Transient Analysis of DFIG Wind Turbine during Voltage Sag

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ABSTRACT

Wind power plants often located in remote areas are characterized by weak grids and they are frequently subjected to power system disturbance like voltage sag, short circuit fault and dynamic loading. This paper presents a study of the dynamic performance of variable speed DFIG-coupled wind turbine plant under power system disturbance. Modeling and simulation of induction machines, power system components and controller design is done using MATLAB. Vector control approach is being implemented in MATLAB/SIMULINK platform for DFIG active, reactive power control, and variable speed operation. Results obtained from simulation are enumerated and verified from literature.

Index term- Double fed induction generator (DFIG), vector control, voltage sag.

I.INTRODUCTION

Both fixed speed squirrel cage induction machine and variable speed double fed induction generators are widely used for Wind Energy conversion system. Recently DFIG find increasing application in wind-turbine generation. DFIG has the ability to control the active and reactive power and maintain constant frequency operation. With wind speed variation or under power system disturbance, the injected rotor voltage, current or the frequency of the injected rotor voltage can be controlled to achieve constant frequency, stable operation at the stator or grid side. Induction machines are particularly sensitive to unbalanced operation, since localized heating can occur in the stator and lifetime of the machine can be severely affected. Furthermore, negative sequence currents in the machine produces pulsation in the electrical torque, increasing the acoustic noise and reducing the life span of gear box, blade assembly and some parts of wind turbine. Therefore, proper protection system and controller should be designed for faulty and voltage dip operation.

This study deals with power system transient stability and dynamic load behavior analysis. The present investigations are dealing with (i). Wind turbine dynamic modeling, (ii). Steady state and free acceleration characteristics of DFIG (iii). DFIG interaction with power systems, (iv). DFIG current control, (v). Active and reactive power and damping control. DFIG can operate in both sub-synchronous and super-synchronous operation mode to impart power to the grid or from the grid with a minimum rotor power input in both steady and variable speed wind turbine operation mode.

II.DYNAMIC MODLING OF WIND TURBINE

A wind turbine mathematical modeling contains basic functional components like wind turbine aerodynamic model, wind-turbine drive train model, DFIG model interfaced with a converter in the rotor side, electric grid model and the controller design.

A. Wind turbine

The aerodynamic modeling of wind turbine estimated from its power-speed characteristics. Steady state mechanical power output is given by:

$$P_m = \frac{1}{2}\rho A C_p u^3 \tag{1}$$

Where C_p is the power co-efficient depends on turbine design and can be updated from look up table each time. In general turbine and generator are modeled as two mass systems and the coupling flexible shaft is being modeled as a spring in equivalent mechanical system. In this two mass spring damper modeled, each component is being characterized by its own inertia (J_t, J_g), friction damping (D_t, D_g) and stiffness constant (K_{sh}) and then all the model parameters are variables are referred to turbine side. Then, the governing equation describing the mechanical system is:

$$T_t - K_{sh}(\theta_t - \theta_g) - D_t\omega_t = J_t\frac{d\omega_t}{dt} \tag{2}$$

$$K_{sh}(\theta_t - \theta_g) - T_g - D_g\omega_g = J_g \frac{d\omega_g}{dt} \quad (3)$$

$$K_{sh}(\theta_t - \theta_g) = T_g \quad (4)$$

B. Pitch angle controller Design:

For variable speed wind turbine, pitch angle control is essential for accurate modeling and simulation studies. The main function of Pitch angle control is to provide suitable speed and power limit for smooth turbine operation and to contribute maximum wind energy capture. As described in subsection-1, in order to maximize the maximum output power, C_p is dependent upon wind speed and rotor data and can be adjusted by controlling the pitch angle (β). The wind and rotor data will define the possible power available limit *(P_s)*. Now, the pitch angle controller adjusts the β value to limit the *(P_s)* to *(P_{rated})*. The pitch angle control is realized by a PI controller. This model accounts for a servo time constant (T_s) and a limitation of both pitch angle and its rate of change.

