CHAPTER ONE

INTRODUCTION

1.1 Introduction

An induction machine (IM) can be operated as a stand-alone generator. Capacitive Self-excitation of IM has been known for over 70 years. The fundamental superiority of an IG is its ability to generate power at constant voltage constant frequency (CVCF) when driven by a variable speed source. Therefore, in the wind power applications, most of the generators are IGs, which are Grid connected. The voltage source can be controlled by using pulse width modulation .It is obvious that the steady-state frequency value depends on the excitation capacitance and the load. Therefore, the excitation capacitance should be adjusted at each step where the load and the wind speed have a deviation from their values, to ensure a constant frequency at steady-state[1-2].Self-excitation of IM is initiated by means of the residual magnetism existing in the core of the machine. These types of generators are then called self-excited induction generators (SEIG). However, there have been few examples for stand-alone (not grid connected) applications of IG due to some important drawbacks of this method. The main drawback of the induction generator is its reactive power demand for excitation. Therefore, capacitors should be connected across the generator terminals[3]. Another drawback is that they have poor voltage and frequency regulations under varying load and wind speeds. This type of operation requires active and reactive power balances every time. Reactive power balance requires variable capacitance, which can be supplied with power semi-conductors circuits. Active power balance, on the other hand requires external elements to divert the excessive power from the system, When the source power exceeds the amount required by the load. Excessive power can be absorbed by the resistors connected to the rotor terminals or by the resistors connected to the stator terminals. Another drawback is that, the machine demagnetizes and stops generating voltage either when the wind speed falls below or the load rises beyond certain values. After that, even with the wind speed and the load returning to the rated values, the IG cannot start working again without the help of an auxiliary energy source and controller. Therefore these drawbacks should be considered during the design phase[4]. The volt-ampere reactive (VAR) requirements of the IG and the load are supplied by means of VAR Generator connected to the stator terminals. There are various possibilities to generate reactive power :

i. Synchronous Condenser
ii. The combination of capacitors and saturated reactors
iii. Static exciters

Static exciters are classified into :

i. Inverter based schemes
ii. Force-commutated cycloconverters
iii. Naturally-commutated cycloconverters with an auxiliary high frequency bank to facilitate commutation
iv. Full- or half-wave controlled rectifier loaded with a single dc inductor and connected in parallel to a fixed capacitors
v. Two controlled rectifiers one is naturally-commutated and the other force commutated, connected in parallel and loaded by a single dc inductor
vi. Thyristor-controlled inductor connected in parallel to a fixed capacitor
vii. Thyristor-switched capacitors
viii. The combination of thyristor-switched capacitor and a thyristor-controlled inductor.

The active power balance is also a major problem of a variable speed IG when there is no control of it is speed . If the source power exceeds the amount required by the load, then, the excessive power should be absorbed from the system by resistors connected [5].

i. to rotor terminals (when using wound-rotor IM)

ii. to stator terminals

The effective value of the rotor or stator external resistances should also be modified according to the variations in the supply power or the load demand. In recent years, SEIGs have been identified as a possible source of energy to be used with the modern power electronics applications. There are some practical examples of applications. The operating principles and the potential applications of a SEIG are discussed in various studies. It has been shown that, by means of a static exciter and a static rotor resistance controller, the IG can satisfactorily be operated as a variable speed, CVCF supply for isolated loads. Reduced order model of the system was obtained and the control strategies were developed which permit the successful utilization of SEIG's in wind power applications[6-7]. The frequency and magnitude of voltage generated by the self-excited induction generator (SEIG) is completely governed by the rotor speed, the excitation and the load. There exists minimum and maximum capacitance for the self-excited [8-10] .

The analysis of the SEIG under steady-state conditions and imposed speed is already known however there are few papers about steady -transient operation**.** In the last few years the development of microelectronics, power electronics, controls techniques and digital systems have made possible the construction of more efficient VR’s[11].

1.2 Problem Statement

Extract maximum power with Constant voltage constant frequency is a problem of a variable speed wind turbine and Low efficiency facing the wind energy conversion system.

1.3 Objectives

The objective of this project is to extract maximum power from wind with constant voltage and constant frequency with isolated load.

1.4 Methodology

In this project the mathematical model of wind turbine and self-excited induction generator is derived, three-phase capacitor bank is connected across the stator terminals of the induction generator.

The maximum power point tracking scheme and constant voltage constant frequency scheme are derived. MATLAB/SIMULINK is used to simulate the complete model of the system.

1.5 Thesis Layout

This thesis is containing five chapters. Chapter one provides a brief introduction to the IG, the contribution of the thesis and the outline of the thesis.

Chapter two presents a literature review of the SEIG system and an overview of the control for induction machines.

Chapter three presents the dynamic and mathematical models of the induction generator also presents the control scheme and wind turbine model.

In chapter four the MATLAB/SIMULINK software is used to simulate the control schemes of the SEIG system to give constant voltage and constant frequency when feeding isolated loads. The dynamic model of the system is completed by involved a capacitor bank connected to the stator terminals into the model which is accommodate to provide reactive power to the generator to build up of its voltage. The results of the simulation are analyzed , discussed and used to demonstrate the constant voltage and constant frequency .

Chapter five presents the conclusions and recommendation of the thesis and suggestions for the future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The wind has been used to power sailing ships for many centuries. Wind was almost the only source of power for ships until Watt invented the steam engine in the 18th Century. Wind turbines are used back many centuries. It has been reported that the Babylonian emperor Hammurabi planned to use wind turbines for irrigation in the seventeenth century B.C. [1]

Renewable energy sources presently provide significant amount of energy in many countries. Renewable energy sources currently supply about 10 % of the world energy demand . There are many types of renewable energy such as: wind energy systems (WES), biomass energy systems and Photovoltaic Energy Systems (PVES). But much more experience is needed to predict the future economics and markets for the emerging technologies[2].

The renewable energy is environmental friendly compared to current level of emission associated with electricity generation. Such a contribution from renewable energy systems would also reduce substantially the low level of other pollutants that cause acid rain, smog and other local environmental hazards.

The renewable energy has many other benefits such as: Create significant new employment opportunities in energy infrastructure, manufacturing, installation and etc., Contribute to the securing of long term, cost-effective environmentally sustainable energy supplies and offer low operating costs[3-4]. The major types of renewable energy sources can be summarized as follows[5]:

i. Wind Energy.
ii. Solar Energy.
iii. Hydro Energy.
iv. Tidal Energy.
v. Biomass Energy

2.1.1 Development Of Wind Energy System

Windmills have been existence for at least three thousand years, mainly for grinding grain or pumping water . By the mid-ages, windmills were in wide spread use around the Mediterranean Sea. These windmills were used for corn grinding. At the end of 18th century, about 10,000 Wind Turban Generators (WTG) were in use in Netherlands only with the similar number in use in Britain .

Denmark was the first country to use the wind for generating electricity from a wind station[6].

Mankind has used wind as a source of energy for thousands of years. It was one of the most utilized sources of energy together with hydro power during the seventeenth and eighteenth centuries . By the end of the nineteenth century the first experiments were carried out on the use of windmills for generating electricity. Thereafter, there was a long period of a low interest in the use of wind power. The international oil crisis in 1972 initiated a restart of the utilization of renewable resources on a large scale, wind power, among others. Currently, wind power is a fully established branch on the electricity market and it is treated accordingly. Energy production is not the only criterion to be considered when installing new wind turbines; cost efficiency, the impact on the environment and the impact on the electric grid are some of important issues of significant interest when making decisions about new wind turbine installations.

Political support for and public interest in renewable energy has caused a massive increase in wind power utilization and improvement of wind turbine technology is a natural consequence. Presently, wind power meets about 2% of the total electricity demand in Europe i.e., more than 23 000MW of which about 5 800MW was installed in the last year (2002). According to , this development is going to continue in coming years[7-8].

From 1980 till now there is a competition between Europe and North America in the generation of electricity from wind. Figure. 2.1 shows the global wind energy market.

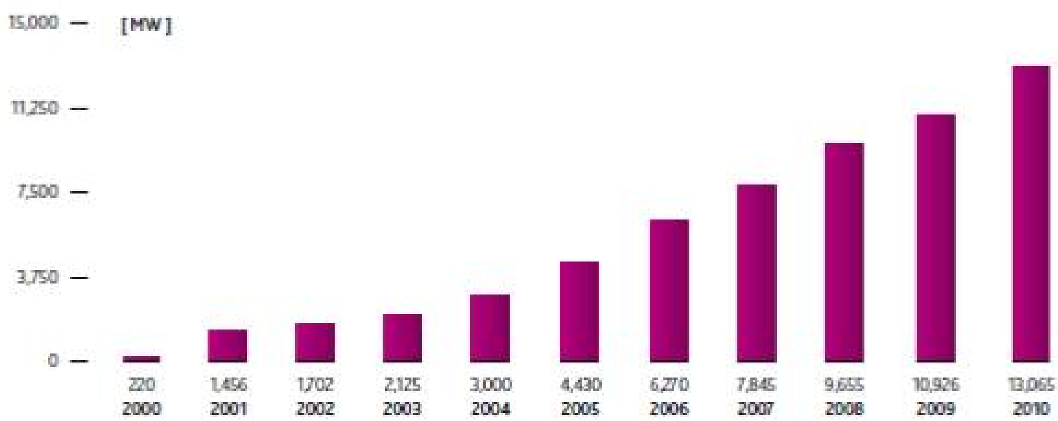

Figure 2.1: The global wind energy market[2]

2.1.2 Wind Power

Wind power is a form of solar energy produced by heating of the earth's surface. As a power source, wind power is less predictable than solar power, but it is also typically available for more hours in a given day. Wind resources are influence by the type of the land surface and the elevation of the land surface. Generally, if the land is in high elevation then it is good for wind Energy conversion. Since the wind speed is extremely important for the amount of energy a wind turbine can convert it to electricity[9].

2.1.3 Wind Energy

Wind energy is the part of the renewable energy sources and its usage in Latvian territory is most frequently researched and discussed. It takes lot of time and financial costs to find a new generation wind turbine. Designing of the turbine is an important process but in order to see how the real turbine operates in the wind area the turbine should be built and tested in air tunnels or good weather conditions with stable wind[10].

Renewable energy is quickly gaining momentum as a viable driving force for powering industrialization and for domestic use in many countries. As the focus shifts towards green energy sources, methods for improving efficiency in power conversion take the limelight. Wind energy is freely available and is clean and easily converted into electricity. Wind turbines are available in two major configurations: Vertical Axis Wind Turbines and Horizontal Axis Wind Turbines (HAWT). The more common HAWT may operate either with fixed rotor speed or variable speed. Due to the constant variability of wind speed, design of controllers capable of extracting maximum power from the wind is a constant challenge, and various techniques have been developed to obtain higher efficiency from wind turbines. This should, in the long run, make wind power an economically viable alternative to non-renewable energy sources. Generation of wind power involves extraction of energy from the wind by use of a wind turbine generator[11-12]

The wind speed at which electric power production starts called the cut-in wind speed. The turbine will develop enough mechanical power to rotate itself at slightly lower speeds, but this wind speed will actually supply all the generator and transmission losses so that useful electric power cannot be produced. At rated wind speed the power input to the wind turbine will reach the limit for continuous operation (rated power). When the wind speed exceeds this level the excess power in the wind must be discarded by varying the pitch angle of the blades to prevent the turbine over loading. The power is maintained at its rated value until a maximum wind speed is reached the cut-off wind speed ($V_{cut-off}$) then the turbine will shut down[13-15]. The actual WTG output power with the wind speed is shown in Figure 2.2 [7].

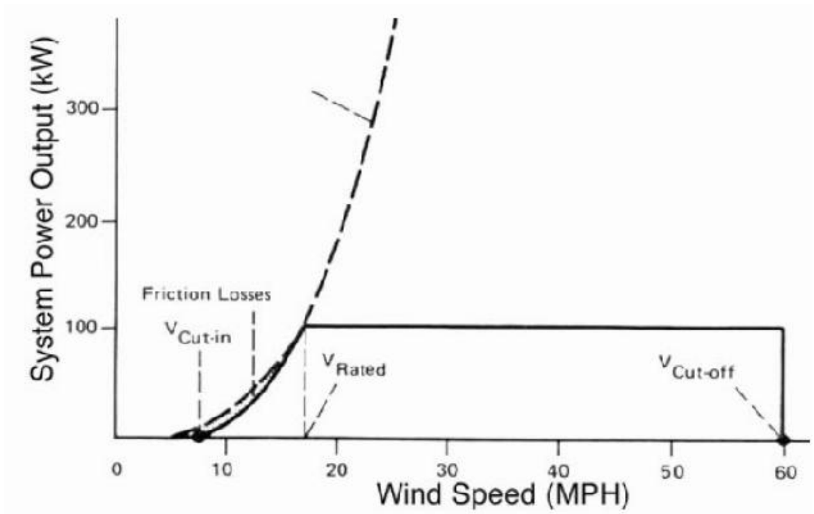

Figure 2.2:Actual WTG output power with wind speed

Development and utilization of wind energy has become an important part of world sustainable energy development strategy. Wind power generation is the most important form of the development and utilization of wind energy[16]. Wind power generation system can be divided into two categories that the constant speed constant frequency and variable speed constant frequency (VSCF),VSCF wind power generation system divided into two drive modes which is indirect and direct drive. The direct drive wind power system use the permanent magnet synchronous generator with low speed to transform the wind generator output power into alternating current which is frequency and constant voltage into the grid. So the system has the advantages of simple structure. It has become one of the main current of wind power generation[17-18].

Computer software and the applications today help conduct research in many areas. Wind industry can be one of the industries where the simulation of the virtual models is helping to test turbines by making use of the virtual turbine model [19]. Around the world virtual models are built to fully reflect all the turbine components and the control process, however, the main problem that researchers come across when building virtual models is related to actual parameters of the turbine aerodynamic process and the data about the aerodynamic process. The main tasks of this work are design and study of the virtual turbine model, simulation of the virtual model operation with the help of the virtual model in MATLAB SIMULINK application as well as evaluation of the possible turbine operation as a stand-alone turbine in the wind fields[28-20].

2.1.4 The Kinetic Energy

The kinetic energy in the varying wind velocity is converted into mechanical energy by the wind turbine rotor. The rotor blades are made up of reinforced fiber glass, which is mounted on a steel shaft. The wind turbine may be stall-regulated machine or pitch regulated machine. For Stall-regulated machines this pitch angle is fixed at the time of installation whereas in pitch regulated machine, it varies various wind velocities to maintain the output power constant at rated value[21].

2.2 Generators

With the important exception of electrostatic generators such as the Van de Graf machine, all commercially important schemes for converting the energy of mechanical motion into electrical energy depend on Faraday's

Law of induction from beginning physics. This Law states that the strength of the instantaneous total electromotive force (EMF) in volts around any closed path, whether in a conductor or otherwise, is proportional to the time rate of change (not the absolute value) of the magnetic flux passing through or linking that closed path. Because we know that magnetic fields close on themselves, we can think of an EMF path and its parent magnetic field as relating to each other like successive links in an ordinary chain. Technologists have found several ways to create this required changing magnetic field[22-23]. Three examples are:

1) A constant-magnitude magnetic field pattern is moved repeatedly in space past a stationary path, as in the synchronous generator whose magnetized rotor poles move repeatedly past its stator windings.

2) A path for an EMF in space (a coil of wire) is moved repeatedly past a constant magnetic field fixed in space, as in a DC generator with a commutated armature. (The source of the magnetic field for these two examples can be either one or more permanent magnets or externally supplied currents in coils of wire. Permanent magnet generators are highly popular because of their simplicity and ease of construction. They require no field windings, no field circuitry, nor external power sources.).

3) A magnetic field that both varies in time and moves in space sweeps past a stationary path, as in the squirrel cage induction generator. Here, low-frequency currents are induced in the rotor and create a changing magnetic field that sweeps repeatedly past the stationary stator windings. To complete examples of Faraday's Law, one should mention the case of a power transformer. Although both the magnetic flux and the EMF path are fixed in space, the alternating current in the transformer primary creates the required changing magnetic field that links a path for an EMF in the transformer secondary, thereby creating an external voltage[24-25].

