University of Southern Queensland

Faculty of Health, Engineering and Sciences

Urban Wind Turbine Characterization System

A dissertation submitted by

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Abstract

With the inclusion of a 3D printer at the University of Southern Queensland, it has presented a new research path for the prototyping of intricate detailed models. One path that was created was that of urban wind turbines. These wind energy converters have been operating in the society for many years and from doing so a vast amount of variations have been created. Through a theoretical prediction of renewable energy in future exponentially increasing, this project was developed to allow for new experimental turbine models to go from an idea to a reality. This statement forms the basis of the project as it leads to the need of a characterization system that has the ability to create new wind turbine models that can meet the requirements of a specific environment.

The objective of this project is to construct a characterization that will have the ability to allow for:

- Fast prototyping of new ideas
- Incorporates natural shapes
- Test normal, turbulent and over speed characteristics
- Modify and optimize for efficiency, low noise pollution and better aesthetic appearance.

Along with these objectives, the project aims to allow other design engineers the ability to use this system. This may involve using the wind turbine characterization system as a whole or portioning the research gain in a specific area to help others with their projects. The whole characterization system can be separated into three methodology parts, design, build and test.

The first is the 3D modeling of the turbines whether taken from a 3D scanner or created in modeling software. Secondly is the constructing phase and consists of implementing a 3D printer to form the models for accuracies and alternations reasons. Lastly, the test phase involves using a controllable wind source, USQ wind tunnel or fan and a

programmable device for data acquisition and load adjustment to acquire the response characteristics of a wind turbine model.

With these three phases fully analyzed and researched, the system allows for fast prototyping of wind turbine new ideas. Through the development of two separate models the overall system was developed to satisfy the main objective of this project, give students at the university level the ability to prototype wind turbines in a fast and professional manner.

Certification

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

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

John William Sutcliffe

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Signature

22nd October 2013

Date

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JOHN W SUTCLIFFE

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Nomenclature

A	Swept area by rotor blades
A1	Swept area at the start of the free airstream
A2	Swept area of airstream after the rotor
V	Velocity at the rotor
V1	Velocity at the start of the free airstream
V2	Velocity of airstream after the rotor
E	Kinetic energy
P	Mechanic energy available from wind turbine
m	mass
v	Velocity
ρ	Density of air, 1kg/m^3
c_p	Betz coefficient of performance , 59%

Chapter 1

Introduction

Life's most persistent and urgent question is, 'What are you doing for others'

Martin Luther King, Jnr (King, 2013)

1.1 Introduction

The need to help others no matter what environment they are in was widely recognized and identified by Martin Luther King Jnr. The purpose and scope of this study is detailed in 1.3 Project Aims.

When any new creative idea is thought of, the first few steps are critically in determining whether the idea becomes a reality. It is for this reason why modeling and prototyping of ideas is a very important step in ensuring products will have a good viability in today's society. Like many renewable resources, wind has countless production companies, universities and other professions that thoroughly research in its potential. Through this extensive research it will ensure the right wind turbine system is chosen correctly for the specific area of placement.

It can be seen in today's society that there are many factors that concern the use of wind turbines in urban areas. These reasons can be of the following genre.

Urban use:

- Specific applications e.g. street lighting

- Turbulent verses Laminar airflow

- Noise issues, health issues and unwanted effects on fauna

- Over-speed characteristics

These causes will be discussed further in the detail in the sub-chapter 2.3 Extraction techniques. It is evident from just the few dot points above that many factors need to be considered when ensuring the right wind turbine is chosen for a specific environment. These turbine specifications can range from axis of rotation, pitch, aerofoils design, number of blades, length, etc. So in summary there is a great need for a development system as it will allow new models of turbines to be designed to a specific situation.

1.2 Background

Although this part of the project is not of high significance only a brief explanation will be given, it is still of some importance as it is the first step taken in a simple design process. With the vast amount of information available, the origin of a device that can transform kinetic energy contained in the wind to mechanical energy is very controversial and unclear. There are some contradicting reports detailing contraptions early as 200 AD. The first reliable information from historical sources is a type of vertical windmill used in the region of Persian Afghan border around the time of 644 AD (Hau 2000, p. 1). The figure below is of the same structural design as those used in the past and they were mostly used for grain milling.

Figure 1.2a Early Persian vertical grain milling machine, 7th century design (Shahmiri 2009)

Along with this time era there are specific claims that state an Ancient Chinese wind wheel used for pumping water to drain rice fields was developed years before this milling contraption. Though there are many contradicting information sources available, it is evident that wind energy converting devices have been utilized in the society for

many centuries. One of the major milestones in the history of wind converters is when a turbine with aerodynamically shaped blades was used to generate electricity.

Made roughly around a half a century ago, many large scale projects were undertaken by engineers. In the early 1950's a German constructor, Allgaier was one of the first to go into mass production of wind turbines. These were designed for the single purpose of supplying far reach farmsteads with electricity (Heier 1998 p. 6). From these early creations it developed a very high interest in wind turbine technology and many projects/prototypes were developed to harness wind energy.

1.3 Project Aims

Despite wind turbines having an extremely amount of time to be re-engineered, the aim of this project is to provide a system where new wind energy extraction techniques can be explored and creative designs ideas of vertical and horizontal wind turbines can be tested. Although the testing phase of this project will only consists of a controlled wind environment, such outdoor factors like turbulence can still be replicated to an extent. In saying this, turbulence can be simulated through the placing of stationary objects in a stamina flow which will create a type of turbulence, wind vortices.

Also with the use of this wind tunnel and other wind sources, the over-speed characteristics of the prototypes can be explored thoroughly. With the system fully functional it can allow for fast prototyping of these new ideas and the ability to discover the optimum extraction curve for a specific design. Another main area which this system is developed for is to incorporate natural shapes into the designs. This evidently involves using a 3D scanner to extract natural shapes that openly exists in the environment. The main reason for this is that human kind has constantly been studying 'mother natures' ability to adapt to a specific ecosystem. For example this procedure may involve studying the effects of a seed pod that has the ability float/glide in the wind to help the tree germinate its new seedlings. Other specific aims that are more relevant to the design and construction of the prototypes are of the following:

Modify and optimize prototypes for:

- ✓ efficiency
- ✓ low noise pollution
- ✓ aesthetic appearance

These design factors have an important role in determining the products viability. Along with the development of this project a study was created to investigate the plausibility of a variable pitch control system on vertical wind turbines to gain higher efficiencies than fixed systems. These types of wind turbines are labeled self-acting variable pitch vertical axis wind turbines or SAVPVAWT's for short. This study is discussed further in Chapter 4.

1.4 Specific Objectives

Along with the project aims above, one of the major achievable outcomes within this project is to allow other design engineers the ability to use this system. This may involve implementing the whole of the wind turbine characterization system or portioning the research gain in a specific area to help them in theirs.

With this statement in mind, the objectives of this project can be divided into three main methodology areas, design, build and test. Along with these three areas, outcomes of a fourth can be created that is primary based on analyzing the findings.

Below is a brief explanation for each of these three mains project areas. Refer to Chapter 3.1 Methodology for higher clarifications.

A) Design – incorporates the use of 3D modeling software like Google Sketchup and CAD

    – 3D scanning of objects using David's 3D laser scanner

B) Build – Primarily this consists of using the available 3D printer HD3500Plus supplied by the   University of Southern Queensland.

  – Other, if a suitable model exists that can withstand testing forces.

C) Test – PLC based control system with a shunt resistor load and DC permanent machine.

– USQ Water Engineering/Thermofluids laboratory wind tunnel

With these project areas, the main goal was to develop a fully functioning system with at least one test turbine and all relevant data gathered. Refer to 3.4 Time guidelines for the explicit time regions when these areas and this ambition were completed.

1.5 Conclusion

This dissertation aims to provide students at the university level as means of experimenting with new turbine technology, and design ideas that may become beneficial to them if a particular company was approached.

The construction of a fully working characterization system will allow future students to easily research their projects, and may also assists others in their projects that may include aerodynamics, control loading, data acquisition and design engineering. As briefly discussed above when the system is fully functional, a plausibility study was be carried out to test this array of procedures. The outcome of this study may be used for future design and development of variable pitch vertical axis wind turbines. A possible future study area will be the optimization of the research found from this study, primarily on these types of wind extraction techniques.

Chapter 2

Literature Survey

2.1 Introduction

This chapter will review wind energy based literature to establish information on wind characteristics in general and in an urban wind turbulent environment. Also extraction techniques already implemented and possible design ideas, the aerodynamic losses and the monitoring equipment that will allow correct data extraction from the proposed controlled wind tunnel will be researched. These are primarily based on the requirements of the research topics; data, methodology and equipment.

2.2 Wind characteristics

To successful extract energy from the wind and to justify such wind turbine characteristics as efficiency first and foremost, there are three major areas that require justification. Through the *Energy available* section of this sub-chapter the renewable energy element, wind will be categorized to what it is and how much energy in the wind is available to extract. The second area, *Wind Statistics* is primarily when and where wind will flow. Corresponding to this area, *Urban Wind Environment* is comprised of what wind factors like turbulence play important role in congested populated areas.

2.2.1 Energy available

The law of conservation of energy states energy cannot be created nor destroyed; it can only be transfer from one form to another. This refers to converting the kinetic energy contained in the wind into mechanical energy via a wind turbine. This form of mechanical energy can then be transform into electrical energy through the use of a generator setup that than can be used to power cities and homes. Along with many other renewable energy and generating systems they have a certain limit of energy that can be extracted from the source for a given setup. The credit of applying physical principles to that of wind turbines to understand this limit goes to Albert Betz (Hau 2000, p. 59).

In the between the time of 1922 and 1925 he published his findings of that the amount of mechanical energy that is available to extract from any given air stream is confined to that of fixed ratio, which is determined from the 'Momentum theory' (Hau 2000, p. 59). In summary of this theory, the efficiency of any given bladed wind energy converter is this fixed ratio of the velocity of the free stream in front of the converter to that of the velocity behind it.

Molded from the standard equation of kinetic energy, equation B.1, the maximum amount of kinetic energy that is contained within a free airstream is given by the equation below.

$$P = \frac{1}{2}\rho v^3 A \qquad\qquad 2.1$$

Where P = energy, ρ = air density 1.000 kg/m^3 normally, v = velocity of the airstream and A is the area at which wind energy is to be extracted from. To illustrate these variables and to gain a visual reference for the next few sections the diagram below is a graphical representation of what happens to airflow after an extraction technique has been implemented.
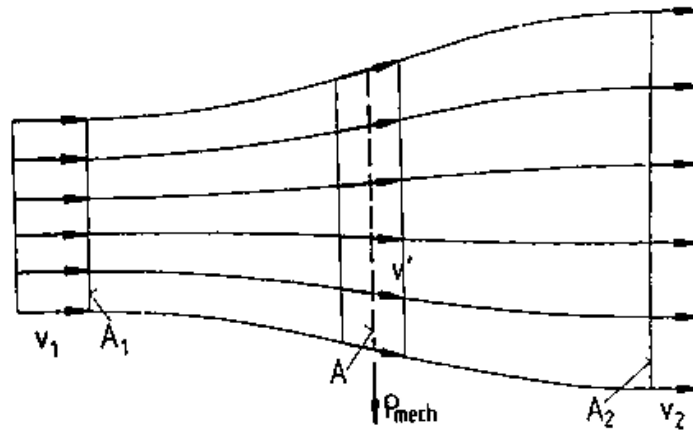
Figure 2.2.1a Flow condition due to the extraction of mechanical energy from a free-stream air flow according to the elementary momentum theory (Hau 2000 pg. 60)

Using the equations that were extracted from this diagram, Betz was able to derive a fixed portion of kinetic energy to mechanical energy. Known as the Betz factor the maximum ideal power coefficient is

$$C_p = \frac{16}{27} = 59\%$$

Also with this value it was determine that it could only be reached at $v_2/v_1 = 1/3$. With the technology available and though the use of sophisticated aerofoils, in some literature it states that 'power coefficients of 0.5 can be reached' (Gasch 2002 p. 29) in today's wind turbines. This statement will be discussed further in 2.2.3 Urban Wind Environment where types of blades will be analyzed.

2.2.2 Wind Statistics

Within this section, information regarding where can wind energy can be harness and primarily what the future may hold for such a renewable energy source, will be discussed and thoroughly reviewed. The figure 2.2.2a below is for illustrative purposes detailing the global concentration of wind energy represented by its velocity form.
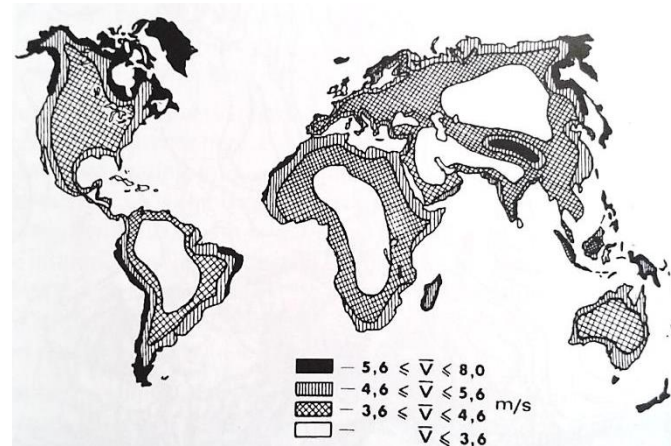
Figure 2.2.2a Global Wind Speed Distribution (Gasch 2002 pg 107)

It can be seen in the picture above, the higher concentration of wind energy can be generally found near coastal areas, a large sea mass and where mountains tend to cluster. For example in the bottom left of this image it is evident that the coastal regions of the large land mass, South America experiences high velocity winds of up to 8m/s but then the wind rapidly dissipates inland. With all this wind available only 27% of the earth land mass has suitable wind to extract energy from. Even from this only 4% might

be available for such wind farming techniques due to the harsh terrain, close proximity to cities and other non-controllable factors (Jenkins 1997 p.15). In saying these numbers, a few projects have been underway where large floating platoons have been implementing to place megawatt wind turbines offshore.
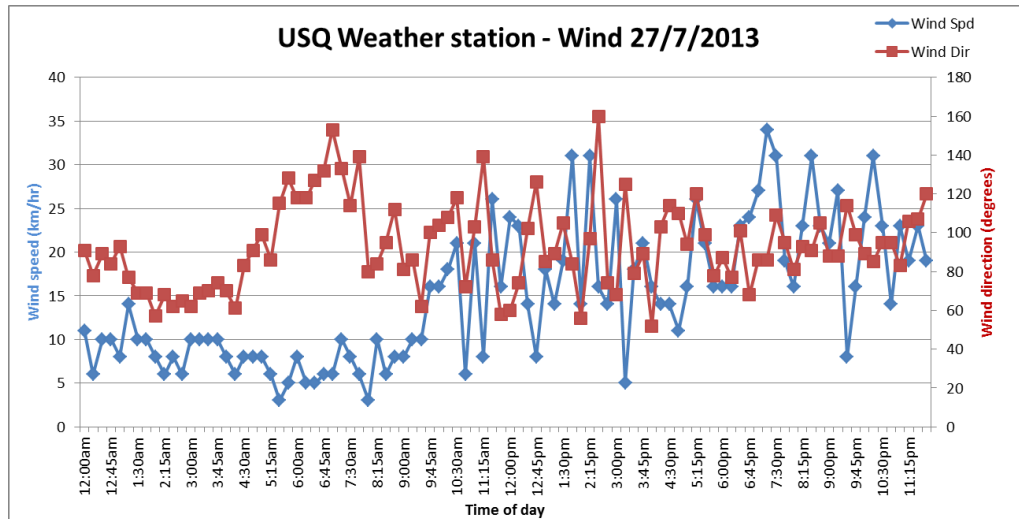
Figure 2.2.2b USQ Weather station – wind of 27/7/2013 from 12am to 11.15pm

The graph above represents the variety of wind speed and direction information of the date 27/07/2013 from the 5th floor weather station on top of the University of Southern Queensland Z block. It is evident in the above graph how unpredictable the wind can be in a normal day of operation.

A major aspect that this graph represents when referring to this projects aim, is that of the frequent change in direction of the wind. For a horizontal axis turbine only maximum efficiency is only when directly facing into the wind, or behind if downwind setup are used. This is a main leverage point for vertical turbines as most are considered to be omni-directional. This topic will be discussed further in the 2.3.2 Vertical Axis Wind Turbines section of this review. Along with this information another graph was formed to represent the data as a histogram curve.
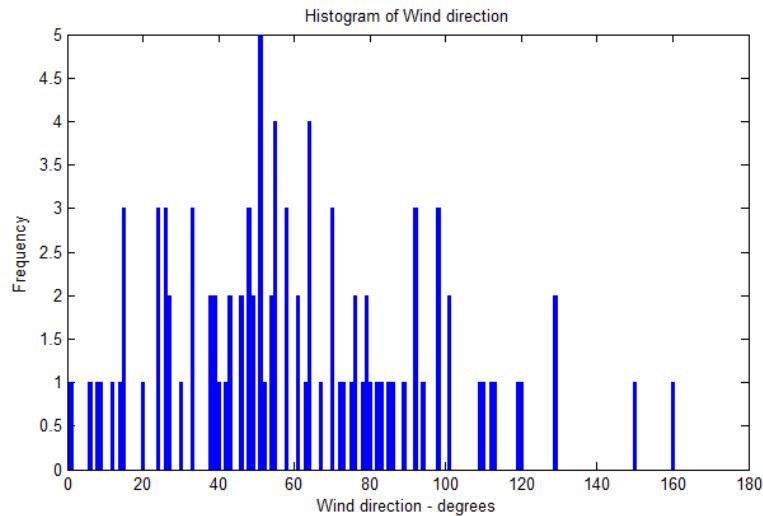
Figure 2.2.2c Histogram of the wind direction taken from USQ's weather station.

As seen by the bell shape curve above, although the wind direction can center around one azimuth degree there is still a lot of variance. In designing a turbine for its specific area of placement, one of the main factors to consider is what type of wind is available, turbulent or stamina from a certain direction. For example if a horizontal turbine was to achieve its maximum efficiency it must be pointing directly into the wind and to help maintenance cost, not a lot of wind direction variance. All these factors have to be considered when design a new turbine concept.

2.2.3 Urban Wind Environment

Following on to what was discussed earlier this segment is to review the information that is available regarding factors that reside in an urban environment and to analysis the forecast view of renewable energy.

Factors in an urban environment may be considered of being of a physical and ethical background. For this part of analyzing the environment only the physical effects will be focus upon. The ethical part will be discussed further in the subchapter 2.5 Assessment of Consequential Effects. This section was of a major research focus as it helps define what factors of the wind turbine should be tested during the third phase of the characterization system, Testing.

One of the main factors to be considered is that of turbulence. There are many different interpretations and misconceptions of lamina and turbulent airflow. For example lamina

airflow doesn't necessary have to travel in a straight line, it can be define as at any one point the wind is of a constant form. In the figure below sourced from the technical journal 'Wind Power Plants' published by R.Gasch and J. Twele it illustrates the different conditions the wind may experience when an object obstructs the flow of air. This understanding can be separated into three main event parts.
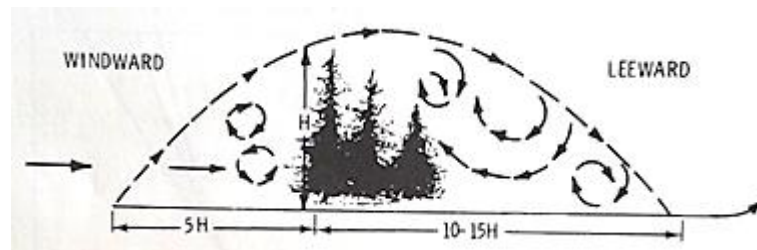
Figure 2.2.3a Disturbance of the airstream by a cluster of trees. (Gasch 2002, pg 116)

The first part, starting on the left demonstrates the upward direction the wind takes when there is ground interference. Known as a positive pressure gradient the wind is directed upwards to the higher airflow thus pressuring the air and increasing it speeds. The second part is at the top of the interference object which evidently has the highest wind velocity. For most applications this is where wind turbines systems can be installed. Lastly the third part is where the air experiences a negative pressure gradient and as a result the wind can slow down enough to that it can actually change direction. The slowing of the airflow can result in vortices/swirls and Eddie winds which can be known as turbulence. Many objects in today's urban areas can create large scaled turbulence and it is for this reason why finding an ideal location for the turbine installation is a very important task.

