PERFORMANCE ANALYSIS OF PMSG BASED WIND ENERGY CONVERSION SYSTEM

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Submitted by

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CERTIFICATE

I here by certified that the dissertation entitled, " **PERFORMANCE ANALYSIS OF PMSG BASED WIND ENERGY CONVERSION SYSTEM"** which is being submitted by Tejinder Singh in fulfillment of the requirements for the award of the M.E. (power system) in EIED Thapar University Patiala is bona-fide record of candidates own work carried out by him under my supervision and guidance. The matter contained in the dissertation has not been submitted, neither in part nor in full to any other university or institute for award of any degree.

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ABSTRACT

Due to the increasing concern about the various aspects of conventional generating units such as depleting fossil fuel, environment issues like release of pollutants in the air have forced the research companies to exploit the renewable energy resources using small generating units. One of the renewable energy sources is wind energy which has a great potential and being exploited by many. The share of the wind energy in the power sector is quite less, but nowadays its share is growing at high rate. Consequently, researchers have been trying to develop ways to take advantage of different types of clean and renewable energy sources. Wind energy production, in particular, has been growing at an increasingly rapid rate, and will continue to do so in the future. In fact, it has become an integral part in supplying future energy needs, making further advancements in the field exceedingly critical. Basically the work reported in this thesis is performance analysis of PMSG based wind energy conversion system during the different operating conditions. PMSG has been utilized in this system due to its various advantages over other generators. The model based on wind energy system has been implemented into the MATLAB/SIMULINK software and simulation results regarding the performance of the system is studied and discussed under normal and fault operating conditions.

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LIST OF SYMBOLS

Symbol	Description
ρ	Air density (approximately $1.225\ kgm^{-3}$)
V	Upwind Free Mean Wind Speed in m/s
A	Swept Area of Rotor Blades in m^2
C_p	Power Coefficient (The Reduction Factor of Power Transferred from Wind to the Wind Turbine Rotor)
λ	The Tip Speed Ratio (The Ratio of the Tangential Speed at the Blade Tip to the Actual Wind Speed)
l	Length of the Blade
r	Radius of the Hub
ω	Angular Speed of Wind Turbine Blades
P_m	Mechanical Power of the Wind Turbine
ω_m	Mechanical Speed of the Generator inside Wind Turbine
β	Pitch Angle of Blade of the Wind Turbine
λ_i	Initial Value of Tip Speed Ratio when $\beta = 0$ deg.
f	Rated Frequency of the Grid in Hz
P	Active Power in MW
Q	Reactive Power in MVAR
δ	The Phase Difference
x	Reactance
η_g	Gear Train Ratio
P_r	Power Flow into the Rotor
P_g	Power Flow out of the Grid
m_a	Modulation Index
V_{DC}	DC Output Voltage
V_{LL}	Line to Line Voltage

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

“Alternative energy”, “sustainability”, and “green” have become buzz words that are heard on an almost daily basis. This is mainly due to rising concerns about the impact humans have on the environment as well as the future state of the production and transmission of the power the world depends on. With the rising cost of oil and increasing demand for energy, countries around the world have taken the initiative to increase the production of renewable types of energies. This has lead to an interest in the ability to capture energy from natural resources such as wind, water and sunlight.

The reason behind the popularity of wind energy is due to its non polluting nature, greater efficiency and mainly due to its low operation cost. The increasing development of wind energy has resulted in many new modeling and improved simulation methods. Wind power harnessing procedure has been a task for many years. Since long back wind mills were put into the task of pumping water and grinding grain. Many new technologies such as pitch control and variable speed control methods have been tested and put forward since. Sometimes, wind turbine work in an isolating mode; therefore, there is no grid. Usually there are two, three or even more than three blades on a wind turbine. However according to aerodynamics concept, three blades is the optimum number of blades for a wind turbine. Asynchronous and synchronous ac machines are the main generators that are used in the wind turbines. A wind turbine produced the kinetic energy with the help of the wind and transforms it into the mechanical energy. Finally, this mechanical energy is converted to electrical energy with the help of a generator. Therefore, the complete system that involves converting the energy of the wind to electricity is called wind energy conversion system. A wind turbine generates the maximum amount of energy from the wind when it is operating at an optimal rotor speed. The optimal rotor speed varies due to the variable nature of the wind speed.

1.2 LITERATURE REVIEW

The authors “Lalit Kumar Gautam, Mugdha Mishra” [1] explains about the wind energy is the most common renewable energy thanks to the amount of power produced over the plant cost, compared with other renewable resources. Due to the increasing consumption of fossil fuel for the generation of energy and power which badly affect the all the non living and living beings includes the whole environment. That’s why it is very important to have a alternate source of energy.

Kaki shanmukesh, Mr.D.V.N.Ananth [2] describes that now for the reduction of these harmful emissions of these pollutants there is alternate source of energy which is called the green energy source and techniques for these sources of energy are developing continuously. For bringing the awareness among the people for the installation of wind energy system MNRE scheme (The Ministry of New & Renewable energy) is introduced.

Bouzid Mohamed Amine, Massoum Ahmed, Allaoui Tayeb, Zine Souhila [3]. According to the Research done in the previous work it shows that the variable speed operation of the rotor results in a higher energy production as compare it to a system operating at constant speed. A wind turbine model consists of blades, a generator, a power electronic converter, and power grid. Blades are used to extract power from the wind.

A.Bharathi sankar, Dr.R.Seyezhai [4]. Illustrates about the operating the blades at optimal tip speed ratio, maximum amount of energy can be extracts from the variable speed wind turbine. The maximum power point tracking (MPPT) control of variable speed operation is used to achieve high efficiency in wind power systems. The MPPT control is operated using the machine side control system. The function of pitch angle control scheme is to regulate the pitch angle by keeping the output power at rated value even when the wind speed experiences gusts.

Omessaad Elbeji, Mouna Ben Hamed, LassaadSbita [5]. Nowadays, DFIG are widely utilized in variable speed wind turbine but the major issue is the requirement of gear box to match turbine and rotor speed. Another drawback of the gearbox is that it mostly requires a regular maintenance which makes the system unreliable. In case of constant wind speed reliability can be improve by using the PMSG. For the extraction of maximum power from the wind energy resource there are various control strategies. In case of PMSG based wind energy system control strategies has been developed in which generator side rectifier is controlled to obtain the maximum power from wind energy source .This method consist of one switching device IGBT, which is utilized to control generator torque for the extraction of maximum power.

Bipin Biharee Srivastava, Er. Sudhanshu Tripathi [6]. Authors discusses that since there is insurmountable evidence of the many ways that the burning of fossil fuels pollute the planet, many are stepping up to the worldwide challenge of decreasing dependency upon them. According to the Global Status Report from the Renewable Energy Policy Network for the 21st Century (REN21), as of 2009, there were 85 countries with policy goals intended to increase the renewable energy usage and production. The major types of “renewable energy” described in these goals include wind, solar, hydroelectric, geothermal, and biomass.

Nandini.A, Isha T.B [7]. Describes about the model in which experimental set up of the system is designed in which the wind turbine was built by utilizing the separately excited dc motor mechanically coupled to the PM machine and in this model the load voltage and frequency was kept constant.

Kajal Kushwah, C.S. Sharma [8].Illustrates the effects on the power quality due to several variables which influences the output of the system and creates the problem such as harmonics and resonance in the system which are described with the respect to the analysis method.

Mirza Mohd.Shadab, Abu Tariq [9]. Discusses about the different type of PMSG machines in which multi pole PMSG is chosen because it offers the better performance due to higher efficiency and less requirement of maintenance because it does not have rotor current and it can be utilized without gearbox.

Hyong Sik Kim, Dylan Dah-Chuan Lu [10] explains the dynamic modeling concepts about the wind energy conversion system based on different generator concepts. It shows the advantages and disadvantages of different generator set utilized with the wind energy conversion system. It is basically the survey of WECS using different generators such as PMSG, DFIG, WRSG etc. the operation of the models during the variable speed, during constant speed. And various power quality issues are discussed in this due to increasing utility of wind energy power stations.

The work of Miguel López Jean-Claude Vannier [11] discuss about the working of standalone system of wind energy conversion system. A cascaded step up/step down power electronic topology is proposed in this to control wind energy system in the whole wind speed range. This control system is made up of DC/DC power electronic converter which helps in modification of the input voltage and changing the machine voltage and consequently changes the generator's rotor speed.

The C. Carrillo, E. Diaz-Dorado, M. Silva-Ucha and F. Perez-Sabín [12] present the technical requirement about the various parameters of PMSG which helps in the improving the performance of small wind energy generator. It explains about the main components which are utilized in the formation of wind energy conversion system. The settings of WECS affect the performance of small wind turbine generators, especially the parameters which are related with minimum and maximum voltages.

Kapil Parikh, Ashish Maheshwari, Vinesh Agarwal [13] . In order to transform the wind energy to the utility grid different sub models are utilized to form the wind energy conversion system. This segment explains that for understanding the system behavior and for developing the advanced control strategies Variable speed wind power generation system designs and simulation are essential methods.

Jay Verma, Yogesh Tiwari, Anup Mishra, Nirbhay Singh [14]. Describes the modeling of PMSG based wind energy conversion system (WECS) is connected with two converters with common DC link. PWM technique is developed to improve the power quality issues in wind energy conversion system.

Raghuvendra Kumar Tiwari, Krishna Kant Sharma [15]. Discussed the cost of production of the wind turbine system due to increase in size of the generation during the last few years from 20KW to 5MW.There currently exist a competition among different technologies generator systems whose differences lie among the complexity, cost and degree of control over the system characteristics of the system working. This paper deals with the generation of power with the utilization of PMSG and DFIG with variable speed.

Suji Muhammed Krishnakumari V [16]. They proposed the working of wind energy conversion system based on the PMSG during both the fixed speed operation and variable speed operations. Various converter topologies are also discussed in this paper on which working of system depends and their advantages and disadvantages are also discussed which gives us the direction and support for the understanding of this technique. Due to increasing global warming problems or issues these techniques for generation of power are quite essential.

Prerna Badoni1, S. Bhanu Prakash [17] describes the working model of wind energy conversion system. The modeling of wind turbine and PMSG is developed in the MATLAB/SIMULINK to determine NATURE of the system. WECS consists different components which are widely utilized in formation of the system and they are Wind turbine, Generator, rectifier-inverter, controller system including transformer, grid etc.

Harika G, Jayakumar N, Thrivonasundari D [18] represents the design and simulation of inverter based energy storage systems for wind energy system. The detailed version of the model explaining its design and simulation of dual inverter based Wind energy system initiates with wind turbine coupled PMSG which is connected to three phase diode rectifier and inverter connected on the side of utility load.

R.Karthick, S.Manoharan, S.Rajkumar [19] explains the grid interface of a PMSG based wind energy conversion system with power quality improvement features of the system. In this paper importance of the grid side converter plays a dual role of interfacing the wind energy to grid as well as to supply reactive power as demanded by the non-linear load connected at the PCC. A simple model of the proposed system is developed and simulated in MATLAB environment.

Abhishek M. Patel, Dr. Jatin J [20] Patel discussed about the PMSG with inverter using the park's transformation for transient fault analysis. The proposed control strategy can provide maximum power to grid and can also control the reactive power to maintain terminal voltage of grid is constant. The symmetrical and unsymmetrical faults is analyses for network disturbance at two different locations of the transmission line are discussed in this paper which help in the understanding the condition of the system during fault conditions.

Ali Tahmasebi Sohi, Shahram Javadi, SZ Moussavi [21] explains the power flow control of grid connected wind energy system by utilizing the harmonic elimination added function. In this paper the method for the improvement of the power quality are proposed and another method called the maximum power point tracking based on the controlling of the optimum torque.

V. Arulalan, R. Dhanasekaran [22] discussed about the wind energy power application of this technique in India. Due to the rapid growth of the renewable energy utilization and the immense potential for future needs there is serious consideration for the improvement of the reliability of the power supply with the benefits of economic problems such cost inflation and it can be achieved by various means and it is explained in this paper. Wind power is being adapted the world as one of the most efficient power generation source that does not cause greenhouse emissions and do not creates the pollutants in the enviorment.

1.3 OBJECTIVE OF THESIS

The objective of the thesis is to study and analyze the performance of permanent magnet synchronous generator based wind energy conversion system. The behavior of the system during the normal operating condition and fault operating condition is studied and discussed. It can be beneficial in case of emergency such as shutdown or outage of grid. In essence, the wind turbine will be used to provide electricity to the properties, such as a farm, industries etc. with mains electricity supply in India.

1.4 ORGANISATION OF THESIS

The thesis work has been divided into six chapters:-

In chapter 1 includes the introduction part which comprises of the overview of the thesis work, literature survey and objective of the thesis has been discussed.

In the 2nd chapter, wind energy conversion system is discussed. Basically it forms the base for this system in which various parts such as wind turbine component, wind energy characteristics tip speed ratio etc. has been studied.

In chapter 3, PMSG based wind energy conversion system is discussed. In this modeling of PMSG has also been studied and power converter interface with the system is also explained.

In chapter 4, implementation of PMSG based wind energy conversion system in the MATLAB/SIMULINK has been done. It includes the sub parts such as wind turbine model, two mass drive train model, AC-DC-AC converters is also explained.

