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PSCAD를 이용한 DFIG풍력발전 최대출력 풍력발전 제어방법에 관한 연구

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Simulation Study on Capturing Maximum Wind Power Control Method of DFIG based on PSCAD/EMTDC

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Abstract - Doubly Fed Induction Generator (DFIG) used in variable speed constant frequency wind energy generation system can capture wind energy with the highest efficiency by using the stator flux oriented vector control method.

This paper sets up a DFIG modeling of wind generation system in PSCAD/EMTDC to simulate the operational performance with wind speed variation. In order to achieve the characteristics of the maximum utilization of wind power, this paper uses the vector control technology to track largest wind power and the independent control of generator active and reactive power.

1. Introduction

WITH growing concerns about environmental pollution and a possible energy shortage, great efforts have been taken around the world to implement renewable energy programs, based mainly on wind power, solar energy, small hydro-electric power, etc.[1]

In the recent years, variable-speed wind turbines with doubly fed induction generators (DFIG) connected to the national networks has become very popular for the use in the variable speed constant frequency wind turbines. DFIG-based wind turbines offer variable speed operation, four-quadrant active and reactive power capabilities, lower converter cost, and reduced power loss compared to wind turbines using fixed speed induction generators or fully-fed synchronous generators with full-sized converters.

Maximum electricity generation by wind turbines is an interesting topic in electrical engineering. Use of a variable speed generating system in wind power application can increase the captured power from wind. This paper is organized: The aerodynamic characteristics of wind turbine is explained in section 2. The system configuration, circuit topology, rotor side converter control are discussed in section 3. In section 4 simulation results are presented.

2. Running Characters of Wind Turbine

The amount of mechanical power captured from wind by a wind turbine could be formulated as:

$$P_m = \begin{cases} 0 & v < v_{in} \\ C_p(\lambda,\beta)\frac{1}{2}\rho A v^3 & v_{in} \le v < v_R \\ P_R & v_R \le v < v_{out} \\ 0 & v \ge v_{out} \end{cases} \quad (1)$$

where, ρ:air density, A:swept area, C_p:power coefficient of the wind turbine, v:wind speed, λ:tip speed ratio, β:pitch angle, P_R:rated power.

In fact, C_p is the efficiency of the generator transforms the wind energy to the mechanical energy, it is the function of the tip speed ratio λ and the pitch angle β which are given by:

$$C_p(\lambda_i,\beta) = 0.22\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{\frac{-12.5}{\lambda_i}} \quad (2)$$

$$where,\ \frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$

and $$\lambda = \frac{R\omega}{v} \quad (3)$$

in (3) ω is the mechanical angular speed; R is the radius of the turbine blade; v is the wind speed.

The coefficient function in (2) is shown in Fig.1. From the Fig.1, we can see that C_p has its maximum value which results in the optimum efficiency at λ_{opt}, therefore the maximum power is captured from the wind by the wind-turbine.

At lower wind speed, the pitch angle is set to a null value, because, the maximum power coefficient is obtained for this angle. Hence, the maximum power coefficient is computed by the following nonlinear mathematical programming:

maximize $C_p(\beta,\lambda_i)$
subject to $\lambda \ge 0$
giving $C_p(0,\lambda_i)_{\max} = 0.438$ for $\lambda_{opt} = 6.3$

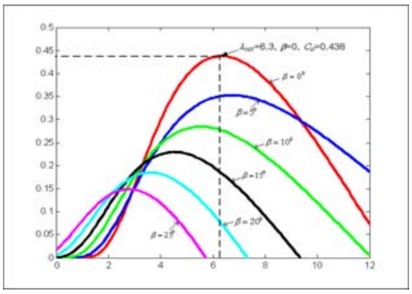

Figure.1 $C_p(\lambda,\beta) - curve$

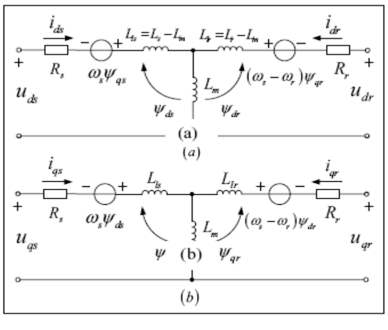

Fig.2 The d-q dynamic equivalent circuit of double-fed generator

3. Designing the Control Strategy

3.1 Mathematic Model

The voltage equation under $d-q$ coordinate system as follows[2]:

$$\begin{cases} u_{ds} = R_s i_{ds} + d\psi_{ds}/dt - \omega_s \psi_{qs} \\ u_{qs} = R_s i_{qs} + d\psi_{qs}/dt + \omega_s \psi_{ds} \\ u_{dr} = R_s i_{dr} + d\psi_{dr}/dt - s\omega_s \psi_{qr} \\ u_{qr} = R_r i_{qr} + d\psi_{qr}/dt + s\omega_s \psi_{dr} \end{cases} \tag{4}$$

The flux linkage equation[2]:

$$\begin{bmatrix} \psi_{ds} \\ \psi_{qs} \\ \psi_{dr} \\ \psi_{qr} \end{bmatrix} = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} \tag{5}$$

where, u: voltage, i:current, ψ:flux linkage, R: resistance, L: self inductance, L_m: mutual inductance.

