Design of A Small Wind Turbine for Electric Power Generation (1-5kW)

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***Abstract* - This dissertation is the documentation of the design and development of a sustainable wind energy conversion system to be employed as a stand-alone electrical energy generator for isolated communities and dwellings. As our global population increases at an exponential rate and our consumerism grows with it, a sustainable source of energy needs to be developed to meet our power requirements. Because of the fast depletion of fossil fuels, there is a current global need for clean and renewable energy sources. Among all the renewable resources wind power is one of the most efficient and environmentally friendly. At present, India is fifth in wind power generation across the world. It is speculated that at most of the places in India wind turbines are not viable due to low wind speed. Hence a wind turbine, which produces energy even at very low wind speed is required. This paper is concerned with the design, implementation and monitoring of such wind turbines for domestic applications. The proposed system is composed of 3 blades using NACA-63215 profile, which is made up of fiber glass materials. A permanent magnet synchronous generator is used for power generation of 250 W. The generated power is rectified and used to charge a lead acid battery of 24 V, 40 Ah. The battery power is then inverted by a pulse width modulation inverter before utilized by the load. The charge controller prevents the battery from overcharging and/or deep discharging. This type of small/micro-wind turbine operates even at low wind speed.**

***Index Terms* - Turbine, Wind Energy Conversion System (WECS), steel tower.**

INTRODUCTION

The renewable energies such as Biomass, Geothermal, Hydro, Wind, Solar and Ocean Energy can be converted into more useful energy like electricity. They deliver power with minimal impact on the environment. These sources are typically more green/cleaner than conventional energies like oil or coal. Among all the renewable energy sources, wind and solar have recently experienced a rapid growth around the world. Ultimately the aim of this project is to make use of a natural resource to supply mankind’s energy requirements in a sustainable manner. If a wind turbine can be designed and constructed so that it can produce more power over its lifetime than it takes to be produced and maintained over its useful life, then it is a sustainable answer to our global energy requirements. It is obvious now that we are facing an oncoming global energy shortage. Fossil fuel prices are rising in conjunction with the decrease in their stockpiles and it is vital that alternative methods of energy production be investigated and introduced on a global scale to maintain our standard of life. Wind energy has the potential to meet our requirements and several nations have already begun effectively producing and harvesting this form of green energy.

PROPOSED SYSTEM

This document proposes a design for a small-scale wind turbine that could be used to recharge households, will help residents reduce the health risks associated with rising temperatures, such as heat exhaustion or heat stroke. When designing the turbine, we assumed that it would generate approximately 0.5 W of electrical power. Our estimated output was determined from the capabilities of Motors RF-370CA DC generator, . We also assumed that the turbine will be mounted above the laminar boundary layer during operation, allowing it to take advantage of the maximum windspeed in a particular location. Since portability and ease of installation were critical, we constrained the overall size of our device to a 2 ft3 volume, and the overall cost of its materials will not exceed $20.our power output remains inherently limited. Second, our material resources are constrained by the project requirements, as published by our department. mined limitations do not pose a major threat to our creativity. Nonetheless, each limitation must be considered. In the following subsections, we will address those limitations, alongside different aspects of our design process. First, we will discuss the customer needs and specifications that we established for our small-scale wind turbine.

OBJECTIVES

As previously mentioned, the electricity producing wind turbine is an already existing technology and this project is focused on redesigning and adapting mechanical and electrical engineering principles to achieve the specified energy output. Realistically the simplest method to achieve the goal in this project would be to scale down an existing turbine until its power output fell into the category of 1-5 kW. However, it is vital that a good understanding of the concepts and principles behind wind turbine design is developed so that existing methods of wind energy production can be improved and made more efficient. There are a wide variety of wind energy converters already available on the market and many of these will be investigated throughout the course of the report.

- To provide thorough background information on wind energy and wind turbines
- To employ mechanical design principles gained over the duration of a BENG Mechanical degree.
- To design a suitable wind turbine to meet the specifications set out in the project outline.
- To develop a sustainable, environmentally friendly alternative to fossil fuel consuming energy production.

The design project is to develop a mechanical system that is capable of providing driving force to a generator using only the energy contained in wind. The generator in the system is the mechanical-electrical converter in the wind turbine and the gearbox and rotor blades need to be designed to supply the generator with an input that will yield the desired output power. This being said, a suitable generator first needs to be selected and tested to determine the input speed required to produce 5 kW before any other design goes ahead. Once this has been determined a rotor system and gearbox can be designed to produce the required revolution speed and torque to supply mechanical power to the generator. In selecting a generator consideration needs to be made as to what type of current is being produced and where it will flow to, if it will be stored or if it will be directly applied in an electrical device.

