

Modelling and Simulation of DFIG for Wind Energy Generation Using Stator Voltage Orientation Control

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ABSTRACT

This paper is about the modelling and simulation of wind driven doubly fed induction generator. A converter setup that is back to back PWM with stator voltage oriented vector control is used to control the DFIG. The back to back PWM converter set up consists of the Rotor Side Converter and the Grid Side Converter with intermediate DC link. Decoupled control of the DC link voltage and the grid reactive power is obtained through Voltage oriented control of GSC. Similarly independent control of power from wind and reactive power of DFIG is carried out by stator voltage oriented vector control of RSC. Coordinated control of the back to back converter setup in both subsynchronous and supersynchronous mode is presented This simulink model includes the grid connection, the induction generator as well as the control parts.

Keywords – DFIG, decoupled control, grid side converter, Matlab/Simulink, rotor side converter, stator voltage orientation scheme

I. INTRODUCTION

Now a days as one of the most important renewable source of energy is wind energy that is gaining interest due to its ecofriendly nature. In a few last years variable speed wind turbines with DFIG are the most applied wind turbine. The great interest for variable speed wind turbine is because of very good characteristics with modern semiconductor converters and digital control systems. This paper is about the modelling and simulation of wind driven doubly fed induction generator. A converter setup that is back to back PWM with stator voltage oriented vector control is used to control the DFIG. The back to back PWM converter set up consists of the Rotor Side Converter and the Grid Side Converter with intermediate DC link. Decoupled control of the DC link voltage and the grid reactive power is obtained through Voltage oriented control of GSC. Similarly independent control of power from wind and reactive power of DFIG is carried out by stator voltage oriented vector control of RSC. Coordinated control of the back to back converter setup in both subsynchronous and supersynchronous mode is presented.

II. BASIC STRUCTURE OF THE DFIG WIND TURBINE CONTROL SYSTEM

Typical configuration of the wind turbine with DFIG consists of an induction wound rotor generator with stator winding connected directly to the three phase grid and rotor winding connected to the three phase grid by the use of back-to-back power semiconductor converter. Back-to-back is bi-

directional semiconductor power converter consists of two pulse-width voltage converter (converter connected to the rotor and converter connected to the grid side with voltage PWM inverter) and common DC link. The active and reactive power control system of the wind turbine is based on the theory of the induction machine vector control. That theory mean two-axis control described in three different reference frames. The active and reactive power control system of the wind turbine with DFIG and back-to back converter connected to the electric grid is shown in Fig. 1.

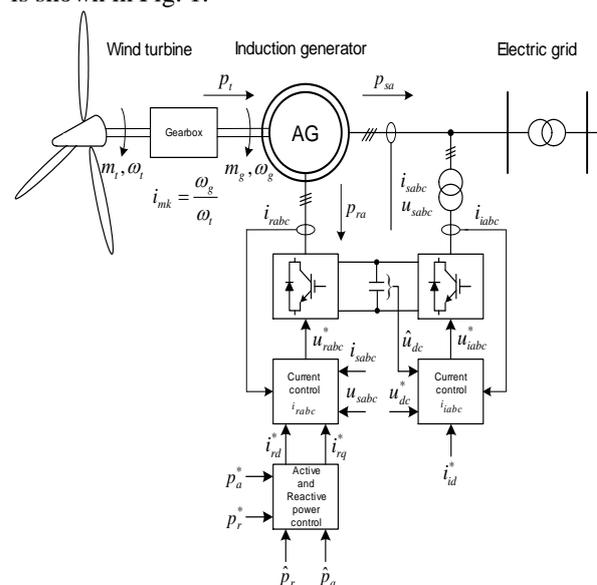


Fig. 1. Wind turbine control system with DFIG

The main rule of DFIG is conversion of power given from the wind turbine to the electric power and

electric power delivery from DFIG stator to the electric grid. Doubly fed electric machines are generators or motors are those that have windings on both stationary and rotating parts, where both windings transfer significant active power between shaft and electrical system. Usually the stator winding is directly connected to the three-phase grid and the three-phase rotor winding is fed from the grid through a rotating or static frequency converter. The DFIG is an attractive and popular option for large wind turbines (multi-MW) due to its flexibility in variable speed range and the lower cost of the power. In the DFIG configuration, the generator rotor operates at a variable speed in order to optimize the tip-speed ratio. Therefore the generator system operates in both a sub-synchronous and super-synchronous mode, typically between +/- 30% of synchronous speed. The rotor winding is fed through a variable frequency power converter, typically based on two AC/DC/IGBT based linked voltage source converter through a dc bus. The variable frequency rotor supply from the converter enables the rotor mechanical speed to be decoupled from the synchronous frequency of the electrical network, thereby allowing a variable speed operation of the turbine.