These objects can consist of buildings, trees, hills and other wind turbines. As stated above in the projects aim, basic stationary objects can be placed within the wind tunnel to simulate turbulence of an urban area. The physical shapes of these objects are not of high concern along as the tests are done with the same configuration and therefore the same amount of turbulence will created for each test. To help visualize the typical turbulent profile that a turbine may experience, the following figure represents the boundary layer near the ground.
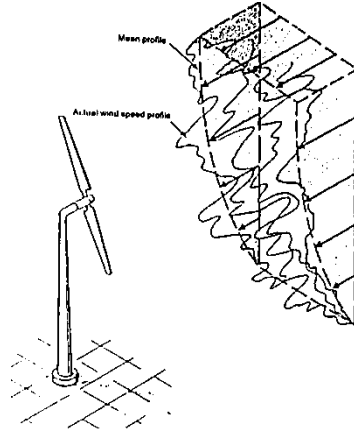
Figure 2.2.3b Vertical wind gradient (Jenkins 2000 pg.7)

Along with the visualization of the actual wind speed profile and the turbulent wind involved, the figure also illustrates the wind speeds that exist at different heights. It can be seen that at a higher altitude the wind profile has a higher speed value to that of ground level mostly due to less interference.

Another important section is that of viability of wind energy converters in the future. With a realistic view/goal of giving others the ability to use this project for future endeavors, the following literature provides support for the sustainability of renewable generation.
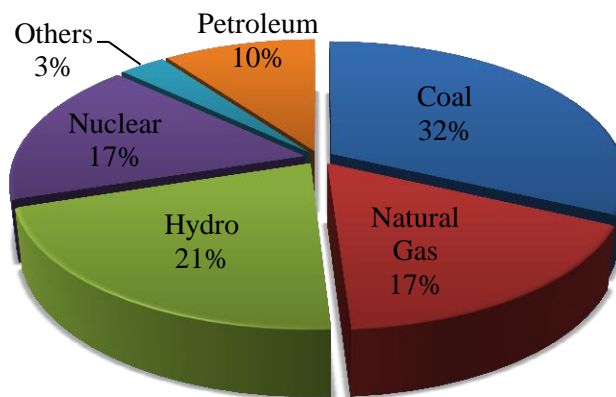
Figure 2.2.3c Pie chart of share of the global electricity supply

The above pie chart was constructed by reviewing different literature and it represents an approximate share of the global electricity supply at the present time. This basic overall illustration reveals the importance of renewable/other energy in today's market

of only 3%. Although this is value is quite small once compared to the cheaper alternative of coal, the amount of urban wind and solar projects are rapidly becoming more frequent. There are many reasons for this, some may involve financial government incentives or simply the companies/customers want a green electricity environment. To help with the forecast of the importance of renewable energy in the future the figure below gives an approximation of what should be expected in the next few deaceds. Whether this scenario becomes fact or fiction in the future, this project still will become of some relevance to help create ideas for a more renewable base future.
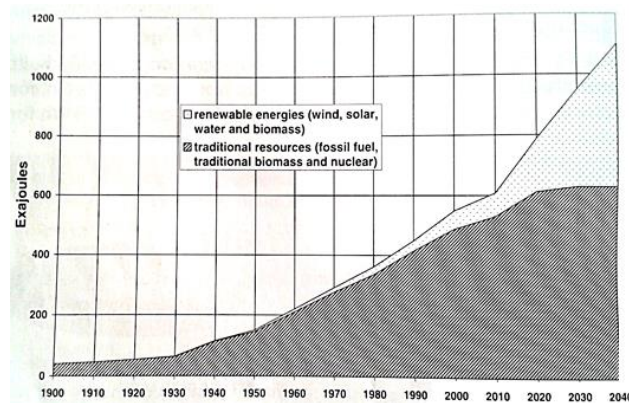
Figure 2.2.3d A scenario for meeting future global energy demand (Gasch 2002 pg10)

2.3 Extraction techniques

With a basic amount of theory behind the renewable wind energy source now established, this sub-chapter focuses on how this energy can be transfer into useable power. There are many revolutionary ideas commercially available though as stated before many have already been thoroughly explore by companies, universities and other professions. In saying this, they're three main areas which help define this projects area of interest. The first section will comment on the widely available horizontal turbines and their purposes. Also within this area, relevant information regarding wind turbines, for example suitability and range of urban implementation will be extracted.

The second section is predominantly the same context as the first though for the different axis of rotation, vertical. Within this section the two types of wind turbines, lift and drag types rotors will be discussed and their characteristics explored. One of the main differences that this section will review is that of self-starting turbines. This a

major influence in the selection phase of designing certain wind turbines since in fact most lift type vertical wind turbine require some sort of start-up system. This is due the blade profile having a high performance at high rotation speeds which evidently lacks torque at low wind speeds

The third is a major area for quantitative research and testing of news ideas. This is one of the major keys aspects that this project will focus upon after establishing a fully functional characterization system. Losses in any system are of a great importance to any company and therefore require a substantial amount of focus. This statement can be easily reinforced by a finding a company found on efficiency.

For every $1 spent on efficiency, you'll save $3 on energy costs. (Efficiency 2009)

For next the part of this literature review, refer to diagram B.2 of the appendix B. The illustrative diagram basically represents the efficiency curves of different types of turbines under different wind speeds.

2.3.1 Horizontal Axis Wind Turbines

With its increasing popularity, horizontal axis turbines can be seen as the most widely available and used type of a wind energy converting technique. As stated in 1.2 Background of this report, these types of wind turbines also known as windmills and wind wheels have been considerably used for a very long period of time. Although some vertical axis lift and drag type designs have been experimented with by utilizing them horizontally this area will focus on the more common bladed turbines. From this review of horizontal axis wind turbines it will become more evident the availability of designs and how they can be adopted into urban areas.

As seen in figure B.2 from the appendix B, HAWT's can range from single bladed rotors to a standard American wind turbine that are mostly used for farming and water pumping purposes. The fact that the three bladed rotors have a higher efficiency than the American design windmill; it just reinforces the idea that turbines are design for a specific task and environment. As the American requires a large amount of torque and robustness for water pumping and the three bladed rotors are primarily used for

electricity generation with a gearbox configuration. The following image is of 3D model of a wind turbine created in Google Sketch Up 8 with added captions.

Figure 2.3.1a 3D model of a wind turbine through using the program Google Sketch up 8.

Developed in the first part of this projects methodology 'Design' section and through using the free version of Google Sketch Up 8 this 3D model resembles a basic construction of a large HAWT system. Most horizontal designs can be broken down into these five parts: the rotor, nacelle, tower, switch box and foundation. With these five parts in consideration, the type of turbine system installed can be set to achieve maximum efficiency of researching purposes and/or maximum profit for commercial selling. The following image is an example of already existing urban turbine that is commercially available.

Figure 2.3.1b USQ's urban wind turbine

This wind turbine is located outside the administration block of the University of Southern Queensland and provides a great example for a standard structure of an existing urban wind turbine. Using this standard design, this project can be used to develop concepts with less turbulence and major decrease amount of noise pollution. All of which will stay at the small scaled model level for the length of this project for health and liability reasons.

With the development of new designs and the research that follows of wind turbines every year, this project will help satisfy the need of a development system for students at the university level and can also be used as a teaching tool for other types of students as well.

Using the above statement as a guide and a main project objective, the ideas gain in this particular research area of a horizontal axis wind turbines can be used as a teaching tool using a standard 3 bladed turbine. Although there any many types available, (refer to figure B.2 of Appendix B) it is most likely the students would have previously encountered these common bladed turbines for generation purposes. Whether this interaction is of urban size or large scale it still reinforces the idea that this can be used as a guide/teaching tool for how wind energy can be extracted.

In the test section of the methodology, 3.1.3, a graphical user interface program is developed to give the user a visual reference of the loading and power output of the test generator. With an easy to use touch screen, it will enable the user to quickly test and re-test different wind turbine prototypes. The main purpose of this basic view is to get more people involved in engineering and the renewable side of electricity generation.

With more people realizing the simplicity of adding their own wind generation system to their roof or farm, these simple turbines are becoming more readily available. For example a standard electronics store today can have a range of wind turbines from 200 W and upward. Though these systems are easy accessible and quick to install finding the optimal location for installation can be hard. A reason for this is that the location for urban placement must try to concede with the consequential effects. This will be discussed further in the chapter, 2.5 Assessment of the Consequential Effects.

2.3.2 Vertical Axis Wind Turbines

Although vertical wind converters are becoming more frequently available, they are still a minority among wind turbines when compared to that of horizontal axis. With new revolutionary design projects being developed, the feasibility of VAWT's overtaking HAWT's in the sense of commercially availability, is still plausible in the distant future. This is one of the main points of creating this project as it will fast prototyping of new concept ideas for feasibility studies.

As stated briefly above in 2.2.2 Wind Statistics at the moment the only large advantage/leverage to select vertical over horizontal is the fact they are some are omnidirectional. For urban areas this is the greatest trait for a wind turbine to inherit as it will allow better performance from rapidly changing directions of turbulent wind.

Primarily there are two basic types of vertical axis wind turbines, lift and drag. Despite the fact there are some vertical wind turbines that have a combination of these two, they still were developed from the concepts of them.

Predominantly a drag type wind turbine is the easiest concept to understand, build and test. The main reason for this is that some have a basic design involving two parts that can be easily built and tested at low winds. In many cases, the blades of these wind turbines are in the shape of two semicircles, also known as a Savonius design. Referring to the diagram, a drag type is defined as a turbine that to get rotation one side of the axis has to have a higher drag coefficient than the other. The example below is of a drag type wind turbine called an anemometer.
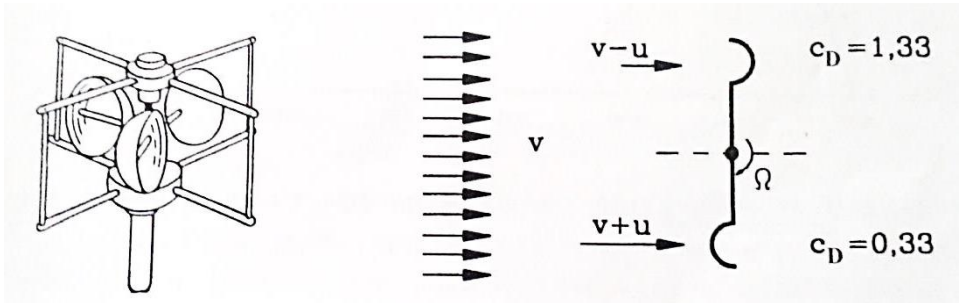
Figure 2.3.2a LEFT- Cup anemometer RIGHT- substitute model (Gasch 2002 pg32)

This device is widely used for wind speed readings. It is evident on the right side of this diagram that the drag coefficient, c_D, illustrates the statement above about one side having a higher coefficient than the other. Basically to revolve, the driving force on side must be greater than the drag force on the other. For a visual reference, a water wheel works by the same principles, force from the water pushing onto the paddles outweighs the drag force above the water level. To calculate the force on one side of the turbine the following equation is used.

$$D = c_D \frac{\rho}{2} a w^2 \qquad (2.2)$$

Where D = drag force, ρ = air density, a = swept area and w = (v-u) or (v+u) resultant / stream velocity. Using the known values of the drag coefficient, density, area, wind velocity v, and the power equation below a drag type turbine can be simulated for all tip speeds. Seen in figure B.2 of appendix B, a Savonius drag type has a rather low tip speed and low rotor power coefficient.

$$P = (D_{dr} - D_{sl})u \qquad (2.3)$$

In this power equation D_{dr}= driving force, D_{sl} = drag force and u is the rotor speed. Using this equation different design concepts can be optimized and tested. The second type of wind turbines is lift. These in general can achieve a higher power coefficient as evident in the figure B.2. One of the most common vertical axis lift type wind turbines is the Darrieus. In its original oval shape or H-rotor shape these lift types work by implementing their aerofoil shaped blades to create a rotational lift force. Another example of a turbine using these types of blades is a helical turbine. The two images below are of helical model developed in Google sketch up 8 basic at different rotated angles.
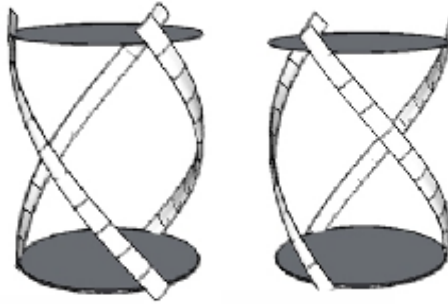
Figure 2.3.2b Helical turbines developed in Google Sketch up 8 basic

The main idea behind taking a simple H-rotor and twisting it is for the self-starting of the wind turbine. As seen in the example above the start of one blade overlaps the end of the other. This enables the rotor to always have a small turning force no matter the direction of the incoming wind. In a construction sense this design is very complex when compared to that of a simple Darrieus. The main reason for this was found during the designing of this model as a lot of time was consumed to keep the back edge of the aerofoil on the same surface as the rotation of the rotor. In other terms to keep the helical shape perfect, a new aerofoil was designed accordingly to the radius of the rotor so it can be curved correctly.

To calculate the amount of force these lift types of vertical axis wind turbines use as there driving force the simple equation below can be used. This aerofoil lift equation can only be implemented for one blade and not the entire rotor.

$$L = c_L \frac{\rho}{2} a v^2 \tag{2.4}$$

Where L =lift force, c_L = lift coefficient, ρ = density, area = length of blade x width of aerofoil and v = velocity. These lift coefficient values are specific to each different angle of attack and the actual shape, camber and length of the aerofoil. Similar to that of the drag type turbines, the higher the driving/lift force is to the drag force the better an aerofoil will perform. For most aerofoils this occurs in the low positive region of the angle of attack. Using this basic equation and modeling software, turbines can be simulated to give an approximated power output and efficiency.

Two examples of a combination of lift and drag type are: Savonius and Darrieus both on the same axis or a Savonius fused with a Darrieus. Through combining two turbines

the overall model can exhibit a more of an averaged performance over a range of wind speeds. This is because in both cases the Savonius will provide high momentum in low winds and the Darrieus will peak in high winds. The term averaging is used lightly as although the advantages of both are carried across the disadvantages are as well, but by how much is based on the design of the turbines.

From the above discussion about lift and drag type vertical axis wind turbines, for experimental reasons both types will primarily be used. Discussed in the later sections two turbines are created. Known as Project Seashell a drag type prototype was developed and through conducting research on a SAVPVAWT a lift model was tested. will be performed. A self-acting variable pitched vertical wind turbine is a type of Darrieus H-rotor that gives the ability to pitch each blade at its optimal angle for different angles of rotation.

2.3.3 Aerodynamic losses

This is a very important factor in any system that tries to achieve a good performance and interacts with the wind. Systems that have the same principles applied to that of wind turbines are airplanes. Basically the propeller and wings of a standard plane will face the same aerodynamic losses as a wind turbine. For example the wing tips of a plane and the blades tip of a turbine both experience tip vortices losses that lower the performance of the machine. The image below is a vortex model of a horizontal wind turbine.
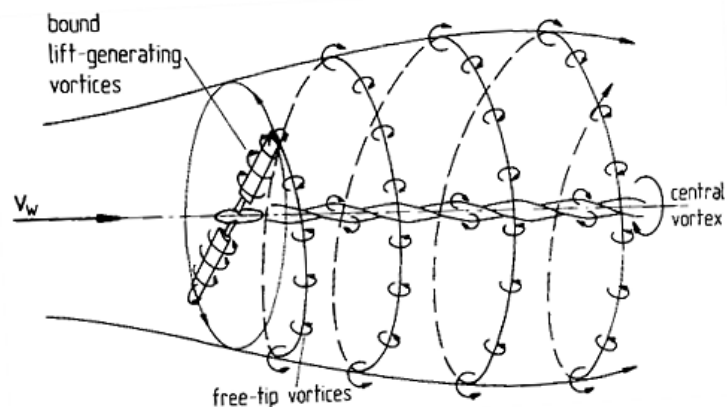
Figure 2.3.3a Vortex model of rotor flow (Hau 2000 p.74)

The multiple flow structures behind the two bladed wind turbine are illustrated above. This diagram represents three main vortex structures and how they flow after being created. The lift-generating vortices are bound around the aerofoil blades and are essential for turning. Located at the edge of the rotor wake are the strong tip vortices and at the root of the turbine the central vortex structure is developed. Among these vortices, the tip and root vortices have been studied in different investigations over the past few decades with root structure generally not as important as the tip vortices (Arjomandi M 2013). The main reason for this is the distance between where each set of vortices are created and destroyed is smaller for the central than it is for the tips.

With strong tip vortices being at approximately seven times or greater than the wind speed there has been some investigation into the plausibility of wing tips. Using the same principle as wings tips on large jet airliners these are designed to reduce the amount of drag produced from having a large vortex structure behind each blade. In saying with more research and experimenting of different design concepts, such plausibility of wing tips may become a positive investment than what some studies have shown as a different type of wing braking system.

An aerodynamics loss that is not illustrated within the flow structure of 2.3.3a, is the turbulence created by the tower. Although this turbulence only greatly affects downstream wind turbines it can have a major influence on the performance of that system. For urban use, the small poles or structure that hold the prototypes will have little influence in upstream turbines and therefore will not be considered as a importance issue. However the structure integrity will be, as the holding configuration must withstand high wind tunnel speeds.

2.4 Monitoring equipment

This sub-chapter will focus upon what types of metering is available for both wind and power readings. For the types of equipment required for generator testing, a PLC was investigated.

A programmable logic controller system is implemented within the testing area of the methodology. There are two types of PLC's that were easily accessible, a Siemen S7

1200 AC-DC-Relay and a DC-DC-DC version. Refer to 3.1.3 Test for the verification on which one was applied. Also with these two PLC's being of common S7 1200 versions, it meant an only single professional controller software could be researched and implemented that could be used for both. Siemens Simatic Step7 V11 is a micro controller software program in the TIA portal that utilizes blocks to perform a range of commands. For example the, move memory blocks, perform calculations, control pulse width modulated signals, clock bits and other commands.

The next set of equipment investigated revolves around measuring the controlled environment of the testing area. Primarily only two pieces of equipment were required for this for action, anemometer and a density meter. As discussed earlier an anemometer is a device used to measure the wind speed. This device will be widely used during the testing phase of each wind turbine prototype and they can range from a simple cup, bladed turbine to a laser anemometer. The second most important piece of equipment is an air density meter. Although a density of 1 kg.m^{-3} will be assumed for most basic calculations, this device will be used when any claiming of results like turbine efficiency is required.

Figure 2.4a Weather multi-meter including anemometer

A good example of these two devices together is a weather multi-meter, illustrated in the above image, which has a ranged of useful measuring equipment. Some other tools that these multi-meters can be equipped with are a barometer, temperature and humidity sensor. With all these sensors and PLC system required for testing, some other basic equipment like hook up wires, stands and power supplies are very much required.

2.5 Assessment of Consequential Effects

The main outcome of this project is to allow ideas become a reality in a fast and professional manner. If a design concept was to exceed past the small scale modeling stage through achieving exemplarily factors like efficiency and sound reduction, the model must then meet the requirements of urban and social environment consequential effects. This chapter is separated into two main areas of focus. The first part directly relates to the consequential effects that this projects models will foretold onto the society and the second is the ethical responsibility of the owner of the wind turbine.

2.5.1 Consequential Effects

Although this system can be used to model any size of a wind turbine, the overall project caters for more of the small commercial products than off shore giants. In saying this, only some of consequential effects that occur with the large wind farms have to be considered. This refers to the noise factor, sleep disruption, the studies on epileptic cases and radio interference. These are very important factors when considering the available locations for placement of standalone systems.