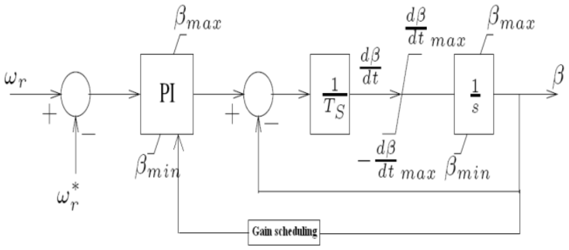


Fig.1: Pitch angle controller design

C.DFIG Modeling:

In order to improve the quality and controllability of the generated electrical power, wind turbine with a doubly fed induction generator is preferred. Here the converter connected to the rotor winding is of lower rating. The filter required for power factor control is also of lesser rating. However, the major drawback of this configuration is their operation during grid fault. For, analysis an accurate numerical modeling of DFIG must be provided to find out the dynamic performances. Here, stator side is directly connected to the grid while rotor is interfaced with the converter and rotor current is being sensed for control operation. The controllability of DFIG (i.e., variable speed operation, active and reactive power control) is achieved through rotor current control applying vector control technique. In order to provide a decoupled control action, first the induction machine is modeled in d-q reference frame (park model) rotating at synchronous speed. Using, the generator convention, the governing equations are as such:

$$v_{qs} = -R_s i_{qs} + \frac{d}{dt}\psi_{qs} + \omega_e \psi_{ds} \quad (5)$$

$$v_{ds} = -R_s i_{ds} + \frac{d}{dt}\psi_{ds} - \omega_e \psi_{qs} \quad (6)$$

$$v_{qr} = -R_r i_{qr} + \frac{d}{dt}\psi_{qr} + \omega_e \psi_{dr} \quad (7)$$

$$v_{dr} = -R_r i_{dr} + \frac{d}{dt}\psi_{dr} - \omega_e \psi_{qr} \quad (8)$$

In order to represent all the variables in a common reference frame the θ_s, θ_r, ω_r and the co-efficient of mutual coupling is fed back as the input along with machine parameter. The machine variables expressed in common reference frame has taken from [5].

The air gap flux linkage can be expressed as:

$$\psi_{qm} = L_m\ (i_{qs}+i_{qr}) \qquad (9)$$

$$\psi_{dm} = L_m\ (i_{ds}+i_{dr}) \qquad (10)$$

and the electromagnetic torque developed by the machine is given by:

$$T_e = \left(\psi_{qm}\, i_{dr} - \psi_{dm}\, i_{qr}\right) \qquad (11)$$

Then re-arranging the voltage variable equations and representing them in state space form all the current variables can be evaluated at each instant. Subsequent rotor speed and electromagnetic torque can also be estimated. Approximating R_s to be negligible and $\frac{d\psi_{ds}}{dt}$ =0 under steady state, then v_{ds} is in phase and proportional to ψ_{qm}, while v_{qs} is in phase and proportional to ψ_{dm} then if v_{ds} is in phase and proportional to v_{ds} is set to zero flux ψ_{qm} vanishes. Then, the developed torque and reactive power reduced to $T_e = \psi_{dm}\, \mathrm{i}_{qr}$ and $Q_s = \frac{L_s}{L_m}\psi_{dm}{}^{2} - \psi_{dm}\,\mathrm{i}_{dr}^{2}$ From, those expressions it is found that active and reactive power can be controlled by rotor injected voltage. i_{dr} and i_{qr} errors are processed by a PI controller to give desired v_{dr} and v_{qr}.

In the above equations $v_{ds}, v_{qs}, v_{dr}, v_{qr}, i_{ds}, i_{qs}, i_{dr}, i_{qr}, \psi_{ds}, \psi_{qs}, \psi_{dr}$ and ψ_{qr} are the *d* and *q* components of the stator and rotor voltages, currents.

D. Rotor side Controller design

DFIG is a wound rotor induction motor with stator winding directly connected to the grid whereas rotor side is connected with a VSC. However, the converter supplies or absorbs reactive power to the DFIG depends its operation either at super or sub-synchronous mode. Neglecting the stator and rotor losses, expression of power at different nodes of the system is given as:

$$P_{rotor} = sP_{stator}; P_{stator} = \frac{1}{1-s}P_{grid} = \frac{\eta_g P_m}{1-s}$$

Here P_m is the mechanical output of turbine. So, from the rotor variable and rotor speed P_{stator} or P_{grid} can be obtained. Then active and reactive power control can be achieved in the following manner. Reactive power controller operates in automatic voltage regulator mode. The reference current I_{rq}^{ref} and I_{rd}^{ref} are restricted within the converter current rating. The injected voltage at the rotor side is also restricted so as not exceed the maximum rotor side converter voltage rating.

