CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Energy is the basic necessity for the economic development of any country. Many indispensable functions for present-day living grind to halt when the supply of energy stops. As such, it is practically impossible to estimate the actual magnitude of the part that energy has played in the building up of the 21st century civilization. The availability of huge amount of energy – whether in the crude and unprocessed form or in the form consumable by people – in developed economies has resulted in shorter working day and hour, higher agricultural and industrial production, a healthier and more balanced life-style (Mehta & Mehta, 2013). In fact, there is a close relationship between the energy used per person and his standard of living. The greater the per capita consumption of energy in a country, the higher is the standard of living of her citizens.

Energy exists in different forms in nature, but the most important form is the electrical energy (Mehta & Mehta, 2013). The modern society is so much dependent upon the use of electrical energy that it has become part and parcel of people's life. Electrical energy is a manufactured commodity like clothing, furniture or tools. Just as the manufacture of a commodity involves the conversion of raw material available in nature into the desired form, similarly, electrical energy is produced from the forms of energy available in nature. The energy available in nature is referred to as energy resources (Uppal & Rao, 2012). However, electrical energy differs in one important aspect. Whereas other commodities may be produced at will and consumed as needed, electrical energy (though could be stored) must be produced and transmitted to the point of use at the instance it is needed. The entire process takes only a fraction of a second. This instantaneous production of electrical energy introduces technical and economical considerations unique to the electrical power industry. The conversion of energy available in different forms in nature into electrical energy is known as generation of electrical energy or simply as power generation (Uppal & Rao, 2012).

Energy, it has to be reiterated, is available in various forms from different natural sources such as pressure head of water, chemical energy of fuels, nuclear energy of radioactive substances, etc. All these forms of energy can be converted into electrical energy by the use of suitable arrangements. The arrangement, according to Mehta and Mehta (2013) essentially employs an alternator (generator) coupled to a prime mover. The prime mover is driven by the energy from various sources such as burning of fuel, pressure of water, force of wind, and so forth. For example, chemical energy of a fuel; say, coal, can be used to produce steam at high temperature and pressure. The steam is fed to a prime mover which may be a steam engine or a steam turbine. The turbine converts heat energy of steam into mechanical energy (of a rotating shaft), which is further converted into electrical energy by the alternator. Similarly, other forms of energy can be converted into electrical energy by employing suitable machinery and equipment.

Since electrical energy is produced from energy available in various forms in nature, it is germane and desirable to mention some of the various sources of energy as these constitute part of the background of this research. Some of these sources of energy are: water, fuels, nuclear energy, sun, and wind. Out of these delineated sources, the energy due to wind has not been utilized on large scale, in Nigeria, due to a number of limitations to be discussed later. At present, the other two sources viz., water and fuels, are primarily used for the generation of electrical energy in Nigeria. Worried by the inherent fears of depletion of these two seemingly reliable sources, the researcher is laden with the burden of evaluating the prospects of a workable wind turbine for application in Owerre-Ezukala, in Orumba-South Area Council of Anambra State.

1.2 Statement of the Problem

Energy supply in Nigeria today is a major problem for both small scale and large scale purposes. The conventional energy supply has not equally been distributed, and is inadequate in meeting the economic needs of the populace. This looming problem had affected productivity in every facet of her economy. At one point or the other, government brings out scheme to better the efficiency of power and energy supply. These programmes often fail to materialize, perhaps, because of either managerial inadequacies or insufficient generation of energy to satisfy the need of the teaming Nigerian populace. Manufacturing and pharmaceutical industries, suffer serious regression in their operation, as a sequel. The quest to resolve the above identified problem set the researcher into thinking of an alternative energy source that can adequately satisfy the electricity need of the designated geographical area. However large Nigeria's energy resource of fossil fuel may be, it is being consumed at a high rate, and one day, the fuel resource will become so depleted that the normal existence of energy-dependent firms will be seriously disrupted, unless other energy sources have become available on the scale necessary to meet the country's energy demand. Many warnings, Sambo (2006), have been given over the years about Nigeria's rate of fuel refining and consumption, and the prospects of future fuel shortage. Nevertheless, each time the crisis has passed and the nation has continued on its unrealizable strategies. There is a renewed awareness of the importance of harnessing other energy sources, and the need for a long-term planning for the country's future energy supply. Owing to protracted energy scarcity in the designated community, the researcher is motivated to investigate the energy generation requirement and wind energy potential of this community. Wind energy is basically the harnessing of wind power to produce electricity. The kinetic energy of the wind is converted into electrical energy (Yunus & Michael, 2011). The kinetic energy of the wind varies directly as the electrical energy. Taking other mechanical factors for granted, the higher the speed of the wind, the higher the electrical energy; and vice versa.

1.3 Aim and Objectives of the Study

The aim of this dissertation is to undertake an evaluation of the *energy consumption requirement and wind energy generation potential of a rural community*. The study was centered around Owerre-Ezukala, in Anambra

State. Achieving this aim is actually targeted through the following objectives:

- To determine research areas that would guarantee sustainable wind speed and record these values
- To develop a novel mathematical model for the determination of power output of the wind turbine/s
- To compare the Betz' mathematical model with the developed mathematical model, in terms of their co-efficient of performance and rated power outputs
- To test the contingent variables in the generated mathematical model for statistical significance using analysis of variance (ANOVA)
- To perform a sensitivity analysis of the Betz' mathematical model and the developed mathematical model.

1.4 Significance of the Study

A large quantity of electrical energy is needed to sustain industrial growth, agricultural production, and domestic use. The existing sources of energy such as coal, fossil fuels, and geothermal etc. may not be adequate to meet the ever increasing energy demands. These conventional sources of energy are also depleting, and may be exhausted in no distant time (Gordon & Yon, 2011). Consequently, sincere and unrelenting efforts shall have to be made by scientists and engineers, in exploring the possibilities of harnessing energy from several non-conventional energy sources. According to energy experts, the non-conventional energy sources can be used with advantage for power generation as well as other applications in a large number of locations, and situations**.** The geographical layout of Owerre-Ezukala encourages a sustainable wind velocity across the year.

1.5 Scope of the Study

This study is primarily concerned about the geographical and climatic conditions with respect to monthly and annual wind speed in Owerre-Ezukala axis of Anambra State. Therefore, the work is meant to evaluate the prospects of wind energy generation in this community. The wind data were obtained from an anemometer at an altitude of 10m. By the application of statistical tool of the Analysis of Variance (ANOVA), the dependent and independent variables in the generated mathematical model were tested for statistical significance. While limiting discussions mainly on ecological factors that affect wind speed, this study shall, also, address topics like: parametric design of a turbine blade, design of wind farm for the designated area, energy audit of the research area, system design, cost analysis of the produced electrical energy, and aerodynamic blade design.

CHAPTER TWO

LITERATURE REVIEW

2.1 Renewable Energy Resources in Nigeria

Nigeria is endowed with huge conventional energy resources (crude oil, tar sands, natural and coal) as well as reasonable amount of renewable energy resources (e.g. hydro, solar, wind and biomass). According to the OPEC annual statistical bulletin 2017, Nigeria proven crude oil reserves and natural gas are 37.2 billion barrels and 5,292 trillion standard cubic metres, respectively. In addition, the estimated reserve of tar sands and proven reserves of coals are about 30 billion barrels of oil equivalent and 639 million tons (with inferred reserves of about 2.75 billion tons), respectively (ECN, 2003). The estimate of renewable energy resources in Nigeria are presented in Table A2.1.

Table A2.1. Renewable Energy Resources and Estimated Reserves in Nigeria.

Hydropower (large/small scale)	14,750 MW
Solar radiation	3.5 - 7.0 $KWhm^2$/day
Wind	2-4 m/s at 10m height
Biomass	144 million tons/year
Wave and tidal energy	150,000 TJ/year

Source: Ibitoye and Adenikinju, 2007

By the end of 2008, Nigeria was expected to have been generating 15000 MW of electricity. However, as at the time of this research, the electricity generation from all the available power stations is about 3100 MW, which is about 50% of installed electricity capacity as at 2004 and 20% of the 2008 projected capacity(Ibitoye and Adenikinju, 2007). The shortage in electricity production from thermal stations (which accounted for about 70% of installed electricity capacity), is surprisingly, attributed mainly to lack or shortage of gas supply. The overall targets of renewable energy and total electricity generation are presented in Table 2.2. This table shows that Nigeria is already behind these values as regards wind energy contribution. Surprisingly, the hydropower reserve data, as shown in Table 2.1 and supported by other sources e.g. Manohar and Adeyanju, (2009); Sambo, (2006) is far less than the long term target (Table A2.2) for this resource. This disparity can be linked to insufficient and inaccurate information or over ambition on the part of Nigeria government agency that made these projections.

Table A2.2. Targets for renewable electricity generation (MW) in Nigeria

Resource	**Short term 2008**	**Medium term 2015**	**Long term 2030**
Hydro (large)	1930	5930	48000
Hydro (small)	100	743	19000
Solar PV	5	120	500
Solar Thermal	-	1	5
Biomass	-	100	800
Wind	1	20	40
All Renewable	2,036	6,905	68,345
All Energy Resources	15,000	30,000	190,000

Source: Sambo (2006)

Due to recent development in wind energy mostly in developed countries (especially in Europe) with desire to reduce environmental impacts of the conventional energy resources, there is a general growing interest in wind energy development in Nigeria. The global cumulative installed capacity of wind power gradually increased from 6,100 MW in 1996 to 158,505 MW in 2009 (GWEC, 2010). In Africa, Egypt, Morocco and Tunisia are the leading countries with installed capacity of 430 MW, 253 MW and 54 MW, respectively, at end of 2009 (GWEC, 2010). The questions are: Can Nigeria benefit from the global development in wind energy resource? Can investment by government at all levels and private organizations in this resource help to ease electricity crisis in Nigeria? To answer these questions, knowledge about the availability and distribution of wind speed across this country is essential. The general notion is that Nigeria has enough wind energy resource and therefore, investment in it can help in solving her electricity crisis. Part of the focus of this chapter is to survey some of the works that reported wind speed and wind energy potential in Nigeria and discuss the potential uses of this resource. This information will be helpful to the government and any organization to make an informed decision regarding investment in wind energy resource.

It is unequivocal to aver that energy plays a central role in economic development and industrialization of any nation. Fossil fuels have been the major resources that supply the world energy demand. However, fossil fuel reserves are limited and usage of fossil fuels to generate energy has negative environmental effects. The world energy demand is continuously increasing with increasing population such that the present fossil fuel reserves cannot meet this demand (Kamau et al., 2010). As a result, energy policies of many nations are geared towards ensuring a supply of reliable, economical and environmentally friendly energy resources in a form that supports the targets for growth and social development (Ucar and Balo, 2009). Wind energy applications have been recently (Weisser and Garcia, 2006) described as an economic and environmentally friendly solution to the urgent energy problems of many countries. Wind is an effect caused as a result of pressure differences over regions and heights in the atmosphere resulting in bulk motion of air masses. The force carried by the moving air mass (wind) can be harnessed for useful purposes such as grinding grain (in windmills) and generating electricity (in wind turbine generators). It is estimated that between 1.5 to 2.5% of the global solar radiation received on the surface of the earth is converted to wind (Vosburgh, 1983). Hence, wind energy, which contributes very little pollution and few greenhouse gases to the environment, is a valuable alternative to the non-renewable and environmentally hazardous fossil fuels (Taylor, 1983). Thus, the utilization of wind energy has been increasing around the world at an accelerating pace. The extent to which wind can be exploited as a source of energy depends on the probability density of occurrence of different speeds at the site, which is essentially, site-specific. However, the development of new wind projects continues to be hampered by the lack of reliable and accurate wind resource data in many parts of the developing world.

To optimize the design of a wind energy conversion device, data on speed range over which the device must operate to maximize energy extraction is required, which requires the knowledge of the frequency distribution of the wind speed. Among the probability density functions that have been proposed for wind speed frequency distributions of most locations, the

Weibull distribution has been the most acceptable and forms the basis for commercial wind energy applications and software (Seyit and Ali, 2009). Some of the wind energy software based on the Weibull distribution includes the Wind Atlas Analysis and Application Program (WAsP) and the recently developed Nigerian Wind Energy Information System (WIS). In earlier works by experts, (Enibe, 1987; Ugwuoke et al., 2008; Odo et al., 2010), the theoretical potentials of wind at various heights above the ground, based on annual average values of wind speed, have been assessed for many Nigerian locations. These analyses were carried out using measured data over various periods ranging from 1 to 10 years. In these analyses, little or no attention was given to the frequency distribution patterns of wind speed over the studied periods for the locations. In this dissertation, the distribution of daily averages of wind speed for three locations in Owerre-Ezukala, in Orumba-South, Anambra State, over a longer period of up to 1 year, is examined. The results of this analysis are expected to be very useful to designers of wind turbines, for various wind energy applications, for the locations.

Wind is an inexhaustible resource that can provide significant quantities of energy to support a country’s needs. Since the earliest recorded history, man has been harnessing the energy of the wind (Ahmed and Hanitsch, 2006). Windmills have been in use for many centuries for pumping water and for grinding grains or milling. The interest in wind energy is growing worldwide because of its environmental benefit and advancement of its technology, which is highly competitive with conventional energy technology. Today wind energy can be harnessed for grid and non-grid electricity generation, water pumping, irrigation, milling etc. The oil crisis of 1973 brought a terrific surge of research activity on global scale to develop alternative and renewable energy sources. During the last decade wind energy was taken seriously as a potential method of supplying a proportion of our future energy needs. Large and medium sized wind turbines are in use in many parts of the world, and there is a steady growth in the number of wind turbines connected to established power grids. According to Celik, (2003), wind energy is currently the most economic renewable energy apart from hydropower. The ability to use it as a decentralized energy form makes its applications possible in rural areas where it is technically and economically feasible in the country. The major challenge of using wind as a source of electricity generation is that wind is intermitted and it is not available always when electricity is needed. In order to meet up the demand of the populace, solar and wind energy are some of the alternative source of energy that can be exploited to meet some of the needs of populace. It is, therefore, necessary to evaluate the wind regimes in the country and assess the potential in various part of the country.

Babatunde, in Ibitoye et al (1997) considered 10 years (1986—1995) hourly and daily wind speed of some selected sites in North East and North West of Nigeria. Using statistical method of regression analysis to find the correlation coefficient of the observed data and the developed theoretical distribution model, he found out that Weibull and exponential probability distribution model were the best fit for most of the sites (Jamil et al, 1995). For example, wind speed in Kano and Kaduna in the north-west of Nigeria are described by Weibull and Rayleigh models, respectively. He also found that the theoretical power density ranges between 5.7W/m^2 in Bauchi and 113W/m^2 in Kano. In another development, Tijani, (2006), in his presentation of the statistical analysis of wind power density based on the Weibull and Rayleigh models in north-western Nigeria (Yelwa, Kaduna, Gusau, Sokoto and Kano) used 15 year (1986 to 2000) monthly mean wind speed data of the selected towns.

Table A2.3. Geographical Data of the Locations

Locations	**State**	**Latitude (N)**	**Longitude (E)**	**Altitude (M)**
Gombe	Gombe	10' 54" N	11' 15" E	152.3
Maiduguri	Borno	11' 51" N	13' 05" E	353.6
Yola	Adamawa	9' 14" N	12' 28" E	185.9

Source: NIMET (2005)

The study found out that the average monthly power density ranges between 1.87W/m^2 and 108.8W/m^2. In this presentation NIMET (2005), 12 year (1994 to 2005) monthly mean wind speed data are obtained from Nigerian Metrological Agency (NIMET), Oshodi for some selected towns in North Eastern Zone (Gombe, Maiduguri, and Yola). These were statistically analyzed to evaluate wind power density based on the Rayleigh and Weibull models. The availability of energy has a great effect on the socio-economic make up of a place, while its variability can lead to fluctuations in the population (Ajayi et al, 2014). While electricity from hydropower plant is widely acknowledged as environmentally friendly, those from fossil fuels and nuclear power have associated environmental limitations. This is because of the harmful effects of their by-products (Ajayi et al., 2014; Omole and Ndambuki, 2014). They opined that energy production from fossil sources (both in the form of electricity and heating) is one of the major sources of anthropogenic emissions of CO_2 and other green-house gases. This has led to the need for ways to create a balance between sustainable socio-economic development and energy security.

Adopting renewable energy resources for electricity production and other energy needs has become a notable objective, globally. While countries have started to look at ways of harnessing the abundant environmentally friendly renewable resources, some others have already proved it and are extending their generation capacities. China, United States, Germany, Spain, India are some examples of countries who have annual installed wind power capacities in the regions of some Giga-Watt (GW) of electricity (Omole and Ndambuki, 2014; Ajayi, 2013a). The African continent, though improving in generation capacities, represents the least developed in terms of installed wind power and wind electricity adoption. North Africa, with Egypt (550 MW) and Morocco (286 MW) leads the way. Tunisia (54 MW), South Africa (10 MW) and Kenya are other promising countries. Moreover, projections reveal that in the near future wind power capacities up to few GW will be achieved in places like Egypt, Morocco and South Africa. In sub-Saharan Africa, particularly the West African region, no country has yet generated grid electricity from wind despite the identified opportunities (Ajayi, 2013b). The challenges of wind energy project development in West Africa may however be linked to inadequate measurements, incomplete assessment studies and/or improper wind classification of the countries in the region. This is partly due to the fact that wind resources are site specific. Therefore, in order to properly classify a country's wind profile, assessment of as many sites as possible, will be required. Nigeria's wind profile assessment has gone through various developmental stages. Various policy issues have been generated with the government demonstrating the intention to generate electricity from wind (Ajayi, 2013a; and Ajayi, 2013b).

2.2 Development of Wind Energy in Nigeria

Wind, as a source of energy, is gradually gaining prominence around the world, although backed by long history. However, many countries are yet to embrace it. Today, wind power is not used in Nigeria, what is available are relics and shades pointing to efforts by energy professionals at different levels. However, the desire to seek for a lasting solution to the energy situation of Nigeria has prompted the government as well as independent researchers to assess the nation's potentials for wind energy. The government appointed two groups of consultants to ascertain the potential for wind energy and also carry out wind resource surveys for the country (Ajayi, 2009). Individual researchers on their part have made various assessments of potentials and availability to determine the magnitude of wind resources. Asiegbu and Iwuoha,(2007), studied the wind in Umudike, South-East, Nigeria and assessed its economic viability at a hub height of 65 m above the ground with annual mean wind speed of 5.36 m/s using 10 years (1994–2003) wind speed data.

Fadare, (2008), carried out a statistical analysis of wind energy potential in Ibadan (a city in Oyo State of Nigeria), using the Weibull distribution function and 10 years (1995–2004) daily wind speed data. The outcome was that the city experiences average wind speed and power density of 2.947 m/s and 15.484 W/m^2. Ogbonnaya et al., (2009), on the other hand worked on the prospects of wind energy in Nigeria using 4 years of wind data from seven cities (Enugu, Jos, Ikeja, Abuja, Warri, Sokoto and Calabar). The annual wind speed at 10 m above the ground varied from 2.3 to 3.4m/s for sites along the coastal areas and 3.0 to 3.9 m/s for high land areas and semi-arid regions. It was also reported that monthly average wind power was 50.1 W/m^2 along the coastal areas; and Sokoto is capable of a power potential as high as 97 MWh/yr.

Further works by researchers are profiled in academic papers (Ajayi, 2009). Each of these initiatives, in the limits of their uncertainties, have identified that great prospects exist for wind energy utilization for power generation. Moreover, wind speeds are generally weak in the south except for the coastal regions and offshore, which are windy. Off-shore areas from Lagos through Ondo, Delta, Rivers, Bayelsa to Akwa Ibom States were reported to have potentialities for harvesting strong wind energy throughout the year. In land, the wind was reported strongest in the hilly regions of the North, while the mountainous terrains of the middle belt and northern fringes demonstrated high potential for great wind energy harvest. It was, however, observed that, due to varying topography and roughness of the country, large differences may exist within the same locality. The values for the wind speeds range from a low 1.4 to 3.0 m/s in the southern areas and 4.0 to 5.12 m/s in the extreme North, at 10 m height. Peak wind speed was shown to generally occur between April and August for most sites in the analysis. (Ajayi, 2009). Further analysis of these wind resources also revealed that the North-Central and South-East of the nation possess enormous potential for harvesting wind energy, with possible wind speeds reaching as high as 8.70 m/s in the north (Ajayi, 2007). Moreover, each of the aforementioned and other reports was based on measurements from few wind stations located within the country. For instance, Adekoya and Adewale, (1992) analyzed wind data of 30 stations, while Ajayi, (2007), analyzed ten years data from 10 wind stations. Increasing both the number of stations and reference years would increase the accuracy of the results. Thus, latest results (NIMET, 2009) based on the outcome of using 40 years (1968 −2007) available average wind data from the whole forty-four wind stations across the states of the federation showed that (Fig. 2.1), the country's wind regime is found to lie majorly between poor to moderate regimes, with the southern states having their mean wind profile at 10 m height in the range between 3.0 −3.5 m/s, depending on the states, and Northern states capable with mean wind speeds of between 4.0 −7.5 m/s. This means that, Nigeria has good wind resources over most part of the country. Although, wind speeds in the southern states are low, they can however be employed for stand-alone power generating systems using small scale wind turbines. This, if employed, will be a major breakthrough for rural and sub-rural areas not connected to national electricity grid.

Various initiatives, both from governments and individual researchers exist (Ajayi, 2009; Ajayi, 2010). The characterization of Nigeria's wind profile started way back in the mid-nineties. Fagbenle *et al*, (1980), summarized the earliest studies on wind energy in Nigeria to include works by Adejokun, (1966), Fagbenle *et al.*, (1980) and Ojosu and Salawu, (1990). Adejokun, (1966), explained the wind speed distribution across the seasons. Fagbenle *et al.*, (1980), studied the wind power potential of Nigeria and found that a modal class of about 3.0 m/s characterized the 1951 to 1960 surface wind data at 10 m height from twelve meteorological stations. It also showed that

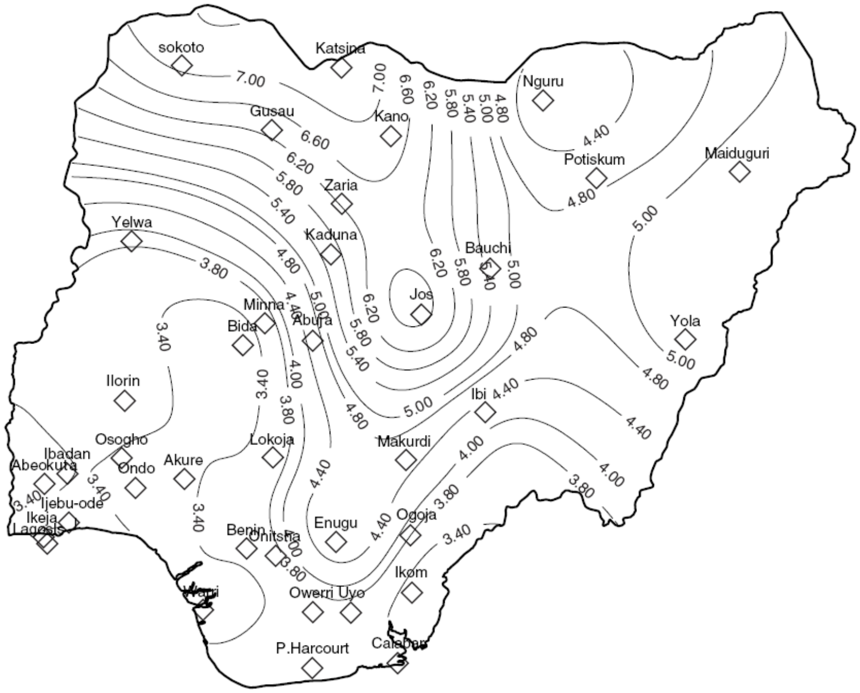

Fig. 2.1: Isovents in m/s determined from 40 year's measurements at 10 m Height, Nigeria meteorological department, Oshodi, Lagos State, Nigeria. (NIMET, 2009).

mean wind speeds in the North were twice as high as those of the South, while the high-altitude Jos station in Plateau State had the highest mean wind speed of about 3.6 m/s. Ojosu and Salawu, 1990, analyzed annual average wind data from 22 meteorological stations for the period 1951–1975. They concluded that the high-latitude Sokoto station was the windiest, with a monthly average wind speed of 5.12 m/s in June and an annual mean of 3.92 m/s. The report also showed that the middle belt and the southern parts had wind speed values of at most 2.0 m/s.

Other studies include that of Adekoya and Adewale, (1992), who analyzed wind speed data of 30 stations in Nigeria and determined the annual mean wind speeds and power flux densities to vary from 1.5 to 4.1 m/s and 5.7 to

22.5 W/m^2, respectively. Fagbenle and Karayiannis, (1994), on the other hand, did an analysis of 10 years' wind data from 1979 to 1988. It considered the surface and upper winds as well as the maximum gusts. Asiegbu and Iwuoha, (2007), studied the wind resource availability in Umudike, South-East, Nigeria using 10 years (1994–2003) of wind speed data. They found that the economic viability of the site required a hub height of 65 m above the ground with an annual mean wind speed of 5.36 m/s. Fadare, (2008), carried out a statistical analysis of wind energy potential in Ibadan, using a Weibull distribution function on 10 years (1995–2004) of daily wind speed data. The outcome showed that the city experienced an average wind speed and power density of 2.947 m/s and 15.484 W/m^2. Ogbonnaya et al., (2009), on the other hand, worked on the prospects of wind energy in Nigeria. Four years' wind data from seven cities (Enugu, Jos, Ikeja, Abuja, Warri, Sokoto and Calabar) cutting across the different geopolitical zones of the federation were employed. The outcome showed that the annual wind speed at 10 m height for the cities varied from 2.3 to 3.4 m/s for sites along the coastal areas and 3.0–3.9 m/s for high land areas and semi-arid regions. It was also reported that monthly average wind power could be about 50.1 W/m^2, and that it was possible to generate a wind power of 97 MWh/yr from the Sokoto site. Also, Ngala et al., (2007), did a statistical analysis of the wind energy potential in Maiduguri (Borno State). It employed the Weibull distribution with 10 years (1995–2004) of wind data. Further reports on the various assessment studies both by researchers and government agencies are profiled in Ajayi's work (Ajayi, 2009; Ajayi, 2010).

