IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 1, Issue 4, Aug-Sept, 2013
ISSN: 2320 - 8791
www.ijreat.org

Control of Double Fed Induction Wind Generator Using Vector Control Computing Technique under Fault Conditions

B V S Prahasith dasari, M.Tech,
Assistant professor, St.Ann's college of Engineering & Technology, Chirala, A.P.

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 number of renewable energy units are 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 this paper. 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.*

NOMENCLATURE

v_{ds} ,v_{qs}Stator dand qwinding voltage.
i_{ds} , i_{qs}Stator and qwinding current.
v_{dr},, v_{qr}Rotor d and q winding voltage.
i_{dr} ,i_{qr}Rotor d and q winding current.
Ψ_{ds}, Ψ_{qs} Stator d and q winding flux linkage.

Ψ_{dr} Ψ_{qr}Rotor d and q winding flux linkage

T_e Electromagnetic Torque
T_mMechanical torque
Q_sStator reactive power.
P_s Stator active power
L_m Generator magnetizing inductance.
L_s,L_rStator and rotor per phase winding inductance.
L_{ls},L_{lr}Stator and rotor per phase leakage inductance.
R_s,R_rStator and rotor per phase winding resistance.
P Number of generator poles.
H System moment of inertia.
B System frictional constant.
W Synchronous rotational speed (50 Hz).
W_r Rotor mechanical speed.
W_b Base speed

I.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 problemsassociated 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.

II. 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

IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 1, Issue 4, Aug-Sept, 2013
ISSN: 2320 - 8791
www.ijreat.org

either constant speed or variable speed generator. In this paper only variable speed wind turbines will be considered.

A. 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 2 (b) illustrates the block diagram of the main components of DFIG based wind turbines:

a) *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.

b) *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. A gain scheduling control of the pitch angle is implemented in order to compensate for the nonlinear aerodynamic characteristics.

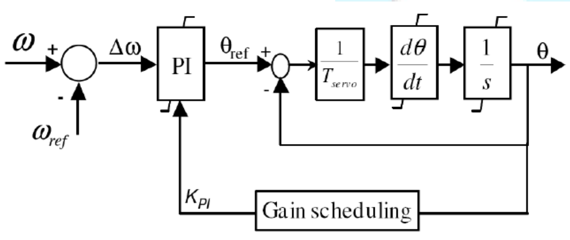

Fig 1 Pitch Angle Factor

The rate-of-change limitation is very important during grid faults, because it decides how fast the aerodynamic power can be reduced in order to prevent over-speeding during faults. In this work, the pitch rate limit is set to a typical value of 10 deg/s.

Note that the pitch angle control prevents over-speeding both in normal operation and during grid faults, due to the fact that the pitch angle controls directly the generator speed. In case of over-speeding, the aerodynamic power is automatically reduced while the speed is controlled to its rated value. This means that there is no need to design an additional pitch control solution as it is done in [21] and [22] to improve the dynamic stability during grid fault.

B.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).

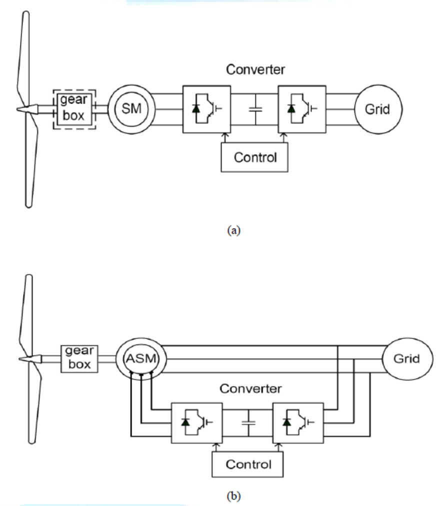

Fig 2 a) Variable speed-wind turbinesWith full size converter
b) with doubly-fed induction generator

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:

$$P=0.5\rho AC_p V^3 \qquad (1)$$

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 by using equation [2] and generates the mechanical power.

$$P=K_p\omega^3 \quad (2)$$

The power described by equation [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.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 operations 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.

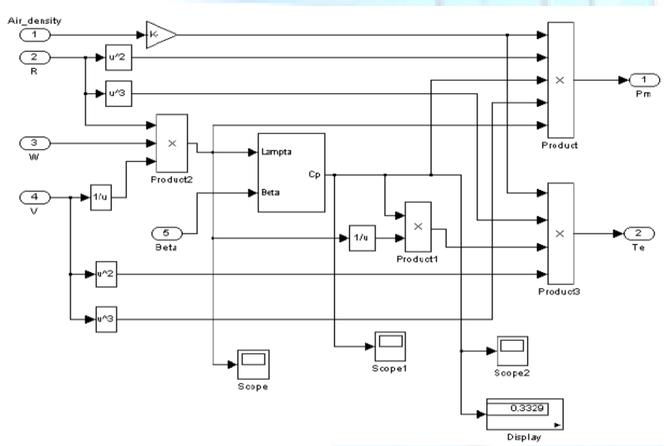

Fig 4 Simulink model of wind turbine

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.

C. 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. 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 DFIGs 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 paper only rotor side converter control is considered. Grid side converter control is not considered in this analysis.

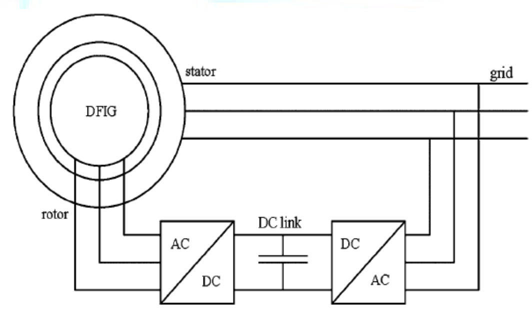

Fig 5 Double Fed Induction Machine

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).

Many different d-q control algorithms have been proposed and used for controlling the DFIG machine and grid-side converters for obtaining certain dynamic and transient performance of DFIGs.

Most of them are based on a real and reactive power control concept, a popular DFIG converter control mechanism used in modern wind turbines. This control configuration is usually divided into machine and grid-side converter controls. The rotor-side converter controls the active and reactive power of the DFIG independently, and the grid-side converter is controlled in such a way as to maintain the DC-link capacitor voltage in a set value and to maintain the converter operation with a desired power factor.

The rotor side controller, consisting of a reactive power controller and an active power controller, is commonly a two stage controller as shown in Fig 5 and also shown in Fig.6 the simulink model in MATLAB/SIMULINK.

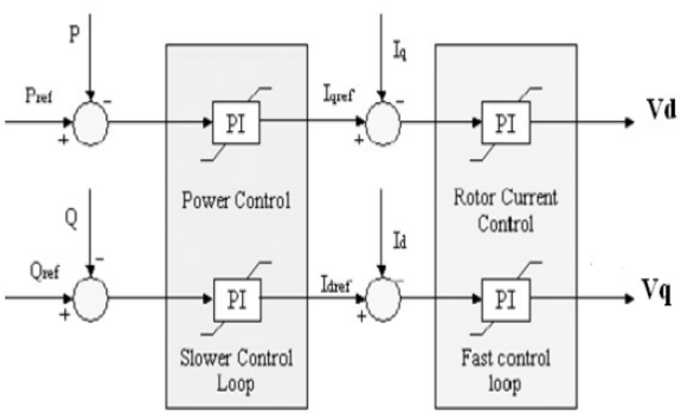

Fig 6 DFIG Rotor Side Controller

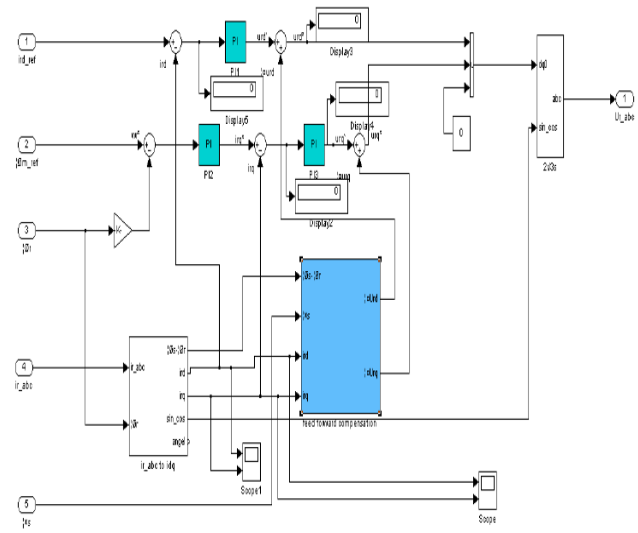

Fig .7 Simulink Model of Rotor Side Controller

It operates in either stator flux or stator-voltage oriented reference frame and hence the q-axis current component represents active power and the d-axis component represents reactive power. The two controllers in the machine-side controller determine inverter d- and q-voltages by comparing the d- and q-current set points to the actual d- and q- currents of the induction machine.

