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Dynamic response of doubly fed induction generator variable speed wind turbine under fault

A.A. El-Sattar, N.H. Saad, M.Z. Shams El-Dein *

Faculty of Engineering, Ain Shams University, Egypt

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Abstract

The performance of doubly fed induction generator (DFIG) variable speed wind turbine under network fault is studied using simulator developed in MATLAB/SIMULINK. Simulation results show the transient behavior of the doubly fed induction generator when a sudden short circuit at the generator bus is introduced. After the clearance of the short-circuit fault the control schemes manage to restore the wind turbine's normal operation. The controller performance is demonstrated by simulation results both during the fault and after the clearance of the fault. A crowbar is used to protect the rotor converter against short-circuit current during faults.

Keywords: Doubly fed induction generator (DFIG); Induction machine modeling; Variable speed wind turbine; Short-circuit fault

1. Introduction

The doubly fed induction generator variable speed wind turbine introduces itself as a very attractive option for installations with a fast growing market demand. The fundamental feature of the DFIG is that the power processed by the power converter is only a fraction of the total wind turbine power, and therefore its size, cost and losses are much smaller compared to a full size power converter.

The increase in electrical power generation from wind power is likely to affect the operation of the networks, especially the power system stability. When a fault happens, the grid connected wind turbine should restore its normal operation without disconnection from the grid. The reason is that the disconnection of wind turbines may cause an important loss of generation that may threaten the power system stability.

This paper studies the transient response of variable speed wind turbines with DFIG after the clearance of short-circuit fault at the generator bus. A simulation model of a 2 MW wind turbine with DFIG is presented, and the control schemes of the wind turbine are described in detail. Based on the wind turbine model, the stability of wind turbine after a short-circuit fault has been investigated. The simulation results show how the control schemes effectively manage to restore the wind turbine's normal operation after the clearance of an external short-circuit fault.

During faults a high rotor currents will flow in the rotor converter which could damage it. A crowbar is used to disconnect the rotor converter during fault to protect it against short-circuit currents.

2. Dynamic modeling

The general turbine model with DFIG is shown in Fig. 1. This model consists of a wind turbine, gearbox and a DFIG with IGBT converter connected between rotor winding and grid through three phase injecting transformer.

2.1. Turbine model

The turbine model consists of number of sub-models including aerodynamic model, two mass model and pitch angle controller model.

2.1.1. Aerodynamic model

The aerodynamic model of a wind turbine is determined by its power speed characteristics [1,9]. For a horizontal axis wind turbine, the mechanical power output P_m (w) that a turbine can

* Corresponding author. Tel.: +20 02 2261 8913.
E-mail address: eng_mz_shams@yahoo.com (M.Z.S. El-Dein).

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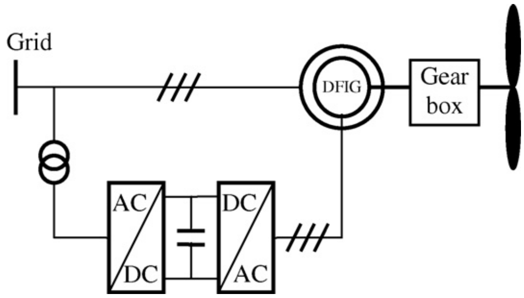

Fig. 1. Variable speed DFIG with IGBT converter.

produce in steady state is given by:

$$P_{\mathrm{m}} = \frac{1}{2}\rho A u^3 C_{\mathrm{P}}(\beta, \lambda) \quad (1)$$

where ρ is the air density (kg/m^3), A is the turbine rotor cross sectional area (m^2), u is the wind speed (m/s) and $C_{\mathrm{p}}(\beta,\lambda)$ is the power coefficient that depends on both, pitch angle β and tip speed ratio λ. The tip speed ratio is defined as:

$$\lambda = \frac{\omega_{\mathrm{T}} R_{\mathrm{T}}}{u} \quad (2)$$

where ω_{T} is the turbine rotor angular speed (rad/s) and R_{T} is the wind turbine rotor radius (m).

