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SMALL WIND TURBINE

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SMALL WIND TURBINE

ABSTRACT

The main objective is to develop a project on installing a small wind turbine at the University of Glyndwr in Wrexham Wales. Today are immersed in a world seeking clean energy for reduce greenhouse gases because this problem is becoming a global reality.

So installing a small wind turbine at the university would provide large quantity of clean energy to supply a workshop and also reduce the expulsion of CO2 into the atmosphere.

The main characteristic of the turbine under consideration is the permanent magnet alternator that incorporates, whose rotor is coupled to the main axis of the machine without using an intermediate for the coupling, making this type of wind turbines an attractive solution in concerns regarding costs since it simplifies design and reduces maintenance costs.

The disadvantage of this type of machine is performance that present. Since all energy of wind cannot transform into electric power and also there are a number of mechanical and electrical losses. So will be do a report on the weather conditions trough by a wind study done at the University of Glyndwr and calculate how much energy we can generate with the small wind turbines.

Finally is showed that for this university the install a small wind turbine is profitable long period also would be a good subject of study for students and teachers, such as seeking greater energy efficiency, increased performance of the turbine and so on.

ACKNOWLEDGMENTS

First and foremost, I would like to thank my family but over all to my mother for all their support and help during my academic years and to my friend Jose Luis who he helped me in my stay in abroad.

I would also like to express my gratitude to my friends that I made in Wrexham.

Last but not least, I am grateful to Graham Smith for her guidance and supervision during the realization of this dissertation and to my friend Ivan that he helped me to start the dissertation.

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CHAPTER 1: INTRODUCTION

This chapter is detailed the main objectives of the project and is defined the studies that be conducted along this.

Firstly is performed a theoretical study on small wind turbine, and everything that surrounds it, also a comprehensive study of wind and this is crucial when installing a wind turbine, as it gives us a report on its profitability and the energy production.

The second part of the project will be based on a study on energy needs of the workshop also on the design and installation of the small wind turbine, as the power generated, losses, place location of the wind turbine to harness wind power more.

Besides will be discussed on the policy in question to renewable energy production, current situation in UK, such as subsidies, administrative support, etc…

Finally, we perform environmental study and an economic study where will be calculate the project estimate and will be analyze its economic viability.

1.1. -AIM

The project's main objective is to design a low-power turbine, whose mission is to supply electricity to a workshop at the University of Glyndwr in Wrexham Wales, taking into account the energy needs of the same and that the turbine is economically competitive.

1.2. -OBJECTIVES

The objectives to learn and to carry out the design and installation of a mini generator Glyndwr University:

Research

- Wind energy and wind small turbines
- Components of a small wind turbines
- Type of install of the small wind turbines to electric grid.
- Current situation of small wind turbines in EU and UK

Design

- Estimation of wind speed
- Estimation of energy needs
- Estimation of losses
- Estimation of energy generation
- Estimation of the place location
- Options: on or off the Grid. Stand- alone system or Grid-Connected system.

Choice of the power of mini small wind turbines

- Estimation of CO_2 savings
- Economic study of the small wind systems

Conclusion

1.3. - WORKING PLAN

In the following table it can immediately observe all the work that is going to do this year. But it can have small changes.

The final project started to do on 12th October 2009.

	YEAR 2009									YEAR 2010												
TASK NAME	OCTOBER			NOVEMBER			DECEMBER			JANAURY			FEBRUARY			MARCH			APRIL			MAY
	B	M	E	B	M	E	B	M	E	B	M	E	B	M	E	B	M	E	B	M	E	B
• Resarch																						
Wind energy and wind turbines		■	■	■	■																	
Component of small wind turbines			■	■	■																	
Type of installation to electric grid				■	■	■																
Situation in UK and UE						■	■	■														
• Design																						
Speed wind											■	■	■									
Information from renewable energies department												■	■									
Estimation of energy needs														■	■							
Estimation of losses															■	■	■					
Estimation of energy generation																■	■					
Estimation the place lacation																		■	■			
Type of install: Stand-Alone System or Grid-Connected System																		■	■			
• Others Characteristic																						
Economic study																			■			
• Conclusion																				■		
• Report						■	■											■	■	■	■	
• Powerpoint file							■													■	■	■
• Literature of the project and final presentation							■														■	■
• Logbook	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Figure 1.1: Working Plan

CHAPTER 2: WIND ENERGY AND WIND TURBINES

In this first chapter to be exposed a small introduction to wind energy and wind turbines and are discussed summary from some factors to take into account in the design and choose a preferred location for it.

2.1. -WIND POWER

The use of wind energy is one of the methods of harnessing renewable energy oldest that exist and industrial use may be cited as examples the windmills used for pumping water or grain mill. Today is the era of commercial exploitation as a producer of electricity.

Wind power as all sources of energy (except tidal and geothermal energy) comes from the sun.

2.1.1-ORIGIN OF WIND

Wind energy is associated with the kinetic energy of wind. It was create from point where the sun's radiation, which in combination with other factors such as tilt and displacement of the Earth in Space or the distribution of continents and oceans, it active the circulation of air masses on the globe after heating differently the different areas of the surface and atmosphere.

A large scale, exist a number of dominant wind currents that circulate around the planet into layers of the stratosphere. These winds global are governed by changes in temperature and atmospheric pressure, but also by other factors.

Moreover, near the land surface, locally, are blowing other winds more specifics it is characterized by the terrain and other variables such as roughness or height.

• Roughness: A very rough surface like a forest or an agglomeration of houses will provoke turbulence and will slow the wind, while another very smooth like the sea or the airport runway will encourage air movement.

• Height: If the terrain is rugged, wind turbines will require greater height to achieve the same wind speed that others in other locations flat.

2.1.2-VARIATION IN WIND

For the wind industry is very important to be able to describe the change in wind speed. This is because the designers need the information to optimize the design of wind turbines and to minimize their costs. A model used to describe the variation of the wind in a given location is the Weibull distribution.

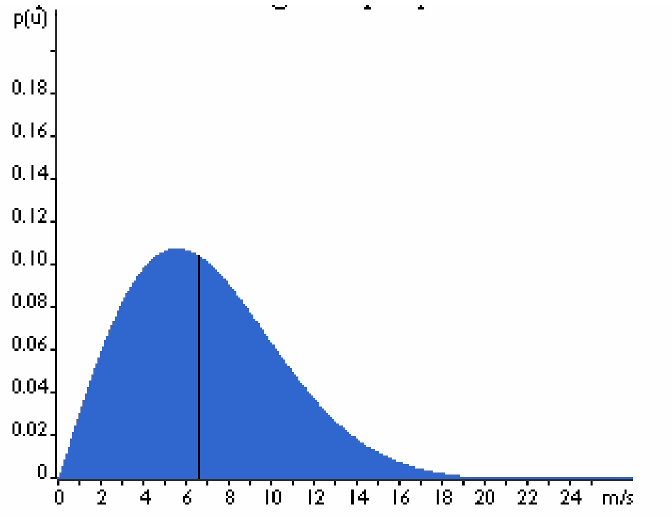

Figure 2.1: Distribution de Weibull [1]

The graph in Figure 2.1.2 shows a probability distribution. The area under the curve is always worth exactly 1, since the probability that the wind blows at any speed, including zero, must be 100%. The Weibull distribution shows that the probability that the wind blows at low speeds is higher than in the case of the wind blows at high speeds, whether measured wind speeds during a year we can see that in most areas the strong winds are rare, while that the winds fresh and winds moderate are common.

The statistical distribution of wind speeds varies from place to place on the globe, depending on the local climate, landscape and of its surface.

A notable aspect when designing a wind turbine is that not enough with to take data of speeds and then use the average speed for the calculations, one must consider the probability of each wind speed with a corresponding amount of power that is capable take out at that speed.

2.1.3-LOCATION

When selecting a proper location to install a wind turbine is not enough make a study of wind maps and wind action on the site.

In addition to this, there are must take into account other factors that can greatly influence the future behavior of the turbine.

Wind speeds are affected by friction with the earth´s surface. In general, the more pronounced the roughness of the terrain the greater the slowdown being experienced by the wind.

Turbulence decreases the possibility of using wind energy effectively in a wind turbine. Turbulence produces higher breakage and wear of the wind turbine.

The obstacles that are found the wind such as buildings, trees, rock formations, and so on. They can reduce wind speed significantly and often create turbulence around them. So the best thing is to avoid large obstacles close to wind turbines and in particular if they are located directly in front.

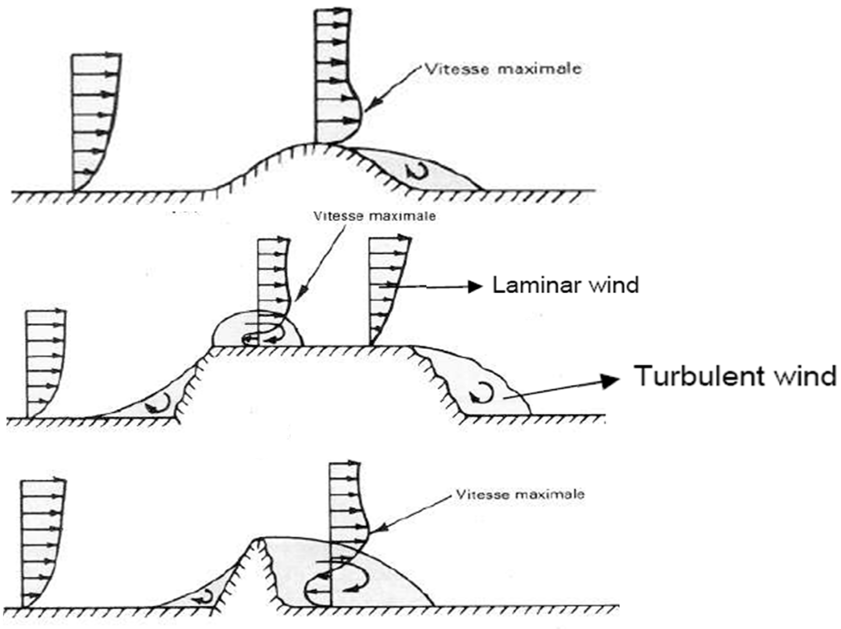

Figure 2.2: Turbulent wind [24]

Each turbine creates a coat in the direction that the wind blows is what is called wake effect. In fact, it creates a wake behind the turbine, ie a long tail wind quite turbulent and slowed. That is why in the wind farms to avoid this effect, one must maintain a minimum distance between turbines.

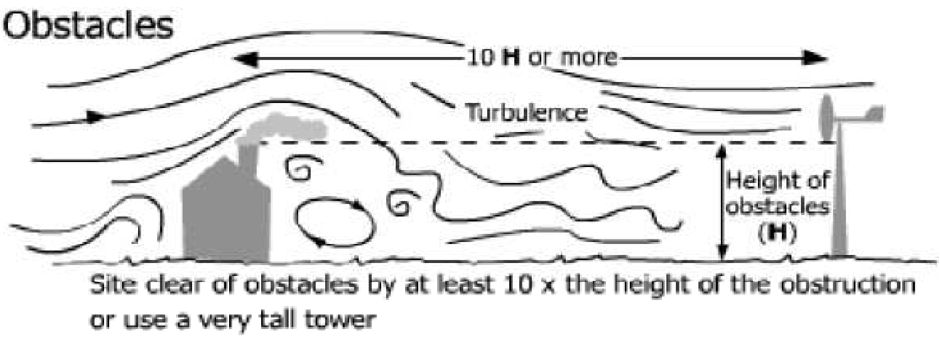

Figure 2.3: Turbulent wind [24]

Another effect to consider is the tunnel effect consists to place the turbine in a narrow pass between mountains. In this way the air is compressed at the mountain that is exposed to wind and its speed is greatly increased.

Another common way to deploy wind turbines is to place them on hills. In the hills can be seen that higher wind speeds that in surrounding areas.

It is therefore important to place wind turbines in the direction of prevailing winds, with minimal obstacles and roughness as low as possible in this direction taking into account hills and tunnel effects.

2.3- SMALL WIND TURBINES

According to Ron Stimmel September 2008 American Wind Energy Association (202) 383-2546:

> "The greatest challenges to small-scale renewable energy are not technical, but rather financial, political, and regulatory. Confusing, inconsistent or even absent permitting processes discourage the very people a forward-thinking community would want to enable: those with the motivation and resources to generate their own clean electricity."

Harnessing wind for power generation is almost as old as civilization. The first and simplest application was the candle for navigation.

A small wind turbine is a device that produces electricity from wind and whose installed power is equal or less 100KW. Moving air causes the turbine to rotate, which generates clean, emissions-free energy that can be used to power a home, farm, school, or small business.

The following sections describe briefly the types of turbine, components that make up small wind turbines, the operating principle of it and its classification.

2.3.1-TYPES SMALL WIND TURBINES

2.3.1.1- VERTICAL *-AXIS.*

It is a vertical axis machine, very simple from the standpoint of constructive and operational.

Besides simplicity, has the advantage of being very robust and have a strong starting torque, that possible the starting even with very weak winds.

But can be used only with reduced powers and that the turbine works well with light winds, while its yield decreases with high winds and even becomes vulnerable, so their size cannot exceed certain limits.

Figure 2.4: Vertical-Axis [10]

2.3.1.2-HORIZONTAL-AXIS

Currently horizontal axis turbines are the most used due to its higher performance featuring high winds, easy maintenance and low cost.

Although there are various configurations of wind turbines, one blade, two blades, three and Multi blades, removing the one blade and multi blades which are for special cases, the two blades and three blades are the most used.

But the three blades are used more because its energy produced is greater and its robustness makes them stronger to stronger winds and it is created less impact visual.

Therefore this project will be based on this type of turbine as it will be this model that will install at Glyndwr University.

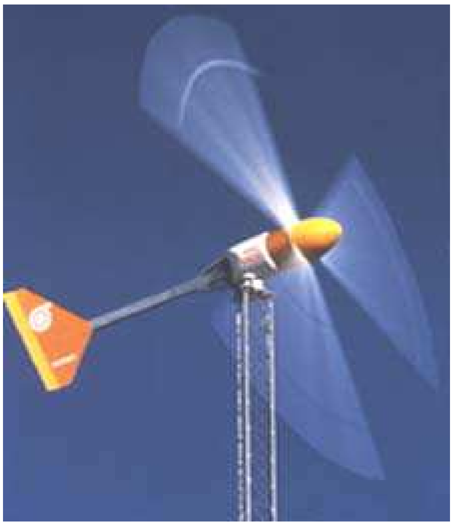

Figure 2.5: Horizontal-Axis 10KW [27]

2.4-PARTS SMALL WIND TURBINES

A small wind turbine is technologically advanced but mechanically simple, with only two or three moving parts. Most feature three blades of 2-15 feet in length, a generator located at the hub, and a tail y los component of system: controllers, inverters and batteries.

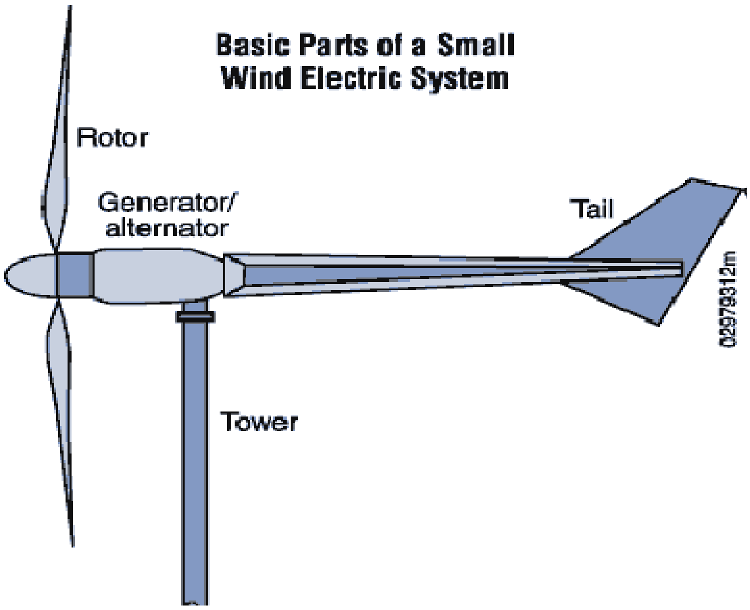

Figure 2.6: Basic Parts of a small Wind Electric System [11]

2.4.1- MATERIAL COMPOSITION OF THE BLADES

Most small wind turbines use blades made of plated metal: polyester reinforced with fiberglass or a lesser extent, carbon fiber, wood rarely. It has stopped using aluminum for its tendency to deform under stress.

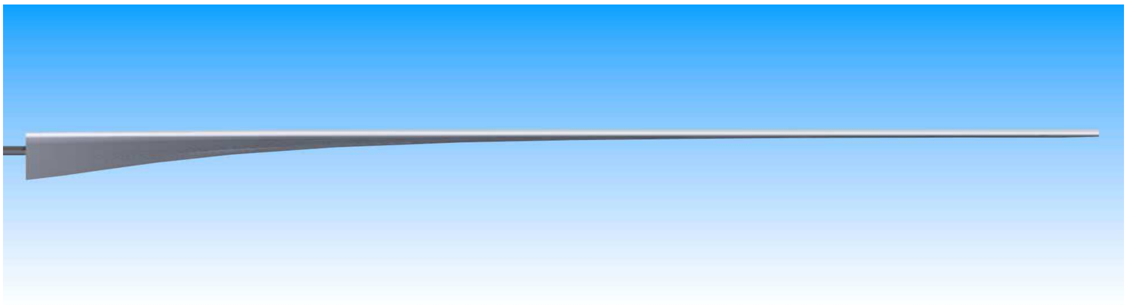

Figure 2.7: Blade [11]

2.4.2- ORIENTATION

The small size of mini-wind turbines cannot put motors with orientation of rotor facing the wind direction or other metal components that it has the turbines of size medium: almost all small wind turbines have directional arms to guide the rotor into the wind. The tail keeps the turbine facing into the wind.

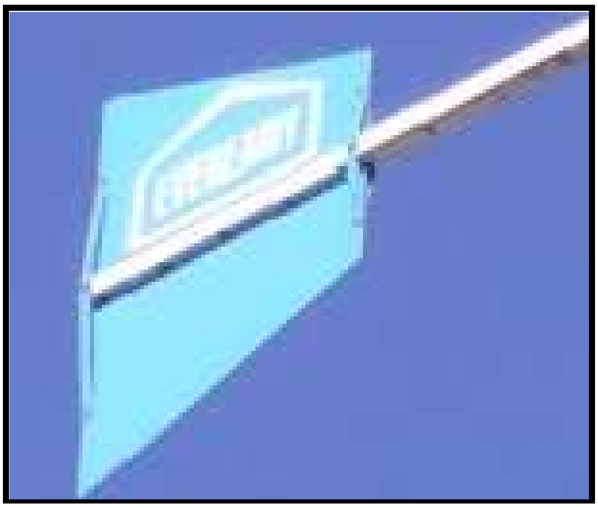

Figure 2.8: Tail [6]

2.4.3- ROBUSTNESS

For best performance, the turbines have to be in places with influence by winds consistent: for small wind turbines machines, given their small size, robustness is essential.

The heavier wind turbines have proved to be more robust and reliable than the lighter ones. The weight of a turbine mini wind compared with area swept by its rotor-called specific mass, measured in kg/mq- is therefore a good indicator of choice between different machines. Typically, a higher specific mass carries a higher price.

2.4.4- POWER CONTROL

In strong wind regime, the turbines have to have a passive positioning system that deflects the rotor about the rotational axis of the blade. Most micro and mini-turbines was bends a hinge so that the rotor turns to the arm directional: some vertical, others horizontal. The wind speed at which the misalignment is performed and how that which takes place depends on the hinge placed between the directional arm and the gondola.

2.4.5- GENERATORS

Most wind turbines use permanent magnet alternators: the configuration is simple and robust. Turbines for domestic use, the alternator configurations can be: permanent magnet alternator field winding conventional and induction generator.

Figure 2.9: Synchronous Motor [5]

2.4.6- TOWER

Because wind speeds increase with height, the turbine is mounted on a tower. In general, the higher the tower, the more power the wind system can produce. The tower also raises the turbine above the air turbulence that can exist close to the ground because of obstructions such as hills, buildings, and trees. A general rule of thumb is to install a wind turbine on a tower with the bottom of the rotor blades at least 30 feet (9 meters) above any obstacle that is within 300 feet (90 meters) of the tower. Relatively small investments in increased tower height can yield very high rates of return in power production. For instance, to raise a 10-kW generator from a 60-foot tower height to a 100-foot tower involves a 10% increase in overall system cost, but it can produce 29% more power.

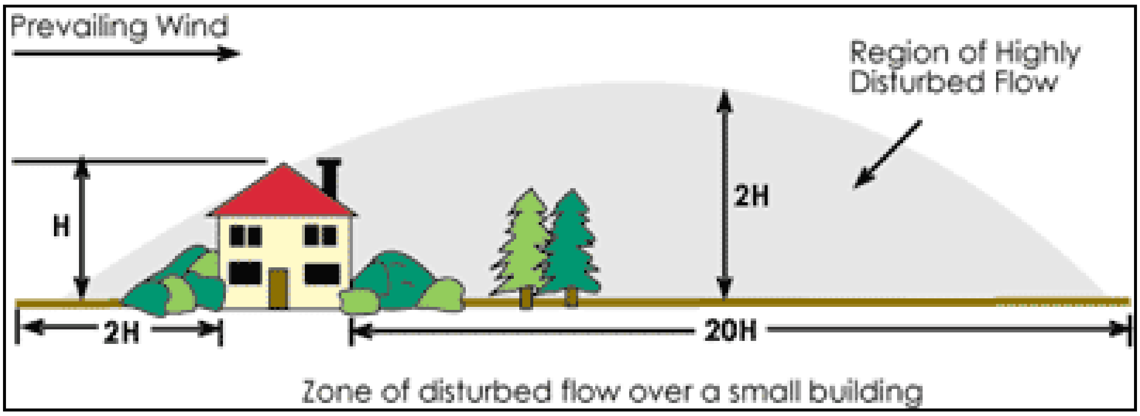

Figure 2.10: Region of Highly Disturbed Flow [24]

There are two basic types of towers: self-supporting (free standing) and guyed. Most home wind power systems use a guyed tower. Guyed towers, which are the least expensive, can consist of lattice sections, pipe, or tubing (depending on the design), and supporting guy wires. They are easier to install than self-supporting towers. However, because the guy radius must be one-half to three-quarters of the tower height, guyed towers require enough space to accommodate them. Although tilt-down towers are more expensive, they offer the consumer an easy way to perform maintenance on smaller light-weight turbines, usually 5 kW or less.

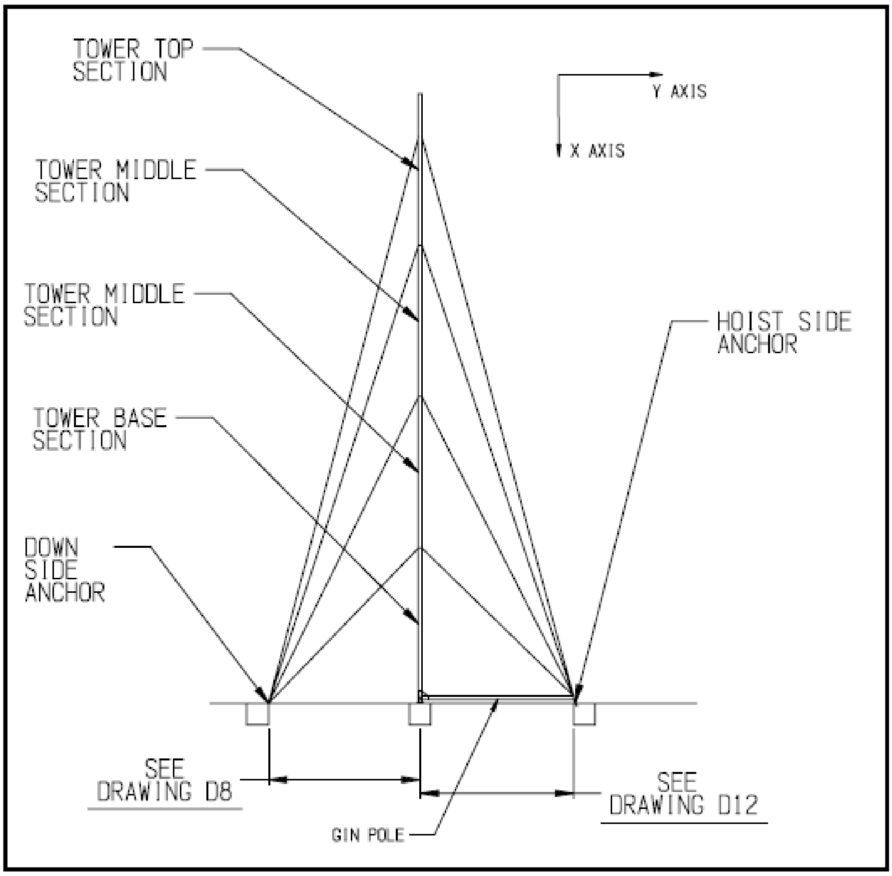

Figure 2.11: Parts of Tower [13]

2.5. OPERATION OF A WIND TURBINE

Wind turbines derive their power input by converting the wind into torque acting on the rotor blades. The amount of energy transferred to the rotor by the wind depends on the density of air, swept area of rotor blades and wind speed.

The kinetic energy of a moving body is proportional to its mass. Thus, the kinetic energy of wind depends on the density of air. At normal atmospheric pressure and 15 º C air density is 1.255 kg/m3 although this value decreases slightly with increasing humidity.

Referring to the swept area of the blades, it determines how much wind power is capable of capturing the wind turbine. Larger diameter blades, the surface is greater and therefore the energy absorbed by the rotor is greater.

Wind speed is an important parameter for the amount of energy a wind turbine can convert into electricity. The faster the speed of wind, the energy captures the wind turbine is higher.

