EXPERIMENTAL STUDY OF VARIABLE FREQUENCY INDUCTION GENERATOR FOR SMALL SCALE WIND POWER DEVELOPMENT AT KUMBOTSO VILLAGE, KANO.

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA

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Declaration

I declare that the work in this thesis entitled **Experimental Study of Variable frequency Induction Generator for Small scale Wind Power Development at Kumbotso Village, Kano** was carried out by me in the Department of Electrical and Computer Engineering. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this project thesis was previously presented for another degree or diploma at this or any other Institution.

Olayinka Eric Olumoko _____ _____

Signature Date

Certification

This project thesis entitled **EXPERIMENTAL STUDY OF VARIABLE FREQUENCY INDUCTION GENERATOR FOR SMALL SCALE WIND POWER DEVELOPMENT AT KUMBOTSO VILLAGE, KANO** by Olayinka Eric OLUMOKO meets the regulations governing the award of the degree of Master of Science (MSc) of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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Dedication

This thesis is dedicated to the glory of Almighty God

and my Children; Emmanuela, Daniel and Joan.

Acknowledgement

My unprecedented, heartfelt and profound gratitude goes unto God for his unfailing providence, protection, guidance and faithfulness unto me throughout the duration of my study at Ahmadu Bello University (A.B.U Zaria).

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Table of Contents

Contents **Page**

Title Page

Declaration i

Certification ii

Dedication iii

Acknowledgement.....iv

Table of Content.....v-vii

List of Figures .....viii-x

List of Tables.....xi

List of Appendix xii

Definition of Terms.....xiii

Abstract

Chapter One

1.0 Introduction.....2

1.1 Background.....2

1.2 Motivation.....4

1.3 Statement of Problem.....5

1.4 Aim……...5

1.5 Objectives…….5

1.6 Methodology.....6

Chapter Two

2.0 Literature Review and Theoretical Background.....7

2.1 Literature Review.....7

2.2 Introduction to Theoretical Background……13

2.3 Wind Speed as Means of Power Generation.....14

2.3.1 Power Extracted from the Wind.....16

2.3.2 Rotor Swept Area.....18

2.3.3 Rayleigh Parameters of the Wind Speed.....19

2.4 Introduction to Induction Machine.....20

2.4.1 Principle of Operation of Induction Machine.....21

2.4.2 Induction Motor and Generator.....22

2.4.3 Induction Motor Operation.....23

2.4.4 Stand –alone Induction Generator Operation.....25

2.4.5 The Concept of Rotor Slip.....26

2.5 Background on Conversion from Induction Motor to Induction Generator.....27

2.5.1 Self-Excitation Capacitance.....28

2.5.2 Selection of an Induction Motor used as a Generator.....29

2.6 Power Conversion: Wind Speed, V_m and the Induction Generator.....33

Chapter Three

3.0 Collection and Analysis of Wind Speed Data of Kumbotso Village…….36

3.1 Wind Velocity Frequency Distribution of Kano.....36

3.2 Design Parameters for Vertical Axis Wind Turbine.....50

Chapter Four

4.0 Conversion of Induction Motor to Generator……52

4.1 Conversion Parameters of the Induction Motor Used……52

4.2 Determination of Parameter of the Capacitors Used…….53

4.3 Laboratory Experiment and Measurements……...54

4.4 Test Circuit…….54

Chapter Five

5.0 Results and Discussion.....57

5.1 Result.....57

5.2 Variable-Speed Control using Power Electronics.....64

Chapter Six

6.0 Recommendations and Conclusion.....68

6.1 Remarks.....68

6.2 Conclusion.....68

Reference.....71

Appendix 78

List of Figures

Figure	Title	Page
Figure 2.1:	Rotor efficiency versus Vo/V ratio.	18
Figure 2.2:	Torque versus Speed Characteristic of the Induction Machine in three operating modes.	25
Figure 2.3:	Self-excited induction generator with external capacitor	28
Figure 2.4:	Hysteresis Loop	29
Figure 2.5:	The hysteresis curves of two different materials	32
Figure 2.6:	Rotor efficiency versus tip speed ratio for rotors with different numbers of blades.	35
Figure 3.1:	Daily average Wind Speed for January.	41
Figure 3.2:	Daily average Wind Speed for April.	41
Figure 3.3:	Daily average Wind Speed for July.	42
Figure 3.4:	Daily average Wind Speed for October.	42
Figure 3.5:	Annual daily average Wind Speed	43
Figure 3.6:	Raleigh Distribution of average Wind Speed for January.	43
Figure 3.7:	Raleigh Distribution of average Wind Speed for February	44
Figure 3.8:	Raleigh Distribution of average Wind Speed for March	44
Figure 3.9:	Raleigh Distribution of average Wind Speed for April	45

Figure 3.10: Raleigh Distribution of average Wind Speed for May 45

Figure 3.11: Raleigh Distribution of average Wind Speed for June 46

Figure 3.12: Raleigh Distribution of average Wind Speed for July 46

Figure 3.13: Raleigh Distribution of average Wind Speed for August. 47

Figure 3.14: Raleigh Distribution of average Wind Speed for September 47

Figure 3.15: Raleigh Distribution of average Wind Speed for October 48

Figure 3.16: Raleigh Distribution of average Wind Speed for November 48

Figure 3.16: Raleigh Distribution of average Wind Speed for December. 49

Figure 3.17: Raleigh Distribution of Annual average Wind Speed. 49

Figure 4.1: Block Diagram of Experimental Setup to determine single phase Voltages as the Speed varies. 54

Figure 4.2: Test Circuit Type I (Delta Connection) 54

Figure 4.3: Test Circuit Type II (Star Connection) 55

Figure 4.4: Test Circuit Type III (Parallel Connection) 55

Figure 4.5: Experiment set up 56

Figure 4.6: Experiment set up 56

Figure 5.1: The Speed (rpm) versus the Stator Output Voltage of the Generator for 16µF (Delta type of circuit connection) 59

Figure 5.2: The Speed (rpm) versus the Stator Output Voltage of the Generator for 24µF (Delta type of circuit connection) 59

Figure 5.3: The Speed (rpm) versus the Stator Output Voltage of the Generator for 35µF (Delta type of circuit connection) 60

Figure 5.4: The Speed (rpm) versus the Stator Output Voltage of the Generator for 50µF (Delta type of circuit connection) 60

Figure 5.5: The Speed (rpm) versus the Stator Output Voltage of the Generator for 35µF (Star type of circuit connection) 61

Figure 5.6: The Speed (rpm) versus the Stator Output Voltage of the Generator for 50µF (Star type of circuit connection) 61

Figure 5.7: The Speed (rpm) versus the Stator Output Voltage of the Generator for 35µF (Parallel type of circuit connection) 62

Figure 5.8: The Speed (rpm) versus the Stator Output Voltage of the Generator for 50µF (Parallel type of circuit connection) 62

Figure 5.9: The Speed (450-950rpm) versus the Stator Output Voltage of the Generator for 50µF. (Delta type of circuit connection) 63

Figure 5.10: Block Diagram of variable Speed and constant Voltage Output 64

Figure 5.11: Three-phase full bridge AC to DC silicon-controlled rectifier circuit. 65

Figure 5.12: DC to three-phase AC inverter circuit 66

List of Tables

Table **Title** **Page**

Table 3.1 Averaged Hourly Wind Speed for the Month of Jan- Dec. at 50m above the Surface of the Earth for Indicated GMT Times (m/s) Estimated from N.A.S.A. Data. 38

Table 3.2: Minimum and Maximum Difference from Monthly Average in Percentage (%) and their corresponding Value in Metre per Second (m/s) 39

Table 3.3: Normalized Wind Speed Data for Hourly Periods of each Month Extracted from N.A.S.A Data 40

Table 3.4: Monthly Averaged Wind Speed at 50m above the surface of the Earth (m/s) 40

Table 5.1: Voltages (volt) obtained from circuit connection type I (Delta) 57

Table 5.2: Voltages (volt) obtained from circuit connection type II (Star) 57

Table 5.3: Voltages (volt) obtained from circuit connection type III (Parallel) 58

Table 5.4: The Speed (rpm) and the Stator Output Voltage (volts) with 50μF capacitor connected 58

List of Appendices

Appendix	Page
The Wind velocity data as recorded by National Aeronautic and Space Administration (NASA) USA surface Meteorology and Solar Energy at 50m height.	74

Definition of Symbols

f : Frequency

C_p: Coefficient of performance or Rotor Efficiency

ρ : Air Density

m : Mass

A : Area Swept by the Rotor Blade

N: Rotor Speed (rpm)

DC: Direct Current

AC: Alternating Current

K: Proportionality Constant

T : Torque

I : Current

V: Voltage

Q: Reactive Power

C : Capacitor

X_C: Capacitive Reactance

e : Electromagnetic Induction

v : Velocity of Air

: Tip- speed Ratio

Abstract

This study investigated the wind energy potential for wind turbine development in Kumbotso village in Kano State, (Latitude 11.88^0 and Longitude 8.5^0).Ten (10) years average wind velocity data as recorded by National Aeronautic and Space Administration (NASA) USA, surface Meteorology and Solar Energy at 50m height and five (5) years average wind velocity data from Nigeria Meteorological Institute, Aminu Kano International Airport (NIMET) at 10m height were collected. The NASA hourly wind velocity data was preferred and used because it gives a thorough description of the energy extracted from the wind compared to the wind velocity values provided by NIMET that are spanned over large intervals of speed. The NASA hourly wind velocity was subjected to two parameters Rayleigh function analysis to predict the wind energy output of the wind power system in the area with a view to convert a squirrel cage induction motor to a generator for wind turbine for domestic application in the village. The monthly mean wind speed observed is between 3.07 m/s – 4.74 m/s having the highest monthly mean wind speed in the month of March and April and yearly average wind speed of 4.0 m/s. The conversion design was carried out and a minimum value of 14µF capacitor was calculated for the reactive power for an old 800W, 940rpm three-phase induction generator and three different types of capacitor arrangement/connection (Delta, Star and Parallel) were considered to achieve maximum power output. A voltage range of 150 Volts to 306 Volts were achieved with the capacitor values of 16µF, 24µF, 35µF and 50µF for the three types of circuit connection at the speed of 956, 706, 512 and 500 rpm. The power output from each arrangement/connection was compared and was observed that the Delta connection/arrangement gave a better voltage output.

CHAPTER ONE

INTRODUCTION

1.1 Research Background

Energy is a powerful and essential tool for the techno-industrial and socio-economic development for any country. Good standard of living in industrialized countries and improved living conditions in developing countries therefore requires that energy consumption pattern be thoroughly studied and understood. Bulk of means of energy generation are fossil-based whose reserves are fast being depleted and environmentally non-friendly; thus forcing modern research attention to be focused on different sources of renewable (alternative) energy such as wind, solar, hydro (large and small) and biomass. Energy from renewable sources have been gaining prominence in developed countries over years with increasing efficiency of renewable energy technologies and the associated decreasing costs.

The main advantages of renewable power generation are the usage of an infinitely available primary source (such as wind, sunlight or biomass) and the less severe environmental consequences. On the other hand, the main advantages of conventional thermal, nuclear and hydro power generation are the low price of the generated electricity and the controllability and the flexibility of their output. Many governments tend to value the advantages of renewable power generation more than those of conventional power generations (Danish Wind Industry, 1997).

Today, most electrical energy is generated by burning huge fossil fuels and special weather conditions such as acid rain and snow, climate change, urban smog, regional haze, several tornados, etc., have happened around the whole world. The installation of a number of wind turbine generators could effectively reduce environmental pollution, fossil fuel consumption

and the costs of overall electricity generation. Although wind is only an intermittent source of energy, it represents a reliable energy resource from a long-term energy policy viewpoint. Among various renewable energy resources, wind power energy is one of the most popular and promising energy resources in the world today. At a typical wind farm, the available electricity generated by a wind power generation system depends on mean wind speed (MWS), standard deviation of wind predict and the location of installation (Akpinar *et al.*, 2004).

Presently in Nigeria, the Government is committed to the task of finding a long-term solution to the energy crisis through the adoption of the Renewable Energy Master Plan (REMP) with a target of increasing the 5,000MW generation capacity to 16,000MW by the year 2015 through the exploration of renewable energy resources (Iloje and Ewah, 2002). In order to realize this goal, the exploration of wind energy resources is one of the key elements of this master plan. Wind energy is among the potential alternatives as renewable clean energy. At present the share of wind energy in the national energy consumption has remained on the lower end with no commercial wind power plants connected to the national grid, while natural gas, hydroelectricity, fuelwood, and petroleum products constitute 5.22%, 3.05%, 50.45% and 41.28% share, respectively (Akinbami , 2001). Only a few number of stand-alone wind power plants have been installed in the early 1960s in some northern states mainly to power water pumps such as at in Kedada in Bauchi state, Gidan-Gada village and Goronyo in Sokoto state (Energy Commission of Nigeria, 1997).

Nearly all wind turbines installed at present use one of the following systems:

(a) Permanent magnet alternators

(b) Squirrel cage induction generator.

(c) Doubly fed (wound rotor) induction generator.

(d) Direct drive synchronous generator.

A fixed-speed wind turbine with a squirrel cage induction generator is the simplest type of wind turbine technology. The rotational speed of the generator, depending on the number of poles, is relatively high (in the other of 1000-1500rpm for a 50Hz system frequency). Such a rotational speed is too high for the turbine speed in respect to the turbine efficiency and mechanical stress. For this reason, the generator speed must be stepped down using a gearbox with an appropriate gear ratio.

An induction generator consumes a significant amount of reactive power (even during zero power production), which increases along with the active power output. Accordingly, a capacitor bank must be provided in the generator terminal.

Because the mechanical power is converted directly to a three-phase electrical system by means of an induction generator, no complex controller is involved in the electrical part of a fixed-speed wind turbine as required in doubly fed (wound rotor) induction generator and direct drive synchronous generator (Abram, 2006.)

1.2 Motivation

Considering the high cost involved in transmitting electric power from the National grid with about 40-45% losses, rural communities all over the country can benefit from alternative energy source in view of the relative high cost of electric power supply from the grid to such locations (Energy Commission of Nigeria, 1997). The needs of these communities are basic, including lighting, water pumping and powering of basic medical facilities requiring few kVA power source.

To increase the power supply to the industries or commercial consumers the residential consumers can be supplied through a renewable energy source. The challenge can be

overcome either by wind or solar energy. This study has taken a deeper and closer look at how the need can be achieved by wind technology for areas where there is sufficient wind energy. Also there is need to recycle old induction motors as generators for WECS rather than having them as junks.

1.3 Statement of Problem

Due to insufficient electricity supply from the PHCN, there is large load shedding in Kumbotso village in Kano State. Therefore, there is need to find another means of generating electricity to supplement what is obtained from PHCN and since there is probability of wind energy in this region there is need to recycle an old induction motor as induction generator due to their high magnetic properties for wind energy conversion system (WECS).

1.4 Aim

The aim is to carryout conversion design of an induction motor for use as wind turbine generator in Kumbotso village.

1.5 Objectives

The objectives of this research are to:

1. collect and analyze wind speed data for wind energy conversion system in Kumbotso.
2. convert 800W induction motor to a generator that will be able to supply the local consumers.
3. carry out laboratory experiment to determine the capacitor ratings and diagram of the electrical connection of those capacitors with the induction motor that will aid a better output condition and match the wind data analysis with that of the input of the new generator to see how the output can be conditioned through power electronics to meet the basic power supply qualities.

1.6 Methodology

This can be divided into the following sections:

(a).The daily wind speed data for this study were collected from Nigeria Meteorological Institute, Aminu Kano International Airport Kano (NIMET) and from National Aeronautic and Space Administration (NASA) surface Meteorology and Solar Energy.

(b) The collected wind speed data was analyzed using the Probability distribution function techniques.

(c) An old three phase, low-speed induction motor of 940 rpm and 800W was selected and converted to a generator using capacitors value of 16µF, 24µF, 35µF and 50µF.

(d) An experiment (Laboratory) was carried out to determine some important Induction motor parameters such as; the required capacitor value to be used to aid maximum output power and the speed (rpm). This is needed to match the expected mean wind speed with the speed of the motor during the design of the wind turbine.

Furthermore, the capacitors were connected in Delta, Star and Parallel ways and the various output voltages of the generator were compared to know the best capacitor connection.

CHAPTER TWO

LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 Literature Review

The characteristics and pattern of wind speed across Nigeria have been investigated by researchers in the past. Due to accessibility to wind speed data information, some researchers reported wind speed data in one or two locations **(Fagbenle *et al.*, 2011)** while others reported wind speed data across the country **(Adekoya *et al.*, 1992). Ojosu *et al.* (1990)** reported wind speed data from 1951–1975 from 22 stations across the country and concluded that Sokoto area (in northern part) have highest wind speed of about 5.12 m/s in the month of June with annual mean of 3.92 m/s. **Adekoya and Adewale (1992)** based on wind data from 30 stations reported that the mean wind speed in Nigeria is in the range of 1.5–4.1 m/s. In addition, noted that the annual mean wind speed is equal to or greater than 2.5 m/s in the northern parts of the country while the mean wind of less than 2.5 m/s was observed in the southern locations. Similarly, based on wind data from 1979–1988 for 18 stations, **Fagbenle and Karayiannis (1994)** reported that mean wind speeds in Nigeria ranged from about 2 m/s to about 4 m/s with highest mean speeds of about 3.5 m/s and 7.5 m/s in the southern and northern areas, respectively. Furthermore, **Chineke (2009)** reported the monthly mean wind speed measured at 10 m height from 1961 to 1990 in the 36 states capitals of Nigeria. Similar to previous studies, reported that the monthly mean wind speed range from 1.3 m/s in Oshogbo in the south west to about 3.9 m/s in Jos (north central) and Katsina (north west) areas. However, while the above cited studies reported that the wind speed in Nigeria varied from 2 m/s to 4 m/s. Recent measured wind data presented by **Fadare (2010)** shows that the annual wind speeds range from about 2 m/s to 9.5 m/s. The different in the range of wind speeds reported by these authors may be related to the period in which the wind data were

recorded. While Adekoya and Adewale and other researchers used wind speed data that ranged from 1951–1992 for their analysis, Fadare on the other hand used recent data from 1983–2003 for his analysis. Furthermore, the higher measured wind data reported by Fadare may be due to increment in wind speed as a result of deforestation activities across the country. Also, most recent wind data (1987–2007) reported by Fagbenle *et al.*, for two locations (Maiduguri and Potiskum) in the north-east part of the country is in agreement with Fadare findings. For instance, while Ojosu and Salawu reported that the monthly mean wind speed for Maiduguri and Potiskum varied from 2.22 m/s to 3.52 m/s and 2.16 m/s to 4.84 m/s respectively, **Fagbenle *et al*. (2011)** reported that the monthly mean wind speed for these two locations respectively varied from 3.90 m/s to 5.85 m/s and from 4.35 m/s to 6.33 m/s. The observed difference is in agreement with finding of **Fagbenle and Karayiannis (1994).** These authors reported that the Weibull function scale parameter and shape parameter and hence, wind speed, depends on the period and duration when the wind data were collected.

Aidan and Ododo (2010) in their work titled "Wind Speed Distribution and Power Densities of some cities in Northern Nigeria", the Wind Speed data of eight cities in Northern Nigeria (Bida, Mnna, Yelwa, Yola, Gusau, Kaduna, Maiduguri and Zaria) have been fitted to four distribution functions (Normal, Weibull, Rayleigh and Gamma). Considering the predicted wind speed variation at various heights above the ground, it is seen that the potential for utility-scale wind power generation at a height of about 80m is very satisfactory especially for Gusau, Kaduna, Maiduguri and Zaria but implies too high a height compare with 10m or 50m height. It is also observed that in the research work, the wind speed distribution and power densities of Kano State is not considered.

Bhattacharya and Bhattacharjee (2010) present some methods for estimating Weibull parameters, namely, shape (k) and scale parameter (c). The Weibull distribution is an important distribution especially for reliability and maintainability analysis. The suitable

values for both shape parameter and scale parameters of Weibull distribution are important for selecting locations of installing wind turbine generators. The scale parameter of Weibull distribution is also important to determine whether a wind farm is good or not**. Fadere (2010)** shows that even though ANN (artificial neural net work) technique is proved to be efficient and accurate when compared with other statistical techniques used in wind data modeling, the two-parameter Weibull probability distribution function is the commonly most appropriate. Therefore, the two-parameter Weibull probability distribution function is used in this research work.

Some of the research work on induction generators includes; The comparison and evaluation of induction generator models in wind turbine systems for transient stability of power system, various mathematical models including the detailed and reduced generator models as well as the one-mass and two-mass shaft system model were presented **(H.Li *et al.*, 2009).** In the research work carried out by **Perdana (2006)** dynamic models of wind turbines for power system stability studies were developed. In developing the wind turbine models, each part of the wind turbine was examined to define relevant behaviors' that significantly influence the power system response. Correspondingly, mathematical models of these parts were then presented with various possible levels of details. The research work presented by **H.Li *et al.* (2009)** and **Abram Perdana (2006)** have only presented a study on an existing machine and mathematical model developed rather than the design and construction of a prototype.

A work carried out by **Force Field *et al.* (2004),** titled "Alternator and Generator Comparison for Wind Power" compared the use of Alternator and Generator such as; the Vehicle Alternator, Permanent Magnet Alternator made from Volvo brake disc, Induction motor conversion Alternators, DC Generators and Brushless DC Permanent Servo motors for Wind Power **(Field et.al, 2004).** The advantages and the disadvantages of the listed Alternators and Generators were discussed. The biggest problem with using car Alternator for Wind Power is

that they are designed to rotate at too high speed which is not good for Wind applications without significant modification. Also the brushes and slip rings wear out, requiring more maintenance. The Permanent Magnets are to be the most powerful and cost effective solution for building a Wind generator. The work has presented the conversion of Alternators and Generators using Permanent Magnet, the conversion of Induction motor to Generator using capacitor bank were not considered as an alternative to absence of Permanent Magnet.

Carlson *et al.* (2006) present an overview of voltage stability phenomena in power system in relation to wind power generation. Suitable models of wind power generation for long- and short-term power system stability studies are proposed. Important aspects, such as fault ride-through and reactive power production capability are also taken into account. The study concentrated more on reactive power from the grid and not how the reactive power can be achieved from a capacitor bank.