i) Modeling of DFIG

The voltage equations of an induction machine in an arbitrary reference frame can be written in terms of the currents as shown in Eq. (3)

$$\begin{bmatrix} v_{qs} \\ v_{ds} \\ v_{0s} \\ v'_{qr} \\ v'_{dr} \\ v'_{0r} \end{bmatrix} = \begin{bmatrix} R_s + \frac{P}{\omega_b}X_{ss} & \frac{\omega}{\omega_b}X_{ss} & 0 & \frac{P}{\omega_b}X_m & \frac{\omega}{\omega_b}X_m & 0 \\ -\frac{\omega}{\omega_b}X_{ss} & R_s + \frac{P}{\omega_b}X_{ss} & 0 & -\frac{\omega}{\omega_b}X_m & \frac{P}{\omega_b}X_m & 0 \\ 0 & 0 & R_s + \frac{P}{\omega_b}X_{ls} & 0 & 0 & 0 \\ -\frac{P}{\omega_b}X_m & \frac{\omega-\omega_r}{\omega_b}X_m & 0 & R_r + \frac{P}{\omega_b}X'_{rr} & \frac{\omega-\omega_r}{\omega_b}X'_{rr} & 0 \\ -\frac{\omega-\omega_r}{\omega_b}X_m & \frac{P}{\omega_b}X_m & 0 & -\frac{\omega-\omega_r}{\omega_b}X'_{rr} & R_r + \frac{P}{\omega_b}X'_{rr} & 0 \\ 0 & 0 & 0 & 0 & 0 & R_r + \frac{P}{\omega_b}X'_{lr} \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{ds} \\ i_{0s} \\ i'_{qr} \\ i'_{dr} \\ i'_{0r} \end{bmatrix}$$

Where v_{qs} , v_{ds} are q-axis and d-axis stator voltages i_{qa}, i_{ds} are q-axis and d-axis stator currents v_{qr}', v_{dr}' , i_{qr}' , and i'_{dr} are q-axis and d-axis rotor voltages and currents referred to the stator windings by appropriate turns ratio, ω is the rotating speed of the arbitrary reference frame, ω_r is the rotor speed, X_{ss} , X_{rr}' are stator and rotor self inductive reactance's, X_m is the mutual reactance, and, X_{ls}, X_{rr}', R_s and R_r' are stator and rotor leakage reactance's and resistances. If we select $\omega = \omega_b$ that is, the rotating speed of the reference frame work is same as 260 rad/s, this reference frame is called a synchronously rotating reference frame or synchronous reference frame. The air gap flux linkages Ψ_{qm} and Ψ_{dm} can be expressed as

$\Psi_{qm} = L_m (i_{qs} + i_{qr}')$ (4)

$\boldsymbol{\Psi_{dm} = L_m (i_{ds} + i_{dr}')}$ **(5)**

And electromagnetic torque T_e can be expressed as

$$T_e = (3/2)\,(p/2)[\Psi_{qm}\, i_{dr} - \Psi_{dm}\, i_{qr}] \quad (6)$$

Generally, the power losses associated with the stator resistance are small enough to be ignored; hence the approximation of electromagnetic power can be written as

Active power

$$P_s = (v_{ds}\, i_{ds} - v_{ds}\, i_{ds}) (7)$$

While the reactive power that the stator absorbs from, or injects into the power system can be calculated as

$$Q_s = (v_{qs}\, i_{ds} - v_{ds}\, i_{qs}) (8)$$

Assume that the reference frame is the synchronous reference frame and that all quantities are in per unit value. Eq. can be further written as:

$$X = AX + BU \quad (9)$$

Where

$$X = \begin{bmatrix} i_{ds} \\ i_{ds} \\ i_{0s} \\ i_{qr}' \\ i_{dr}' \\ i_{0r}' \end{bmatrix} \text{ and } B = \begin{bmatrix} \frac{X_{ss}}{\omega_b} & 0 & 0 & \frac{X_m}{\omega_b} & 0 & 0 \\ 0 & \frac{X_{ss}}{\omega_b} & 0 & 0 & \frac{X_m}{\omega_b} & 0 \\ 0 & 0 & \frac{X_{ls}}{\omega_b} & 0 & 0 & 0 \\ \frac{X_m}{\omega_b} & 0 & 0 & \frac{X_{rr}'}{\omega_b} & 0 & 0 \\ 0 & \frac{X_m}{\omega_b} & 0 & 0 & \frac{X_{rr}'}{\omega_b} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}^{-1}$$

$$A = -B \begin{bmatrix} R_s & \frac{\omega}{\omega_b} X_{ss} & 0 & 0 & \frac{\omega}{\omega_b} X_m & 0 \\ -\frac{\omega}{\omega_b} X_{ss} & R_s & 0 & -\frac{\omega}{\omega_b} X_m & 0 & 0 \\ 0 & 0 & R_s & 0 & 0 & 0 \\ 0 & \frac{\omega - \omega_r}{\omega_b} X_m & 0 & R_r' & \frac{\omega - \omega_r}{\omega_b} X_{rr}' & 0 \\ -\frac{\omega - \omega_r}{\omega_b} X_m & 0 & 0 & \frac{\omega - \omega_r}{\omega_b} X_{rr}' & R_r' & 0 \\ 0 & 0 & 0 & 0 & 0 & R_r' \end{bmatrix} \quad (10)$$

The swing equation is

$$T_e = 2\dot{H}\omega_r + T_m (11)$$

Where the mechanical torque T_m and H is the inertia.

The differential equations (3) and (11) represent the induction machine with its fifth-order model.

The entire double fed induction generator model block consists of both the swing equation (11), current state space model from equation (3) and rotor side controller.

II.DYNAMIC RESPONSE OF DFIG UNDER UNBALANCE CONDITION

Unbalance may be defined as in several views it can be voltage dip (also the word voltage sag is used) is a sudden reduction (between 10% and 90%) of the voltage at a point in the electrical system, and sudden change of load (dynamic load) .There can be many causes for a voltage dip: short circuits somewhere in the grid, switching operations associated with a temporary disconnection of a supply, the flow of the heavy currents that are caused by the start of large motor loads, or large currents drawn by arc furnaces or by transformer saturation. Voltage dips due to short-circuit faults cause the majority of equipment trip and therefore of most interest. Faults are either symmetrical (three-phase or three phase-to-ground faults) or nonsymmetrical (single-phase or double-phase or double-phase-to ground faults). Depending on the type of fault, the magnitudes of the voltage dips of each phase might be equal (symmetrical fault) or unequal (nonsymmetrical faults). The magnitude of a voltage dip at a certain point in the system depends mainly on the type of the fault, the distance to the fault, the system configuration, and the fault impedance.

The dynamics of the DFIG have two poorly damped poles in the transfer function of the machine, with an oscillation frequency close to the line frequency. These poles will cause oscillations in the flux if the doubly-fed induction machine is exposed to a grid disturbance. After such a disturbance, an increased rotor voltage will be needed to control the rotor currents. When this required voltage exceeds the voltage limit of the converter, it is not possible any longer to control the current as desired.

This implies that a voltage dip can cause high induced voltages or currents in the rotor circuit. The high currents might destroy the converter, if nothing is done to protect it.

A. Double fed induction machine under faults

IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 1, Issue 4, Aug-Sept, 2013
ISSN: 2320 - 8791
www.ijreat.org

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.8 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.

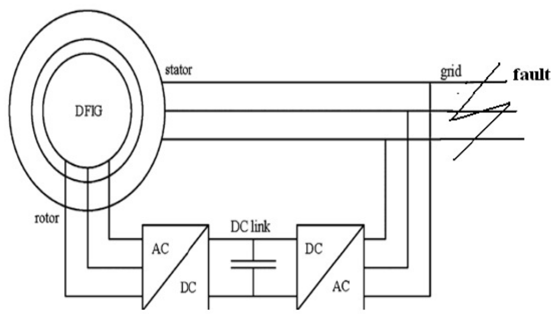

Fig.
8 Block Diagram of DFIG with Fault in Grid Side

i) Behavior immediately after the fault

In the fault instant, the voltage at the DFIG generator terminal drops and it leads to a corresponding decrease of the stator and rotor flux in the generator. As the stator flux decreases, the magnetization that has been stored in the magnetic field has to be released. The generator starts thus its demagnetization over the stator by the reactive power peak in the moment of the fault. In the fault moment, as the stator voltage decreases significantly, high current transients appear in the stator and rotor windings.

ii) Behavior at Fault Clearance

During the fault, the stator voltage and rotor flux have been reduced, the injected rotor voltage has been changed and the rotor speed has been increased. Immediately the fault is cleared the stator voltage is restored, and the demagnetized stator and rotor oppose this change in flux thus leading to an increase in the rotor and stator currents.

