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Dynamic Modeling & Active and Reactive Power Control of DFIG for Wind Power Generation

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ABSTRACT

This paper presents the simulation of dynamic modeling & active and reactive power control of doubly fed induction generator for variable speed wind energy system. The main reason for the popularity of the doubly fed wind induction generator connected to the power network is its ability to supply power at constant voltage and frequency while the rotor speed varies. The doubly fed induction machine is modeled in synchronous rotating reference frame theory with vectorized dynamic model, the advantage of this model we can use for both motoring and generating mode of operation. The choice of synchronous rotating reference frame makes it particularly favorable for the simulation of double-output configuration in transient conditions. The injected rotor voltages (at slip frequency) are derived from PI controllers that regulate the active and reactive powers delivered by the generator. The main goal of this project is to simulate doubly fed induction generator (DFIG) & to control the rotor and stator voltages by injecting the proper rotor voltage to the DFIG derived from PI controller. The complete simulation model is developed for such machine under variable speed operation using MATLAB Simulink.

Index Terms: Vector control, synchronous rotating reference frame, Wind power generation & Doubly fed induction generator.

1. INTRODUCTION

At present scenario many of the countries in the world are suffering with two major problems namely power crisis and degradation of conventional energy sources. To solve this challenge, researchers conclude alternate energy sources are the best choice and amongst those wind power generation is one of the best choice for geographically suitable countries like India. Wind generators play an important role among all possible renewable energy resources, they considered as the most promising in terms of competitiveness in electrical power production. From past thousand years the wind energy used for water pumping, grinding grain, and other low-power applications. There were several early attempts to build large-scale wind powered systems to generate the electrical energy. The first production of electrical energy with wind power was done in 1887 by Charles Brush in Cleveland, Ohio. The rated Power of the used dc-generator was 12kW and was designed to charge batteries. The induction machine was used at the first time in 1951. Recently Enercon constructed a wind turbine of 4.5 MW and rotor diameter of more than 112.8 meters. Wind energy is the fastest growing and most promising renewable energy source among them due to economically viable [1-3]. In India, the total installed capacity of wind power generation is 8754 MW in the year 2008 and by 2012 it was 12000 MW. By the end of 2014, the total installed capacity is going to be reached to 21262.23 MW according to ministry of new and renewable energy, India.

In wind energy system wind is trapped with the help of rotor blades, which is connected to the rotor hub of the wind turbine system. The trapped mechanical energy from the wind is transferred to a high-speed shaft by the means of a low speed shaft and gearbox arrangement [4].The mechanical to a high-speed which is trapped from rotor machine with the aid of low speed and high speed shafts which acts as a mechanical input to the electrical machine. Induction machines are used in the process of generating to the main hub called power grid through transmission lines [5]. Though conventional power generation units uses synchronous machine as generators, wind power plants makes use of induction machines as one of the major modern wind power generating facilities.

2. WIND-TURBINE TECHNOLOGY

There are two basic options of wind power conversion system such as fixed speed and variable speed operation. In fixed speed operation, the wind turbine can be operated at a constant speed by pitch control even under varying wind speeds. This option was very common because of the cost involved with the power converter needed in the variable speed generation to convert the variable frequency to match the constant grid frequency. In variable speed operation, the wind turbine rotational speed can be allowed to vary with wind to maintain a constant and optimum tip speed ratio. The variable speed operation by active pitch control allows optimum efficiency operation of the turbine over a wide range of wind speeds, resulting in increasing power outputs and reduced mechanical stresses on the rotor [6].

For variable speed generation, an induction generator is the ultimate choice due to its flexible rotor speed characteristics in contrast to the constant speed characteristics of synchronous generator. DFIG is best suited for variable speed generation since it can be controlled from rotor side as well as stator side. This is possible since rotor circuit is capable of bidirectional power flow. The rotor will observe slip power from the in sub-synchronous operation and can feed slip power back to grid in super-synchronous operation. The rotor converter needs thus only to be rated for a fraction 25% (Slip Power) of the total output power [7]. All these advantages make the DFIG a favourable candidate for variable speed operation.