The kinetic energy is captured by wind turbine through blades of rotor. When the wind strikes against the blades, they revolve around the rotor shaft and therefore they spin the low speed shaft that is coupled to a hub. This thanks to the multiplier turns the high speed shaft that is coupled to the generator, which is the producer of electricity.

The wind turbine rotor moves through the lift that occurs in the blades. The lift is a force perpendicular to the wind direction and occurs because the pressure difference on both sides of the blade, i.e. due to the fact that the air that slides along the upper surface of the wing moves faster than the bottom surface. If the inclination of the blades is very high can produce the phenomenon known as lost of lift, in which airflow from the upper surface is no longer in contact with the surface of the wing and therefore the blades stop rotating. It is for this reason that the wind turbine blades are twisted so that the angle of attack is the best along the whole length of it and there is no such phenomenon.

Like all energy processing machines wind turbines are not able to transform all the available wind energy into mechanical energy of wind and therefore must take into account a performance called power coefficient Cp. The power coefficient is the relationship between the wind power of emplacement and mechanical power that obtained. This coefficient depends on wind speed (see Fig. 3.3), to low-speed the performance of wind turbine is greater than at high speed.

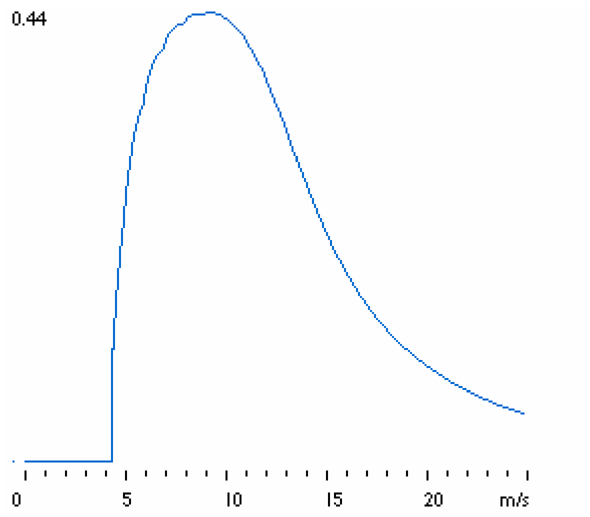

Figure 2.12: Power coefficient Cp [1]

Just as the power coefficient, the power of a wind turbine varies with wind speed (see Fig. 3.4). This is reflected in the power curves of wind turbines, which shows the electrical power available in a wind turbine at different wind speeds.

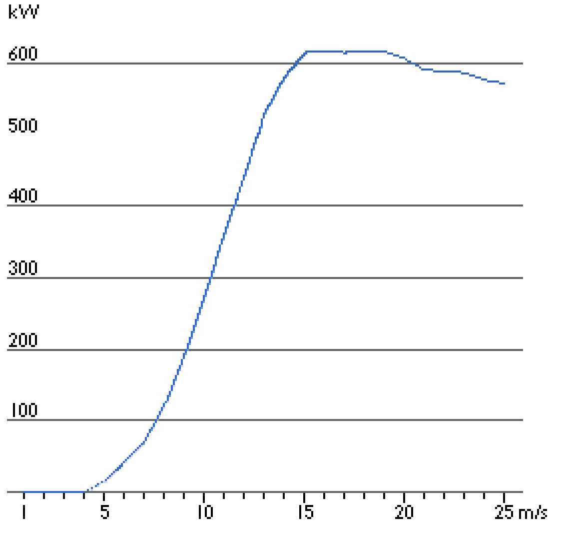

Figure 2.13: Wind Turbine Power [1]

CHAPTER 3: SMALL WIND TURBINE SYSTEM

Wind turbines are not generally connected directly to electrical loads. This is because wind power varies constantly, so the voltage and frequency will constantly be changing. The simplest solution is to use a battery bank plus inverter or only inverter, depending system.

This chapter explains the small turbine systems for defining the general installation, depending on consumption of the place to which must be supplied and the power of the wind turbine is chosen one or another option, since for large consumption where the wind turbine cannot provide all the required load power we must choose the other option as this helps deficit of electric supply, if otherwise the calculation gives that wind turbine is capable of supplying all the power demand will choose the first option and so get a total energy clean.

These options are:

- Stand alone system
- Stand Grid-connected system

3.1 STAND ALONE SYSTEMS

This system that is not connected to the Grid of supply, require the use batteries for store the excess generate energy, and use it when don't exist wind. Also, require a controller load for protect batteries of a overcharging. A inverter for rectifying the electric current from batteries to alternate current. Although this dispositive lowers slightly the efficiency global of the system, it allows that electric installation of the workshop is designed for system alternate current, which is the better option for moneylender, electric official standards, but the problem that for large loads, this type of system is wrong, for example, three-phase motor because it consumed intensity very large in the short time and the system will not be qualified

For safety, batteries should be installed in isolation from the living areas and electronics equipment because they contain corrosive or explosive substance. Also, lead-acid batteries need to be protected from extreme temperatures.

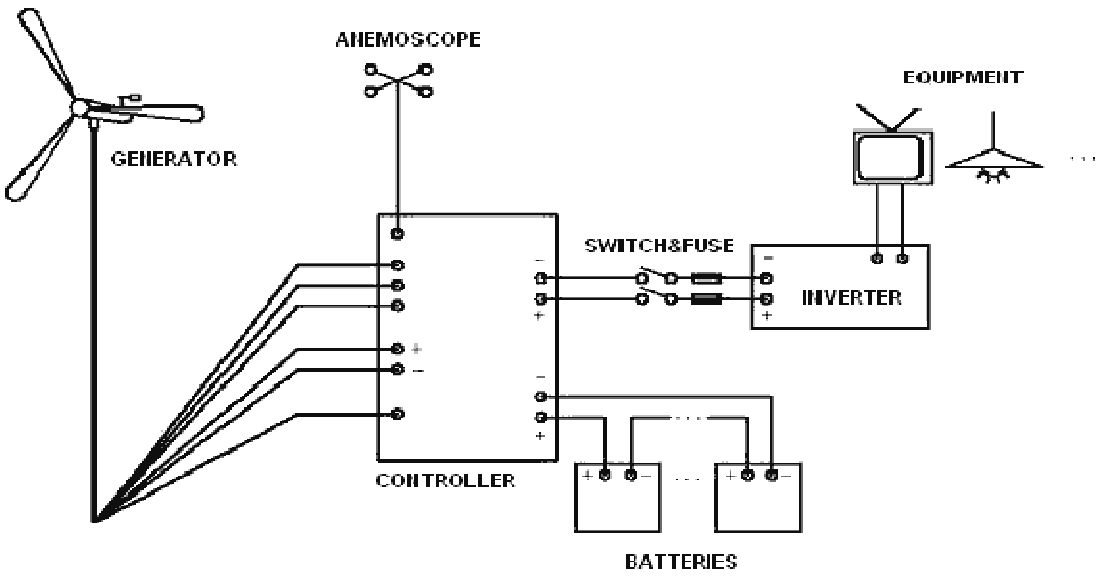

Figure 3.1: Electric scheme of standalone system [20].

3.2 GRID-CONNECTED SYSTEMS

In first place has been chosen grid-connected system for design of small wind turbine system for to get a save in the electric bill, apart from small wind turbine system cannot supply of power the entire workshop.

A grid-connected system allows it to power a home or small business with renewable energy during those periods (diurnal as well as seasonal) when the sun is shining, the water is running, or the wind is blowing. Any excess electricity you produce is fed back into the grid. When renewable resources are unavailable, electricity from the grid supplies your needs, thus eliminating the expense of electricity storage devices like batteries.

In such systems, the only additional equipment required is the investor, which makes the electricity generated by the turbine is compatible with the network. In general, do not require the use of batteries. When there is more demand than it consumes the charge can sell electricity to the grid or otherwise if there is problem of electric power can take from the grid.

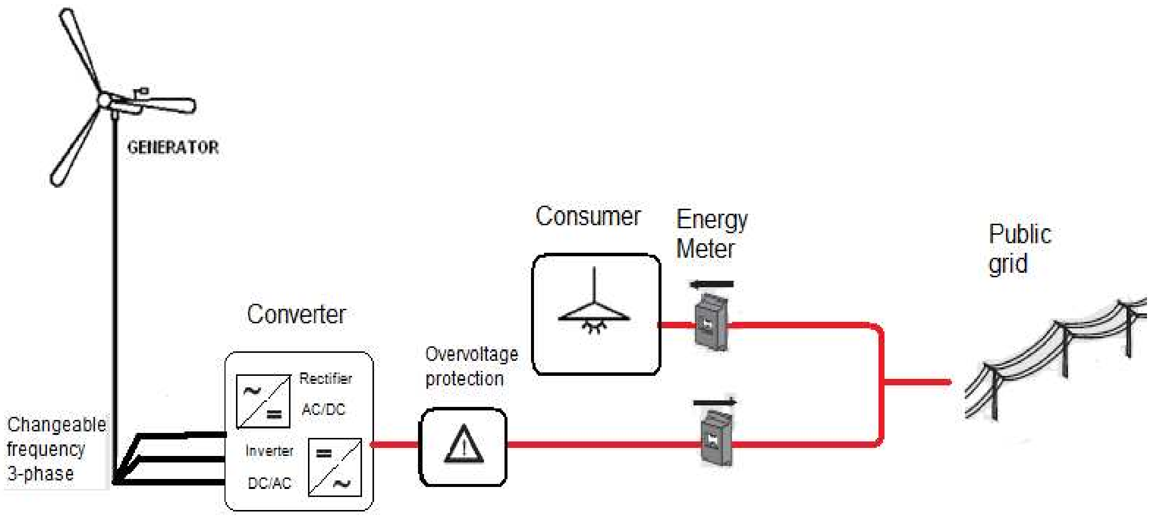

Figure 3.2: Schema of Grid-connected systems [20].

3.2.1. EQUIPMENT FOR GRID-CONNECTED SYSTEMS

Converter

Root Mean Square (RMS) Values

Most electrical appliances and equipment in Europe run on alternating current (AC) electricity, 230-volt AC service in homes, offices and some manufacturing facilities and in factories are 400V. The electricity flow is a sine wave (Figure 1) that oscillates between -330 volts and +303 volts. The rate of oscillation for the sine wave is 50 cycles per second and the AC term is used for the voltage, current and power.

The value of AC voltage is continually changing from zero up to the positive peak, through zero to the negative peak and back to zero again (Figure 1). For most of the time, the value of the voltage is less than the peak voltage and is not a good measure of its actual value. Instead we use the root mean square voltage (VRMS) which is 0.707 (or about 71%) of the peak voltage (Vpeak). The Root Mean Square (RMS) value is the effective value of a varying voltage or current. It is the equivalent of steady direct current (DC) constant value giving the same effect.

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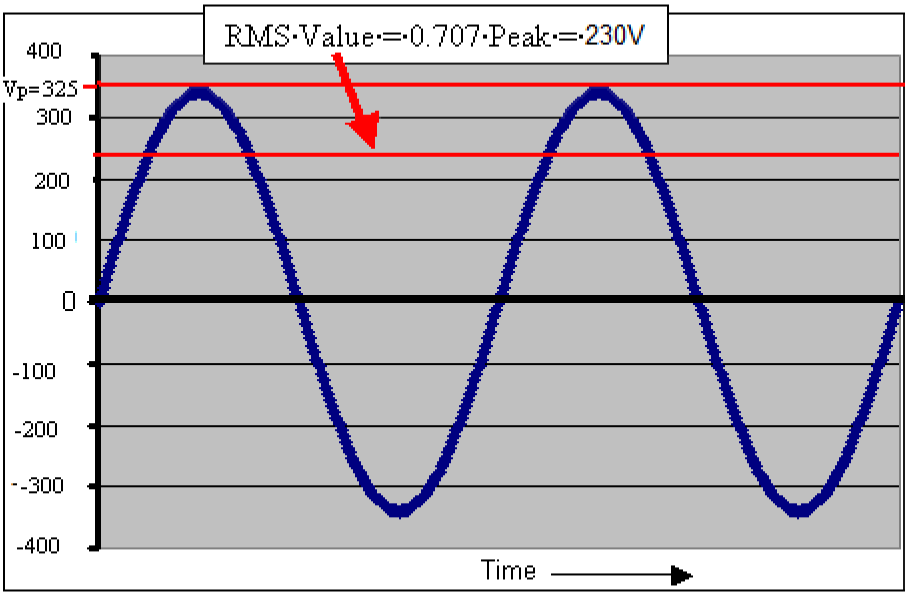


Figure 3.3: Sine wave, RMS Value [20].

Many available renewable energy technologies, such as photovoltaic's (PV), produce direct current (DC) electricity. To run many standard AC appliances, the DC electricity must first be converted to AC electricity using inverters and related equipment. Note the RMS value of an AC sine wave is the equivalent DC power if you are using a resistive load like a toaster.

There are four basic elements to an inverter:

- Conversion—of constant DC power to oscillating AC power
- Frequency of the AC cycles—should be 60 cycles per second
- Voltage consistency—extent to which the RMS output voltage fluctuates
- Quality of the AC sine curve—whether the shape of the AC wave is smooth as shown or jagged (with switching noise or distortion).

Simple electric devices, such as hair dryers and incandescent light bulbs, can run on fairly low-quality electricity. A consistent voltage and smooth sine curve are more important for sensitive electronic equipment, such as computers or microwave ovens, which cannot tolerate much power distortion.

Inverters condition electricity so that it matches the requirements of the load. If you plan to tie your system to the electricity grid, you will need to purchase conditioning equipment that can match the voltage, phase, frequency, and sine wave profile of the electricity produced by your system to that flowing through the grid.

When you install an investor should consult the power company because the company that imposes its rules to ensure that the quality of electricity it purchases is high.

These factors affect the cost of inverters:

- Application (utility-interconnected, stand-alone, or both)
- Quality of the electricity it needs to produce for stand-alone
- Voltage of the incoming current
- AC wattage required by your loads (for stand-alone systems only)
- Power required for the starting surge of some equipment
- Additional inverter features such as meters and indicator lights.

3.2.2. SAFETY EQUIPMENT FOR GRID-CONNECTED SYSTEMS

Safety features protect grid-connected small renewable energy systems from being damaged or harming people.

Here are the major safety features that system will need:

- Safety disconnects

Automatic and manual safety disconnects protect the wiring and components of the small renewable-energy system from power surges and other equipment malfunctions. They also ensure that system can be shut down safely for maintenance and repair. In the case of grid-connected systems, safety disconnects ensure that generating equipment is isolated from the grid, which is important for the safety of people working on the grid transmission and distribution systems.

- Grounding equipment

This equipment provides a well-defined, low-resistance path from system to the ground to protect system against current surges from lightning strikes or equipment malfunctions.

- Surge protection

These devices also help protect your system in the event that it, or nearby power lines (in the case of grid-connected systems), are struck by lightning.

3.2.3. METERS AND INSTRUMENTATION FOR GRID-CONNECTED SYSTEMS

Connect system to the electricity grid, will be need meters to keep track of the electricity your system produces and the electricity you use from the grid. Some power providers allow to use a single meter to record the excess electricity of system feeds back into the grid (the meter spins forward when the workshop consume electricity of the grid, and backward when your system is producing it).

Power providers that don't allow such a net metering arrangement require that you install a second meter to measure the electricity your system feeds into the grid.

CHAPTER 4: SMALL WIND TURBINE DESIGN

This chapter defined the turbine power that will be installed in the wind turbine previously a study of the energy needs of the workshop to determine the minimum power required and a wind study to determine the location and wind speed.

Before performing these studies need to mention that the wind turbine design will be a horizontal axis machine upwind since it has a higher efficiency than vertical axis machines.

The fundamental idea of this design is to make a realistic study on installing a mini wind generator to supply part of a workshop. Therefore, a system of medium size, installed power capacity of around 10kW has been chosen.

The majority of the results shown in this chapter are the result of simulations using tools; HOMER 6.8 to below, a brief introduction of these software programs is presented.

<u>HOMER 6.8</u> [12]

The HOMER program can be defined as follows according to the manual April 2005 **National Renewable Energy Laboratory:**

"HOMER, the micropower optimization model, simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. When you design a power system, you must make many decisions about the configuration of the system: What components does it make sense to include in the system design? How many and what size of each component should you use? The large number of technology options and the variation in technology costs and availability of energy resources make these decisions difficult. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations."

As be explained in the preceding paragraph is a very complete program, was achieved with the help of forums and expert in wind energy.

4.1. STUDY PRIOR TO SELECTING THE POWER

To define the performance of the turbine is necessary to study the electrical power needed of the workshop to which it will supply electricity and wind power in the area where it is located.

4.1.1. ENERGY STUDY OF WORKSHOP

The study of electric power is to add the power consumed by all electrical equipment of workshop, but because not all devices will be connected at once, one must consider this value by a factor of simultaneity F. Below is Table 4.1, the list of all electrical appliances and lighting detailing the power they consume and the hours that are estimated to be connected. Knowing the power they consume and the average time they are connected per day are calculated at the same table, the average energy consumed by each of them.

Being a large workshop and since it is very difficult to calculate all the devices that are connected to grid, is made a study of load forecasting of four laboratories and communal area which have the workshop.

- LAB 1

Project Laboratory					
	Nº	Power (W)	Power Total(W)	Hour of consumption (h/d)	Total (W*H/day)
Electronics Soldiers	12	200	2400	1	2400
Oscilloscope	13	40	520	1	520
Lamps	6*2	30	360	5	1800
Frequency Generator	13	45	585	1	585
Sources of electricity	12	80	960	0.4	384
Over head projector	1	250	250	0.3	75
Total:			5,075		5,764

- LAB 2

Avionics with Instrumentation & Control					
	Nº	Power (W)	Power Total(W)	Hour of Consumption (h/d)	Total (W*H/day)
Computers	17	200	3400	1.5	5100
Over head projector	1	250	250	0.3	75
LAB TEST MCC	2	750	1500	0.2	300
Lamps	11*2	30	660	5	3300
Fans	2	90	180	0.2	36
Sources of electricity	10	80	800	0.4	320
Total:			6,790		9,131

- LAB 3

Robotics & Power electronics					
	Nº	Power (W)	Power Total (W)	Hour of Consumption (h/d)	Total (W*H/day)
Lamps	2*6	30	360	5	1800
Oscilloscope	13	40	520	1	520
Frequency Generator	22	45	990	1	990
Sources of electricity	12	80	960	0.4	384
Fans	1	90	90	0.2	18
Computer	2	200	400	1.5	600
Study Motor 1	2	1000	2000	0.1	200
Study Motor 2	4	750	3000	0.1	300
Total:			8,320		4,812

- LAB 4

Electronics Laboratories					
	Nº	Power (W)	Power Total (W)	Hour of Consumption (h/d)	Total (W*H/day)
Oscilloscope	11	40	440	1	440
Digital Multimeter	18	40	720	0.9	648
Frequency Generator	11	45	495	1	495
Computers	16	200	3200	1.5	4800
Lamps	2*20	30	1200	5	6000
Over head projector	1	250	250	0.5	125
Electric heater	1	3000	3000	0.3	900
Total:			9305		13408

Communal areas			
LIGHTING	Power Total (W)	Hour of Consumption (h/d)	Total (W*H/day)
Corridors	800	6	4800
Bathroom 1	120	2	240
Bathroom 2	120	2	240
Meeting Room	200	2	400
Total:	1240		5680

Total:	**30,730 W**	**Total:**	**38,795 W*h/day**

Table 4.1 Power electric study (Installed Power)

As mentioned above the power consumed by all the equipment or installed capacity does not correspond to the minimum power which must be able to supply the wind turbine. From Eq. 4.1 the minimum power is the total electrical power weighted per a coefficient of simultaneity F. is estimated a coefficient at 50%, I e is consumed than 50% of the installed power.

$P_{Minimum\ Installed}$ =F*P =0.5 *30,730 =15,365kW (Eq. 4.1)

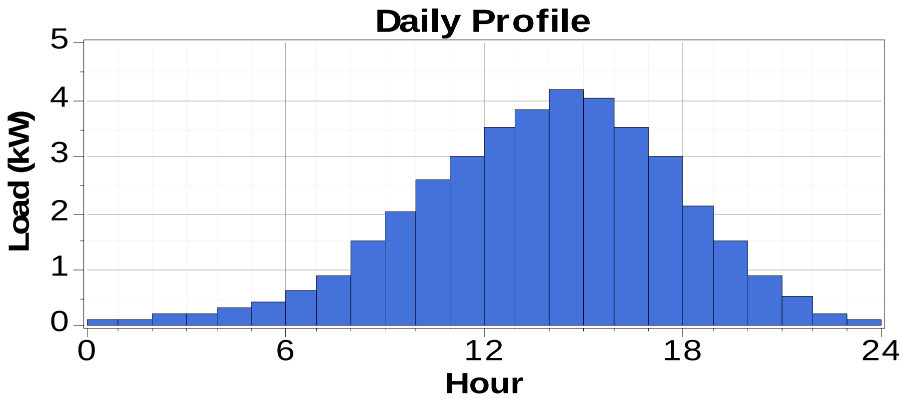


Figure 4.1: Simulation consumption per day.[12]

4.1.2 CHOICE OF THE SYSTEM

The choice of the system (stand-alone or grid-connected) has been made also considering the fore mentioned Feed-in Tariff (FIT) system (see appendix D). As a reminder, simply mention that this new system comes into effect in April 2010 and proposes an initial export tariff of 3p£/kWh and a generation tariff of 26.7p£/kWh.

The price that Glyndŵr University paid the electricity in August 2008 was 6.8674p£/kWh in its daytime rate and 3.8716p£/kWh in its night rate (information provided by the Department of Built Environment of Glyndŵr University). This information together with the initial export tariff proposed by FIT system indicates that consuming during the night the energy generated is less cost-effective than exporting it to the grid.

This last idea might suggest that a stand-alone system is possibly the best option for the design of the system, but it is likely that the energy consumption of workshop of the university is higher also there are days that wind turbine isn´t working. Next figure shows monthly averages the energy consumption at workshop Glyndŵr from January to December (information provided by the table 4.1: Power electric study, with simulation of HOMER software).

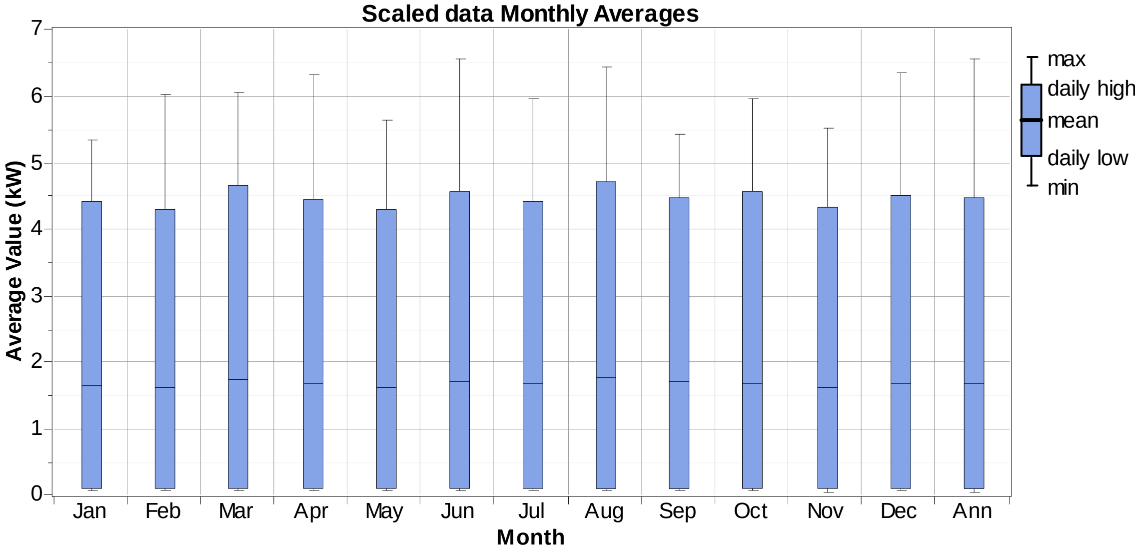


Figure 4.2: Simulation consumption of electricity at workshop (Monthly Average).[12]

In the figure above can be seen that the monthly average is near 2 KW, spite that the energy that small wind turbine can supply is 3.2KW, as can be seen in the figure there are days of month that the workshop can consume 5KW. Therefore the best option is choice the grid-connected.

4.2 WIND STUDY

Once carry out study of electric power, is necessary to know how much power will be able to provide the site chosen to install the wind turbine.

Wind power in an area is determined by Eq. 4.2 [2] [3] and it depends on air density, wind speed and the area swept by the blades.

$$P_{wind} = \frac{1}{2}\rho * A * V^3 \qquad \text{(Eq. 4.2)}$$

4.2.1. ESTIMATION OF WIND SPEED

The area where the turbine is installed is Northern Welsh town of Wrexham in particular at the University of Glyndwr. This will serve to estimate the average wind speed.

Glyndŵr University: Latitude: 53.024

Longitude: -3.005

Figure 4.3 – Aerial view of the main buildings of Glyndŵr University in Wrexham [14].

Image from Google map, the image of Glyndŵr University. Show the Location of the Small wind turbine.

The installation will be the closest to the building which will supply it of power electricity, which is the Block E, with this will get less lost in the transport of energy and save on the installation of cable as it reduces the work civil.