either to the rotor or from the rotor, thereby either absorbing or injecting active power to the grid. In either case, the active power flows in only one direction through both converters. The converter arrangement allows for a variable frequency (associated with the variable rotor speed) to maximize active power extraction. As the two converters are decoupled via the DC-link, the connection to the grid can be maintained at the grid frequency and the voltage controlled to synchronize with the grid. The basis for injecting or absorbing active power is the varying operation of the DFIG when it goes from sub-synchronous speed to super-synchronous speed. Active power flows as a function of slip.

III. MODELING OF THE ACTIVE AND REACTIVE POWER CONTROL SYSTEM OF THE DFIG WIND TURBINE MODELING OF THE WIND TURBINE

Dynamical model of the wind turbine describes the main parts of the wind turbine drive train system and induction generator that participate in interaction of the wind turbine with electric power system.

IV. DYNAMIC MODEL OF THE DFIG

In the wind turbine system connected to the grid side with vector control of active and reactive power of DFIG, usually is used transformation of current, voltage and magnetic fluxes vectors of stator and rotor from original abc reference frame into two-phase rotating dq reference frame. Grid side converter control is used to regulate the voltage across the DC link and sometime also to compensate harmonics. This is a two stage controller scheme which is achieved by grid voltage oriented vector control scheme i.e. by aligning the dq- axis in the direction of grid voltage. Grid converter is typically a three phase, two level voltage source converter which uses IGBT as a switching device. As we have discussed earlier, the main purpose of grid side converter control is done to regulate the DC link voltage. This is done by implementing grid voltage oriented control scheme. In the voltage orientation control, the grid voltage is measured the angle θ_g is detected from phase lock loop (PLL) for the voltage orientation. Assuming that the grid voltage $v_{ag}, v_{bg},$ and v_{cg} , that are three phase balanced sinusoidal waveforms, and angle θ_g can be obtained by

$$\theta_g = \tan^{-1} \frac{v_{bg}}{v_{ag}}$$

Where

$$v_{\alpha} = \frac{2}{3} \left(v_{ag} - \frac{1}{2} v_{bg} - \frac{1}{2} v_{cg} \right) = v_{ag}$$

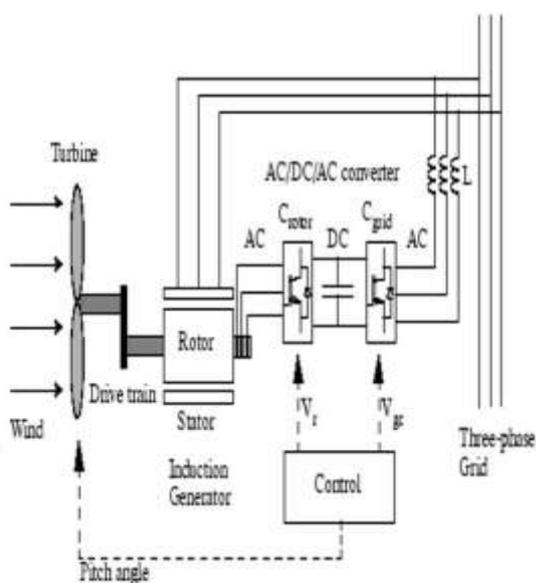


Fig. 2. Working principle of DFIG.