With large wind turbines the blade tips can reach a considerable high subsonic speed due to high tip speed ratio of around 7, see figure B.2. For example, a wind speed of 10m/s or 36km/hr can influence the blades of the turbine greatly such that the tips can be spinning up to 70m/s or 252km/hr if appropriate air breaking and loading techniques are not applied. Although some designs today do allow for quiet revolution at these high speeds, it is still evident that small scale version will make some noise when in operation. This low frequency noise referred to as a "swoosh" or "whoff" sound is mostly created when the high pressure wind meets the low pressure at the trailing edge of the blade and also with partial influence from the gear box and generator.

Granting the fact that the next two consequential effects of a wind turbine are of a rare occurrence their outcomes can have a large medical influence on those affected. With only a few studies on how urban wind turbines can have an impact on epilepsy and sleep disruption, the following will described how well placed turbines could result in these issues.

Due to the fast turning blades and with an appropriate positioned light source the turbine could be considered as an epileptic problem. Either through directly looking at the energy converter or even the shadow of the system with the blades continually interrupting the light source an intense flashing occurs. For obvious reasons certain types of horizontal and Darrieus lift wind converters that have these fast turning blades aren't recommend for homes with people that may be affected. Some drag Savonius converters can be optional, because due to their slow turning blades and their bulk build they often do not let any light through and thus not causing a flashing effect.

Sleep disruption caused by wind turbines can occur for multiple reasons, vibration and noise. As discussed above noise is a very important factor in determining the correct location of the wind turbine. Although some new slow turning wind turbines have considerably reduced this noise effect to zero without a correctly fitted base the second factor can occur, vibration. Without a firm foundation the turning of the model can create a moderate vibration if placed on a roof of a house.

Although in these two cases the highest occurrence for these consequential effects is from large wind farms with the right position they can happen in the urban environment. Another issue is that of radio interference. For most applications urban wind turbine are placed on top of roofs where the blades may interfere the reception of the antenna either for commercial television or communication purposes.

A factor that is very relevant to urban wind turbines in general and greatly improves their finical success in the society is aesthetic appearance. For urban situations the aesthetic appearance of a wind turbine may not be appealing to its surrounding. With this is mind, the main outcome of this project will allow for such visual interesting wind turbine models to be prototyped in a fast and professional manner.

When designing urban friendly wind turbines all these factors should be taken into consideration so the placement of these turbines become easier and in doing so becoming more commercially available. Although a well-placed turbine should be able to avoid such factors, a model that reduced these effects may have an economic advantage.

2.5.2 Ethical Responsibility

To ensure that the placement of the vertical and horizontal wind turbines is suitable for an urban environment, an ethical background check must be developed. As stated above, responsibilities that refer to low noise pollution, aesthetic appealing, the epileptic condition in some cases and the radio interference must be adhered to. Two of which are the highest of concern for this project and in general to urban wind turbines is that of noise and appearance.

Although there are multiple case studies reviewing the effect of wind turbines with radio interference and epilepsy, these factors tend to more towards the large scale generation than under 5kw urban designs.

Another consequential effect that the owner of the turbine should be responsible for is that of the general safety of the public and animals. Although this project doesn't directly relate to such an issue the outcomes of a model can. If this advancement happens from model to full size the Internal Standard, IEC 61400 Requirements for wind turbines should be sourced and analyzed.

Chapter 3

Research Design and Methodology

With a large amount of information and research behind how wind energy can be transformed though the use of turbines, this chapter focuses on how the characterization system was created. Starting with the methodology, it describes how the system functions and what steps were required to go from a simple idea to a small scale working model. Secondly is the assessment of the risk involved through creating such a system. Then lastly the resource requirement and time guidelines are discussed.

3.1 Methodology

The following subchapter is the methodology behind the characterization system and is separated into three mains project area. These three simple research areas of design, build and test and they primarily form the basis of this project. With the implementation of the procedures developed an model idea will be evaluated, a SAVPVAWT: self-acting variable pitch vertical axis wind turbine. Along with the testing of the system a project called "Project seashell", which will be explained later in Design part, was constructed parallel with the system to help ensure all parts were considered during the developing of this system.

3.1.1 Design

The design sector consists of incorporating the use of 3D modeling software like Google Sketch up, Creo and CAD, and also using a 3D scanner if a suitable object with idealistic turbine blade properties can be found. The 3D scanner implemented for the use of scanning of objects was that of the David's laser scanner. Kind regards are given to Dr. Albert Chong and Dr. John Leis for the lending of this apparatus. Although the quality of the 3D image was restricted by the low resolution camera used, this scanning system was still of high importance. The main reason for this reason for this was it was

a simple and fast process to take an object from the environment and then for the scanning software to create a model ready for 3D rendering.

As seen in the images below the David 3D scanner (David's 2013) has a quite simple setup with a stationary web camera, a back board of reference points and the object positioned in the middle. What is not seen in these images is the line laser used. The following three steps were the initial setup of the scanning apparatus

1. The camera used (web cam or any other video capture device) is positioned so the dots on the calibration board can all be seen.
2. Using the camera the software calibrates the captured image so it can extract exactly the size, distance and angle of the backboard.
3. The object is placed in the middle of the two calibration boards. Now the scanning can commence
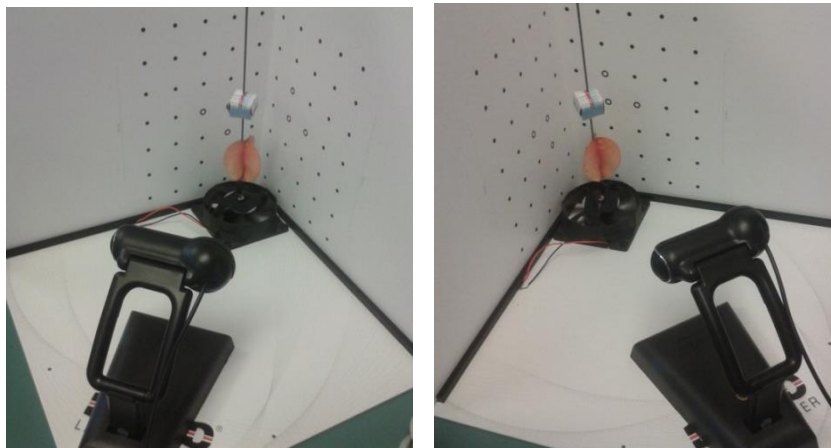
Figure 3.1.1a Two images of the setup of Davids 3D scanner

Using a line laser in a type of vertical sweeping motion at an appropriate angle above the camera, the scanning software can read the distorted line from the laser as it reflects off the objects surface to the camera. This creates a 3D shell of one side of the object. So with the implementation of this basic concept over approximately six times at different angles of rotation, (depending on the complexity of the object), a full 3D object can be digitally recreated. The converging of these 3D shells was completed using the David's scanner software. This basic stitching software required the user input to decide exactly were each shell/ wireframe should be placed on the overall project. If

an appropriate turn table is implemented than the software can automatic construct the 3D object through the user input of the turn angle (30°, 45°,etc). For areas that are missing the program will construct a shell to bridge these holes.

Seen in the images above a rod with a cardboard box taped to CPU fan was used as a cheap alternative to a turn table. The main reason behind the use of the slanted cardboard box is that after a few trial runs and different models it was determined that with similar shaped objects (three sided seed pod) a type of reference object was required so the software can join these multiple faces. Otherwise for example the software will join face1 with face 3 as they may have similar build.

Figure 3.1.1b Finish 3D model of a seed pod turbine

The model above is of a multiple three sided seed pods on a rod which were scanned individually. After extracting a digital version of these seed pods, object and material files (.obj and .mtl) of a certain object it can be imported into most 3D modeling software. Due to cost constraints the free version of Google sketch up 8 was used to model and re-shape the object so it can be ready for the next stage. Using the above 3D model of the seed pod turbine, the idea of extracting natural curves from the environment was fulfilled.

After this, a type of cross referencing analysis between used vertical wind turbines and this seed pod creation was undertaken. This was a major part within this project as it consumed a considerable amount of work hours modeling and ensuring that when it progresses to the next stage it will all go together and work effectively.

Through this visual inspection analysis, it was determined that the natural outside arc of the seed pod and also the variety of surface deformation on the blades was to be conveyed across. With these design considerations added to the overall design, an idea of better performance over a larger range of wind speeds was introduce through the use of multiple and scaled blades. Named project Seashell the images below illustrate the vast capability of the modeling software.
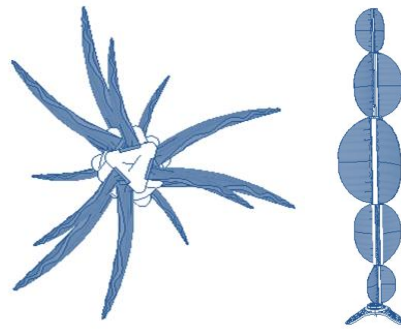
Figure 3.1.1c –3D Google Sketchup model

Using the information extracted from the literature review of this project the curved blade shape from the Savonius and the arc of the Darrieus vertical axis wind turbine was similarly constructed through using a 1:2:3:2:1 type of scaling and placement of blades. Also seen in the above 3D model diagram, the turbines blades have been design with the rough edges from the original seed pod. This type of aerofoil forming gave the blades a sinusoidal sea shell design or crinkle chip like effect.
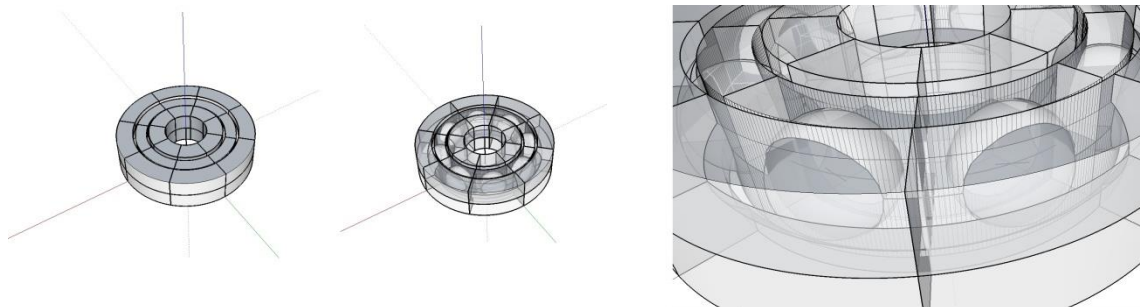
Figure 3.1.1d – 3D model of a ball bearing

Using the basic version of Google Sketch Up 8 a bearing was developed. This bearing will help the turbine rotate freely with little friction. One of the many achievements

throughout this project was the actual printing of this object. Discussed in the next section a 3D printer with the capability of printing a fully working model was used. Designed with eight 2mm diameter balls and an outer diameter of 10mm the bearing was constructed without any flaws. After thorough cleaning with hot water, ear buds and pins, the wax was removed and the bearing was fully operational.

3.1.2 Build

After the 3D model above was finalized, thoroughly checked and a Standard Tessellation language, .stl file was created. Primarily this stage involved implementing the available 3D printer HD3500Plus supplied by the University of Southern Queensland. Although this printer was available during the development of this project if a suitable model exists that can withstand testing forces applied by a wind source than this system still can be used. This also refers to using dissimilar 3D printers or other methods of prototyping, for example CNC.

Two of the main reasons why this particular method of modeling was chosen, were that of its availability and the resolution that these 3D printers can construct models at. For example the printer used within this project is the Projet HD3500Plus by the company '3Dsystems' which has a printing resolution called 'XHD mode' that is able to print at 694 x 750 x 1600(xyz) DPI (dots per inch) or in other terms it prints 16μm thick layers of plastic. To visualize this layer thickness human hair can range 17μm to 150μm and standard printing paper approximately around 100μm in thickness. The image below is of the 3Dsystems printer.

Figure 3.1.2a ProjetHD3500Plus Printer

With this printer available a full working model can be created up to 298mm, 185mm, and 203mm. Although these measurements may not fit a particular model, using the first step again the turbine can be separated into collapsible parts and then rebuilt later using a type of bonding agent, super glue. To test this project area and the printer, the seashell design from part one was deconstructed and then printed. Firstly the model was loaded into a slicer program which virtually develops the layers to be printed. Then the system will read this file and start the warm up process. This is basically a 2 hour process and it is to ensure all of the plastic and wax is in a liquid form to start ejecting out of the nozzle. With this particular printer it will first print a layer about 2mm thick of wax and this is to ensure that the model will not slide when in operation.

Figure 3.1.2b The outcome of the 3D printer after 8 hours

The image above is the produce after an 8 hour print job. As briefly mention above and now evident in this image, another reason why good 3D printers were included in this project was of their ability to print working models. This refers to the printed bearing, as the wax substance which is used as a support structure and gives the plastic a surface to print on can be melted away later. This gives a lot of opportunity to print impossible objects no matter the complexity of the model.

From this piece of aluminum with plastic and wax adhere to it, the seashell project started to take shape from its earlier digital form. After the base plate with the model still on it was extracted from the machine, it was then placed on a frozen surface. Through completing such an action the aluminum will contracted in size just enough for the wax base of the piece to peel/crack off. The second step was the melting of the wax and this process was done in a special type of oven that has a set temperature of 60°C. The main reason for this low temperature is that it is preferred that only the wax is melted away and not the actual plastic model. From this the piece are placed into an ultrasonic liquid cleanser or a smart deep fryer to further clear any wax inside the model, for example the bearing.

The use of the two heated elements above, only work to an extent as they only remove the large quantities of wax. So to ensure that only the plastic model is left, the pieces may require the following treatment.

- A warm soapy water bath for clearing the oil
- A thorough scrub with a toothbrush or paper towels.
- Toothpick and cotton bud for small places, e.g. the casing around the balls, in a bearing.

With the pieces cleaned, the model was ready to be constructed. As seen in the following image when the plastic is fully clean it is of a clear appearance. This is only due the type of plastic used to print with. Through using the Projet HD3500 the plastic itself used was the strongest type of material available for this type of printer. Other printers may use PLA, poly lactic acid and ABS which can be in various colours. For 3D printers with lower resolution the models may require surface treatment for

aerodynamic and accuracy reasons. This may include using sandpaper to smooth large edges or an acetone surface smoothing technique. These methods weren't required due to the high resolution of the printer used for the bulk of this project.

Figure 3.1.2c Finished clean turbine parts

It was found during the reconstruction of the turbine that due to the model being created through printed layers of plastic it had a perfect porous surface for super glue to adhere to. Using this simple bonding agent, the blades adhered to the main rotor axle almost instantaneously. Due to a lot of time spent in the design phase it ensured that when the blades where to join the axle they could fit accurately. One of the main design features that were implemented to guarantee this was that of an extruding base on the blades and guide veins in the axles. Basically a large trench joint or housing joint was used to ensure the blades could not twist when under load and during construction.

The finished vertical axis wind turbine that was extracted from a seed pod and then remodel in Google Sketchup is displayed in the image below along with its 3D digital model on the left.
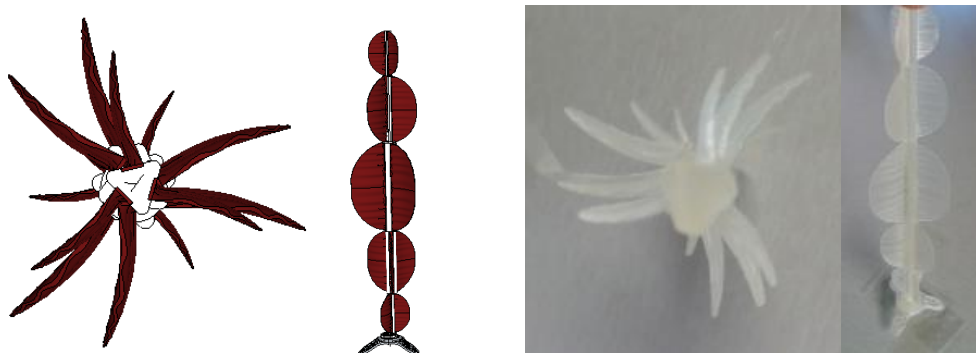
Figure 3.1.2d– Top and side view, Left: 3D Google Sketchup model, Right: Physical printed model

These two images is the pinnacle of this research project as it reveals that a simple idea of an intricate turbine design becoming a reality that is ready for testing. With the base tripod only for holding purposes the design is ready to be fitted to a generator configuration.

As discussed earlier in the design section of this project and now evident in the above images how the blades are augmented and scaled around the axle. The idea behind the offsetting of the blades is to help with the self-starting of the turbine as it enable the rotor to experience some rotational force no matter which direction the wind is coming from. This was a crucial part of this project as it is a main goal to design turbines fit for urban environments where the wind direction varies greatly.

Also apparent in the above images is the scaling of the blades with respect to each other. This design aspect theoretically was to improve the efficiency of the turbine over a large wind speed range. Basically it was to average the performance of the turbine over this range by adding different size turbines onto the same axle which perform better at different speeds. For example the large middle will perform better at low speed wind and to compensate for the high speed the smaller turbines where added.

3.1.3 Test
With the first two steps fully operational the last main project area of this project is that of testing of the turbines. This area was of the highest time consuming part of the whole development system as it consisted of a lot of research about programming a PLC and testing a DC machine. To ensure the cost of purchasing inadequate equipment and time wasting procedures was kept to a minimum a major planning process was implemented. This involved researching the different types of equipment available, like that of generators, PWM's, motor controllers, etc.

3.1.3 (i) Programmable Logic Controller
With the availability of multiple PLC's and their different configurations it was evident within this project such a device will be the main controller of the loading. There are two mains reasons for this: the first is the certain PLC's have a pulse width modulation function that can be controlled, and the second reason is for the analog data acquisition

function. This data function was used to record wattage readings so they can be used later for comparisons.

The next step of the planning process was which type and version of PLC to implement. It was evident after a few loading tests that some with a mechanical relay like the S7 1200 AC, DC, Relay was to slow for PWM operation and the relay contacts would wear to easy. Although that this PLC has relay outputs that can switch up to 24v at 1 amp a slightly different version was chosen with standard outputs. A DC,DC,DC S7 1200 PLC (1214c) has 24 integrated input and outputs which will are used to monitor the performance of the generator through the optional analog input add on and to control the loading of the generator through pulsing a switching device.

After researching into the many switching devices that are widely available it was decided upon that a solid state relay will be used. Although electrical components like MOSFETS and transistors were tested it was more beneficial to have the switching of the load separate from the power supply of the PLC. There are many other reasons for this separation, like leakage current interfering with the data acquisition of the generator. Also with a large solid state relay emplace it will enable for higher loads up to 100V and 40 A, so it will be able to handle future improvements of larger models. The following image is of the solid state relay and the PLC used.
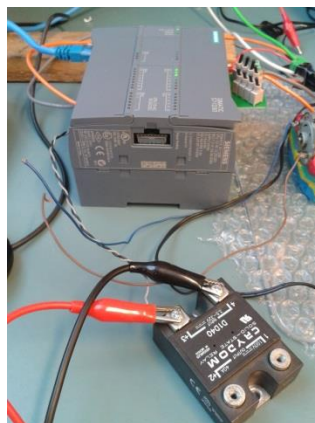
Figure 3.1.3.a – Top and side view, Left: 3D Google Sketchup model, Right: Physical printed model

The load control of the generator was only a third of the main development of the testing phase and the second was the data acquisition of the generator. To ensure that

the solid state was working properly with the PLC before any more steps were taken an oscilloscope was used to view the pulses. As briefly stated above this data recording was perform through using the analog inputs of the PLC. This input is voltage reading in steps of 3200 = 1V. Although it was found that the losses in the solid state relay was enough for the small type of generator used, a reference resistor was implemented. With this added component in the circuit the voltage across it could be read by the PLC and then the program (discussed later) can manipulate this signal. From this the voltage and wattage can be calculated. Basically using the ohms law and the power equation the wattage was calculated by using this simple equation

$$P = \frac{V^2}{R} \tag{3.1}$$

During the testing of the data acquisition system, two values of loading resistors were used. The first was a 1 ohm 5 watt resistor and although the generator was still tested to an extent the voltage readings was immensely small. The second resistor tested was 100 ohm 5 watt which developed an exceptional reading of the voltage signal. While this method of reading a voltage across a resistance does not represent the complete loading of the generator as the solid state relay has a small voltage drop, it still can be used for comparison testing of different wind turbines. From using the same setup, a variety of turbines can be tested and compared to find the optimal shapes.