IV.IMPLEMENTATION OF PROPOSED MODEL IN MATLAB/SIMULINK

A. Main model of DFIG WITH CONTROLLER

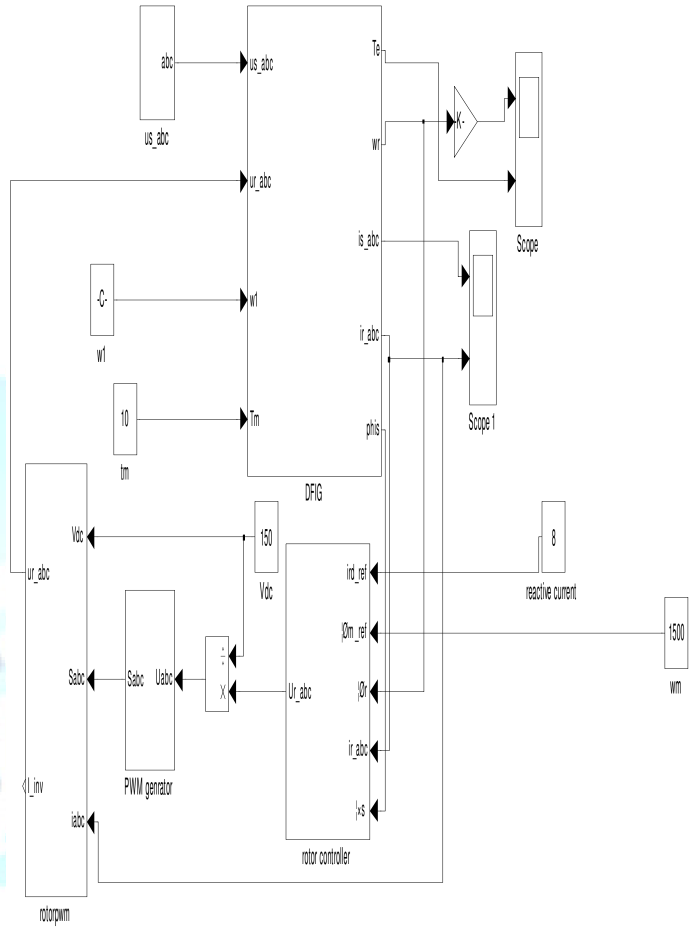

Fig 8 Detailed Model of DFIG in Simulink

***B.**Model for DFIG with DC Motor with Balanced and Unbalanced Fault*

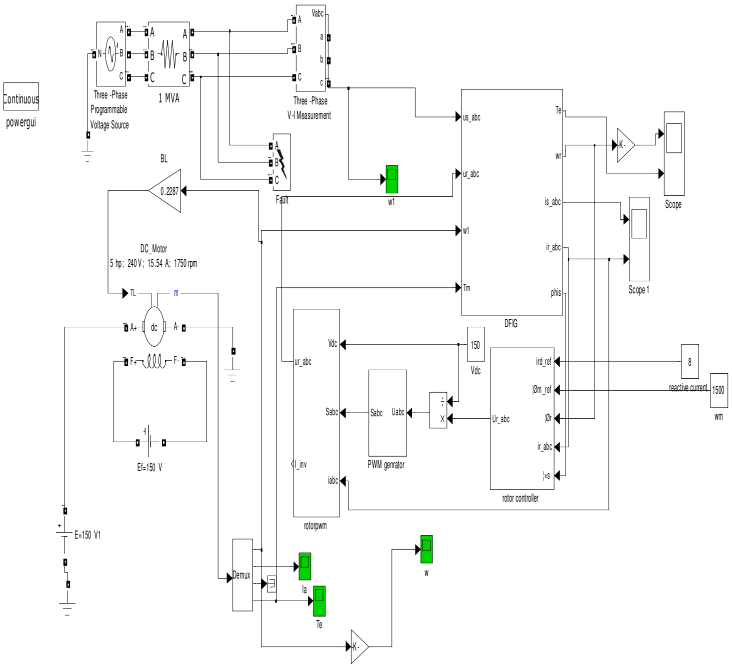

Fig 9 Simulink Model for DFIG with DC Motor with Balanced and Unbalanced Fault

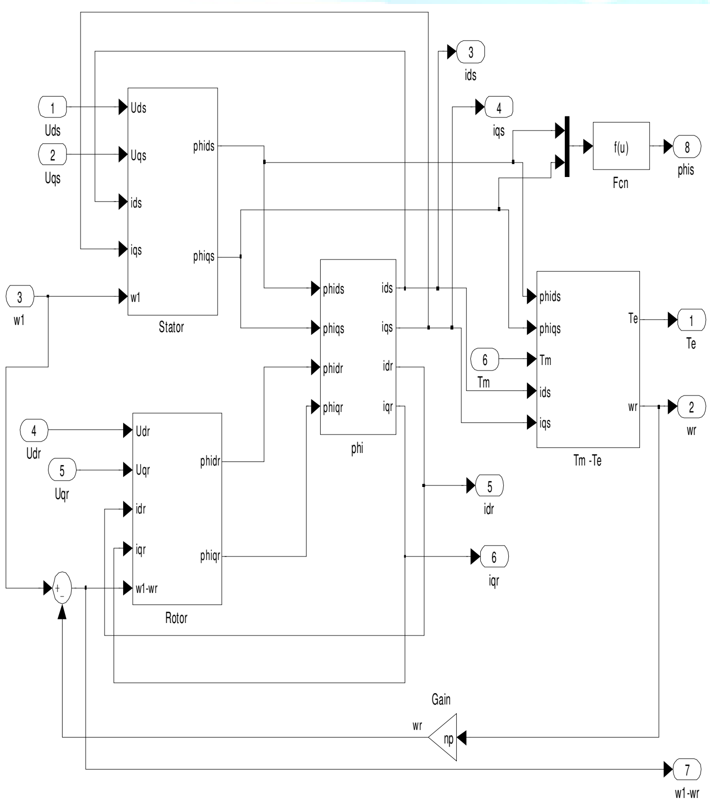

Fig 10 Model of Double Fed Induction Generator

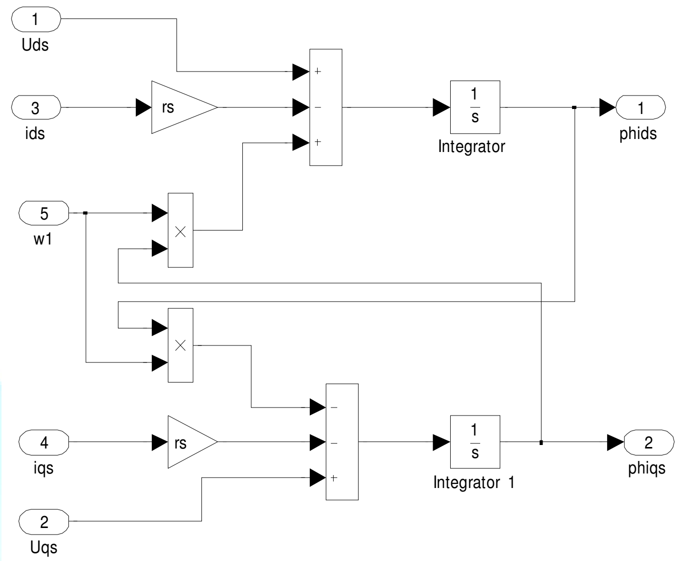

Fig 11. PHI_{ds} and PHI_{qs} in Terms of V_{ds},V_{qs} and I_{ds} and I_{qs}

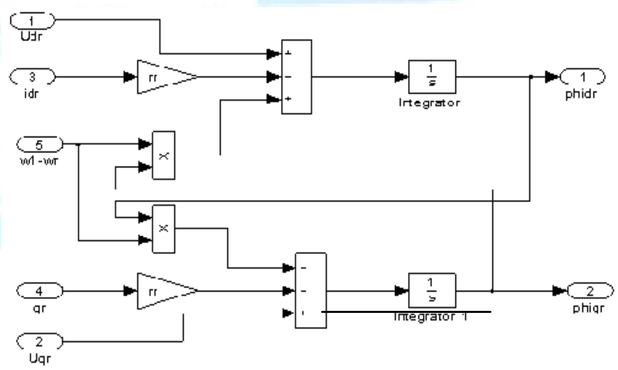

Fig 12. PHI_{dr} and PHI_{qr} in Terms of V_{dr},V_{qr} and I_{dr},I_{qr}

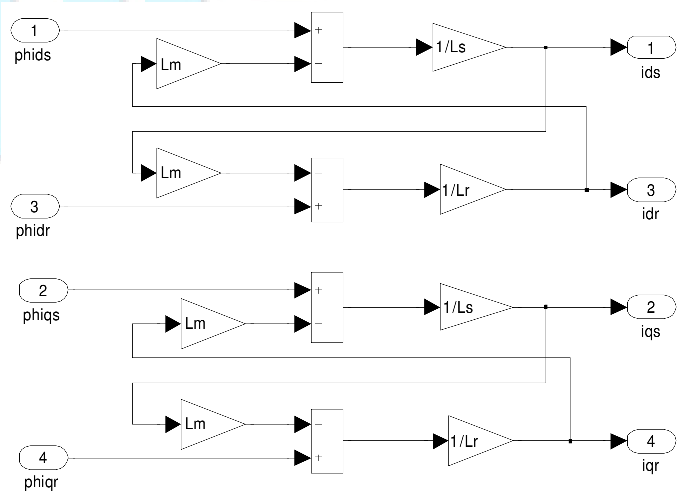

Fig 13 D-Axis and Q-Axis Currents in Terms of D-Axis and Q-Axis Flux Linkages

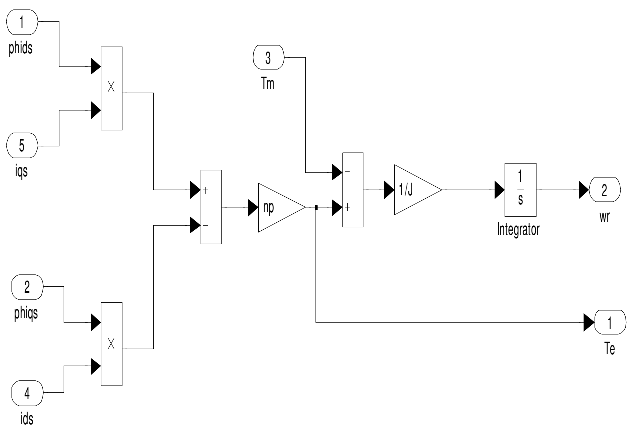

Fig 14 Torque and Speed In Terms of Flux Linkages and Currents

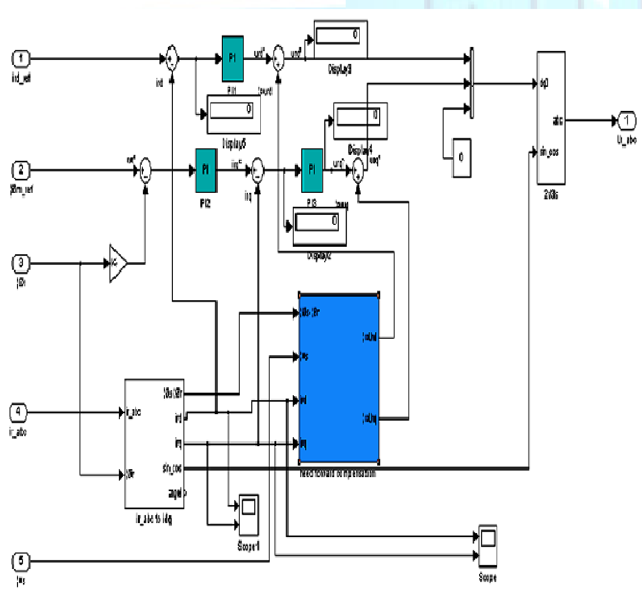

Fig 15.Rotor Controller

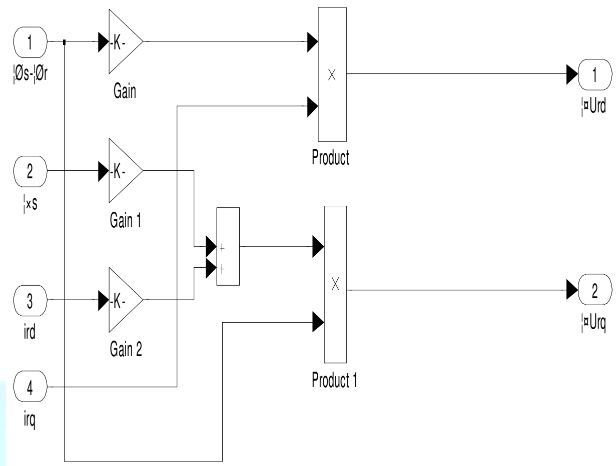

Fig 16 Feed Forward Compensator

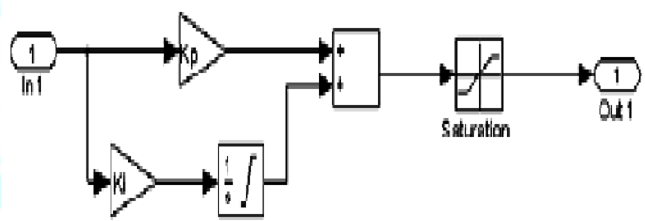

Fig 17 PI Controller

Fig 8 shows the model of DFIG with rotor controller for obtaining the normal performance characteristics. In this model a constant voltage source of 440v is employed instead of connecting a programmable voltage source and the synchronous reference speed is taken as 1500 rpm. Constant reference reactive current is taken as 8 amps and the base speed is considered to be the synchronous speed i.e. 1500 rpm.

Fig 9 gives the detailed model of double fed induction generator with direct current motor, instead of connecting to the constants for obtaining the dynamic performance characteristics during running conditions .fig 10 shows the detailed model of double fed induction generator using the sub blocks given in fig 11,12,13,14 which are modeled by observing the equation.

