A SIMULATION COMPARISONS AND IMPLEMENTATION OF INDUCTION GENERATOR IN WIND POWER SYSTEMS

Muhammed Shahid[1], Ahmer Mahmood[2]

[1] Assistant Prof.,Department of Electrical & Electronics Engineering, Al-falah University, (India)

[2] Student,M.Tech, Department of Electrical & Electronics Engineering, Al-falah University, India)

ABSTRACT

This paper describes the performance comparison of a wind power systems based on two different induction generators as well as the experimental demonstration of a wind turbine simulator for the maximum power extraction. The two induction machines studied for the comparison are the squirrel-cage induction generator (SCIG) and the doubly fed induction generator (DFIG). The techniques of direct grid integration, independent power control, and the droop phenomenon of distribution line are studied and compared between the SCIG and DFIG systems. With a competitive cost for electricity generation, wind energy conversion system (WECS) is nowadays deployed for meeting both grid-connected and stand-alone load demands. However, wind flow by nature is intermittent. In order to ensure continuous supply of power suitable storage technology is used as backup. The sustainability of a 4-kW hybrid of wind and battery system is investigated for meeting the requirements of a 3-kW stand-alone dc load representing a base telecom station. A charge controller for battery bank based on turbine maximum power point tracking and battery state of charge is developed to ensure controlled charging and discharging of battery. The mechanical safety of the WECS is assured by means of pitch control technique.Both systems are modeled in Mat lab/Simulink environment, and the operation is tested for the wind turbine maximum power extraction algorithm results. Based on the simulated wind turbine parameters, a commercial induction motor drive was programmed to emulate the wind turbine and is coupled to the experimental generator systems. The turbine experimental results matched well with the theoretical turbine operation.

Keywords: SCIG, DFIG, Wind Turbine, Wind Energy, Battery System, WECS, MATLAB, Reactive Power.

I INTRODUCTION

This known to all that the burning of fossil fuels are having a vital influence on the global climatic conditions. Effective changes in the climatic condition will require deep reduction in the emission of greenhouse gases. The electricity systems are viewed as easier to transfer to low carbon energy source than most of the challenging sectors of an economy such as surface and air transport. Hence the significant use of cost-effective and reliable low carbon electricity generation sources, in addition to demand-side measures are becoming the most important objective of energy policies in many countries. Over the past decades, wind energy has been accounted for the fastest rate of growth among any form of electricity generation with its development stimulated by concerns over the climatic changes, energy diversities and security of supply by many policy makers. The maximum energy that can be taken out from the 0-100 meters layer of the atmosphere has been approximated to be around 10-12 kWh per year, which is having the same potential as hydro-electric generation With a shortage of fossil fuels and global concerns for environmental sustainability, the demand for renewable energy is increasing steadily. Wind energy conversion system (WECS) is generally connected to the electric power grid and supplies electric power to supplement the base power from other generation systems using fossil fuel or nuclear energy. The increasing emphasis on renewable wind energy has given rise to augmented attention on more reliable and advantageous electrical generator systems. Induction generator systems have been widely used and studied in wind power system because of their advantages over synchronous generators, such as smaller size, lower cost, and lower requirement of maintenance. The straightforward power conversion technique using squirrel cage induction generator (SCIG) is widely accepted in fixed-speed applications with less emphasis on the high efficiency and control of power flow. The other major problem with SCIG power system is the source of reactive power; that is, an external reactive power compensator is required to hold the distribution line voltage and prevent the whole system from overload. On the other hand, the doubly fed induction generator (DFIG) with variable-speed ability has higher energy capture efficiency and improved power quality and thus has attracted more attentions. and a dc link, acts as an optimal operation tracking interface between generator and grid. Although high robustness, reliability, and low maintenance cost are the advantages of this system, it is a demerit that both the machine speed and the generated power are not controllable but simply determined by the wind speed.

II THEORETICAL BACKGROUND

2.1 Singly Fed Induction Generator

The most common generator used in wind turbines is the induction generator. It has several advantages, such as robustness and mechanical simplicity and, as it is produced in large series, it also has a low price. The major disadvantage is that the stator needs a reactive magnetizing current. The asynchronous generator does not contain permanent magnets and is not separately excited. Therefore, it has to receive its exciting current from another source and consumes reactive power. The reactive power may be supplied by the grid or by a power electronic system. The