In chapter 5, SIMULATION results has been carried out and discussed during the different operating conditions.

In chapter 6, conclusion and future scope of the thesis work has been discussed.

CHAPTER 2
WIND ENERGY CONVERSION SYSTEM

2.1 INTRODUCTION

Wind turbines are utilized to transform the wind energy to electricity. At first wind turbine was built and designed by Charles F. Brush in 1887- 1888 in Cleveland, Ohio. It was equipped with 144 cedar blades and having a rotating diameter of 17 m. It has the generation power of about 12 kW for charging the batteries that supply DC current to the various lamps and electric motors. At present a typically three blades type wind turbine are utilized which are operating at relative high wind speeds for generating the power output to the several megawatts.

2.2 WIND ENERGY CHARACTERISTICS

Wind energy is another form of kinetic energy as it flows in air. It can be converted into electrical energy through power conversion mechanism. The wind turbine extracts kinetic energy from the swept area of the blades as shown in the Figure 2.1. The power in the air flow can be calculated is by:

$$P_{air} = \frac{1}{2\rho A \upsilon 3} \qquad (1)$$

Where

ρ=air density (approx. 1.225 kgm−3)

A= area swept by the rotor

υ = Upwind free mean wind speed

The wind power is transferred to the wind turbine rotor and it is reduced by the factor called the power coefficient and power coefficient is given by the formulae given below in the equation 2.

Power Coefficient, Cp :

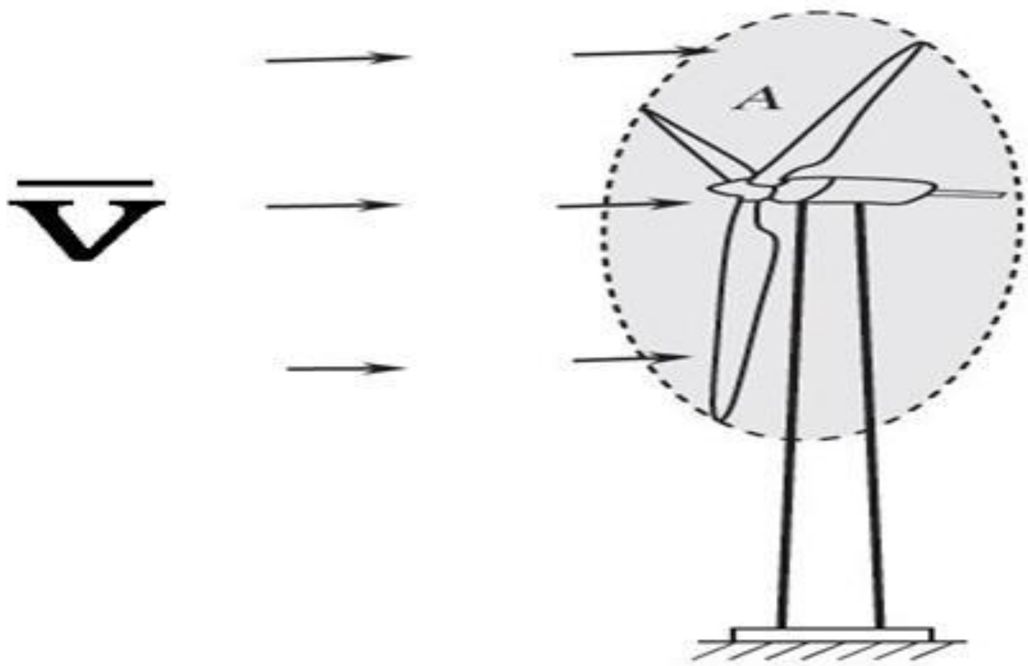

Figure-2.1: Area Swept by Wind Turbine Blades

$$C_p = \frac{P_{mechanical\,power}}{\mathrm{P_{air}}} \qquad 2$$

The maximum value of Cp is called Betz limit. In an ideal wind turbine case maximum efficiency was derived by Lanchester in 1915 and Betz in 1920. This is known as Lanchester – Betz limit or Lanchester– Betz law.

Then

$$P_{mechanical\,power} = C_p\,P_{air} = \frac{1}{2\,\rho A\upsilon 3} \qquad 3$$

For obtaining the higher wind power, there is requirement of higher wind speed, a longer length of blades so that large area is swept under them, and a higher air density. Due to even a small variation in wind speed it can result in large change in the power because of the fact that the wind power output is proportional to the cubic of wind speed.

2.2.1 TIP SPEED RATIO

Another important factor is the tip speed ratio in the formation of wind turbine design and it is defined as ratio of tangential speed at the blade tip to the actual wind speed.

$$\boldsymbol{\lambda} = \frac{(l + r)\omega}{\upsilon} \qquad 4$$

Where

l is the length of the blade

r is the radius of the hub

ω is the angular speed of blades

To illustrate the performance of any size of wind turbine rotor there are two factors which are responsible are tip-speed ratio λ and the power coefficient Cp because they are dimensionless. As shown in the Figure 2.2 that the maximum power coefficient can only be achieved at a single tip-speed ratio and for a fixed rotational speed of the wind turbine this only occurs at a single wind speed.

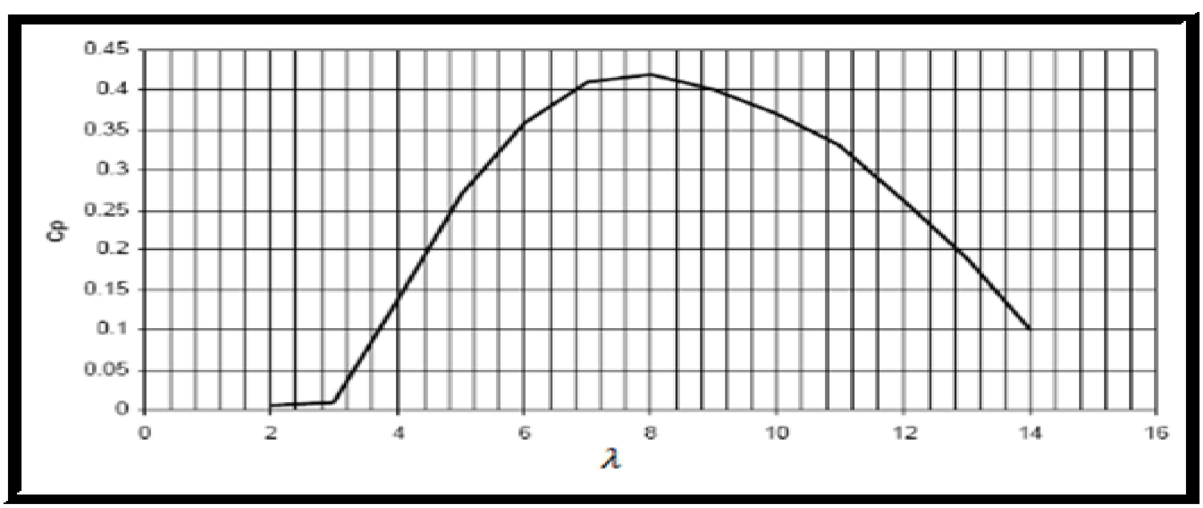

Figure-2.2: Illustration of Power Coefficient /Speed Ratio Curve, C_p/ λ

2.3 POWER CURVE

The power curve of a wind turbine represents the power output in KW or MW ranges of the wind turbine as a function of the wind speeds in m/s. As shown in Figure 2.3, the wind turbine starts generating the usable power at a low wind speed, defined as the cut –in 12 speeds. As there is increase in the speed of the wind there is continuously increase in the power output until the saturated point and value at that point is defined as the rated output power. The speed at that saturated point is called the rated speed. After the rated speed value more increase in wind speed will not increase the power output due to activation power control. The final value of wind speed is called cut-out wind speed which is that maximum value of allowed value of wind speed for the normal operation of the wind turbine, more than it the turbine is stopped.

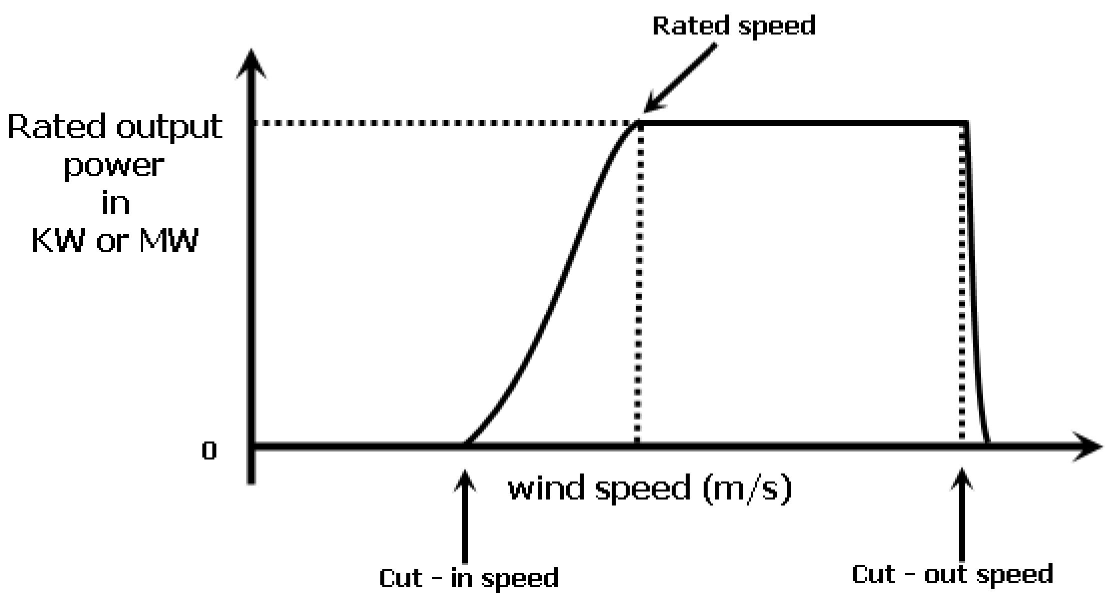

Figure-2.3: Typical Wind Turbine Power Curve

2.4 WIND TURBINE COMPONENTS

One of the first commercial wind turbines to generate electricity and feed it into the grid was the VESTAS V-15 with a rated power of 55 KW, as shown in Figure 2.4. In the beginning of the 1980s, it was manufactured and installed in large numbers. It already had all essential components of grid-connected wind turbines:

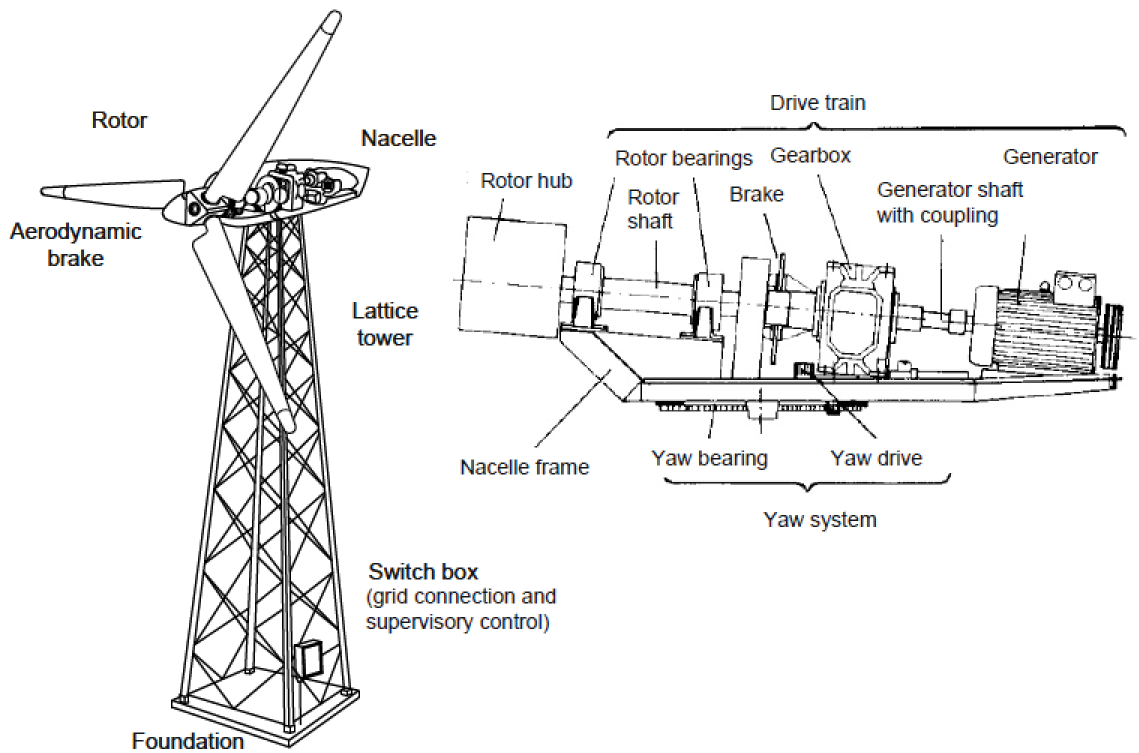

Figure-2.4: VESTAS V15, General View and Nacelle Section

- Rotor: rotor blades, aerodynamic brake and hub
- Drive train: rotor shaft, bearings, brake, gearbox and generator
- Electrical components for control and grid connection.
- Yaw system between nacelle and tower: yaw bearing and yaw drive
- Supporting structure: tower and basis

For 30 years in the working life of the wind turbines, the components of any typical horizontal type wind turbine that is shown in Figure 2.4 did not change. The changes that was happened only in the size and rating of the generator, height of the tower, with or without Gearbox, and long of the blades.

