University of Southern Queensland

Faculty of Engineering and Surveying

The Development of a Wind and Solar Power Calculator for Use Within the Private Sector

A dissertation submitted by

Mr. Michael Haenke

In fulfilment of the requirement of

Bachelor of Engineering (Mechatronics)

November 2010

Abstract

This dissertation is the documentation and design of a power calculator for use within the private sector. A power calculator is a way of determining an expected output from a given energy source over a specific time. This calculator is focused on power produced from solar and wind energies.

We live in exponential times, both in terms of population growth and energy consumption. A nation is defined by this consumption. As the primary sources of fuelling power stations dwindle, and as these fuels affect the earth, it is becoming more and more important to find alternative forms of energy.

The development of an energy calculator is used to develop an assessment of the viability of implementing specific power sources. The major feature of this calculator is to determine factors such as power output, sizing and cost. An individual calculator needs to be developed for both solar and wind energy.

Although these two forms of energy provide cleaner and more sustainable options than the major energy forms currently in use, they struggle to compete across all fields. Both energy forms are more expensive and cannot operate one hundred per cent of the time as there are restrictions on where and when they can work.

As a prediction, the calculator can only give- at best, a monthly representation, as weather conditions will change daily. It will also not be completely accurate, though the calculator does give a real value for expected power generation.

The calculator is limited by this lack of accuracy. As a monthly representation it does give a solid representation of a specific model of either a solar or wind source.

Certification

I certify that the ideas, designs and experimental work, result, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any courses or institutions, except where specifically stated.

Student name Michael Haenke

Student number 0050041924

____

Signature

____

Date

Acknowledgements

This research was conducted under the supervision and guidance of Dr Fouad Kamel.

The application of the wind power calculator was tested for use with the National Centre of Engineering in Agriculture (NCEA) and was verified under the supervision of Erik Schmidt and the NCEA - USQ

Appreciation is also due to the Faculty of Engineering and Surveying at The University of Southern Queensland

Contents

List of figures

List of tables

List of appendices

Chapter 1

The world we live in today has been described as an electronic world: a world in which human kind has become so dependent on electricity that without it we could not live a normal life as we know it.

Emanuel (1985, p.1)

Project Outline

This project is the development and production of an energy calculator: a way to determine the viability of implementing a specific power source. The calculator will be designed to test the predicted outputs of both solar and wind energy. The primary development of this project is for use within a nursery but the calculator is easily transferable in use to any part of the private sector. It is important to make use of as many details as possible, limiting the error of the output. The resulting calculators' main focus is on adaptability and accuracy. The calculated will be used to develop specific case studies to represent examples of its use.

Literature Review

Because of the demand for power made throughout the modern world there is an almost limitless amount of literature available. Papers and articles pertaining to solar and wind are also becoming increasingly popular within the engineering community as the need for alternate forms of power become necessary.

The aim of the project is not only to produce a power calculator but to provide background knowledge so that the requirements of the process are understood. This does not only mean specific to solar and wind but also in a more general form. The development of those other forms of energy gives rise to the reason why there is a need to invest in wind and solar, as well as their relative viability.

Literature specific to wind power

The initiative to start trying to utilise wind power on a large scale has been ongoing for forty years. Most small scale systems use induction generators, whose history dates back to the 19th century. As a result there is a limit to how much new information can be written. This is of benefit as most literature on the subject will not become outdated.

New literature on the subject relates to improving existing designs, mostly in relation to blade design and methods of capture. Allowances within the calculator need to be made for changes that can be present within each individual turbine as each turbine has individual specifications.

Most of the technology associated with the use of generators within the system has been well developed and currently the only significant developments within the field of wind energy production are in the design of the turbine blades. As the blade design only affects the efficiency of the system, the adaptations required due to development over time are limited.

Some features, such as the roughness factor (used to describe surrounding wind interference), are not set values and can change between sources. For values to be decided upon all reasoning for their values needs to be considered and a final value needs to be justified.

Equations have developed to a point where they are widely accepted and quite well developed. Limitations are placed on these equations though as it is hard to accommodate for weather, a feature where data is hard to define or predict. This will affect the calculator as it is hard to find resources that have the specific information required for increasing the accuracy of the calculator.

Literature specific to solar power

The basis of solar power, unlike most other forms of energy, lies within theory rather than practice. The phenomenon has given rise to the theory of quantum physics and has led to important technological developments. As its practical application has only been testable over recent years it is still a rapidly developing field and unique literature is still being produced on the topic. This places great importance on the date of publication of works and this development places a strain on the literature available, as older sources can differ from current ones.

As with wind power, solar power is dependent on meteorological data. Unlike wind however the sun is always there and the limiting factors within weather data do not have as great an importance on the results as features that affect the calculator are easier to predict.

Introduction

This project is the development and production of an energy calculator- a way to determine the viability of a power source. The project will ideally be used for an economical analysis between the use of mains power and that of installing a renewable resource. Although the main driving factor for most commercial operations, financial reasons are not the only factor in considering renewable energy. Mains power, utilising primarily fossil fuels, depends on a power source that is both finite and damaging. A move to a renewable resource will hopefully curb this dependence on fossil fuels.

The design of a calculator that gives monthly and yearly power generation can be transcribed directly to cost of instillation and maintenance for direct comparison of the cost of power drawn from the mains. Hopefully this comparison will show the viability of installing a renewable resource, not only to the financial benefit of the installer but also to the environment.

Wind and solar technology, while still developing, are not new technologies, and as such, have already had many models developed around their use. This project does is not intended for the development of new equations, rather it is the use, and hopefully optimisation, of this knowledge in the development of the calculators.

Ultimately the aim of this project is to show the practicality of switching from mains power to a renewable resource. As fossil fuels are depleting it is becoming necessary to focus on the use of other forms of energy and hopefully this project will give drive towards their development.

Project objectives

As previously stated, the models for the production of energy from both solar and wind have been comprehensively developed, the aim of this project is the implementation of these models into a functional calculator. Through this it is essential that a comprehensive knowledge is known about all influencing attributes of both wind and solar energy. This background knowledge will provide a basis for the equations used within the calculators. The more fully developed these equations, the more accurate the resulting output. There are a wide variety of resources available and it is crucial to discern their relevance and application.

Objectives

- To provide a thorough background wind energy and its use.
- To validate and utilise equations concerned in wind energy production
- To develop these equations into a functioning calculator
- To provide a thorough background solar energy and its use.
- To validate and utilise equations concerned in solar energy production
- To develop these equations into a functioning calculator
- To employ knowledge and development techniques gained through the duration of a BENG Mechatronic degree
- To entice the use of renewable energies through economic validation

The main objective of this project is to develop a calculator that can determine the power generation from any wind turbine or solar cell relative to any given location. A list of inputs required by the calculator needs to be produced, and the minimised to make the program as simple to use as possible. Although trying to limit the amount of inputs, this cannot come at the expense of accuracy.

Possible Consequences

The increasing strain on global power supply, and the subsequent demand on power sources, is increasing the need for alternative energy sources.

Hopefully, a result of this project is that people will move towards installing their own renewable energy resource and consequently, the population's dependence on the fossil fuel run mains power will diminish. This move will hopefully provide financial benefits to the installer as well as environmental benefits for everyone. An increase in the demand for these sources of energy would also have the added benefit of driving down prices as production increases.

Governments have seen similar incentives and have recently been investing billions of dollars in the development of large renewable energy power stations.

In a more immediate sense, the wind calculator is currently being developed into a website in conjunction with the National Centre for Engineering in Agriculture (NCEA). This website is initially aimed towards nurseries looking to install their own power sources but is by no means limited to this field. The development of the calculator with a company also offers the opportunity for the calculator's continued development. As technologies increase, and more effective equations are developed, the calculator can be adapted to make use of these.

A possible negative consequence of this project could occur if a private user installed a photovoltaic panel or wind turbine and the resulting energy from the system was drastically less than the calculator had predicted. The effect of this would be that the installer would still have to rely on mains power while having just installed an expensive display piece.

Calculator Design Methodology

The idea of developing a power prediction calculator is to allow someone who is interested in the idea of investing in a renewable resource but unsure of the outcome of such an endeavour. As private billing of electricity is given in monthly values this seems the most useful way of displaying the results. This can easily be converted into an expected yearly output as the summation of the monthly results.

The design of a power calculator is reliant on thorough background knowledge to be able to develop the necessary steps required to convert a known input into an expected output power. Logic dictates that weather data taken from the Bureau of Meteorology would be a reliable source as it is a Governmental Department devoted to work in this field. It will also give an idea as to the data available.

While simple in theory, this requires the accumulation of a large amount of variables to develop the calculator to the point where it is considered viably accurate. This places a very large restriction upon the energy calculator, the amount and the quality of input. Data is usually reliant on weather stations, and the absence of a weather station within an area can mean there is no actual input available for an entire district. Data collection may also be dated and because of changing weather patterns may not be accurate. These features need to be accounted for in the development of the calculator.

Design process step by step

1. To develop the calculator it is important to develop background knowledge so the equations can be manipulated into a usable form. It also gives knowledge of the limitations of the calculator. A background knowledge will also give an idea of likely changes, or areas where developments are likely, allowing for the adaptation of the calculator. As the development of the calculator is based on theory and has no physical development the need for a safety analysis is limited. Resource requirements are also readily available as this only relates to the need for relevant literature.

2. The key factors need to be identified so that what is needed and what is readily available can be assessed. Sources of data need to be found so that limitations can be identified early in the process. This step is also important for weeding out factors that are not relative to the calculator.

3. As many relevant equations as possible need to be gathered and validated to try to increase the accuracy of the calculator. This process will increase the usable inputs. This process also needs to continue the exclusion of factors that will have little to no effect on the outcome.