CONSEQUENTIAL EFFECTS OF OUTCOMES

In our current global situation, both environmental and economic, it is evident that drastic changes need to be made to the way we treat our planet and each other. Rather than dwell on the problems of the past and present, this research project aims at creating an understanding of a proven environmentally friendly alternative to fossil fuel-based power production. Although as yet a wind turbine on its own cannot provide the same scale of power as a steam turbine in a coal fired power plant, it is a technology that will long outlast fossil fuel technology.

A potential consequence of the success of this project would ultimately be the refinement of the design and future production and commercialization of the turbine. For the purpose of the project, the design of the turbine is for the demonstration of applied technical knowledge gained over the duration of a mechanical engineering degree. However, particularly in this project there is a great opportunity to continue research and development beyond the timelines and aims mentioned in the project specification. One of the issues on a social level with wind turbines is the aesthetic appeal of the structure. If every house in a community had a wind turbine in its back yard, understandably there would be an issue with noise and aesthetic appeal. However, if the turbines were grouped, as in a wind farm either on land or out at sea the issue could be successfully avoided, however a power distribution network would need to be created. A power distribution network would alleviate the issue of storing the electricity once it has been produced, rather than subsequently having one battery in every household which would see costs increase dramatically, not to mention the environmental effects incurred by the eventual disposal of the batteries.

1.3 METHODOLOGY

The process of designing a wind turbine involves the conceptual implementation of a number of electrical and mechanical subsystems to create a machine capable of converting the energy contained in wind to useful electrical energy. This process is constrained by various factors, the most notable being the economic viability of the design. If the machine can be designed and is able to produce energy at a cost less than its opposition of fossil fuels and nuclear energy, then the project is deemed economically viable. However, in today's global situation there is also the challenge of environmental and ethical viability to contend with. Renewable energy projects should be prioritised and subsidised by the appropriate government agencies due to the benefits they offer to society. However, along with the majority of design projects, it is a fundamental design goal to keep the energy cost at a lower level than of existing energy producing systems.

DESIGN PROCEDURE OUTLINE

There are a variety of different approaches that can be taken in wind turbine design and accordingly there are also a number of issues that need to be taken into account. The design procedure outlined in "(McGowan 2003) sets guidelines for the design of a wind energy converter and has been taken into consideration for application in this project.

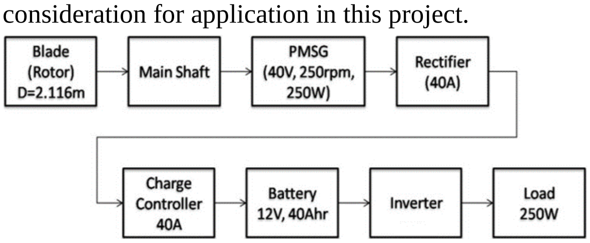


Fig. 1. Block Diagram

INITIAL BLADE DESIGN METHODOLGY

The design of the turbines rotors is perhaps the most mathematically involving element of the entire turbine design. The rotors use aerodynamic lift to provide a turning moment and consequently an input torque to the gearbox. The sizing and configuration of the blades is based upon the relative power coefficient of the turbine and the energy in the stream tube. The energy in the stream tube depends on the swept area of the blades and the wind speed. For the purpose of this project, mathematical modelling and analysis is utilised to determine the rotor sizing, however some assumptions have to be made in order to obtain a realistic geometry. The design of the blades used in this project is based on blade element theory and the Betz equation and will investigate the blade shape for ideal rotors with and without wake rotation.

Twist and chord distribution for a Betz optimum blade				
r/R	Chord, m	Twist angle	Angle of Rel.	Section pitch
		(deg.)	Wind (deg.)	(deg.)
0.1	1.375	38.2	43.6	36.6
0.2	0.858	20	25.5	18.5
0.3	0.604	12.2	17.6	10.6
0.4	0.462	8	13.4	6.4
0.5	0.373	5.3	10.8	3.8
0.6	0.313	3.6	9	2
0.7	0.269	2.3	7.7	0.7
0.8	0.236	1.3	6.8	-0.2
0.9	0.21	0.6	6	-1
1	0.189	0	5.4	-1.6

For experimental purposes a set of scaled blades will be created for testing and employment in a small wind turbine to be constructed during the duration of the project, time permitting. The blades will be based on the ideal blade shape for a rotor without wake rotation. The blades will be created using a fibreglass mould which will then be filled with two part expanding foam. The cured foam will take up the shape of the blade and once cured will be glassed to give increased strength and rigidity