2.5 SPEED CONTROL OF WIND TURBINES

.The wind turbine speed can be control by controlling the speed of the generator and it can be done by adjusting the blade angle and the rotation of entire wind turbine can be adjusted. And the method called the pitch and yaw control through which we can control the rotation of turbine and by adjusting the blade angle.

The main purpose of pitch angle control of the blades is to adjust the optimum blade angle to achieve the certain rotor speeds or power output, i.e. a method of getting the maximum power at wind speeds more than rated value.

The main purpose of Yaw control is to ensure that the turbine is constantly facing the wind so that it helps in maximizing the adequate area swept by the rotor and as a result, the output power. Because of wind direction can vary quickly, the turbine may miss Aligning with the oncoming wind and cause losses in power output.

2.5.1 CONTROL STRATEGIES

Following there are certain control techniques which can be used to manage the mechanism of turbine by controlling the speed of the pitch and generator and these control techniques are given as follows:-

Fixed-Speed Fixed-Pitch (FS-FP):

Fixed speed fixed pitch has a turbine’s generator which is coupled directly with the power grid in this way it lock the generator speed with the power line frequency and fix the rotational speed. The gearbox ratio selection is one of the important aspects for the passive control because it ensures that the rated power and wind speed are not exceeded.

Fixed-Speed Variable-Pitch (FS-VP):

In this control strategy it explains about the fixed-speed operation which implies a maximum output power at constant wind speed. In this configuration to limit the power the power output one can utilized the both blade and stall pitch control methods. FS-VP turbine has a near optimum efficiency if the speed is below the rated wind speed and it is shown in the figure 2.5 around Region II.

Variable-Speed Fixed-Pitch (VS-FP):

In VS-FP turbine assumes that generator is connected indirectly to the grid so that rotor of the generator and the drive train can rotate independently at the grid frequency. To limit the power fixed pitch relies mainly on the design of the blade.

Variable-Speed Variable-Pitch (VS-VP):

For maximizing the capture of energy and for the improvement of VS-VP turbine is operated below the rated wind speed. And if we operated this turbine above the rated wind speed then it permits the efficient power regulation at the rated power and wind speed.

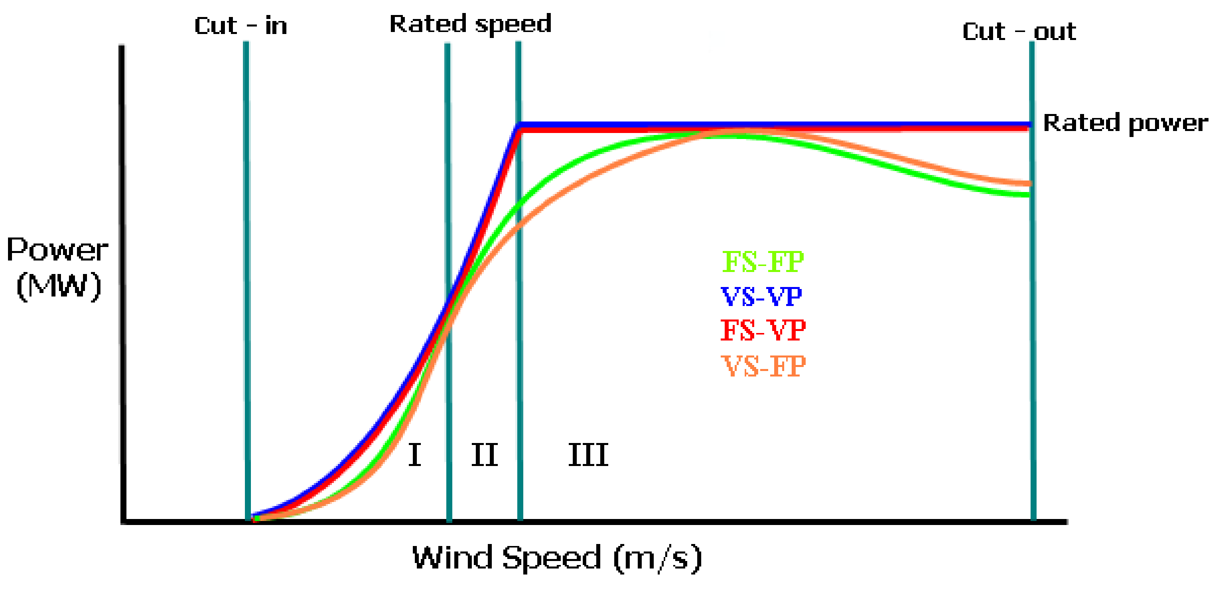

Figure-2.5: Power and Wind Speed Graph at Different Pitches

2.6 CONTROL TECHNIQUES OF WIND TURBINE SYSTEMS

A controller continuously monitors and regulates the functions of the wind turbine. This is done in order to achieve the maximum amount of efficiency. The objective of the controller is to stop the turbine as soon as an error is generated.

2.6.1 PITCH ANGLE CONTROL

This method is implemented to control the mechanical power input at the nominal value. Whenever the velocity of wind exceeds the rated value of power, a mechanical method is implemented so as to control the blade angle of the wind turbine from being damaged. At low wind speed, a control system technique is applied so that highest amount of power can be extracted from the wind. In this case, blades are turned back for the extraction of maximum amount of energy. While during the gusty wind condition the pitch angle is adjusted to limit the power extraction. This is done by turning the blades away from the wind. A pitch controller is used to regulate the blade angle by using proper simulation technique for capturing the wind energy. The conventional PI method was used before regarding the pitch angle control.

To examine the performance of wind turbine rotor of any size the tip speed ratio and the power coefficient Cp are utilized because of the fact that they are dimensionless. The power coefficient Cp can be calculated by utilizing the theory which is based on the ratio of rotor and wind speed i.e. a given tip speed ratio. With the tip speed ratio one can develop the power coefficient of rotor at fixed rotor speed or for the variable rotor speed at constant speed. If the rotor is provided with blade pitch control then the power coefficient curves must be calculated for different blade pitch angle β which are utilized in this operation.

The equation which is utilized to defines the model Cp (λ , β) based on the modeling turbine characteristics is given by:

$$P_m = \frac{\partial E_W}{\partial t\ C_P} = \frac{1}{2\rho\upsilon 3wCp} \qquad 5$$

$$Cp(\lambda,\beta) = 0.5176\left(\frac{116}{\lambda 1} - 0.4\beta - 5\right)e - \frac{21}{\lambda 1} + 0.0068\lambda \qquad 6$$

Where

ρ Air density (Kg/m3)

υ_w Wind speed (m/sec),

,

Cp is the performance coefficient and it depends on the turbine characteristics which creates the losses in the process of energy conversion.

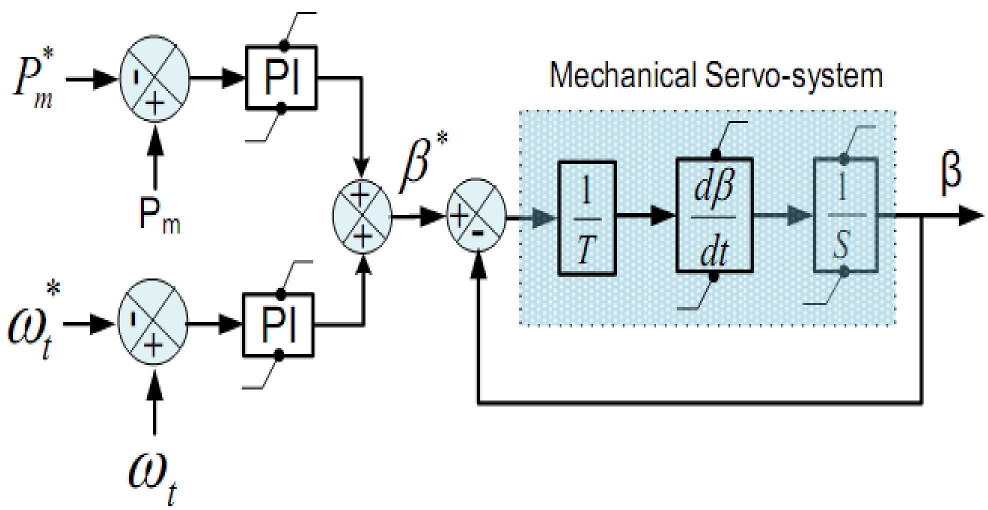

Figure-2.6: Scheme for the Pitch Angle Control

The mathematical model for explaining the Cp used in this work is $\lambda_1 = f(\lambda, \beta)$ and it is given by

$$P_m = \frac{\omega R}{\upsilon w} \quad 7$$

$$\frac{1}{\lambda_1} = \frac{1}{\lambda} + 0.08\beta - \frac{0.035}{\beta^3} + 1 \quad 8$$

Where,

R Blade radius of the wind turbine

ω Turbine speed

.

This value of Cp is used to calculate the mechanical power which is generated by wind turbine. In fact, when modeling of the pitch control, it is very important to develop the rate of change of angle. The variation of the pitch should be limited to the size of about 10 degree/s during normal operation and 20 degree/s for emergencies

2.6.2 MAXIMUM POWER POINT TRACKING CONTROL

Maximum power point scheme is used to extract highest amount of available energy from the wind, while it is operating over a large range of wind speed. According to maximum power point tracking the generator speed is adjusted according to the variations of wind speed. This is done so that the tip speed relation can be maintained at its optimal value λ. The conventional control schemes included the control mode of operation which used to depend on the setting of reference values.

2.7 TWO MASS DRIVE TRAIN

WECS is consists of two-mass drive train model. The mechanical dynamics is represented by the differential equation which is given as follows:-

By utilizing the Newton's second law for rotation system on the rotor, the mathematical model will be:

$$J_r\, \omega_t \;+\; B_r\, \omega_{\,t} = T_{\,a} - T_{ls} \qquad 9$$

Where

w_t = angle speed

B_r = rotor damping effect

J_r = moment of inertia

T_{ls} = shaft torque

T_a = applied torque

Similarly we can calculate for a driving gear and it is basically a moment of inertia which is cancelled, this will conclude:

$$J_{ls} + B_{ls}\,(\omega_t - \omega_{ls}) + K_{ls}(q_t - q_{ls}) = T_{ls} \qquad 10$$

Where

W_{ls} = angular speed at low speed shaft

B_{ls} = damping effect

J_{ls} = moment of inertia

This will yield

$$T_{ls} = B_{ls}(\omega_t - \omega_{ls}) + K_{ls}(\theta_t - \theta_{ls}) \qquad 11$$

Representation of mathematical model for generator is given by:

$$J_g \omega_g + B_g \omega_g = T_{sh} - T_{gen} \qquad 12$$

Where

J1s = moment of inertia of generator,

wg = high speed shaft angular speed,

B_g = high speed damping effect,

T_{sh} = shaft torque at high speed,

T_{gen} = electromagnetic torque of generator

The gear train ratio ng is calculated by

$$\eta_g = \frac{T_{ls}}{T_{sh}} = \frac{\omega_g}{\omega_{ls}} = \frac{\theta_g}{\theta_{ls}} \qquad 13$$

Where,

W_g = angular displacement of shaft

CHAPTER 3

PMSG BASED WIND ENERGY CONVERSION SYSTEM

3.1 INTRODUCTION

In a WECS, the electrical power conversion interface mainly consists of electrical generator and power converters. With recent advancements in power conversion interface for wind turbines, various WECS configuration using variety of electrical generators and power converter topologies were developed. Among the wind energy conversion systems (WECSs), there are different types of generators are utilized for the construction of the system. For example there is DFIG generators which are widely used in the conversion systems but the major issue is the requirement of the gearbox and having a same speed between the rotor and turbine speed. In case of PMSG there is no requirement of gearbox in that way losses and costs are also reduced and it also beneficial in case of maintenance because it requires the low maintenance and high efficiency and good controllability. Companies such as Siemens Power Generation and GE Energy are widely utilized these PMSGs generator in their systems.

3.2 PERMANENT MAGNET SYNCHRONOUS GENERATOR

Synchronous generators (SG) are extensively used in today's WECS with operating power range from kilowatts to few megawatts. SGs are majorly classified into two types: WRSG and PMSG. Both generators use different methods to produce rotor flux, rotor field windings are used in WRSG, whereas permanent magnets are used in PMSG.

The PMSGs are considered to be the promising option for the emerging direct driven (i.e. without gearbox) wind turbine applications**.** Removal of gearbox can result in numerous benefits like: improved energy conversion efficiency, reduction in the weight of the wind turbine, no oil maintenance is required, precision associated with positioning is improved, reduced cost of power production, high torque density and higher overall efficiency is achieved. Operating at higher efficiency in low speed, high torque application can result in huge cost savings throughout the life span of the power drive. Also for a given mechanical specification, using PMSG in WECS results in: a) smaller system size for rated efficiency and power factor and b) higher power density leading to maximum overall efficiency. Despite the higher initial cost, the attributes and benefits mentioned above makes PMSG an ideal choice for direct-driven WECS.

