Current Trends in Technology and Science
www.ctts.in, ISSN: 2279-0535, September 2022, Volume: 11, Issue: 5

Performance of DFIG-based Wind Turbine during Conditions of Grid Disturbances

Amit Kumar, Saurabh Gupta
Department of Electrical & Electronics Engineering,
Technocrats Institute of Technology & Science Bhopal

Abstract:-Wind power establishes frequently situated in far-off regions are portrayed by feeble matrices, and they are now and again exposed to control power system disturbances like voltage sag, short circuit fault and dynamic loading. This paper investigates the unique exhibition of variable speed DFIG-coupled wind turbine plants under power system unsettling influence. Displaying and reproducing enlistment machines, power system parts and regulator configuration is finished using MATLAB. The vector control approach is being carried out in MATLAB/SIMULINK stage for DFIG dynamic, responsive power control, and variable speed activity. Results obtained from the Simulation are obtained and checked from the literature.

Keywords:-Double-fed induction generator (DFIG), vector control, voltage dip, MATLAB/SIMULINK

1. Introduction

Nowadays, large-scale wind farms are required to be controllable both in active and reactive power and to have low voltage ride-through capability when disturbances in the grid. Because of its ability to provide variable speed operation and independent active and reactive power control cost-effectively, the doubly fed induction generator (DFIG) has had the most significant world market share of wind turbine concepts in the last 10 years [1, 2]. Many researchers have studied the low-voltage ride-through capability of DFIG [3-7], and most are focused on the behaviours and protections of DFIG under fault conditions. Squirrel cage induction machines and variable-speed double-fed induction generators are widely used for Wind Energy conversion systems. Recently DFIG has found increasing applications in wind-turbine generation. DFIG, shown in fig. (1), can 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 and stable operation at the stator or grid side. Induction machines are susceptible to unbalanced operation since localised heating can occur in the stator, and the machine's lifetime can be severely affected. Furthermore, negative sequence currents in the machine produce pulsation in the electrical torque, increasing the acoustic noise and reducing the life span of the gearbox, blade assembly and some parts of the wind turbine. Therefore, a proper protection system and controller should be designed for faulty and voltage dip operation.

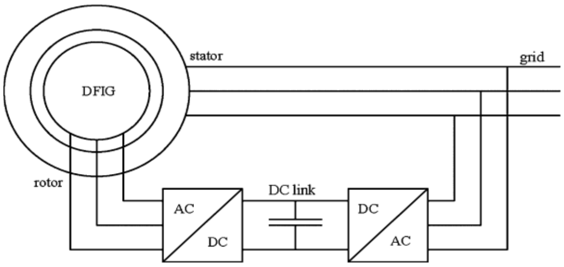


Fig. (1) Double-fed induction machine

This study deals with power system transient stability and dynamic load behaviour analysis. The present investigations deal with (i). Wind turbine dynamic modelling, (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 (vi) THD analysis of stator voltage and current. DFIG can operate in both sub-synchronous and super-synchronous operation modes to impart power to the grid or from the grid with a minimum rotor power input in both steady and variable wind turbine speed in different operation modes.

2. Dynamic modelling of wind turbine

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

2.1. Wind Turbine

The aerodynamic modelling of wind turbines is estimated from their power-speed characteristics. Steady-state mechanical power output is given in equation 1.

$$P_m = \frac{1}{2}\rho A C_p u^3 \qquad (1)$$

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

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

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

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

2.2 *Pitch angle controller Design*

For a variable-speed wind turbine, pitch angle control is essential for accurate modelling and simulation studies. The primary function of Pitch angle control is to provide suitable speed and power limits for smooth turbine operation and to contribute maximum wind energy capture. As described in subsection 1, Cp depends on wind speed and rotor data to maximise the maximum output power 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})*. A PI controller realises the pitch angle control. This model accounts for a servo time constant (T_s) and a limitation of both pitch angle and its rate of change.