4. The actual design of the calculator and the application of the accumulated equations. The process needs to be correct so that dependent calculations do not cumulate errors. The initial calculator is to be design using an Excel spreadsheet, with further development into a website in conjunction with the National Centre for Engineering in Agriculture (NCEA).

5. Design of, and accumulation of, data for some relevant case studies, to give a comparison between different areas where the calculator might be utilised.

6. The calculator's results need to be tested using relevant case studies. The results of these case studies should be checked against known reliable sources to check the validity of the output.

7. Through this process find and define any problems/ errors that may factor into the calculator

Some additional considerations need to be noted in the development of this calculator. As there is no physical development required, there is a limited need for a safety analysis that extends beyond normal office workplace health and safety practices. Similarly there is a limited need for resource requirements beyond access to the required literature.

Chapter 2

Energy

Introduction to energy

The development of the human race into civilised society can be seen in our ability to create and control energy. From the development of rudimentary tools to our progress through the metals ages, and our ability to control beast and machine has been in the pursuit of knowledge and a way of adding value to our existence. (Gross 1986)

In modern life, energy is a term used often to define electrical power, used to run all electrical appliances from light bulbs to complicated medical surgery equipment. It is a necessary commodity of current life, and a lack of supply is considered unacceptable within society.

The demand for electrical power has lead to the development of the most readily accessible and most productive power sources. Unfortunately the majority of these power sources have had a developing negative effect on the environment, and as communities become more socially aware, pressure has been placed on power providers to become more environmentally friendly.

In opposition to this need to protect the environment is the need to maintain current living standards. People expect their current energy consumption to be maintained while limiting the resultant damage to the earth.

History of Energy Development

A brief history of the development of electrical power is given in the following time line

~1750	Benjamin Franklin developed the theory that electricity flows due to the differing of charge levels between two points.
1786	Alessandro Volt invented the first primitive battery
~1820	Michael Faraday developed the first crude motor, though this was a hindered development at the time as there was no means of powering the motor.
1827	George Ohm discovered the relationship between voltage, resistance, current resistance and power, resulting in ohms law V = IR and the power law P = VI
~1850	Gustav Kirchhoff extended on the laws developed by Ohm.
1860's	James Maxwell deduced the relationship between electrical and magnetic fields.
1880	Thomas Edison invented the first viable light bulb.
1882	Power plants were operating in United States and United Kingdom, driving by hydro power
1831	The transformer was developed, allowing step up voltage
	Steam turbine developed, allowing thermal energy to be converted to electrical energy
1839	The photovoltaic effect is noticed for the first time by Alexander-Edmond Becquerel
1887	War of Currents ends, AC becomes the preferred form of supplying power
1888	The first windmill used for electricity production is built in America by Charles Brush
1903	The first gas turbine is built in France

1918	The washing machine is invented
1919	The refrigerator is invented
1930's	Initial development of nuclear power
	Most of the cities in the USA and many throughout Europe were electrified
1898-1938	Denmark invest substantial in Wind power as the country lacks access to fuels like coal
1969	The first laws started to appear that were enacted to protect the environment

Global consumption

Power has become a necessity of modern life. The use and consumption of this energy is directly comparable to the wealth of a person. This wealth can be seen in the comparison of the use of energy per capita between established economies and developing nations.

The reason this power is seen as wealth is because it is used to operate production facilities, run medical equipment and maintain food supplies. The display of this wealth can be seen in the consumption of energy per capita, refer to Appendix A.

The increase in population as a result of easier living conditions, coupled with the power requirements of this increase in technology gives rise to an exponential demand for power.

This demand is tied in with the need for a constant supply- refrigerators cannot stop working or food will go off and surgery equipment cannot stop working during an operation. The development of fossil fuels as a power source is integral in this. It provided an easily accessible, cheap, high content fuel that could be used in any conditions.

Primarily, alternate forms of energy were developed only when there was a shortage of fossil fuels but as the harm that these sources of energy become more prevalent, there is a growing emphasis on these alternate forms. This has led to the development of nuclear energy. Although the negative effects of nuclear energy are well know it has substantial benefits to counter this.

New forms of energy are being developed as a counter to the damage produced by already established suppliers of energy as well as providing a source of energy if the existing supplies become limited.

Chapter 3

Wind Power

‘The pessimist complains about the wind, the optimist expects it to change, the realist adjusts his sails.’

William Arthur Ward

Introduction to Wind Power

Though there are restrictions of the quantity of wind energy available in an area it is a global commodity and can be accessed by every person. From the sudden importance in countries that do not have developed power systems to the future of nations dependent on fossil fuels

Wind is generated by air moving from high pressure zones to low pressure zones. The main two driving factors for the creation of wind are the expansion of air due to heat from the sun creating a high system and the rotation of the Earth causing turbulence in the atmosphere. The transference of this energy can be captured by use of wind generators.

The major advantage in utilising wind energy as opposed to solar energy is that wind energy can function at night, though due to the temperance of nature, the energy output predictions from this process is made more difficult and less accurate.

The most important information available is based on wind run- how far the wind travels in a day. From this, it is necessary to develop a model, as average wind speed is not enough. It is crucial to have a model for wind speeds as the average is not an accurate way of determining power output. The energy output of a wind turbine is proportional to the velocity of wind cubed. The effects of this can be seen quite simply. If there is an average wind speed of 5m/s and the wind is constant compared to that of a wind with the same average but runs at 10m/s for half the time then the latter produces four times the energy**.**

The best way to model wind speed is by using a specific Weibull distribution known as the Rayleigh. This simulates the variance in wind speeds required to produce the determined average.

Other factors have less impact but are still important. Wind speed is affected by the height of the tower, as there is less obstruction the higher above the ground the faster the winds, as well as how much interference there is at ground level, resulting in a roughness factor.

Density is also a factor as it determines how many air molecules pass the blades and as a result relates to how much force is transferred through the blades.

Along with the environmental effects, it is also important to know the size and capacity of the wind turbine, but like solar power this is quite varied and the information would be attained from a quote from a dealer.

A brief History of Wind Energy Use

Sailing boats

Mankind has made use of wind energy as far back as antiquity. The first known forms of this use occurred in boats in ancient Egypt, around 3200BC, that used sails as a form of propulsion.

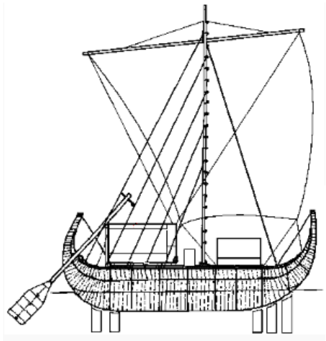

Fig 3.1 Reed Sailboat

Persia

Wind power was first utilised as a mechanical form of energy the 10th century when the Persians used windmills to convert this energy for uses in grinding grain. These first windmills operated on a vertical axis. The design of these mills had a very limited efficiency as they could only operate in winds from a certain direction.

Fig 3.2 Persian Windmill

Medieval Europe and China

This technology passed to areas in Europe and China. This wide spread use stimulated the development of different ideas, resulting in varied designs of operation. In transference to Europe the windmill changed to a design that operated on a horizontal axis. Further development of this design resulted in a windmill that could turn to face the wind, making direction irrelevant.

Fig 3.3 Dutch Windmill

Until the development of coal power during the industrialisation period, wind and hydro were the main providers of power in the world. The main use of these hydro and windmills was for grinding grain and pumping water.

America

During the late 19^{th} and early 20^{th} centuries windmills saw a resurgence for private use on farms. In areas that were too remote to access to a grid network, primarily in countries like Argentina, Australia, Canada and the United States, they provided an effective pump for water. The Halladay design is design to produce a large torque output. This large torque limits the speed, allowing the windmill to operate in low and very high wind conditions. This design is unsuitable for power design though, as the main factor behind producing a large power output is the development of high speeds.

Fig 3.4 Halladay Windmill

Wind power as an electric source

Power production from wind

This same isolation that led to the development of the Halliday design provided the inspiration for the first wind chargers. As development of electricity became widespread a source of power was required for houses that did not have direct access to a power station.

Through this expansion of the use of electricity the concept of using wind as a source of electricity became evident in countries that did not have ready access to coal resources, the primary fuel source of the industrial era.

Denmark

One of the most notable countries in the development of wind technologies is Denmark. From the end of the 19th century to the start of the Second World War, Denmark saw a large development of wind turbines. This was due to Denmark's accelerating development with the absence of fossil fuels. After World War II, apart from a few resource shortages during major conflicts, coal become readily available to all developed countries and wind power become unviable as it could not compete in price. This limited Denmark's dependence on, and investment in, wind energy and it is only recently that Denmark has become once more interested in its development.

Current projects

Towards the end of the 20th century, with the looming threat of global warming and significant advancements in technology, wind power has once again seen an increase in use and viability now that environmental gains can be enough to overcome economic shortfalls. The largest single turbine to date is the Enercon E-126 and it is rated at 7.MWatts. the largest wind farm is the Markbydgen Wind Farm, situated in northern Sweden it has a capacity of 4GigW.

Current designs

Vertical axis

Darrieus

The Darrieus is a wind turbine that consists of aerofoils rotating about a vertical axis. The design was invented by, and named for, Georges Jean Marie Darrieus. The design has the theoretical ability to match that of any other turbine design but is severely limited in that it requires a constant wind speed to reach this efficiency.

Fig 3.5 Gyromill (H-rotor)

The Darrieus design is constructed using two, or more, wing shaped blades spaced evenly around the rotating vertical axis. Each blade is orientated so that the wing cuts into the direction of spin. Once the blades have motion, regardless of present winds, there is a motion of air particles over the blades. This motion can be added to any present wind vectors. Except for when the blades are in a direct line with the wind, where the blades moving in opposite direction cancel each other out, there is a constant positive angle of attack, with the momentum of the turbine used to traverse the brief void section. As the vector of the wind added to the vector created by the travelling blade has a changing angle the resultant power produced is a variable output.

