CURRENT AND FREQUENCY CONTROL OF INDUCTION GENERATOR: SIMULATION USING MATLAB

TAUFIK BIN MOHD NOR

UNIVERSITY MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

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Saya   **TAUFIK BIN MOHD NOR (870110-06-5657)**

(HURUF BESAR)

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Alamat Tetap:

L-6 FELDA ULU JEMPOL   **MUHAMMAD IKRAM BIN MOHD RASHID**
26400 BANDAR JENGKA   (Nama Penyelia)
PAHANG

Tarikh: **29 NOVEMBER 2010**   Tarikh: : **29 NOVEMBER 2010**

CURRENT AND FREQUENCY CONTROL OF INDUCTION GENERATOR:
SIMULATION USING MATLAB

TAUFIK BIN MOHD NOR

A thesis submitted in partial fulfillment of the

requirements for the awarded of the Degree of Bachelor of Electrical &

Electronic Engineering

Faculty of Electrical & Electronic Engineering

University Malaysia Pahang

NOVEMBER, 2010

I declare that this thesis entitled *"Current and Frequency Control of Induction Generator: Simulation Using MATLAB"* is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Name   : TAUFIK BIN MOHD NOR

Date   : 29 NOVEMBER 2010

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To my beloved mother and father and those who have guided and inspired me

throughout my journey of learning.

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ABSTRACT

Induction machine is the most widely used machine nowadays in industry and generation systems. It haves two mains types that usually use, squirrel cage and wound type. This project is about the control of current and frequency of wound rotor induction generator in wind turbine generation system. By controlling the current and frequency at the rotor of the generator, the active and reactive power produce by the generator can be regulate and maximize the generator performance. To control the current and frequency of induction generator in wind turbine application, this project uses an AC/DC/AC converter that directly connected to rotor. AC/DC/AC converter is a bi-directional converter that enables the generator to operate above and below the synchronous speed thus allow the generator to generate and absorb power from the grid. This system is called Doubly Fed Induction Generator (DFIG) in wind turbine application system where the stator is directly connected to grid and the rotor is connected to grid via AC/DC/AC converter. This project use MATLAB software to simulate the system and analyze the result obtains from the simulation. From the result, it shows that this system is function successfully and the objective is achieved.

ABSTRAK

Mesin induksi adalah mesin yang paling meluas penggunaanya pada masa kini di industri dan sistem penjanaan. Mesin ini terbahagi kepada dua jenis iaitu jenis sangkar tupai dan rotor luka. Projek ini adalah tentang kawalan arus dan frekuensi penjana induksi dalam sistem penjanaan turbin angin. Dengan mengawal arus dan frekuensi di rotor penjana itu, kuasa aktiv dan reaktiv yang terhasil dari penjana boleh dilaraskan dan dapat memaksimumkan prestasi penjana itu. Untuk mengawal arus dan frekuensi penjana induksi dalam aplikasi turbin angin, projek ini menggunakan pengubah AC/DC/AC yang disambungkan terus pada rotor.Pengubah AC/DC/AC adalah pengubah dua arah yang membolehkan penjana untuk beroperasi di atas dan di bawah kelajuan penyegerakan dan seterusnya membenarkan penjana untuk menghasilkan dan menyerap tenaga dari grid. Sistem ini dipanggil Penjana Induksi Suapan Bergabung (PISB) dalam aplikasi turbin angin dimana stator disambung terus kepada grid dan rotor disambungkan ke grid melalui pengubah AC/DC/AC. Projek ini menggunakan perisian MATLAB untuk mensimulasi sistem yang dibina dan menganalisis hasil yang didapati dari simulasi. Dari hasil itu. Ia menunjukkan yang sistem ini berfungsi dengan berjayanya dan telah mencapai objektif.

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LIST OF SIMBOL

P   -   Active power

Q   -   Reactive power

A   -   Area of rotor

V   -   Wind velocity

D   -   Air density

P_R -   Rotor power

P_{airgap} -   Air gap power

s   -   Slip

P_G -   Generator power

P_{WW} -   Wind wheel turbine power

T_m -   Mechanical torque

ω_r -   Rotor speed

P_s -   Stator power

T_{em} -   Electromagnetic torque

ω_s -   Stator speed

Idr   -   d-axis current

Iqr   -   q-axis current

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LIST OF ABBREVIATIONS

DFIG   Doubly Fed Induction Generator

PM   Permanet Magnet

DTC   Direct Torque Control

RSC   Rotor Side Converter

GSC   Grid Side Converter

PWM   Pulse Width Modulation

IGBT   Insulated Gate Bipolar Transistor

AC   Alternating Current

DC   Direct Current

PI   Proportional Integral

Crotor   Rotor Converter

Cgrid   Grid Converter

Tm   Mechanical Torque

PLL   Phase Locked Loop

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CHAPTER 1

INTRODUCTION

1.1   Background of Study

Induction machine is the most widely used machine nowadays in industry and generation system. It has two main types, squirrel –cage and wound rotor type for this project, wound rotor type will be use because of its advantages in wind turbine application. This paper describes wind generation models that use Doubly fed induction generator (DFIG) system for operation within power system in order to perform stability analysis and rotor control to maximize the power generated with the lowest impact on the grid voltage and frequency during normal operation and under several disturbances, such as a variable wind speed and transmission line earth fault. The discussed methods consider wind turbines based on induction generator and a grid-connected converter. The study is performed within the multiple technologies design tool MATLAB/Simulink.

1.1.1 Induction Generator

The technology of induction generator is based on the relatively mature electric motor technology. Induction motors are perhaps the most common types of electric motors used throughout the industry. Early developments in induction generators were made using fixed capacitors for excitation, since suitable active power devices were not available. This resulted in unstable power output since the excitation could not be adjusted as the load or speed deviated from the nominal values. This approach became possible only where a large power system with infinite bus was available, such as in a utility power system. In this case the excitation was provided from the infinite bus. [1]With the availability of high power switching devices, induction generator can be provided with adjustable excitation and operate in isolation in a stable manner with appropriate controls.Induction generator also has two electromagnetic components: the rotating magnetic field constructed using high conductivity, high strength bars located in a slotted iron core to form a squirrel cage; and the stationary armature similar to the one described in the previous paragraph for PM technology. Figure 1.1 shows the construction of a typical induction generator in a cross sectional view.
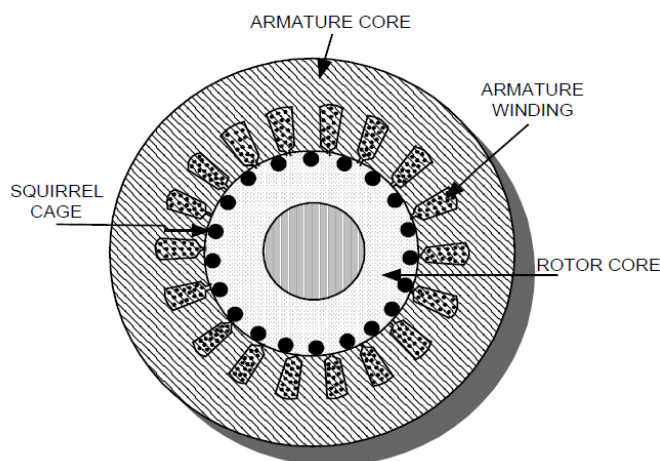
Figure 1.1   Induction Generator Cross- sectional view [1]

The voltage output from the generator is regulated, multiple phase AC. The control of the voltage is accomplished in a closed loop operation where the excitation

current is adjusted to generate constant output voltage regardless of the variations of speed and load current. The excitation current, its magnitude and frequency is determined by the control system. The excitation current is supplied to the stationary armature winding from which it is induced into the short circuited squirrel cage secondary winding in the rotor.

1.1.2 Doubly Fed Induction Generator (DFIG)

Doubly Fed Induction Generator is a generating principle widely used in wind turbines. It is based on an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. The principle of the DFIG is that rotor windings are connected to the grid via slip rings and back-to-back voltage source converter that controls both the rotor and the grid currents. Thus rotor frequency can freely differ from the grid frequency (50 or 60 Hz). By controlling the rotor currents by the converter it is possible to adjust the active and reactive power fed to the grid from the stator independently of the generators turning speed. The control principle used is either the two-axis current vector control or direct torque control (DTC). DTC has turned out to have better stability than current vector control especially when high reactive currents are required from the generator. Figure 1.2 shows the Principle of a Doubly Fed Induction Generator.
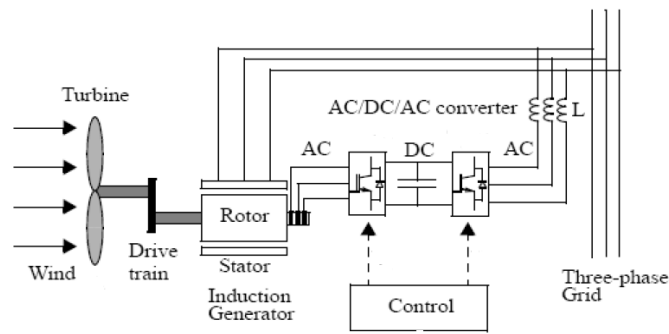

converter (GSC) that controlled by pulse width modulation (PWM). The RSC is the converter that directly connected to rotor of the the induction generator while GSC is the converter that connect to the grid. This converter have diffirent function where the RSC function to control the current of the rotor while the GSC function to control the frequency of the generator. MATLAB/Simulink software is used to design and simulate this system.
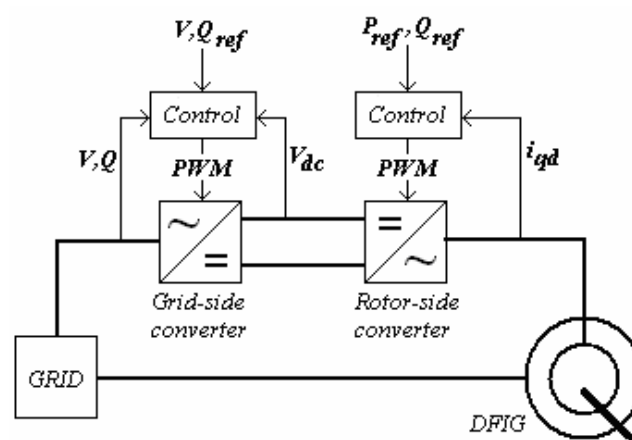
Figure 1.3   General Doubly Fed Induction Generator control structure[3]

1.3   Objective of Project

The objectives of this project are to:

1.   Construct and simulate the current and frequency control of induction generator using Simulink in MATLAB

2.   Design and simulate a wind generation model using doubly fed induction generator (DFIG) system using Simulink in MATLAB

3.   Take the result obtains from the simulation and analyzes it to prove the theory

1.4   Scope of the Project

For this project, there two main scopes that must be completed in order to make sure this project will success:

1. Construct three phase AC/DC/AC converter in MATLAB that can control the current and frequency of the induction generator in Doubly Fed Induction Generator (DFIG) System.

2. Design and simulate a complete wind turbine generating system with focus on the generator side control using Doubly Fed Induction Generator (DFIG) system, where the stator side is directly connected to grid and the rotor side is connected to PWM converter. This system will also combine the entire controller and analyze the power flow and result of current and frequency of the generator to make sure the simulation have done as desired and success to control the current and frequency of the induction generator.

1.5   Thesis Outline

This thesis contains five chapters that clearly explaining about this project starting from introduction on Chapter 1, followed by literiture review on Chapter 2, methodology on Chapter 3, result and discussion on Chapter 4 and conclusion on Chapter 5

Chapter 1 is explaining about the background of study that explain about induction generator and DFIG. Secondly is the problem statement that clearly state about the fundamental of this project. After that, the objective of this project that show the objective or the reason of this project to be done followed by scope of the project and thesis outline.

Chapter 2 provides the information about literature review that explain about the paper that used as the references for this project. This chapter show the the present and previous method and technique used in control the induction generator.

Chapter 3 focuses on the method that have been used for this project including flowchart, methamatical modeling, metahmatical expression and electrical circuit. This chapter also discuss the basic about MATLAB and the method use in MATLAB to control the induction generator.

Chapter 4 discuss about the MATLAB block function as the result from method that use on Chapter 3 and analysis of the result obtain from the simulation using MATLAB.

Chapter 5 is about the conclusion, the problem encountered during this project and future recomendation for this project to improve this project.