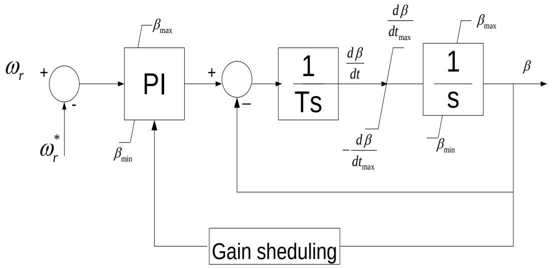


Fig. (2) Pitch angle controller design

2.3 DFIG Modeling

In order to improve the quality and controllability of the generated electrical power, a wind turbine with a doubly-fed induction generator is preferred [8-16]. Here the converter connected to the rotor winding is of a lower rating. The filter required for power factor control is also of lesser rating. However, the major drawback of this configuration is wind turbine operation during grid faults. For analysis, accurate numerical modelling of DFIG must be provided to determine the dynamic performances [16, 17]. Here, the stator side is directly connected to the grid while the rotor is interfaced with the converter and the rotor current is sensed for control operation[18][19]. 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 modelled in a d-q reference frame (park model) rotating at a synchronous speed [20, 21]. Using the convention generator to the governing equations are as such:

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

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

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

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

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 are fed back as the input along with the machine parameter. The machine variables expressed in the standard 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 it 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 $T_e = \psi_{dm}\, i_{qr}$ and $Q_s = \frac{L_s}{L_m}\psi_{dm}^{\;2} - \psi_{dm}\, i_{dr}^2$ 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.

2.4 Rotor side Controller design

DFIG is a wound rotor in an induction motor with stator winding directly connected to the grid, whereas the rotor side is connected with a VSC [23]-[25]. However, the converter supplies or absorbs reactive power to the DFIG, depending on its operation, either in 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 the turbine. So, 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. The 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 not to exceed the maximum towards the rotor side to converter voltage rating.

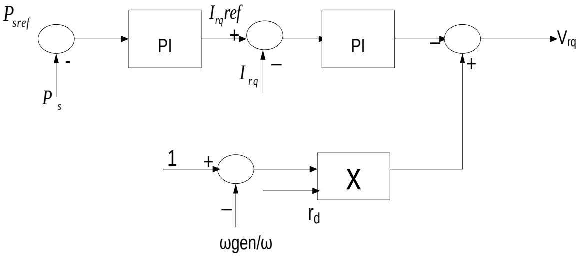
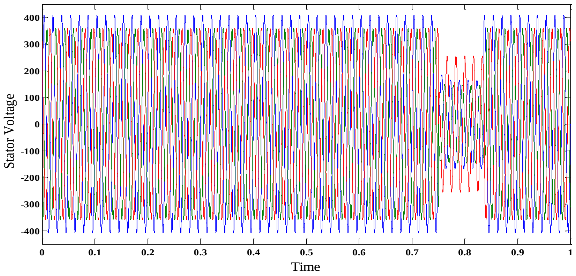


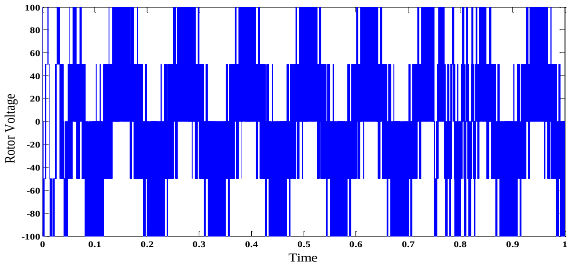
Fig.(3) active and reactive power controller

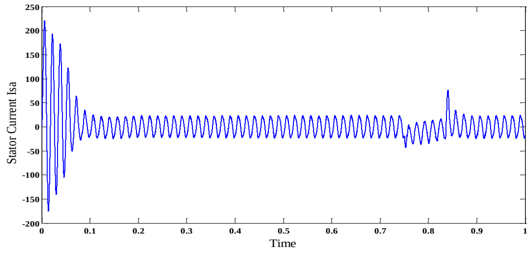
Regular operation's active power set point is defined from the maximum power tracking curve and generator speed. Whereas under fault P_{ref}^{grid} is changed to the output value of the damping controller. One damping controller is introduced to damp out torsional oscillation aroused due to the drive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

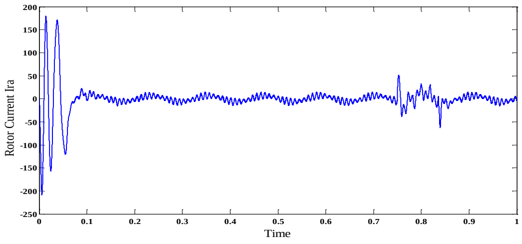
3. Simulation Results

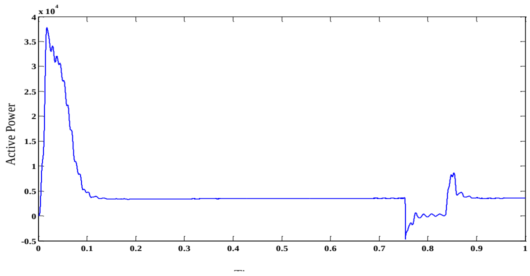
The dynamic response and transient performance of DFIG are evaluated under different fault, and operating conditions and the voltage ride-through capability of the turbine is studied. Here, a DFIG – wind plant of 2 KVA Capacity is studied for analysis. Only the rotor side converter and the controller control the machine speed and the reactive power supplied through the stator 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 the current, voltage, power speed and torque) for voltage sag and short circuit condition are shown in fig. 4 and fig. 5, respectively.