Problems arise from the method of operation. The need for the turbine to be rotating to generate the positive angle of attack results in the turbine needing an initiating velocity after a period without wind. The constant change of wind vector produces a fluctuating stress upon the structure of the turbine. This fluctuating stress, especially if the fluctuations near harmonic frequency, can cause a build up of fatigue stress within the structure of the system. To limit these effects blades can be sloped to spread out the effects of resulting stress as well as there being an odd number of blades to limit the dead spot in rotation.

Fig 3.6 Troposkein

Savonius

The Savonius design relies on drag forces. Wings are created in the design of a scoop so that they have a greater drag on one side then the other. Multiple wings are then placed around a pivot point so that there is always at least one wing capturing oncoming breeze.

Because of the simplicity of its design, the Savonius is highly reliable. Though as it is dependent on drag forces it is not as efficient as many other designs.

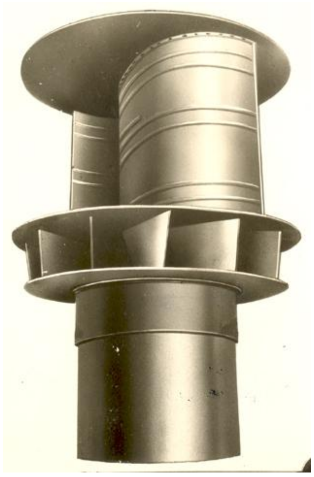

Fig 3.7 Savonius

Horizontal axis

Standard wind turbine

Mounted on a horizontal axis the standard wind turbine makes use of lift principles by utilising blades. To reduce fatigue wearing blades need to be counter balance around the pivot point. Single blade turbines can be used, but often require balancing.

The most important feature on a standard wind turbine is the amount of blades powering the system. The easiest part to the selection process of the number of blades is determining if the amount of blades is odd or even. Most modern turbines make use of an odd number of blades. Because of the spread of the blades, they are considered a disk when the dynamics of the system are assessed. This is in contradiction to an even number of blades. The reason that a system with an even number of blades is not assessed as a disk is because of the timing of the blade locations. The maximum transference of energy through a blade occurs when it is at is zenith. The minimum transference of energy through the blade occurs when it passes in line with the tower structure. When there is an even number of blades this happens at the same time, resulting in a large distortion in the distribution of pressure which can cause fatigue damage to the system.

Three blade concept

Most modern wind turbines make use of three blades per system, known as the Danish Three-Blade Concept. Although the larger the amount of blades, the larger the power that can be taken from the wind fewer blade systems are usually preferred. The amount of blades used by a system is usually limited by economic factors, the fewer the blades the smaller the production cost. Few blades also mean less weight and because they capture less energy from the wind air that has passed the blades retains more energy. The better retention of energy of the wind after passing the system allows for a faster rotation around the hub, an important feature of a wind turbine system.

Two blade concept

Two blade systems are sometimes developed in favour of the three blade design. Two blade systems have the advantage of a lower production cost as well as being a lighter system. Because they capture less energy from the win the blades must operate at a higher speed to produce the same amount of energy. Rotating at higher speeds can result in a louder system and can become more of a visual intrusion.

One blade system

Although as first it may seem a one bladed system is the cheapest option, lowest possible production cost, they are very rare due to the draw backs of the design. The blade needs to be balanced against the weight, automatically reducing the benefits of production cost as well as increasing the weight to that similar of the two blade design. All problems associated with two blade systems exist within the one blade design but to an even greater extent.

Final design process

The blades rely on lift to turn. This lift is produced by the shape of the blades, which induce a high pressure on one side and a low pressure on the other. The blades are then arranged so that they all rotate in the same direction so that they complement each other's movement.

There is a compromise in the number of blades a tower has. Fewer blades result in a higher relative speed, whereas more blades result in a higher torque output. Most major developments utilise a tri blade system though two blade turbines are quite common.

Fig 3.8 Three Blade Wind Turbine

Generators

Since the war of currents in 1887 AC power has been the preferred form of power supply. AC power is far more efficient in use over longer distances than DC power. The development of the generator was the key factor in this and it is the simplest way to produce AC power.

Wind power is the transformation of the physical energy produced by the wind into electrical energy. This process relies on generators to act as a medium between mechanical and electrical power. As the AC generator has existed for more than one hundred years many designs have been developed. The two most notable of these are the induction generator and the synchronous generator. Both types of generators have advantages and disadvantages with their use and the choice is dependent on their final application.

The transference from wind energy to electrical energy relies primarily on generators. Generators turn mechanical energy into electric energy by use of Faraday's Law

> *The induced electromotive force (EMF) in any closed circuit is equal to the time rate of change of the magnetic flux through the circuit.*

Either induction generators or synchronous generators can perform the task of transferring the mechanical energy of the wind into electrical energy.

Induction generator

Induction generators have magnets, in order of alternating polar opposite, positioned around a rotor that rotates within an armature core, that consists of a core and winding. When DC power is fed into the core the rotor is driven, creating a motor. When the rotor is rotated faster the synchronous frequency of this motor it becomes a generator and produces electricity.

As the system generates electricity whenever it is faster than the synchronous speed, it has the ability to produce power at varying rotor speeds. As the induction generator does not use brushes or commutators it is a mechanically and electrically simpler machine as well as being more easily maintained.

A limitation of the induction generator is that it is not self exciting and requires power to initiate the rotating magnetic flux. The generator can supply the power to maintain the flux itself but only after it has started to produce the power required and requires the initial external start up power. At speeds lower than synchronous speed the rotor draws in current to rotate, at speeds higher than synchronous speed the rotor produces power.

The magnetic flux of the rotor is established by a capacitor bank within stand alone systems and for grid connected systems the magnetising current is drawn from the grid.

Asynchronous generators change speed due to the changes in force of the torque applied to the generator. The change in speed limits the build up of wear and tear on the gearbox. The limitation of stresses on the system increasing life and limits the required maintenance.

Synchronous generator

The synchronous generator uses similar principles as the induction generator to operate. To create a magnetic field either permanent magnets are used or field windings are placed in slots on the rotor. Energy is transferred to the windings using brushes or slip rings and the supplied power comes from an exciter, a variable DC power source. The rotor is turned, using the mechanical energy input, within a stator to create a rotating magnetic field. This induces an AC voltage in the stator windings. Usually there are three sets of stator windings to create three phase power. There are always the same amount of poles for the stator and the rotor.

Permanent magnets are usually only used In very small machines but most systems use rotor windings energised with direct current through slip rings and brushes.

Permanent magnets are not used in larger machines due to the cost of the magnetic material and the demagnetisation caused in larger voltage generators.

Synchronous generators can utilise either permanent or electro magnets. Permanent magnets are expensive and, in high magnetic fields, can be subject to a loss of charge. Electro magnets require a constant connection to the grid network, along with an AC to DC converter. This process also requires the use of slip rings and brushes to operate.

Chapter 4

Wind behaviour

Introduction

'Wind is the result of horizontal differences in air pressure. Air flows from areas of high pressure to low pressure. Wind is nature's attempt to balance large scale inequalities in air pressure.' (Lutgens & Tarbuck 1995, p147).

There are two main factors that contribute to the generation of wind on the earth's surface, heating by the sun and turbulence created by the rotations of the earth (the Coriolis effect). The sun causes this reaction by heating air, causing it to expand, creating a greater pressure. This high pressure area then moves towards low pressure areas trying to equalise the pressures.

A very general view of global wind patterns, though these can vary greatly in areas depending on conditions.

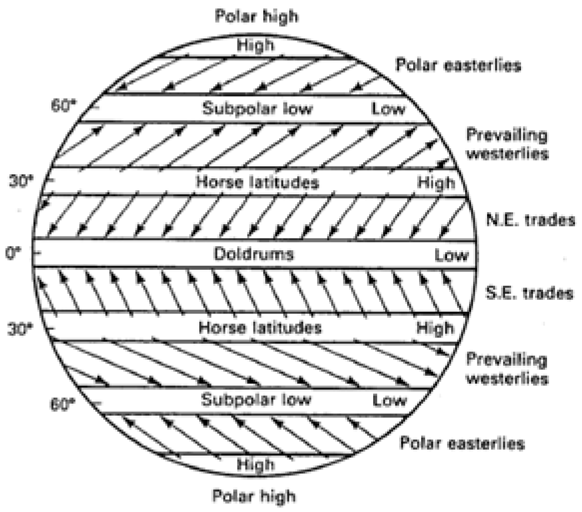

Fig 4.1 Global Wind Patterns

'All free moving objects, including wind, are deflected to the right of their path of motion in the northern hemisphere and to the left in the southern hemisphere.' (Lutgens & Tarbuck 1995, p149)

Energy within wind

There are many factors that determine how much energy is possessed within wind. The culmination of these forces needs to be broken down before a full value of this wind can be determined.

Most equations concerning the amount of energy within the wind have a basis in, or relevance to, the general equation

P = ½ * Area * density * wind speed cubed

This energy is determined relative to a specific area. This area can be used to determine the flow rate of particles.

Speed

The rate at which air is transferred from one area to another

Structures/terrain

Friction created by landmasses, vegetation and structures reduces the speed of the wind. The further the wind turbine is raised above the earth's surface the faster the resulting wind. The discrepancy between speeds due to terrain cover lessens the further the elevation from ground level.

The equation for the speed of wind due to height is given by

Relative velocity = v * log (H/z) / log (10/z)

V = wind speed at 10m

H = the height of the wind turbine

Z = roughness factor

The roughness factor is determined by the interference caused by the roughness of the earth. This value is relative to the height of surrounding disruptions. There are no set values for the roughness factor. The value is based loosely upon the roughness height in meters divided by ten. So that for open water, with a roughness height of 2mm becomes a roughness factor of 0.0002.

