IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Dynamic Behaviour of DFIG Driven by Wind Turbine

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Abstract

The global electrical energy consumption is rising and there is steady increase of the demand on power generation. So in addition to conventional power generation units a large no. of renewable energy units is being integrated into the power system. A wind electrical generation system is the most cost competitive of all the environmentally clean and safe renewable energy sources in world. The recent evolution of power semiconductors and variable frequency drive technology has aided the acceptance of variable speed generation systems. Both fixed-speed squirrel-cage induction generator and variable speed double fed induction generator are used in wind turbine generation technology. Therefore, a detailed model of induction generator coupled to wind turbine system is presented in the thesis. Modeling and simulation of induction machine using vector control computing technique is done in MATLAB/SIMULINK platform. The significant result of the analysis is also shown and being compared with the existing literature to validate approach.

DFIG–wind turbine is an integrated part of distributed generation system. Therefore, any abnormalities associates with grid are going to affect the system performance considerably. Taking this into account, the performance of double fed induction generator (DFIG) variable speed wind turbine under network fault is studied using simulation developed in MATLAB/SIMULINK results show the transient behavior of the double fed induction generator when a sudden short circuit at the generator. After the clearance the short circuit fault the control schemes manage to restore the wind turbine's normal operation. The controller performance is demonstrated by simulation result both during fault and the clearance of the fault. A crowbar is used to protect the rotor converter against short-circuit current during faults.

Keywords: DFIG, MATLAB, TURBINE, ENERGY.

Introduction

Wind energy generation equipment is most often installed in remote, rural areas. These remote areas usually have weak grids, often with voltage unbalances and under voltage conditions. When the stator phase voltages supplied by the grid are unbalanced, the torque produced by the induction generator is not constant. Instead, the torque has periodic pulsations at twice the grid frequency, which can result in acoustic noise at low levels and at high levels can damage the rotor shaft, gearbox, or blade assembly. Also an induction generator connected to an unbalanced grid will draw unbalanced current. These unbalanced current tend to magnify the grid voltage unbalance and cause over current problems as well.

Wind energy has been the subject of much recent research and development. In order to overcome the problems associated with fixed speed wind turbine system and to maximize the wind energy capture, many new wind farms will employ variable speed wind turbine. DFIG (Double Fed Induction Generator) is one of the components of Variable speed wind turbine system. DFIG offers several advantages when compared with fixed speed generators including speed control. These merits are primarily achieved via control of the rotor side converter. Many works have been proposed for studying the behavior of DFIG based wind turbine system connected to the grid. Most existing models widely use vector control Double Fed Induction Generator.

The stator is directly connected to the grid and the rotor is fed to magnetize the machine. Wind electrical power system are recently getting lot of attention, because they are cost competitive, environmental clean and safe renewable power sources, as compared fossil fuel and nuclear power generation.

The reason for the world wide interest in developing wind generation plants is the rapidly increasing demand for electrical energy and the consequent depletion reserves of fossil fuels, namely, oil and coal. Many places also do not have the potential for generating hydel power.

Nuclear power generation was once treated with great optimism, but with the knowledge of the environmental hazard with the possible leakage from nuclear power plants, most countries have decided not to install them anymore.

The growing awareness of these problems led to heightened research efforts for Developing alternative of energy sources for generation of electricity. The most desirable source would be one that non-pollutant, available in abundance and renewable and can be harnessed at an acceptable cost in both large-scale and small scale system. The most promising source satisfying all these requirement is wind, a natural source energy source.

The development of wind energy for electrical power generation got a boost when, in the early decades of the twentieth century, aviation technology resulted in an improved understanding of the forces acting on the blades moving through air. This resulted in the development of wind turbine with two or three blades. High speed and high efficiency of turbines were the condition for successful electricity generation. Through the efforts of countless scientists and engineer from various disciplines, wind energy has now matured as an economically viable renewable source of energy.

Wind energy is one of the most available and exploitable forms of renewable energy. Wind blows from a region of higher atmospheric pressure to one of the lower atmospheric pressure. The difference in pressure is caused by (A) the fact that earth’s surface is not uniformly heated by the sun and (B) the earth’s rotation. Wind energy is the byproduct of solar energy, available in the form of the kinetics energy of air. Wind has been known to man as a natural source of mechanical power for long. The technology of wind power has evolved over this long period. Of the various renewable energy sources, wind energy has emerged as the most viable source of electrical power and is economically competitive with conventional sources.

The global electrical energy is rising and there is a steady rise of the demand on power generation, transmission, distribution and utilization. The maximum extractable energy from the 0-100m layer of air has been estimated to be the order of 1012 KWh/annum, which is of the same order as hydroelectric potential. The terms “wind energy” or “wind power” describe the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding gain or pumping water) or a generator can convert this mechanical power into electricity.

Since earliest recorded history, wind power has been used to move ships, grind grain and pump water. This is the evidence that wind energy was used to propel boats along the Nile River as early 5000 B.C. within several centuries before Christ, simple windmills were used in china to pump water.

In the United States, millions of windmills were erected as the American West was developed during the late 19th century. Most of them were used to pump water for farms and ranches. By 1900, small electric wind systems were developed to generate current, but most of these units fail into disuse as inexpensive grid power was extended to rural areas during the 1930s. By 1910, wind turbine generators were producing electricity in many European countries.

Wind turbines are available in a variety of size, and therefore power ratings. The largest machine, such as the one built in Hawaii, has propellers that span the more than the length of a football field and stands 20 building stories high, and produces enough electricity to power 1400 homes. A small home-sized wind machine has rotors between 8 and 25 feet in diameter and stands upwards of 30 feet and can supply the power needs of an all-electric home or small business.

All electric-generating wind turbines, no matter what size, are comprised of a few basic components: the (the part that actually rotates in the wind), the electrical generator, a speed control system, and a tower. Some wind machine have fail-safe shutdown system so that if part of the machine fails, the shutdown system turn the blades out of the wind or puts brakes. Just like solar electric system, wind powered system can be used in two ways: off-grid or on-grid is when your home or business is entirely disconnected from electric utility company and you generate absolutely all of the electricity you need. Usually these systems cost about 30% more than an on-grid .A grid tie wind power system sends all of its electricity back into the public electrical network (grid) which the electric company gives you credits for. At the month, the electric company sums up your credits with how much your home or consumed, and if you are lucky the electric company will owe you money! Most electric companies only pay you a small fraction of what they change you for those kilowatt-you have created. So its usually ideal to design a system that very closely offsets how much electricity you consume or just little less, than attempting to make money from the electric company

Literature Survey

In [1] the DFIG control strategy that enhances the standard speed and reactive power control with controllers that can compensate for the problems caused by an unbalanced grid by balancing the stator currents and eliminating torque and reactive power pulsations.

[2] Describe the controller to be controlled in positive and negative sequence independently. In order to implement the separated positive and negative sequence controllers of DFIG, two methods to separate positive and negative sequence in real time are compared.

[3] Presents a centralized supervision of the reactive power control for a wind farm. A weighting distribution strategy has been used in order to determine the reactive power reference for each wind generator.

[4] Explain a novel control strategy to overcome these problems; furthermore, it reduces the rotor voltage, improving the control of the rotor current and it accelerates the dumping of the flux oscillations.

[5] Explain a new methodology to compensate the stator voltage unbalance of DFIG has been proposed. The effects of voltage unbalances in DFIG have been discussed, equivalent circuits and small-signal models, appropriate to design the current control loops, have been proposed. Experimental results have been presented to validate the proposed control methodology. For stand-alone and grid-connected applications the performance of the control system has been tested considering variable-speed operation, fixed-speed operation and step connection of unbalanced loads.

[6] A technique is described which the objective to keep the generator has connected to the grid in case of a grid failure so that it can resume power generation after clearance of the fault in the grid. The key of the technique is to limit the high currents and to provide a bypass for it in the rotor circuit via a set of resistors that are connected to the rotor windings without disconnecting the converter from the rotor or from the grid. The wind turbine can resume normal operation within a few hundred milliseconds after the fault has been cleared.

[7] Describe the two alternative fault detection methods, namely the Absolute Normalized DC Current Method and the Sampling Point Comparison Method. The former method provides similar fault detection capability while requiring less computational time than the Modified Normalized DC Current Method.

[8] Describes the dynamic behavior of a typical fixed speed wind turbine connected to the grid; the model is developed in the simulation tool MATLAB/SIMULINK and created as a modular structure. The pitch control system is used for stabilization of the wind turbine at grid faults. In this way, voltage stability of the system with grid-connected wind turbines can be improved by using blade angle control for a temporary reduction of the wind turbine power during a short-circuit fault in the grid.

Introduction: Variable speed ac drives have been used in the past to perform relatively undemanding roles in application which preclude the use of dc motors, either because of the working environment limits. Because of the high cost efficient, fast switching frequency static inverter. The lower cost of ac motors has also been a decisive economic factor in multi motor systems. However as a result of the progress in the field of power electronics, the continuing trend is towards cheaper and more effective power converters, and a single motor ac drives complete favorably on a purely economic basis with a dc drives.

Among the various ac drive systems, those which contain the cage induction motor have a particular cost advantage. The cage motor is simple and rugged and is one of the cheapest machines available at all power ratings. Owing to their excellent control capabilities, the variable speed drives incorporating ac motors and employing modern static converters and torque control can well complete with high performance four quadrant dc drives.

The Induction motors (IM) for many years have been regarded as the workhorse in industry. Recently, the induction motors were evolved from being a constant speed motors to a variable speed. In addition, the most famous method for controlling induction motor is by varying the stator voltage or frequency. To use this method, the ratio of the motor voltage and frequency should be approximately constant. With the invention of Field Orientated Control, the complex induction motor can be modeled as a DC motor by performing simple transformations. In a similar manner to a dc machine, in induction motor the armature winding is also on the rotor, while the field is generated by currents in the stator winding. However the rotor current is not directly derived from an external source but results from the emf induced in the winding as a result of the relative motion of the rotor conductors with respect to the stator field. In other words, the stator current is the source of both the magnetic field and armature current. In the most commonly used, squirrel cage motor, only the stator current can directly be controlled, since the rotor winding is not accessible. Optimal torque production condition are not inherent due to the absence of a fixed physical disposition between the stator and rotor fields, and the torque equation is non linear. In effect, independent and efficient control of the field and torque is not as simple and straightforward as in the dc motor.