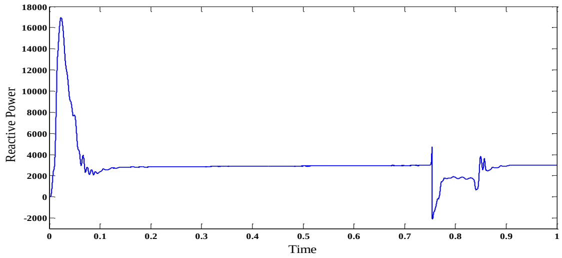


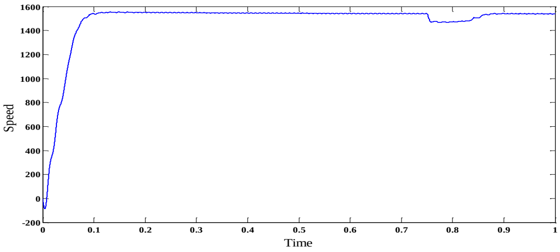












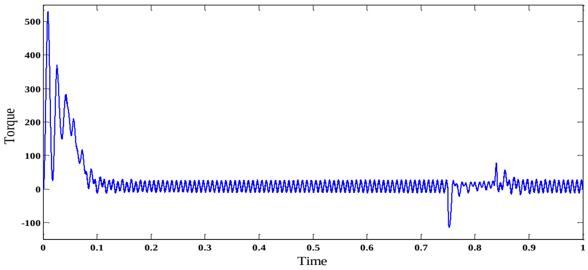
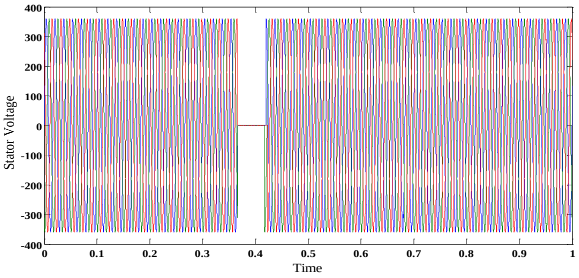
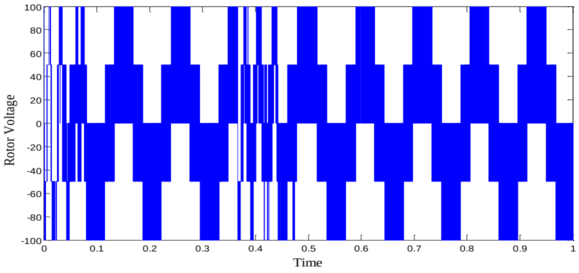
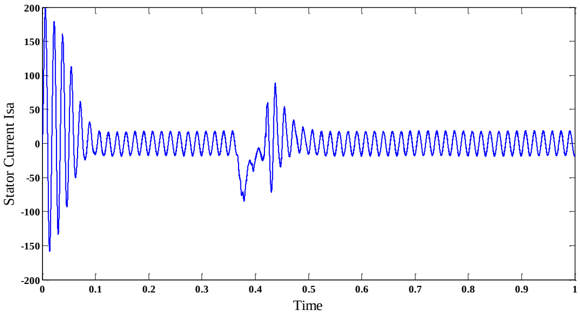
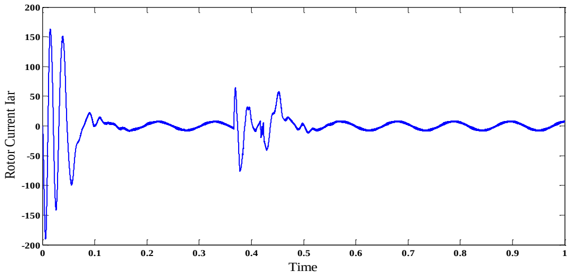


