Simulation and Analysis of a DFIG Wind Energy Conversion System with Genetic Fuzzy Controller

B. Babypriya, **N. Devarajan**

Abstract— The behavior of a grid connected, wind energy conversion system (WECS) is simulated using MATLAB in this paper. This analysis is presented for different fault conditions like line to ground faults, line to line faults, double line to ground faults and three phase symmetric faults. A genetic algorithm based fuzzy controller is incorporated into the Doubly fed Induction Generator (DFIG) Wind Energy Conversion System. The dynamic behavior of a DFIG Wind Energy Conversion system with genetic fuzzy controller is simulated for different fault conditions and the results are compared to that of the system with PI Controllers. The comparison shows that the incorporation of the Genetic fuzzy controller results in an improvement in the dynamic behavior of the system under transient conditions.

Index Terms- Doubly fed Induction Generator, Wind Energy Conversion System, Genetic Fuzzy Controller.

I. INTRODUCTION

Though harnessing of wind power goes back nearly 4000 years, interest was renewed recently. Wind power is a potential source for electricity generation due to its minimum impact on the environment. With advanced aerodynamic designs, wind turbines capable of producing several megawatts of power are now available. When such wind energy conversion systems (WECS) are connected to the grid, they produce a huge amount of power that supplements power generated by thermal, nuclear, or hydro power plants. A WECS size varies from a few 100 kilowatts to several megawatts and it is this size that determines the choice of the generator/converter system. While asynchronous generators are used with systems up to 2MW, permanent magnet synchronous machines are preferred for higher power production. This paper describes the advantages and disadvantages of different generators used in Wind Energy Conversion Systems. A 6 MW capacity wind Energy conversion system using doubly fed induction generators was simulated and its dynamic behavior is studied. A Genetic fuzzy controller was designed to improve the system's dynamic behavior. The performance of the Wind energy conversion system with the Genetic Fuzzy Controller was simulated and analyzed.

Manuscript received on April 14, 2012.

B. Babypriya, Department of EEE, Institute of Road and Transport Technology, Erode, India, Mobile No. 9486937393,
(e-mail: ramachandran.priya93@gamil.com).
Dr.N. Devarajan, Department of EEE, Government College of Technology, Coimbatore, India, Mobile No.9443245163
(e-mail: profdevarajan@yahoo.com).

II. DIFFERENT SCHEMES FOR WIND ENERGY CONVERSION SYSTEMS

A traditional wind energy conversion system comprises of a stall-regulated or a pitch controlled turbine linked to a synchronous generator through a gearbox as shown in Fig. 1[1]. But the wind's turbulent nature produced unsteady input torque that caused fluctuations in the generator's output power which is harmful to power systems. The system's synchronous generator operates only at constant speed. So the turbine should be connected to the generator rotor through a highly compliant shaft. This helps the generator to isolate itself from the turbine's wind speed variations.

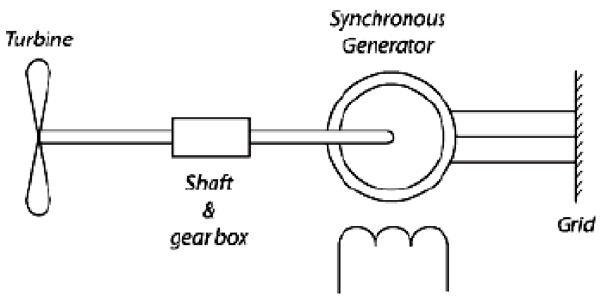


Fig 1: Wind energy system with a synchronous generator

The necessity of a flexible shaft allowed the use of induction generators as these generators allow 1 - 5 % variation in the generator speeds [2]. The induction generator also isolates the grid from the input power transients. The synchronous generator, are a source of reactive power, where as the induction generator draws reactive power from the grid for its operation.

Variable speed induction generators using v / f control enable efficient wind energy capture as shown in Fig 2. The generator-side converter can be controlled to vary the speed of the induction generator. The grid-side converter can be controlled to inject the desired real power and reactive power into the grid. Thus, this system provides reactive power support to the grid, if required. But the only disadvantage to this configuration is the large cost associated with the power converter, since the converter has to be rated for the maximum power output of the generator.

*Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication*

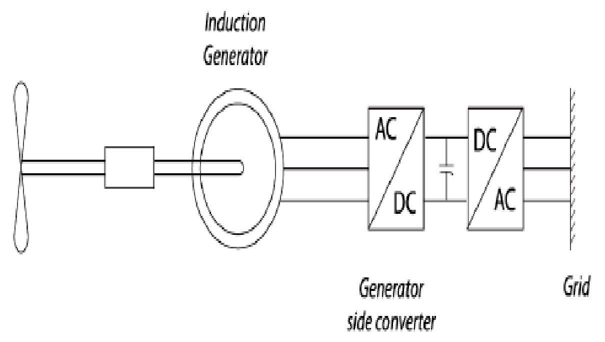


Fig 2: V/ f Hertz controlled induction generator

Rotor side control of wound rotor induction machines is an attractive scheme for Wind Energy Conversion because with this system the cost of the power electronic converters is very less, as the converters have to be rated only for the rotor power, which is generally a fraction of the rated power. The system has a limited speed capability that suits the wind power generation applications, as the generator speeds need to vary by only 10 %. The disadvantage with wound rotor induction machines is that they are not as not as rugged as squirrel cage machines. The advantages of rotor-controlled systems overcome this disadvantage. One of the earliest rotor control schemes was the rotor resistance control as shown in Fig. 3 [3]. The speed of the induction machine is controlled by the changing the external resistance in the rotor circuit. The method enables fast response, since power electronic converters are used to vary the external resistance. But the major drawback of this type of control is the large losses in the external resistance especially at high speed, which causes a reduction in the efficiency of the overall system.

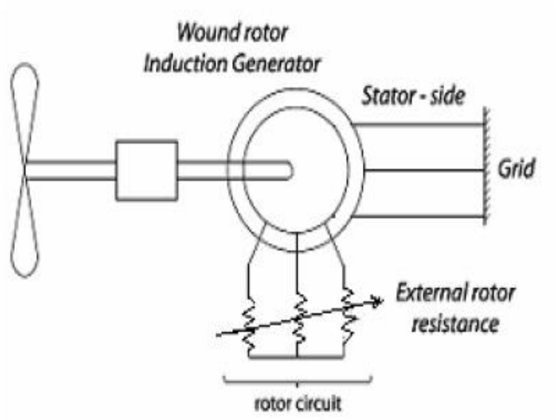


Fig 3: Rotor resistance control of a wound rotor induction machine

The disadvantage of the rotor resistance controller can be overcome by the use of a slip-power recovery induction generator (also called the Static Kramer Drive, as shown in Fig. 4) as the rotor power is fed back into the grid [4]. The grid-side converter can be used to control the speed of the generator and the converter rating is typically 50 % of the rated power [5]. However, the power flows only from the rotor to the grid, due to the use of the diode bridge rectifier on the rotor side. Because of this unidirectional power flow the generation action of the machine is limited to only super-synchronous speeds. This limitation, which is also a drawback of the rotor resistance controller, does not enable wind power capture at low speeds.

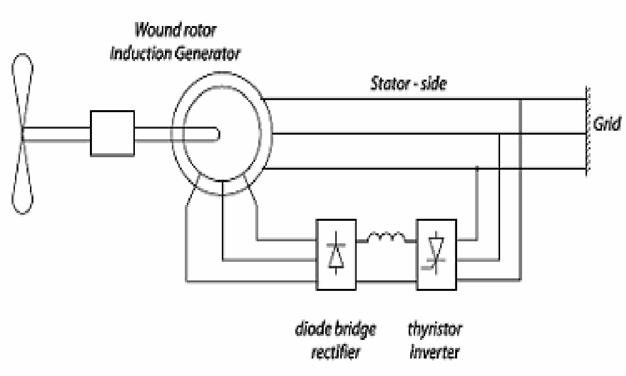


Fig 4: Slip power recovery induction generators

The doubly fed induction machine as shown in Fig. 5 is a modification of the slip-power recovery scheme, where the converter and the rectifier on the rotor side are replaced by bi-directional converters [6]. By injecting currents into the rotor, the machine can be made to act like a generator at both sub-synchronous and super-synchronous speeds. The converter rating is about 15 % of the rated power [5]. By controlling the grid side converter power factor control (about ± 10 % of the unity power factor) is also possible.