2.3 Wind Availability and Measurement

Wind energy can only be economical in areas of good wind availability. Wind energy differs with region and season, and also, possibly to an even greater degree, with local terrain and vegetation. Although wind speeds generally increase with height/altitude, varying speeds are found over different kinds of terrain. In developed economies, observations of wind speeds are carried out at meteorological stations, airports and lighthouses; and are recorded regularly with ten minute mean values being taken every three hours at an attitude of 10m. Also, combinations of various other factors, mean that reading can be misleading. It is difficult therefore, to determine the real wind speed of a certain place without actual *in situ* measurements.

The world meteorological organization (WMO) has accepted four methods of wind recording (Rajput, 2013);

i. Human observation and log book
ii. Mechanical cup-counter anemometer
iii. Data logger
iv. Continuous record of velocity and direction

2.3.1 Human Observation and Log Book

This involves using the Beaufort scale of wind strengths which defines visible symptoms attributable to different wind speeds. This method is cheap and easily implemented but is often unreliable. The best that can be said of such records is that they are better than nothing.

2.3.2 Mechanical Cup-Counter Anemometer

This finds application in meteorological stations. By taking the readings twice or three times a day, it is impossible to estimate the mean wind speed. This is a low cost method, but is only relatively reliable. The instrument has to be in good working order. It has to be correctly sited, and should be reliably read, at least daily.

2.3.3 Data Logger

The equipment summarizes velocity frequency and direction. It is more expensive and prone to technical failures, but gives accurate data. This method is tailored to the production of readily interpretable data of relevance to wind energy assessment; it does not keep a time series record, but presents the data in processed form.

2.3.4 Continuous Records of Velocity and Direction

This is how data is recorded at major airports of permanently manned meteorological stations. The equipment is expensive and technically complex, but it retains a detailed times-series record (second-by-second) of wind direction and wind speed. Results are given in copious quantities of data which requires length and expensive analysis.

2.4 Aerodynamics of Wind Turbine

Modern utility-scale wind turbines use airfoils (shapes similar to an aircraft wing) shown in Fig. 2.2 to harness the kinetic energy in the wind. Two wind-induced forces act on the airfoil; lift and drag. Turbines depend predominantly on lift force to apply torque to rotor blades, though some torque is caused by the drag force as well. The lift force is shown perpendicular to effective airflow direction; it is primarily responsible for the torque that rotates the rotor. The tips of the blades, being farthest from the hub, are responsible for the major part of the torque.

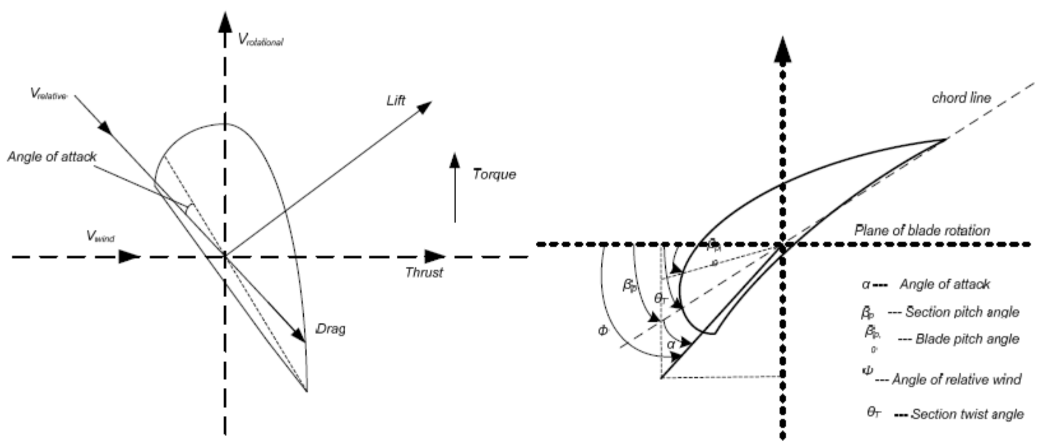

Fig. 2.2: Cross Section of Wind Turbine Blade Airfoil (left) and Relevant Angles (right).

The wind systems that exist over the earth's surface are a result of variations in air pressure. These are, in turn, due to the variations in solar heating. Warm air rises and cooler air rushes in to take its place. Wind is merely the movement of air from one place to another. There are global wind patterns related to large scale solar heating of different regions of the earth's surface and seasonal variations in solar incidence. There are also localized wind patterns due to the effects of temperature differences between land and seas, or mountains and valleys. Wind results from air in motion due to pressure gradient that is caused by the solar energy irradiating the earth. Wind speed generally increases with height above ground. This is because the roughness of ground features such as vegetation and houses cause the wind to be slowed. Wind possesses energy by virtue of its motion. Any device capable of slowing down the mass of moving air can extract part of the energy and convert into useful work.

The following factors control the output of wind energy converter:

- The wind speed
- Cross-section of the wind swept by rotor
- Conversion efficiently of rotor
- Generator
- Transmission system

Theoretically it is possible to get 100% efficiency by halting and preventing the passage of air through the rotor. However, a rotor is able to decelerate the air column only to one third of its free velocity. A 100% efficient wind generator is able to convert maximum up to 60% of the available energy in wind into mechanical energy. In addition to this, losses incurred in the generator decrease the overall efficiency of power generation to 35%.

Wind mills or turbines work on the principle of converting kinetic energy of the wind into mechanical energy.

Power available from wind mill = $\frac{1}{2} \rho A V^3$

Where, ρ – air density = 1.225 Kg. / m^3 at sea level. (changes by 10-15% due to temperature and pressure variations)

A – area swept by windmill rotor = πD^2 sq-m. (D – diameter)

V – wind speed m/sec.

Air density, which linearly affects the power output at a given speed, is a function of altitude, temperature and barometric pressure. Variation in temperature and pressure can affect air density up to 10 % in either direction. Warm climate reduces air density.

Practically, wind turbines are able to convert only a fraction of available wind power into useful power. As the free wind stream passes through the rotor, it transfers some of its energy to the rotor and its speed decreases to a minimum in the rotor wake. After some distance from the rotor wind stream regains its speed from the surrounding air. We can also observe drop in pressure as the wind stream passes through the rotor. Finally, air speed and pressure increases to ambient atmospheric condition.

Wind - electric conversion system consists of the following components:

- Wind Turbine (WT): Converts wind energy into rotational (mechanical) energy
- Gear system and coupling (G/C): It steps up the speed and transmits it to the generator rotor
- Generator (G): Converts rotational energy into electrical energy.
- Controller (C): Senses wind direction, wind speed generator output and temperature and initiates appropriate control signals to take control action.

- Yaw motor gear: The area of the wind stream swept by the wind turbine is maximum when blades face into the wind. Alignment of the blade angle with respect to the wind direction to get maximum wind energy can be achieved with the help of yaw control that rotates wind turbine about the vertical axis.

In smaller wind turbines, yaw action is controlled by tail vane whereas, in larger turbines, it is operated by servomechanism. The fact that the power is proportional to the cube of the wind speed is very significant. This can be demonstrated by pointing out that if the wind speed doubles, the power in the wind increases by a factor of eight. It is, therefore, worthwhile finding a site which has a relatively high mean wind speed.

Although the power equation (cf. Eqn. 3.8) brings to the fore the power in the wind, the actual power that could be extracted from the wind is significantly less than this figure suggests. The actual power will depend on several factors, such as the type of machine and rotor used, the sophistication of blade design, friction losses, and the losses in the other equipment connected to the wind machine. There are also physical limits to the amount of power that can be extracted realistically from the wind. A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. To this day, this is known as the *Betz Limit* or *Betz' Law***.** The practical or actual maximum power efficiency of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the "power coefficient" and is defined as:

$$C_{pmax} = 0.59$$

Also, wind turbines cannot operate at this maximum limit. The C_p value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once the various engineering requirements of a wind turbine are incorporated into the design - strength and durability in particular – the real-world-limit is well below the *Betz Limit* with values of 0.35 - 0.48, common even in the best designed wind turbines. By the time the designer takes into account the other factors in a complete wind turbine system; e.g. the gearbox, bearings, generator and so on - only 10-30% of the power of the wind is ever actually converted into usable electricity. Hence, the power coefficient needs to be factored in equation 3.8, and the extractable power from the wind is given as in equation 3.13.

Wind power depends on amount of air (volume), speed of air (velocity), mass of air (density) flowing through the area of interest (flux). The proportionality relation is represented mathematically as:

$$P \propto AV^3$$

From equation 3.8, the following inferences can be drawn:

- Power ~ Cube of velocity
- Power ~ Air density
- Power ~ Rotor Swept Area

High power output is possible with: high tower for high wind speed; and long blades for large swept area. The fact that wind power is proportional to the cube of the wind speed is very significant. This can be demonstrated by pointing out that if the wind speed doubles, then the power in the wind increases by a factor of eight. It is, therefore, worthwhile finding a site which has a relatively high mean wind speed.

2.5 Challenges Facing Wind Energy Development

The factors that tend to limit wind energy development within the country include:

- **Non-Existent Policy, Legal or Regulatory Framework Relating to Wind Energy Technology**

Identifying the crises state of Nigeria's energy system and knowing the prospects which are existent in wind for power generation within the country, the government needs to develop robust policy framework of legal and regulatory mechanisms that would encourage the development of wind energy technology (WET), attract foreign and indigenous investors and also set standards for wind farm creation and management. As at today, no popular fiscal, legal or regulatory policy exists for WET. Potential investors always will hope to see the level of seriousness which the governments have demonstrated and what opportunities have been put in place to enhance marketability of WET within the country before investing their money. Such seriousness is basically demonstrated in policy documents that have been put in place. An example of such policy is the Denmark renewable energy policy (Meyer, 2004). This policy contain among many other things factors that have improved wind power development in Denmark for over 2 decades, making the country one of the leading nations utilizing wind energy for productive purposes. Part of the policy statement includes those that favour regulated feed-in tariff for electricity from wind and other renewables, different subsidies and remuneration rates for wind energy investors, the right to connect renewable generation to the national electricity grid, legal obligations for electric utilities to purchase wind energy and promotion of private individuals, farmers and cooperatives to own wind turbine installations. The overall goal of the Danish energy policy was to promote sustainable energy development and to comply with commitments to reduce greenhouse gas emission in an effort towards the mitigation of climate change (DME, 1990; DMEE, 1996). Germany and South Africa (SADME, 2002; SADME, 2003) have also adapted the Danish energy policy to develop their own energy policy and Nigeria can do likewise. For Nigeria, the policy must contain like others, vital market components which will serve as incentives to willing investors. The act of making a single policy to represent for all energy sources (combining both renewable and non renewable or combining all renewable energy sources together) may not be very reassuring, because individual energy sources represents specific dynamics and should in policy development be individualized. In addition, such well rounded policy should contain among other issues, the quota of WET contribution to national portfolio on energy mix and this should be set and fixed for specific entry year probably say 2020. With this, the nation and the external public will be informed at what pace the WET development should go and what level of investment would be required.

- **Poor Government Motivation on WET**

The governments although have been looking for ways of getting the nation out of the energy poverty, they have however not done enough at all levels to create enabling business environment to promote and encourage WET development. It is well known that the initial capital cost for wind and other renewable energy technology is very high compared to other conventional energy sources, if however, the governments (local, state and federal) would give tax incentives or holidays to willing investors, remove/reduce custom duties payable on importation of WET, give subsidies to sales/purchases of WET applications, provide low or interest free loans through banks primarily for WET investors and also restructure the energy framework of the nation to include WET, the awareness level of the public will be enhanced and invariably there would be rapid embracing of the technology of wind for power generation.

- **Lack of Adequate Research and Development**

Research and Development (R & D) tailored towards WET in the nation have been few, slow and not encouraging. The available data have not also been adequately employed to develop physical models that would translate the huge resources of wind to power. Until recently, what was available was small data system pointing to the availability of wind as a source of potential electricity production within the nation. Basic researches into the act of tapping wind for electricity have been non-existent within the country. This is because, such practices involve funding and such funds have not been available anywhere for access by wind energy researchers. More so, research tailored towards development of low cost materials for wind turbines and other renewable energy technology applications should begin. This will invariably eliminate the huge initial capital involved in starting wind energy business and also further reduce the operating and management cost of the technology. Other areas of research include more robust wind resource assessment for the nation to cover both on-shore and off-shore areas. This may involve establishing more wind stations across the states and geopolitical zones of the nation for data collection, development of suitable national wind atlas, such that could be used in wind power assessments at specific sites, site specific assessment of performance of wind turbines, development and validation of novel wind turbines that generates high amount of electricity at moderate/low wind regimes, also research into best ways of integrating wind turbines to the grid may be carried out.

- **Lack of Focus on the Renewable Energy Master Plan**

One of the two federal government initiatives at resolving the country's energy poverty led to the creation of the nation's Renewable Energy Master Plan in 2005 (ECN-UNDP, 2005). This master plan stipulates that the country should endeavour to increase the energy generation capacity from 5000 MW to 16000 MW by 2015 through the exploration of renewable energy resources. As at present, there has not been single grid generation of electricity from renewable energy sources probably as a result of government's lack of focus and commitment to the plan. The governments at all levels need to be committed to a plan they have initiated and agreed to if there must be meaningful development. The renewable energy master plan will be a vital resource if there can be serious devotion to the suggestions contained therein. Part of this suggestions include suspension of the Renewable Energy (RE) import duties, integration of RE into non-energy sector policies, establishment of national RE development agency, standardization of RE products and establishment of RE fund to provide incentives, micro-credits schemes, training and also fund R & D (ECN – UNDP,2005). Moreover, there may be a useful need for the master plan to be broken down into renewable source components, with each addressing expected contributions from particular type of renewable resources.

- **Lack of Statistical or Computational Representative Models for Predicting Wind Energy Resource Potentials of the Nation**

Even though only few results are available on the prospects of wind energy in Nigeria, none of them have created representative models that can be used to evaluate or forecast at any time the amount of wind energy and wind power fluxes per annum that will correspond to particular sets of wind speeds for the nation. The development of such models will be based on historical wind data for different sites and states across the nation and through regression and other statistical distributions, a predictive model which can be used at any time for forecasting the wind power situation of a place can be successfully developed. The model will be vital at fore-knowing the amount of energy harvestable from particular states, zone or whole nation when the available data on the locations are converted to statistically significant models, also, such model could be used in a way to determine the most probable wind speed of a site and also justify what size of wind investments and returns could be possible at different places within the nation and also it can serve as a complimentary information source for a wind atlas. Investors are always willing to know before-hand the viability of a product in the market before entering into that market. This is equally true for wind investors. Having a model which can be used by them to check what size of energy will be derived from the available wind data of a place would greatly enhance their investment decision and promote WET development in the country. Further simulating such model to make it amenable to the computer will be added advantage.

- **Lack of Adequate Funding**

Lack of adequate funding have invariably been a major set-back in the growth of WET and other renewable energy technology in Nigeria. Annually, the percentages of the federal budget to education and science and technology ministries have not been encouraging. With the meager sum made available to these ministries, much productive research and development may not be started or supported. The corporate bodies also would need to be encouraged to collaborate with research institutions to fund researches aimed at national development, some of which include wind-for-power projects (both small and medium scale turbines), nationwide wind energy resource assessment, development of adequate and explanatory national wind atlas/map that would provide information on quantity, distribution, quality and utilization possibilities to determine the commercial feasibility of wind energy generation and decision making on investment (ECN-UNDP,2005) and development of national wind turbine tests and certification (Meyer, 2004).

- **Other Challenges**

Apart from all the earlier mentioned challenges which if overcome will move the nation forward in utilizing wind for power generation, there are other challenges which include lack of awareness and technical ineptitude. The level of awareness on the viability of wind as a good prospect for electricity or power generation is very low in the country. Majority of the schools' curriculum lack adequate expository information on wind and other renewable resources, the technology, potentialities and their environmental situations. The mass media too has not helped in any way. Hardly can information regarding wind energy utilization or technology be seen on the pages of newspaper or heard discussed on television or radio. This lack of awareness has also led to high level technical ineptitude, thereby making adoption of wind as veritable source of power generation a difficulty (Ajayi, 2009).

2.6 Response Surface Methodology (RSM)

This is a collection of mathematical and statistical techniques for empirical model building. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). In statistics, response surface methodology (RSM) explores the relationship between several explanatory variables and one or more response variables. The method was introduced by George E. P. Box and K. B. Wilson in 1951. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. Box and Wilson suggest using a second-degree polynomial model to do this. They acknowledge that this model is only an approximation, but they use it because such a model is easy to estimate and apply, even when little is known about the process. Statistical approaches such as RSM can be employed to maximize the production of a special substance by optimization of operational factors. In contrast to conventional methods, the interaction among process variables can be determined by statistical technique. In this dissertation, the independent variables of interest are ambient air temperature and relative humidity (Asadi et al, 2017). These input variables have linear correlation with specific wind speed which ultimately enables the determination of wind power, the output variable.

2.7 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences among group *means* and their associated procedures (such as variation among and between groups) developed by statistician and evolutionary biologist, Ronald Fisher. In the ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the *means* of several groups are equal, and therefore, generalizes the t-test to more than two groups (https.//en.m.wikipedia.org)). ANOVAs are useful for comparing (testing) three or more *means* (groups or variables) for statistical significance. It is conceptually similar to multiple two-sample tests, but is more conservative, and is therefore, suited to a wide range of practical problems.

An experimental design is a plan which is established in order to determine the data that must be collected to perform a particular experiment. The experiment could pertain to such things as teaching style, sales techniques, changes in prizes of commodities, and collection of localized wind data for application in aerodynamic design and analysis. The specific *thing* being studied is referred to as a factor (Clark, 1991). The possible options which are being investigated are the levels of the factors, and are generally referred to as *treatments* (ibid). Analysis of Variance (ANOVA) is a technique which is used to test for the equality of two or more contingent *means* in experimental design settings. Besides testing the null hypothesis, ANOVA enables a researcher to test two or more computational *means* simultaneously. The more general approach to use in expressing the null hypothesis is:

$$H_o: \mu_1 = \mu_2 = \ldots = \mu_k, \qquad (3.1)$$

where k equals the number of experimental means included in the test.

When testing an analysis of variance problem using the F-test, we typically set up an ANOVA table which assists in calculating the values that will eventually lead us to the determination of the F-statistic. The table for the one-way or completely randomized design is typically set up in the following manner,

Table 2.4: ANOVA Table

Source	SS	Df	MS	F	P
Between groups					
Within groups					
Total					

Where : SS=Sum of Squares

Df=Degree of freedom

MS=Mean square

F=Fisherman's ratio

P=Percentage level

2.8 Factors Affecting Wind Speed

The speeds of wind in any geographical area are dependent on some factors, such as:

Altitude: Wind speed increases with height from the surface to the upper troposphere. There are several reasons that explain this tendency. First, the pressure gradient increases with height especially in the middle latitudes. A second reason to consider is surface friction. Surface objects such as trees, rocks, houses, etc. slow the air as it collides into them. The influence this friction is less with height above the ground; thus, the wind speed increases with height. A third reason is the influence of air density. The density of air, is highest at the surface, and decreases with height. A force imparted on air will cause the air to move more easily with the *mass* of air is less. Dense air requires a greater force to move it in the same speed as less dense air. With air density decreasing with height, it is easier to move the less dense air at a higher wind speed.

Vegetation: Vegetation lowers wind speed near the ground. Even in areas that are generally windy, local conditions may determine whether the wind resource is adequate or not. Vegetation and land use, like increased height, affect wind speed. For example, rough surfaces like forests reduce near-surface wind speed.

Topography: At the surface of the earth, topographic variations may affect wind direction and speed. This factor does not operate exclusively of pressure influences. For example, in mountainous regions, wind will switch from blowing up- and down-slope, depending on the time of the day. This has to do with differential heating, pressure and air-parcel weights. At nights, heavy cold air rolls down into the valley troughs. During the day, heating of surrounding slopes draws winds out of these troughs.

Relative Humidity: Wind is the product of pressure gradients established between high and low pressure systems. These systems are constantly moving and changing. The constant movement of the pressure systems is due to the *Coriolis effect*. The Coriolis effect describes the apparent deflection (curving) of an object traveling in a straight line. The variation in air pressure is brought about by the moisture content of the air. The higher the relative humidity, the more dense air would be, and the speed ultimately reduces.

Temperature: Air temperature varies between day and night, and from season to season due to the changes in the heating Earth's atmosphere. Because of the sun's warming effect, there are more winds during the day. Air masses, also, differ in temperature. A warm front precedes a warm air-mass. Warm air is less dense than cold air, so warm air rides up and overtakes the cloud air, causing winds. Conversely, a cold front, the leading edge of a cold air mass, also creates wind.

2.9 Summary of Literature

It has to be reiterated that wind speed is location specific; it is stochastic in nature. A lot of research had been undertaken in other parts of the country (particularly the northern states and few parts of the south-south and south-west regions), to determine the wind characteristics. From available literature, the data that are handy for the south-east are based on NIMET's extrapolations. A *gedanken* projection of this parameter may be inaccurate, and will definitely lead to error in evaluation of the wind energy generation potential of any geographical area of interest. This work strives to provide an *in situ* measurement of the average annual wind speed of the research sites; which will form part of NIMET's database, and for future referencing by researchers.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Materials

In this section, a description of the material, equipment, and software used in the research is undertaken; and their working principles stated. Thereafter, the procedure involved in investigating the available wind regime in different locations, at 10m altitudes, is delineated. Apart from the anemometer and its accessories, other minor equipment used in this research are laptop computers.

3.1.1 Digital Anemometer

Wind observations are taken at fixed locations using two parameters: wind speed and wind direction. Referenced with respect to true North, the direction that the wind is flowing from is measured in degrees. Wind speed is a measurement of the speed of the movement of the air; and is typically reported in miles per hour (mph), kilometer per hour (kph) or meter per second (mps). Wind speed and wind direction can be measured with a variety of tools. The most common is the anemometer, which consists of a rotating vane to measure direction, and a shaft with cups attached that spins with the wind, to measure its speed. In this research, a hybrid digital anemometer is employed. A digital anemometer is used for air flow measurements in homes, office environment; and for individual researcher's need. A tachometer is an electromechanical device which converts mechanical energy into electrical pulses to give a digital readout of the speed of a motor. A digital anemometer works on the same principle. Spinning cups turn a paddle wheel inside a metal canister under a digital anemometer. Each time the paddle wheel rotates, it breaks a light beam and generates a pulse of current. An electronic circuit times the pulses, and uses them to calculate the wind speed.

A good anemometer usually gives a wind speed reading accurate to about ±0.5 m/s (±2km/h or ±1mph), that is often far more accurate than one actually needs. Worthy of note is the fact that the wind speed is not constant – it varies all the time. Unless a person is in a wind tunnel, where the speed is constant, any measurement one makes, is going to be, at very best, a rough guide on how fast the air is actually moving. Instrumentation was carried out with the MK 14-D-4TDS model of anemometer (**cf. Fig. 3.1**). Eight pieces of this device were handy during the collection of data. These were used in alternation, so as to ensure that continuity was maintained during the field work. They are of the same model and are uniformly calibrated to ensure uniformity of data.

Fig. 3.1: The MK 14-D-4TDS Anemometer

The specification of this device is as tabulated.

Table 3.1: The specification of MK 14-D-4TDS Anemometer

Parameter	**Value**
Display (LCD)	9mm (0.35″)
Range of Operation	0 – 100 meters
Battery	6000 mAh
Memory	8 GB RAM/64 GB ROM
Thermometer	NTC Thermometer
Operating Temperature	-10°C – +45°C
Operating Humidity	Less than 90% RH
Storage Temperature	-40°C – +60°C
Current Consumption	Approximately 1.9 mA
Dimension	(6 x 4 x 2)″
Company	A-Grain
Country	Ambala, India
Year of Manufacture	2014

3.2 Method of Data Collection

Data gathering for this design commenced on 18th February 2016 and ended on 15th March 2017. The electronic digital anemometer was used to measure the average wind velocity in the designated areas. The kind of device used here, is an improved technology; it is altitude free and insensitive, in that a researcher only needs to key-in the required altitude or height, in meters, at which the device is to operate. This is done standing on the ground. If, for instance a 10m height is preferred, the device is kept on a place with minimal disturbance, where it can record the wind speed at the designated height. The recording of the wind velocity is a minute by minute process. These readings are collated every two days, and the process continues. A lithium cell (battery) with a life expectancy of about five years, ensures a smooth running of this contrivance. The *modus operandi* (mode of operation) of the anemometer can be summarized thus;

- Place a small table on a level land with minimal or no disturbance, in the site already mapped out.
- Power the anemometer
- Achieve a Bluetooth connectivity between the device and a laptop
- Key-in the altitude of interest in the device (in our case, 10 m)
- Press the start button for the appliance to begin to work

The battery of the anemometer is recharged when it gets to 15 % threshold. At such times, a spare battery makes data collection possible. Besides, to ensure that there is no interruption in this important stage of the research, another anemometer of the same capacity is powered for use when transferring stored readings of wind speed to the computer.

3.3 Location Descriptive

Owerre-Ezukala is in Orumba-South local government area of Anambra State. It is a border town located South-East of the capital territory. The town is surrounded in the north by Awlaw in Enugu State; in the east by Isuochi in Abia State; in the south by Nneato also in Abia State. The closest town in Anambra State to Owerre-Ezukala is Ogbunka. Its geographical coordinates are: longitude 6^{o} 1′ 0″ North, and latitude 7^{o} 19′ 0″ East.

(www.maplandia.com/ng/owerre-ezukala). Owerre-Ezukala is the home of the famous Ogba-Ukwu cave and over fifty-feet-high waterfall (cf. Appendix 1 and Appendix 2). It has an average population of 120,000 people (https://en.m.wikipedia.org) based on the 2006 census, with about 80% of the people living in the village. Hence, the town has a *projected* average electricity consumption need of 1 MW. The community is popularly noted for stone extraction and quarry; and these form major sources of sustenance for the autochthonous people, aside farming. The leading topography of this community indicates a favorable potential for sustainable and efficient wind energy generation. Fig. 3.2 shows the Satellite Earth map of this geographical area. A large mountainous plane that surrounds the community would guarantee a sustained annual wind speed. This informed the choice of the study locations, which means that siting a wind farm there, no doubt, would help ameliorate the electricity problem of the community.