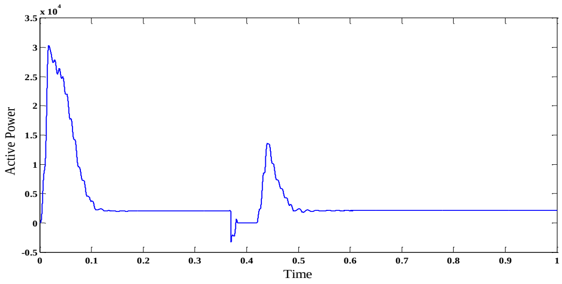
Fig.(4) DFIG during voltage sag

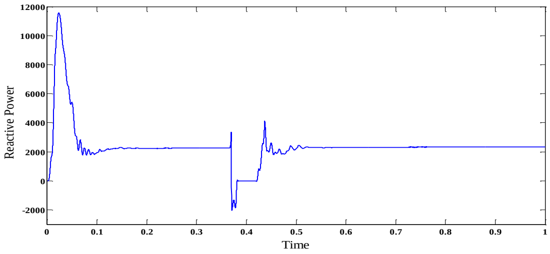


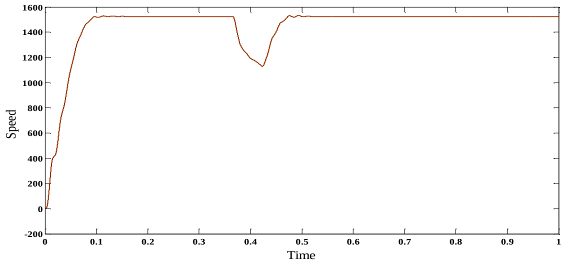












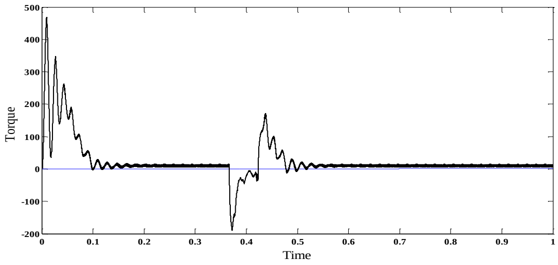


Fig.(5) DFIG during short circuit fault (3-phase fault)

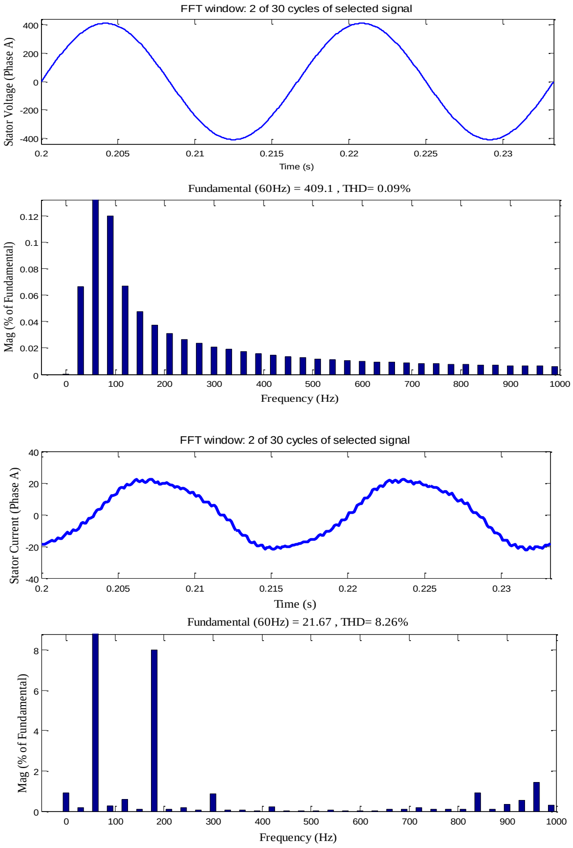


Fig.(6) THD in Stator Voltage and Current

***CASE*-1:** Under voltage sag, stator flux has been reduced, increasing the rotor current (1.2 pu), but the variations are within the allowable range of the converter and machine. After clearance of sag, again retain back to a normal steady-state value. The voltage sag period is from 0.26 to 0.335 seconds observed in fig. 4.