3.2.1 CONSTRUCTION OF PMSG

In the construction of PMSG it has a stator and a rotor. A typical construction of PMSG is shown in Figure 3.1. Since the stator construction is similar to that of the induction generator. Usage of permanent magnets for flux production makes the PMSG a brushless machine; this highly reduces the maintenance cost. Due to the absence of rotor windings, achieving a higher power density is possible through reduced weight and size of the machine. With zero or negligible winding loss, the thermal stress on the rotor is highly reduced. The main drawback of PMSG is the usage of highly expensive permanent magnets that are prone to demagnetization. Based on the mounting of permanent magnets, the PMSG can be classified into two types: surface-mounted and inset PM generator.

Figure-3.1: Construction of PMSG

3.2.2 PERMANENT MAGNET SYNCHRONOUS MACHINE MODEL

The electrical and mechanical system of PMSG machine is developed by utilizing the state space model. For obtaining the sinusoidal electromotive force firstly stator flux which is generated by the permanent magnets must be in the sinusoidal form Due to presence of a large air gap generally found in PMSG, it is assumed that the machine has a linear magnetic circuit and the core of either stator or rotor does not saturate. The equations of the electrical and mechanical system are given below. An arbitrary dq-frame is used as reference for stator and rotor quantities.

For developing the mathematical model for a PMSG, there are some assumptions following given.

- ✓ Saturation is neglected.
- ✓ Induced electromotive force (EMF) is sinusoidal.
- ✓ Eddy currents and hysteresis losses are negligible.
- ✓ Conductivity of the permanent magnet is zero.

The rotation of wind turbine causes the rotor of the PMSG to rotate and it is represented in the form of d-q coordinate system, which is given as follows:

$$V_{qs} = -R_s\, I_{qs} \;+\; L_{qs}\frac{d}{dt}I_{qs} - \omega_r L_{ds} I_{ds} \;+\; \omega_r \frac{dy}{dx}\psi_{ds} \qquad 14$$

$$V_{ds} \;=\; -R_s I_{ds} \;+\; L_{ds}\frac{d}{dt}I_{ds} + \;\omega_r L_{qs} I_{qs} \qquad 15$$

Where

V_{qs} Quadrature-axis (q-axis) stator voltage

V_{ds} Direct-axis (d-axis) stator voltage

I_{ds} D-axis stator current

I_{qs} Q-axis stator current

ω_r Angular velocity of generator rotor

R_s Resistance of the stator winding

L_{ds} Stator inductance in d-axis

L_{qs} Stator inductance in q-axis

$\frac{d}{dt}\psi_{ds}$ Amplitude of the flux linkages

The equation for the electromagnetic torque can be described by:

$$T_e = \frac{3P}{4} [i_{ds}i_{qs}(L_{ds} - L_{qs}) + i_{qs} \frac{d}{dt}\psi_{ds} \quad 16$$

Where

Te Electromagnetic torque

P Pole number of generator stator.

The formula defines the relationship between the angular velocity and the mechanical angular velocity given as follows.

$$\omega = \frac{2\omega_r}{PG} \quad 17$$

$$\frac{d}{dt}\omega_r = \frac{P}{2J} (T_m - T_e) \quad 18$$

Where

Tm Input torque to the generator rotor

J Inertia of the generator rotor

G Gear ratio

The input torque to the generator is given by the formula shown in equation 19.

$$T_m = \frac{T_t}{G} \qquad 19$$

Assumption is that the torque loss through the mechanical transmission system is neglected.

3.3 POWER ELECTRONIC CONVERTER INTERFACE

Power converters are used in a wide range of applications in WECS. In variable-speed WECS, they are mainly used for providing control access to torque and speed of the machine. In fixed-speed WECS, they are used in reducing torque oscillation and high inrush currents during the start-up. A maximum power point tracking control system includes a power converter for operating the generator to track the optimum reference speed. This allows the wind turbine to be operated at optimum tip speed ratio and in turn achieve maximum power extraction from the wind. Also the power converters are employed to control active or reactive power and regulate voltage and frequency of power supplied to the grid or load. Depending upon the choice of the electrical generator and power ratings, several power converter configurations are possible for WECS. In this project, a pulse width modulation (PWM) controlled two-level three-phase voltage source converter with back-to-back connection is used in the simulation study.

The back-to-back converter (rectifier-inverter pair) is the predominantly used configuration for the variable speed WECS, consisting of PWM controlled voltage source converters (VSC) connected back-to-back. This configuration is a bidirectional power converter unit, where one converter works as rectifier and other converter operates as inverter throughout the power conversion process in either direction of power flow. A DC-link capacitor is connected in parallel between the two converters to achieve complete control over the current injected into the load or grid, the DC-link voltage across the capacitor is maintained at a higher magnitude than the load side line-to-line voltage.

In Figure 3.7, the converter output voltage in phase-a with respect to the point N in the DC bus i.e. phase voltage V_{aN} under linear modulation is given by the below expression.

$$V_{aN} = \frac{m_a V_{dc}}{2} \qquad 20$$

Where, m_a is the modulation index. The value of v_{aN} depends only on V_{dc} and state of the switch. Since one of the switches per leg is always ON at any given time, $V_{a\,N}$ is independent of load current. In order to operate the VSC, a PWM scheme is used and this is discussed in the next section.

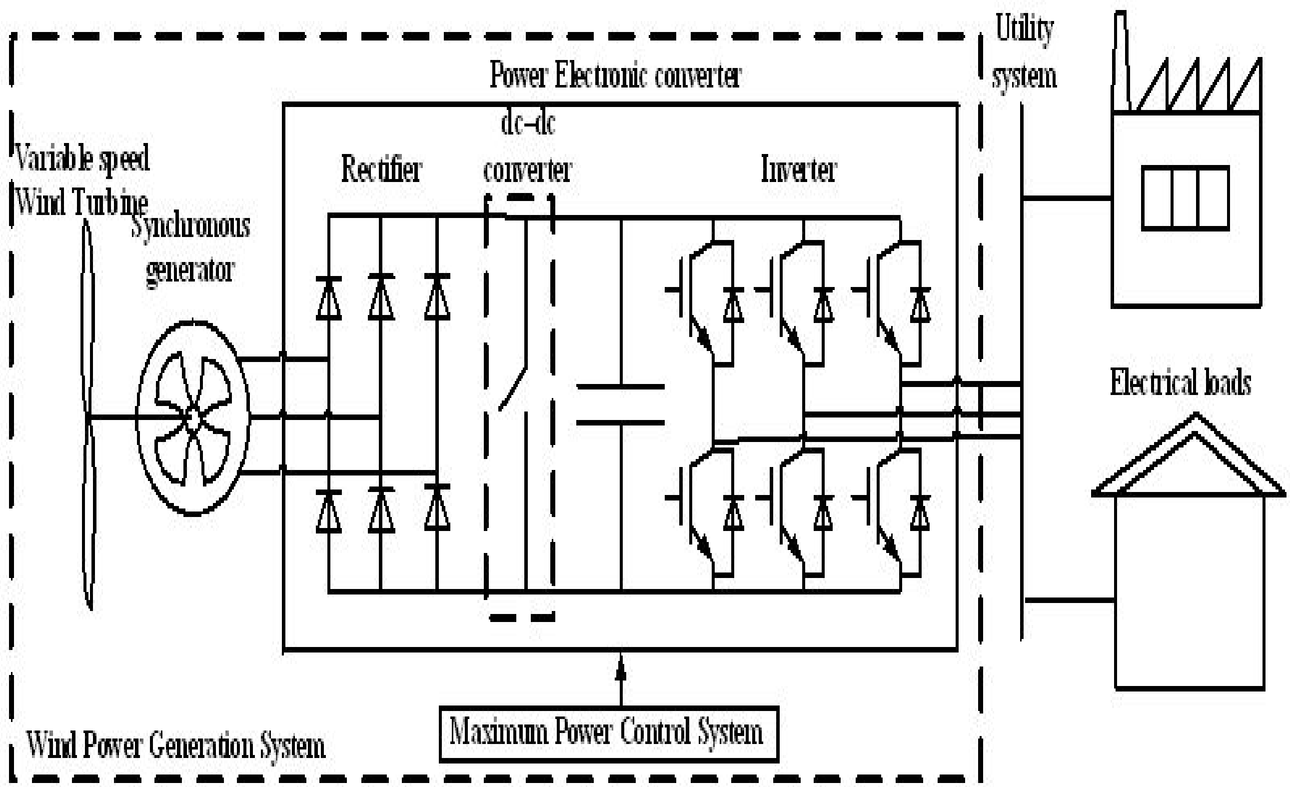

Figure-3.2: PMSG Based WECS Connected with Utility Load

These converters are consisting of a bidirectional voltage source converter connecting through the rotor of the generator .Basically these converters are made up of VSIs equipped with switches as IGBTs body diodes which permit a bi-directional current flow. Output switching harmonics of the GSC is diminished by the filters.

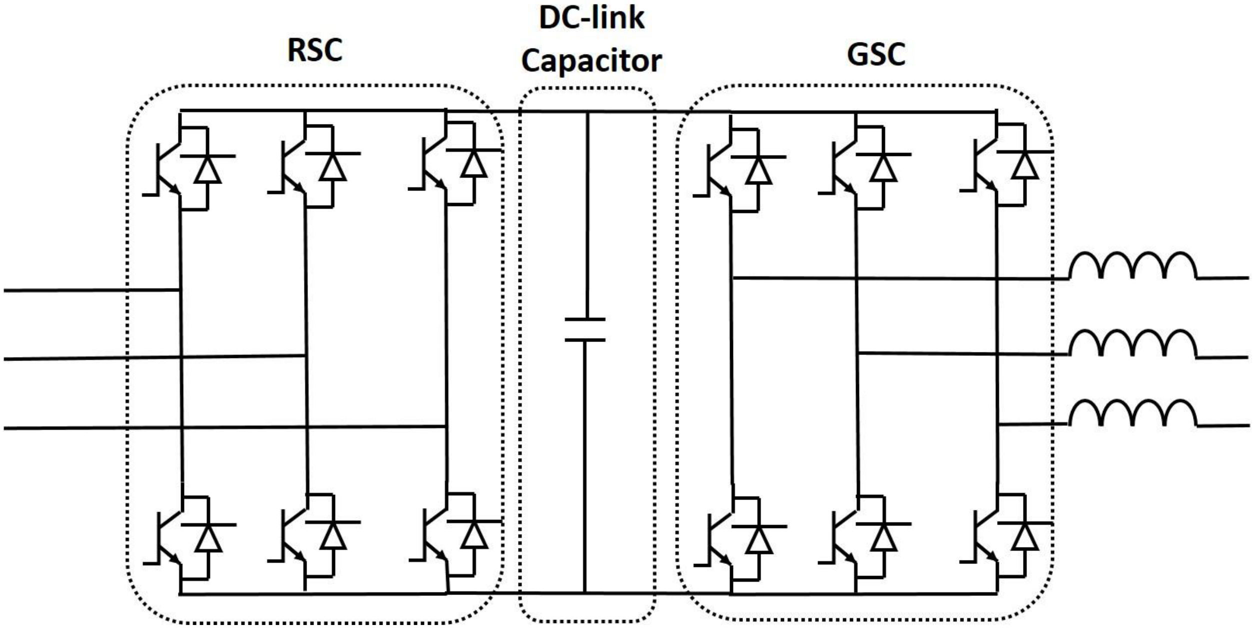

Figure-3.3: Machine Side and Load Side Converter Set

Power conversion for wind energy systems generally occurs in two stages. The first stage is rectification, where the alternating current (AC) is transformed into direct current (DC). The second stage is where the direct current is transformed back into alternating current.

Machine Side Converter

Rectifiers are the first stage in power conversion, also called the AC/DC stage. The most basic form of a rectifier is a three-phase diode bridge, where the top diode will pass the positive cycle of a sine wave, and the bottom diode will pass the negative cycle of a sine wave, making both cycles positive. A single phase of the DC output can be calculated by the equation below.

$$V_{DC} = \frac{2V_{peak}}{\Pi}$$

For a three-phase bridge, however, this will have to be multiplied by 3.

A rectification system can also be active, by using either MOSFETs or IGBTs as switching devices. These systems are more complex because they require switching signals, such as a pulse width modulated (PWM) signal. However, they tend to be slightly more efficient than the passive diode bridge, and a controls system can be incorporated through them, which will improve the power quality of the system. A reservoir capacitor is typically used to smooth the output of the rectification stage, since the rectified waveform tends to still be somewhat sinusoidal. This is generally known as the DC link.

Grid side converter

The inversion stage is used to turn the output of the DC link back into AC. This is done through three phases of switching circuits, typically MOSFETs or IGBTs. This will produce more of a square wave output due to the on and off nature of the switches. Again control signals must be sent to the switches, typically done via PWM, and a control system can be implemented through them as well. The PWM scheme is most commonly used because of the possibility of voltage regulation, but it will also cancel out multiples of the third harmonic to help improve output power quality.