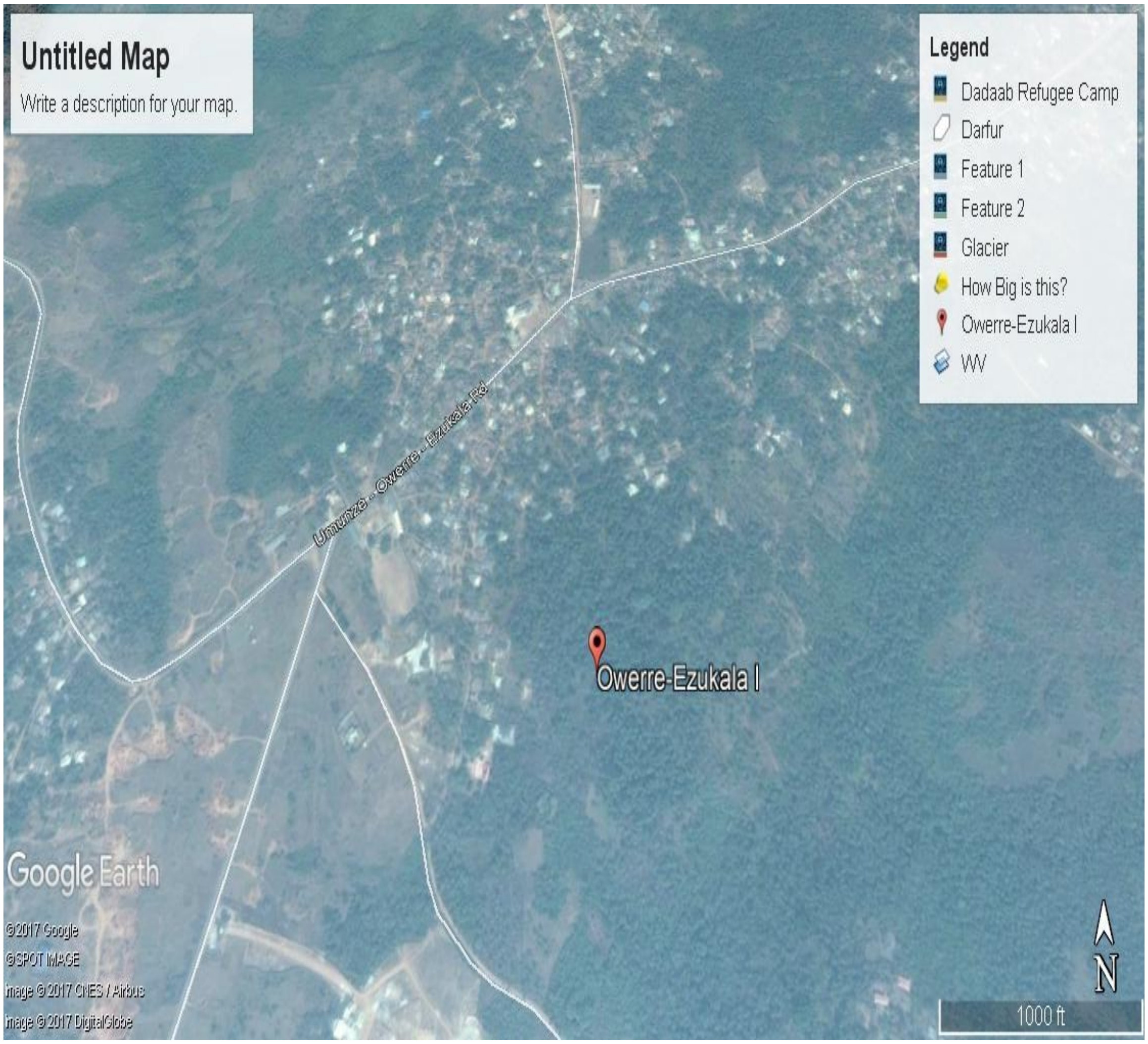

Fig. 3.2: Satellite Earth Map of Owerre-Ezukala

Source: Google Earth Pro-Software; Accessed 12th July, 2017

3.4 Theoretical Background of Wind Turbines

There are parameters that affect or influence the performance of a wind turbine. The theoretical parameters are discussed as follows:

3.4.1 The Betz Law

Table A3.2 shows the definition of various variables used in this model:

Table A3.2: Definition of Variables in Betz Model

Quantity	Symbol	Units
Kinetic Energy	E	J
Mass	m	Kg
Swept Area	A	m^2
Power	P	W
Radius	r	M
Mass Flow Rate	$\dot{m}$	Kg/s
Distance	X	M
Energy Flow Rate	dE/dt	J/s
Density	P	Kg/m^3
Time	T	s
Wind Speed	v	m/s
Power Coefficient	C_p	Nil
Volume	V	m^3

Under constant acceleration, the kinetic energy of an object having mass, m and velocity, v**,** is equal to the work done, W in displacing that object from rest to a distance, **s**, under a force, F , i.e.:

$$E = W = Fs$$

According to Newton's Law, we have:

$$F = ma$$

Hence,

$$E = mas \qquad (3.1)$$

Using the third equation of motion:

$$v^2 = u^2 + 2as$$

we get:

$$a = \frac{(v^2 - u^2)}{2s}$$

Since the initial velocity of the object is zero, i.e.

$$u = 0$$

we get:

$$a = \frac{v^2}{2s}$$

Substituting the value of *a*, in equation (3.1), we get that the kinetic energy of a mass in motions is:

$$E = \frac{1}{2}mv^2 \qquad (3.2)$$

The power in the wind is given by the rate of change of energy:

$$P = \frac{dE}{dt} = \frac{1}{2}v^2\frac{dm}{dt} \qquad (3.3)$$

As mass flow rate is given by:

$$\frac{dm}{dt} = \rho A \frac{dx}{dt}$$

and the rate of change of distance is given by:

$$\frac{dx}{dt} = v$$

we get:

$$\frac{dm}{dt} = \rho A v$$

The swept area of the turbine can be calculated from the length of the turbine blades using the equation for the area of a circle:

$$A = \pi r^2 \tag{3.4}$$

where the radius, *r*, is equal to the blade length.

If there is energy, there is a possibility to do work. Wind turbines extract and use energy from the wind to produce power. Other types of turbines and propellers have the theoretically upper limit of efficiency of 100 percent. This means they can possibly convert all of the energy being supplied to the propeller to produce energy coming from the airstream. Wind turbines cannot convert all the energy into work and, unlike other generators, can only produce energy in response to the wind that is immediately available. It is not possible to store wind and use it at a later time. In the horizontal axis wind turbine, the wind that blows along the axis and the circle area traced by the blades is the capture area (Crowe et al., 2010). The Betz law calculates the maximum power that can be harnessed from a wind turbine in an open flow.

Wind energy is the kinetic energy of moving air where *m*, is the mass of moving air and *v*, is the velocity, as in equation (3.2).

The mass, *m* (kg), can be defined from density ρ (kg/m^3) of the air and volume V (m^3) by

$$m = \rho V \tag{3.5}$$

Therefore, $\dot{m} = \rho A V$

The following equation shows, then, the kinetic energy of wind,

$$E_{kin,wind} = \frac{1}{2}\rho V v^2 \tag{3.6}$$

Power is energy divided by time. A short period of time, Δt, where air particles travel a distance $s=v\Delta t$, to flow through. The distance is then multiplied with the wind turbine's capture area, or rotor area, in a resulting volume of

$$\Delta V = A v \Delta t \tag{3.7}$$

Then the power associated with the wind passing through the capture area is where wind power increases with the cube of the wind speed. When the speed of the wind is doubled, the wind speed gives eight times the wind power. This is the reason why location is important for wind turbines. (http://unileipzig.de/~energy/ef/15.htm. [Accessed 4 February 2017]). The wind power is then,

$$P_{wind} = \frac{E_{in,wind}}{\Delta t} = \frac{\Delta V \rho v^2}{2\Delta t} = \frac{\rho A v^3}{2} \tag{3.8}$$

In reality, the wind power is less than the equation above shows. The speed of the wind cannot be zero behind the wind turbine since no air could follow. As a result, only a part of the kinetic energy can be utilized.

As seen in Fig. 3.3, the wind speed v_1 is larger than v_2. Because the wind flow must be constant, area A_2 will be larger than area A_1 before the turbine.

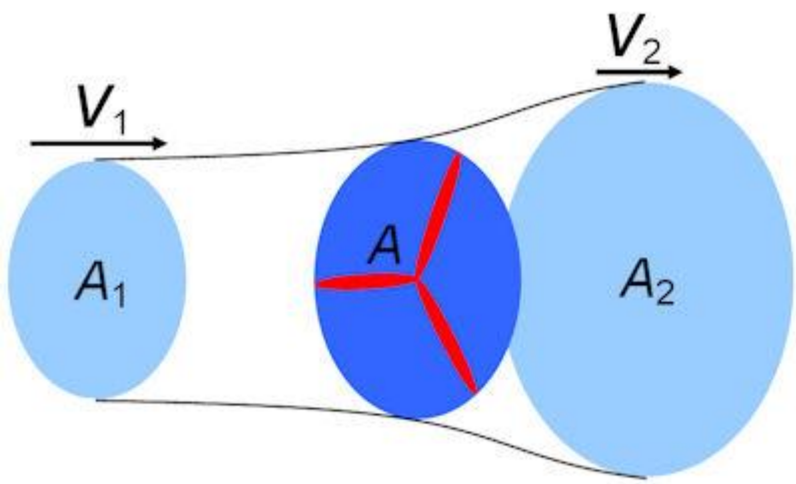

Fig. 3.3: A sketch of wind speed in front of and behind a wind turbine (http://unileipzig.de/~energy/ef/15.htm. [Accessed 4 Febuary 2017]).

The effective power is the difference between the two wind powers, shown in Equation 3.9, is

$$P_{eff} = P_1 - P_2 = \frac{\rho A}{4}(v_1^2 + v_2^2)(v_1^2 - v_2^2) \tag{3.9}$$

There is no net efficiency if the difference in both speeds is zero. If the airflow through the rotor is hindered too much, the difference in speed is too big. The power coefficient gives

$$c_p = \frac{P_{eff}}{P_{wind}} = \frac{(v_1 + v_2)(v_1^2 - v_2^2)}{2v_1^3} = \frac{(1+x)(1-x^2)}{2} \tag{3.10}$$

An assumption has to be made to derive the above equation. The assumption is that

$$A_1 v_1 = A_2 v_2 = \frac{A(v_1 + v_2)}{2} \tag{3.11}$$

The ratio $\frac{V_1}{V_2}$ (velocity ratio of the smaller and bigger wind turbines) is replaced with *x* on the right side of the equation. By finding the value of *x* gives the maximum value of c_p. Next is to derive with respect to *x* and set it equal to zero. This will give the maximum drawing power for 3 and the ideal power coefficient, called the Betz limit is then,

$$c_p = \frac{P_{eff}}{P_{wind}} = \frac{16}{27} \tag{3.12}$$

This ratio is called the Betz ratio, which is the theoretical maximum efficiency of a horizontal axis wind turbine.

$$P_{max} = \frac{16}{27}\left(\frac{1}{2}\rho v^3 A\right) \tag{3.13}$$

Equation 2.13 shows the theoretical maximum power from a wind turbine.

The aerodynamic torque developed (in Nm) can then be calculated using:

$$\Gamma_{rotor} = \frac{P_{rotor}}{\omega_{rotor}} = \frac{\frac{1}{2}\rho \cdot C_p \cdot \pi {R_{rotor}}^2 \cdot {V_{wind}}^3}{\omega_{rotor}} \tag{3.14}$$

The performance of a wind mill is defined as ‘co-efficient of performance’ (C_p). This can be calculated thus:

The coefficient, $C_{p,}$ is:

$$\frac{\left(1+\frac{V_{out}}{V_{in}}\right)\left[1-\left(\frac{V_{out}}{V_{in}}\right)^2\right]}{2} \tag{3.15}$$

$$\text{But } V_r = V_{out}/V_{in} \tag{3.16}$$

Therefore, the coefficient, C_p, is:

$$\frac{(1+V_r)(1-V_r^2)}{2} \tag{3.17}$$

It must be noted that only two-third of the wind hitting the rotor is converted into useful work (Grogg, 2005). Hence:

$$V_{out} = 2/3V_{in} \tag{3.18}$$

In the case of a wind turbine, *A* is the area swept by the rotor blades. Only a part of this power may be captured due to the non-ideal nature of the rotor, hence the need for the coefficient, C_P. The result is shown in the following equation;

$$P_{rotor} = \frac{1}{2}\rho \cdot C_p \cdot \pi R_{rotor}{}^2 \cdot V_{wind}{}^3 \tag{3.19}$$

3.4.2 Tip Speed Ratio

It is important to design wind turbines to match the angular velocity of the rotor with wind speed to obtain optimal or maximum efficiency of the rotor. A rotor rotating slowly will allow the wind to pass undisturbed through the gaps between the blades. In a fast rotating rotor, the rotating blades will act as a solid wall which will obstruct the wind flow, again reducing the power extraction. Wind turbines have to be designed to operate at their optimal wind tip speed ratio to extract as much power as possible. Wind tip speed ratios are dependent on turbine design being used, rotor airfoil profile uses, and the number of blades being used (Ragheb, 2011). Generally speaking, a high tip speed ratio, or TSR, is desirable because it will result in high shaft rotational speed which is needed for efficient operation of an electrical generator, resulting in more electrical production. But high TSR can result in erosion, noise, vibration, starting difficulties if the shaft is stiff to start rotation, drag and tip losses resulting in poorer efficiency of the rotor and excessive rotor speeds would result in runaway turbine, which could lead to catastrophic failures and even destruction (Ragheb, 2011).

The relationship between wind speed and the rotation rate, called the tip speed ratio:

$$\lambda = \frac{u}{v} = \frac{\omega r}{v} \tag{3.20}$$

Where, v is wind speed (m/s), u is velocity of the rotor tip (m/s), r is the rotor radius (m), and ω the angular velocity (rad/s).

Fig. 3.4 shows comparisons of various wind turbines and the tip speed ratio; where the coefficient of performance is at a maximum. HAWT and the Darrieus turbine have similar values when it comes to the power capture, but the HAWT can operate at a higher tip speed ratios. The figure also shows how the drag-based Savonuis turbine is inefficient compared to lift-based turbines (http://people.bu.edu/noahb/files/wind_turbine_main.pdf. [Accessed 6 March 2017])

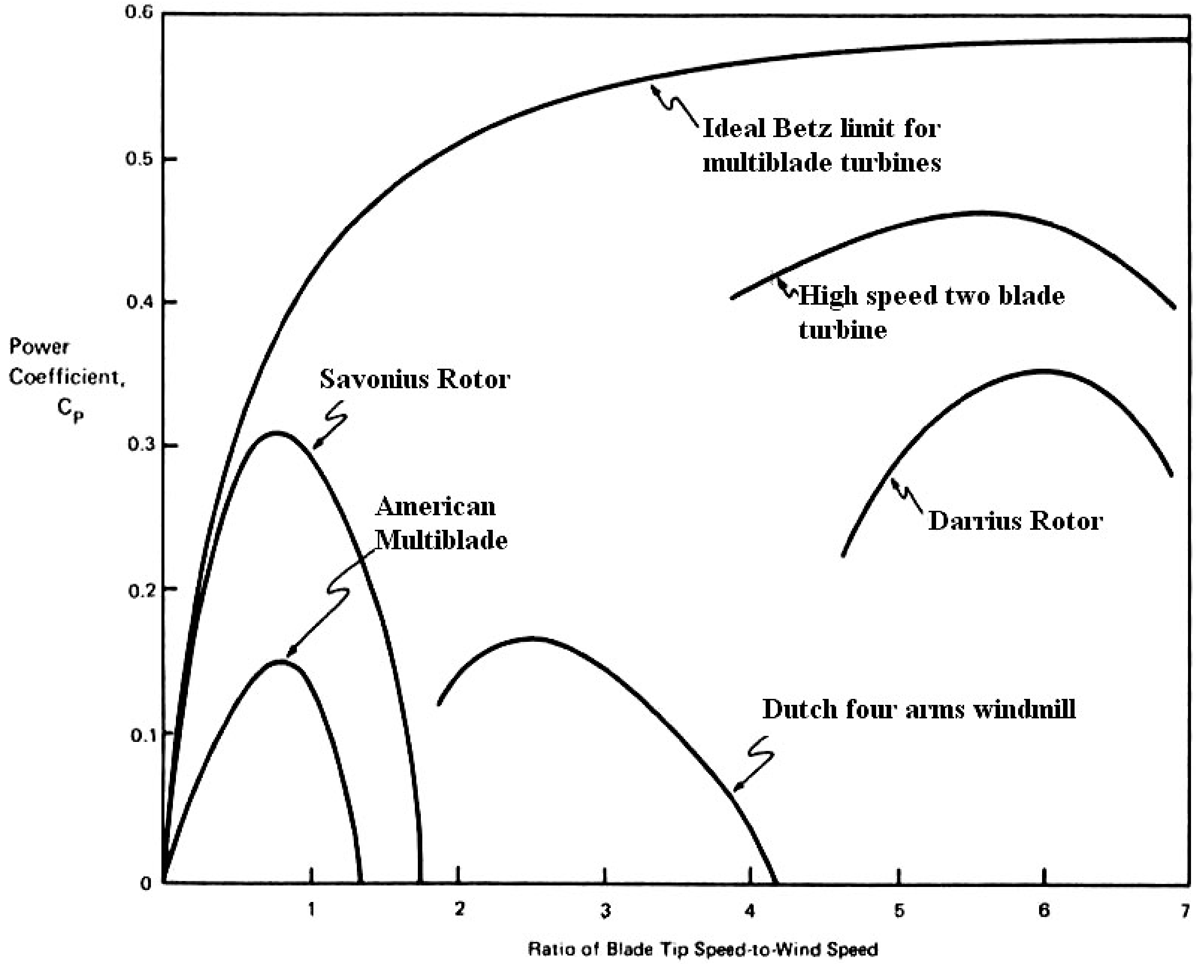

Fig. 3.4: The relationship between the coefficient of power and the TSR for various wind turbines (http://people.bu.edu/noahb/files/wind_turbine_main.pdf. [Accessed 6 March 2017])

Table A3.3 indicates various rotor performances with respect to optimum coefficient of power and range of TSR to wind speed ratio.

Table A3.3: Power Coefficients of Various Rotors (Jha, 2011)

Rotor Type	*Optimum C_p*	*Range of Tip-speed-to-wind-speed ratio*
Savonius	0.3	0.8 – 0.85
Dutch for arm	0.14	2.0 – 3.0
Darrieus	0.32	5.5 – 6.5
Two-blade	0.43	4.5 – 6.5
Propeller (ideal)	0.55	3.0 – 7.0

3.4.3 Power Curve

The power curve is a measure of wind turbine performance and an indicator of overall wind turbine health. Because of losses in the gear train and the generator, the power captured by the rotor is greater than the electrical power output from the generator. Equation 3.21 shows the power output of a wind turbine:

$$P_T = C_P \eta_g \eta_b \left(\frac{1}{2} A \rho v^3\right) \tag{3.21}$$

Where, η_g is efficiency of a generator and η_b is efficiency of a gearbox. The efficiency for a gearbox is typically 90-95 percent and the efficiency for a generator is range from around 90 percent to almost 100 percent. (http://people.bu.edu/dew11/windturbine.html. [Accessed 10 March 2017]).

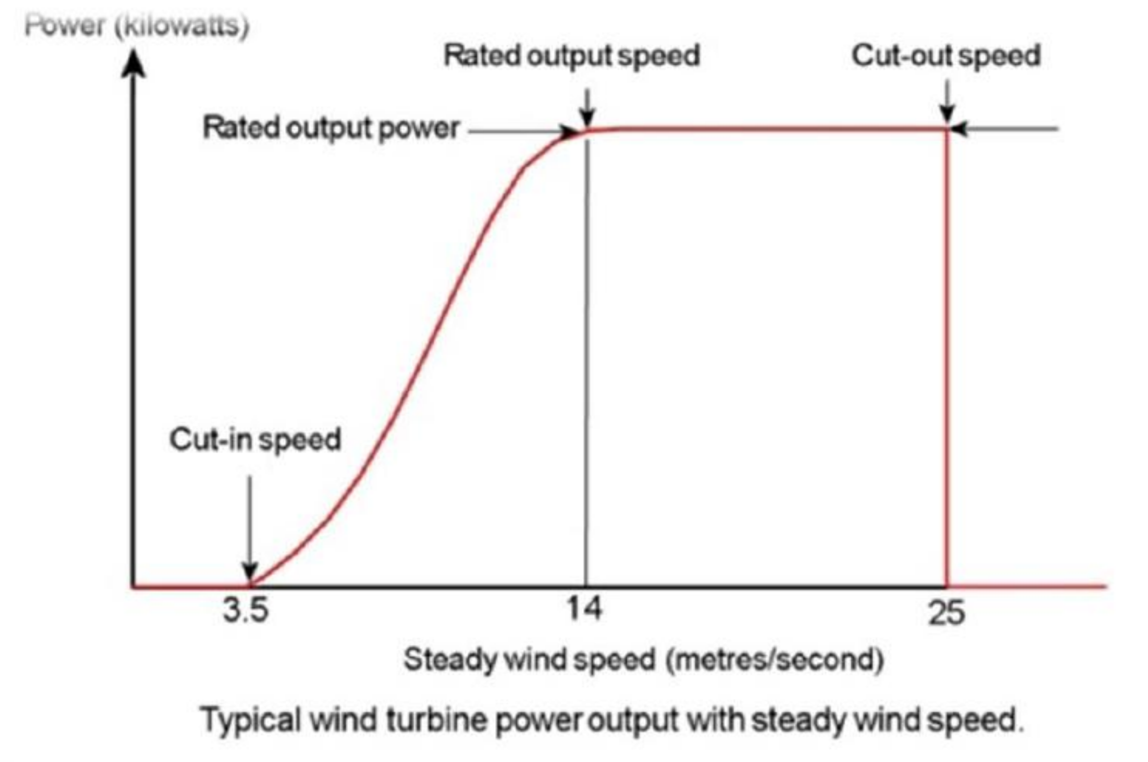

Fig. 3.5: The power curve, where cut-in speed and cut-out speed is presented (http://www.wind-power-rogram.com/turbine_characteristics.htm. [Accessed 10 March 2017])

The cut-in-speed is when the turbine will start to generate power at its lower wind speed. This usually happens between 3.5 m/s and 5 m/s for HAWTs and varies between wind turbines. Also, as seen on Fig. 3.5, when the wind rises above the cut-in-speed, the electrical output rises quickly. The power output will reach the limit the generator is capable of somewhere between 12 m/s and 17 m/s. This limit is called the rated power output and the rated output and the wind speed where this limit is reached is called the rated output wind speed. But the power output of the turbine is at maximum at that point.

The design of the turbine is controlled to limit the power to this maximum level and the rise in output power stops. It varies depending on design how this goal is reached, but for bigger turbines, it is done by adjusting the angle of the blades. **The cut-out speed** is the wind speed where the wind turbine stops being able to increase its power output, even if the wind increases, and is usually around 25 m/s. This is based on the limit of what the alternator can achieve and beyond this point, there is a great danger of damaging the turbine and structure from high loads. (http://people.bu.edu/dew11/windturbine.html. [Accessed 10 March 2017]; Uluyol, 2011).

3.4.4 Lift and Drag Forces

Two types of aerodynamic forces are created when an air flows over any surface: drag forces and lift forces. Drag force is in the airflow direction while lift force is right-angled to the airflow. Both lift and drag can generate forces needed to rotate the blades of a wind turbine. Drag forces are used to generate electricity in vertical based wind turbines. Savonius and Darrieus rotors, conversely, use lift forces in the same purpose, where the force of the wind pushes against the surface of the blade for effective functioning. (http://people.bu.edu/dew11/windturbine.html. [Accessed 10 March 2017]). Lift forces are used to generate horizontal based wind turbines by using lift instead of drag. Those wind turbines need specially shaped airfoil surfaces. This shape is designed to create pressure difference between upper and lower surfaces. This leads to a net force in the direction that is right-angled to the wind direction. Lift-drag rotors must be carefully oriented so they can maintain ability to harness the power from the wind as the wind speed changes. (http://people.bu.edu/noahb/files/wind_turbine_main.pdf.[Accessed 6 March 2017]).

• Lift turbines are those that have the blades designed as airfoils similar to aircraft wings. The apparent wind creates lift from a pressure differential between the upper and lower air surfaces. They are also more efficient than drag turbines. (http://people.bu.edu/noahb/files/wind_turbine_main.pdf. [Accessed 6 March 2017]).

• Drag turbines operate purely by the force of the wind pushing the blade (http://people.bu.edu/noahb/files/wind_turbine_main.pdf. [Accessed 6 March 2017]).

3.4.5 Friction

The roughness of the earth causes friction which has a significant effect on wind as high as 100 metres. The roughness of the surface and the speed of the wind determine the magnitude of the frictional force as the air closer to the ground is more affected by friction. Friction makes the air slow down, but as the height increases, the velocity of the wind increases since it becomes less affected by the roughness friction (Roussy, 2006). Since wind speed increases with height, the wind turbines are attached to a high tower in respect to the friction near the surface. The landscape is an important configuration when choosing a site. Factors like valleys, hills, bodies of water and other obstacles have a significant effect on the efficiency of the turbine.

3.4.6 Turbulence

The word turbulence is used to describe instability or disturbance. It can also be used to refer to atmospheric instability, like unpredictable air movements coming from winds. Turbulence is the main factor that causes fatigue damage on major components of the turbine, but there are two different sources of turbulence. It can be generated by terrain features, also called ambient turbulence intensity, and by neighboring wind turbines, called induced turbulence. Ambient turbulence is caused by forest, hill, cliffs, thermal effects, and so on. It is possible to reduce the ambient turbulence by avoiding the terrain features that causes the turbulence. Turbulence caused by wake has more of an effect than the ambient turbulence intensity. By decreasing the space between turbines, the turbulence created by the wakes of neighboring turbines increases. If the turbines are stationed too close to one another, the fatigue loads can be too high. To ensure the lifetime of the wind turbine, some wind turbines might have to be turned off when they are in operation and are suffering from the wake effect from neighboring turbines. (http://www.wwindea.org/technology/ch02/en/2_4_1.html. [Accessed 24 March 2017]). If there is high friction, and therefore high turbulence, the turbulence can also be avoided by building higher towers, or higher hubs. The manufactures offer several models with different tower/hub heights and rotor diameter as well as custom made turbines according to the site and power output requirements. Air that is affected by the surface of the Earth is called a boundary layer.