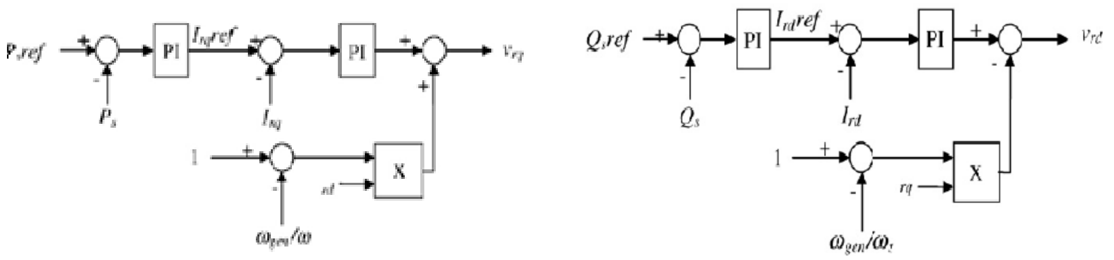
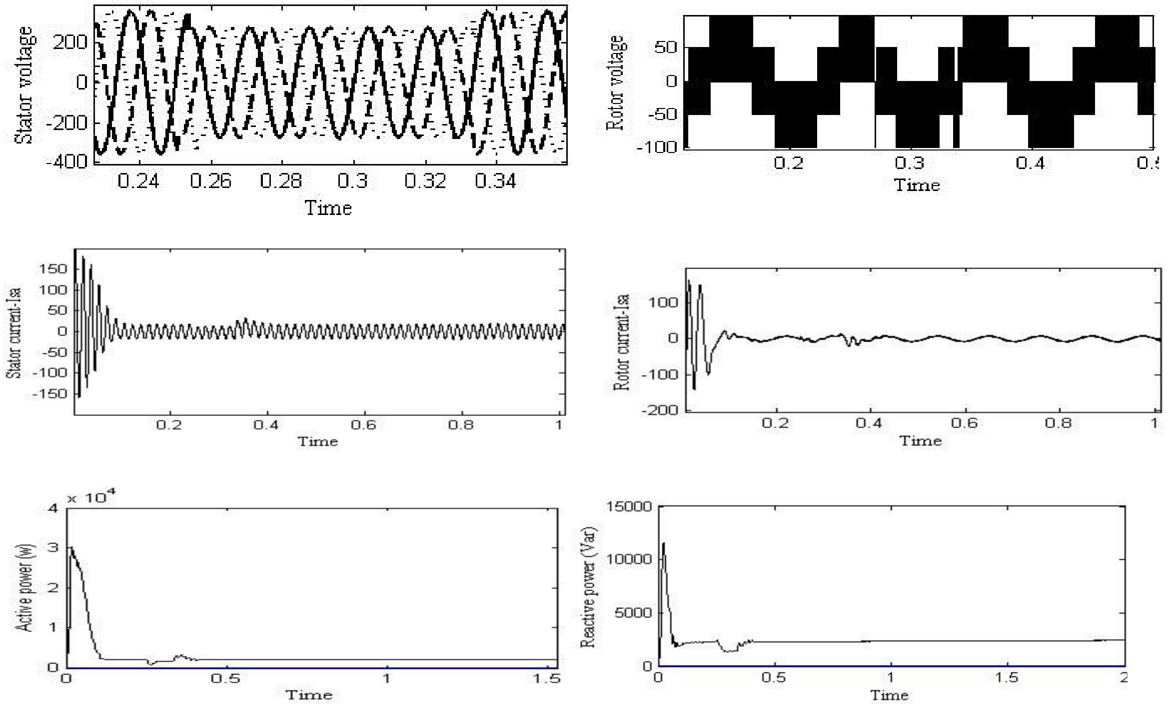


Fig.2: active and reactive power controller

In normal operation, the active power set point P_{ref}^{grid} is defined from maximum power tracking curve and generator speed. Whereas under fault P_{ref}^{grid} is changed to the output value of damping controller. One damping controller is introduced to damp out torsional oscillation aroused due to drive train system.

III.SIMULATION STUDIES

The dynamic response and transient performance of DFIG is evaluated under different fault and operating conditions and the voltage ride-through capability of the turbine is studied. Here, a DFIG –wind plant of 2 KVA Capacity is studied for analysis. Only rotor side converter along with the controller is used to control the machine speed and the reactive power supplied through the machine stator so as to maintain the nominal terminal voltage. Two cases of grid disturbance: (1). voltage sag (10%), (2). short circuit fault condition has been taken for analysis. The dynamic responses of variables (like, current, voltage, power speed and torque) for voltage sag and short circuit condition are shown in fig.3 and fig. 4 respectively.