3. WIND TURBINE WITH DFIG

Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter [8]. It is a 4-quadrant converter which can realize bidirectional flowing of energy. On the one hand, the rotor can absorb energy from power grid and on the other hand, it can feed the energy back to the power grid under certain conditions. 4-quadrant means the excitation power supply can operate on positive resistive, pure capacitive, negative resistive and pure inductive the four typical state.

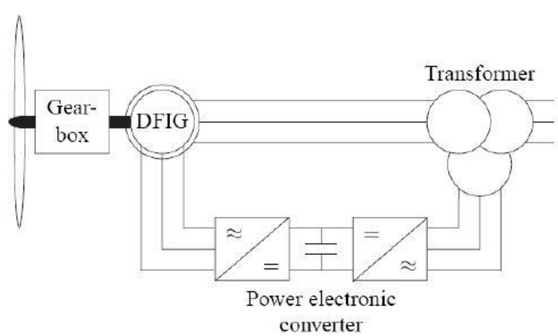


Figure 1 Wind turbine with a doubly-fed induction generator (DFIG)

The stator is directly connected to the AC mains, whilst the wound rotor is fed from the Power Electronics Converter via slip rings to allow DIFG to operate at a variety of speeds in response to changing wind speed. Indeed, the basic concept is to interpose a frequency converter between the variable frequency induction generator and fixed frequency grid. The DC capacitor linking stator- and rotor-side converters allows the storage of power from induction generator for further generation. To achieve full control of grid current, the DC-link voltage must be boosted to a level higher than the amplitude of grid line-to-line voltage. The slip power can flow in both directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor- or stator-side converter in both super and sub-synchronous speed ranges. At the synchronous speed, slip power is taken from supply to excite the rotor windings and in this case machine behaves as a synchronous machine.

4. DYNAMIC MODELING OF DFIG

The electrical part of the DFIG is represented by a fourth-order state space model, which is constructed using the synchronously rotating reference frame (dq-frame), where the d-axis is oriented along the stator-flux vector position. The relation between the three phase quantities and the dq components is defined by Park's transformation.

The voltage equations of the DFIG are:

$$V_{qs} \bullet R_s.I_{qs} \bullet \frac{d\bullet_{qs}}{dt} \bullet\bullet\bullet\bullet_{e}\,{}_{ds} \qquad (1)$$

$$V_{ds} \bullet R_s.I_{ds} \bullet \frac{d\bullet_{ds}}{dt} \bullet\bullet\bullet\bullet_{e}\,{}_{qs} \qquad (2)$$

$$V_{qr} \bullet R_r.I_{qr} \bullet \frac{d\bullet_{qr}}{dt} \bullet (\bullet_e \bullet\bullet_r)\bullet_{dr} \qquad (3)$$

$$V_{dr} \bullet R_r.I_{dr} \bullet \frac{d\bullet_{dr}}{dt} \bullet (\bullet_e \bullet\bullet_r)\bullet_{qr} \qquad (4)$$

In the DFIG system the state variables are normally currents, fluxes etc. In the following section the state space equations for the DFIG in synchronously rotating frame has been derived with flux linkages as the state variables. Since the machine and power system parameters are nearly always given in ohms or percent or per unit of base impedance, it is convenient to express the voltage and flux linkage equations in terms of reactance rather than inductances. The above stated voltage and flux equations can be reworked as follows:

$$V_{qs} = R_s.I_{qs} + \frac{1}{w_b}.\frac{d\psi_{qs}}{dt} + \frac{\omega}{\omega_b}\psi_{ds} \qquad (5)$$

$$V_{ds} = R_s.I_{ds} + \frac{1}{\omega_b}.\frac{d\psi_{ds}}{dt} - \frac{\omega_e}{\omega_b}\psi_{qs} \qquad (6)$$

$$V_{qr} = R_r.I_{qr} + \frac{1}{\omega_b}.\frac{d\psi_{qr}}{dt} + \frac{(\omega-\omega)}{\omega_b}\psi_{dr} \qquad (7)$$

$$V_{dr} = R_r.I_{dr} + \frac{1}{\omega_b}\frac{d\psi_{dr}}{dt} - \frac{(\omega-\omega_{er})}{\omega_b}\psi_{qr} \qquad (8)$$