3.4.7 Angle of Attack

The angle of attack plays an important role in shaping the performance of the turbine blades. The angle of attack is one factor in determining the performance of the wind turbine when it comes to determining the power output and over-speed induced stress protection. The blade must be twisted by an angle and not flat because in order to have a good lift force, the airflow must hit the blade at a proper angle. This angle is the angle of attack. (http://www.articlebiz.com/article /516343 -1-wind-urbinephysicsfactorsaffecting-performance/%22target=%22_blank.; Schubel and Crossley, 2012; Hemami, 2012; Jha, 2011). The airfoil of the blades uses lift to harness the motion of the wind. When the edge of the airfoil is angled out of the wind direction, the air moves faster on the downstream side of the blade, which creates a low pressure and lifts the airfoil upwards (Grogg, 2005).The amount of lift for a certain airfoil depends greatly on the angle that it makes with the direction of the relative wind, known as the angle of attack. Increased angle of attack means increased lift, but also more drag, which detracts from the desired motion. In cases where the angle of attack is too big, turbulence develops and drag increases greatly, but the lift is lost (Grogg, 2005). When it comes to wind turbines, the angle of attack can be changed by creating a specific geometry for the blades along the span, or letting the blades to rotate around the axis perpendicular to their cross-section which is also along the span. In order to make the rotor rotate at a constant speed, it is important to change the angle of attack to maintain precise amount of lift. (www.articlebiz.com/article/516343-1-wind-turbine-physicsfactorsaffecting-performance/%22target=%22_blank).

3.4.8 Twist Angle

The twist angle is dependent of TSR and angle of attack of the airfoil. The tip of the blade is not parallel to the root of the blade. The blade must be twisted by an angle and not flat because in order to have a good lift force, the airflow must hit the blade at a proper angle. The blades of the wind turbine have a built-in twist along the span because the blade has to have different angles of attack so the entire blade is able to feel a consistent force. The twist also limits stress on the blades (Grogg, 2005).

3.4.9 Pitch Angle

The role of a pitch angle is to maintain a near uniform rotor speed under different wind circumstances to achieve optimum power output from the turbine. The pitch angle helps the blades to maximize the capture of the energy. Only a small change in the pitch-setting angle can have a huge effect on the power output of the wind turbine. If a rotor is designed with a certain optimal operation in mind at a certain wind condition, then the pitch blade can adjust the wind turbine to other conditions (Burton et al., 2011; Schubel and Crossley, 2012; Hemami, 2012; Jha, 2011).

After viewing and discussing the parameters that affect or influence the performance of a wind turbine, it is expedient to present the horizontal axis wind turbine along with its critical components.

3.5 Design Matrix of the Response Surface Methodology

Table A3.4: The Regressor Matrix

Months	(Intercept)	FO(Rel_Hum, Mean_Temp)Rel_Hum	FO(Rel_Hum, Mean_Temp)Mean_Temp
1. Jan	1	76	25
2. Feb.	1	80	27.5
3. Mar	1	76	30
4. April	1	81	29
5. May	1	81	27.5
6. June	1	85	26
7. July	1	89	24.5
8. Aug	1	87	25.5
9. Sept	1	86	25.5
10. Oct	1	85	25.5
11. Nov	1	73	28
12. Dec	1	76	26.5

Av_Wind_Speed = f(Rel_Hum, Mean_Temp))

The design matrix for the RSM model is a 12 x 3 matrix provided in the table above. Each row represents an individual month, with the successive columns corresponding to the variables, and their specific values for that month. As already indicated, the relative humidity and average ambient temperature are the independent variables, while the wind speed is the dependent variable.

3.6 Development of a Mathematical Model

The following table shows the definition of various variables used in the developed mathematical model.

Table A3.5: Definition of Parameters in the Developed Model

Quantity	Symbol	Unit
Wind Power Density	P_w	W/m^2
Tower Height	H	M
Mean Ambient Temperature	T	^oC
Average Relative Humidity (%)	H_R	Nil
Months of the year	M	Nil
Wind Speed	V	m/s
Area Swept by the Blade	A	M
Co-efficient of Performance	K	nil

For all wind turbines, it is stated that wind power is proportional to wind speed cubed and area swept by the blade. In other words, doubling the wind speed gives eight times the wind power. Similarly, if the swept area is doubled, the power output will also double

Therefore, $P_W \alpha AV^3$ (3.22)

$$P_W = KAV^3 \quad (3.23)$$

The speed of wind (V), can be said to be partly constant, and partly varies directly with ambient temperature (T), and inversely as relative humidity (H_R)

Thus, $$V = K(H + M \frac{T}{H_R}) \quad (3.24)$$

Taking Hub Height (H) = 10m, and treating the whole months of the year as unit, (M) = 1. Therefore, mean annual wind speed equals 5.6 m/s. From equation (3.24), using the annual mean temperature of 26.7 ^oC, and annual average relative humidity of 81.25 %, the coefficient of performance, K, is determined to be 0.49.

It then follows from equation (3.23) that,

$$P_W = KA\left(H + M\frac{T}{H_R}\right)^3 \tag{3.25}$$

From equation (3.25)

$$P_W = 0.49A\left(10 + M\frac{T}{H_R}\right)^3 \tag{3.26}$$

Recall that swept area, A = 176.74 m^2, and tower height = 10 m

Therefore, $P_W = 0.49 \times 176.74\left(10 + M\frac{T}{H_R}\right)^3$ (3.27)

This gives, $P_W = 86.60\left(10 + M\frac{T}{H_R}\right)^3$ (3.28)

Equation (3.28) is called Revek's mathematical model. It shows the correlation between wind speed and ambient temperature (T), relative humidity (H_R), and tower height (H). In this relation, month of the year (M) remains a unit.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Wind Speed Distribution

Table A4.1 (cf. Appendix 3) shows the average values of wind speed taken over a 12-month period using a high-tech anemometer. These readings in meter per second (m/s), were obtained at various times of the day, and different seasons, at an altitude of 10m. This is represented in a chart in Fig. 4.1.

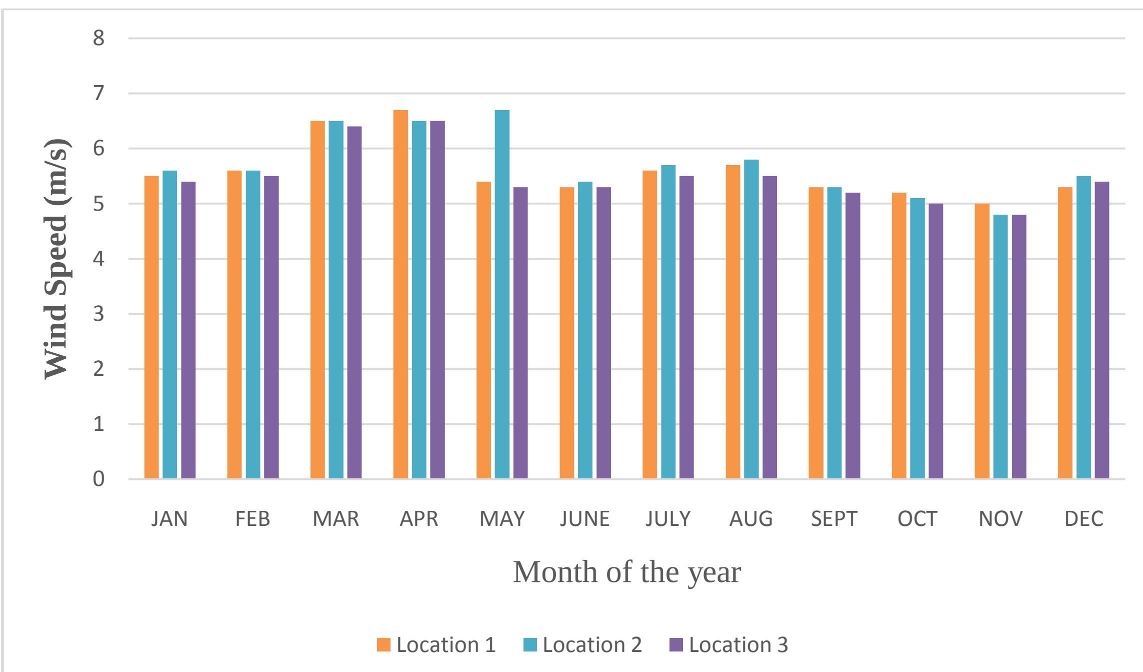

Fig. 4.1: Measured Wind Speed Distribution in Owerre-Ezukala

With reference to Fig. 4.1, the measured wind speed, for location 1(Ugwu-Osu), is highest in the month of April with a value of 6.7 m/s, while November has the lowest value of 5.0 m/s. Location 2 (Okegbe) records a highest wind speed of 6.7 m/s in the month of May, and recedes to 4.8 m/s in November. Similarly, location 3 (Ogba-Ukwu) reaches its peak value of 6.5 m/s in April, and comes down to 4.8 m/s, also, in November. One can then conclude that a shift from one season to another, brings about a significant change in the recorded wind speed.

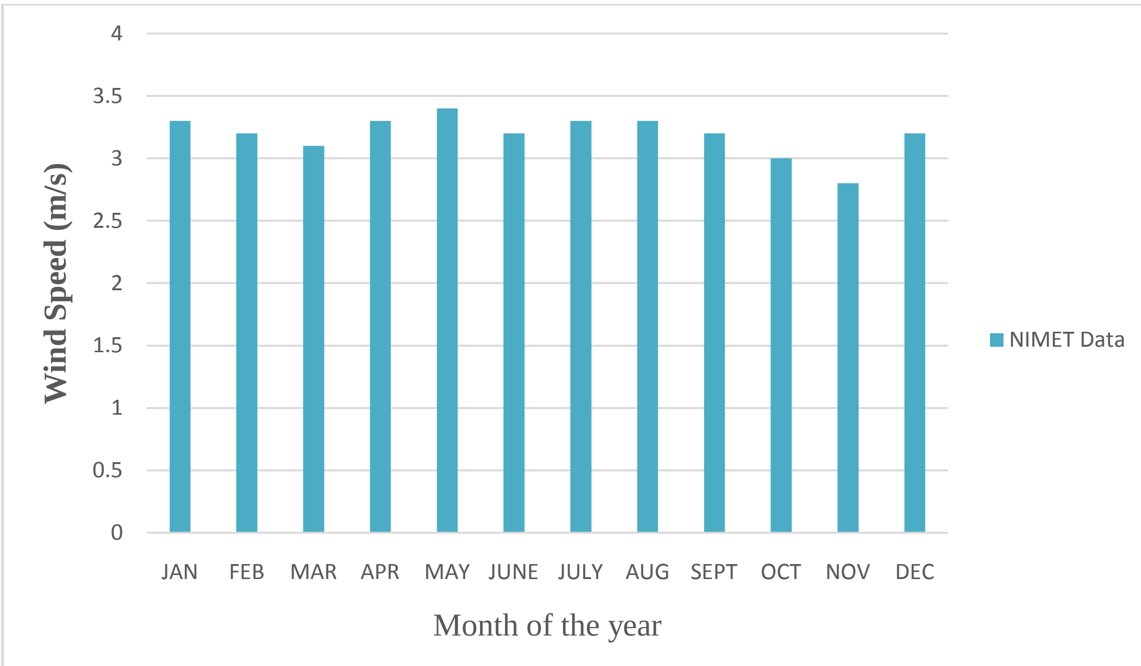

Fig. 4.2: NIMET Wind Speed Data

According to Nigerian Metrological Agency (NIMET), Oshodi, the mean wind speed (velocity) V_{mean} of this geographical coordinate (longitude 6^{o} 1′ 0″ North, and latitude 7^{o} 19′ 0″ East), (www.maplandia.com/ng/owerre-ezukala)., at an altitude of 10m, approximates to 3.2 m/s; as shown in Table A4.2 (cf. Appendix 4). It must be noted that NIMET has a wind speed data of the geographical coordinate earlier stated. A graphical representation of these values is shown in Fig. 4.2.

4.2 Comparison of Measured Wind Speed with NIMET Data

The measured wind speeds of the three locations are plotted, separately, against the NIMET wind data for easy comparison.

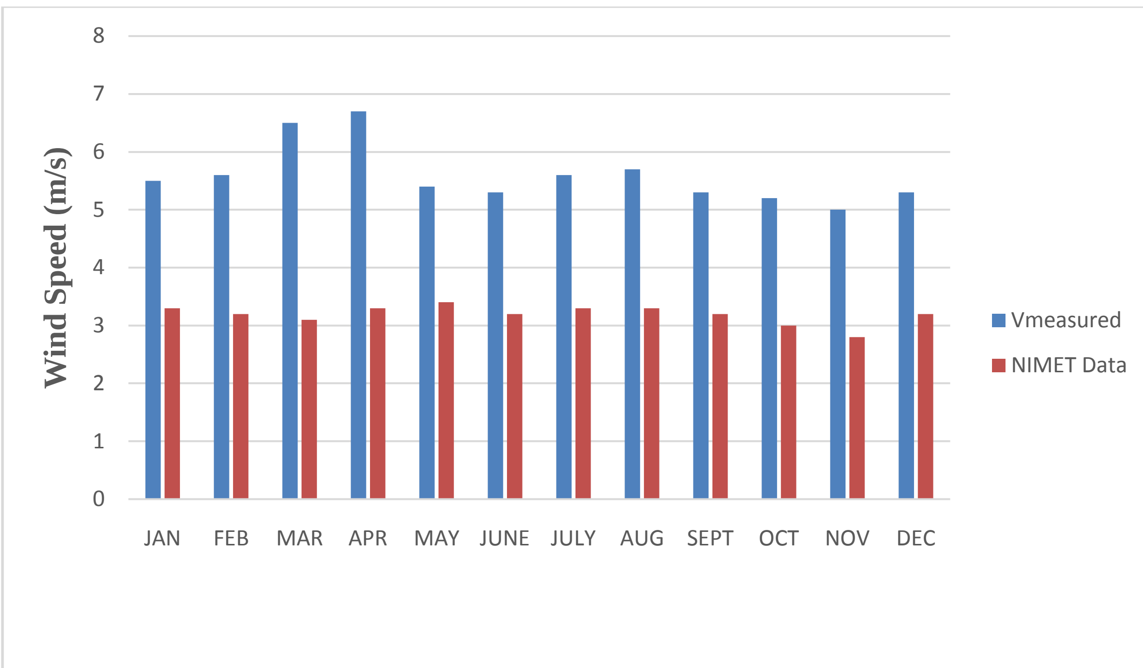

Fig. 4.3: Location 1 (Ugwu-Osu)

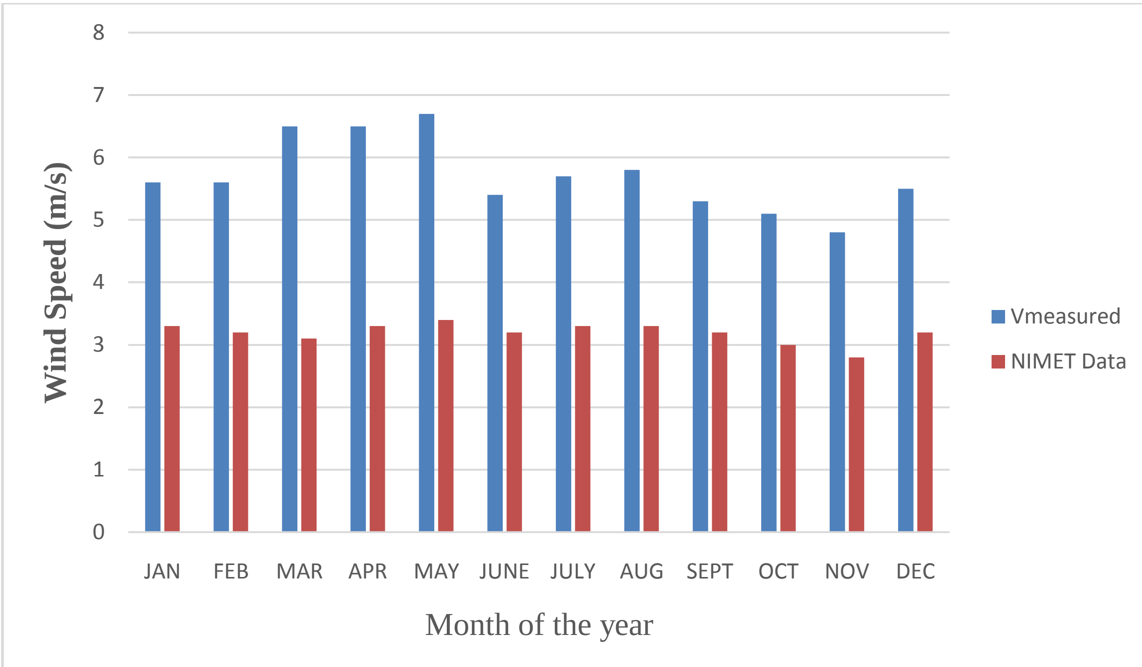

Fig. 4.4: Location 2 (Okegbe)

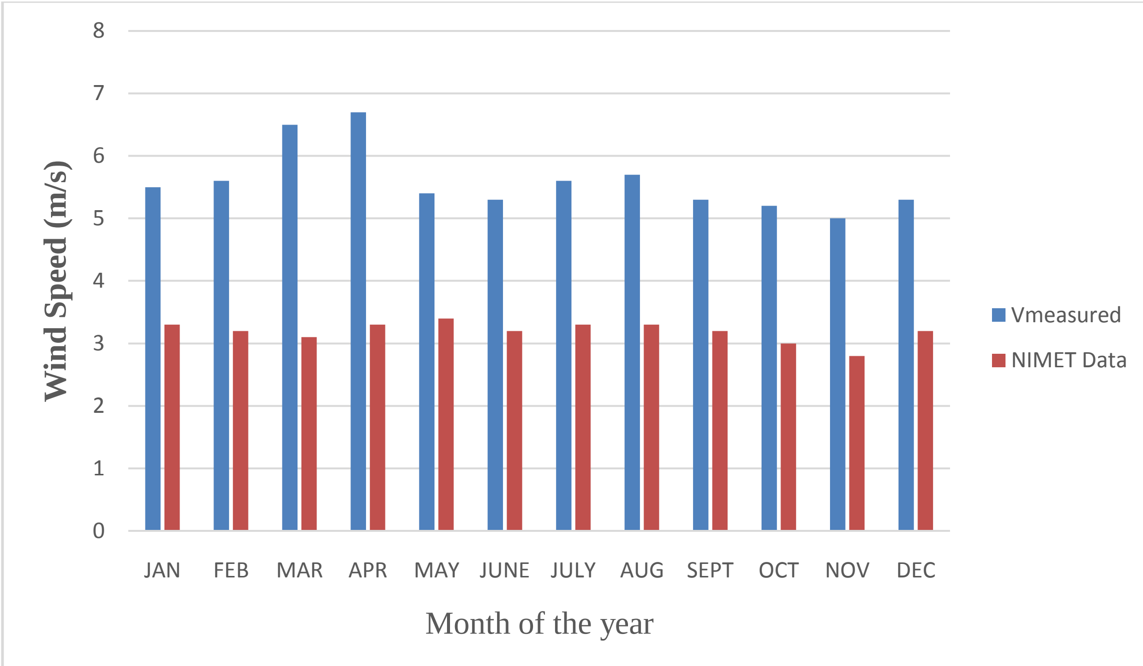

Fig. 4.5: Location 3 (Ogba-Ukwu)

The graphs in Fig. 4.3; Fig. 4.4; and Fig. 4.5, reveal the discrepancy in the actual measusred wind spead and NIMET values. The values of the measured wind speeds are much bigger than the NIMET data. For instance, the measured wind speed values for the month of April in Location 1, 2, and 3 are: 6.7m/s, 6.5m/s, and 6.5m/s respectively. The corresponding NIMET values for the three locations are: 3.3m/s, 3.3m/s, and 3.3m/s.

4.3 Comparison of Measured Wind Speed with Calculated Wind Speed

The measured velocities in Figs. 4.6 – 4.8 were calculated using the Betz mathematical model

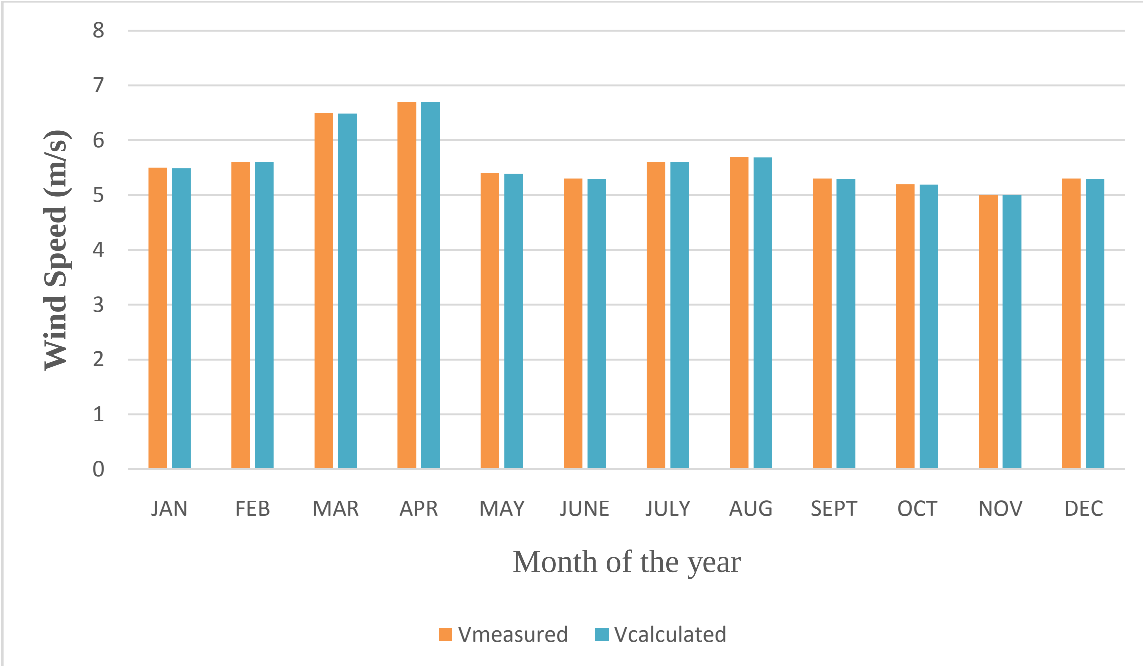

Fig. 4.6: Location 1 (Ugwu-Osu)

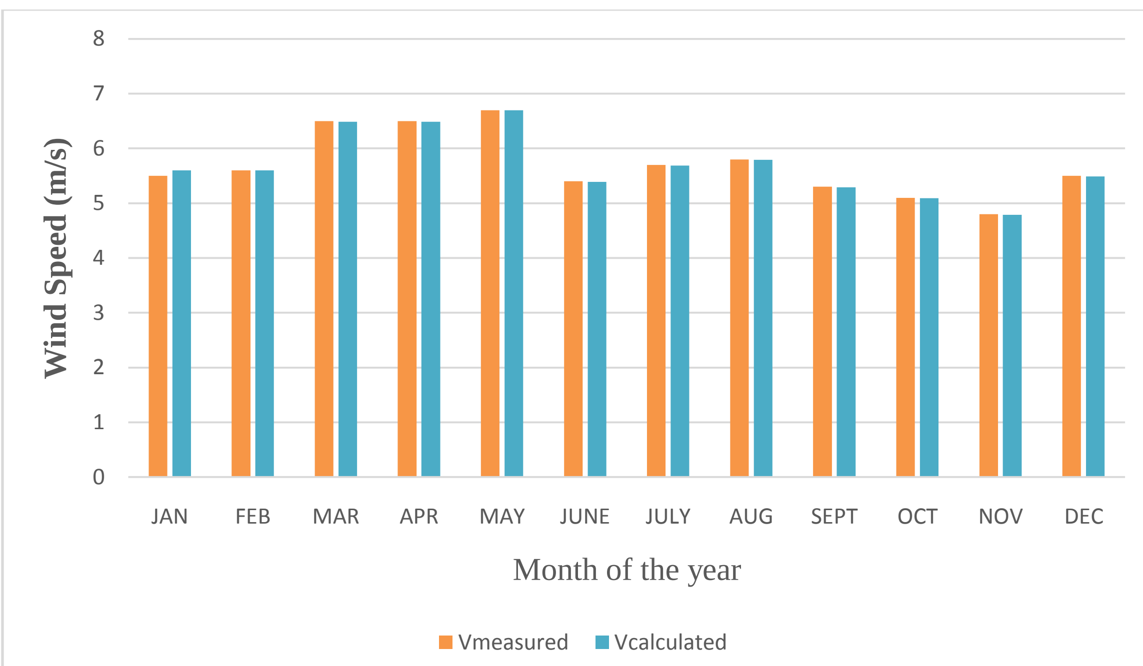

Fig. 4.7: Location 2 (Okegbe)

