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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.

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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 deve oped. MATLAB/Simulink has an advantage over other m chine 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.

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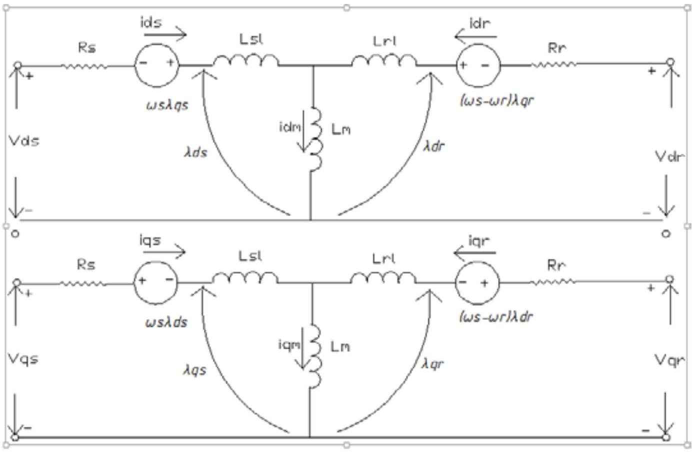

Figure 1: The dq0 equivalent circuit of an induction motor [4]

The stator and rotor voltages in terms of d-q axis can be written as follows:

$$\begin{cases} v\_sd = R\_s\, i\_sd + (d\Phi\_sd)/dt - \omega\_s\, \Phi\_sq; \\ v\_sq = R\_s\, i\_sq + (d\Phi\_sq)/dt + \omega\_s\, \Phi\_sd; \\ v\_rd = R\_r\, i\_rd + (d\Phi\_rd)/dt - \omega\_r\, \Phi\_rq; \\ v\_rq = R\_r\, i\_rq + (d\Phi\_rq)/dt + \omega\_r\, \Phi\_rd; \end{cases} \quad (1)$$

The stator and rotor flux can be written as follows:

$$\begin{cases} \Phi_{sd} = L_s i_{sd} + L_m i_{rd}; \\ \Phi_{sq} = L_s i_{sq} + L_m i_{rq}; \\ \Phi_{rd} = L_r i_{rd} + L_m i_{sd}; \\ \Phi_{rq} = L_r i_{rq} + L_m i_{sq}; \end{cases} \quad (2)$$

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

$$\begin{cases} P_s = (v_{sd}\, i_{sd} + v_{sq}\, i_{sq}); \\ Q_s = v_{sq} i_{sd} - v_{sd} i_{sq}; \end{cases} \quad (3)$$

$$\begin{cases} P_r = (v_{rd}\, i_{rd} + v_{rq} i_{rq}); \\ Q_r = v_{rq} i_{rd} - v_{rd} i_{rq}; \end{cases} \quad (4)$$

The electromagnetic torque is expressed as

$$T_e = P_n(\Phi_{rq} i_{rd} - \Phi_{rd}\, i_{rq}); \quad (5)$$

3 Controller Design

3.1 Control Strategy of Active and Reactive Power

PI controller has been developed for this system. By setting the Quadrature component of the stator to the null values as follows:

By neglecting $R_s; v_{sd} \approx 0$;

So, $v_{sd} = 0$; and $v_{sq} = V_s$;

Considered, $P_n = 1$

Using the above equations stator active and reactive power can be expressed only versus these rotor currents as:

$$\begin{cases} P\_s = v\_sq\; i\_sq = V\_s\,(-L\_m/L\_s\; i\_rq) \\ Q\_s = v\_sq\; i\_sd = V\_s\,(1/L\_s\; \Phi\_s - L\_m/L\_s\; i\_rd) \end{cases} \quad (6)$$

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

$$\begin{cases} C\_rd = \sigma L\_r\, \omega\_r\, i\_rq; \\ C\_rq = -\omega\_r\,(\sigma L\_r\, i\_rd + L\_m/L\_s\; \Phi\_s); \end{cases} \quad (7)$$

And

$$\begin{cases} u_{rd} = v_{rd} + C_{rd}; \\ u_{rq} = v_{rq} + C_{rq}; \end{cases} \quad (8)$$

The rotor current equations are as follows:

$$\begin{cases} I\_rd\ (s) = 1/(R\_r + \sigma L\_r\, s)\; U\_rd\ (s); \\ I\_rq\ (s) = 1/(R\_r + \sigma L\_r\, s)\; U\_rq\ (s); \end{cases} \quad (9)$$

Let,

$K\_ci = 1/R\_r$; And $T\_Ci = (\sigma L\_r)/R\_r$; then

$$\begin{cases} I\_rd\ (s) = K\_ci/(1 + T\_Ci\, s)\; U\_rd\ (s); \\ I\_rq\ (s) = K\_ci/(1 + T\_Ci\, s)\; U\_rq\ (s); \end{cases} \quad (10)$$

The open-loop transfer function of current controller is

$$\begin{cases} G\_Oid\ (s) = (I\_rd\ (s))/(U\_rd\ (s)) = K\_ci/(1 + T\_Ci\, s); \\ G\_Oiq\ (s) = (I\_rq\ (s))/(U\_rq\ (s)) = K\_ci/(1 + T\_Ci\, s); \end{cases} \quad (11)$$

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.

$$\begin{cases} U\_rd = (K_{Pi} + K\_li/S)(I_{rd}^{*} - I\_rd); \\ U\_rq = (K\_Pi + K\_li/S)\ (〖I\_rq〗^{\wedge}{*} - I_{rq}); \end{cases} \quad (12)$$

Here K_{Pi} and K_{Ii} are the constant.