generator's magnetic field is established only if it is connected to the grid. In the case of AC excitation, the created magnetic field rotates at a speed determined jointly by the number of poles in the winding and the frequency of the current, the synchronous speed. Thus, if the rotor rotates at a speed that exceeds the synchronous speed, an electric field is induced between the rotor and the rotating stator field by a relative motion (slip), which causes a current in the rotor windings. The interaction of the associated magnetic field of the rotor with the stator field results in the torque acting on the rotor. So far, the Squirrel Cage Induction Generator (SCIG) has been the prevalent choice because of its mechanical simplicity, high efficiency and low maintenance requirements. The SCIG is directly coupled to grid. Hence this is normally used in Fixed Speed configuration as the generator frequency and grid frequency should match for synchronism.
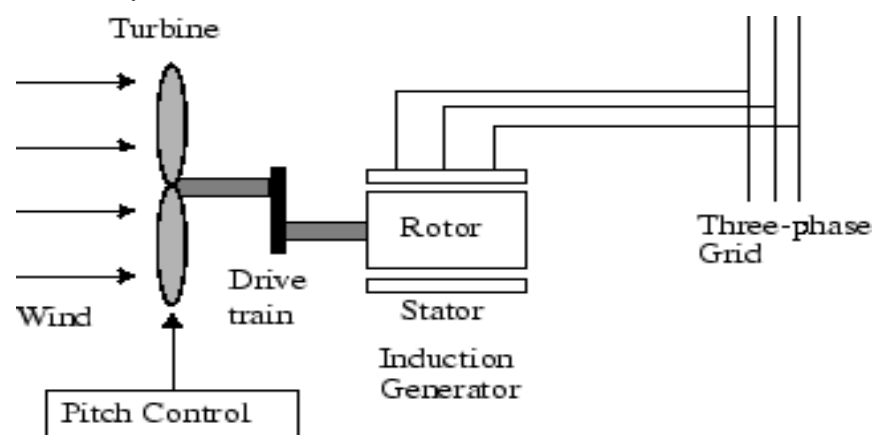

Fig 2.1 Squirrel cage Induction Generator connected to the grid on the stator and wind turbine on the rotor

2.2 Doubly Fed Induction Generator

The Doubly Fed Induction Generator (DFIG) comes under the category of Wound Rotor Induction Generators (WRIG). In the case of a WRIG, the electrical characteristics of the rotor can be controlled from the outside, and thereby a rotor voltage can be impressed. The windings of the wound rotor can be externally connected through slip rings and brushes or by means of power electronic equipment, which may or may not require slip rings and brushes. By using power electronics, the power can be extracted or impressed to the rotor circuit and the generator can be magnetized from either the stator circuit or the rotor circuit. It is thus also possible to recover slip energy from the rotor circuit and feed it into the output of the stator. The disadvantage of the WRIG is that it is more expensive than the SCIG and not as robust as the SCIG.The DFIG consists of a WRIG with the stator windings directly connected to the constant-frequency three-phase grid and with the rotor windings mounted to a bidirectional back-to-back IGBT voltage source converter. The term 'doubly fed' refers to the fact that the voltage on the stator is applied from the grid and the voltage on the rotor is induced by the power converter. This system allows a variable-speed operation over a large, but restricted, range. The converter compensates the difference between the mechanical and electrical frequency by injecting a rotor current with a variable frequency. Both during normal operation and faults

the behavior of the generator is thus governed by the power converter and its controllers. The power converter consists of two converters, the rotor-side converter and grid-side converter, which are controlled independently of each other.
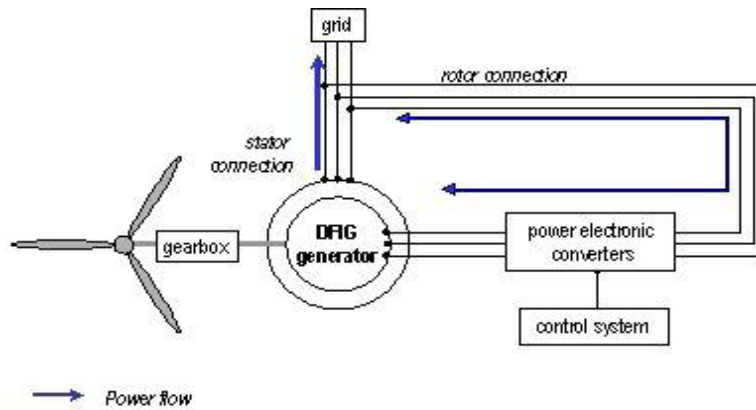

Fig.2.2 Rotor of the DFIG connected through the power electronics to the grid and the stator is connected directly to the grid