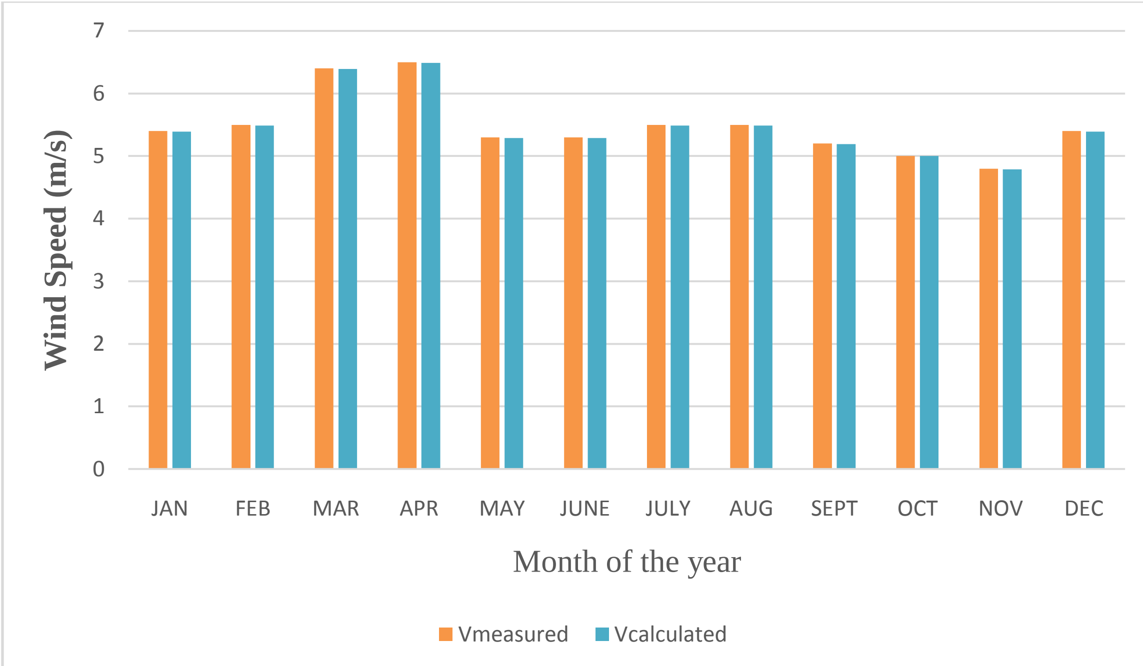

Fig. 4.8: Location 3 (Ogba-Ukwu)

The measured wind speed compared with the calculated wind speed, for location 1, gave the highest value in April (6.7 m/s: 6.7 m/s). For location 2, the comparison gave the highest value in May (6.7 m/s: 6.7 m/s). In the same vein, the analysis gave the highest value in April (6.5 m/s: 6.49 m/s), for location 3. The lowest values for the three locations occurring in November, correspond to 5.0 m/s: 5.0 m/s (Ugwu-Osu), 4.8 m/s: 4.79 m/s (Okegbe), and 4.8 m/s: 4.79 m/s (Ogba-Ukwu). The closeness of the measured wind speed and the calculated wind speeds, indicate that the Betz Mathematical Model used in this research is in tandem with the projected outcome of the analysis. (cf. Tables A4.7, A4.8, & A4.9; Appendix 6)

4.4 Comparison of Measured Wind Speed with Calculated Wind Power

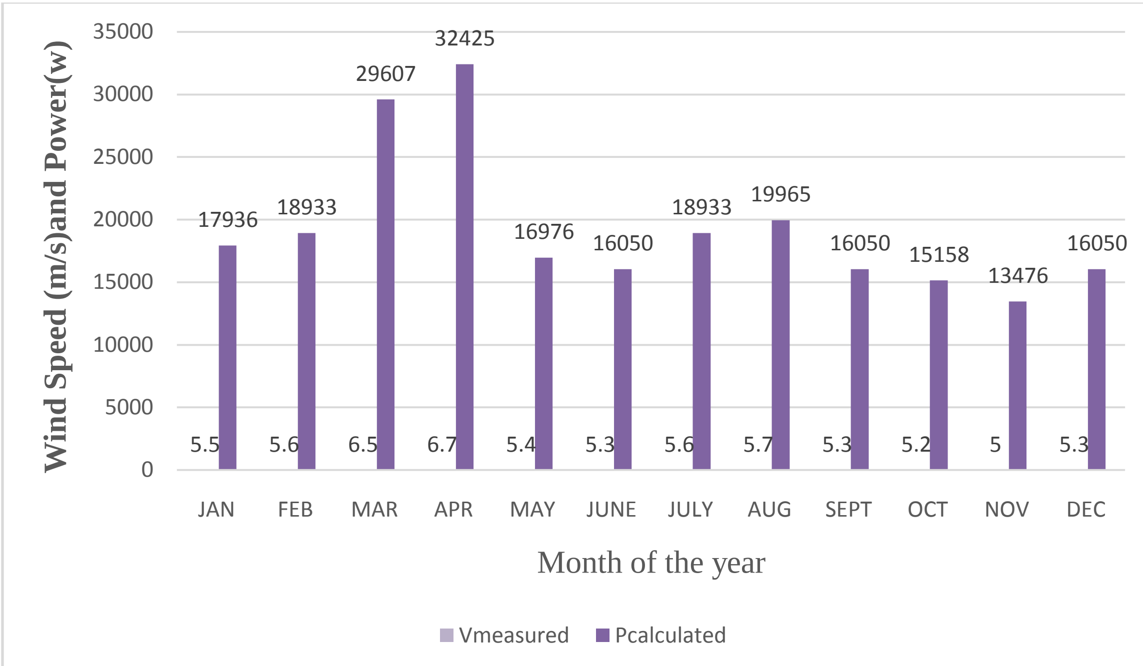

Fig. 4.9: Location 1 (Ugwu-Osu)

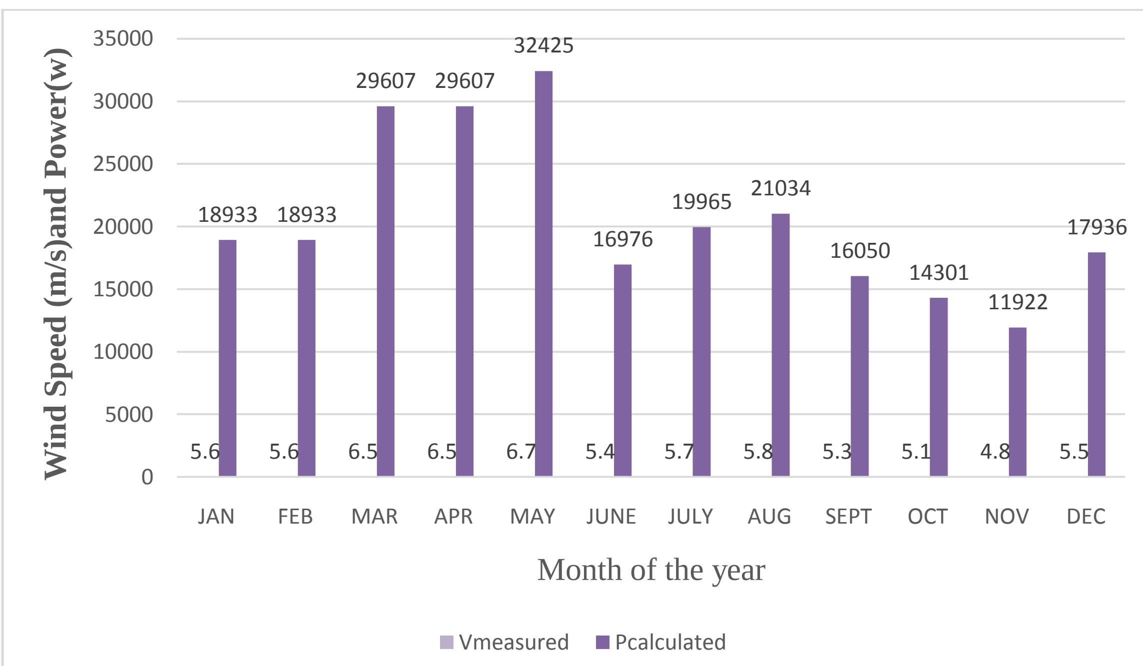

Fig. 4.10: Location 2 (Okegbe)

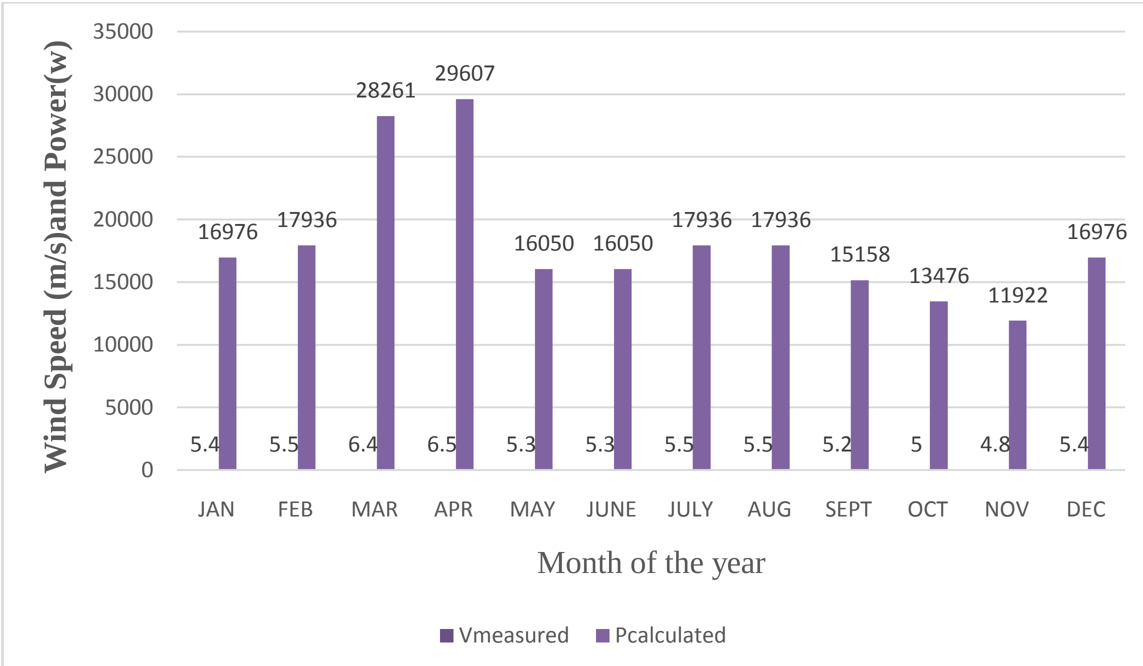

Fig. 4.11: Location 3 (Ogba-Ukwu)

It can be concluded from the graphs in Figs. 9 – 11, that the greater the wind speed, the more likely will the power output of the wind turbine be greater. The Betz' mathematical model was applied to determine the power that each measured monthly wind speed could generate. The calculated values of the wind power, reveal the high prospects of the research locations for siting wind farm. (cf. Appendix 6).

4.5 Average Monthly Temperature, and Relative Humidity in Owerre-Ezukala

In Appendix 7 the average monthly mean temperature, and the relative humidity in Owerre-Ezukala are contained. These data are the same for the entire community, hence, for the three locations studied. The graphical representations of these input variables are shown in Fig 4.12 and Fig. 4.13

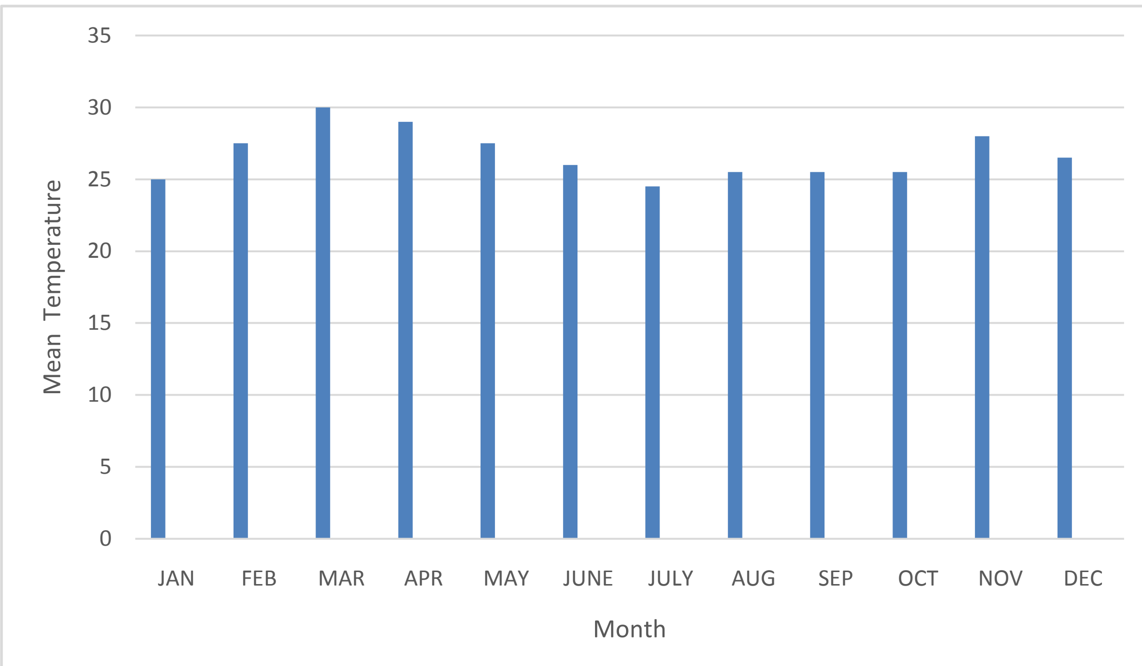

Fig. 4.12: Average Monthly Mean Temperature

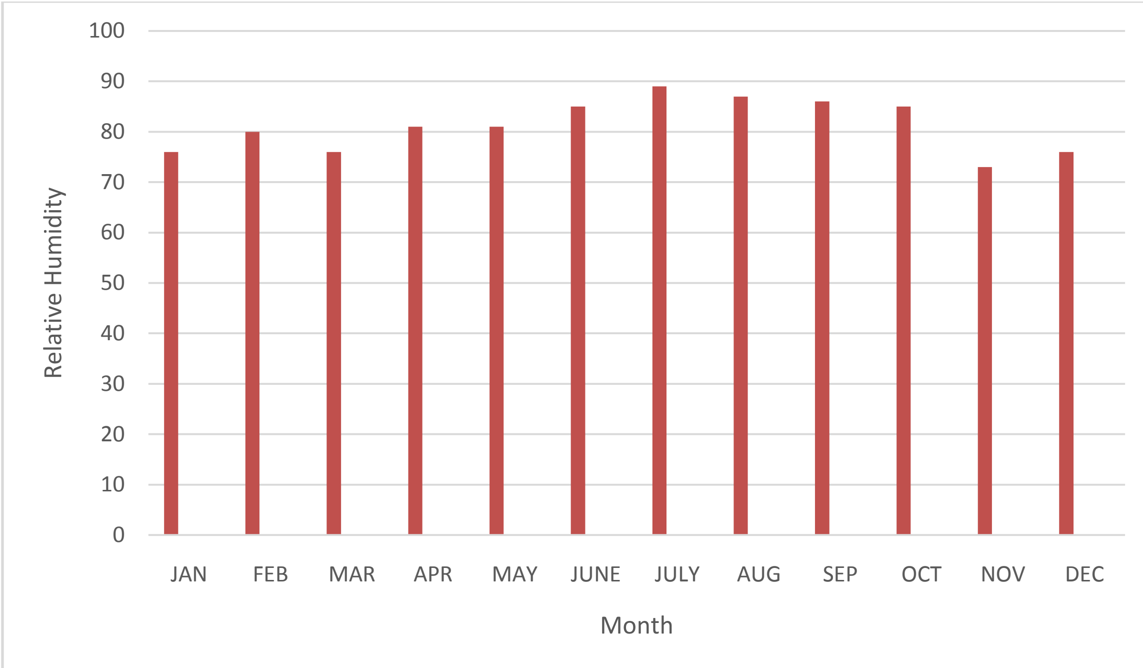

Fig. 4.13: Monthly Relative Humidity

4.6 Performance Evaluation of a Three-Blade HAWT

In other to determine the prospects of energy generation from the measured average annual wind speed of the three research sites, it is expedient to undertake the performance evaluation, based on the speed of 5.6 m/s (This is the calculated annual mean wind speed of the three locations). Appendix 5, shows the basic operating parameters and assumed values of a possible turbine that could be functional in the designated area.

4.6.1 Estimation of the Swept Area of the Turbine

The turbine blades always make a circular motion as they rotate. Hence, the swept area of a turbine corresponds to the area of the circle thus hypothetically formed. This is usually calculated from the length of the turbine blades referred to as radius of the blade, (cf. Appendix 5) using equation (3.4), for the area of a circle;

$$A = 176.74 \text{ m}^2 \qquad (4.1)$$

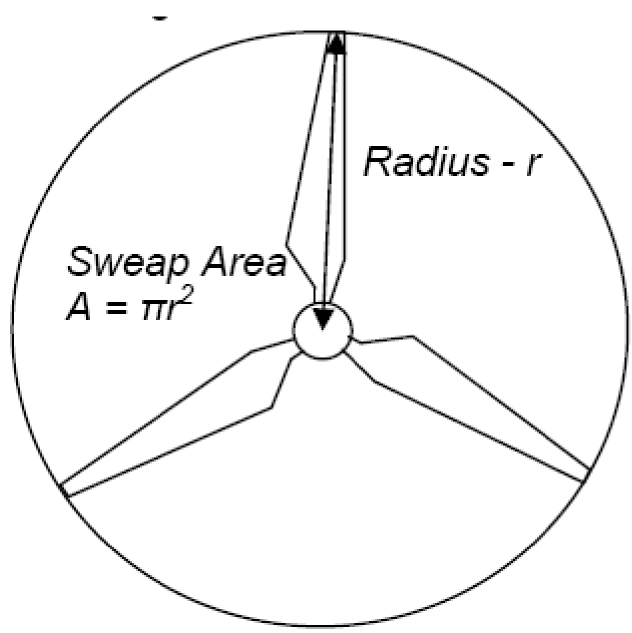

Fig. 4.14: Swept Area of a Wind Turbine

4.6.2 Determination of the Aerodynamics of Wind Turbines

Wind turbine power production depends on interaction between the wind turbine rotor and the wind. The mean power output is determined by the mean wind speed, thus only steady-state aerodynamics has been considered to be important in this project and turbulence has been ignored. Power available in the wind is given in Eqn. 3.8:

$P_{Wind} = 18.93 \text{ kW}$ (4.2)

In Eqn. 3.8, ρ is air density, A is area swept by blades, and V_{wind} is wind speed. Betz proved that the maximum power extractable by an ideal turbine rotor with infinite blades from wind under ideal conditions is 59.26% (0.5926 times) of the power available in the wind. This limit is known as the Betz limit. In practice, the present analysis is limited to three blades due to a combination of structural and economic considerations. The amount of power they can extract is closer to about 50% (0.5 times) of the available power. The ratio of extractable power to available power is expressed as the rotor power coefficient C_P. The extractable power can thus be calculated from Eqn. 3.13:

$P_{Wind.Actual} = 11.22 \text{ kW}$

4.6.3 Calculation of the Tip-Speed Ratio

The tip-speed ratio or TSR, denoted by λ, is the ratio of the blade-tip linear speed to the wind speed (Manwell and McGowan, 2003). The TSR determines the fraction of available power extracted from the wind by the wind turbine rotor. In a fixed-speed wind turbine, the blade tip speed is held relatively constant since the rotor is connected directly to the induction generator via a gearbox, and the induction generator is directly connected to the grid. The TSR can be calculated using Eqn. 3.14, as follows:

Blade Tip Speed = 11.78 m/s; therefore, $\lambda = 2.1$ (4.3)

4.6.4 Calculation of Rotor Power Coefficient (C_P)

The TSR, together with the user-defined blade pitch angle β, are used to calculate the rotor power coefficient, denoted by C_P. The rotor power coefficient is a measure of the rotor efficiency and is defined as in Eqn. 3.12:

$$\text{Rotor Power Coefficient} = 0.59 \tag{4.4}$$

There is a constant value of λ which, if maintained for all wind speeds, will result in an optimal C_P curve and optimal power extraction from the wind. Variable-speed wind turbines are equipped with a pitch-change mechanism to adjust the blade pitch angle and obtain a better power coefficient profile.

4.6.5 Aerodynamic Torque Calculation

The aerodynamic torque developed by the rotor blades is calculated in this subsystem using the theory given in (Manwell and McGowan, 2003). The kinetic energy E (in J) of an air mass m (in kg), moving at a speed V_{wind} (in m/s) is given in Eqn. 3.5. If the air density is ρ (kg/m^3), mass flow through an area A is given by:

$$\dot{m} = 1207.49 \text{ Kgs}^{-1}$$

Thus, an equation for the power (in W) through a cross-sectional area, A normal to the wind is given in eqn. (3.5). The power in the rotor can be determined using eqn. (3.19). The aerodynamic torque developed (in Nm) can then be calculated using eqn. (3.14):

$$\Gamma_{rotor} = 3555.24 \text{ Nm} \quad (4.5)$$

4.6.6 Calculation of Performance of Wind Mills

The performance of a wind mill is defined as 'co-efficient of performance' (C_p). This can be calculated using Eqn. 3.17:

The wind that passes through the rotor, V_{out} can be determined from Eqn. 3.18 as:

$$V_{out} = 3.7 \text{ m/s}$$

Similarly, V_r is got from eqn. (3.16) as:

$$V_r = 0.6607$$

It follows that one can calculate the performance of the wind turbine. This is achieved using eqn. (3.17):

Performance of the Wind Turbine = 0.47 (4.6)

When calculated in terms of percentage, the result gives;

79.66 %

4.7 Testing of the Contingent Variables in the Generated Model for Statistical Significance using ANOVA

	X_1	X_1^2	X_2	X_2^2	X_3	X_3^2
1	25.0	625	25.0	625	25.0	625
2	27.5	756.25	27.5	756.25	27.5	756.25
3	30.0	900	30.0	900	30.0	900
4	29.0	841	29.0	841	29.0	841
5	27.5	756.25	27.5	756.25	27.5	756.25
6	26.0	676	26.0	676	26.0	676
7	24.5	600.25	24.5	600.25	24.5	600.25
8	25.5	650.25	25.5	650.25	25.5	650.25
9	25.5	650.25	25.5	650.25	25.5	650.25
10	25.5	650.25	25.5	650.25	25.5	650.25
11	28.0	784	28.0	784	28.0	784
12	26.5	702.25	26.5	702.25	26.5	702.25
Σ	320.5	8591.75	320.5	8591.75	320.5	8591.75

X_1, X_2, X_3 are the values of mean temperature for the three locations. Though the same for the three sites, they are, however, delineated in their specific columns in the above table, for the sake of clarity

$\Sigma x = 961.5$

$\Sigma x^2 = 25775.25$

$N = 36$

Computation of SS total

$SS\ total = 95.19$

Computation of SS between

$SS\ between = 0.1$

Computation of SS within

SS within = 95.09

Calculation of degree of freedom

Df between = 2

Df within = 33

Df total = 35

Determination of mean square

$$Mean\ square = \frac{sum\ of degrees\ of\ k}{degrees\ of freedom}$$

$$MS = \frac{SS}{Df}$$

$$MS\ between = 0.05$$

$$MS\ within = 2.88$$

$$MS\ between = \ 2.72$$

Calculation of F- ratio: $F = 0.017$

Table 4.17: Summary of one way ANOVA for V calculated

Source	SS	DF	MS	F	P
Betweengroups	0.1	2	0.05	0.017	0.05
Within groups	95.09	33	2.88		
Total	95.19	35			

Referring to F- table (cf. Table A4.17) with 2 and 33 Df, and at 0.05 level of significance. The table is entered now where these two values intersect, we find 3.28 the value of F required for significance. Therefore, since the F value of 0.017 is less than 3.28, we accept the null hypothesis which states that there is no significant difference among the group mean.

N.B: F tabulated is gotten by interpolating between 32 Df and 34 Df;

$$\frac{3.30 + 3.20}{2} = \frac{6.58}{2} = 3.28$$

4.8 Comparison of Betz' Mathematical Model with the Generated Model in Terms of Power Output

Recall that from Table A4.3 (Appendix 5), air density, $\rho = 1.22\ kg/m^3$

From equation (3.8), $P_{w(Available)} = \frac{1}{2}\rho AV^3$ (Betz)

Similarly, from equation (3.13), $P_{w(Actual)} = \frac{16}{27}(\frac{1}{2}\rho AV^3)$ (Betz)

From equation (3.17), using the Betz' model, the coefficient of performance of the wind turbine, K, equals 0.47. In the same vein, from equation (3.28),

$$P_{W(Gen.)} = 86.60(10 + M\frac{T}{H_R})^3.$$

Therefore, the values of $P_{w(Available)}$, $P_{w(Actual)}$, $P_{W(Gen.)(Available)}$ and $P_{W(Gen.)(Actual)}$ can be calculated for the months of the year as in Table A4.18

According to Betz, by the time the designer takes into account the other factors in a complete wind turbine system; e.g. the gearbox, bearings, generator and so on, only about 30% of the power of the wind is ever actually converted into usable electricity (Rivkin et al, 2011).

Therefore, in real life situation, $P_{W(Gen.)(Actual)} = \frac{1}{3} P_{W(Gen.)(Available)}$

Table A4.18: Parameters for the Generated and Betz' Models

S/N	Mnth.	Ave. Speed (m/s)	Mean Temp (^oC)	Rel. Hum (%)	Height (m)	Swept Area (m^2)	P_w Avail. (kW)	P_w Actl. (kW)	P_w Gen. Avail. (kW)	P_w Gen. Actl. (kW)
1.	Jan.	5.5	25	76	10	176.74	17.94	10.59	86.80	28.93
2.	Feb.	5.6	27.5	80	10	176.74	18.93	11.17	86.81	28.94
3.	Mar.	6.5	30	76	10	176.74	29.61	17.47	86.83	28.94
4.	April	6.6	29	81	10	176.74	31.00	18.29	86.82	28.94
5.	May	5.8	27.5	81	10	176.74	21.04	12.41	86.81	28.94
6.	Jun.	5.3	26	85	10	176.74	16.05	9.47	86.79	28.93
7.	July	5.6	24.5	89	10	176.74	18.93	11.17	86.78	28.93
8.	Aug.	5.7	25.5	87	10	176.74	19.97	11.78	86.79	28.93
9.	Sept.	5.3	25.5	86	10	176.74	16.05	9.47	86.79	28.93
10.	Oct.	5.1	25.5	85	10	176.74	14.30	8.44	86.79	28.93
11.	Nov.	4.9	28	73	10	176.74	12.69	7.49	86.83	28.94
12.	Dec.	5.4	26.5	76	10	176.74	16.98	10.02	86.81	28.94
			26.7	81.25				11.48		28.94

Moreover, from equation (3.24), using the Generated model, the performance of the wind turbine, K, equals 0.49. The Generated mathematical model gave a higher value of the coefficient of performance than the existing Betz' model. However, the calculated value falls within Betz' upper limit of 0.59; indicating that the Generated model is in tandem with the accepted engineering computations on wind energy technology. The comparison, also, showed that the Generated model, produced a higher value for each month, when used to calculate the rated power output of the contrivance, than the already existing Betz' model. Unlike Betz, the researcher took into cognizance, the interplay between the contingent variables in formulating the model used in rated power calculations. This seems to indicate that the Generated mathematical model is more encompassing than the former model.