CHAPTER 2

LITERATURE REVIEW

2.1   Induction Generator operation

        The operation of the induction motor occurs in a stable manner in the region of the speed torque curve indicated in Figure 2.1. The torque output as well as the power delivered by the motor varies as the motor speed changes.[3] At synchronous speed no power is delivered at all. The difference between the synchronous speed and the operating speed is called the slip. The output torque and power vary linearly with the slip.
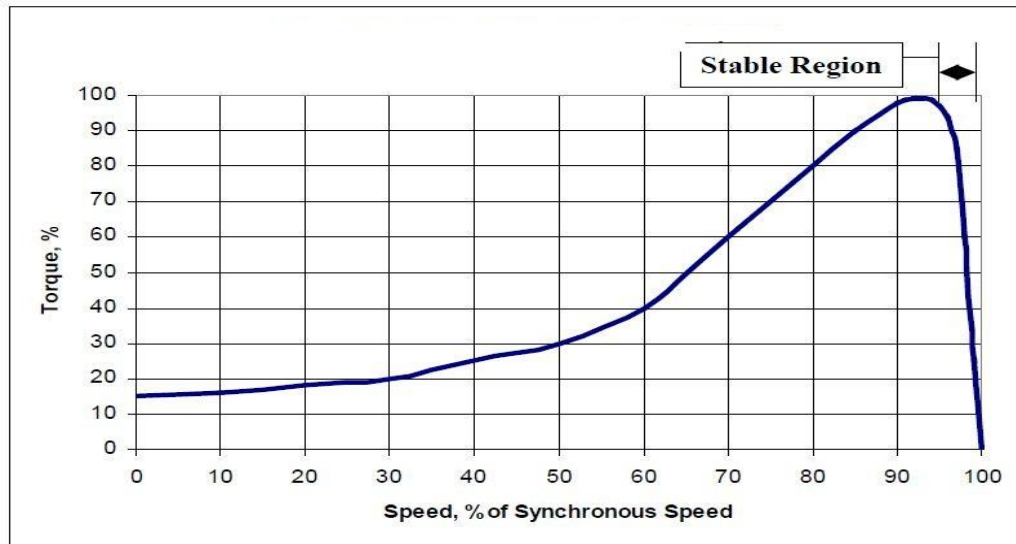
Figure 2.1   Induction motor torque v/s speed characteristic[3]

If the induction motor is driven to a speed higher than the synchronous speed, the speed torque curve reverses as shown in Figure 2.2. In the stable region of this curve, electric power is generated utilizing the mechanical input power from the prime mover. Once again the generated power is a function of the slip, and varies with the slip itself

Figure 2.2   Induction generator torque v/s speed characteristic[3]

In the generator mode, if the slip is controlled in accordance with the load requirements,the induction generator will deliver the necessary power. It must be remembered that the synchronous speed is a function of the electrical frequency applied to the generator terminals. On the other hand, the operating shaft speed is determined by the prime mover. Therefore to generate power, the electrical frequency must be adjusted as the changes in the load and the pri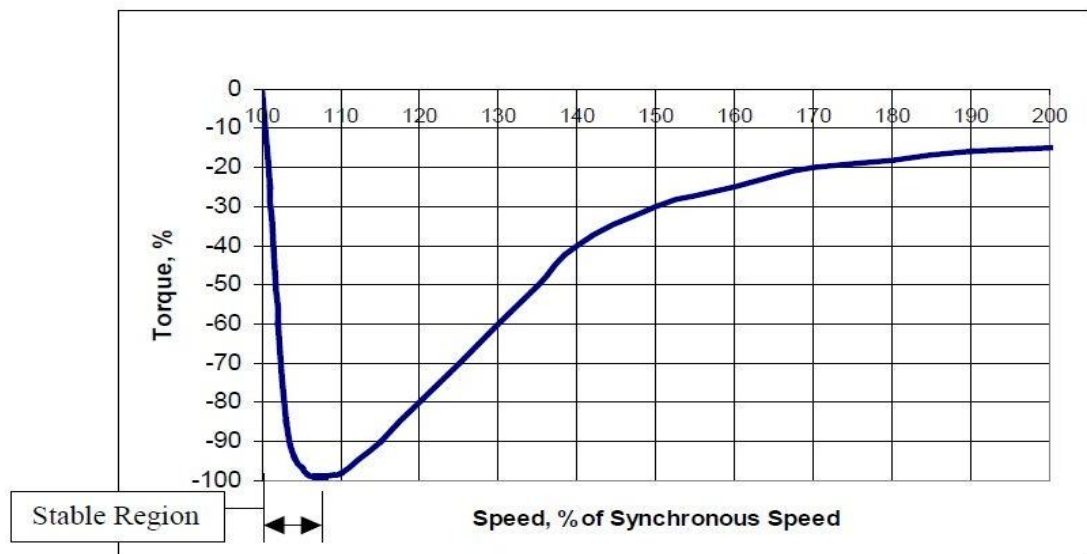me mover speed occur. In addition to the requirement stated above, [5]the excitation current must be provided to the generator stator windings for induction into the rotor. The magnitude of the excitation current will determine the voltage at the bus. Thus the excitation current must be regulated at specific levels to obtain a constant bus voltage.

.2.2   Induction Generator Control

In wind turbine application, the generator control system is very important in order to control the power transfered to the grid and to maximize the power extracted from the wind. There are many types of induction generator controller nowadays use for wind turbine application and some of that will be discuss in this chapter.

2.2.1   Induction Generator with Dynamic Slip Control

The dynamics slip-control system influences the torque and power transfered from the rotor to the stator by changing the rotor slip according to the following equation :

$$P_R = P_{airgap}\, s \tag{2.1}$$

$$P_S = P_{airgap}\,(1-s) \approx P_G \tag{2.2}$$

$$P_{airgap} \approx P_{WW} \tag{2.3}$$

where P_R = machine rotor power

   P_S = machine stator power

   P_{WW} = wind wheel (turbine power)

[6]In squirrel-cage rotor induction machine, the slip variations are small and the mechanical power variation pass into the stator side of the machine almost directly. Using wounded rotor (slip ring) induction machines, by adding resistor to the rotor, it is posibble to change the machine mechanical characteristic by changing the rotor slip.

The second of the equation (2.2) show how it works. When the power P_{WW} extracted form the wind changes, the controller change the rotor slip s to compensate the variation and to keep the elecrical power P_G constant.
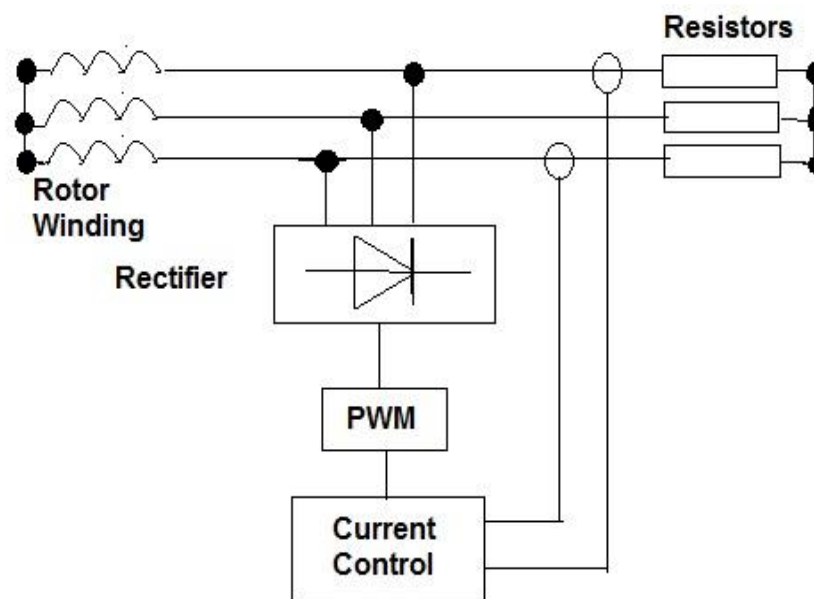

Figure 2.3   Dynamic slip control system

The major task of the controller located in the machine rotor is the rotor current control (Figure 2.1), assuming that the current is proportional to the power output, the required resistance is achieved by pulse width modulation (PWM) of the resistor using IGBT (Insulated Gate Bipolar Transistor) as DC switches. The switch frequency is approximately 3 kHz.

2.2.2   Induction Generator with Over-Synchronous Cascade Control

Utilization of an induction generator with wounded rotor and with additional resistor connected to the rotor winding enables it to influence the rotor speed but at the same time this action causes an increase of the power losses. To eliminate this, a converter allowing energy transfer from the rotor to the grid can be used.

The converter consists of a diode rectifier, reactor and current source inverter. The converter enables transfer of the power in one direction and therefore, the generator can operate only at a speed above that of the synchronous one[7]. The advantages of this system is that it is a relatively simple controller, which consists of a speed regulator (SR) and an intermediate circuit current regulator (ICCR).

The references speed ω_{ref} is calculated by using the speed versus active power nonlinear function. The speed regulator computes the immediate circuit current references i_{dref}. The ICCR generate signal controlling the inverter valves (thyristor or transistor).

2.2.3   Doubly Fed Induction Generator (DFIG)

The Doubly Fed Induction Generator System (DFIG) with a converter making it possible to transfer energy in both direction (bidirectional converter) and enables the generator to operate above and below the synchronous speed. When the machines operate at over-synchronous speed, the power flows from the rotor to the grid. When the machines operates at the sub-synchronous speed, the power flow from the grid to the rotor.

[8]By controlling the rotor current (magnitude and phase) it is possible to influence highly (over the wide range) the machine slip and the active and reactive power transfered to grid. The ability to change the generator rotor speed over a wide range enables us to increase the power production.

The power production can increase because the inheret energy in the wind is extracted more effectively when the rotor speed allowed to vary.So, the power output can be optimized.The exploitation of the rotational energy in the generator rotor also can increase the power production by storing the energy excess as rotational energy and using it when the wind velocity is lowered.

By rapid adjustment to different wind speeds, we also can increase the power production. [9]The rapid adjustment allows the rotor speed to vary rapidly and therefore, to exploit energy in transient gusts. The energy would be lost when a relatively slow pitch angle control mechanism is used. On the other hands, the converter allows the pitch angle control system to operate slowly, decreasing the stress and overloading in the blades and the rotor shaft.

CHAPTER 3

METHODOLOGY

3.1   Introduction

The methodology of this project consists of several approaches and procedures in completing this project, many aspects had been taken into consideration. The procedures that had been taken are referred from literature review through many journals and articles founded about current and frequency control of induction generator and DFIG system.This project have several stage in order to complete the scope of the project.

3.2   Doubly Fed induction Generator

Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed.

Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel-cage induction generator. Where Vr is the rotor voltage and Vgc is grid side voltage. The AC/DC/AC converter is basically a PWM converter which uses sinusoidal PWM technique to reduce the harmonics present in the wind turbine driven DFIG system. Here Crotor is rotor side converter and Cgrid is grid side converter. To control the speed of wind turbine gear boxes or electronic control can be used.

3.2.1   Operating Principles

The stator is directly connected to the AC mains, whilst the wound rotor is fed from the Power Electronics Converter via slip rings to allow DIFG to operate at a variety of speeds in response to changing wind speed. Indeed, the basic concept is to interpose a frequency converter between the variable frequency induction generator and fixed frequency grid. The DC capacitor linking stator- and rotor-side converters

allows the storage of power from induction generator for further generation. To achieve full control of grid current, the DC-link voltage must be boosted to a level higher than the amplitude of grid line-to-line voltage.
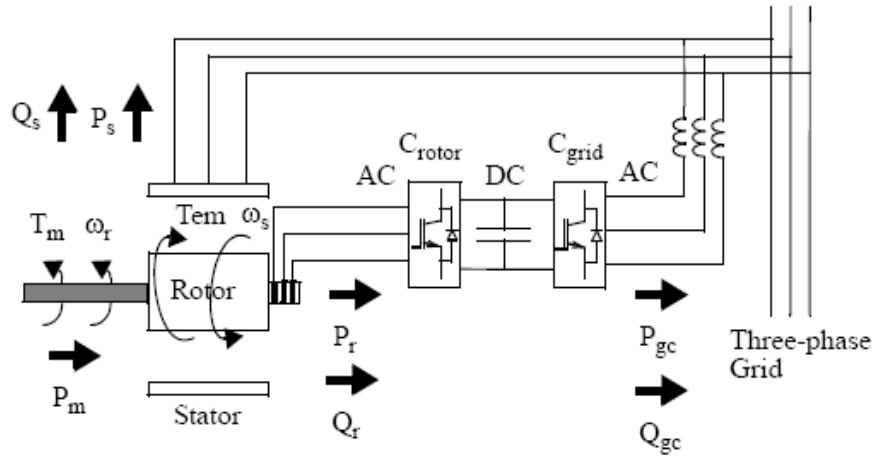

Figure 3.1   DFIG operating principles

The slip power can flow in both directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor- or stator-side converter in both super and sub synchronous speed ranges. As a result, the machine can be controlled as a generator or a motor in both super and sub-synchronous operating modes realizing four operating modes. Below the synchronous speed in the motoring mode and above the synchronous speed in the generating mode, rotor-side converter operates as a rectifier and stator-side converter as an inverter, where slip power is returned to the stator.

Below the synchronous speed in the generating mode and above the synchronous speed in the motoring mode, rotor-side converter operates as an inverter and stator side converter as a rectifier, where slip power is supplied to the rotor. At the synchronous speed, slip power is taken from supply to excite the rotor windings and in this case machine behaves as a synchronous machine.

The mechanical power and the stator electric power output are computed as follows:

$$P_r = T_m * \omega_r \tag{3.1}$$

$$P_s = T_{em} * \omega_s \tag{3.2}$$

For a loss less generator the mechanical equation is:

$$J\frac{d\omega r}{dt} = T_m - T_{em} \tag{3.3}$$

In steady-state at fixed speed for a loss less generator

$$T_m = T_{em} \quad \text{and} \quad P_m = P_s + P_r \tag{3.4}$$

It follow that

$$P_r = P_m - P_s = T_m \, \omega_r - T_{em} \, \omega_s = -sP_S \tag{3.5}$$

Where

$$s = (\omega_S - \omega_r)/\omega_S \tag{3.6}$$

Generally the absolute value of slip is much lower than 1 and, consequently, Pr is only a fraction of Ps. Since Tm is positive for power generation and since ωs is positive and constant for a constant frequency grid voltage, the sign of Pr is a function of the slip sign. Pr is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed). For supersynchronous speed operation, Pr is transmitted to DC bus capacitor and tends to rise the DC voltage.