III INDUCTION GENERATOR

3.1 SCIG Wind Power System

The schematics of the SCIG system including the wind turbine, pitch control, and reactive power compensator. The entire system includes three stages for delivering the energy from wind turbine to the power grid. The first one is wind farm stage which handles with low voltage Vwt, the second is distribution stage which has medium voltage Vdis, and the third is grid transmission stage which has high voltage Vgrid. The three-phase transformers take care of the interface between stages [9]. As mentioned, nominal power PnSCIG is considered as active power reference to regulate the pitch angle while Vdis and Idis denote the distribution line-to-line voltage and phase current, and they are monitored to favor the reactive power compensation for distribution line.
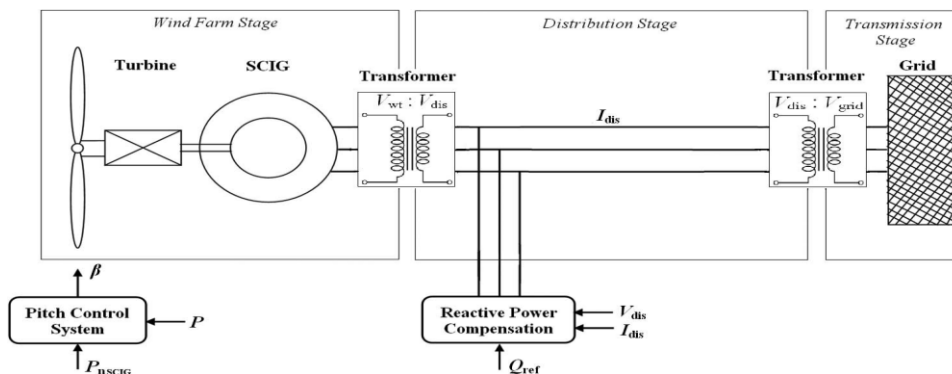

Fig. 3.1 SCIG wind power system topology.

This fairly straightforward technique was first used since it is simple and has rugged construction, reliable operation, and low cost. However, the fixed-speed essential and potential voltage instability problems severely limit the operations of wind turbine [1], [5]. Since SCIG is of fixed-speed generator, for a particular wind speed, the output active power is fixed as well. Thus, with the increase of wind speed, so does the output power until the nominal power is reached.

Pitch angle control is called nominal wind speed. Beyond this speed, the pitch angle system will prevent the output power from exceeding the nominal value. That is, when the wind speed is below nominalvalue, the power capture can vary with the change of wind speed; and when the wind speed is above nominal value, the pitch angle control system will limit the generated power by changing the pitch angle. In such way, the output power will be stabilized at nominal value where the wind speed is always above nominal speed.. Due to the huge size of blade and, thus, inertia, pitch angle has to change in a slow rate and a reasonable range. It is also worthy to notice that, without reactive power source, in Section V, the SCIG system tends to lead to a voltage droop in distribution line which will cause overload problem.

3.2. DFIG Wind Power System

Traditionally, the dynamic slip control is employed to fulfill the variable-speed operation in wind turbine system, in which the rotor windings are connected to variable resistor and control the slip by the varied resistance [5], [10]. This type of system can achieve limited variations of generator speed, but external reactive power source is still necessary. Consequently, to completely remove the reactive power compensation and to control both active and reactive power independently, DFIG wind power system is one of most popular methods in wind energy applications [1], [5], [7]. This paper reproduces DFIG model first of all and then concentrates on the controlling schemes of power converters, in which the active and reactive power are controlled independently. In particular, the stator-side converter control involving an RL series choke is proposed Both controlling of rotor- and stator-side converter voltages end up with a current regulation part and a cross-coupling part. The wind turbine driving DFIG wind power system consists of a wound-rotor induction generator and an ac/dc/ac insulated gate bipolar transistor (IGBT)-based pulse width-modulated (PWM) converter (back-to-back converter with capacitor dc link), as shown in Fig. 7. In this configuration, the back-to-back converter consists of two parts: the stator-/grid-side converter and the rotor-side converter. Both are voltage source converters using IGBTs, while a capacitor between two converters acts as a dc voltage source. The generator stator windings are connected directly to grid (with fixed voltage and frequency of grid) while the rotor winding is fed by rotor-side converter through slip rings and brushes, at variable frequency. The control system is divided into two parts—stator-side converter control system and rotor-side converter control system. An equivalent circuit of DFIG is depicted in Fig. 8, and the relation equations for voltage V , current I, flux Ψ, and torque Teinvolve [4], [11], [12] are:

$$V_{ds} = R_s I_{ds} - \omega_s \Psi_{qs} + \frac{d\Psi_{ds}}{dt}$$

$$V_{qs} = R_s I_{qs} + \omega_s \Psi_{ds} + \frac{d\Psi_{qs}}{dt} \tag{5}$$

$$V_{dr} = R_r I_{dr} - s\omega_s \Psi_{qr} + \frac{d\Psi_{dr}}{dt}$$

$$V_{qr} = R_r I_{qr} + s\omega_s \Psi_{dr} + \frac{d\Psi_{qr}}{dt} \tag{6}$$

$$\Psi_{ds} = L_s I_{ds} + L_m I_{dr}$$

$$\Psi_{qs} = L_s I_{qs} + L_m I_{qr} \tag{7}$$

$$\Psi_{dr} = L_r I_{dr} + L_m I_{ds}$$

$$\Psi_{qr} = L_r I_{qr} + L_m I_{qs} \tag{8}$$

$$T_e = \frac{3}{2} n_p (\Psi_{ds} I_{qs} - \Psi_{qs} I_{ds}) \tag{9}$$

where Ls= Lls+ Lm; Lr= Llr+ Lm; sωs= ωs− ωr represents the difference between synchronous speed and rotorspeed; subscripts r, s, d, and q denote the rotor, stator, d-axis, and q-axis components, respectively; Te is electromagnetic torque; and Lm, np, and J are generator mutual inductance, the number of pole pairs, and the inertia coefficient, respectively.
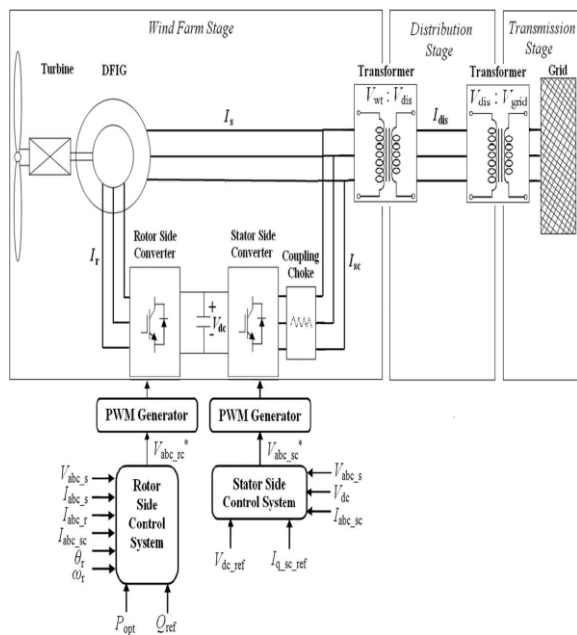

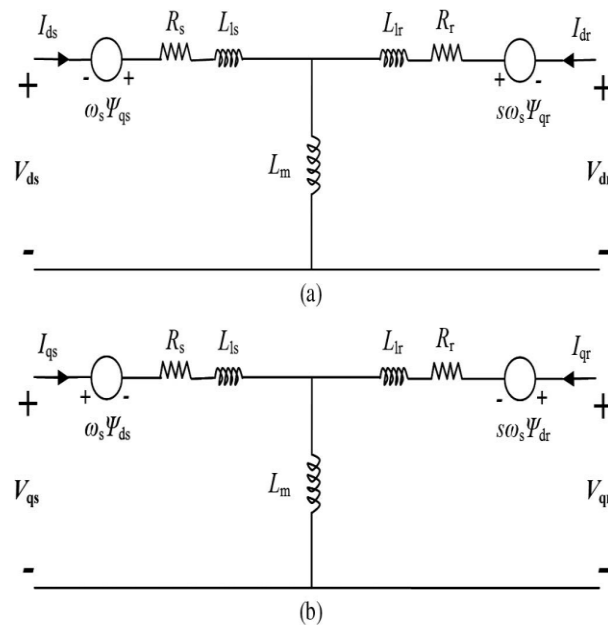**Fig. 3.2 Wind turbine–doubly fed induction generator system configuration**