To minimize the switching losses in the GSC, it operates at UPF and its rating is obtained by maximum slip power. The GSC is usually committed to controlling the dc-link voltage only. During a fault the converter is used to support grid reactive power. The grid-side converter is used to boost grid power quality.

Direct AC/AC Conversion

There is a semi-unconventional method of power conversion that is available to designers known as direct AC/AC conversion. This does not require the intermediate DC link, which can both be bulky and possibly reduce the life of the system. On the other hand, it is less common due to the increased number of switches and the higher complexity in modulation and analysis. The DC link in the typical power conversion scheme will decouple both stages providing easier control and creating a basically independent source for the inverter.

There are a couple different AC/AC converters available right now. The first is known as the direct matrix converter, which will perform voltage and current conversion in a single stage. This type of converter requires and especially complex modulation technique. The second type is a modified version of the direct matrix converter and is known as the indirect matrix converter. This style utilizes two stages for voltage and current conversion, but it still does not require an intermediate DC link. The separation of the stages allows for easier control, but it still involves more switching devices than the typical conversion scheme, making it more expensive.

Energy Storage

The amount of energy stored in the dc-link capacitor bank can be written as:

$$E_C = \int P dt = \frac{1}{2} C V^2{}_{dc} \qquad 22$$

Where P the net power flow into the capacitor is, C is the dc-link capacitor value and V_{dc} is voltage across the capacitor.

$$P = P_r - P_g \qquad 23$$

Where $_r$

P_r is power flow into the rotor

P_g is power flow out of the grid.

Since wind is a natural occurrence, caused by the warming of the earth, it can hardly be an ideal source of electrical power. For instance, wind behaves differently depending upon many elements such as location, climate, season, and even time of day. To compensate for this and to help provide more constant power, storage systems have been implemented in wind energy conversion systems. Since battery technology has been around and been improved for years, they are a less expensive choice, and therefore, more commonplace. Ultra capacitors, however, are an up and coming technology, and have also been tried. Ultra capacitors have a lower internal resistance, so they can provide a surge of power faster than a battery, however, batteries can provide power for a longer period of time.

3.4 PULSE WIDTH MODULATION SCHEME

The main objective of the PWM scheme is to provide control signals to the power converters and in turn control the magnitude and frequency of the output voltage supplied to the load or grid. A sinusoidal pulse width modulation (PWM) technique is used in this work.

Figure 3.8 shows the waveforms of sinusoidal PWM signal generated for operating a two-level three-phase VSC, where a saw-tooth wave represents the carrier signal and the three modulating signals are represented by V_a, V_b and V_c. The amplitude modulation index m_a is used in controlling the fundamental frequency component of the converter output voltage and it is given by below equation.

$$m_a = \frac{V_m}{V_{carrier}} \qquad 24$$

Where, $V_{carrier}$ and Vm are the peak voltage of carrier and modulating signal respectively.

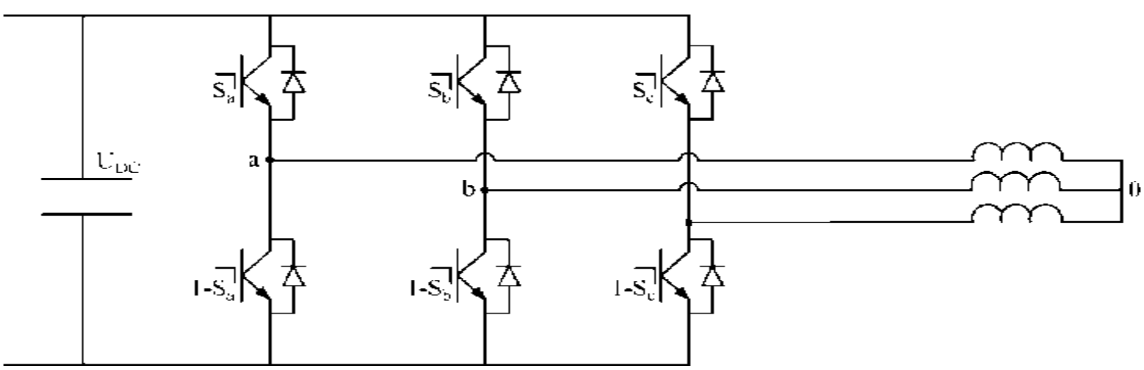

Figure-3.4: Working Model of Load Side Converter

The switching pulse for the switches S1 to S6, shown in figure, is generated by comparing the carrier signal and the modulating signal. Considering only one leg in the converter, when $v_a > V_{carrier}$, S1 is ON and S4 is OFF. During this period the converter terminal voltage i.e. the phase voltage with respect to negative DC bus is equal to V_{dc}. Similarly when $va < V_{carrier}$, S4 is ON and S1 is OFF, during this period the converter terminal voltage is zero. In order to avoid the occurrence of short circuit between the two switches in the same leg of the converter, a blanking time is introduced and both switches are maintained at OFF state during this time.

Under linear modulation (i.e. ma <1), the fundamental frequency component of the line-to-line output voltage V_{LL} of the converter is given by below equation.

$$V_{LL} = \sqrt{\frac{3}{2}}\ V_{a_N} = \frac{\sqrt{3}}{2\sqrt{2}}\ m_a\ V_{DC} = 0.612\ m_a\ V_{DC} \qquad 25$$

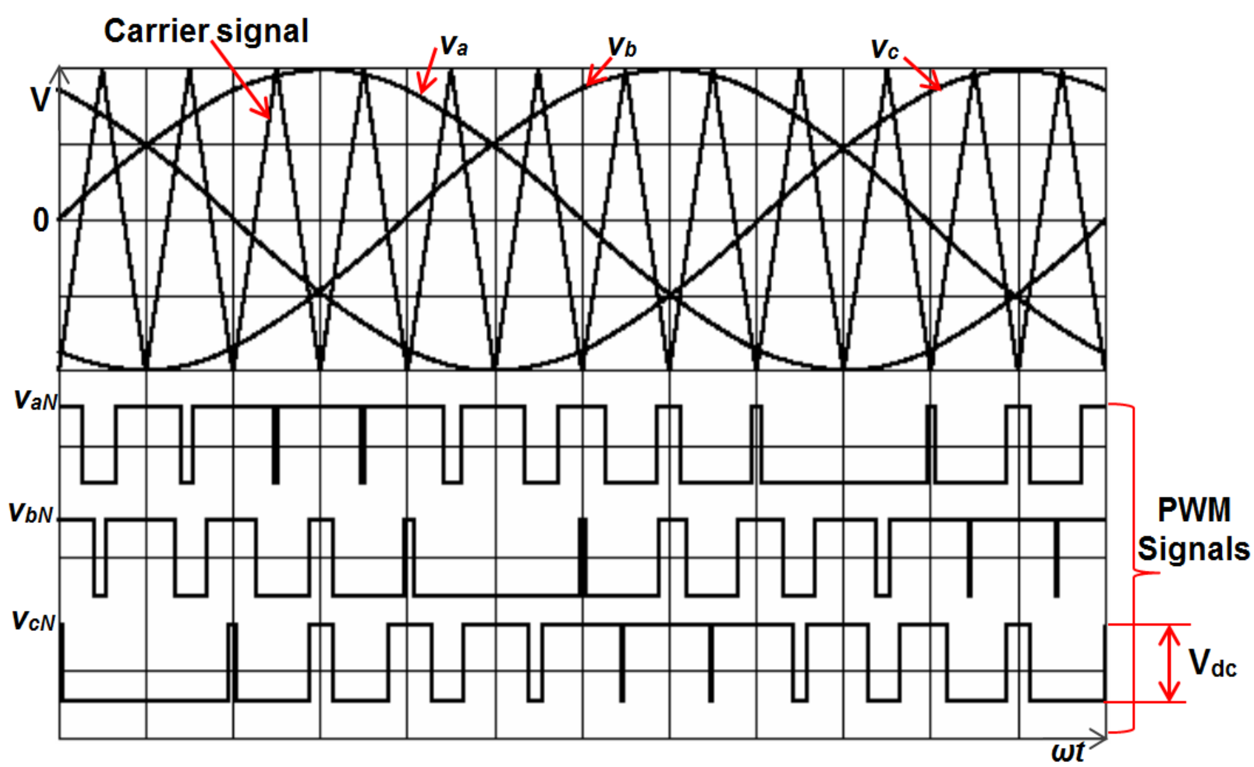

Figure-3.5: Signal Waveform of Carrier Signal, Phase Voltages and Neutral Voltages

CHAPTER 4

IMPLEMENTATION OF PMSG BASED WECS IN MATLAB

4.1 INTRODUCTION

In this chapter, the wind energy conversion systems (WECS) includes the essential parts such as wind turbine model, two mass drive train models, power converter set and then are implemented in MATLAB/SIMULINK environment.

4.2 PMSG BASED WECS MODEL

For study the performance of WECS the proposed model utilizing the MATLAB/SIMULINK software is needed. It includes various block sets which has been used to perform the working of proposed model. The block sets called the SIMPOWER SYSTEM has been utilized to design this following model shown in the Figure 4.1. And then proposed model of PMSG based WECS is implemented into the SIMULINK to study the performance of the model during the different operating conditions.

The wind energy conversion system presented in this work begins with a permanent magnet synchronous generator. It is followed by a passive rectification system. The inverter chosen for this project is a PWM controlled set of IGBTs with incorporated controls system. Following that is a harmonic filter and a step up transformer connected to the AC supply grid. Following in the Figure 4.1 is shows the block diagram of the entire wind energy system.

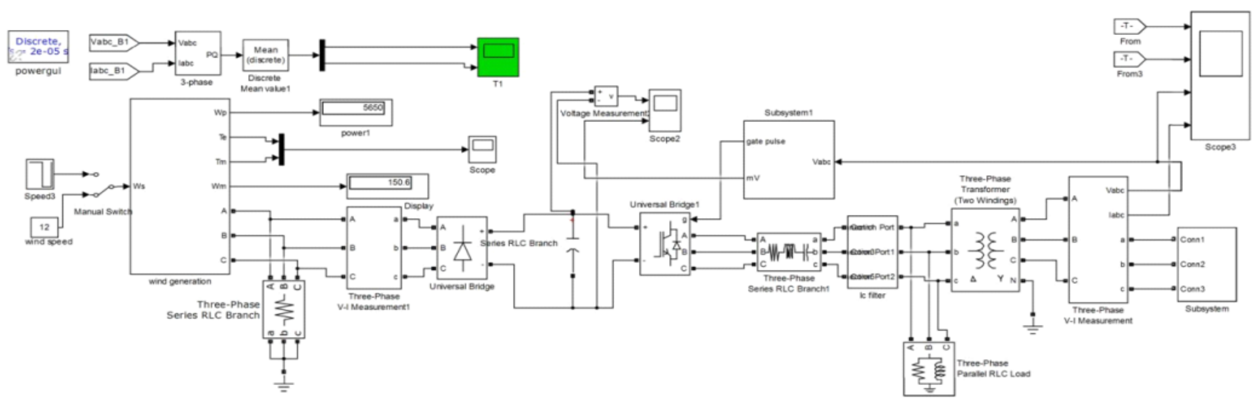

Figure-4.1: SIMULINK Model of PMSG Based WECS System

The input to the permanent magnet synchronous generator (PMSG) was chosen to be a constant torque, which is a simulated output of a wind turbine. From there the electrical current runs through a diode bridge for full rectification. A capacitor bank was chosen to smooth the waveforms from the rectifier to charge to a constant voltage. Afterwards, this electrical energy is transformed back into AC through a full bridge IGBT inverter. This inverter is fed by a PWM signal to control the switches. The PWM signal is a series of six signals (two for each set of IGBTs), which change widths depending upon the modulation waveform. When the value of the reference signal, or the sine wave, is greater than the modulation signal, the PWM signal is in a high state (or a logical 1). Otherwise, it is in a low state.

4.3 WIND TURBINE MODEL

The wind turbine model built and designed in the MATLAB/SIMULINK as shown in Figure 4.2. The performance coefficient Cp of the turbine is defines as the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle.

There are different parameters on which it depends and they are given as following.