So that z =

Z value	name	description
0.0002	Open water	Open water, tidal flat
0.005	Smooth	Featureless land, ice
0.03	Open	Flat terrain with grass or very low vegetation, airport
0.1	Roughly open	cultivated area, low crops, obstacles of height H separated by at least 20 H
0.25	Rough	open landscape, scattered shelter belts, obstacles separated by 15 H or so
0.5	Very rough	landscape with bushes, young dense forest etc separated by 10 H or so
1	Closed	open spaces comparable with H, eg mature forest, low-rise built-up area
2	caotic	irregular distribution of large elements, eg city centre, large forest with clearings

Table1

http://www-das.uwyo.edu/~geerts/cwx/notes/chap14/roughness.html

Density

'In still air, two factors, temperature and density, largely determine the amount of pressure that a particular gas exerts' (Lutgens & Tarbuck 1995, p142).

The dependence of pressure in relation to temperature and density is given by the ideal gas law where

Density = pressure / (constant of proportionality * temperature)

Rho = P / (R * T)

The standard atmosphere at sea level is 101325 N/m^2 (standard figure). (Zillman 1975, p34)

The higher the density of the air, the more particles will be within a unit volume. An increase in the density of has a direct impact on how many particles move past the wind turbine blade.

This increase in wind particles increases the effects of lift upon each blade. This increase in lift has a direct relationship on how much energy can be extracted from wind energy.

There are a few key elements which affect the relative density of an area.

Altitude

As you move away from the surface of the earth the effects of gravity lessen. This drop in gravitational force affects the density of the air. With less force acting on the air molecules begin to move apart, lowering the density.

The equation for density due to altitude can be given by:

$$p = p_0 \cdot \left(1 - \frac{L \cdot h}{T_0}\right)^{\frac{g \cdot M}{R \cdot L}}$$

Where p = density

Po = standard air pressure at sea level = 101325

L = temperature lapse rate = 0.0065K/m

H = the height of reference above sea level (m)

To = sea level temperature (degrees Kelvin)

G = acceleration due to gravity = 9.80665m/s^2

M = molar mass = 0.0289644 kg/mol

R = universal gas constant = 8.31447 J/mol.K

Temperature

Temperature is the representation of heat energy within the air. An increase in energy causes an increase in movement from molecules. As molecules start to speed up they push further apart, so that at higher temperatures the density of the air is reduced.

Air density = absolute pressure / (specific gas constant x temperature)

The specific gas constant = 287.058J/kg.K

Temperature is in degrees Kelvin

Humidity

An increase in humidity has a counter intuitive affect on air pressure. An increase in water particles within the air would seem to increase the pressure, though this is not the case. The water particles molecular mass is less than that of the air, so that the space filled by water particles is not as dense as it would be if filled by air particles.

Ph = Pd / (Rd x T) + Pv / (Rv x T)

Where

Ph = density of humid air (kg/m^3)

Pd = partial pressure of dry air (Pa)

Rd = specific gas constant for dry air = 287.058 J/kg.K

T = temperature (degrees Kelvin)

Pv = partial pressure of water vapour (Pa)

Rv = specific gas constant for water vapour = 461.495 J/kg.K

To solve this equation a value is neede for Pv

Pv = phi x Psat

Where

Phi = relative humidity

Psat = saturation vapour pressure

As the saturation pressure is relative to temperature

Pmb = 6.1078 x 10^[(7.5 x T – 2048.625) / (T – 35.85)]

Efficiency

The efficiency of a wind turbine is composed of two parts. The first part is the efficiency of the turbine to convert wind energy into a usable form of mechanical energy within the system. The second part of the efficiency is the eficiency of the generator in converting the mechanical energy into electrical.

The efficiency of the turbine in converting thw wind into usable mechanical energy is usually around 40%. The efficiency of the generator to turn the mechanical energy into eletrical is usually around 80%. As the two are dependent on each other, the resulting efficiency of the turbine as a whole is usually around 30%.

Weibull Distribution

'For more than half a century the Weibull distribution has attracted the attention of statisticians working on the theory and methods as well as in various fields of applied statistics. Hundreds or even thousands of papers have been written on this distribution and the research is ongoing. The Weibull distribution is – without any doubt – the most popular model in modern statistics. It is of utmost interest to theory-orientated statisticians because of its great number of special features and to practitioners because of its ability to fit data from various fields, ranging from life data to weather data or observations made in economics and business administration, in hydrology, in biology or in engineering sciences.'

'The history and discovery of what is now known as the Weibull distribution is even more exciting than that of the normal distribution, which lasted 60 to 70 years. The key events in the derivation of the Weibull distribution took place between 1922 and 1943. This process is so astonishing because there were three groups of persons working independently with very different aims, thus forming a chain of three links. Waloddi Weibull (1887 – 1979) is the last of this chain. The distribution bears his name for good reasons because it was he who propagated this distribution internationally and interdisciplinary. Two of the approaches leading to this distribution are located in engineering practice and are more or less heuristic whereas the third approach, the oldest and purely scientific one, is based on theoretical reasoning and is located in research on statistical methods and probability theory.'

(Horst 2009, p. 3-4)

There is a specific value of n, the shaping factor, used to produce each form of Weibull graph. In the case of wind the shaping constant should be considerate of a few features

It is very rare to have no wind in any direction

High wind speeds usually occur in gusts. The duration of high wind speeds is minimal.

It is impossible to have a negative wind speed

The best value for n to fit wind patterns is 2. This value for n occurs on a regular basis in statistics and is termed a Rayleigh Distribution, named for John Strut, 3rd baron Rayleigh.

‘the Rayleigh distribution was originally derived by lord Rayleigh in connection with a a problem in the field of acoustics’ (Johnson, kotz & Balakrishnan 1994, p.456)

Basic properties (page 456 – 459)

A Rayleigh random variable X has probability density function with N = 2

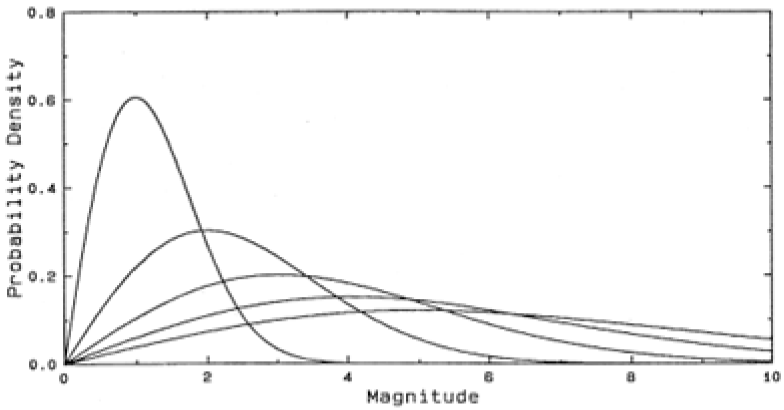

Fig 4.2 Rayleigh Distribution with Differing Averages

Problems associated with Wind Energy

By regarding the information it is possible to determine some of the major problems associated with wind energy.

The wind is inconsistent- high winds occur in short gusts and most of the time, due to the shape of the distribution, wind speed is below average.

The systems require constant maintenance throughout their lifetime – the need to be balance to limit fatigue stress and the safety and reliability of the system needs to be emphasised.

The system produces noise – the system does produce noise, mainly when the blade passes close to the tower structure, and within the private sector it is hard to escape the noise affected zone if there are any space constraints

The system can be visually obtrusive – the size relationship of both the blade length and tower height is easily seen where larger system will produce far greater amounts of energy. While some people like the look of wind turbines many do not and a large system may create unrest while a smaller system might not reach its potential.

The blades can interfere with local wildlife – though not common place a wind turbine within the flight path of local birds or bats can do great damage to the animals. The tips of the blades can travel very quickly and would be able to inflict a large amount of damage if it were to hit wildlife.

Chapter 5

Solar

'The sun with all those planets revolving around

it and dependant on it, can still ripen a bunch of

grapes as if it has nothing better in the universe to do'

Galileo Galilei

Introduction to Solar Energy

The sun can be considered the original source of energy for most power sources. Not just solar and wind, resulting from the expanding air due to heating, but fossil fuels as well, originally plant life. Although these forms of energy come from the sun, only photovoltaics and solar thermal make direct use of it.

The magnitude of radiation hitting an area of the Earth does not have the same quantity globally. The amount of direct sunlight received by a specific area is proportional to latitude as well as more minor factors like the time of year. During summer months, the sun is closer to being directly overhead and as a result there is an increased amount of solar energy available to be harnessed. This effect usually leads to the angling of the solar panels so that they face towards the winter sun. This can result in a total energy output decrease but allows for a more uniform yearly output, so that the panels don't just produce power in summer.

Sunlight can also be affected by humidity, mainly in the form of clouds, which can stop direct sunlight and impede the photovoltaic process. Other factors like ambient temperature can also affect the efficiency of the process.

As a result of this the development the solar calculator was driven primarily by the inputs radiation per day, the number of cloudy days and the angle of panel based on latitude, this data was attained from the bureau of meteorology. Specifics of the solar panels as well as the installation costs are relative to local areas and can be provided by any supplier.

A brief History of Solar Power

Man has actively sought to use solar energy since ancient Greece, as early as 4000BC. The Romans furthered this use by using glass windows to trap the warmth, going as far as to create laws making it illegal to obscure a neighbour's light. This capture of light also made it possible for them to construct the first greenhouses, so that plants from the far reaches of the empire could be grown in Rome. The Pueblo people, native to south-west America, reportedly also made passive use of sunlight in their dwellings.

The French scientist Lavoisier, though making many contributions to physics and chemistry, is most notable in the case of solar power due to his solar furnace. A heliostat, used to concentrate light to power the boiler.

