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Active and reactive power control of the doubly fed induction generator based on wind energy conversion system

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ABSTRACT

This paper presents a dynamic modeling and control of doubly fed induction-generator (DFIG) based on the wind turbine systems. Active and reactive power control of the DFIG are based on the feedback technique by using the suitable voltage vectors on the rotor side. The rotor flux has no impact on the changes of the stator active and reactive power. The proposed controller is based on the feedback technique in order to reduce the oscillation of the generator. The control approach is estimated through the simulation result of the feedback controller assembled with DFIG wind turbines. It is applied by the feedback control based techniques in order to control the power flowing of DFIG and the power grid. Hence, an improved feedback control technique is adopted to get a better power flow transfer and to improve the dynamic system and transient stability. In stable condition, the improved performance of the controller, the proposed method is verified for the effectiveness of the control method is done in stable conditions.

1. Introduction

The renewable energy resources have emerged as a new model to meet the energy requirements of our society. In recent years, the production of electricity from hydropower, solar, the wind and geothermal energy, tides, waves and biomass energy sources have gained much attention (Yaramasu et al., 2015). Energy is considered to be the decisive input for the growth of the wind energy. Nowadays, conventional resource depletion is more concerned about environmental degradation and takes advantage of renewable energy resources to meet growing energy demands. Energy production cost is very low as compared to the conventional method. The potential sources of clean energy are considered for the future such as wind energy. For electricity production through wind energy, DFIG is commonly used for this purpose because of its numerous advantages over its counterparts (Dinesh and Rajasekaran, 2015; Ebrahimi et al., 2016).

Variable speed operation of the DFIG wind turbine based on the active and reactive power abilities, lower cost of the converter and power losses are decreased as compared to wind turbine by using the fixed speed generator. Variable speed wind turbines with the new standards are effective because of their improved efficiency in capturing more wind power and their ability to achieve the higher power quality (Luna et al., 2011; Tohidi and Behnam, 2016).

Moreover, wind turbine of the variable speed with control of the speed of the turbine output power and reduces the load stress on different parts of the turbine structure, including the blades and tower. As a result, higher energy efficiency, longer life time, and improve the quality of energy to make these wind turbines inexpensively competitive, despite the high initial costs (Zhan et al., 2014; Baloch et al., 2016; Yang et al., 2012). The dynamic model of DFIG depends upon the non-linear parameters such as electromagnetic torque, stator current; rotor current and stator flux are controlled with state feedback linearization techniques to get the better results as compared to the exit method (Baroudi et al., 2007; Hu et al., 2010). Implementation of DFIG is increasing for many reasons, such as reducing the mechanical stress, to mitigate the noise, and flexible control of the active and reactive power on the basis of back to back converter between the induction machine and the power grid (Mishra et al., 2009; Rahimi, 2016).

As a result, the complexity of the system increases and it becomes difficult to analyze without a systematic point of view. In short terms, there must be the ability to support dynamic frequency of wind energy rapidly in the near future to ensure the stability of the frequency of the system. In addition, it can be

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contributed to the inertia of wind energy to further improve the accessibility of wind power in the grid (Zhan et al., 2014; Xiao et al., 2013; Hu et al., 2010). In order to control the generator speed is used to rotor side converter (RSC) and reactive power controlled with grid side converter (GSC) is connected to the grid through grid filter and is used to control the dc link voltage and reactive power exchange with the grid.

Hence with increased penetration of the DFIG, the inertia of the effective system will be reduced. Grid integration of this variable power in increased capacity raises concerns about its impact on the power system stability (Carrasco et al., 2006; Gayen et al., 2015). Nonetheless, it is imperative for large scale transient strength studies to consider the rotor field elements of the induction generator since it assumes a critical part in deciding the inner voltage behind transient reactance. In order to reduce the efficiency of the machine due to the response of reactive power is increased. But state feedback linearization control technique is used to improve the efficiency of the machine and reduce the transient effect in the system. (Yousefi-Talouki et al., 2014; Abdel-Khalik et al., 2013).

This paper proposes a new strategy for feedback control systems for wind power generation on the basis of DFIG with constant switching frequency to improve transient performance. The direct method in calculating the required voltage circuit control the transition period, based on the estimated stator flux, active and reactive power, and their errors. The transient performance of the nonlinear model of the DFIG is described by the limit of the rotor control voltage with a direct method of the active and reactive power. The aim of this paper is to provide a great idea for the dynamic behavior of the DFIG wind turbine. Control of DFIG parameters has a significant effect on the dynamic performance of wind turbines. The controller of the DFIG will play an important role in the energy system in the future with the increased penetration of the wind energy conversion system (WECS) (Bourdoulis and Alexandridis, 2014; Wang and Wang, 2011).