2.2.1Induction Generators

The simplest form of AC generator (after the PM type) and the type that has most often been used in wind turbines is the induction generator. The induction generator depends on an external voltage source (e.g., the Electric utility) to produce a magnetic field in the stator, which is to say that this device consumes VARS in order to produce watts. The current in the rotor is induced by the differential speed of the rotor coils with respect to the spinning stator field. The simplest form of induction generator is the squirrel cage, in which the rotor is formed from welded copper bars, rods, or copper castings embedded in a soft iron cylindrical rotor. Induction generators are also constructed using wound rotors, in which rotor currents are induced in windings of copper or aluminum wire. When wound rotors are accessible through slip rings, a variable resistance can be inserted. This can control the electrical torque and will control the percentage of slip. Alternatively, a power electronics module can be substituted for the external resistance, thus allowing the injection of currents of appropriate frequency into the rotor windings[26]. There are two types of induction generator:

1- Normal type (none isolated), where excitation required are provided by an external A.C source.

2- Isolated type (self-excited) in which excitation is provided by a terminal capacitor. In the first type, the frequency and voltage are equal to that of system. However, in the second type, the frequency and induced voltage change with speed, excitation capacitor, load impedance and its associated power factor. The frequency of the induced voltage is always less than the synchronous frequency (corresponding to input shaft speed) [27].

The generators used in wind energy applications should be simple to use with low maintenance, and have low initial cost. Induction generator satisfies most of these requirements. Also, the WTGs employ permanent magnet, synchronous and variable reluctance generator systems[28].

For Like any transformer, there is a certain resistance and self-inductance in the primary (stator) windings, which must be represented in the equivalent circuit of the machine. The stator resistance will be called R_1 and the stator leakage reactance will be called X_1[29]. These two components appear right at the input to the machine model. Like any transformer with an iron core, the flux in the machine is related to the integral of the applied voltage E_1[38]. The magnet motive force-versus-flux curve (magnetization curve) for this machine is compared to a similar curve a power transformer[30].

2.2.2 Rotor Circuit Model

In an induction machine when the voltage is applied to the stator windings. A voltage is induced in the rotor windings of the machine. In general, the greater the relative motions between the rotor and the stator magnetic fields, the greater the resulting rotor voltage. The largest relative motion occurs when the rotor is stationary, called the locked-rotor or blocked rotor condition, so the largest voltage is induced in the rotor at the condition .The smallest voltage (OV) occurs when the rotor moves at the same speed as the rotor magnetic field, resulting in no relative motion. The voltage induced in the rotor at any speed between these extremes is directly proportional to the slip of the rotor. Therefore, if the induced rotor voltage at locked-rotor conditions is called E_{r0}, .This voltage is induced in a rotor containing both resistance and reactance .The rotor resistance R_r is a constant, independent of slip, while the rotor reactance is affected in a more complicated way by slip. The reactance of an induction motor rotor depends on the inductance of the rotor and the frequency of the voltage and current in the rotor. With a rotor inductance of L_r, the rotor reactance is given by[15]

2.2.3 Operation Of Induction Generator

The induction motor can also run as a generator. This simply happens when you, instead of forcing the rotor to turn at a rotational speed lower than the synchronous speed, exceed this synchronous speed by applying an outside energy source, the greater the difference between the rotating magnetic field of the stator and the speed of the rotor, the greater the torque produced by the rotor [19].

When it is a working as a generator, the rotating field however acts as a brake in slowing the rotor. The stator experiences a variable magnetic field from the rotor that 'drags' its rotating magnetic field and thereby induces an electrical current in the stator. The faster the rotor turns in relation to the rotating magnetic field of the stator, the greater the induction in the stator and the greater the production of power [12].

An induction generator cannot produce reactive power. In fact it consumes reactive power, and an external source of reactive power must be connected to it at all times to maintain its stator magnetic field. This external source of reactive power must also control the terminal voltage of the generator. With no field current, an induction generator cannot control its own output voltage [17].

2.2.4 Analysis Of Induction Generator

For a wind energy conversion system that uses induction generator, a dc link converter is essential for power conversion. The induction generator produces current at variable frequency. This current is rectified onto the dc link using a converter with six active switches. To convert the dc to a fixed frequency of the utility, a second converter with six switches is needed. This results in many switches needed for wind energy conversion system. Hence a new method that uses a six-switch current regulated pulse width modulated inverter and a zero sequence filter is proposed to eliminate some of the switches used and still retaining the original functionality of the system [18]. An approach employing a boost converter to control the DC link is shown in Figure 2.3 [18]

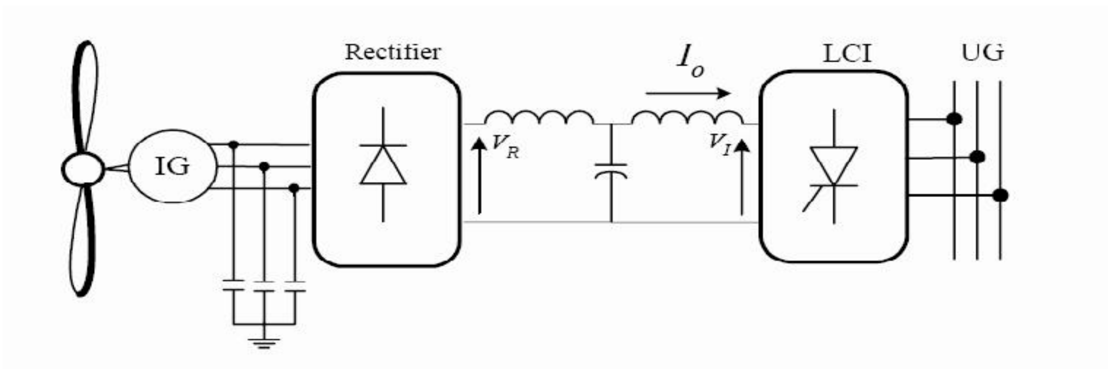

Figure 2.3: Interfacing of SCIG to electric utility via diode bridge rectifier and LCI

The study of induction generator steady state analysis and performance characteristics is important due to the speed fluctuations of unregulated wind turbines, the terminal voltage may increase to dangerously high levels to cause capacitor failure at wind farms. Over-voltages are the major cause of excitation capacitor failure. Using a satiable transformer connected to the terminals of the induction generator will improve voltage regulation and also protection against over-voltages [11].

2.2.5 Excitation Of Three Phase Induction Generator

Any induction machine requires current to magnetize the core and produce a rotating magnetic field. The excitation current for an induction generator connected to an external source, such as grid, is supplied from that external source an isolated induction generator without any excitation will not generate voltage and will not be able to supply electric power irrespective of rotor speed. In general an induction generator requires reactive power for its operation[20].

Three charged capacitors connected to the stator terminals of induction generator can supply the reactive power required by the induction generator. Provided that the conditions for self-excitation are satisfied the charged capacitors cause the terminal voltage to build up at the stator terminals of induction generator. When the charged capacitors are connected to the terminals a transient exciting current will flow and Produce a magnetic flux. This magnetic flux will generate voltage and the generated voltage will be able to build the charge in the capacitor. As the charge increases, more exciting current is supplied to the induction generator. The magnetic flux continues to increase hence producing a higher generated voltage. In this way voltage is built up[21-22].

However, if the capacitors are not charged, and a remnant magnetic flux in the core exists, then a small voltage will be generated at the terminals of induction generator due to that remnant flux. This small voltage will charge the capacitor. The charged capacitor will now be able to produce a small exciting current. With time the exciting current grows and produces magnetic flux more than the remnant magnetic flux and voltage will be built up. This is similar to the way that current and voltage for the voltage to build up across the terminals of the induction generator, there are certain requirements for minimum rotor speed and capacitance value that must be met. When capacitors are connected across the stator terminals of an induction machine, driven by an external prime mover, voltage will be induced at its terminals. The induced emf and current in the stator windings will continue to rise until steady state is attained. At this operating point the voltage and current will continue to oscillate at a given peak value and frequency[23-24]. The rise of voltage and current is influenced by the magnetic saturation of the machine. In order for self-excitation to occur with a particular capacitance value there is a corresponding minimum speed. Self-excited induction generators are good candidates for the wind powered electricity generation, especially in remote areas, because they do not need an external power supply to produce the excitation magnetic field. However the generated voltage increases linearly with wind turbine speed. An induction generator can cope with a small increase in speed from its rated value because, due to saturation, the rate of increase of generated voltage is not linear with speed. Furthermore when there is a short circuit at the terminals of the self-excited induction generator (SEIG) the voltage collapses providing a self-protection mechanism [9-12].

2.2.6 Capacitor Calculation

Induction generator works with constant speed constant frequency systems as well as variable speed constant frequency systems.

The main drawback of induction generator in wind energy conversion systems applications is its need for leading reactive power to build up the terminal voltage and to generate electric power. Using terminal capacitor across generator terminals can generate this leading reactive power. The capacitance value of the terminal capacitor is not constant but it is varying with many system parameters like shaft speed, load power and its power factor. If the proper value of capacitance is selected, the generator will operate in self-excited mode. The capacitance of the excitation capacitor can be changed by many techniques like switching capacitor bank [13], thyristor controlled reactor and thyristor controlled DC voltage regulator . In last decade many researches uses PWM technique to provide the desired excitation by controlling the modulation index and the delay angle of the control waveform .

A self-excited three-phase induction generator is provided with reactive power by a three- phase capacitor bank connected across the stator terminals to ensure stable operation and maintain output voltage when the rotor is supplied by a mechanical power source. Self-excitation and, hence, the load voltage is maintained when the slip is negative[14]. An application limitation of the capacitive compensated three-phase induction generator is the drastic change of the voltage regulation with Load and rotor speed variations. Furthermore, when the active power demand of the load is higher than the input rotor mechanical power, the load voltage collapses[15]. So a proper selection of the capacitor bank is necessary. In practice, the capacitors are connected between each pair of output terminals, that is, they are subjected to the line-to-line voltages. Analyzing the total amount of reactive power associated with these capacitors, it can easily be found that the per-phase capacitance, C, equals the actual capacitance, act C, of the single capacitor only when stator windings are connected in delta (which is the predominant practical Connection). With stator windings connected in star, C = 3Cact. The self-excitation is the result of the interaction between the voltage provided by Induction Motor residual magnetic flux and the three-phase capacitor Excitation bank[16-18].

2.3 Power Electronic

Almost all of the previously described grid-connected variable-speed techniques have one factor in common. They must all use power electronic devices of some type coupled to the rotor, stator, or both. These devices contain electronic switches of some form. Since the 1960s, the advances in solid-state electronics have been phenomenal, both in efficiency, in component size, and in power-handling capability. But the last 15 years has witnessed an even more accelerated advance in high-power (voltage and current) devices. Some of the earliest sophisticated devices, such as thyristors, (silicon-controlled rectifiers.

SCRs; gate turn-off thyristors-GTOs) were applied to variable-speed wind turbine designs before 1975. Since then, designs using bipolar junction transistors (BJTs), metal-oxide-semiconductor field-effect transistors (MOSFETs), and insulated-gate bipolar transistors (IGBTs) have all been applied to wind Turbine designs. These devices as well as other circuit elements can be combined in a range of ways to control switching, current flow, resistance, and voltages. In the 1990s the costs for many of these devices have come down sharply while power-handling capabilities have increased, making their application on a large scale more economic. Manufacturing processes continue to improve and new devices are under development that may make the existing devices obsolete within the next 10 years Since the 1960s, the advances in solid-state electronics have been phenomenal, both in efficiency, in component size, and in power-handling capability. But the last 15 years has witnessed an even more accelerated advance in high-power (voltage and current) devices. Some of the earliest sophisticated devices, such as thyristors, (silicon-controlled rectifiers. SCRs; gate turn-off thyristors-GTOs) were applied to variable-speed wind turbine designs before 1975. Since then, designs using bipolar junction transistors (BJTs), metal-oxide-semiconductor field-effect transistors (MOSFETs), and insulated-gate bipolar transistors (IGBTs) have all been applied to wind turbine designs. These devices as well as other circuit elements can be combined in a range of ways to control switching, current flow, resistance, and voltages. In the 1990s the costs for many of these devices have come down sharply while power-handling capabilities have increased, making their application on a large scale more economic. Manufacturing processes continue to improve and new devices are under development that may make the existing devices obsolete within the next 10 years[19-22].

The devices each have different characteristics that make them more or less useful for the different applications. In addition to the devices themselves, a major element in their successful application is the multiplicity of circuits in which they can be employed. These devices are, in essence, very fast switches. It is the sequence in which they are turned on and the rate at which they ramp up to full capacity and turn off that gives them the ability to modulate currents and voltages to generate usable wave forms for injection into the electrical grid. Small computers and logic controllers or other simple circuit elements to perform a wide range of functions can control this switching. The earliest and still most widely used type of these power semiconductor circuits uses the AC/DC/AC topology, in which the variable frequency, variable voltage from a variable or wide .Source is first rectified to DC. This steady direct current is then inverted to utility-grade alternating current of constant voltage and frequency. For each of these successive transformations there is a wide choice of circuits that could be selected, thus leading to an even larger number of complete AC/DC/AC systems. For example, a simple three-phase diode bridge or a phase-controlled rectifier using SCRs could be used to convert the wild AC to DC. The latter could control the current drawn and therefore the torque required to drive the generator. Similarly, the DC bus could have a capacitor connected across it, which would tend to hold its voltage constant, or, it could have an inductor in series with it, which would tend to hold the DC bus current constant even more choices are available for the conversion of the DC bus energy to utility frequency and voltage. The First inverters were 6- or 12-pulse bridges of SCRs that connected the DC bus in various ways to the AC line 6 or 12 times per cycle. Switching losses were low but harmonics such as the fifth and seventh were strong and filtering was necessary. Later, with the widening choice of devices mentioned above, pulse width modulation (PWM) inverter techniques became common. In these circuits the DC bus is connected to the output for various durations several hundred times per cycle. This, of course, allows fabrication of a much-improved approximation to a sinusoid, which results in weaker and much higher frequency harmonics that are much easier to filter out. Instead of using a DC link as in the family just described, one can substitute a high-frequency resonant circuit. Recall that if an electric pulse is injected into a coil and capacitor circuit, it tends to .ring.. That is, a damped sinusoid of voltage and current will briefly exist. This can be used to advantage by a control circuit if it actuates the semiconductor switches when a link voltage or current to be switched is crossing through zero. The switching losses become minimal if a semiconductor does not have to interrupt a finite current or voltage, Thereby improving conversion efficiency. Still another approach is to omit the center DC link altogether. With the addition of a few more semiconductor switches, we have a cycloconverter. One power electronics approach is to use an AC-DC-AC current link. This design uses semiconductor switches to convert the turbine (wide) AC to DC and DC back to utility AC at the grid. For instance, the wind turbine rotor is commanded to spin at the optimum rpm in relation to the wind. A computer controller senses the wind and determines what frequency the stator voltage should be for optimum operation of the turbine. The power switches can be switched on and off in rapid sequences to allow current to flow in such a way as to appear as a waveform of the necessary frequency. One method for controlling this switching is pulse width modulation, in which current flow is controlled by the length of time the switch is closed. In order for this to work efficiently, the switches must be capable of very rapid actuation. With a DC current link, two sets of switching modules are set up, one either side of the DC link (one to control the frequency to the stator and the other to control the frequency of the lines output to the grid). One set of switches may be controlled based on wind speed input, and another set may be controlled based on the grid frequency. The AC-DC-AC current link converter and PWM control for the design of the KVS-33 wind turbine. This machine used two squirrel cage generators connected to a single dual-output gearbox. The power electronics links were capable of 600 amps at 1400 volts. Switching was accomplished using IGBTs and a PWM switching technique. The control algorithm was designed to control the torque of the generator and limit changes in the torque load. This arrangement provided for bi-directional power flow and would allow to motoring the turbine as well as power production [24-27].