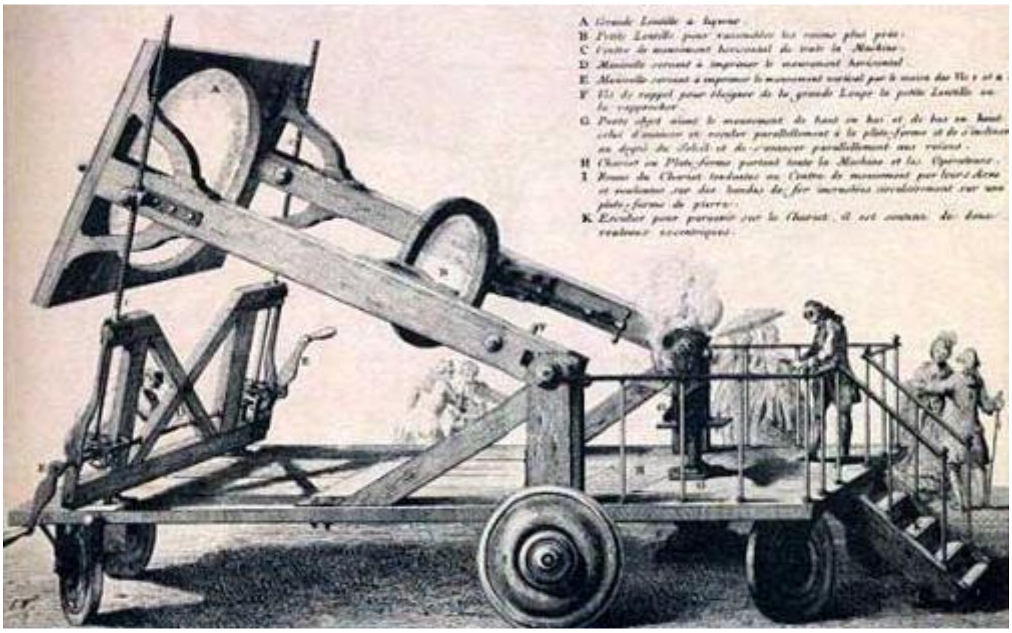

Fig 5.1 Lavoisier's Solar Furnace

The first noticed case of the photovoltaic effect was reported by Edmund Bequerel. In 1839 he noticed an increase in conductivity due to light acting on silver coated platinum immersed in electrolyte.

William Adams and Richard Day, in 1876, produced a photocurrent by using light on a junction between a sample of selenium placed in contact with two heated platinum contacts.

Charles Fritts in 1894 produced what is believed to be the first solar cell, made from a layer of selenium and an extremely thin layer of gold.

These early cells were thin film Schottky barrier devices, differing from p-n junctions due to their lower junction voltage.

Further observations were made with copper and copper oxide thin film structures, lead sulphide and thallium sulphide.

In 1921 Albert Einstein received a Nobel prize for his 1905 paper on his theory of photoelectricity. This was a pivotal step in photovoltaic development. The paper described how the photoelectric effect was caused by absorption of photons.

The initial findings of the effects of light energy gave possibilities that overshadowed the production of voltage. The large costs that made power generation unviable were not an issue when used in very small amounts, like that required of a photographic light meter.

Even though silicon was first manufactured in 1918, by Jan Czochralski, it was not until 1941 that the first silicon solar cell was developed.

Even though silicon cells could now be developed it was still too expensive for rated its output to be a sustainable option and it was not until the space program that solar became cells became a valid option. The most important aspect of a power source being transported into space is the limit of weight. As the method for powering a photovoltaic cell is present outside of Earth's atmosphere there is no need for an additional fuel source.

The first artificial satellite to make use of photovoltaic technology was the Vanguard i, launched in 1958, it was in service for 8 years.

The largest plant to date is Sarnia in Canada, and is rated at a max capacity of 80MW

Fig 5.2 Sarnia Photovoltaic Power Station

As interest in, and the demand for fuels other than fossil fuels increased, photovoltaics started to rapidly increase through the 1990’s the price of photovoltaics started to proportionally decline.

Power production of solar-physics

The current theory believed to be accurate, Einstein's theory of photoelectricity, defines the makeup of light as photons. The theory states that the energy contained within a certain frequency of light is equal to the frequency of the light times a constant, known as Planck's constant. A photon, once it was greater than a threshold, would eject a single electron. It has recent been shown in studies that this theory, more widely known as quantum, is not needed to calculate the probability of an electron being produced. The most current modern method of determining if electrons are produced is Fermi's golden rule. Although following similar rules it relies on the idea that light is a wave that causes a transition in atoms and their constituent electrons from one form of energy to another.

Photoelectricity

The energy of the photon needs to be enough to overcome the energy of the electron binding energy. If the photon energy is too low the electron will not be able to overcome the binding energy and no energy is produced. Increasing the intensity of the light increases the amount of photons, increasing the number of protons emitted but not the energy of each proton. Therefore the resultant energy does not depend on the intensity of the light energy but on the individual photon energy. The energy contained within a photon is dependent on the frequency of the light.

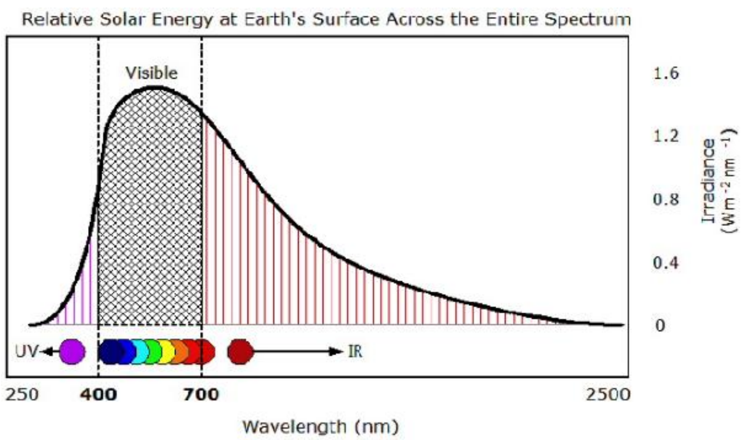

Fig 5.3 Earth's Light Spectrum

Most irradiance occurs in the visible wave length spetrum300-800 nm

Silicon

The main types of current photovoltaics are made from silicon. Silicon has come to prominence within the electrical age, in the use of components like transistors and integrated circuits.

Silicon is a semiconductor, having properties between good conductors and insulators. At 0degrees Kelvin semiconductors become insulators, but as temperature rises, in direct contrast to metal conductors, resistivity decreases.

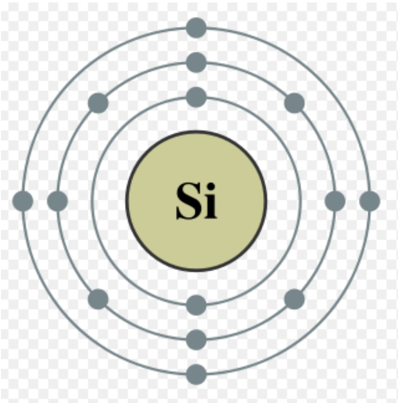

Fig 5.4 Silicon

Silicon is made up of 14 protons, which, in a stable atom, results in 4 electrons in the outer shell. To maintain this stability the atoms try to produce a full outer shell of 8 electrons. This results in the silicon sharing its electrons with other silicon atoms to create a lattice made of four electron bonds, each bond consisting of two electrons creating a chemical bond with another silicon atom. In this structure there is no possible way to conduct electric current. Current flow can only occur if one of the electrons moves out of its bond, creating a hole where another electron will try to fill. This free electron is able to produce a charge while other electrons move within the silicon to fill the hole its movement created. In this process the hole also is able to move, following the path of the electrons that fill each successive hole.

Doping

The addition of other elements to silicon is termed doping. The addition of an element containing 5 electrons in the outer shell will result in an addition electron afer the bonds are formed. Similarly if an element is added   that has only 3 electrons in the outer shell a hole is produced in one of the bonds. The addition of boron, only having three electrons in its out shell, creates p-type silicon where holes create a charge. The addition of phosphorous, having five electrons in its outer shell, creates n-type silicon where electrons create the charge. Charge caused by electrons moves by diffusion, and charge caused by holes moves through drift.

Diffusion

Charge carriers will move about randomly through the crystal within an isolated piece of silicon. This movement is caused by heat energy exciting the electrons, causing them to vibrate. The more heat energy the faster the resulting vibrations, causing faster movement of charge within the silicon. The effect of this movement is the spreading out of electrons to create an even concentration. This movement is called diffusion.

Electric charge, from point to point, moves under the force of an electric field. This process occurs if silicon is attached to terminals with applied voltage. Due to the reactions of charges the electrons will move towards the positive terminal and the holes towards the negative. This movement, due to electric field, is called drift.

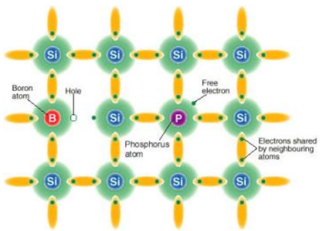

Fig 5.5 Doped Silicon

Through this there are two states and electron can be in, either tied into a bond, where the energy values associated with this are known as the valence band, or free to move and conduct, known as conduction band. These two states correspond to an energy value, with no middle state.

An increase in thermal energy, or heat, increases the energy available to electrons making them more likely to be able to break free from the valance band into the conduction band. This is why semiconductors have an inverse temperature resistance coefficient. This effect means that photovoltaic power production.

Absorption of light

When a photon hits silicon and connects with an electron, it is absorbed by the electron. The resulting gain of energy depends on how much energy was within the photon of light. This connection will have one of three results

> If there is not enough energy in the photon the electron will remain within the valence band. In this case the photon will continue to travel through the silicon.
>
> If the photon energy is equal to the band gap energy, the energy needed to reach the conduction band from the valence band, then the electron will enter the conduction band and a pair will be created between this electron and the resultant hole.
>
> If the energy of the photon is greater than this then a pair is created between the hole and the free electron and the excess energy is turned into heat.