Fig. 3.3 Equivalent circuit of DFIG. (a) d-axis model. (b) q-axis model

IV SIMULATION MODEL DEVELOPMENT

4.1 SCIG Model in MATLAB

In MATLAB, the SCIG is represented using a phasor model. This model is adapted to simulate the low frequency electromechanical oscillations over long periods of time. In phasor simulation method, the sinusoidal voltages and currents are replaced by phasor quantities at the system nominal frequency (50Hz). This model is mostly used for transient stability studies of wind turbines. Shown in Fig.4.1 is the model of the SCIG used in MATLAB.
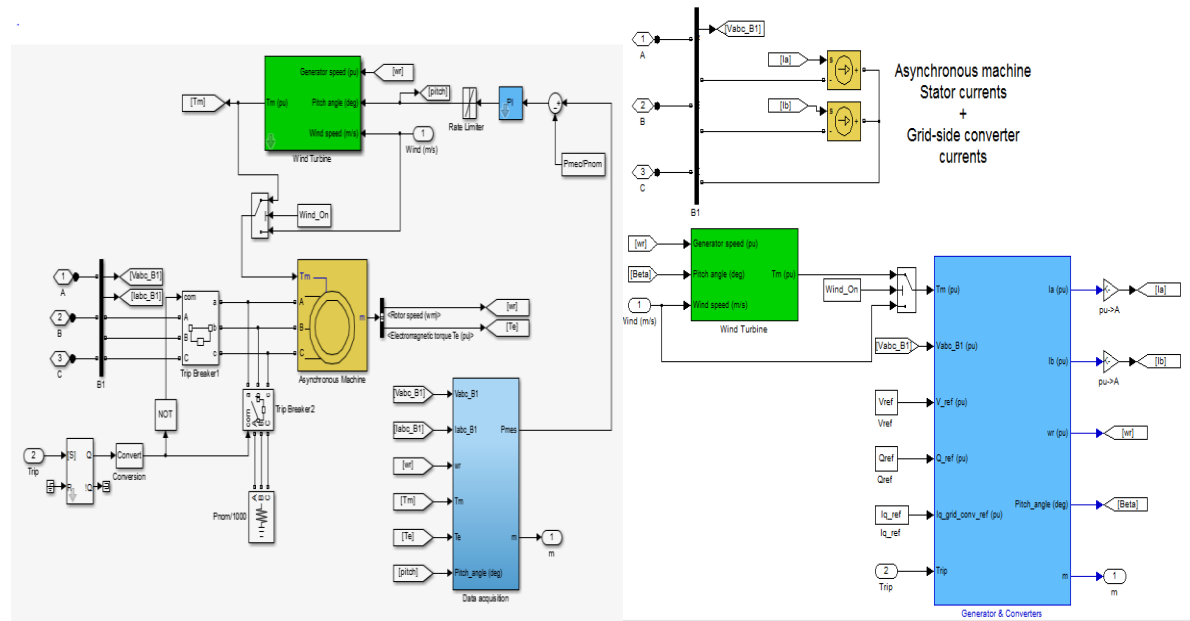

Fig.4.1 Model of the SCIG in MATLAB Simulink   Fig.4.2 Model of the DFIG in MATLAB Simulink

4.2 Doubly Fed Induction Generator Model in MATLAB

In MATLAB, the DFIG is represented using a phasor model. This model is adapted to simulate the low frequency electromechanical oscillations over long periods of time. In phasor simulation method, the sinusoidal voltages and currents are replaced by phasor quantities at the system nominal frequency (50Hz). This model is mostly used for transient stability studies of wind turbines. Shown in Fig.4.2 is the model of the Double Fed Induction Generator used in MATLAB.