Lund *et al.* (2005) compared the commercial simulation tools: PSCAD, Power Factory, Simpow and PSS/E for analyzing fault sequences defined in the Danish grid code requirements for wind turbines connected to a voltage level below 100 kV. Both symmetrical and unsymmetrical faults were analyzed. The deviations and the reasons for the deviations between the tools are stated. The simulation models are implemented using the built-in library components of the simulation tools with exception of the mechanical drive-train model, which must be user-modelled in Power Factory and PSS/E. The simulation tools were carried out only on wind turbine connected to the grid and not on the isolated wind turbine.

Martins *et al.* (2004) compared a recorded case obtained from a fixed-speed stall regulated 180 kW wind turbine during a grid disturbance against simulation results. The paper also includes a study of the performance of two induction generator models, neglecting and including the electromagnetic transients in the stator respectively. This paper also discusses the convenience of representing the elastic coupling and the effect of mechanical damping.

Abram Perdana *et al.* (2006) proved that fixed speed wind turbine perform better in Finland than variable speed turbine. This work lack the consideration of effects of high and low wind effects on the output of WECS.

Tande *et al.* (2009) presents a systematic approach on model benchmark testing for dynamic wind generation models for power system stability studies, including example benchmark test results comparing model performance with measurements of wind turbine response to voltage dips. The tests are performed for both a fixed-speed wind turbine with squirrel cage induction generator and variable-speed wind turbine with doubly feed induction generator. The test data include three-phase measurements of instantaneous voltage and currents at the wind turbine terminals during a voltage dip. The benchmark test procedure includes transforming these measurements to RMS fundamental positive sequence values of voltage, active power and reactive power for comparison with simulation results. Results give a clear indication of accuracy and usability of the models tested, and pin-point need both for model development and testing.

Perdana *et al*. (2004) in their work titled "Dynamic response of a wind turbine with DFIG during disturbances," A model of a wind turbine with DFIG connected to the power system has been developed in this paper in order to investigate dynamic responses of the turbine during a grid disturbance. This model includes aerodynamics, the mechanical drive train, the induction generator as well as the control parts. The response of the system during grid disturbances is studied. An inclusion of saturation effects in the generator during faults is included as well. The work by **Tande *et al.* (2009) and Perdana *et al*. (2004),** does not consider SEIG in isolation.

Rovio *et al.* (2008) in the work titled "Axial and Radial Flux Generators in Small Scale Wind Power Production", explores the requirements imposed on the generator of a direct-driven, stall-regulated, and independent small-scale wind power plant. Two prototype generators

have been designed, constructed and tested. Neodymium-Iron-Boron magnets were chosen to acquire high force density. However, this type of magnet is relatively sensitive to heat and demagnetizes above certain temperature, which depends on the grade of the magnet material. Therefore, the generator must have sufficient cooling to prevent demagnetization-without fanning. Attention was given to design and construction of permanent magnet alternator of wind turbine rather than the use of capacitors as exciter.

The work carried out by **Ackermann (2005)** based on the rotor-generator systems, turbines are classified into four types:

i. Type A: Fixed speed
ii. Type B: Limited variable speed
iii. Type C: Variable speed with partial scale energy converter
iv. Type D: Variable speed with full scale energy converter **(Ackermann, 2005).**

As mentioned previously, the recent studies have shown that there is significant difference in recent wind speed data (1971–2007) and those based on wind data from around 1951 to 1992. Therefore, there is need to analyse the wind speed data across the country based on current or recent information, since update information about wind speed are essential if right decision have been made regarding the wind energy development. Most previous studies have identified the northern (especially the North-West) part of Nigeria as the more suitable region for wind energy resource development. This study therefore aims at further investigating and quantifying the wind characteristics as well as the possibility of adopting wind energy as an electricity generation source in kumbotso, kano state. Furthermore, most previous studies focus on the wind speed and wind power density distribution while less attention was given to evaluation of the performance of commercial wind turbines. The information about the performance wind turbine will be helpful to government and any organization to make an

informed decision regarding investment in wind energy resource in this part of the country. In addition, business investors will also find this information useful.

2.2 Introduction to Theoretical Background

The aggressive state level renewable portfolio standards (RPS) are helping to reduce the nation's dependence on fossil fuel power generation and driving expansion of the wind industry in the United States. The states of Colorado and California, for example, are aiming for thirty percent of their energy to come from renewable energy source including wind power by 2020 (Murry *et al*., 1994). Seeing this growth potential, wind turbine manufacturers around the world have their sights set on expanding operations in the U.S. to satisfy the growing demand.

Nigeria is richly endowed with both fossil energy resources such as crude oil, biomass, biogas, etc. For many decades, fossil fuels and firewood (conventional energy resources) have continually remained the major energy which accounts over 90% of the national energy consumption (Fadare, 2008). However, in recent times, there has been a continual decline in supply of conventional energy due to the depletion of the national reserve while the demand has continued to increase resulting in energy crisis with incessant power outages. The environmental pollution and health hazards associated with the use of fossil fuels are another driving force towards the global switch to renewable energy. Energy is considered a prime agent in the generation of wealth, a significant factor in economic development and the driving force of industrialization (Ohunakin, 2010).

Induction machines in view of their robustness and controllability are the leading machines used in renewable energy sources such as wind, micro-hydro schemes. These energy sources drive the shaft of the induction machines to generate electric power to feed autonomous loads

or may be connected to the three-phase grids. For autonomous applications, reactive power requirements of the induction machine are provided by either voltage source controlled converters which deliver variable reactive power or fixed capacitors which provide voltage dependent reactive power (Ojo, 1995).

In view of this development, a number of studies have been carried out on modeling of wind speed variation in the estimation of the wind energy potential for a typical site and wind power generating system.

2.3 Wind Speed as Means of Power Generation

The wind turbine captures the wind's kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to enhance the energy capture. Numerous wind turbines are installed at one site to build a wind farm of the desired power production capacity. Obviously, sites with steady high wind produce more energy over the year. Two distinctly different configurations are available for the turbine design, the horizontal axis configuration and the vertical axis configuration. The vertical axis machine has the shape of an egg beater, and is often called the Darrieus rotor after its inventor. It has been used in the past because of specific structural advantage. However, most modern wind turbines use horizontal-axis design. Except for the rotor, all other components are the same in both designs, with some difference in their placement.

The kinetic energy in air of mass "m" moving with speed *v* is given by the following in SI units:

$$Kinetic\ Energy = \frac{1}{2}\, m\, v^2 \qquad joules \tag{2.1}$$

The power in moving air is the flow rate of kinetic energy per second.

Therefore:

$$Power = \frac{1}{2}\ (mass\ flow\ rate\ per\ second)$$

(2.2)

let P be mechanical power in the moving air

ρ is air density, kg/m3

A is area swept by the rotor blades, m^2

v is velocity of the air, m/s

Then, the volumetric flow rate is A·*v*, the mass flow rate of the air in kilograms per second is ρ·A·*v*, and the power is given by the following:

$$P = \frac{1}{2}\ (\rho A v\ ) v^2 = \frac{1}{2}\ \rho A v^3 \qquad watts$$

(2.3)

This is the power in the upstream wind. It varies linearly with the density of the air sweeping the blades, and with the cube of the wind speed. All of the upstream wind power cannot be extracted by the blades, as some power is left in the downstream air which continues to move with reduced speed (Patel, 1999).

2.3.1 Power Extracted from the Wind

The actual power extracted by the rotor blades is the difference between the upstream and the downstream wind powers. That is, using Equation 2.2:

$$P_o\ = \frac{1}{2}\ \rho A v\ \{v^2 - \ {v_o}^2\ \}$$

(2.4)

Where P_o is mechanical power extracted by the rotor, i.e. the turbine output power.

v, is upstream wind velocity at the entrance of the rotor blades

v_o, is downstream wind velocity at the exit of the rotor blades.

The air velocity is discontinuous from v to v_o at the "plane" of the rotor blades in the macroscopic sense. The mass flow rate of air through the rotating blades is, therefore, derived by multiplying the density with the average velocity.

The mechanical power extracted by the rotor, which is driving the electrical generator, is therefore:

$$P_o = \frac{1}{2}\rho A v^3 \frac{\left[1+\frac{v_o}{v}\right]\left[1-\left(\frac{v_o}{v}\right)^2\right]}{2} \quad (2.5)$$

The power extracted by the blades is customarily expressed as a fraction of the upstream wind power as follows:

$$P_o = \frac{1}{2}\rho A v^3 C_p \quad (2.6)$$

Where $$C_p = \frac{\left[1+\frac{v_o}{v}\right]\left[1-\left(\frac{v_o}{v}\right)^2\right]}{2} \quad (2.7)$$

The Cp is the fraction of the upstream wind power, which is captured by the rotor blades. The remaining power is discharged or wasted in the downstream wind. The factor Cp is called the power coefficient of the rotor or the rotor efficiency.

For a given upstream wind speed, the value of Cp depends on the ratio of the downstream to the upstream wind speeds, that is (v_o/v). The plot of power coefficient versus (v_o/v) shows that Cp is a single, maximum-value function (Figure 2.1). It has the maximum value of 0.59 when the (v_o /v) is one-third. The maximum power is extracted from the wind at that speed ratio, when the downstream wind speed equals one-third of the upstream speed. Under this condition:

$$P_{max} = \frac{1}{2}\rho A v^3\ 0.59 \quad (2.8)$$

The theoretical maximum value of Cp is 0.59. In practical designs, the maximum achievable Cp is below 0.5 for high-speed, two-blade turbines, and between 0.2 and 0.4 for slow speed turbines with more blades (Figure 2.6).

If 0.5 is the practical maximum rotor efficiency, the maximum power output of the wind turbine becomes a simple expression (Gary, 2001; Anyanwu *et al*., 1995).

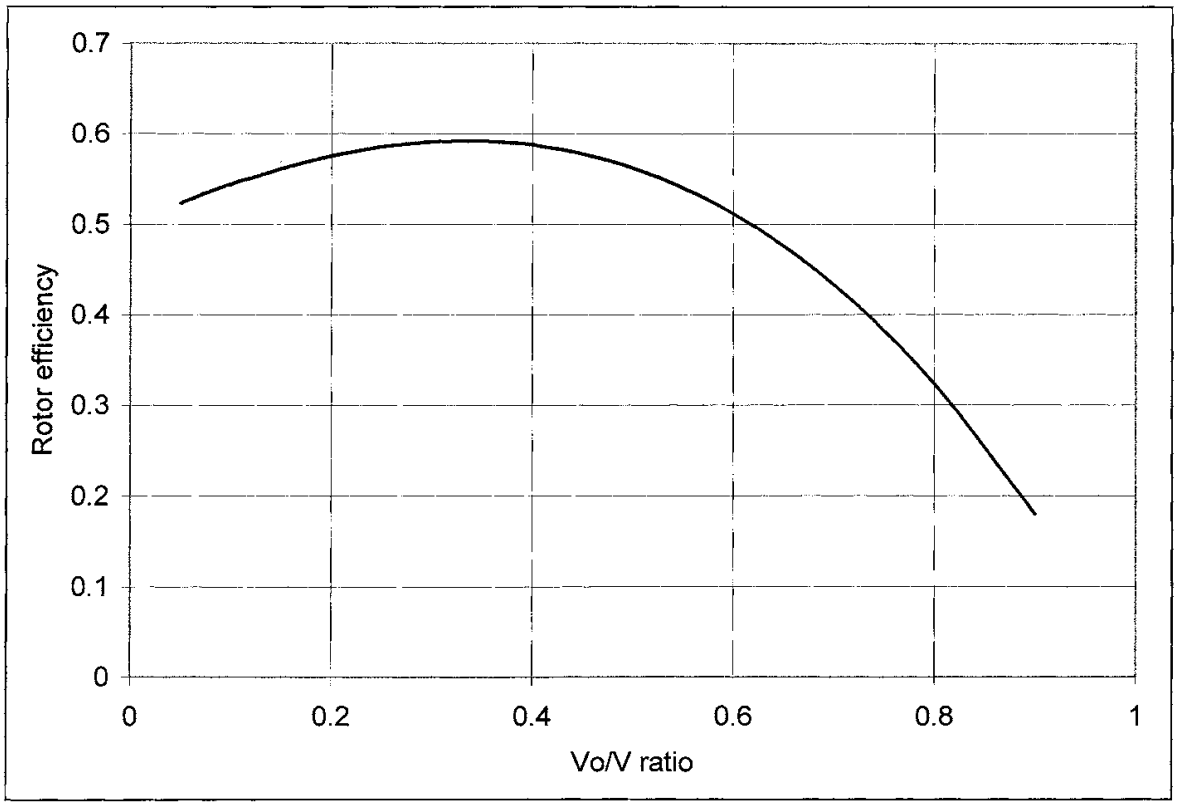


Figure. 2.1 Rotor Efficiency versus Vo/V ratio.

Rotor efficiency versus Vo/V ratio has single maximum. Rotor efficiency is the fraction of available wind power extracted by the rotor and fed to the electrical generator(Tony *et al*., 2001).

2.3.2 Rotor Swept Area

As seen in the power equation (2.8), the output power of the wind turbine varies linearly with the rotor swept area. For the horizontal axis turbine, the rotor swept area is given by:

$$A = \frac{\pi}{4} D^2$$

(2.9)

For the Darrieus vertical axis machine, determination of the swept area is complex, as it involves elliptical integrals. However, approximating the blade shape as a parabola leads to the following simple expression for the swept area:

$$A = \frac{2}{3} (maximum\ rotor\ width\ at\ the\ center)(Height\ of\ the\ rotor)$$

(2.10)

2.3.3 Rayleigh Parameters of the Wind Speed

The speed of the wind is continuously changing, making it desirable to describe the wind by statistical methods. There are several density functions which can be used to describe the wind speed frequency curve (Mike *et al.,* 2010). The two most common ones are the Weibull and the Rayleigh functions. The Weibull is a special case of the Pearson Type III or generalized gamma distribution, while the Rayleigh [or chi with two degrees of freedom (chi-2)] distribution is a subset of the Weibull. The Weibull is a two parameter distribution while the Rayleigh has only one parameter.

Since wind is driven by

I. The sun
II. The season

The wind pattern generally repeats over the period of one year. The wind site is usually described by speed data averaged over the calendar months. The wind speed variations and the period can be described by a probability distribution function.

At most sites the wind speed has the weibull distribution with K = 2 which is specifically known as the Rayleigh distribution. The actual measurement data taken at most sites compare

well with the Rayleigh distribution. The Rayleigh distribution is then a simple and accurate enough representation of the wind speed with just one parameter, the scale parameter 'c'

The probability density function of the weibull distribution is given as:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right]$$

(2.11)

Where f(v) is the probability of observing wind speed v, k is dimensionless weibull shape parameter and c is the weibull scale parameter, which have reference value in the units of wind speed (Fadare, 2008).

When k =1, it is the exponential distribution.

When k =2, it becomes Rayleigh distribution.

When k =3,4 it appears similar to the Normal distribution (Gray, 2001; Danish Industry, 2003).

The annual mean speed is therefore the weighted average speed and is as follows

$$V_{mean} = \frac{1}{8760}\int_0^{\infty} f.v.dv$$

(2.12)

For c and k values in the range found at most sites, the integral expression can be approximated to the gamma function.

For Rayleigh distribution with K = 2, the gamma function can be further approximated to the following

$$V_{mean} = 0.90c$$

(2.13)

Thus, we have the Rayleigh distribution of the site using the generally reported mean speed as follows (Ohunakin, 2010)

$$f(v) = \frac{2v}{c^2}\, e^{-(\frac{v}{c})^2} = \frac{2v}{(V_{mean})^2}\, e^{-(\frac{v}{V_{mean}})^2}$$

(2.14)

2.4 Introduction to Induction Machine

In the electromagnetic structure of the induction generator, the stator is made of numerous coils with three groups (phases), and is supplied with three-phase current. The three coils are physically spread around the stator periphery and carry currents which are out of time-phase. This combination produces a rotating magnetic field, which is a key feature of the working of the induction machine. The angular speed of the rotating magnetic field is called the synchronous speed. It is denoted by N_s.

$N_s = \frac{60f}{p}$ revolutions per minutes (rpm)

(2.15)

Where; f is frequency of the stator excitation

p is number of magnetic pole pairs.

The stator coils are embedded in slots of high-permeability magnetic core to produce the required magnetic field intensity with low exciting current. The rotor, however, has a completely different structure. It is made of solid conducting bars embedded in the slots of a magnetic core. The bars are connected together at both ends by the conducting end rings. Because of its resemblance, the rotor is called the squirrel cage rotor or the cage rotor in short (Akagi *et al*., 2007).

2.4.1 Principle of Operation of Induction Machine

The stator magnetic field is rotating at the synchronous speed determined by Equation 2.15. The relative speed between the rotating field and the rotor induces the voltage in each rotor

turn linking the stator flux φ. The magnitude of the induced voltage is given by Faraday's law of electromagnetic induction, namely:

$$e = -\frac{d\varphi}{dt} \tag{2.16}$$

Where, φ = the magnetic flux linking the rotor turn.

This voltage in turn sets up the circulating current in the rotor. The electromagnetic interaction of the rotor current and the stator flux produces the torque.

The rotor will accelerate under this torque. If the rotor was on frictionless bearings with no mechanical load attached, it is completely free to rotate with zero resistance. Under this condition, the rotor will attain the same speed as the stator field, namely, the synchronous speed. At this speed, the current induced in the rotor speed is zero, no torque is produced and none is required. The rotor finds equilibrium at this speed and will continue to run at the synchronous speed (Patel, 1999).

If the rotor is now attached to a mechanical load such as a fan, it will slow down. The stator flux, which always rotates at the constant, synchronous speed, will have relative speed with respect to the rotor. As a result, the electromagnetically induced voltage, current, and torque are produced in the rotor. The torque produced must equal that needed to drive the load at that speed. The machine works as the motor in this condition.

If the rotor is attached to a wind turbine and drive it faster than the synchronous speed, the induced current and the torque in the rotor reverse the direction. The machine now works as the generator, converting the mechanical power of the turbine into electrical power delivered to the load connected to the stator terminals. If the machine was connected to a grid, it would feed power into the grid.

2.4.2 Induction Motor and Generator

Induction Machine from electrical point of view, Consist of two parts: a fixed, wound stator core and the rotor that rotates in the centre. The stator winding consist of coils of insulated copper wire fixed into slots in the core to form a distributed winding of similar type to that used in synchronous generator.

The standard squirrel cage rotor core is cylindrical and built up from thin sheets of steel into which slots have been punched for the conductors. The conductors generally consist of aluminium bars that are short-circuited at each end by aluminium rings. For small machines, the bars and end rings are cast in one operation using the rotor core as part of the die. For large machines, copper or aluminium bars are welded or brazed to the end.

2.4.3 Induction Motor Operation

In order to understand the operation of a stand alone, i.e. non grid connected induction generator, it is easier to take motor operation as a starting point.

When an induction machine is connected to an a.c supply, magnetizing current flows from the supply and creates a rotating magnetic field in the machine.

The rotating magnetic field cuts the short-circuited rotor bars, inducing currents in them which, because they are flowing in the magnetic field, react with it producing a torque. This torque drags the rotor round with the field, but at a slightly lower speed. The small difference in speed arises because without it no current would be produced to turn it. When a load is applied to the motor the speed difference will increase as a greater torque must be produced. The difference between the speed of the rotor and the speed of the rotating field is called the 'slip' and is defined as:

Slip, $s = \frac{(N_S - N_r)}{N_S}$

Where; N_s is the Synchronous speed (Speed of the rotating field) and N_r is the rotor speed

If the same supply-connected induction machine is now driven at above synchronous speed, so that the slip becomes negative ($N_r \square N_s$), a torque is supplied to the rotor rather than by the rotor and the machine acts as a generator, supplying power to the network. However, it still takes its magnetizing current from the supply in order to create the rotating field, just as though it were a motor. The full load power output is achieved at a slip of similar value (but negative) to the full load motoring slip (Nigel Smith, 2001). If the slip is varied over a wide range, the torque-speed characteristic as shown in Figure 2.2 is attained. In the region of negative slip, the machine works as the generator powering the electrical load connected to its terminals. In the region of positive slip, it works as the motor turning the mechanical load connected to its shaft. In addition to the motoring and the generating regions, the induction machine has a third operating mode, and that is the braking mode. If the machine is operated at slips greater 1 by turning it backward, it absorbs power without putting anything out that is, it works as a brake (Patel, 1999). The power in this case is converted into I^2R loss in the rotor conductors, which must be dissipated as heat. The eddy current brake works on this principle. As such, in case of emergencies, the grid-connected induction generator can be used as brake by reversing the three-phase voltage sequence at the stator terminals

.

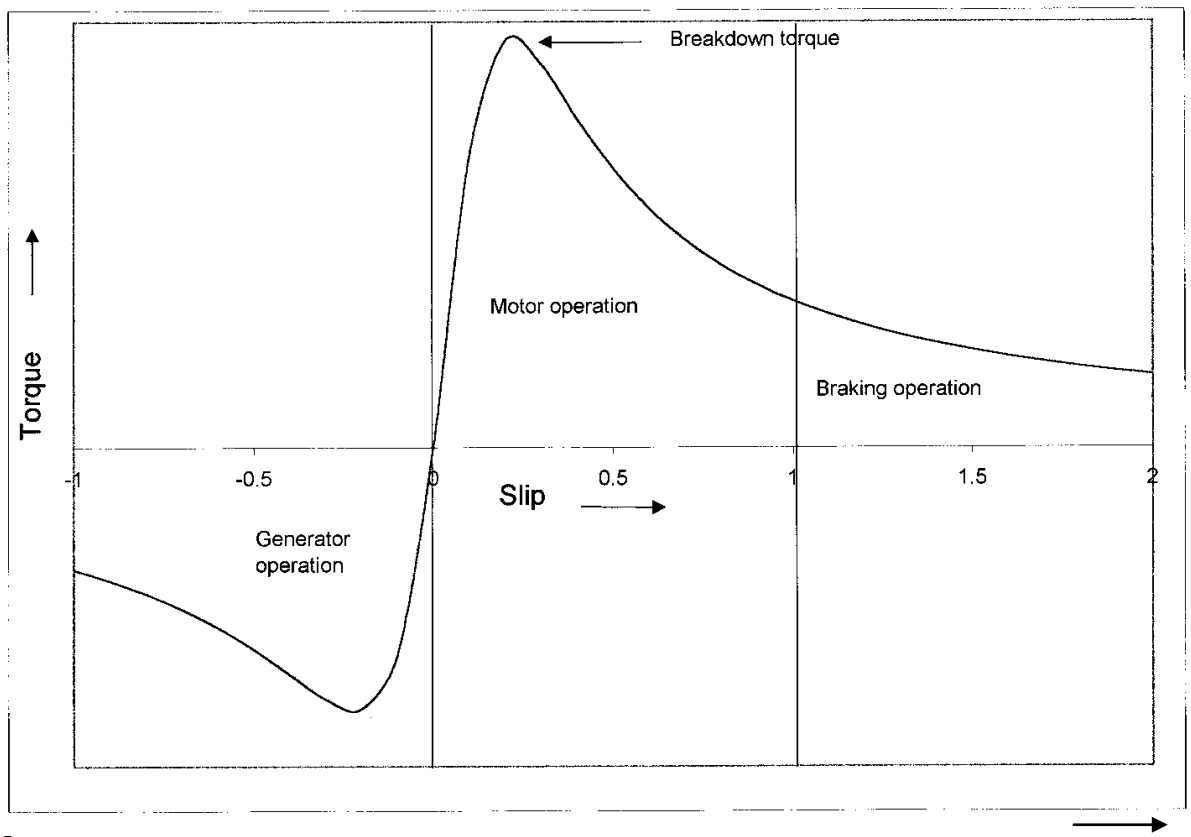


Figure.2.2 Torque versus Speed Characteristic of the Induction Motor in three operating modes

2.4.4 Stand –alone Induction Generator Operation

The magnetizing current of an induction machine can be supplied, in total or in part by capacitors. In fact, capacitors are often fitted to large induction motors and supply-connected induction generators to reduce the reactive current drawn from the supply, especially when the electricity company imposes charges for poor power factor.