The energy required to overcome the band gap is dependent on the type of semiconductor.

P-N junction

Normally p silicon or n silicon by themselves would act only as a resistor, but when a p and n silicon are connected they form a p-n junction. This combination results in the free electrons in the n silicon moving to fill the hole that are in the p silicon. The net charge within the hybrid will roughly equal zero but charge develops on either side of the silicon due to the movement of the electrons and holes.

How this all comes together

The p-n junction is orientated to the sun so that it is able to receive photons. These photons penetrate the silicon until they connect with electrons and in some cases gives them enough energy to overcome their bonds and break free, creating an electron-hole pair. The efficiency of the electrons to break free due to the influx of photons is dependent on the absorbing material (silicon). Once an electron breaks free it creates an electron-hole pair. This free electron needs to be collected before it can settle back within the hole.

The movement of the electrons after breaking free is driven by the constant charge of the p-n junction. For an electron to be used it first needs to move across the depletion layer of the junction. This movement is the movement of electrons towards the n-silicon.

Once the electrons have traversed the depletion layer they need to be connected by contacts.

Light collection

The metal contacts, while providing a crucial part in the production of energy, create a problem with light collection. As the contacts are made of metal photons will not be to penetrate, and will not be useable, so that no area covered by a contact can produce power. Reduction in the area of contacts to create a larger production area is limited by the fact that lowering the contact are increases the resistance of the photovoltaic cell. A too great a spacing between the contacts also enables the electrons to settle back into holes, so that contacts must remain relatively close.

It is also crucial that the cell is able to absorb as much as possible. This is a duel process, the surface needs to be shaped to limit reflexion and the surface needs to be dimmed to limit reflection. To shape the surface of the cell it is treated with acid to create a pyramidal texture. To limit the reflection the surface is oxidised, with the silicon dioxide acting as an anti-reflectant. This increase in light absorption makes the photovoltaic cells appear dark in colour.

To make full use of the light it is also important that it is absorbed before passing through the cell. The longer the wavelength of the light the further it will penetrate. A metal surface on the back surface can double the length the light has to travel by reflecting it back through the cell.

There are features that make the recombination of electrons with holes more likely. To increase the efficiency of the cell these factors need to be limited.

> Impurities within the silicon limit efficiency. A better quality cell will be more efficient.
>
> Impurities in the structure of the silicon also limit the efficiency of the silicon. Mono-crystalline silicon is the most efficient.

Types of photovoltaic

Although silicon is used, because it is the most widely available, for an explanation of solar production above it is not the only type of photovoltaic cell. Different production methods of each material will produce cells with different characteristics.

There are two main types of silicon wafer cells that are produced in bulk. The mono-crystalline cell has a uniform cell structure. This consistency through the cell results in a uniform colour. The other type of cell is the poly-crystalline, consisting of many crystals within each cell. The overlapping of the crystal within a poly-crystalline cell produces an overhang of cells that creates dangling bonds between crystals, limiting the efficiency of the cell.

High efficiency cells can be manufactured with a greater input effort. A form of higher efficiency cell is the laser grooved buried contact cells. These are created by using a laser to cut a groove within a silicon wafer. The contacts are then inserted into the grooves. This allows the contacts to have less interference on the surface of the cell though the groove needs to be specially treated to reduce the contact resistance as well as maintain the barrier between the p-type silicon.

Thin film cells can be produced instead of wafer technology. These cells are formed using amorphous material, such as silicon or cadmium sulphide, and their atomic structure is random. Because of the limited structure of amorphous silicon there are many dangling bonds which limit efficiency. Treatment can limit this problem. These cells absorb photons more strongly than wafer cells and as a result the amount of material needed to make the cell is reduced.

Chapter 6

Solar Behaviour

Introduction

The power output of a cell is dependent on a complex interaction between the properties of the cell and its surrounding environment. Under stand alone conditions the cells performance is also reliant on the load at which it is required to supply energy but in this case the load is that which produces the most power, as the connection to the grid allows a variable load to be applied to make this possible.

As a simplification, a photovoltaic cell can be considered a constant voltage source. The irradiance determines the amount of electrons being released, which determines the current flow of the cell. The system will then deliver whatever voltage is require by the load to maintain the required current. This is true so long as the load remains under the limiting voltage. Once the load demands more than the limiting voltage, the current will collapse.

Maximum power point

As a result of the constant current source there is a variable power output. The maximum power output termed peak power, PP, is dependent on a load that is proportional to the irradiance received by the cell.

Temperature effects

As mentioned previously the more heat within silicon the smaller the band gap energy, so that less photon energy is required to create an electron-hole pair. As more electron-hole pairs are produced at higher temperatures a greater current will also be produced. This effect is only small however and the extra current produced will be marginal.

The effects of heat upon the voltage have a reverse affect to that of current due to temperature. As the temperature increases more electron-hole pairs are created. The creation of more electron-hole pairs causes the start to the break down the depletion layer. The reduction of the depletion layer can drastically reduce the available voltage.

Energy from the sun

Fill Factor

Although considered a constant current source in theory, there is always going to be a reduction in the supply current as resistance is increased. An equation is needed to show this limitation, as maximum power will never quite be able to produce the ideal power.

$FF = P_{mp} / (V_{oc} \times I_{sc}) = V_{mp} \times I_{mp} / (V_{oc} \times I_{sc})$

FF = fill factor

Voc = maximum voltage

Isc = supply current

Vmp = voltage at maximum power

Imp = current at maximum power

Module Temperature Rise

As the photovoltaic cell is exposed to radiation the cell will start to produce heat as a by product. As the temperature of the cell can determine its operating characteristics it is important to know how much the temperature will increase.

$T_{cell} = T_a + k \times G$

Tcell = cell temperature (degrees Celsius)

Ta = ambient temperature (degrees Celsius)

K = cell temperature coefficient (degrees Celsius/Wm^2)

G = irradiance (W/m^2)

Nominal Operating Cell Temperature (NOCT)

Within the specifications of a cell, it is not the temperature coefficient that is supplied, but the NOCT. This is directly relatable to the k value and the cell temperature can be found as a result.

$K = (NOCT - 20) / 800$

A list of Important Temperature Coefficients

These values are found under standard test conditions (STC)

$I_{sc,t} = I_{sc,stc} \times (1 + a \times (T_{cell} - T_{stc}))$

$V_{oc,t} = V_{oc,stc} \times (b1 - beta \times (T_{cell} - T_{stc}))$

$P_{mp,t} = P_{mp,stc} \times (1 - gamma \times (T_{cell} - T_{stc}))$

Where

$I_{sc,t}$ = short circuit current at temperature T (A)

$I_{sc,stc}$ = short circuit current at STC (A)

$V_{oc,t}$ = open cicuit voltage at temperature T (V)

$V_{oc,stc}$ = open voltage circuit at STC (V)

$P_{mp,t}$ = maximum power at temperature T (W)

$P_{mp,stc}$ = maximum power at STC (W)

T_{stc} = temperature under STC (per degree Cellsius)

T_{cell} = temper of the cell (per degree Celsius)

a = temperature coefficient of current

beta = temperature coefficient of voltage

gamma = temperature coefficient of power

Power Conversion Efficiency

Although usually listed in the cell specifications it may become necessary to determine.

Pin = G x A

Pin = power input (W)

G = irradiance (W/m^2)

A = area (m)

Efficiency = Pmp / Pin = Vmp x Imp / (G x A)

Or alternatively

Efficiency = Voc x Isc x FF / (G x A)

Irradiance

Any information on the Bureau of Meteorology concerning energy from the sun is in the form of Joules, and therefore needs to be converted to Watts before the values can be used.

1 W = 1 J / 1 sec

Problems associated with solar energy

By regarding the information it is possible to determine some of the major problems associated with solar energy.

The locations of the best sites are often unfeasible – the areas of the earth that receive the most irradiation are in deserts closest to the equator. As these environments prove to have harsh living conditions there are very few people who would be able to benefit from solar plants built in the most productive areas. These areas are usually too far for it to be viable to transport electricity to inhabited regions.

Solar power can only produce energy during the day – this is a major problem in energy production as the human race demands power at all times. Only being able to average twelve production hours out of a day of twenty-four hours places a massive strain on the grid system during the night time.

If an area has a relatively high humidity it will never be very productive – an area with a high humidity is going to have a large amount of days with heavy cloud cover. Cloud cover directly inhibits energy production within photovoltaic cells.

Areas that occupy regions with large latitude values will struggle to produce energy – because of the angle of the ground relative to the angle of incoming light regions with large latitude values, either in the far north or far south, the amount of energy available for capture is severely limited and will struggle to ever be a viable option, even in summer months where daylight hours can last nearly twenty-four hours a day.

Chapter 7

Calculator Design

Design

The comparison of data available compared to the equations needed determined how the calculator would operate. Limitations became apparent as it was noted that there was a limit to the amount of data available. The calculator still needed to be able to give a reasonable value, even if the data was missing. This resulted in some values needing to be assumed.

Wind

List of inputs in relation to the system

Tower height

Blade length

Power rating

Efficiency

List of inputs in relation to location

Wind run

Temperature

Humidity

Roughness factor

Expected output

Wind speed at hub height

Monthly power evaluation

Year power evaluation

Solar

List of inputs in relation to the system

Maximum power voltage at maximum power

Current at maximum power

Short circuit current

Open circuit voltage

Temperature coefficient of short circuit current

NOCT

List of inputs in relation to location

Solar Energy

Ambient temperature

Sunrise time

Sunset time

Location, in longitude and latitude

Cloudy days

Cloud free days

Expected outputs

Power rating per month

A total annual power rating

Chapter 8

Test Results

Wind Calculator Results

The effects of surrounding landscape as well as the height of the structural tower can be seen in Tables 12, 13 and 14. A note needs to be made on the fact that for very high values of z the calculator can return a negative value for wind speed at lower heights. In reality this would be like trying to build a 5m high wind turbine in the middle of a city. Because of this and the fact that wind speed can never actually be a negative value, the value for this anomaly must be assumed as zero.