The proposed technique is considered by the feedback controller to regulate the rotor currents and the grid current. In order to consider the effects of the rotor and the filter of network parameters to control the dynamic performance DFIG under voltage dips. It represents the vital phenomena that are much faster than the phenomena of interest in transient stability analysis. The use of the detailed model in the study of transient stability leads to a harsh mathematical model with fast transients and long simulation times and greatly increases the computational effort. In any case, as a result of complexity of the DFIG model, extra suppositions are utilized as a part of the transient stability program for simplifying it (Naidu et al., 2014; Trilla et al., 2014). In this paper, feedback control design is developed and considered for the DFIG wind turbine system. Non-linear dynamic model of the DFIG is essentially based on stator flux as compared to conventional flux model of the wound rotor induction generator and GSC model. Non-linear dynamic model of the DFIG is improved by using the feedback control technique for alignment of the rotor and grid sides. Active and reactive power of the DFIG stator and GSC output are connected to the grid. This paper is organized as follows: in Section 2 wind turbine model is described. In Section 3 dynamic model of the DFIG wind energy System is developed. In Section 4, a controller is designed for a DFIG Wind Turbine System. The simulation results are shown in Section 5. Final conclusion of the paper is described in Section 6.

2. Wind turbine model

The captured mechanical power from a wind turbine is given as follows (Yang et al., 2012):

$$P_m = 0.5\rho A V_\omega^3 C_p(\lambda, \beta), \quad (1)$$

where ρ represents the air density, R_T represents the wind turbine radius, V_w represents the wind speed and C_p represents the wind turbine power coefficient is given by

$$C_p(\lambda, \beta) = 22\left(\frac{1.16}{\lambda_i} - 0.004\beta - 0.05\right)e^{-12.5\frac{1}{\lambda_i}}, \quad (2)$$

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

where β represents the blade pitch angle and λ represents the tip speed ratio as described below.

$$\lambda = \frac{\omega_r R_T}{V_w}. \quad (4)$$

Owing to the presence of a gearbox with the gear ratio n_g, the dynamic model wind turbine rotational speed ω_r is associated to the rotor speed ω_r is given as follows:

$$\omega_r = n_g \omega_r^{optimum}. \quad (5)$$

The exact dynamic model of the torque equation of the generator is given by,

$$T_m \omega_r = P_m \quad (6)$$

where, T_m represents the rotor torque, ω_r represents the wind turbine speed, it is a measure of the ratio of wind power turbines. Power coefficient is a function of wind turbine speed. C_p is 0.59 the theoretical limit, but practical range is 0.2–0.4 (Patel, 2005).

$$\omega_r^{optimum} = \frac{1}{R_T}\lambda_{optimum} n_g V_w. \quad (7)$$

Which corresponds to the most extreme extraction of wind energy $P_m^{\max}$, at that point in the determination of the rotor torque of the generator can be determined as

$$T_m^{optimum} = 0.5\rho\pi R_T^5 C_p^{optimum} \omega_r^{optimum}\left(\lambda_{optimum}^3\right)^{-1}. \quad (8)$$

It is obvious that the wind turbine operates with ideal rotational speed and with the optimum torque of the doubly fed induction generator.

3. Dynamic model of the DFIG wind energy system

The power convertor of the wind turbine generator contains the rotor converter to control the generator speed and grid convertor to inject reactive power in the grid. The grid side converter components of the real and reactive power are shown in Fig. 1. The instantaneous power can be defined as follows (Krause et al., 2013):

$$P_s = 1.5(V_{ds}I_{ds} + V_{qs}I_{qs}); \quad (9)$$

$$Q_s = 1.5(V_{qs}I_{ds} - V_{ds}I_{qs}), \quad (10)$$

$$P_g = 1.5(V_{ds}I_{dg} + V_{qs}I_{qg}) \quad (11)$$

$$Q_g = 1.5(V_{qs}I_{dg} - V_{ds}I_{qg}) \quad (12)$$

where P_s and Q_s represent the active and reactive power stator of the DFIG respectively, and P_g and Q_g represent the active and reactive power of the grid respectively. The nonlinear dynamic model of the DFIG wind turbine is normally described by the active and reactive powers. To simplify the dynamic model is assuming an approximately constant stator voltage for DFIG. This assumption is used only under a steady state condition and grid voltages vary at the point of the common coupling typically less than ± 0.005 p.u.