For sub-synchronous speed operation, Pr is taken out of DC bus capacitor and tends to decrease the DC voltage. Cgrid is used to generate or absorb the power Pgc in order to keep the DC voltage constant. In steady-state for a lossless AC/DC/AC converter Pgc is equal to Pr and the speed of the wind turbine is determined by the power Pr absorbed or generated by Crotor.

The phase-sequence of the AC voltage generated by Crotor is positive for sub-synchronous speed and negative for supersynchronous speed. The frequency of this voltage is equal to the product of the grid frequency and the absolute value of the slip. Crotor and Cgrid have the capability for generating or absorbing reactive power and could be used to control the reactive power or the voltage at the grid terminals.

3.3   AC/DC/AC converter modelling

The back to back PWM converter has two converters, one is connected to rotor side and anotheris connected to grid side. Control by both converters has been discussed here.

3.3.1 Rotor side converter control system

The rotor-side converter is used to control the wind turbine output power and the voltage measured at the grid terminals. The power is controlled in order to follow a pre-defined power-speed characteristic, named tracking characteristic. This characteristic is illustrated by the ABCD curve superimposed to the mechanical power characteristics of the turbine obtained at different wind speeds.
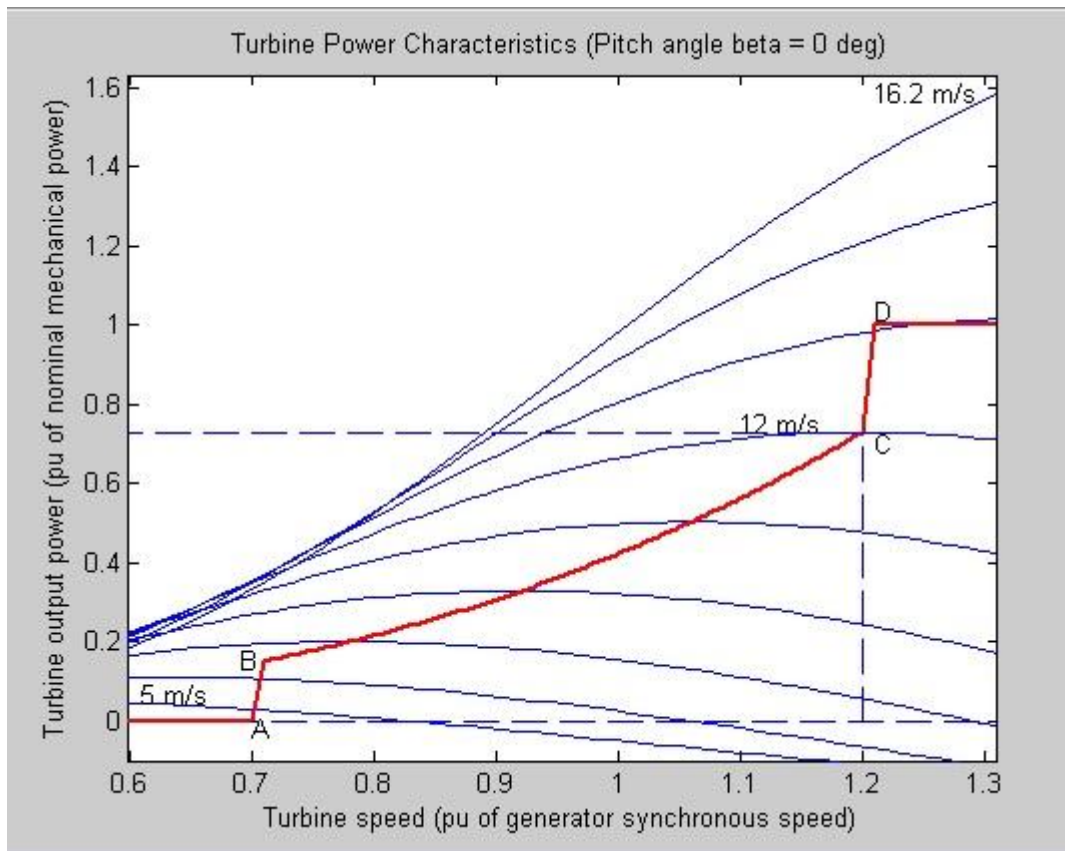

Figure 3.2   Turbine power characteristics

The actual speed of the turbine ωr is measured and the corresponding mechanical power of the tracking characteristic is used as the reference power for the powercontrol loop. The tracking characteristic is defined by four points: A, B, C and D. From zerospeed to speed of point A the reference power is zero. Between point A and point B the tracking characteristic is a straight line.

Between point B and point C the tracking characteristic is the locus of the maximum power of the turbine (maxima of the turbine power vs turbine speed curves). The tracking characteristic is a straight line from point C and point D. The power at point D is one per unit. Beyond point D the reference power is a constant equal to one per unit.
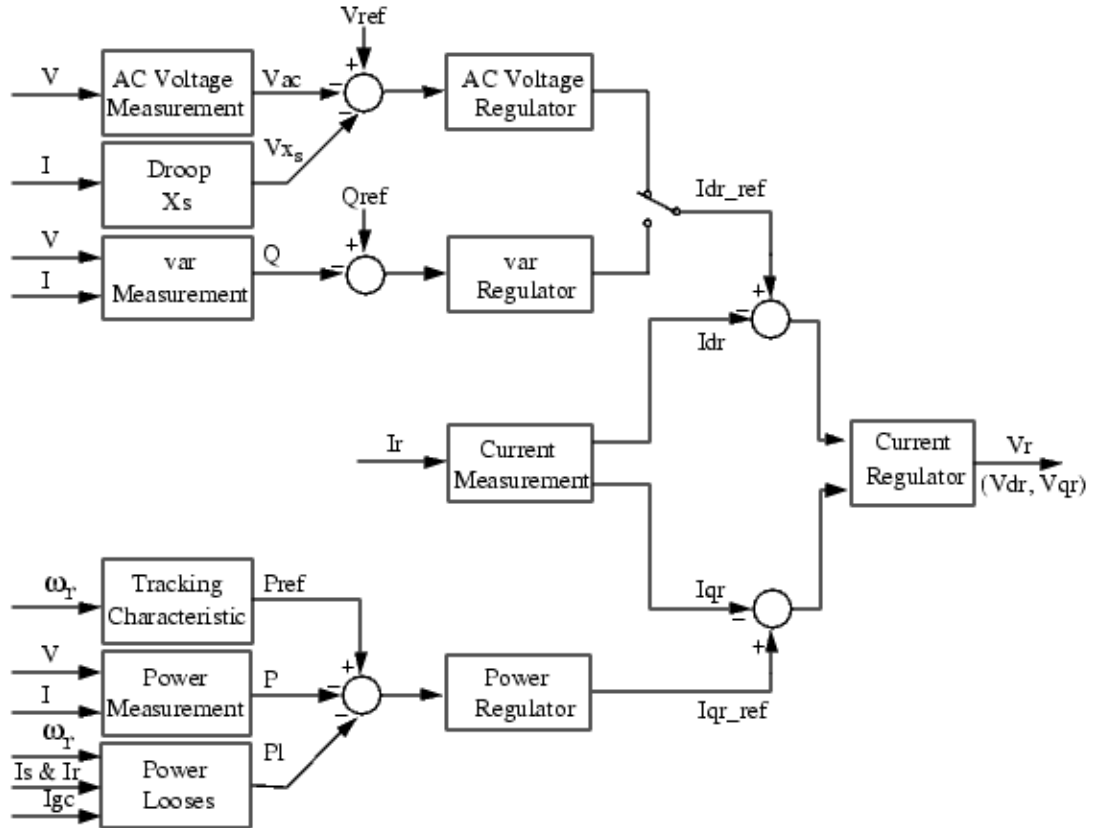

Figure 3.3   rotor side converter control diagram

For the rotor-side controller the d-axis of the rotating reference frame used for d-q transformation is aligned with air-gap flux. The actual electrical output power, measured at the grid terminals of the wind turbine, is added to the total power losses (mechanical and electrical) and is compared with the reference power obtained from the tracking characteristic. A Proportional-Integral (PI) regulator is used to reduce the power error to zero. The output of this regulator is the reference rotor current Iqr_ref that must be injected in the rotor by converter Crotor.

This is the current component that produces the electromagnetic torque Tem. The actual Iqr component is compared to Iqr_ref and the error is reduced to zero by a current regulator (PI). The output of this current controller is the voltage Vqr generated by Crotor. The current regulator is assisted by feed forward terms which predict Vqr. The voltage at grid terminals is controlled by the reactive power generated or absorbed by the converter Crotor. The reactive power is exchanged between Crotor and the grid, through the generator. In the exchange process the generator absorbs reactive power to supply its mutual and leakage inductances. The excess of reactive power is sentto the grid or to Crotor.
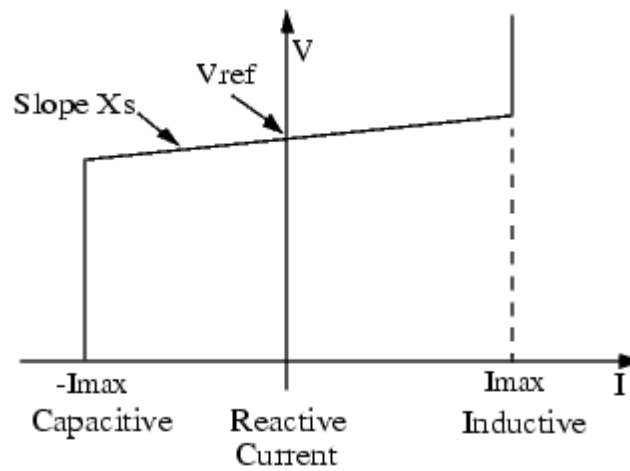
Figure 3.4   V-I characteristic of turbine

The wind turbine control implements the V-I characteristic illustrated in Figure 3.4. As long as the reactive current stays within the maximum current values (-Imax, Imax) imposed by the converter rating, the voltage is regulated at the reference voltage Vref. A voltage droop is used for the V-I characteristic shown in Fig. (3% at maximum reactive power output).

$$V = Vref. + I * Xs \qquad\qquad (3.7)$$

where :

V = Positive sequence voltage (p.u.)

I = Reactive current (p.u./Pnom) (I > 0 indicates an inductive current)

Xs = Slope or droop reactance (p.u./Pnom)

When the wind turbine is operated in var regulation mode the reactive power at grid terminals is kept constant by a var regulator. The output of the voltage regulator or the var regulator is the reference d-axis current Idr_ref that must be injected in the rotor by converter Crotor. The same current regulator as for the power control is used to regulate the actual Idr component of positive-sequence current to its reference value. The output of this regulator is the d-axis voltage Vdr generated by Crotor. The current regulator is assisted by feed forward terms which predict Vdr. Vdr and Vqr are respectively the d-axis and q-axis of the voltage Vr.

3.3.2 Grid side converter control system

The grid side converter is used to regulate the voltage of the DC bus capacitor. For the grid-side controller the d-axis of the rotating reference frame used for d-q transformation is aligned with the positive sequence of grid voltage. This controller consists of:
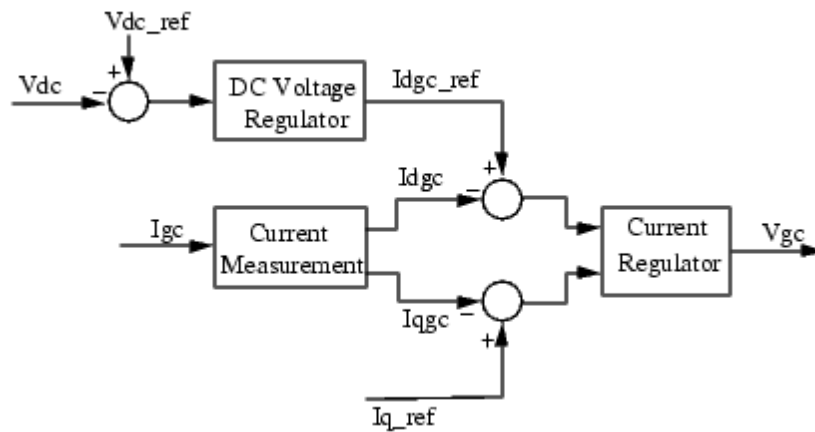
Figure 3.5   Grid side converter control system

1. A measurement system measuring the d and q components of AC currents to be controlled as well as the DC voltage Vdc.

2. An outer regulation loop consisting of a DC voltage Regulator.

3. An inner current regulation loop consisting of a current Regulator.

The current regulator controls the magnitude and phase of the voltage generated by converter Cgrid (Vgc) from the Idgc_ref produced by the DC voltage regulator and specified Iq_ref reference. The current regulator is assisted by feed forward terms which predict the Cgrid output voltage.