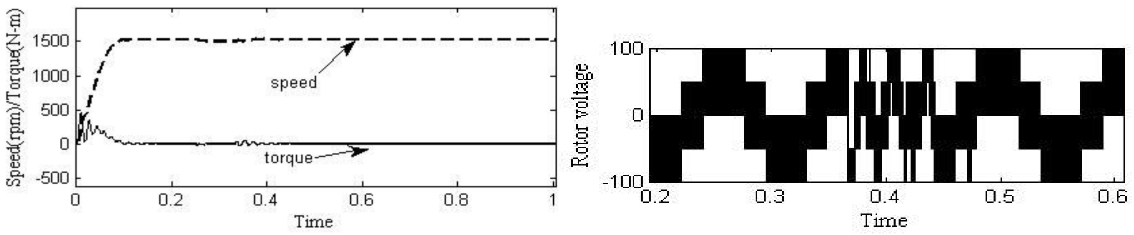


Fig.3: DFIG during voltage sag

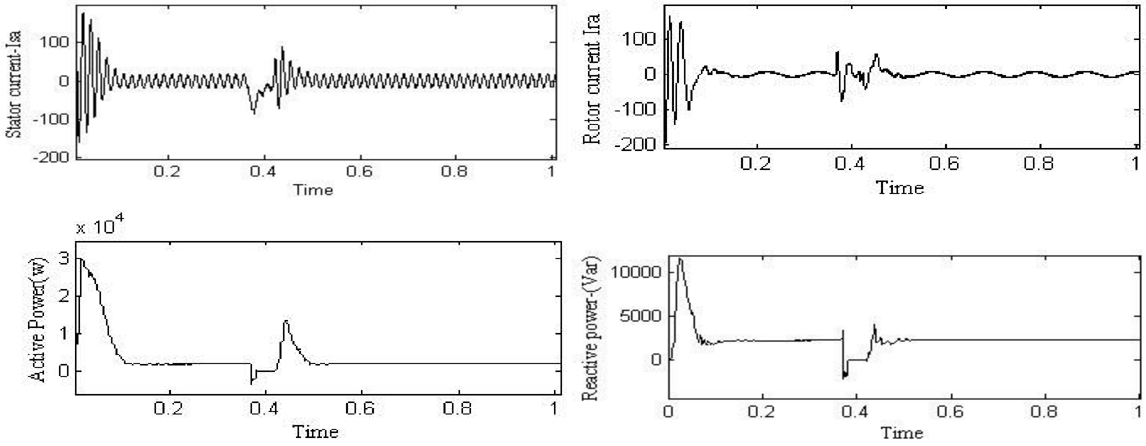


Fig.4: DFIG during short circuit fault (3-phase fault)

***CASE*-1:** Under voltage sag, stator flux has been reduced which in turn increases the rotor current (1.2 pu), but the variations are within allowable range of converter and machine. After clearance of sag, again retain back to normal steady state value. The voltage sag period is from 0.26 to 0.335 seconds observed in fig. 3.

***CASE*-2:** During a fault, the transient currents on the stator are reflected on the rotor windings. The rotor side converter is designed to with stand the heavy currents. Here the rotor current control is achieved through machine faults. Fault was created at 0.36 seconds and cleared at 0.42 seconds (3-4 cycles). The maximum current observed at rotor side is around (3-3.2 pu). The controller parameters are designed so as to quickly damp out the torsional oscillation arise in the drive train systems and controls the β value to avoid rotor from over speeding during the fault. This model usually implemented at a faster rate, so as to allow the rotor side converter enough time to oppose the rotor current induced by stator flux weakening. During the fault DFIG response was smooth with little oscillation in the output power and terminal voltage variables. Here DFIG is consuming active power from the grid. Amore sluggish response was observed during fault recovery when grid terminal voltage returns to its nominal value. This method has an advantage of not requiring any additional requirements.

IV.CONCLUSION

In this paper a variable speed wind generation system based on DFIG under power system disturbance has been simulated and a suitable controller is designed to supply the deficit reactive power to the grid and help in grid recovery. By as the generator and converter stay connected, the synchronism of operation remain established during and after the fault and normal operation can be continued immediately after the fault has been cleared. Here the reactive power is being supplied to the grid during longer duration voltage dips in order to facilitate voltage restoration. Proper controller designed is adopted to improve the transient and dynamic performance of DFIG coupled Wind turbine under these abnormal grid conditions.This paper analyzes the DFIG transient behavior and control possibility under grid disturbances like fault and large voltage dips etc. In this model, with the help of only one rotor side converter we are able to control the active and reactive power and maintain the stability of grid under faulty conditions.

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