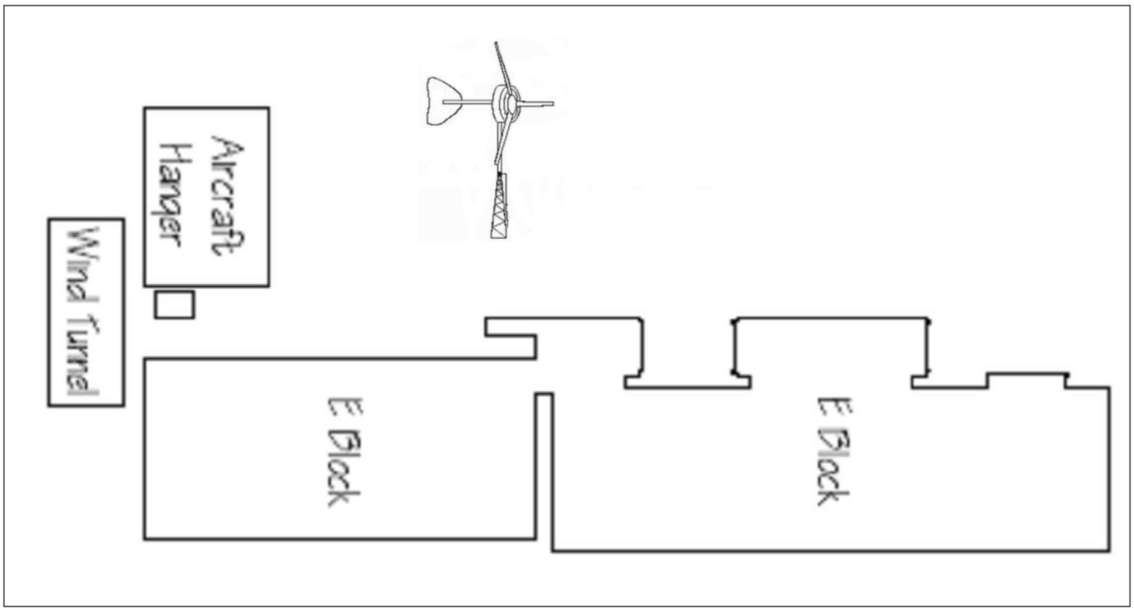


Figure 4.4 – Identification of B Block at Glyndŵr University.

Table 4.1 are detailed data on average speeds and the annual average monthly collected in 2009 by Wrexham Weather[8] (see appendix E). Data measured 10 meters above the ground level.

Month	Wind Speed (m/s)
January	7.4
February	6.7
March	7.1
April	6.1
May	6.8
June	5.7
July	5.4
August	5.9
September	5.9
October	6.4
November	6.2
December	7.1
Annual Average:	**6.4**

Table 4.2 Average Monthly wind speeds [8].

10m Mean Annual average wind speed: 6.4m/s

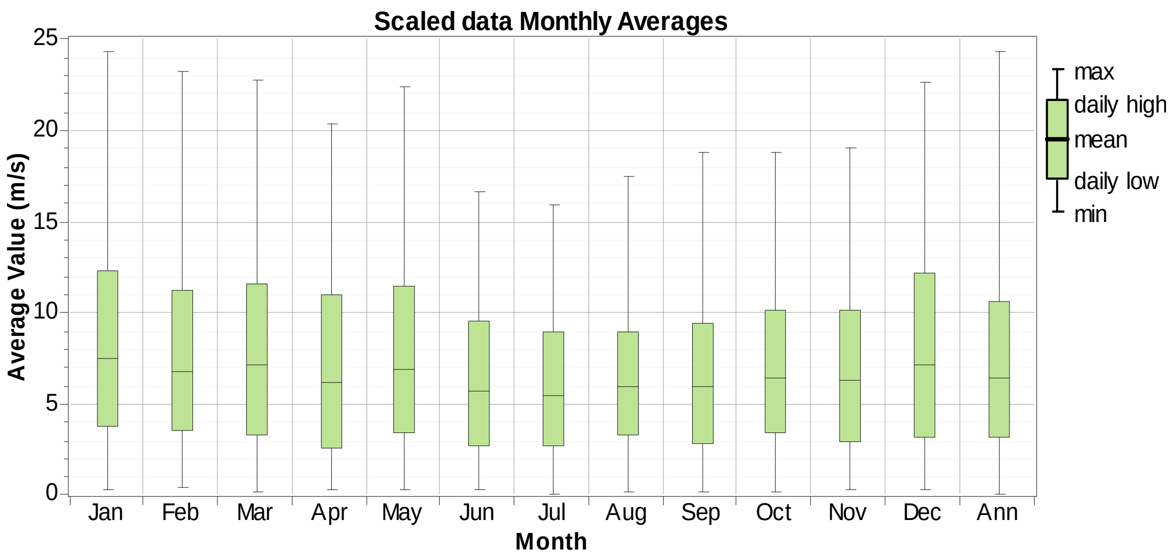


Figure 4.5 Simulation of average monthly wind speeds for each month of the year. [12]

But because the change in velocity that depends on the terrain and the height at which it is taken, we must correct the average velocity calculated from Eq. 4.3 [3].

$$V_{h_2} = V_{h_1} * \left(\frac{h_2}{h_1}\right)^b \qquad \text{(Eq. 4.3)}$$

Where V_{h_1}, V_{h_2} represent the wind speeds at the heights h1 and h2 and b is a coefficient that depends on the level of roughness of the terrain. Table 4.3 detail different values of the coefficient b in function of different types of terrain.

Level terrain roughness	b
No Rough (sand, snow, sea)	0,10-0,13
Little Rough (grass, grain field)	0,13-0,20
Rough (forest, small houses)	0,20-0,27
Very Rough (Heavy trees, several buildings, hilly, mountainous terrain.)	0,27-0,40

Table 4.3: Level terrain roughness [1].

Thus, assuming that the turbine rotor is located 15 m in height and located the area where there is little rough (b = 0.2) corrected speed is the one shown in the Eq. 4.4.

$$V_{15m} = V_{10m} * \left(\frac{h_2}{h_1}\right)^{0.2} = 6.4 * \left(\frac{15}{10}\right)^{0.2} = 6.94\ m/s \quad \text{(Eq. 4.4)}$$

4.2.2 –ESTIMATION OF WEIBULL DISTRIBUTION

As discussed in the previous chapter, the wind follows a Weibull distribution.

This distribution is often used in engineering of wind power, because it fits well with the distribution of average wind speed in the long term observed in a number of sites.

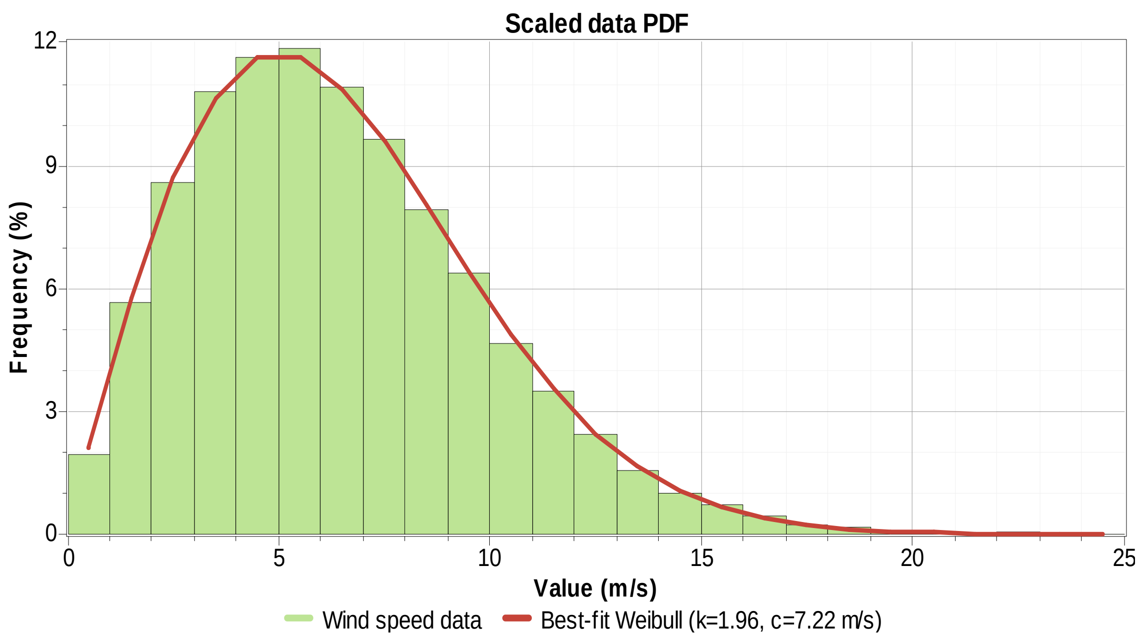


Figure 4.6: Weibull distribution according with HOMER software. [12]

Distribution of hourly wind speeds throughout the year. Hourly wind speeds were sorted into bins with a width of 1m/s. Each vertical bar represents the frequency with which wind speeds occurred in each bin. For example, a vertical bar centered on 5m/s reaching up to 12% means that wind speeds are between 5m/s and 6m/s for 12% of the time.

A narrow distribution of wind speeds means that the wind is very consistent at your location. A wide distribution means that the wind varies greatly. In wind resource assessment, the vertical bars are often approximated using a statistical distribution called the Weibull distribution (see appendix C). This distribution is characterized by the shape parameter “c” and scale parameter “k”. The solid line shows the Weibull distribution that best fits the hourly wind speed values. The corresponding “c” and “k” values are given in the bottom of the figure.

Therefore according to the graph of Weibull at a height of 15m the hub average wind speed is V = 7.22m / s.

4.2.3 –ESTIMATION WIND ROSE

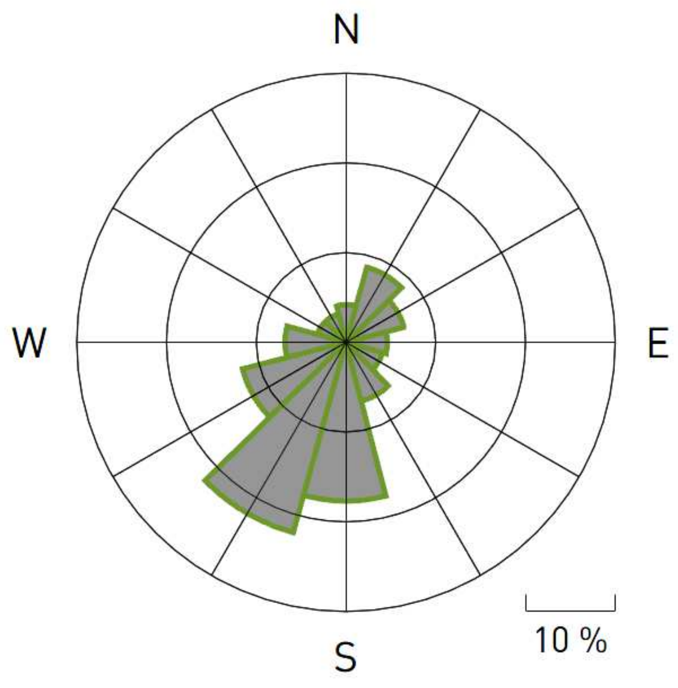


Figure 4.7: Wind rose according with HOMER software.[12]

Wind rose for all hourly wind speeds during the year (see appendix E). The wind rose indicates the frequency with which the wind blows from a given direction (N- North, E – East, S- South, W – West). The length of each wedge indicates the frequency, with the distance between two concentric circles representing a frequency of 10%. For example, a wedge directed straight up (N) and extending 3 rings means that the wind blows from the North 30% of the time. Directional bins are 30º wide.

Therefore the directional where more blow the wind is S-W (South-West) with frequency of 22% of the time. Directional bins are between 225 and 255.

Taking a speed of 7.22 m / s and an air density of 1.255 kg/m3, the only factor that can be varied to meet the electrical power required for the workshop is the diameter of the swept area of the blades.

4.3 WIND TURBINES SELECTION

For building wind turbine integration, some factors are important, how the diameter and the nominal power.

The project selected small wind turbines have diameters between 1 and 8 meters, with 1 to 10 kW, for installation on the city. In the market manufacturers there are Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT).

4.3.1 SMALL WIND TURBINE

As mentioned earlier, is chosen a 10kW turbine, therefore be looking for in market catalog of this instruction and be chosen the most appropriate that satisfy the needs of workshop.

The BWC EXCEL has been chosen for its characteristics in urban areas and high performance and price. Is a modern 7 meter (23 ft) diameter, 10,000W wind turbine designed for high reliability, low maintenance, and automatic operation in adverse weather conditions. It is available in two configurations: battery charging and grid-connected.

These are its main features for greater detail, the catalog is found in the appendix F:

General Configuration:	
Make, Model, Serial Number	Bergey WindPower, Excel, #9900550
Rotation Axis (H/V)	Horizontal
Orientation (upwind/downwind)	Upwind
Number of Blades	3
Rotor Hub Type	Rigid
Rotor Diameter (m)	7.0
Hub Height (m)	37
Performance:	
Rated Electrical Power (KW)	10
Rated Wind Speed (m/s)	13..0
Cut-In Wind Speed (m/s)	3.1
Cut-Out Wind Speed (m/s)	none
Rotor:	

Swept Area (m²)	38.4
Blade Pitch Control	Powerflex® Passive Pitch with Pitch Weights
Direction of Rotation	Clockwise
Rotor Speed (rpm)	0-400
Power Regulation (active or passive)	Passive
Tower:	
Type	Bergey Self-supporting
Height (m)	15
Control/ Electrical system:	
Controller: Make, Type	Bergey Gridtek Inverter
Electrical Output Voltage	Nominal 230-Volt single Phase
Yaw System:	
Wind Direction Sensor	Tail vane

Table 4.4: General configuration BWC Excel-S [27]

The power data that be introduced in Excel for calculate power Curve of wind turbine is found in the appendix C:

Power Curve (sea level):

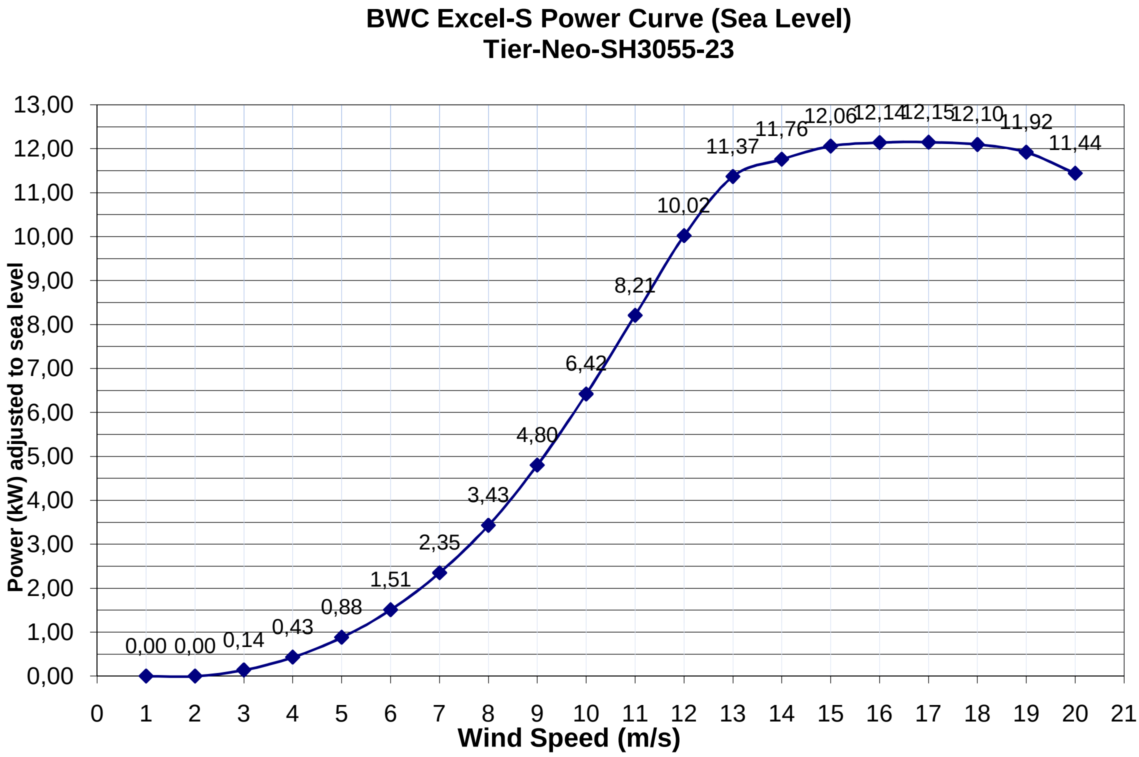


Figure 4.8: BWC Excel-S power curve (sea level). [27]

As expected at low wind speeds the generator power output is low, with increasing wind speed, the values of power that be obtained are higher, up to 17 m / sec where it reaches the production of design.

Also this curve and the study of the wind is what enables with the Computer aided estimating an annual production of electricity, since it has measurements of direction and intensity of prevailing winds in the possible location area.

On the other hand requires a special infrastructure for the installation of these generators.

The tower requires a strong anchor to which one must make a base or foundation of reinforced concrete dimensions according to the characteristics of the soil where you want to install the wind turbine.

The purpose for which it is designed this generator will require additional components such as inverter DC to AC converter and finally a direct converter of generation to variables voltage and power frequency as the aim is to deliver energy to the grid.

Wind power is estimated based removable diameter blade sweep area, according to (Eq.4.2) being the diameter of 7 meter as previously mentioned.

$$P = \frac{1}{2}\rho * A * V^3 \qquad \text{(Eq.4.2)}$$

$$P = 9068.9$$

The results of Eq. (4.2) do not refer to electric power if not to wind power, so these results must be corrected according to Equation 4.4 assuming a power coefficient of 0.55 (the theoretical maximum that can be achieved according to Betz 'Law is Cp = 0.59 [2]).

Assuming that the average speed on the rotor area is the sum of v1 speed (speed at the front of the turbine, see Figure 4.9) and v2 (speed at the rear of the turbine, see Figure 4.9), knowing that Wind power P extracted by the rotor is equal to mass times the squared difference of wind speed and linking it with the power of wind without pass by turbine Po Betz Law shown in Eq. 4.5.

$$\left(\frac{P}{P_0}\right) = \left(\frac{1}{2}\right) * \left(1 - \left(\frac{V_2}{V_1}\right)^2\right) * \left(1 + \frac{V_2}{V_1}\right) \qquad \text{(Eq. 4.5)}$$

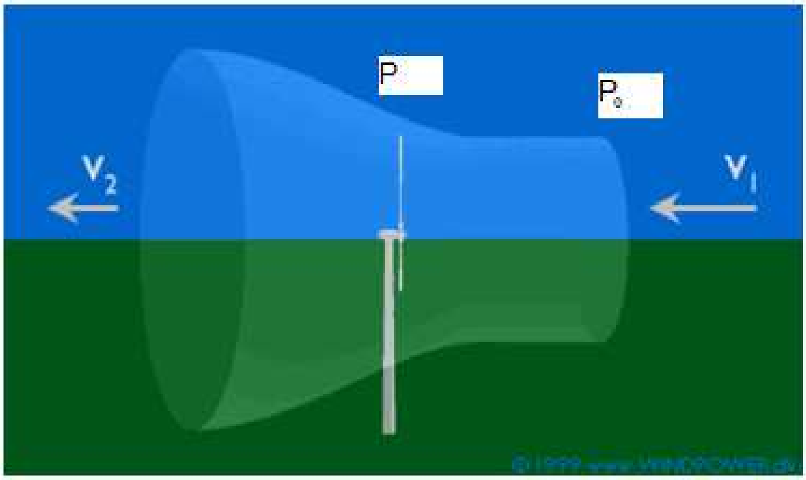


Figure 4.9: Variation of the wind, passage through the turbine [1]

If is interpreted Eq. 4.5. According to v2/v1, is shown in Fig 4.10 that the function reaches its maximum for the relationship $\frac{V_2}{V_1} = \frac{1}{3}$.

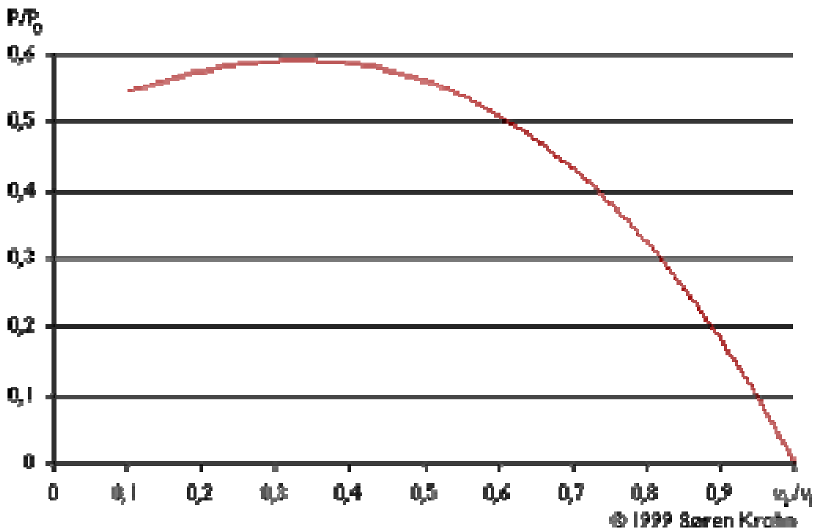


Figure 4.10: P/Po according to v2/v1 [1]

Substituting the optimal value of v2/v1 in Equation 4.5, is found that the relationship between wind power by wind turbine and the swept surface of the blades is 0.59 (see Equation 4.6), i.e. the wind turbine takes 59% of the available wind energy for a velocity ratio before and after passing through the turbine optimum.

$$\left(\frac{P}{P_0}\right) = \left(\frac{1}{2}\right) * \left(1 - \left(\frac{V_2}{V_1}\right)^2\right) * \left(1 + \frac{V_2}{V_1}\right) = \frac{16}{27} = 0.59 \qquad \text{(Eq. 4.6)}$$

After briefly explain which consist Act Betz be continues with the calculation of electric power in Table 4.4. Therefore, this assumes a yield of 0.95 electrical systems. Eq. 4.7 shows the expression to convert wind power to electric power.

$$P_{electric} = \eta_{\mathrm{Syst.electric}} * \mathrm{P_{mechanical}} = \eta_{\mathrm{Syst.electric}} * \mathrm{C_p} * \mathrm{P_{wind}} \qquad \text{(Eq. 4.7)}$$

$$P_{electric} = 4738.5W$$

It is noted that the electrical power in theory is larger than the data reflecting the turbine that has been chosen and is due in practice there are more loses, as the mechanical, electrical and the wind, which are omitted in the formulas for simplify the calculations. But he notes that it is a good approximation to reality.

4.4 INVERTER CHOSEN

The inverse that has choice is GridTek 10 Power Processor (its datasheet can be found in Appendix F).

The Bergey Excel operates at variable speed to optimize performance and reduce structural loads. The output is 3-phase power that varies in both voltage and frequency with wind speed. This variable power (wild AC) is not compatible with the utility grid. To make it compatible, the wind power is converted into grid-quality 240 VAC, single phase, 50 hertz power in the GridTek Power Processor, an IGBT-type synchronous inverter. However, due to the availability of only 3-phase power at the Recycling Center, this single phase power will be converted to 3-phase, 220 VAC prior to connection directly to a grid-connected circuit breaker panel. Operation of the system is fully automatic. In the event of a utility power outage, the GridTek will automatically shut down the wind turbine.

4.4.1 How the Grid Connected Inverter Works

- Stand-by mode:

In stand-by mode the inverter is ready to switch into Grid mode. If the power generated by the wind turbine is insufficient for grid operation, the inverter remains in stand-by mode until the wind turbine has generated sufficient power to switch into 'connecting mode'.

- Connecting mode:

After all system checks have been performed, in the course of which it is tested whether all connection conditions have been complied with, the inverter switches from stand-by mode to connecting mode. The inverter continues to check system values for the predefined connecting period, and if system checks are still OK, the inverter connects to the grid. Minimum connecting times are specified by utilities and authorities and may differ from region to region.

- Grid mode:

In this mode the inverter is connected to the grid and delivers power to the grid. The inverter only leaves grid mode if a failure occurs or the wind power disappears. In this mode the inverter always works in the MPPT (maximum power point tracking) mode. This is the device's normal operating mode. The power taken by the inverter from the wind generator is also shown below this on the display. This is always more than the power supplied by the network. The difference is the so-called power loss of the inverter. It determines the conversion efficiency of the device. The power loss is emitted as heat.

- Fault

When there is a fault happen, the inverter will switching off and go into fault mode to protect the wind power system.

- Dumping load

When under strong wind conditions, high turbine rotation speeds makes the output voltage of wind generator raise to a dangerous high value. In order to protect the wind turbine, reduce the turbine rotation speed and the generator output voltage can be carried out by switching in a resistor assembly (Dump load).In this mode, the electrical energy generated by the turbine is then converted to heat.

Connecting to the Grid

The inverter operation is fully automatic, and the inverter automatically detects when grid connection is possible. The inverter works as follows when connecting to the grid:

- When wind power is available and the wind turbine starts to rotate,wind generator starts to power.
- The rectifier starts charging the DC bus to 600 V

- The AC modules receive power from the DC bus and start operating. The AC modules then switch into stand-by mode.
- If the DC input voltage exceeds 650V, inverter is allowed in grid operation.
- The inverter checks that grid conditions are OK.
- The inverter monitors grid conditions for 30 seconds and then connects to the AC grid.

Supplying Power to the Grid

After grid connection, go into MPPT mode and control input voltage to achieve maximum power transfer. During grid connection, all inverter and grid parameters are monitored.

Disconnecting from the Grid

If wind power is insufficient to generate power for the grid (when internal inverter power consumption is more or less equal to the available wind power), the inverter disconnects from the grid and goes into stand-by mode. The inverter continues to monitor the wind power available. If the wind power becomes available again within 5 minutes, a new grid connection procedure is initiated. If no wind power is available after 5 minutes, the inverter goes into stand-by mode to save power.

Conditions that cause the Grid Tie Inverter to be disconnected from the grid:

Grid voltage:

The grid voltage may be within a range of –15% and +10% of the nominal grid voltage. Once the grid voltage exceeds this range the inverter is disconnected from the grid with 0.2s.

Grid frequency:

The grid frequency may be within a range of Hz of the nominal grid frequency. Once the grid frequency exceeds this range the WG20K3TL is disconnected from the grid with 0.2s

4.5 TOWER CHOSEN

The NRG Systems Self-Supporting tower is especially well suited to this application due to its inherent safety. Being a tower more robust and heavy, it will not present an 'attractive nuisance'. But have the disadvantage of being more expensive and require a crane for installation. The self-supported towers, necessarily, must be determined with foundations, Annex a table with the dimensions of the foundation necessary depending on the type of terrain and height. To install the turbine on the tower, you need an adapter that allows the blades rotate without danger of hitting the tower.