In the case of a stand-alone induction generator, the capacitors are the only external source of magnetizing current. Therefore, in order to obtain the required operating voltage at the desired frequency, the amount of capacitors must be carefully chosen

2.4.5 The Concept of Rotor Slip

The voltage induced in a rotor bar of an induction motor depends on the speed of the rotor relative to magnetic fields. Since the behavior of an induction motor depends on the rotor's voltage and current, it is often more logical to talk about this relative speed. Two terms are commonly used to define relative motion of the rotor and the magnetic fields .One is slip speed, defined as the difference between synchronous speed and rotor speed:

$$N_{slip} = N_s - N_r \tag{2.17}$$

Where N_{slip} is Slip speed of the machine

N_s is Speed of magnetic fields = $\frac{60f}{p}$

N_r is Mechanical shaft speed of motor

The other term used to describe the relative motion is slip, which is the relative speed, expressed on a per-unit or a percentage basis. That is, slip is defined as

$$s = \frac{N_{slip}}{N_s} \ (\times 100\%) \tag{2.18}$$

$$s = \frac{N_s - N_r}{N_s} \ (\times 100\%) \tag{2.19}$$

This equation can also be expressed in terms of angular velocity ω (radians per second) as

$$s = \frac{\omega_s - \omega_r}{\omega_s} \ (\times 100\%) \tag{2.20}$$

The slip is generally considered positive in the motoring operation. In the generator mode, the slip would therefore be negative. In both the motoring mode and the generating mode, higher rotor slips induce higher current in the rotor and higher electromechanical power conversion. In both modes, the value of the slip is generally a few to several percent. Higher slips result in

greater electrical loss, which must be effectively dissipated from the rotor to keep the operating temperature below the allowable limit (Nigel Smith, 2001).

The heat is removed from the machine by the fan blades attached to one end-ring of the rotor.

2.5 Background on Conversion from Induction Motor to Induction Generator

The magnetizing current of an induction machine can be supplied by capacitors added to the induction motor power leads and when driven at synchronous speed, the motor will generate ac voltage. The capacitance helps to induce currents into the rotor conductors and causes it to produce ac current. The power is taken off of the motor power leads, since they are all in parallel. This system depends upon the residual magnetism in the rotor to start generating. Almost all the motors tried begin generating just fine with the appropriate capacitor connected to it.

If a motor does not start generating on the very first try, then apply 120V ac or 12 or more dc volt to the motor for a few seconds. That will usually work to magnetize the rotor and the generator will start by itself from then onward.

The capacitors used must be the type designated as “running” capacitors and NOT “starting” capacitors. Starting capacitors are used for a very short time, usually less than a second or two, and would be destroyed by being connected across the ac line continuously. Running capacitors are designed to be connected while the motor is powered.

When choosing the capacitor values it is important to choose those with sufficient voltage rating. They could explode when this rating is underestimated. For safety choose 350V capacitors i.e, at least 1.5 times the nominal rating (Melkebeek *et al.*, 1983).

2.5.1 Self-Excitation Capacitance

As the generator, the induction machine has one drawback of requiring reactive power for excitation. The exciting power can be provided by an external capacitor connected to the generator terminals (Figure 2.3). No separate AC supply is needed in this case. In the grid-connected generator, the reactive power is supplied from the synchronous generators working at the other end of the grid. Where the grid capacity of supplying the reactive power is limited, local capacitors can be used to partly supply the needed reactive power (Gary, 2001).

The induction generator will self-excite using the external capacitor only if the rotor has an adequate residual magnetic field. In the self-excited mode, the generator output frequency and voltage are affected by the speed, the load, and the capacitance value in Farads (Seyoum, 2003).

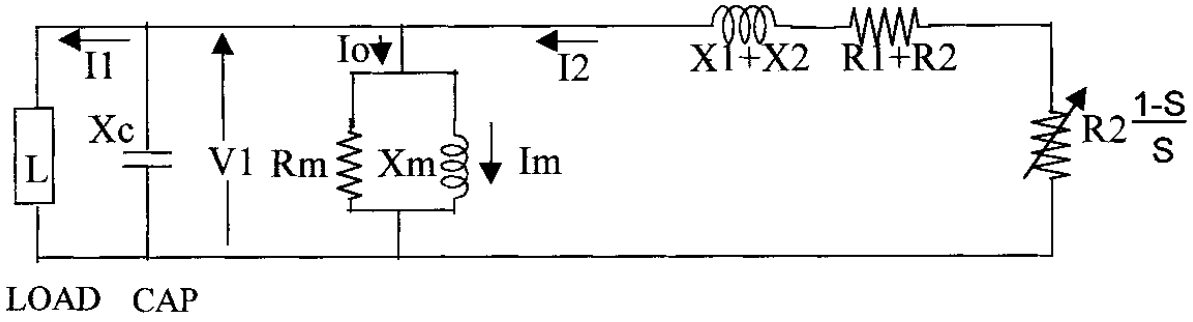


Fig.2.3 Self-excited induction generator with external capacitor.

The operating frequency is determined below in terms of the approximate equivalent circuit of Figure 2.3.

$$f = \frac{1}{2\pi C X_m} \tag{2.21}$$

Equation 2.21 determined the induction generator output frequency with a given value of the capacitance. Inversely, they can be used to determine the required value of the capacitance for the desired frequency and the voltage (Patel, 1999).

2.5.2 Selection of an Induction Motor for use as a Generator

The process of voltage buildup in an induction generator needs a suitable value of residual magnetism present in the rotor. In the absence of a proper value of residual magnetism the voltage will not buildup. So it is desirable to maintain a high level of residual magnetism, as it does ease the process of machine excitation. In view of this, a great deal of information can be learned about the magnetic properties of a material by studying its hysteresis loop. A hysteresis loop shows the relationship between the induced magnetic flux density (**B)** and the magnetizing force **(H).** It is often referred to as the B-H loop. The magnetic properties of the induction motor rotor selected have a high level of residual magnetism which depends on the B-H loop. An example of hysteresis loop is shown in figure 2.4.

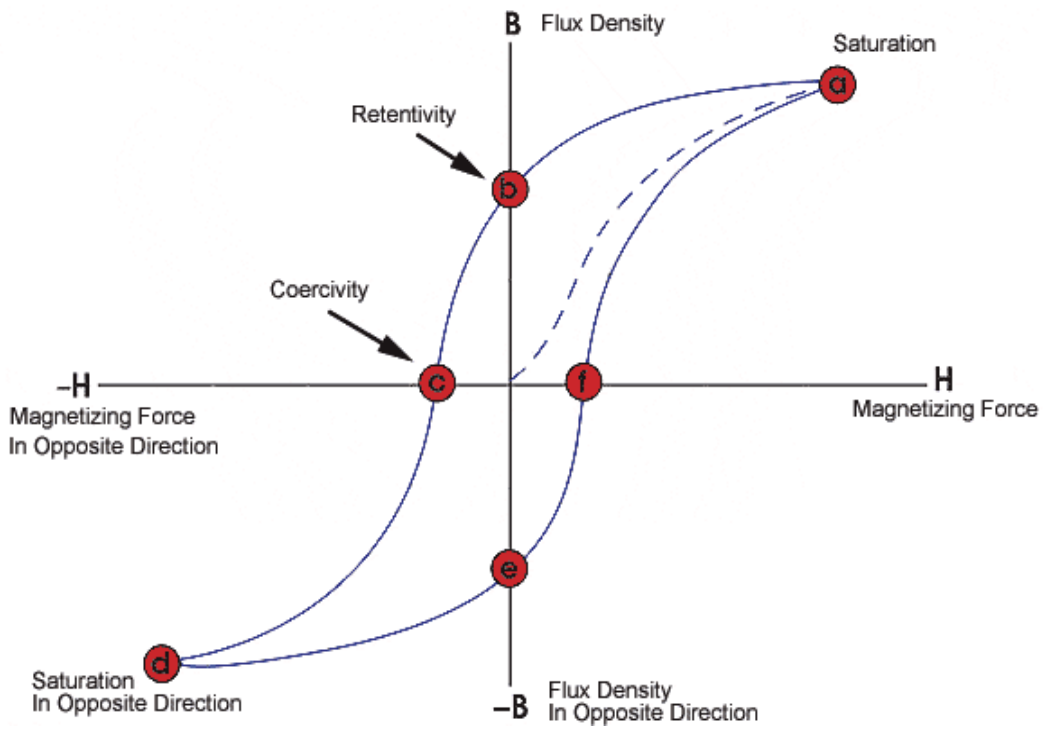


Figure.2.4 Hysteresis Loop

The loop is generated by measuring the magnetic flux of a ferromagnetic material while the

magnetizing force is changed. A ferromagnetic material that has never been previously magnetized or has been thoroughly demagnetized will follow the dashed line as **H** is increased. As the line demonstrates, the greater the amount of current applied **(H+)**, the stronger the magnetic field in the component **(B+)**. At point "a" almost all of the magnetic domains are aligned and an additional increase in the magnetizing force will produce very little increase in magnetic flux. The material has reached the point of magnetic saturation. When **H** is reduced to zero, the curve will move from point "a" to point "b." At this point, it can be seen that some magnetic flux remains in the material even though the magnetizing force is zero. This is referred to as the point of retentivity on the graph and indicates the level of residual magnetism in the material. (Some of the magnetic domains remain aligned but some have lost their alignment.) As the magnetizing force is reversed, the curve moves to point "c", where the flux has been reduced to zero. This is called the point of coercivity on the curve. (The reversed magnetizing force has flipped enough of the domains so that the net flux within the material is zero.) The force required to remove the residual magnetism from the material is called the coercive force or coercivity of the material.

As the magnetizing force is increased in the negative direction, the material will again become magnetically saturated but in the opposite direction (point "d"). Reducing **H** to zero brings the curve to point "e." It will have a level of residual magnetism equal to that achieved in the other direction. Increasing **H** back in the positive direction will return **B** to zero. Notice that the curve did not return to the origin of the graph because some force is required to remove the residual magnetism. The curve will take a different path from point "f" back to the saturation point where it with complete the loop.

From the hysteresis loop, a number of primary magnetic properties of a material can be

determined.

1. **Retentivity** - A measure of the residual flux density corresponding to the saturation induction of a magnetic material. In other words, it is a material's ability to retain a certain amount of residual magnetic field when the magnetizing force is removed after achieving saturation. (The value of **B** at point b on the hysteresis curve.)
2. **Residual Magnetism** or **Residual Flux** - the magnetic flux density that remains in a material when the magnetizing force is zero. Note that residual magnetism and retentivity are the same when the material has been magnetized to the saturation point. However, the level of residual magnetism may be lower than the retentivity value when the magnetizing force did not reach the saturation level.
3. **Coercive Force** - The amount of reverse magnetic field which must be applied to a magnetic material to make the magnetic flux return to zero. (The value of **H** at point c on the hysteresis curve.)
4. **Permeability, m** - A property of a material that describes the ease with which a magnetic flux is established in the component.
5. **Reluctance** - Is the opposition that a ferromagnetic material shows to the establishment of a magnetic field. Reluctance is analogous to the resistance in an electrical circuit.

The shape of the hysteresis loop tells a great deal about the material being magnetized. The hysteresis curves of two different materials are shown in figure 2.5.

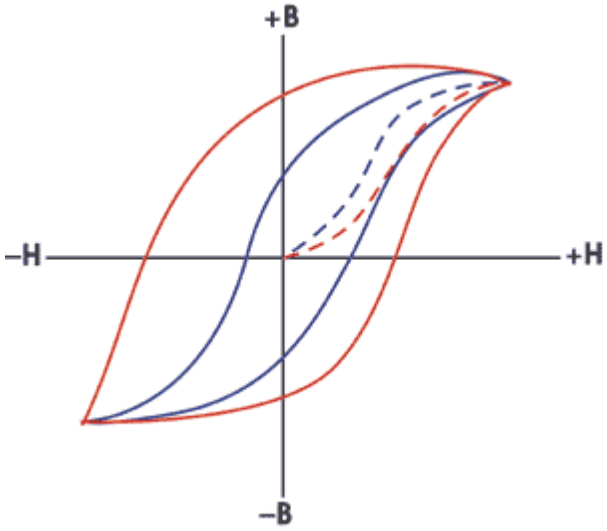


Figure.2.5 The hysteresis curves of two different materials

Relative to other materials, a material with a wider hysteresis loop has:

i. Lower Permeability
ii. Higher Retentivity
iii. Higher Coercivity
iv. Higher Reluctance
v. Higher Residual Magnetism

Relative to other materials, a material with the narrower hysteresis loop has:

i. Higher Permeability
ii. Lower Retentivity
iii. Lower Coercivity
iv. Lower Reluctance
v. Lower Residual Magnetism.

In magnetic particle testing, the level of residual magnetism is important. Residual magnetic fields are affected by the permeability, which can be related to the carbon content and alloying of the material. A component with high carbon content will have low permeability and will retain more magnetic flux than a material with low carbon content. Therefore, the motor selected for this study is an old 800w, 940rpm three-phase induction motor which have the properties of high carbon content to retain more magnetic flux**.** (Berg, 1973; Concordia *et al.*, 1982)

2.6 Power Conversion: Wind Speed, V_m and the Induction Generator.

The fraction of power extracted from the power in the wind by a practical wind turbine is usually given by the symbol C_p, standing for the coefficient of performance. This coefficient of performance is not constant, but varies with the wind speed, the rotational speed of the turbine, and turbine blade parameters like angle of attack and the pitch angle. Then from equation (2.6) the shaft power and the rotor speed is as given in equation (2.22) and (2.23) respectively.

$$Shaft\ Power, P = \frac{1}{2} C_P\ {V_m}^3 A\rho$$

(2.22)

$$Rotor\ Speed, N = \frac{60\ \lambda\ V_m}{\pi D}$$

(2.23)

Where :

C_P is the Coefficient of performance,

A, is the swept area of the blade, ρ is the Air density,

D is the Blade diameter,

$\boldsymbol{\lambda}$ is the Tip Speed ratio,

V_m is the mean wind speed.

The value of $\boldsymbol{\lambda}$ is obtained from a graph of C_p versus $\boldsymbol{\lambda}$ for different type of Wind Turbine. (Figure 2.6)

The shaft power output is not normally used directly, but is usually coupled to a load through a transmission or a gear box, and the load in this study is the induction machine. There are two speed shafts, namely: The low speed shaft which is part of the rotor, is design with a low speed of range 30 – 60 rotations per minutes and the high speed shaft that is connected to the low speed shaft through a gear box to increase the rotational speed from 30 – 60 rotations per minute (rpm) to about 1000 – 1800 rpm, the rotational speed required by most induction generators to produce electricity. The maximum practical gear ratio per stage is 6:1 for maximum efficiency and cost (Gary, 2001).

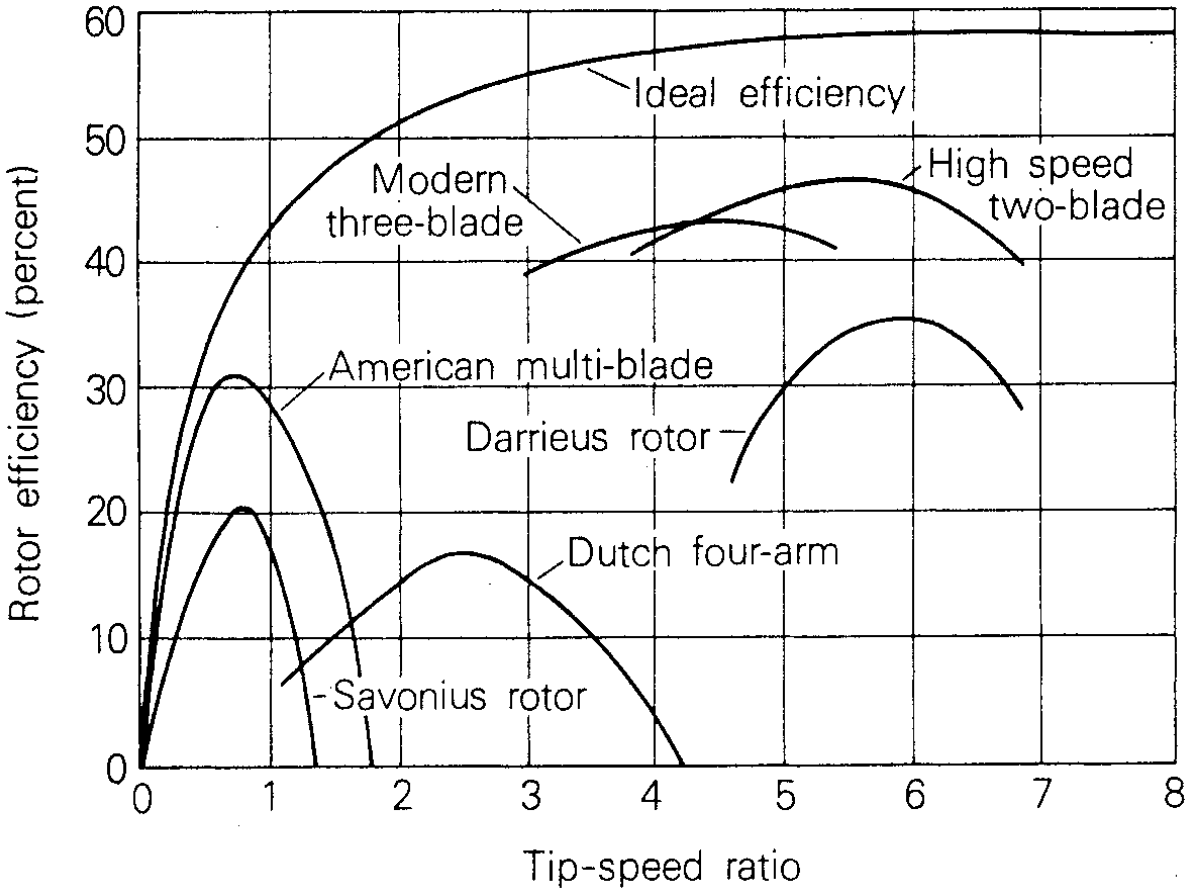


Figure. 2.6 Rotor efficiency versus tip speed ratio for rotors with different numbers of blades. Two-blade rotors have the highest efficiency. (Source: Eldridge, F.R., Wind Machines, Energy Research and Development Administration, Washington, DC, Report AER-75-12937, p. 55, 1975).

The wind turbine efficiently intercepts the wind energy flowing through the entire swept area even though it has only two or three thin blades with solidity between 5 to 10 percent. The solidity is defined as the ratio of the solid area to the swept area of the blades. The modern two blade turbine has low solidity ratio. Hence, it requires little blade material to sweep large areas (Patel, 1999).

CHAPTER THREE

COLLECTION AND ANALYSIS OF WIND SPEED DATA OF KUMBOTSO VILLAGE

3.1 Wind Velocity Frequency Distribution of Kano

The Wind velocity data as recorded by National Aeronautic and Space Administration (NASA) surface Meteorology and Solar Energy at 50m height was collected (Appendix) and analyzed. The most important parameters, necessary for the work are wind velocity value and the frequency of occurrence of such velocity. The data collected from NASA surface meteorology and solar energy available tables indicate a ten year average of a monthly averaged wind speed at 50m above the surface of the earth (m/s), Minimum and Maximum difference from monthly averaged wind speed at 50m height (%) and a three hours interval of a monthly averaged Wind Speed at 50m above the surface of the earth for different GMT times (m/s). Therefore, with this known facts an average hourly wind speed for the month of January to December at 50m above the surface of the earth were estimated. Furthermore a normalized wind speed data for hourly periods of each month were extracted for the months of January to December.

Given a set of wind speed data X_1, X_2, X_3 and X_4 with X_2 and X_3 unknown, where the minimum and maximum difference from the average Wind Speed data is given. Then;

$$\left.\begin{array}{l} X_2 = \Delta_{min} + X_{av} \quad \text{and} \\ X_3 = \Delta_{max} + X_{av} \quad \text{if } X_1 \square X_4 \end{array}\right\} \quad (3.1)$$

OR

$$\left.\begin{array}{l} X_2 = \Delta_{max} + X_{av} \quad \text{and} \\ X_3 = \Delta_{min} + X_{av} \quad \text{if } X_1 \square X_4 \end{array}\right\} \quad (3.2)$$

Where, Δ_{min} (Minimum difference of the Ave.) = – a% of Average a = 1,2,3,4,5,.....

Δ_{max} (Maximum difference of the Ave.) = b% of Average b = 1,2,3,4,5,.....