Where V_{qs}, V_{ds}, V_{qr}, V_{dr} are the q- and d- axis of the stator and rotor voltages; I_{qs}, I_{ds}, I_{qr}, I_{dr} are the q- and d- axis of the stator and rotor currents; $\bullet_{qs}$, $\bullet_{ds}$, $\bullet_{qr}$, $\bullet_{dr}$ are the q- and d-axis of the stator and rotor fluxes; R_s, R_r are the stator and rotor resistance; $\bullet_e$ is the speed of the reference frame and $\bullet_r$ is the rotor speed. The flux equations of the DFIG are

$$\bullet_{qs} \bullet L_s.I_{qs} \bullet L_m.I_{qr} \qquad (9)$$

$$\bullet_{ds} \bullet L_s . I_{ds} \bullet L_m . I_{dr} \qquad (10)$$

$$\bullet_{qr} \bullet L_r . I_{qr} \bullet L_m . I_{qs} \qquad (11)$$

$$\bullet_{dr} \bullet L_r . I_{dr} \bullet L_m . I_{ds} \qquad (12)$$

Where L_s , L_r , L_m are the stator, rotor and mutual

From the above equations (1-12) the mathematical model for the induction generator is done in synchronous rotating reference frame and per unit description. The induction generator is modeled with MATLAB/ SIMULINK.

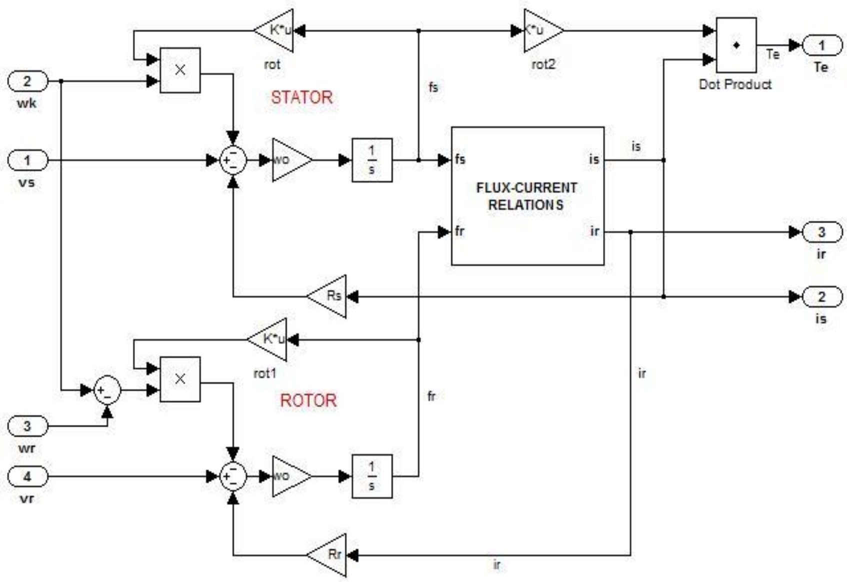


Figure 2 Dynamic Modeling of DFIG

5. ACTIVE AND REACTIVE POWER CONTROL OF DFIG

Generation of energy extraction from a DFIG wind turbine depends not only on the induction generator but also on the control techniques developed using different orientation frames. The DFIG usually operates in vector control mode based on the PI controllers in a synchronous rotating reference frame. The DFIG with PI controllers and its performance under normal operation conditions has been discussed in a number of papers. [9-10].