As important note, connect Ground the tower to protect it from possible static electricity and lightning strikes.

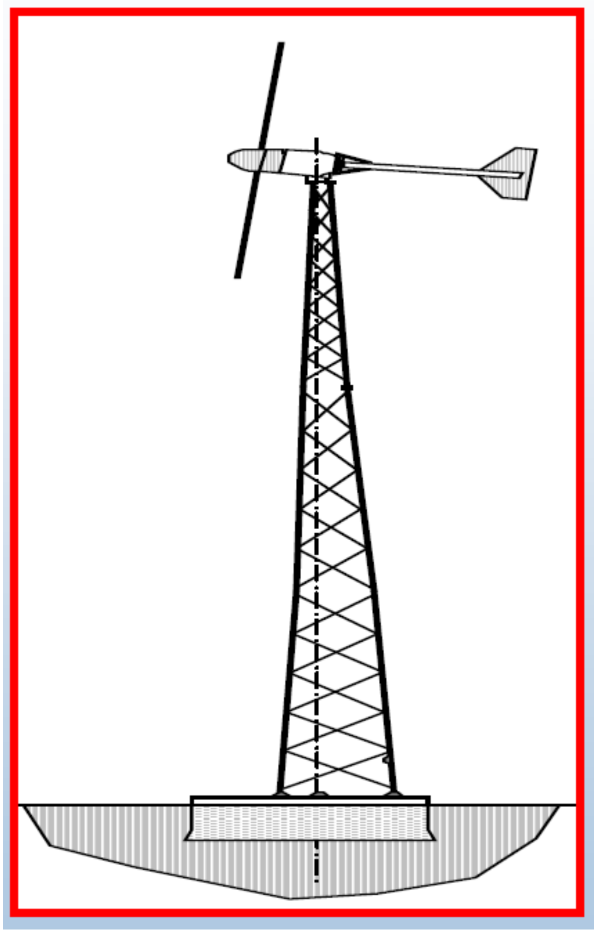


Figure 4.11: NRG Systems Self-Supporting tower [13]

4.6 ENERGETIC STUDY OF THE SMALL WIND TURBINE

The process that has been carried out so as to obtain the value of the expected annual energy production is described in this point of the dissertation.

4.6.1 -MICROPOWER SYSTEM MODELING WITH HOMER

HOMER model can be used worldwide with great ease to evaluate energy production, life cycle costs with purposes of reducing emissions of greenhouse gases, and for projects with applications Grid-connected , Network isolated and off-grid to large-scale (multiple turbines) and small-scale (Wind-Diesel Hybrid Systems singles).

The program is used only as a simulation tool. Is proved a setting: a small turbine system grid-connected, to supply a workshop, as can be seen in Figure 4.12.

4.6.2- WIND TURBINE SYSTEM CONFIGURATIONS

The system is designed to supply approximately 80% of total electricity demand of the workshop. The system configuration is summarized in Figure 4.12.

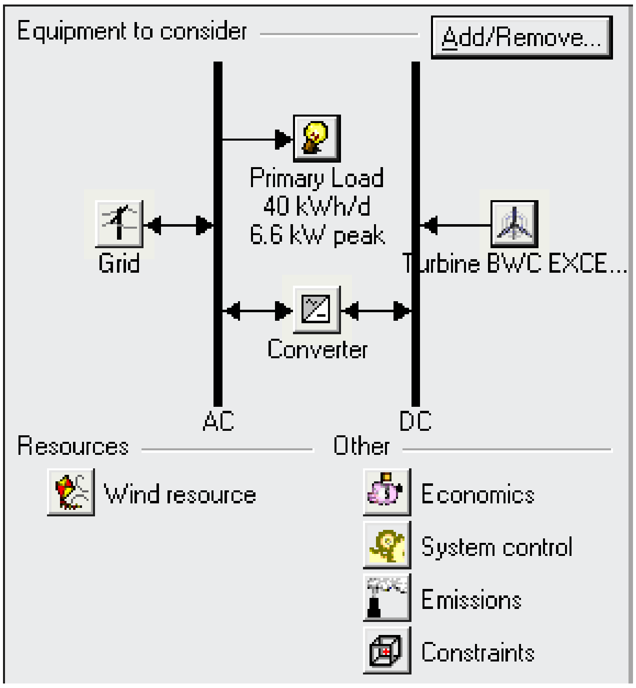


Figure 4.12: Example of calculation of Grid-connected wind system using HOMER software.

Figure 4.12 shows a typical grid-connected renewable, energy system. The renewable energy source produces DC electricity, which is converted into 240V AC by the GI-inverter. This AC electricity is used by the electrical appliances and equipment (load or demand). If there is surplus electricity being generated, the inverter will feed it into the main grid. Conversely, if the load is greater than what is being supplied by the energy source, the grid automatically supplies the house, via the inverter.

Also introduced as input the electric consumption of the workshop, as the graph shows the daily consumption is 40Kwh/day.

At the bottom see the source, designed to show the monthly figures of wind.

After entering the data, the HOMER software is designed to obtain results on the installation, with each of its details, so this software is chosen to calculate everything related to the installation.

4.6.2.1 TOTAL ENERGY

The gross energy production is the total annual energy produced by the energy facilities, considering the losses, the wind speed, air pressure and temperature in the locality. HOMER is used to determine the delivery of renewable energy.

The estimation of energy production of the small wind turbine system has been carried out using HOMER software. The values previously calculated are necessary for the simulation with this computing tool. Although the next table 4.5, 4.6 shows the results, the complete simulation can be seen in Appendix B of this document.

1.

Production	kWh/yr	%
Wind turbine	29,151	84
Grid purchases	5,403	16
Total	34,554	100

Table 4.5 Estimated of energy production by the wind turbine system.[12]

2.

Consumption	kWh/yr	%
AC primary load	14,600	46
Grid sales	17,087	54
Total	31,687	100

Table 4.6 Estimated of energy consumption by the wind turbine system [12]

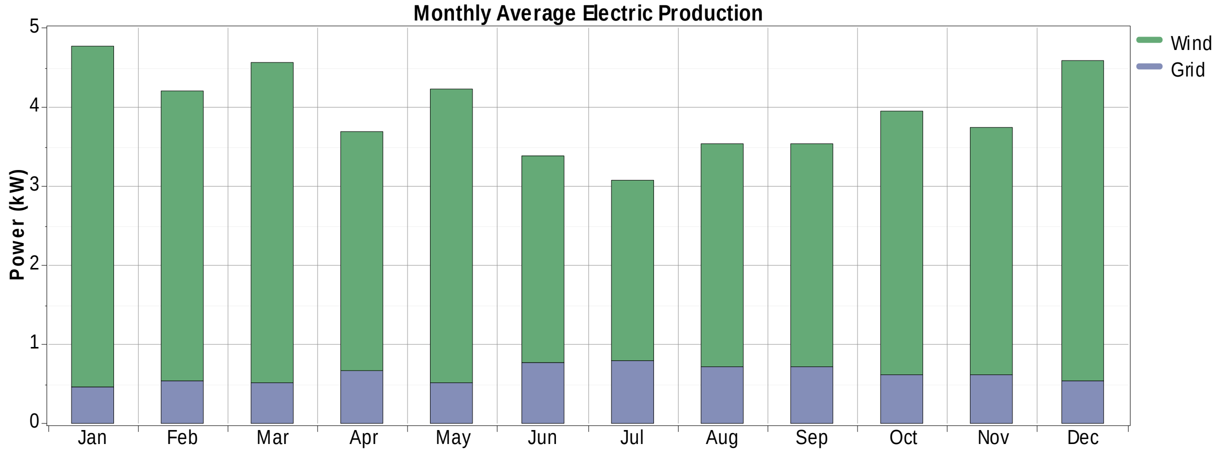


Figure 4.13: Monthly average Electric Production.[12]

The graph shows the monthly average of total energy supplied to both, the turbine and the Grid, the green color reflects the energy that produces wind turbine and the blue that produced by the electric Grid.

As can be see the energy that produces the wind turbines is much higher than that purchases from the grid but it is necessary that the workshop is connected to it, because they do not always wind blowing so should be consume from the power supply . Also, when there is more energy production can sell excess power to the grid and generate a profit to electric the installation.

Next be explaining the energy production of each of the elements that make up the Wind micro-generation.

4.6.2.2 ENERGY PRODUCTION BY WIND TURBINE OF 10KW

HOMER software calculates the energy production of wind turbine (wind). This corresponds to the energy that one or more turbines produce at normal temperature and atmospheric pressure. The calculation is based on energy production curve of the turbine selected (the database) and the average wind speed at hub height in the given site.

Quantity	Value	Units
Total rated capacity	10.0	kW
Mean output	3.3	kW
Capacity factor	33.3	%
Total production	29,151	kWh/yr

Table 4.7: Estimated of energy production by the wind turbine 10Kw. [12]

Quantity	Value	Units
Minimum output	0.0	kW
Maximum output	12.1	kW
Wind penetration	200	%
Hours of operation	8,171	hr/yr
Levelized cost	0.127	£/kWh

Table 4.8: Data of production wind turbine 10Kw.[12]

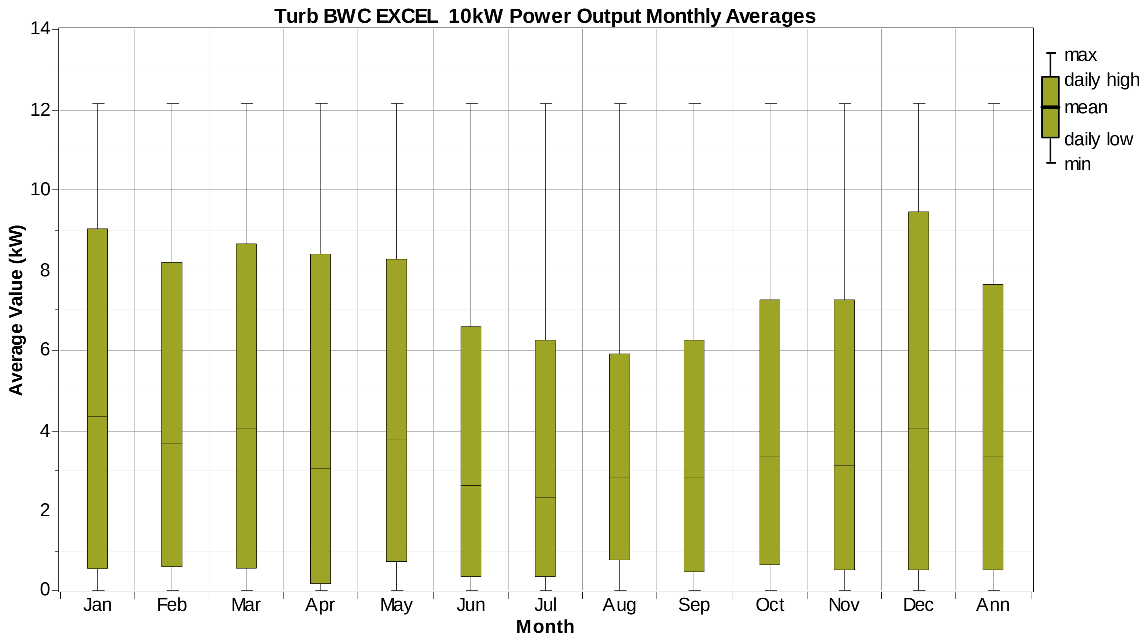


Figure 4.14: Turbine BWC Excel 10KW Power out Monthly Averages.[12]

As shown the production of wind energy by the turbine is 29.151 kWh / yr, this is a good production in view of the turbine is working 8.171 h / year.

Show in the graphic in the months where there is less wind is where the production is lower.

Show in the table 4.7 the mean output of generator is 3.3Kw however in the previous paragraph with the theoretical calculations is 4.78Kw, and this is due to theoretical calculations does not take into account losses in the blades, mechanical and electrical losses.

4.6.2.3 -ENERGY INVERTER BY CONVERTER

The inverter can operate in parallel with another ac power source such as the grid. Doing so requires the inverter to synchronize to the ac frequency.

A converter is a device that converts electric power from dc to ac in a process called inversion, and/or from ac to dc in a process called rectification.

Quantity	Inverter	Rectifier	Units
Capacity	10.0	9.20	kW
Mean output	3.0	0.00	kW
Minimum output	0.0	0.00	kW
Maximum output	10.0	0.00	kW
Capacity factor	30.0	0.0	%

Table 4.9: Data Power of Converter 10Kw.[12]

The converter size, which is 10Kw, refers to the inverter capacity, meaning the maximum amount of ac power that the device can produce by inverting dc power. The rectifier capacity is 9.2Kw, which is the maximum amount of dc power that the device can produce by rectifying ac power, as a percentage of the inverter capacity.

Table 2 gives us all the energy that goes in and the energy invested and the total loss that occurs is 2.285 KW.

Quantity	Inverter	Rectifier	Units
Hours of operation	8,171	0	hrs/yr
Energy in	28,570	0	kWh/yr
Energy out	26,285	0	kWh/yr
Losses	2,285	0	kWh/yr

Table 4.10: The Performance data of the Inverter in a year.[12]

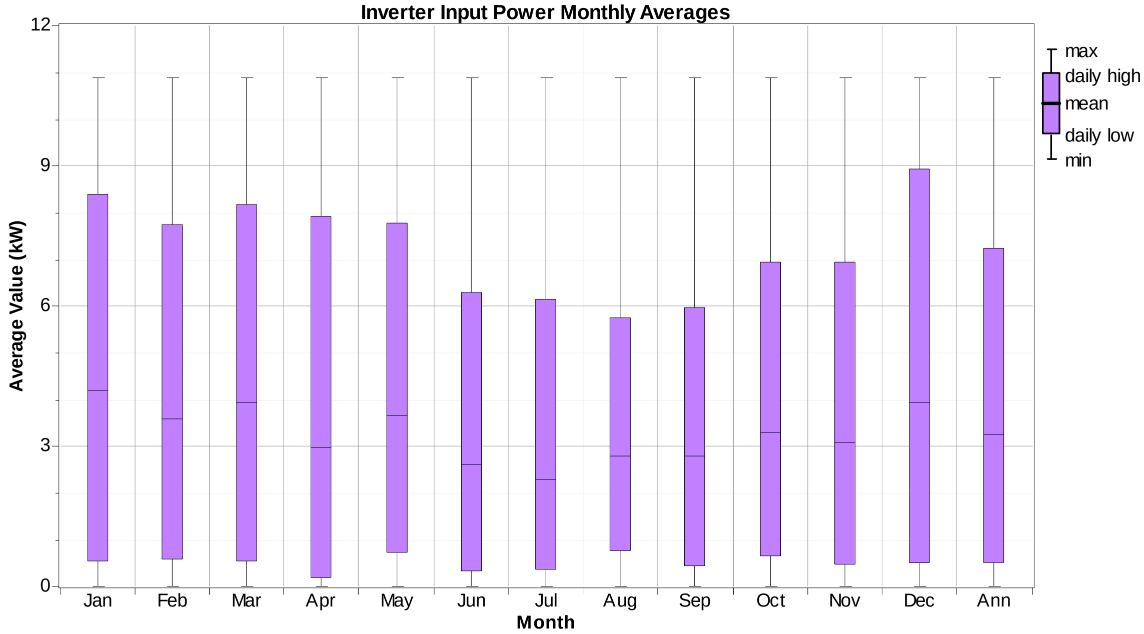


Figure 4.15 Inverter Input Power Monthly Averages.[12]

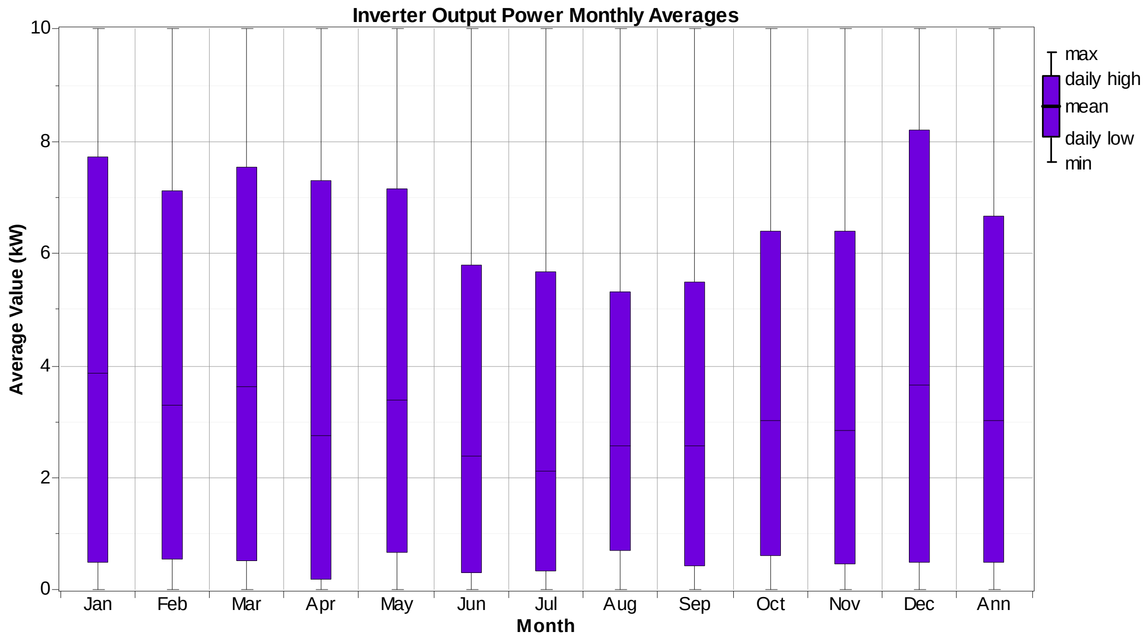


Figure 4.16: Inverter Output Power Monthly Averages.[12]

The converter is divided into two graphs the first of her, is input power of converter which coincides with that generated by the wind turbine and the following is output power of converter, is lost power due to changing in AC / DC, DC / AC, as in its interior is composed of power electronic components such as diode, resistance ... and are elements that dissipate much heat and therefore it produces many lost, so the manufacturer provides an efficiency of 92 %, if the input is 10kw to output of rectifier is 9.2Kw.

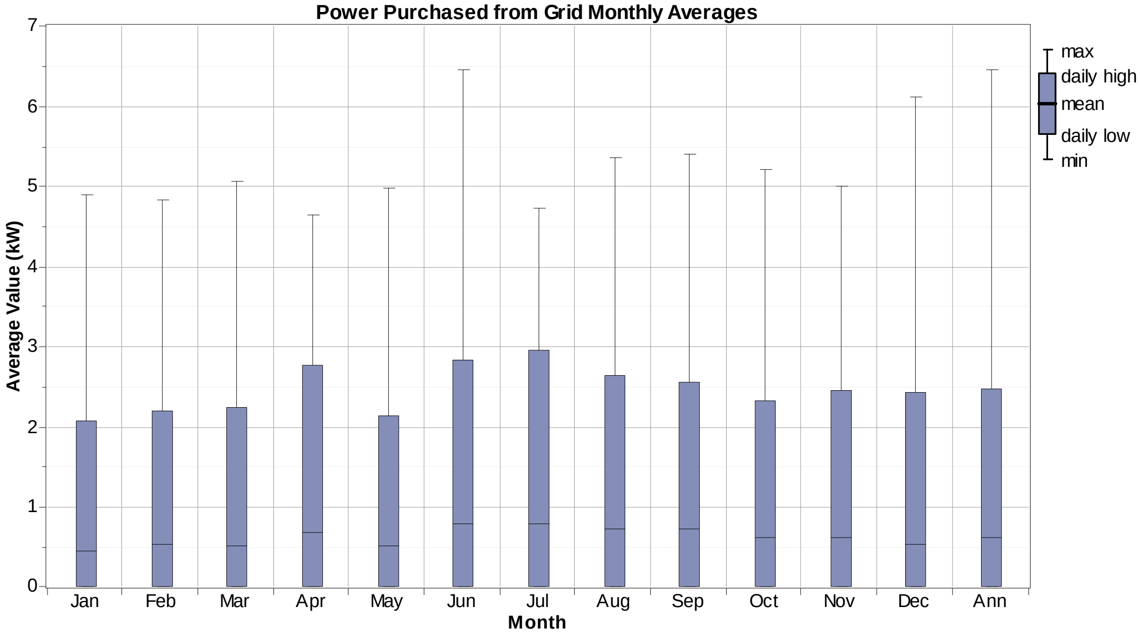
4.6.2.4.-EXCHANGE WITH THE GRID

A grid connection is an interface where energy can flow in either direction; from the grid or into the gird. The energy flow is metered and the total monthly amounts are used to calculate the grid energy bill.

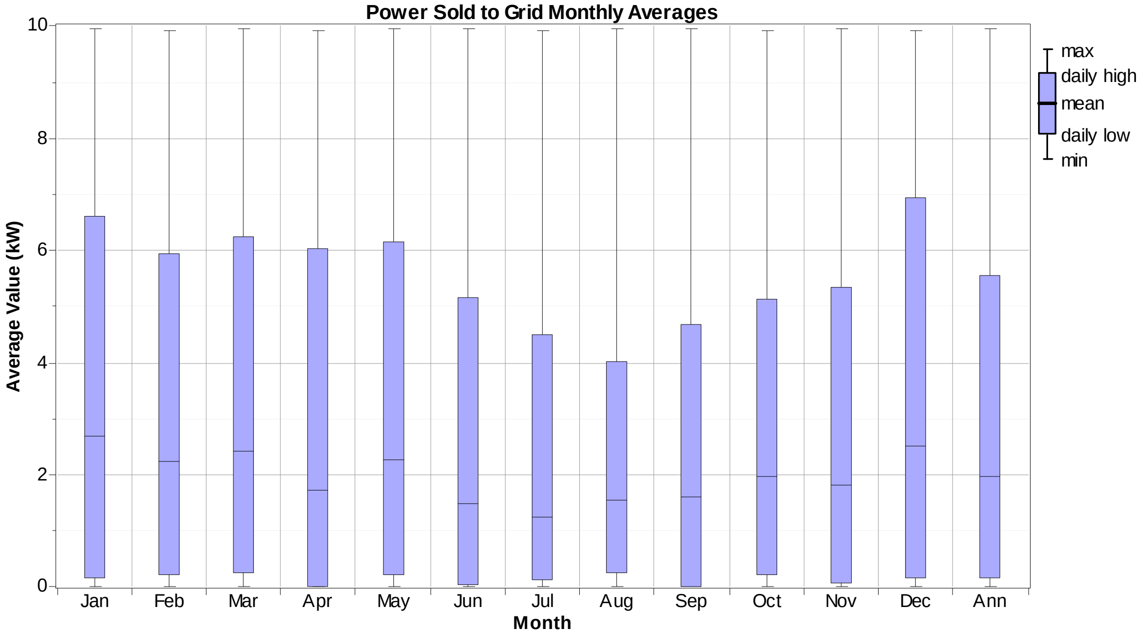
The table shows a monthly record of the energy that is demanded of the grid and how much is sold to the grid, showing an annual bottom line by giving a positive balance of energy sold 11.685 Kwh wing network. The electric company buys energy from wind to 0.03 £ / kWh. Therefore there is a gain of 350.55 pounds per year (besides a generation tariff).

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)	Energy Charge (£)	Demand Charge (£)
Jan	335	1,991	-1,656	5	0	0
Feb	358	1,496	-1,138	5	0	0
Mar	384	1,801	-1,417	5	0	0
Apr	480	1,247	-767	5	0	0
May	374	1,676	-1,302	5	0	0
Jun	555	1,056	-501	6	0	0
Jul	584	916	-332	5	0	0
Aug	532	1,133	-600	5	0	0
Sep	516	1,139	-623	5	0	0
Oct	449	1,452	-1,003	5	0	0
Nov	440	1,310	-871	5	0	0
Dec	395	1,870	-1,475	6	0	0
Annual	5,403	17,087	-11,685	6	-350.55	0

Table 4.11: Averages monthly data of flow energy. [12]



Figures 4.17: Power Purchased from Grid Monthly Averages.[12]



Figures 4.18: Power Sold to Grid Monthly Averages.[12]

4.2.3 ESTIMATION OF ANNUAL CO2 SAVINGS

The combustion of the derivative of the oil or solid fuels causes emissions of gases harmful to the environment, which include: carbon dioxide (CO2), sulfur oxides (SOx) and nitrogen (NOx).

Wind energy produces no pollution that affects the environment. Generating electricity without any combustion process or a thermal processing step is a highly favorable for being clean. For every kW • h generated by wind power instead of coal generation is avoided:

- 0.60 kg de CO2
- 1.33 gr de SO2
- 1.67 gr de NOx

Total generated energy by the wind turbine: 29,151Kwh/yr

In the next table is possible to know this savings:

Pollutant	Emissions (kg/yr)
Carbon dioxide	-17,500
Sulfur dioxide	-39
Nitrogen oxides	-48.7

Table 4.12: Dates of annual reductions [12]

4.7 ELECTRICAL CONNECTION

In order to use the electricity generated by the turbine, it needs to be connected to the mains electrical supply via an electrical panel. This panel performs a number of functions including:

1. It contains a rectifier which converts the three phase “wild” AC from the turbine into DC suitable for use by the inverters.
2. It holds the inverter(s) which convert from DC to grid synchronized AC.
3. It has safety fuses and isolator switches, for the input from the turbine, and output to the grid.
4. It holds various meters for measuring the energy generated by the system and the voltage and current coming from the turbine.

The electrical connection may be either to a single or three-phase supply, depending upon the type of electricity supply to workshop.