***CASE*-2:** During a fault, the transient currents on the stator are reflected on the rotor windings. The rotor side converter is designed to withstand heavy currents. Here the rotor current control is achieved through machine faults. The fault was created at 0.36 seconds and cleared at 0.42 seconds (3-4 cycles). The maximum current observed at the rotor side is around (3-3.2 pu). The controller parameters are designed to quickly damp out the torsional oscillation in the drive train systems and control the β value to prevent the rotor from over-speeding during the fault. This model is usually implemented faster, allowing the rotor side converter enough time to oppose the rotor current induced by stator flux weakening. During the fault, the DFIG response was smooth, with slight 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 the grid terminal voltage returned to its nominal value. This method has the advantage of not requiring any additional requirements. The Total Harmonics Distortion (THD)analysis in DFIG under Fault is done by the FFT Tool of MATLAB/Simulink. The THD In Stator Voltage was found to be only 0.09%, and THD in Stator Current was 8.26% Shown in fig. 6.

4. 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 as the generator and converter stay connected, the synchronism of operation remains established during and after the fault. Normal operation can be continued immediately after the fault has been cleared. Here the reactive power is supplied to the grid during longer-duration voltage dips to facilitate voltage restoration. A proper controller design is adopted to improve the transient and dynamic performance of DFIG coupled Wind turbines under these abnormal grid conditions. This paper analyses the DFIG dynamic behaviour and control possibility under grid disturbances like faults and significant voltage dips. In this model, with the help of only one rotor side converter, we can control the active and reactive power and maintain the grid's stability under faulty conditions.

APPENDIX

Generator rating- 2KVA, 440V, 1500rpm

Generator parameter:

Rotor winding resistance (R_r) = 0.816 ohm
Stator winding resistance (R_s) = 0.435 ohm
Rotor winding reactance (X_r) = 0.446 ohm
Stator winding reactance (X_s) = 0.446 ohm
Mutual reactance between rotor and stator windings (X_m) = 0.443 ohm
Number of poles (P) = 4
Moment of inertia (J) = 0.08 Kg.m^2

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, pages 129-135.

[2]. T. Ackermann "Wind power in power systems", John Wiley & Sons, ISBN: 0-470-85508-8, 2005.

[3]. J. Morren, J.T.G. Pierik, S.W.H. de Haan, J. Bozelie, "Grid interaction of offshore wind farms. Part 1.

Models for dynamic simulation", WindEnergy, 8 (3): JUL-SEP 2005.

[4]. J. Pierik, J. Morren, E.J. Wiggelinkhuizen, S.W.H de Haan, T.G. van Engelen, J. Bozelie, "Electrical and control aspects of offshore wind farms II (Erao II), Volume 2: Offshore wind farm case studies", Technical report of ECN&TUD, ECN-C-04-051, Netherlands, 2004.

[5]. Akhmatov, "Analysis of dynamic behaviour of electric power systems with a large amount of wind power", PhD thesis of Electrical power engineering, ISBN: 87-91184-18-5, Technical University of Denmark, April 2003.

[6]. Petersson, "Analysis, modelling and control of doubly-fed induction generators for wind turbines", PhD thesis, Electric Power Engineering, Chalmers University of Technology, 2005, Sweden.

[7]. L. Holdsworth, X.G. Wu, J.B. Ekanayake, "Comparison of fixed speed and doubly fed induction wind turbines during power system disturbances", IEE Proceedings of Generation, Transmission and Distribution, Pages: 343-352, Vol. 150, Issue. 3, May 2003

[8]. 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

[9]. 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 June 2005 pages 435-441 vol. 20.

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

[11]. 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

[12]. Ahmed M. Kassem, Khaled M. Hasaneen, Ali M. Yousef " Dynamic modelling and robust power control of DFIG driven by a wind turbine at infinite grid" International journal Electrical Power and Energy Systems 49 (2013) 234–242

[13]. Rahimi Mohsen, Parniani Mostafa " Dynamic behaviour analysis of doubly-fed induction generator wind turbines – the influence of rotor and speed controller parameters". Int J Electr Power Energy Syst 2010;32(5):464–77.

[14]. Poitiers F, Bouaouiche T, Machmoum M. "Advanced control of a doubly-fed induction generator for wind energy conversion" Electric Power Syst Res 2009;79:1085–96.

[15]. Ourici Amel. "Double flux orientation control for a doubly fed induction machine". Int J Electr Power Energy Syst 2012;43(01):617–20.

[16]. Lopez-Garcı'a I, Espinosa-Perez G, Siguerdidjane H, Doria-Cerezo A. On the passivity-based power control of a doubly-fed induction machine. Int J Electr Power Energy Syst 2013;46(in progress):303–12.

[17]. 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

[18]. 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

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

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

[21]. 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.

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

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