4.3 Topology of Wind Turbines for Comparison of Wind Turbine

The wind turbines are connected to produce 1.5 MW of real power excluding losses. The above mentioned models were used in MATLAB. Fig 4.3 shows the topology of the wind turbines in the wind farm.
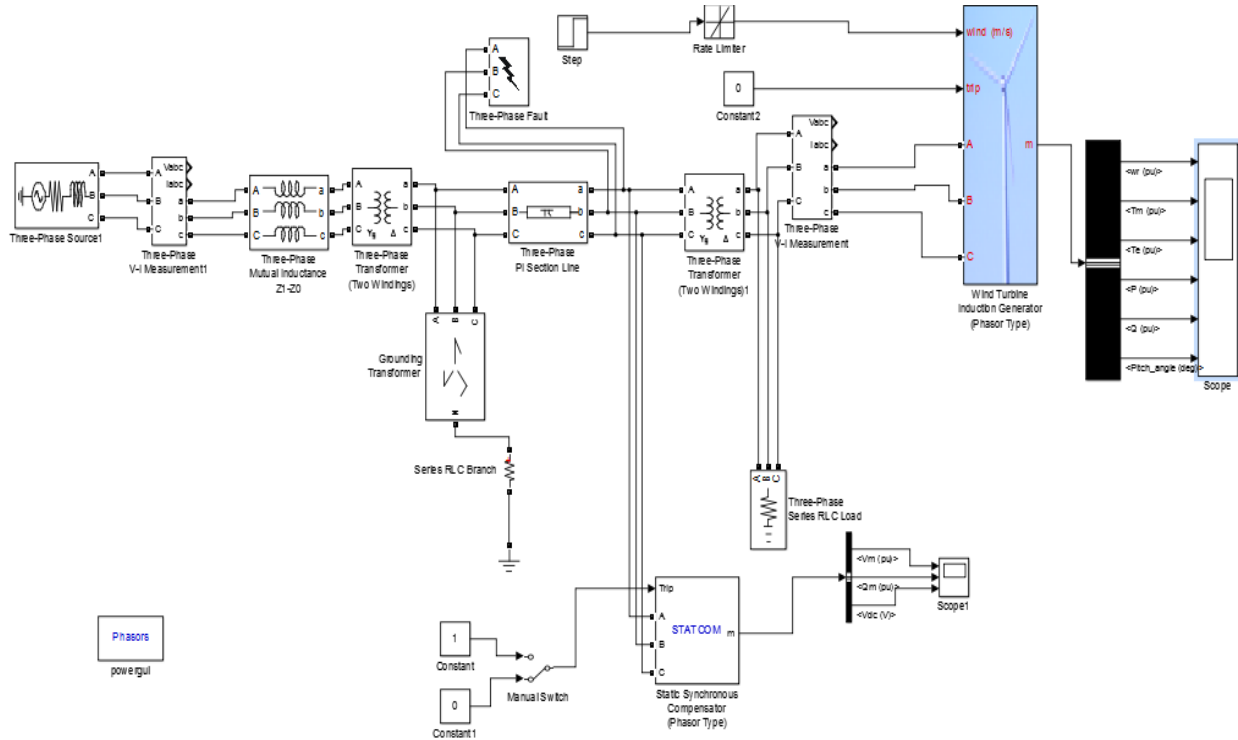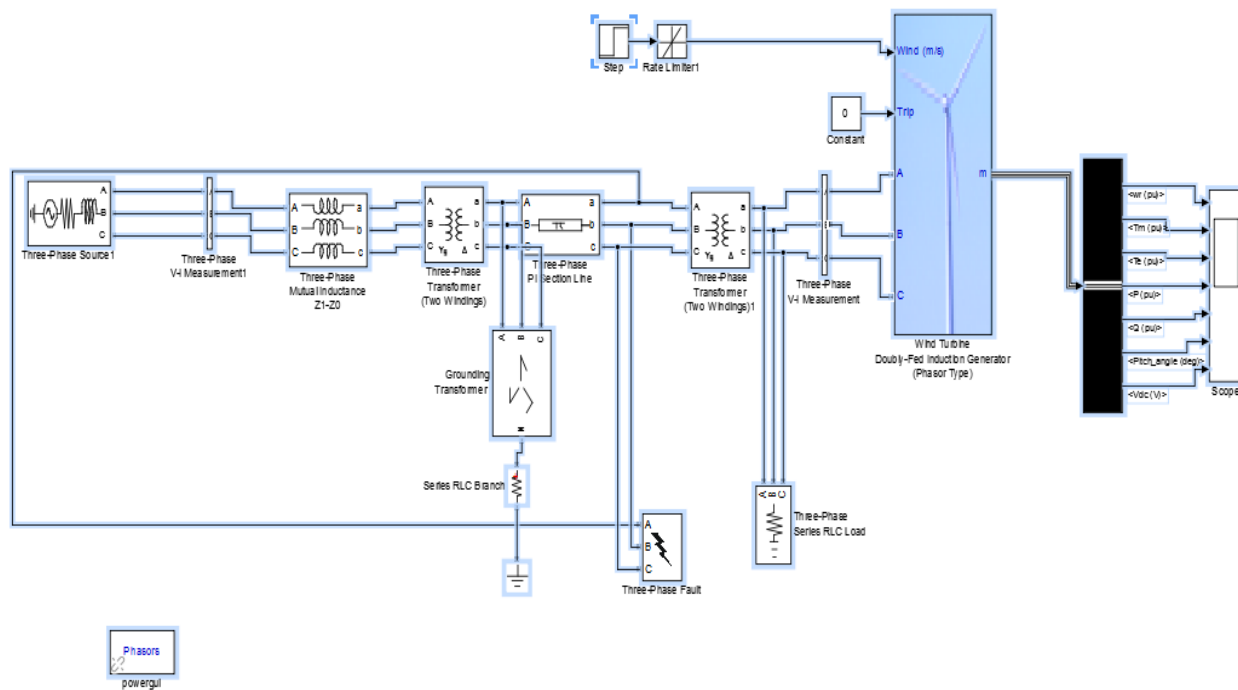
Fig 4.3 SIMULINK Model Of SCIG

Fig 4.4 SIMULINK Model Of DFIG

V SIMULATION RESULT

5.1 PARAMETERS OF DFIG& SCIG

Parameter	Value
Nominal Power(MW)	1.5
Nominal Voltage(V)	575
Nominal Power Factor	0.9
Stator Resistance(pu)	0.00706
Stator Leakage Inductance(pu)	0.171
Rotor Resistance(pu)	0.005
Rotor Leakage Inductance(pu)	0.156
Magnetizing Inductance(pu)	2.9
Inertia Constant	5.04
Friction Factor	0.01
Pole Pairs	3

Parameter	Value
Nominal Power(MW)	1.5
Nominal Voltage(V)	575
Nominal Power Factor	0.9
Stator Resistance(pu)	0.004843
Stator Leakage Inductance(pu)	0.1248
Rotor Resistance(pu)	0.004377
Rotor Leakage Inductance(pu)	0.1791
Magnetizing Inductance(pu)	6.77
Inertia Constant	5.04
Friction Factor	0.01
Pole Pairs	3