4.9 Response Surface Methodology (RSM)

Apart from relative humidity and ambient temperature, the other three variables are constant. They are not affected by vagaries of time and space. The interaction among process variables can be determined by statistical techniques such as RSM. Table A4.13 shows the values of two of these variables for location 1. The three-dimensional graphs of average monthly wind speed, mean temperature, and relative humidity are shown in Fig. 4.15

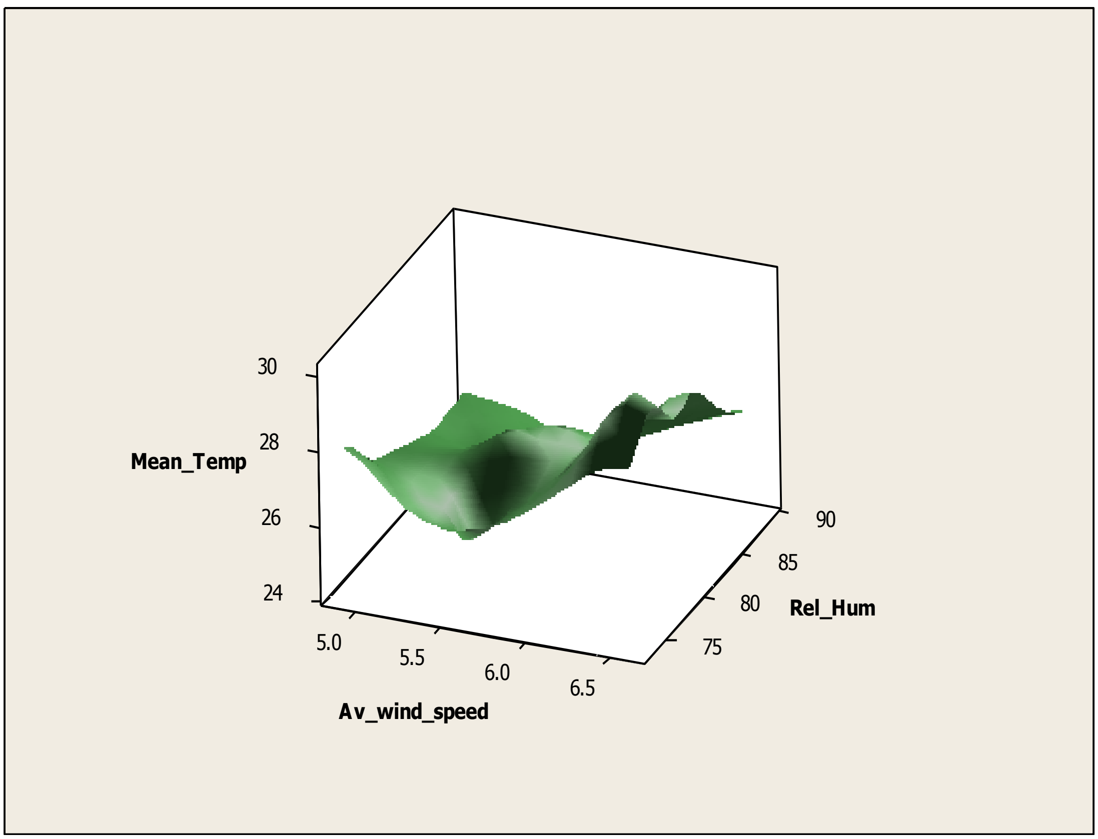

Fig. 4.15: 3D Graph of Average Monthly Wind Speed versus Mean Temp versus Relative Hum

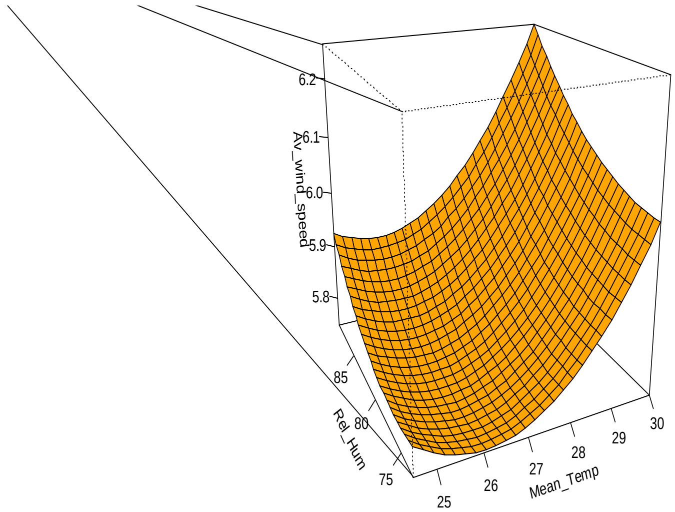

Fig.4.16: RSM of Average Wind Speed, Mean Temp, and Rel. Humidity

Table A4.13 contains information on maximum temperature, minimum temperature, mean temperature, and relative humidity of Owerre-Ezukala. This table indicates that the town experienced the hottest temperature in the month of March, and also recorded the lowest minimum temperature in the month of January. In addition, it could be inferred from the tables that the highest monthly relative humidity was in July with 89 %, closely followed by August which had 87 %. Also, the lowest relative humidity was experienced in November with 73 %. January, March and December had the same relative humidity of 76 %, which were the second lowest for the year. Air density, which linearly affects the power output at a given speed, is a function of altitude, temperature and relative humidity. Variation in temperature and pressure can affect air density up to 10 % in either direction. Warm climate reduces air density, and invariably increases wind speed. Irrespective of the homogeneity in temperature and relative humidity in Owerre-Ezukala, the three locations investigated recorded slight difference in wind speed. This is explained in terms of specific topography, vegetation and existence of human activities, with respect to these sites.

It could be stated that an increase in ambient temperature brings about a decrease in relative humidity, as is evident in the months of March and November. Conversely, low temperature environment produces high relative humidity as shown in July, August, September, and October (cf. Location 1). Notice that an increase in ambient temperature gives also an increase in relative humidity in April, May, and June, for instance. This is attributed to plants leaves being heavy (thick vegetation), and less evaporation occurring irrespective of high temperature. On the contrary during the dry season, when rainfall has receded, plants tend to shed their leaves. Temperature is high and moisture content in the atmosphere is low. This is typical of the months of March and November as earlier mentioned. Here vegetation is thin. Furthermore, at the height of 10 m, the joint effects of topography, vegetation, temperature and relative humidity give a considerable high wind speed. One would expect wind speed to be outstandingly high between November, and January, when harmattan is at its peak. The speed of harmattan wind is not dependent on temperature within the environment; but largely on existing vegetation and other anthropogenic activities. These factors promote turbulence and unnecessary gust which bring about regression in the wind speed, at lower altitudes (say 10 m) during the harmattan season. Temperature can easily be as low as 22 ^{o}C all day, but sometimes can also soar to as high as high as 30 ^{o}C, while the relative humidity drops drastically. When harmattan wind blows over a region, the air is particularly dry and desiccating.

Whatever had been said about LOCATION 1, could also be adduced for LOCATION 2. The same climatic conditions of mean temperature and relative humidity recorded in Ugwu-Osu site, prevail in Okegbe region. A variation in topography and vegetation is noticed in the latter which produces a slight difference in the measured wind speed of these locations. The topography of Okegbe is better than that of Ugwu-Osu, in that a good topography favours increase in wind speed. However, there are higher human activities in Okegbe than in Ugwu-Osu (Anthropogenic activities lowers wind speed because of friction). The combined effects of ambient temperature, relative humidity, topography and vegetations give an average annual wind speed for LOCATION 2 to be 5.6 m/s. These ecological factors bring about the recorded wind speed from January to December.

Similarly, in LOCATION 3, there is a linear correlation between ambient temperature and relative humidity. An increase in the former, brings about a corresponding decrease in the latter. This is evident in the months of March and November, with the mean temperature values of 30 ^{0}C and 28 ^{0}C; and the relative humidity values of 76% and 73% respectively. This relation, sometimes, are violated by the factors of dense vegetation and high water retention capacity of plants’ leaves and shrubs. The good topography and mountainous nature of Ogba-Ukwu area yield an increase in wind speed.

However, these advantages are countered by the inherent heavy vegetation of this location, giving an annual wind speed of 5.5 m/s.

The average wind speed of the three locations is calculated and treated as a unit. The monthly and annual values of this parameter at 10 m altitude are contained in Appendix 3. From Table A4.1, average wind speed is highest in April, with a value of 6.6 m/s; and least in November, with a value of 4.9 m/s. The annual average value of wind speed is 5.6 m/s. From the graph, it could be averred that wind speed varies directly as high temperature, and inversely as low humidity as can be seen in March and November. Sometimes, a shift from this perceived proportionality occurs: even though the ambient temperature is high, relative humidity is also appreciably high. Irrespective of high temperature, evaporation occurs minimally thereby more water vapour is suspended on the atmosphere. This phenomenon is prevalent, for instance, in the months of April, May, and June.

4.10 Sensitivity Analysis of the Developed and Betz' Models

Table A4.19: Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Betz	11.4808	12	3.29695	.95175
	Generated	28.9350	12	.00522	.00151

The result of the paired sample statistics found the mean power of the two models to be 11.4808 and 28.9350 for Betz and Generated methods respectively.

Table A4.20: Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Betz & Author	12	.421	.173

Result showed that there exist a weak positive relationship between the power produced by Betz model and Generated model.

Table A4.21: Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Betz - Genetd	-17.4547	3.29476	.95112	-19.54756	-15.36078	-18.351	11	.000

It was found that a mean difference of -17.45 exists between the power produced by Betz' and Generated model. Further result revealed that there exists significant difference between Betz' and Generated Model with a p-value of 0.000 which falls on the rejection region of the hypothesis, as shown in Fig. 4.17.

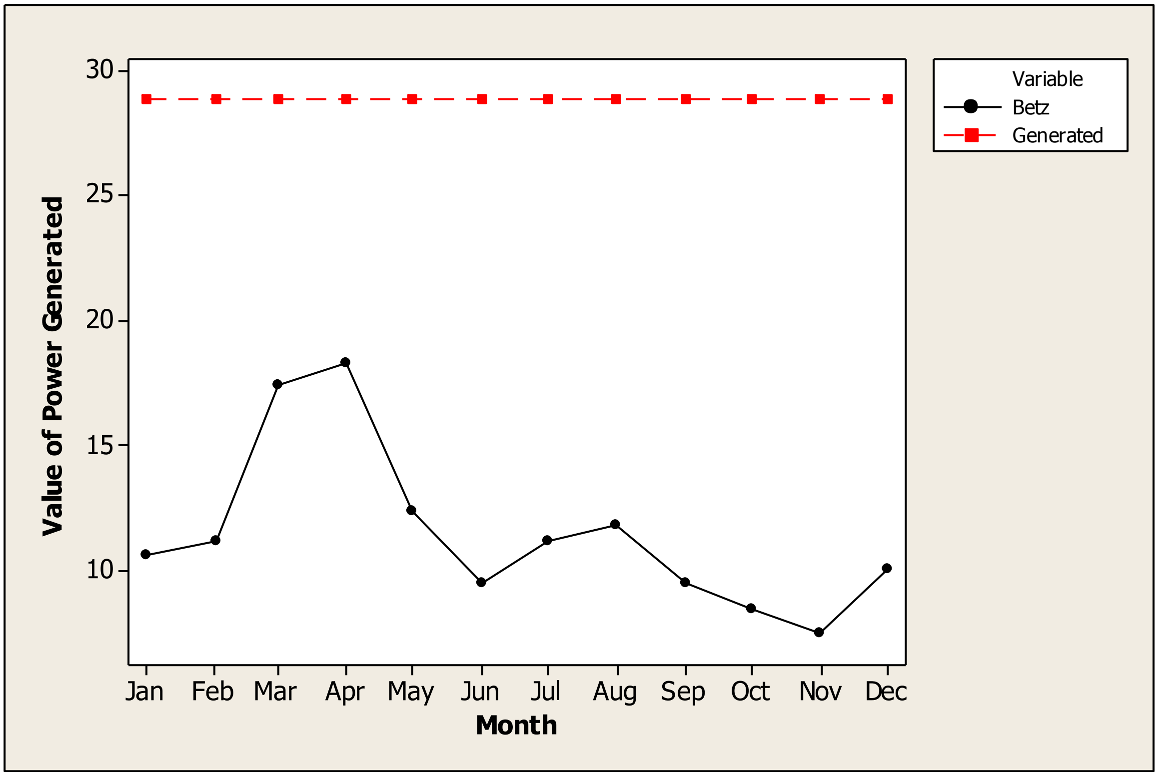

Fig. 4.17: Graph showing Power Produced by Betz' and Generated Models

4.11 Weibull and Cauchy Distribution Analysis

Weibull Distribution Analysis for X1(Av. Wind Speed)

Table A4.22 presents the estimated Weibull parameters for variable X1 (Av. Wind Speed) which comprises of the shape parameter of 138.78975 and the Scale parameter of 24.74705 with their corresponding standard error of 56.59276 and 10.10904 respectively.

Table A4.22: Parameters for the Weibull distribution for X1.

Parameter	Type	Estimate	S.E.
Shape	shape	138.78975	56.59276
Scale	scale	24.74705	10.10904

Weibull Distribution Analysis for X2 (Max.Temp.)

Table A4.23 presents the estimated Weibull parameters for variable X2 (Max Temp) which comprises of the shape parameter of 155.8769 and the Scale parameter of 4.974793with their corresponding standard error of 63.56853 and 2.032041respectively.

Table A4.23: Parameters for the Weibull distribution for X2.

Parameter	Type	Estimate	S.E.
Shape	shape	155.8769	63.56853
Scale	scale	4.974793	2.032041

Weibull Distribution Analysis for X3 (Min. Temp)

Table A4.24 presents the estimated Weibull parameters for variable X3 (Min. Temp.) which comprises of the shape parameter of 129.1527and the Scale parameter of 5.848425 with their corresponding standard error of 52.65848and 2.389157 respectively.

Table A4.24: Parameters for the Weibull distribution for X3

Parameter	Type	Estimate	S.E.
Shape	shape	129.1527	52.65848
Scale	scale	5.848425	2.389157

Weibull Distribution Analysis for X4 (Mean Temp.)

Table A4.25 presents the estimated Weibull parameters for variable X4 (Mean Temp.) which comprises of the shape parameter of 275.1669 and the

Scale parameter of 10.30265 with their corresponding standard error of 112.2684 and 4.207318 respectively.

Table A4.25: Parameters for the Weibull distribution for X4.

Parameter	Type	Estimate	S.E.
Shape	shape	275.1669	112.2684
Scale	scale	10.30265	4.207318

Weibull Distribution Analysis for X5 (Rel. Hum.)

Table A4.26 presents the estimated Weibull parameters for variable X5 (Rel. Hum.) which comprises of the shape parameter of 265.6526 and the Scale parameter of 3.269549 with their corresponding standard error of 108.3842 and 1.335207 respectively.

Table A4.26: Parameters for the Weibull distribution for X5.

Parameter	Type	Estimate	S.E.
Shape	shape	265.6526	108.3842
Scale	scale	3.269549	1.335207

Table A4.27 presents the estimated Weibull density values for variable X1 to X5 across the months. The mean density value was obtained in the following order of magnitude X1= 0.609816, X4=0.168896, X3=0.147597, X2=0.102285and X5=0.052605. This result implies that X1(Av. Wind Speed) recorded the highest mean density value while X5 (Rel. Hum) recorded the least mean density value. Figure 4.19 validated the result afore-stated where dX1 (density value for X1) was observed to have a steeply increasing trend than the other variables.

Table A4.27: Summary of Density Count of the Variables using the Weibull Distribution

Month	dX1	dX2	dX3	dX4	dX5
Jan	0.831903	0.150249	0.020164	0.146967	0.047898
Feb	0.838636	0.121914	0.205759	0.21368	0.078711
March	0.147674	0.052813	0.064304	0.031928	0.047898
April	0.101901	0.085803	0.119176	0.087485	0.080149
May	0.74814	0.150249	0.176778	0.21368	0.080149
June	0.712813	0.143502	0.205759	0.230576	0.058119
July	0.838636	0.068754	0.183729	0.099745	0.023439
Aug	0.809075	0.108916	0.205759	0.194049	0.039583
Sept	0.712813	0.068754	0.176778	0.194049	0.04883
Oct	0.501884	0.068754	0.176778	0.194049	0.058119
Nov	0.285846	0.121914	0.176778	0.17299	0.020473
Dec	0.788473	0.085803	0.059403	0.247557	0.047898
Mean Density value	0.609816	0.102285	0.147597	0.168896	0.052605

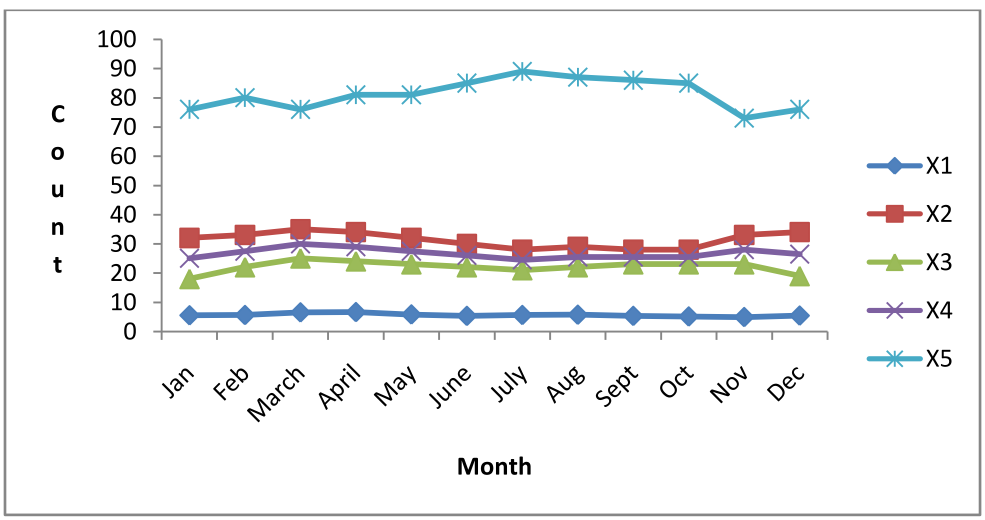

Figure 4.18: Graph showing the Observed values for the Variables

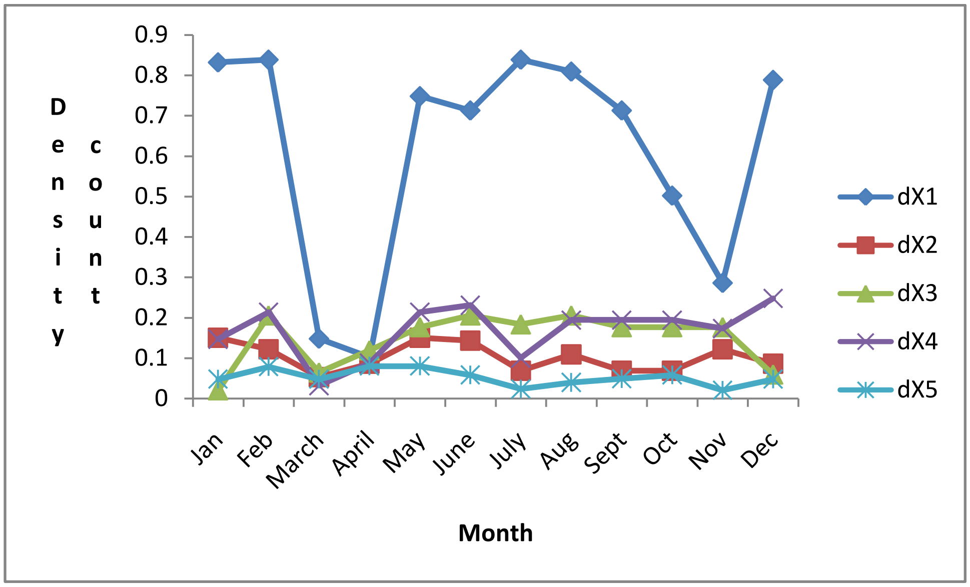

Figure 4.19: Graph showing the Density Count using the Weibull Distribution

Result of Cauchy Distribution Analysis

Cauchy Distribution Analysis for X1 (Av. Wind Speed)

Table A4.28 presents the estimated Cauchy parameters for variable X1 (Av. Wind Speed) which comprises of the location parameter of 0.96306 and the Scale parameter of 0.62383with their corresponding standard error of 0.17053 and 0.40825 respectively.

Table A4.28: Parameters for the Cauchy Distribution for X1

Coefficients	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept): loge(location) 1	0.96306	0.17053	5.647	1.63e-08
(Intercept): loge(scale) 2	0.62383	0.40825	1.528	0.126
X1	0.50570	0.02883	17.539	<2e-16

Cauchy Distribution Analysis for X2= Max Temp

Table A4.29 presents the estimated Cauchy parameters for variable X2 (Max Temp) which comprises of the location parameter of -13.5034 and the Scale parameter of 15.53909 with their corresponding standard error of 1.56905 and 0.40825 respectively.

Table A4.29: Parameters for the Cauchy Distribution for X2

Coefficients	Estimate	Std. Error	Zvalue	Pr(>|z|)
(Intercept): loge(location) 1	-13.5034	1.56905	-8.606	<2e-16
(Intercept): loge(scale) 2	15.53909	0.40825	38.063	<2e-16
X2	0.94034	0.04522	20.795	<2e-16

Cauchy Distribution Analysis for X3 (Min. Temp)

Table A4.30 presents the estimated Cauchy parameters for variable X3 (Min Temp) which comprises of the location parameter of 0.9999 and the Scale parameter of 0.6659 with their corresponding standard error of 5.93 * 10^-05 and 0.4082 respectively.

Table A4.30: Parameters for the Cauchy Distribution for X3

Coefficients	Estimate	Std. Error	Zvalue	Pr(>|z|)
(Intercept): loge(location) 1	0.9999	5.93E-05	16880	<2e-16
(Intercept): loge(scale) 2	0.6659	0.4082	1.631	0.103
X3	0.5	2.46E-06	203100	<2e-16

Cauchy Distribution Analysis for X4 (Mean Temp)

Table A4.31 presents the estimated Cauchy parameters for variable X4 (Mean Temp) which comprises of the location parameter of 1.72065 and the Scale parameter of 10.46801 with their corresponding standard error of 0.112861 and 0.408248 respectively.

Table A4.31: Parameters for the Cauchy Distribution for X4

Coefficients	Estimate	Std. Error	Zvalue	Pr(>|z|)
(Intercept): loge(location) 1	1.72065	0.112861	15.25	<2e-16
(Intercept): loge(scale) 2	10.46801	0.408248	25.64	<2e-16
X4	0.472234	0.003874	121.88	<2e-16

Cauchy Distribution Analysis for X5 (Rel. Hum)

Table A4.32 presents the estimated Cauchy parameters for variable X5 (Rel. Hum) which comprises of the location parameter of -14.9554 and the Scale parameter of 40.63299 with their corresponding standard error of 0.210025 and 0.408248 respectively.

Table A4.32: Parameters for the Cauchy Distribution

Coefficients	Estimate	Std. Error	Zvalue	Pr(>|z|)
(Intercept): loge(location) 1	-14.9554	0.210025	-71.21	<2e-16
(Intercept): loge(scale) 2	40.63299	0.408248	99.53	<2e-16
X5	0.70094	0.002365	296.43	<2e-16

Table A4.33 presents the estimated Cauchy density values for variable X1 to X5 across the months. The mean density value was obtained in the following order of magnitude X1=0.009304, X4=0.004578, X2=0.002212, X5=0.001192 and X3=0.000489. This result implies that X1(Av. Wind Speed) recorded the highest mean density value while X3 (Min Temp) recorded the least mean density value. Figure 4.20 validated the result afore-stated where dX1 (density value for X1) was observed to have a clear increasing trend than the other variables.