In consideration of the tests cases performed in relation to Toowoomba and Helidon it can be seen that the resulting value is appropriate. The annual wind run for Toowoomba is substantial, and the resulting power output can be expected to be fairly high. In comparison to the Toowoomba output the Helidon output is very limited. As Helidon is situated at the bottom of a range this is to be expected. In reality it would not be wise to build a wind turbine in Helidon but could be quite viable within the Toowoomba district.

Solar Calculator Results

The calculator was able to find all values associated with the system specifics. Unfortunately the results given for power output are either not a number or an irrational value. Within Appendix F it is possible to see the effects the system and surrounding area has on the expected power.

Chapter 9

Conclusions

Conclusion

Although these two forms of energy provide cleaner and more sustainable options than the major energy forms currently in use, they struggle to compete across all fields. Both energy forms are more expensive over the short term and cannot operate one hundred per cent of the time as there are restrictions on where and when they can work.

The idea behind the power calculator is that the systems being installed are still connected to the mains power. This means that the instillation of batteries is not needed, a major expense in installing self contained systems. It also means that while still connected surplus power produced by the system can be sold back into the grid, while times of low wind or no sunlight do not mean no electricity. The comparison between the monthly outputs can be compared directly to a power bill.

The test cases showed a few important points. The most important is the lack of available data in some areas. The wind tests for Helidon are the best examples of the limitations of data. The closest bureau of meteorology site is the Toowoomba airfield yet the more accurate is the Amberley base, even though it is 60km away. The reason that the data collected from Amberley is more accurate than that of the Toowoomba airfield is due to the Great Dividing Range. The range produces great interference with wind patterns and results in far less wind runs east of the range.

This variance in wind produced by the range is shown by the massive difference in the total power output, which ends up being almost ten times larger in Toowoomba then in Helidon.

The data for the solar calculator is more readily available. The results were not that varied between Helidon and Toowoomba. Slight local differences occurred between daily solar exposure and the number of cloudy days.

The problems emphasised by the case studies associated with wind power are primarily the lack of available data, a possible incorrect input for the roughness factor and the accuracy of the distribution of the Weibull factor used.

The solar power calculator appears to be more accurate though it is harder to account for weather where sunshine is required. A week of rain means a week without any power produced.

Future Work

I am currently working with the NCEA to develop a website for the wind calculator. I am hoping to further develop the calculators to increase their accuracy though they can never be completely accurate. Because of the work with the NCEA the wind calculator has been my primary concern.

There are still one or two small errors with the solar calculators that are present that will require more time to fix. Because of the follow on nature of the calculator a single problem within the process will result in no output, or a completely irrational output.

Appendix A – Global Power consumption

	Country	Power consumption per capita	
1	Iceland	28,213	kWh
2	Norway	24,645	kWh
3	Canada	17,156	kWh
4	Finland	16,780	kWh
5	Luxembourg	16,462	kWh
6	Qatar	15,853	kWh
7	Sweden	15,424	kWh
8	Kuwait	14,955	kWh
9	United States	13,351	kWh
10	United Arab Emirates	11,331	kWh
123	Nigeria	104	kWh
124	Burma	104	kWh
125	Congo, DR	93	kWh
126	Sudan	92	kWh
127	Togo	87	kWh
128	Nepal	69	kWh
129	Benin	67	kWh
130	Tanzania	53	kWh
131	Ethiopia	33	kWh
132	Haiti	30	kWh

Table 2

http://www.nationmaster.com/graph/ene_ele_pow_con_kwh_percap-power-consumption-kwh-per-capita

Appendix B – Toowoomba Weather Data

Toowoomba City 27.56 degrees South, 151.95 degrees East

Altitude 700m

Toowoomba	Mean Max Temp	mean min temp	mean temp	mean temp (K)	mean daily wind run
January	28.2	17.5	22.85	296	556
February	27.3	17.6	22.45	295.6	568
March	26.2	16.2	21.2	294.35	542
April	23.4	13.4	18.4	291.55	485
May	19.9	10	14.95	288.1	423
June	17	7.5	12.25	285.4	435
July	16.6	6.4	11.5	284.65	410
August	18.7	7.5	13.1	286.25	441
September	22.4	10.6	16.5	289.65	459
October	24.7	12.8	18.75	291.9	503
November	25.7	14.5	20.1	293.25	508
December	27.7	16.7	22.2	295.35	517

Table 3

				Days	
9am humidity	3pm humidity	mean daily solar exposure		clear	cloudy
75	57	25.5	Mj/m^2	4.9	13.1
79	61	22.2	Mj/m^3	3.9	11.6
77	58	20.9	Mj/m^4	6.7	9.8
73	56	17.5	Mj/m^5	7.5	8.4
75	57	13.9	Mj/m^6	10.3	8
76	57	12.2	Mj/m^7	10.3	9.2
73	53	13.1	Mj/m^8	12.5	7.5
68	47	16.5	Mj/m^9	14.1	5.9
65	44	20.1	Mj/m^10	13.7	4.8
66	49	22.7	Mj/m^11	11.3	7.7
66	49	24.8	Mj/m^12	6.8	11.7
70	51	25.7	Mj/m^13	5.9	11

Table 4

Appendix C – Toowoomba Expected Power Results

Wind Results

System Ratings		Month	Power Output	
		January	738.77583	kWhr
		February	748.12203	kWhr
Rated Output	1kW	March	728.10714	kWhr
Effiency	40%	April	675.97738	kWhr
Tower Height	30m	May	603.18917	kWhr
Blade Length	2m	June	620.47413	kWhr
Roughness F	0.5	July	586.65788	kWhr
Cut-In Speed	3m/s	August	627.56591	kWhr
		September	647.77645	kWhr
		October	693.84301	kWhr
		November	698.1262	kWhr
		December	705.83731	kWhr
		TOTAL 12 months	8.0744524	MWhr

Table 5

System Ratings		Month	Power Output	
		January	1276.6588	kWhr
		February	1300.2581	kWhr
Rated Output	2kW	March	1249.3094	kWhr
Effiency	40%	April	1120.1853	kWhr
Tower Height	30m	May	948.89243	kWhr
Blade Length	2m	June	987.51518	kWhr
Roughness F	0.5	July	910.73697	kWhr
Cut-In Speed	3m/s	August	1004.2421	kWhr
		September	1052.5274	kWhr
		October	1163.8102	kWhr
		November	1174.6843	kWhr
		December	1194.1804	kWhr
		TOTAL 12 months	13.383001	MWhr

Table 6

System Ratings	
Rated Output	6kW
Effiency	40%
Tower Height	30m
Blade Length	2m
Roughness F	0.5
Cut-In Speed	3m/s

Month	Power Output	
January	2734.2111	kWhr
February	1852.8366	kWhr
March	1898.0981	kWhr
April	1489.5675	kWhr
May	1133.0875	kWhr
June	1182.8635	kWhr
July	1056.4113	kWhr
August	1259.1908	kWhr
September	1325.0336	kWhr
October	1655.8061	kWhr
November	1629.0149	kWhr
December	1734.3614	kWhr
TOTAL 12 months	18.193183	MWhr

Table 7

Solar Results

System		
pmax	90	w
vmp	20	V
imp	4.5	A
isc	5	A
voc	22	v
NOCT	50	degrees C
STC	25	degrees C
FF	0.818182	
k	0.0375	

Table 8

Unfortunately the final Result calculations gave a Not a Number Response. There is a problem in the calculator and needs further time to complete.

Appendix D – Helidon Weather Data

Helidon 27.55degrees South, 152.13 degrees East

Altitude 640m

Helidon	Mean Max Temp	mean min temp	mean temp	mean temp (K)	mean daily wind run
January	31.1	19.6	25.35	298.5	271
February	30.4	19.5	24.95	298.1	262
March	29.4	17.7	23.55	296.7	252
April	27.2	14	20.6	293.75	211
May	24	10	17	290.15	191
June	21.6	7	14.3	287.45	200
July	21.2	5.3	13.25	286.4	202
August	22.7	6.3	14.5	287.65	215
September	25.5	9.5	17.5	290.65	246
October	27.7	13.4	20.55	293.7	272
November	29.5	16.3	22.9	296.05	278
December	30.9	18.4	24.65	297.8	278

Table 9

9am humidity	3pm humidity	daily sun exposure
67	51	24.3
70	54	21.3
71	52	20.2
72	48	17.1
76	48	13.8
77	46	12.2
74	42	13.4
68	38	16.3
62	38	19.9
60	43	22
60	46	24.1
63	49	25.1

Table 10

Appendix E – Helidon Expected Power Results

Wind Results

System Ratings	
Rated Output	6kW
Efficiency	40%
Tower Height	30m
Blade Length	2m
Roughness F	0.5
Cut-In Speed	3m/s

Month	Power Output	
January	414.9484002	Whr
February	374.9281555	Whr
March	333.7215745	Whr
April	191.9832457	Whr
May	139.7945799	Whr
June	164.0500122	Whr
July	169.934474	Whr
August	207.1585268	Whr
September	314.0649625	Whr
October	424.0822038	Whr
November	450.3926909	Whr
December	448.7131369	Whr
TOTAL 12 months	3.633771963	kWhr

Table 11

Appendix F – General Calculator Results

Roughness Factor	0.005			
Average 10m Wind Speed	Ground Level	20m	30m	40m
0	0	0	0	0
1	0.605871502	1.091193	1.144537	1.182385
2	1.211743003	2.182385	2.289074	2.364771
3	1.817614505	3.273578	3.433611	3.547156
4	2.423486006	4.364771	4.578148	4.729542
5	3.029357508	5.455964	5.722685	5.911927
6	3.635229009	6.547156	6.867223	7.094313
7	4.241100511	7.638349	8.01176	8.276698
8	4.846972012	8.729542	9.156297	9.459084
9	5.452843514	9.820735	10.30083	10.64147
10	6.058715015	10.91193	11.44537	11.82385