3.1.3(ii) Programming the PLC

With the exact type of PLC chosen the programming for this microcontroller commenced. This entitled using two computer aided software programs to logically control and display the results of micro-controller/generator system. Siemen's Simatic Step 7 using the V11 portal was the first software program to be experimented with and basically allows the user to fully control all the functions of the PLC. Using an array of logic blocks the user can create a program that interfaces with the controller's memory, its on-board functions like clock and pulse width modulation, and also program to calculate standard mathematical operations. After a few experiments and researching how Step 7 can interface with the PLC, a program was developed to fit the following criteria:

- Create a PWM signal

- Step this signal with time or user interface

- Manual override buttons

- Read the exact voltage level

- Calculate the wattage

- Export the results to a memory slot

One of the main factors why a PLC system was chosen was of its ability to create and control a PWM signal. As explained in earlier sections this signal is linked to a solid-state really to control the loading of the generator. Using a PWM controller block and adjusting the settings of the PLC a signal was produced to the first output port, (Q0.1). With a few tests of this block a substantial amount of research was undertaken to ensure that this approach to generate a pulse signal was the most efficient method. Illustrated in the diagram below the PWM controller requires an on pulse, the pulse it's controlling in this case 'Pulse 1', an enable bit and then a status location. One of the many things that have to be set before in operational mode is the cycle length and this was chosen to be 100μs.
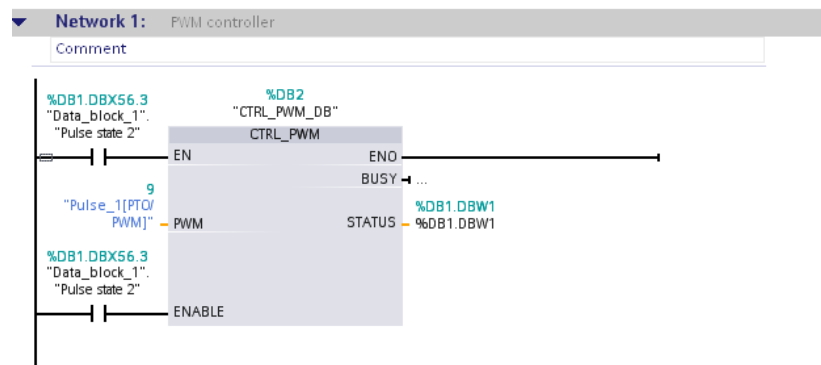
Figure 3.1.3.b – Siemens Simatic Step 7 : PWM controller

To gather speed and load related curves of a particular turbine, the pulse 'on' PWM signal was varied with time between 0 to 100%. After a substantial amount of research on how this action can be carried out, two different logical methods were examined. The first method is a manual approach which involved having each step period, 0 – 100% an individual part of the program. The image below represents a single setting of the pulse and for this manual approach this simple line was copied 10 times. In addition

to this setting of the pulse each line had a clock time to activate, a compare bit and a move block which set the individual on period of the PWM signal. Although this method worked to an extent it did not allow for easy user input and future improvement of the step period.
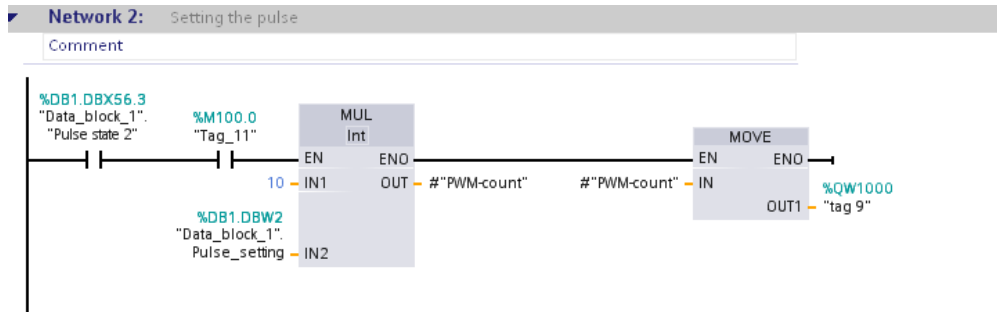
Figure 3.1.3.c – Siemens Simatic Step 7 : stepping blocks

The second attempt of setting the load was the use of a counter block. While at first, a few tests with a set and reset type of clock proved unsuccessful after some adjustments to the PLC settings, the system had plausible results. Using the available on board clock bit system a memory location was dedicated to a 1 Hz clock pulse. From this addition of a clock bit, resulted in the counter working to what was expected with it counting up to 21 and resetting itself. Illustrated in the diagram below the 'on' of the counter block is controlled by the clock bit M100.0 and the reset is a counter value compared with a set parameter of 21.
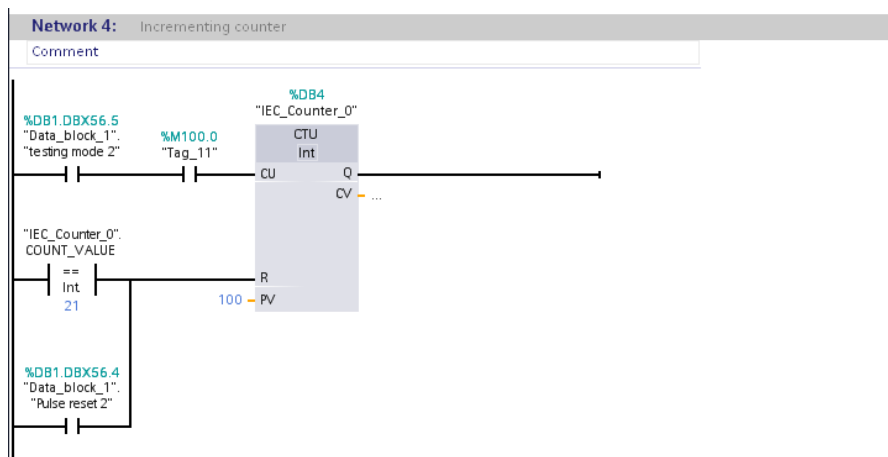
Figure 3.1.3d – Siemens Simatic Step 7 : counter blocks

From this simple example of using the 1 Hz clock now investigated, it was decided to make this pulse worldwide in terms of the program. This refers to allowing others parts of the program to use the same unanimous switching period to sync most operations. One of the main reasons for this is to reduce unnecessary updates to the PWM controller when no new period is required. With the final adjustment of this counter block to the system and the set parameters of 10 steps at 0.5s each, the program had a successful autonomous way to vary the loading of the generator with time.

During the testing phase of this part of the characterization system manual input switches were used to interface with the program directly. It was found after converting these buttons to the user interface in the next software program, a manual override system was still required. Although with the system fully functional the interface caters for all needs of testing and emergency shutdown, manual buttons was deemed the safest option if a problem ascended.

The second most important factor of choosing a PLC as a base for this system was of its analogue inputs. Utilizing these inputs the user can easily understand how the generator responds to different loading by reading the voltage and calculating the wattage of the system. An advantage of using Siemens Simatic Step 7 is its ability to have different pages of a program. For example the bulk of program explained before was developed in the main page where as a way for converting the analog voltage into decimal form can be done in a function page. Through using such a function page and then calling to it to the main page reduces the complexity of the main program by program separation. The following diagram illustrates a general analog converting operation in the function page.
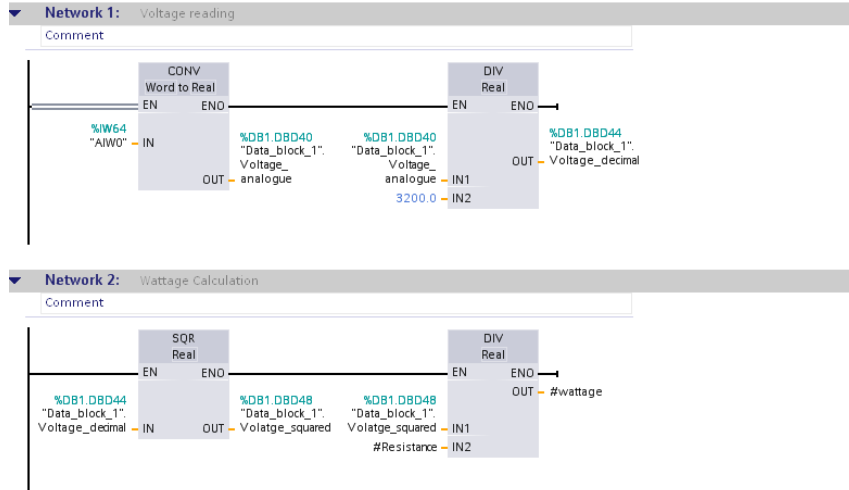
Figure 3.1.3.e– Siemens Simatic Step 7 : converting voltage and calculating wattage

It was found through some research the analog input is at a 3200 resolution. By means of a dividing block this reading was converted to a decimal form for further calculation. Also evident in the diagram above is the approach used to determine the wattage. Explained in 3.1.3(i) a simple voltage resistor power equation is used to calculate the wattage and in this diagram in how it programmed. Via a squared block and a division block this calculation was evaluated.

As briefly stated before the main program calls the function page to activate its purpose and this is evaluated through having its block in the main with its corresponding inputs and outputs. The inputs for this page are that of the resistor value, seen on the right of block in the above image and the output wattage is on the left. The last dot point refers to the operation of storing the values determine and calculated into a memory slot in the PLC for the next program to extract from.

Siemens Simatic Win CC flexible is a graphical user interface that directs controls and reads the functions of the PLC when in operational mode. With the addition of the physical manual buttons as stated earlier, extra code was added to the logic program which allowed this GUI to control the inputs and outputs of the PLC, a function which dramatically helped during the construction of this program.

The dot points below are a simplified version of what important factors this GUI was developed for.

- Create an easy to use, friendly interface for the PLC
- Display the results – generator loading, wattage and voltage
- Start, stop and reset button for ease of use
- Record button that exports data to an excel spreadsheet

The first dot point illustrates the purpose of others using this project for their own personal use. With this in mind after the majority of this GUI program was developed, a redesigning phase was implemented which basically reshaped the system to be more user friendly in terms of large buttons and clearly read headings. Although this step wasn't labor intensive a lot of time was taken to ensure the program ran smoothly and the user could understand the actions of the PLC as testing of the generator commenced. To give an example of what the GUI program look likes when constructed and running the following image is of the first page of the system.
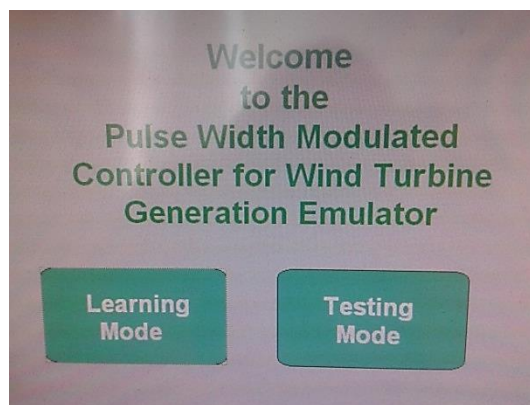
Figure 3.1.3.f – Siemens Simatic Win CC Flexible: first page

Apparent in this image are the two buttons for learning and testing mode. The learning mode was an addition to the overall system as basically the user can control the loading of the generator manually by moving the scroll bar. Taken as a simplified version of the testing mode it will allow inexperienced users to experiment with wind generators and their capabilities. Below is an image of the testing mode page and reveals the type of set up used to display the data and control the actions of the PLC system.

Figure 3.1.3g– Siemens Simatic Win CC Flexible: Testing page

As illustrated in the image above there are the two types of graphs used to display the loading value of generator and the wattage. The first one on the left is a type of vertical scroll bar graph and indicates the loading of the generator as a percentage of the pulse length, 'on' period to the length of the cycle. Secondly is the main graph of this page and reveals the wattage calculated and the voltage of the shunt resistor. Also evident in this diagram is the start, stop and reset buttons. With extra code added to the logic program these buttons can interface with the PLC to:

Start button:

> Activate the loading of generator through starting the counter and PWM signal
> Start the two graphs of loading and wattage
> Activate the recording function of trends.

Stop button: opposite actions of start

> Pauses the loading sequence
> Pauses the graphs for closer investigation
> Stops the recording function

Reset button:

> Stops the loading and moves zero bits in all variables of logic program like counter and PWM controller width

➢ Refreshes the two graphs

➢ Exports the data to a csv. file

➢ Clears any other variables from GUI program

With these three simple buttons the user will be able to start the system, stop for closer inspection on a particular wattage trend/curve, start again from the exact spot stopped and then when completely finished with one test, a reset function can be activated to carry out more tests later. For example one test can be simply a sequence of using start, stop and reset, than others at a different turbine blade pitch may require start and stop multiple times to fully examine each rise trend and self-starting abilities.

A unique ability that is highlighted in the last dot point of the GUI and the third of the reset button is that of a record function. After a substantial amount of testing and research in this particular area, a lot of ways were found to perform such an action with Win CC flexible. Subsequently with some settings of the program adjusted, a function called 'Exporttrenddata' was implemented. This function exports the trends of wattage and voltage to two different csv, files with their appropriate time of record. These files can then be opened in Microsoft Excel, and then joined together for further graph production and historical data acquisition.

By means of these three buttons fully integrated into the system, a basic fourth button was added to serve as a back function for users to switch between modes. With the user now able to utilize all basic commands the GUI program started to take its final form only some visual adjustment was required. Through using a combination of Siemens Simatic Step 7 and Win CC flexible it allows the characterization to have user friendly way of gathering wind turbine data.

3.1.3(iii) Generator configuration

In this part of the sub-chapter, different types of generators were investigated. With most of the Testing system constructed one of the last steps was to examine what type of generator would be appropriate for such a wind turbine generator system. Seen in the image below two types of configurations were tested: three phase motor and a permanent DC machine. By means of an appropriate motor directly coupled to the

generator side of the build platform to simulate that of a wind turbine, each generator set was tested.

Figure 3.1.3.h – TOP: three-phase generator, MID: PMDC machine, BOTTOM: tachometer

The above image is the setup used within the development of the PWM generator system representing the two generator configurations. In the mid-section of the image is the first generator tested, a permanent magnet DC machine coupled with a 12v motor on the right. Using a piece of plastic dowel with black tape and a white strip the two machines were coupled directly together. This white strip was for tachometer purposes and provides no structural support. At the top is a three-phase motor coupled with a DC motor and a three-phase switch board.

Each generator set was tested individually with the PLC system developed earlier and the oscilloscope. It was concluded that the wind turbine models would only be capable of achieving low revolution per minute, rpm count so the generator set which delivered the best results at these specifications will be used in the overall system. After a few test runs the permanent DC machine provided the best results. There are two main reasons why the three-phase system wasn't chosen:

- High voltage per rpm count
- Switching board dropping voltage across its diodes

Although a better three-phase generator could have been implemented the permanent magnet DC machine performed smoothly with the switching from the relay.

It was found during the testing of the motors, the vibration due to turning of the rotors was quite substantial and anti-measures were required. Using strong modeling clay like

dough the machines were fixed firmly to the base plate to ensure no sideward movement would happen when in operation. Another counter-measure implemented was that of bubble-wrap. Although a very simplistic and cost effective solution to a vibration mat it proved rather successful.

3.1.3(iv) Filtering

Illustrated on the oscilloscope screen below, the voltage waveform from the generator can vary about 30% of its average reading for these low rpm operation. From this waveform, depending on the exact time the PLC will take the reading will result in a dramatic fluctuation of incomparable results. So, to help with the voltage readings of the resistor two forms of filtering was developed and tested.
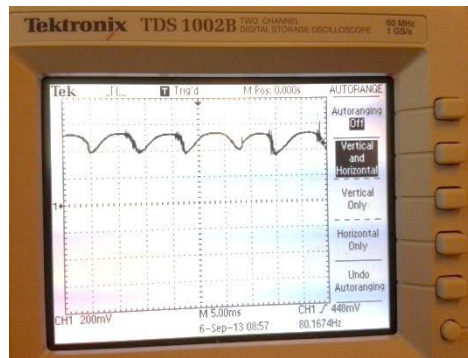
Figure 3.1.3i – Screen of oscilloscope – generator voltage waveform

The first form of filtering added to the system was a simple physical approach of adding an inductor in series to improve the current deformation. Using this approach by itself proved an advantage with a minimal filtering effect. With the addition of a capacitor bank the fluctuation of the waveform reduce in size to 10% of the average reading. Each electrolytic capacitor has a rating of 25V 2200 µF.

Although this physical approach had some filtering effect and different sizes of capacitors and inductors were tested, the large fluctuation of the voltage waveform was deemed too high to be perfectly filtered without affecting the high change in generator loading. With this said, the physical approach was still added to an extent and the next form of filtering was investigated.

Explained in the '3.1.3(ii) Programming the PLC' section of this subchapter a program called Siemens Simatic Step 7 was used to control the micro-controller and reading the analog signals. An extra slot of code was added to the overall program to help with the voltage filtering. This coded approach proved quite successful after some testing and adjustment was added. Through using a counter block, some math's blocks like addition and division the section of the program takes five 100 milliseconds readings, averages them and then exports the result to the user interface program, Win CC flexible.

3.1.3(v) Overall circuit

With all these components of the testing analyzed and finalized, this last section is to conclude the overall system circuit so it can be used for future research. From these added filtering devices explained above the overall circuit was of the following diagram.
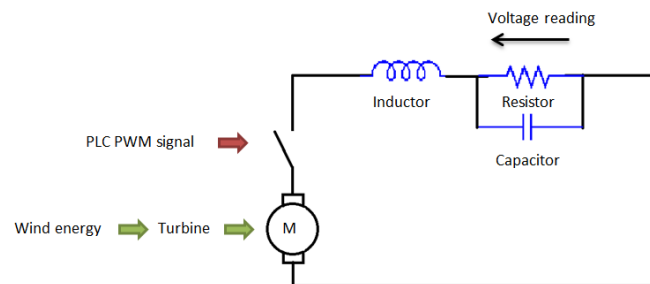
Figure 3.1.3j – Simplified Circuit of the testing system

Evident in this diagram is the type of chopper circuit used to vary the loading on the generator. For comparison use only the voltage is read across the shunt resistor.

3.2 Risk Assessment

This is an important role in any work place, as helps ensures a safe common practice is adhered to. This subchapter is separated into two parts, the identification of potential risk and how the probability of that risk was reduced. During the construction and after the finalization of this system, identifying and fixing a potential hazard that may cause harm to the user was of a very high concern. Two of the main reasons for this are that this system is designed to be user friendly and that small fast turning blades of the model wind turbines can be seen as a hazard.

3.2.1 Risk Identification

Throughout the three steps of making this wind turbine characterization many potential risks were identified and a risk assessment developed. Refer to Appendix D for all risk assessment sheets. These risks ranged from using the laser scanner to operating the generator and the occasion they would happen from rarely to frequently.

The first and largest hazard identified was that of the wind tunnel. Although fully concealed in a steel cage it can be seen as a risk due to the structure integrity of the objects placed in the wind turbine and the shear speeds of wind it can produced. Similar to any other wind source used for the testing phase of this system caution must be taken to ensure no bystanders cross the airstream unwillingly.

Using David's 3D laser scanner a hazard was identified before its use as due to the width swept angle of the laser module used it could cause harm to the user and to others who are close by. Although this was consider as a minor occurrence when the system is used correctly under its own specific guidelines, the laser can cause serious harm to the eye region if such a probability happens. Seen in the image below the David laser scanner laser does already have warning labels adhered to its casing.

Figure 3.2.1k – David's 3D laser scanner laser module

Even though the cleaning of the turbines parts could be considered as a part of risk assessment due to the chemicals used only the trained professional for 3D printing handle these parts during this stage. A hazard that involved the turbine after this construction phase was that of its stand. For some models a stand will be required to

interface the turbine directly with the wind source, e.g fan. With the addition of some models added on top of the stand, a potential hazard was identified due to the fact it could fall over. Identified as a physical hazard, harm could have come to the surrounding people mostly below knee level.