The input to the double fed induction generator in this model given through a dc motor having parameters 5hp,240v,15.54 amps and which provide both torque of 10 N-m and a reference speed of 1750 rpm. The rotor controller is designed on the basis of transformation theory involving inverse transformation 2phase to 3 phase and machine modeling involving transformation 3phase to 2 phase.

The outputs torque, speed, rotor currents are fed as input to the rotor controller in which the outputs of double fed induction generator are compared with reference signal and again fed back to the rotor as input in order to obtain the normal characteristics during fault condition .

Fig 15 shows the detailed modeling of rotor controller employed for double fed induction generator. It mainly consists of feed forward compensator and proportional integral controller which are shown in fig 16 and 17 respectively .Feed forward compensator is shown in fig16, proportional integral controller is employed with proportional time constant of 10 and integral time constant of 5 in order to obtain the steady state condition in 0.5 milli sec whenever a unbalanced fault is occurred .

V.SIMULATION RESULTS AND DISCUSSION

A. Free acceleration characteristics

i)Curent component ~ Time

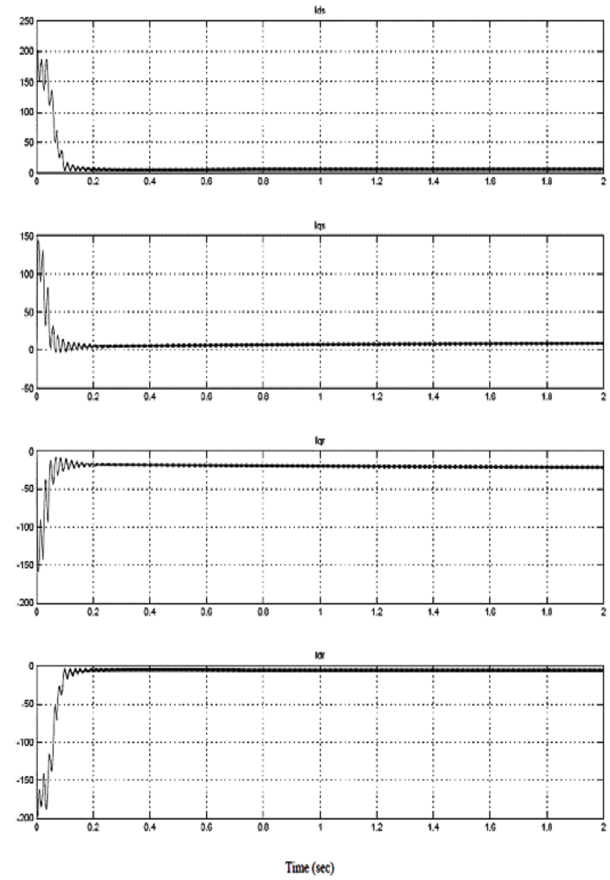

Fig 18 Free Acceleration Characteristics of Current Component (i_{ds}, i_{qs}, i_{dr}, i_{qr})

ii) Speed ~torque characteristics

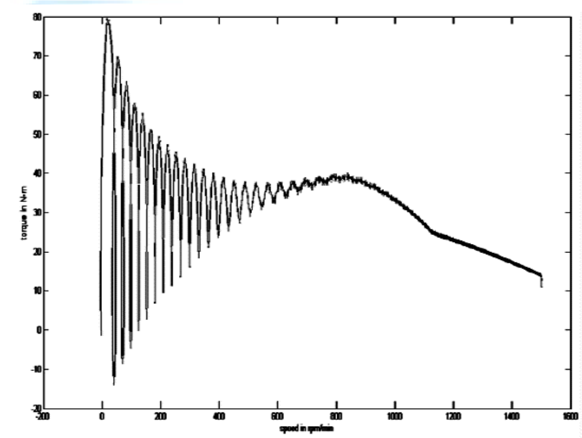

Fig 19 Speed Torque Characteristics

The torque verses speed characteristics during free acceleration shown in fig. 18 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.17 here the zero position of the reference is selected so that v_{qs} is the amplitude of the stator applied phase voltages and $v_{ds} = 0$.