2.3.1 Soft-Starter

The soft-starter is a simple and cheap power electrical component used in fixed speed wind turbines during their connection to the grid.

The soft-starters function is to reduce the in-rush current, thereby limiting the disturbances to the grid. Without a soft-starter, the in-rush current can be up to 7–8 times the rated current.

It contains two thyristors as commutation devices in each phase. They are connected ant parallel for each phase [30].

CHAPTER THREE

MATHEMATICAL MODEL

3.1 Introduction

In this chapter, the dynamic model of the SEIG is derived. The model is contain a resistive load. The steady-state operating conditions are obtained. The dynamic model of the three phase IM is very complex, because the three-phase rotor windings move with respect to the three-phase stator windings .Coupling coefficients between the stator and the rotor phases change continuously with the change of the angle between the corresponding phases of the stator and the rotor, θ. First, the transformation techniques are applied to eliminate the presence of θ in the equations. Completed model is obtained in a synchronously rotating reference frame. Second, the current variables are replaced by equivalent flux linkage variables and the terminal equations corresponding to the excitation capacitors and the load is included to obtain the complete mathematical model of the system[14-15].

3.2 Mathematical Model Of Induction Machine

Figure 3.1 shows the idealized three-phase induction machine. The angle between winding R and Y is $\theta_2 = \Theta - 2\pi/3$ and the angle between winding R and B is $\theta_3 = \Theta + 2\pi/3$

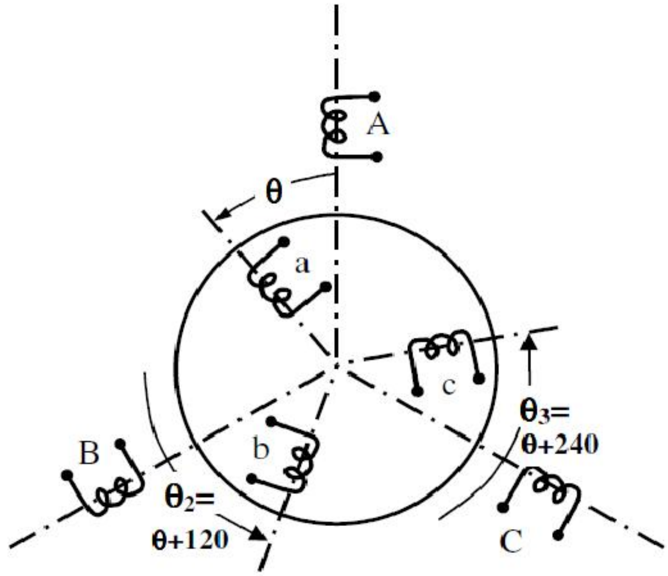

Figure 3.1: the idealized Three-Phase Induction Machine

From figure 3.1 the voltage-current relationship of the three-phase IM can be written as follows [15];

Stator voltage equations:

$$V_R = R_S I_R + \frac{d\lambda_R}{dt} \tag{3.1}$$

$$V_Y = R_S I_Y + \frac{d\lambda_Y}{dt} \tag{3.2}$$

$$V_B = R_S I_B + \frac{d\lambda_B}{dt} \tag{3.3}$$

And rotor voltage equations are:

$$V_r = R_r I_r + \frac{d\lambda_r}{dt} \tag{3.4}$$

$$V_y = R_r I_y + \frac{d\lambda_y}{dt} \tag{3.5}$$

$$V_b = R_r I_b + \frac{d\lambda_b}{dt} \tag{3.6}$$

Where $\Lambda's$ are flux linkages, R_s and R_r are stator and rotor phase resistances, R,Y and B represent stator winding while r,y, and b represent rotor windings.

Flux linkages of the stator and the rotor windings can be written in terms of the winding inductances and the currents. Equations[(3.10)] is obtained using the following assumptions [7]

i. The effects of hysteresis and eddy currents are ignored,
ii. teeth and slot effects are neglected,
iii. the IM is balanced and the saturation reduces all the component fluxes in a particular region of the machine, and
iv. the fundamental and thirds harmonic components of the mutual inductances are assumed to be the general characteristic.

Using figure 3.1 and equations 3.1 to 3.7 The voltage ,current and inductance can be written in matrix form as:

$$[V]=\begin{bmatrix} v_R \\ v_Y \\ v_B \\ v_r \\ v_y \\ v_b \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.7)$$

$$[I]=\begin{bmatrix} i_R \\ i_Y \\ i_B \\ i_r \\ i_y \\ i_b \end{bmatrix}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.8)$$

$[Z] =$

$$\begin{bmatrix} R_S+\hat{L}_S P & P\widehat{M_S} & P\widehat{M_S} & \widehat{M}pCOS\Theta+\widehat{M_3}pCOS3\Theta & \widehat{M}pCOS\Theta_2+\widehat{M_3}pCOS3\Theta & \widehat{M}pCOS\Theta_3+\widehat{M_3}pCOS3\Theta \\ P\widehat{M_S} & R_S+\hat{L}_S P & P\widehat{M_S} & \widehat{M}pCOS\Theta_2+\widehat{M_3}pCOS3\Theta & \widehat{M}pCOS\Theta_3+\widehat{M_3}pCOS3\Theta & \widehat{M}pCOS\Theta+\widehat{M_3}pCOS3\Theta \\ P\widehat{M_S} & P\widehat{M_S} & R_S+\hat{L}_S P & \widehat{M}pCOS\Theta_3+\widehat{M_3}pCOS3\Theta & \widehat{M}pCOS\Theta+\widehat{M_3}pCOS3\Theta & \widehat{M}pCOS\Theta_2+\widehat{M_3}pCOS3\Theta \\ \widehat{M}pCOS\Theta+\widehat{M_3}pCOS3\Theta & \widehat{M}pCOS\Theta_2+\widehat{M_3}pCOS3\Theta & \widehat{M}pCOS\Theta_3+\widehat{M_3}pCOS3\Theta & R_r+\hat{L}_r P & P\widehat{M_r} & P\widehat{M_r} \\ \widehat{M}pCOS\Theta_2+\widehat{M_3}pCOS3\Theta & \widehat{M}pCOS\Theta_3+\widehat{M_3}pCOS3\Theta & \widehat{M}pCOS\Theta+\widehat{M_3}pCOS3\Theta & P\widehat{M_r} & R_r+\hat{L}_r P & P\widehat{M_r} \\ \widehat{M}pCOS\Theta_3+\widehat{M_3}pCOS3\Theta & \widehat{M}pCOS\Theta+\widehat{M_3}pCOS3\Theta & \widehat{M}pCOS\Theta_2+\widehat{M_3}pCOS3\Theta & P\widehat{M_r} & P\widehat{M_r} & R_r+\hat{L}_r P \end{bmatrix}$$

…………………………..(3.9)

And the voltage equation is

$[V] = [Z][I]$ ………………………………………………………........(3.10)

Where:

$\Theta_2 = \Theta - 2\pi/3$, $\Theta_3 = \Theta + 2\pi/3$

R_S = is the stator resistance.

R_r = is the rotor resistance.

$\hat{L}_S$ = is the stator self-inductance.

$\hat{L}_r$ = is the rotor self-inductance.

$\widehat{M_S}$ = is mutual inductance between stator phases.

$\widehat{M_r}$ = is mutual inductance between rotor phases.

$\widehat{M}$, $\widehat{M_3}$= are the fundamental and third harmonic components of the inductance between stator and corresponding rotor phases windings at Θ =0.

Hence, to carry out mathematical expressions on terms of the form ($\frac{d}{dt}cos\Theta(t)i(t)$), where L is a non-linear function of i, becomes difficult. This difficulty can be overcome by using separation principle stated.

3.2.1 The Transformation Of 3-phase To Two Phase

Since the current-voltage relations of the three-phase IM is quite complex and involve non-linearity's due to the presence of cosinusoidal functions of the rotor angle Θ, the variable transformation techniques are applied to obtain a new model of the IM in a different reference frame.

The transformation matrix from R, Y, B, r, y and b to D, Q, d, q variables is obtained by using the phase transformation matrix C_1

$$C_1 = \sqrt{\frac{2}{3}} \begin{vmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{vmatrix} \quad \ldots\ldots(3.11)$$

In compact form

The system impedance matrix is $[Z] = \begin{vmatrix} Z_{SS} & Z_{Sr} \\ Z_{rS} & Z_{rr} \end{vmatrix}$ ……………….........(3.12)

The transformation matrix is $C = \begin{vmatrix} C_1 & 0 \\ 0 & C_1 \end{vmatrix}$ ……………..……….............(3.13)

So

$$\grave{Z} = C_{1t}\, Z C_1 \quad \ldots\ldots(3.14)$$

The new transformed impedance

$$[\grave{Z}] = \begin{vmatrix} C_{1t} & 0 \\ 0 & C_{1t} \end{vmatrix} \begin{vmatrix} Z_{SS} & Z_{Sr} \\ Z_{rS} & Z_{rr} \end{vmatrix} \begin{vmatrix} C_1 & 0 \\ 0 & C_1 \end{vmatrix} = \begin{vmatrix} C_{1t} Z_{SS} C_1 & C_{1t} Z_{Sr} C_1 \\ C_{1t} Z_{rS} C_1 & C_{1t} Z_{rr} C_1 \end{vmatrix} \quad \ldots\ldots(3.15)$$

- Stator Impedance:

$$Z_{SS} = \begin{bmatrix} R_S + \hat{L}_S P & P\widehat{M_S} & P\widehat{M_S} \\ P\widehat{M_S} & R_S + \hat{L}_S P & P\widehat{M_S} \\ P\widehat{M_S} & P\widehat{M_S} & R_S + \hat{L}_S P \end{bmatrix} \quad \ldots\ldots(3.16)$$

$$Z'_{SS} = C_{1t} Z_{SS} C_1 = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.17)$$

$$\sqrt{\frac{2}{3}}\begin{vmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{vmatrix} \begin{bmatrix} R_S + \hat{L}_S P & P\widehat{M_S} & P\widehat{M_S} \\ P\widehat{M_S} & R_S + \hat{L}_S P & P\widehat{M_S} \\ P\widehat{M_S} & P\widehat{M_S} & R_S + \hat{L}_S P \end{bmatrix} \sqrt{\frac{2}{3}}\begin{vmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{vmatrix} =$$

$$Z'_{SS} = \begin{vmatrix} R_S + L_{S0}P & 0 & 0 \\ 0 & R_S + L_S P & 0 \\ 0 & 0 & R_S + L_S P \end{vmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.18)$$

Where:

$$L_{S0} = \hat{L}_S + 2\widehat{M}_S \quad , \quad L_S = \hat{L}_S - \widehat{M}_S$$

- Rotor /Stator Impedance:

The mutual inductance between the stator and rotor are the most important part of induction motor performance. The nine elements of Z_{rs} may be measured quite easily. Each stator phase in turn is energized and the three rotor phase voltages are measured in each case. The coefficients of mutual inductance naturally vary with rotor position. The complete impedance matrix can be written as:

$$Z_{rs} = \begin{bmatrix} \widehat{M}pCOS\Theta & \widehat{M}pCOS\Theta_2 & \widehat{M}pCOS\Theta \\ \widehat{M}pCOS\Theta_2 & \widehat{M}pCOS\Theta_3 & \widehat{M}pCOS\Theta_3 \\ \widehat{M}pCOS\Theta_3 & \widehat{M}pCOS\Theta & \widehat{M}pCOS\Theta_2 \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.19)$$

$$Z'_{rs} = C_{1t} Z_{rS} C_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.20)$$

$Z_{rs}C_1 =$

$$\begin{bmatrix} \hat{M}pCOS\Theta & \hat{M}pCOS\Theta_2 & \hat{M}pCOS\Theta \\ \hat{M}pCOS\Theta_2 & \hat{M}pCOS\Theta_3 & \hat{M}pCOS\Theta_3 \\ \hat{M}pCOS\Theta_3 & \hat{M}pCOS\Theta & \hat{M}pCOS\Theta_2 \end{bmatrix} \sqrt{\frac{2}{3}} \begin{vmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{vmatrix} \quad \text{.............(3.21)}$$

$$= \sqrt{\frac{2}{3}} \begin{bmatrix} 0 & \hat{M}pCOS\Theta & \hat{M}pCOS\Theta \\ 0 & \hat{M}pCOS\Theta_2 & \hat{M}pCOS\Theta_2 \\ 0 & \hat{M}pCOS\Theta_3 & \hat{M}pCOS\Theta_3 \end{bmatrix} \quad \text{...(3.22)}$$

Since it is easy to show that:

$$COS\Theta + COS\Theta_2 + COS\Theta_3 = 0$$

$$COS\Theta_3 - COS\Theta_2 = \sqrt{3}Sin\Theta$$

$$COS\Theta - COS\Theta_3 = \sqrt{3}Sin\Theta_2$$

$$COS\Theta_2 - COS\Theta = \sqrt{3}Sin\Theta_3$$

To complete the transformation there is:

$$Z'_{rs} = C_{1t}Z_{SS}C_1 \quad \text{...,(3.23)}$$

$$\sqrt{\frac{2}{3}} \begin{vmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{vmatrix} * \sqrt{\frac{2}{3}} \begin{bmatrix} 0 & \hat{M}pCOS\Theta & \hat{M}pCOS\Theta \\ 0 & \hat{M}pCOS\Theta_2 & \hat{M}pCOS\Theta_2 \\ 0 & \hat{M}pCOS\Theta_3 & \hat{M}pCOS\Theta_3 \end{bmatrix} \quad \text{.....................(3.24)}$$

$$Z'_{rs} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & \hat{M}pCOS\Theta & \hat{M}pSin\Theta \\ 0 & -\hat{M}pSin\Theta & \hat{M}pCOS\Theta \end{bmatrix} \quad \text{...,(3. 25)}$$

- Stator /rotor impedance:

$$Z_{sr}=\begin{bmatrix} \hat{M}pCOS\Theta & \hat{M}pCOS\Theta_2 & \hat{M}pCOS\Theta_3 \\ \hat{M}pCOS\Theta_2 & \hat{M}pCOS\Theta_3 & \hat{M}pCOS\Theta \\ \hat{M}pCOS\Theta_3 & \hat{M}pCOS\Theta & \hat{M}pCOS\Theta_2 \end{bmatrix} \quad (3.26)$$

$$Z'_{sr} = Z'_{rst} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & \hat{M}pCOS\Theta & -\hat{M}pSin\Theta \\ 0 & \hat{M}pSin\Theta & \hat{M}pCOS\Theta \end{bmatrix} \quad (3.27)$$

➢ Rotor impedance:

$$Z_{rr}=\begin{bmatrix} R_r+\hat{L}_rP & P\widehat{M_r} & P\widehat{M_r} \\ P\widehat{M_r} & R_r+\hat{L}_rP & P\widehat{M_r} \\ P\widehat{M_r} & P\widehat{M_r} & R_r+\hat{L}_rP \end{bmatrix} \quad (3.28)$$

$$Z'_{rr} = C_{1t}Z_{rr}C_1 =$$

$$\sqrt{\frac{2}{3}}\begin{vmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{vmatrix} \begin{bmatrix} R_r+\hat{L}_rP & P\widehat{M_r} & P\widehat{M_r} \\ P\widehat{M_r} & R_r+\hat{L}_rP & P\widehat{M_r} \\ P\widehat{M_r} & P\widehat{M_r} & R_r+\hat{L}_rP \end{bmatrix} \sqrt{\frac{2}{3}}\begin{vmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{vmatrix} =$$

$$\begin{vmatrix} R_r+L_{r0}P & 0 & 0 \\ 0 & R_r+L_rP & 0 \\ 0 & 0 & R_r+L_rP \end{vmatrix} \quad (3.29)$$

Where:

$L_{r0} = \hat{L}_r + 2\hat{M}_r$, $L_r = \hat{L}_r - \hat{M}_r$

The new matrix will be:

$$[Z]` = \begin{bmatrix} R_S+L_{S0}P & 0 & 0 & M_3p\cos 3\Theta & 0 & 0 \\ 0 & R_S+L_SP & 0 & 0 & Mp\cos\Theta & Mp\sin\Theta \\ 0 & 0 & R_S+L_SP & 0 & -Mp\sin\Theta & Mp\cos\Theta \\ M_3p\cos\Theta & 0 & 0 & R_r+L_{r0}P & 0 & 0 \\ 0 & Mp\cos\Theta & -Mp\sin\Theta & 0 & R_r+L_rP & 0 \\ 0 & Mp\sin\Theta & Mp\cos\Theta & 0 & 0 & R_r+L_rP \end{bmatrix}$$

$$(3.30)$$

Under normal condition the zero component(I_0) represents the imbalances in the R, Y, and B phase currents and it is called zero-sequence component of the current. Cannot flow and can ignore the zero component. The impedance will be:

$$[Z]` = \begin{bmatrix} R_S + L_S P & 0 & Mpcos\Theta & Mpsin\Theta \\ 0 & R_S + L_S P & Mpsin\Theta & -Mpcos\Theta \\ Mpcos\Theta & Mpsin\Theta & R_r + L_r P & 0 \\ Mpsin\Theta & -Mpcos\Theta & 0 & R_r + L_r P \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots..(3.31)$$

The same transformation can be applied to the voltages and the fluxes both for the stator and the rotor variables. The differential equations corresponding to this representation are given as

$$\begin{bmatrix} V_D \\ V_d \\ V_Q \\ V_q \end{bmatrix} = \begin{bmatrix} R_S + L_S P & 0 & Mpcos\Theta & Mpsin\Theta \\ 0 & R_S + L_S P & Mpsin\Theta & -Mpcos\Theta \\ Mpcos\Theta & Mpsin\Theta & R_r + L_r P & 0 \\ Mpsin\Theta & -Mpcos\Theta & 0 & R_r + L_r P \end{bmatrix} \begin{bmatrix} I_D \\ I_d \\ I_Q \\ I_q \end{bmatrix} \ldots\ldots\ldots\ldots (3.32)$$

The commutator transformation is applied to eliminate the rotor angle ϴ in equation 3.31

Figure 3.2 shows the schematic Representation of Stationary and Rotating Axis

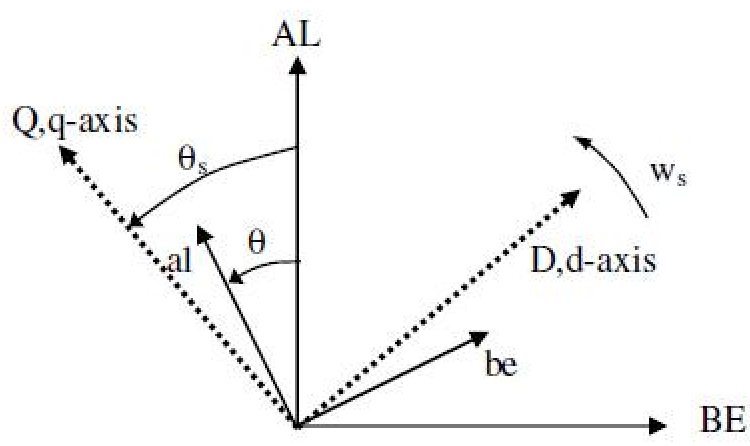

Figure 3.2 :Schematic Representations of Stationary and Rotating Axis

From figure 3.2 ϴ is the instantaneous angular position of the reference frame in that case, the transformation matrix for the stator AL, BE to D, Q variables is given as D, Q and the transformation matrix for the rotor to al, be variables is given as d, q.To transform the two phase machine to commutator machine by using C_2 , the stator is not requires a transformation.

Where:

$$C_2 = \begin{vmatrix} sin\Theta & cos\Theta \\ cos\Theta & -sin\Theta \end{vmatrix} \quad (3.33)$$

$$[Z"] = \begin{vmatrix} U & 0 \\ 0 & C_{2t} \end{vmatrix} \begin{vmatrix} Z'_{SS} & Z'_{Sr} \\ Z'_{rS} & Z'_{rr} \end{vmatrix} \begin{vmatrix} U & 0 \\ 0 & C_2 \end{vmatrix} = \begin{vmatrix} Z'_{SS} & Z'_{Sr}C_2 \\ C_{2t}Z'_{rS} & C_{2t}Z'_{rr}C_2 \end{vmatrix} \quad (3.34)$$

The commutator equivalent of the IM obtained as follows:

$$[Z"] = \begin{bmatrix} R_S + L_S P & MP & 0 & 0 \\ MP & R_r + L_r P & \omega_m M & \omega_m L_r \\ 0 & 0 & R_S + L_S P & MP \\ -\omega_m M & -\omega_m L_r & MP & R_r + L_r P \end{bmatrix} \quad (3.35)$$

$$[V"] = [Z"][I"] \quad (3.36)$$

Where

$$[V"] = \begin{bmatrix} V_D \\ V_d \\ V_Q \\ V_q \end{bmatrix} \quad (3.37)$$

$$[I"] = \begin{bmatrix} i_D \\ i_d \\ i_Q \\ i_q \end{bmatrix} \quad (3.38)$$

By arranging the elements of the matrix then:

$$\begin{bmatrix} V_D \\ V_d \\ V_Q \\ V_q \end{bmatrix} = \begin{bmatrix} R_S + L_S P & MP & 0 & 0 \\ MP & R_r + L_r P & \omega_m M & \omega_m L_r \\ 0 & 0 & R_S + L_S P & MP \\ -\omega_m M & -\omega_m L_r & MP & R_r + L_r P \end{bmatrix} \begin{bmatrix} i_D \\ i_d \\ i_Q \\ i_q \end{bmatrix} \quad \text{(3.39)}$$

Where

$\omega_m = \frac{d\Theta}{dt}$ is a constant and is defined as the synchronous speed of rotation of the reference frame.

$$[V] = [R][i] + [L]P[i] + \omega_m [G][i] \quad \text{(3.40)}$$

$$P[i] = [L]^{-1}([V] - [R][i] - \omega_m[G][i]) \quad \text{(3.41)}$$

3.2.2. Model Of Self Excited Induction Generator:

The model of SEIG is similar to an induction motor. The difference is that the self-excited induction generator has capacitors connected across the stator terminals. The conventional steady state per-phase equivalent circuit representation of an induction machine is convenient to use for steady state analysis. However, the *d-q* representation is used to model the self-excited induction generator under dynamic conditions. The *d-q* representation of SEIG with capacitors connected at the terminals of the windings and without any electrical input from rotor side is shown in figure 3.3 [4].

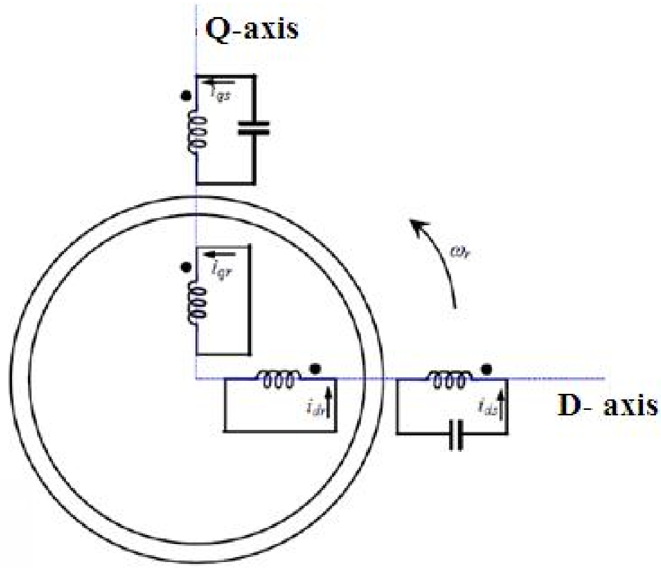

Figure 3.3: $d-q$ representation of self-excited induction generator (SEIG) with capacitor

From the figure 3.4 the induction machine voltage equations are:

$V_{ds} = R_s i_{ds} - \omega_e \Psi_{qs} + p\Psi_{ds}$ ……………………………………………(3.42)

$V_{qs} = R_s i_{qs} - \omega_e \Psi_{ds} + p\Psi_{qs}$ ……………………………………………(3. 43)

$V_{dr} = 0 = R_r i_{ds} - (\omega_e - \omega_r)\Psi_{qs} + p\Psi_{ds}$ ………………………………(3.44)

$V_{qr} = 0 = R_r i_{qs} - (\omega_e - \omega_r)\Psi_{ds} + p\Psi_{qs}$ ………………………………(3.45)

The induction machine flux and current equations are:

$\Psi_{ds} = L_s i_{ds} + L_m i_{ds}$ ……………………………………………………(3.46)

$\Psi_{qs} = L_s i_{qs} + L_m i_{qs}$ ……………………………………………………(3.47)

$\Psi_{dr} = L_r i_{dr} + L_m i_{ds}$ ……………………………………………………(3.48)

$\Psi_{qr} = L_r i_{qr} + L_m i_{qs}$ ……………………………………………………(3.49)

$i_{dm} = i_{ds} + i_{dr}$ ……………………………………………………………(3.50) direct axis magnetizing current

$$i_{qm} = i_{qs} + i_{qr} \text{..}(3.51)$$

quadrature axis magnetizing current

$$i_m = \sqrt{{i_{dm}}^2 + {i_{qm}}^2} \text{..}(3.52)$$

magnetizing current in the machine with neglecting leakage

$$\Psi_{dm} = L_m i_{dm} = \frac{f_m(i_m)}{i_m} i_{dm} \text{..}(3.53)$$

$$\Psi_{qm} = L_m i_{qm} = \frac{f_m(i_n)}{i_n} i_{qm} \text{..}(3.54)$$

Equations (3.53) and (3.54) can be redrawn in detail, in a stationary stator reference frame, with direct and quadrature circuits separately represented as shown in figure 3.4

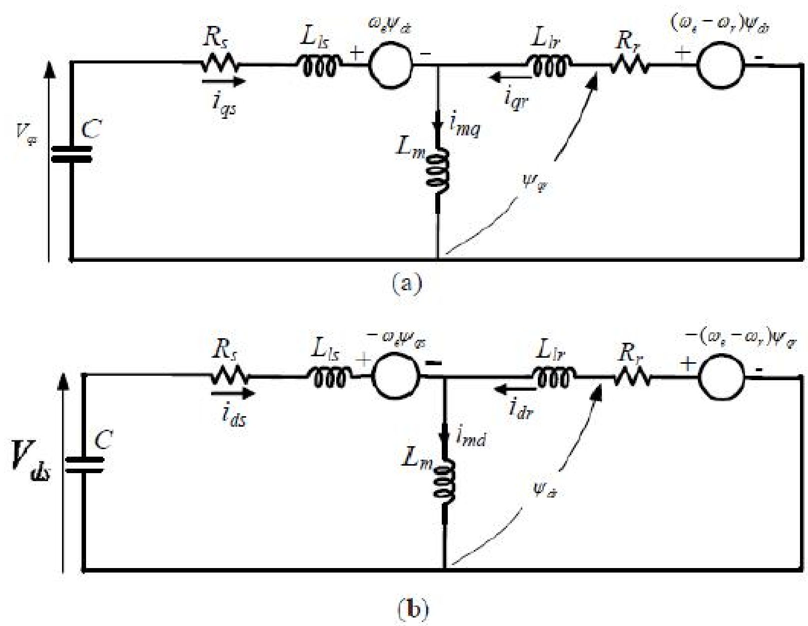

Figure 3.4: Detailed d-q model of SEIG in stationary reference frame (a) q- axis circuit (b) d- axis circuit

The capacitor in figure (3.6) can be represented as

$$V_{cq} = \frac{1}{C}\int i_{qs}dt \qquad (3.55)$$

$$V_{cd} = \frac{1}{C}\int i_{ds}dt \qquad (3.56)$$

The matrix equation for the d-q model of self-excited induction generator in the stationary stator reference frame, using the SEIG model given in figure 3.4 is given as

$$\begin{bmatrix} V_{ds} \\ 0 \\ V_{qs} \\ 0 \end{bmatrix} = \begin{bmatrix} R_S + L_S P + \frac{1}{pC} & MP & 0 & 0 \\ MP & R_r + L_r P + \frac{1}{pC} & \omega_m M & \omega_m L_r \\ 0 & 0 & R_S + L_S P & MP \\ -\omega_m M & -\omega_m L_r & MP & R_r + L_r P \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{dr} \\ i_{qs} \\ i_{qr} \end{bmatrix} \qquad (3.57)$$

The SEIG equivalent circuit shown in figure 3.5 can be loaded with a resistive load by connecting a resistance R_L across the capacitor, C. with resistive load equation (3.39) is modified to the equation (3.58)[11-12]

$$\begin{bmatrix} V_{ds} \\ 0 \\ V_{qs} \\ 0 \end{bmatrix} = \begin{bmatrix} R_S + L_S P + \frac{R_L}{1+R_L pC} & MP & 0 & 0 \\ MP & R_r + L_r P + \frac{R_L}{1+R_L pC} & \omega_m M & \omega_m L_r \\ 0 & 0 & R_S + L_S P & MP \\ -\omega_m M & -\omega_m L_r & MP & R_r + L_r P \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{dr} \\ i_{qs} \\ i_{qr} \end{bmatrix} \qquad (3.58)$$

3.3. Calculation Of Shunt Capacitor For SEIG

To calculate the value of shunt capacitor of SEIG there are two methods available [8].

i. Loop impedance method.

ii. Nodal analysis method.

3.3.1. Loop Impedance Method

Figure 3.5 shows the loop impedance method.

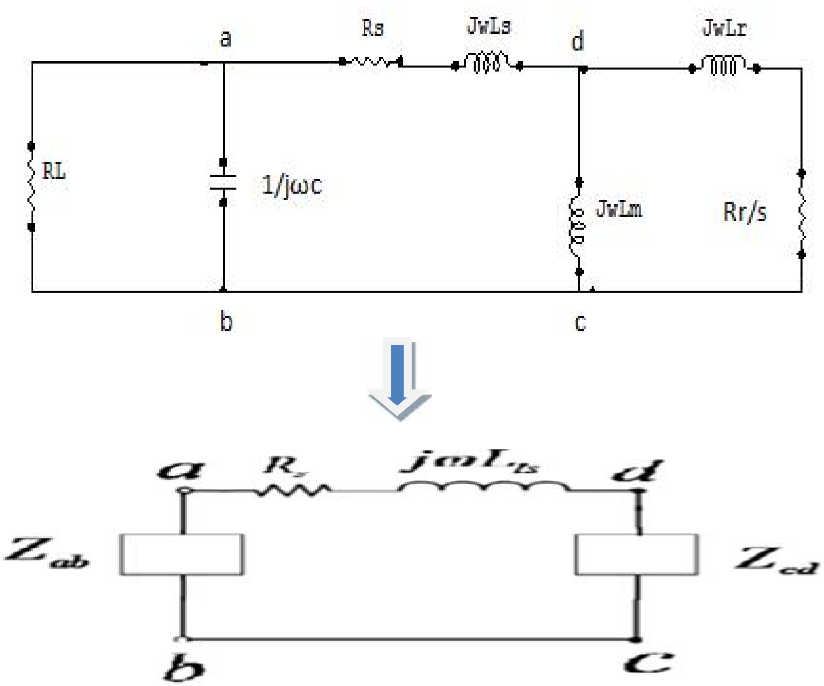

Figure 3.5: Loop impedance method

For loop impedance, considering the loop $a\ b\ c\ d\ a$ and applying KVL

$Z_{ab} + Z_{cd} + Z_{ad} = 0$…………………………………………………......(3.59)

By equating real and imaginary part from equation (3.59) the form of solution will be

$$\left.\begin{aligned} F(f, X_C) &= 0 \\ G(f, X_C) &= 0 \end{aligned}\right\} \quad \text{……………………….(3.60)}$$

It can be shown that for a *R-L* load, the degrees of X_C in the two equations are order and order respectively. One of the variables can't be easily eliminated from the earlier and an iterative technique for solving the two variables simultaneously [11].