Like any workplace environment that uses electricity it is always a major risk assessment factor. Through the use of electrical apparatus like the oscilloscope, power supply and PLC, the risk of electrocution was very minor. One of the main factors considered to be a hazard was that of the generator terminals. Although identified as a risk, due to the size of the models sued the generator during testing had output less than 1 watt.

3.2.2 Risk Evaluation

With the appropriate supervisor and signage the risk behind using a fan as a type of controlled wind tunnel for large models was significantly reduced. Also ensuring there were no bystanders in close proximity to the turbine and fan system when in operation helped reduced the probability of a risk considerably.

After thoroughly reading the instructions and correctly setting up the apparatus in the corner, the possibility of direct eye contact with the laser was lowered. Using the given calibration board as the background and a duty of care to those surrounding in the room, no potential risks were developed. A recommendation for the future is that although the laser is under 5mW and therefore under the guidelines of Australian laws, safety laser glasses should be worn for significant use of the laser module.

As briefly stated in the fan section of this risk evaluation part, appendix D care will be taken when operating the turbine and correct signage should be placed when operating the turbine stand. This can refer to using a larger heavier base to support the stand from wind forces. Also when not in operation mode the stand and turbine models should be correctly laid horizontally on the ground in a storage container or area so the risk of its falling onto someone is reduced.

Lastly the problem of exposed generator terminals was overcome with the use of heat shrink. Using this type of electrical insulator meant there was a very slight chance of

physical harm coming to its users. Also with the correct implementation of shielded hook up wires there a minimal chance of this type of hazard becoming a significant risk.

3.3 Resource Requirements

As stated in the monitoring equipment section and in the methodology, a large range of interesting pieces were used to evidently create a fully functioning system.

The list of equipment for the testing phase

- ✓ PLC with all required cables supplied by supervisor
- ✓ SSR solid state relay for pulse width modulation
- ✓ Standard shunt resistor
- ✓ A few connecting wires
- ✓ DC permanent machine for generation
- ✓ All monitoring equipment stated in 2.4 Monitoring Equipment

Although more equipment may be required to support these when a problem occurs, this list is the basic configuration.

3.4 Time Guidelines

Within this section, the main project timelines and milestones are discussed and then represented in a graphical form known as a basic Gantt chart. With continually updating and preparing new Gantt charts during the construction of this thesis, the following time guidelines represent the major planned activities and events. Refer figures B.3 and B.4 to view the overall Gantt charts for semester 1 and 2.

The first foremost important part of this project was the project proposal and specification. Without this and the backing of the supervisor this project would have not been possible. These stages or also called project milestones was completed within the first four weeks of the semester.

After this element in the timeline was approved, the literature review was started. This step was a major influence in what areas this project will specialize in as it helped detail what factors need to be considered when designing and testing such wind turbines

designs. Also within this area, research was undertaken to reveal what type of designs already exist in society. Phase one of the methodology commenced at week 3 of 2013 first semester along with the literature review in week 4. The following are a few dot points revealing minor milestones developed in the first eight weeks.

- Research possibly 3D modeling programs and 3D scanning systems
- Design and test 3D programs, test 3D scanning
- Determine accuracy of 3D design
- Prepare an example model (seed pod)

From implementing the models developed from the 3D scanning with the 3D modeling software to alter the scanned images this step in the design phase was considered to be at the same time. The next phase involves the actual construction of the rotors. Although the research of phase 2 of the project started in week 5 and 6 the physical was planned to start in week 12. Some major timeline events were of the following:

- Research different construction types
- Gain permission for printer use
- Review the specs of HD3500 Plus
- Print and examine a 3D example

One of the last steps of this phase was a major milestone which showcased a major project objective; make an idea a reality through fast prototyping. After these two phases are completed to a satisfactory level the third was commenced after the June/July break. This project area was of the largest timing consuming areas in a practical sense since it required the full construction of the wind turbine apparatus and the implementation of PLC with a solid state relay, shunt resistor and a permanent DC machine. Although the typing of the thesis began at the very start of the year 2013 it was only until week 2 of the semester every part was formed into one report.

Chapter 4

Measured performance of the system: Feasibility study of a SAVPVAWT

Within this chapter a feasibility study was developed to examine the results of this dissertation that gives students the ability to design, build and test a wind turbine of their own design. Through completing the system in the month September of year 2013, an idea thought of during creating the literature review that can test this system was developed. A self-acting variable pitch vertical axis wind turbine or SAVPVAWT for short is a type of wind turbine that has the ability to adjust the pitch of each one of its blades to give optimal performance. Although to achieve this performance enhancement the system has to overcome the mechanical strain of adjusted each blade and the common ability of vertical axis wind turbines, omni-directional has to be sacrificed. The following image is how such a wind turbines works
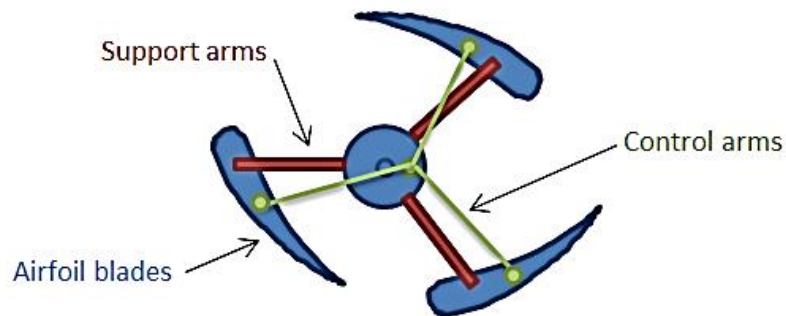
Figure 4a– Basic configuration of a SAVPVAWT

Although the size aerofoils are a bit exaggerated within this diagram, it illustrates that this turbine uses an off center axle point to control the pitch of the blades accordingly as they rotate. This point illustrated as the center of the three green control arms only moves with the direction of the wind and not with the rotation of the turbine.

4.1 – Introduction

To ensure that this dissertation gives students the ability to design, build and test a wind turbine of their own design easily, an idea about a vertical axis turbine that can manipulate the pitch of each blade was to be tested. A wind extracting system that can perform such an action was to be designed of a reasonable size such that it would allow for easy constant adjustments and different testing modes. The self-acting part refers to self-starting and variable pitch is the mode of operation. To achieve this enhancement in efficiency a common ability of vertical axis wind turbines, omni-directional will be restrained.

This trade-off is due to the fact that the wind turbine system requires to be facing into the wind so each one of its blades can be pitched at their optimal angle. The main project aim is to investigate this basic idea of pitch variation improves efficiency of the whole wind turbine system.

4.1.1 Outline of the study

Within this feasibility study such factors of both the type of wind turbine developed; SAVPVAWT and the performance of characterization system will be tested. Using the development system to its full capability of the three phases, different tests will be designed to investigate whether variable pitch has a chance out performing fixed pitch in terms of a vertical axis wind turbine. Although to achieve such an advantage the wind turbine system has to overcome the mechanical strain of physical adjustment of each blade during a rotation period.

4.1.2 Research objectives

With the above sub-chapter in mind the three main objectives of this feasibility study are to:

- Showcase the importance of wind turbine characterization system for modeling and experimenting purposes
- Construct a fully operational model of a SAVPVAWT with adjustable pitch for comparisons.
- Test and compare the results of fixed pitched VAWT and variable pitched.

Using the characterization system to its full extent of its Design, Build and Test sectors a suitable model was created for testing. With a few extra materials like, aluminum rod, bearings, bolts and nuts this study was ready to test the characterization system.

4.1.3 Conclusions

To investigate the addition of pitch variation on vertical axis wind turbines multiple testes will be carried out on both modes to explore the performance of the system. These tests refer to adjusting the pitch of the blades, having different wind speeds and finally through analyzing the results of the first round of testing to fine tune the variable pitch adjuster to get maximum performance. With all these factors to be taken into consideration a sizable model was to be created to allow for easy modification and exploration of different pitch combinations.

Whether or not the SAVPVAWT proved to have successful results or had a possibility of achieving greater results than a fixed pitched turbine, the project of a wind turbine characterization system was to be explored thoroughly. In conclusion though the use of a simple statement; it may or it may not work though it was explored, the feasibility study designed to test the performance of this characterization project commenced.

4.2 – Research design and literature review

Split into two main areas, this sub-chapter will develop a type of literature review of self-acting variable pitched vertical axis wind turbines and explore the three phases of constructing a model. Through the use of a literature review, similar concepts that use the principle of adjusting the pitch of each blade for every rotation will be explored. Using the three phases of design, build and test such a wind turbine system will be investigated and the results analyzed.

4.2.1 Similar designs

Through developing the feasibility study of this characterization project, a concept of an offset center axle that's control the pitch of the wind turbine blades was established. Although the system created in the next section for researching purposes was entirely of an own design, there are other models based on the same concept. Referring to figure 4a

Basic configuration of a SAVPVAWT, this concept uses that fact that different angles of attack for the aerofoils have a different performance values.

As well as this by minimizing the amount of drag an incoming blade/wing has into a wind stream may result if a further performance enhancement. Using these two different concepts this feasibility was created to test a turbine that tries to control each blade to reach their optimum performance.

4.3 Methodology

Through implementing the whole of the characterization system this study area can be separated into its three main areas of focus, design, build and test. Seeing that this feasibility study was designed to test this project, it will also serve as a type of guide for others that may follow such a research path. Therefore with this mind the following is a summary of the areas investigated for those that may want to quickly design an idea. Otherwise refer to 4.3.1 Introduction.

This design section primarily consists of using a 3D modeling software or scanner to develop a suitable model for printing. The software involves any stereolithograhpy CAD software like that of Google Sketchup, CAD 3D, Creo and etc that is capable of exporting a Standard Tessellation language, .stl file. These programs can be used in conjunction with the 3D scanner if the scanned objects require modification. For example; the 3D scanner researched within the dissertation, David's laser can be used to extract natural shapes from the environment and then these shapes can be developed into a turbine like shape including an axle.

After the 3D model above has been finalized, thoroughly checked and the appropriate file has been created it can than continue to the build. Predominantly this stage consists of implementing the available 3D printer HD3500Plus supplied by the University of Southern Queensland. While this printer was available during the development of the dissertation any other means of developing a model that can withstand testing forces is still appropriate. This other means can refer to using different 3D printers, CNC or other methods of prototyping.

With a suitable model available it can be attached directly to the DC machine for testing. The testing phase consists of using the human interface program; developed using WinCC Flexible to control the loading of the DC machine through a programmable logic controller, PLC pulse width modulated signal and relay. All that is required from the user is to select the test mode on the first screen and then start and stop as necessary. The program on the PLC will control the loading of the generator from 0 to 100% and record the wattage in a suitable file that can be exported to a Microsoft Excel spread sheet.

4.3.1 Introduction

With the basic knowledge of how this characterization system works and what this turbine should be capable of doing from the 4.2.1 Similar design sector, this methodology sub chapter is to develop a three bladed wind turbine model that has an overall dimension approximately 200mm wide by 300mm high. These dimensions were developed by the research found in the literature survey of Chapter 2 of this project. It was determined that turbines which have a height to diameter ratio lower than 1 had a slight increase in efficiency and power.

4.3.2 Design

Starting with a few hand drawn sketches of how the overall the project will be constructed and with the existing materials of aluminum, bearings, bolts and nuts the design area of the characterization system commenced. Using the free version of Google SketchUp 8, three sorts of models were created. In the first section the aerofoils of the vertical turbine blades were designed. Seeing that this feasibility study was created to research and compare different modes of the same turbine, the actual shape and design of these aerofoils was not of a high concern. Using the spinning radius of the wind turbine, 100mm a suitable model was developed. The image below is of the chosen aerofoil design.
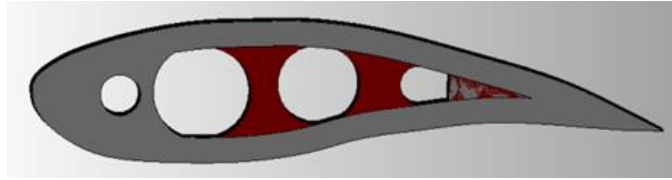
Figure 4.3.2a– Netfabb Studio Basic 4.9 model of Aerofoil used

This design was chosen as it was intended for the turbine to have minimum rotation losses by having the top arc, upper camber of the aerofoil the same as the circle of rotation. With continual design concepts of the lower camber and the overall length, an online simulation program was used to approximate the above aerofoil lift/ drag coefficient. Using a camber of 10.95% and thickness 15.8%, the Nasa FoilSim III Version 1.4d aerofoil plotter approximated a lift coefficient of 1.26 at angle 0° and a maximum 2.3 at 14°. Although during the construction of the turbine blades the thickness of the aerofoil increase, the program gave a clear indication on how much can the lift force can change at different angles.

Two design types of the same aerofoil were created, top and bottom. The top piece had an additional guide rails for the changing of pitch and the bottom had a unique design which will use less plastic when printed, illustrated in the above image.

In the second set of models the two different diameters of the aluminum tubes were used to design the wind turbines frame, 10mm and 5mm. Through carefully planning and measuring, these aluminum rods fitted with ease into structures support connectors. For stability purposes a standard number of three turbine blades were used. Within this model were one middle tri-connector, six end pieces and one controlling connector. See the second image below. The controlling connector, seen in red is used with the next section.

The last model section contains the most important key factor of this feasibility study. The guide bed and its adjacent cart are the objects that create the pitch variation of the blades during operation. This idea of variable pitch is not to be confused with the same guide rails as in section above about the aerofoils, as this set of models will allow the turbines blades to be constantly adjusted in actual operation to give optimal blades performance. Whereas in the aerofoil section, it is only to be set once permanently when

a suitable angle is found. See section 4.1.1 'Outline of study' for the methodology behind this variable action.
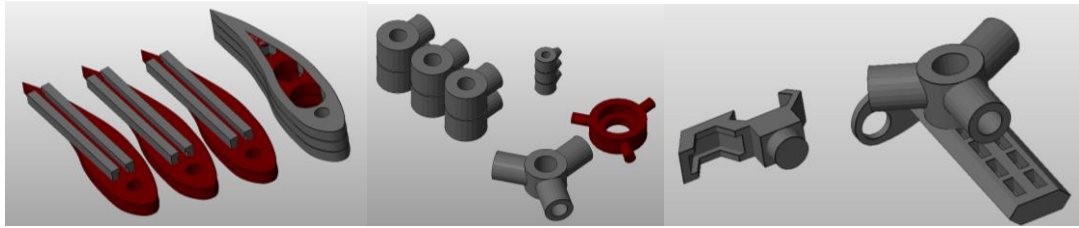
Figure 4.3.2b– Netfabb Studio Basic 4.9 model of complete printed parts

The 3D images above were taken from the free version of a software program, Netfabb Studio Basic 4.9. This program was used to fix the .stl files exported from Google Sketch Up 8 as they may contain holes. If these holes did proceed to the printing stage, the pieces would collapse in on its self as only a simple hollow shell will be printed and not a whole solid object.

To ensure that all these pieces could be correctly fitted to the aluminum rods and nuts a lot of time was taken to virtually construct the wind turbine within Google Sketchup 8. The main reason for this as although the individual parts may work with each other well, when the pieces are brought together after being printed they may be of a different sizing to what is expected. So through a thorough inspection and importing the files into one model helped guarantee no waste product was developed by consecutive printed of the same part.

4.3.3 Build

With the completion of these 3D models, this build step entitled the entire construction process of the wind turbine. Using the knowledge gained in the projects methodology 3.1.2 Build as a guide a considerable amount of time was endure within this phase. Throughout this section factors like the following steps were predominantly developed and explored. See Appendix C SAVPVAWT for extra build images.

- 3D print the models
- Clean and prepare models for gluing
- Prepare the extras like the aluminum rod

- Construct the support frame of the turbine

- Build the aerofoils frame and its hard covering

- Finally fully construct the model, all parts requires including sturdy base

From the basic steps above the wind turbine model was able to go from an idea to reality in a fast and appropriate professional manner. The first step is that of taking the designed models which are already prepared in a printable format (stl.) to a physical form. From this projects research, it was found the easiest method to acquire a physical form of a model was to use that of a 3D printer. The mains reason for this chosen approach was that one particular printer was easy to access and has a high resolution that is suitable for small wind turbine parts.

Through the expertise of Adrian Blokland, a technical officer in the Faculty of Health, Science and Engineering section of USQ this 3D printing stage was completed in a quick professional manner. Using the USQ's Projet HD3500Plus made by the company '3Dsystems', the above turbine parts were printed at 16µm thick high strength plastics layers. Although for most tall print jobs the time of completion can be upwards of 24 hours since the models were arranged partially on the print area to have a low height, the overall time was only a 9 hours. Again through the help of Adrian the large portion of the supporting wax was melted away.

Figure 4.3.3a– Model on aluminum base plate

The image above is of all the models on the aluminum base plate as they were released from the printing machine. It is evident at the top of this image a type of calibration structure is printed as well. The main reason for this is that for the extra high definition the printer requires a known constant structure for correctly printing extensive jobs.

While using an array of ovens and ultrasonic cleans baths cleared most of the wax, further treatment was required. This was in the form of using cotton bubs and stiff wire to clean the project. With the wax softened by a warm water bath a lot of time was expended using the wire to clean the insides of the connectors. To ensure that a correct fit and a strong grip from the glue between these parts and the aluminum all wax had to be removed.

Figure 4.3.3b– Model cleaned and ready for construction

Illustrated in the image the high strength plastic is actually of a clear presentation when thoroughly cleaned. As found in the 3.1.2 Build section of this report, this cleaning was done using paper towels, the cotton buds, tooth brush and a lot of patience. The holes second form the left array of aerofoils was developed in the design section which the primary purpose of reducing printing cost.

As per the dot points stated earlier the next part of the build phase was to prepare the extras like the aluminum rods, rulers, metal support rods, bolts and nuts. Refer to image C.1.1 for the lengths of aluminum rods cut and the rulers used. The cutting of the 5mm hollow aluminum rods was done using a hobby hack saw and the control rods through the use of wire cutters. With lengths of the support arm aluminum rods carefully measured and cut to 95 mm each, it was to ensure the wind turbine frame will still have the previous determine dimension of 200mm by 300mm. These six aluminum rods serve a tri-support connector arm to hold the main and blades axles.
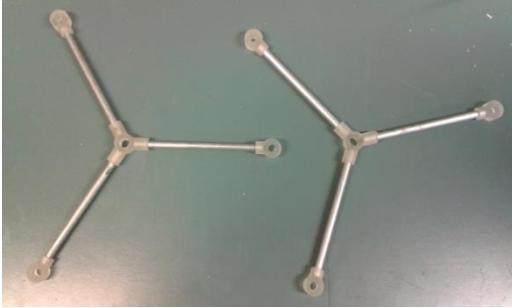
Figure 4.3.3c– Tri-connectors for support and frame

The image above represents the two tri-support arms, one for top and bottom of wind turbine. Using the knowledge found about the plastic having the perfect porous material for a bonding agent to adhere to, a combination of super glue and hot glue was. The reasoning behind using both was that the hot glue provided a great rough surface area on the aluminum rod for the super glue to bond to. After a few initial tests this hot glue was also implemented to construct the three wind turbine blades structures. These structures consisted of three primary parts, the aluminum axle/rod and ruler area, aerofoils and lastly the covering.