CHAPTER 4

RESULT AND DISCUSSION

4.1   Introduction

This chapter will discuss on the result that obtain from the MATLAB modeling and the description of the DFIG and control system.
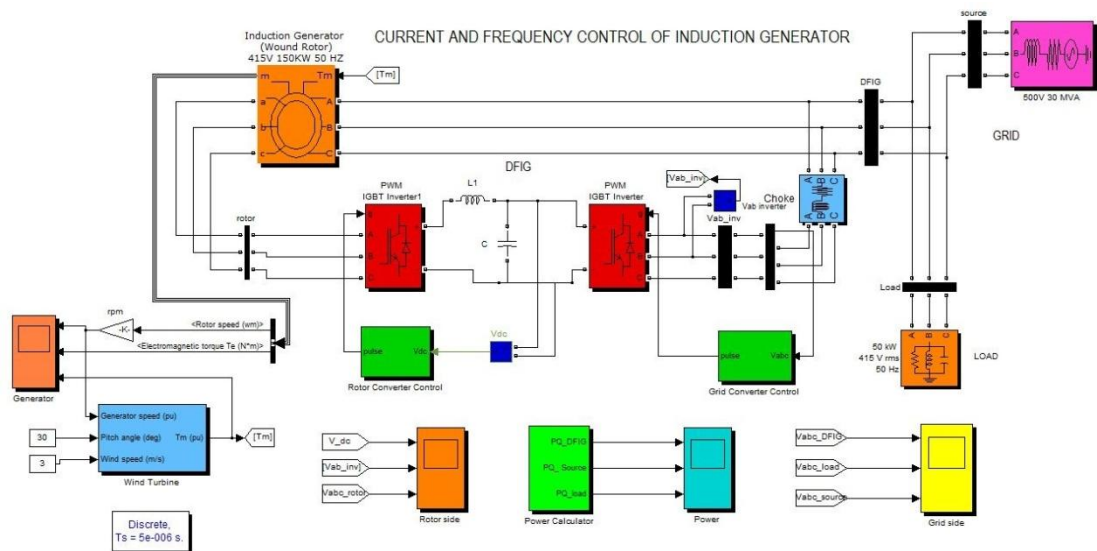
Figure 4.1   DFIG modeling in MATLAB

4.2   MATLAB modeling

MATLAB modeling is one of the result that obtain from this project. This part will explain about the model and the parameter use in this simulation.

4.2.1   Induction Generator

This Induction generator block is taken from machine library in simpower system library. Its can operates in either generator or motor mode. The mode of operation is dictated by the sign of the mechanical torque:

- If Tm is positive, the machine acts as a motor.

- If Tm is negative, the machine acts as a generator.

The electrical part of the machine is represented by a fourth-order state-space model and the mechanical part by a second-order system. All electrical variables and parameters are referred to the stator.. All stator and rotor quantities are in the arbitrary two-axis reference frame (dq frame). Figure 4.2 show the block mask and Figure 4.3 show the parameter of the block.
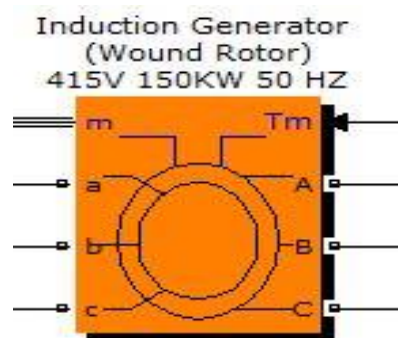
Figure 4.2   Induction generator block

Table 4.1   Induction Generator parameter

Nominal Power (kVA)	150
Voltage (V)	415
Frequency (Hz)	50
Stator resistance Rs (ohm)	0.01818
Stator inductance Ls (H)	0.00019
Rotor resistance Rr (ohm)	0.09956
Rotor Inductance Lr (H)	0.00019
Mutual Inductance Lm (H)	0.009415
Inertia (Kg.m^2)	2.6
Friction Factor (Nms)	0.04789
Pole	4

4.2.2   AC/DC/AC converter

Figure 4.3 show the AC/DC/AC converter with reactance and capacitor that act as the DC link for the system. The converter is also taken from simpower system library in MATLAB that use IGBT as the switching device. The Universal Bridge block implements a universal three-phase power converter that consists of up to six power switches connected in a bridge configuration. The type of power switch and converter configuration are selectable from the dialog box. Figure 4.3 show the converter parameter that calculate using this formula:

$$R_S > 2 \frac{T_S}{C_S} \qquad (4.1)$$

$$C_S < \frac{P_n}{1000\ (2\pi f)V_n^2} \qquad (4.2)$$
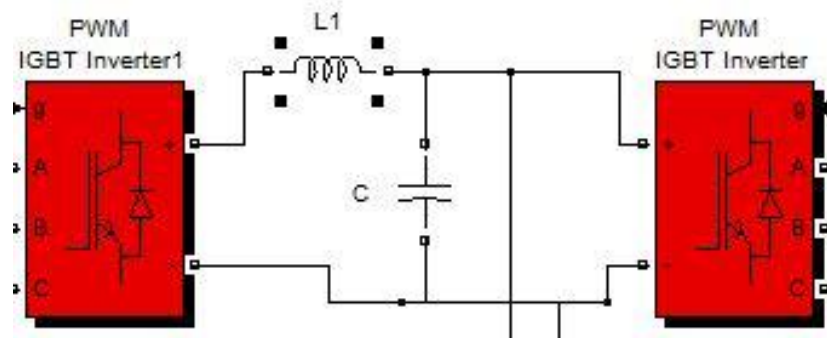
Figure 4.3   AC/DC/AC converter design

Table 4.2   Converter parameter

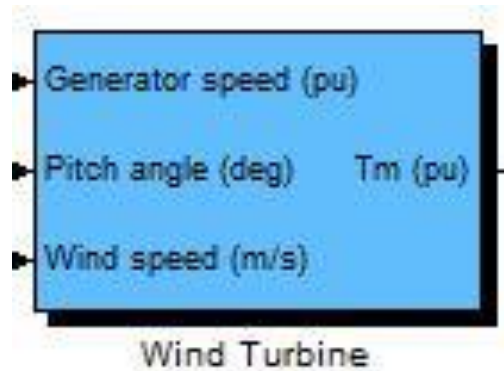| No. of bridge arm	3
Snubber resistance Rs (ohm)	1.44283 Gohm
Snubber capacitance Cs (F)	2.7723 nF
Power electronics device	IGBT

4.2.3 Wind Turbine

Figure 4.4   Wind turbine block

Figure 4.4 show wind turbine block where the   model is based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine. The output power of the turbine is given by the following equation.

$$P_m = c_p\ (\lambda, \beta)\frac{\rho A}{2}v^2 wind \tag{4.3}$$

where

P_m Mechanical output power of the turbine (W)

c_p Performance coefficient of the turbine

ρ Air density (kg/m^3)

A   Turbine swept area (m^2)

v_{wind} Wind speed (m/s)

λ Tip speed ratio of the rotor blade tip speed to wind speed

β Blade pitch angle (deg)

Table 4.3   Wind turbine block parameter

Mechanical Output power (W)	100 K
Base power of electrical generator (VA)	100 K
Base wind speed (m/s)	3

4.2.4   Grid system
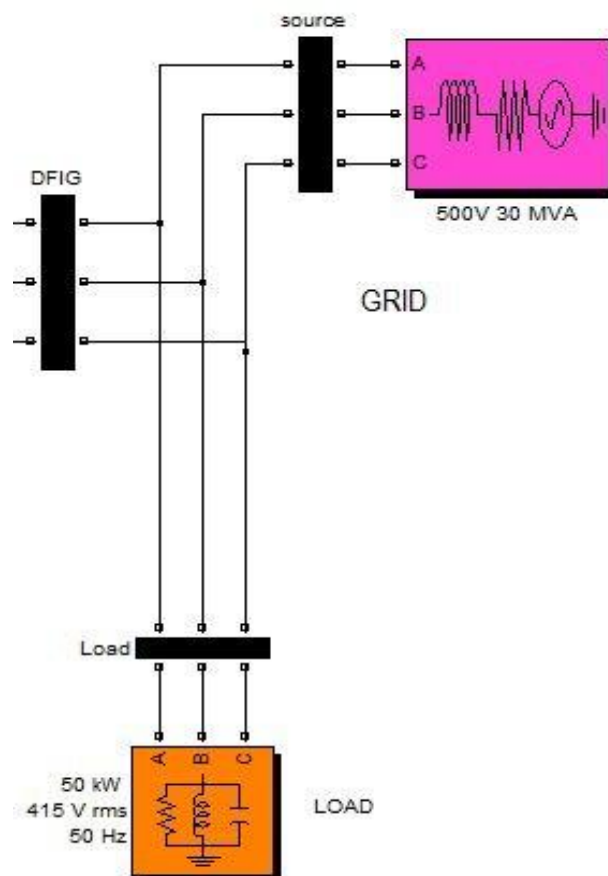
Figure 4.5   Grid system design

Figure 4.5 show the grid system that use in this simulation, the grid consists of a source and a load that represent the low voltgae side or at the main substation after the transformer step down the voltage from 11kV to 415 V, 3 phase. This figure also show how the DFIG connected to grid. The DFIG is connected between the source and load, where the power will directly supply to consumer.

4.2.5 Converter control system

The converter control system is seperated into two main part, rotor side and grid side converter where the rotor side converter control system is shown in Figure 4.6 and the grid side converter control system is shown in Figure 4.7.
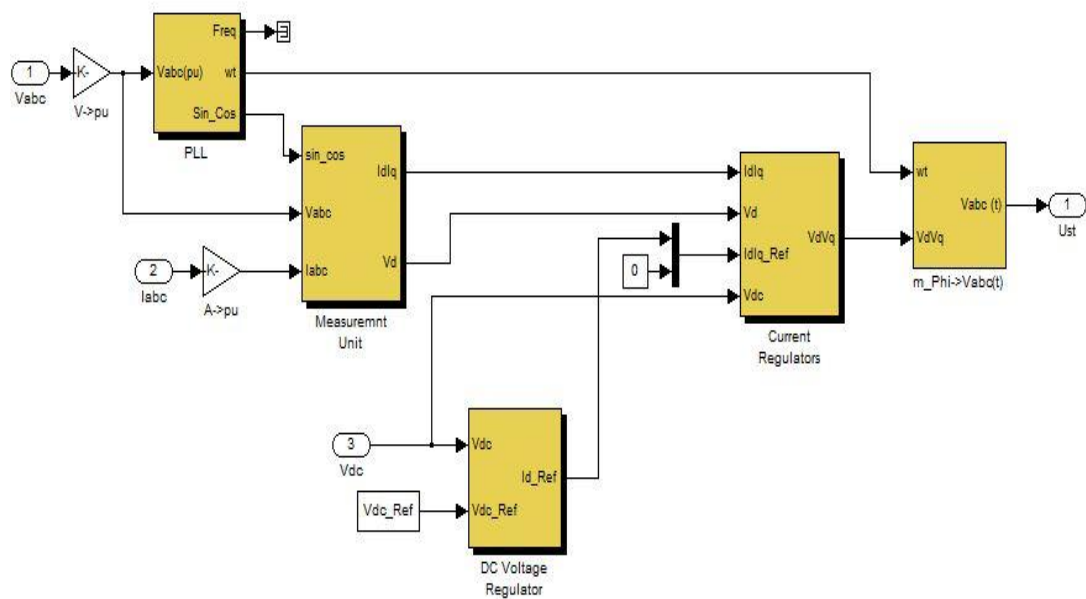
Figure 4.6   MATLAB rotor side converter control system

The rotor side converter control system is function to control the current at the generator rotor and at the same time regulate the DC voltage to make sure it stay constant. The Phase-Locked Loop (PLL) block is a feedback control system

that automatically adjusts the phase of a locally generated signal to match the phase of an input signal. This block is most appropriate when the input is a narrowband signal. Measurement unit block is use to perform Park transformation from three-phase (abc) reference frame to dq0 reference frame part while the current regulator take the data from measurement unit and DC voltage regulator to control the current at the rotor side.
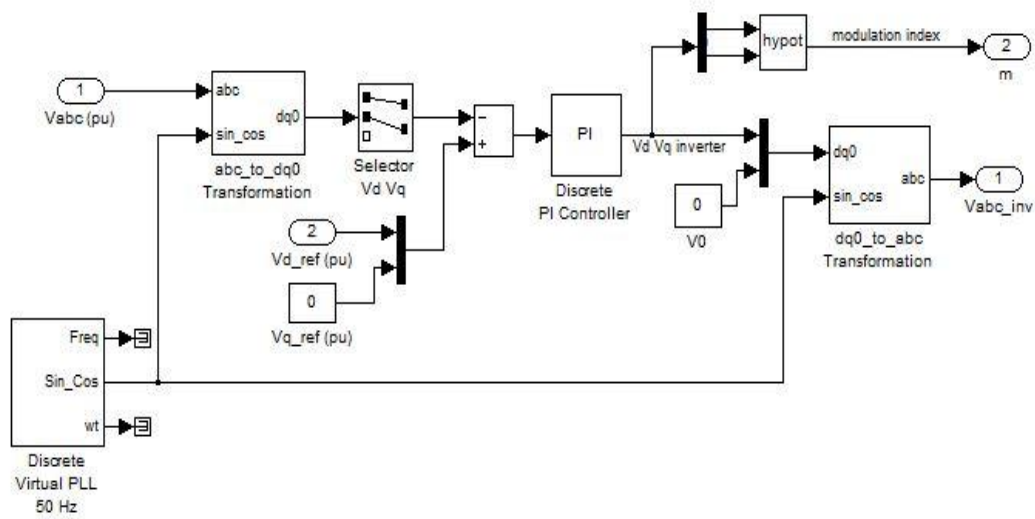

Figure 4.7   MATLAB grid side converter control system

The grid side is function to control the frequency at the grid.So, the load voltage is regulated at 1 pu (415 V rms) by a PI voltage regulator using abc_to_dq and dq_to_abc transfomations. The first output of the voltage regulator is a vector containing the three modulating signals used by the PMW Generator to generate the 6 IGBT pulses. The second output returns the modulation index.