3.3.1. Nodal Analysis Method

Figure 3.6 shows the Nodal analysis method

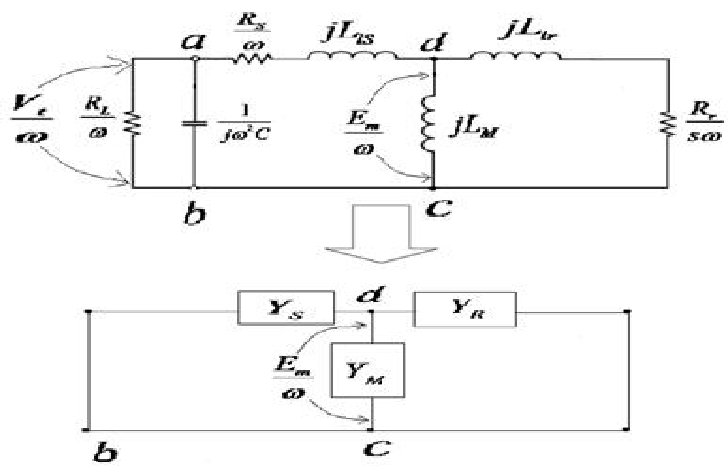

Figure 3.6: Nodal analysis method

A transformation has been applied so that all the reactance and voltage are referred to the base frequency (ω). For self excite, the excitation capacitance must be equal to minimum value of capacitor. In order to operate at stable voltage, the machine must operate at an appropriate level of magnetic saturation. Accordingly the magnetizing reactance X_M is not constant but varies with load condition[10].

At node d, the algebraic sum of current meeting is equal to zero.

$$\frac{E_m}{\omega}(Y_S + Y_R + Y_M) = 0 \quad \text{...(3.61)}$$

Since E_m can't be zero

$$Y_S + Y_R + Y_M = 0 \quad (3.62)$$

This equation can be expanded, so real and imaginary parts equation equal to zero.

Equating real parts

$$\frac{R_{1L}/\omega}{(R_{1L}/\omega)^2 + L_{1L}{}^2} + \frac{R_r/s\omega}{(R_r/s\omega)^2 + L_{lr}{}^2} = 0 \quad (3.\ 63)$$

And equating imaginary parts

$$\frac{1}{L_n} + \frac{L_{1L}}{(R_{1L}/\omega)^2 + L_{1L}{}^2} + \frac{L_{Lr}}{(R_r/s\omega)^2 + L_{1r}{}^2} = 0 \quad (3.64)$$

Where:

$$L_{1L} = L_S - \frac{CR_L}{(\omega CR_L)^2 + 1} \quad (3.65)$$

And

$$R_{1L} = R_S + \frac{R_L}{(\omega CR_L)^2 + 1} \quad (3.66)$$

R_{1L} and L_{1L} are the effective resistance and inductance respectively the stator winding and load as seen by node d. Equation (3.63) can be used to find out capacitance required after having known slip and equation (3.64) can be used to find out L_M.

The following set of equations is used for a computer-based analysis of the induction generator operating with the output frequency, ω. A purely resistive Load R_L, is assumed. The load, capacitor, and stator currents, $\hat{I}_L$, $\hat{I}_C$, and $\hat{I}_S$, respectively, are determined as

$$\hat{I}_L = \frac{\hat{V}_s}{R_L} \quad \text{......(3.67)}$$

$$\hat{I}_C = \frac{\hat{V}_s}{JX_C} \quad \text{......(3.68)}$$

$$\hat{I}_s = \hat{I}_L + \hat{I}_C \quad \text{......(3.69)}$$

Now the stator EMF ,E_S can be found as

$$\hat{E}_s = \hat{V}_s + (R_S + jX_{lS})\,\hat{I}_s \quad \text{......(3.70)}$$

And the magnetizing current $\hat{I}_m$, as

$$\hat{I}_m = f^{-1}(\hat{E}_s)e^{j(\theta_E - \frac{\pi}{2})} \quad \text{......(3.71)}$$

Where θ_E denotes the angle of phasor $\hat{E}_s$. Finally, the rotor current, $\hat{I}_r$ is given by

$$\hat{I}_r = \hat{I}_s + \hat{I}_m \quad \text{......(3.72)}$$

The stator voltage, $\hat{V}_s$=V_s (reference phase), in equations (3.67),(3.68), (3.69)

Must be such that the balance of reactive powers,

$$X_C {I_C}^2 = X_{ls} {I_s}^2 + X_{lr} {I_r}^2 + X_m {I_m}^2 \quad \text{......(3.73)}$$

Is satisfied, this in addition to the nonlinear relation between the stator EMF and magnetizing current, requiring an iterative approach to the computations. Once the currents have been found, the balance of real power[11].

$$-R_C {I_C}^2 = R_r {I_r}^2 + R_s {I_s}^2 + R_L {I_L}^2 \quad \text{......(3.74)}$$

3.4 Modeling of gear

The mechanical system of the wind turbines plays a big role in the energy transformation. Most of the simple wind turbine gear box consists of two main shafts, the low speed shaft which is basically connected with the wind turbine blades, and the second one which is called the high speed shaft connected directly to the generator as shown in figure 3.7.

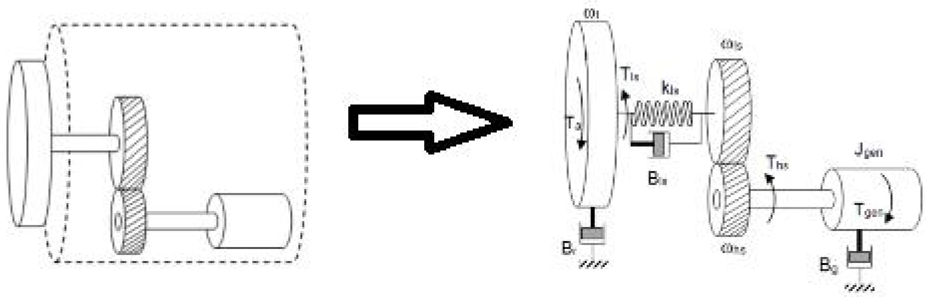

Figure 3.7: Typical gear of wind turbine

By applying Newton's second law for rotation system or using energy principles on the rotor, the mathematical model will be: [12]

$$J_r \dot{W}_t + B_r W_t = T_a - T_{ls} \quad \text{……………………………………………}(3.75)$$

Where ,

J_r = rotor moment of inertia.

$\dot{W}_t$ = rotor angular speed.

B_r = rotor damping effect.

T_a =applied torque on the rotor.

T_{ls} =low speed shaft torque.

Whereas the same technique is applied for the driving gear, which basically its moment of inertia is cancelled, this will yield:

$$J_{ls}\dot{W}_t + B_{ls}(W_t - W_{ls}) + K_{ls}(\theta_t - \theta_{ls}) = T_{ls} \quad \text{.............................(3.76)}$$

Where,

J_{ls} =driver moment of inertia (cancelled).

W_{ls} =angular speed of the low speed shaft.

K_{ls} =stiffness of low speed shaft.

θ_t = rotor angular displacement.

θ_{ls} = low speed angular displacement.

Since the moment of inertia of gear one is considered, and then the mathematical model of it is calculated as

$$T_{G1} = J_{G1}\dot{W}_{ls} + B_{ls}W_{ls} + K_{sl}(\theta_{sl} - \theta_t) \quad \text{.......................................(3.77)}$$

Whereas for gear 2, the dynamic equation is written as:

$$T_{hs} = J_{G2}\dot{W}_{hs} + B_g W_{ls} + K_{hs}(\theta_{hs} - \theta_g) \quad \text{.......................................(3.78)}$$

3.5 Modeling Of Wind Turbine (WT)

The output power of wind turbine is given by

$$P_m = C_p * (\lambda * \beta) * \frac{\rho A}{2} * V^3{}_{wind} \quad \text{...(3.79)}$$

Where,

P_m – Mechanical output power of wind turbine,

C_p – Performance coefficient of wind turbine (0.48-0.5)

ρ – Air density (kg/m^3),

A – Area of the blades (m^2)

V_{wind} – wind speed (m/s)

λ – Tip speed ratio (V_{tip}/V_{wind})

β – Blade pitch angle (deg) [12].

3.6 Modeling of VSC

Voltage-source converter (VSC) is connected to a single capacitor and battery on the DC side. The VSC is switched by SVM technique and the line to line voltages are given by

$$v_{ab} = v_{an} - v_{bn} \quad (3.80)$$

$$v_{bc} = v_{bn} - v_{an} \quad (3.81)$$

$$v_{ca} = v_{cn} - v_{an} \quad (3.82)$$

v Phase voltage is given by

$$\begin{bmatrix} v_{ab} \\ v_{bc} \\ v_{ca} \end{bmatrix} = \begin{bmatrix} \frac{2}{3} & \frac{-1}{3} & \frac{-1}{3} \\ \frac{-1}{3} & \frac{2}{3} & \frac{-1}{3} \\ \frac{-1}{3} & \frac{-1}{3} & \frac{2}{3} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (3.83)$$

Where a, b, c are switching variable vector[9]

3.7 Control Scheme Based On SVM

SVM treats the sinusoidal voltage as a constant amplitude vector rotating at constant frequency. This PWM technique approximates the reference voltage V_{ref} by a combination of the eight switching patterns (V_0 to V_7). The proposed control scheme based on SVM which are shown in figure 3.8. The speed and load errors are directly sent through PI controller. Controller generates voltage reference V_d and V_q in the stator flux frames. SVM is calculated from V_d and V_q and then drives the inverter. To implement the space vector PWM, the voltage equations in the abc reference frame can be transformed into the stationary $d\ q$

reference frame that consists of the horizontal (d) and vertical (q) axis .Figure 3.7 shows the relationship of abc reference frame and stationary $d\ q$ reference frame.

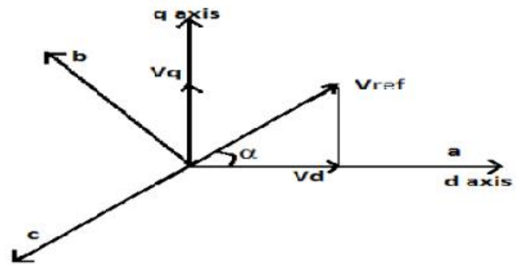

Figure. 3.8: The relationship of abc reference frame and stationary $d\ q$ reference frame[24].

According to the relationship among abc and dq axis, it can get the following equation

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} \quad \text{.........(3.84)}$$

$$V_{ref} = \sqrt{{V_d}^2 + {V_q}^2} \quad \text{.........(3.85)}$$

$$\Theta_s = tan^{-1}\left(\frac{V_q}{V_d}\right) = \omega * t = 2\pi f * t \quad \text{.........(3.86)}$$

Where f = fundamental frequency the objective of space vector PWM technique is to approximate the reference voltage vector V_{ref} using the eight switching patterns. One simple method of approximation is to generate the average output of the inverter in a small period, T to be the same as that of V_{ref} in the same period. The figure 3.8 shows the basic switching vector and sector which are shown below[24]

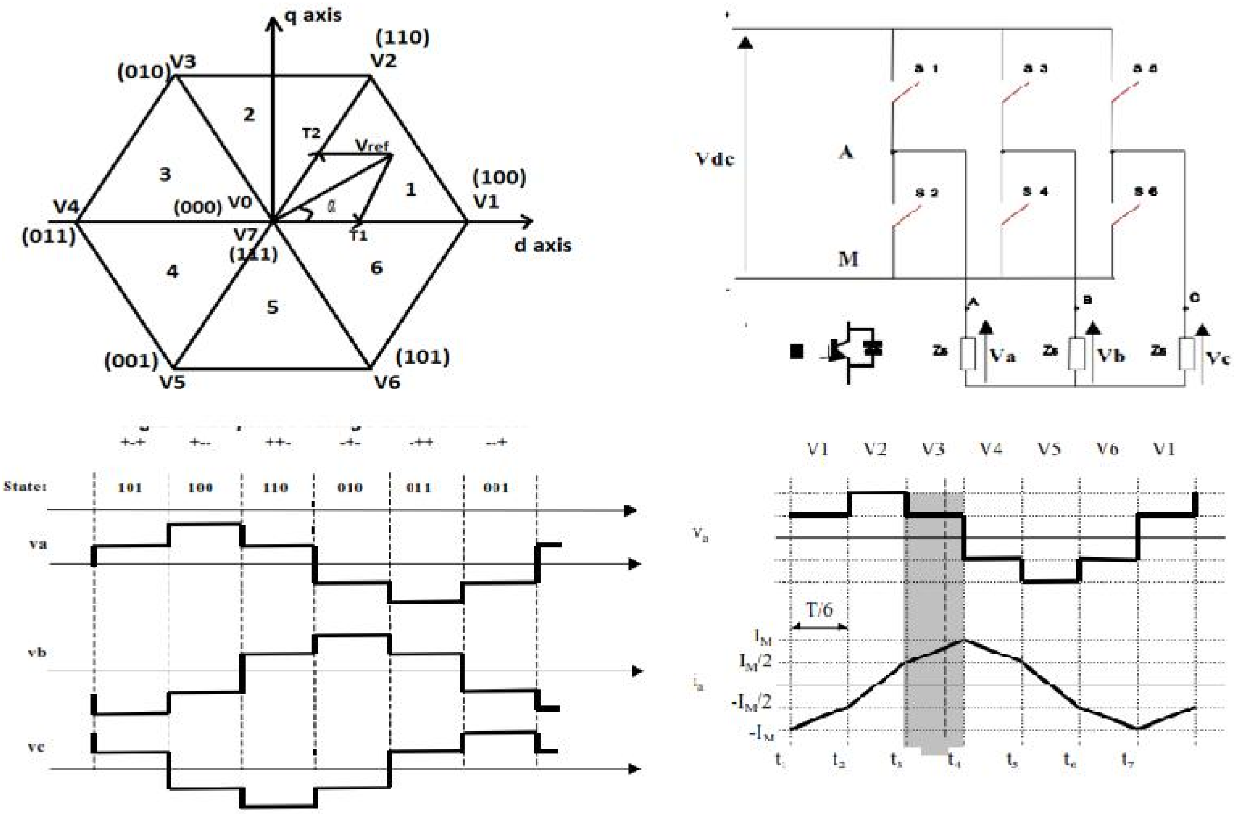

Figure 3.9: Basic switching vector and sector

The vectors (V_1 to V_6) divide the plane into six sectors (each sector 60 degrees). For each sector, the switching time duration (T_1, T_2, T_0) are calculated by

$$T_1 = \frac{\sqrt{3}T_z|\overline{V_{ref}}|}{V_{dc}}\left(sin\left(\frac{n\pi}{3}\right) * cos(\Theta_s) - cos\left(\frac{n\pi}{3}\right) * sin\,(\Theta_s)\right) \text{.................(3.87)}$$

$$T_2 = \frac{\sqrt{3}T_z|\overline{V_{ref}}|}{V_{dc}}\left(sin\left(\frac{(n-1)\pi}{3}\right) * cos(\Theta_s) - cos\left(\frac{(n-1)\pi}{3}\right) * sin\,(\Theta_s)\right) \text{..........(3.88)}$$

$$T_0 = T_z + T_1 - T_2 \text{..(3.89)}$$

Table.3.1 The switching time at each sector[24]

SECTOR	UPPER SWITCHES (S1, S_3, S_5)	LOWER SWITCHES (S_4, S_6, S_2)
1	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_2 + T_0/2$ S_5 = T0/2	$S_4 = T_0/2$ $S_6 = T_1 + T_0/2$ $S_2 = T_1 + T_2 + T_0/2$
2	$S_1 = T_1 + T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_0/2$	$S_4 = T_2 + T_0/2$ $S_6 = T_0/2$ $S_2 = T_1 + T_2 + T_0/2$
3	$S_1 = T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_2 + T_0/2$	$S_4 = T_1 + T_2 + T_0/2$ $S_6 = T_0/2$ $S_2 = T_1 + T_0/2$
4	$S_1 = T_0/2$ $S_3 = T_1 + T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1 + T_2 + T_0/2$ $S_6 = T_2 + T_0/2$ $S_2 = T_0/2$
5	$S_1 = T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1 + T_0/2$ $S_6 = T_1 + T_2 + T_0/2$ $S_2 = T_0/2$
6	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_0/2$	$S_4 = T_0/2$ $S_6 = T_1 + T_2 + T_0/2$ $S_2 = T_2 + T_0/2$

From the table 3.1 the switching times of each transistor are calculated which helps to control the VSC.