Seen in the image C.1.2 the aluminum ruler and rod combo were simply bonded together through the use of the hot glue. The idea behind the ruler is to give internal support to the aerofoil structure. As stated briefly before the purpose of the aluminum rod/axles is to fit inside the tri-support connectors and allow the blades to rotate and change pitch. The next part of constructing the aerofoils assembly was completed through using a type of hobby foam called 'depron' and the printed plastic aerofoils. Utilizing these printed parts as a stencil three internal support aerofoils were created for each blade. At 3 mm thickness, two foam aerofoils were bonded together using a special foam safe glue to give more strength to the structure. Through cutting slits in the sides of these aerofoils and deploying both hot glue and foam safe glue the following internal assembly of each blade were fabricated.
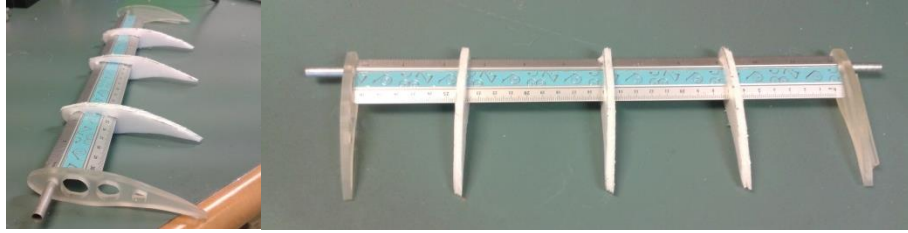
Figure 4.3.3d– LEFT Side view of aerofoil structure, RIGHT top view of the air structure

Lastly with internal structures fully dried and rigid the next step was the covering. Using the same 3mm foam as before and taping the outer side, this foam was forced into the aerofoil shape. Through a few experiments the sticky taping seemed necessary due to how resilient the foam was to bend at sharp angles. It would simply snap without this clear covering. See images C.1.3-5 for the visualization of the foam bending. Starting with the bottom curve of the aerofoil and using the corner of the bench the curves were force rolled into the foam. After this rolling and with the two glues ready each foam board was bonded to the structures above to give the overall shape of a plane wing.
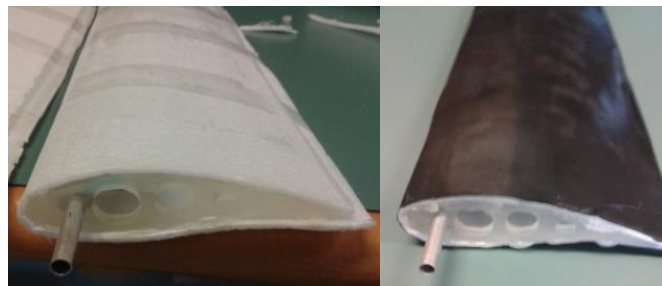
Figure 4.3.3e– Finish aerofoil blades, before and after black covering

Above are two images that portray an end view of one blade, after drying and the finish product. Evident in the image of the right, to finish the wind turbine blades a thick black book covering plastic was implemented to give a tight firm final cover. This will ensure that at high speeds the weakest points of the blades, the foam between the internal supports will flex less and distribute the force evenly over the entire wing surface.

With the blades and the connecting arms finished, one of the last sections of the entire build phase is to construct the pitch adjusting mechanism. Referring to the image displayed earlier this mechanism is designed to offset the pitch controlling arms of the

blades to a specific desired magnitude. Consisting of two areas, the variable pitch and the fixed pitch system they will allow the wind turbine to experience different modes of testing.

The first to be contrasted was that of the variable pitched system. By the use of one long plastic bolt, two nuts and a small piece of aluminum rod this mechanism was constructed. Evident in the image below to the left is the actual control bed with the plastics screw and on the right is the adjustable sliding pivot point or cart for the controlling arms to be attached to. Through simply turning the bolt at one end and moving the cart it will adjust how much the variable pitch system will have an effect on the blades.
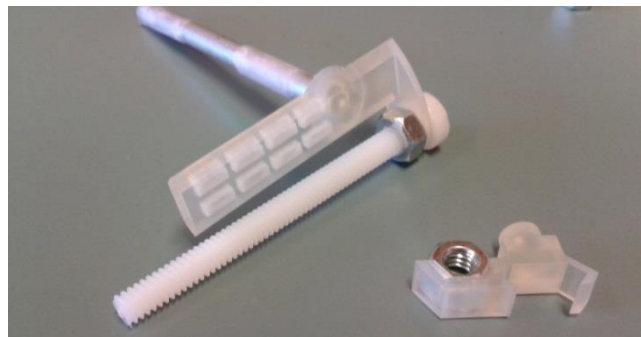
Figure 4.3.3f– Variable control pitch mechanism

Also evident in the above image is the rectangle shape indents on the underside in the guide rail. Through previous printing experiences it was found that although the plastic is high strength a type of support design is still required. The main purpose of the aluminum rod is to fit inside the main axle and provide support to the mechanism when the axle is turning. Apparent in image C.1.6 a ball bearing was added at the base to reduce the amount of friction between the stationary mechanism and rotating main axle.

Through the use of another ball bearing the variable pitched system can be connected to the fixed pitch blade configuration. Implementing the metal rod which was stated earlier in material list, the control arm plastic center tri connector, the three end control arm connectors and few bolts with nuts and washers the fixed pitch mechanism was built. By means of super glue the connectors were bonded to the bended rods. These rods were formed into a particular shape that would allow them to not interfere with the

plastic screw of the variable pitch mechanism though still able to connect to the guide rail on the aerofoil blade. Seen in the two images below is how the overall system interfaces with the wind turbine axle and main blades.
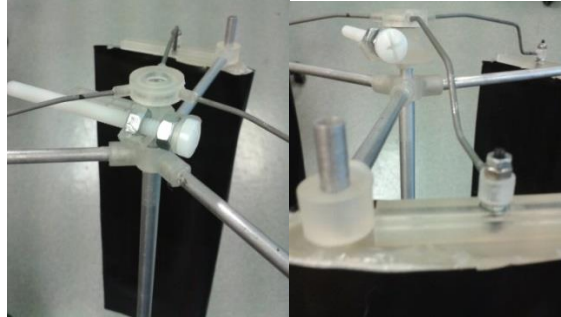
Figure 4.3.3g– Control Arms connected to variable pitch mechanism

With placing the head of the metal bolt in the guide rail of plastic aerofoil, seen in the right image above, then using multiple nuts and washers, the connectors with the metal arms already attached secured the to the blades. The image on the right is the control arm plastic center tri connector with the metal arms attached to the sliding cart of the variable system.

To conclude the build phase of the construction a self-acting variable pitch vertical axis system, the main 10mm thick aluminum tubing/axle was carefully pressed into position between the two middle tri-connectors and the variable mechanism stability rod. With the system fully built, to allow for easy rotation of the wind turbine, the main axle was inserted into cylinder which had two ball bearings placed 100mm apart and attached to a sturdy metal base. The image below is the final system fully constructed and ready for testing.

Figure 4.3.3h– Finish wind turbine – ready for testing

4.3.4 Test

Though using the testing system built in 3.1.3 Test section of this report, which has a simple graphic user interface and a basic RLC generator circuit, the testing of this particular type of wind turbine was completed in a fast and professional manner. Testing of this wind turbine was completed in two combinations, variable and fixed. To conclude that variable pitched has a possibility of outperforming fixed, these two stages were of:

Fixed pitched – 9 tests

- Three angles of attack
- Wind speeds 1-3

Variable pitched – 8 tests

- One optimal angle of attack
- Winds speeds 2
- Magnitude 10mm
- Position of variable mechanism, North west, North, North East, etc

Although multiple pre-tests were developed with the variable and fixed pitched systems for the purpose of this feasibility study only a select few were analyzed. With the variable system, the position of the mechanism refers to the direction it's facing in regards to the wind direction. For example, north is referring to the negative magnitude of the mechanism (lowers the angle of attack, pitch) to be directly facing into the wind, see diagram below. This diagram represents the basic setup of the wind turbine testing system used.
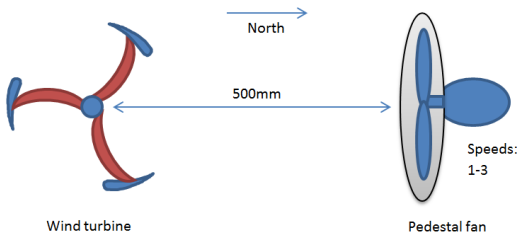
Figure 4.3.4a– Wind turbine and fan configuration

Also with a few pre-tests it was found that the optimal distance between the wind source, an electrical pedestal fan, and the wind turbine was that of 500mm. This measurement was determined a good half way point between too much wind dispersion, 1000mm and too much wind distortion 0mm. While a shroud around the fan could have helped the wind distortion, due to its close proximity to the turbine it wasn't ideally necessary. Similarly using the same setup meant that the wind turbine will experience the same turbulent wind for every test.

Using a simple plastic connector the main axle of the wind turbine was directly coupled to the generator of the characterization system. As discussed earlier this testing phase of the characterization system utilizes a PWM chopper circuit to vary the loading on this generator. Implementing the same circuit and PLC system finalized in the project the tests were down in lots of three: keep the same pitch though adjusted the wind speed. Three winds speeds were available, slow mid and fast, and although there was a slight turbulence factor due to the uneven propulsion of wind from the fan blades the average speed measured by an anemometer is …

As stated before after a few initial tests only a select few angles were chosen for further investigation. The main reasoning behind this is that the angles either side of the maximum power output at -20° experienced a dramatic decrease in performance. This decrease was a major influence in the turbines pitch capability. For example, 10° from this -20° the wind turbine would not spin. Using the measurements from the center of the tri-connecter for the control arms and the guide rail bolt, each blade was individually set at a pitch. The table below represents this distance and its approximate angle from the guide rail. This angle is referred to the angle of attack in the case of aerofoils. For an angle of attack equals 0° the guide rail is at 90° the aluminum support arm

Table 4.3.4 Angel of Attack and measured distance

Distance between the two point (cm)	Approximate angle of attack. (°)
11.24	25
11.44	20
11.62	15

4.4 – Results and Discussion

By means of using the Siemens Simatic Win CC graphical user interface program developed in the test section of this project, the testing of the wind turbine was completed by pressing the start and stop button. During the stop period the fan was turned off and the angle of attack was modified to the three set angles, 25°, 20° and 15° by adjusting the guide rail bolt position. For the on period or recording period multiple runs of the same test were established to give an average performance for that specific angle and speed. The first results were that of angle 25° at speeds 1 to 3.
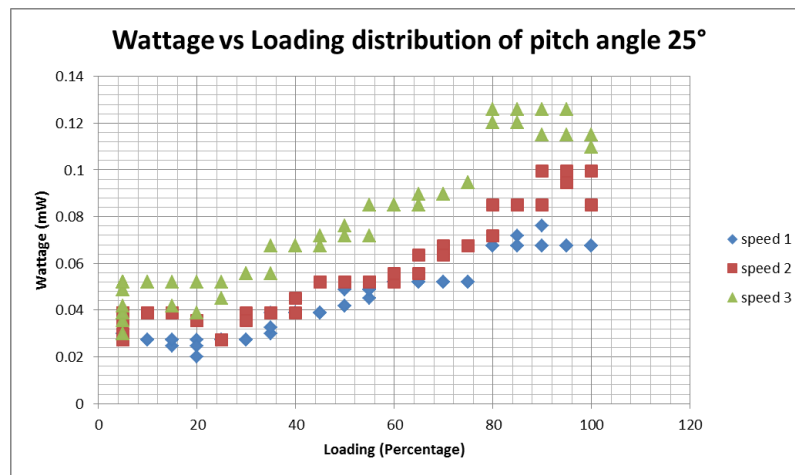
Figure 4.4a– Distribution graph for wattage and loading of the angle of attack of 25°

Evident in the above distribution graph of all tests completed, at the angle of attack of 25° the wind turbine was still able to perform with a positive wattage slope only with a slight decrease at maximum loading capacity 100%. At this point the turbine was slowing down and its efficiency dropping. Although the wattage readings were of micro values, due to an inefficient generator and losses in the solid state, power curves were extracted of similar trends for each test. Due to a light loaded generator the majority of the distribution graph above of the positive slope. From increasing the load of the generator from using the chopper circuit the load current increased which evidently increased the voltage reading across the shunt resistor.

Table 4.4 Available Fan speeds and average wind velocity

Available Fan speeds	Average wind velocity (m/s)
1	2.7
2	3.8
3	4.6

The above repents the available speeds sourced from the electrical fan. These measurements were determined through using the anemometer built in the weather multi-meter. Other information that regarded the testing environment is that of temperature, approximately kept constant at 25.1°C and relative humidity of 61%. A point of interest on this particular graph is that of the 80% loading mark as at this point a dramatic increase in wattage occurred. The thought behind why such an increase occurred was developed while watching the turbine as it was tested. At low revolutions per minute, rpm the turbine regained a lot of its stability and from this increased its ease to rotate. For angle of attacks 20° and 15° refer to Appendix C images C.2.1 and C.2.2 and for data C.3.

The second portion of the wind turbine data acquisition was that of the variable pitch system. As mentioned only a few tests were able to be performed on this type of wind turbine configurations due to the small performance range the aerofoil used. Through analyzing the data gathered about the fixed angles, the preset of the variable angle was selected to be 20°. With this value the magnitude of the variable pitch mechanism set to 10mm, which in terms of angles ± 5 degrees. For example if the mechanism:

- Was pointed due north, facing into the wind, when a turbine blade is closest to the fan it is at 15° and furthest is at 25°
- Was pointed north-west, facing slight left, when a turbine blade is at north west it is at 15° and opposite is at 25°

The following graph of the average distribution portrays the wattage versus landing at a variable angle 20°.
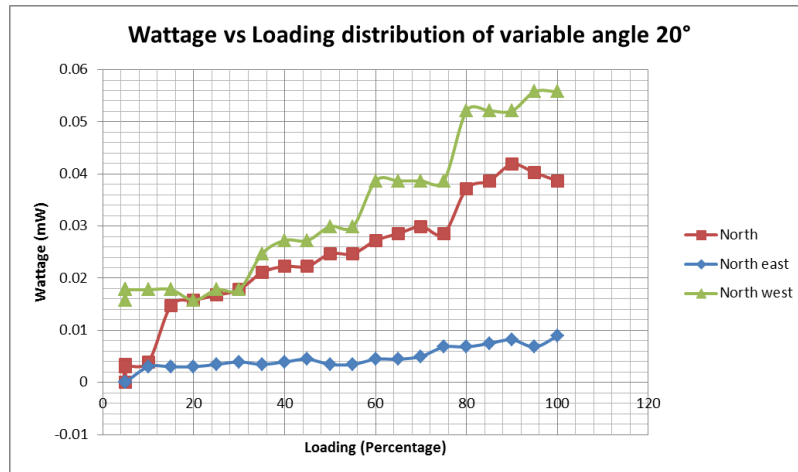
Figure 4.4b– Distribution graph for wattage and loading of the variable angle of attack of 20°

Graph C.2.3 represents the distribution of all results for this variable pitch test. While other cardinal directions were tested only north-west to north-east proved to have constant results. Apparent in the above graph is that north-west has a higher output than that of the north and north-east. One of the main reasons for this is that the turbine spun clockwise into the wind, so evidently blades in the North-West position will have a lower drag coefficient and vice versa for the opposite side. This method of shifting the amount of drag experienced from a blade entering the wind stream to one that's exiting results in a greater power output.

Using the same methodology, the tests proved that in the north-east position the overall wind turbine output is lower than the north position. In other terminology the blade that faces into the wind which provides the lift and thus propulsion of the turbine, acts more of a wind break with its higher angle of attack.
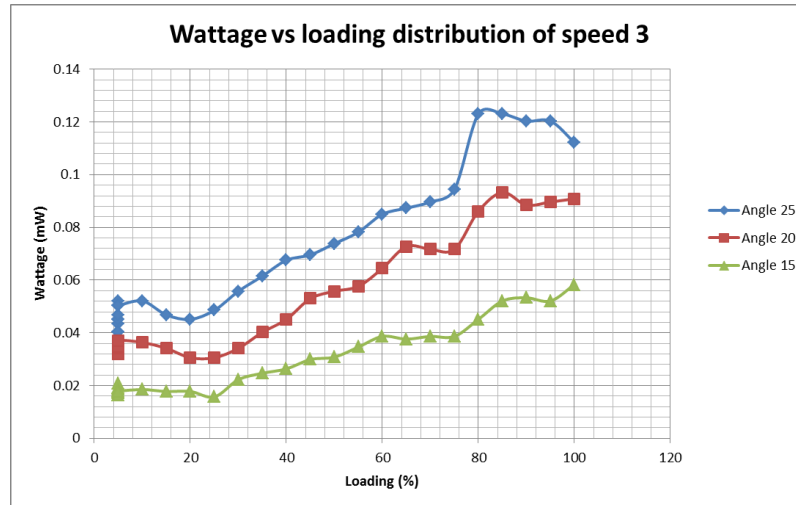
Figure 4.4c– Average graph for wattage and loading of the wind speed 3

The graph above summarizes the wattage output of the three angles at different speeds. It can be seen in this graph that although the wattage readings are extremely low the turbine was still able to give persistent loading curve. Through interpreting this curve it can be seen that through the configuration built within this feasibility study that a high angle of attack resulted in a greater performance. Many factors may have contribute to this increase like the following

- stability of the turbine turning
- lower air friction as aerofoil wings were pointed closer to the center
- low wind conditions

The first point is that of stability, noticed during the testing of the wind turbine a slight shake developed at blades turned. With the weight of the blades closer towards the middle because of the higher angle of attack, resulted in less undesired movement and better reachable speeds. Also with more of the wings surface experiencing the slow turbulent wind in the center of the wind turbine and not greatly being affected by the high flow outside resulted in less drag and higher rpm.

Chapter 5

Interpretation of results

From the construction of a feasibility study to test this characterization system, the results were of a reasonable performance. Using this array of procedures and equipment from start to finish helped fix certain areas of the wind turbine system and finalize parts of the three phases. These areas were of minor adjustments that will allow the system to cater for larger models in the future. The following analysis of results is separated into two major areas, in terms of results of implementing the characterization with an idea and then the actual performance of that idea. In the case of this project the idea was a feasibility study that researched into a wind turbine that had the capability of manipulating the pitch of the blades as it rotates.

5.1 Characterization system

First and foremost, it was found that the system performed to a satisfactory professional level when a model required to be taken from a simple idea to a reality. As stated earlier the main purpose of the feasibility study was to ensure all areas of this project where fully capable of operation. Only with a few adjustments to the overall system a model was produced and tested in a fast and professional manner with the use of this array of procedures.

The first phase of this system to be tested was that of design. In the section 4.3.2 Design details the steps that were endured to finalize a working system. Although primarily only the 3D modeling software, Google Sketch Up 8 Basic, was implemented the research completed on the 3D laser scanner may be used for other ideas in the future. Even though a lot of time was spent within this section to ensure the model wasn't flawed in any particular way, this phase was of a basic concept and thus did not require any further adjustment.

Again of a basic concept, the section of build required the use of a 3D printer to construct a physical model. Using the available printer located at the first floor of the University of Southern Queensland Engineering an d Surveying block, only a few recommendations were required for larger models. Stated in the sub-chapter section 4.3.3 Build, the model required adjusting in the Design stage to be able to print in the build platform of that printer. In the case of the USQ's Projet HD3500Plus this build platform was of 298mm, 185mm, and 203mm for its extra high definition mode. Another recommendation was that of designing the wind turbines parts so less plastic will be used and thus less cost to manufacture one particular design. Otherwise this area of the characterization system was fully functional.

Lastly the test section was where most of the adjustment was located as both the circuit and program needed to test a larger than expected model. These adjustments were in the order of testing different resistances values and generators for this different size model. Also a portion of the program was altered so larger wattage values can be displayed. Apart from these slight adjustments the GUI was simple to use and with the export to a Microsoft excel readable file really helped to further examine the results. Being able just to press start, see the results as a graph and stop whenever it was necessary was a very positive feedback.

5.2 SAVPVAWT

In this sub-chapter, factors that regard the performance on the feasibility study produced will be summarized. With the system fully functional the results were as of expected for the self-acting variable pitch vertical axis wind turbine. Although some modifications were required the system performed well in gathering the test data for further analysis. By running each test multiple times any unseen events that may happen to the turbine or the PLC testing system would have presented itself later in the analysis of the data. This procedure was a type of data contingency plan developed in the testing phase which ensured the data from each test was accurate and accountable.