B. Wind Turbine DFIG With Normal Condition

i) Stator currents time

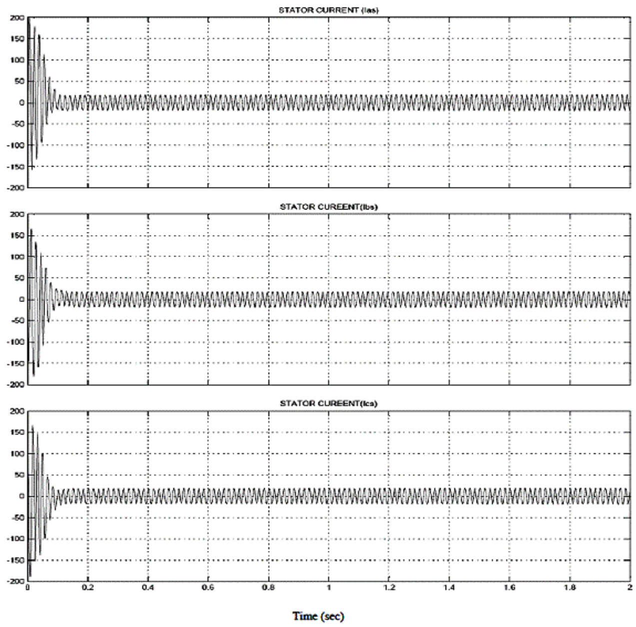

Fig 20. Stator Currents (i_{as}, i_{bs}, i_{cs}) During Balance Condition

ii) Rotor currents ~time

Fig 21 Rotor Currents (i_{ar}, i_{br}, i_{cr}) During Balance Condition

ii) speed and electromagnetic ~torque time

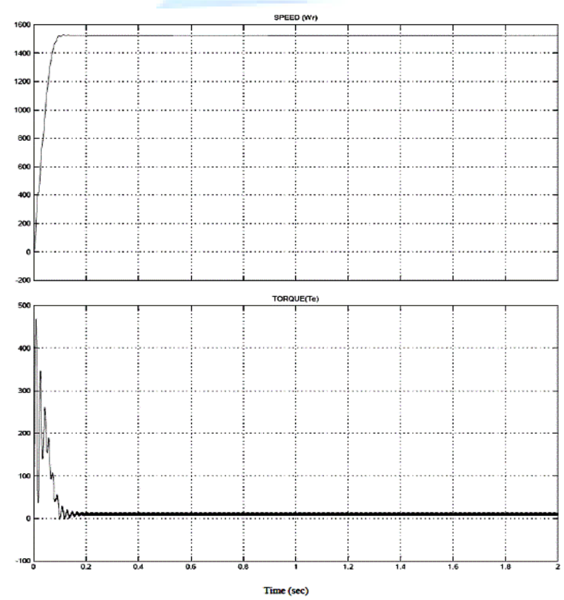

Fig 22 Speed and Torque (ω_r, T_e) During Balance Condition

iv) Power characteristics ~time

ISSN: 2320 - 8791
www.ijreat.org

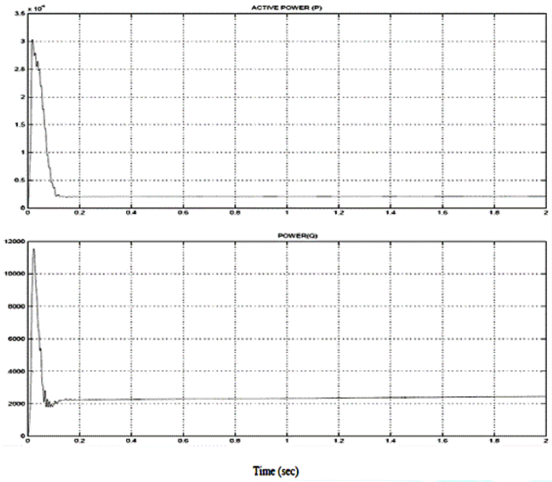

Fig 23. Active Power (P) and Reactive Power (Q) During Balance Condition

The transient torque and speed characteristics with time are different from the steady state torque and speed characteristics with time shown in fig.22 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.20 and fig.21 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.