The proposes a simple sensor less maximum power extraction control strategy for a variable speed wind energy conversion system (VSWECS) based on self-excited induction generator (SEIG).The SEIG is connected to the load through a switch mode rectifier and a three phase voltage source inverter (VSI). Control of the generator side converter is used to achieve maximum power point tracking from the available wind power. This by Simple estimating of SEIG generator speed and using the estimated generator speed to calculate mechanical power generated from wind power. So, the optimum power coefficient of the wind turbine can be achieved from the governed relation between the generator speed and mechanical power. The load side voltage source inverter uses a constant voltage constant frequency controller to supply power at unity power factor into the load. Extensive simulations have been performed using MATALB/SIMULINK. Simulation results demonstrate that the controller can extract maximum power from available wind power and achieve unity power factor at the load with different wind speeds[22].

Figure 3.9 Shows the power circuit topology and control structure of the proposed variable speed wind turbine. The system consists of the Wind turbine, Self-Excited Induction generator (SEIG), which is directly driven by the wind turbine without using a gearbox, a single switch three phase mode rectifier, which consists of a three phase diode bridge rectifier and DC-DC boost converter, uses a simple sensor less control to achieve maximum power from available wind power. A three phase VSI which is connected to the load through a passive L filter. It uses a constant voltage constant frequency controller to achieve unity power factor at the load. The phase voltage and its frequency at the load are 550V and 50Hz, respectively. The proposed model has been modeled and simulated using MATLAB/SIMULIN

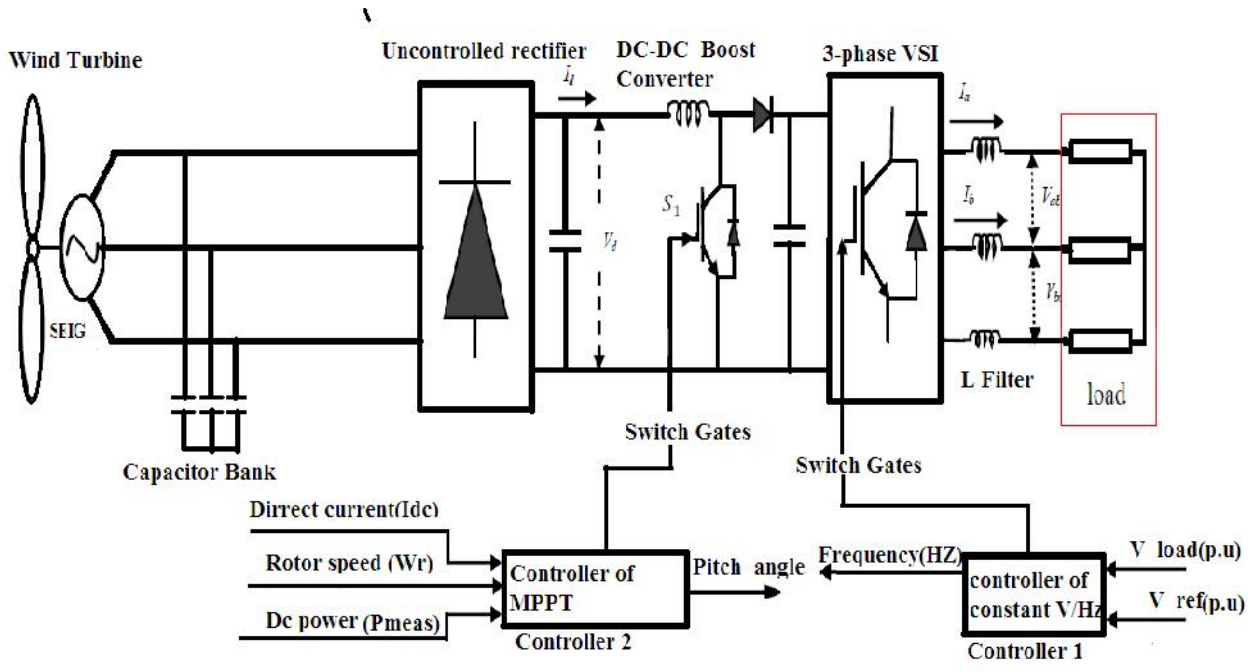

Figure 3.10: Power Circuit topology combined with control structure.

3.8 Diode Bridge Rectifier And DC Link

Three phase uncontrolled bridge rectifier is used to convert the variable voltage and variable frequency at the induction generator terminal into rectified dc voltage. To simplify the analysis, all the diodes are assumed to be ideal (no power losses or on-state voltage drop).The dc voltage V_{dc}contains six pulses (humps) per cycle of the supply frequency. therefore, commonly known as a six-pulse.

3.9 Maximum Power Point Tracking (DC-DC Boost Converter)

The maximum mechanical power P_{m-max} is obtained from equation 3.79 and can be written as equation 3.86

$P_m = 0.5 * C_P * \rho * A * v_w{}^3$ ………………………………….....................(3.90)

Figure 3.10 shows the wind turbine power curve for different wind speed.

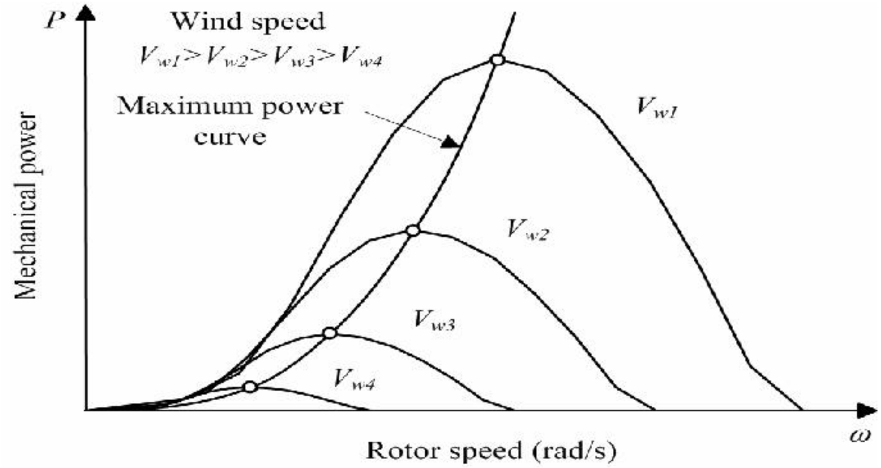

Figure 3.11: Mechanical power versus rotor speed characteristics

The output energy is determined by the power coefficient (C_P) if the swept area, air density, and wind speed are assumed to be constant. C_P is function in tip speed ratio (λ) and pitch angle (β) in degree. If β is equal zero, in this case C_P is only function in λ and which is function of rotor mechanical speed, rotor radius of blade and wind speed [2-3]

$$C_P(\lambda) = \frac{60.04-4.69\lambda}{\lambda} e^{\left(\frac{-21+0.735\lambda}{\lambda}\right)} + \frac{0.0068*\lambda}{1-0.035*\lambda} \quad \text{……………………….(3.91)}$$

$$\lambda = \frac{\omega_r * R}{v_w} \quad \text{……………………..…………………………………………(3.92)}$$

Where ω_r the rotational speed (rad/sec.) and R is the radius of blade (m)[3].

The relation between C_p and λ when β equal zero degree it can be noticed that the optimum value of C_p is about 0.32 for λ equal 5.5 Maximum power extraction from wind turbine can be achieved when the turbine operate at optimumC_p (C_{p_opt}).Therefore, it is necessary to adjust the rotor speed at optimum λ (λ_{opt}) with wind speed variation. When the generator speed is always controlled at the optimum speed, the tip-speed ratio remains the optimum value and the maximum power point tracking (MPPT) control can be achieved. In this case, information on wind speed is required. At any wind speed, it can calculate the optimum rotational speed of the generator from (3.90), and then the maximum mechanical power is calculated from (3.91).

$$P_{m-opt} = 0.5 * \rho * A * C_{P-opt} * \left(\frac{\omega_{r-opt} * R}{\lambda_{opt}}\right)^3 \quad \text{.....................................(3. 93)}$$

$$\omega_{r\_opt} = \frac{\lambda_{opt}}{R} v_w \quad \text{...(3.94)}$$

$$P_{m-opt} = K_{P-opt} * {\omega_{r\_opt}}^3 \quad \text{...(3.95)}$$

$$K_{P-opt} = \frac{0.5 * \rho * A * C_{P-opt} * R^3}{{\lambda_{opt}}^3} \quad \text{...(3.96)}$$

Figure 3.11 shows the relation between mechanical powers and rotor speeds for different wind speeds indicate that the mechanical powers generated by the turbine as a function of rotor speeds for different wind speeds. The maximum power extraction within the allowable range can be achieved if the controller can properly follow the optimum curve with variation of wind speed.

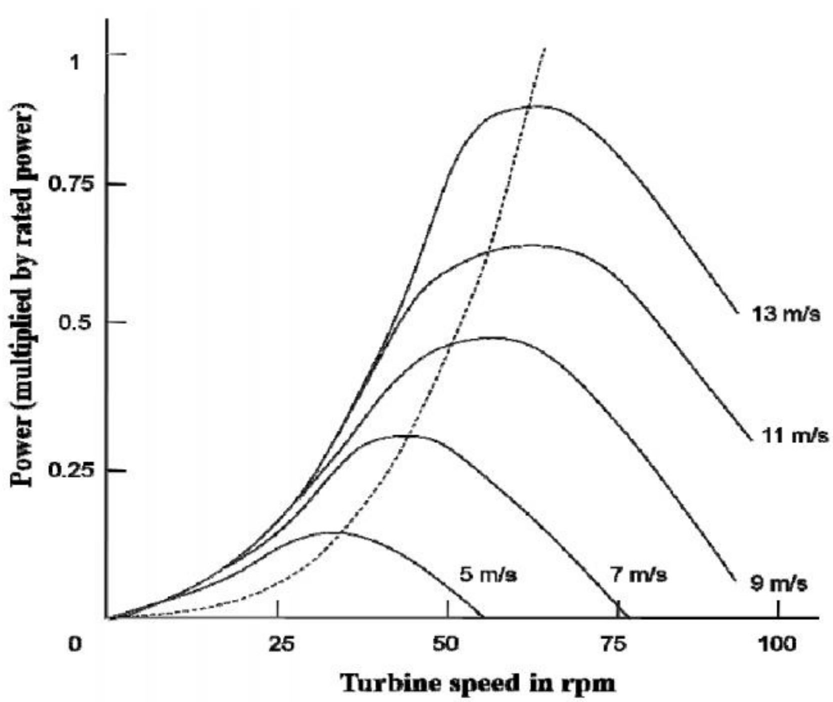

Figure 3.12: the relation among generated mechanical powers and rotor speeds for different wind speeds

The generator side converter (a single switch three phase mode rectifier) is controlled to extract maximum power from the available wind turbine power. Hence, the wind turbine can produce maximum power when the turbine Operates at C_{p_opt}. So it is necessary to adjust the rotor speed at λ_{opt}.The structure of the proposed control strategy of the switch mode rectifier is shown in figure 3.9 The controller objective is control the duty cycle of the DC-DC boost converter switch S_1 which is shown in figure 3.9 to extract maximum power from the available wind turbine power.

3.10 PWM Invert

The output power of the rectifier is filtered by using LC filter. By using PWM inverter DC power is converted into AC power employing double edge sinusoidal pulse width modulation technique[25]. The PWM signals are used to switch on the IGBTs in the inverter. The IGBTs are connected anti parallel with the diodes. If diode conducts energy will fed back to the source. The carrier wave is compared with the reference signal corresponding to a phase to generate gating signals. The instantaneous line-to-line output voltage is

$$V_{AB} = VS\,(g_1 - g_3) \qquad (3.93)$$

The sinusoidal PWM inverter converts the DC bus voltage to that of a fixed frequency of 50Hz. The modulation phase voltage can be analyzed by applying a Fourier analysis. In this thesis only the fundamental harmonic of the inverter is Considered. The fundamental harmonic of the inverter output voltage can be shown to be of the following form.

$$V_{1ph}(t) = \frac{V_{dc}}{2} sin(\omega t) \qquad (3.94)$$

Where:

m is the modulation index.

V_{ph1} The fundamental harmonic of the phase voltage

To simplify the analysis the initial orientation of q axis is taken such that it coincides with the output voltage, hence, the q and d axis components of the inverter output voltage (line to neural)

$$V_{qinv} = V_{1phm} = m\frac{V_{dc}}{2} \quad \text{.....(3.95)}$$

$$V_{din} = 0$$

Assuming the ínverter to be lossless, and neglecting the harmonic components in the output waveform. Consequently, the DC and AC powers at the inverter sides are equal

$$V_{dc} * I_{in} = \frac{3}{2}V_{qinv}I_{qinv} \quad \text{.....(3. 96)}$$

The q axis of inverter output current may be expressed by

$$I_{qinv} = \frac{4}{3m}I_{in} \quad \text{.....(3. 97)}$$

For resistance load, RL, transforming the load to the DC side of the inverter it get[24]

$$R_{Ldc} = \frac{8}{3m^2}R_L \quad \text{.....(3.98)}$$

CHAPTER FOUR

Results and Discussions

4.1 Introduction

In this chapter, The mathematical model of the system developed in chapter three is used to simulate the system. A variable speed self-excited induction generator with self-excitation capacitance and a resistive load is modeled using MATLAB/SIMULINK. Two control loop schemes are developed. The control schemes aim to ensure a maximum power point tracking (MPPT) and constant voltage-constant frequency operation. A cage type induction machine can be used with controlled external loads to a constant voltage-constant frequency supply.

Maximum Power Point Tracking is an important component of efficiently wind power. Selection of the right control strategy is therefore important to ensure that the system performs optimally.

4.2 System Configuration

The induction machine shaft is driven using wind turbine as prime mover at a steady speed. For excitation, three-phase, star connected capacitor bank calculated by the nodal analysis method, is applied to the stator terminals. The rated power of machine is1.5MW , stator voltage is 690V (rated voltage) and other parameters of machine are shown in appendix (A) the speed of rotation is then altered until a steady-state. AMPPT algorithm has designed and implemented as a controller for the wind system.