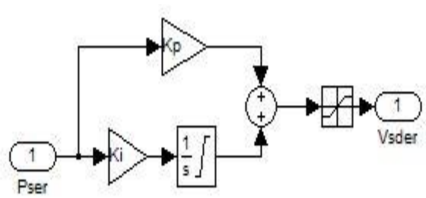


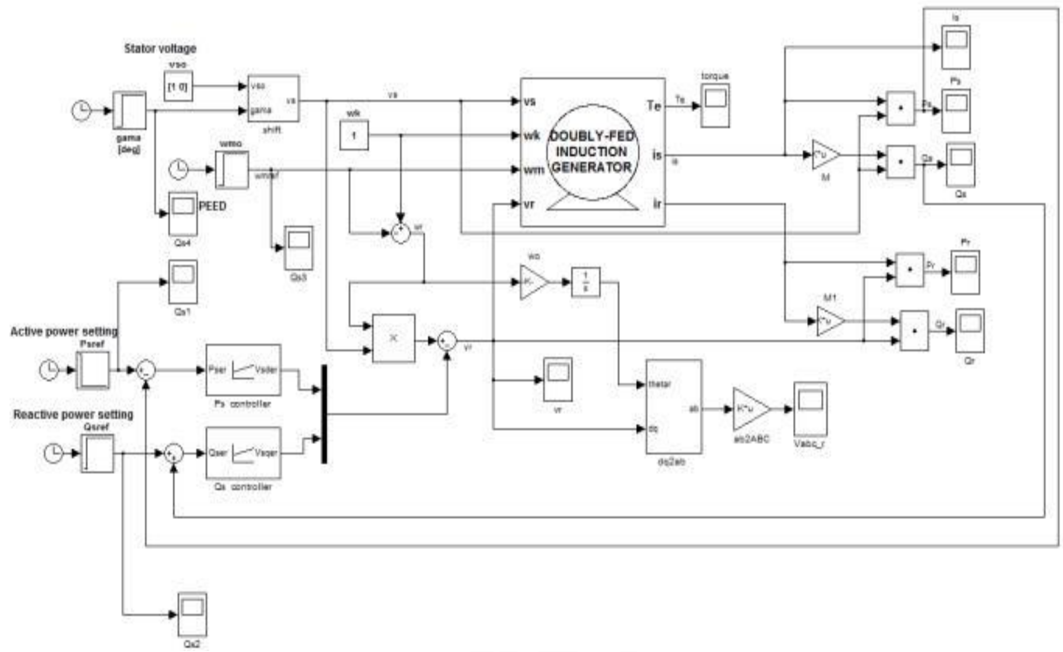
Figure 3 PI controller

It is well known that the DFIG performance with PI controllers is excellent in allowing independent control of the stator active and reactive power [11- 12]. In this report special approaches to improve DFIG stability under unbalanced conditions using the synchronous rotating reference frame. In a [13] DFIG system model in the positive and negative synchronous reference frames is presented to enhance the stability of the DFIG under unbalanced voltage supply.

This PI controller is used to control the active and reactive power in the DFIG which was applied to the stator. By using this we can control the stator active and reactive power at any instant. The injected rotor voltages (at slip frequency) are derived from PI controllers that regulate the active and reactive powers delivered by the generator. The speed is adjusted by the turbine pitch control to maximize the power generated at a given wind speed.

6. IMPLEMENTATION OF DFIG MODEL AND ACTIVE & REACTIVE POWER USING SIMULINK

For implementation of DFIG model we had seen in above method and for control of active and reactive power can also controlled by PI controller by combining these two in MATLAB/SIMULINK. We can control the stator active and reactive power of the DFIG at any instant. In this implementation we have the four inputs by changing any of the input we want to get the desired active and reactive power.