Table 12

Roughness Factor	0.1			
Average 10m Wind Speed	Ground Level	20m	30m	40m
0	0	0	0	0
1	0.349485002	1.150515	1.238561	1.30103
2	0.698970004	2.30103	2.477121	2.60206
3	1.048455007	3.451545	3.715682	3.90309
4	1.397940009	4.60206	4.954243	5.20412
5	1.747425011	5.752575	6.192803	6.50515
6	2.096910013	6.90309	7.431364	7.80618
7	2.446395015	8.053605	8.669924	9.10721
8	2.795880017	9.20412	9.908485	10.40824
9	3.14536502	10.35463	11.14705	11.70927
10	3.494850022	11.50515	12.38561	13.0103

Table 13

Roughness Factor	2			
Average 10m Wind Speed	Ground Level	20m	30m	40m
0	0	0	0	0
1	-0.861353116	1.430677	1.682606	1.861353
2	-1.722706232	2.861353	3.365212	3.722706
3	-2.584059348	4.29203	5.047819	5.584059
4	-3.445412465	5.722706	6.730425	7.445412
5	-4.306765581	7.153383	8.413031	9.306766
6	-5.168118697	8.584059	10.09564	11.16812
7	-6.029471813	10.01474	11.77824	13.02947
8	-6.890824929	11.44541	13.46085	14.89082
9	-7.752178045	12.87609	15.14346	16.75218
10	-8.613531161	14.30677	16.82606	18.61353

Table 14

Appendix G - Bibliography

TransWeb Educational Services, Noida, India, viewed 10 October 2010, <www.transtutors.com>

Forcefield, Fort Collins, Colorado, viewed 9 October 2010, <www.otherpower.com>

Emanuel, P, 1985, *Motors, Generators, Transformers and Energy*, Prentice Hall inc., New Jersey

Danish Wind Industry Association, 1981, Frederiksberg, Denmark, viewed 6 October 2010, <guidedtour.windpower.org/en/htm>

Khaligh, A and Onar, OC, 2010, *Energy Harvesting Solar, Wind and Ocean Energy Conversion Systems*, Taylor & Francis Group, Boca Ranton

Nelson, J, 2003, *The Physics of Solar Cells*, Imperial College Press, Covent Garden

Johnson, NL, Kotz, S & Balakrishnan, N, 1994, *Continuous Univariate Distributions Volume 1*, 2nd edn, John Wiley & Sons, inc., Ney York

Markvart, T (ed.) 1994, *Solar Electricity*, 2nd edn, John Wiley & Sons, inc., Chichester

Ratto, CF & Solari, G (ed.) 1997, *Wind Energy and Landscape*, A.A. Balkema, Rotterdam

Pasqualetti, MJ, Gipe, P, and Righter, RW (ed.) 2002, *Wind Power in View*, Academic Press, San Diego

Zillman, JW, 1975, *Manual of Meteorology Part 1 General Meteorology*, Australian Government Publishing Service, Canberra

Department of Administrative Services - Bureau of Meteorology 2010, *Bureau of Meteorology*, Australian Government, Canberra, viewed 5 June 2010, <www.bom.gov.au>

Lutgens, FK & Tarbuck, ET, 1995, *The Atmosphere*, 6th edn, A Simon & Schuster Company, Englewood cliffs

Horst, R, 2009, *Weibull Distribution A Handbook*, Taylor & Francis Group, Boca Ranton

De Brogue, 1937, *Matter and light: the New Physics*, Dover Publications, inc., New York

Yogi Goswami, D & Kreith, F, 2008, *Energy Conversion*, Taylor & Francis Group, Boca Ranton

Gross, CA, 1986, *Power System Analysis*, John Wiley & Sons, Inc., Chichester

Stanford SOLAR Centre, 2010, Stanford, viewed 21 October 2010 <www.pvresources.com/en/history.php>

DIgSILENT, 2002, Gomaringen, viewed 22 october 2010 <http://www.digsilent.de/Consulting/Publications/PaperDelft_DIgSILENT_Voith.pdf>

Egypt Cyber Trade, 2010, Wilmington, viewed 20 September2010 <http://www.kingtutshop.com/freeinfo/egyptian-boats.htm>

Viewed 27 October 2010 <http://bbs.keyhole.com/ubb/ubbthreads.php?ubb=showflat&Number=945349&site_id=1#import >

Vestergaard, J, Brandstrup, L & Goddard, RD, 2004, Arhus, viewed 27 October 2010 <http://www.hha.dk/man/cmsdocs/publications/windmill_paper1.pdf>

Linacre, E & Geerts, B, 1999, viewed 1 August 2010 <http://www-das.uwyo.edu/~geerts/cwx/notes/chap14/roughness.html>

Bourke, P, 2001, viewed 10 july 2010 <http://local.wasp.uwa.edu.au/~pbourke/miscellaneous/functions/>

Butter Nut Ridge Farm, 2006, viewed 15 July 2010 <http://www.butternutridgefarm.com/windmill.htm>

Gipe, P, 2004, *Wind Power*, Chelsea Green Publishing Company, White River Junction

Appendix H – Figure References

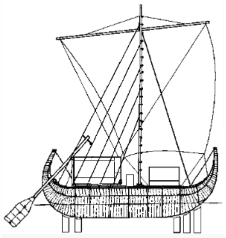

Fig 3.1 Reed Sailboat
http://bbs.keyhole.com/ubb/ubbthreads.php?ubb=showflat&Number=945349&site_id=1#import

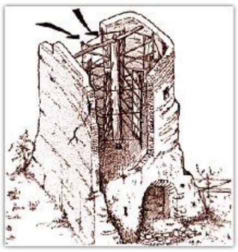

Fig 3.2 Persian Windmill http://www.catpress.com/bplanet9/eeolica.htm

Fig 3.3 Dutch Windmill http://en.wikipedia.org/wiki/File:Pitstone-windmill.600px.jpg

Fig 3.4 Halladay Windmill http://www.butternutridgefarm.com/windmill.htm

Fig 3.5 Gyromill (H-rotor) http://www.greenestchoices.com/renewable-energy-sources/wind-turbine-energy.php 2008

Fig 3.6 Troposkein http://www.tuvie.com/natura-levo-wind-turbine/#more-722 2010

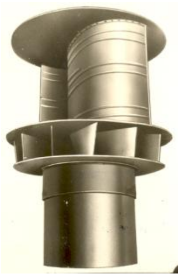

Fig 3.7 Savonius http://scienceservice.si.edu/pages/100001.htm

Fig 3.8 Three Blade Wind Turbine http://ecee.colorado.edu/~ecen2060/wind.html

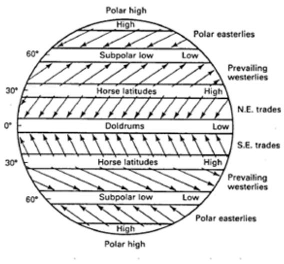

Fig 4.1 Global Wind Patterns http://www.rpc.com.au/products/windturbines/wind-book/wind2.pdf

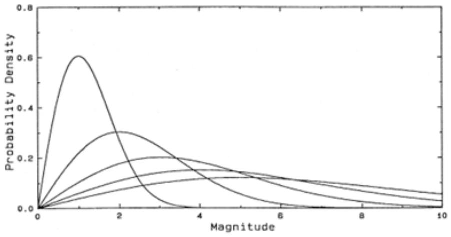

Fig 4.2 Rayleigh distribution with Differing Averages
http://local.wasp.uwa.edu.au/~pbourke/miscellaneous/functions/

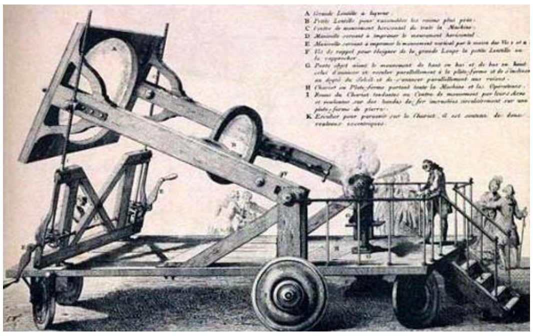

Fig 5.1 Lavoisier’s Solar Furnace www.green-planet-solar-energy.com/atom.html

Fig 5.2 Sarnia Photovoltaic Power Plant http://www.pv-tech.org/news/_a/enbridge_ups_first_solar_built_20mw_sarnia_project_to_80mw_by_end_of_2010/

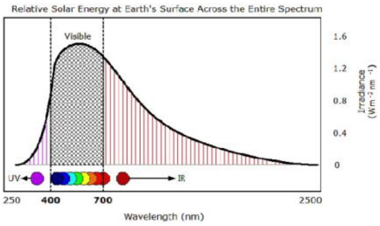

Fig 5.3 Earth’s Light Spectrum http://www.pulsespectrum-design.com/wp-content/uploads/2009/12/Solar-Spectrum-earth-surface.jpg

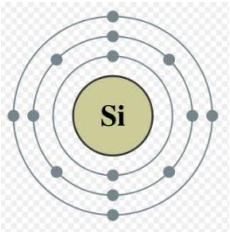

Fig 5.4 Silicon http://commons.wikimedia.org/wiki/File:Electron_shell_014_Silicon.svg

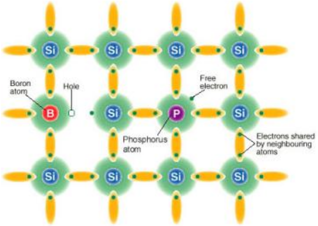

Fig 5.5 Doped Silicon http://www.rise.org.au/info/Tech/pv/index.html