Electromagnetism torque[2]:

$$T_e = \frac{3}{2}\left(\frac{p}{2}\right) L_m (i_{qs} i_{dr} - i_{ds} i_{qr}) \tag{6}$$

3.2 Structure of the System with DFIG

The DFIG System's component elements wind park, wound rotor induction machine, grid converter controls and generator converter controls are depicted in Fig.3. Fig.4 shows power coefficient C_p model which is converted by the tip speed ratio λ and the pitch angle β in PSCAD/EMTDC.

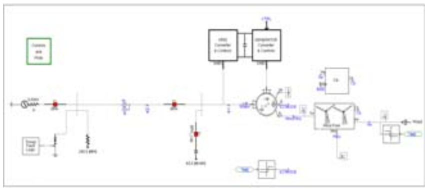

Figure.3 System Structure of DFIG

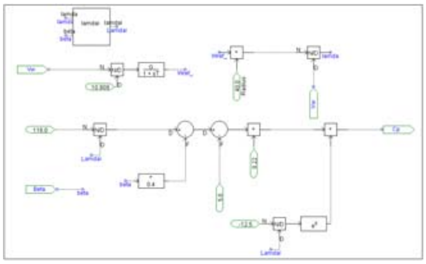

Figure.4 Power coefficient C_p model

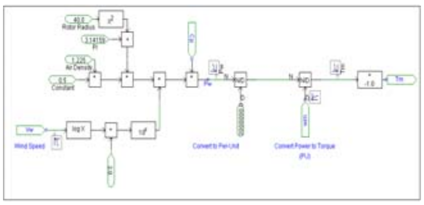

Figure.5 Convert wind speed to machine torque

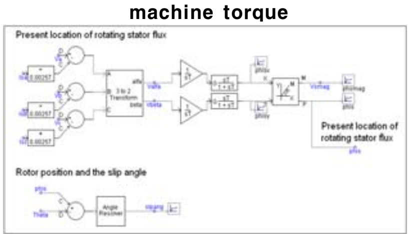

Figure.6 Control structure for determining the present location of the rotating flux vector

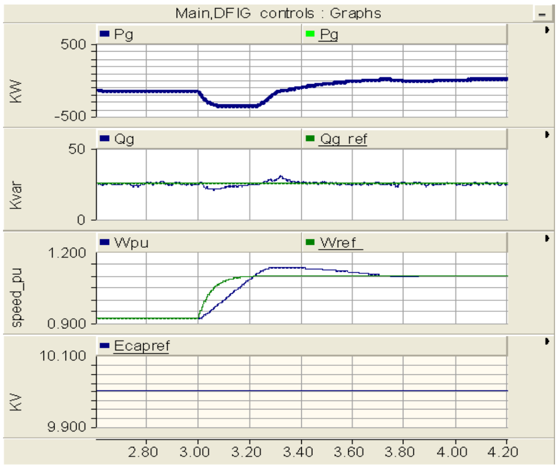

Figure.7 The speed controller reacts to a step change in the wind speed

3.2.1 Torque Converter Control

This part convert the wind speed to the machine torque which is shown in Fig.5.

3.2.2 Rotor Side Converter control

In Fig.6, the three phase stator voltages (after removal of resistive voltage drop) are converted into the CLARKE components v_α, v_β, which are orthogonal in the balanced steady state. This transformation is given by:

$$\begin{pmatrix} v_\alpha \\ v_\beta \end{pmatrix} = \frac{2}{3} \begin{pmatrix} 0 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_a \\ v_b \\ v_c \end{pmatrix} \tag{7}$$

Integrating v_α, v_β, we obtain λ_α and λ_β, the CLARKE components of stator flux. Converting to polar form:

$$|\lambda| = \sqrt{\lambda_\alpha^2 + \lambda_\beta^2}, \Phi_s = \tan^{-1}\left(\frac{\lambda_\beta}{\lambda_\alpha}\right) \tag{8}$$

4. Simulation Results

Fig.7 shows the speed controller reacts to a step change in the wind speed. In the simulation, E_{capref} is DC voltage, w_{pu}, P_g, Q_g are the speed, real power and reactive power of generator. As wind speed changes, machine speed is changed to operate at maximum C_p and maintain the tip speed ration for maximum wind power. It depicts the power regulation process of the generator and the wind machine in tracing the maximum wind power energy process.

5. Conclusion

This paper presents the rotor side converter structure of the DFIG and related simple method that can be used to implement maximum power tracking in wind turbine application when the wind speed changes. Through controlling the real power of the generator to adjust the electromagnetism torque, maintain the constant optimum tip speed ratio in the wind speed changing situation in order to capture the maximum wind power energy.

[Reference]

[1] V. Akhmatov, "Analysis of Dynamic Behavior of Electric Power Systems With Large Amount of Wind Power," Ph.D.thesis, Technical Univ. Denmark, Lyngby, Denmark, Apr. 2003.

[2] Xie Hua, Zhang Dehong "Control of Capturing the Maximum Wind Energy with DFIG" Proceedings of the 27th Chinese Control Conference July 16-18, 2008, Kunming,Yunnan, China