0.4	10	0.07	260.4	W-WNW
04/05/2009	09:01:05	244.4	2.5	97.76	0.6	10	0.10	284.6	WNW-NW
04/05/2009	09:23:06	243.5	2.4	101.46	0.6	10	0.10	281.9	
04/05/2009	11:11:09	243.3	2.3	105.78	0.6	10	0.10	280.7	
04/05/2009	12:39:12	242.3	2.2	110.14	0.5	10	0.08	278.9	
04/05/2009	13:23:13	241.5	2.2	109.77	0.5	10	0.08	277.2	WSW-W
04/05/2009	14:50:16	239.9	1.9	126.26	0.5	10	0.08	269.5	
05/05/2009	13:35:57	244.8	2.6	94.15	0.6	10	0.10	287.2	
05/05/2009	16:14:02	241.1	2.1	114.81	0.5	10	0.08	274.5	
05/05/2009	17:42:05	238.8	1.8	132.67	0.4	10	0.07	262.8	SW-WSW
05/05/2009	17:52:05	241.5	2.1	115.00	0.5	10	0.08	276.1	
05/05/2009	18:16:05	241.1	2.1	114.81	0.5	10	0.08	273.9	
05/05/2009	19:06:07	240.6	2	120.30	0.5	10	0.08	271.6	
05/05/2009	19:09:07	238.7	1.8	132.61	0.4	10	0.07	264	
06/05/2009	14:29:42	242.2	2.2	110.09	0.5	10	0.08	278.6	
06/05/2009	14:45:42	240.7	2	120.35	0.5	10	0.08	271.9	
06/05/2009	15:49:45	243.5	2.4	101.46	0.6	10	0.10	283.2	
06/05/2009	16:44:46	241.9	2.2	109.95	0.5	10	0.08	277.8	
06/05/2009	17:07:47	239.3	1.8	132.94	0.4	10	0.07	265.9	
06/05/2009	17:30:48	241.9	2.2	109.95	0.5	10	0.08	276.8	
06/05/2009	17:47:48	240.9	2.1	114.71	0.5	10	0.08	274.7	
Average		**241.5**	**2.1**	**114.7**	**0.5**	**10.0**	**0.1**	**274.9**	

- Table 7

Reference Data		Voltage	Amp	Ω	Power kW	Wind	Cp	Rpm	
12/05/2009	16:36:07	242.6	2.2	110.27	0.5	10	0.08	280.1	ESE-SE
12/05/2009	17:42:10	243.2	2.2	110.55	0.5	10	0.08	280.6	
12/05/2009	19:44:13	244.2	2.4	101.75	0.6	10	0.10	284.2	
12/05/2009	21:38:17	244	2.3	106.09	0.6	10	0.10	281	
13/05/2009	10:01:39	242.1	2.1	115.29	0.5	10	0.08	274.3	E-ESE
13/05/2009	10:09:40	243.2	2.3	105.74	0.5	10	0.08	278.9	
13/05/2009	10:37:40	243.6	2.3	105.91	0.6	10	0.10	280.1	
13/05/2009	11:09:42	241.6	2	120.80	0.5	10	0.08	273.8	
13/05/2009	11:58:43	242.8	2.2	110.36	0.5	10	0.08	279.5	
13/05/2009	13:13:45	242.6	2.2	110.27	0.5	10	0.08	280.4	
13/05/2009	15:11:49	240.9	1.9	126.79	0.5	10	0.08	273.2	
13/05/2009	18:13:54	242.7	2.1	115.57	0.5	10	0.08	277.4	
13/05/2009	18:36:55	240.1	1.8	133.39	0.4	10	0.07	264.2	
13/05/2009	19:15:56	240.8	1.9	126.74	0.4	10	0.07	269	
13/05/2009	19:58:58	243.6	2.3	105.91	0.5	10	0.08	280.5	
13/05/2009	20:56:59	243.3	2.2	110.59	0.5	10	0.08	278.3	
13/05/2009	22:08:02	242.6	2.2	110.27	0.5	10	0.08	276.2	
14/05/2009	00:09:05	243.9	2.3	106.04	0.6	10	0.10	279.6	ENE-E
14/05/2009	08:29:20	244.2	2.4	101.75	0.6	10	0.10	281.1	
14/05/2009	13:10:29	242.9	2.2	110.41	0.5	10	0.08	281.2	
14/05/2009	15:47:33	241	1.9	126.84	0.5	10	0.08	273.9	
14/05/2009	16:52:35	241.9	2	120.95	0.5	10	0.08	277.3	
14/05/2009	17:25:36	241.8	2.1	115.14	0.5	10	0.08	278.4	
14/05/2009	18:34:39	243.7	2.3	105.96	0.6	10	0.10	283.8	
14/05/2009	20:38:43	242	2.1	115.24	0.5	10	0.08	274.7	
14/05/2009	20:57:43	242.9	2.2	110.41	0.5	10	0.08	277.7	
15/05/2009	05:01:58	245.3	2.5	98.12	0.6	10	0.10	284.3	ENE-E

15/05/2009	05:17:58	243.5	2.3	105.87	0.6	10	0.10	277.1	
15/05/2009	06:25:00	242.4	2.1	115.43	0.5	10	0.08	273.8	
15/05/2009	10:17:07	241.1	1.9	126.89	0.5	10	0.08	269	
15/05/2009	12:54:12	243.4	2.3	105.83	0.5	10	0.08	279.2	
15/05/2009	13:14:12	241.8	2.1	115.14	0.5	10	0.08	274.5	
15/05/2009	14:33:15	243.6	2.3	105.91	0.6	10	0.10	281.4	
15/05/2009	14:53:15	240.1	1.8	133.39	0.4	10	0.07	265.9	
15/05/2009	15:13:16	243.5	2.3	105.87	0.6	10	0.10	280.4	
15/05/2009	16:54:19	242.1	2.1	115.29	0.5	10	0.08	274.8	
15/05/2009	17:29:20	242.1	2.1	115.29	0.5	10	0.08	274.5	
Average		**242.5**	**2.2**	**113.4**	**0.5**	**10**	**0.1**	**276.9**	

Appendix B

Figure 66 shows the logger and the inverter during visit on Friday 28 of August at 15:30 pm.