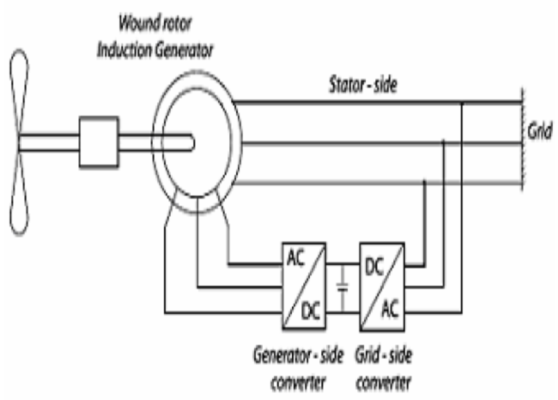


Fig 5: Doubly fed Induction Generator

The higher cost of the machine due to the slip rings is compensated by a reduction in the sizing of the power converters. The generator rating can also be reduced compared to other singly fed machines. Comparative studies of wind energy conversion systems with cage rotor machines and doubly fed induction machines show that for a machine of similar rating, energy capture can be significantly enhanced by using a wound rotor induction machine. In this case, the rated torque is maintained even at super synchronous speeds whereas, in a system using cage rotor machine, field weakening has to be employed beyond synchronous speed, leading to reduction of torque. The use of doubly fed induction machines enables operation up to higher wind velocities. The voltage rating of the power devices and dc bus capacitor is substantially reduced. The size of the line side inductor also decreases.

III. MODEL OF THE DOUBLY FED INDUCTION GENERATOR

Fig. 6 shows a wind turbine connected to a DFIG. The AC/DC/AC converter is divided into two components: the rotor-side converter (Crotor) and the grid-side converter (Cgrid). Crotor and Cgrid are Voltage-Sourced Converters that use forced-commutated power electronic devices (IGBTs) to synthesize an AC voltage from a DC voltage source. A capacitor connected on the DC side acts as the DC voltage source. A coupling inductor L is used to connect Cgrid to the grid. The three-phase rotor winding is connected to Crotor by slip rings and brushes and the three-phase stator winding is directly connected to the grid. The power captured by the wind turbine is converted into electrical power by the induction generator and it is transmitted to the grid by the stator and the rotor windings. The control system generates the pitch angle command and the voltage command signals Vr and Vgc for Crotor and Cgrid respectively in order to control the power of the wind turbine, the DC bus voltage and the reactive power or the voltage at the grid terminals.

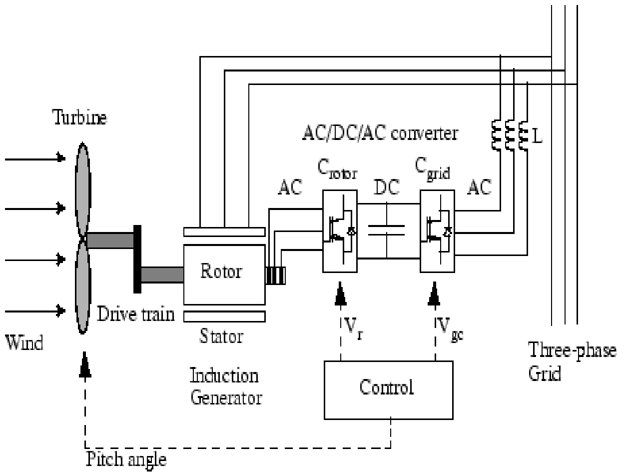


Fig.6: DFIG Wind Energy Conversion System

The generic power control loop is illustrated in the fig. 7.a called Rotor-Side Converter Control System. 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 of positive-sequence current 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.

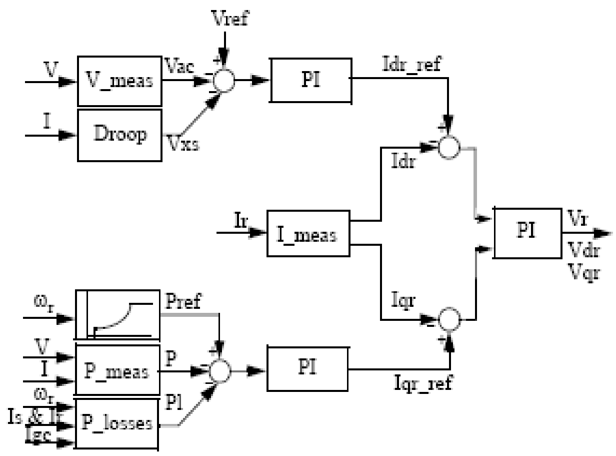
The converter Cgrid is used to regulate the voltage of the DC bus capacitor. In addition, this model allows using Cgrid converter to generate or absorb reactive power. The control system, illustrated in the figure 7.b called Grid-Side Converter Control System, consists of:

Measurement systems measuring the d and q components of AC positive-sequence currents to be controlled as well as the DC voltage Vdc. An outer regulation loop consists of a DC voltage regulator. The output of the DC voltage regulator is the reference current Idgc_ref for the current regulator (Idgc = current in phase with grid voltage which controls active power flow). An inner current regulation loop consists of a current regulator. The current regulator controls the magnitude and phase of the voltage generated by converter C_{grid} (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 C_{grid} output voltage.

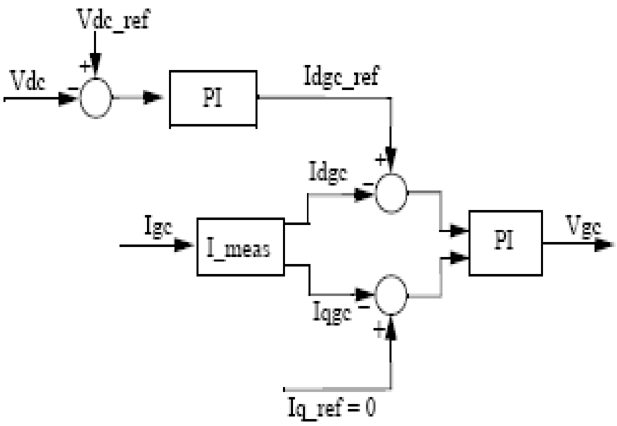
The magnitude of the reference grid converter current Igc_ref is equal to

$$\sqrt{I_{dgc\_ref}^2 + I_{qr\_ref}^2}$$

The maximum value of this current is limited to a value defined by the converter maximum power at nominal voltage. When Idgc_ref and Iq_ref are such that the magnitude is higher than this maximum value the Iq_ref component is reduced in order to bring back the magnitude to its maximum value.



a. Rotor - side controller



b. Grid - side controller

Fig.7: Rotor and Grid Side Control System

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

IV. DESCRIPTION OF THE WECS USED FOR SIMULATION

The Wind Energy conversion system taken for simulation shown in fig.8 consists of a 6 MW Windfarm using four 1.5 MW doubly fed induction generators. The voltage generated by the windfarm is stepped up to 25 KV using a three phase transformer unit. The power is then transmitted over a 15 KM transmission line and a three phase step up transformer unit to the grid. The designed system consists of a 2-MVA plant consisting of a 1.68MW induction motor load along with a 200-kW resistive load at bus B25.