(Little and Rubin, 1987)

The average hourly Wind Speed is essential because it is more thorough in the description of the energy extracted from the Wind compare to the wind speed values provided by aviation synoptic stations that are spanned over large intervals of speed. From calm speed of zero to above 17.5m/s are divided just into five; 0 – 0.5; 0.575 - 5.15; 5.7 – 11; 11.33 – 17; and above 17.5 as against readings of short intervals like 0 – 1, 1 – 2; 2 – 3; 3 – 4; 4 – 5; 5 – 6; etc. Values of short intervals are more in number, making it easy to plot and analyze as frequency curves. It is difficult to deal with wide interval values. The large Wind Speed interval given by the data collected from NIMET indicate a large power difference between the Wind Speed of the same group.

The result of the data collected from NASA surface meteorology and solar energy is the summary of monthly frequency of occurrence of wind velocity values, which are presented in Tables 3.1 to 3.4.

Table 3.1 Averaged Hourly Wind Speed for the Month of Jan- Dec. at 50m above the Surface of the Earth for Indicated GMT Times (m/s). Estimated from N.A.S.A. Data.

Time	Jan Wind Speed (m/s)	Feb Wind Speed (m/s)	March Wind Speed (m/s)	April Wind Speed (m/s)	May Wind Speed (m/s)	June Wind Speed (m/s)	July Wind Speed (m/s)	Aug Wind Speed (m/s)	Sep Wind Speed (m/s)	Oct Wind Speed (m/s)	Nov Wind Speed (m/s)	Dec Wind Speed (m/s)
0130	5.09	5.01	5.62	5.83	5.65	4.47	4.92	4.75	4.25	4.36	4.92	5.41
0230	5.35	5.27	4.09	4.29	5.08	4.04	3.97	3.95	3.52	3.71	4.51	5.12
0330	3.51	2.99	5.55	5.08	3.92	3.52	3.26	2.81	2.60	2.86	3.41	3.73
0430	4.95	4.88	5.68	5.87	5.64	4.55	4.57	4.55	4.09	4.13	4.78	5.31
0530	5.35	5.27	5.55	5.08	5.08	4.04	3.97	3.95	3.52	2.86	4.51	5.12
0630	3.51	2.99	4.09	4.29	3.92	3.52	3.26	2.81	2.60	3.71	3.41	3.73
0730	3.50	3.46	4.33	4.94	4.37	3.27	2.38	2.27	2.10	2.46	3.13	3.71
0830	3.51	2.99	4.09	4.29	3.92	3.52	3.26	2.81	2.60	2.86	3.41	3.73
0930	5.35	5.27	5.55	5.08	5.08	4.04	3.97	3.95	3.52	3.71	3.51	5.12
1030	4.26	4.38	4.95	5.08	4.67	3.86	3.50	3.15	2.70	2.83	3.63	4.23
1130	5.35	5.27	5.55	5.08	5.08	4.04	3.97	3.95	3.52	3.71	4.51	5.12
1230	3.51	2.99	4.09	4.29	3.92	3.52	3.26	2.81	2.60	2.86	3.41	3.73
1330	3.72	3.45	3.40	2.98	2.84	2.57	2.67	2.46	2.12	2.41	3.12	3.76
1430	5.35	5.27	5.55	5.08	5.08	4.04	3.97	3.95	2.60	2.86	4.51	5.12
1530	3.51	2.99	4.09	4.29	3.92	3.52	3.26	2.81	3.52	3.71	3.41	3.73
1630	3.10	2.88	3.05	2.90	2.78	2.50	2.47	2.42	2.19	2.61	3.11	3.35
1730	3.51	2.99	4.09	4.29	3.92	3.52	3.26	2.81	2.60	2.86	3.41	3.73
1830	5.35	5.27	5.55	5.08	5.08	4.04	3.97	3.95	3.52	3.71	4.51	5.12
1930	4.47	4.16	4.37	4.22	4.22	3.85	3.52	3.26	3.26	3.71	4.16	4.76
2030	3.51	2.99	4.09	4.29	3.92	3.52	3.26	2.81	2.60	2.86	3.41	3,73
2130	5.35	5.27	5.55	5.08	5.08	4.04	3.97	3.95	3.52	3.71	4.51	5.12
2230	5.14	4.95	5.39	5.45	5.55	4.92	4.63	4.19	4.04	4.49	4.82	5.40
2330	5.35	2.99	4.09	4.29	3.92	4.04	3.26	2.81	2.60	3.71	3.41	3.73
0030	3.51	5.27	5.55	5.08	5.08	3.52	3.97	3.95	3.52	2.86	4.51	5.12

Table 3.2 Minimum and Maximum Difference from Monthly Average in Percentage (%) and their corresponding Value in Metre per Second (m/s).

	AVERAGE MINIMUM (%)	AVERAGE MINIMUM VALUE (m/s)	AVERAGE MAXIMUM (%)	AVERAGE MAXIMUM VALUE (m/s)
JANUARY	-18%	3.51	25%	5.35
FEBRUARY	-28%	2.99	27%	5.27
MARCH	-11%	4.09	21%	5.55
APRIL	-8%	4.29	9%	5.08
MAY	-12%	3.92	14%	5.08
JUNE	-7%	3.52	7%	4.04
JULY	-9%	3.26	11%	3.97
AUGUST	-17%	2.81	17%	3.95
SEPTEMBER	-16%	2.60	14%	3.52
OCTOBER	-15%	2.86	10%	3.71
NOVEMBER	-14%	3.41	14%	4.51
DECEMBER	-17%	3.73	14%	5.12

Table 3.3 Normalized Wind Speed Data for Hourly Periods of each Month Extracted from N.A.S.A Data (2012)

Time	Jan Wind Speed (m/s)	Feb Wind Speed (m/s)	March Wind Speed (m/s)	April Wind Speed (m/s)	May Wind Speed (m/s)	June Wind Speed (m/s)	July Wind Speed (m/s)	Aug Wind Speed (m/s)	Sep Wind Speed (m/s)	Oct Wind Speed (m/s)	Nov Wind Speed (m/s)	Dec Wind Speed (m/s)
0100	4.30	5.14	5.59	5.46	5.37	4.14	4.45	4.35	3.89	3.61	4.72	5.27
0200	5.22	5.14	4.86	5.06	5.37	4.40	4.45	4.35	3.89	4.04	4.72	5.27
0300	4.43	4.13	4.82	4.69	4.50	3.78	3.62	3.38	3.06	3.29	3.96	4.43
0400	4.23	3.94	5.62	5.48	4.78	4.04	3.92	3.68	3.35	3.50	4.10	4.52
0500	5.15	5.07	5.62	5.48	5.36	4.30	4.27	4.25	3.81	3.50	4.65	5.22
0600	4.43	4.13	4.84	4.69	4.50	3.78	3.62	3.38	3.02	3.29	3.96	4.43
0700	3.50	3.23	4.21	4.62	4.15	3.40	2.82	2.54	2.35	3.09	3.27	3.72
0800	3.50	3.23	4.21	4.62	4.15	3.40	2.82	2.54	2.35	2.66	3.27	3.72
0900	4.43	4.13	4.82	4.69	4.50	3.78	3.62	3.38	3.06	3.29	3.96	4.43
1000	4.80	4.83	5.25	5.08	4.88	3.95	3.74	3.55	3.11	3.27	4.07	4.68
1100	4.80	4.83	5.25	5.08	4.88	3.95	3.74	3.55	3.11	3.27	4.07	4.68
1200	4.43	4.13	4.82	4.69	4.50	3.78	3.62	3.38	3.06	3.29	3.96	4.43
1300	3.60	3.22	3.75	3.64	3.38	3.05	2.97	2.64	2.36	2.64	3.27	3.75
1400	4.54	4.36	4.48	4.03	3.96	3.31	3.32	3.30	2.36	2.64	3.82	4.44
1500	4.43	4.13	4.82	4.69	4.50	3.78	3.62	3.38	3.06	3.29	3.96	4.43
1600	3.30	2.94	3.57	3.60	3.35	3.01	2.87	2.62	2.86	3.16	3.26	3.54
1700	3.30	2.94	3.57	3.60	3.35	3.01	2.87	2.62	2.40	2.74	3.26	3.54
1800	4.43	4.13	4.82	4.69	4.50	3.78	3.62	3.38	3.06	3.29	3.96	4.43
1900	4.91	4.72	4.96	4.65	4.65	3.95	3.75	3.61	3.39	3.71	4.34	4.94
2000	3.99	3.58	4.23	4.26	4.07	3.69	3.39	3.04	2.93	3.29	3.79	4.25
2100	4.43	4.13	4.82	4.69	4.50	3.78	3.62	3.38	3.06	3.29	3.96	4.43
2200	5.25	5.11	5.47	5.27	5.32	4.48	4.30	4.07	3.78	4.10	4.67	5.26
2300	5.25	3.97	4.74	4.87	4.74	4.48	3.95	3.50	3.32	4.10	4.12	4.57
0000	4.43	4.13	4.82	4.69	4.50	3.78	3.62	3.38	3.06	3.29	3.96	4.43

Table 3.4: Monthly Averaged Wind Speed at 50m above the surface of the Earth (m/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Ave	4.38	4.14	4.74	4.68	4.49	3.78	3.60	3.38	3.07	3.32	3.96	4.45	

The ten (10) years monthly average wind speed from January to December is as given table 3.4.

From the data presented in table 3.3 the daily average hourly wind speed variation in kumbotso for the month of January, April, July and October between 2002 and 2012 is given below.

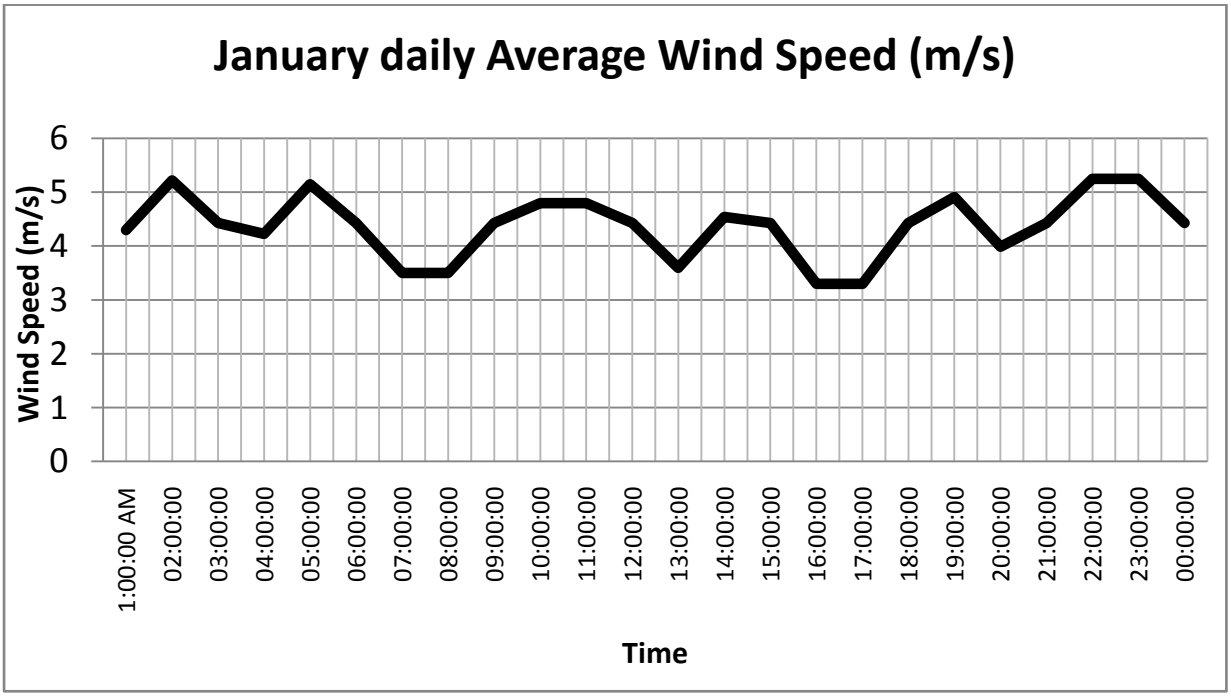


Figure.3.1 Daily average Wind Speed for January

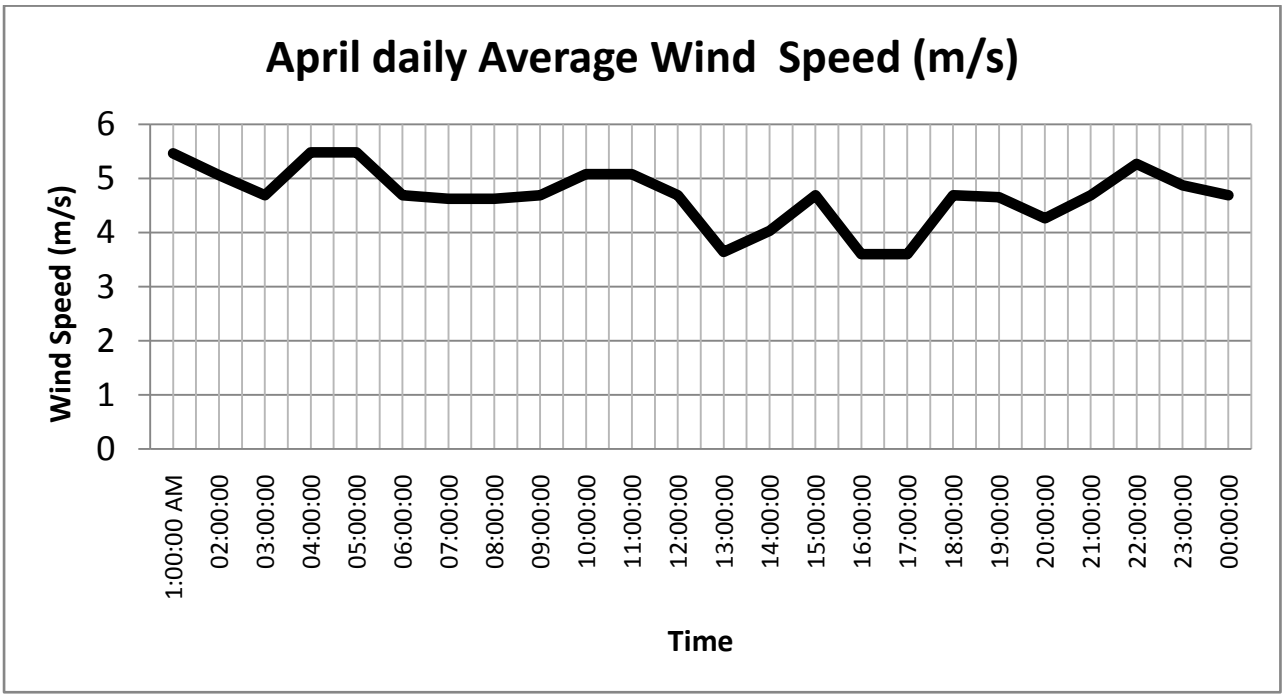


Figure.3.2 Daily average Wind Speed for April

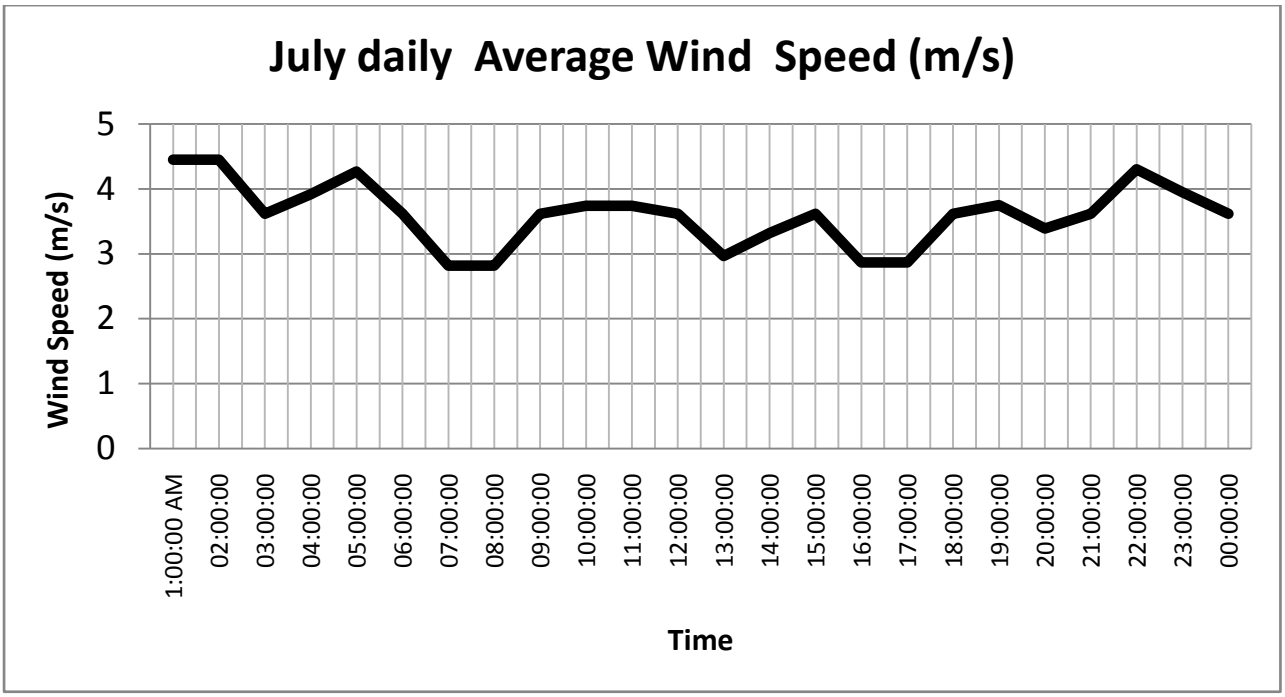


Figure.3.3 Daily average Wind Speed for July

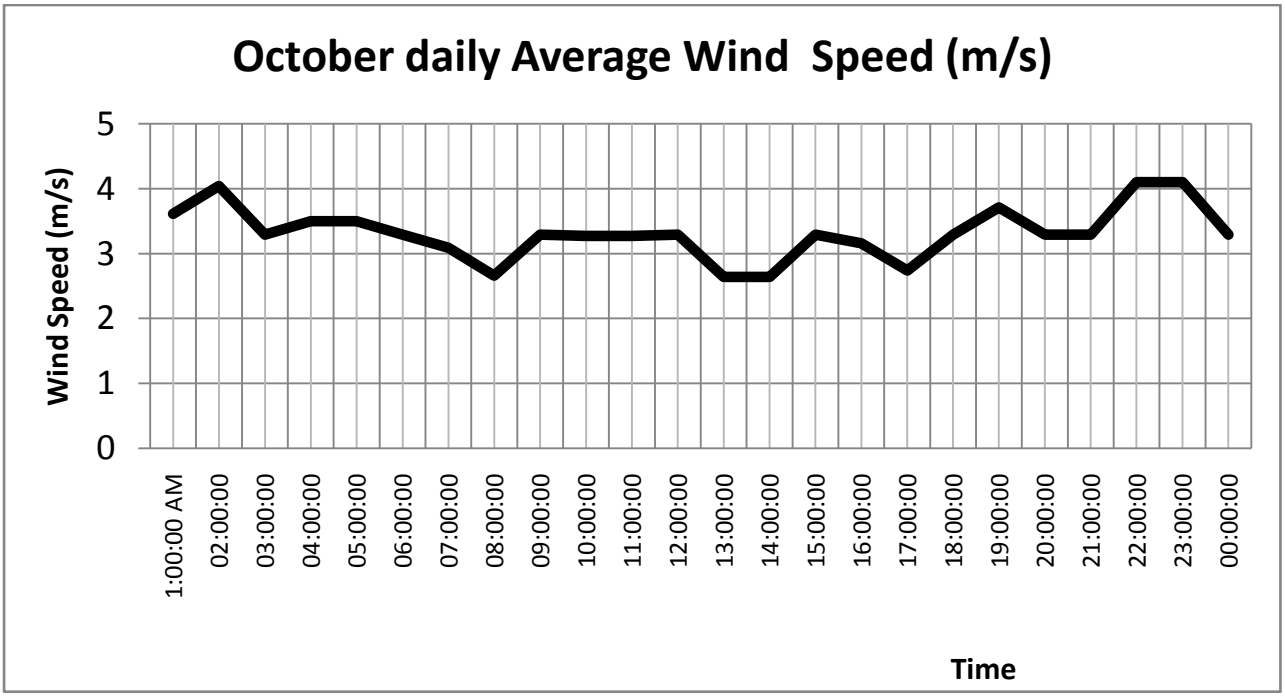


Figure.3.4 Daily average Wind Speed for October

Using equation 2.13 and 2.14 with Raleigh distribution k = 2, the Raleigh distribution function of the measured average Wind Speed for the Month of January to December is as given below.

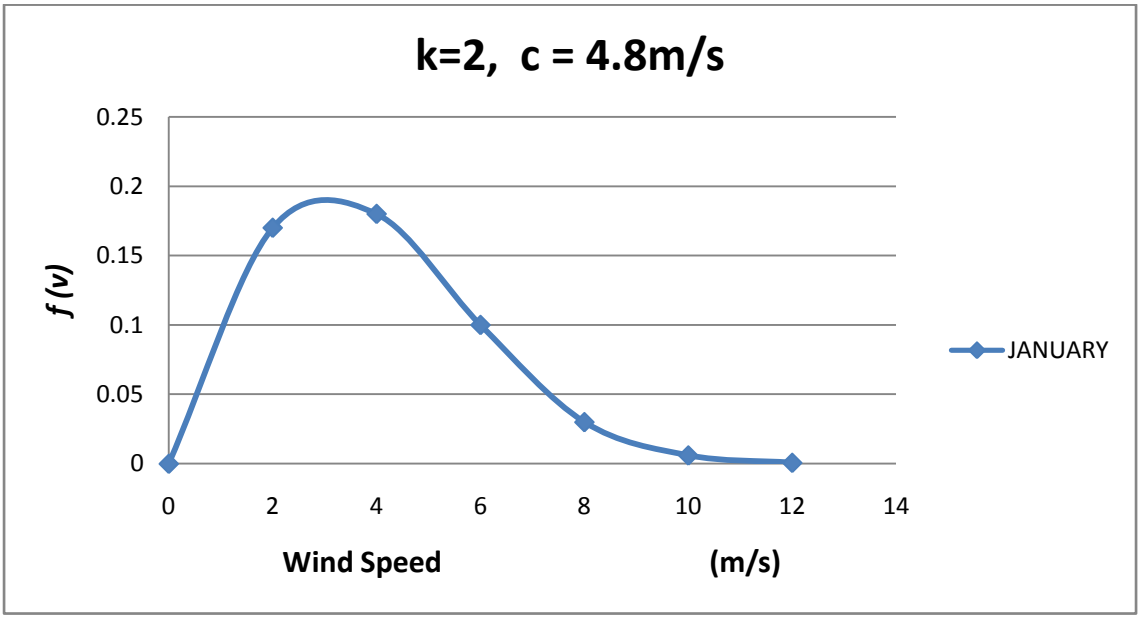


Figure.3.5 Raleigh Distribution of average Wind Speed for January.