4.3   Analysis result for and discussion constant wind speed

The first simulation of this design is using constant wind speed. This simulation will show the generator data, converter data, power data and voltage data during the simulation.Wind speed that use in this simulation is 3m/s (Figure 4.8) that represent the average wind speed at UMP Pekan that have been measured by weather station..
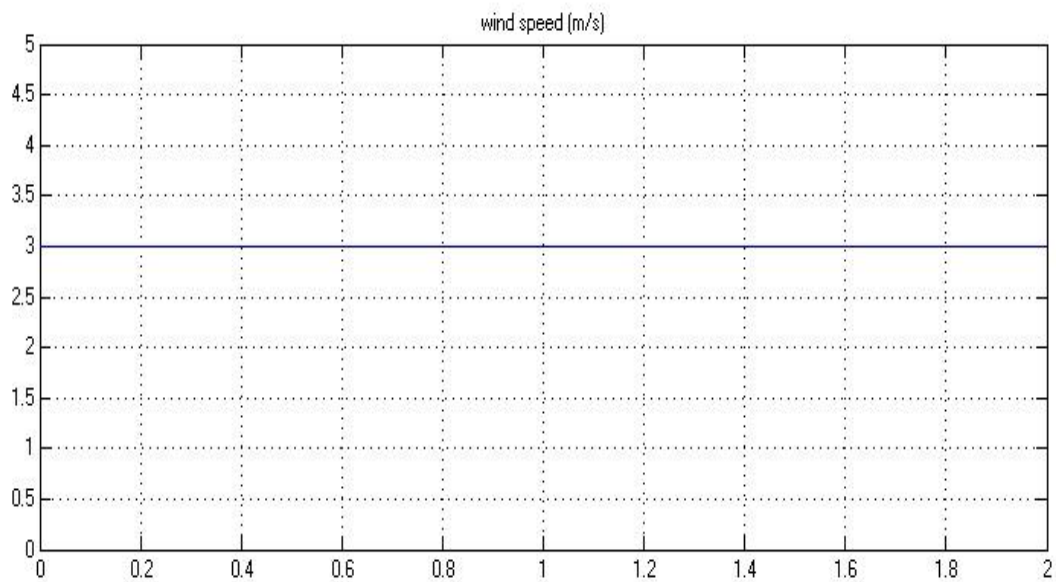
Figure 4.8   Wind speed data for constant wind speed

The first data is take from the induction generator that measure the rotor speed, electromagnetic torque and mechanical torque (Tm).Figure 4.9 show the induction generator data for constant wind speed for 0 to 2 second.
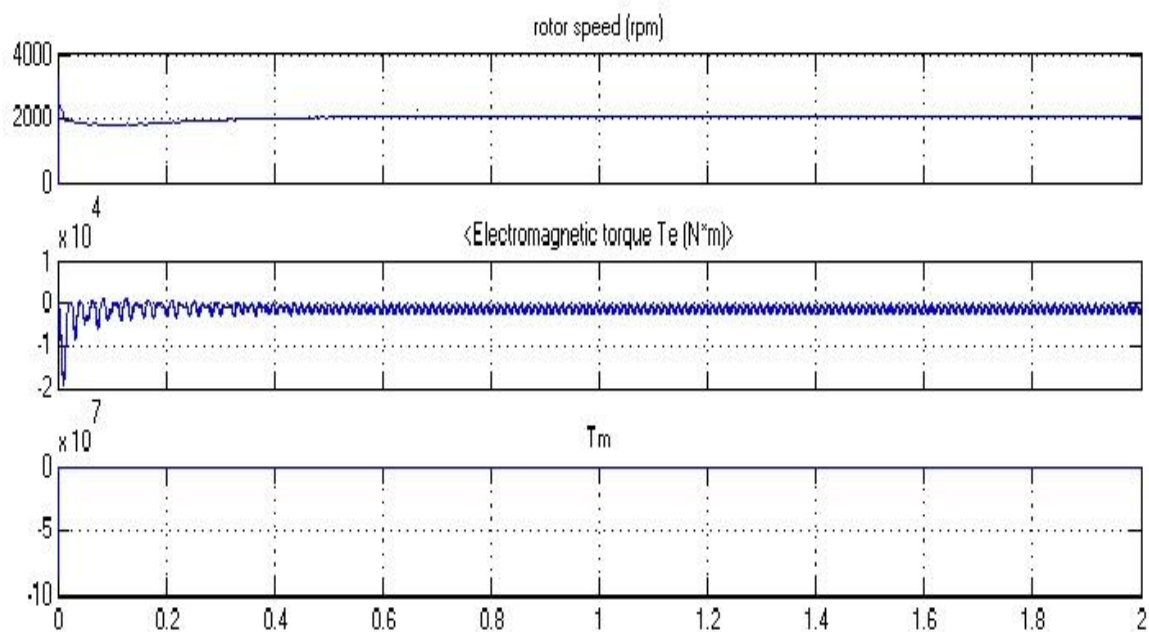
Figure 4.9   Induction generator data for constant wind speed
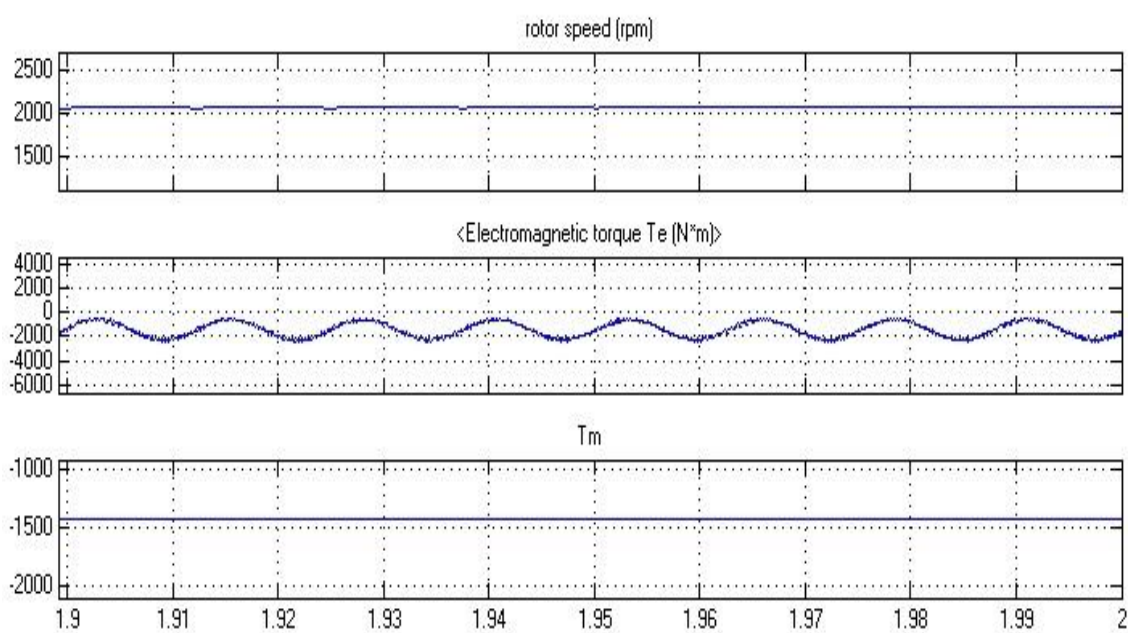
Figure 4.10   Induction generator detailed data for constant wind speed

Figure 4.10 show the detailed data of the induction after the system stable. From the graph, rotor speed is 2000 rpm that is 130% of the synchronous speed that prove this machine is in generator mode[10]. The other two data also show that this machine is in generator mode because electromagnetic torque and mechanical torque must be negative to make this block become generator. The equation below show the synchronous speed calculation:

$$n_{sync} = \frac{120}{P} f_e \tag{4.4}$$

$$\frac{120 \ (50 \ Hz)}{4 \ poles} = 1500 \ \text{rpm} \tag{4.5}$$

$$\frac{2000}{1500} \ \text{X} \ 100\% = 133.33 \ \% \tag{4.6}$$
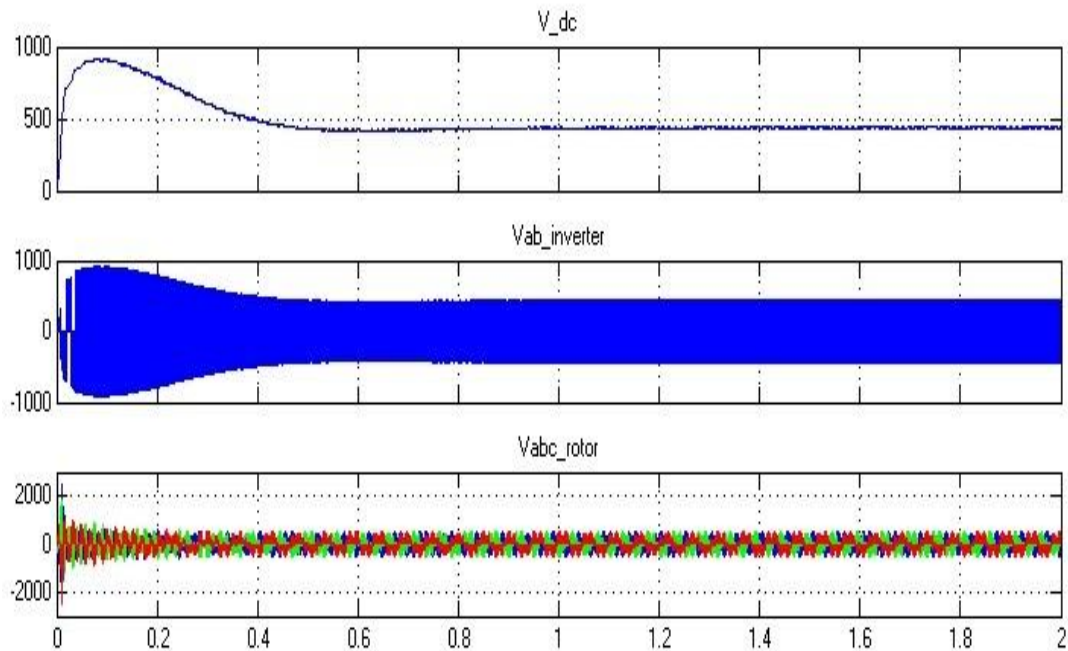
Figure 4.11   Converter and rotor data for constant wind speed

Figure 4.11 show the converter and rotor voltage that measure at DC link, inverter and rotor to analyze the data at that point. Figure 4.12 show the detailed view of the data.
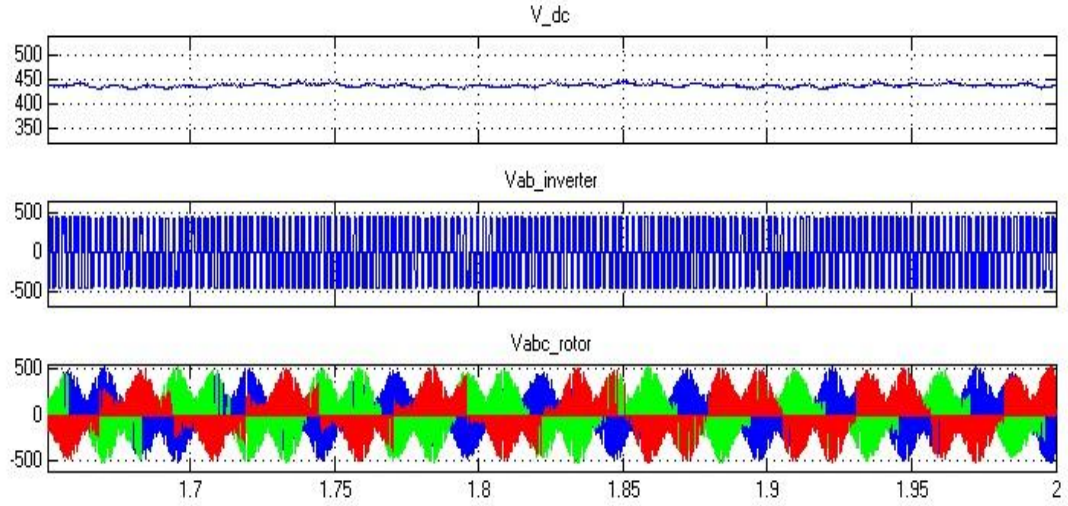
Figure 4.12   Converter and rotor detailed data for constant wind speed