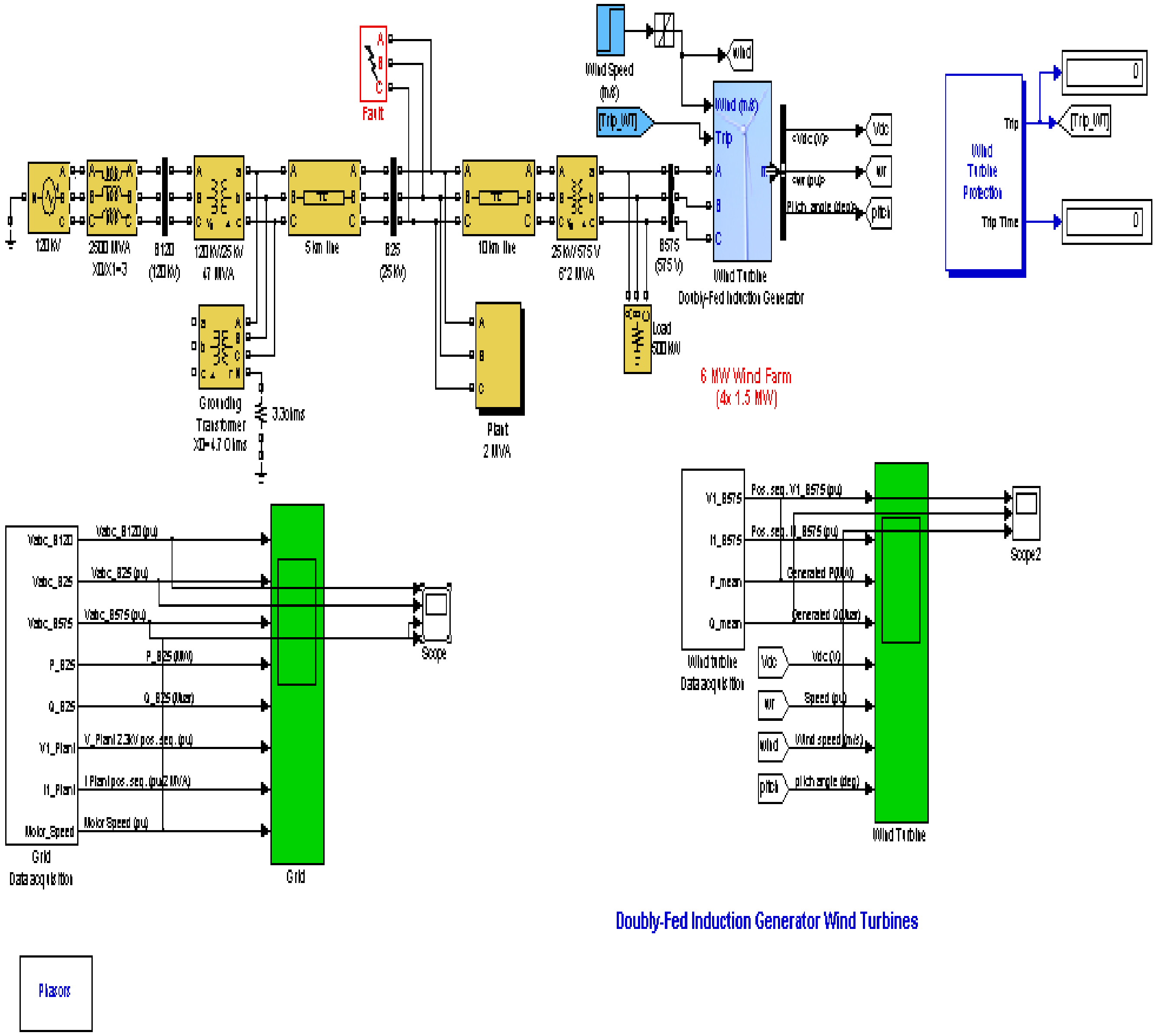
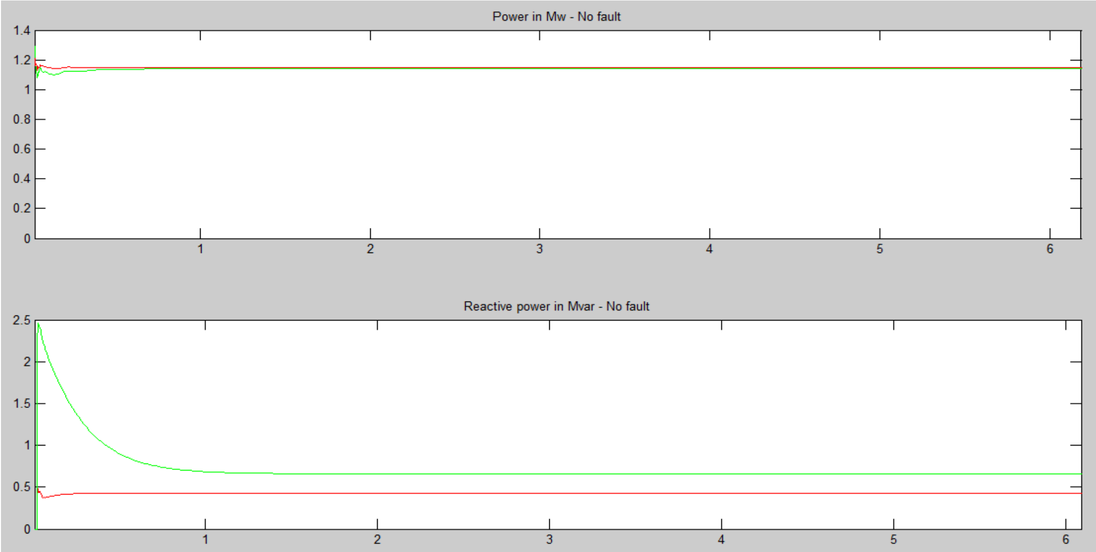
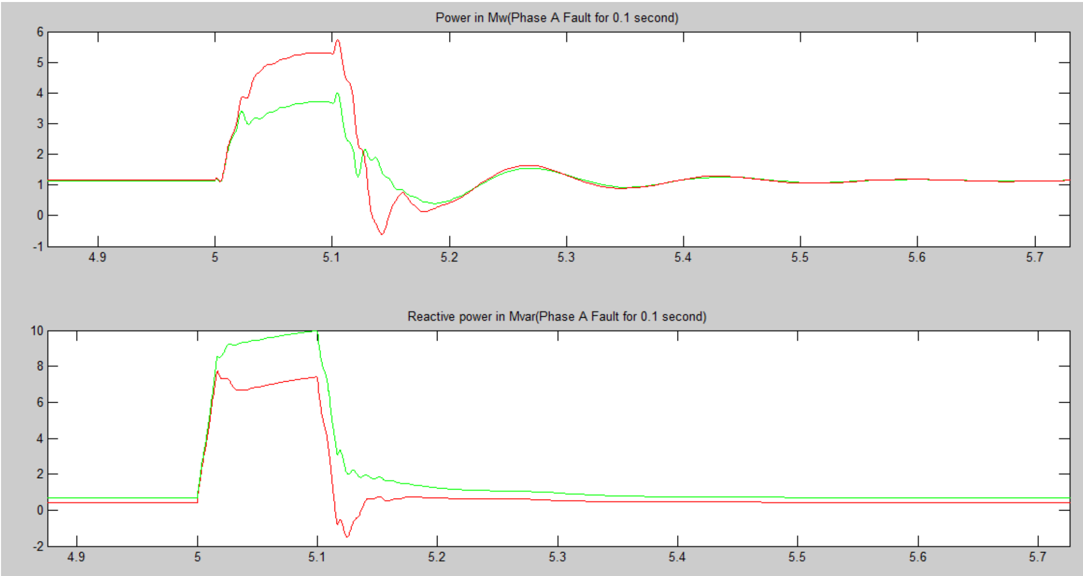