Dynamic d-q Model:

R.H. Park in 1920's proposed a model for synchronous machine with respect to stationary reference frame. H.C. Stanley in 1930's proposed a model for induction machine with respect to stationary reference frame. Later G.Bryon's proposed a transformation of both stator and rotor variables to a synchronously rotating reference frame that moves with the rotating magnetic field. Lastly Krause and Thomas proposed a model for induction machine with respect to stationary reference frame.

Induction Machine Control:

Squirrel cage induction machines are simple and rugged and are considered to be the workhorses of industry. However, the control structure of an induction motor is complicated since the stator field is revolving, and further complications arises due to the fact that the rotor currents or rotor flux of a squirrel cage induction motor can not be directly monitored The mechanism of torque production in an ac machine and in a dc machine is similar. Unfortunately this similarity was not emphasized before the 1970s, and this is one of the reasons why the technique of vector control did not emerge earlier. The formulae given in many well known textbook of the machine theory have also implied that, for the monitoring of the instantaneous electromagnetic torque of an induction machine, it is also necessary to monitor the rotor currents and the rotor position. Even in the 1980s some publications seemed to strengthen this false conception, which only arose because the complicated formulae derived for the expression of the instantaneous electromagnetic torque have not been simplified. However by using fundamental physical laws or space vector theory, it is easy to show that, similar to the expression of the electromagnetic torque of a separately exited dc machine, the instantaneous electromagnetic torque of an induction motor can be expressed as the product of a flux producing current and a torque producing current, if a special flux oriented reference is used.

DC Drive Analogy:

Ideally, a vector controlled induction motor drive operates like a separately excited dc motor drive in fig 2.5. In a dc machine, neglecting the armature reaction effect and field saturation, the developed torque is given by

$$\mathbf{T_e = K_t\, \Psi_f\, \Psi_a = K_t' I_f\, I_a}$$

Where I_a= Armature Current

I_f = Field Current

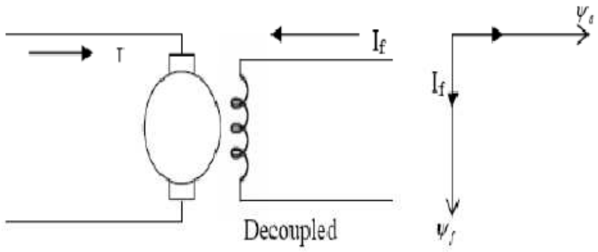


Fig 1: Separately excited DC motor

Principle of Vector Control:

The fundamentals of vector control implementation can be explained with the help of fig. 2.7 where the machine model is represented in a synchronously rotating reference frame. The inverter is omitted from the figure, assuming that it has unity current gain, that is, it generates currents i_a, i_b, and i_c *as* dictated by the corresponding commands currents i_a^*, i_b^* and i_c^* from the controller. A machine model with internal conversions is shown on the right. The machine terminal phase currents i_a, i_b, and i_c are converted to i_a^*, i_b^* and i_c^* component by 3Φ / 2Φ transformation.

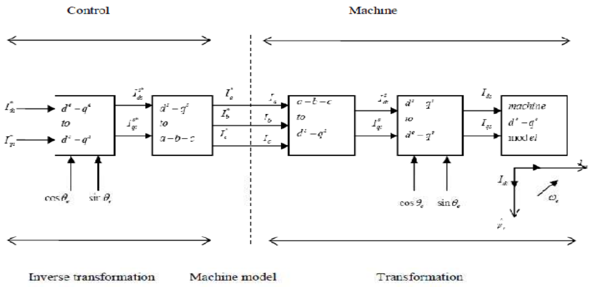


Fig 2.Vector control implementation principle with machine (d_e-q_e) model

Wind Turbine

Wind turbines convert aerodynamic power into electrical energy. In a wind turbine two conversion processes take place. The aerodynamic power (available in the wind) is first converted into mechanical power. Next, that mechanical power is converted into electrical power. Wind turbines can be either constant speed or variable speed generator. In this thesis only variable speed wind turbines will be considered.

Wind Turbine Basics:

The mechanical power produced by a wind turbine is proportional to the cube of the wind speed. The rotational speed of the wind turbine for which maximum power is obtained is different for different wind speeds. Therefore variable speed operation is necessary to maximize the energy yield. Variable speed turbines are connected to the grid via a PEC that decouples the rotational speed of the wind turbine from the grid frequency, enabling variable speed operation. Two basic concepts exist for variable speed turbines. The first concept has a electric generator with a converter connected between the stator windings and the grid network shown in Fig. 3.2(a). The converter has to be designed for the rated power of the turbine. The generator is mostly a (permanent magnet) synchronous machine. Some types do not have a gearbox: the direct-drive concept. An alternative concept is a wind turbine with a doubly-fed induction generator (DFIG), which has a converter connected to the rotor windings of the wound-rotor induction machine, in Fig. 3.2(b). This converter can be designed for a fraction (~ 30%) of the rated power.

System Configuration of a Variable-Speed DFIG Wind Turbine:

To simulate a realistic response of a DFIG wind turbine subjected to power system faults, the main electrical components as well as the mechanical parts and the controllers have to be considered in the simulation model. The applied DFIG wind turbine model is the same as described in [4], [5], and therefore only briefly described here. Fig.3.2 (b) illustrates the block diagram of the main components of DFIG based wind turbines:

- Drive train and aerodynamics
- Pitch angle control system

Drive Train and Aerodynamics*:* A simplified aerodynamic model is sufficient to illustrate the effect of the speed and pitch angle changes on the aerodynamic power during grid faults. This simplified aerodynamic model is typically based on a two-dimensional aerodynamic torque coefficient C_q-table [18], provided by a standard aerodynamic program.

In stability analysis, when the system response to heavy disturbances is analyzed, the drive train system must be approximated by at least a two mass spring and damper model [20]. The turbine and generator masses are connected through a flexible shaft, which is characterized by a stiffness *k* and a damping *c*. The idea of using a two-mass mechanical model is to get a more accurate response from the generator and the power converter during grid faults and to have a more accurate prediction of the impact on the power system.

Pitch angle control system: The pitch angle control is realized by a PI controller. In order to get a realistic response in the pitch angle control system, the servomechanism model accounts for a servo time constant T_{servo} and a limitation of both the pitch angle and its rate-of-change, as illustrated in Fig.3.1. A gain scheduling control of the pitch angle is implemented in order to compensate for the nonlinear aerodynamic characteristics [18].

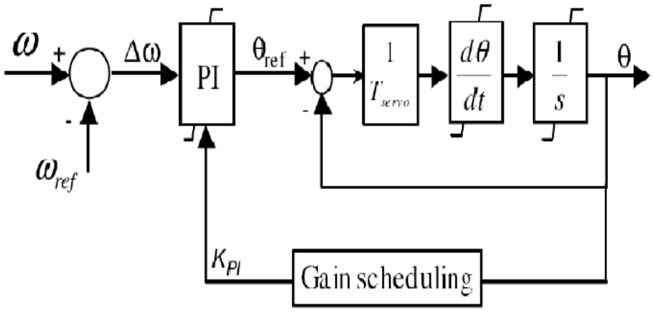


Fig 3. Pitch angle factor

Wind Turbine Modeling

In wind parks, many wind turbines are equipped with fixed frequency induction generators. Thus the power generated is not optimized for all wind conditions. To operate a wind turbine at its optimum at different wind speeds, the wind turbine should be operated at its maximum power coefficient ($C_{p.optimum}$= 0.3-0.5). To operate around its maximum power coefficient, the wind turbine should be operated at a constant tip-speed ratio, which is proportional to ratio of the rotor speed to the wind speed. As the wind speed increases, the rotor speed should follow the variation of the wind speed. In general, the load to the wind turbine is regulated as a cube function of the rotor rpm to operate the wind turbine at the optimum efficiency. The aerodynamic power generated by wind turbine can be written as:

$$P=0.5\rho A C_p V^3 \qquad (3.1)$$

Where the aerodynamic power is expressed as a function of the specific density **(ρ)** of the air, the swept area of the blades **(A)** and the wind speed (v). To operate the wind turbine at its optimum efficiency ($C_{p.optimum}$) the rotor speed must be varied in the same proportion as the wind-speed variation. If we can track the wind speed precisely, the power can also be expressed in terms of the rotor speed. The Simulink model is shown in fig. 3.3 by using equation [3.2] and generates the mechanical power.

$$P=K_p\omega^3 \qquad (3.2)$$

The power described by equation [3.2] will be called. This is the power to be generated by the generator at different rotor rpm. One way to convert a wind turbine from fixed speed operation to variable-speed operation is to modify the system from a utility-connected induction generator to a self excited operation. Ideally if the inertia of the wind turbine rotor is negligible, the rotor speed can follow the variation of the wind speed if the output power of the generator is controlled to produce the power-speed characteristic described in equation 3.2. Thus the wind turbine will always operate at ($C_{p.optimum}$). In reality, the wind turbine rotor has a significantly large inertia due to the blade inertia and other components

The wind turbine operation can only 30 in the vicinity ($C_{p.optimum}$). However, compared to fixed-speed operation, the energy captured in variable-speed operation is significantly higher.