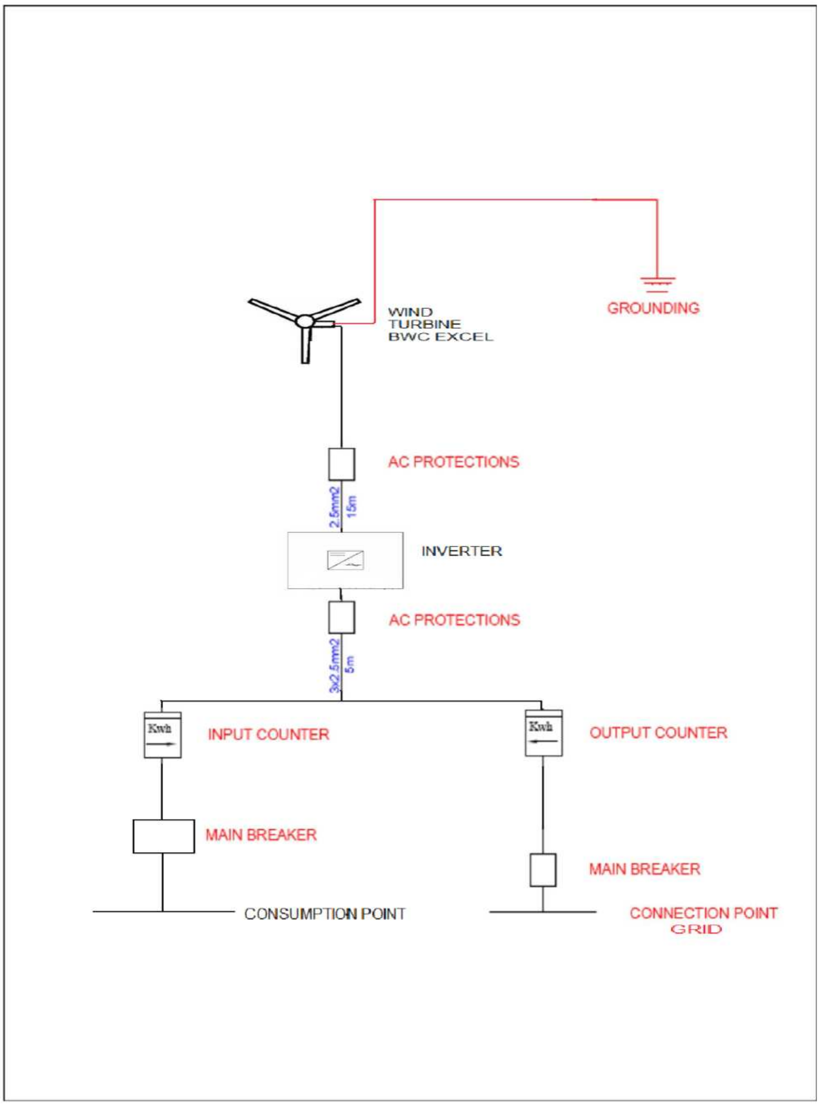


Figure 4.19: Line diagram of the Wind system.

5. ECONOMIC ANALYSIS

This chapter discusses the economic circumstances of the project to see if the project is feasible from the economic standpoint. First of all it is estimated the project budget and it is studied from the ROI and payback period of investment.

5.1. – BUDGET

The following tables show the estimated cost of the small wind turbine system:

ELEMENT	PRICE (£)
10 Kw Bergey Excel-S wind turbine with GridTek inverter	23,750.00
P 1250 Systems self-supporting tower w/ gin pole and all hardware, 15m	7,500.00
Electrical modifications at Recycling center to allow grid connection of the wind turbine	2,000.00
Installation labor (including supervising electrician and labor and Industry inspection)	2,200.00
Site improvements (concrete, concrete forms, and rebar for foundations, and wire run to service panel)	2,500.00
Excavation and back-fill for footings and conduit trench	800.00
Data collection system (data logger, sensors, hardware)	2,000.00
Total	40,750.00
Industrial Benefits (6%)	2,445.00
VAT (5%)	2,037.50
Total Project	45,232.50

Table 5.1: Estimated cost of Small wind Turbine system [18].

5.2 INCOME

This subsection determines the price of kWh generated by the low-power wind turbine in following table shows the estimated income for two year of operation of the wind turbine system. This estimation has been carried out using the tariff proposed for the Feed-in Tariff, (see appendix D) system for Wind systems which rated power is between 1.5kW and 15KW.

	WIND SYSTEM
	The BWC EXCEL, 10kW
Annual energy produced [KWh]	29,151.00
Price per energy produced [£/KWh]	0.267
TOTAL GENERATION TARIFF [£]	7,783.317
Annual energy savings [KWh]	14,600.00
Price per energy savings [£/KWh]	0.068674
TOTAL SAVINGS TARIFF [£]	1,002.64
Annual energy export tariff to Grid [KWh]	11,685.00
Price per energy export tariff [£/KWh]	0.03
TOTAL ENERGY EXPORT TARIFF [£]	350.55
TOTAL INCOME [£]	9,136.507

Table 5.2: Expected revenue for the first two years of operation of the wind system.

As is mentioned in appendix D, in the specific case of Wind systems, an annual digression of 4.5% that affects only to generation tariff exists. This fact has been considered during the payback period calculation.

5.3. PAYBACK PERIOD

The payback period of investment is the time until that pays the investment. This requires studying the movement of funds during the early years of operation of the facility. The movement of funds is the difference between expenditure and investment income generated. This parameter has been calculated using Microsoft Excel (see appendix C).

In order to be capable of running the simulation, some factors have been assumed:

- Debt ratio = 50% (what means that half of the initial investment is paid for Glyndŵr University Wrexham in the moment that the Wind system begins its operation).
- Debt interest rate = 5%
- Debt term = 2 years
- Incentives and grants = £2,500
- Operation & Maintenance costs = £384 annual
- Inflation rate = 2%
- Project life = 25 years

Apart from these factors, the annual digression (4.53%) of the generation tariff has been considered. In order to obtain an average value for the whole project life, the next mathematical expression has been used in Excel:

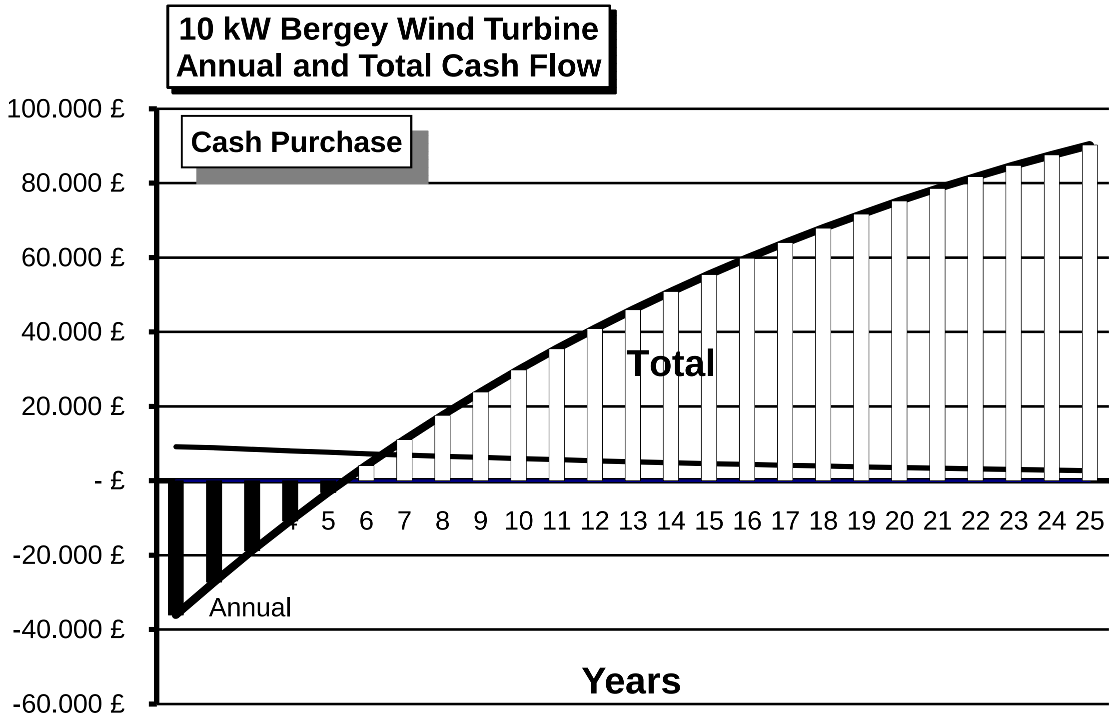
$$\text{Net Energy} = EO * \left[Ec * \left(1 + \left(\frac{-4.53}{100}\right)\right)^{\sum_{N=2}^{PL}(N-2)}\right]$$

Annual Cash Flow= Net Energy (£) – O&M Costs (£)

Total Cash Flow = Annual Cash Flow (£) – Total Installed Cost (£)

- Net energy: Total of income energy (£)
- EO: Annual Energy Output (kWh)
- Ec: Total Electricity Cost ($/kWh)
- PL: Project life = 25 years

The complete simulation can be seen in Appendix B of this document.



Figures 5.1: Total cash flows graph according to Microsoft Excel.

In short, knowing the cost of initial investment and operating costs maintenance and income generated, one can calculate the return period of investment. Figure 5.1 details the movement of funds annually, which shows that the return period (PAYBACK) is 5.5 years.

CHAPTER 6: DISCUSSION

The purpose of this chapter is to discuss the adequacy of some assumptions made during the realization of this dissertation as well as Small wind energy installations require planning permission and local consultation with relevant stakeholders, such as neighbours. Deciding factors include environmental considerations, access to the site, noise and visual effect. Once that want be carry out the project is very important take account this section.

6.1 CHOICE OF THE SYSTEM

As discussed in section 4.1.2 one of the major problems of renewable energy and specifically the wind is very irregular since the production of energy fundamentally depends that wind blows, so one of the important reasons that be chose grid-connected is the inability of the wind turbine to power supply at all hours of day and steadily.

In next figure according to HOMER software in which are superimpose two variables, on the right side is the production of wind with respect to wind speed and left side is the Grid purchases according to wind speed.

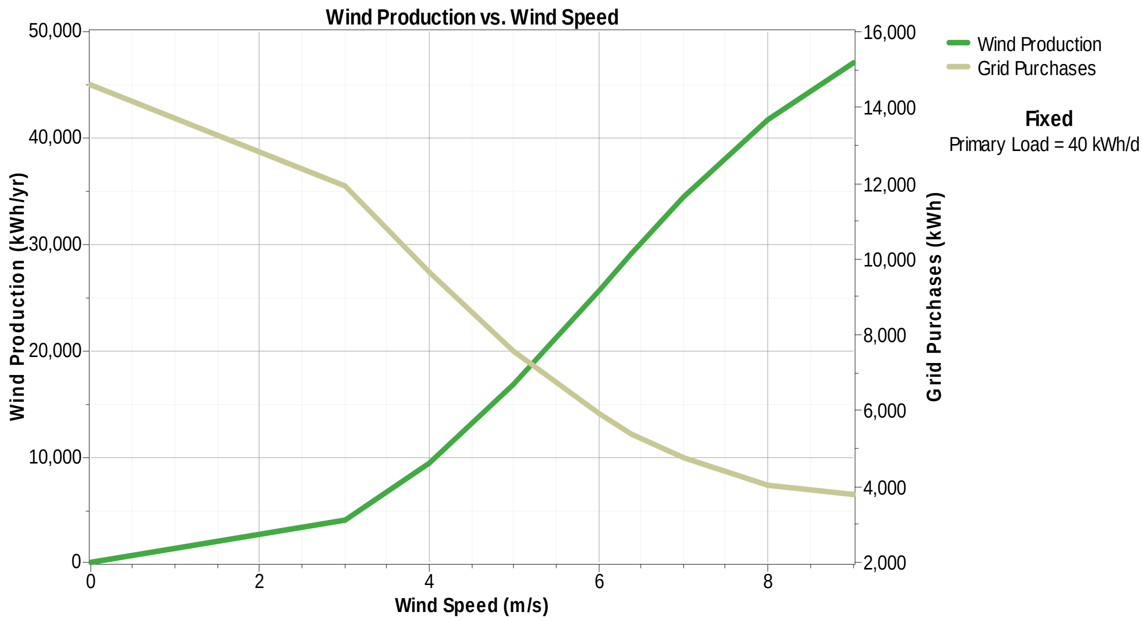


Figure 6.1 Wind Production Vs. Wind Speed and Grid Purchases Vs. Wind Speed [12].

As can be seen is this graph is shown that is necessary to make the grid connected system to continue to supply the workshop of electricity, period where no wind blows it is observed that the Grid is supplying 14.600 KWh / year that is all consumption demanded by the load. Once the wind speed increases is observed the decrease the purchases of energy to the Grid since increased of energy production of the wind turbine.

Finally the wind is an inexhaustible source of energy but above all it is not constant therefore is necessary an external power source to continue with the operation of the place of consumption.

6.2 PAYBACK PERIOD

The payback Period Calculated in Chapter 5 shows that the payback of investment is short so the installation of a small wind turbine at the University of Glyndwr would come out profitable.

However, factors that can change in the payback period are the hours of operation of small wind turbine and wind speed. The project was design for an operating time around 94% (8234h) (see table 4.8) and a constant wind of 6.4 m/s.

In the worst case if it is varied the operating time of the small wind turbine, and is reduced to 40% (3,500h) since some days unable to work due to lack of wind or maintenance of turbine, is obtained annual production energy of 11,620kWh/year and it is a very low result.
In the next figure, it is calculated the return period more unfavorable, with an operation time of 3,500h annual.

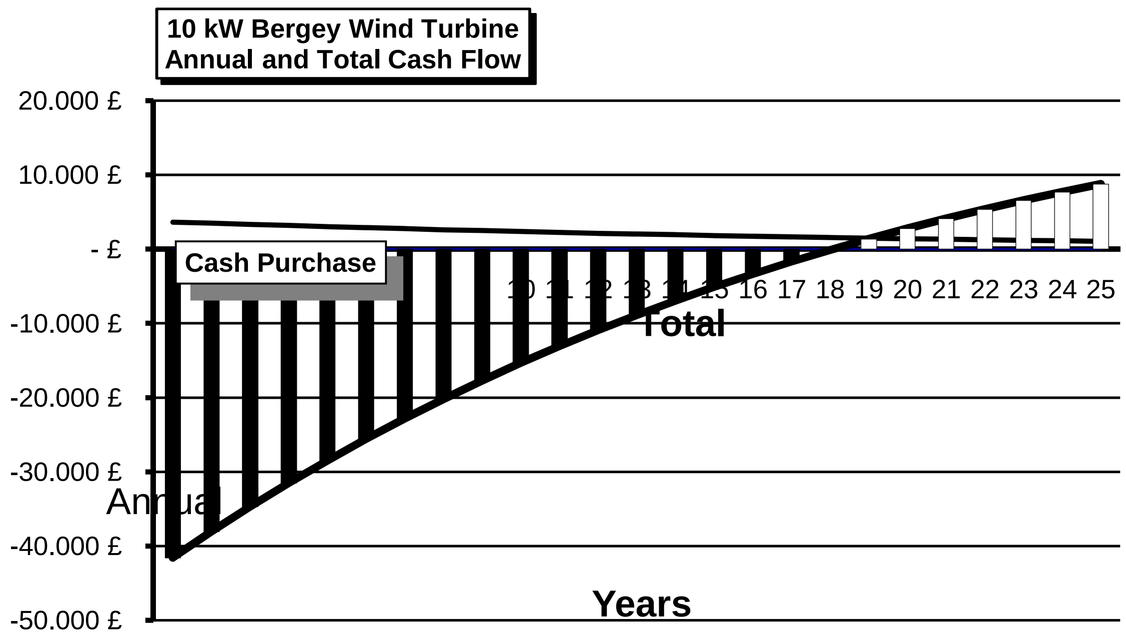


Figure 6.2 Payback period, if it is changed the period of operation of the turbine.

Is observed that the payback period has been increased to 18 years, however the lifetime of the mini generator is 25 years, therefore the installation would be profitable and it would generate benefits after 18 year.

6.3 PLANNING CONSIDERATION.

Maintenance

Inside the maintenance tasks will distinguish between preventive maintenance or planned and the corrective or unplanned as responses to problems identified by the user.

This chapter discusses preventive maintenance. Among the maintenance tasks should be carried out annual inspections of:

-Inspection and adjustment nuts
- Inspection of blades
- Inspection of the axes
- Inspection of Alternator
- Grease the bearings supporting the gondola
- Inspection of electrical connections

After 10 years, blades and bearings may need to be completely replaced. With proper installation and maintenance, your turbine can last 20-30 years or longer. Proper maintenance will also minimize the amount of mechanical noise produced by your wind turbine.

Environmental Analysis

The environmental analysis aims to identify, describe and assess the likely impacts that the project itself can cause over natural resources and environment. This will assess the possible impacts in all phases of the project.

Planning and Design phase

From the design stage of the turbine is taken into account certain aspects that can cause significant impact during the operational phase or operation. One of the negative effects produced by wind turbines is the noise they make when in operation, therefore, must be sought blade designs and mechanical transmission elements that do not produce much noise.

Within this phase, it has to find a site that does not generate optimum visual impact or impact resulting from the shadows produced by the turbine and to respect the existing birds in the area. Obviously, obtaining a zero impact is impossible, so look for sites where it is minimal.

Construction phase

During the construction phase there is a considerable impact on the flora of the area where will be installed due to earthworks, foundations, driveways, roads, etc... In the case of a low-power turbine the consequences of its installation will be minimal it is as well desirable after installation leave the ground as close as possible to the natural environment.

Operation phase

The operation phase is one of the most important in terms environmental impact concerns as they have to consider various aspects such as the birds, the visual impact, impact from noise and impact of the shadow produces the wind turbine.

Avifauna

In reference to the effects on birds, there are individual cases of bird collisions with wind turbines. You should still take into account the routes of migration and unique areas with high numbers of susceptible species or endangered. Anyway being a small wind turbine, the impacts on birds is minimal.

The mortality in birds over this event is less than 0.003%, in comparison to those caused by human factors [15].

Regarding the visual impact, include the difficulty of assessing the same, because if it is true that wind turbines attract attention, the fact remains that the reaction shown by the observers is subjective and difficult to quantify.

The visual impact of a mini-turbines power 20kW or less is comparable with other infrastructure such as a lightning rod, mobile phone antennas, radio antennas, etc...

Impact from noise

The impact derived from the noise made by wind turbines during operation can be divided into two types depending on the nature of their source: mechanical noise from generator, gearbox and transmission components and noise aerodynamic produced by the motion of the blades.

The first can be reduced by improving the designs. In contrast, the second depends on the number of blades, the shapes of them and the local turbulence. By increasing wind speed increases the rotational speed and therefore noise is intensifies, so it is recommended designs in which the rotor speed is not excessive.
Despite these recommendations with a view to lessen this effect, it is important to ensure that the turbine does not exceed the permissible limits of noise.

Impact derived from the shadows

Wind turbines, like other tall structures, cast a shadow in the neighboring areas when the sun is visible. If there are people who live near the turbine can be bothered if the rotor blades cut the sunlight, causing a flickering effect when the rotor is in motion. If you know the area where the potential flicker effect is going to have a certain size, it is capable of putting the turbines so as to avoid any nuisance to neighbors.

This kind of visual impact, all that can produce discomfort or even very rarely seizures is unlikely to be of small size turbines, since they have narrower blades and rotate at a much faster rate than large-scale wind turbines.

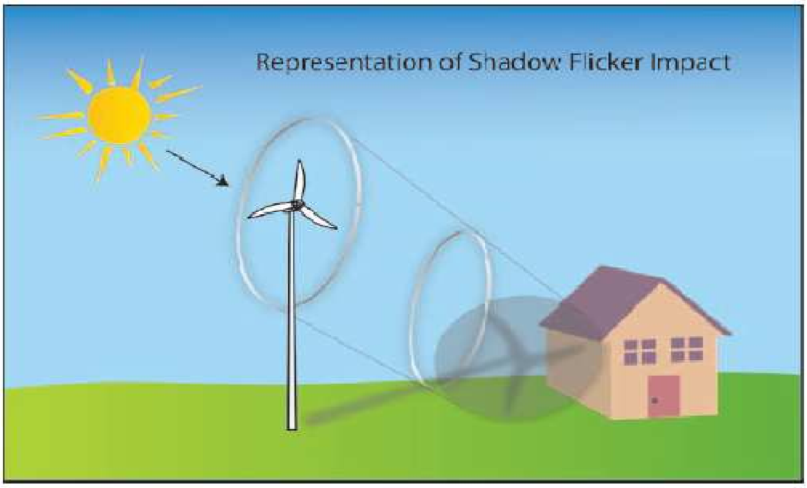


Figure 6.4: Representation of Shadow Flicker Impact. [25]

CHAPTER 7: CONCLUSIONS

Several conclusions can be drawn from the implementation of this project, mainly related to the design of the turbine, energy and money to it and also can draw conclusions about the operation of the turbine as wind speed and hours of operation.

In the chapter of the turbine design has been obtained daily energy demand of the workshop and the characteristic curve of wind turbine and monthly averages of wind on the Glyndŵr University. According to the simulation with the HOMER software shows a sense of the electrical behavior of the system. This chapter also served to establish that points should be studied more accurately, that due to the impossibility of working with a real wind turbine has not been able to make and are considered important points, such as the relationship between power coefficient and the accurate characterization of electrical circuit.

With the assumption of placing the turbine in a location with a very moderate wind, you get a very high power generation but we must take into account the hours of operation of the turbine, since this result can be reduced, and also the performance of the facility is low. Application performance depends on the performance of the blades and alternator performance. Basically the performance of wind turbines is low for the process of transforming wind into mechanical energy (performance of the blades). Thus the choice of Grid-Connected system has been very successful for those days where the wind is not blowing.

The period of return on investment is 5.5 years, so in the 25 years of life of the turbine will generate benefits (savings of monthly electricity bill, plus the grants obtained by the UK government and the sale of surplus energy to the electric company).

Finally, as an important point to this installation is the environmental impact because with the wind system significantly reduces the expulsion of CO_2 into the atmosphere, so today the governments of the U.E are awarded grants to those owners who choose to install renewable energy system. It is a good point to Glyndŵr University is decided to install a small wind turbine.

Recommendations for further work:

- Redesign the study of the wind, taking more values, such as every hour in the exact place where the turbine will be installed to prevent approximations and will be closer to reality.
- Study more the losses generated by the installation as mechanical and electrical.
- Make a more detailed study of the electrical installation with electrical diagrams: wiring, protection devices and power meters.
- Look in more detail the conditions for government aid and also requirements that must be fulfill with the electricity company to which wants to sell excess energy.

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APPENDICES

APPENDICES:

APPENDIX A: PLANS.

APPENDIX B: SIMULATION.

I. WIND SPEED.
II. SMALL WIND TURBINE.
III. LOAD.
IV. GRID PURCHASES.
V. GRID SALES.
VI. CO2 SAVINGS.

APPENDIX C: GRAPHIC AND DATA TABLE IN MICROSOFT EXCEL.

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II. WEIBULL CALCULATION.
III. PAYBACK PERIOD.

APPENDIX D: GRANTS FOR RENEWABLE ENERGY INSTALLATION.

APPENDIX E: WEATHER INFORMATION.

APPENDIX F: CATALOGUES.

APPEDIX A:

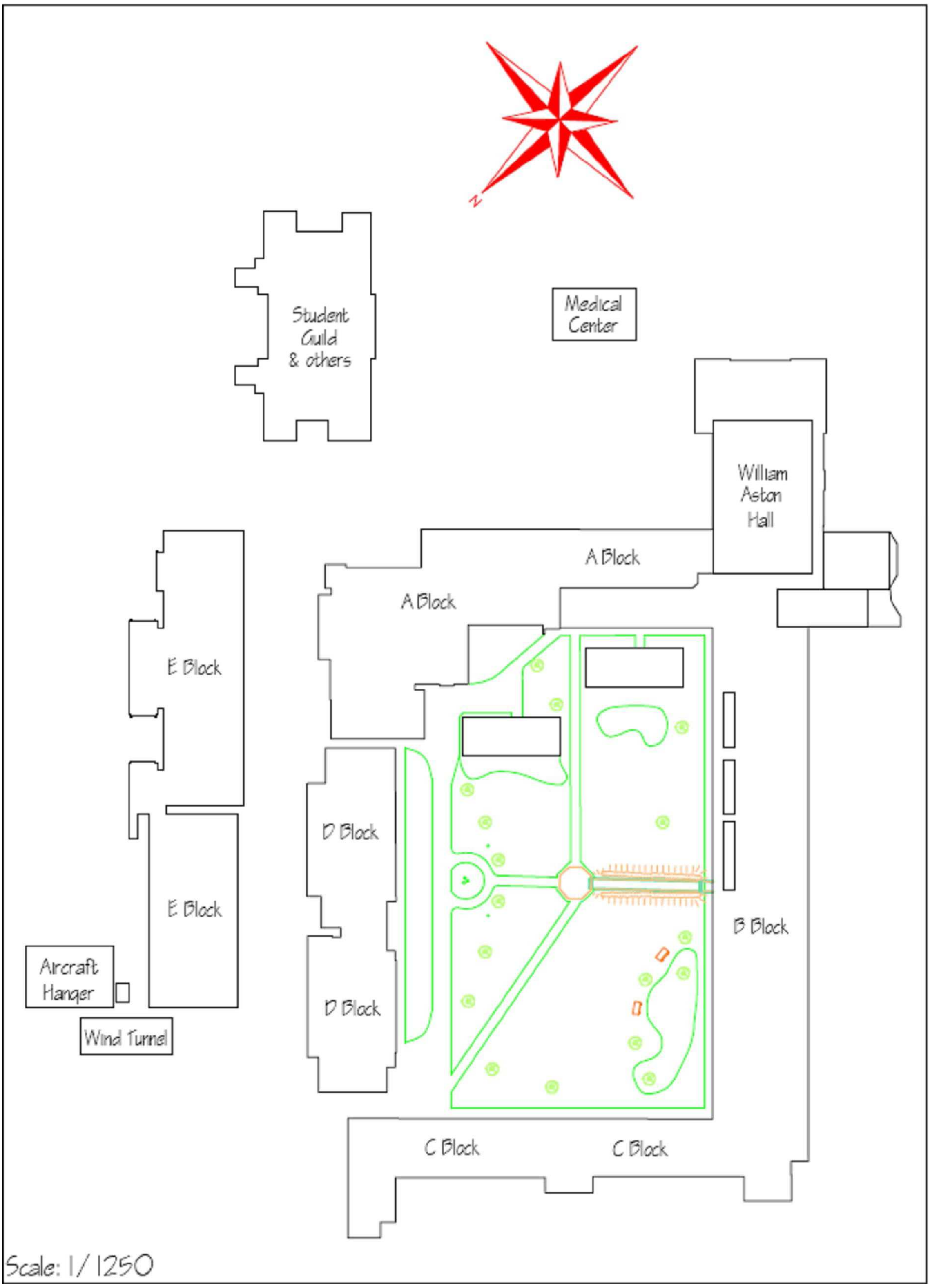


Figure A.1 – Main buildings of Glyndŵr University.