From the figure, we can see that the the rotor voltage is sinusodial and than convert to DC by rectifier and become volatge at Vdc.[11] The Vdc is remain constant that show the system is stable and Vab inverter show that voltage at the inverter that change the DC voltage at DC link to AC before smoothing by filter. The output of DFIG we can see at Figure 4.13 that also show the voltage measure at source (grid) and load.
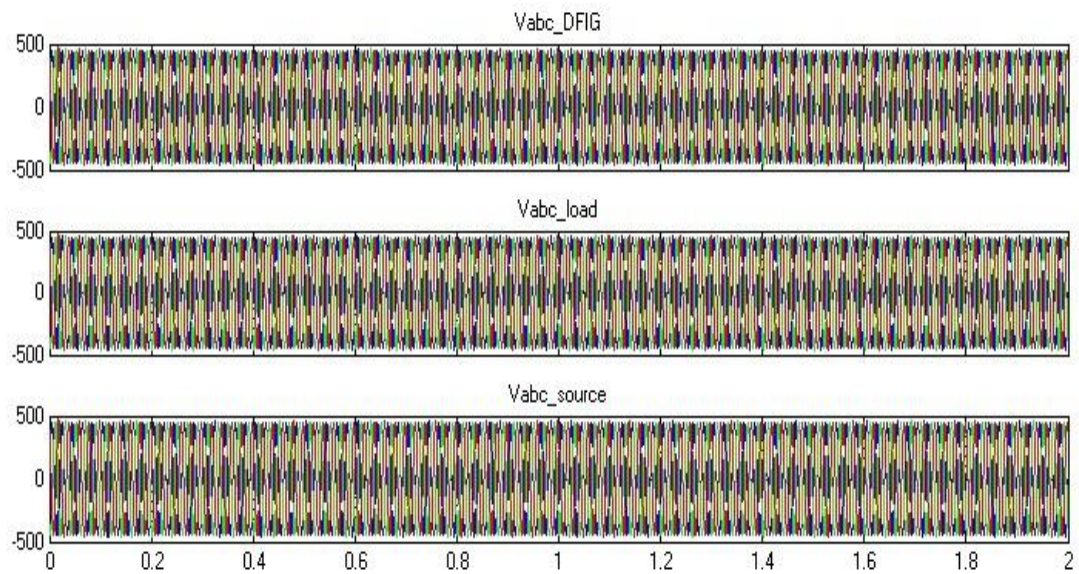

Figure 4.13   Voltage data for constant wind speed

Figure 4.14 show the detailed view of the voltage at the three point. The graph show that the voltage is same at all the point, that is 3 phase 415 V.This prove that this design is sucessfully connected to grid and synchronize with the grid voltage and work succesfully.
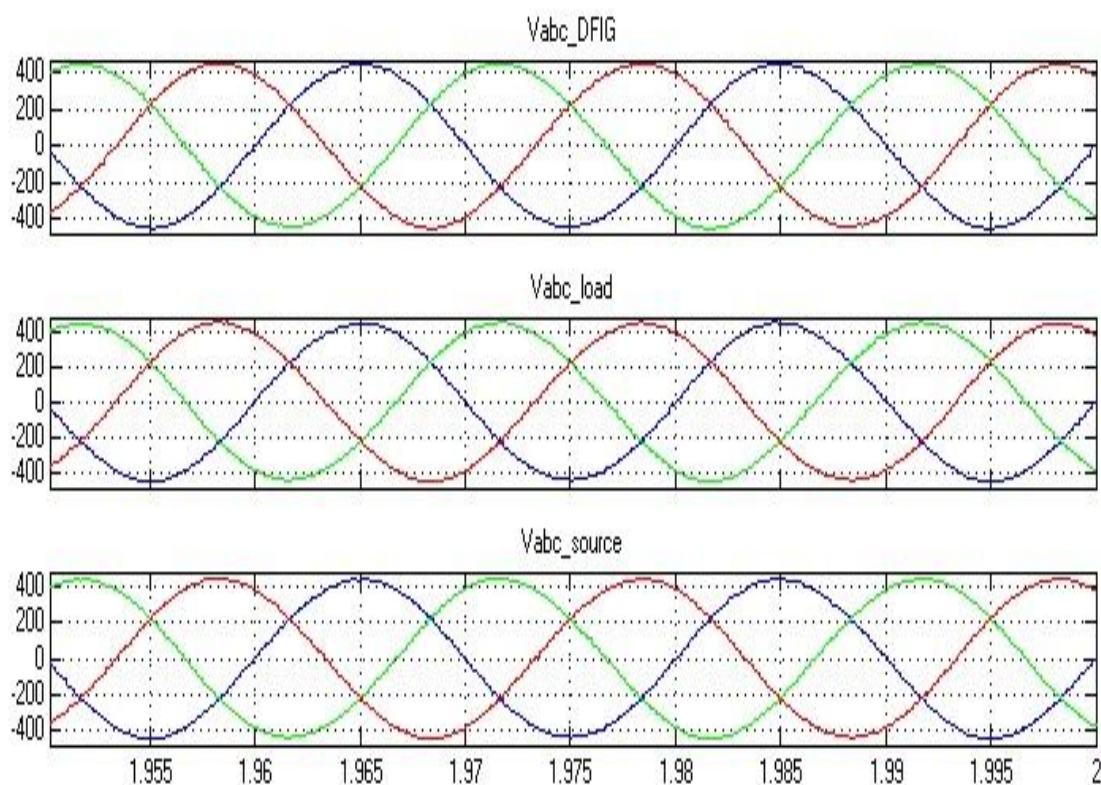
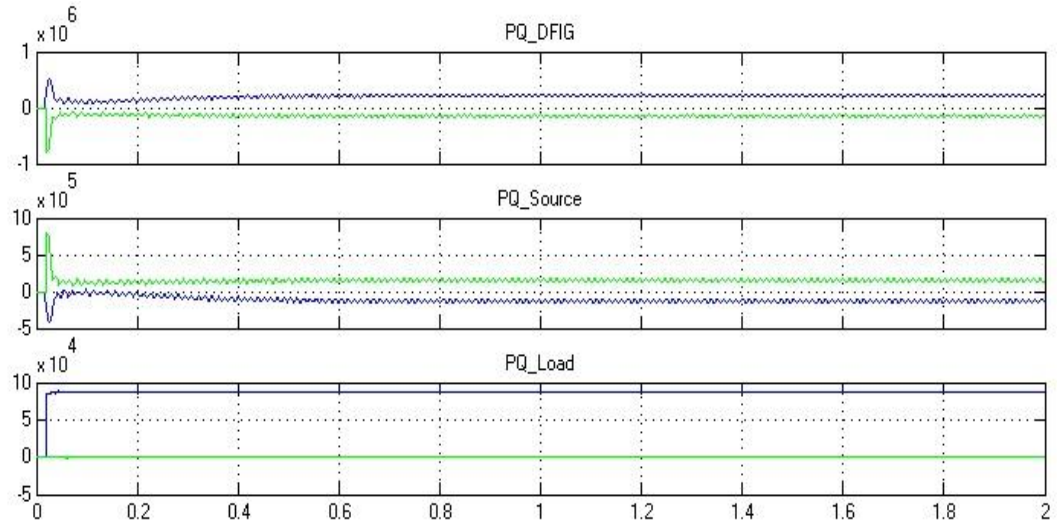**Figure 4.14**   Detailed voltage data for constant wind speed

Figure 4.15   Output power data for constant wind speed

The last part of this analysis is about the power that DFIG supply to the grid and load. As discussed on previous chapter, DFIG can absorb power and supply power to the grid, Figure 4.15 show the power of DFIG, source (grid) and load. The detailed view on Figure 4.16 show that the active power of DFIG (blue) is about 250 kW, the active power of source is -170 kW. It show that DFIG is transfered to the grid. The active power at load is about 80 kW. So, 250 kW minus 170 kW we get 80 kW more, it was use by the load. So, the balance of the power can use as the standy to the grid when load increase.
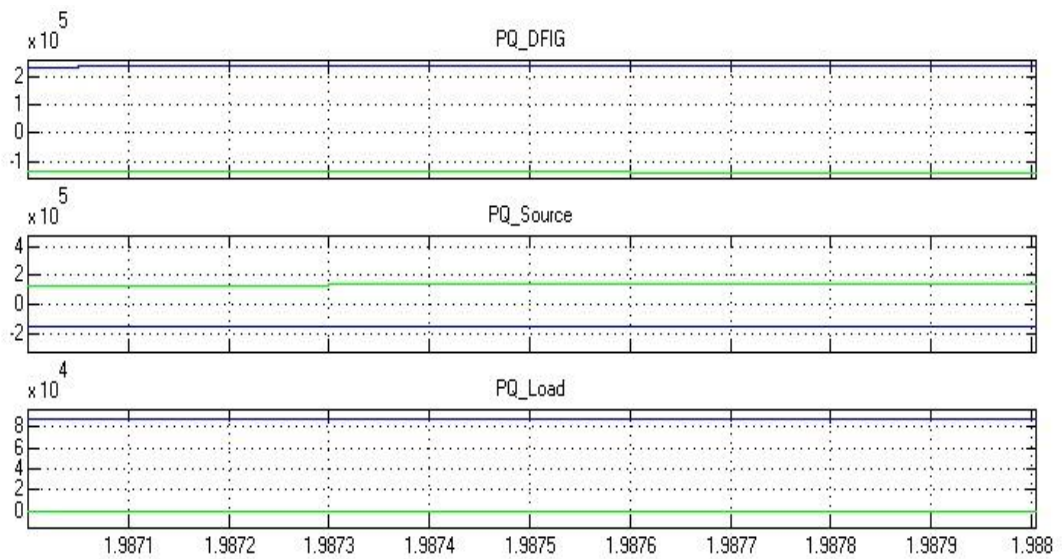
Figure 4.16   Output Power detailed data for constant wind speed
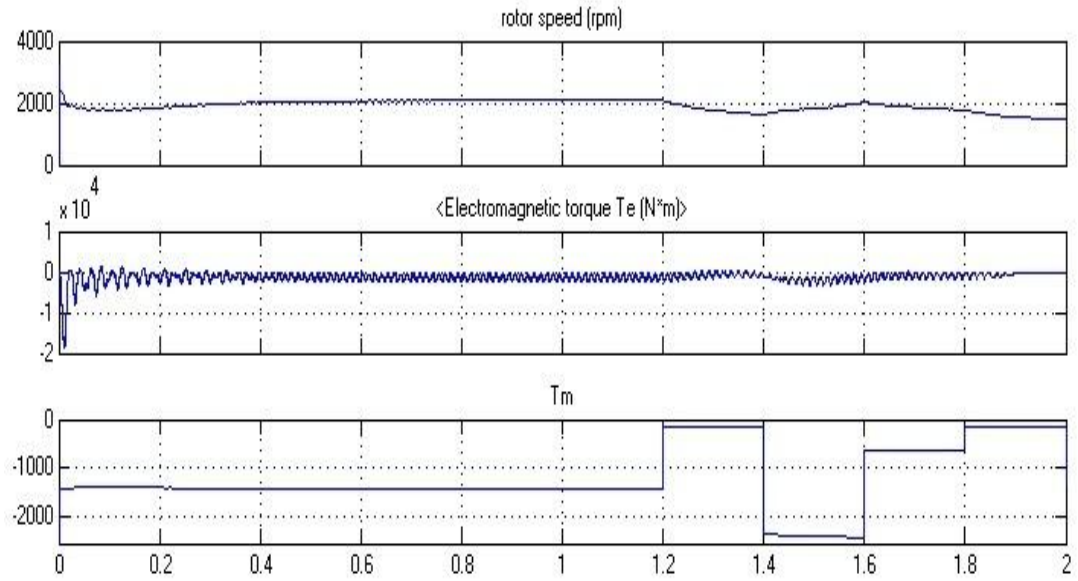
Figure 4.18   Generator data for variable wind speed

Figure 4.19 show the data at the converter that also change when speed change. Vdc show the change when the wind speed start to drop at 1 second and try to rise back at 1.4 second and decrease down to zero lastly. Vab inverter and Vabc rotor also show the same behavior. But this change will not effect the voltage that supply to the grid.
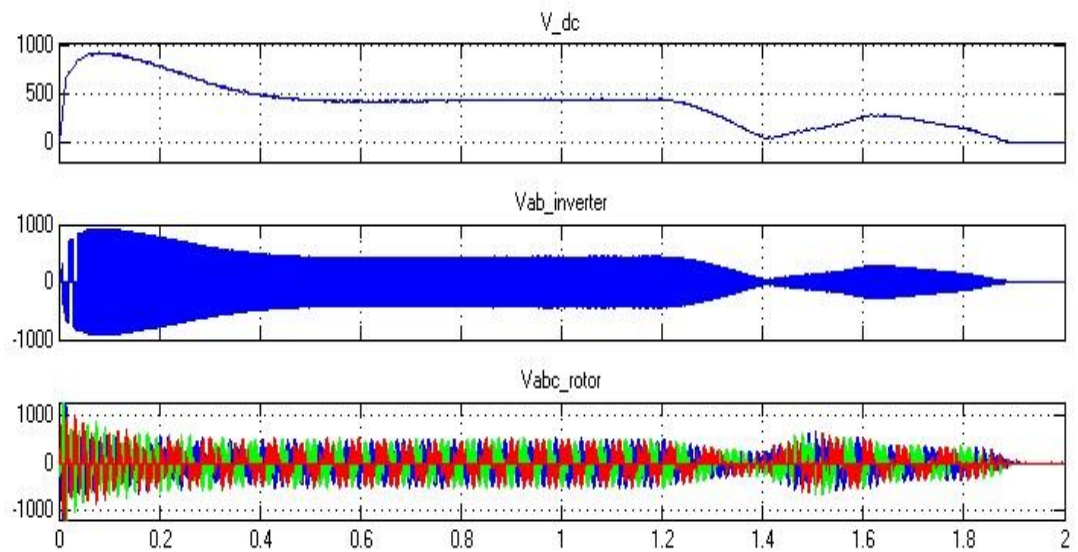