Table : 1 Parameters Of DFIG   **Table : 2 Parameters Of SCIG**
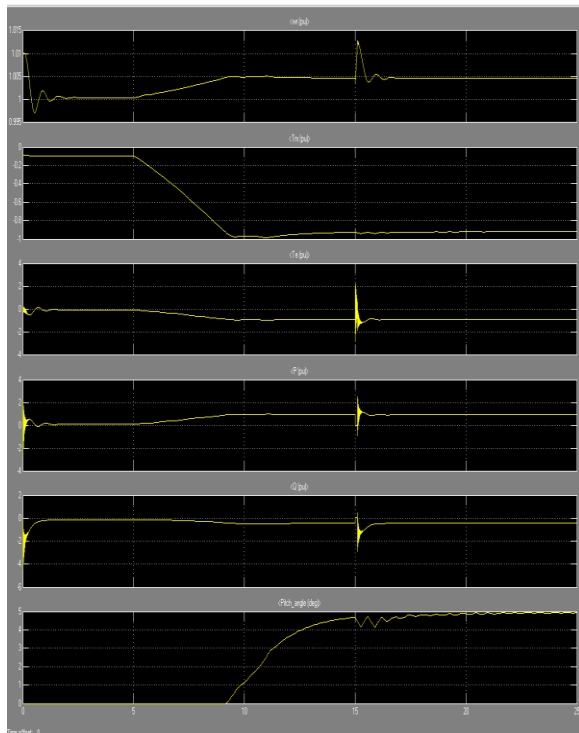

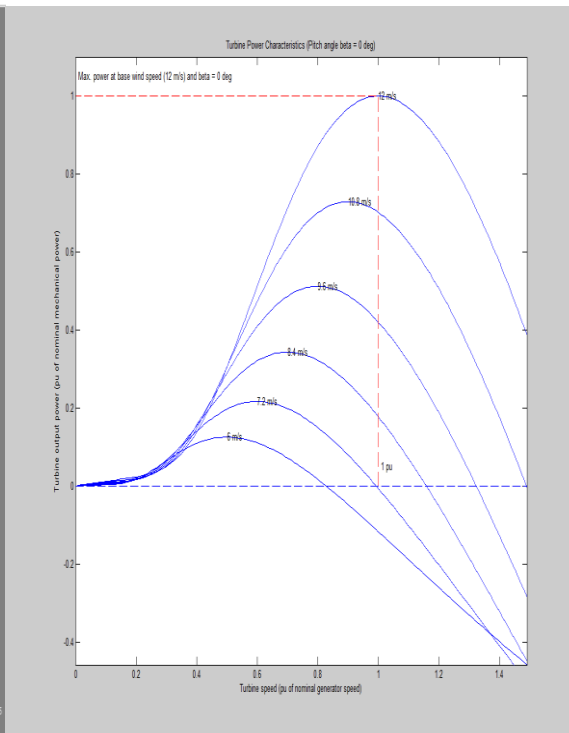**Fig 5.1 Simulation Result Of SCIG**   **Fig 5.2 Wind Tubine Power CharcterisitcsOf SCIG**
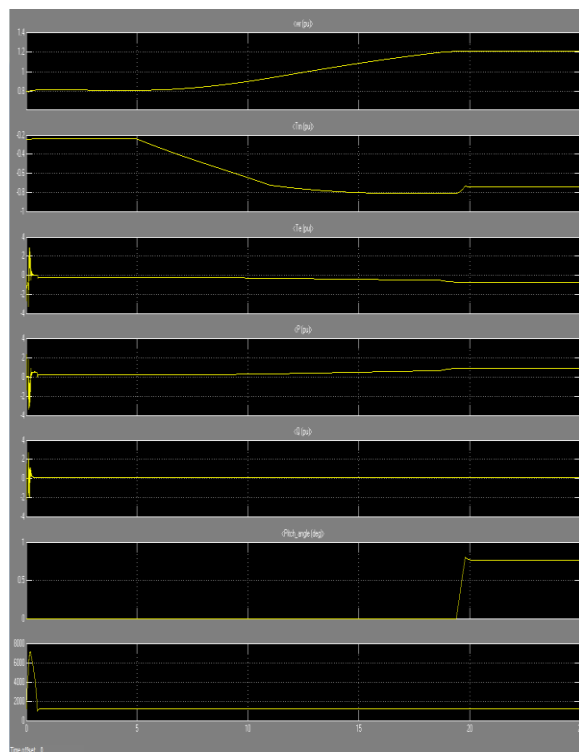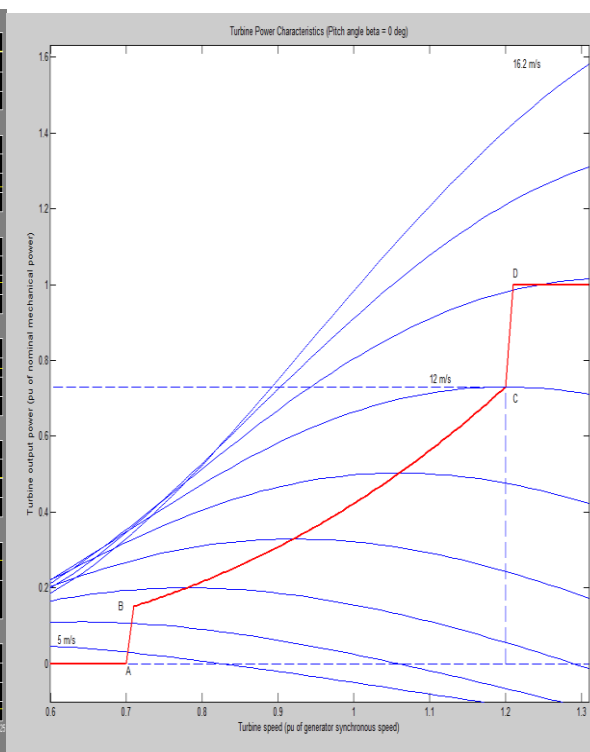
Fig 5.3 Simulation Result Of DFIG   **Fig 5.4 Wind Tubine Power Characteristics of DFIG**