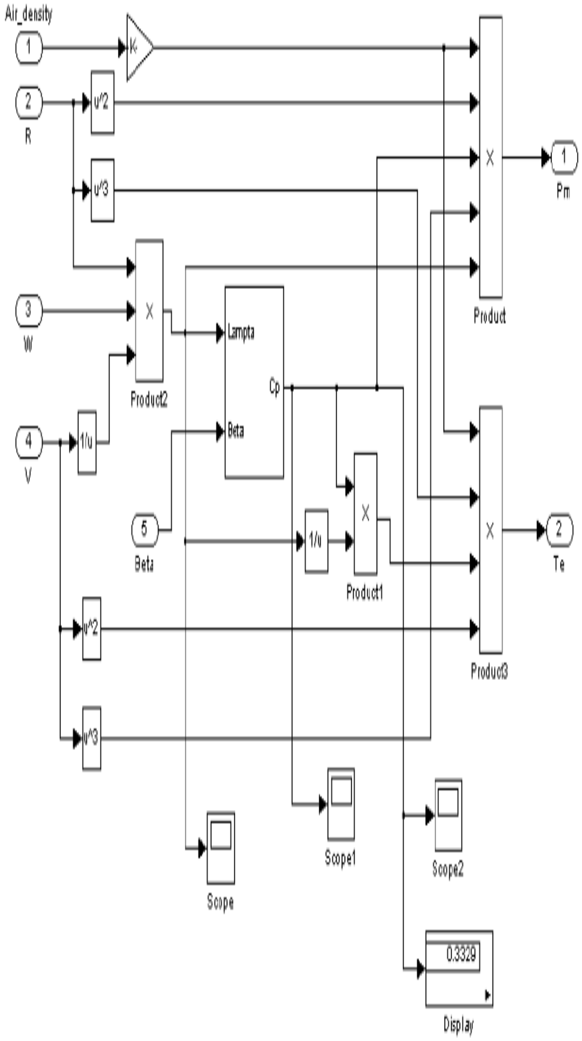


Fig 4 Simulink model, of wind turbine

With variable-speed operation and sufficiently large rotor inertia, there is a buffer between the energy source (wind) and energy sink (utility). Allowing the rotor speed to vary has the advantage of using the kinetic energy to be transferred in and out of the rotor inertia. Thus, the aerodynamic power that fluctuates with the wind input is filtered by the inertia before it is transmitted to the utility grid. This concept is very similar to the use of dc filter capacitor at the dc bus of a dc-dc converter. The dc capacitor filters the voltage ripple so that the voltage output presented to the load will be a smooth output voltage.

It is expected that the turbulent content in wind input will not be transmitted directly to the mechanical drives (gearbox) of the wind 31 turbines thus the mechanical stress and fatigues on mechanical components can be relieved. Thus, the lifetime of the mechanical drives and other components of the wind turbine can be extended by variable-speed operation.

Double Fed Induction Generator:

A double fed induction generator is a standard, wound rotor induction machine with its stator windings is directly connected to grid and its rotor windings is connected to the grid through an AC/DC/AC converter. AC/DC converter connected to rotor winding is called rotor side converter and another DC/AC is grid side converter. Doubly fed induction generator (DFIG), is used extensively for high-power wind applications (Fig. 3.4). DFIG‟s ability to control rotor currents allows for reactive power control and variable speed operation, so it can operate at maximum efficiency over a wide range of wind speeds. The research goal is to develop a control method and analysis to dynamic performance of DFIG‟s rotor control capabilities for unbalanced stator voltages, grid disturbances and dynamic load condition. This will allow DFIGs to stay connected to the grid under faulty conditions in which they would normally be disconnected for their own protection. In this thesis only rotor side converter control is considered. Grid side converter control is not considered in this analysis.

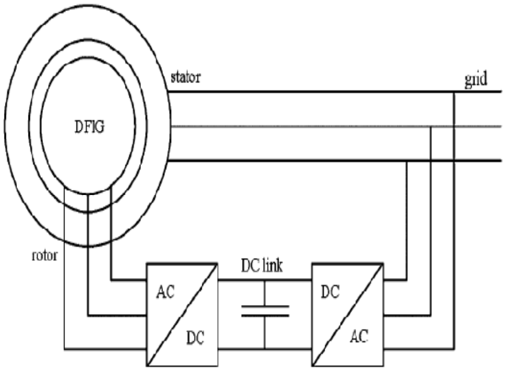


Fig 5 Double Fed Induction Machine

In modern DFIG designs, the frequency converter is built by self-commutated PWM converters, a machine-side converter, with an intermediate DC voltage link. Variable speed operation is obtained by injecting a variable voltage into the rotor at slip frequency. The injected rotor voltage is obtained using DC/AC insulated gate bipolar transistor based voltage source converters

(VSC), linked by a DC bus. By controlling the converters, the DFIG characteristics can be adjusted so as to achieve maximum of effective power conversion or capturing capability for a wind turbine and to control its power generation with less fluctuation.

Power converters are usually controlled utilizing vector control techniques [24], which allow decoupled control of both active and reactive power. In normal operation the aim of the rotor side converter is to control independently the active and reactive power on the grid, while the grid side converter has to keep the dc-link capacitor voltage at a set value regardless of the magnitude and the direction of the rotor power and to guarantee a converter operation with unity power factor (zero reactive power).

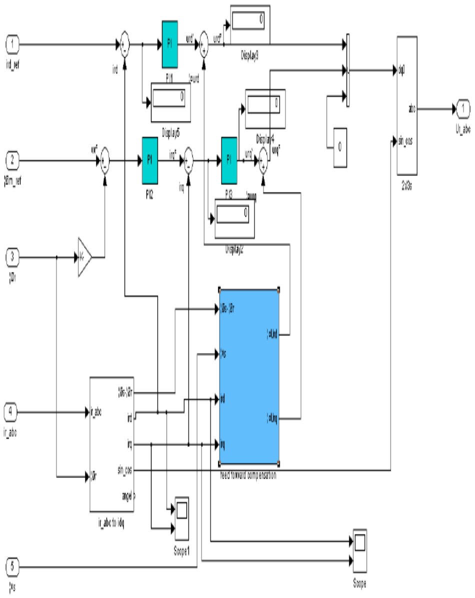
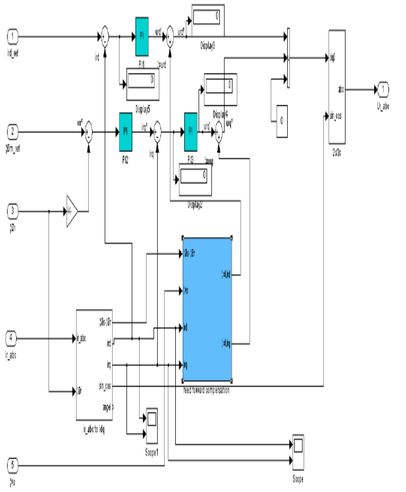


Fig 6 Simulink Model of Rotor Side Controller



DFIG Driven by dc Motor:

Double fed induction generator driven by the dc machine. The DC motor has decoupled with double fed induction generator in stead of wind turbine. The simulation model of DC motor with DFIG shown in fig. 3.9 In this thesis another one thing analyze in stead of wind turbine the prime mover of induction generator has been connected with DC motor. And observe that the characteristics of current component vector and electromagnetic torque almost same with and without grid fault condition.

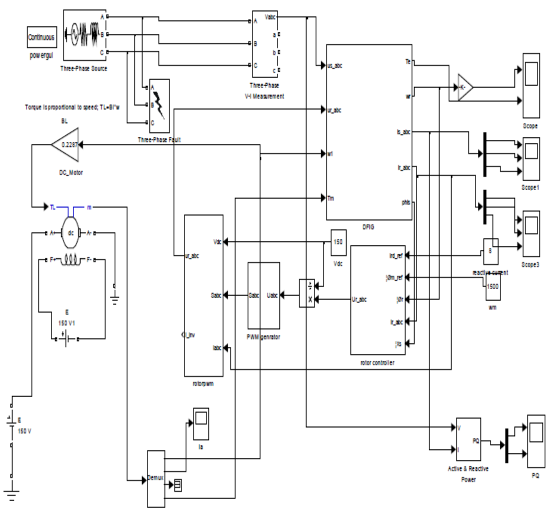


Fig. 7 Simulink Model of DFIG with DC Motor with Three Phase Fault

Double Fed Induction Machine Under Faults :

Consider DFIG in which, immediately after a 3-phase fault occurs, the stator voltage and flux reduces toward zero. The voltage drop depends, of course, on the location of the fault. The rotor current then increases to attempt to maintain the flux linkage within the rotor windings constant. DFIG under fault can be shown in fig. 4.1 However, for a DFIG the increase in the rotor current immediately after a fault will be determined by two factors. The first is the change in the stator flux and the second is the change in the rotor injected voltage.

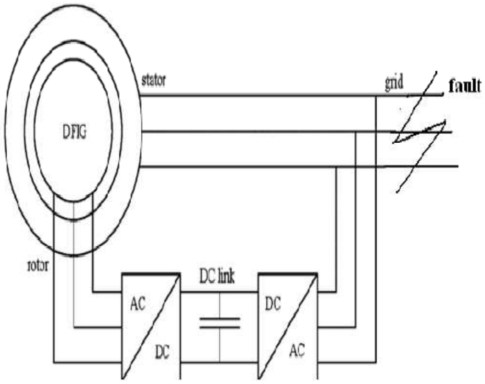


Fig. 8 Block Diagram of DFIG with Fault in Grid Side

Simulation Results

FREE ACCELERATION CHARACTERISTICS

Current component ~ Time

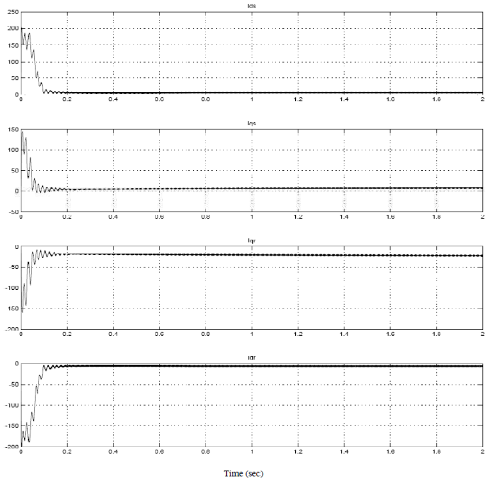
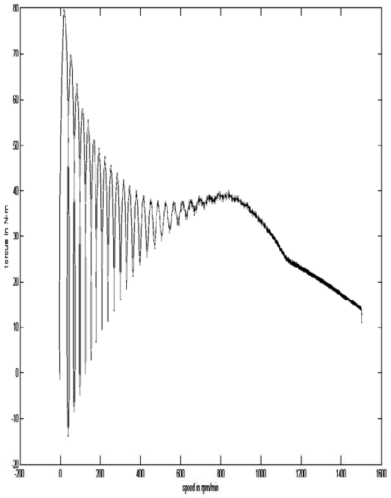


Fig. 4.1.1 Free Acceleration Characteristics of Current Component (i_{ds}, i_{qs}, i_{dr}, i_{qr})

2 Speed ~torque characteristics



4.1.2 Speed torque characteristics

Discussion:

The torque verses speed characteristics during free acceleration shown in fig. 4.1.2 when the induction generator is started, initially it shows transients and this region of operation is called as unstable region of operation due to inverting rotor voltage. After some time torque increases and a steady state is reached. Free acceleration with the reference frame of rotating in synchronism with the electrical speed of the applied voltage is shown in fig. 4.1.1 here the zero position of the reference is selected so that v_{qs} is the amplitude of the stator applied phase voltages and $v_{ds}=0$.