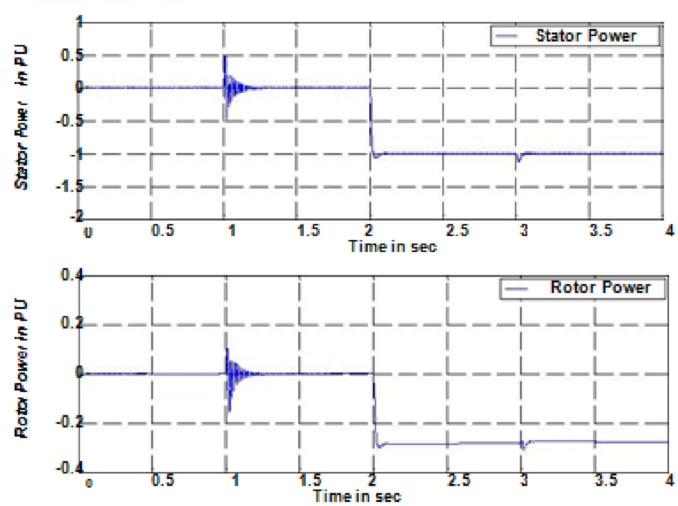


7. RESULTS AND DISCUSSION

In the DFIG we have four modes of operation they are motoring and generating mode in super-synchronous mode and sub-synchronous mode.

At super-synchronous mode:

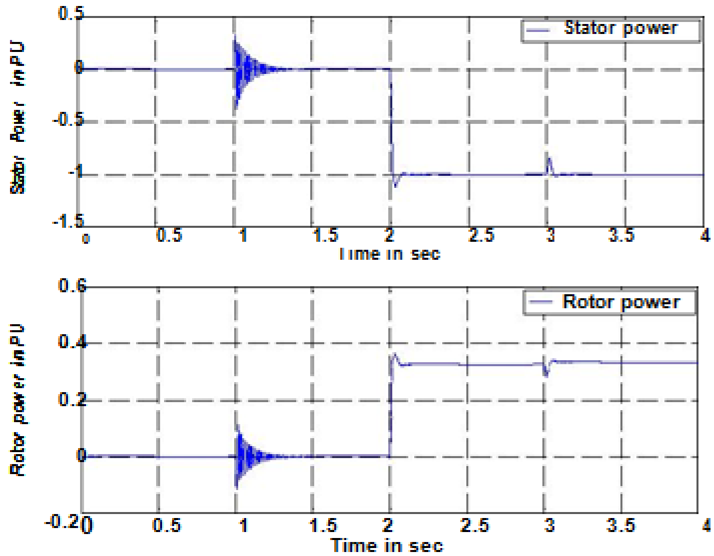
At super synchronous speed shaft power is '(1+s)P' in this case stator power 'P' is fed to grid and remaining 'sP' is fed to grid through rotor .so in this case stator and rotor is negative. We can see these results in the MATLAB.



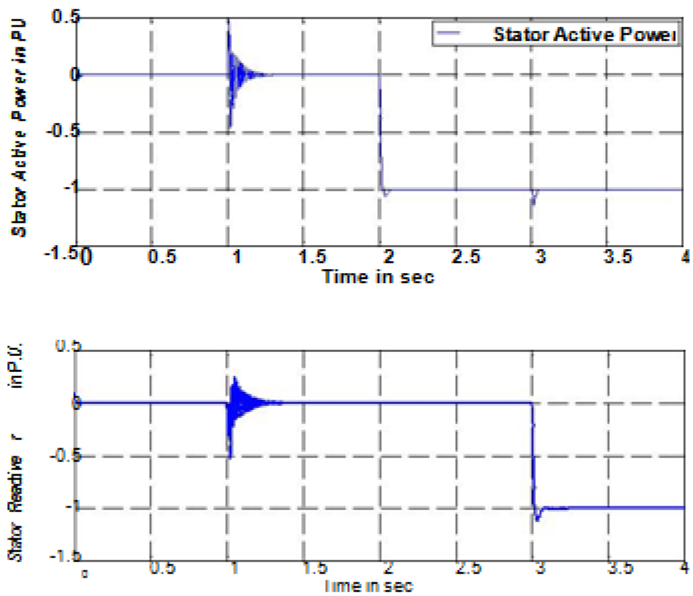
So in the graphs we can see that stator and rotor is supplying power to the grid in super-synchronous mode after 2 sec, here negative value means generating the power and positive value means absorbing the power from grid.

