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ScienceDirect
Energy Procedia 100 (2016) 551 – 555
Energy Procedia

3rd International Conference on Power and Energy Systems Engineering, CPESE 2016, 8-12 September 2016, Kitakyushu, Japan

Different control strategies on the rotor side converter in DFIG-based wind turbines

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Abstract

This paper applied different control strategies on the rotor side converter (RSC) of a 2 MW doubly fed induction generator (DFIG) wind turbine. Usually, the wind turbine is operated on the maximum power point tracking (MPPT) mode to obtain its maximum efficiency. Flux oriented control (FOC), voltage oriented control (VOC), direct torque control (DTC) and direct power control (DPC) are the most common control strategies on the RSC. These control methods play important roles in tracking the MPPT operating mode. The simulation of various control methods on the MPPT is necessary, and the performance of each control method needs to be evaluated, which can provide a reference to engineers and operators of a wind farm. The range of wind speeds in this simulation is from 3.5 m/s (cut in) to 25 m/s (cut out). In this study, the grid side converter (GSC) of the wind turbine utilized voltage oriented control (VOC) to maintain a constant DC voltage on the DC capacitor bus, and the reactive power is set to 0. All of the simulations were implemented by PSCAD/EMTDC software.

Peer-review under responsibility of the organizing committee of CPESE 2016

Keywords: DFIG;Flux oriented control;Voltage oriented control;Direct torque control;Direct power control;PSCAD/EMTDC

1. Introduction

Doubly fed induction generators that are one of the most popular types of onshore or offshore wind turbines have shared more than 50% wind generator market nowadays. The overview or fundamental concept for DFIGs is described in [1]. The stator of the DFIG is connected to the power grid and the rotor is connected to AC-DC-AC converter. Two control loops are applied to RSC and GSC individually. The main purpose of this study is to perform

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Peer-review under responsibility of the organizing committee of CPESE 2016
doi:10.1016/j.egypro.2016.10.217

the dynamic response of two different control methods and evaluate the best response characteristics in MPPT power curve by using the two control methods. Generally, the vector control used in DFIGs includes flux oriented control [2] and voltage oriented control [3]. This control method decouples the control value to $d-q$ reference frame in order to reduce the calculation burden owing to sophisticated mathematically equations. Besides vector-control methods, several common utilized control strategies also include direct torque control and direct power control [4]. These control methods directly detect the error of torque, flux, real power and reactive power and then choose a desired rotor voltage to IGBTs via a lookup table. Comparing with traditional vector controls, DTC and DPC methods obtain fast response time and less dependence on DFIG parameters. However, the vector control must generate the constant frequency signal that is applied to IGBTs through PWM, but the direct control method generates the variable-frequency signal. In recent years, many novel direct control methods have been proposed. For instance, the dual direct torque control [5] has been developed, it uses two switching table to voltage source inverter (VSI) on the stator and rotor, and [6] adopts virtual torque control without PI regulator. Some literatures developed constant frequency algorithms [7-8] to accomplish a constant frequency signal for IGBTs. In this study, DFIGs are operated in MPPT mode and, therefore, speed measurement is necessary for the control strategy on the RSC. Vector control and DTC can control the electrical torque indirectly or directly; however, DPC can only control power at the stator. Consequently, the difference of the control characteristics on DPC would generate incorrect result and influence the results of the MPPT algorithm [9].