INDUCTION MOTOR/GENERATOR THEORY

Both synchronous and DC machines can be used as either generators or motors and in the same way induction motors can be made to operate as an induction generator. Since thEenergy crisis of the 1970's engineers and scientists have developed uses for induction motors as generators particularly in wind energy converters as they are a suitable mechanism for transforming mechanical energy into useful electrical energy. Induction generators are also referred to as asynchronous generators as the rotor does not operate at synchronous speed. When a voltage, V, is applied to the stator winding of an induction motor, a current made up of two components flows into it. The two current components are the magnetizing component and the real power component. The magnetizing component lags the applied voltage by 90° and is responsible for creating the magnetic field or rotating flux (rotating stator field). The real component is in phase with the applied voltage and supplies the real or active power (watts) to the induction motor. This component consequently induces rotation to the shaft of the motor and is responsible for the mechanical output and internal losses.

For the purpose of physical analysis a 750 W induction motor/generator was disassembled to give physical representation of an induction machines internal components.

The machine investigated was a Brazilian made WEG-EFF E2 induction motor. Induction motor specifics:

3 phases

V	Hz	kW	RPM	A	cosφ
220 DELTA	50	0.75	910	3.47	0.74
380 Y	50	0.75	910	2.01	0.74
230 DELTA	50	0.75	920	3.37	0.72
400 Y	50	0.75	920	1.94	0.72
415 Y	50	0.75	930	1.92	0.70
440 Y	60	0.85	1110	1.96	0.74
460 Y	60	0.85	1120	1.92	0.72

THE GEARING SYSTEM AND MACHINE ELEMENTS

Typically, a large energy producing wind turbine's rotor speed is 25-50 rpm, this varies however depending on the size of the turbine. Induction generators for application in wind energy converters operate at speeds of 750-3600 rpm. A gearing system needs to be employed to provide the required rotational speed to the rotor of the induction generator for effective energy conversion to take place. The type of gearing system and configuration depends upon the selected induction motors synchronous speed. The lower the synchronous speed the better, as this will require a lower gearing ratio and will consequently result in a lower input torque requirement. In gearing reduction systems there is a high-speed input with a low-speed high torque output.

BEARINGS

Bearings are mechanical components designed to reduce the friction between two components in relative motion to one another, generally in rotation. Bearings come in a wide variety varying in design depending upon the relative direction and magnitude of loading. The majority if bearings in use in a wind turbine can be found acting upon the various shafts in the gearbox and drive train. Bearings for high speed applications such as this are generally ball bearings, roller bearings or tapered roller bearings and are designed to accommodate for radial loads and also approximately 30% axial loading. There are however other types of bearing in use in the machine such as the axial thrust bearing which supports the nacelle and its rotation about the turbine tower. Axial thrust bearings allow for low-speed rotation under high axial loading conditions.

CLUTCH AND BRAKING MECHANISM

Clutches are torque transmission mechanisms that are activation dependent. Clutches are therefore optional mechanisms that activate certain functions of a machine. One of the more common types of clutching mechanisms is the pad clutch. This type of clutch operates by initiating contact between a rotating surface and the clutch's pads. The pads are typically made from a material with a relatively high surface friction coefficient and temperature resistant properties. The high levels of friction between the two surfaces cause the two elements to link and cause the clutch side to adopt the drive side's behaviour of motion.

THE GEAR BOX

The expected operating speed of the rotor system at its rated wind speed of 12m/s is approximately 180 rpm. The generator being used has a rated running speed of 1000 rpm. Therefore, a speed increase gear box was designed to provide the generator with its rated running speed. Gears are defined as toothed members that transmit rotary motion from one shaft to another. Among the various methods of power transmission, namely gears, belts and chains, gears are the most rugged and durable. Gears have a transmission efficiency of around 98% and do not suffer from any slippage.

Turbine Blades

PT =$4a(1-a)^2[\rho A uo3]$ (1)

a is the perturbation factor

ρ is the density of the air

A is the swept area of the blades and

u_o is the speed of the upstream wind

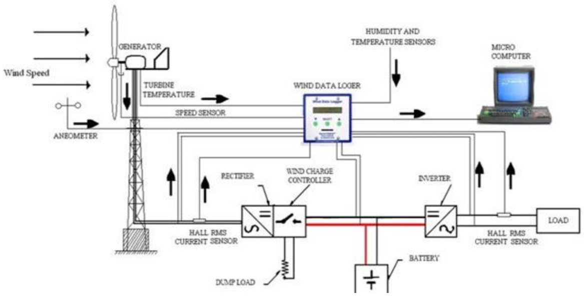
TABLE BLADE SPECIFICATION

Parameters	Specification
No of blades	3 no's (1m each)
Sweep area	3.5 m^2
Material	Fiber glass
Design type	up wind design
Twisted angle (θ)	0 18.4