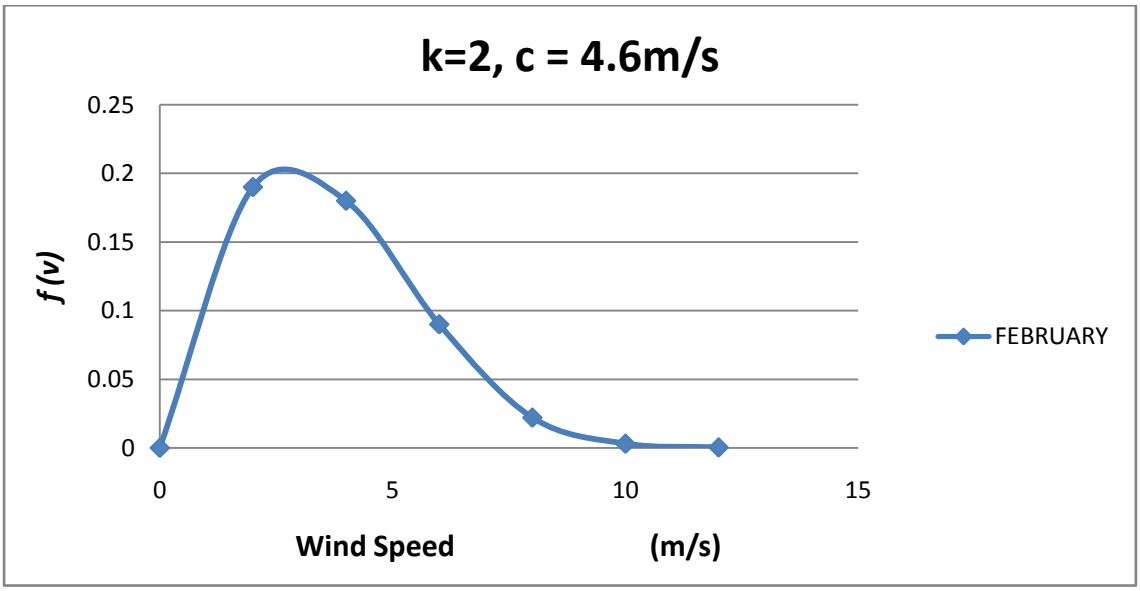


Figure.3.6 Raleigh Distribution of average Wind Speed for February

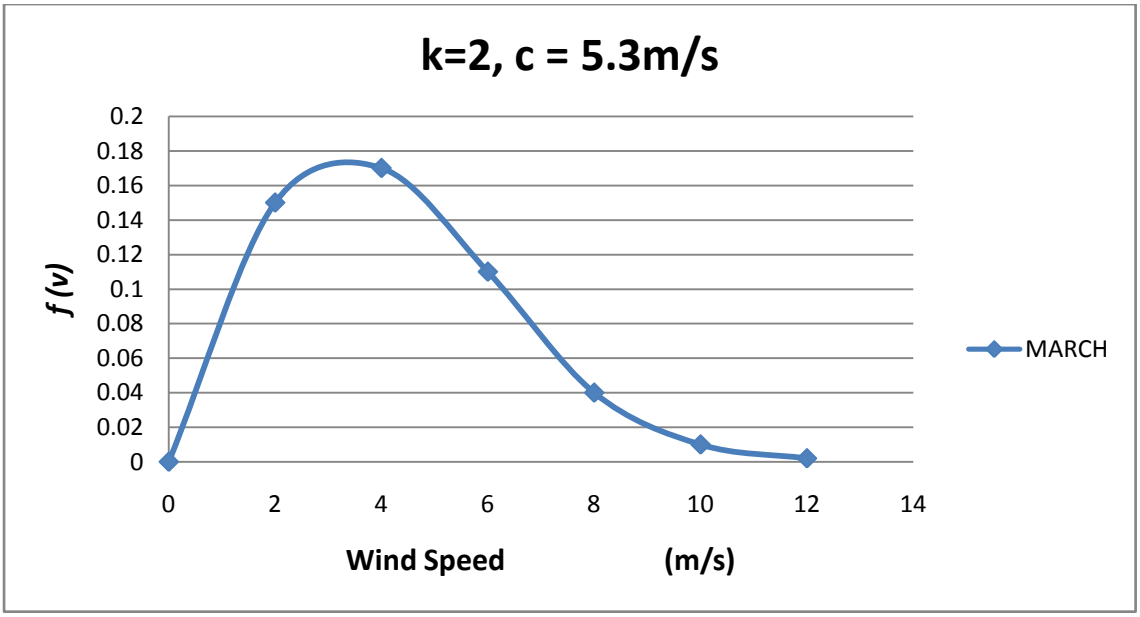


Figure.3.7 Raleigh Distribution of average Wind Speed for March.

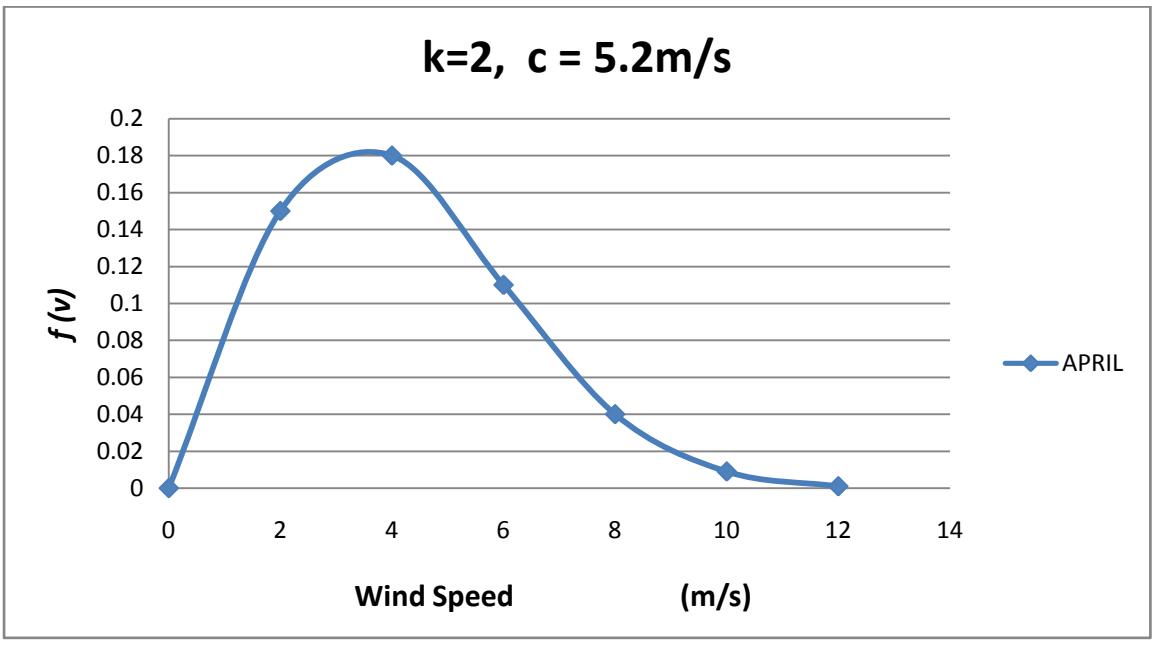


Figure.3.8 Raleigh Distribution of average Wind Speed for April

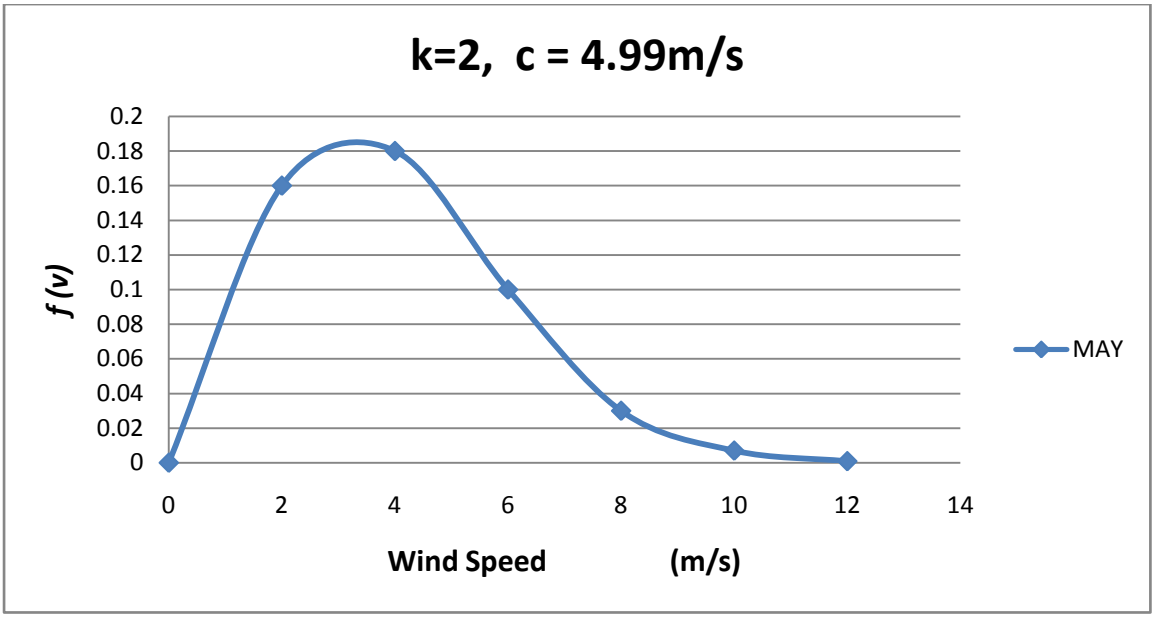


Figure.3.9 Raleigh Distribution of average Wind Speed for May

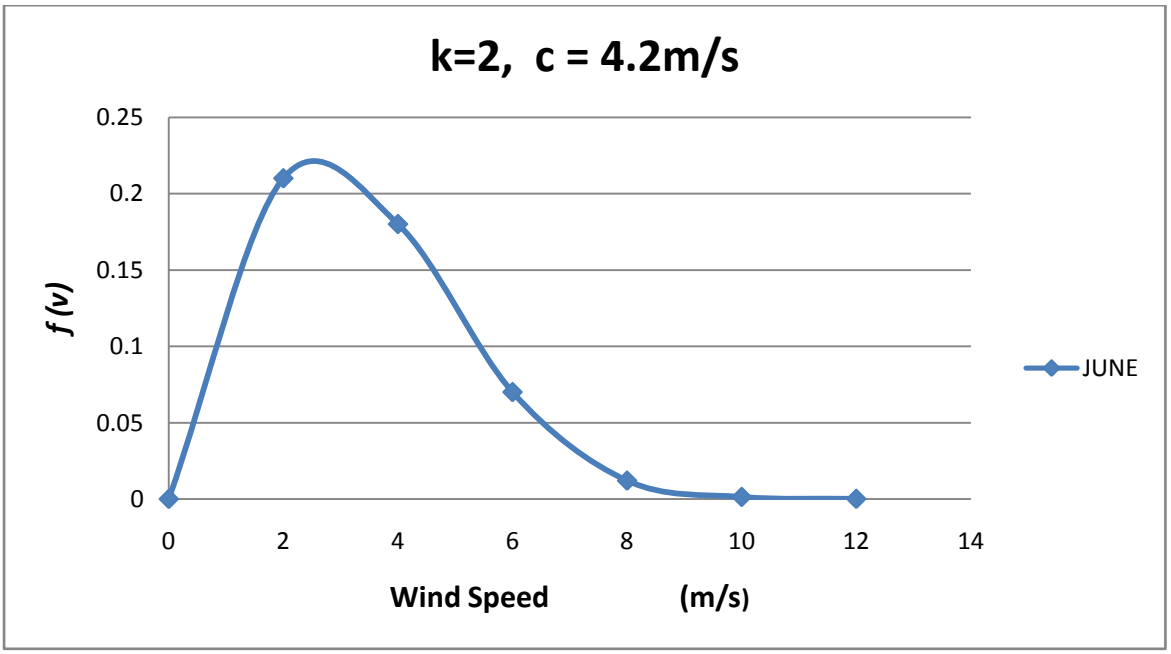


Figure.3.10 Raleigh Distribution of average Wind Speed for June

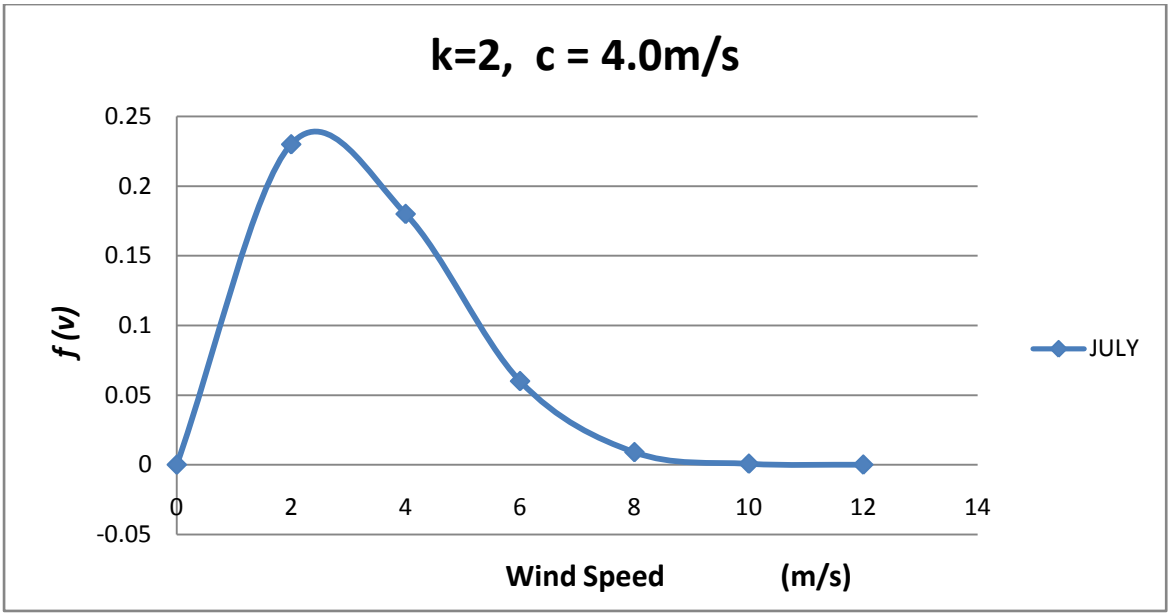


Figure.3.11 Raleigh Distribution of average Wind Speed for July

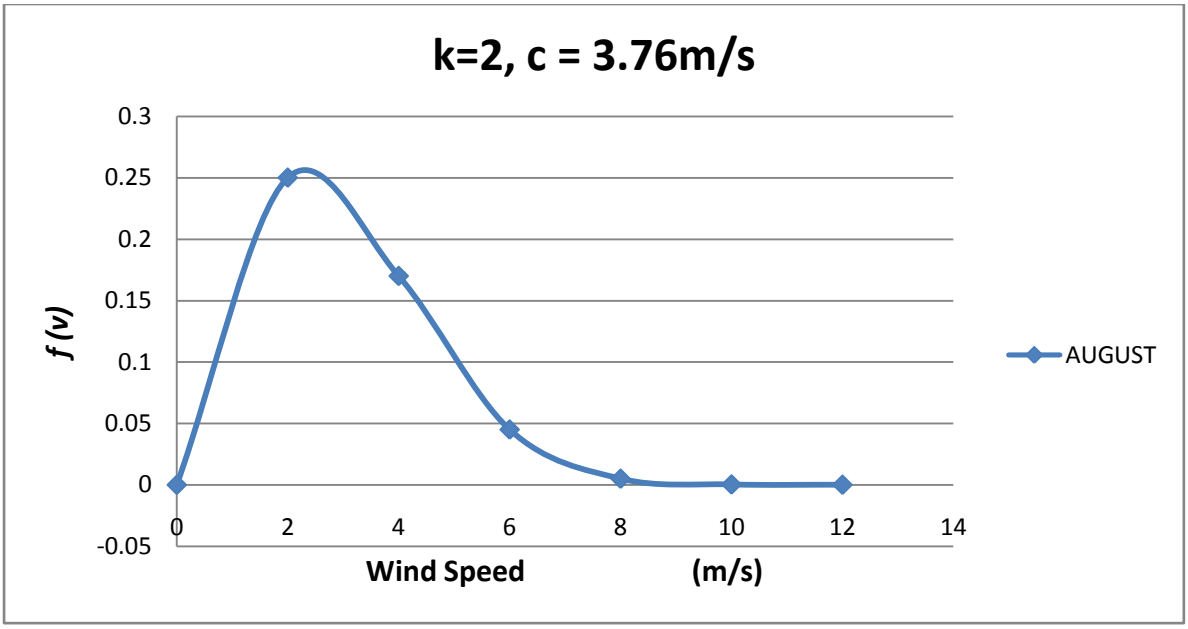


Figure.3.12 Raleigh Distribution of average Wind Speed for August.

