Design and Simulation of Active and Reactive Power Control of Double-Fed Induction Generator for Wind Energy Conversion

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Abstract — Wind energy plays an increasingly important role in the world because it is friendly to the environment. During the last decades, the concept of a variable-speed wind turbine has been receiving increasing attention due to the fact that it is more controllable and efficient, and has good power quality. As the demand of controllability of variable speed wind turbines increases, it is therefore important and necessary to investigate the modeling for wind turbine-generator systems that are capable of accurately simulating the behavior of each component in the wind turbine-generator systems. Therefore, this thesis will provide detailed models of a grid-connected wind turbine system equipped with a doubly-fed induction generator (DFIG). In order to control the power flowing from the rotor of the DFIG and the power network, a control law is synthesized using PI controller. The performance is compared in terms of power reference tracking. The power reference tracking was smooth and overshoot was negligible at the transient points.

Index Terms—Active and Reactive Power, DFIG, Field Oriented Control, PI Controller, Power Reference Tracking, Wind Energy, Wind Turbine.

1 INTRODUCTION

Wind energy is one of the most important and promising source of renewable energy all over the world, mainly because it reduces the environmental pollution caused by traditional power plants as well as the dependence on fossil fuel, which have limited reserves. Electric energy, generated by wind power plants is the fastest developing and most promising renewable energy source. Off-shore wind power plants provide higher yields because of better conditions. With increased penetration of wind power into electrical grids, wind turbines are largely deployed due to their variable speed feature and hence influencing system dynamics. But unbalances in wind energy are highly impacting the energy conversion and this problem can be overcome by using a Doubly Fed Induction Generator (DFIG). Doubly fed wound rotor induction machine with vector control is very attractive to the high performance variable speed drive and generating applications. In variable speed drive application, the so called slip power recovery scheme is a common practice here the power due to the rotor slip below or above synchronous speed is recovered to or supplied from the power source resulting in a highly efficient variable speed system. Slip power control can be obtained by using popular Static Scherbius drive for bi directional power flow.

The major advantage of the DFIG is that the power electronic equipment used i.e. a back to back converter that handles a fraction of (20-30%) total system power. The back to back converter consists of two converters i.e. Grid Side Converter (GSC) and Rotor Side Converter (RSC) connected back to back through a dc link capacitor for energy storage purpose. In this paper a control strategy is presented for DFIG and Stator Active and Reactive power control principle is also presented. In order to decouple the active and reactive powers Stator Flux Oriented control is used and hence the induction machine model is developed. The grid side converter and the rotor side converter are used for the control of the active and reactive powers and various wind speed applications. The simulation model is developed and implemented using MATLAB/SIMULINK software. But there are some drawback which boosts the demands on the hardware and the robustness of the control system, like complexity of control structure, especially under parameters variations condition of DFIG. The active and reactive power can be controlled by PI controller [1].

2 MODELING OF DOUBLE-FED INDUCTION GENERATOR

DFIG mathematical model is expressed by the vector control technique which is also known as field oriented control (FOC) and then with d-q synchronously rotating reference frame and then state equations in terms of stator current and rotor flux are derived to develop the DFIG model in MATLAB/Simulink. The dynamic analysis of the symmetrical induction machines in the arbitrary reference frame has been intensively used as a standard simulation approach from which any particular mode of operation may then be developed. MATLAB/Simulink has an advantage over other machine simulators in modeling the induction machine using dq0 axis transformation [2, 3]. It can be a powerful technique in implementing the machine equations as they are transferred to a particular reference frame. Thus, every single equation among the model equations can be easily implemented in one block so that all the machine variables can be made available for control and verification purposes.
The stator and rotor voltages in terms of d-q axis can be written as follows:

\[ v_{sd} = R_s i_{sd} + (d\Phi_{sd})/dt - \omega_s \Phi_{sq} \]
\[ v_{sq} = R_s i_{sq} + (d\Phi_{sq})/dt + \omega_s \Phi_{sd} \]
\[ v_{rd} = R_r i_{rd} + (d\Phi_{rd})/dt - \omega_r \Phi_{rq} \]
\[ v_{rq} = R_r i_{rq} + (d\Phi_{rq})/dt + \omega_r \Phi_{rd} \]  

(1)

The stator and rotor flux can be written as follows:

\[ \Phi_{sd} = L_{dS} i_{sd} + L_{mrd} i_{rd} \]
\[ \Phi_{sq} = L_{qS} i_{sq} + L_{mrd} i_{rd} \]
\[ \Phi_{rd} = L_{rd} i_{rd} + L_{mrd} i_{rd} \]
\[ \Phi_{rq} = L_{rq} i_{rq} + L_{mrd} i_{rd} \]  

(2)

The active and reactive powers at the stator and rotor are defined as follows:

\[ P_s = (v_{sd} i_{sd} + v_{sq} i_{sq}) \]
\[ Q_s = (v_{sd} i_{sq} - v_{sq} i_{sd}) \]
\[ P_r = (v_{rd} i_{rd} + v_{rq} i_{rq}) \]
\[ Q_r = (v_{rd} i_{rq} - v_{rq} i_{rd}) \]  

(3)

The electromagnetic torque is expressed as

\[ T_e = P_n (\Phi_{rd} i_{rq} - \Phi_{rq} i_{rd}) \]  

(4)

\[ P_s = v_{sq} i_{sq} = V_s (-L_m/L_s i_{rq}) \]
\[ Q_s = v_{sq} i_{sd} = V_s (1/L_s \Phi_s - L_m/L_s i_{rd}) \]  

(6)

So it is observed that the electromagnetic torque and subsequently the active power depend on the rotor current along the q-axis.