The rotor winding is fed through a variable frequency power converter, typically based on two AC/DC/IGBT based linked voltage source converter through a dc bus. The variable frequency rotor supply from the converter enables the rotor mechanical speed to be decoupled from the synchronous frequency of the electrical network, thereby allowing a variable speed operation of the wind turbine. In the rotor circuit, active power flows in one direction,

$$v_{\beta} = \frac{2}{3} \left(\frac{\sqrt{3}}{2} v_{bg} - \frac{\sqrt{3}}{2} v_{cg} \right) = \frac{\sqrt{3}}{3} (v_{ag} + 2v_{bg})$$

For $v_{ag} + v_{bg} + v_{cg} = 0$

The above equation indicates that there is no need to measure the phase-c grid voltage. In practice, the grid voltage may contain harmonics and be distorted, so digital filters or phase locked loop (PLLs) may be used for the detection of the grid voltage angle θ_g .

To achieve the VOC control scheme, the d-axis of the synchronous frame is aligned with the grid voltage vector, therefore the d-axis grid voltage is equal to its magnitude ($v_{dg} = v_g$) and the resultant q-axis voltage v_{qg} is then equal to zero, from which the active and reactive power of the system can be calculated by

$$P_g = \frac{3}{2} (v_{dg} i_{dg})$$

$$Q_g = -\frac{3}{2} (v_{dg} i_{qg})$$

The q-axis current reference i_{qg}^* can be obtained from

$$i_{qg}^* = \frac{Q_g}{-1.5 v_{dg}}$$

Where Q_g^* is the reference for the reactive power, which can be set to zero for unity power factor operation, a negative value shows the leading power factor operation, or a positive value shows the lagging power factor operation. The grid side converter performs two main function that is, it keeps the dc link voltage constant and provides the reactive power to the grid when required. The reactive power can be set to zero for unity power factor operation. It is seen that the DC-link voltage can be controlled via i_{dg} .

At rotor- side converter the torque equation:

$$T_e = \frac{2P}{\omega} (i_{qs} \lambda_{ds} - i_{ds} \lambda_{qs})$$

Putting the value of current and flux linkages the torque equation is:

$$T_e = \frac{3PL_m}{2L_s} (-i_{qr} \lambda_{ds} + i_{dr} \lambda_{qs})$$

The above torque equation shows that the T_e is the function of rotor current and stator flux linkages. In this system the stator voltage is constant, since it is directly connected to the grid

V. MODELLING AND SIMULATION

Vector control of active and reactive power control of wind turbine is decoupled power control of DFIG.

In vector control of active and reactive power control of wind turbine is applied next reference frames:

- induction generator is modeled in dq reference frame that, by comparison with original abc reference frame, is at rest.
- semiconductor power converter connected to the rotor side is modeled in dq reference frame; vector of stator voltage is aligned to d-axis,
- semiconductor power converter connected to the electric grid side is modeled in dq reference frame; vector of grid voltage is aligned to d-axis.

Simulations in this paper have performed by constant DC link voltage.

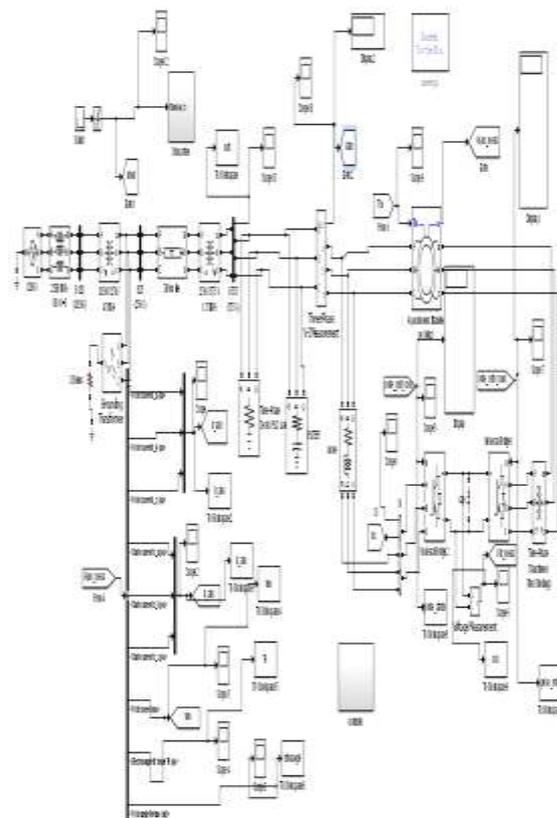


Fig.3. Simulink diagram of DFIG wind energy conversion system at variable wind speed.