- ✓ Base power of the electrical generator is given as: 8.5e3/0.9
- ✓ Mechanical output power of the model: 8.5e3
- ✓ Base wind speed of system : 8
- ✓ Maximum power at base wind speed 0.8
- ✓ Base rotational speed :1

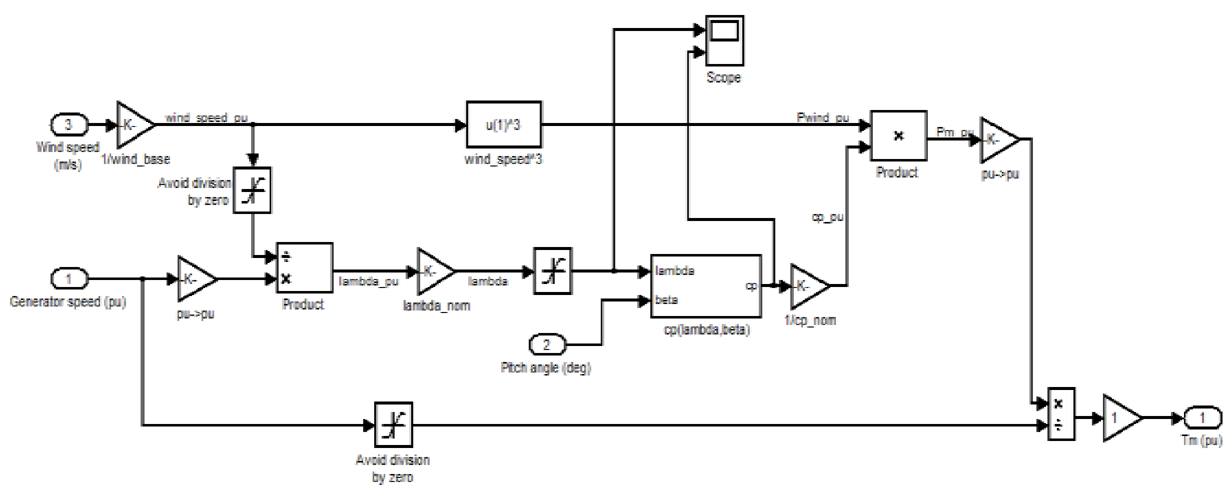

Figure-4.2: SIMULINK Model of Wind Turbine

4.4 TWO MASS DRIVE TRAIN MODEL

The drive train model is included in the wind turbine model. It represents in the wind turbine and shaft coupling system.

The above model will provide us with:

- ✓ $shaft\ torque = T_{shaft}$ (per unit)
- ✓ $output = \omega_{wt}$
- ✓ $genreatot\ speed\ as\ input(p.u) = T_{wt}$
- ✓ Closed loop control system is that in which feedback is supplied just before the gain.

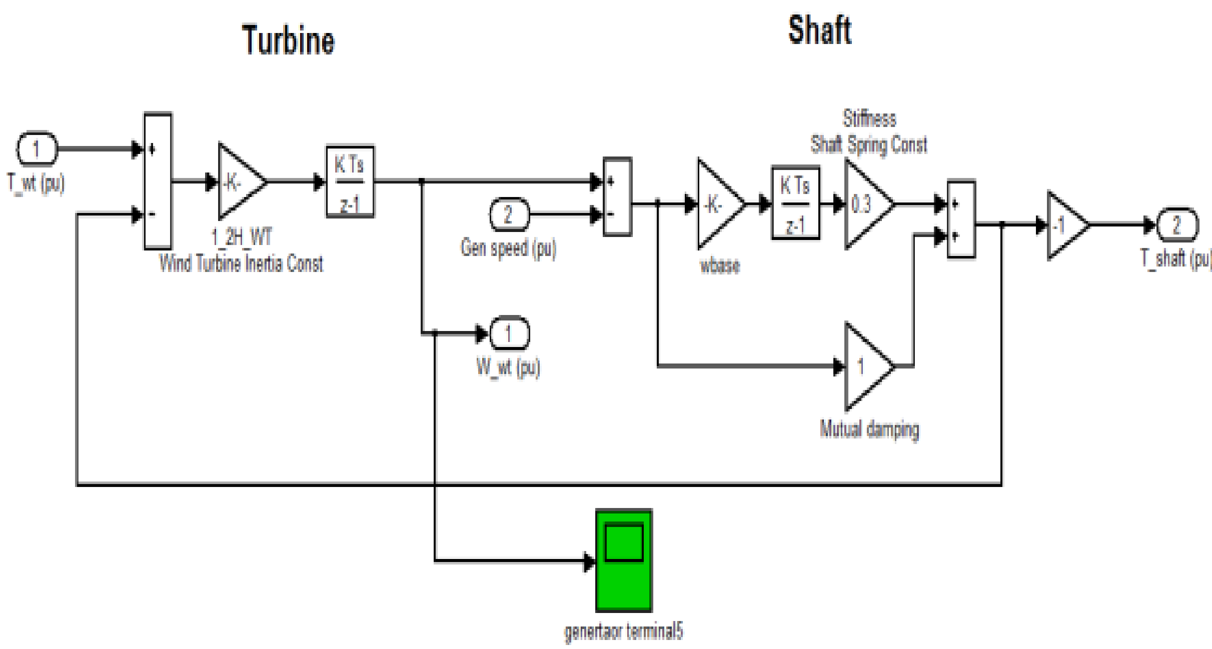

Figure-4.3: SIMULINK Model of Two Mass Drive Train

4.5 AC DC AC PWM CONVERTERS

In the PWM Converter is connected with the wind energy conversion system and it is designed in MATLAB/SIMULINK. The PWM controller is designed to produce the gate pulse so that it is supplied to the load side inverter.

Voltage controller is designed as shown in the Figure 4.4:

- $Proportional\ gain\ (Kp)$: 0.4,
- $Integral\ gain\ (Ki)$: 500,
- $Carrier\ frequency\ (Hz)$: 2000.

The abc to dqo transformation, discrete virtual PLL, discrete PID controller, dqo to abc Transformation, discrete PWM generator utilized in the formation of wind energy conversion system are developed in MATLAB/SIMULINK software.

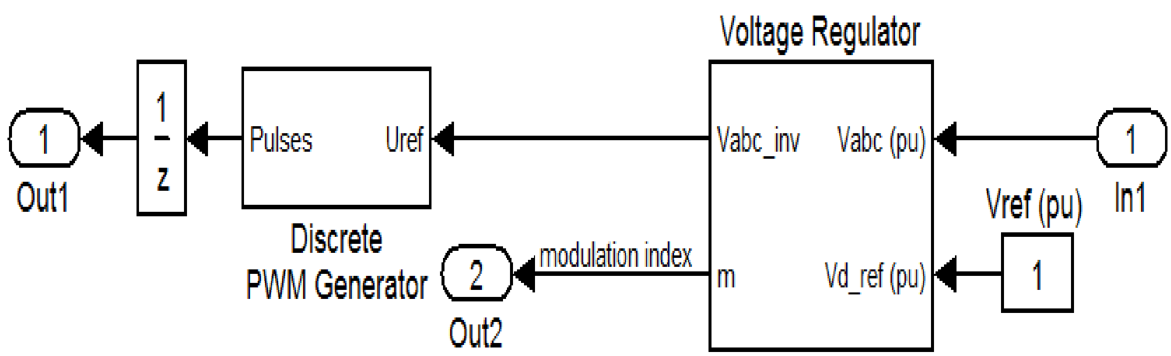

Figure-4.4: SIMULINK Model of PWM Controller

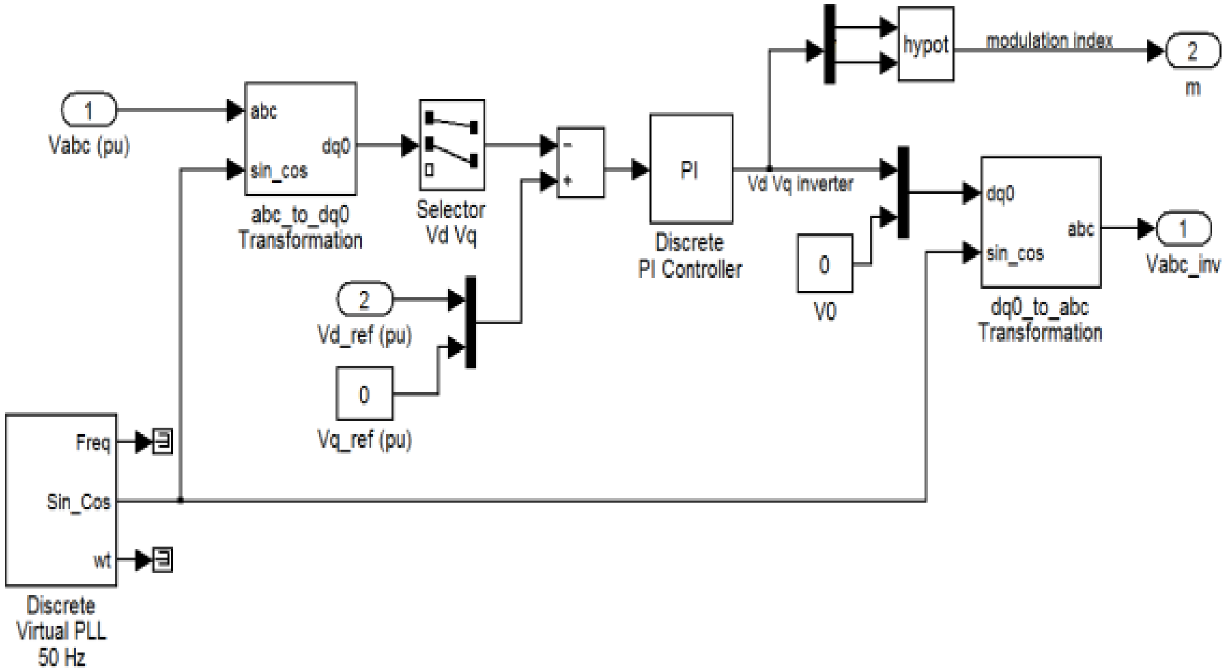

Figure-4.6: SIMULINK Model of Voltage Controller

Integral gain (Ki) is connected to the Discrete-Time Integrator block to form a purely discrete system. The zero order hold and Discrete-Time Integrator block applied as input to the sum and saturation block is connected between the sum and output block.

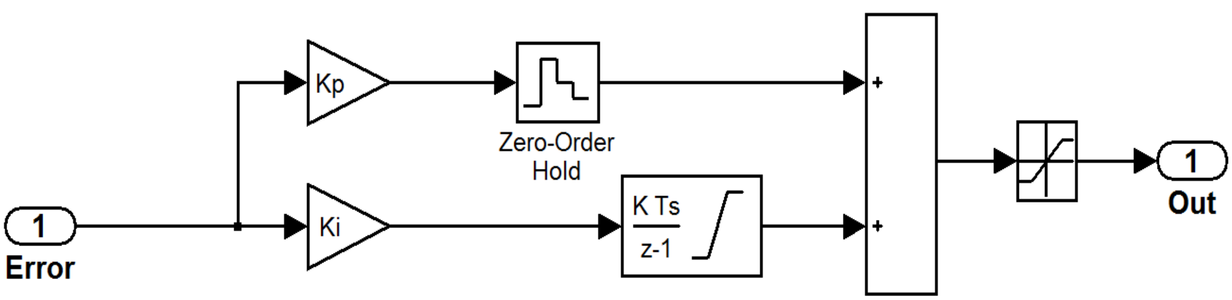

Figure-4.7: SIMULINK Model of Discrete PID Controller

CHAPTER 5

RESULTS AND DISCUSSION

5.1 SIMULATION RESULTS

The presented method and simulation results are implemented in MATLAB/SIMULINK. . In this chapter the performance of the PMSG based wind energy conversion system connected with power converter is studied and discussed. The power is extracted from wind through the wind energy system connected with PMSG generator then the power is transferred to the generator side rectifier and then to the load utility side inverter. Active and reactive powers for constant speed remain steady. The simulated waveform of voltage and current during the normal and faulted conditions across the source and load is discussed in the chapter .The figures shows the performance of wind energy conversion system in terms of voltage and current waveforms. Various other parameters such as active and reactive power and electrical and mechanical torques are also shown in terms of their waveforms.

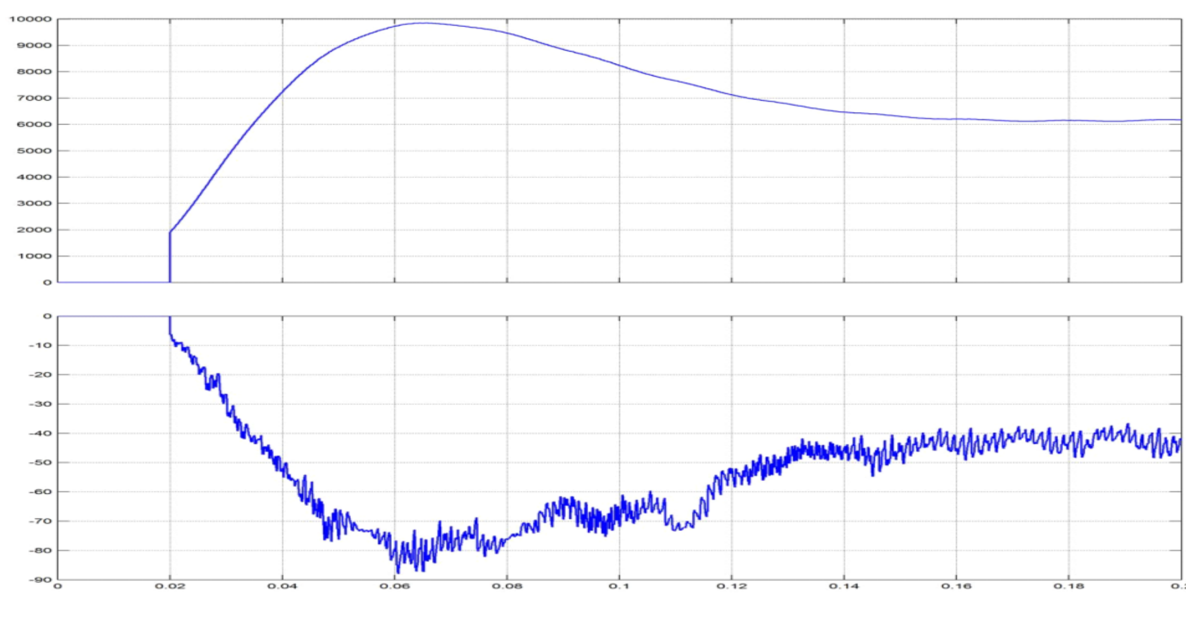

Figure-5.1: Active and Reactive Power Output

Figure 5.2 shows the DC link voltage value and the Modulation index value. DC link voltage is maintained constant value so that the load side converter control system has the good performance.