C. Wind Turbine DFIG During Grid Fault

i) Stator voltages ~ time

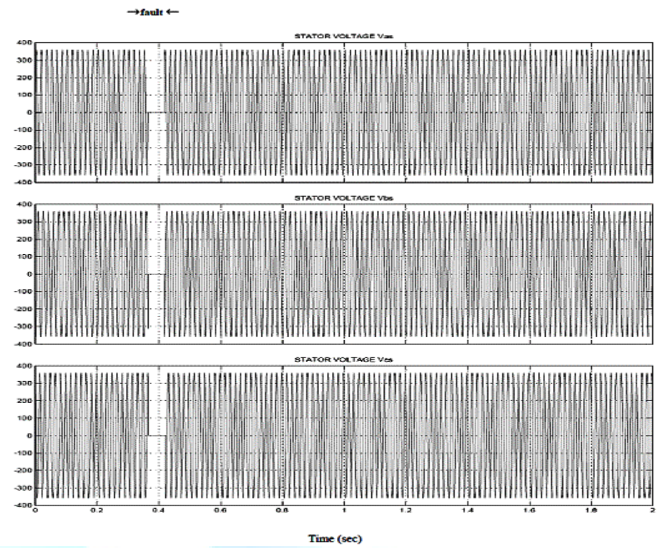

Fig 24 Stator Voltages v_{as}, v_{bs}, v_{cs} During Grid Fault

ii) Stator currents ~ time

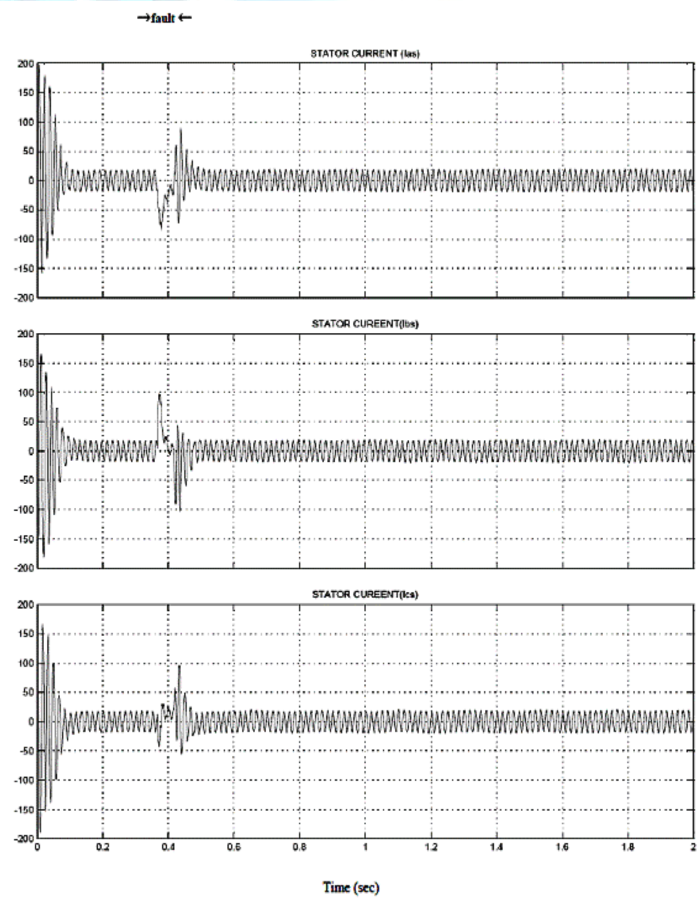

Fig.25 Stator Currents (i_{as}, i_{bs}, i_{cs}) During Grid Fault

iii) Rotor currents~ time

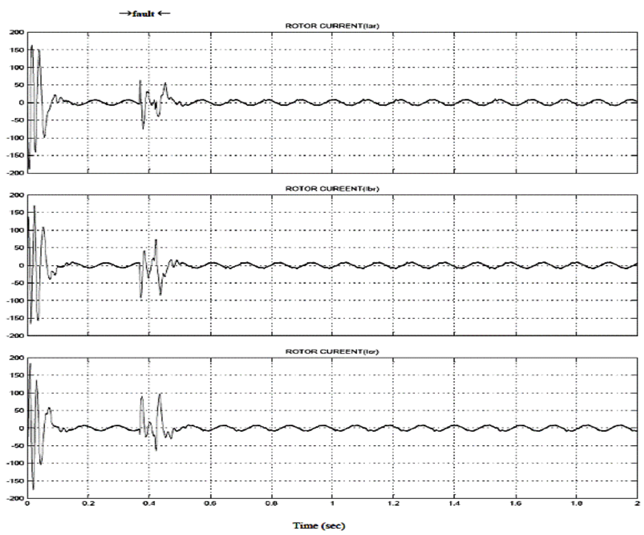

Fig 26 Rotor Currents (i_{ar}, i_{br}, i_{cr}) During Grid Fault

iv) Speed and electromagnetic torque~ time

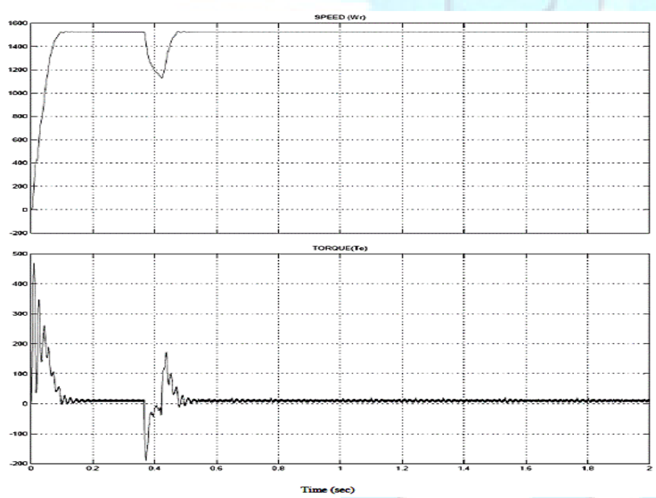

Fig 27. Speed and Torque (ω_r, T_e) During Fault Condition

v) Power characteristics~ time

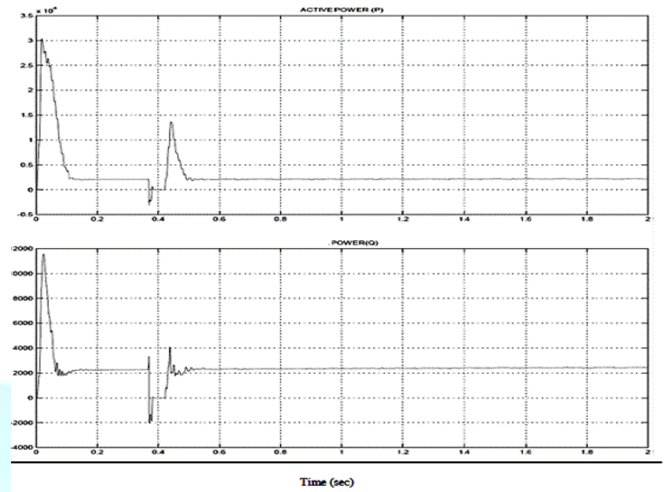

Fig 28 Active Power (P) and Reactive Power (Q) During Fault Condition

The dynamic performance of the induction generator is shown respectively in figures 22.23 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 24 at the time of the fault shown in figures gives rise to decaying in both stator and rotor currents shown in fig 25 and fig 26.

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 27 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 27

D. Wind Turbine DFIG During Unbalance Condition

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

i) Stator currents ~time

ISSN: 2320 - 8791
www.ijreat.org

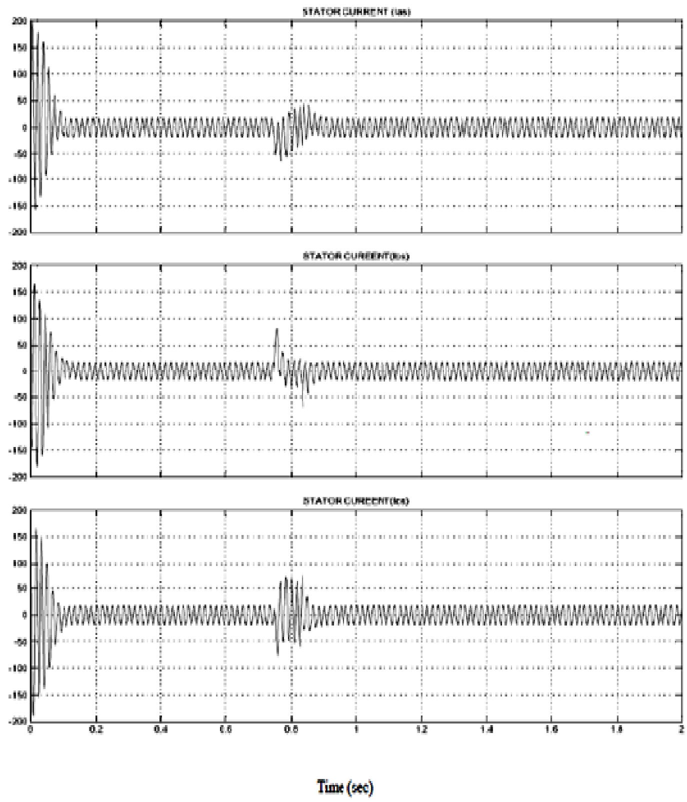

Fig 29 Stator Currents (i_{as}, i_{bs}, i_{cs}) During Dynamic Loading

ii) Rotor currents ~ time

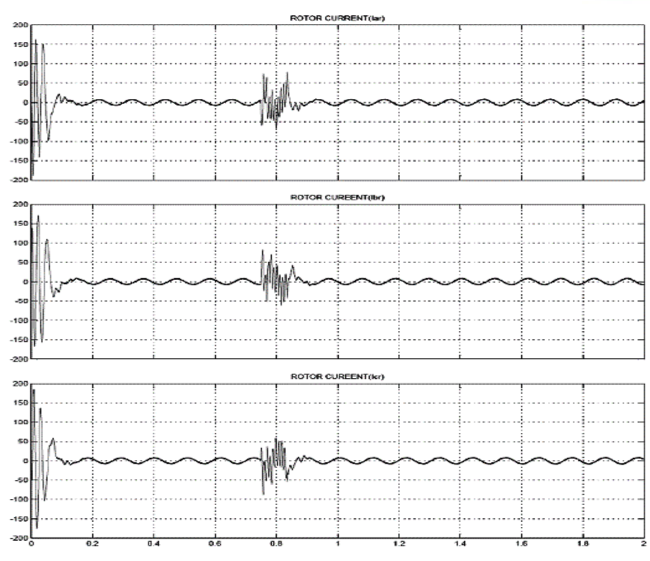

Fig 30 Rotor Currents (i_{ar}, i_{br}, i_{cr}) During Dynamic Loading

iii) Speed and electromagnetic torque~ time

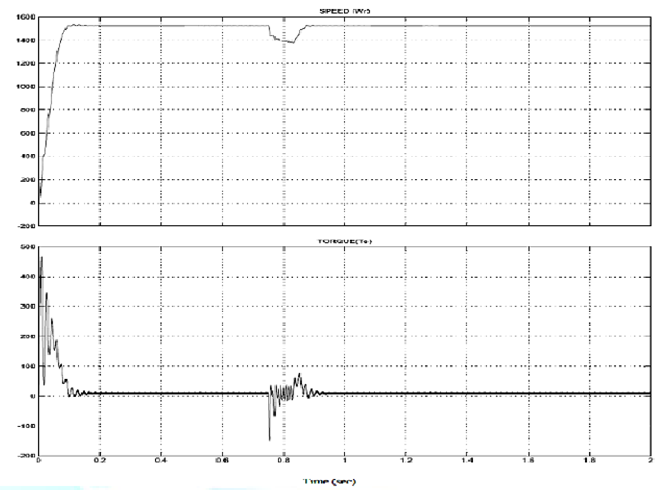

Fig 31 Speed and Torque (ω_r, T_m) During Dynamic Loading

iv) Power characteristics~ time

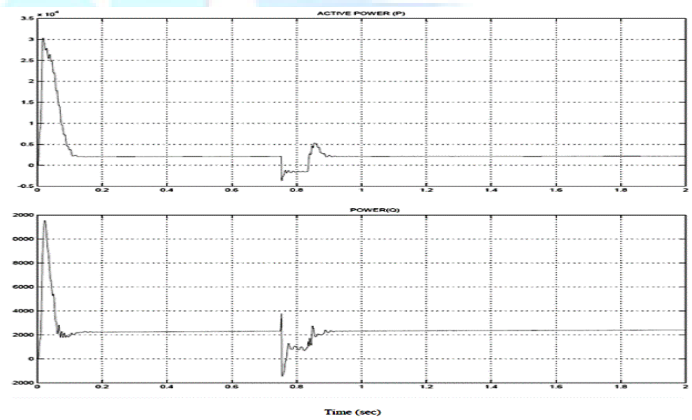

Fig 32 Active Power (P) and Reactive Power (Q) During Dynamic Loading

*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.