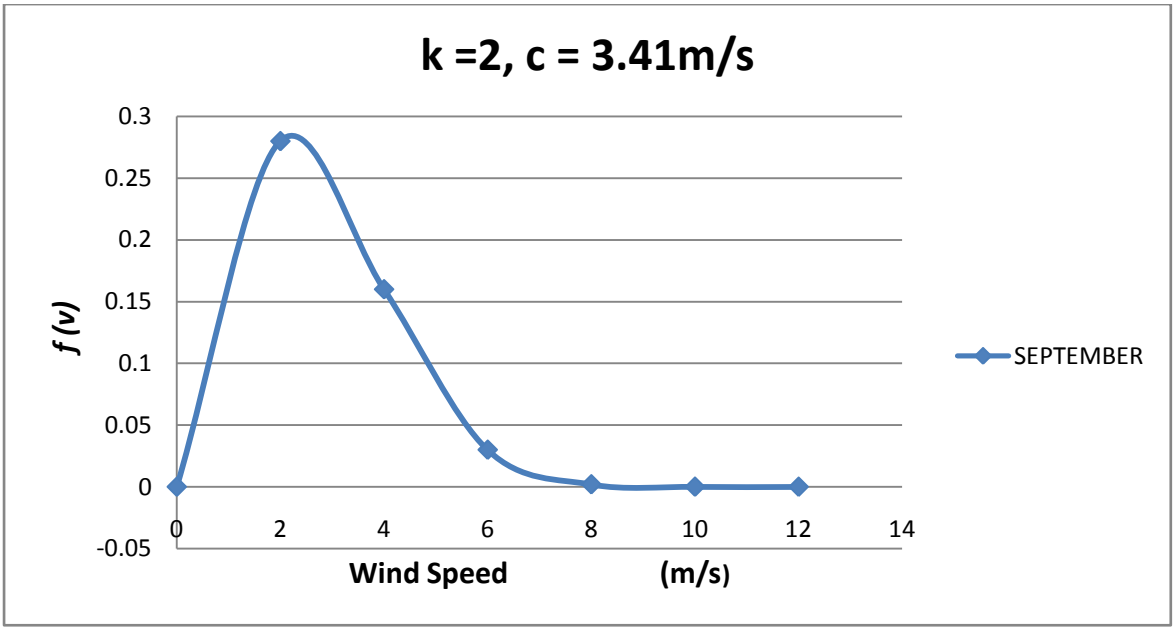


Figure.3.13 Raleigh Distribution of average Wind Speed for September

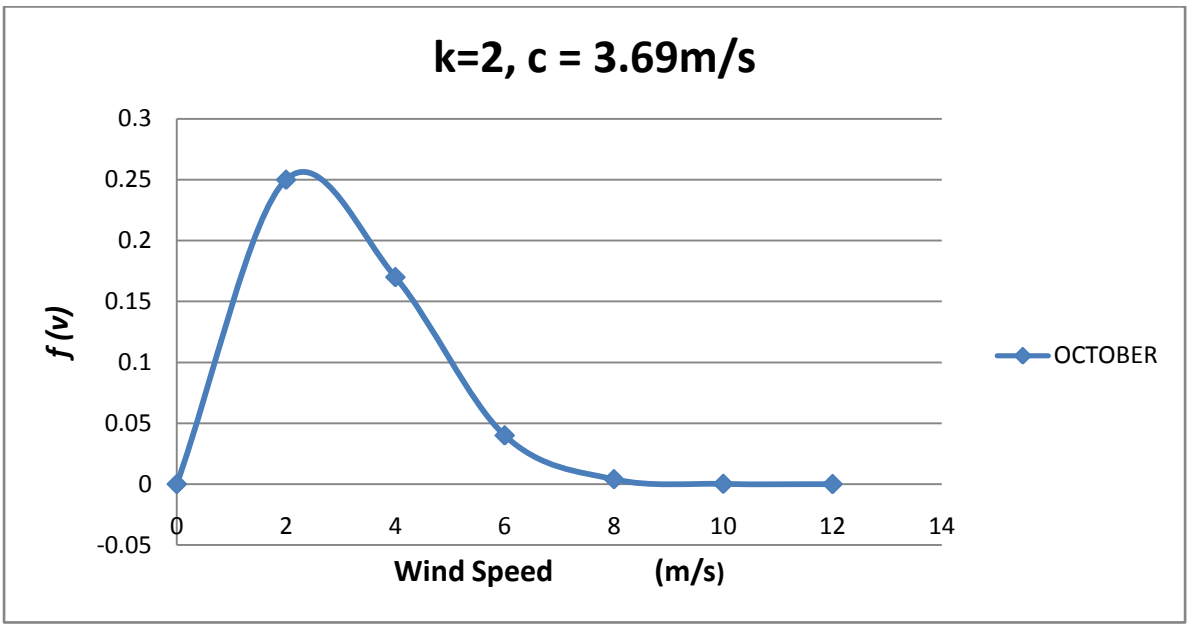


Figure.3.14 Raleigh Distribution of average Wind Speed for October

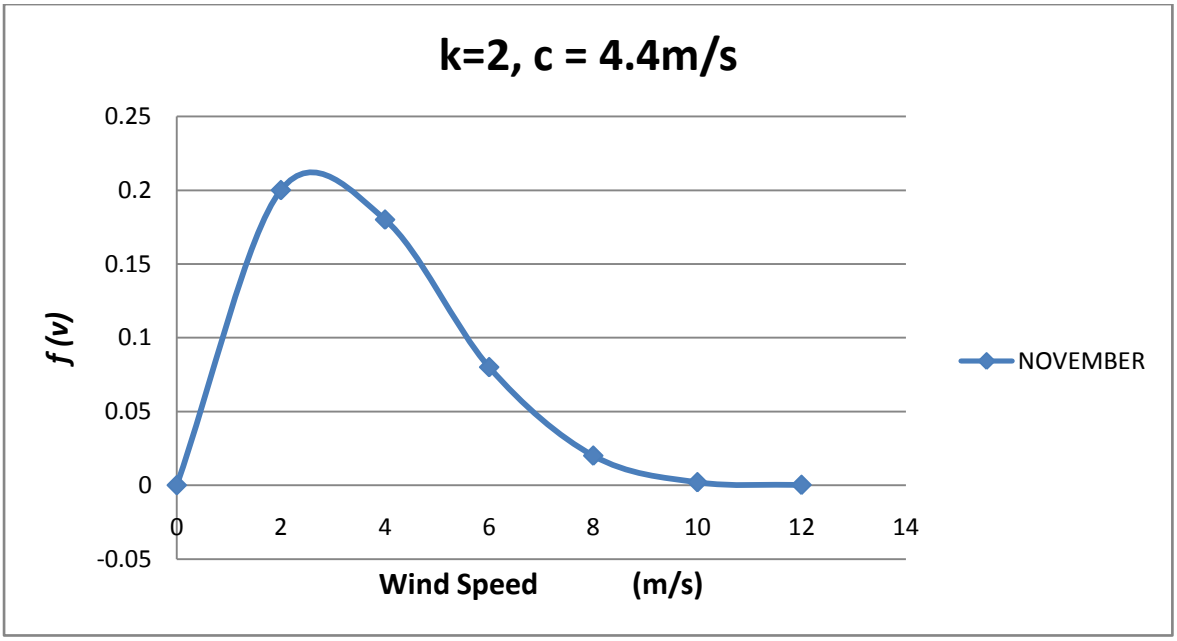


Figure.3.15 Raleigh Distribution of average Wind Speed for November

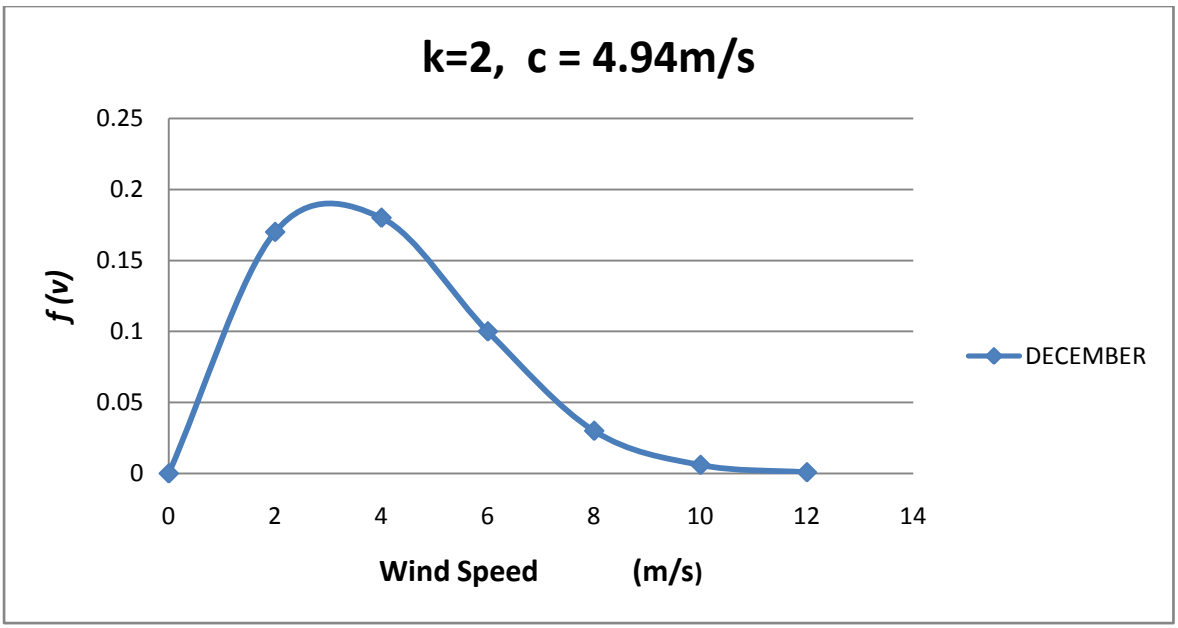


Figure.3.16 Raleigh Distribution of average Wind Speed for December.

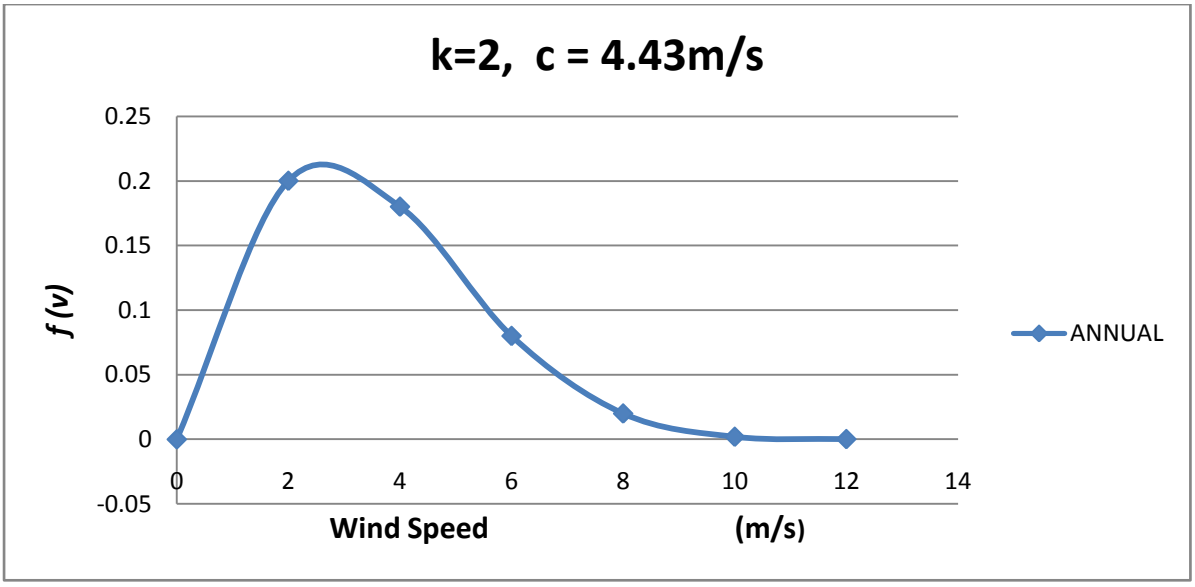


Figure.3.17 Raleigh Distribution of Annual average Wind Speed.

3.2 Design Parameters for Vertical Axis Wind Turbine

It is clear that a small Blade Area (A) would produce small power while large Blade Area produces large power. Density and speed are properties of the air, which in most locations remain within a certain range. The blade area is the only factor which is design and production based. Hence, large area is aimed in order to produce meaningful power. Long blades demand higher towers, since the heavier weight cannot be propelled by the low wind speed at small heights. Horizontal Wind Turbines have vanes that must rotate them to the wind before flying. For the change in wind direction, the blade stall, and are then positioned again by the vane to fly. Vertical Wind Turbines are Omni-directional. Once there is wind, the rotation is continuous. There is always a blade in its direction to hit. Thus for the same blade area, Vertical Wind Turbines accesses more energy from the wind than Horizontal Wind Turbine and are limited to low power productions of not more than 20,000 watts, whereas, the Horizontal Wind Turbine can be constructed to any height to produce any

desired quantity of power. Further increases in the blade area conspicuously lead to sagging and obstruction creation to existing structures. Vertical Wind Turbines are placed to access wind at low heights. Another advantage is that the power train, generator, and controls are all located near ground level, hence are easier to construct and maintain. The efficiency is nearly as good as that of the horizontal axis propeller turbine, so the Darrieus holds considerable promise as a cost effective turbine (Patel, 1999).

One disadvantage of the Darrieus is that it is not normally self starting. That is, if the turbine has stopped during a period of low wind speeds, it will not usually start when the wind speed increases. Starting is usually accomplished by a savonious rotor connected to the system. Also, a disc brake which can be applied mechanically, electrically or hydraulically to stop the rotor in emergencies is connected to the system (Krause *et al.*, 2002).

In the design the following parameters are considered.

(a) A mean speed, V_m of 4.0m/s (which is annual mean wind speed)

(b) Swept area, A (depend on the choice of diameter)

(c) Coefficient of performance, C_p = 0.35 (this is obtained in figure 2.6 based on the type of wind turbine rotor)

(d) The Air density, ρ =1.23 kg /m^3

(e) Transmission efficiency, E =0.85

(f) Tip-speed ratio, $\boldsymbol{\lambda} = 6$ (obtained in figure 2.6)

I. Using equation 2.22, the maximum shaft power can be calculated as:

$$P = \frac{1}{2} \times 1.23 \times A \times 4.0^3 \times 0.35$$

$$A = \frac{2}{3}\,(maximum\ rotor\ width\ at\ the\ center)(Height\ of\ the\ rotor)$$

$$maximum\ rotor\ width\ at\ the\ center = 8\text{m}^2$$

$$Height\ of\ the\ rotor = 2m$$

$A = \frac{2}{3} \times 8 \times 2 \ = 10.6666\, m^2$

$P_o \ = 146.94 \quad watt.$

II. Obtainable Shaft Power will be, $P_s = E \times P_o \ = 0.85 \times \ 179.34 \ = 124.90 \quad watt.$

Using equation 2.23, $Rotor\ Speed, N = \frac{60\ \lambda\ V_m}{\pi D}$

$N = \frac{60 \times 6 \times 4.0}{\pi\ 8}$ r p m

$N = 57.2\ r\ p\ m$

CHAPTER FOUR

CONVERSION OF INDUCTION MOTOR TO GENERATOR

4.1 Conversion Parameters of the Induction Motor used.

Use of an induction machine as a generator is becoming more and more popular for the renewable sources. Reactive power consumption and poor voltage regulation under varying speed are the major drawbacks of the induction generators, but the development of static power converters has facilitated the control of the output voltage of induction generators (Bansal, 2005).

To convert induction motor to a generator and in order to obtain the required operating voltage at a desired frequency, the amount of capacitance must be carefully chosen. Therefore, the induction motor characteristic according to the motor nameplate by the manufacturer is an important factor considered in the selection of the capacitors. The characteristic of the induction motor used is as given below.

Motor Nameplate.

Cos φ = 0.73

Power in Watt = 800W

Nominal Voltage (V) = 400/440

Current (I) = 2.1A

Frequency = 50Hz

Speed (r p m) = 940

Temperature = 40℃

The magnetizing current (I_m) required by an induction machine as a function of terminal voltage can be found by running the machine as a motor at no load and measuring its armature current as a function of terminal voltage. The current limit on an induction motor is based on the maximum acceptable heating (Temperature) in the motor's windings and the

power limit is set by the combination of the voltage and current ratings with the machine's power factor and efficiency as given by the name plate.

4.2 Determination of Parameters of the Capacitors used.

From the data given by the induction motor manufacturer as stated in section 4.1, other parameters are determined as follows:

$\varphi = \cos^{-1} 0.73, \quad \varphi = 43.11°$

$\sin \varphi = 0.68$

Reactive Power (Q) = $\sqrt{3} \times I \times V \times \sin 0.68$

Reactive Power (Q) = 989.35 var

$Q = I^2 X_C$

$X_C = \frac{Q}{I^2}$ Where X_C is the reactance.

$X_C = \frac{989.35}{(2.1)^2}$

$X_C = 224.34\ \Omega$

Capacitor value, $C = \frac{1}{2\pi f X_C}$

$C = \frac{1}{2\times\pi\times50\times224.34} = 14.19\mu F$

∴ The minimum capacitor needed for the motor excitation is $14.19\mu F$

The capacitor values used in this research includes:

a. $16\mu F \ \ 350VAC \ \ 50/60Hz$;
b. $24\mu F \ \ 350VAC \ \ 50/60Hz$;
c. $35\mu F \ \ 450VAC \ \ 50Hz$; and
d. $50\mu F \ \ 450VAC \ \ 50Hz$

4.3 Laboratory Experiment and Measurements

The block diagram of the Laboratory Experiment of the variable speed wind turbine model is depicted in figure 4.1.

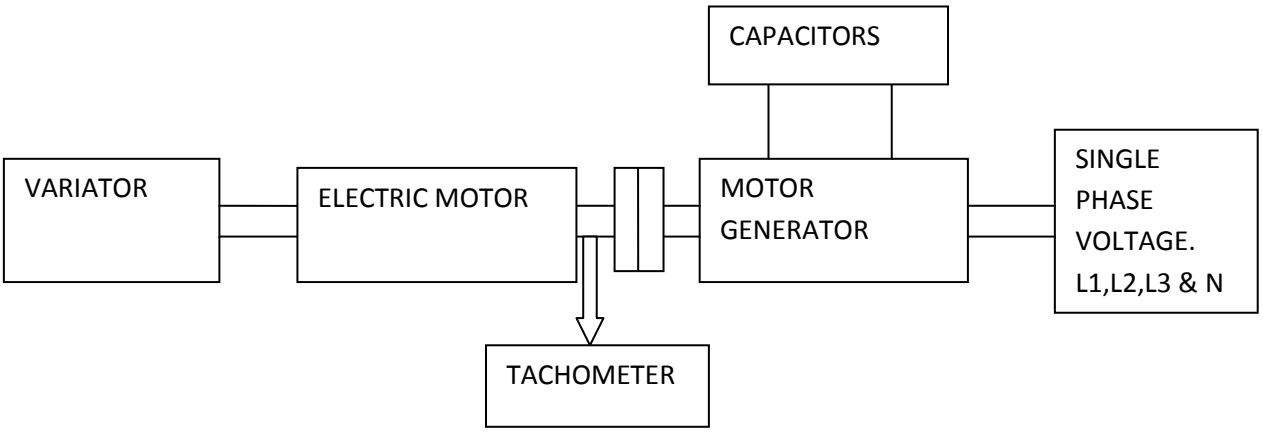


Figure 4.1 Block Diagram of Experimental Setup to determine single phase Voltages as the Speed varies.

4.4 Test Circuit

The following circuit connections were considered so as to compare their output voltages.

Type I

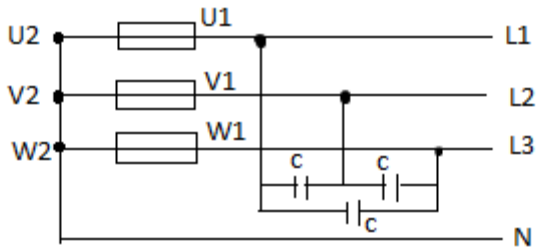


Figure.4.2 Test circuit Type I (Delta Connection)

Type II

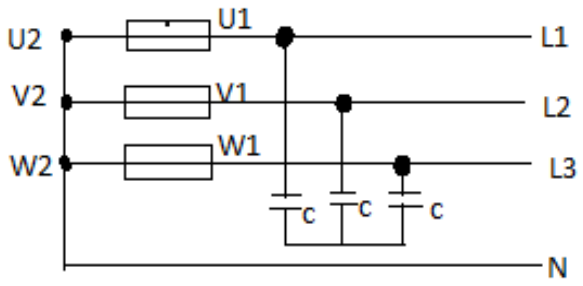


Figure.4.3 Test circuit Type II (Star Connection)

Type III

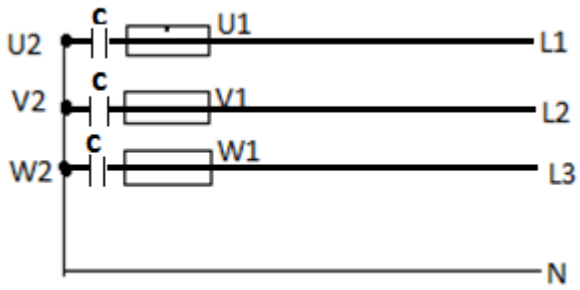


Figure.4.4. Test circuit Type III (Parallel Connection)

Where; U_1 U_2, V_1 V_2 and W_1 W_2 are the power lead (Terminal board) of the induction generator.

C is the capacitor. L1, L2 and L3 are the output lines.



Figure.4.5 Experiment set up

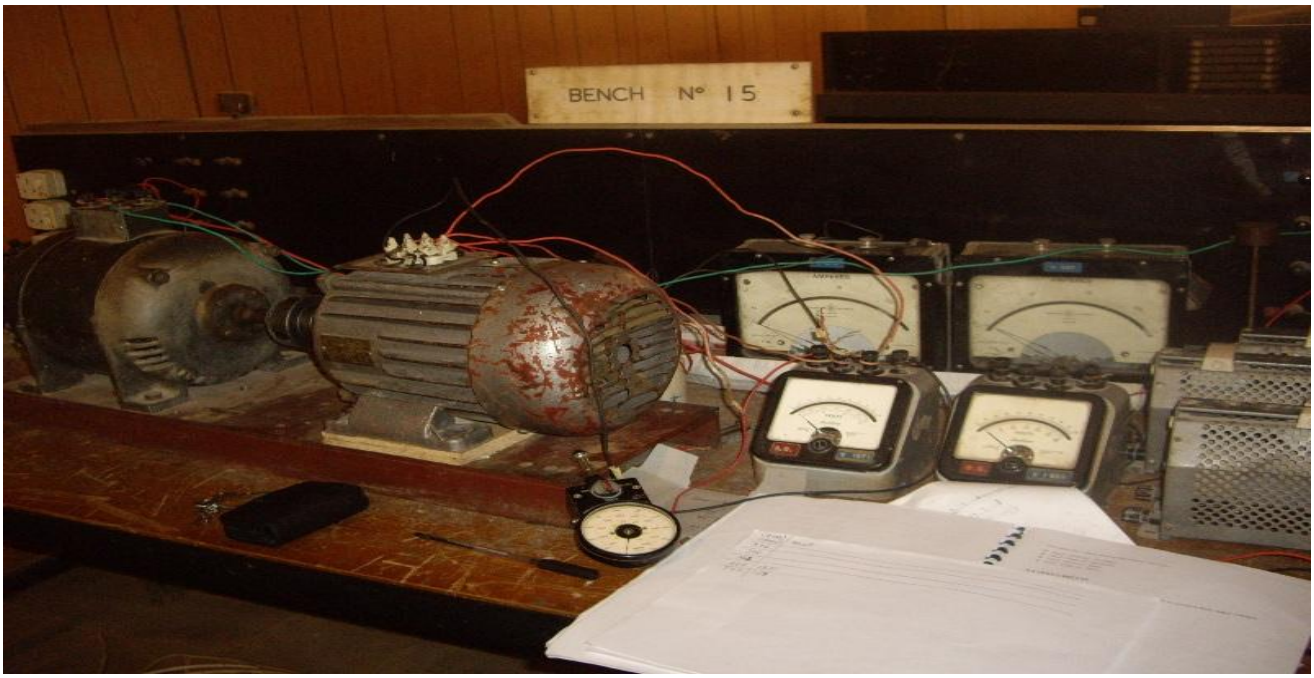


Figure.4.6 Experiment set up (Showing the Tachometer and the Voltmeters)

CHARPTER FIVE

RESULTS AND DISCUSSION

5.1 Result

The NASA hourly wind velocity was subjected to two parameters Rayleigh function analysis and shows that the most frequently occur average wind speed annually is 3m/s. The monthly mean wind speed as it is shown in table 3.4 is between 3.07 m/s – 4.74 m/s having the highest monthly mean wind speed in the month of March and April and yearly average wind speed of 4.0m/s.

A three-phase, 800W, 8-pole, 50 Hz squirrel cage induction machine is operated as a self-exited induction generator. Three-phase ac capacitors were connected in delta, star and parallel configuration across the generator terminals to act as the source for the excitation current. The generator is run at different rotor speeds commanded by a variator connected to electric motor and setting the appropriate rotor speed by a tachometer.

Tables 5.1, 5.2 and 5.3 give AC voltage value for capacitor 16µF, 24µF, 35µF and 50µF for the three types of circuit connection at speed of 956, 706 512 and 500 rpm.

Table 5.1: Voltages (Volt) Obtained from Circuit Connection Type I (Delta connection)

	CAPACITOR (16µF)			CAPACITOR (24µF)			CAPACITOR (35µF)			CAPACITOR (50µF)		
SPEED (RPM)	L1-N	L2-N	L3-N	L1-N	L2-N	L3-N	L1-N	L2-N	L3-N	L1-N	L2-N	L3-N
956	200	204	202	200	198	199	306	308	306	305	306	305
706	0	0	0	0	0	0	253	253	252	252	252	253
512	0	0	0	0	0	0	154	154	154	154	154	153
500	0	0	0	0	0	0	150	150	150	150	150	150

Table 5.2: Voltages (Volt) Obtained from Circuit Connection Type II(Star connection)

	CAPACITOR (16μF)			CAPACITOR (24μF)			CAPACITOR (35μF)			CAPACITOR (50μF)		
SPEED (RPM)	L1-N	L2-N	L3-N	L1-N	L2-N	L3-N	L1-N	L2-N	L3-N	L1-N	L2-N	L3-N
956	0	0	0	0	0	0	146	146	145	152	152	153
706	0	0	0	0	0	0	0	0	0	0	0	0
512	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.3: Voltages (Volt) Obtained from Circuit Connection Type III(Parallel connection)

	CAPACITOR (16μF)			CAPACITOR (24μF)			CAPACITOR (35μF)			CAPACITOR (50μF)		
SPEED (RPM)	L1-N	L2-N	L3-N	L1-N	L2-N	L3-N	L1-N	L2-N	L3-N	L1-N	L2-N	L3-N
956	0	0	0	0	0	0	101	101	101	102	102	102
706	0	0	0	0	0	0	0	0	0	0	0	0
512	0	0	0	0	0	0	0	0	0	0	0	0

From the voltages (Volts) Obtained from Circuit Connection Type I (Delta connection) in table 5.1, further experiment was carried out using capacitor 50μF and the result is as shown in table 5.4.