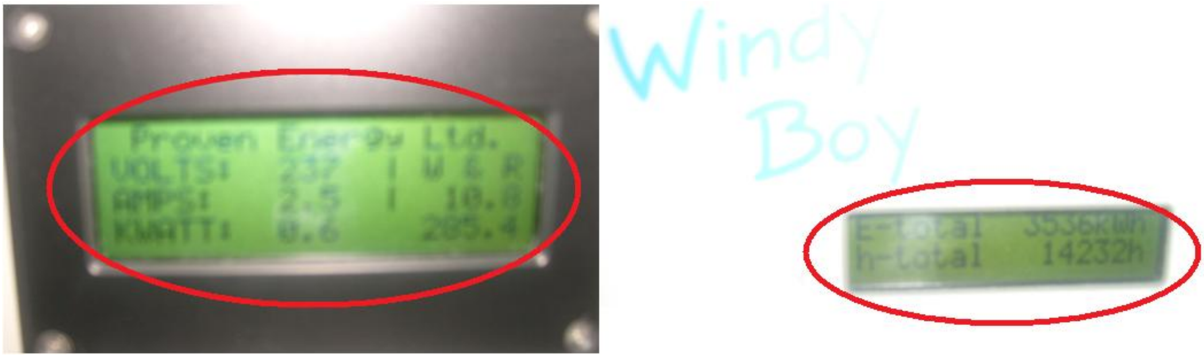

Figure 67

Figure 68

Figure 69

Figure 70

Appendix C

Donnachadh McCarthy on behalf of 3 Acorns Eco-Audits

Sent: 23 August 2009 10:08

To: Antonio Sanchez Luque

Hiya

sorry I seem to have missed replying

AFAIAA most small wind turbines in urban areas produce v little energy - I think either Carbon Trust or EST recently produced a report confirming this.

Mine has produced about 30KwH over 3 years only !! 8(

Manufacturers grossly exaggerate potential and usually at a height and wind speed not prevaling at your location.

There is a new gadget called a power predictor which very accurately preducts output at your site.

I have used a sunny boy inverter

I hope this helps;

Donnachadh

Antonio Sanchez Luque wrote:

Dear Donnachadh McCarthy ;

My name is Antonio Sanchez Luque, I'm student of the Strathclyde University, Glasgow UK.

I'm doing a Msc in Energy system and the environment and now I'm doing my dissertation, I'm study a small scale wind turbine in the Glasgow school of art.

Basically this wind turbine is producing less energy than it is expected and my and my supervisor (Andy Grant, Senior lecture at the Strathclyde), we are thinking that it could be the inverter, which control the wind turbine.

We are trying to find a similar case that i could give an idea about what is it happening with this wind turbine.

I would ask you if it is possible that you share with us some information about your inverter case?

Regards

Antonio

Donnachadh McCarthy on behalf of 3 Acorns Eco-Audits

Sent: 28 August 2009 10:35

To:
Antonio Sanchez Luque

The electronics were originally set up wrongly but even when corrected despite almost doubling the output, double of almost nothing is still almost nothing. :-(
These is also a theory going round that because sunny boy inverters need 3 minutes of smooth continuous production, and as small wind turbines almost never do this, then significant amounts of the output is not being recorded.
I understand some research is being carried out on this in some Scottish university.
best
Donnachadh

Antonio Sanchez Luque wrote:
Dear McCarthy;

Thank you for your email.
Everything will help me with this dissertation.
Inverter problems were because the weather station was installed in a wrong position, or this device was working wrongly?
Glasgow school of art has the same inverter and we are thinking that it is the weather station rather than electronic problems.

Regards
Antonio

Appendix D

re: Message from Weather data order form at http://www.metoffice.gov.uk/education/teachers/weather_data_order_form.html on the

website

Sent: 21 July 2009 12:33

To:
Antonio Sanchez Luque

Dear Antonio,

Thank you for completing our online data order form.

I have supplied you with the data you requested on your order, which can be found in the attached EXCEL spreadsheets. A decode of the headers used can be found beneath the data in each file.

The person (the user) who receives and uses this data, hereby agrees to the following restriction on the use of the data:

i.data only to be used for educational purposes;
ii.data only to be used by the user
iii.under no circumstances may the data be passed to a third party or commercially exploited.

I hope you will find this information helpful. If you have any further questions, please contact our Weather Desk Advisors on 0870 900 0100. This number is open 24 hours a day, seven days a week.

Kind regards
Helen

Weather Desk Advisor
Met Office, FitzRoy Road, Exeter, Devon, EX1 3PB, United Kingdom.
Tel: 0870 900 0100 Fax: 0870 900 5050 Email: enquiries@metoffice.gov.uk

Met Office climate change predictions can now be viewed on Google Earth
http://www.metoffice.gov.uk/climatechange/guide/keyfacts/google.html

It is also interesting to see that the wind direction (p 64) section, wind direction did not affect the power output. Even considering that for different wind directions the wind speeds were stronger, the power output did not increased and it remained stable at maximum value between 0.3 to 0.7 kW.

Appendix E