### A. PI Regulator Synthesis

To design the controller it is defined that

\[ C_{rd} = \sigma L_r \omega_r i_{rq} \]
\[ C_{rq} = -\omega_r (\sigma L_r i_{rd} + L_m/L_s \Phi_s) \]  

(7)

And

\[ \overline{i}_{rd} = v_{rd} + C_{rd} \]
\[ \overline{i}_{rq} = v_{rq} + C_{rq} \]  

(8)

The rotor current equations are as follows:

\[ i_{rd} (s) = 1/(R_r + \sigma L_r s) U_{rd} (s) \]
\[ i_{rq} (s) = 1/(R_r + \sigma L_r s) U_{rq} (s) \]  

(9)

Let

\[ K_{ci} = 1/R_r \]
\[ T_{Ci} = (\sigma L_r)/R_r \]  

then

\[ i_{rd} (s) = K_{ci} / (1 + T_{Ci} s) U_{rd} (s) \]
\[ i_{rq} (s) = K_{ci} / (1 + T_{Ci} s) U_{rq} (s) \]  

(10)

The open-loop transfer function of current controller is

\[ G_{Oi d} (s) = (i_{rd} (s)) / (U_{rd} (s)) = K_{ci} / (1 + T_{Ci} s) \]
\[ G_{Oi q} (s) = (i_{rq} (s)) / (U_{rq} (s)) = K_{ci} / (1 + T_{Ci} s) \]  

(11)

Thus, the dynamic of the d-axis and q-axis currents are now represented by simple linear first-order differential equations. There, it is possible to effectively control the currents with a PI controller.

\[ U_{rd} = (K_{pi} + K_{ii} / S) (i_{rd} - I_{rd}^*) \]
\[ U_{rq} = (K_{pi} + K_{ii} / S) (i_{rq} - I_{rq}^*) \]  

(12)

Here \( K_{pi} \) and \( K_{ii} \) are the constant.

\[ K_{pi} = (2aT_{Ci} - 1)/K_{Ci} \]
\[ K_{ii} = (a^2T_{Ci}^2)/K_{Ci} \]

The value of \( a \) is chosen such a way the \( K_{pi} \) and \( K_{ii} \) are greater than zero.

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**Figure 1:** The dq0 equivalent circuit of an induction motor [4]

**Figure 2:** Control System of DFIG
4 SIMULATION RESULTS AND DISCUSSIONS

To investigate the performance of PI controller reference tracking technique is applied. After simulating all the equations of double fed induction generator and PI controller, a better response is found. As fewer amounts reactive power is desired, the reactive power curves showing nearly zero but there is some fluctuation whereas the real power is having maximum value. Comparing with the reference there are some fluctuations to the real power also. But it can be a further work to improve the response. Overall it is seen that better controlling the rotor currents provides better real power as output.

The real power depends on this quadrature or Q axis rotor current. As the equation we know,
\[ P_s = V_{sq} I_{sq} = V_s (-L_m / L_s) I_{rq} \]
Therefore the real power curves are

In figure 3, it represents the Real Power Curve where, blue represents the real power and the red represents the reference Real Power. Both of the curves are calculated in per unit.

5 CONCLUSION

This paper presents the direct control of the power flow of the DFIG used in variable speed wind turbine power generation. The simulation tests confirm the high dynamic performance and the decoupled active and reactive power obtained by proposed controller. The proposed controller is suitable for energy generation applications, where restricted variations of the speed around the synchronous velocity are present. For the purpose of future extension instead of standard PI controllers fuzzy controllers etc. can be used.

NOMENCLATURE

- \( i_{sd}, i_{sq} \): Stator d-axis and q-axis currents;
- \( i_{rd}, i_{rq} \): Rotor d-axis and q-axis currents;
- \( v_s, v_r \): Vector Stator and Rotor voltages;
- \( v_{sd}, v_{sq} \): Rotor d-axis and q-axis currents;
- \( v_{rd}, v_{rq} \): Stator d-axis and q-axis currents;
- \( \Phi_s, \Phi_r \): Vector Stator and Rotor fluxes;
- \( \Phi_{sd}, \Phi_{sq} \): Rotor d-axis and q-axis fluxes;
- \( \Phi_{rd}, \Phi_{rq} \): Stator d-axis and q-axis fluxes;
- \( \Phi_m \): Vector magnetizing flux;
- \( \omega_s \): Synchronous speed;
- \( \omega_r \): Rotor speed;
- \( \omega_m \): Sleep speed;
- \( \sigma \): Flux leakage co-efficient;
- \( L_s \): Stator inductance;
- \( L_r \): Rotor inductance;
- \( L_m \): Mutual inductance;
- \( R_s \): Stator resistance;
- \( R_r \): Rotor resistance;
- \( P_p \): Pole pair;
- \( J \): Inertia;
- \( D \): Friction co-efficient;
- \( P_s, Q_s \): Stator active and reactive power;
- \( P_r, Q_r \): Rotor active and reactive power;
- \( T_e \): Electromagnetic torque

PARAMETERS

- Output power \( Po = 15 \text{ KW} \);
- Frequency \( f = 50 \text{ Hz} \);
- Mechanical speed \( N_m = 1460 \text{ rpm} \);
- Stator resistance \( R_s = 0.2147 \text{ ohm} \);
- Rotor resistance \( R_r = 0.2205 \text{ ohm} \);
- Mutual inductance \( L_m = 0.0642 \text{ H} \);
- Stator inductance \( L_s = 0.0652 \text{ H} \);
- Rotor inductance \( L_r = 0.0652 \text{ H} \);
- Inertia \( J_m = 50 \text{ kg-m}^2 \);
- Synchronous speed \( N_s = 1500 \text{ rpm} \);
- Rotor speed \( N_r = 40 \text{ rpm} \);
- Flux leakage co-efficient \( \sigma = 0.03027 \)
REFERENCES


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