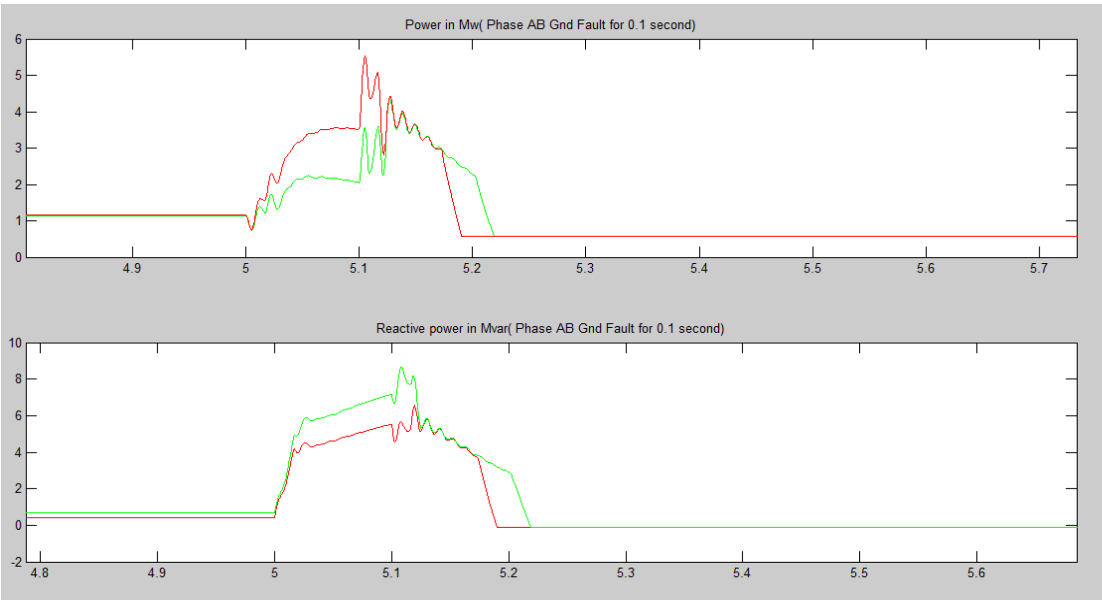
Fig 8. Simulation Set up

V. RESULTS AND DISCUSSIONS

The rotor side converter control system and the grid side converter control system of the above system uses PI controllers. The dynamic behavior of the above system for different faults such as line to ground fault, line to line fault, double line to ground fault and symmetric fault are studied and the graphs of the generated, real power, reactive power and the wind speed are presented in the figure. The PI controllers of the above system are replaced by fuzzy logic controllers applying Genetic algorithm. The simulation results of the dynamic behavior of the system with Genetic fuzzy controllers are presented in fig. 9. A comparison of the results shows that the system with the Genetic fuzzy controller is able to recover from all the faults except symmetrical fault.