VI CONCLUSION

This paper has presented the comparison of the wind turbinesystems using SCIG and DFIG generator systems. With theexperimentally investigated wind turbine model, a SCIG anda DFIG wind power systems are modeled and simulated inMatlab/Simulink. An optimal active-power-versus-rotor-speed relationship has been proposed for turbine model first, and it functions as a lookup table for tracking the maximum output active power. The SCIG system presents the need of external reactive power source to support grid voltage, and it can keep the output power at the nominal level by pitch control but cannot accordingly change the rotor speed to achieve maximum wind power capture at different wind speeds. In contrast, the DFIG system does not need reactive power compensator to hold distribution line voltage and achieves optimal active power controlling. Both voltage control schemes for two converters consist of a current regulation part and a cross-coupling part. The turbine emulator system performs well and follows the theoretical and simulated maximum power extraction points in different operating conditions.

REFERENCES

[1] M. Orabi, T. Ahmed, and M. Nakaoka, "Efficient performances of inductiongenerator for wind energy utilization," in Proc. 30th Annu.Conf.IEEE Ind. Elect. Soc., Nov. 2004, pp. 838–843.

[2] M. Molinas, J. A. Suul, and T. Undeland, "Low voltage ride through ofwind farms with cage generators: STATCOM versus SVC," IEEE Trans.Power Electron., vol. 23, no. 3, pp. 1104–1117, May 2008.

[3] Z. Chen, J. M. Guerrero, and F. Blaabjerg, "A review of the state of thEart of power electronics for wind turbines," IEEE Trans. Power Electron.,vol. 24, no. 8, pp. 1859–1875, Aug. 2009.

[4] Y. Lei, A. Mullane, and G. Lightbody, "Modeling of the wind turbine witha doubly fed induction generator for grid integration studies," IEEE Trans.Energy Convers., vol. 21, no. 1, pp. 257–264, Mar. 2006.

[5] R. Ganon, G. Sybille, and S. Bernard, "Modeling and real-time simulationof a doubly-fed induction generator driven by a wind turbine," presentedat the Int. Conf. Power Systems Transients,Montreal, QC, Canada,
Jun. 2005, Paper IPST05-162.

[6] H. Sun, Y. Ren, and H. Li, "DFIG wind power generation based on backto-back PWM converter," in Proc. IEEE Int. Conf. Mechatron. Autom.,Aug. 2009, pp. 2276–2280.

[7] L. Xu and P. Cartwright, "Direct active and reactive power control ofDFIG for wind energy generation," IEEE Trans. Energy Convers., vol. 21,no. 3, pp. 750–758, Sep. 2006.

[8] S. Heier, Grid Integration of Wind Energy Conversion Systems.Hoboken, NJ, USA: Wiley, 2006.

[9] N. W. Miller, W. W. Price, and J. J. Sanchez-Gasca, "Dynamic modelingof GE 1.5 And 3.6 wind turbine-generators," GE Power Systems EnergyConsulting, Gen. Elect. Int., Inc., Schenectady, NY, USA, Oct. 2003.

[10] R. Pena, J. C. Clare, and G. M. Asher, "Doubly fed induction generatorusing back-to-back PWM converters and its application to variable-speedwind-energy generation," Proc. Inst. Elect. Eng.—Elect. Power Appl.,
vol. 143, no. 3, pp. 231–241, May 1996.

[11] Feijoo, J. Cidras, and C. Carrillo, "Third order model for the doubly-fedinduction machine," Elect. Power Syst. Res., vol. 56, no. 2, pp. 121–127,Nov. 2000.