Figure 4.19   Converter and rotor data for variable wind speed

Figure 4.20 show that the voltage supply to the grid is not interupted even though other component is distrub by the wind speed. This show that the controller at the grid side converter is function effectively to stabilize the voltage that supply to the grid.
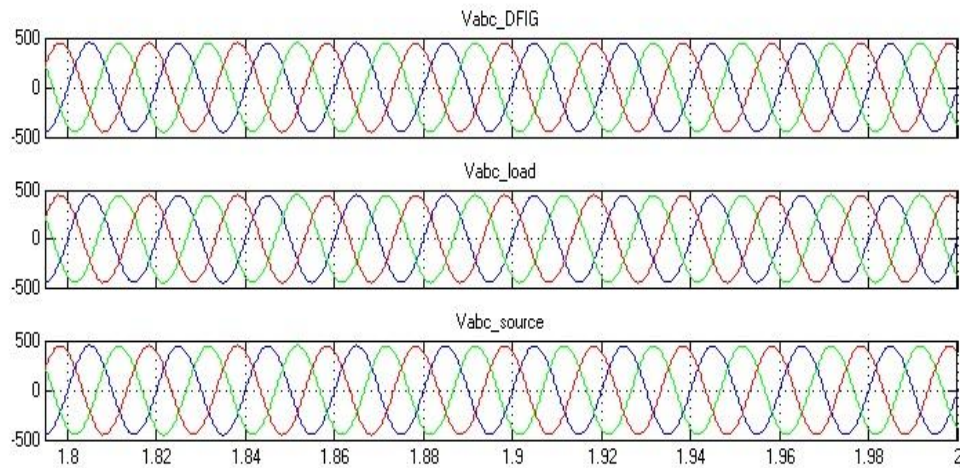

Figure 4.20   Voltage data for variable wind speed

Lastly the analysis at active power at DFIG, source and load. As shown in Figure 4.21, the active power of DFIG is decrease and down to zero at 2 second but at the same time, power from grid cover the problem as rise gradually to make sure the power at load is not interupted. It show that this system is suitable for variable wind speed becuase the load (consumer) will not have any interuption when wind speed change.
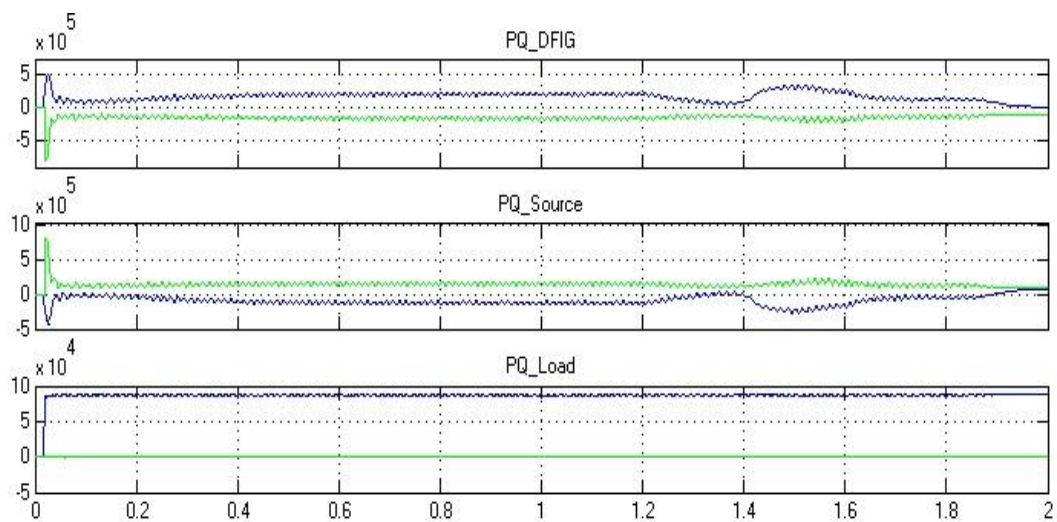

Figure 4.21   Output power data for variables wind speed

4.5   Analysis result and discussion for variable load

For variable load analysis, the wind speed is kept constant but the load change at 1 second from 90 kW to 180 kw. Figure 4.22 show the wind data.
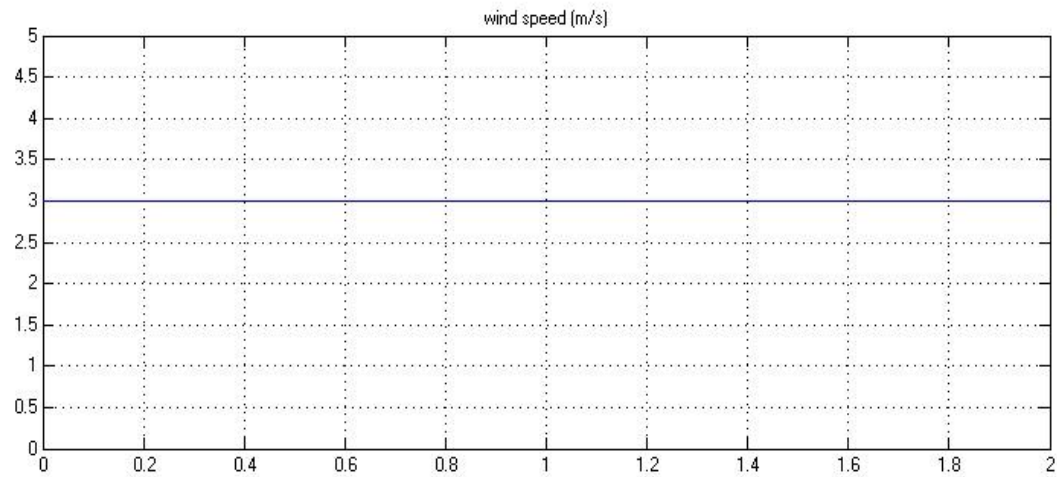

Figure 4.22   Wind speed data for variable load

Figure 4.23 show the generator data, it show that the generator is not effected when load change. DFIG will keep working as usual an the generator speed remain at 2000 rpm to make sure this system will supply the power to grid contineuosly.
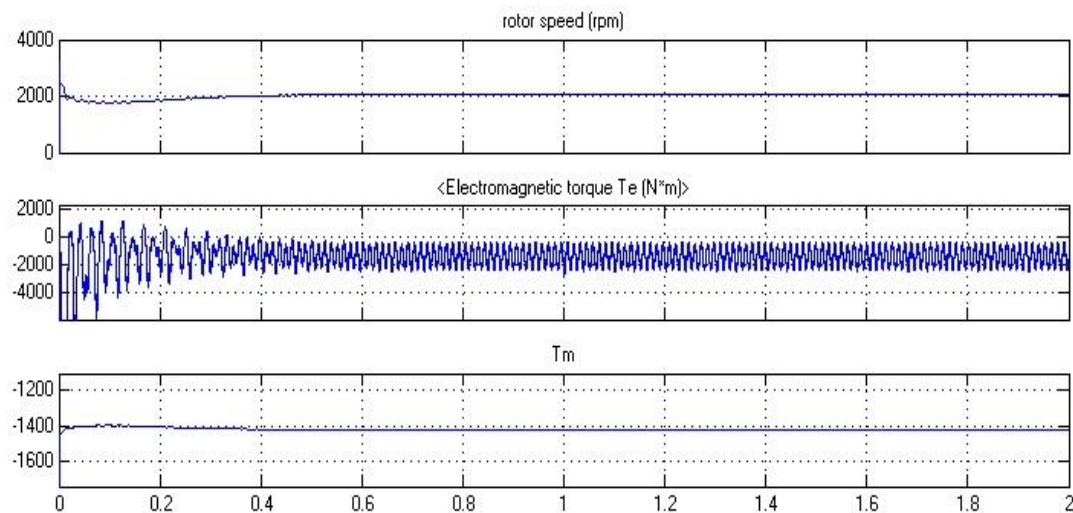

Figure 4.23   Induction generator data for variable load

Figure 4.24 shows the data at the converter that also not change when the load change. The Vdc is kept constant and other to signal have the same behavior. This show that the load change is not effect the DFIG.
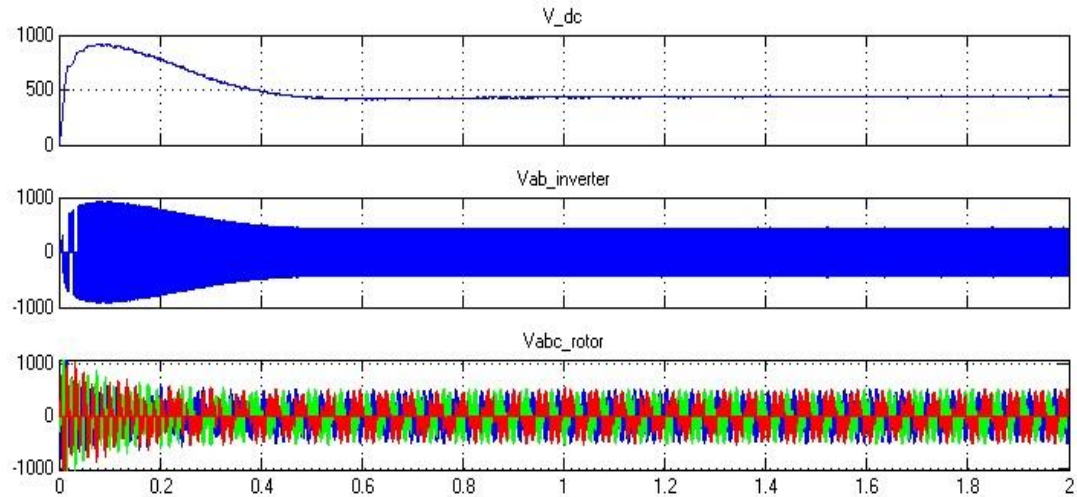

Figure 4.24   Converter and rotor data for variable load

Figure 4.25 show the voltage variation at DFIG, source and load. From the graph we can see some disturbance at one phase (green) of the voltage. This happen because of the swithcinf of the load from 90 kW to 180 kW. But, the disturbance is not danger or interupt the consumer because it just happen for 0.015 second.
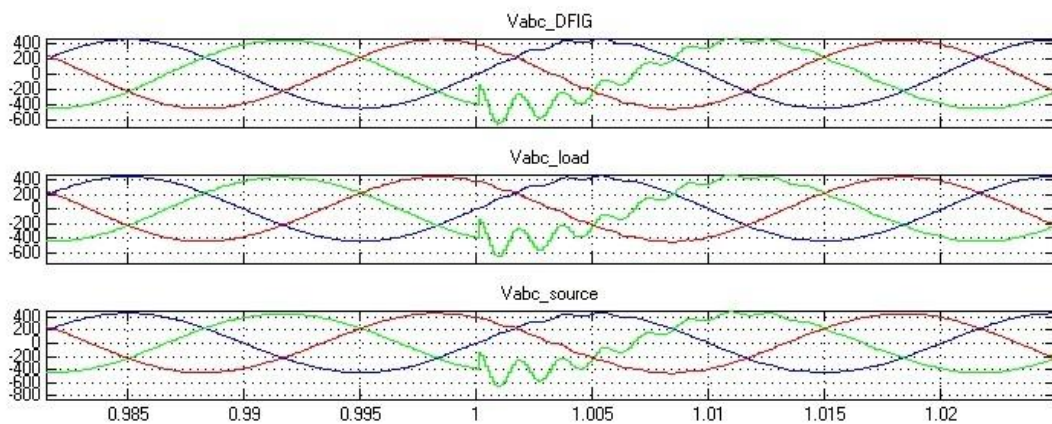

Figure 4.25   Voltage data for variable load

Figure 4.26 show the active power at DFIG, source and load. The figure show that the active power of DFIG is remain constant while the active power of source are increase. This happen because the grid supply the power to the load when the load increasing without disturb the power of DFIG.[12] It show that when load change or increase, the power of DFIG will not change because the grid power is larger then from DFIG and will supply the load demand.
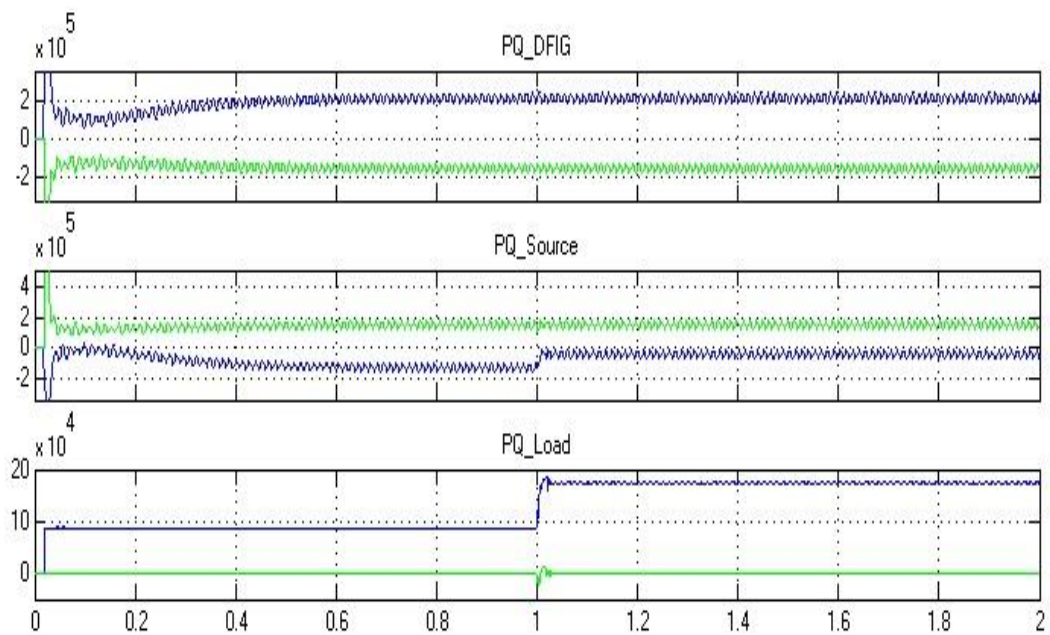

Figure 4.26   Output power data for variable load

CHAPTER 5

CONCLUSION AND RECOMENDATION

5.1   Conclusion

We have discussed here the basic operation of DFIG and it's controls using AC/DC/AC converter. First we simulated with constant wind speed and after that with variable wind speed and lastly with variable load, the DFIG system that used which is connected to grid side and has good control. The rotor side converter (RSC) usually provides active and reactive power control of the machine while the grid-side converter (GSC) keeps the voltage of the DC-link constant. The DFIG is able to provide a considerable contribution to grid voltage support during short circuit periods. Considering the results it can be said that doubly fed induction generator proved to be more reliable and stable system when connected to grid side with the proper converter control systems.