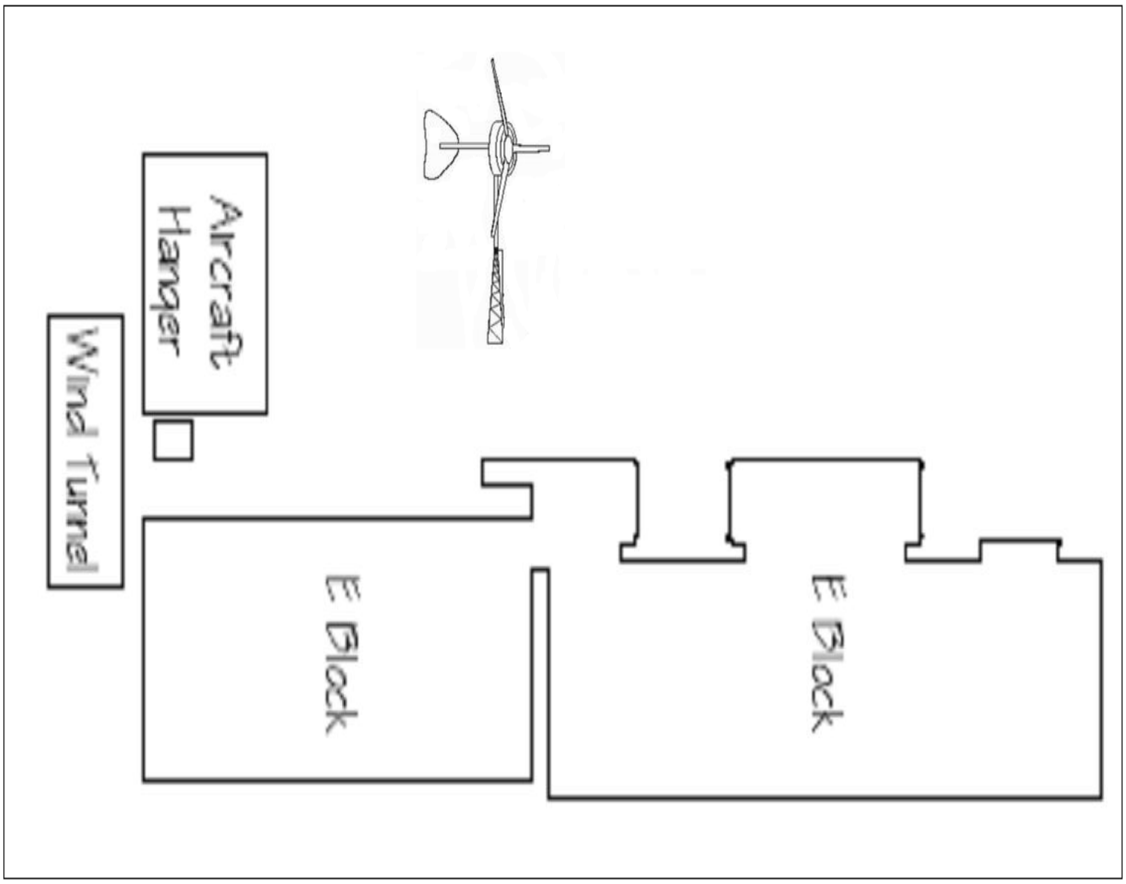


Figure A.2: Workshop of Glyndwr University.

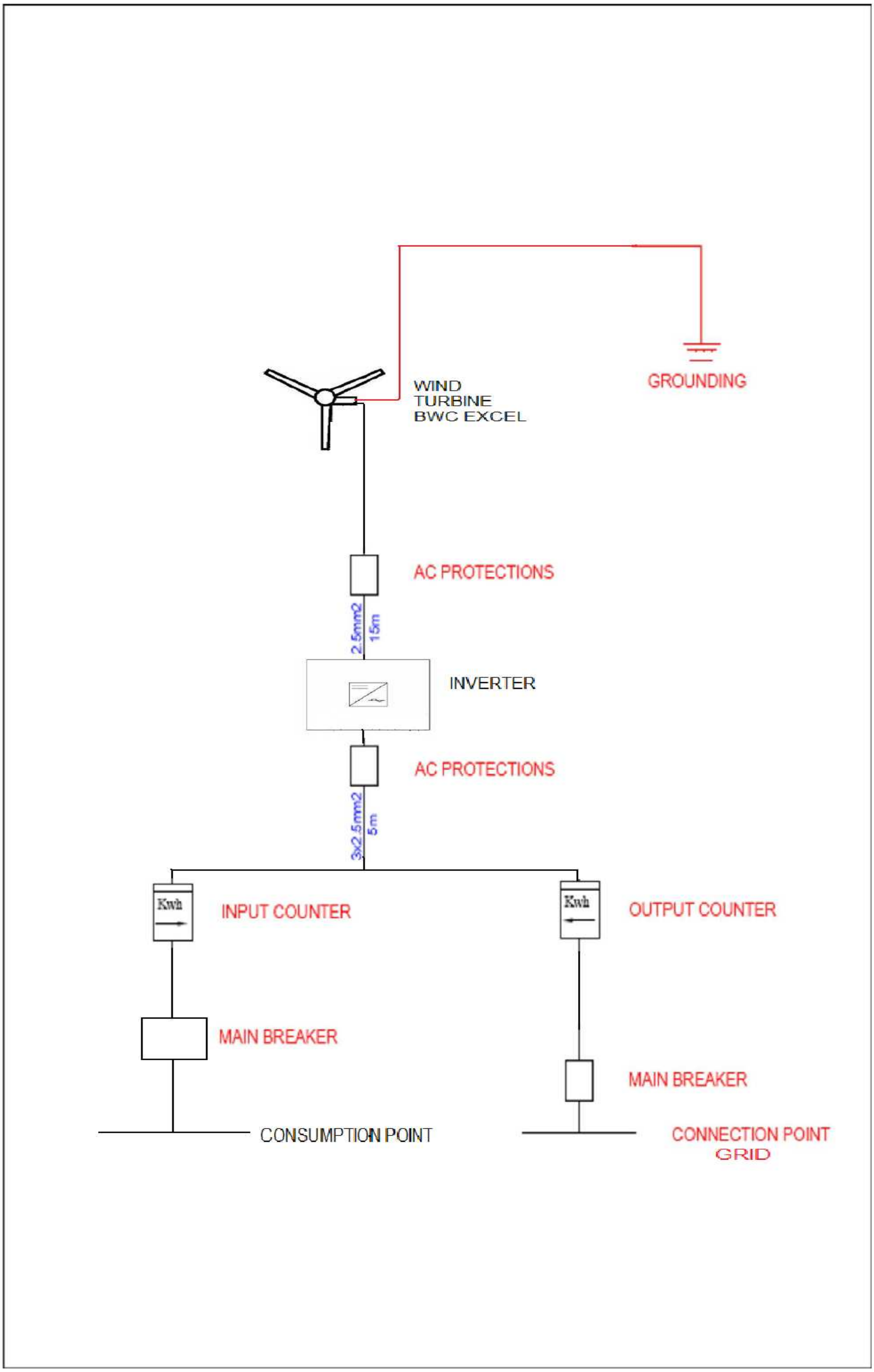


Figure A.3: Schema electric.

APPENDIX B: SIMULATIONS

I. Wind Speed

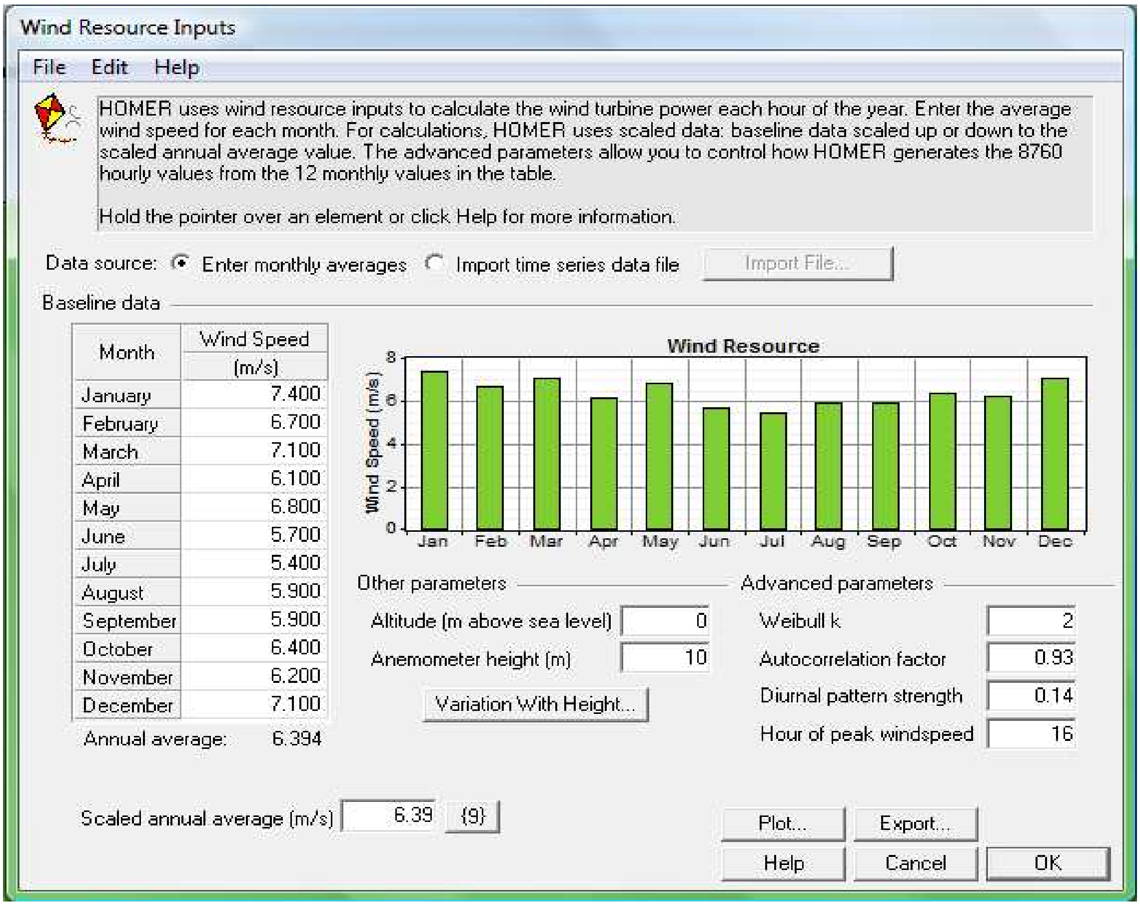


Figure B.1: Wind Resource Inputs.

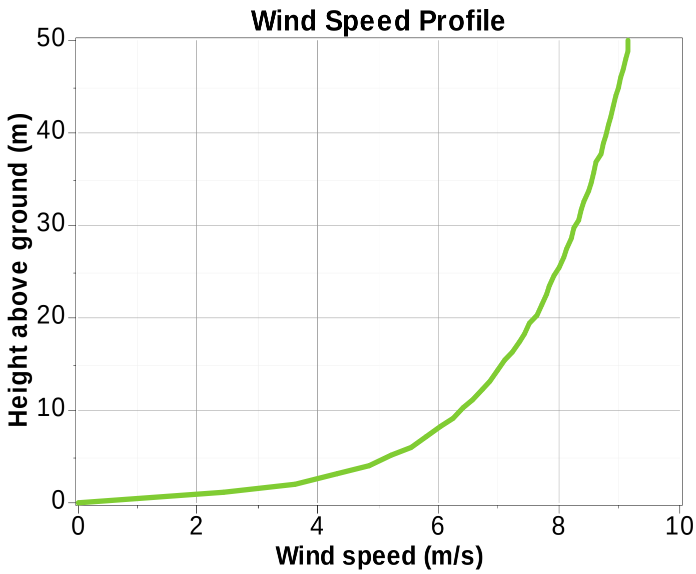


Figure B.2: Variation of Wind speed with Height.

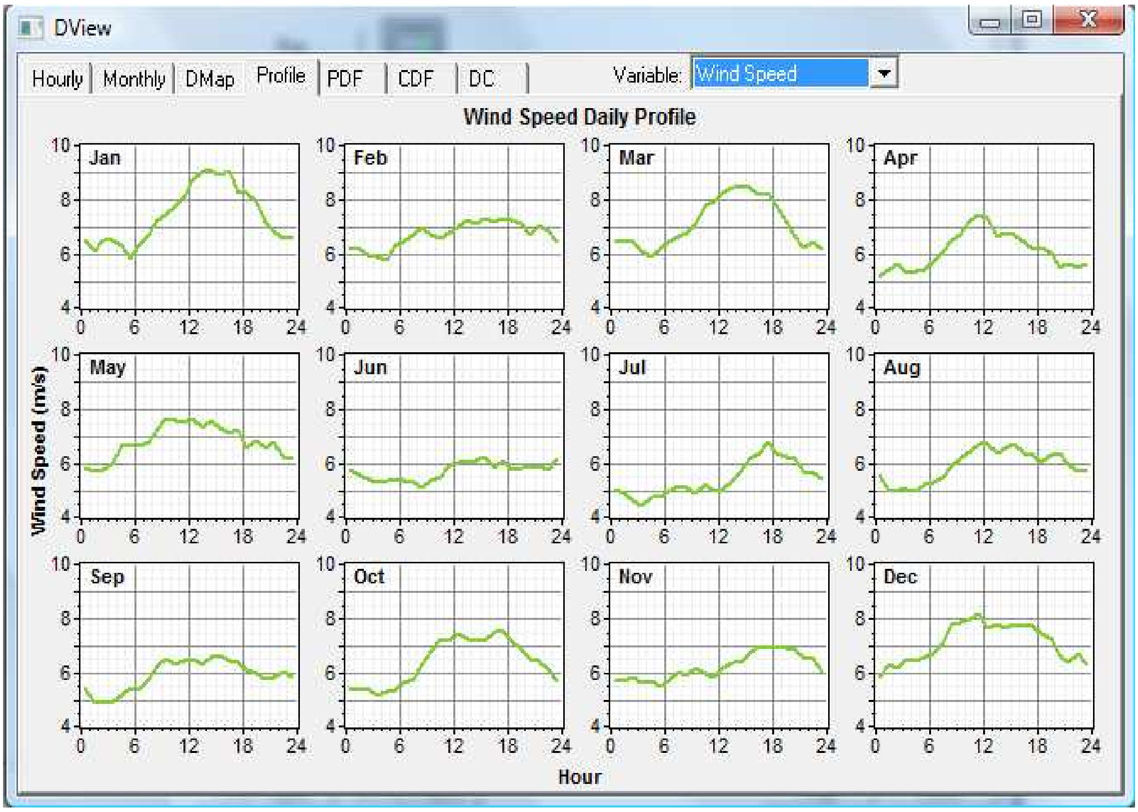


Figure B.3: Variation of wind speed daily profile.

II. SMALL WIND TURBINE (BWC EXCEL)

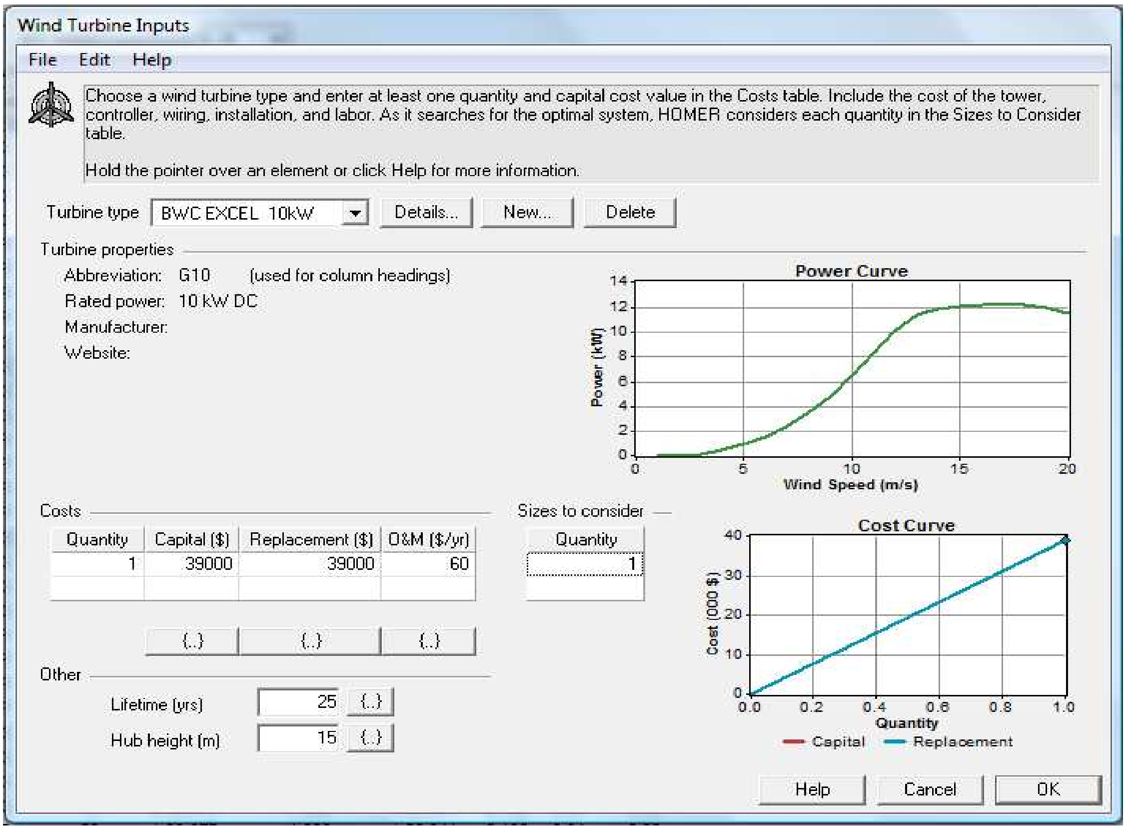


Figure B.4: Wind Turbine Inputs.

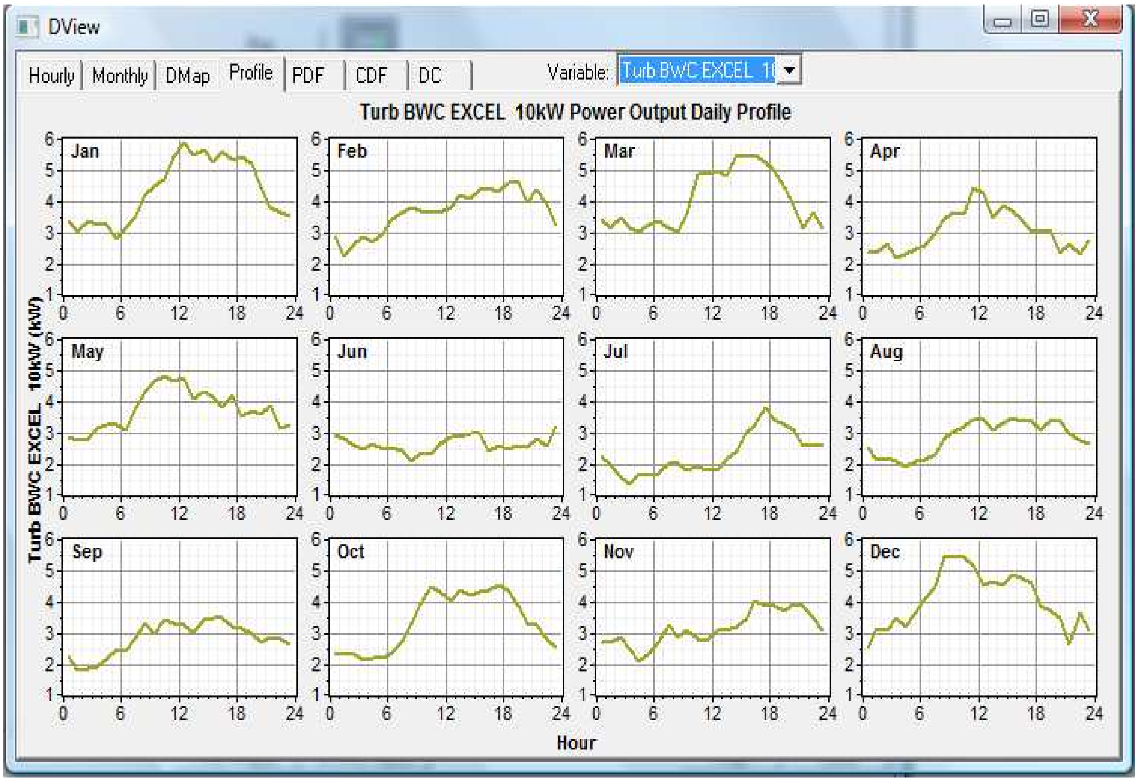


Figure B.5: Turbine BWC EXCEL 10KW Power output daily profile.

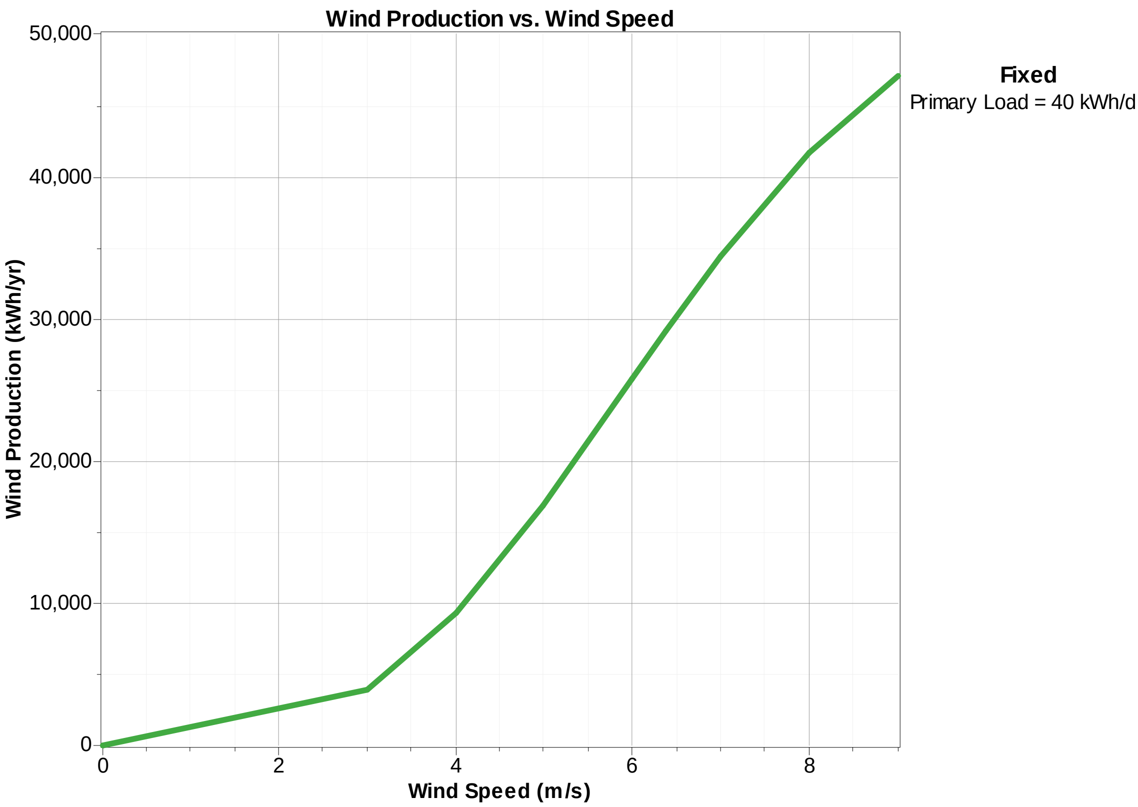


Figure B.6: Wind turbine production according to wind speed.