2. Speed control of a DFIG-based wind turbine

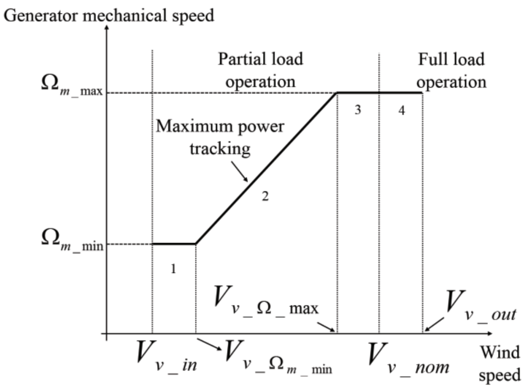

Fig. 1. Wind turbine control strategy based on four operating regions

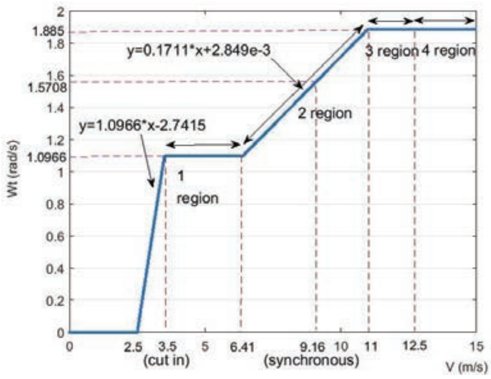

Fig. 2. Simulation on generator speeds

Figure 1 shows the four operation regions of a wind turbine generator for the mechanical speed. For DFIG-based wind turbines, this operation curve in Fig. 1 represents various operating regions that give the limitation of the slip (about $\pm 30\%$ synchronous speed) and the maximum power by the calculation from the power coefficient, C_p value and tip speed ratio. In Fig. 1, $\Omega_{m\_\min}$ and $\Omega_{m\_\max}$ is the minimum and maximum operation speed of the DFIG, respectively. V_{v_in} , V_{v_nom} and V_{v_out} are the cut-in speed, nominal speed and cut-out speed for the DFIG, respectively. Figure 2 shows the simulated mechanical speed. The two figures indicate that the mechanical speed must follow the limitation in the four operation regions:

The 1st region: the DFIG operates at the minimum speed with a constant mechanical rotation speed.

The 2nd region: the DFIG operates following the curve of maximum power extraction from variable speed operation via optimal tip speed ratio, i.e., equation (1).

The 3rd region: the DFIG operates at the maximum speed with a constant mechanical rotation speed, but its generation is still lower than its rated power.

The 4th region: the DFIG operates at the maximum speed with a constant mechanical rotation speed, and its generation is up to its rated power by using the power coefficient function to maintain at constant, i.e., equation (2).

Equation (1) shows the definition of tip speed ratio, where R is the wind turbine blade radius; Ω_t is the mechanical rotation speed and V_v is the wind speed.

$$\lambda = \frac{R\Omega_t}{V_v} \qquad (1)$$

Equation (2) shows the power coefficient function, where β is the pitch angle

$$Cp = 0.73\left(\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right)e^{\frac{-18.4}{\lambda_i}} \qquad (2)$$

$$\lambda_i = \left(\frac{1}{\lambda + 0.02\beta} + \frac{0.003}{\beta^3 + 1}\right)^{-1}$$

3. Pitch control and calculation for the reference value of mechanical power

This study utilized equation (2) to plot the DFIG's power coefficient curve. Figures 3 and 4 show the relationship among power coefficient, torque coefficient and tip speed ratio depending on different pitch angles. As the DFIG operates at rated power, one can use equation (2) to calculate the value of pitch angle. Figure 5 shows the relationship between pitch angle and tip speed ratio. From Fig.5, one can calculate the reference power, which is an input signal for the RSC control when DFIGs operates at rated power. Table 1 lists the DFIG parameters used in our simulation.

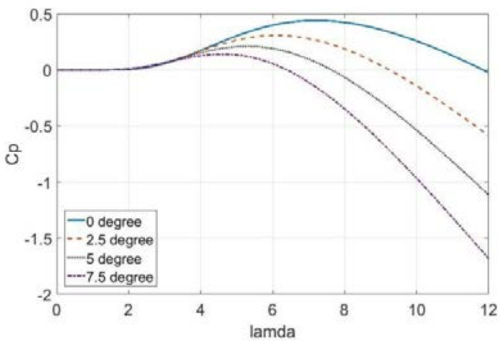

Fig. 3. Power coefficient and tip speed ratio

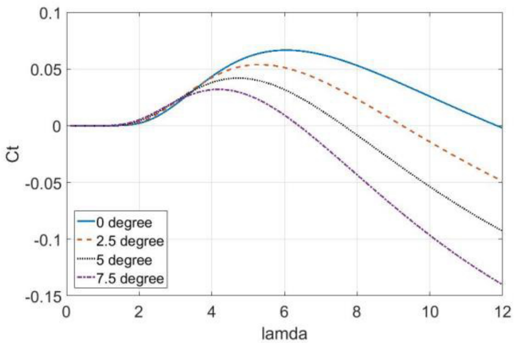

Fig. 4. Torque coefficient and tip speed ratio

Table 1. The parameters of DFIG

Rated power	2 MW	L_s	0.002587 H
Frequency	50 Hz	L_r	0.002587 H
pole	2 pairs	L_m	0.0025 H
V_{dc}	1297 V	R	42 m
R_s	0.0026 Ω	L_s	0.002587 H
R_r	0.0029 Ω	Air density	1.1225 kg/m^3
N (gear box)	100		