Through interpreting the results of the two graphs 4.4b and C.2.1, the turbine experienced a higher wattage distribution for that of the fixed pitched system than the variable. Although many different configurations were tested the losses on the variable

system was too high for the turbine system to outperform the maximum performance of the fixed pitch system; attack angle equals 20°. There are two main reasons why this occurred for the variable pitched system; the mechanical stress due to its design and the friction of rotating.

From understanding the exact principles of how a variable system works it can be seen that the force of pitching the blades will increase as the turbine improves its performance. With more research and experiments on different design concepts, the mechanical force required to control all the blades can be dramatically reduced though improving the variable mechanism.

The second major factor is also directly related to this mechanism. While both the control arms and main axle were rotating with the blades, this mechanism was primarily in a fixed position. Though as stated in the 4.3.3 Build ball bearings were placed between these rotating surfaces to reduce this difference in speeds, the adjuster of the variable pitch system still experienced a lot of friction.

Using the above two factors as a guide it is evident that although the results were of reasonable values, the system could have performed better if a fully optimized and one set configuration turbine was implemented. This set configuration alludes to another factor that may have influenced the results of turbine, the ability to change arrangements. While this feasibility study system was produced to investigate the performance of multiple configurations a final solution can still be optimized. To conclude this factor, without the added weight and air drag of a research turbine, a final system could experience a better performance.

Primarily only using the graph 4.4b the variable system with an angle of attack of 20°, it illustrated that a self-acting variable pitched turbine system has a small potential of achieving higher outputs. As explained below this graph, when the controlling mechanism was placed in the north-west position, the wind turbine experienced a lower drag coefficient when a blade was entering the wind flow, which in fact improved the performance of the overall system.

Chapter 6

Conclusions

Throughout developing project Seashell, a parallel task to help with its development and then a feasibility study on a SAVPVAWT to finalize it, a characterization system which enables a researcher to take an idea, design and build it then test for its performance was fully constructed. The following chapter will summarized what this project set out to achieve in the case of aims and objectives, how these were achieve in the methodology and how they were proved in the results.

5.1 Aim and objectives

Despite the fact that wind turbines have been around for many years, the aim of this project was to provide a system where new wind energy extraction techniques can be explored. With new creative ideas for urban wind turbine being developed constantly like that of a self-acting variable pitch system, this system was able to be fully functional in terms of creating a model.

To fulfill the aim of using natural shapes in the design of a wind turbine, a procedure known as 3D scanning was researched and experimented with. Using a system called David's 3D laser scanner – laser module (David's 2013) a seed pod was digitally recreated for later analysis. With the research also completed in the 3D modeling software like that of Google Sketch Up 8 basic, it will enable for even more intricate designs to be developed and then explored. Using a combination of these two prototyping methods, potential researchers will endless amount of possibilities to explore with different designs, shapes, configurations, sizes and methods of wind energy attraction.

From the use of this design section of methodology, 3.1.1 other specific aims that are more relevant to the performance, ethical responsibility and appearance were that of the following:

- efficiency
- low noise pollution
- aesthetic appearance

Efficiency of the wind turbines can be calculated through determining the efficiency of the generator used for that particular model and the losses in the circuit. Although some ethical responsibilities were analyzed, the low pollution factor was only evident if a small model is taken to the large scale urban environment. Also with the use of a 3D modeling adjustments and remodeling of a certain design can be performed in a fast and professional manner to help gain better aesthetic appearance when in a public domain.

As explained in the next sub-chapter, the objectives of this project were fulfilled by not only development the system though through its intensive testing as well. One of the major other objectives within this project was to allow other design engineers at the university level the ability to use this system. For this objective to be performed successfully in the future, the feasibility study was created to ensure that when others may use such an array of procedures to construct a wind turbine it will operate efficiency. Whether this may involve implementing the whole of the wind turbine characterization system or portioning the research gain in a specific area to help them in theirs, users still have the ability to prototype a creative idea in a fast and appropriate style.

5.2 Methodology and Results

As mention throughout this project the methodology of this characterization system is separated into three main area of research. Though as briefly mentioned in 1.4 Specific objectives a fourth was created to examine the findings of this system to ensure that when completed prototypes can be easily modeled. In saying this, the following sub-chapter will summarize the findings found in both the methodology and the results determined.

Design

Through exploring two different methods, 3D scanning and modeling software, of producing a 3D digital model that is ready for the next stage of the development cycle, some recommendations were made for easier deployment. An example of this was the finding and the creation of a simple slanted boxed. From implementing a 3D shape similar to this box, can result in a faster method of prototyping as that procedure of scanning and preparing a natural object to a digital form will become easier. As explained in 3.1.1 Design this slanted box serves as a reference object for the stitching program to use and was created after multiple experiments.

Build

With a Standard Tessellation language, .stl file produced from the above stereolithography CAD modeling software this phase of the development system was to explore the possibilities of making this digital model into a physical reality. Through exploring the capabilities of 3D printers like that of University of Southern Queensland Projet HD3500Plus manufactured by the company '3Dsystems', it resulted in one being implemented within the system due to its high resolution of creating models. Evident in the build section, 3.1.2 the intricate design of Project Seashell was printed from 16μm thick layers of plastic. After implementing this pinnacle piece of prototyping machinery, findings were developed regarding the construction and cleaning of the turbine parts.

Although some parts of future research wind turbines may require a deconstruction to print within the available area (298mm, 185mm, and 203mm) a simple bonding liquid can be used to recreate the model. It was found due to the perfect porous surface of the printed plastics layers, bonding agent such as super glue had a great adhesive strength in joining pieces together.

Another method found during this build stage was that of cleaning the parts when they were extracted from the printer. While most of the support wax was removed to use any bonding agent the plastic had to be a fully uncontaminated surface. It was found the easiest method of clearing the wax without damaging the integrity of the model was that

of using warm water, paper towels, tooth brush and pins. The plastic should be clear when fully cleaned.

Test

This section consumed the most time of this project, as it involved researching the different types of equipment available, like that of generators, PWM's, motor controllers, etc. and then implementing them into a circuit for data acquisition and load controlling. Through the use of two programs, Siemen's Simatic Step 7 using the V11 portal and Win CC the graphical user interface, GUI program a control system was designed to enable the user to just simply connect the turbine model to the chosen generator and press start for one test. Refer to 3.1.3 Test for a further explanation.

Using the digital outputs of a Siemens DC, DC, DC S7 1200 PLC, 1214c PLC, the overall system controlled the loading of the generator through a generated pulse width modulated, PWM signal and a solid state relay. Evidently a type of RLC chopper circuit was designed with the voltage readings taken from shunt resistor. From the use of a PLC analog port to read this voltage signal and the known value of the resistor, the program calculates the amount of power developed by the generator.

To help get a constant reading two forms of filtering was applied. Although the first of using inductor and capacitor had some effect on the waveform the second form was developed. A digital method of averaging was implemented to calculate the power at 0.5 seconds intervals.

Lastly with the program interfacing with the circuit correctly the system can be operated into two modes, test and learn. The learning mode was an addition to the overall system as it is basically gives the user complete control over the loading of the generator through adjusting a scroll bar. Taken as a simplified version of the testing mode it will allow researchers to experiment with wind generators and their capabilities. For testing purposes, the second mode is for researching purposes only and autonomously steps from 0 to 100% loading capacity at 5% intervals of 0.5 seconds each.

Analyze

Although project seashell was established parallel with development of this project to help guide the major areas, a final analysis and model was created to ensure that system would operate efficiently. Explained thoroughly in Chapter 4 Measured performance of the system; Feasibility study of a SAVPVAWT and Chapter 5 Interpretation of Results, an idea of a wind turbine developed from gathering information for the literature review of this project was constructed and tested. The following is a summary of the results founds.

The wind turbine illustrated in the image 4.3.3h, was tested multiple times at different configurations. These were at different modes of operation; variable or fixed pitch, different fixed angles of attack and diverse wind speeds.

With the use of electrical fan as a wind source three speeds were achievable, speed 1: 2.7m/s, speed 2: 3.8m/s and speed 3: 4.6m/s. Using the guide rails on the aerofoils at an type fixed pitch adjuster three different angles of attack were tested, -25°, -20° and -15°. As stated in 4.3.4 Test although multiple tests were carried out, only seventeen were commendable of further investigation due to performance issues.

From the results of these tests it was found that through using the turbine arrangement developed in 4.3 Methodology at a fixed pitch angle of -25° the turbine had the greatest maximum output. Although the highest output of variable mode was in close proximity to these fixed mode values, the results were as expected for a small scale researching model. These two modes refer to whether the center on controlling arms is in the middle for fixed and off-centered for variable. For a visual reference refer to image 4a.

While the results of this SAVPVAWT model weren't completely successful in the sense of variable pitch prevailing over fixed, as hypothesized, through inspecting the turbine as it was tested that variable mode revealed signs of a self-starting. In other terms, although the turbine didn't have the greatest maximum power it inherent another important factor of self-acting.

To conclude the performance of the variable mode it determine from the graph 4.4b, variable angle of 20° that the turbine presented signs of further improvement with the North-West position having a greater positive power slope than the control, North. From all the above factors and tests of a self-acting variable pitched system, the idea of using such a characterization system to turn an idea of a wind turbine to a reality is still evidently clear.

5.3 Conclusions

This research topic was aimed to construct a fully functional characterization system that will allow future students to easily investigate into the renewable energy source, wind by developing and analyzing models of their own urban wind turbine design. Through developing three main phases of design, build and test, and then also constructing two prototypes of Project Seashell and the feasibility study of an SAVPVAWT this was achieved.

Using the specification sheet developed at the start of this project as a guide, refer to appendix A, it is evident from the above technical analysis that all dot points were completely satisfied. For example the first point to be concluded was that of the literature review which had the very important role of establishing such factor-like wind characteristics, extraction techniques, monitoring equipment and consequential effects of this project. It was from this research of background information that established a turbine idea for which this system could be analyzed with.

Though the actual results of this SAVPVAWT demonstrated to have a plausibly possibility of achieving higher outcomes, the idea proved successful in determining what factors of the wind turbine characterization system required further before this projects finalization.

With this in mind, from creating an array of procedures from start to finish it has not only created this research path for wind turbines in urban environments though may help other projects that may include aerodynamics, control loading, data acquisition, programming PLC, generators and design engineering. Discussed in the next section a

possible future study area will be the optimization of the research found from this study, primarily on this self-acting variable pitch wind extraction technique.

5.4 Further Research and Recommendations

Through investigating the properties of wind energy and the types of wind extractors available within this sub-chapter future improvements and recommendation this research path will be briefly discussed. Although the system worked to expectations the turbine model SAVPVAWT can be still further optimized. Through using different shapes, sizes, configurations and methods of wind energy attraction, factors that negatively influenced the performance of the wind turbine can be reduced further. For example that of the reducing air drag of the components and the amount of mechanical force required to control the pitch arms.

Also with these negative factors considered, the positive can be researched and enhanced further. This refers to using different aerofoil shapes that perform better at different winds and tip speeds. Lastly seeing that this project is based on giving students at the university level a means of experimenting with wind turbine technology and models the following dot points are a few recommendations on where further endeavors can be researched.

- 3D scanning, modeling, printing
- Generator loading –PWM function
- Data acquisition
- PLC programming – logic and GUI

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Appendix A – Project Specification

University of southern Queensland

FACUTLY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research project

Project specification

FOR:	**JOHN SUTCLIFFE**
TOPIC:	URBAN WIND TURBINE CHARACTERISATION SYSTEM
SUPERVISIOR:	Dr. Leslie Bowtell
ENROLMENT:	ENG 4111 – S1, ONCAMPUS, 2013 ENG 4112 – S2, ONCAMPUS, 2013
PROJECT AIM:	This project is to develop an evaluation system to determine typical operational and over-speed characteristics of scale versions of VAWT's and HAWT's.
PROGRAMME:	**Issue B, 27th March 2013**
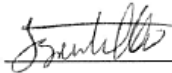
1. Research background information on vertical and horizontal axis wind turbines, listing their main attributes with respect to suitability to an urban environment

2. Develop a system to compare the scale-version wind turbines over a range of loads and wind conditions including smooth and turbulent airflows.

3. Develop a program allowing a PLC based control system to control loading and monitor turbine speed under various load conditions. This will allow for relative efficiency and speed regulation data to be acquired.

4. Design a number of typical VAWT's and HAWT's using 3D modeling software. Model prototyping will be carried out using the USQ 3Dsystems HP3500Plus 3D printer.

5. VAWT and HAWT scale models will be tested with the USQ Water Engineering/Thermofluids laboratory wind tunnel. To accurately model key aspects of each turbine multiple tests will need to be conducted.

6. Production of typical efficiency curves, inherent speed characteristics, and examination of their sensitivity to design factors such as turbulence.

AGREED _____ (student)   _____ (supervisor)

Date: 27/3/ 2013   Date: 27/3/ 2013

Examiner/Co-examiner:_____

Appendix B – Project information

Equation

B.1 $\qquad$ Kinetic Energy $= \frac{1}{2}mv^2$

Figures

B.2 $\qquad$ Power coefficients of various wind turbines (Hau 2000, pg. 79)
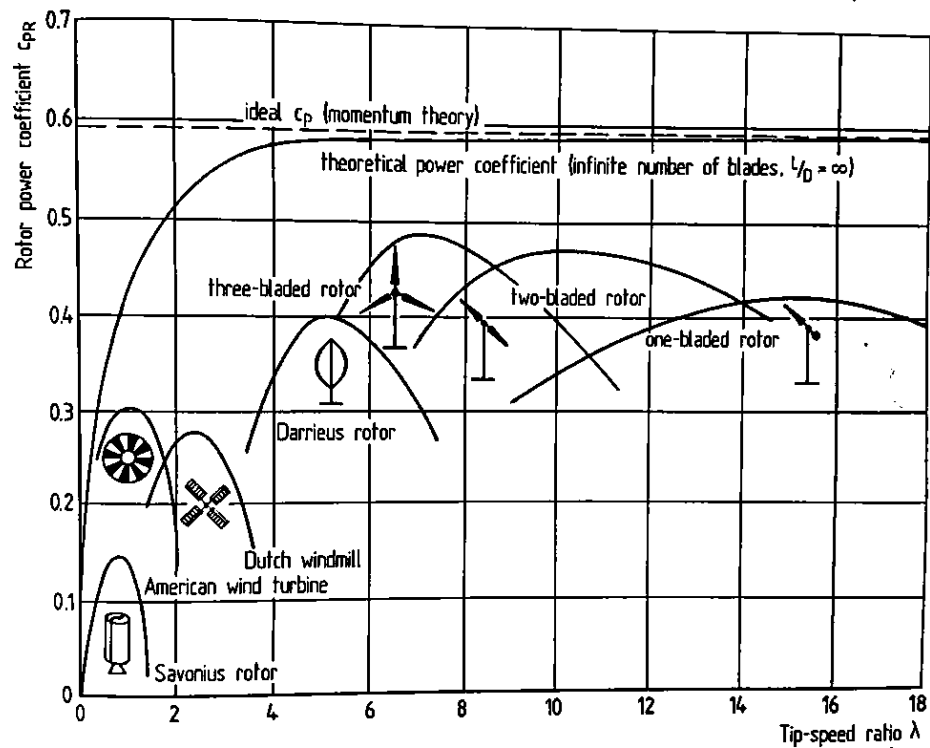
B.3 Gantt chart semester 1

		Weeks															
Project timelines – Semester 1																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Assessment	Project proposal	█	█														
	Project specification		█	█	█												
Phase 1 Design	Research possibly 3D modeling programs			█	█	█											
	Research possibly 3D scanning programs			█	█	█											
	Design and test 3D programs						█	█									
	Design and test 3D scanning						█	█									
	Determine accuracy of 3D design								█								
	Prepare an example model (seed pod)								█								
Assessment	Presentation							█	█	█							
	Start preliminary report							█	█	█							
	Literature review										█	█	█	█			
	Assessment of Consequential Effects											█	█				
	Methodology												█				
	Finalize the report												█	█			
Phase 2 Build	Research different construction types							█	█								
	Gain permission for printer use												█				
	Review the specs of HD3500 Plus													█	█		
	Print and examine a 3D example														█	█	

B.4 Gantt chart semester 2

		Weeks															
Project timelines – Semester 2																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Phase 3 Build	Construct an apparatus for wind tunnel	█															
	Integrate this with the tunnel with stability		█														
	Design a PLC program			█	█												
	Integrate PLC with SSR					█	█										
	Integrate the permanent DC machine					█	█										
	Test the system by hand movement						█										
	Compile the system								█								
	Test turbines								█	█	█						
Assessment	Dissertation		█	█	█	█	█	█	█	█	█						
Data Review	Analyze data gathered from test								█	█	█						
	Develop an overall turbine											█	█				
	Project appraisal												█				

Appendix C – SAVPVAWT

C.1 Images

C.1.1 Aluminum material

C.1.2 Aluminum ruler bonded with rod through using hot glue
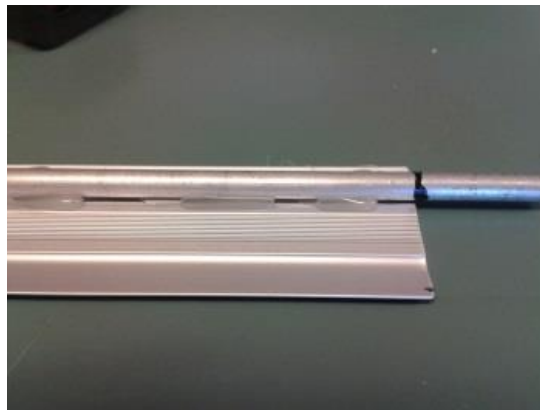
C.1.3 3mm Depron foam bended into shape

C.1.4 Depron glue to the aerofoil structure

C.1.5 Close up of the structure

C.1.6 Variable adjuster on bearing

C.2 Graphs

C.2.1 pitch angle 20°
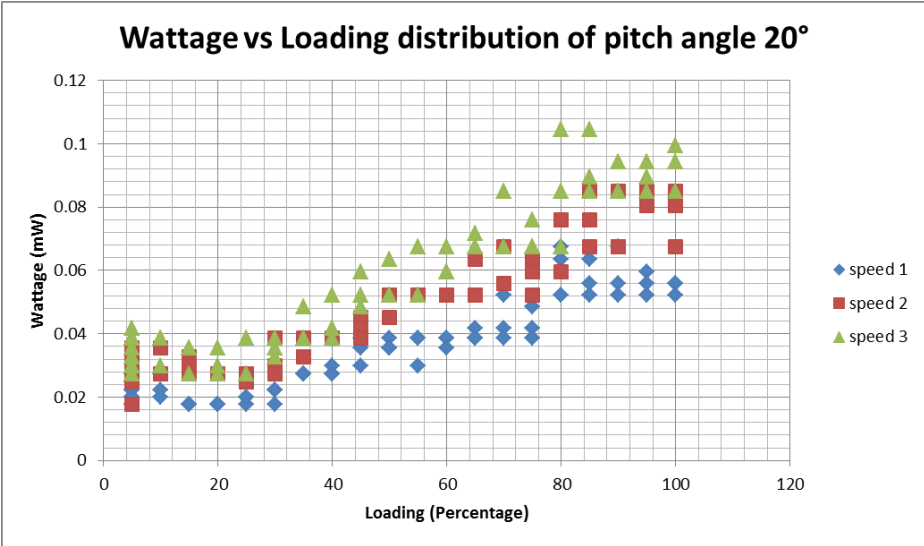
C.2.2 pitch angle 15°