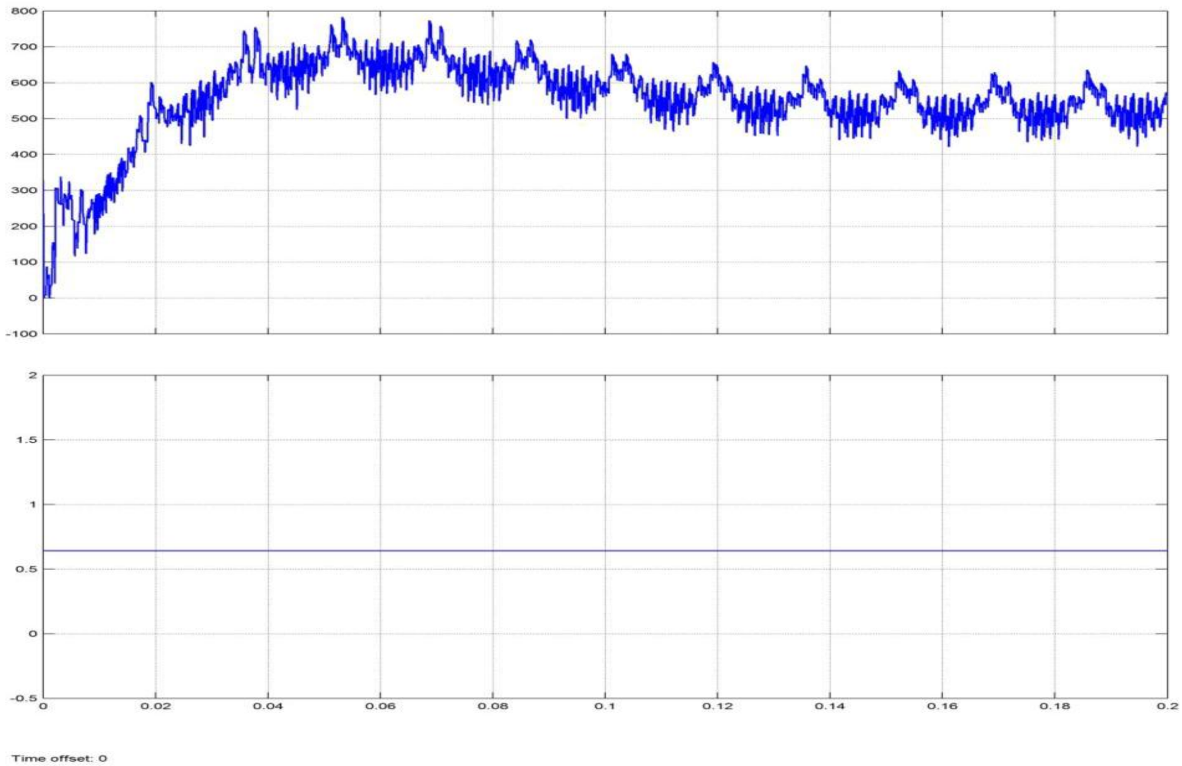

Figure-5.2: DC link and Modulation Index

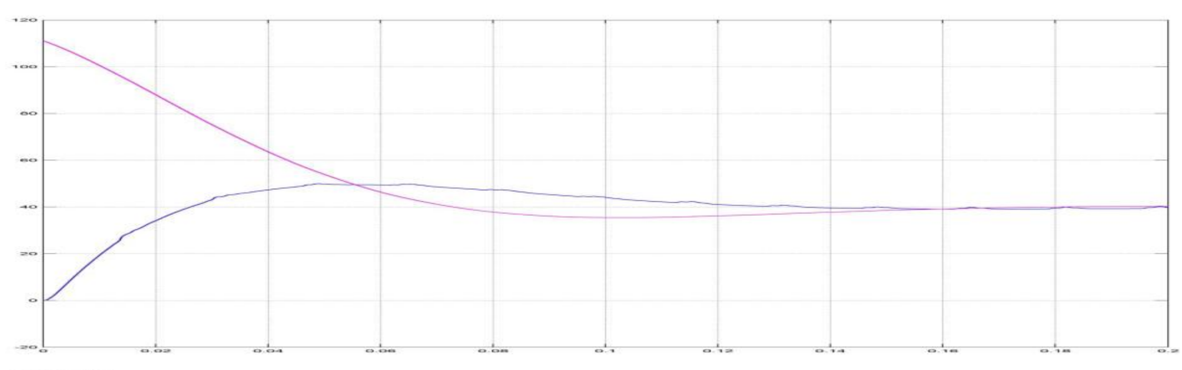

Figure-5.3: Electrical and Mechanical Torque

In the following Figure 5.4 it shows the voltage and current waveforms across the source of WECS. As shown in the figure there is harmonic content in the voltage waveform across the source which means that the power quality one should get from the wind energy system is not that much good power quality. So if source has that much of harmonic content then voltage waveform across the load is also of lower power quality. And in the second waveform which is a current waveform also bring the losses.

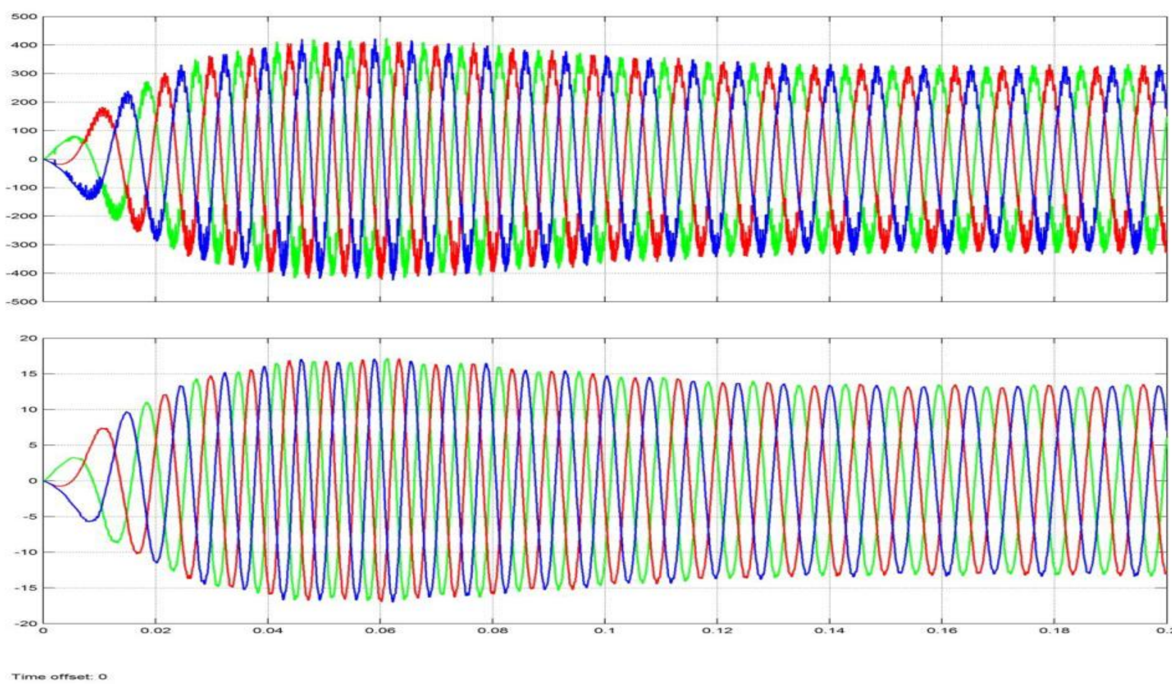

Figure-5.4: Voltage and Current Waveforms across Source of WECS without Filter

Now in the Figure 5.4 there ripple factor or harmonic content in the voltage waveform so therefore to improve power quality of voltage waveform one should connect LC filter in the system. As shown in the Figure 5.5 harmonic content in the voltage waveform across the source is reduced and shown the much better performance as compare to the voltage waveform shown in the Figure 5.4. There is also a current waveform across the source shown in the figure given below. From this point of view it is essential that filter should be connected in the model of the system. Since the system is operated in stand-alone mode, the load power consumption is equal to the wind turbine power output. Occurrence of power fluctuations at the load end power converter is reduced by LC filters.

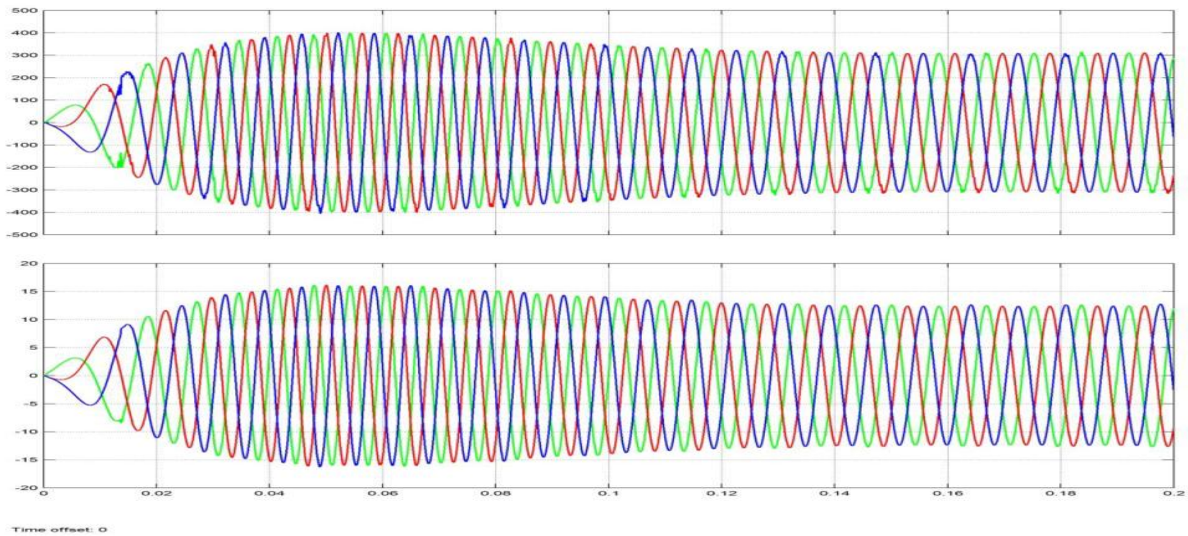

Figure-5.5: Source Voltage and Current Waveforms of WECS with Filter

In the Figure 5.6 voltage and current waveform is shown across the load. Now as per shows in figure the voltage waveform in its initial time period there are harmonic distortions. As the time period increases the harmonic distortion starts getting reduced. This means there may be second order or third order harmonic distortion occurs due to the fluctuation in the wind power supply voltage. Second waveform is the current waveform across the load.

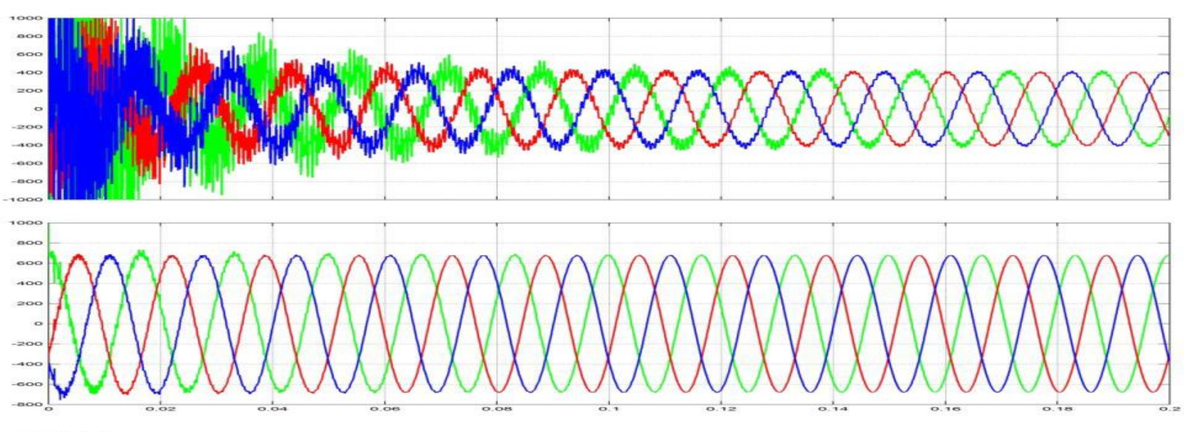

Figure-5.6: Voltage and Current Waveforms across the Load during Normal Operating Condition

Figure 5.7 shows the voltage and current waveforms across the load utility of the WECS during the fault condition. Now as shown in the Figure 5.6 the voltage and current waveforms across the load when there is no fault in the system. When there is occurrence of fault in the system there is change in the voltage and current waveforms. In the Figure given below when the fault is occur between the time period of 1/60 seconds to 5/60 seconds there is change in the voltage waveform and aftermath signal takes the few seconds to become stable after the fault occurrence. Now in case of current waveform when fault occurs between the transition times of 1/60 second to 5/60 seconds value of current become maximum across the load than the value of current during the final part of waveform. So now one can understand the voltage and current waveforms values during the normal operating condition and fault operating conditions as shown in the Figure 5.6 and Figure 5.7.