WIND TURBINE DFIG WITH NORMAL CONDITION

Stator currents time

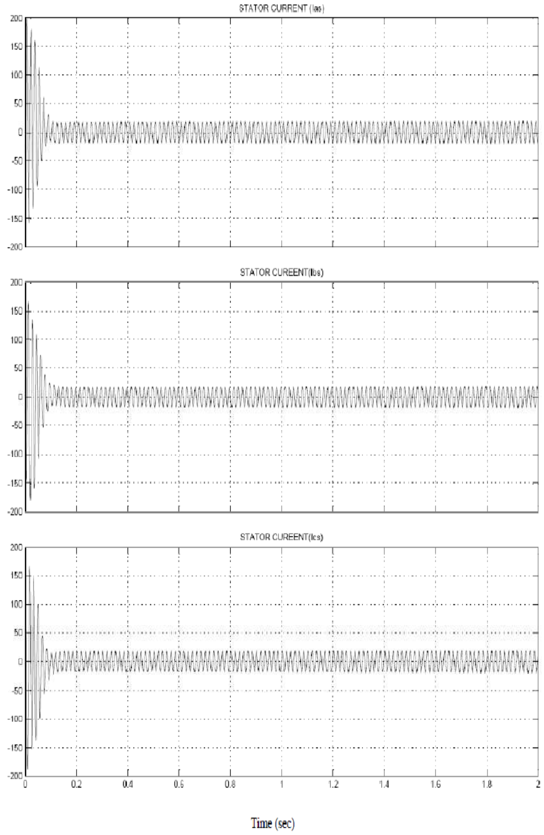


Fig .4.2.1 stator currents (i_{as}, i_{bs}, i_{cs}) during balance condition

Rotor currents ~time:

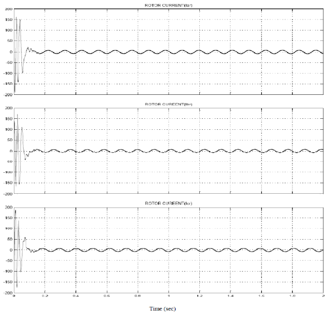


Fig. 4.2.2 rotor currents (i_{ar}, i_{br}, i_{cr}) during balance condition

Speed and electromagnetic ~torque time:

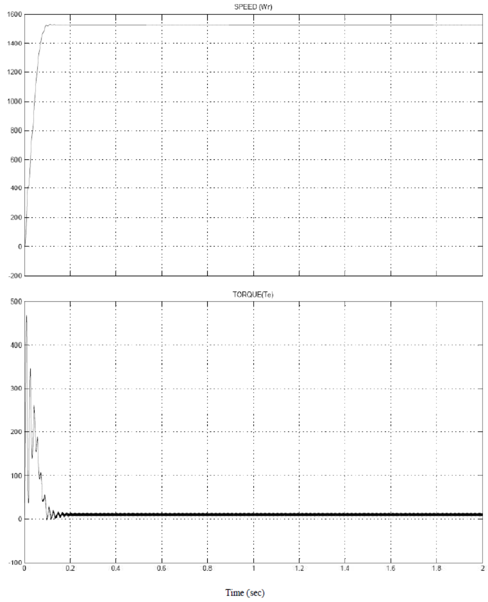


Fig. 4.2.3 speed and torque (ω_r, T_e) during balance condition

Power characteristics ~time:

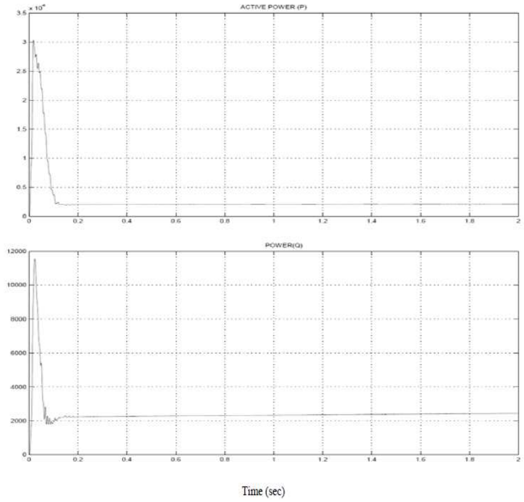


Fig.4.2.4 active power (P) and reactive power (Q) during balance condition

Discussion:

The transient torque and speed characteristics with time are different from the steady state torque and speed characteristics with time shown in fig.4.2.3 in several respects. The instantaneous electromagnetic torque following the application of the stator voltages varies at 60Hz about an average positive value. The decaying, 60 Hz variation in instantaneous torque is due to the transient offset in stator currents. Although the offset in each of the currents depends upon the value of source voltage at the time of application, the instantaneous torque is independent of the initial values of balanced source voltage because the machine is symmetrical.

We also note from the currents plots shown in fig. 4.2.1 and fig. 4.2.2 that the envelope of the machine currents varies during transient period. It is shown in a subsequent that this due to the interaction of the stator and rotor electric transients.

WIND TURBINE DFIG DURING GRID FAULT

Stator voltages ~ time

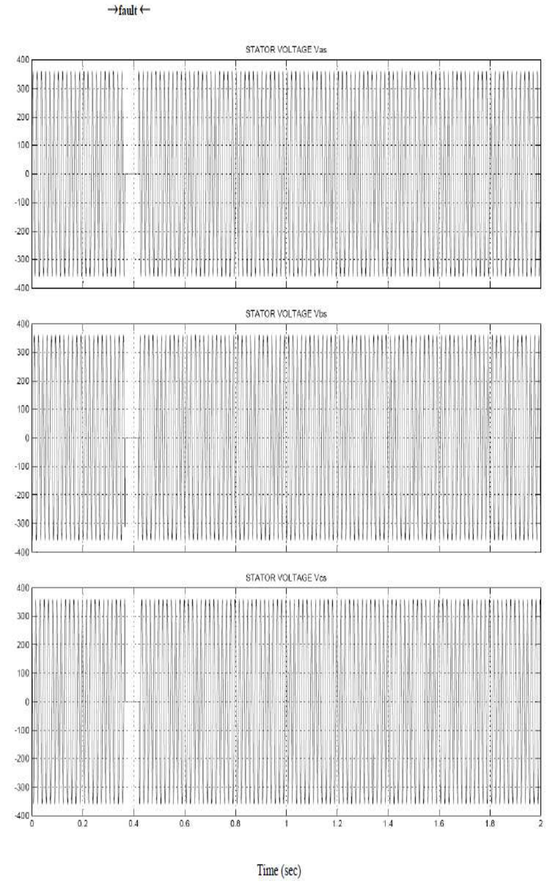


Fig. 4.3.1 stator voltages v_{as},v_{bs},v_{cs} during grid fault

Stator currents ~ time

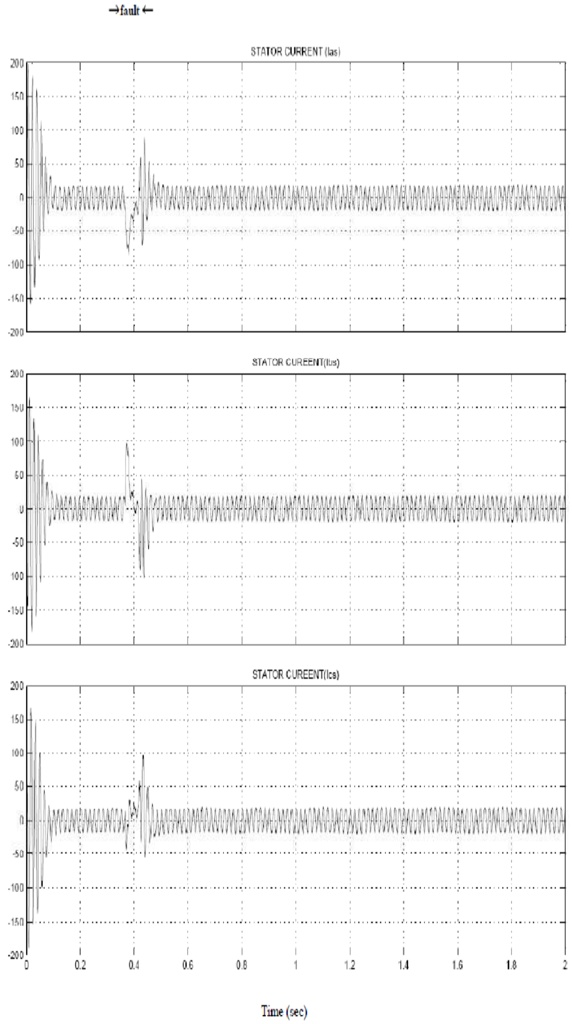


Fig 4.3.2 stator currents (i_{as}, i_{bs}, i_{cs}) during grid fault

Rotor currents~ time:

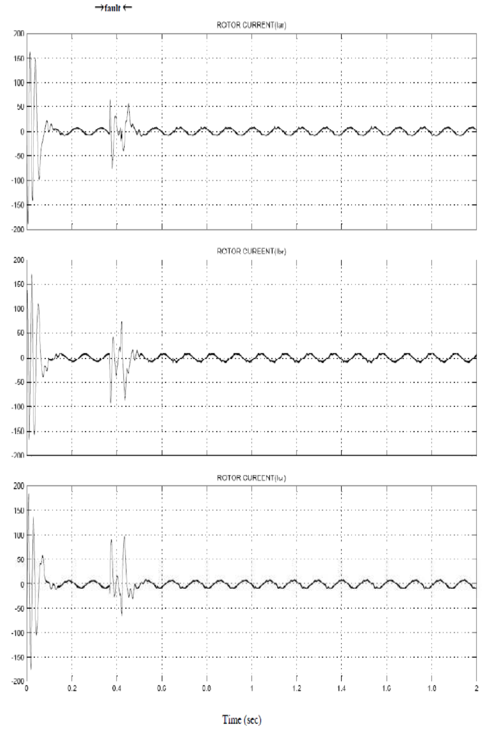


Fig. 4.3.3 rotor currents (i_{ar}, i_{br}, i_{cr}) during grid fault

Speed and electromagnetic torque~ time:

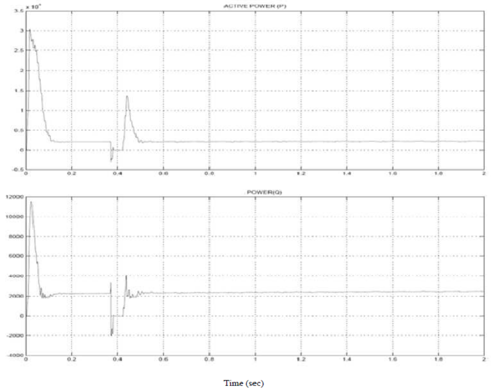


Fig. 4.3.4 speed and torque (ω_r, T_e) during fault condition

Power characteristics~ time:

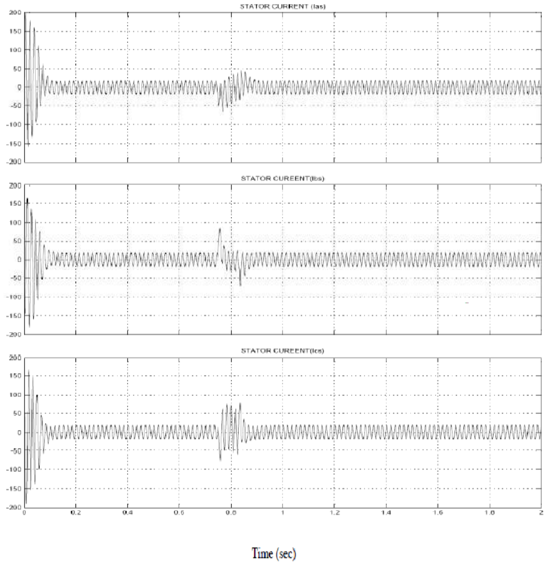


Fig.4.3.5 active power (P) and reactive power (Q) during fault condition

Discussion:

The dynamic performance of the induction generator is shown respectively in figures 4.3.2, 4.3.3, 4, and 5 during a 3 phase fault at terminals. Initially generator is operating at essentially rated condition with a load torque to base torque. The 3-phase fault at the terminals is simulated by setting $v_{as,}$ v_{bs}, v_{cs} to zero at the instant v_{as} passes through zero going positive. After few cycle the source voltage reapplied. The stepping of the terminal voltages to zero shown in fig. 5.3.1 at the time of the fault shown in figures gives rise to decaying in both stator and rotor currents shown in fig. 4.3.2, fig.4.3.3.

These transient offsets in the stator currents appear in the rotor circuits as decaying oscillations of near 60hz(because the rotor speed is slightly less than synchronous) shown fig 4.3.4 which are superimposed upon the transients of the rotor circuits. Similarly the transient offset in the rotor currents appears as decaying to the rotor speed. In case of these machines, both stator and rotor transient are highly damped and subside before the fault is removed and the voltages reapplied. The electromagnetic torque is, of course damping in fig. 4.3.4.

WIND TURBINE DFIG DURING UNBALANCE CONDITION

Condition – 1 when the sudden change of dynamic load is applied for few cycles.

4.4.1 Stator currents ~time

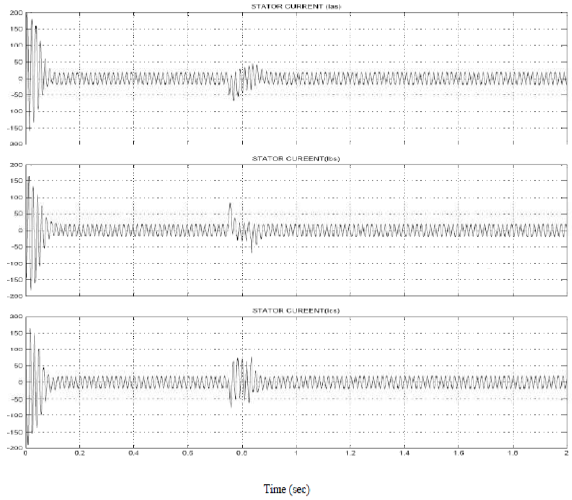


Fig 4.4.1 stator currents ($i_{as,}$ $i_{bs,}$$i_{cs}$) during dynamic loading

Rotor currents ~ time

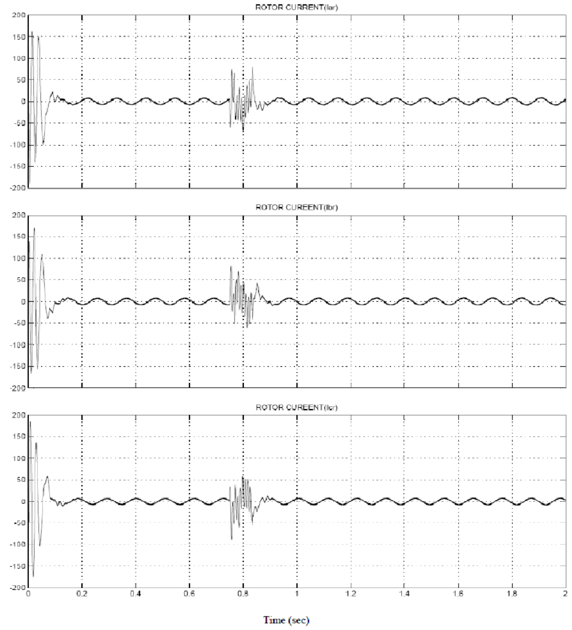


Fig. 4.4.2 rotor currents (i_{ar}, i_{br}, i_{cr}) during dynamic loading

Speed and electromagnetic torque~ time:

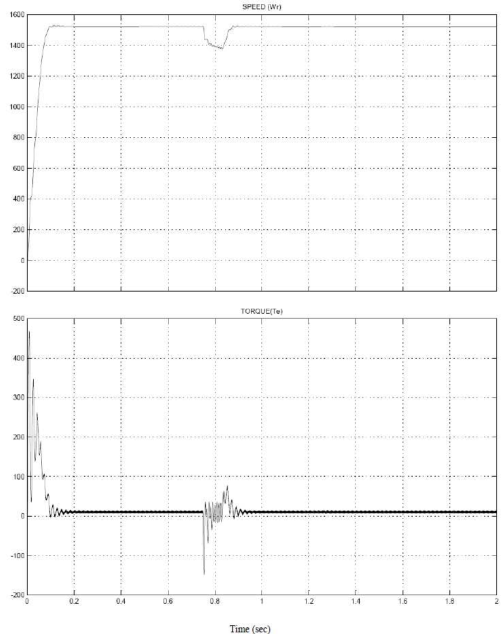


Fig. 4.4.3 speed and torque (ω_r, T_m) during dynamic loading

Power characteristics~ time

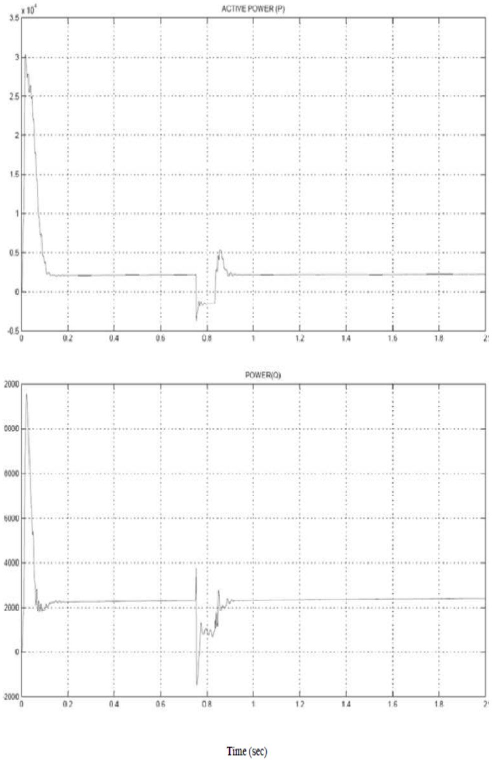


Fig.5.4.4 active power (P) and reactive power (Q) during dynamic loading

Condition 2 when the voltage sag (voltage dip) is created for a little cycle. It is a sudden reduction (between 10% and 90%) of terminal voltage.