One way to get C_{p} is by using a look up table [2], another way is by approximating C_{p} by using a non-linear function [3]. The second method is used in this paper because it gives more accurate results and is faster in simulation.

$$C_{\mathrm{p}}(\lambda, \beta) = 0.22\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)\mathrm{e}^{(-12.5/\lambda_i)} \quad (3)$$

where λ_i is given by:

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (4)$$

2.1.2. Two mass model

A lumped model is presented in Fig. 2. It includes turbine inertia J_{T} (N m s^2/rad), generator inertia J_{G} (N m s^2/rad), turbine friction damping D_{T} (N m s/rad), generator friction damping D_{G} (N m s/rad) and shaft stiffness K_{sh} (N m/rad). In this model all parameters and variables are referred to turbine side. This lumped model is simple and it is considered as a more exact simulation model.

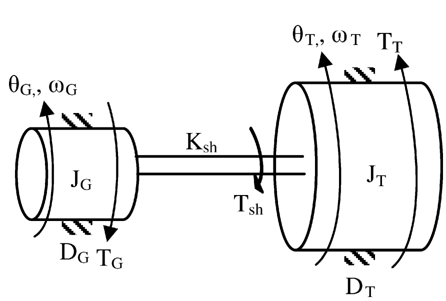

Fig. 2. Two mass model of wind turbine.

$$T_{\mathrm{T}} - K_{\mathrm{sh}}(\theta_{\mathrm{T}} - \theta_{\mathrm{G}}) - D_{\mathrm{T}}\omega_{\mathrm{T}} = J_{\mathrm{T}}\frac{\mathrm{d}\omega_{\mathrm{T}}}{\mathrm{d}t} \quad (5)$$

$$K_{\mathrm{sh}}(\theta_{\mathrm{T}} - \theta_{\mathrm{G}}) - T_{\mathrm{G}} - D_{\mathrm{G}}\omega_{\mathrm{G}} = J_{\mathrm{G}}\frac{\mathrm{d}\omega_{\mathrm{G}}}{\mathrm{d}t} \quad (6)$$

$$T_{\mathrm{sh}} = K_{\mathrm{sh}}(\theta_{\mathrm{T}} - \theta_{\mathrm{G}}) \quad (7)$$

where T_{T}, T_{G} and T_{sh} are turbine, generator and shaft torques (N m), ω_{G} is the generator angular speed (rad/s), θ_{T} and θ_{G} are turbine and generator angular positions (rad).

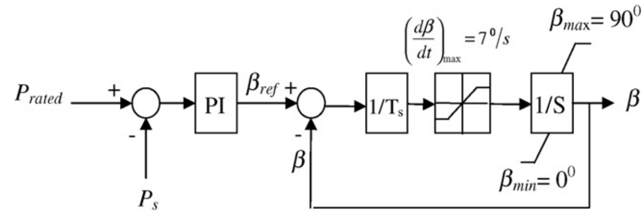

Fig. 3. Pitch angle controller.

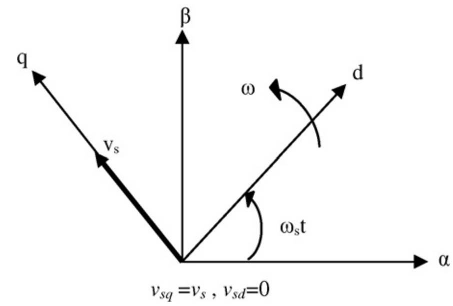

Fig. 4. D, q reference frame orientation.

2.1.3. Pitch angle controller

Pitch angle controller has a task to increase or decrease the pitch angle in order to limit the generated power P_{s} to the rated power P_{rated}.

Fig. 3 shows the pitch angle control loop. It should be taken into account that the pitch angle β cannot change immediately, but only at a slow rate due to the size of the rotor blades. In order to get realistic simulation, the rate is limited to 7°/s [4] and the pitch angle is limited to 90° [3]. Also the effect of servo time constant T_{s} (s) must be considered.

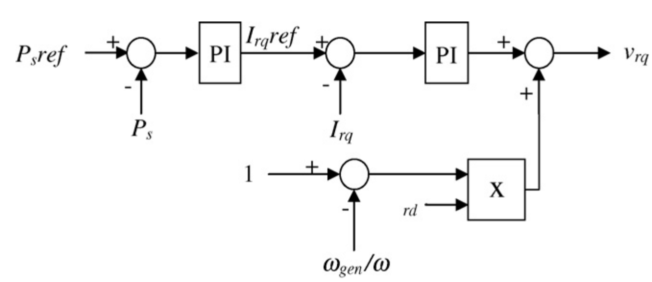

Fig. 5. Active power PI controller.