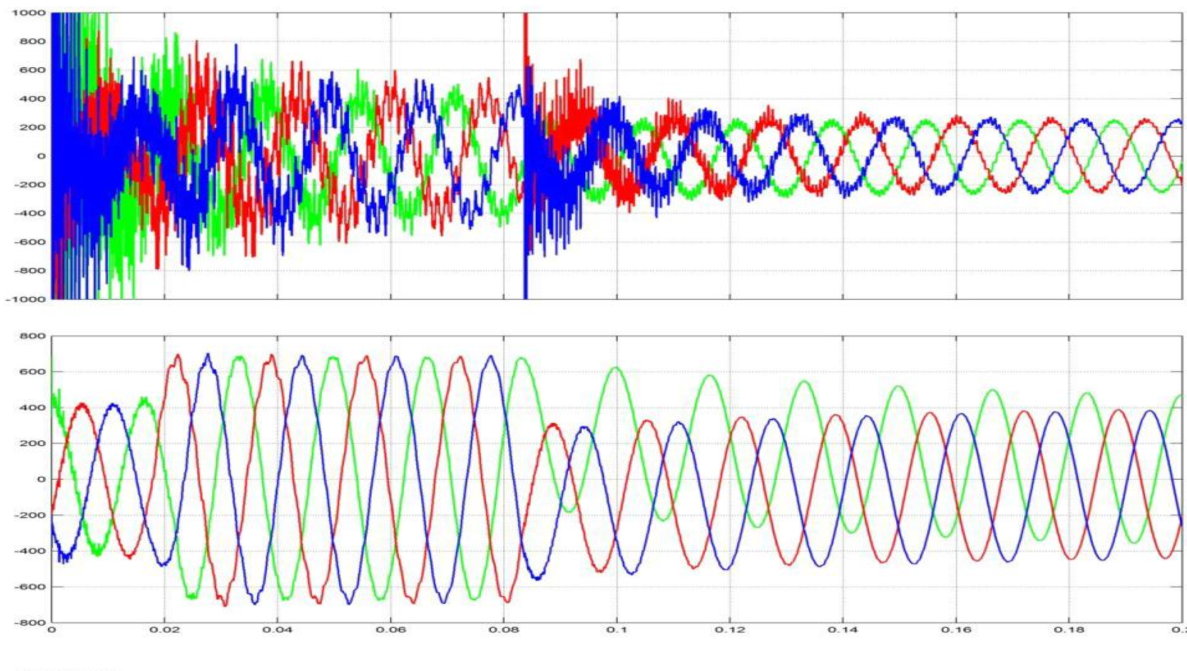

Figure-5.7: Voltage and Current Waveforms across the Load during Fault Condition

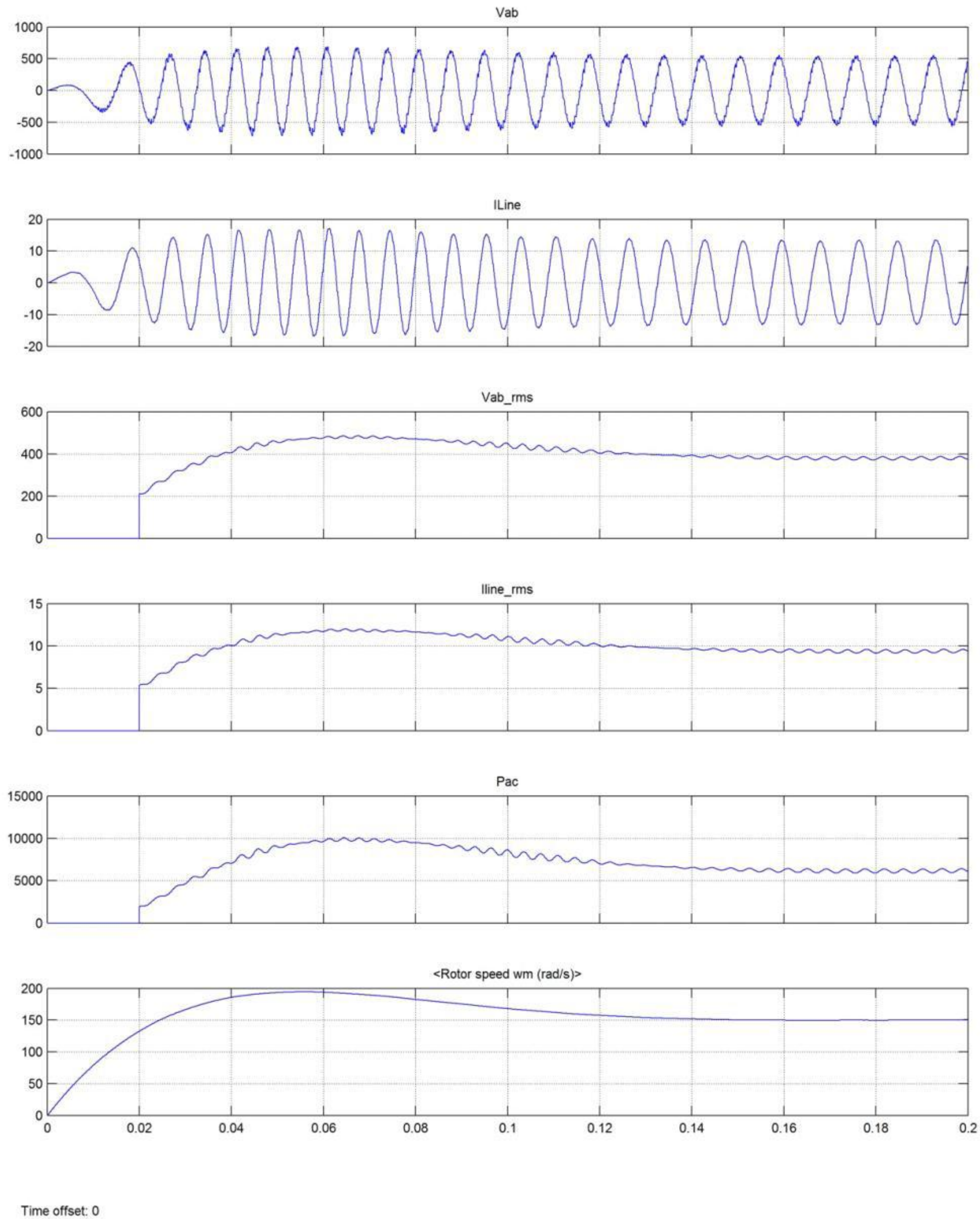

Figure-5.8: RMS Voltage, RMS Current, Active Power and Rotor Speed Waveforms of the System

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

The performance of PMSG based wind energy conversion system (WECS) has been studied during the normal operating condition and during the fault conditions. The proposed PMSG based WECS model is useful especially in rural coastal areas to effectively supply the electrical power demand of the consumers. This solution will also prove to be beneficial for the consumers to have a reliable electric power supply. This can also be beneficial for the electricity authorities or boards to meet the emergency loads of their areas in the event of an emergency shut down or an outage. Another fact is that this will help in reducing the amount of pollutants released into the environment, it also promote the energy stability and the economic security by reducing the dependability on the fossil fuels.

6.2 FUTURE SCOPE

In the future scope we can say that the output performance of the PMSG based wind energy conversion can be improved by utilizing the advanced control techniques such as fuzzy logic, sliding mode control. There is possibility of the addition of the sources like storage unit; solar photovoltaic etc. to the hybrid system and it will increase the reliability of the system. In this way we can increase the stability and performance of the PMSG based wind energy conversion system.

REFRENCES

[1] Lalit Kumar Gautam, Mugdha Mishra "Permanent Magnet Synchronous Generator Based Wind Energy Conversion System" International Journal of Electrical Electronics & Computer Science Engineering Volume 1, Issue 1 (February 2014).

[2] Kaki shanmukesh, Mr.D.V.N.Ananth " ANALYSIS OF PMSG BASED WIND ENERGY CONVERSION SYSTEM OPERATING UNDER DIFFERENT GRID FAULT" International Journal of Science, Engineering and Technology Research (IJSETR), Volume 4, Issue 9, September 2015.

[3] BOUZID Mohamed Amine, MASSOUM Ahmed, ALLAOUI Tayeb, ZINE SOUHILA "MODELLING AND CONTROL OF STANDALONE WIND ENERGY CONVERSION SYSTEM" International Journal of Advances in Engineering & Technology, Jan. 2014.

[4] A.Bharathi sankar, Dr.R.Seyezhai "MATLAB Simulation of Power Electronic Converter for PMSG Based Wind Energy Conversion System" INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING Vol. 1, Issue 8, November 2013.

[5] Omessaad Elbeji, Mouna Ben Hamed, LassaadSbita "PMSG Wind Energy Conversion System Modeling and Control" International Journal of Modern Nonlinear Theory and Application,2014.

[6] Bipin Biharee Srivastava, Er. Sudhanshu Tripathi "Tracking of Maximum Power from Wind Using Fuzzy Logic Controller Based On PMSG" International Journal Of Modern Engineering Research.

[7] Nandini.A, Isha T.B "PERMANENT MAGNET SYNCHRONOUS GENERATOR BASED STANDALONE SYSTEM" International journal of advanced engineering and global technology.

[8] Kajal Kushwah, C.S. Sharma “Improvement Of Voltage Stability In WECS Using Of Two Mass Drive Train And PWM Converter” International Journal of Research in Engineering & Advanced Technology, Volume 3, Issue 4, Aug-Sept, 2015.

[9] Mirza Mohd.Shadab, Abu Tariq “PERFORMANCE ANALYSIS OF PERMANENT MAGNET SYNCHRONOUS GENERATOR CONNECTED WITH WIND TURBINE” International Journal of Advanced Technology & Engineering Research.

[10] Hyong Sik Kim, Dylan Dah-Chuan Lu “Wind Energy Conversion System from Electrical Perspective —A Survey” Smart Grid and Renewable Energy, 2010 Published Online November 2010 (http://www.SciRP.org/journal/sgre).

[11] C. Carrillo, E. Diaz-Dorado, M. Silva-Ucha and F. Perez-Sabín “Effects of WECS settings and PMSG Parameters in the Performance of a Small Wind Energy Generator” International Symposium on Power Electronics, Electrical Drives, Automation and Motion.

[12] Miguel López Jean-Claude Vannier “STAND ALONE WIND ENERGY CONVERSION SYSTEM WITH MAXIMUM POWER TRANSFER CONTROL” Ingeniare. Revista chilena de ingenieria,vol.17 No 3, 2009.

[13] Kapil Parikh, Ashish Maheshwari, Vinesh Agarwal “Modeling, Simulation And Perfomance Analysis of AC-DC-AC PWM Converters Based Wind Energy Conversion System” International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-2, Issue-4, September 2013.

[14] Raghuvendra Kumar Tiwari, Krishna Kant Sharma “Simulation and Modeling of Wind Turbine using PMSG” International Journal of Recent Research and Review,Vol. VII, Issue 2, June 2014.

[15] Jay Verma, Yogesh Tiwari, Anup Mishra, Nirbhay Singh “ Performance, Analysis and Simulation of Wind Energy Conversion System Connected With Grid” International Journal

of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-2, Issue-6, January 2014.

[16] Suji Muhammed Krishnakumari V "Performance Analysis of a PMSG Based Wind Energy Conversion System" International Journal of Engineering Research & Technology (IJERT) Vol. 3 Issue 8, August – 2014.

[17] Prerna Badoni, S. Bhanu Prakash "Modeling and Simulation of 2 MW PMSG Wind Energy Conversion Systems"IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 9, Issue 4 Ver. I (Jul – Aug. 2014).

[18] R.Karthick, S.Manoharan, S.Rajkumar "Grid Interface Of A Pmsg Based Wind Energy Conversion System With Power Quality Improvement Features" Journal of Theoretical and Applied Information Technology 20th October 2014.

[19] Ali Tahmasebi Sohi, Shahram Javadi, SZ Moussavi "Power Flow Control in Grid-Connected Wind Energy Conversion System Using PMSG with Harmonic Elimination Added Function" IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), Volume 10, Issue 1 Ver. II (Jan – Feb. 2015).

[20] Abhishek M. Patel, Dr. Jatin J. Patel " PMSG with Inverter using Park's Transformation for Transient Fault Analysis" IJSRD - International Journal for Scientific Research & Development| Vol. 3, Issue 03, 2015.

[21] Harika G, Jayakumar N, Thrivonasundari D "Design and Simulation of Dual Inverter Based Energy Storage Systems for Wind Energy Systems Using MATLAB/SIMULINK" Int. Journal of Engineering Research and Applicationswww.ijera.com ISSN : 2248-9622, Vol. 4, Issue 4(Version 7), April 2014.

[22] V. Arulalan, R. Dhanasekaran "Wind Power Applications in India – Survey" International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Special Issue 4, October 2013)

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