At sub-synchronous mode:

At sub synchronous speeds the power given to the shaft is "(1-s)*P" and the stator power is always 'P'. So remaining 'sP' power is fed from the rotor. So rotor power is positive in this case and the stator power is negative.



The stator active and reactive power is controlled at the instant of 2 and 3 sec as



8. CONCLUSION

This paper contributes in simulation of induction machine modelling in vectorized form with synchronous rotating reference frame. The injected rotor voltages (at slip frequency) are derived from PI controllers that regulate the active and reactive powers delivered by the generator. Furthermore, vector control strategy has been examined for controlling active and reactive power of stator side. The behavior of the system was investigated during step change in wind variations. At any instant we can control the stator active and reactive and we can see how the power is transferring in different modes of operation.

REFERENCE

1. S. Muller, M. Deicke and R. W. De Doncker, "Doubly fed induction generator systems for wind turbine", IEEE Industry Applications Magazine, Vol.8, No. 3, 2002, pp. 26-33.
2. A.Tapia, G.Tapia, J.X.Ostolaza, J.R Saenz, "Modeling and control of a wind turbine driven doubly fed induction generator", IEEE Transactions on Energy Conversion, vol.18, June 2003, pp.194-204.
3. Luianc Mihet-Popa, Frede Blaabrierg, "Wind Turbine Generator Modeling and Simulation Where Rotational Speed is the Controlled Variable", IEEE Transactions on

Industry Applications, Vol.21, No.1, January/February 2004.
4. Thomas Ackerman, Wind Power in Power System, Royal `Institute of Technology, John Wiley & Sons, Inc., England.
5. J.G. Slootweg, H. Polinder and W.L. Kling, "Dynamic Modeling of a Wind Turbine with Doubly Fed Induction Generator", Proceedings of IEEE, 2001.
6. S. Chondrogiannis M. Barnes "Stability of doubly-fed induction generator under stator voltage orientated vector control", Transaction on IET Renewable Power Generation, Vol. 2, No. 3, 2008, pp. 170–180.
7. R. Krishnan, Electric Motor Drives - Modeling, Analysis, and Control, Prentice Hall, 2001.
8. S. Chondrogiannis M. Barnes "Stability of doubly-fed induction generator under stator voltage orientated vectorcontrol", Transaction on IET Renewable Power Generation, Vol. 2, No. 3, 2008, pp. 170–180.
9. M.V.A Nunes, J.A. Pecas Lopes, H.H. Zurn ,U. H. Bezerra, and R. G. Almeida, "Influence of the variable-speed wind generators in transient stability margin of the conventional generators integrated in electrical grids," IEEE Trans. Energy Conversion, vol. 19, no. 4, pp. 692-701, Dec. 2004.
10. J.Morren and S.W.H. de Haan, "Ride Through of wind turbines with doubly-fed induction generator during voltage dip," IEEE Trans. Energy Conversion, vol. 20, no. 2, pp. 435-441, Jun. 2005.
11. Stephan Engelhardt, Istvan Erlich, Christian Feltes, J¨org Kretschmann, and Fekadu Shewarega, "Reactive Power Capability of Wind Turbines Based on Doubly Fed Induction Generator," IEEE Trans. on Energy Conversion, vol. 26, no. 1, pp. 364-372, March 2011
12. Cadirci., & Ermi, "Double-output induction generator operating at sub synchronous and super synchronous speeds: steady-state performance Optimization and wind-energy recovery", IEEE Proceedings-B. 139, no.5, 1992, pp. 429-442.
13. Lucian Mihet-Popa, Frede Blaabrierg, "Wind Turbine Generator Modeling and Simulation Where Rotational Speed is the Controlled Variable", IEEE Trans. on Industry Applications, Vol. 40 No.1, January/February 2004.