v) Stator voltages ~time

→seg ←

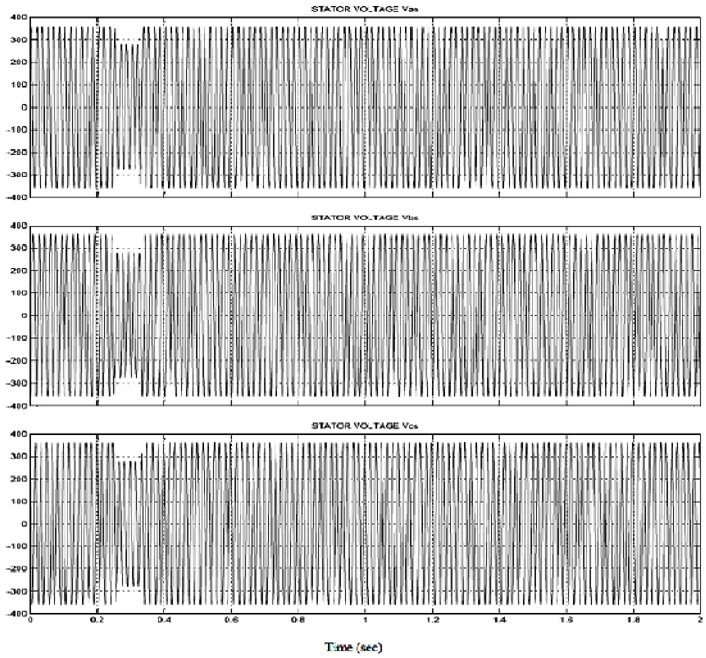

Fig 33 Stator Voltages v_{as}, v_{bs}, v_{cs} During Voltage Dip

vi) Stator currents time

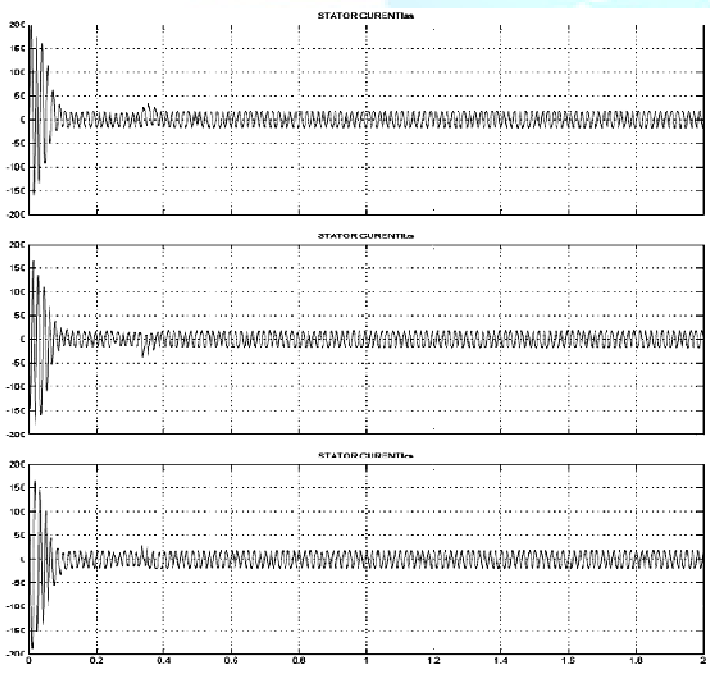

Fig 34 Stator Currents (i_{as}, i_{bs}, i_{cs}) During Voltage Dip

vii) Rotor currents~ time

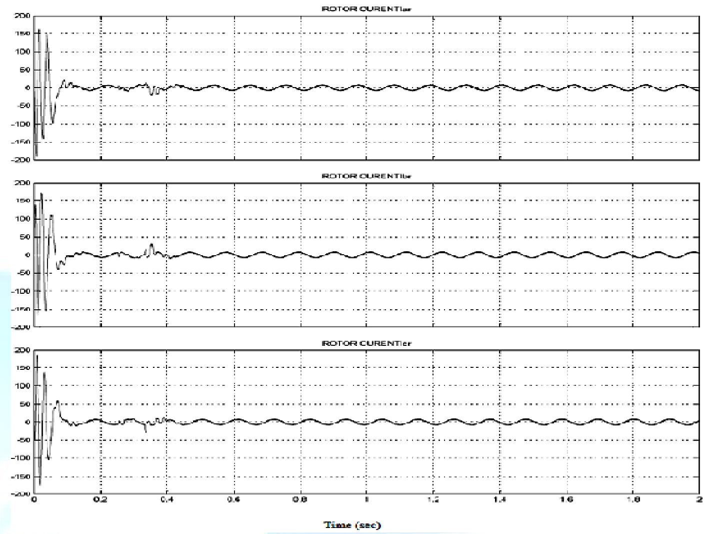

Fig 35 Rotor Currents (i_{ar}, i_{br}, i_{cr}) During Voltage Dip

viii) Speed and electromagnetic torque~ time

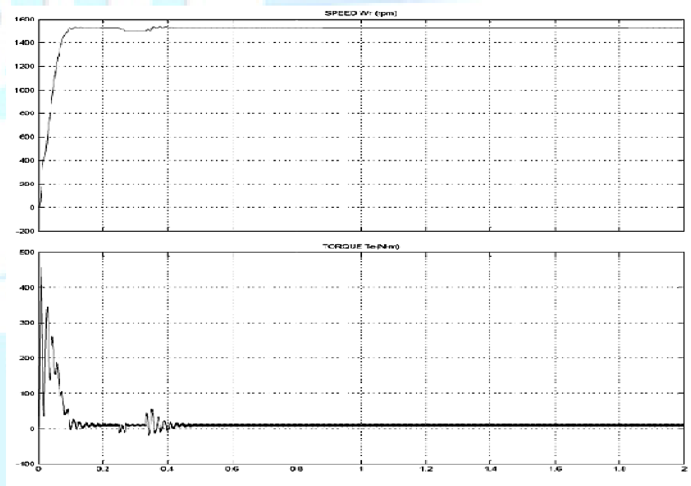

Fig 36 Speed and Torque (ω_r, T_e) During Voltage Dip

ix) Power characteristics~ time

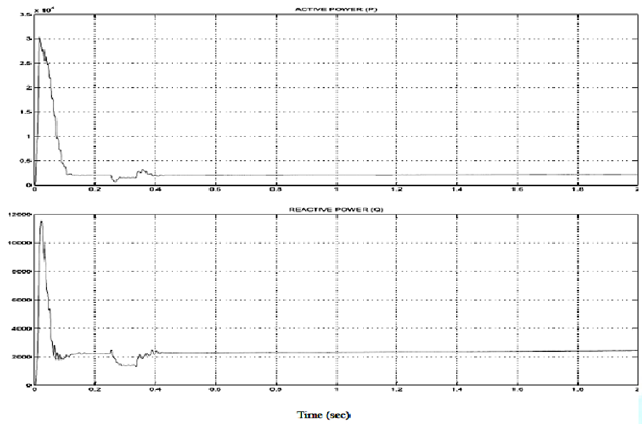

Fig 37 Active Power (P) and Reactive Power (Q) During Voltage Dip

The dynamic behavior of the machine during sudden changes in load shown in fig.29,30,31 and 32 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 29 and 30 and the next unbalance condition by reduction 10% to 90 % of voltage (voltage sag) shown in fig. 33 here be can observe the small dynamics as compare to step changes load shown in fig. 34 ,35 ,36,37.

E. Dc machine coupled with DFIG during fault condition

i) Stator currents time

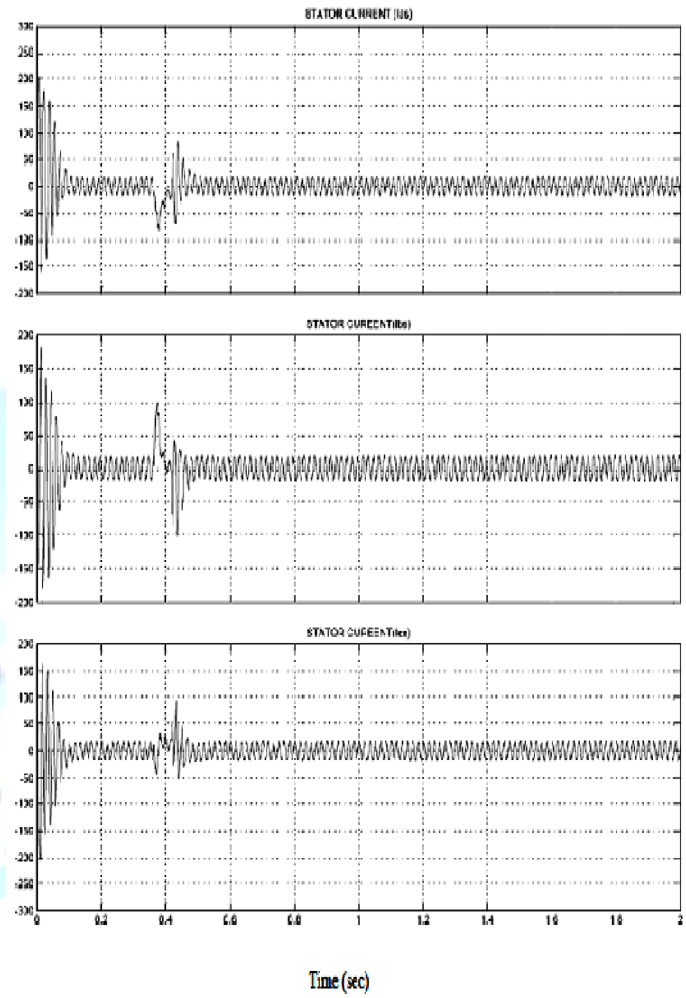

Fig 38 Stator Currents (i_{as}, i_{bs}, i_{cs}) During Fault Condition

ii) Rotor currents ~ time

IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 1, Issue 4, Aug-Sept, 2013
ISSN: 2320 - 8791
www.ijreat.org