C.2.3 Variable pitch angle 20°

Wattage vs Loading distribution of variable angle 20°
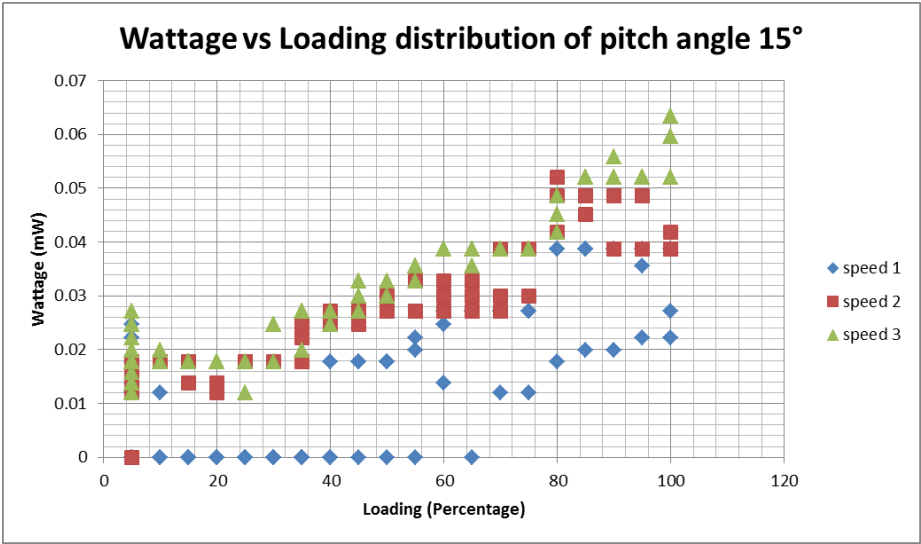
C.2.4 Speed 1
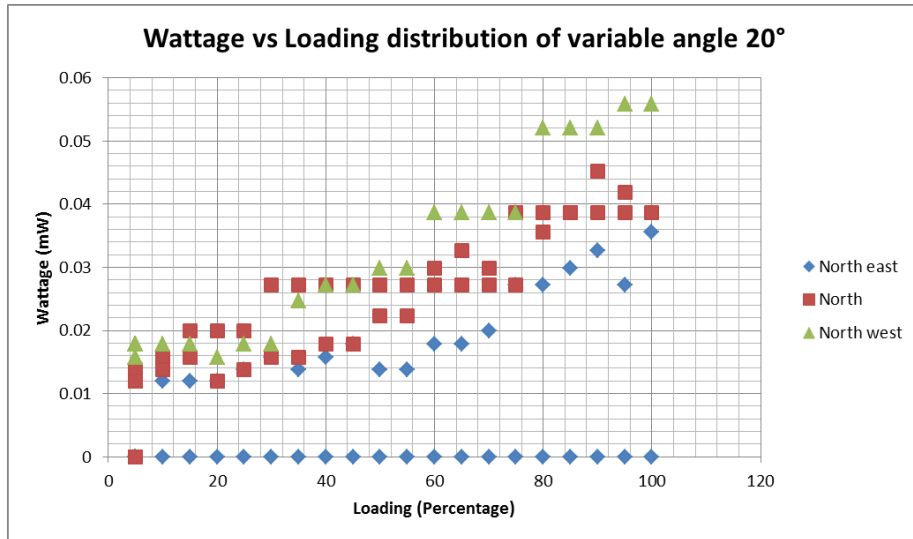
Wattage vs loading distribution of speed 1
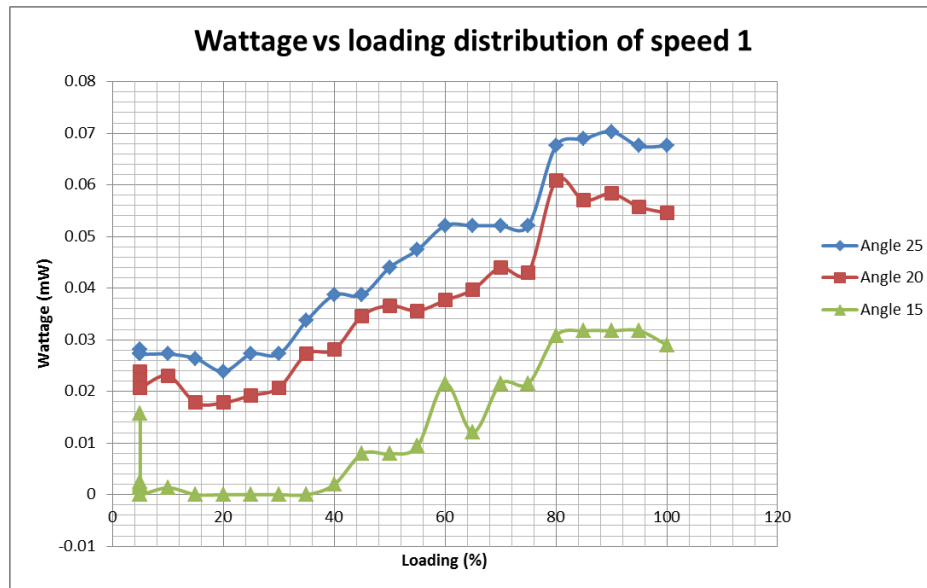
C.2.5 Speed 2
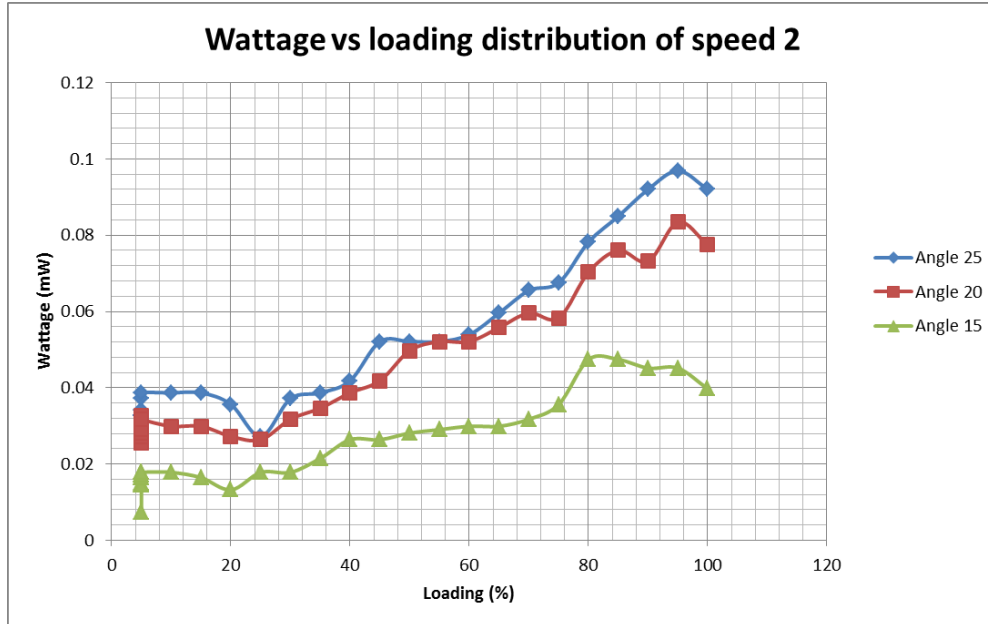
C.3 Raw Data

C.3.1 Fixed pitch, angle of attack = -25°

Loading (%)	Power (W)						
	Speed 1 – 2.7m/s			Speed 2 – 3.6m/s		Speed 3 – 4.8m/s	
5	0.0272	0.0272	0.0272	0.0272	0.0387	0.0387	0.0521
5	0.0272	0.0272	0.0272	0.0272	0.0387	0.0387	0.0521
5	0.0272	0.0272	0.0272	0.0272	0.0387	0.0356	0.0521
5	0.0272	0.0272	0.0272	0.0272	0.0387	0.0299	0.0521
5	0.0272	0.0272	0.0272	0.0272	0.0387	0.0299	0.0521
5	0.0299	0.0272	0.0272	0.0272	0.0387	0.0387	0.0521
5	0.0272	0.0272	0.0272	0.0299	0.0387	0.0418	0.0521
5	0.0272	0.0272	0.0272	0.0272	0.0387	0.0521	0.0521
5	0.0299	0.0272	0.0272	0.0387	0.0356	0.0486	0.0521
5	0.0272	0.0272	0.0272	0.0387	0.0387	0.0486	0.0521
10	0.0272	0.0272	0.0272	0.0387	0.0387	0.0521	0.0521
15	0.0272	0.0247	0.0272	0.0387	0.0387	0.0521	0.0418
20	0.0272	0.0200	0.0247	0.0356	0.0356	0.0521	0.0387
25	0.0272	0.0272	0.0272	0.0272	0.0272	0.0521	0.0451
30	0.0272	0.0272	0.0272	0.0387	0.0356	0.0558	0.0558
35	0.0299	0.0327	0.0387	0.0387	0.0387	0.0675	0.0558
40	0.0387	0.0387	0.0387	0.0451	0.0387	0.0675	0.0675
45	0.0387	0.0387	0.0387	0.0521	0.0521	0.0717	0.0675
50	0.0486	0.0418	0.0418	0.0521	0.0521	0.0760	0.0717
55	0.0451	0.0486	0.0486	0.0521	0.0521	0.0850	0.0717
60	0.0521	0.0521	0.0521	0.0521	0.0558	0.0850	0.0850
65	0.0521	0.0521	0.0521	0.0635	0.0558	0.0897	0.0850
70	0.0521	0.0521	0.0521	0.0675	0.0635	0.0897	0.0897
75	0.0521	0.0521	0.0521	0.0675	0.0675	0.0945	0.0945
80	0.0675	0.0675	0.0675	0.0717	0.0850	0.1203	0.1259
85	0.0675	0.0717	0.0675	0.0850	0.0850	0.1203	0.1259
90	0.0760	0.0675	0.0675	0.0850	0.0994	0.1149	0.1259
95	0.0675	0.0675	0.0675	0.0994	0.0945	0.1259	0.1149
100	0.0675	0.0675	0.0675	0.0850	0.0994	0.1149	0.1096

C.3.2 Fixed pitch, angle of attack = -20°

Loading (%)	Power (W)									
	Speed 1 – 2.7m/s			Speed 2 – 3.6m/s			Speed 3 – 4.8m/s			
5	0.0178	0.0247	0.0200	0.0178	0.0299	0.0299	0.0299	0.0327	0.0418	0.0387
5	0.0178	0.0178	0.0272	0.0247	0.0299	0.0272	0.0272	0.0387	0.0356	0.0387
5	0.0200	0.0223	0.0272	0.0272	0.0299	0.0299	0.0272	0.0299	0.0327	0.0387
5	0.0223	0.0200	0.0272	0.0272	0.0299	0.0356	0.0327	0.0387	0.0299	0.0387
5	0.0178	0.0223	0.0247	0.0272	0.0299	0.0299	0.0327	0.0299	0.0327	0.0387
5	0.0247	0.0223	0.0247	0.0299	0.0272	0.0272	0.0387	0.0299	0.0299	0.0387
5	0.0200	0.0247	0.0178	0.0272	0.0299	0.0299	0.0327	0.0272	0.0299	0.0387
5	0.0223	0.0247	0.0200	0.0272	0.0299	0.0299	0.0299	0.0356	0.0327	0.0387
5	0.0200	0.0247	0.0223	0.0327	0.0299	0.0356	0.0299	0.0387	0.0356	0.0356
5	0.0200	0.0223	0.0200	0.0299	0.0299	0.0356	0.0327	0.0387	0.0387	0.0387
10	0.0223	0.0272	0.0200	0.0272	0.0272	0.0356	0.0299	0.0387	0.0387	0.0387
15	0.0178	0.0178	0.0178	0.0327	0.0272	0.0299	0.0272	0.0356	0.0356	0.0387
20	0.0178	0.0178	0.0178	0.0272	0.0272	0.0272	0.0272	0.0356	0.0299	0.0299
25	0.0178	0.0200	0.0200	0.0272	0.0247	0.0272	0.0272	0.0387	0.0272	0.0299
30	0.0223	0.0178	0.0223	0.0299	0.0272	0.0387	0.0327	0.0387	0.0356	0.0299
35	0.0272	0.0272	0.0272	0.0327	0.0327	0.0387	0.0387	0.0486	0.0387	0.0356
40	0.0272	0.0299	0.0272	0.0387	0.0387	0.0387	0.0387	0.0521	0.0418	0.0486
45	0.0387	0.0356	0.0299	0.0451	0.0418	0.0387	0.0486	0.0596	0.0521	0.0521
50	0.0387	0.0356	0.0356	0.0521	0.0451	0.0521	0.0521	0.0635	0.0521	0.0558
55	0.0387	0.0387	0.0299	0.0521	0.0521	0.0521	0.0521	0.0675	0.0521	0.0596
60	0.0387	0.0387	0.0356	0.0521	0.0521	0.0521	0.0596	0.0675	0.0596	0.0717
65	0.0387	0.0418	0.0387	0.0521	0.0521	0.0635	0.0675	0.0717	0.0675	0.0850
70	0.0418	0.0521	0.0387	0.0558	0.0558	0.0675	0.0675	0.0850	0.0675	0.0675
75	0.0418	0.0486	0.0387	0.0521	0.0596	0.0635	0.0675	0.0760	0.0675	0.0760
80	0.0635	0.0675	0.0521	0.0596	0.0760	0.0760	0.0850	0.1044	0.0675	0.0897
85	0.0635	0.0558	0.0521	0.0675	0.0760	0.0850	0.0850	0.1044	0.0897	0.0945
90	0.0558	0.0675	0.0521	0.0675	0.0850	0.0675	0.0850	0.0945	0.0850	0.0897
95	0.0558	0.0596	0.0521	0.0804	0.0850	0.0850	0.0850	0.0945	0.0897	0.0897
100	0.0558	0.0558	0.0521	0.0675	0.0804	0.0850	0.0850	0.0994	0.0945	0.0850

C.3.3 Fixed pitch, angle of attack = -15°

Loading (%)	Power (W)								
	Speed 1 – 2.7m/s			Speed 2 – 3.6m/s			Speed 3 – 4.8m/s		
5	0	0	0	0.01203	0.01383	0.0178	0.0178	0.0178	0.0178
5	0	0	0	0.01383	0.01383	0.0178	0.0178	0.02227	0.0178
5	0	0	0	0.01203	0.01383	0.0178	0.01575	0.02469	0.0178
5	0.01203	0	0	0	0.01575	0.0178	0.0178	0.02724	0.0178
5	0	0.02227	0	0.01575	0.01575	0.0178	0.01383	0.02469	0.0178
5	0.01203	0.02469	0.01203	0.0178	0.01383	0.0178	0.01203	0.02469	0.0178
5	0	0.0178	0	0.0178	0.01575	0.0178	0.01383	0.01997	0.0178
5	0	0.01383	0	0.0178	0.0178	0.0178	0.01203	0.01997	0.0178
5	0	0.01203	0	0.0178	0.01575	0.0178	0.01383	0.0178	0.0178
5	0	0	0	0.0178	0.0178	0.0178	0.0178	0.0178	0.0178
10	0	0	0.01203	0.0178	0.0178	0.0178	0.0178	0.01997	0.0178
15	0	0	0	0.0178	0.0178	0.01383	0.0178	0.0178	0.0178
20	0	0	0	0.01383	0.01383	0.01203	0.0178	0.0178	0.0178
25	0	0	0	0.0178	0.0178	0.0178	0.01203	0.0178	0.0178
30	0	0	0	0.0178	0.0178	0.0178	0.0178	0.02469	0.02469
35	0	0	0	0.02469	0.0178	0.02227	0.01997	0.02724	0.02724
40	0	0	0.0178	0.02724	0.02469	0.02724	0.02469	0.02724	0.02724
45	0	0.0178	0.0178	0.02724	0.02469	0.02724	0.02724	0.0327	0.02991
50	0	0.0178	0.0178	0.02724	0.02724	0.02991	0.02991	0.0327	0.02991
55	0	0.02227	0.01997	0.02724	0.02724	0.0327	0.0327	0.03563	0.03563
60	0.01383	0.02724	0.02469	0.02991	0.02724	0.0327	0.03867	0.03867	0.03867
65	0	0.02724	0.02724	0.02991	0.02724	0.0327	0.03867	0.03867	0.03563
70	0.01203	0.02724	0.02724	0.02991	0.02724	0.03867	0.03867	0.03867	0.03867
75	0.01203	0.02724	0.02724	0.03867	0.02991	0.03867	0.03867	0.03867	0.03867
80	0.0178	0.03867	0.03867	0.04856	0.04184	0.05211	0.04514	0.04184	0.04856
85	0.01997	0.03867	0.03867	0.04514	0.04856	0.04856	0.05211	0.05211	0.05211
90	0.01997	0.03867	0.03867	0.04856	0.03867	0.04856	0.05578	0.05211	0.05211
95	0.02227	0.03867	0.03563	0.04856	0.03867	0.04856	0.05211	0.05211	0.05211
100	0.02227	0.03867	0.02724	0.04184	0.03867	0.03867	0.0635	0.05211	0.05958

C.3.4 Variable pitch, angle of attack = -20°

Loading (%)	Power (W)		
	North west	North	North east
5	0.0178	0.0000	0.0000
5	0.0178	0.0000	0.0000
5	0.0158	0.0000	0.0000
5	0.0158	0.0035	0.0000
5	0.0178	0.0000	0.0000
5	0.0178	0.0000	0.0000
5	0.0178	0.0030	0.0000
5	0.0178	0.0030	0.0000
5	0.0178	0.0000	0.0000
5	0.0178	0.0030	0.0000
10	0.0178	0.0039	0.0030
15	0.0178	0.0148	0.0030
20	0.0158	0.0158	0.0030
25	0.0178	0.0168	0.0035
30	0.0178	0.0178	0.0039
35	0.0247	0.0211	0.0035
40	0.0272	0.0223	0.0039
45	0.0272	0.0223	0.0044
50	0.0299	0.0247	0.0035
55	0.0299	0.0247	0.0035
60	0.0387	0.0272	0.0044
65	0.0387	0.0286	0.0044
70	0.0387	0.0299	0.0050
75	0.0387	0.0286	0.0068
80	0.0521	0.0371	0.0068
85	0.0521	0.0387	0.0075
90	0.0521	0.0418	0.0082
95	0.0558	0.0402	0.0068
100	0.0558	0.0387	0.0089

Appendix D - Risk Assessment

D.1 Laser Radiation

Risk Management Chart for location. Z311   Hazard Category *Radiation*

Description of Hazards	People At Risk	Number At Risk	Parts of body	Risk level
Exposure to LASER radiation (<10mw)	Operator and surrounding people	2	Eyes	Mod Consequences – low likelihood

Categories	Short term controls	Long term Controls	Completion date
Design	Safety glasses with dark lenses to be worn	Use of special LASER safety glasses	
Substitution			
Redesign	All LASER equipment to be house in a container during use and fully self-operational when scanning.		
Separation			
Administration			
P.P.E			

Additional Notes: This is a short term installation only.

D.2 Non-testing period

Risk Management Chart for location. Z311

Hazard Category *Physical*

Description of Hazards	People At Risk	Number At Risk	Parts of body	Risk level
Physical damage to body due to turbine spinning during non-testing times	Operator and surrounding people	1	All	Low

Categories	Short term controls		Long term Controls	Completion date
Design			• Use of special signage	
Substitution			• Container to avoid sudden wind gust	
Redesign	Ensure the wind turbines axle is locked while not in use			
Separation Administration P.P.E	Wind turbine to be located in corner of room where minimal chance of wind guts and people interaction.			

D.3 Testing periods

Risk Management Chart for location. Z311				Hazard Category *Physical*	
Description of Hazards	**People At Risk**	**Number At Risk**	**Parts of body**	**Risk level**	
Physical damage to body due to turbine spinning during testing times, wind tunnel and fan	Operator	Up to 5	All	Medium	

Categories	**Short term controls**	**Long term Controls**	**Completion date**
Design	Minimal safety distance of a 1.5 meters during testing	• Use of special signage • Wire cage for turbine	
Substitution			
Redesign			
Separation			
Administration			
P.P.E			

D.4 Physical harm due to turbine falling over

Risk Management Chart for location. Z311

Description of Hazards	People At Risk	Number At Risk	Hazard Category *Gravity* Parts of body	Risk level
Wind turbine falling over	Person within 1.5m of turbine	Up to 3	Feet, lower body	Low

Categories	Short term controls		Long term Controls	Completion date
Design Substitution Redesign Separation Administration P.P.E	Wind turbine will at all times have a additional heavy sturdy base		• Solid base, bolted to floor • Collapse for non-testing periods	