The plan of the individual blades is also a influence affecting the overall routine of the rotor. Since the blades require a fairly smooth airflow to perform, they must be strategically arranged around the axis of rotation so that they cause the minimum turbulence to the airflow of adjacent blades. This is the aim why greatest of the rotors have only two or three blades. The blade design calculations are given below. And the finished blade is shown in the

MONITORING WIND TURBAN PARAMETERS

Wind turbine monitoring system is responsible for monitoring the blades, shaft, gear box, generator and the overall conditions in the nacelle. This involves a variety of sensors such as accelerators, rotary encoders, temperature sensors, voltage and current sensors as shown in Fig. 8. Accelerators are used to monitor vibrations of the main shaft, gear box, generator, blades and tower, for the purpose of preventing damage due to the destructive vibrations. Temperature sensors sense the temperature of generator and gear box to ensure equipment are working within a safe temperature range. Encoder is mounted on generator's main bearing to monitor rotating speed of the turbine.



ENERGY STORAGE SYSTEM

As wind energy conversions systems rely on the naturally occurring winds to produce electrical energy the consistency and quality of the energy fluctuates with the behaviour of the wind.The majority of energy used in a household is during the evening hours, a time where there is generally not as much wind as during the morning or midday hours. Because of this there is an excess of energy during the day and a shortage at night when it is needed. Because of this energy storage systems are employed to ensure there is always a constant power supply.

RISK ASSESMENT

The design and construction of a wind turbine incorporates various risks and hazards that need to be brought to the attention to anyone who is involved in the processing of parts, assembly and operation of the machine. The majority of risks and hazards are common in industry and there is professional training available to prepare individuals for safe operation within a hazardous environment.

RESOURCES REQUIRED

Design

As the project deals mainly with the design and implementation of a wind turbine and actual construction is only a secondary project objective that will only be conducted if time permits, the majority of resources will be in the form of software and literature. The design of the wind turbine will be based on existing technology which will be investigated in the literature review. This will provide the background knowledge and aid in optimising the technical design parameters of the project; materials, geometry, structure, electrical generator selection etc... The University Library will be the primary source of information aiding the design procedure along with private publications from industry.

The geometric and physical design and modelling will require a CAD package such as PRO Engineer or SOLID Works. The software is available for use at the university along with ANSYS for finite element analysis of the design and testing of individual components.

Construction, fabrication

If construction of the turbine is to take place a wide variety of machinery, tooling and additional tooling is required. These are listed below:
Milling centres (tooling)
Metal lathe (tooling)
Welding equipment (TIG, MIG)
Workshop equipment (general tooling)
Fibre glassing equipment
Testing facilities (Tensile, impact, fatigue, wind tunnel)

Material
The blades will be optimally constructed using either carbon fibre or fibre glass coated timber.
The mechanical parts within the Hub and gear box will be machined from high tensile steel (4140, 4340) to ensure wear resistance.
The base and housing of the nacelle will be machined and fabricated from aluminium stock.
The tower will optimally be fabricated from appropriately sized steel tubing.

CONCLUSION

Small scale wind energy conversion systems are an effective, environmentally friendly power source for household and other applications. Although they are subject to climatic behaviour and do not always deliver a constant supply of energy, they can be adapted to energy storage units that allow the selective distribution of the energy once it has been converted. All modern wind turbines use lift force to create rotational motion in order to drive their gearbox and generator. For electrical energy generation high rotor speeds are favourable as they reduce the gearbox ratio required to achieve the generator’s optimum operating speed. Low solidity rotors ensure high rotational speeds are generated; however, a rotor must also produce enough torque to overcome the drive train and generator losses. Three bladed turbines are of the most suitable solidity for a broad range of wind speeds and are the most frequently employed as mechanical/electrical converters. (Burton, Sharpe, Jenkins and Bossanyi 2001) State that on a good site, a wind turbine recovers the energy used in its manufacture and installation within the first year of its operation. Whilst this is not always the case, it highlights the potential for wind energy converters as a source of sustainable power supply for the future.

The resultant design of the project is a small scale 0.5 – 2 kW electrical energy producing wind turbine. Its design is based on a 3 bladed horizontal axis wind turbine for the application of charging a battery bank in remote or isolated communities and dwellings. The turbine uses and induction generator to produce AC power which then inverted to DC and governed by a shunt regulator. The rotor has a relatively high torque coefficient and was designed using a cambered aerofoil profile allowing it to produce electricity even at low wind speeds. At low wind speeds the power produced is used to trickle charge a battery bank, the systems energy storage unit. Once the battery bank is fully charged the shunt regulator diverts the supply to a dump load such as a hot water heating unit so no energy is wasted

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