The complete simulation circuit diagram is shown in figure 4.1

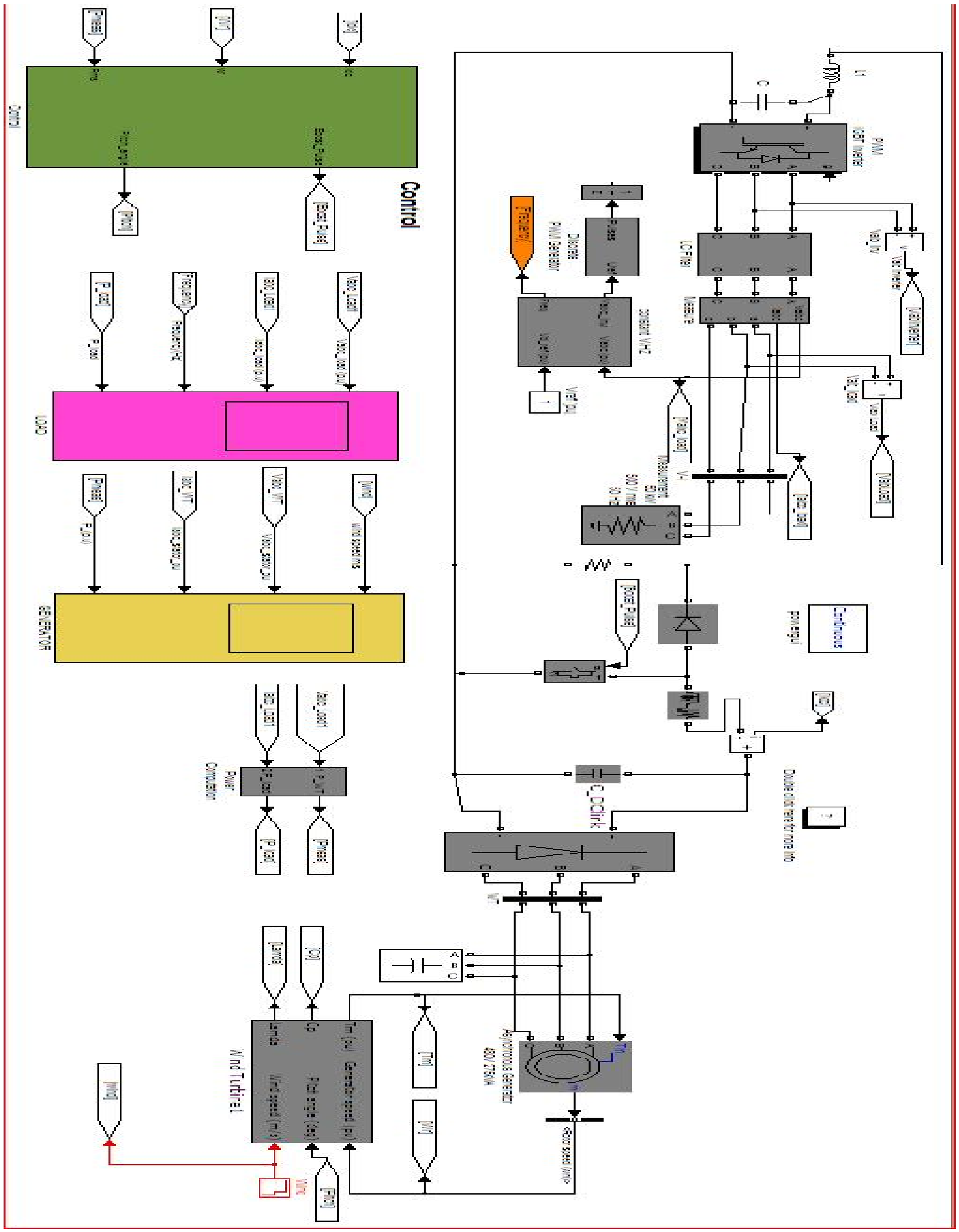

Figure 4.1: complete simulation circuit diagram

From the result analysis, the MPPT has been proven to be useful in tracking the maximum power point, and it is able to respond to the changes of wind speed and store up the wind energy collected instead of dissipate as unused energy. the overall result of the system has been justified to be positive .

The performance of the proposed voltage and frequency controller has been demonstrated for an isolated induction generator driven by fixed pitch wind turbine, which has been found suitable to regulate the voltage and frequency to be constant with variation of the load under varying wind speeds. The total harmonic distortion of terminal voltage and the generator current in such type of worst load condition . The voltage and frequency controller is valid . The filter is functioning as a harmonic eliminator.

4.3 Results

The results of the system is obtained using Matlab/Simulink. The results is obtained before and after filtering.

The characteristics of wind speed is shown in figure 4.2 ,the turbine has 6 speeds but there are a few of them not generate because they not have cut off .

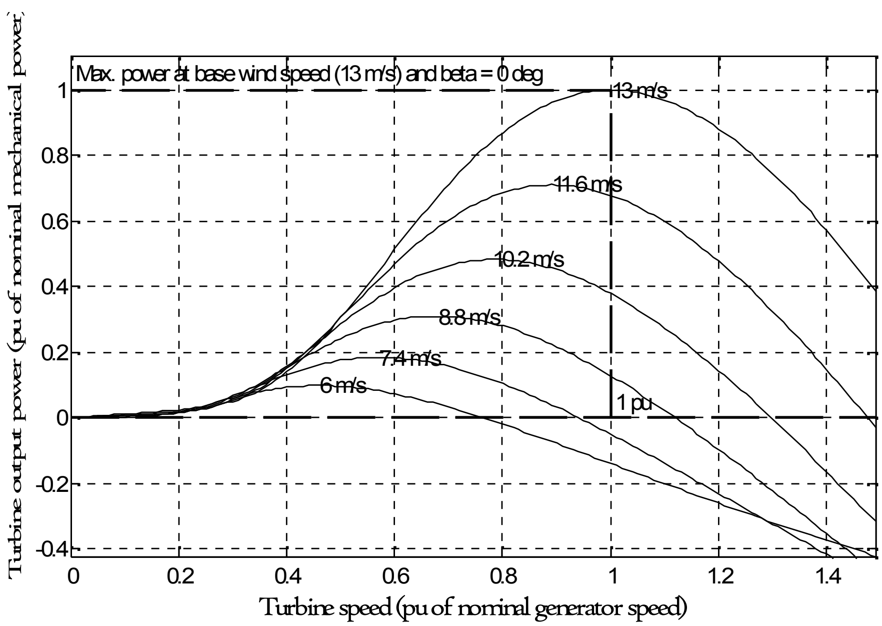

Figure 4.2: turbine characteristics(pitch angle=0deg)

The variation speed of wind turbine is shown in figure 4.3 at different time. It is noticed that wind speed start from13m/s at zero second and at 1.55 second decrease to11.6m/s and at 3.4 second decrease to 10.2m/s as configured. There are other speeds but they do not generator voltage.

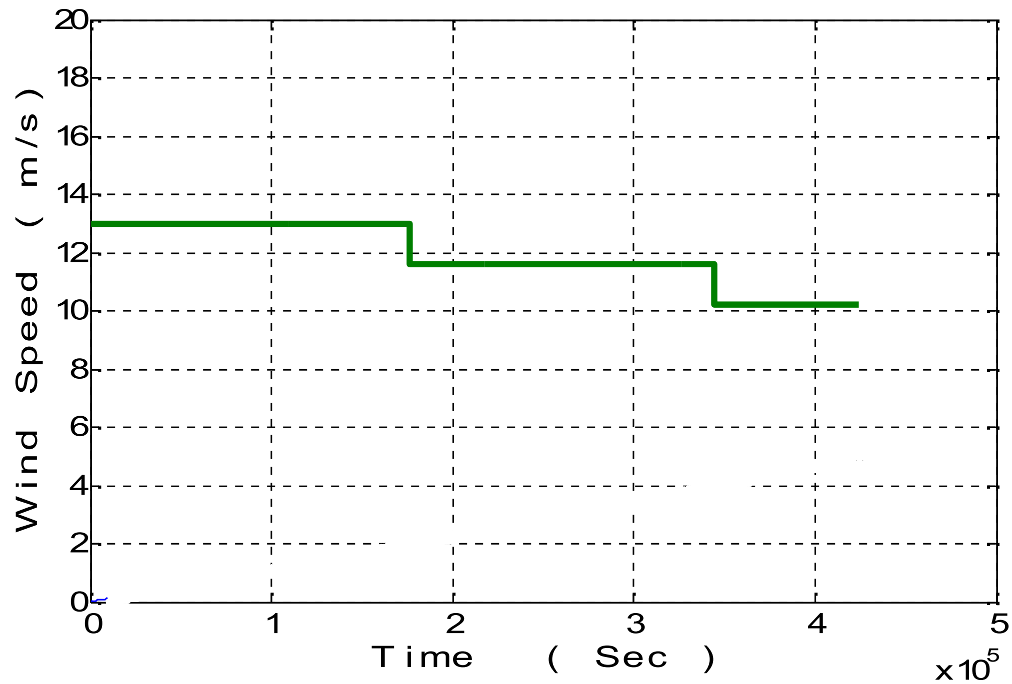

Figure 4.3: Variation of Speed for the wind turbine

The line to line voltages of induction generator are shown in figure 4.4. It observed from the figure that the voltages start at high value at zero second and decay to the steady-state value 2000 (v) at1.5 second. The effect of the capacitor bank is observed .The roll of the external capacitor is to minimize the steady state reaching time and stabilize the system within the minimum time. The output voltage of SEIG depend on capacitance value if the minimum value is selected the machine may not operate and if high value of the capacitance is selected the machine takes longer time to reach its steady-state value or may collapse. Here in this search the value of the capacitance is selected as per the equation derived for choosing the optimum value of the external capacitance.

Also it is observed that voltage depend to the wind speed. When wind speed increase the output voltage of generator increase. The voltage build up process starts with the low frequency and then rises until it reaches its steady state value.

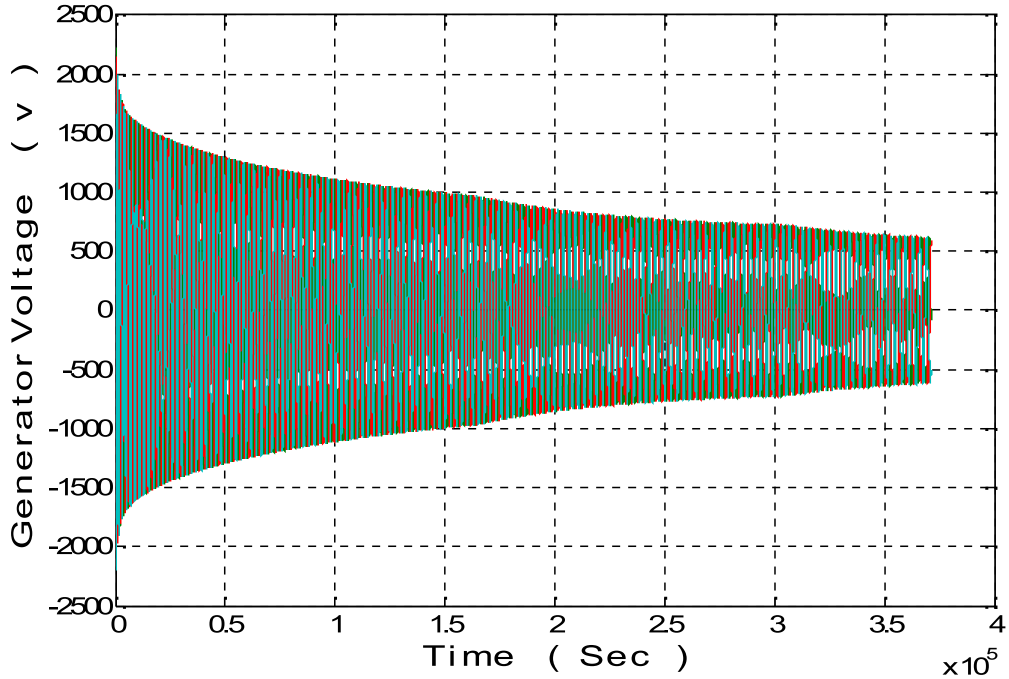

Figure 4.4: Generated voltages of SEIG.

The current of induction generator are shown in figure 4.5. It observed from the figure that the currents start at high value at zero second and decay to the steady state value 2000 (Amp) at 0.5 second.

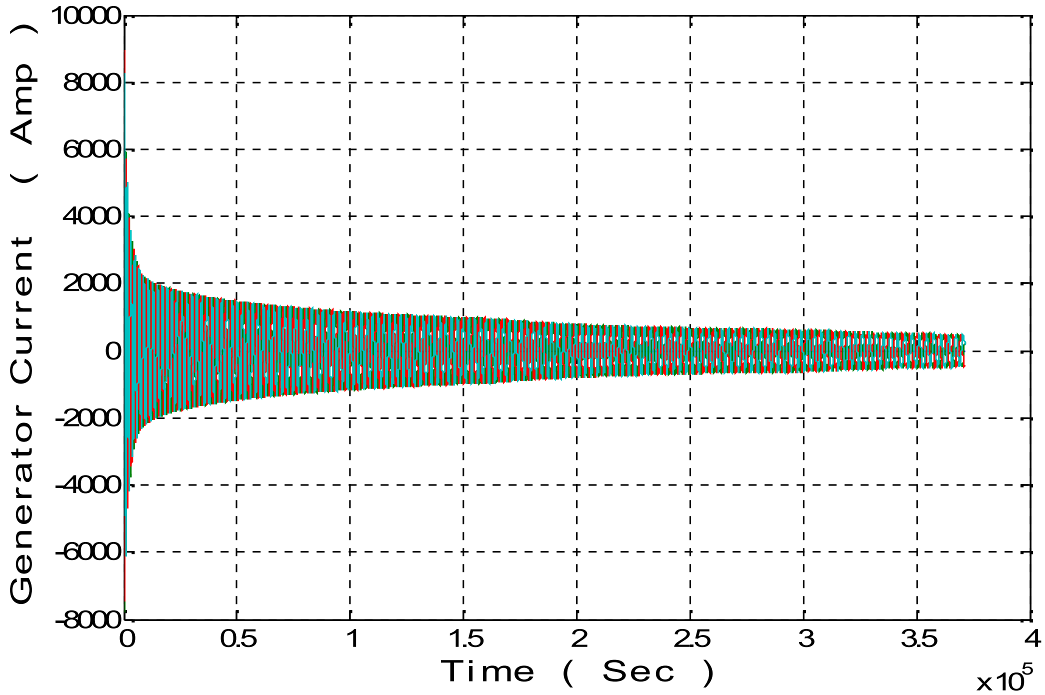

Figure 4.5: Generated currents of SEIG

The line to line voltages of load before filtered are shown in figure 4.6 , which are affected by the harmonics component. It is appear that the distortion of the waves ,harmonic currents can never be totally eliminated from an electrical system. However, to be very significantly reduced by using a harmonic filter, which is tuned to the frequency to be eliminated. The impedance of the filter is zero at the tuning frequency and therefore all of the particular harmonic current is absorbed by the filter. It is necessary to reduce more than one harmonic. Harmonic distortion can cause severe disturbance to certain electrical equipment. When capacitors are used in series with reactors they are rated at higher than system voltage, so when used without reactors they have the ability to withstand higher levels of harmonic overload.

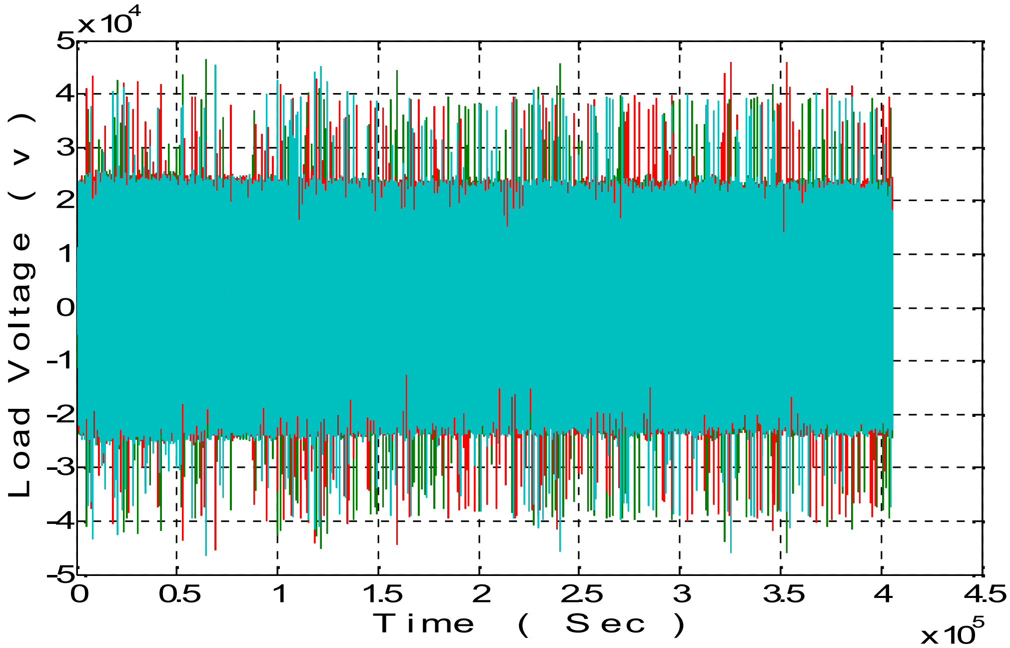

Figure 4.6: Load voltages before filtered

The load currents before filtered are shown in figure 4.7 ,the load currents are distortion and it can damage the load because the load will reach more than what it needs.

