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ORIGINAL ARTICLE

Model-based predictive direct power control of brushless doubly fed reluctance generator for wind power applications

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Abstract In this paper, a predictive direct power control (PDPC) method for the brushless doubly fed reluctance generator (BDFRG) is proposed. Firstly, the BDFRG active and reactive power equations are derived and then the active and reactive power variations have been predicted within a fixed sampling period. The predicted power variations are used to calculate the required voltage of the secondary winding so that the power errors at the end of the following sampling period are eliminated. Switching pulses are produced using space vector pulse width modulation (SVPWM) approach which causes to a fixed switching frequency. The BDFRG model and the proposed control method are simulated in MATLAB/Simulink software. Simulation results indicate the good performance of the control system in tracking of the active and reactive power references in both power step and speed variation conditions. In addition, fast dynamic response and lower output power ripple are other advantages of this control method.

1. Introduction

Nowadays, the brushless doubly fed reluctance generators (BDFRG) have been proposed as a potential alternative to the existing solutions for wind power applications [1–10]. The main reason of this increasing interest could be found in reasonable cost and high reliability of the BDFRG because of its brushless structure. On the other hand, its comparative performance with other generators such as wound and cage rotor induction generator, doubly fed induction generator (DFIG) and brushless doubly fed induction generator (BDFIG) leads to consideration of the BDFRG as a suitable choice for wind power application [11,12]. Previously, the BDFRG couldn't compete with its induction counterpart (BDFIG) because of low saliency ratio of reluctance rotor which caused lower torque in the BDFRG. However, recent developments in reluctance rotors with high saliency ratio, lead to more attention to the BDFRG [2].

The BDFRG needs partially-rated converter in wind power applications like other doubly fed generators [1–3,13]. In addition, the absence of rotor cage makes it more efficient [4] and easier to control [3] in comparison with the BDFIG. On the other hand, its brushless structure ensures high reliability and low maintenance of the BDFRG, which is especially important to off-shore plants [14].

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The BDFRG has two sinusoidal distributed three-phase winding in its stator in which the pole pairs and applied frequencies to these windings are different from each other [14,15]. The primary winding (power winding) is directly connected to the grid and the secondary winding (control winding) is connected to the grid through a back to back IGBT/Diode converter for bi-directional power flow which is shown in Fig. 1 [14].

Since the pole pairs of two stator windings are always different, so with a round rotor, there is ideally no magnetic coupling between them [2]. However, a reluctance rotor with P_r salient poles could make magnetic coupling between the primary winding with P_1 pole pairs and the secondary winding with P_2 pole pairs (supplied with angular frequencies ω_p and ω_s, respectively) by satisfying the following equations [2]:

$$P_r = P_1 + P_2 \tag{1}$$

$$\omega_r = \omega_p + \omega_s \tag{2}$$

where ω_r is the electrical angular velocity of the rotor.

Different methods have been proposed to control the BDFRG over the years. Field orientation control (FOC) [16–24] and vector control (VC) [3,19–26] are two similar methods that are presented to control the BDFRG. The FOC method is based on field orientation and the VC method is based on voltage orientation. Although orientation of voltage in the VC method is simpler, the FOC method has the advantage of inherent decoupled control of active and reactive power, which greatly facilitates the controller design [24]. In these control methods, accurate adjustment of current controller parameters is required to ensure adequate response and stability of system over the whole operating range.

Direct torque control (DTC) method, which is based on decoupled control of flux and torque, has been applied to the BDFRG [27–31]. The absence of current control loops is one the advantages of the DTC method in comparison with the FOC method. Also, dynamic response of the DTC is faster than the FOC/VC. However, switching frequency of the DTC method is variable because of using hysteresis controller. In [32,33], an improved DTC method by combination of power controllers (PI controllers) and space vector modulation is proposed to reach a fixed switching frequency. However, it is required for accurate tuning of PI parameters.

Direct power control (DPC) method, which is based on the DTC principles, is another method for control of the BDFRG [14,34]. Changing control parameters from flux and torque in the DTC to active and reactive powers in the DPC leads to simplicity and robustness of the DPC method (with similar dynamic response). However, switching frequency of the DPC method is also variable because of using hysteresis controller. Variable switching frequency not only causes high output power ripple but also causes increase in harmonic filter cost. A comparative analysis of these control methods has been presented in [35].

In this paper, a predictive direct power control (PDPC) method is proposed to control the BDFRG. The proposed PDPC method has the advantage of fixed switching frequency, whereas its dynamic response is as fast as the DPC method. Fixed switching frequency leads to significant decrease in output power ripple of the proposed method in comparison with the DPC method. In addition, the proposed PDPC method does not need hysteresis controller and uses space vector pulse wide modulation (SVPWM) technique. In Section 2, the BDFRG model in an arbitrary reference frame is presented. Section 3 is dedicated to calculation of the BDFRG power equations. The basic principles of the PDPC strategy are outlined in Section 4. In Section 5, back to back converter control method is expressed. Finally, verifying simulation results for the BDFRG control system are presented in Section 6.

2. BDFRG model

The space vector model of the BDFRG in an arbitrary reference frame rotating at ω can be expressed as follows [36]:

$$\boldsymbol{v}_p = R_p \boldsymbol{i}_p + \frac{d\boldsymbol{\lambda}_p}{dt} + j\omega\boldsymbol{\lambda}_p \tag{3}$$

$$\boldsymbol{v}_s = R_s \boldsymbol{i}_s + \frac{d\boldsymbol{\lambda}_s}{dt} + j(\omega_r - \omega)\boldsymbol{\lambda}_s \tag{4}$$

$$\boldsymbol{\lambda}_p = L_p \boldsymbol{i}_p + L_{ps} \boldsymbol{i}_s^* \tag{5}$$

$$\boldsymbol{\lambda}_s = L_s \boldsymbol{i}_s + L_{ps} \boldsymbol{i}_p^* \tag{6}$$

where R_p, R_s, L_p, L_s and L_{ps} are primary resistance, secondary resistance, primary inductance, secondary inductance and primary to secondary mutual inductance, respectively. $\boldsymbol{x}_p$ and $\boldsymbol{x}_s$ are the space vectors in a reference frame rotating at ω, for the primary and secondary respectively. It should be noted that primary and secondary equations are expressed in two different reference frames: primary equation, (3), in reference frame ω and secondary equation, (4), in reference frame $\omega_r - \omega$. The reference frames that are used in the model are shown in Fig. 2 [5].

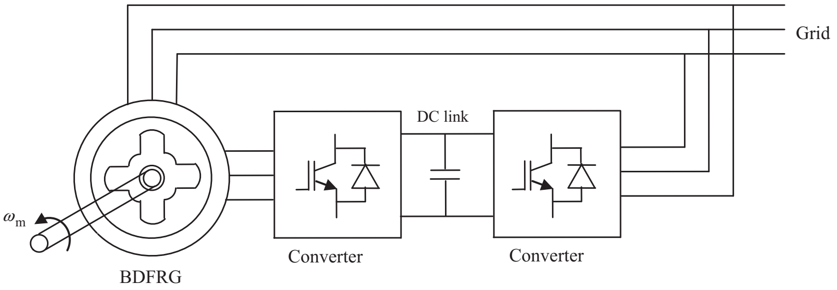

Figure 1 The connection of the BDFRG to the grid.

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