Table 5.4: The Speed (rpm) and the Stator Output Voltage (Volts) with 50μF capacitor connected in Delta.

Speed (rpm)	450	500	550	600	650	700	750	800	850	900	950
Stator Output Voltage (Volts)	0	150	200	232	244	252	260	269	278	289	305

From Table 5.1 the graph of AC voltage (Stator Output) value of the Generator for capacitor 16µF, 24µF, 35µF and 50µF for the Delta type of circuit connection versus speed of 956, 706 512 and 500 rpm are presented in figure 5.1 to figure 5.4

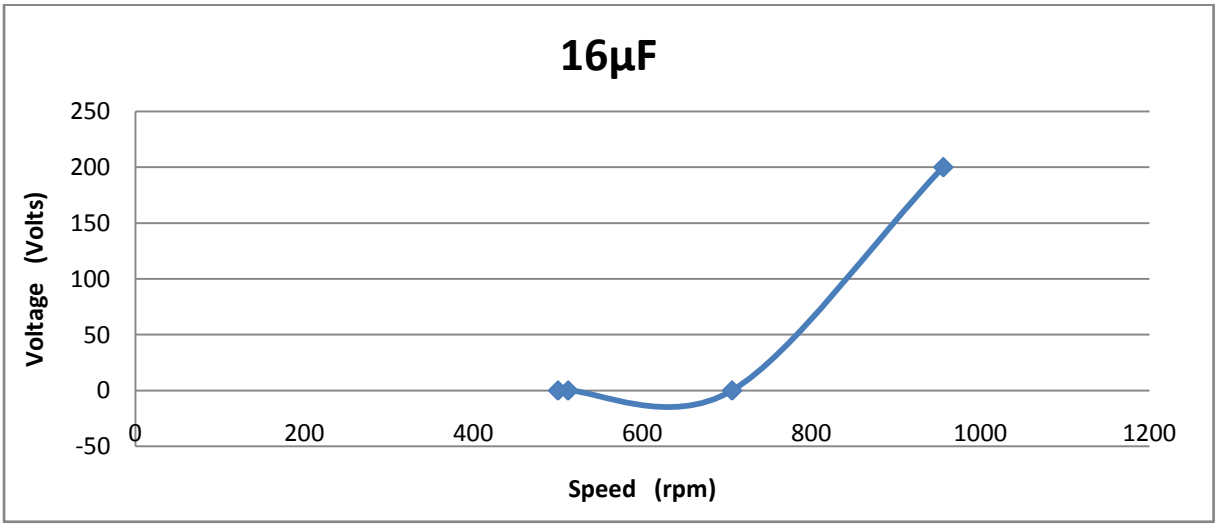


Figure.5.1 The Speed (rpm) versus the Stator Output Voltage of the Generator

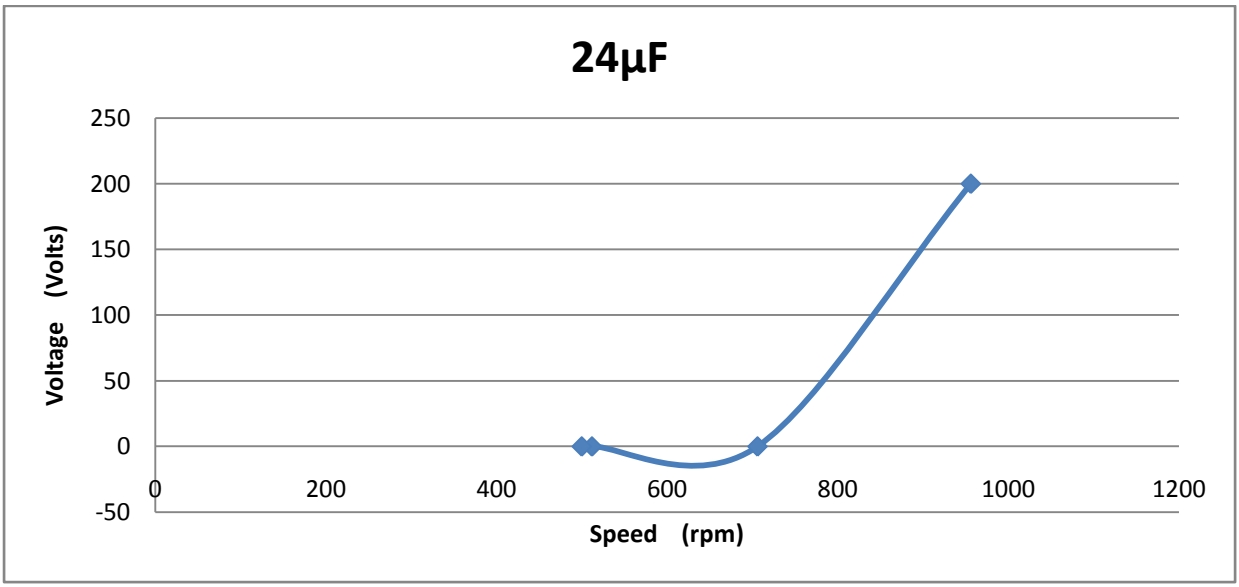


Figure.5.2 The Speed (rpm) versus the Stator Output Voltage of the Generator

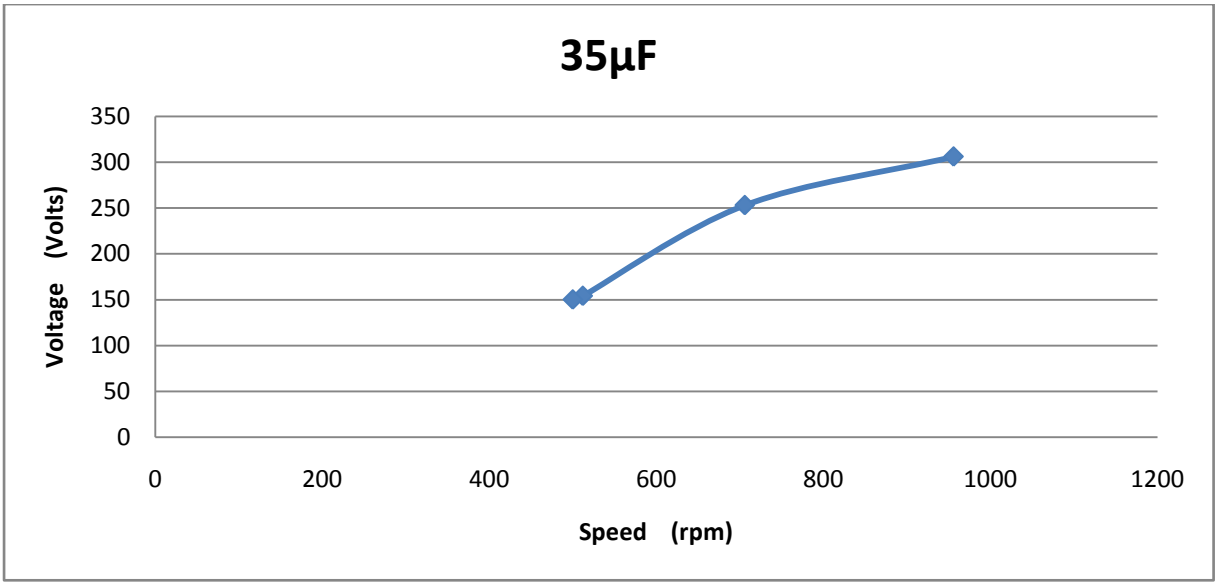


Figure.5.3 The Speed (rpm) versus the Stator Output Voltage of the Generator

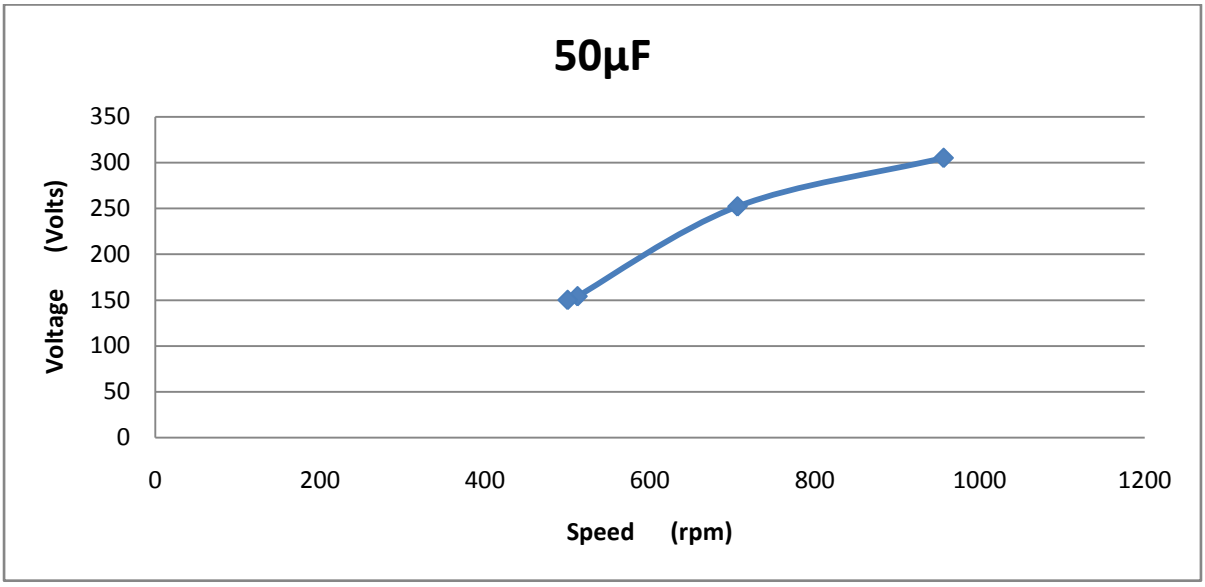


Figure.5.4 The Speed (rpm) versus the Stator Output Voltage of the Generator

From Table 5.2 the graph of AC voltage (Stator Output) value of the Generator for capacitor 35µF and 50µF for the Star type of circuit connection versus speed of 956, 706 512 and 500 rpm are presented in figure 5.5 and 5.6

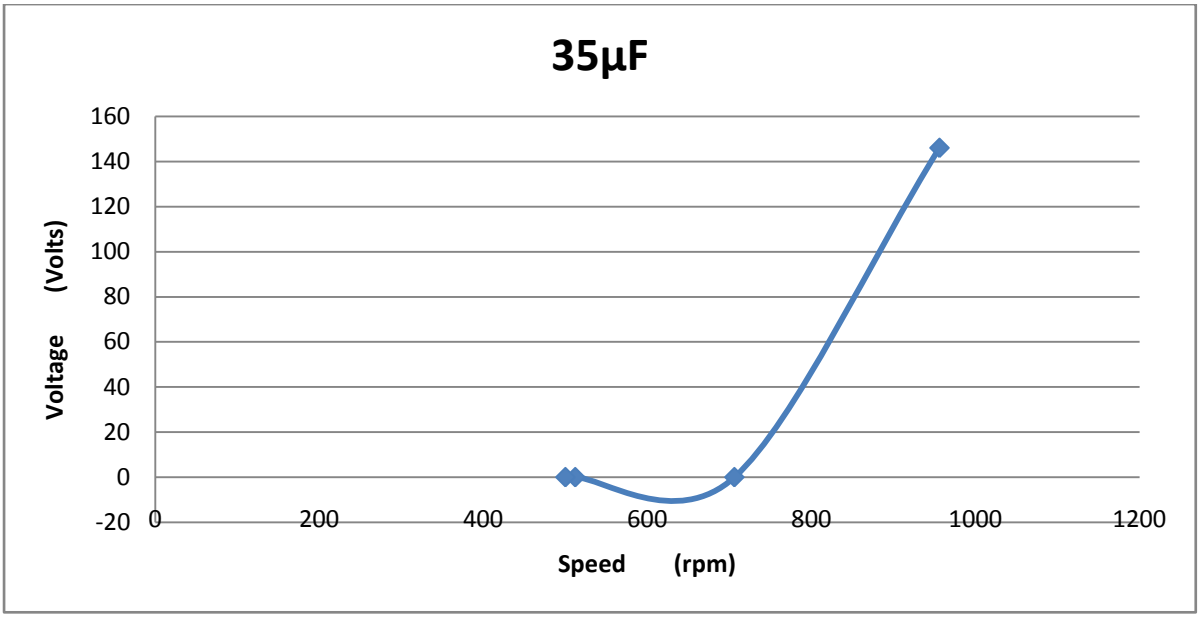


Figure.5.5 The Speed (rpm) versus the Stator Output Voltage of the Generator

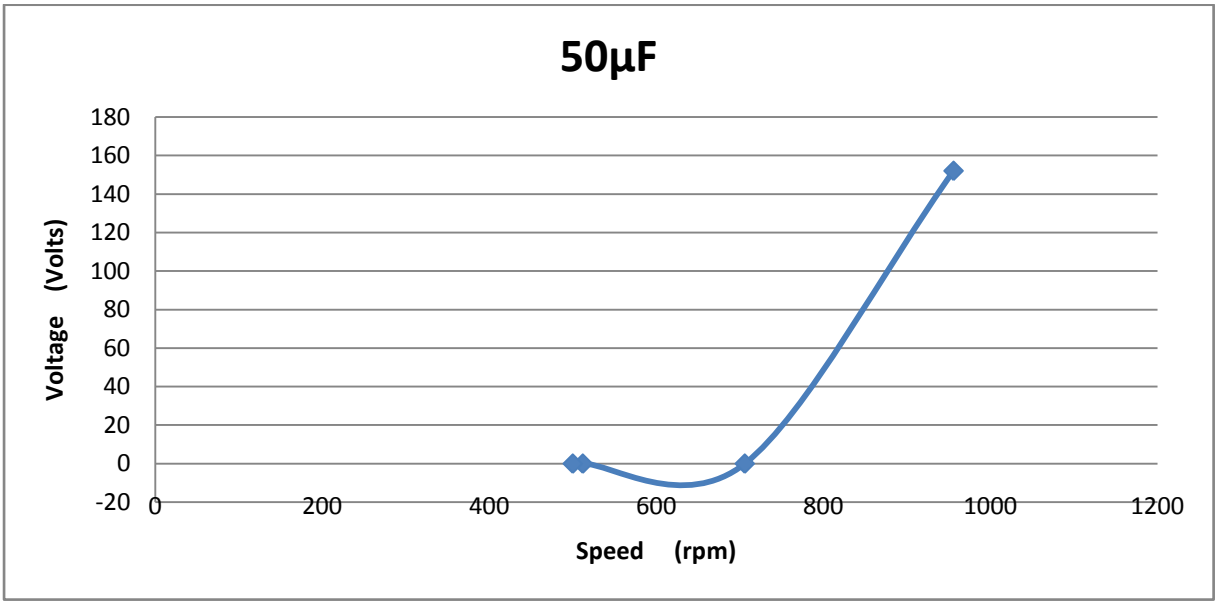


Figure.5.6 The Speed (rpm) versus the Stator Output Voltage of the Generator

From Table 5.3 the graph of AC voltage (Stator Output) value of the Generator for capacitor 35µF and 50µF for the Parallel type of circuit connection versus speed of 956, 706 512 and 500 rpm are presented in figure 5.7 and 5.8

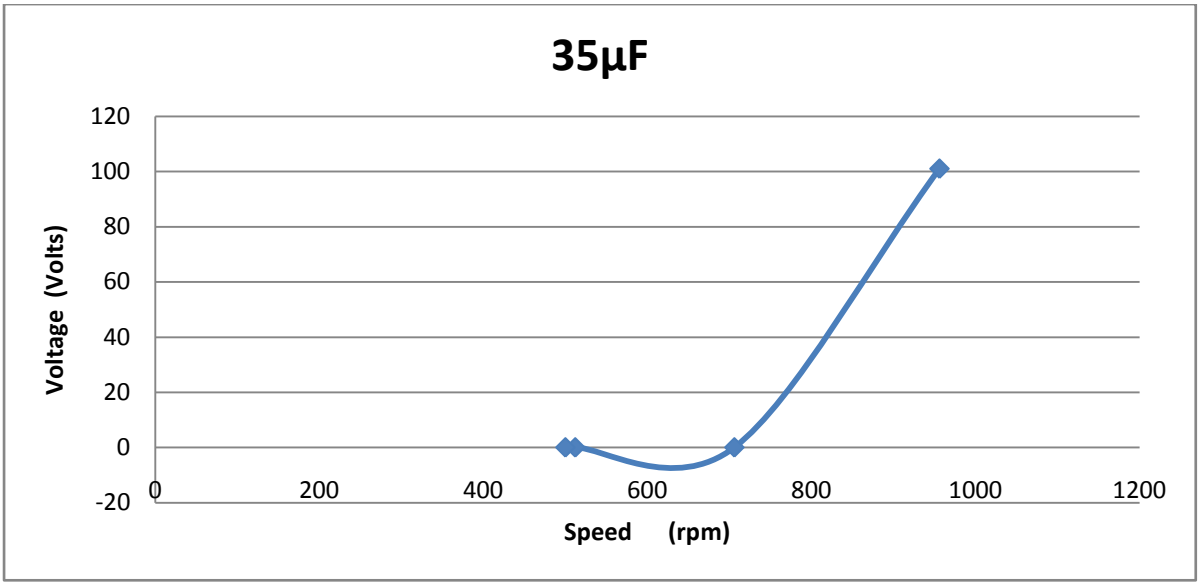


Figure.5.7 The Speed (rpm) versus the Stator Output Voltage of the Generator

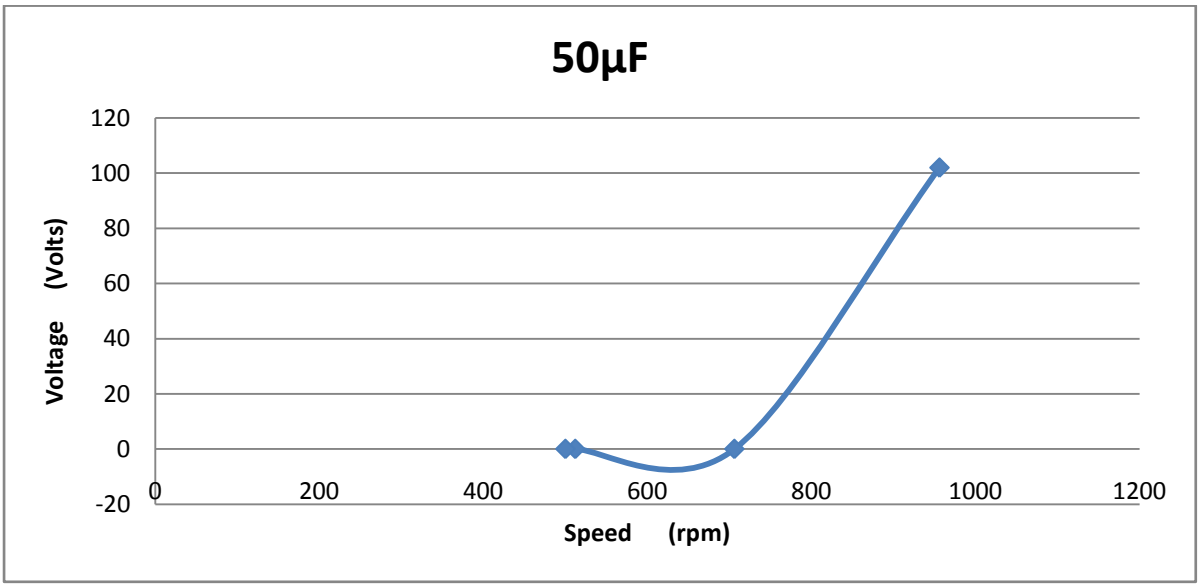


Figure.5.8 The Speed (rpm) versus the Stator Output Voltage of the Generator

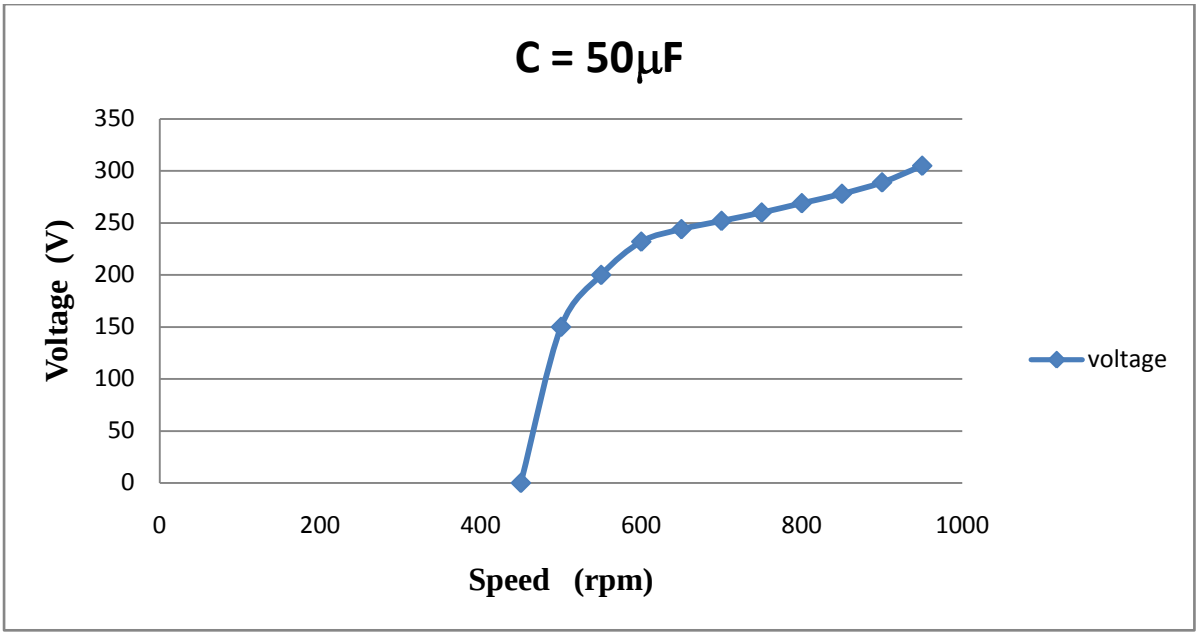


Figure.5.9 The Speed (rpm) versus the Stator Output Voltage of the Generator

From Table 5.4, a graph of Speed (rpm) versus the Stator Output Voltage of the Generator is plotted as seen in figure.5.9. This shows that at no load the voltage of the generator with 50μF capacitive value increases with increase in the speed of the generator. It is also important to note that the voltage rises when the capacitance increases as it is shown in figure 5.9.