III. LOAD

:

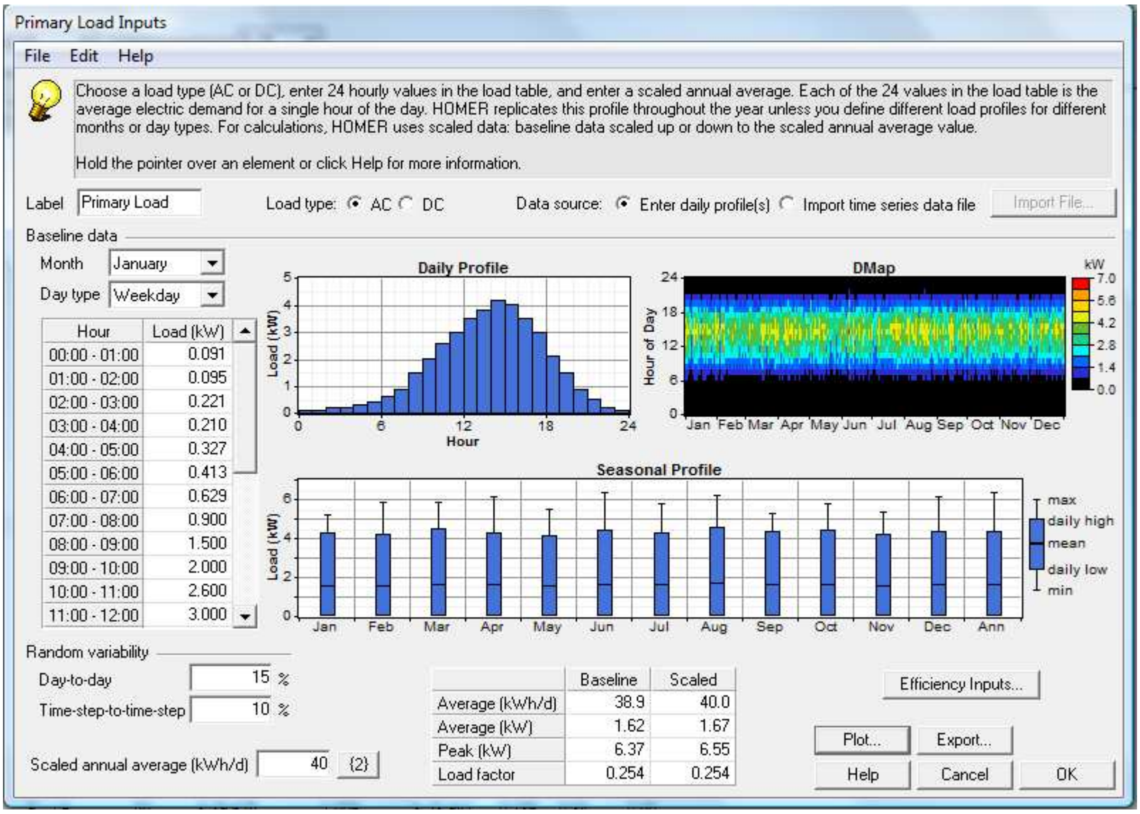


Figure B.7: Primary Load Inputs.

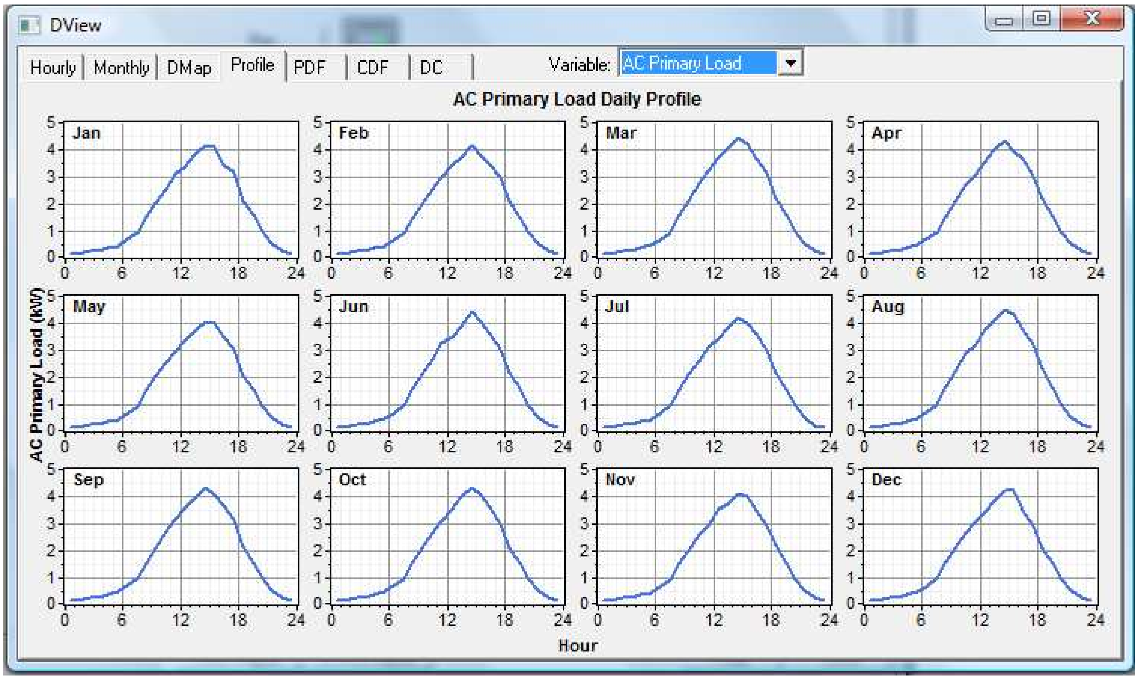


Figure B.8: Consumption of Workshop according with daily profile.

IV. GRID PURCHASES.

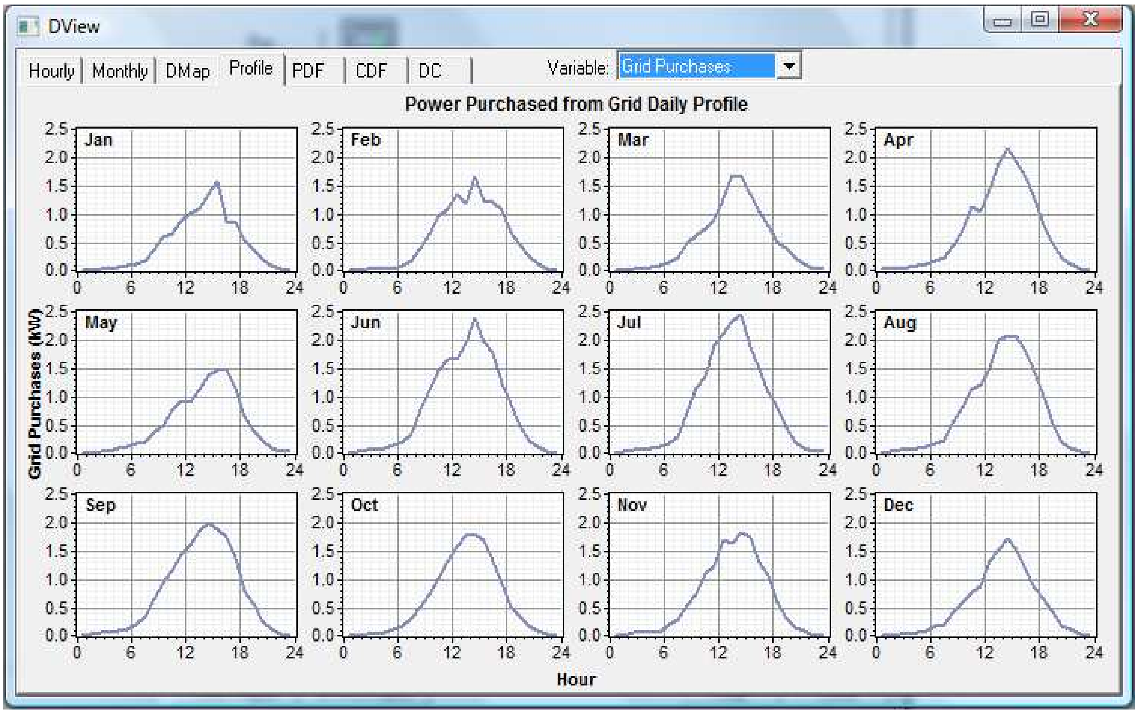


Figure B.9: Power Purchases from Grid daily profile.

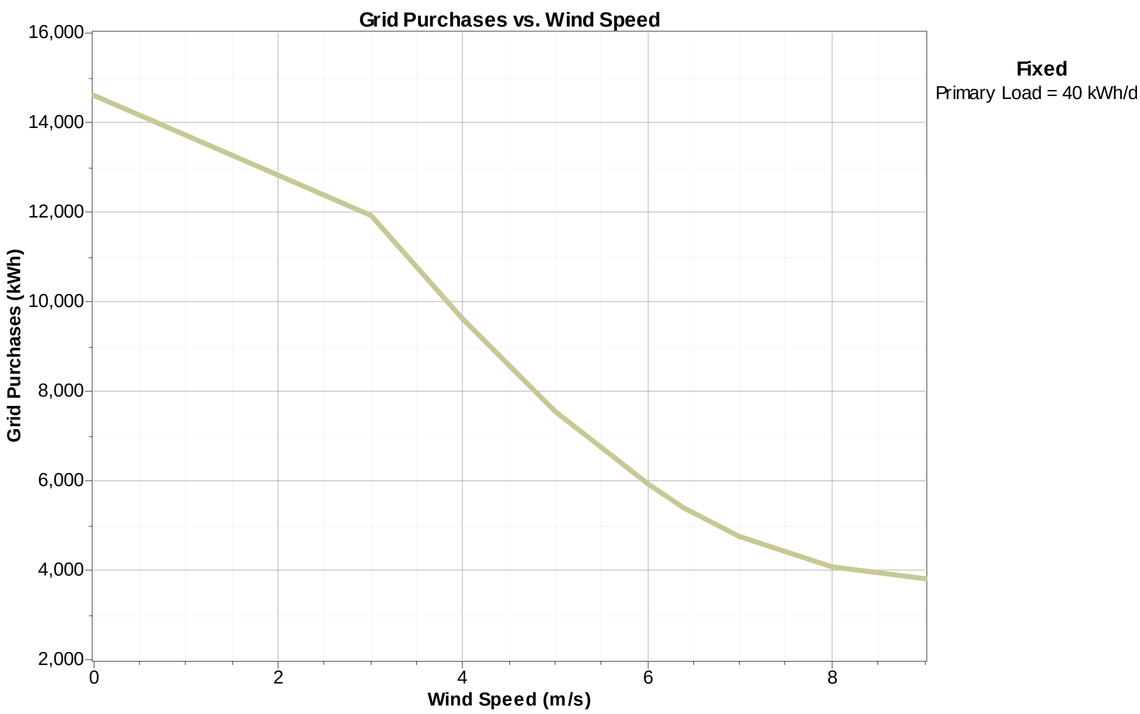


Figure B.10: Grid Purchases Vs. Wind Speed.

V. GRID SALES

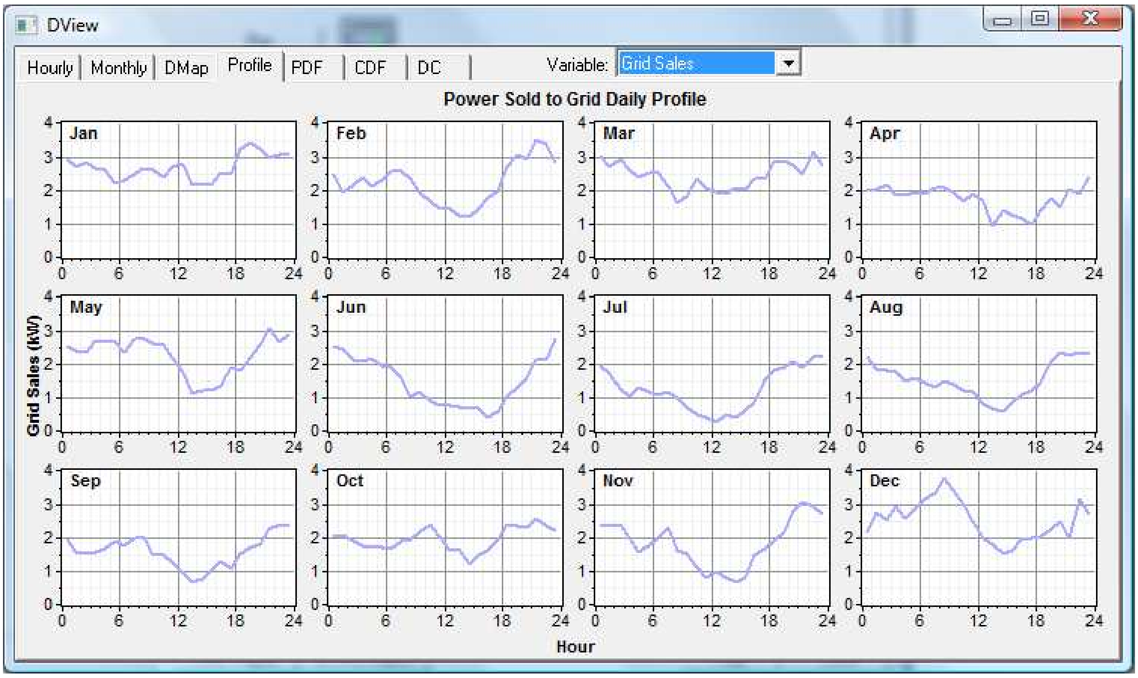


Figure B.12: Power sold to Grid daily profile.

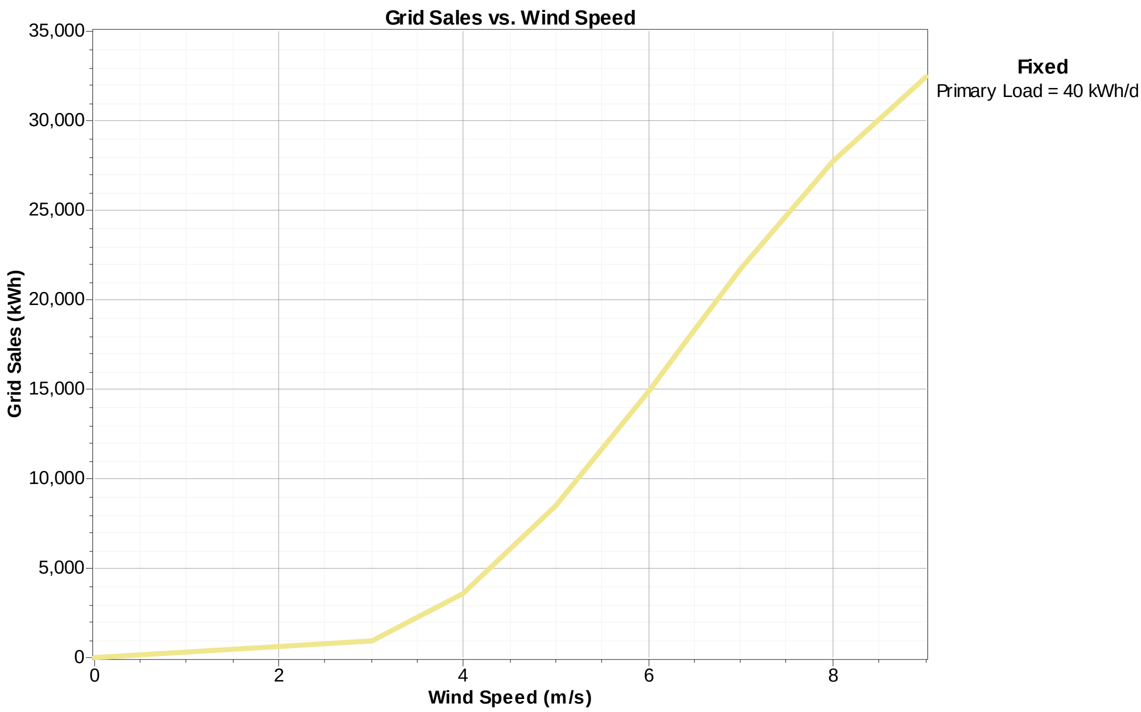


Figure B.13: Grid Sales vs. Wind speed.

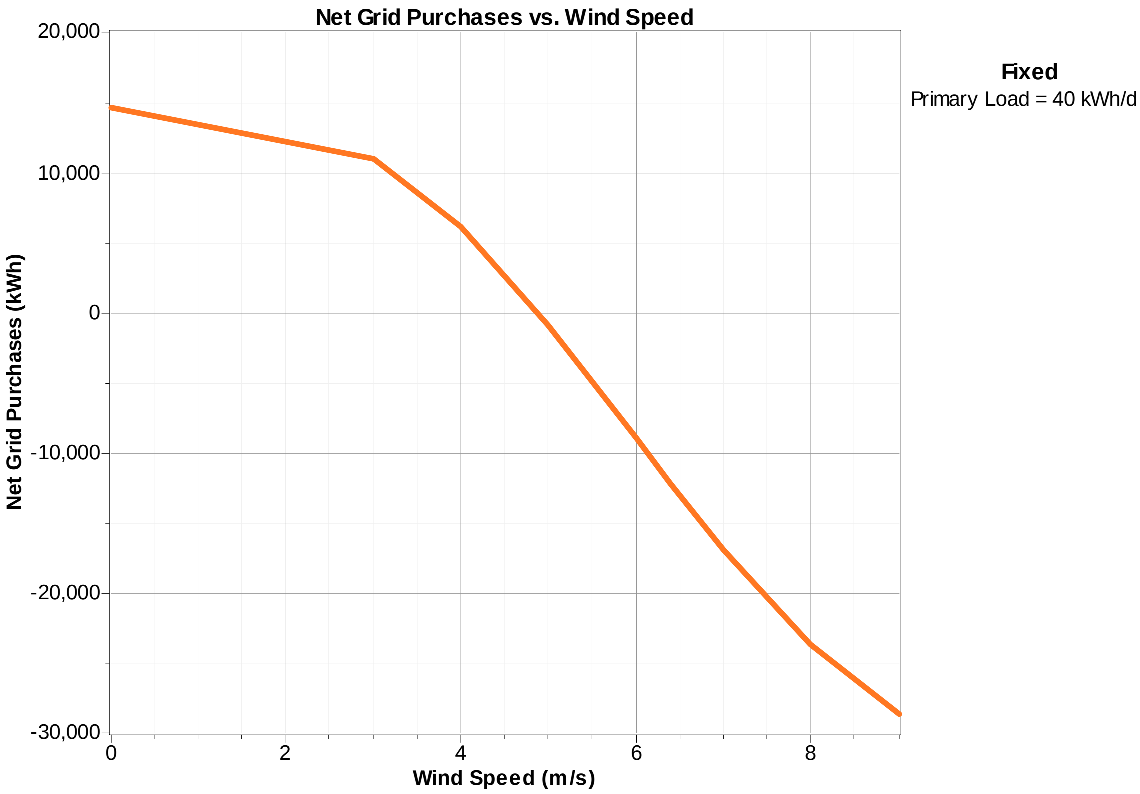


Figure B.14: Net Purchases (Purchases – sales) Vs. Wind Speed.

VI. CO2 SAVINGS

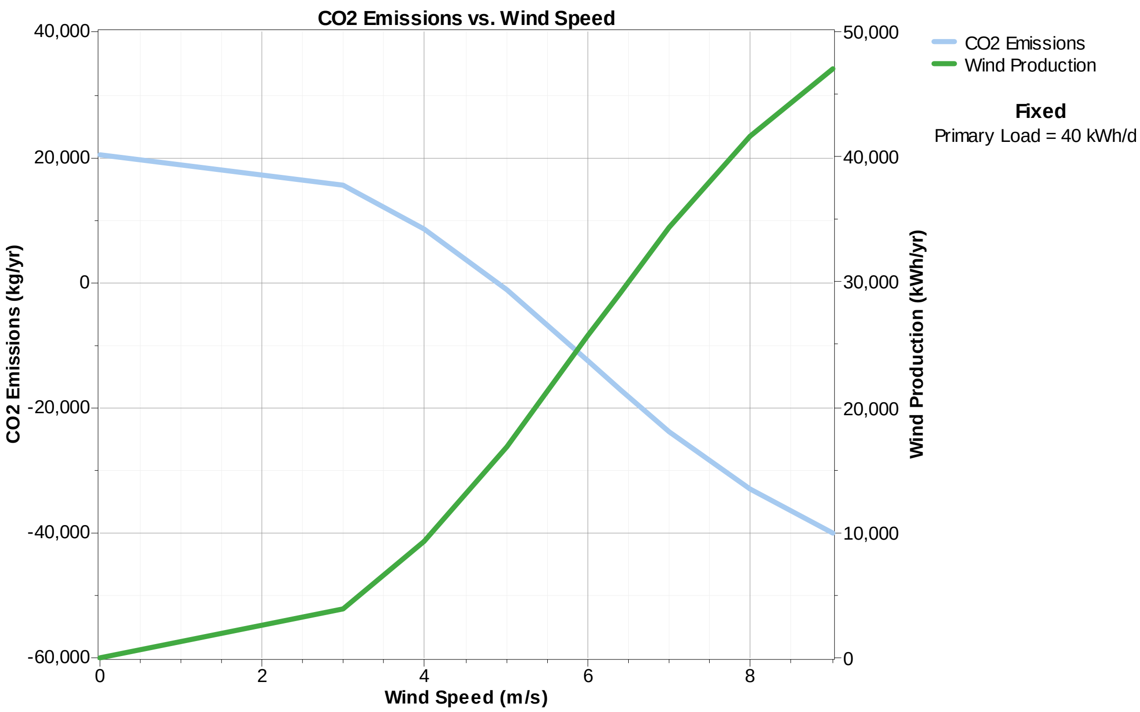


Figure B.15: Compare CO2 Emissions vs. Wind Speed with Wind Turbine Production.

APPENDIX C: GRAPHIC AND DATA TABLE IN MICROSOFT EXCEL.

I. TURBINE

Wind Speed Bin (m/s)	Power (kW) at sea level
1	0,00
2	0,00
3	0,14
4	0,43
5	0,88
6	1,51
7	2,35
8	3,43
9	4,80
10	6,42
11	8,21
12	10,02
13	11,37
14	11,76
15	12,06
16	12,14
17	12,15
18	12,10
19	11,92
20	11,44

Table C.1: Power Curve Data.

II. Weibull Performance Calculations:

Introduction:

The Weibull probability density function expresses the probability *p*(*x*) to have a wind speed *x* during the year, as follows (Hiester and Pennell, 1981):

$$p(x) = \left(\frac{k}{C}\right)\left(\frac{x}{C}\right)^{k-1} \exp\left[-\left(\frac{x}{C}\right)^{k}\right] \quad (1)$$

This expression is valid for $k > 1$, $X >= 0$, and $C > 0$. *k* is the shape factor, specified. The shape factor will typically range from 1 to 3. For a given average wind speed, a lower shape factor indicates a relatively wide distribution of wind speeds around the average while a higher shape factor indicates a relatively narrow distribution of wind speeds around the average. A lower shape factor will normally lead to a higher energy production for a given average wind speed. *C* is the scale factor.

Inputs in Excel: Weibull K=2, C=0.89, Hub Average Wind Speed (m/s) =6.94

Input formula in Excel for calculate wind Probability: = (K/6.94/0.89))*((Wind Speed/(6.94/0,89))^(K-1))*(EXP(-((Wind speed/(6.94/0.89))^2))).

Wind Speed Bin (m/s)	Power (kW)	Wind Probability (f)	Net kW @ V
1	0,00	3,23%	0,000
2	0,00	6,16%	0,000
3	0,14	8,51%	0,012
4	0,43	10,11%	0,043
5	0,88	10,90%	0,096
6	1,51	10,92%	0,165
7	2,35	10,28%	0,242
8	3,43	9,18%	0,315
9	4,80	7,81%	0,375
10	6,42	6,35%	0,408
11	8,21	4,95%	0,406
12	10,02	3,70%	0,370
13	11,37	2,66%	0,302
14	11,76	1,83%	0,216
15	12,06	1,22%	0,147
16	12,14	0,78%	0,095
17	12,15	0,48%	0,059
18	12,10	0,29%	0,035
19	11,92	0,17%	0,020
20	11,44	0,09%	0,010
Turbine BWC	Totals:	99,63%	3,316

Table C.2: Weibull Performance Calculation.

III. PAYBACK PERIOD

Assumptions (Inputs)	
Total Installed Cost ($):	**£ 45.232,500**
Annual Energy Output (kWh):	**29.151**
Electricity Cost ($/kWh):	**£ 0,313**
Electricity Inflation Rate (%):	**-4,53**
Loan Downpayment (%):	**100**
Down Payment (£):	**£ 45.233**
Interest Rate (%):	**5**
Loan Term (Years):	**2**
Net Federal Tax Rate (%):	**35**
Net State Tax Rate (%):	**8**
O & M Cost ($/kWh):	**£ 0,010**
O & M Inflation Rate (%):	**2**

Table C.3: Inputs for calculate Payback period.

Annual Cash Flow Model				
Year	Net Energy	O&M Costs	Annual Cash Flow	Total Cash Flow
0			-£ 45.233	-£ 45.233
1	£ 9.136	$0	£ 9.136	-£ 36.097
2	£ 9.136	-£ 297	£ 8.839	-£ 27.258
3	£ 8.722	-£ 303	£ 8.419	-£ 18.839
4	£ 8.327	-£ 309	£ 8.018	-£ 10.822
5	£ 7.950	-£ 316	£ 7.634	-£ 3.187
6	£ 7.590	-£ 322	£ 7.268	£ 4.080
7	£ 7.246	-£ 328	£ 6.918	£ 10.998
8	£ 6.918	-£ 335	£ 6.583	£ 17.581
9	£ 6.604	-£ 342	£ 6.263	£ 23.843
10	£ 6.305	-£ 348	£ 5.957	£ 29.800
11	£ 6.019	-£ 355	£ 5.664	£ 35.464
12	£ 5.747	-£ 362	£ 5.384	£ 40.848
13	£ 5.486	-£ 370	£ 5.117	£ 45.965
14	£ 5.238	-£ 377	£ 4.861	£ 50.826
15	£ 5.001	-£ 385	£ 4.616	£ 55.442
16	£ 4.774	-£ 392	£ 4.382	£ 59.823
17	£ 4.558	-£ 400	£ 4.158	£ 63.981
18	£ 4.351	-£ 408	£ 3.943	£ 67.924
19	£ 4.154	-£ 416	£ 3.738	£ 71.662
20	£ 3.966	-£ 425	£ 3.541	£ 75.204
21	£ 3.786	-£ 433	£ 3.353	£ 78.557
22	£ 3.615	-£ 442	£ 3.173	£ 81.730
23	£ 3.451	-£ 451	£ 3.000	£ 84.730
24	£ 3.295	-£ 460	£ 2.835	£ 87.565
25	£ 3.146	-£ 469	£ 2.677	£ 90.242

Table C.4: Result of Annual Cash flow.

APPENDIX D: GRANTS FOR RENEWABLE ENERGY INSTALLATION.