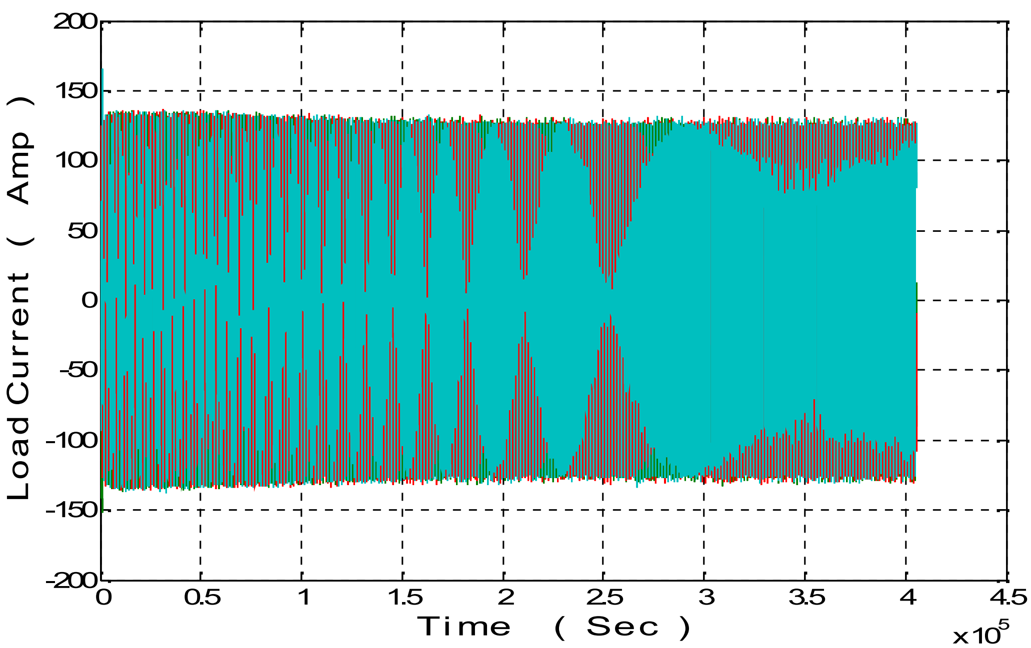

Figure 4.7: Load currents before filtered

The load power before filtered is shown in figure 4.8, which is clearly distortion

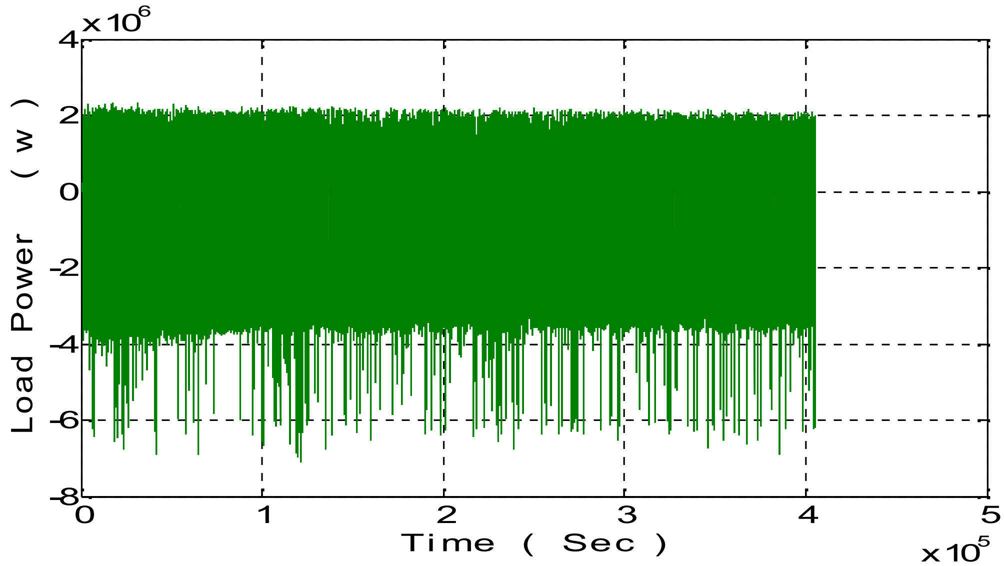

Figure 4.8: Load power before filtered

The load voltages after filtered are shown in figure 4.9. It is noticed that the voltages are constant in 550v although the wind speed changes during the time which is setting .The controller is valid and it noticed that the effect of filter is eliminated most of the harmonics component.

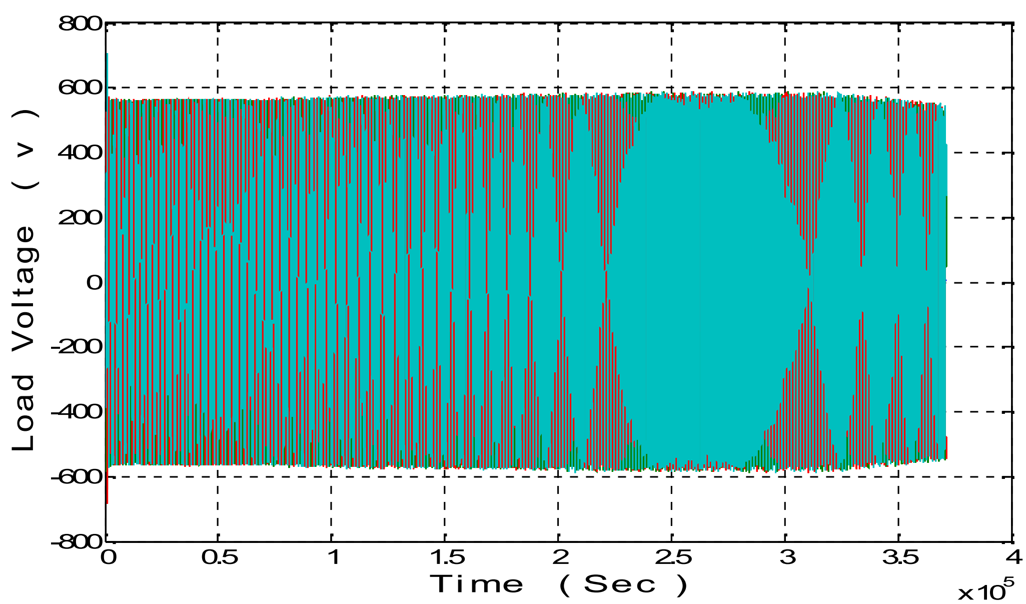

Figure 4.9: Load voltages after filtered

The load currents after filtered are shown in figure 4.10. It is noticed that the currents are constant (110A).

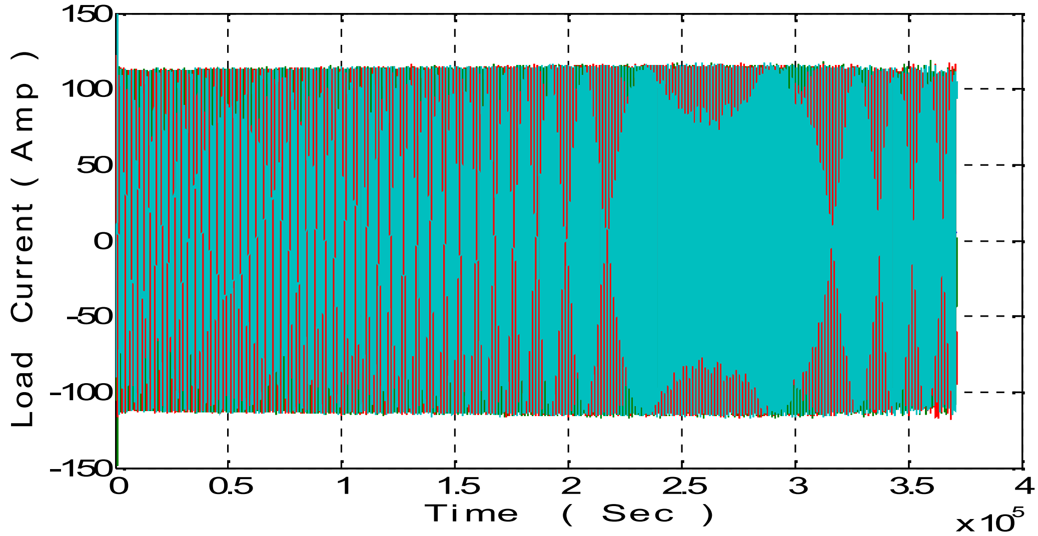

Figure 4.10: Load currents after filtered

The frequency of the load is shown in figure 4.11. It is found from that the frequency is constant (50Hz). This is will quietly sure the controller scheme is valid

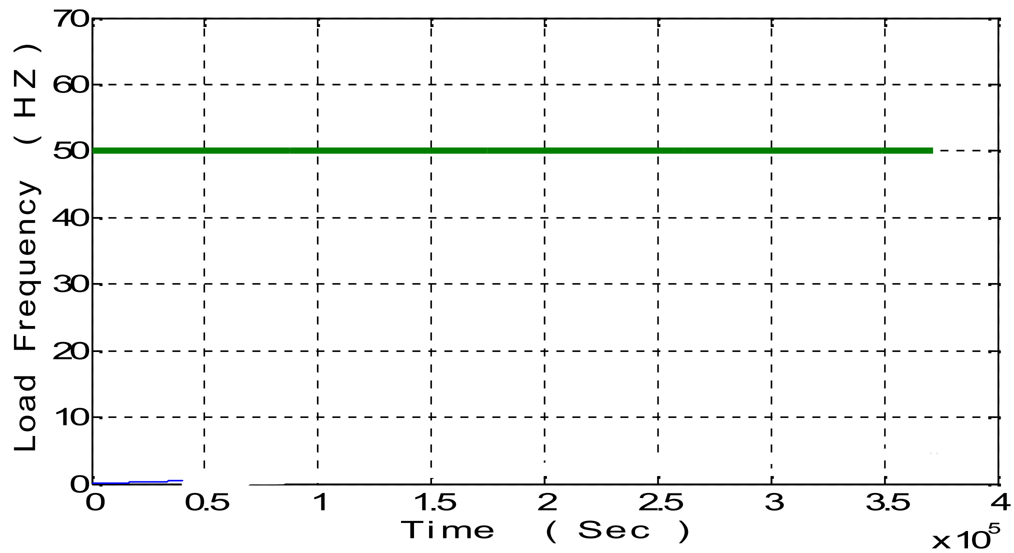

Figure 4.11: Load frequency

The load power after filtered shown in figure 4.12, which is constant

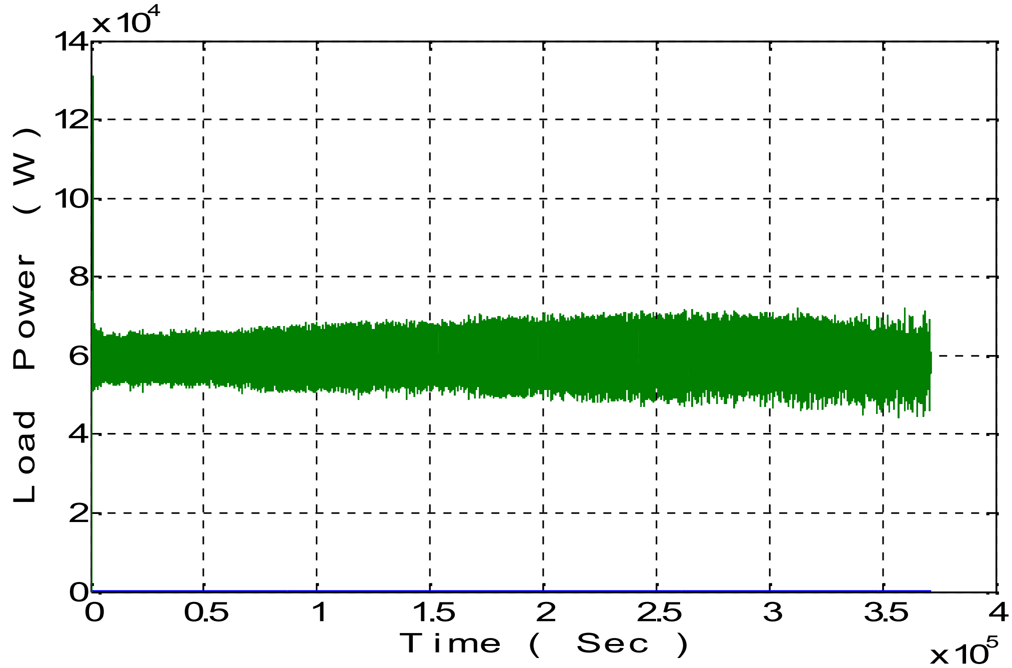

Figure 4.12: power of the Load after filtered

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this thesis, the complete model of the system which consists of induction generator ,wind turbine and isolated load .The overall system have simulated using MATLAB/SIMULINK with the proposed control scheme. The study has started with the description of the various components in the main schematic diagram. The characteristics of the induction generator and the wind turbine are presented .

A procedure for the calculation of excitation capacitance requirement, for the induction generator has described based on the steady-state model. Maximum Point Power Tracking control and space vector PWM techniques have designed to regulate the voltage and the frequency. The techniques have reduced the commutation loss and increased the magnitude of fundamental output voltage. It has observed that the controller results is satisfactory and very effective operation under different speed. Moreover, the controller has a capability of harmonic elimination and load balancing for the induction generator operating in stand-alone with a wind turbine.

5.2 Recommendations

i. Control of the load during normal operation to consume excess active power produced by the induction generator that is not used by the load and cannot be stored in the battery bank of the VSI that is completely charged.

ii. Develop robust controllers which would give high performance control even if subjected to machine parameter variation.

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Appendixes:

Appendix (A):

Table (A) shows the data of model.

Table A. Data of model

Generator data for one wind turbine	
Nominal power	1.5 MVA
Line to line volt	0.69 kV
Frequency	60 HZ
Stator winding resistance	0.0047 pu
Stator leakage inductance	0.08 pu
Rotor winding resistance	0.0021 p.u
Inductance winding resistance	0.0478 p.u
Magnetizing Inductance	6.8 p.u
Angular moment Inertia	0.578 s
Friction factor	0.01 p.u
Pairs' of poles	3
Capacitor bank	8357.222385µf
Turbine data for one wind turbine	
Nominal mechanical output power	1.5 Mw
Regulation method	Pitch control (disabled)
Rotor diameter	63m
Hub height	64m
Number of blades	3
Cut-in wind speed	4 m/s
Cut-out wind speed	20 m/s
Rated wind speed	13 m/s
Rotor speed	19/15 rpm
Filter parameters	
Inductance	2mh
Capacitor	3kvr
Discrete PWM Generator	
Carrier frequency (Hz)	20GHZ

Appendix B

Table (B) shows List of Abbreviation.

Table B: List of Abbreviation

Symbols	Descriptions
SEIG	Self-excited induction generator
IG	Induction generator
IM	Induction machine
G M q	Quadrature- axis
M q d	Direct- axis
MMF	Magnet motive force
EMF	electromotive force
CVCF	Constant voltage - constant frequency
VSCF	variable speed constant frequency
VSWECS	variable speed wind energy conversion system
EMF	Electro motive force
VAR	volt-ampere reactive
MPPT	Maximum Power Point Tracking
WTG	Wind Turban Generators
WES	wind energy systems
PVES	Photovoltaic Energy Systems
HAWT	Horizontal axis wind turbine
VAWT	Vertical axis wind turbine
SCRs	silicon-controlled rectifiers
TCR	Thyristor controlled reactor
GTOs	gate turn-off thyristors
MOSFET	Metal oxide semiconductor field effect transistor
IGBTs	insulated-gate bipolar transistors

BJTs	bipolar junction transistors
VSI	voltage source inverter
VSC	Voltage-source converter
SVM	Space vector modulation
PWM	Pulse width modulation