Power in Mw - No fault
Reactive power in Mvar - No fault


Power in Mw(Phase A Fault for 0.1 second)
Reactive power in Mvar(Phase A Fault for 0.1 second)


Power in Mw(Phase AB Gnd Fault for 0.1 second)
Reactive power in Mvar(Phase AB Gnd Fault for 0.1 second)

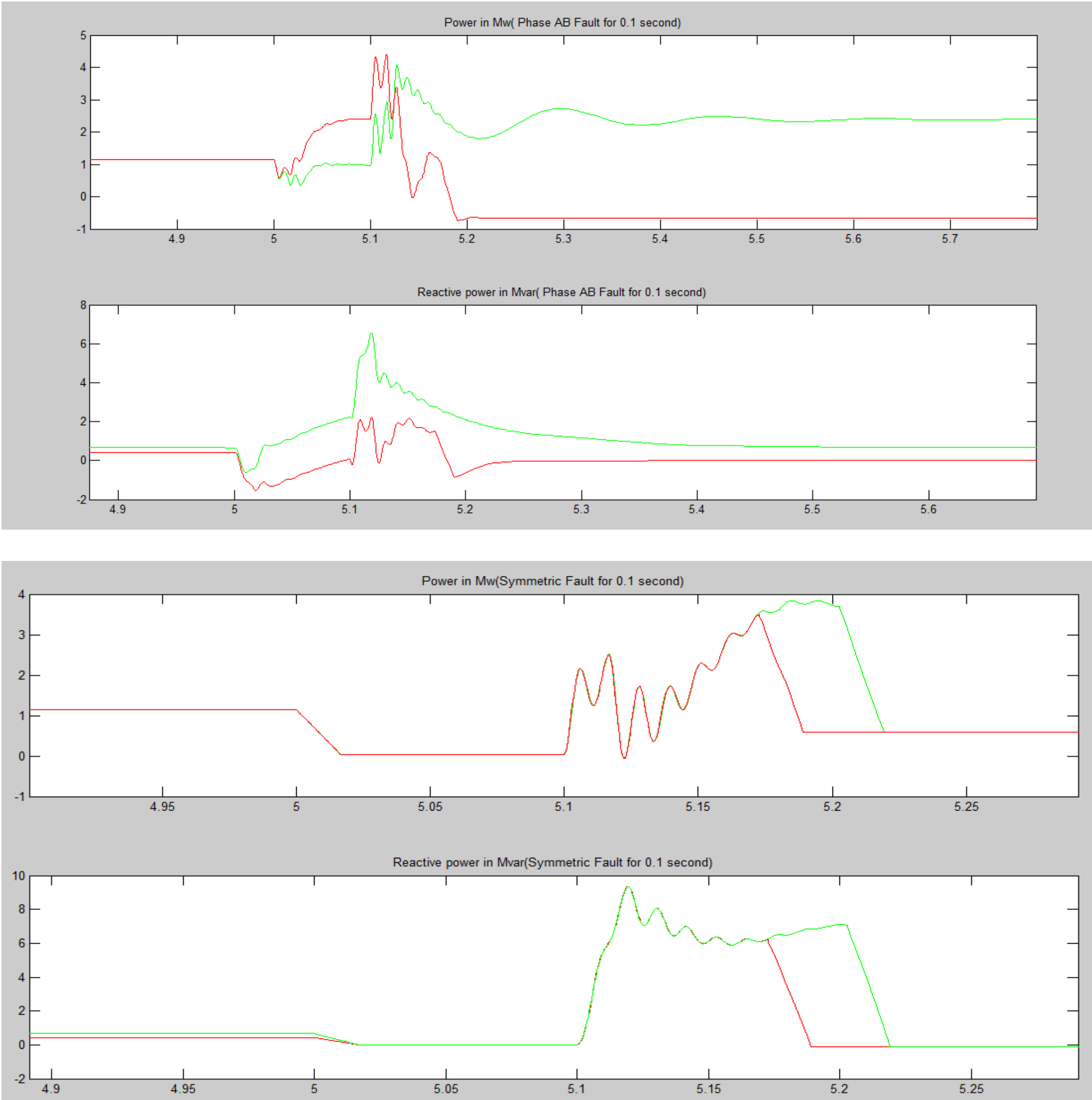


Fig.9. Graphs of Real and reactive power at the fault point (Green – with Genetic Fuzzy Controller)