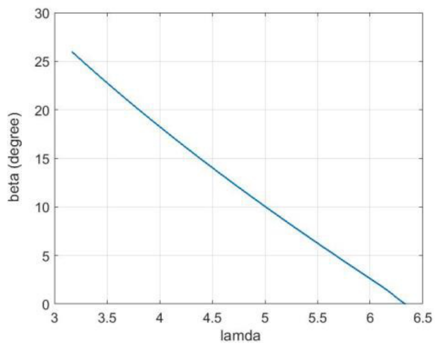

Fig. 5. Relation between pitch angle and TSR

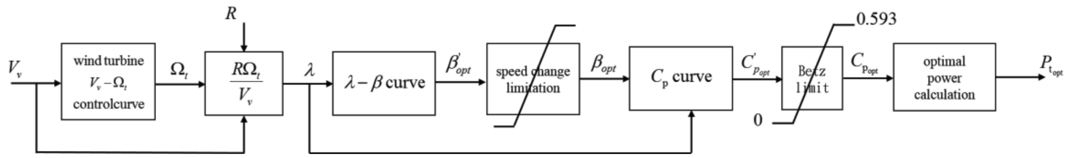

Fig. 6. The block diagram of mechanical power reference value

According to the above-mentioned figures and parameters, one can use the block diagram shown in Fig. 6 to calculate the reference value for the mechanical power and then simulate the DFIG model via different control strategies on RSC by using PSCAD/EMTDC.

4. Different RSC control strategies and simulation results

The utilized DTC and DPC control blocks are shown in Figs. 7 and 8, respectively.

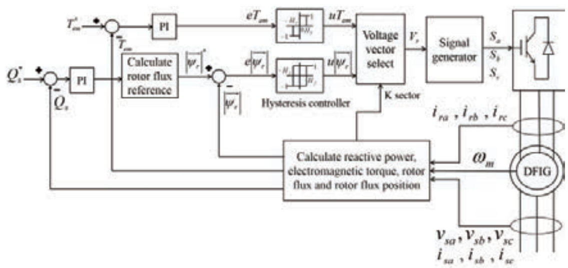

Fig. 7. DTC control block

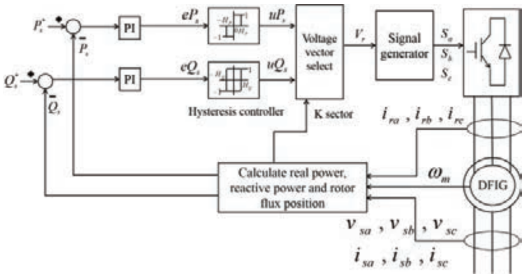

Fig. 8. DPC control block

Figures 9 and 10 show the simulation results based on DTC and DPC, respectively. According to the simulation results, the dynamic response by DTC is better than that by DPC when the DFIG operates at the MPPT mode.