5.2   Problem Encontered

There are a few problem encountered during completing this project and have been solve in order to finish this project successfully. The first problem is about the MATLAB software that I never use before. But this software is no so hard to use and after attend a class for understanding MATLAB, the problem have been solve.

The second problem is to find the suitable and right equation to make DFIG in MATLAB. This problem is resolve by find and make some homework from paper at IEEE website and some book about wind turbine and DFIG.

Lastly is the problem ecountered in designing DFIG in MATLAB because I dont realy understand the blockset and the connection between the block. After seeing my supervisor and help from friend, this problem also have been resolve.

5.3   Recomendation

For future study about this project, we must use another software in order to compare the result of this system. Using another software, we can see where is the weakness of MATLAB and can have a better result when using two software.
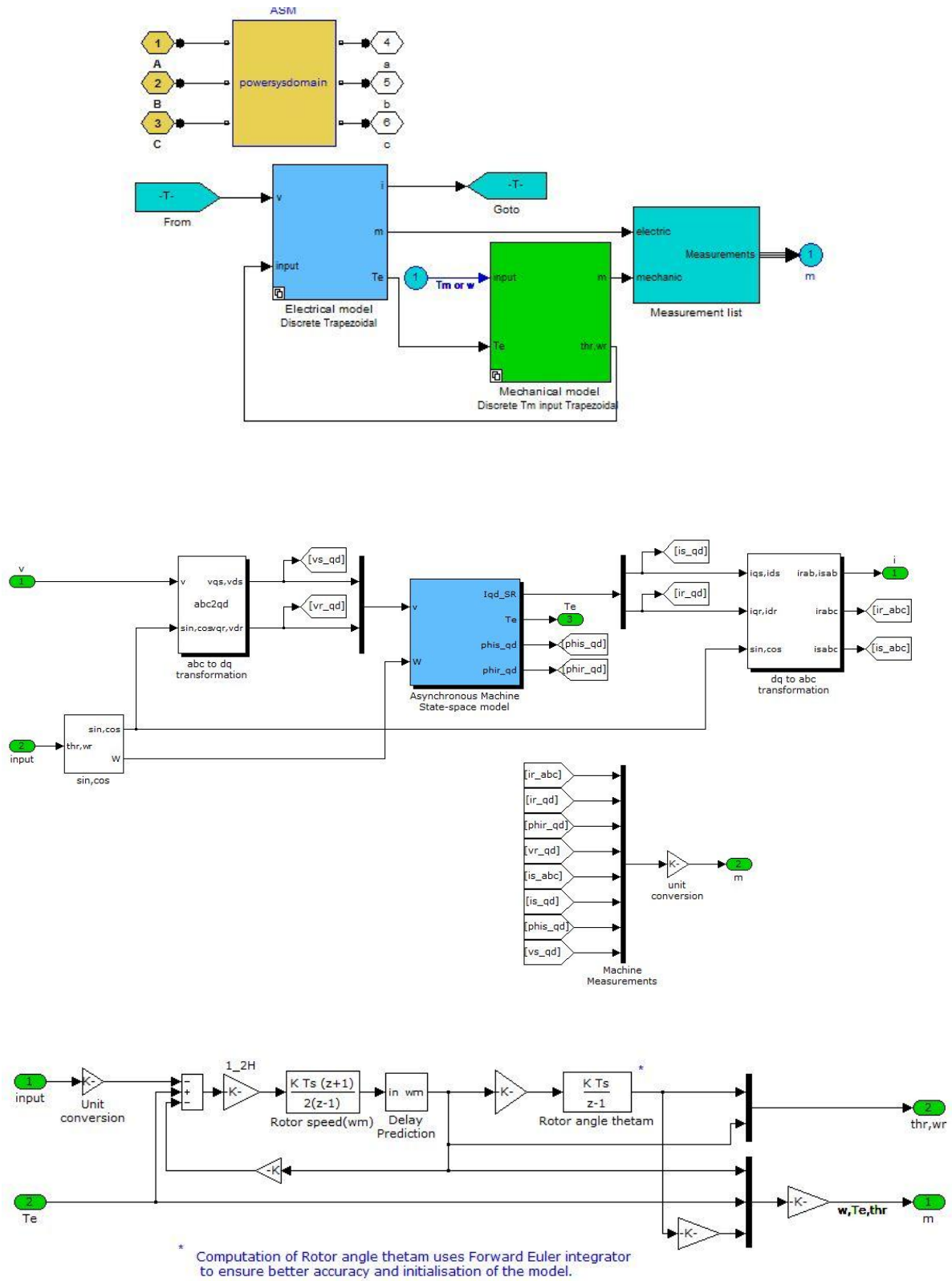
I aslo suggest this project must be also analyze using hardware. Design a small DFIG system and connected to grid to test the AC/DC/AC converter and other component in real time. This method also can give a better result for future study about this project.
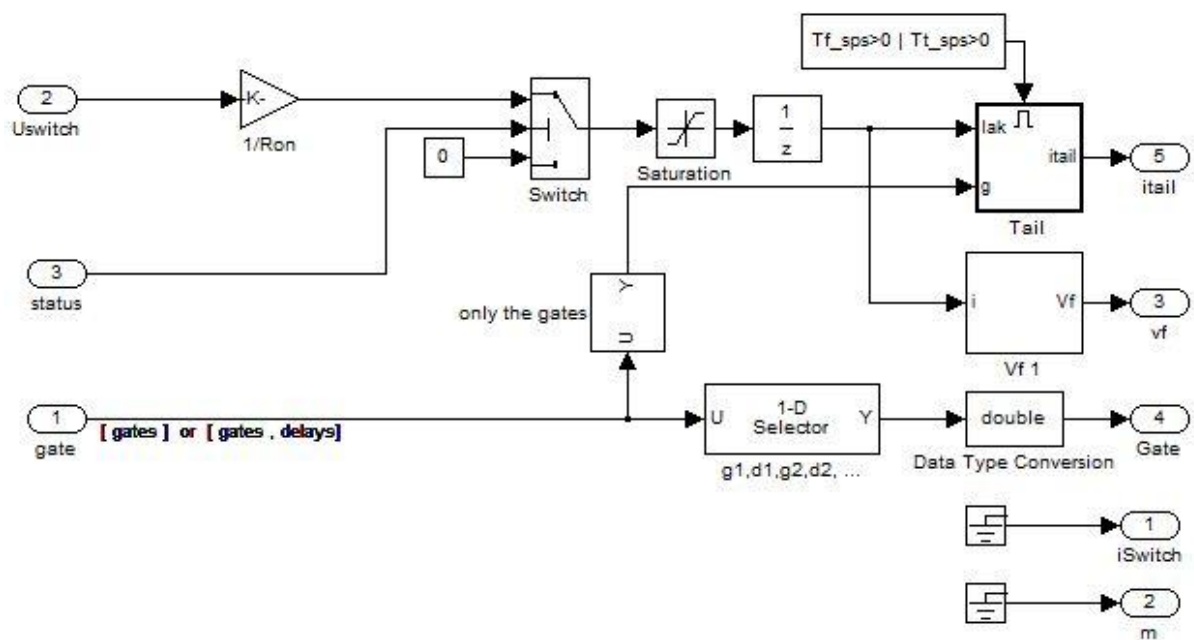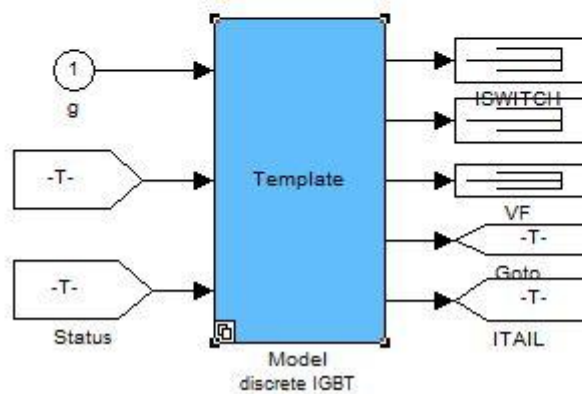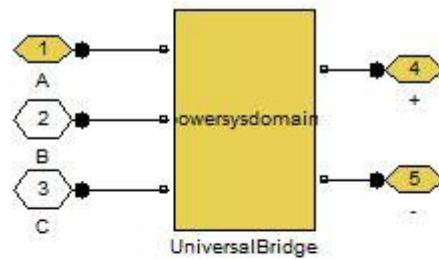
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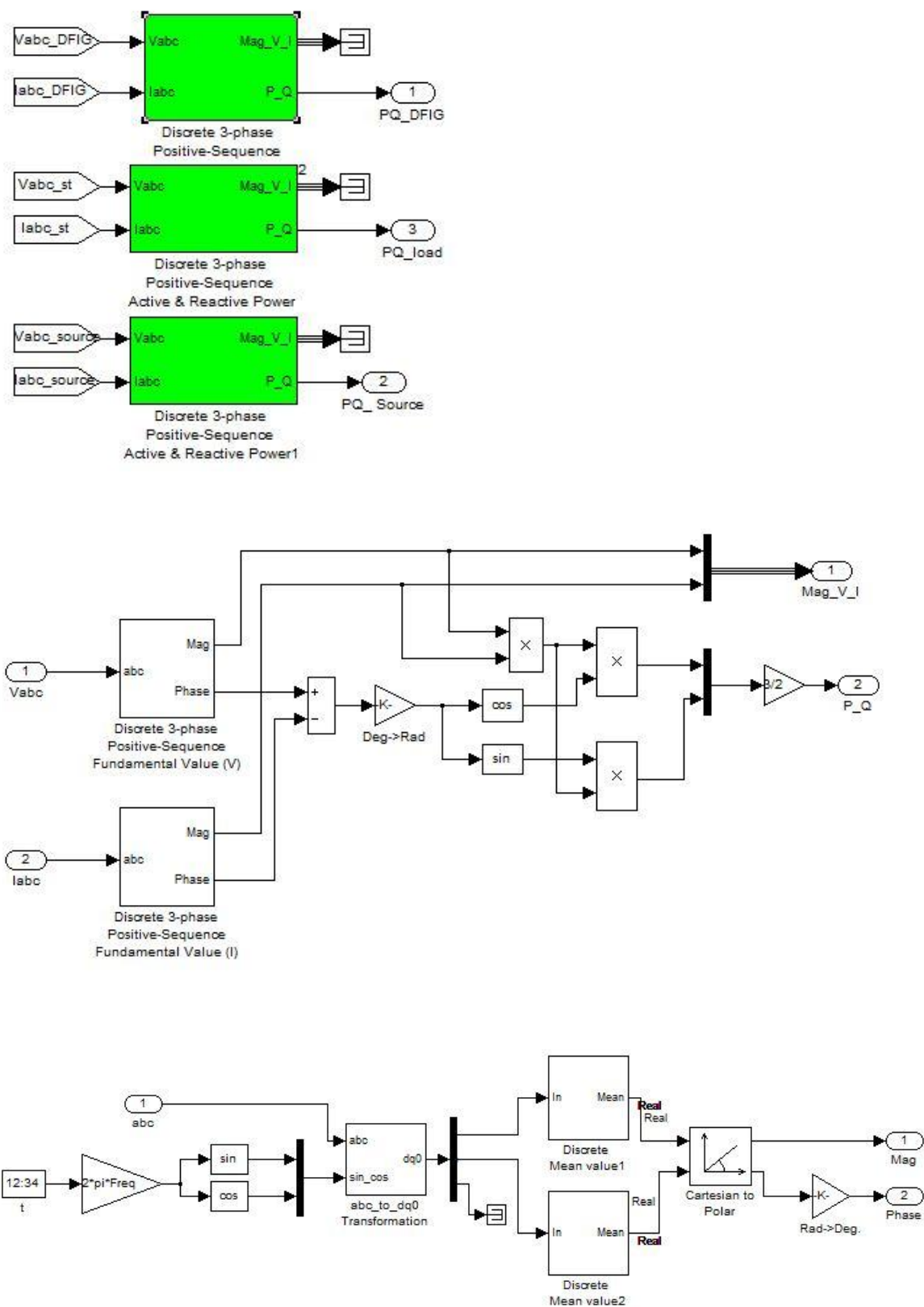
APPENDIX A – INDUCTION GENERATOR BLOCK DIAGRAM (BEHIND MASK)

* Computation of Rotor angle thetam uses Forward Euler integrator
to ensure better accuracy and initialisation of the model.

APEENDIX B – IGBT CONVERTER BLOCK DIAGRAM (BEHIND MASK)

APPENDIX C – POWER CALCULATOR BLOCK DIAGRAM (BEHIND MASK)

APPENDIX D – WIND TURBINE BLOCK DIAGRAM (BEHIND MASK)