5.2 Variable-Speed Control using Power Electronics

In wind power system operating at variable speed for maximum annual energy production, the output frequency and voltage of the induction generator vary with the wind speed. The variable-frequency, variable-voltage output is converted into fixed voltage 60 Hz or 50 Hz terminal output to match with utility requirement. The modern variable-speed drive uses power electronics to convert variable voltage, variable frequency output of the generator into the fixed voltage, fixed frequency output. The technology is similar to that used in the aircraft power system (Berg, 1973). The conventional silicon controlled rectifiers and inverters are presented in this research work, but the modern design in the wind industry appears to prefer

pulse-width-modulated thyristors (Patel, 1999). The variable frequency is first rectified into DC, and the DC is then inverted back into the fixed frequency AC. The rectifying and inverting circuits are presented in figure 5.11 and Figure 5.12

Figure 5.10 shows the block diagram of the rectifying and inverting processes.

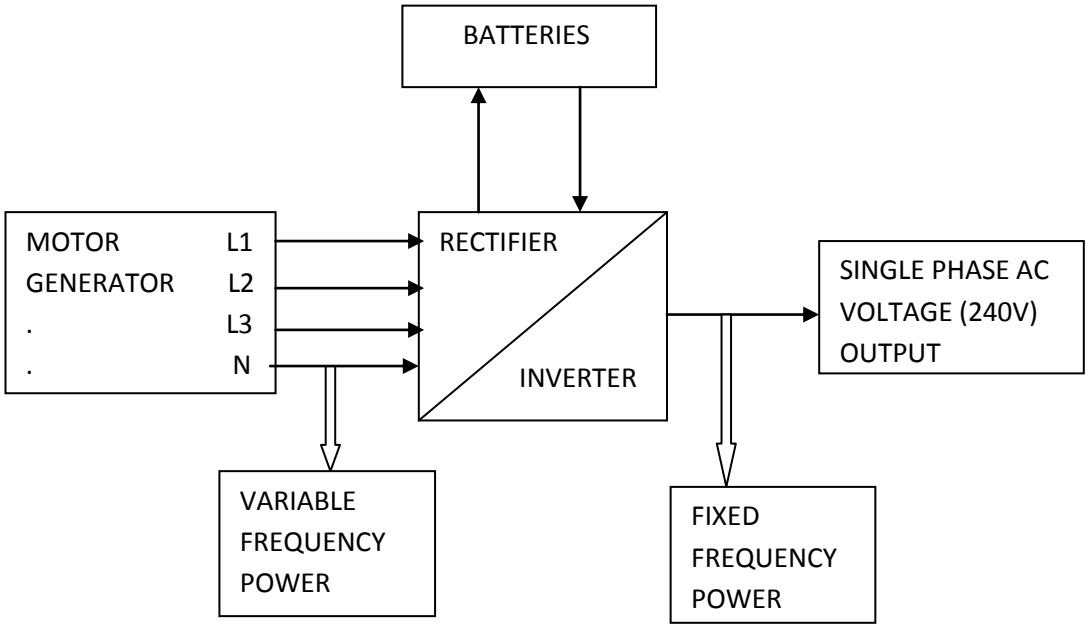


Figure. 5.10 Block Diagram of variable Speed and constant Voltage Output

AC to DC Rectifier

The circuit diagram of the full-bridge, three-phase, AC to DC rectifier is shown in Figure 5.11.The power switch generally used in the rectifier is the silicon-controlled rectifier.

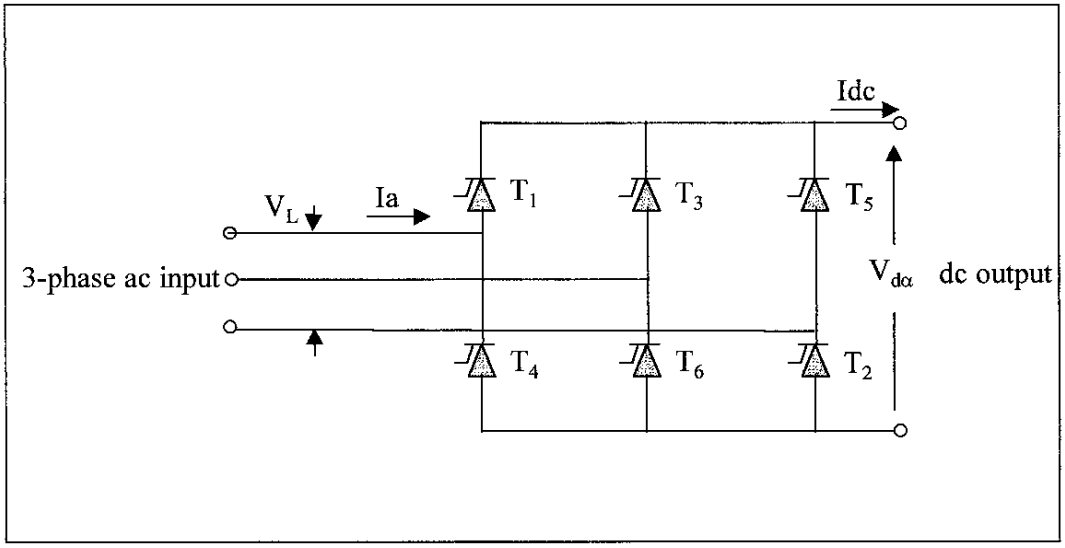


Figure 5.11Three-phase full bridge AC to DC silicon-controlled rectifier circuit.

DC to AC Inverter

The power electronic circuit used to convert DC into AC is known as the inverter. The term "converter" is often used to mean either the rectifier or the inverter. The DC input to the inverter can be from any of the following sources:

• Rectified DC output of the variable speed wind power system.

• DC output of the photovoltaic power modules.

• DC output of the battery used in the wind or photovoltaic power system.

Figure 5.12 shows the DC to three-phase AC inverter circuit diagram. The DC source current is switched successively in a 60 Hz three-phase time sequence such as to power the three-phase load (Sastry *et al.*, 2005).

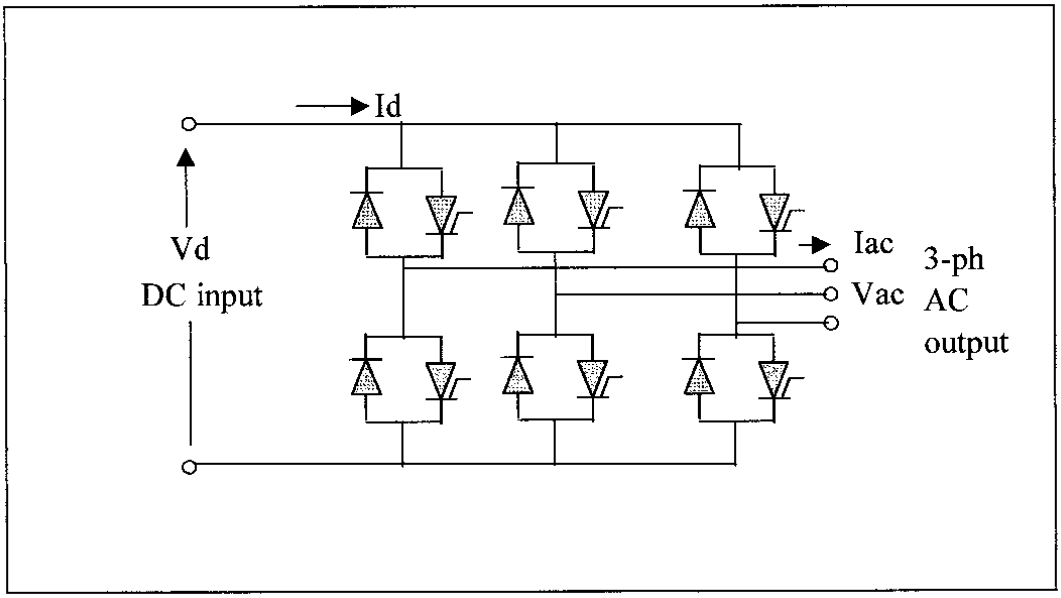


Figure 5.12 DC to three-phase AC inverter circuit

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Remarks

From the designed rotor speed of 57.2 rpm of a Darrieus rotor and the maximum practical gear ratio of 6:1 per stage, the required gear stage to drive the induction generator at the speed of 1000rpm is 1000/57.2 = 17.48:1 which means, operating at 57.2rpm of the rotor speed required a two stage transmission to drive the 1000rpm of the induction motor. Furthermore, the gear ratio of 5:1 per stage is adequate. Using the one stage gear ratio of 6:1 and two stage of 36:1, the rotor speed of 57.2 becomes 2059.2 rpm to drive the induction generator. While one stage gear ratio of 5:1 and two stage of 25:1, will convert the rotor speed of 57.2rpm to 1430rpm to drive the same induction motor. Therefore, the speed to drive the 1000rpm induction motor could be accomplished with gear ratio of 5:1 per stage.

6.2 Conclusion

In statistical modeling of wind velocity variation, many computational techniques have been developed as stated early in literature review. In this study the measured wind speed data for kumbotso, kano state have been analysed statistically based on Rayleigh function two-parameter (Shape parameter “k” and Scale parameter “c”). The analysis were done using Microsoft excel.

This report has presented the monthly mean wind speed required for preliminary design and assessment of wind power plants and a guide to produce a squirrel cage induction generator wind turbine.

The monthly mean wind speed is between 3.07 m/s – 4.74 m/s having the highest monthly mean wind speed in the month of March and April and yearly average wind speed of 4.0m/s

is obtained. This shows that kumbotso is in good wind speed region. Hence, wind power availability in kumbotso can be used for wind power system such as battery charging, for powering street light and water pumps.

An old three phase induction motor is converted to a generator taken into cognizance the speed and power output for a wind power. A low-speed induction motor of 940 rpm and 800W was selected and driven at speeds of; 956, 706, 512 and 500rpm. Results for three different connections (Delta, Star and Parallel) at these given speeds were obtained as shown in table 5.1, 5.2 and 5.3. A voltage range of 150 Volts to 306 Volts were achieved, which can accommodate the 240 Volts user voltage.

Table 5.1 shows that with good selection of the induction motor and capacitor connection, Type I (Delta connection) gave a better result with capacitors 35µF and 50µF. The residual magnetism of the machine rotor is an important factor to generate electricity at low speed. Residual magnetic fields are affected by the permeability, which can be related to the carbon content and alloying of the material. A component with high carbon content will have low permeability and will retain more magnetic flux than a material with low carbon content.

As it was stated early, gears connect the low-speed shaft to the high-speed shaft and increase the rotational speed from about 30-60 rotation per minute (rpm) to about 1000-1800 rpm, the rotational speed required by most generators to produce electricity. This implies that the speed 956 rpm is feasible, based on the standard gear ratio, which is ratio 6:1 for one stage.

An annual average wind speed of 4.0 m/s is translated to a design rotor speed of 57.2 rpm (equation 2.23) and using gear ratio of 4:1 per stage i.e ratio16:1 for the two stages, the induction motor rotor speed is converted to 915.2 rpm. Therefore, the stator output voltage (Volts) as it is presented in Table 5.4 can be achieved.

Finally use of an induction machine as a generator is becoming more and more popular for the renewable sources. Reactive power consumption and poor voltage regulation under varying speed are the major drawbacks of the induction generators, but the development of static power converters has facilitated the control of the output voltage of induction generators. Figure below shows the Block Diagram of the whole procedure on how an output voltage range of 150-278 Volts can be achieved as shown in table 5.4.

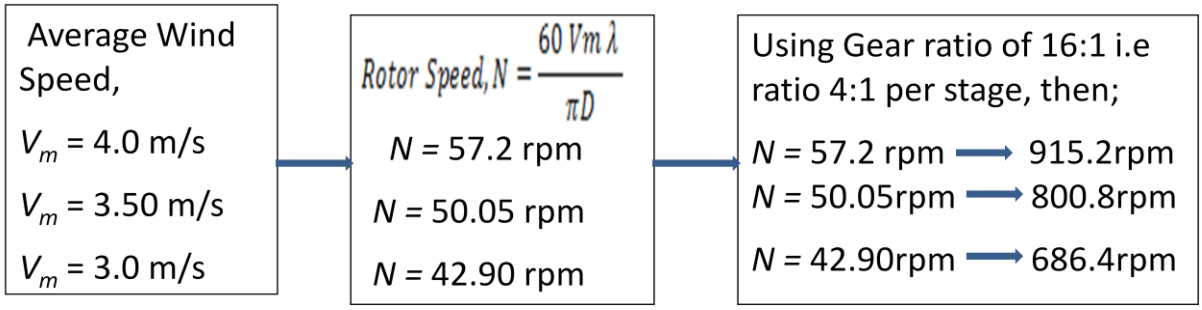


Figure 6.1 Block diagram of the whole conversion procedure.

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APPENDIX I

SSE Homepage | Find A Different Location | Accuracy | Methodology | Parameters (Units & Definition)

ATMOSPHERIC SCIENCE DATA CENTER

NASA Surface meteorology and Solar Energy - Available Tables

Latitude 11.888 / Longitude 8.503 was chosen.

Geometry Information

Elevation: **545** meters
taken from the
NASA GEOS-4
model elevation

Northern boundary
12

Western boundary
8

Center
Latitude **11.5**
Longitude **8.5**

Eastern boundary
9

Southern boundary
11

Meteorology (Wind):

Monthly Averaged Wind Speed At 50 m Above The Surface Of The Earth (m/s)

Lat 11.888 Lon 8.503	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	4.28	4.15	4.59	4.66	4.46	3.78	3.58	3.38	3.09	3.37	3.96	4.49	3.98

Minimum And Maximum Difference From Monthly Averaged Wind Speed At 50 m (%)

Lat 11.888 Lon 8.503	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Minimum	-18	-28	-11	-8	-12	-7	-9	-17	-16	-15	-14	-17	-14
Maximum	25	27	21	9	14	7	11	17	14	10	14	14	15

It is recommended that users of these wind data review the SSE Methodology. The user may wish to correct for biases as well as local effects within the selected grid region.

All height measurements are from the soil, water, or ice/snow surface instead of "effective" surface, which is usually taken to be near the tops of vegetated canopies.

Parameter Definition Units Conversion Chart

Monthly Averaged Percent Of Time The Wind Speed At 50 m Above The Surface Of The Earth Is Within The Indicated Range (%)

Lat 11.888 Lon 8.503	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0 - 2 m/s	20	24	19	17	17	21	27	33	40	31	25	22	25
3 - 6 m/s	66	61	60	63	70	78	73	67	60	69	65	56	66
7 - 10 m/s	13	16	21	20	13	1	0	0	0	0	10	22	10
11 - 14 m/s	0	0	0	0	0	0	0	0	0	0	0	0	0
15 - 18 m/s	0	0	0	0	0	0	0	0	0	0	0	0	0
19 - 25 m/s	0	0	0	0	0	0	0	0	0	0	0	0	0

Parameter Definition

Monthly Averaged Wind Speed At 50 m Above The Surface Of The Earth For Indicated GMT Times (m/s)

Lat 11.888 Lon 8.503	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Average@0130	5.09	5.01	5.62	5.83	5.65	4.75	4.92	4.75	4.25	4.36	4.92	5.41	5.04
Average@0430	4.95	4.88	5.68	5.87	5.64	4.55	4.57	4.55	4.09	4.13	4.78	5.31	4.92
Average@0730	3.50	3.46	4.33	4.94	4.37	3.27	2.38	2.27	2.10	2.46	3.13	3.71	3.32
Average@1030	4.26	4.38	4.95	5.08	4.67	3.86	3.50	3.15	2.70	2.83	3.63	4.23	3.93
Average@1330	3.72	3.45	3.40	2.98	2.84	2.57	2.67	2.46	2.12	2.41	3.12	3.76	2.95
Average@1630	3.10	2.88	3.05	2.90	2.78	2.50	2.47	2.42	2.19	2.61	3.11	3.35	2.78
Average@1930	4.47	4.16	4.37	4.22	4.22	3.85	3.52	3.26	3.26	3.71	4.16	4.76	3.99
Average@2230	5.14	4.95	5.39	5.45	5.55	4.92	4.63	4.19	4.04	4.49	4.82	5.40	4.91

Parameter Definition *Units Conversion Chart*

Monthly Averaged Wind Direction At 50 m Above The Surface Of The Earth (degrees)

Lat 11.888 Lon 8.503	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10-year Average	64	64	73	90	116	152	227	233	239	237	230	221

Parameter Definition

Monthly Averaged Wind Direction At 50 m Above The Surface Of The Earth For Indicated GMT Times (degrees)

Lat 11.888	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Lon 8.503												
Average@0130	49	50	156	202	219	232	237	237	246	218	175	76
Average@0430	60	66	179	211	222	234	235	236	245	224	184	87
Average@0730	76	82	200	226	235	246	236	234	243	234	192	98
Average@1030	84	87	219	241	252	265	255	254	273	262	210	102
Average@1330	80	76	76	209	282	288	270	279	311	45	79	84
Average@1630	59	52	60	66	272	300	284	302	316	59	67	64
Average@1930	47	44	80	134	200	240	261	276	266	180	85	59
Average@2230	46	45	125	182	211	230	241	243	249	206	142	67

Parameter Definition

Monthly Averaged Wind Speed At 10 m Above The Surface Of The Earth For Terrain Similar To Airports (m/s)

Lat 11.888 Lon 8.503	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	3.38	3.28	3.63	3.68	3.52	2.99	2.83	2.67	2.44	2.66	3.13	3.55	3.14

It is recommended that users of these wind data review the SSE Methodology. The user may wish to correct for biases as well as local effects within the selected grid region.

All height measurements are from the soil, water, or ice/snow surface instead of "effective" surface, which is usually taken to be near the tops of vegetated canopies.

Parameter Definition *Units Conversion Chart*

Difference Between The Average Wind Speed At 10 m Above The Surface Of The Earth And The Average Wind speed At 50 m Above The Surface Of The Earth (%)
Vegetation type **"Airport": flat rough grass**

Lat 11.888 Lon 8.503	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	-21	-20	-20	-20	-20	-20	-20	-21	-20	-21	-20	-20	-20

Parameter Definition

Monthly Averaged Wind Speed Adjusted For Height And Vegetation Type (m/s)
Height **10 meters**
Vegetation type **"Airport": flat rough grass**

Lat 11.888 Lon 8.503	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	3.36	3.25	3.61	3.66	3.50	2.96	2.81	2.65	2.42	2.64	3.11	3.52	3.12

Parameter Definition

Monthly Averaged Wind Speed At 50, 100, 150 and 300 m Above The Surface Of The Earth (m/s)
***Vegetation type* "Airport": flat rough grass**

Lat 11.888 Lon 8.503	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
50m	4.28	4.15	4.59	4.66	4.46	3.78	3.58	3.38	3.09	3.37	3.96	4.49	3.98
100m	4.74	4.60	5.10	5.17	4.94	4.19	3.97	3.75	3.42	3.73	4.39	4.98	4.41
150m	5.04	4.89	5.42	5.49	5.25	4.45	4.22	3.98	3.64	3.97	4.66	5.29	4.69
300m	5.59	5.42	6.01	6.09	5.83	4.94	4.68	4.42	4.04	4.40	5.18	5.87	5.21

Parameter Definition

Monthly Averaged Wind Speed For Several Vegetation And Surface Types (m/s)
***Height* 10 meters**

Lat 11.888 Lon 8.503	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
35-m broadleaf-evergreen trees (70% coverage)	2.00	1.94	2.15	2.18	2.09	1.77	1.68	1.58	1.45	1.58	1.85	2.10	1.86
20-m broadleaf-deciduous trees (75% coverage)	2.47	2.36	2.57	2.56	2.38	1.92	1.76	1.71	1.64	1.85	2.21	2.55	2.17
20-m broadleaf and needleleaf trees (75% coverage)	1.88	1.94	2.30	2.40	2.38	2.05	1.94	1.74	1.54	1.60	1.82	2.00	1.97
17-m needleleaf-evergreen trees (75% coverage)	2.14	2.21	2.57	2.69	2.53	2.11	1.97	1.86	1.70	1.82	2.11	2.32	2.17
14-m needleleaf-deciduous trees (50% coverage)	2.21	2.21	2.53	2.65	2.53	2.18	2.07	1.83	1.57	1.65	1.95	2.24	2.13
Savanna:18-m broadleaf trees (30%) & groundcover	2.21	2.14	2.37	2.40	2.30	1.95	1.85	1.74	1.59	1.74	2.04	2.32	2.05
0.6-m perennial groundcover (100%)	2.77	2.68	2.97	3.01	2.88	2.44	2.31	2.18	2.00	2.18	2.56	2.90	2.57

0.5-m broadleaf shrubs (variable %) & groundcover	2.77	2.68	2.97	3.01	2.88	2.44	2.31	2.18	2.00	2.18	2.56	2.90	2.57
0.5-m broadleaf shrubs (10%) with bare soil	2.77	2.68	2.97	3.01	2.88	2.44	2.31	2.18	2.00	2.18	2.56	2.90	2.57
Tundra: 0.6-m trees/shrubs (variable %) & groundcover	2.77	2.68	2.97	3.01	2.88	2.44	2.31	2.18	2.00	2.18	2.56	2.90	2.57
Rough bare soil	3.00	2.91	3.22	3.27	3.13	2.65	2.51	2.37	2.16	2.36	2.77	3.15	2.79
Crop: 20-m broadleaf-deciduous trees (10%) & wheat	2.72	2.56	3.17	2.65	2.53	2.15	2.03	1.92	1.75	1.98	2.40	2.81	2.39
Rough glacial snow/ice	2.43	2.43	2.83	2.96	2.84	2.40	2.28	2.15	1.90	1.98	2.29	2.55	2.42
Smooth sea ice	3.20	3.25	3.79	4.03	3.85	3.27	3.09	2.78	2.42	2.48	2.91	3.30	3.20
Open water	3.64	3.53	3.91	3.96	3.79	3.21	3.04	2.87	2.63	2.86	3.37	3.82	3.39
"Airport": flat rough grass	3.36	3.25	3.61	3.66	3.50	2.96	2.81	2.65	2.42	2.64	3.11	3.52	3.12

Parameter Definition



Back to SSE Data Set Home Page

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