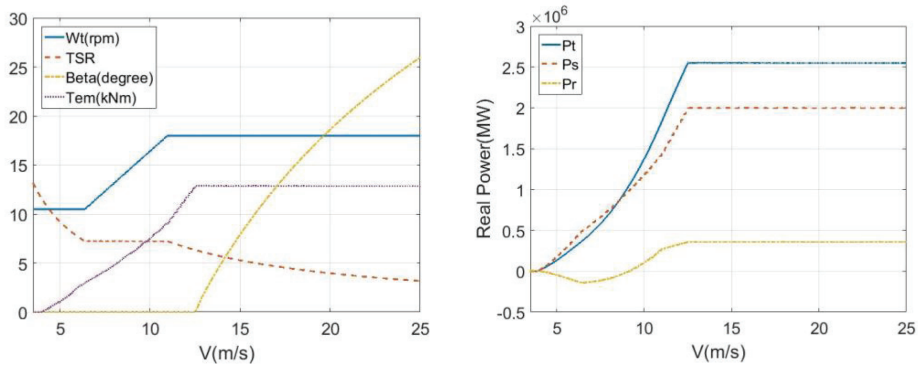

Fig. 9. Dynamic responses of the DFIG-based wind turbine by using DTC

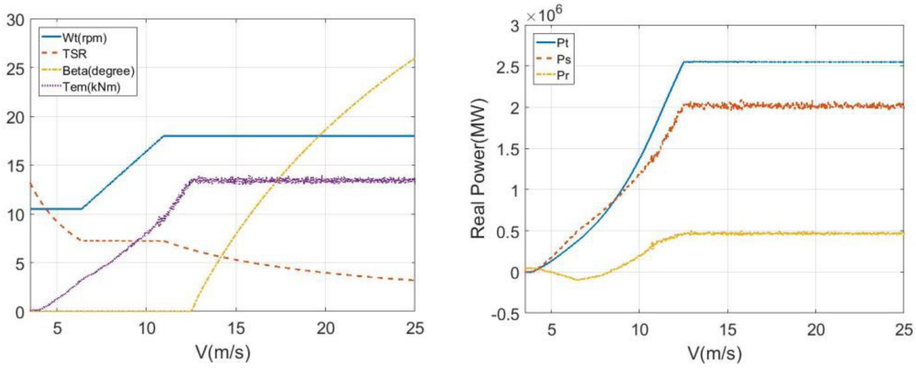

Fig. 10. Dynamic responses of the DFIG-based wind turbine by using DPC

In Figs 9-10, ω_t is the electrical rotor speed (rpm); TSR is the tip speed ratio; Beta is the pitch angle (degree), T_{em} is the electromagnetic torque (kNm), P_t is the mechanical power, P_s is the stator power and P_r is the rotor real power. In the MPPT operating mode, the DPC only controls the stator power, but does not directly or indirectly control electromagnetic torque. Therefore, comparing with the DTC control in which the electrical torque is straightforward controlled, the deviation would generate incorrect results. Figure 10 shows a fluctuation appeared on T_{em}, P_s and P_r. when the DFIG uses DPC in the MPPT operating mode.

5. Conclusion

This paper utilized different control strategies on RSC and built a 2MW DFIG-based wind turbine model to investigate its performance during the MPPT operating mode. It can be clearly observed that the dynamic behavior of the DFIG under different regions. To achieve better dynamic performance, this study adds a PI controller in front of the traditional DTC or DPC control blocks. Finally, this study demonstrated that the DTC control has better operating characteristics compared to DPC because DTC controls electrical torque directly.

References

[1] R. Cardenas, R Pena, S. Alepuz and G. Asher, “Overview of control systems for the operation of DFIGs in wind energy applications,” *IEEE Trans. Ind. Electron*., vol. 60, no. 7, pp. 2776－2798, 2013

[2] R. Pena, J. C. Clare and G. M. Asher, “Doubly fed induction generator using back-to-back PWM converters and its application to variable-speed wind-energy generation,” *IEE Proc. Elect. Power Appl.*, vol. 143, no. 3, pp. 231－241, 1996

[3] R. Pena, J. C. Clare and G. M. Asher, “A doubly fed induction generator using back-to-back PWM converters supplying an isolated load from a variable speed wind turbine,” *IEE Proc. Elec. Power Appl.*, vol. 143, no. 5, pp. 380－387, 1996

[4] Lie Xu and P. Cartwright, “Direct active and reactive power control of DFIG for wind energy generation.” *IEEE Trans. Energy Conv.*, vol. 21, no. 3, pp. 750－758 , 2006

[5] F. BonnetFrancois, P. Vidal and M. Pietrzak-David, “Dual direct torque control of doubly fed induction machine,” *IEEE Trans. Ind. Electron.*, vol. 54, no. 5, pp. 2484－2490, 2007

[6] J. Arbi, M. J. Ghorbal, I. Slama-Belkhodja and L. Charaabi, “Direct virtual torque control for doubly fed induction generator grid connection,” *IEEE Trans. Ind. Electron.*, vol. 56, no. 10, pp. 4163－4173, 2009

[7] S. Z. Chen, N. C. Cheung, K. C. Wong and J. Wu, “Integral variable structure direct torque control of doubly fed induction generator,” *IET Renewable Power Generation*, vol. 5, no. 1, pp. 18－25, 2011

[8] D. Zhi and L. Xu, “Direct power control of DFIG with constant switching frequency and improved transient performance,” *IEEE Trans. Energy Conv.*, vol. 22, no. 1, pp. 110－118, 2007

[9] E. Tremblay, S. Atayde and A. Chandra, “Comparative study of control strategies for the doubly fed induction generator in wind energy conversion systems: a DSP-based implementation approach,” *IEEE Trans. Sustain. Energy*, vol. 2, no. 3, pp. 288－299, 2011