Table A4.33: Summary of Density Count of the Variables using the Cauchy Distribution

Month	dY1	dY2	dY3	dY4	dY5
Jan	0.009468	0.002139	0.000732302	0.005114	0.001303
Feb	0.009071	0.002057	0.000480153	0.004304	0.001212
March	0.006396	0.001907	0.000367704	0.003664	0.001303
April	0.006174	0.00198	0.000400346	0.003903	0.001191
May	0.008349	0.002139	0.000437534	0.004304	0.001191
June	0.010343	0.002318	0.000480153	0.004766	0.001111
July	0.009071	0.002518	0.000529314	0.005302	0.001038
Aug	0.008699	0.002415	0.000480153	0.004936	0.001074
Sept	0.010343	0.002518	0.000437534	0.004936	0.001092
Oct	0.011345	0.002518	0.000437534	0.004936	0.001111
Nov	0.012498	0.002057	0.000437534	0.004164	0.001378
Dec	0.009891	0.00198	0.000653304	0.004605	0.001303
Mean Density Value	0.009304	0.002212	0.000489464	0.004578	0.001192

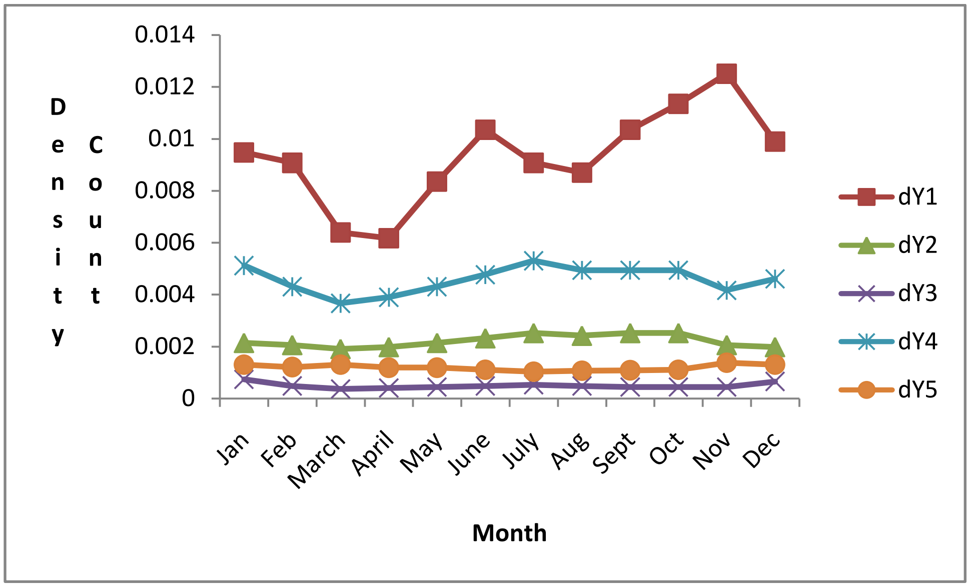

Figure 4.20: Graph showing the Density Count using the Cauchy Distribution

Definition of variables in R-console 3.32 version window of Weibull and Cauchy Distribution Analysis on the (Variables) is shown in Appendix 8

4.12 Parametric Design of a Turbine Blade

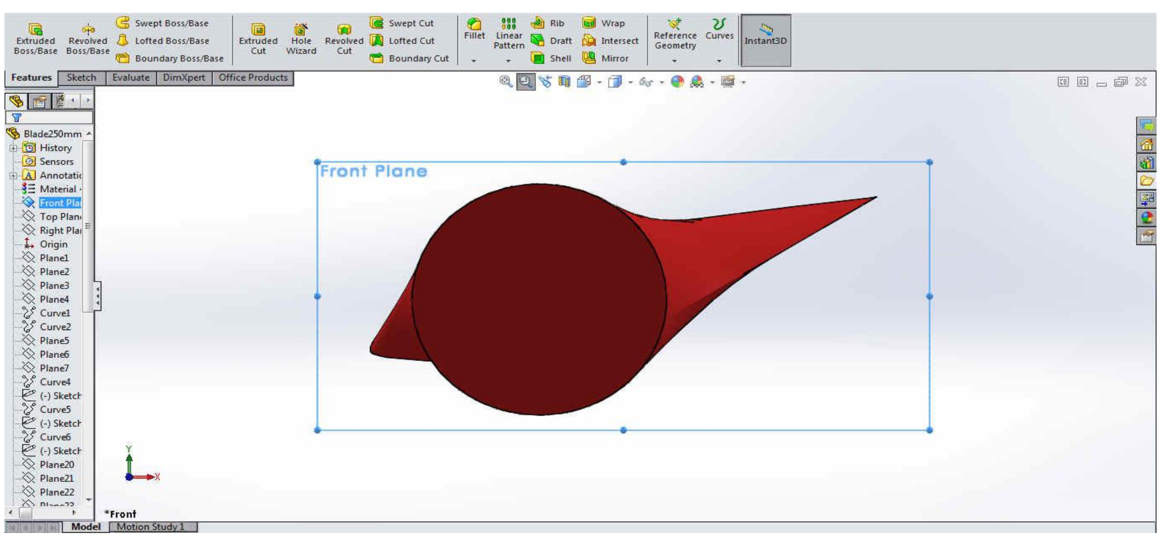

Fig. 4.21: Wind Turbine Blade Hub

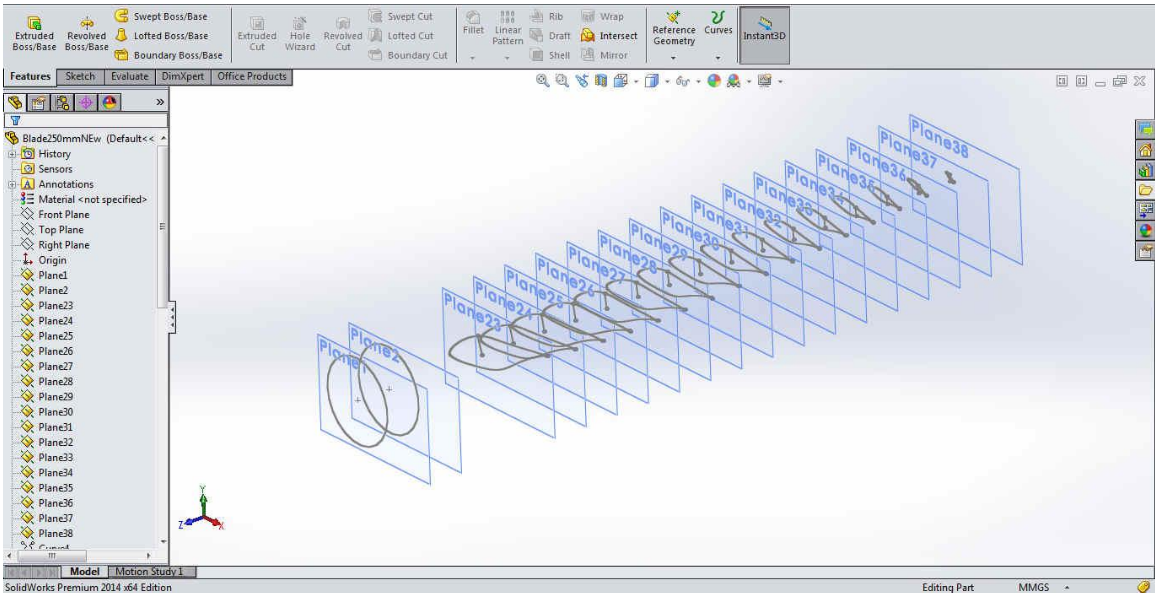

Fig. 4.22: Aerofoil Arrangement along the Wind Turbine Blade Length

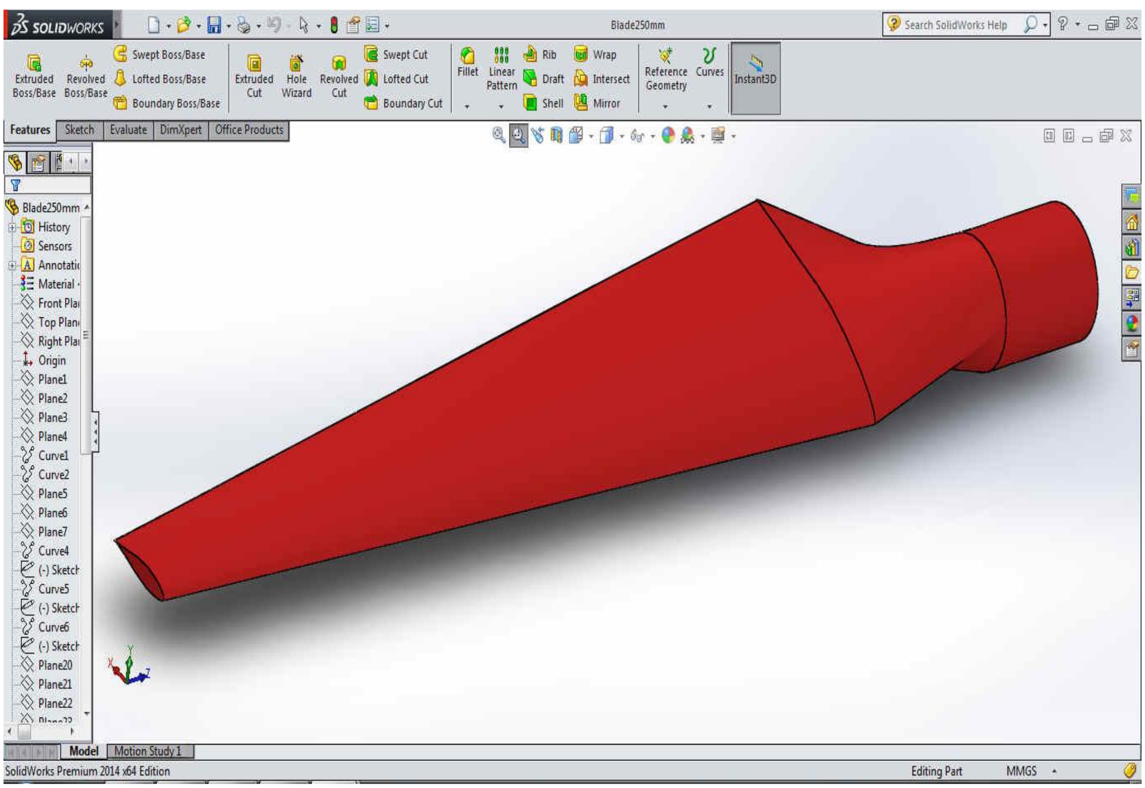

Fig. 4.23: Combined S809 (root) and S814 (tip) Aerofoils

The above design is based on the parameters generated by the author in the course of the research using Solid Works design software. Parameters like the tower height, blade chord length and blade radius are arbitrarily chosen. Moreover, the careful selection of the design variables, and subsequent calculation of the swept area, led to a COP value that is adequate to siting a wind turbine station in the chosen location. A look at Appendixes 10 and 11explain clearly how the blade geometry came to be as shown in Figures 4.21, 4.22 and 4.23 respectively, using the Solid Works design software.

For the root region of a wind turbine blade, structural and dynamic considerations require greater aerofoil thickness. However, for thicknesses over 26 % chord, it is difficult to design desirable performance characteristics into an aerofoil. These characteristics include a high $C_{Lmax.}$ (maximum lift coefficient) that is largely insensitive to roughness effects along with low profile drag over a wide range of lift coefficient. Also, the maximum lift ratio must occur at a high coefficient and the pitching moment should not be excessive. In the case of stall-regulated blades, it is desirable to shift from the high $C_{Lmax.}$ of the root aerofoil to a low $C_{Lmax.}$ for the tip-region aerofoil. Only aerofoils of the categories S809 (for the root) and S814 (for the tip) satisfy these requirements, and are selected for the design.

4.13 Design of Wind Farm for the Designated Area

In this section, an attempt is made to design a functional wind farm that would solve, appreciably, the electricity need of the research area. This involves determining the energy load of the area and subsequent system design.

4.13.1 Energy Audit of the Research Area

This is an assessment of the energy requirements of a building, house, and business premises, in the research area of interest. It involves the estimation of the number of houses in the research area, and the various electrical/electronic appliances that are in use, in terms of their actual power rating and specifications. Owerre-Ezukala comprises eight (8) villages of different sizes. Table A4.34 reveals the categories of residential houses in the designated locations of the study.

Table 4.34: Energy Needs of the Residential Houses of the Research Area

	Villages	No. of Houses	No. of 4-6 BR Aptmts	Power Rating per Aptmt (watts)	No. of 4-8 BR Duplexes	Power Rating per Duplex (watts)	Power Rating of ACs (watts)
1.	Okpoghota	57	47	364	10	780	4474.2
2.	Okpu	79	68	354	11	780	8948.4
3.	Ihie	156	130	390	26	780	5592.75
4.	Iyiaho	152	130	390	22	780	13422.6
5.	Ishiaho	66	57	364	9	780	10066.95
6.	Ogwuada	78	66	390	12	780	10812.65
7.	Lete	53	43	312	10	780	3355.65
8.	Mkputu	154	136	390	18	780	4474.2

Most of the houses use the following appliances: TV set, Radio Set, Fans, and Lightening points. Only very few households make use of electric pressing iron, electric kettle/boiler, and air-conditioners. It is assumed that 26-watts energy saving bulbs are used in the homes. All these contingencies are factored into the power ratings of the homes. In Table A4.35, the summation of energy requirements, in watts, is clearly stated.

Table 4.35: Net Energy Needs of the Residential Houses of the Research Area

	Villages	No. of Homes	No. of 4-6 BR Apts	Power Rating per Apt (W)	Total Power Rating for the Apts (W)	No. of 4-8 BR Dups	Power Rating per Dup. (w)	Total Power Rating for the Dups (W)	Power Rating of ACs (W)	Total Energy Needs (W)
1.	Okpoghota	57	47	364	17,108	10	780	7,800	4,474.2	29,382.2
2.	Okpu	79	68	354	24,752	11	780	8,500	8,948.4	42,280.4
3.	Ihie	156	130	390	50,700	26	780	20,280	5,592.75	76,572.8
4.	Iyiaho	152	130	390	50,700	22	780	17,160	13,422.6	81,282.6
5.	Ishiaho	66	57	364	20,748	9	780	7,020	10,067.0	37,835.0
6.	Ogwuada	78	66	390	25,740	12	780	9,360	10,812.7	45,912.7
7.	Lete	53	43	312	13,416	10	780	7,800	3,355.7	24,571.7
8.	Mkputu	154	136	390	53,040	18	780	14,040	4,474.2	71,554.2
					256,204			92,040	61,147.4	409,391.4

Note: 1 hp = 745.7 watts

1 kVA = 1 kW

The A.C. power need is about 14.96 % of the net energy requirement in the residential homes.

The research includes the appraisal of the number of essential services/commercial infrastructure that would benefit from the design. A survey across the town made the inventory possible; and their specifications are shown in Table A4.36

Table A4.36: Specifications of the Essential Services/Commercial Infrastructure in terms of Power Requirement

	Categories of Services	No.	Total Energy Needs(W)
1.	Schools	11	1,960.00
2.	Churches	12	9,740.00
3.	Mini Filling Station	1	1,118.55
4.	Mini Super Mkt/Medicine Shop	21	1,638.00
5.	Salon	13	870.00
6.	Artisans	11	220,000.00
7	Hospitals	1	720.00
			236,046.55

Each of the clippers used by the barbing salons is rated 15 Watts. Also, the hair dryers for women have a rating of 1500 Watts. The artisans, numbering eleven (11), are mainly welders. Each welding machine consumes a maximum of 20 kW of power. The maximum power consumption of a typical domestic refrigerator is 200 Watts.

It is evident from Table A4.35 and Table A4.36 that the net energy need of the community equals **645,437.95 Watts** (645.43795 kilo-Watts). However, it must be stated that this robust energy need of the community is theoretical. That is, the appliances, usually, do not "run" concurrently. For instance, the owners of the houses with installed air-conditioners live outside the villages; and do not come home at the same time. They can only use their A.Cs whenever they are around. Besides, the churches, schools, and business areas, have some idle periods (when no activities exist). Also, even some of the homes are unoccupied during work hours. Hence, this brings us to the terms: maximum load, connected load, average load, demand factor, and load factor.

4.13.2 System Design

$$\text{Maximum Demand} = 645.43795 \text{ kW} \quad (4.7)$$

Note: The accepted connected load, according to electrical engineering code, is usually 10% in excess of maximum demand.

$$\text{Therefore, Connected Load} \approx 710 \text{ kW} \quad (4.8)$$

$$\text{Demand Factor} = \frac{\text{Maximum Demand}}{\text{Connected Load}} \quad \text{(cf. eqn. 2.52)}$$

$$\text{Annual Average Load} = \frac{No.of\ units\ (kWh) generated\ in\ a\ year}{No.of\ hours\ in\ a\ year} \quad (4.9)$$

$$\text{Annual Load Factor} = \frac{\text{Annual Average Load}}{\text{Maximum Demand}} \quad (4.10)$$

These terms and factors come into play when costing of the generated energy is expedient. Capital investment on the plant is outside the purview of this work. However, their values are contained in Table A4.37.

From Table A4.18

Average Annual P_w Actual of a Turbine (Betz' Model) = 11.48 kW

Average Annual P_w of a Turbine (Generated Model) = 28.94 kW

From the fore-going, a design of a wind farm that would satisfy the electricity need of the research area, is attempted, as shown in Table 4.37. This is done bearing in mind the annual power capacity of a wind-turbine generator unit, based on Betz' and Generated mathematical models respectively.

Table 4.37: Summary of the Wind Farm Design Based on Betz' and Generated Models

	Rated Power of each Unit (kW)	Maximum Demand (kW)	Connected Load (kW)	Estimated No. of Wind Turbines in a Farm	Actual No. of Wind Turbines in a Farm	Dem. Fac.	Ann. Ave. Load (kW)	Ann. Load Fac.
Betz' Model	11.48	645.43795	710	61.8467	62	0.849	265.266	0.411
Gen. Model	28.94	645.43795	710	24.5335	25	0.849	265.266	0.411

Table 4.37 shows the number of wind turbines in a single wind farm based on the two mathematical models earlier mentioned. While the Betz' model admits of sixty-two (62) wind turbines, the Generated model accommodates only twenty-five (25) turbines per farm. A typical wind farm has several identical wind-turbine generator units located in a windy area away from cities and/or forests. The generators are connected in parallel and operate synchronously. An alternation between two or more farms working asynchronously can be established to prolong the life span of each of the turbines and farms. The electrical power delivered by the wind farm power

plant is either supplied to "isolated" houses or into the 3 phase AC Network (cf. Fig.4.23).

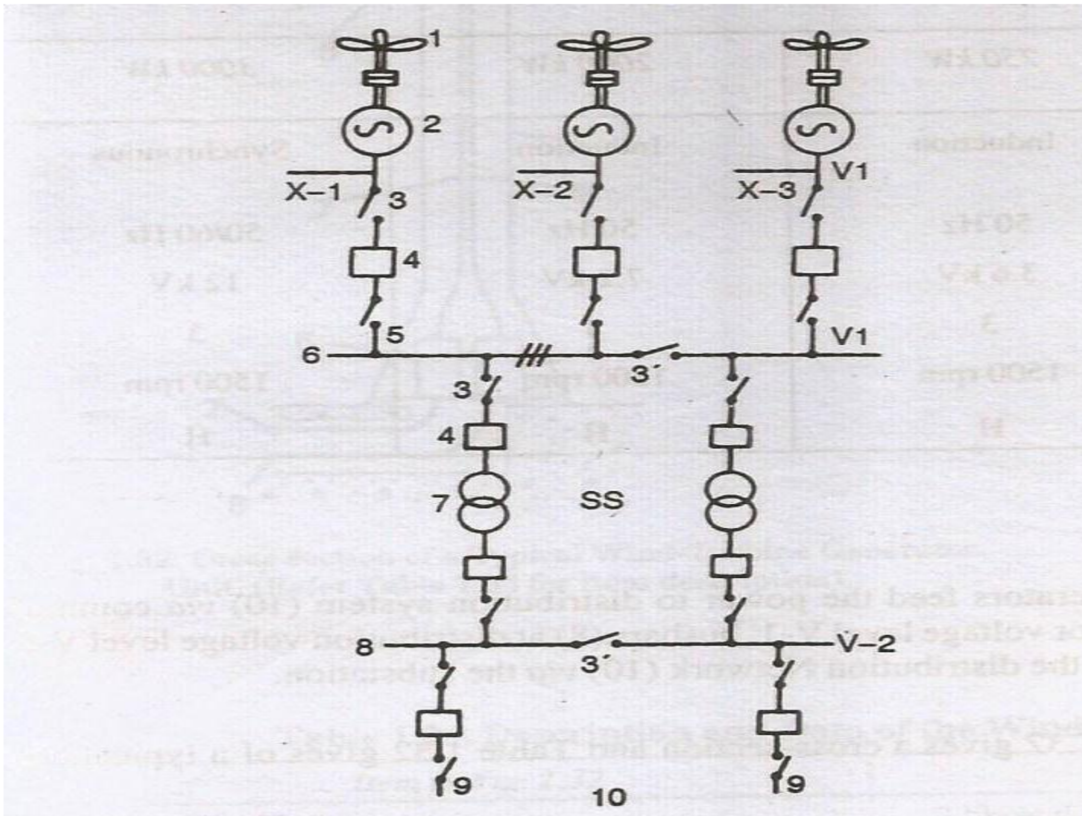

Fig.4.24: Wind-Farm Electrical Power Plant-Schematic of Main Power Circuit Single Line Representation of 3-Phase Systems

1. Wind Turbine 2. AC Generator 3. Isolator 4. Circuit Breaker
5. Isolator 6. Busbar at V-1 7. Power Transformer
8. Busbar at V-2 9. Distribution Feeders
10. Distribution System x_1, x_2…Control Cables

Note the following:

Lateral distance between two (2) turbines in a farm = 3D

Axial distance between two (2) turbines in a farm = 7D

Where D = Rotor Diameter

4.14 An Abridged Template of the Estimated Cost Implication of the Design

Cost of 50 kW Wind Turbine = #1,450,000.13

Projected power rating for the location = 709,981-745 W (710 kW)

Cost of 710 kW Wind Turbine ≈ #21,750,001.95 (https://www.datacommexpress.com)

Therefore, cost of energy required by the location = **#21,750,001.95**

1 Acre of land = 8 Plots

1 plot of land = 50 x 100ft

An acre is a standard unit of measurement used by land sellers; and it is almost equivalent to the size of a standard football field. An acre is about 0.405 hectare, and one hectare contain contains about 2.47 acres. In other words;

1hectare ≈ 2.5 acres

Estimated land need for 25 small sized turbine = 3 acres

Cost of 3 acres in the research area = Freely Donated by the community

Operation and maintenance (O & M) costs constitute a sizeable share of the total annual costs of wind turbine. For a new turbine, O & M costs may easily make up 20 – 25 % of the total levelized cost per kWh (https.//www.wind-energy-the-fact.org)

Hence, estimated lifetime cost of O & M = Part of the running cost of the equipment (www.info.com)

Life expectancy of a turbine = 35-40 years (www.enerdata.net)

Total Cost on Investment = **#21,750,001.95**

The basic unit of electricity is the Kilowatt hour (kWh). In simple terms, 1 kWh is the amount of energy used by a 1 kW (1000 watts) electric heater for 1 hour. If one uses 1000 watts or 1 kilowatt of power for 1 hour, then, the person has consumed 1 unit or 1 kilowatt-Hour (kWh) of electricity. Nowadays, electricity is not cheap. Besides, the tariff is increasing rapidly. The price for electricity depends on four major things: location, tariff class, tariff rate, the quantity of consumed energy (in kWh). The tariff class and rate for Enugu Electricity Distribution Company as it applies to the location of interest, are:

Maximum Tariff = #45.24

Minimum Tariff/kWh = #0.248

Power Factor of the System = $\frac{Active\ \ Power}{Apparent\ \ Power} = \frac{645.43795}{710} = 0.9$

Load Factor = 0.4

Unit Consumed/year = (Max. Demand) x (L.F.) x (Hours in a year)

2,487,840 kWh

Max. Demand in kVA = $\frac{\text{Max .Demand}}{\text{Power Factor}} \approx 789$

Therefore, Annual Bill = Max. Demand Charges + Energy Charges

Max. Demand Charge = Maximum Tariff x Max. Demand in kVA

Energy Charges = Minimum Tariff/kWh x Unit Consumed/year

= #652,673.32

Note that with an annual bill of #652,673.32, it will take approximately thirty-three (33) years to recover the investment on the wind energy generation system. The remaining 4-9 years of its operation would be much gain to the entrepreneur.

4.15 Difficulties Encountered During the Study

A number of constraints confronted the researcher in the course of this investigation. These limitations, sometimes, presented themselves as difficulties that the researcher grappled with in equipment management. Serious attempts were made to resolve these hiccups, but, they, certainly, were beyond the author's control. Some of these snags include:

Limited Number of Anemometer: The measurement of the dependent variable (wind velocity/wind speed), and the independent variables (mean temperature and relative humidity) was possible through the use of digital anemometer. Data collection in Owerre-Ezukala was facilitated by the use of twelve (12) of these devices. Since the number available for this research was limited, extending this investigation into other neighbouring and nearby communities, concurrently, proved arduous. Otherwise, the period allotted to field-work would have been overly prolonged.

Paucity of Researchers in Renewable Energy: The analysis required in this work demands constant visit to the research sites, for supervision of the apparatus, and data collection. Hence, a lot of commitment – physical and intellectual – was inevitable. Traversing a large expanse of area for such academic enterprise, not only weighs the individual researcher down, but is also, counter-productive. More researchers interested in wind energy technology should synergize for wider applicability and coverage.

Inadequate Funding: Data collection and collation, and subsequent analysis, is capital intensive. Most people, who delve into research in this level, are left at the mercy of fate. Lack of finance was a major setback in executing this project. No wonder, only a few geographical areas were sampled.

Constraint of Time: In order to obtain an accurate or near-accurate value of the measured variables, the in situ measurement must be done over and over again. The values from different devices were compared and correct result documented. The whole process consumes ample time. Therefore, enlarging the area to be sampled implies that an individual researcher cannot cope with the demands of co-ordination and management of equipment and human persons involved in the inquiry.

Problem of Transportation: Very often, the researcher needs to move to the sites where actual measurement occurs. Some of these areas are not accessible to commercial drivers or private vehicle owners. The only available option is motor-bike operators, who may not like to ply the route. This, actually, was a cog in the wheel of progress of this research.

Sabotage by Autochthonous People: The anemometer employed in this work, are very expensive. If left in the research sites unguarded, they may easily be stolen by the area-boys. The academic activities of the researchers were strange to these miscreants; hence, they, at one point or the other demanded monetary tips before continuing with the research. To ensure the success of the work, the safety of the equipment, and the field-workers, some of these youths were employed as security agents to safeguard the appliances, at all times, especially, at nights. This has to be done bearing in mind that data collection was a 24 hour, 7 days a week, and completely a full year, activity.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Wind possesses high kinetic energy, and wind mills have been used for many years to drive mill mechanisms. Many wind driven power stations – large and small – have been built and are generating power, in developed countries. The modern wind-mills are much more technically sound than their historical counter-parts, and have benefited from established knowledge of aerodynamic blade design. Such areas of improved engineering knowledge include automatic control of the rotor position to suit changing wind directions, and for adjustment to the blade pitch. Besides, the behaviour of the unit can be controlled and monitored by computers.