VI. CONCLUSION

In this paper an attempt is made to simulate a 6 MW Wind farm using Doubly fed induction generator. The rotor side converter control system and the grid side converter control system use PI controllers. The dynamic behavior of the system is simulated and analysed for different fault conditions. The PI controllers of the above system are replaced with Genetic algorithm based fuzzy controllers and the simulation is carried out for different kinds of faults. A comparison of the simulation results reveals that there is an improvement in the dynamic behavior of the system with Genetic Fuzzy Controller. The graphs of the real power and reactive power at the fault location are presented in figures for both systems. From the graphs it can be seen that, the fluctuations in the real and reactive power during the fault recovery are considerably reduced for the system with Genetic fuzzy controller.

REFERENCES

1. Anderson P.M. and Anjan Bose (1983), 'Stability Simulation of Wind Turbine Systems', IEEE Transactions on power apparatus and systems, Vol. PAS-102, No. 12, pp. 3791-3795.
2. Hinrichsen E.N. (1983), 'Integration of Wind Turbine and Power System Controls', Sixth Biennial Wind Energy Conference and Workshop, pp. 887- 898.
3. Nayar C.V. and Bundell J.H. (1987), 'Output Power Controller for a Wind Driven Induction Generator', IEEE Transactions on Aerospace and Electronic Systems, Vol. Aes-23, No. 3, pp. 388-400.
4. Filho R., Sanchez E., Sanchez B. and Armando V. (1997), 'Control of wound rotor induction machine', International Conference on Power Electronics and Drives, Systems Proceedings IEEE, Vol. 1, pp. 97-102.
5. Nakra H.L. and Benoit Dube (1988), 'Slip Power Recovery Induction Generators for Large Vertical Axis Wind Turbines', Winter Meeting of the IEEE Power Engineering Society, pp. 733-737.
6. Pena R., Clare J.C. and Asher G.M. (1996), 'A Doubly Fed Induction Generator Using back-to-back PWM Converters Supplying an Isolated Load from a Variable Speed wind Turbine', IEEE Proc. B, Electric Power Applications, Vol. 143, pp. 380-387.
7. Datta R. and Ranganathan V.T. (2002), 'Variable Speed Wind Power using Doubly Fed Wound Rotor Induction Machine - A Comparison with Alternative Scheme', IEEE Trans Energy Conversion, Vol. 17, pp. 414-421.
8. Torbjorn Thiringer (2002), 'Grid Friendly Connecting of constant speed wind turbines using external resistance', IEEE Transactions on Energy Conversion, Vol. 17 , No. 4 , pp. 537-542
9. Renewable Energy Sources and Technologies (TERI Energy Data Directory and Yearbook, 2005), pp. 175-183.
10. Riaz M. (1959), 'Energy-Conversion Properties of Induction Machines in Variable-Speed Constant Frequency Generating Systems', Applications an Industry.

AUTHORS PROFILE

B. BabyPriya has completed B.E in Electrical and Electronics Engineering at Government College of Technology, Coimbatore in 1994 and M.E in Electrical Machines from PSG College of Technology, Coimbatore in 1996. She is currently pursuing Ph.D at Anna University of Technology, Coimbatore in the area of Wind Energy Conversion Systems**.**

Dr. N. Devarajan, received the B.E (EEE) and M.E (Power Systems)degrees from GCT Coimbatore in the year 1982 and 1989. He received the Ph.D in the area of Control Systems iin the year 2000. He has published 95 papers in national and international conferences. He has published 27 papers in international journals and 10 in national journals. Under his supervision currently 10 research scholars are working and 4 scholars have completed their Ph.D. His areas of interest are control systems, electrical machines and power systems. He is member of system society of India, ISTE and FIE.