Fig 39 rotor currents (i_{ar}, i_{br}, i_{cr}) during fault condition

iii) Speed and electromagnetic torque ~ time

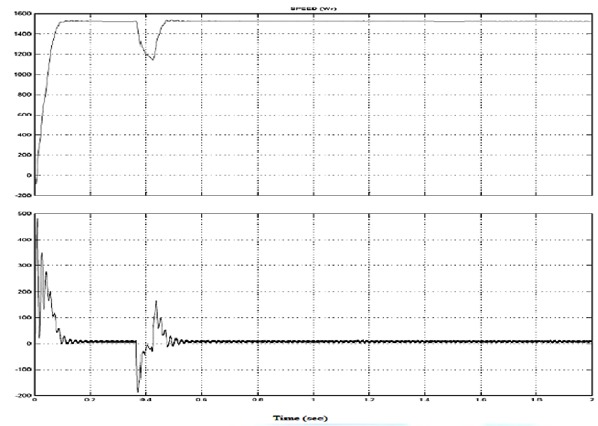

Fig 40. Speed and Torque (ω_r, T_e) During Fault Condition

iv) Power characteristics ~ time

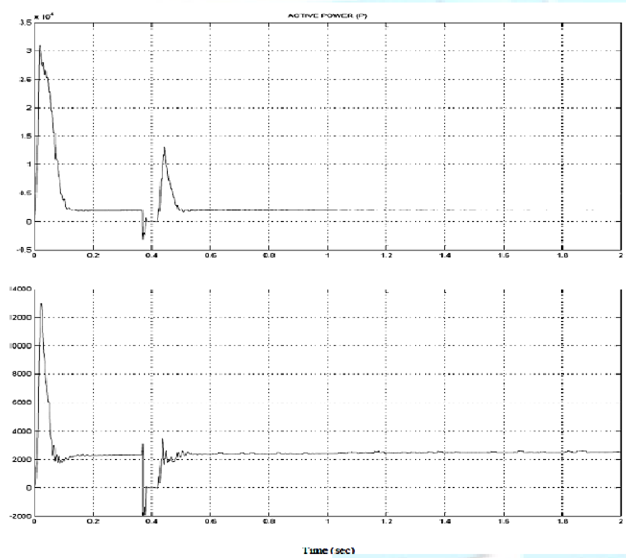

Fig .41 Active Power (P) and Reactive Power (Q) During Fault Condition

F. Dc machine coupled with DFIG during unbalance condition

i) Stator currents time

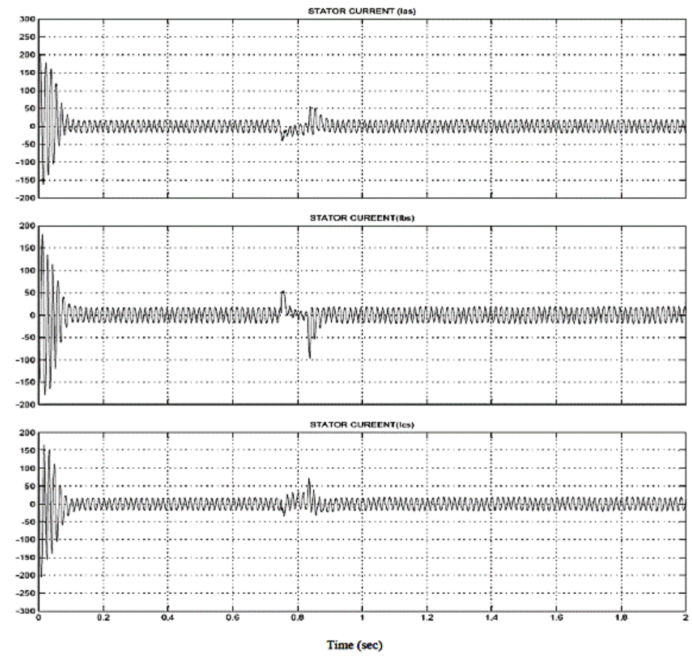

Fig 42 Stator Currents (i_{as}, i_{bs}, i_{cs}) During Unbalance Condition

ii) Rotor currents ~ time

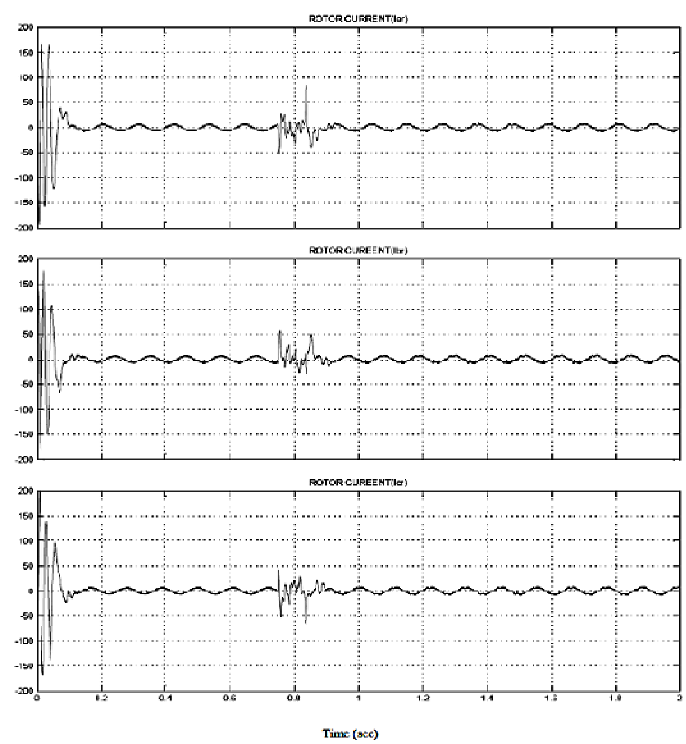

Fig 43 Rotor Currents (i_{ar}, i_{br}, i_{cr}) During Unbalance Condition

iii)Speed and electromagnetic torque ~ time

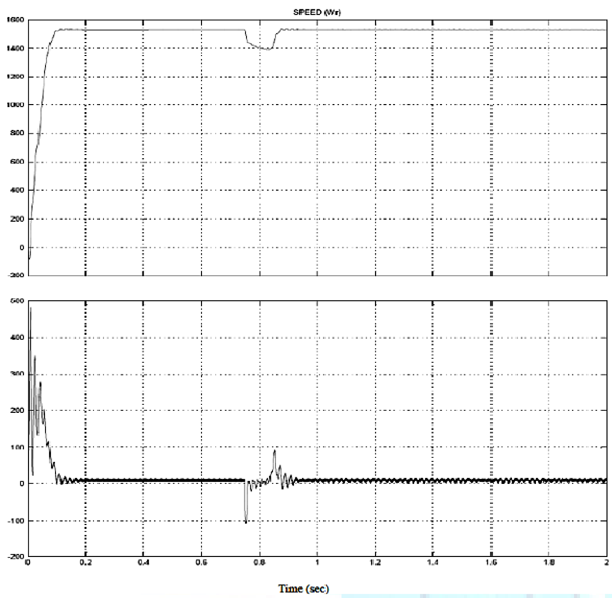

Fig 44. Speed and Torque (ω_r, T_e) During Unbalance Condition

iv) Power characteristics ~ time

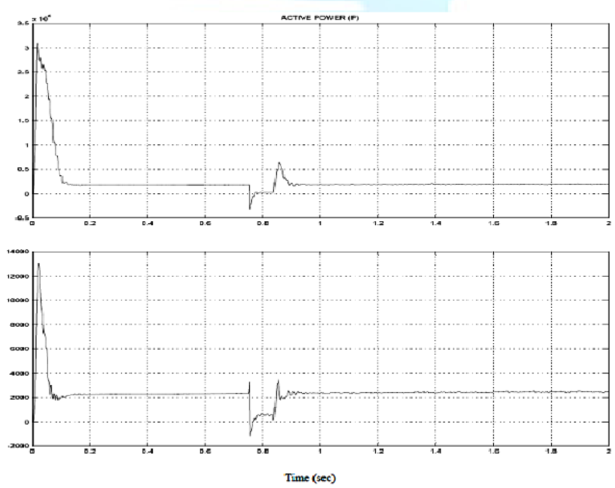

Fig 45 Active Power (P) and Reactive Power (Q) During Unbalance Condition

The dynamic performance of the induction generator coupled with dc machine is shown in figures of section E and F 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.

VI.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 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.

APPENDIX

Induction generator rating**:**

3hp (2.23kw), 440 v, 1500 rpm.
R_S= 0.435 ohm
R_r= 0.816 ohm
X_s= 0.446 ohm
X_m= 0.43 ohm
X_s= 0.446 ohm
Number of pole pair (p) = 2
J = 0.08 kg. m^2

Wind turbine data**:**

Air density ρ = 1.2 kg/ m^3
Wind speed v = 10 m/s

DC motor:

5hp, 240v,15.54A, 1750rpm
R_a= 11.2 ohm
L_a= 0.01215 H
R_f= 281.3 ohm
L_f= 156 H
L_{af}= 0.9483
J=0.02215 Kg. m^2
B= 0.002953
T.F=0.5161

REFERNCES

[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.

[5] 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

[6] 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.

[7] 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

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

[9] 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.