With a COP of 83 %, obtained by the application of the developed mathematical model, it could be stated that siting a wind farm in this community is a viable option, and a good alternative to existing Electricity Company. This, if achieved, will, in no small measure, enhance the living conditions of the autochthonous people of this geographical area; which is one of the objectives of the Millennium Development Goals (MDG) of the previous Nigerian government, and the Sustainable Development Goals (SDG) of the present administration (especially goal 7: affordable and clean energy). It is worthy of note that wind energy assessments are location specific and hence are limited in terms of accuracy due to the non-linear variability of wind characteristics in space and time. Using a minimal number of locations and sampling points to average for the whole nation may affect the accuracy and utilization of the results. Other limiting factors are the effects of the mechanical turbulences resulting from varying topography and roughness of an area and also thermal turbulences produced by diurnal cycles. Therefore, for efficient exploration of the wind energy potentials of a country, robust nationwide assessment is required.

5.2 Recommendation

The wind turbine industry is a fast growing one where constant research is needed in order to maximize the efficiency of the contrivance. It is expedient that more energy experts be engaged in wide-spread measurement of wind characteristics in as many locations as possible, since wind speed is location specific. In the light of the above exposé, the following recommendations are relevant:

- Many locations should be studied as wind speed is stochastic in nature. There is need to undertake this kind of assessment in other communities within the South Eastern part of Nigeria, to provide alternative energy when supply from EEDC becomes inadequate.

5.3 Contribution to Knowledge

Every new research tries to fill some gaps which had earlier been delineated or identified as a statement of the problems (or simply as problematic). The main contributions of this work to knowledge can be couched thus:

- This study assessed and posited the high prospects of a functional wind farm/s in Owerre-Ezukala; a border town in Anambra State.

- The measured wind speed is also a source of data for NIMET record data-upgrade and futuristic referencing.

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APPENDIX 1: The Famous Owerre-Ezukala Waterfall

APPENDIX 2: The Owerre-Ezukala Ogba-Ukwu Cave

APPENDIX 3

Table A4.1: Measured Wind Speed Distribution Parameters at 10m

Month	**Ugwu-Osu**	**Okegbe**	**Ogba-Ukwu**	**Average Wind Speed**
January	5.5	5.6	5.4	5.5
February	5.6	5.6	5.5	5.6
March	6.5	6.5	6.4	6.5
April	6.7	6.5	6.5	6.6
May	5.4	6.7	5.3	5.8
June	5.3	5.4	5.3	5.3
July	5.6	5.7	5.5	5.6
August	5.7	5.8	5.5	5.7
September	5.3	5.3	5.2	5.3
October	5.2	5.1	5.0	5.1
November	5.0	4.8	4.8	4.9
December	5.3	5.5	5.4	5.4
Average Speed	**5.6**	**5.6**	**5.5**	**5.6**

APPENDIX 4

Table A4.2: NIMET Record of Wind Speed Data (2016)

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Speed (m/s)	3.3	3.2	3.1	3.3	3.4	3.2	3.3	3.3	3.2	3.0	2.8	3.2

APPENDIX 5

Table A4.3: The Specification of the Turbine

Basic Operating Parameters	**Assumed Value**
Type of Turbine	3 Blade Upwind
Height of Tower, H	10 m
Turbine Blade Type	S809, S814 Aerofoils
Air Density, ρ	1.22 kg/m^3
The Blade Chord Length, c	6.5 m
Radius of the Blade, r	7.5 m
Rated Average Wind Velocity, V_{in}	5.6 m/s
Drive	Active Yaw Driven
Generator	Synchronous Generators
Cut-in Wind Speed	3.5 m/s
Low Speed Shaft (Driver Shaft)	30 rpm
High Speed Shaft (Driven Shaft)	1800 rpm
Betz Constant	0.5926
Cut-out Wind Speed	25 m/s
Wind Passing through the Rotor, V_{out}	3.7 m/s

APPENDIX 6

COMPARISON OF MEASURED WIND SPEED WITH NIMET DATA

Table A4.4: Location 1 (Ugwu-Osu)

	Month	V Measured (m/s)	NIMET Data(m/s)
1	January	5.5	3.3
2	February	5.6	3.2
3	March	6.5	3.1
4	April	6.7	3.3
5	May	5.4	3.4
6	June	5.3	3.2
7	July	5.6	3.3
8	August	5.7	3.3
9	September	5.3	3.2
10	October	5.2	3.0
11	November	5.0	2.8
12	December	5.3	3.2

Table A4.5: Location 2 (Okegbe)

	Month	V Measured (m/s)	NIMET Data(m/s)
1	January	5.6	3.3
2	February	5.6	3.2
3	March	6.5	3.1
4	April	6.5	3.3
5	May	6.7	3.4
6	June	5.4	3.2
7	July	5.7	3.3
8	August	5.8	3.3
9	September	5.3	3.2
10	October	5.1	3.0
11	November	4.8	2.8
12	December	5.5	3.2

Table A4.6: Location 3 (Ogba-Ukwu)

	Month	V Measured (m/s)	NIMET Data(m/s)
1	January	5.4	3.3
2	February	5.5	3.2
3	March	6.4	3.1
4	April	6.5	3.3
5	May	5.3	3.4
6	June	5.3	3.2
7	July	5.5	3.3
8	August	5.5	3.3
9	September	5.2	3.2
10	October	5.0	3.0
11	November	4.8	2.8
12	December	5.4	3.2

COMPARISON OF MEASURED WIND SPEED WITH CALCULATED WIND SPEED

Table A4.7: Location 1 (Ugwu-Osu)

	Month	V Measured (m/s)	V Calculated (m/s)
1	January	5.5	5.49
2	February	5.6	5.6
3	March	6.5	6.49
4	April	6.7	6.7
5	May	5.4	5.39
6	June	5.3	5.29
7	July	5.6	5.6
8	August	5.7	5.69
9	September	5.3	5.29
10	October	5.2	5.19
11	November	5.0	5.0
12	December	5.3	5.29

Table A4.8: Location 2 (Okegbe)

	Month	V Measured (m/s)	V Calculated (m/s)
1	January	5.6	5.69
2	February	5.6	5.6
3	March	6.5	6.49
4	April	6.5	6.49
5	May	6.7	6.7
6	June	5.4	5.39
7	July	5.7	5.69
8	August	5.8	5.79
9	September	5.3	5.29
10	October	5.1	5.09
11	November	4.8	4.79
12	December	5.5	5.49

Table A4.9: Location 3 (Ogba-Ukwu)

	Month	V Measured (m/s)	V Calculated (m/s)
1	January	5.4	5.39
2	February	5.5	5.49
3	March	6.4	6.39
4	April	6.5	6.49
5	May	5.3	5.29
6	June	5.3	5.29
7	July	5.5	5.49
8	August	5.5	5.49
$_1$9	September	5.2	5.19
10	October	5.0	5.0
11	November	4.8	4.79
12	December	5.4	5.39

COMPARISON OF MEASURED WIND SPEED WITH THE CALCULATED WIND POWER

Table A4.10: Location 1 (Ugwu-Osu)

	Month	V Measured (m/s)	P Calculated (w)
1	January	5.5	17936.80
2	February	5.6	18933.07
3	March	6.5	29607.18
4	April	6.7	32425.10
5	May	5.4	16976.11
6	June	5.3	16050.35
7	July	5.6	18933.07
8	August	5.7	19965.56
9	September	5.3	16050.35
10	October	5.2	15158.87
11	November	5.0	13476.18
12	December	5.3	16050.35

Location 2: Okegbe

	Month	V Measured (m/s)	P Calculated (w)
1	January	5.6	18933.07
2	February	5.6	18933.07
3	March	6.5	29607.18
4	April	6.5	29607.18
5	May	6.7	32425.10
6	June	5.4	16976.11
7	July	5.7	19965.56
8	August	5.8	21034.92
9	September	5.3	16050.35
10	October	5.1	14301.03
11	November	4.8	11922.86
12	December	5.5	17936.80

Location 3: Ogba-Ukwu

	Month	V Measured (m/s)	P Calculated (w)
1	January	5.4	16976.11
2	February	5.5	17936.80
3	March	6.4	28261.61
4	April	6.5	29607.18
5	May	5.3	16050.35
6	June	5.3	16050.35
7	July	5.5	17936.80
8	August	5.5	17936.80
9	September	5.2	15158.87
10	October	5.0	13476.18
11	November	4.8	11 922.86
12	December	5.4	16976.11

APPENDIX 7

Average Monthly Temperature and Relative Humidity in Owerre-Ezukala

Table A4.13: Location 1 (Ugwu-Osu)

Month	Wind Speed (m/s)	Wind Power (w)	Max. Temp. (^oC)	Min. Temp. (^oC)	Mean Temp. (^oC)	Rel. Hum. %
Jan.	5.5	17936.80	32	18	25	76
Feb.	5.6	18933.07	33	22	27.5	80
March	6.5	29607.18	35	25	30	76
April	6.7	32425.10	34	24	29	81
May	5.4	16976.11	32	23	27.5	81
June	5.3	16050.35	30	22	26	85
July	5.6	18933.07	28	21	24.5	89
Aug.	5.7	19965.56	29	22	25.5	87
Sept.	5.3	16050.35	28	23	25.5	86
Oct.	5.2	15158.87	28	23	25.5	85
Nov.	5.0	13476.18	33	23	28	73
Dec.	5.3	16050.35	34	19	26.5	76

Table A4.14: Location 2 (Okegbe)

Month	Wind Speed (m/s)	Wind Power (w)	Max. Temp. (°C)	Min. Temp. (°C)	Mean Temp. (°C)	Rel. Hum. %
Jan.	5.6	18933.07	32	18	25	76
Feb.	5.6	18933.07	33	22	27.5	80
March	6.5	29607.18	35	25	30	76
April	6.5	29607.18	34	24	29	81
May	6.7	32425.10	32	23	27.5	81
June	5.4	16976.11	30	22	26	85
July	5.7	19965.56	28	21	24.5	89
Aug.	5.8	21034.92	29	22	25.5	87
Sept.	5.3	16050.35	28	23	25.5	86
Oct.	5.1	14301.03	28	23	25.5	85
Nov.	4.8	11922.86	33	23	28	73
Dec.	5.5	17936.80	34	19	26.5	76

Table A4.15: Location 3 (Ogba-Ukwu)

Month	Wind Speed (m/s)	Wind Power (w)	Max. Temp. (^oC)	Min. Temp. (^oC)	Mean Temp. (^oC)	Rel. Hum. (%)
Jan.	5.4	16976.11	32	18	25	76
Feb.	5.5	17936.80	33	22	27.5	80
March	6.4	28261.61	35	25	30	76
April	6.5	29607.18	34	24	29	81
May	5.3	16050.35	32	23	27.5	81
June	5.3	16050.35	30	22	26	85
July	5.5	17936.80	28	21	24.5	89
Aug.	5.5	17936.80	29	22	25.5	87
Sept.	5.2	15158.87	28	23	25.5	86
Oct.	5.0	13476.18	28	23	25.5	85
Nov.	4.8	11 922.86	33	23	28	73
Dec.	5.4	16976.11	34	19	26.5	76

Table A4.16: Average Wind Speed Data of the three Locations

Month	Av.Wind Speed (m/s)	Max. Temp. (°C)	Min. Temp. (°C)	Mean Temp. (°C)	Rel. Hum. (%)
Jan.	5.5	32	18	25	76
Feb.	5.6	33	22	27.5	80
March	6.5	35	25	30	76
April	6.6	34	24	29	81
May	5.8	32	23	27.5	81
June	5.3	30	22	26	85
July	5.6	28	21	24.5	89
Aug.	5.7	29	22	25.5	87
Sept.	5.3	28	23	25.5	86
Oct.	5.1	28	23	25.5	85
Nov.	4.9	33	23	28	73
Dec.	5.4	34	19	26.5	76

APPENDIX 8

Definition of variables in R-console 3.32 version window

Weibull and Cauchy Distribution Analysis on the (Variables)

R> X1= "Av_Wind_Speed

R> X2= "Max_Temp"

R>X3= "Min_Temp"

R>X4= "Mean_Temp"

R>X5="Rel_Hum"

R>X1= c(5.5, 5.6, 6.5, 6.6, 5.8, 5.3, 5.6, 5.7, 5.3, 5.1, 4.9, 5.4)

R>X2=c(32, 33, 35, 34, 32, 30, 28, 29, 28, 28, 33, 34)

R>X3=c(18, 22, 25, 24, 23, 22, 21, 22, 23, 23, 23, 19)

R>X4=c(25, 27.5, 30, 29, 27.5, 26, 24.5, 25.5, 25.5, 25.5, 28, 26.5)

R>X5=c(76, 80, 76, 81, 81, 85, 89, 87, 86, 85, 73, 76)

Result of Weibull Distribution Analysis

Weibull Distribution Analysis for X1= Av. Wind Speed

The following R code were used to obtain the estimated parameter for Weibull distribution for X1

R> est.par <- eWeibull(X=X1, method="numerical.MLE"); est.par

R> dX1=dWeibull(x=X1, shape = 138.78975, scale = 24.74705, params = list(shape = 138.78975, scale = 24.74705))

R> dX1

[1] 0.8319031 0.8386357 0.1476739 0.1019011 0.7481403 0.7128125 0.8386357 0.8090751 0.7128125 0.5018841 0.2858463 0.7884727

Weibull Distribution Analysis for X2= Max Temp

The following R code were used to obtain the estimated parameter for Weibull distribution for X2

R> est.par <- eWeibull(X=X2, method="numerical.MLE"); est.par

R> dX2=dWeibull(x=X2, shape = 155.8769, scale = 4.974793, params = list(shape = 155.8769, scale = 4.974793))

R> dX2

[1] 0.15024857 0.12191415 0.05281342 0.08580339 0.15024857 0.14350228 0.06875400 0.10891597 0.06875400 0.06875400 0.12191415 0.08580339

Weibull Distribution Analysis for X3= Min Temp

The following R code were used to obtain the estimated parameter for Weibull distribution for X3

R> est.par <- eWeibull(X=X3, method="numerical.MLE"); est.par

R> dX3=dWeibull(x=X3, shape = 129.1527, scale = 5.848425, params = list(shape = 129.1527, scale = 5.848425))

R> dX3

[1] 0.02016430 0.20575887 0.06430399 0.11917558 0.17677776 0.20575887 0.18372946 0.20575887 0.17677776 0.17677776 0.17677776 0.05940325

Weibull Distribution Analysis for X4= Mean Temp

The following R code were used to obtain the estimated parameter for Weibull distribution for X4

R> est.par <- eWeibull(X=X4, method="numerical.MLE"); est.par

R> dX4=dWeibull(x=X4, shape = 275.1669, scale = 10.30265, params = list(shape = 275.1669, scale = 10.30265))

R> dX4

[1] 0.14696727 0.21368039 0.03192840 0.08748458 0.21368039 0.23057616 0.09974543 0.19404883 0.19404883 0.19404883 0.17299007 0.24755698

Weibull Distribution Analysis for X5 = Rel. Hum

The following R code were used to obtain the estimated parameter for Weibull distribution for X5

R> est.par <- eWeibull(X=X5, method="numerical.MLE"); est.par

R> dX5=dWeibull(x=X5, shape = 265.6526, scale = 3.269549, params = list(shape = 265.6526, scale = 3.269549))

R> dX5

1] 0.04789793 0.07871076 0.04789793 0.08014866 0.08014866 0.05811935 0.02343856 0.03958260 0.04882962 0.05811935 0.02047341 0.04789793

Result of Cauchy Distribution Analysis

Cauchy Distribution Analysis for X1(Av. Wind Speed)

The following R code were used to obtain the estimated parameter for Cauchy distribution for X1

R>cdata <- transform(X1, loc = exp(1 + 0.5 * X1), scale = exp(1))
R>cdata <- transform(cdata, y = rcauchy(12, loc, scale))
R>fit2 <- vglm(y ~ X1, cauchy(lloc = "loge"), data = cdata, trace = TRUE)
R>summary(fit2)

R>dY1=dcauchy(x=X1, location = 0.96306, scale = 0.62383, log = FALSE)
R> dY1

[1] 0.009467952 0.009071167 0.006395855 0.006173662 0.008348538 0.010343216 0.009071167 0.008698673 0.010343216 0.011344701 0.012497671 0.009891174

Cauchy Distribution Analysis for X2(Max Temp)

The following R code were used to obtain the estimated parameter for Cauchy distribution for X2

R>cdata <- transform(X2, loc = exp(1 + 0.5 * X2), scale = exp(1))
R>cdata <- transform(cdata, y = rcauchy(12, loc, scale))
R>fit2 <- vglm(y ~ X2, cauchy(lloc = "loge"), data = cdata, trace = TRUE)
R>summary(fit2)

R>dY2=dcauchy(x=X2, location = -13.5034, scale = 15.53909, log = FALSE)
R>dY2

[1] 0.002139359 0.002057481 0.001906771 0.001980054 0.002139359 0.002317819 0.002518461 0.002415156 0.002518461 0.002518461 0.002057481 0.001980054

Cauchy Distribution Analysis for X3(Min Temp)

The following R code were used to obtain the estimated parameter for Cauchy distribution for X3

R>cdata <- transform(X3, loc = exp(1 + 0.5 * X3), scale = exp(1))
R>cdata <- transform(cdata, y = rcauchy(12, loc, scale))
R>fit2 <- vglm(y ~ X3, cauchy(lloc = "loge"), data = cdata, trace = TRUE)
R>summary(fit2)

R>dY3=dcauchy(x=X3, location = 0.9999, scale = 0.6659, log = FALSE)
R>dY3

[1] 0.0007323022 0.0004801533 0.0003677044 0.0004003463 0.0004375343 0.0004801533 0.0005293143 0.0004801533 0.0004375343 0.0004375343 0.0004375343 0.0006533040

Cauchy Distribution Analysis for X4(Mean Temp)

The following R code were used to obtain the estimated parameter for Cauchy distribution for X4

R>cdata <- transform(X4, loc = exp(1 + 0.5 * X4), scale = exp(1))
R>cdata <- transform(cdata, y = rcauchy(12, loc, scale))
R>fit2 <- vglm(y ~ X4, cauchy(lloc = "loge"), data = cdata, trace = TRUE)

R>summary(fit2)
R>dY4=dcauchy(x=X4, location = 1.72065, scale = 10.46801, log = FALSE)
R>dY4

[1] 0.005114403 0.004304144 0.003664432 0.003902901 0.004304144 0.004766461 0.005301810 0.004936133 0.004936133 0.004936133 0.004164134 0.004604881

Cauchy Distribution Analysis for X5(Rel. Hum)

The following R code were used to obtain the estimated parameter for Cauchy distribution for X5

R>cdata <- transform(X5, loc = exp(1 + 0.5 * X5), scale = exp(1))
R>cdata <- transform(cdata, y = rcauchy(12, loc, scale))
R>fit2 <- vglm(y ~ X5, cauchy(lloc = "loge"), data = cdata, trace = TRUE)
R>summary(fit2)

R> dY5=dcauchy(x=X5, location = -14.9554, scale = 40.63299, log = FALSE)
R> dY5

[1] 0.001303303 0.001212449 0.001303303 0.001191132 0.001191132 0.001110956 0.001038219 0.001073713 0.001092109 0.001110956 0.001377822 0.001303303

APPENDIX 9: DETERMINATION OF F-RATIO USING ANOVA

$\Sigma x = x_{1} + x_{2} + x_{3}$= 320.5 + 320.5 +320.5 = 961.5

$\Sigma x^2 = x_1^2 + x_2^2 + x_3^2$ = 8591.75 + 8591.75 +8591.75 = 25775.25

N = $n_1 + n_2 + n_3$= 12 +12 +12 = 36

Computation of SS total

$$SS\ total = \ \Sigma X^2 - \frac{(\Sigma x)^2}{N} = 25775.25 - \frac{(924482.25)^2}{36}$$

= 25775.25 – 25680.06 = 95.19

Computation of SS between

$$SS\ between = \frac{(\Sigma x_1)^2}{n_1} + \frac{(\Sigma x_2)^2}{n_2} + \frac{(\Sigma x_3)^2}{n_3} + \frac{(\Sigma x_4)^2}{n_4} - \frac{(\Sigma x)^2}{n}$$

$$= \frac{(320.5)^2}{12} + \frac{(320.5)^2}{12} + \frac{(320.5)^2}{12} - \frac{(961.5)^2}{36}$$

= 8560.02 +8560.02 + 8560.02– 25680.05

= 25680.06 – 25680.05

= 0.1

Computation of SS within

SS within = SS total – SS between

= 95.19 – 0.1= 95.09

Calculation of degree of freedom

Df between = k – 1

K = number of times

∴Df between = 3 – 1 = 2

Df within = N – k

where N = total number of times at three different locations

k = number of locations

∴Df within = 36 – 3 = 33

Df total = N – 1

where N = total number of times at three different locations

= 36 – 1 = 35

Determination of mean square

$$Mean\ square = \frac{sum\ of degrees\ of\ k}{degrees\ of\ freedom}$$

$$MS = \frac{SS}{Df}$$

$$MS\ between = \frac{SS\ between}{Df\ between} = \frac{0.1}{2} = 0.05$$

$$MS\ within = \frac{SS\ within}{Df\ within} = \frac{95.09}{33} = 2.88$$

$$MS\ between = \frac{SS\ total}{Df\ total} = \frac{95.19}{35} = 2.72$$

Calculation of F- ratio

$$F = \frac{MSbetween}{MSbetween} = \frac{0.05}{2.88} = 0.017$$

APPENDIX 10: S809 AEROFOIL PROGRAMME

1.000000	0.000000	0
0.996203	0.000487	0
0.985190	0.002373	0
0.967844	0.005960	0
0.945073	0.011024	0
0.917488	0.017033	0
0.885293	0.023458	0
0.848455	0.030280	0
0.807470	0.037766	0
0.763042	0.045974	0
0.715952	0.054872	0
0.667064	0.064353	0
0.617331	0.074214	0
0.567830	0.084095	0
0.519832	0.093268	0
0.474243	0.099392	0
0.428461	0.101760	0
0.382612	0.101840	0
0.337260	0.100070	0
0.292970	0.096703	0
0.250247	0.091908	0
0.209576	0.085851	0
0.171409	0.078687	0
0.136174	0.070580	0
0.104263	0.061697	0

0.076035	0.052224	0
0.051823	0.042352	0
0.031910	0.032299	0
0.016590	0.022290	0
0.006026	0.012615	0
0.000658	0.003723	0
0.000204	0.001942	0
0.000000	-0.000020	0
0.000213	-0.001794	0
0.001045	-0.003477	0
0.001208	-0.003724	0
0.002398	-0.005266	0
0.009313	-0.011499	0
0.023230	-0.020399	0
0.042320	-0.030269	0
0.065877	-0.040821	0
0.093426	-0.051923	0
0.124111	-0.063082	0
0.157653	-0.073730	0
0.193738	-0.083567	0
0.231914	-0.092442	0
0.271438	-0.099905	0
0.311968	-0.105281	0
0.353370	-0.108181	0
0.395329	-0.108011	0
0.438273	-0.104552	0
0.481920	-0.097347	0

0.527928	-0.086571	0
0.576211	-0.073979	0
0.626092	-0.060644	0
0.676744	-0.047441	0
0.727211	-0.035100	0
0.776432	-0.024204	0
0.823285	-0.015163	0
0.866630	-0.008204	0
0.905365	-0.003363	0
0.938474	-0.000487	0
0.965086	0.000743	0
0.984478	0.000775	0
0.996141	0.000290	0
1.000000	0.000000	0

The above is the S809 aerofoil programme, used in solid work for the design of the blade shape. S809 is for the root of the aerofoil.

APPENDIX 11: S814 AEROFOIL PROGRAMME

1.000000	0.000000	0
0.996277	0.001079	0
0.985681	0.004644	0
0.969429	0.010691	0
0.948574	0.018525	0
0.923625	0.027157	0
0.894505	0.035738	0
0.860850	0.044178	0
0.823023	0.052748	0
0.781586	0.061424	0
0.737130	0.070108	0
0.690273	0.078659	0
0.641651	0.086901	0
0.591910	0.094633	0
0.541692	0.101631	0
0.491625	0.107648	0
0.442317	0.112418	0
0.394345	0.115645	0
0.348257	0.116962	0
0.304384	0.115627	0
0.261983	0.111612	0
0.221337	0.105629	0
0.182903	0.097997	0
0.147112	0.088966	0
0.114367	0.078763	0
0.085039	0.067619	0

0.059481	0.055766	0
0.038007	0.043458	0
0.020952	0.030954	0
0.008577	0.018556	0
0.001431	0.006672	0
0.001119	0.005797	0
0.000338	0.002959	0
0.000002	0.000223	0
0.000245	-0.002549	0
0.000678	-0.004584	0
0.000925	-0.005491	0
0.006381	-0.017430	0
0.016792	-0.031576	0
0.031367	-0.046492	0
0.049641	-0.061655	0
0.071240	-0.076713	0
0.095610	-0.091093	0
0.122438	-0.104309	0
0.151203	-0.115726	0
0.181669	-0.124578	0
0.213672	-0.130235	0
0.247139	-0.131310	0
0.283942	-0.127757	0
0.323782	-0.120293	0
0.367326	-0.109093	0
0.414593	-0.095249	0
0.465255	-0.079660	0

0.518814	-0.063236	0
0.574574	-0.046894	0
0.631638	-0.031520	0
0.688908	-0.017904	0
0.745125	-0.006688	0
0.798908	0.001698	0
0.848830	0.007070	0
0.893492	0.009517	0
0.931609	0.009395	0
0.962086	0.007279	0
0.983819	0.003889	0
0.996132	0.001014	0
1.000000	0.000000	0

The above is the S814 aerofoil programme, used in solid work for the design of the blade shape. S814 is for the tip of the aerofoil

APPENDIX 12: COST ESTIMATION TEMPLATE FOR OUR DESIGN

The price for electricity depends on four major things: location, tariff class, tariff rate, the quantity of consumed energy (in kWh). The tariff class and rate for Enugu Electricity Distribution Company as it applies to the location of interest, are:

Maximum Tariff = #45.24

Minimum Tariff/kWh = #0.248

Power Factor of the System = $\frac{Active\ \ Power}{Apparent\ \ Power} = \frac{645.43795}{710} = 0.9$

Load Factor = 0.4

Unit Consumed/year = (Max. Demand) x (L.F.) x (Hours in a year)

Max. Demand in kVA = $\frac{\text{Max .Demand}}{\text{Power Factor}} \approx 789$

Therefore, Annual Bill = Max. Demand Charges + Energy Charges