$K_{Pi} = (2\alpha T\_Ci - 1)/K\_Ci$

$K_{Ii} = (\alpha^{\wedge}2\; T\_Ci)/K\_Ci$

The value of α is chosen such a way the K_{Pi} and K_{Ii} are greater than zero.

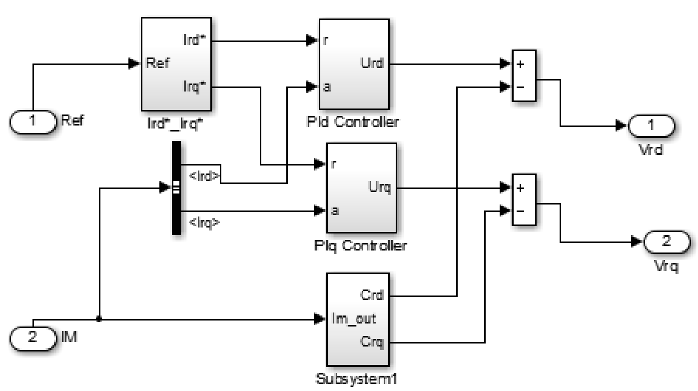

Figure 2: Control System of DFIG

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

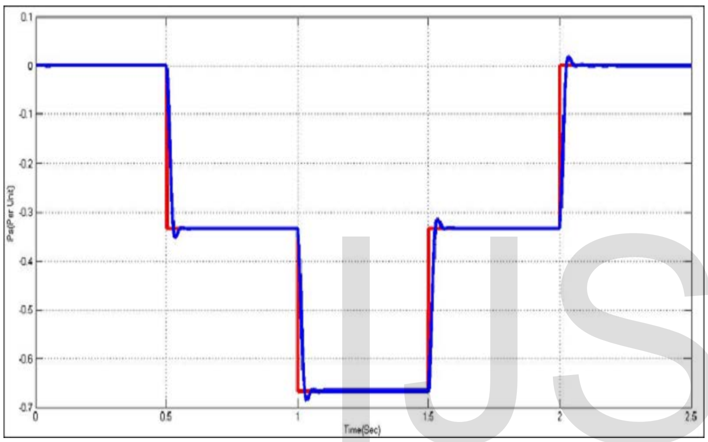

Figure 3: Real Power Curves

In this figure 3 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.
Similarly reactive power depends on the D axis rotor current
$Q_s = V_{sq} I_{sd} = V_s [\phi s/Ls - L_m/L_s I_{rd}]$
So the reactive power curves are

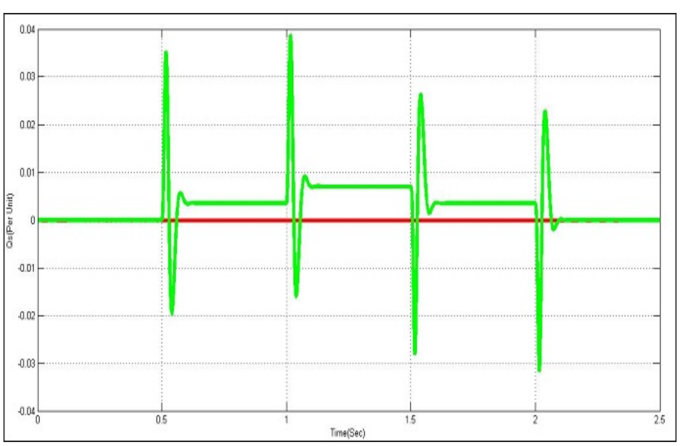

Figure 4: Reactive Power Curves

In figure 4, it represents the Reactive Power Curve where, green represents the reactive power and red represents the reference Reactive 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_{rd}, v_{rq}	Rotor d-axis and q-axis currents;
v_{sd}, v_{sq}	Stator d-axis and q-axis currents;
Φ_s, Φ_r	Vector Stator and Rotor fluxes;
Φ_{sd}, Φ_{sq}	Stator d-axis and q-axis fluxes;
Φ_{rd}, Φ_{rq}	Rotor d-axis and q-axis fluxes
Φ_m	Vector magnetizing flux;
ω_s	Synchronous speed;
ω_m	Rotor speed;
ω_r	Sleep speed;
σ	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_n	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 KW;
Frequency	f =50 Hz;
Mechanical speed	Nm = 1460 rpm
Stator resistance	Rs = 0.2147 ohm
Rotor resistance	Rr = 0.2205 ohm
Mutual inductance	Lm = 0.0642 H
Stator inductance	Ls = 0.0652 H
Rotor inductance	Lr = 0.0652 H
Inertia	Jm = 50 kg-m^2
Synchronous speed	Ns = 1500rpm
Rotor speed	Nr = 40 rpm
Flux leakage co-efficient	σ = 0.03027

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