Stator voltages ~time:

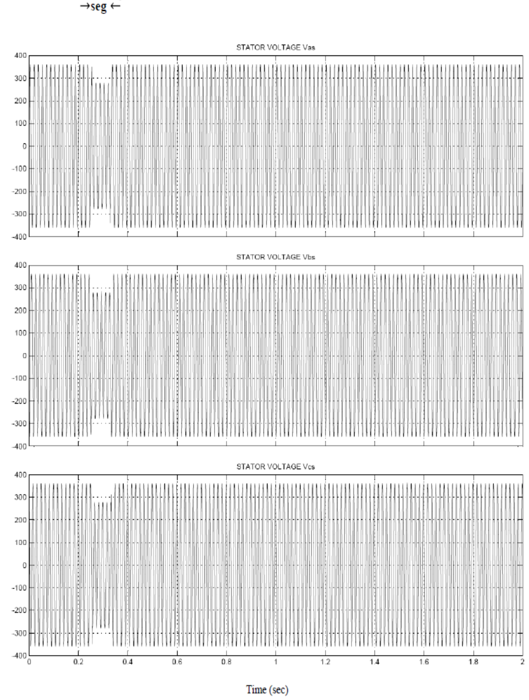


Fig. 4.4.5 stator voltages $v_{as,}$ v_{bs}, v_{cs} during voltage dip

Stator currents time:

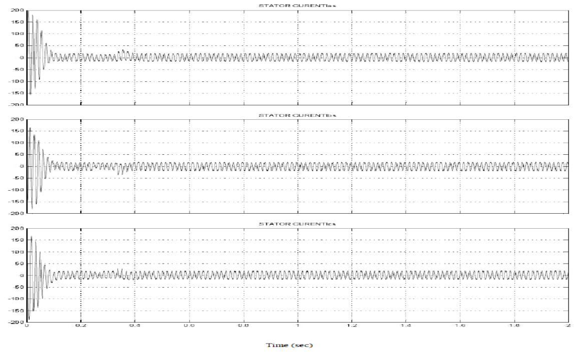


Fig 4.4.6 stator currents ($i_{as,}$ i_{bs}, i_{cs}) during voltage dip

Rotor currents~ time

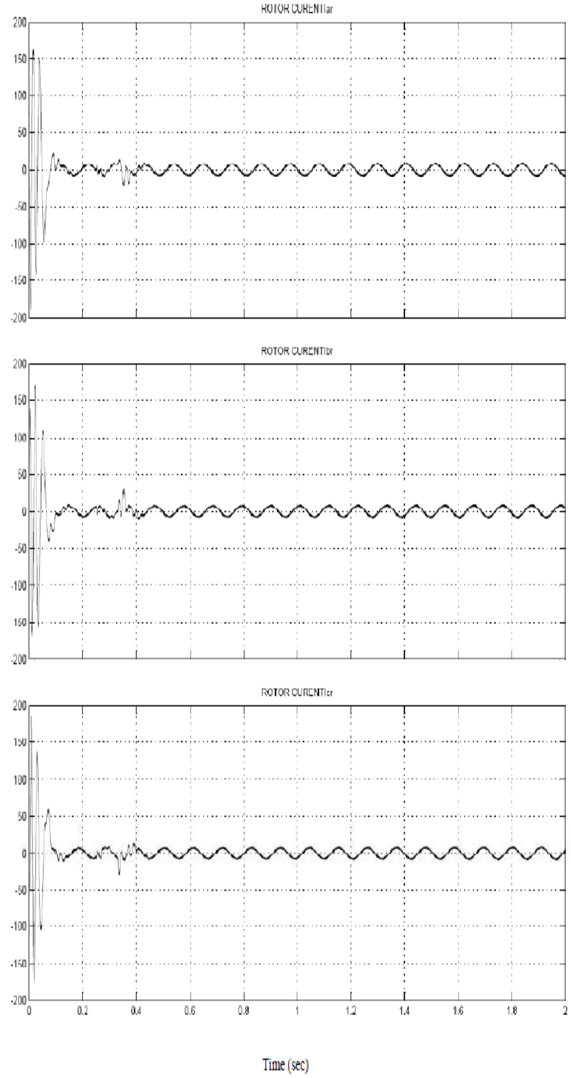


Fig. 4.4.7 rotor currents (i_{ar}, i_{br}, i_{cr}) during voltage dip

Speed and electromagnetic torque~ time

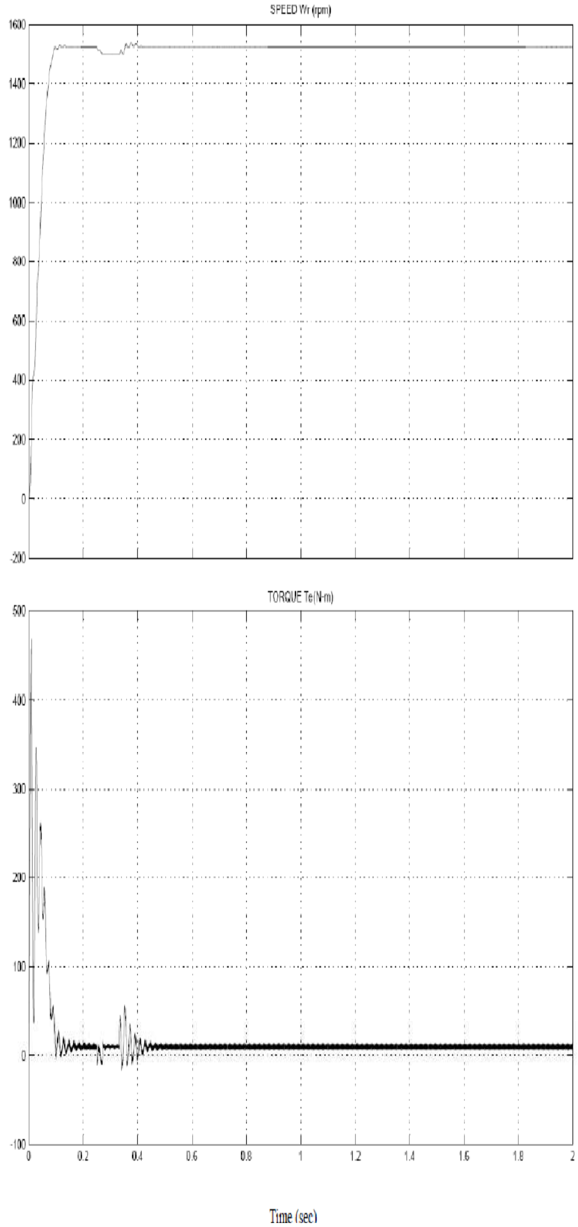


Fig. 4.4.8 speed and torque (ωr, Te) during voltage dip

4.4.9 Power characteristics~ time

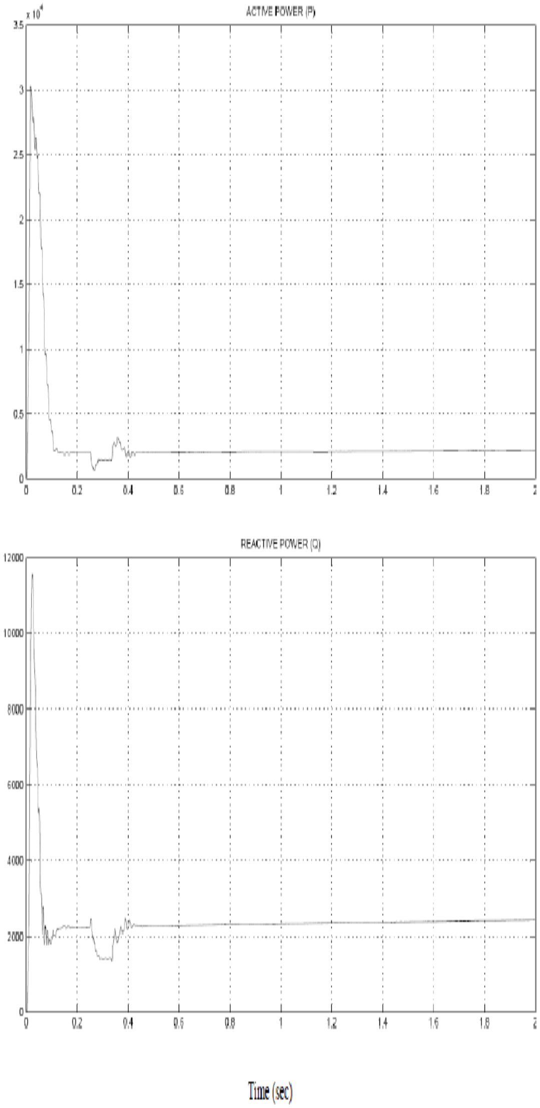


Fig.4.4.9 Active Power (P) and Reactive Power (Q) During Voltage Dip

Discussion:

The dynamic behavior of the machine during sudden changes in load shown in fig. 4.4.1. 4.4.2., 4.4.3 and 4.4.4 respectively. Initially the generating operating at synchronous speed. The load torque is first stepped from zero to base torque (slightly less than rated) and the generator allowed establish this new operating point. Next the load torque is stepped from base torque back to zero whereupon the generator reestablishes its original operating condition. The variable of the machine approach each new operating in an over damped manner. In previous section we found the generator the steady state (balance condition) the torque and speed characteristics nearly same as the free acceleration characteristics. Here we are not surprised to find that dynamics during load changes can be predicted adequately by normal condition speed and torque curves. Due to load changes the terminal voltage is reduced it is depends on the type of load. Therefore the stator current and rotor current increases instantaneously. It is shown in figures 4.4.1 and 4.4.2 and the next unbalance condition by reduction 10% to 90 % of voltage (voltage sag) shown in fig. 4.4.5 here be can observe the small dynamics as compare to step changes load shown in fig. 4.4.6 , 4.4.7 , 4.4.8, 4.4.9

DC MACHINE COUPLED WITH DFIG DURING FAULT CONDITION

Stator currents time :

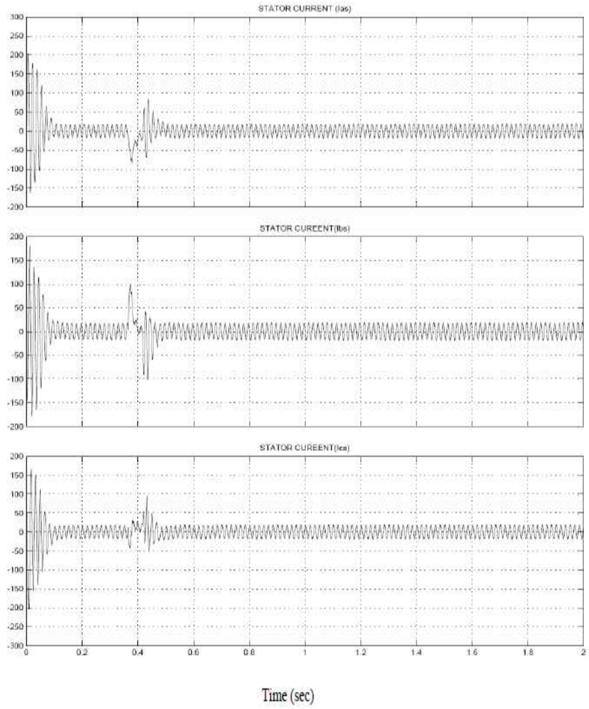


Fig 4.5.1 Stator Currents (i_{as}, i_{bs}, i_{cs}) During Fault Condition

Rotor currents ~ time:

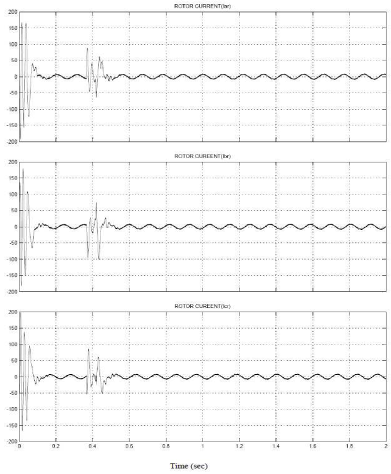


Fig. 4.5.2 rotor currents (i_{ar}, i_{br}, i_{cr}) during fault condition

Speed and electromagnetic torque ~ time

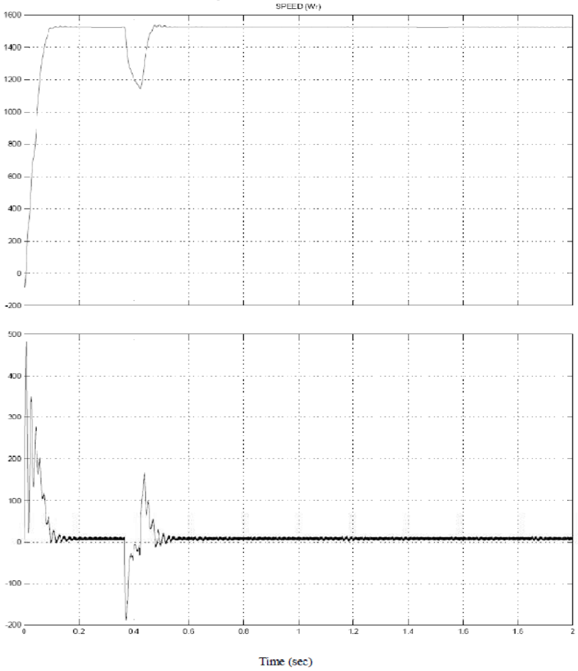


Fig. 4.5.3 Speed and Torque (ω_r, T_e) During Fault Condition

Power characteristics ~ time

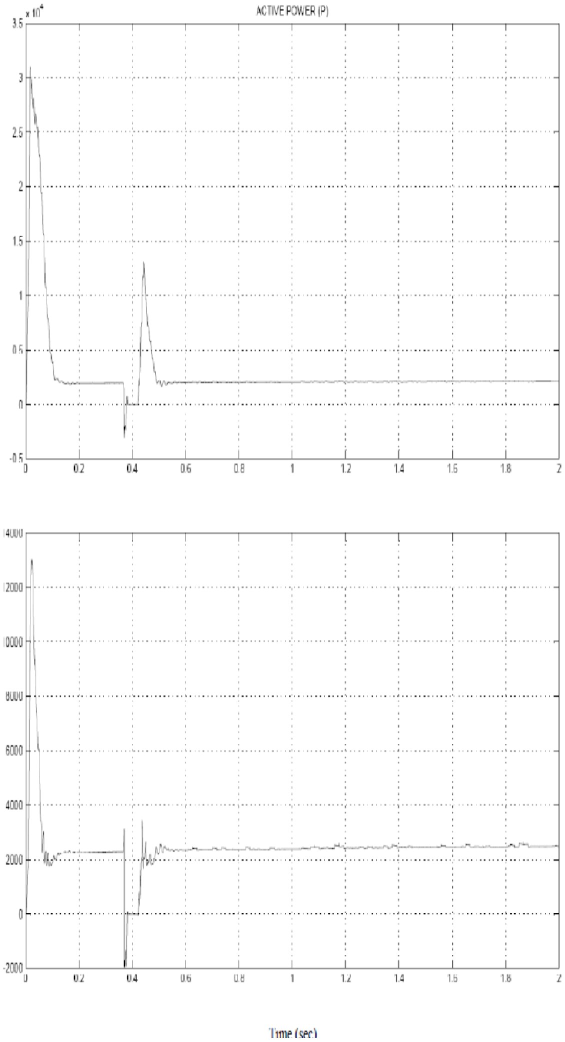


Fig.4.5.4 Active Power (P) and Reactive Power (Q) During Fault Condition

ISSN: 2277-9655

DC MACHINE COUPLED WITH DFIG DURING UNBALANCE CONDITION

Stator currents time

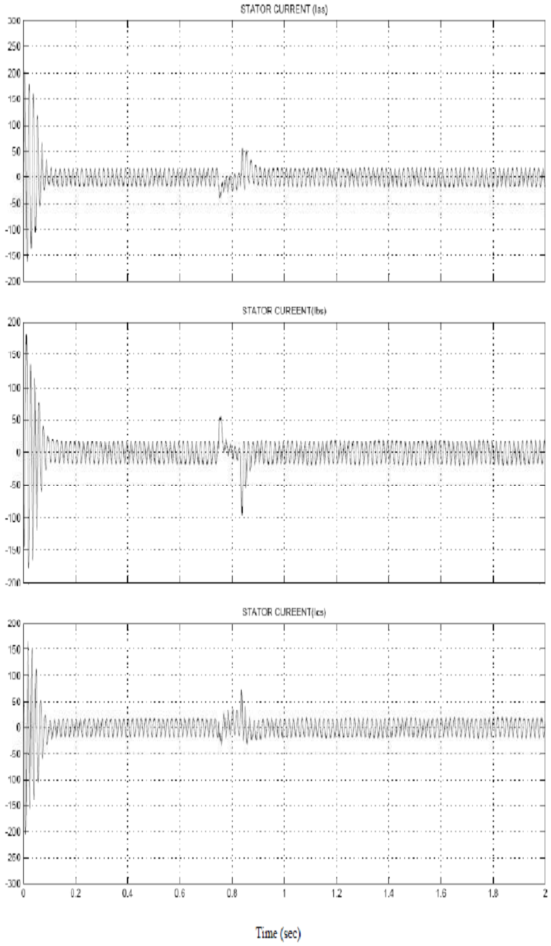


Fig 4.6.1 Stator Currents (i_{as}, i_{bs}, i_{cs}) During Unbalance Condition

Rotor currents ~ time

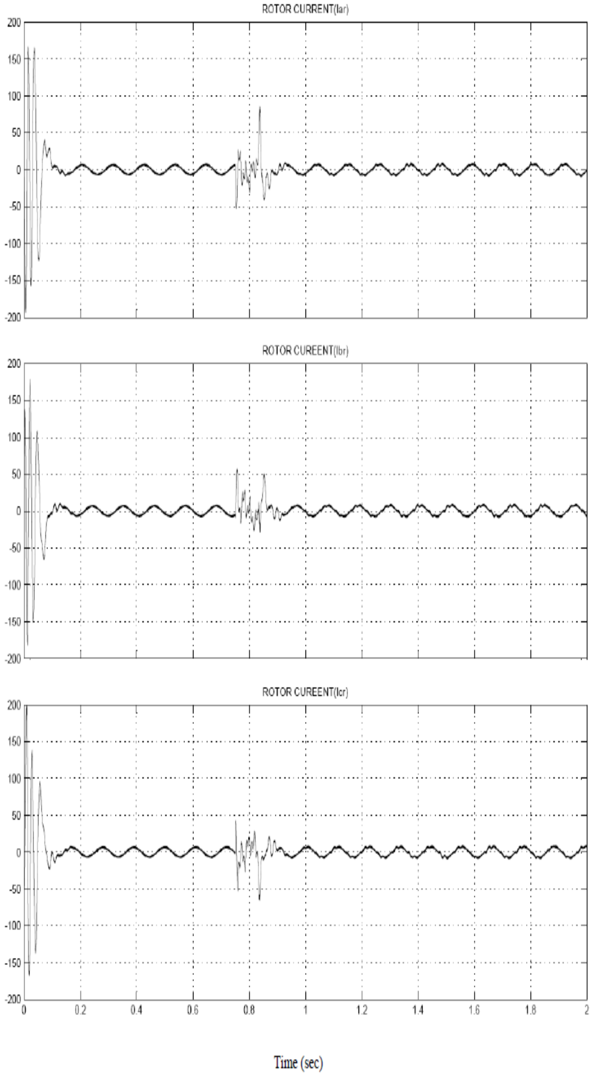


Fig. 4.6.2 Rotor Currents (i_{ar}, i_{br}, i_{cr}) During Unbalance Condition

Speed and electromagnetic torque ~ time

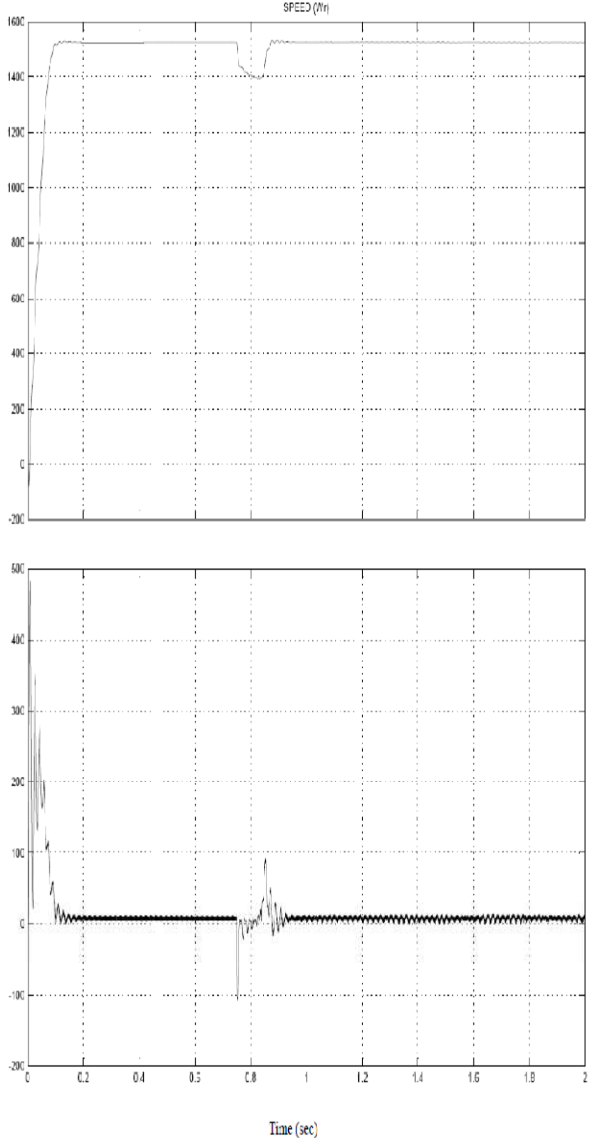


Fig. 4.6.3 Speed and Torque (ω_r, T_e) During Unbalance Condition

Power characteristics ~ time

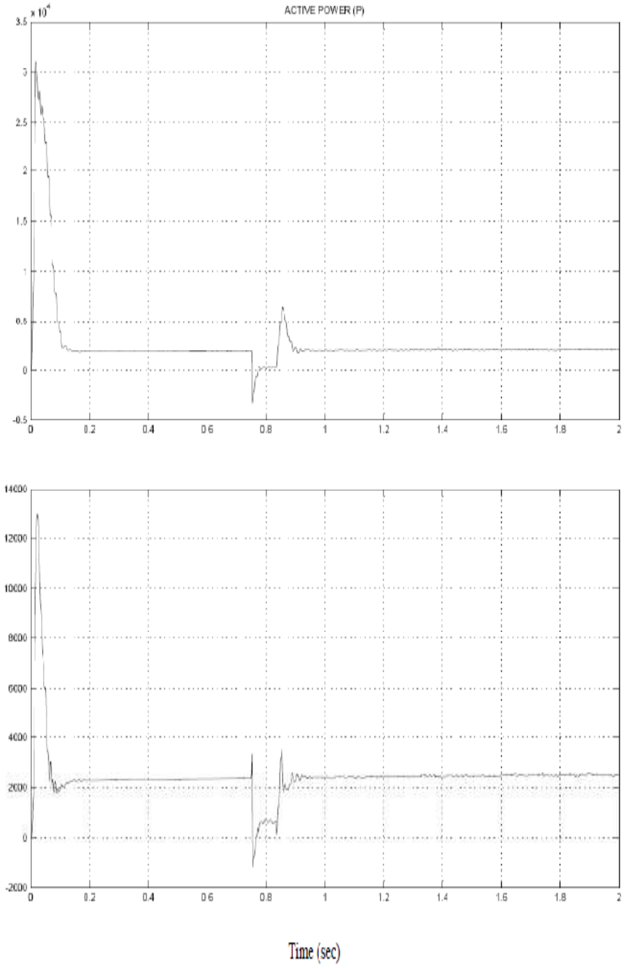


Fig.4.6.4 Active Power (P) and Reactive Power (Q) During Unbalance Condition

Discussion:

The dynamic performance of the induction generator coupled with dc machine is shown in figures of section 5.5 and 5.6 respectively during a 3 phase fault and step changes in load. Similarly as in previous section initially generator is operating at essentially rated condition with a load torque to base torque. Dynamic performances of wind turbine with DFIG and dc machine coupled with DFIG are some different transient because of dc machine has different time constant.

Conclusion

This thesis presents a study of the dynamic performance of variable speed DFIG coupled with either wind turbine or a dc motor and the power system is subjected to disturbances; such as voltage sag, unbalanced operation or short circuit faults. The dynamic behavior of DFIG under power system disturbance was simulated both using MATLAB coding and MATLAB/SIMULINK platform using matrix /vector space control concept. Accurate transient simulations are required to investigate the influence of the wind power on the power system stability.

The DFIG considered in this analysis is a wound rotor induction generator with slip rings. The stator is directly connected to the grid and the rotor is interface via a back to back partial scale power converter (VSC). Power converter are usually controlled utilizing vector control techniques which allow the decoupled control of both active and reactive power flow to the grid. In the present investigation, the dynamic DFIG performance is presented for both normal and abnormal grid conditions. The control performance of DFIG is satisfactory in normal grid conditions and it is found that, both active and reactive power maintains a study pattern in spite of fluctuating wind speed and net electrical power supplied to grid is maintained constant. During grid disturbance, considerable torque pulsation of DFIG and torsion oscillation in drive train system has been observed.

The detailed results of steady state and faulty or unbalance grid conditions has been noted and analyzed in chapter 5 with proper justification. In view of that, future scope aims to

- Develop a controller, which can effectively improve the dynamic stability, transient response of the system during faulty grid conditions.
- To develop a protection system for power converter and DFIG for large disturbances like 3-phase fault of little cycle duration as the power converter is very sensitive to grid disturbance.

References

[1] Ned Mohan, Ted K. A. Brekken "Control of a Doubly Fed Induction Wind Generator Under Unbalanced Grid Voltage Conditions" IEEE Transaction Energy conversion, vol.no22. 1, march 2007 page 129-135.

[2] Y. Zhou, P. Bauer "Control of DFIG under Unsymmetrical Voltage dips" Power Electronics Specialists Conference, 2007. PESC 2007. IEEE 17-21 June 2007 Page(s):933 – 938