Figure shows DFIG wind model simulation in MATLAB/SIM-POWER SIMULINK. The three phase programmable source is generating power at 120 kV, which is stepped down to 25 kV by the two winding transformer and then transmitted by the 30 km transmission line for stepping down the voltage level to the 575 V at the point of common coupling between the grid and the DFIG wind energy conversion systems. The DFIG wind energy conversion system is generating power of 1.5 MW. In this, the wind turbine uses a doubly-fed induction generator (DFIG), which consists of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter. The dc voltage is applied to IGBT/ Diode's of two level inverter. The pulse width modulation technique has been used in this inverter,

in order to achieve higher accuracy, the carrier frequency or switching frequency is 1620 Hz, discrete sample time is, $T_s = 5$ microseconds. The stator winding is connected directly to the 60 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG wind system allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during the gusts of wind. In this, wind speed is maintained constant at 12 m/s.

VI. SIMULATION RESULTS

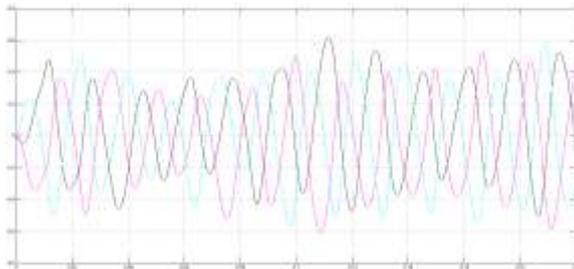


Fig.4.three phase stator voltage

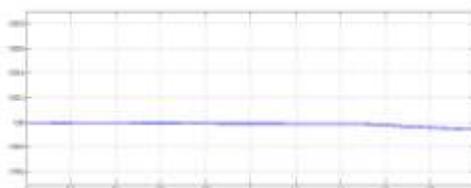


Fig.5.dc link voltage

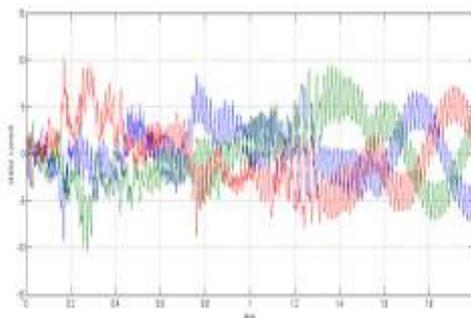


Fig.6.Three phase stator current

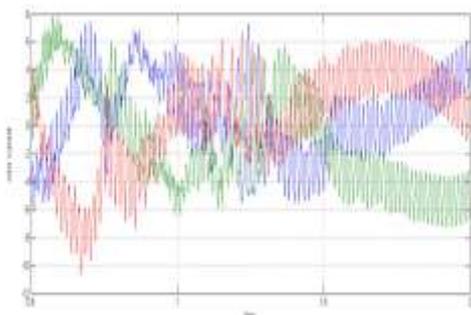


Fig.7.Three phase rotor current.

A DFIG wind system have been modelled and simulated in MATLAB software. And the results are presented in above figures, that is the three phase grid/stator voltage, dc link voltage, stator and rotor current.

VII. CONCLUSION

This paper is about to modelled and simulate a DFIG based wind energy power system and control technique for maximum energy extraction and grid synchronization under stator voltage orientation reference frame and conditions. The simulation is performed for normal, and load conditions on DFIG integrated with grid under MATLAB/ SIMULINK. A rotor-side converter control design has been presented which is the 'key' to work conducted in this paper. The performance assessment of the controller designed has been carried out by analyzing its real/reactive power control in stator-voltage oriented frame, and analyzing its effectiveness in speed control, and the ability of the controller in facilitating effective synchronization with the power grid.

VIII. APPENDIX

Rated power	$P_{gn}=1.5 [MW]$
Nominal voltage	$U_n=575[V]$
Rated frequency	$f_n=60 [Hz]$
Number of pole-pairs	$p=2$
Stator resistance	$R_s=0.007 [pu]$
Rotor resistance	$R_r=0.005 [pu]$
Stator inductance	$L_s=0.171 [pu]$
Rotor inductance	$L_r=0.156 [pu]$
Magnetizing inductance	$L_m=2.9 [pu]$

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