Table of generation tariffs to 2020

Technology	Scale Scheme Year	Tariff level for new installations in period (p/kWh) [NB tariffs will be inflated annually] 1 1/4/10 – 31/3/11	2 to 31/3/12	3 to 31/3/13	4 to 31/3/14	5 to 31/3/15	6 to 31/3/16	7 to 31/3/17	8 to 31/3/18	9 to 31/3/19	10 to 31/3/20	11 to 31/3/21	Tariff lifetime (years)
Anaerobic digestion	≤500kW	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	20
Anaerobic digestion	>500kW	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	20
Hydro	≤15 kW	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	20
Hydro	>15-100 kW	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	20
Hydro	>100 kW-2 MW	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	20
Hydro	>2 MW – 5 MW	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	20
MicroCHP pilot*	≤2 kW*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10
PV	≤4 kW (new build**)	36.1	36.1	33.0	30.2	27.6	25.1	22.9	20.8	19.0	17.2	15.7	25
PV	≤4 kW (retrofit**)	41.3	41.3	37.8	34.6	31.6	28.8	26.2	23.8	21.7	19.7	18.0	25
PV	>4-10 kW	36.1	36.1	33.0	30.2	27.6	25.1	22.9	20.8	19.0	17.2	15.7	25
PV	>10-100 kW	31.4	31.4	28.7	26.3	24.0	21.9	19.9	18.1	16.5	15.0	13.6	25
PV	>100kW-5MW	29.3	29.3	26.8	24.5	22.4	20.4	18.6	16.9	15.4	14.0	12.7	25
PV	Stand alone system**	29.3	29.3	26.8	24.5	22.4	20.4	18.6	16.9	15.4	14.0	12.7	25
Wind	≤1.5kW	34.5	34.5	32.6	30.8	29.1	27.5	26.0	24.6	23.2	21.9	20.7	20
Wind	>1.5-15kW	26.7	26.7	25.5	24.3	23.2	22.2	21.2	20.2	19.3	18.4	17.6	20
Wind	>15-100kW	24.1	24.1	23.0	21.9	20.9	20.0	19.1	18.2	17.4	16.6	15.9	20
Wind	>100-500kW	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	20
Wind	>500kW-1.5MW	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	20
Wind	>1.5MW-5MW	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	20
Existing microgenerators transferred from the RO		9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	to 2027

* Note the microCHP pilot will support up to 30,000 installations with a review to start when the 12,000th installation has occurred

** "Retrofit" means installed on a building which is already occupied ;"New Build" means where installed on a new building before first occupation ; "Stand-alone" means not attached to a building and not wired to provide electricity to an occupied building

Table D.1: Table of generation tariffs to 2020.

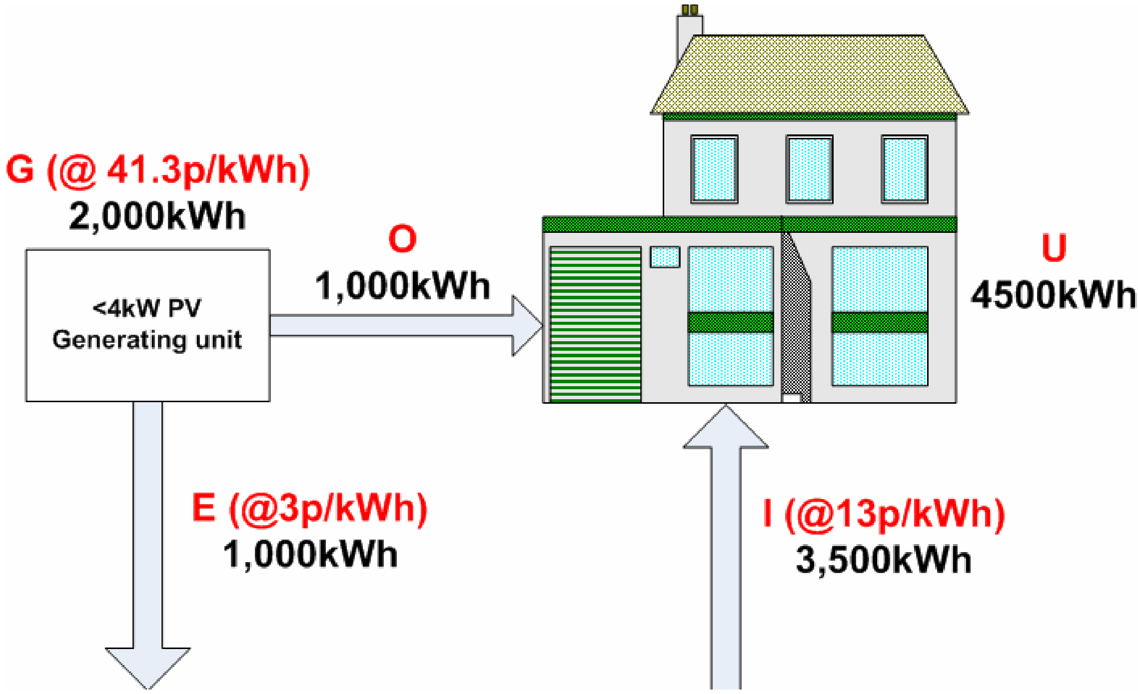


Figure D.1: Explain FITs (Feed-in Tariffs)

In this illustrative example, the site generates (G) 2,000 kilowatt hours (kWh) per annum (here a retrofitted <4kW solar PV panel) which is metered using the site's generation meter. They are then assumed to have exported (E) 50% of their generation onto the local electricity network (either as metered exports or deemed exports) when the electricity is generated at times when the household does not use it. The other 50% of generation is used on-site (O). The household uses (U) a total of 4,500 kWh per annum, therefore, they need to import (I) 3,500 kWh from their electricity supplier.

Using this illustrative example, the generator will receive a FITs payment of £856 per annum (made up of a generation tariff payment of 2,000 kWh x 41.3 p/kWh = £826 plus an export tariff payment of 1,000kWh x 3p/kWh = £30). They also derive a benefit from the 1,000 kWh they generate and use on-site as that will offset 1,000 kWh they would otherwise have had to buy from their electricity supplier. Assuming an import price of 13 p/kWh this would be a saving of £130 (1,000 kWh x 13 p/kWh).

APPENDIX E: WEATHER INFORMATION.

January 2009
Average temperature = 5.0 ℃
Average humidity = 85 %
Average dewpoint = 2.6 ℃
Average barometer = 994.4 mb
Average windspeed = 16.5 mph
Average direction = 211 °(SSW)
Rainfall for month = 0.906 in.
Rainfall for year = 0.906 in.
Maximum rain per minute = 0.060 in on day 20 at time 15:02
Maximum temperature = 12.5 ℃ on day 28 at tim e 15:44
Minimum temperature = 0.6 ℃ on day 21 at time 08:56
Maximum humidity = 95 % on day 22 at time 07:07
Minimum humidity = 62 % on day 24 at time 15:50
Maximum pressure = 1013.8 mb on day 28 at time 20:25
Minimum pressure = 485.2 mb on day 19 at time 12:02
Maximum windspeed = 20.7 mph from 203 °(SSW) on day 20 at time 14:06
Maximum heat index = 12.5 ℃ on day 28 at tim e 15:44

February 2009
Average temperature = 5.8 ℃
Average humidity = 79 %
Average dewpoint = 2.4 ℃
Average barometer = 1013.6 mb
Average windspeed = 15 mph
Average direction = 257 °(WSW)
Rainfall for month = 0.035 in.
Rainfall for year = 0.941 in.
Maximum rain per minute = 0.020 in on day 13 at time 04:15
Maximum temperature = 27.0 ℃ on day 21 at tim e 13:32
Minimum temperature = -1.3 ℃ on day 02 at tim e 02:29
Maximum humidity = 93 % on day 13 at time 05:14
Minimum humidity = 29 % on day 21 at time 14:40
Maximum pressure = 1031.6 mb on day 21 at time 01:29
Minimum pressure = 985.5 mb on day 09 at time 20:46
Maximum heat index = 26.5 ℃ on day 21 at time 13:32

March 2009
Average temperature = 9.8 ℃
Average humidity = 69 %
Average dewpoint = 3.9 ℃
Average barometer = 1015.4 mb
Average windspeed = 15.8 mph
Average direction = 252 °(WSW)
Rainfall for month = 1.685 in.
Rainfall for year = 2.626 in.
Maximum rain per minute = 0.020 in on day 23 at time 14:24
Maximum temperature = 33.3 ℃ on day 16 at tim e 13:32
Minimum temperature = 0.3 ℃ on day 29 at time 07:19
Maximum humidity = 90 % on day 10 at time 03:37
Minimum humidity = 19 % on day 16 at time 14:35
Maximum pressure = 1034.8 mb on day 17 at time 11:39
Minimum pressure = 988.5 mb on day 27 at time 23:55
Maximum windspeed = 21.9 mph from 180 °(S) on day 07 at time 22:25
Maximum heat index = 31.4 ℃ on day 16 at tim e 13:31

April 2009
Average temperature = 12.2 ℃
Average humidity = 68 %
Average dewpoint = 5.7 ℃
Average barometer = 1009.6 mb
Average windspeed = 13.6 mph
Average direction = 219 °(SW)
Rainfall for month = 1.488 in.
Rainfall for year = 4.114 in.
Maximum rain per minute = 0.040 in on day 27 at time 17:35
Maximum temperature = 36.9 ℃ on day 20 at tim e 16:40
Minimum temperature = 2.2 ℃ on day 05 at time 07:10
Maximum humidity = 92 % on day 07 at time 08:18
Minimum humidity = 17 % on day 20 at time 17:15
Maximum pressure = 1026.1 mb on day 20 at time 10:29
Minimum pressure = 989.1 mb on day 27 at time 06:25
Maximum windspeed = 19.6 mph from 180 °(S) on day 07 at time 17:14
Maximum heat index = 34.8 ℃ on day 20 at tim e 16:40

May 2009
Average temperature = 14.4 ℃
Average humidity = 66 %
Average dewpoint = 7.3 ℃
Average barometer = 1013.4 mb
Average windspeed = 15.2 mph
Average direction = 201 °(SSW)
Rainfall for month = 1.799 in.
Rainfall for year = 5.913 in.
Maximum rain per minute = 0.042 in on day 15 at time 16:49
Maximum temperature = 41.9 ℃ on day 31 at tim e 15:30
Minimum temperature = 5.2 ℃ on day 17 at time 05:28
Maximum humidity = 92 % on day 23 at time 05:53
Minimum humidity = 18 % on day 11 at time 17:00
Maximum pressure = 1028.2 mb on day 29 at time 01:49
Minimum pressure = 993.8 mb on day 16 at time 10:14
Maximum windspeed = 52.9 mph from 248 °(WSW) on day 17 at time 04:50
Maximum heat index = 42.6 ℃ on day 31 at tim e 15:30

June 2009
Average temperature = 17.9 ℃
Average humidity = 65 %
Average dewpoint = 10.3 ℃
Average barometer = 1013.9 mb
Average windspeed = 12.75 mph
Average direction = 243 °(WSW)
Rainfall for month = 1.472 in.
Rainfall for year = 7.386 in.
Maximum rain per minute = 0.062 in on day 29 at time 19:00
Maximum temperature = 43.9 ℃ on day 01 at tim e 15:48
Minimum temperature = 6.5 ℃ on day 12 at time 05:24
Maximum humidity = 90 % on day 27 at time 07:36
Minimum humidity = 15 % on day 01 at time 15:50
Maximum pressure = 1025.6 mb on day 23 at time 08:21
Minimum pressure = 995.9 mb on day 05 at time 16:25
Maximum windspeed = 20.7 mph from 203 °(SSW) on day 18 at time 16:28
Maximum gust speed = 20.7 mph from 203 °(SSW) on day 18 at time 16:28
Maximum heat index = 44.4 ℃ on day 23 at tim e 14:56

July 2009
Average temperature = 17.7 ℃
Average humidity = 71 %
Average dewpoint = 11.8 ℃
Average barometer = 1006.4 mb
Average windspeed = 12 mph
Average direction = 214 °(SW)
Rainfall for month = 4.087 in.
Rainfall for year = 11.472 in.
Maximum rain per minute = 0.062 in on day 13 at time 16:52
Maximum temperature = 43.9 ℃ on day 02 at tim e 16:07
Minimum temperature = 9.3 ℃ on day 31 at time 06:10
Maximum humidity = 93 % on day 19 at time 06:06
Minimum humidity = 21 % on day 02 at time 16:07
Maximum pressure = 1018.7 mb on day 01 at time 12:28
Minimum pressure = 992.6 mb on day 22 at time 06:12
Maximum windspeed = 20.7 mph from 180 °(S) on day 13 at time 12:40
Maximum gust speed = 21.9 mph from 203 °(SSW) on day 13 at time 12:41
Maximum heat index = 47.0 ℃ on day 02 at tim e 15:11

August 2009
Average temperature = 18.2 ℃
Average humidity = 71 %
Average dewpoint = 12.3 ℃
Average barometer = 1009.6 mb
Average windspeed = 13.2 mph
Average direction = 203 °(SSW)
Rainfall for month = 1.205 in.
Rainfall for year = 12.677 in.
Maximum rain per minute = 0.021 in on day 31 at time 19:27
Maximum temperature = 36.9 ℃ on day 05 at tim e 15:24
Minimum temperature = 9.6 ℃ on day 29 at time 05:50
Maximum humidity = 93 % on day 31 at time 23:54
Minimum humidity = 24 % on day 22 at time 16:03
Maximum pressure = 1018.5 mb on day 07 at time 23:41
Minimum pressure = 997.1 mb on day 31 at time 23:36
Maximum windspeed = 21.9 mph from 203 °(SSW) on day 20 at time 11:06
Maximum gust speed = 24.2 mph from 158 °(SSE) on day 20 at time 12:45
Maximum heat index = 36.5 ℃ on day 11 at tim e 13:38

September 2009
Average temperature = 16.0 ℃
Average humidity = 71 %
Average dewpoint = 10.2 ℃
Average barometer = 1017.8 mb
Average windspeed = 13.2 mph
Average direction = 226 °(SW)
Rainfall for month = 0.583 in.
Rainfall for year = 13.260 in.
Maximum rain per minute = 0.042 in on day 03 at time 04:00
Maximum temperature = 38.3 ℃ on day 11 at tim e 15:20
Minimum temperature = 7.3 ℃ on day 24 at time 07:25
Maximum humidity = 94 % on day 03 at time 03:15
Minimum humidity = 23 % on day 11 at time 15:29
Maximum pressure = 1035.3 mb on day 11 at time 07:31
Minimum pressure = 984.3 mb on day 03 at time 02:27
Maximum windspeed = 20.7 mph from 203 °(SSW) on day 22 at time 05:53
Maximum heat index = 37.8 ℃ on day 11 at tim e 15:20

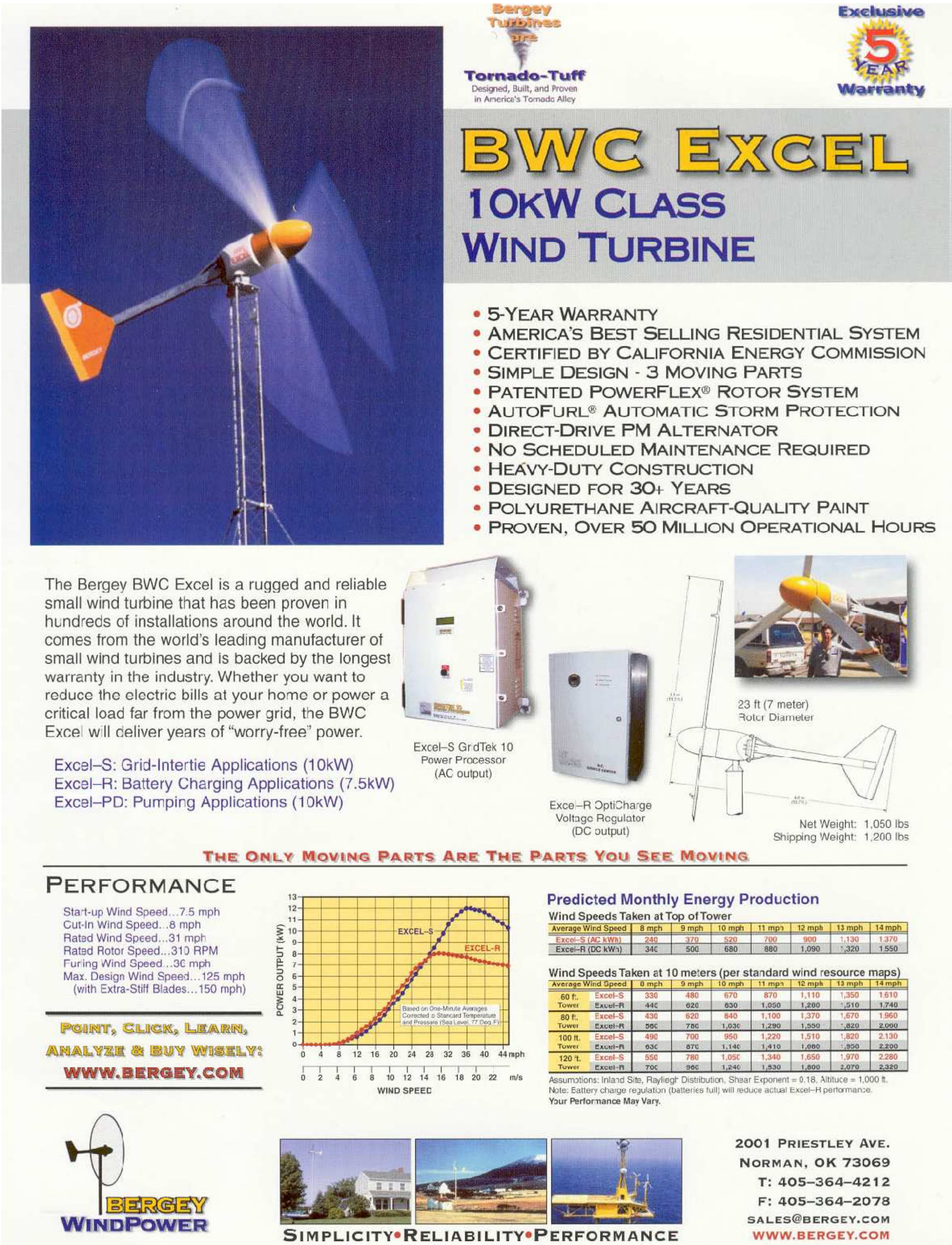
October 2009
Average temperature = 12.8 ℃
Average humidity = 77 %
Average dewpoint = 8.4 ℃
Average barometer = 1011.3 mb
Average windspeed = 14.3 mph
Average direction = 220 ° (SW)
Rainfall for month = 1.575 in.
Rainfall for year = 14.835 in.
Maximum rain per minute = 0.061 in on day 06 at time 18:35
Maximum temperature = 34.8 ℃ on day 05 at tim e 15:26
Minimum temperature = 2.9 ℃ on day 18 at time 08:14
Maximum humidity = 95 % on day 31 at time 10:28
Minimum humidity = 21 % on day 05 at time 15:31
Maximum pressure = 1032.1 mb on day 16 at time 10:54
Minimum pressure = 987.5 mb on day 20 at time 16:48
Maximum windspeed = 21.9 mph from 225 °(SW) on day 25 at time 11:23
Maximum gust speed = 25.3 mph from 315 °(NW) on day 25 at time 01:48
Maximum heat index = 33.1 ℃ on day 05 at tim e 15:26

November 2009
Average temperature = 8.4 ℃
Average humidity = 87 %
Average dewpoint = 6.2 ℃
Average barometer = 994.3 mb
Average windspeed = 13.9 mph
Average direction = 227 ° (SW)
Rainfall for month = 6.240 in.
Rainfall for year = 21.075 in.
Maximum rain per minute = 0.061 in on day 12 at time 15:31
Maximum temperature = 20.6 ℃ on day 01 at tim e 12:58
Minimum temperature = -0.1 ℃ on day 30 at tim e 23:54
Maximum humidity = 96 % on day 21 at time 09:56
Minimum humidity = 45 % on day 04 at time 14:19
Maximum pressure = 1018.2 mb on day 09 at time 08:33
Minimum pressure = 975.2 mb on day 14 at time 13:07
Maximum windspeed = 23.0 mph from 203 °(SSW) on day 19 at time 09:00
Maximum heat index = 26.1 ℃ on day 03 at tim e 15:25

December 2009
Average temperature = 3.4 ℃
Average humidity = 90 %
Average dewpoint = 1.9 ℃
Average barometer = 1002.8 mb
Average windspeed = 15.9 mph
Average direction = 265 ° (W)
Rainfall for month = 2.283 in.
Rainfall for year = 23.358 in.
Maximum rain per minute = 0.020 in on day 30 at time 08:15
Maximum temperature = 11.7 ℃ on day 09 at tim e 13:32
Minimum temperature = -4.0 ℃ on day 19 at tim e 08:17
Maximum humidity = 96 % on day 26 at time 11:13
Minimum humidity = 76 % on day 18 at time 15:26
Maximum pressure = 1033.4 mb on day 12 at time 10:37
Minimum pressure = 979.7 mb on day 22 at time 06:24
Maximum windspeed = 19.6 mph from 180 °(S) on day 07 at time 13:43
Maximum heat index = 11.7 ℃ on day 09 at tim e 13:32

Tables E.1: Weather information at Wrexham from January 09 to December 09.

APPEDIX F: CATALOGUES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- POLYURETHANE AIRCRAFT-QUALITY PAINT
- PROVEN, OVER 50 MILLION OPERATIONAL HOURS

The Bergey BWC Excel is a rugged and reliable small wind turbine that has been proven in hundreds of installations around the world. It comes from the world's leading manufacturer of small wind turbines and is backed by the longest warranty in the industry. Whether you want to reduce the electric bills at your home or power a critical load far from the power grid, the BWC Excel will deliver years of "worry-free" power.

Excel–S: Grid-Intertie Applications (10kW)
Excel–R: Battery Charging Applications (7.5kW)
Excel–PD: Pumping Applications (10kW)

Excel–S GridTek 10 Power Processor (AC output)

Excel–R OptiCharge Voltage Regulator (DC output)

23 ft (7 meter) Rotor Diameter

Net Weight: 1,050 lbs
Shipping Weight: 1,200 lbs

THE ONLY MOVING PARTS ARE THE PARTS YOU SEE MOVING

PERFORMANCE

Start-up Wind Speed...7.5 mph
Cut-In Wind Speed...8 mph
Rated Wind Speed...31 mph
Rated Rotor Speed...310 RPM
Furling Wind Speed...30 mph
Max. Design Wind Speed...125 mph
(with Extra-Stiff Blades...150 mph)

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Predicted Monthly Energy Production

Wind Speeds Taken at Top of Tower

Average Wind Speed	8 mph	9 mph	10 mph	11 mph	12 mph	13 mph	14 mph
Excel–S (AC kWh)	240	370	520	700	900	1,130	1,370
Excel–R (DC kWh)	340	500	680	880	1,090	1,320	1,550

Wind Speeds Taken at 10 meters (per standard wind resource maps)

Average Wind Speed		8 mph	9 mph	10 mph	11 mph	12 mph	13 mph	14 mph
60 ft. Tower	Excel–S	330	480	670	870	1,110	1,350	1,610
	Excel–R	440	620	830	1,050	1,280	1,510	1,740
80 ft. Tower	Excel–S	430	620	840	1,100	1,370	1,670	1,960
	Excel–R	560	780	1,030	1,290	1,550	1,820	2,060
100 ft. Tower	Excel–S	490	700	950	1,220	1,510	1,820	2,130
	Excel–R	630	870	1,140	1,410	1,680	1,950	2,200
120 ft. Tower	Excel–S	550	780	1,050	1,340	1,650	1,970	2,280
	Excel–R	700	960	1,240	1,530	1,800	2,070	2,320

Assumptions: Inland Site, Rayliegh Distribution, Shear Exponent = 0.18, Altitude = 1,000 ft.
Note: Battery charge regulation (batteries full) will reduce actual Excel–R performance.
Your Performance May Vary.

BERGEY WINDPOWER

SIMPLICITY•RELIABILITY•PERFORMANCE

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Figure F.1: Data of Small wind turbine BWC EXCEL 10KW.

GRIDTEK 10

POWER PROCESSOR FOR THE EXCEL-S HOME WIND SYSTEM

The GridTek 10 power processor allows the Bergey Excel-S wind turbine to be connected to the wiring in your home. By making the wind turbine electricity identcial to utility power you can now generate your own power and even sell any excess back to the power company.

The GridTek 10 operates automatically under all conditions. And, it's utility friendly. It meets or exceeds the most stringent national standards for power quality and linemen safety, and it's certified by Underwriters Laboratory.

The GridTek 10 uses a powerful 32-bit microprocessor and state-of-the-art IGBT high-frequency power switches. But, it is specially engineered to make your life simple. It has only one button - a "Reset" button. To keep you informed, it has a digital display of operating status, turbine rotor speed, and output power.

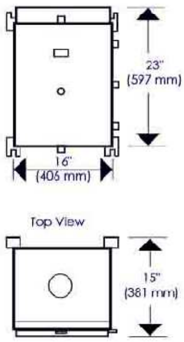
And, it carries Bergey Windpower's exclusive 5-Year warranty!

The GridTek 10 is high technology made simple. Auto everything. One "Reset" button. That's it.

Specifications

Rated Power	10 kW
Efficiency	92%
Output	240 VAC, 60 Hz, 1 Ph. 220 VAC, 50 Hz, 1 Ph.
Power Factor	0.98 - 1.0
Total Harmonic Distortion	2.1%
Controls	DSP Digital
Power Switches	IGBT @ 15+ kHz
Compliances	UL 1741 IEEE 929 & 519
Temperature Range	0 - 40 Deg. C
Weight	115 lbs (53 kgs)
Mounting	Indoors, 16" Stud Spacing
Display	4 Line LCD

Dimensions



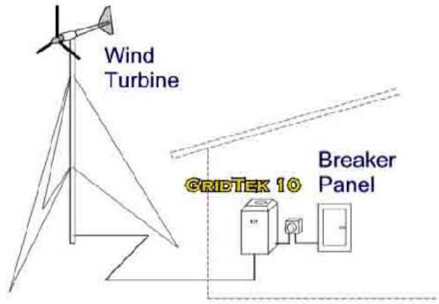


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Figure F.2:Data of Inverter Gridtek 10.