[3] A. Beugniez, T. Ghennam "Centralized supervision of reactive power generation for a wind farm" Power Electronics & Application European conference on 2-5 sep 2007. On page(s): 1-10 ISBN: 978-92 75815-10-8 [4] Jesus Lopez, Pabolo Sanchis "Control of DFIG under Symmetrical Voltage dips" IEEE july 2008. Page(s) 2456-2462.

[4] Rubén Penaa, Roberto Cardenasb,∗, Enrique Escobarb, Jon Clarec, Pat Wheelerc "Control strategy for a Doubly-Fed Induction Generator feeding an unbalanced grid or stand-alone load" Electric Power Systems Research (2009) 355–364.vol.79

[5] Johan Morren, Sjoerd W. H. de Haan, "Ridethrough of Wind Turbines with Doubly-Fed Induction Generator During a Voltage Dip" IEEE transaction on energy conversion june, 2005 pages 435-441 vol. 20.

[6] Sae-Kok, W.,Grant, D.M. "Open Switch Fault Diagnosis for a Doubly-Fed Induction Generator" Power Electronics and Drive Systems, IEEE 2007. PEDS '07. 7th International Conference on 27-30 Nov. 2007 Page(s):131 – 138

[7] L. Dusonchet, F. Massaro and E. Telaretti "Transient stability simulation of a fixed speed wind turbine by Matlab/Simulink"

[8] Zhixin Miao, Lingling Fan " the art of modeling and simulation of induction generator in wind generation application" simulation modling practice and theory 16 (2008) 1239-1253, science direct.

[9] Ruben Pena , Roberto Cardenas , Jon Clare "Control strategy for a DFIG feeding unbalances grid or stand alone load" Electric Power System Research 79(2009) 355-364 science direct.

[10] Wei Qiao; Harley, R.G "Improved Control of DFIG Wind Turbines for Operation with Unbalanced Network Voltages" Industry Applications Society Annual Meeting, 2008. IAS '08. IEEE 5-9 Oct. 2008 Page(s):1 – 7 75

[11] Johan Morren , Sjoerd W. H. de Haan " Ride through of Wind Turbines with Doubly-Fed Induction Generator During a Voltage Dip" IEEE Transaction on energy conversion, VOL. 20, NO. 2, JUNE 2005 435-441

[12] Anca D. Hansen , Gabriele Michalke " fault ride through capability of DFIG wind

turbine" Renewable energy 32 (2007) 1594-1610 Science Direct

[13] Ekanayake, J.B.; Holdsworth, L.; XueGuang Wu; Jenkins, N "Dynamic Modeling of Doubly Fed Induction Generator Wind Turbines".; Power Systems, IEEE Transactions on Volume 18, Issue 2, May 2003 Page(s):803 – 809

[14] Shuhui Li , Haskew T. A. "Analysis of Decoupled d-q Vector Control in DFIG Back-to-Back PWM Converter" Power Engineering Society General Meeting 2007 IEEE Publication Date: 24-28 June 2007

[15] B. K. Bose "Modern power electronics and ac drives" forth impression 2007 Pearson Prentice Hall, ISBN: 81-7758-876-1, 2007.

[16] Paul C. Krause ,Oleg Wasynczuk "Analysis of electrical machines & Drive system" IEEE, ISBN 9812-53-150-2,2007.

[17] Hansen A.D., Jauch C., Sørensen P., Iov F., Blaabjerg F, "Dynamic wind turbine models in power system simulation tool DIgSILENT", Risø-R-1400(EN), 2003.

[18] Hansen A.D., Sørensen P., Iov F., Blaabjerg F., "Centralised power control of wind farm with doubly-fed induction generators." Renewable Energy, 2006, vol. 31, pp 935-951.

[19] Akhmatov V., "Analysis of dynamic behavior of electric power systems with large amount of wind power." PhD thesis, 2003, Ørsted DTU.

[20] Holdsworth L., Charalambous I., Ekanayake J.B., Jenkins N., "Power system fault ridethrough capabilities of induction generator based wind turbines." Wind Engineering, Vol. 28, No 4, 2004, pp 399-412.

[21] Sun T., Chen Z., Blaabjerg F., "Transient stability of DFIG Wind Turbines at an External Short-circuit fault." Wind Energy 2005, No 8, 2005, pp 345-360.

[22] Akhmatov V., "Variable-speed wind turbines with doubly-fed induction generators. Part IV: Uninterrupted operation features at grid faults with converter control coordination." Wind Engineering, Vol. 27, No.6, 2003, pp 519-529.

[23] Heier S., "Grid Integration of Wind Energy Conversion Systems", 1998, ISBN 0 471 97143.