Performance Enhancement of a wind energy conversion System based on Brushless doubly fed induction machine Using PI Controller.

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***Abstract* – This paper discusses the control a new topology of a brushless doubly-fed (induction) machine (BDFM) using back-to-back PWM converters and its application to variable speed wind energy generation. The goal of BDFM control is to achieve a similar dynamic performance to the doubly fed induction machine (DFIM), exploiting the well-known induction motor vector control philosophy. For this purpose, a recently developed unified reference-frame model has been used to develop the vector control strategy. The control strategy for flexible power flow control is developed. Currently the BDFM has been the subject of current investigation and it shows to be a valid alternative for wind energy applications.**

***Index Terms*— brushless doubly-fed machine, d-q vector control, modeling, wind energy applications, simulation.**

I. INTRODUCTION *(HEADING 1)*

The BDFM is a possible alternative to the conventional doubly fed induction machine (DFIG)[2-11]. Recently the DFIG became the popular configuration in variable speed wind energy applications [1]. The development and use of the DFIG machines was dictated by the need for wide operational range as well as the necessity to allow flexible power flow control, grid integration as well as economic reasons [2-4]. The use of the DFIG machines, however, increased the long term cost and complexity of the wind energy generation. The disadvantage associated with the wound-rotor induction machines is that the slip rings and carbon brushes have to be systematically maintained [3][6]. Typical faults of slip rings and brushes are: the increased surface roughness of the rings or the brush contact face, break out of carbon material from the brushes and decreasing contact pressing forces which lead to increased brush sparking and significant performance deterioration [7]. Since wind turbines are installed in remote places, the maintenance costs for such remote installations are significant, [6]. The cost of maintenance for traditional DFIG based wind generators increased the pressure to seek other alternative generator systems [1]. One of such alternatives is offered by the BDFG as shown in Fig. 1 [2-11]. This type of machine was developed by René Epée and Alan Wallace, of Oregon State University (USA). Currently R.A. McMahon of the University of Combridge (UK) and P.C. Roberts of Scientific Generics Ltd. (UK) work on the analysis of the machine operation and the design of different rotor structures [12].

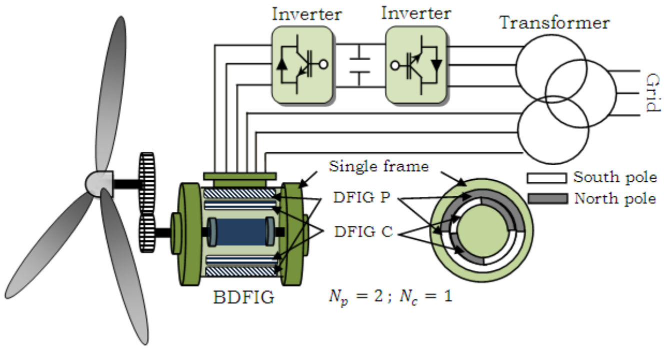

Fig. 1. Example of BDFM

II. DYNAMICAL MODEL OF THE BRUSHLESS DOUBLY FED INDUCTION MACHINE

The BDFM vector model in a common synchronous reference frame of the PW can be written as

$$v_p = R_{sp} i_p + \frac{d\Psi_p}{dt} + j\omega_p \Psi_p \tag{1}$$

$$\Psi_p = L_{sp} i_p + L_{mp} i_r \tag{2}$$

$$v_c = R_{sc} i_c + \frac{d\Psi_c}{dt} + j\left(\omega_p - (p_p + p_c)\omega_r\right)\Psi_c \tag{3}$$

$$\Psi_c = L_{sc} i_c + L_{mc} i_r \tag{4}$$

$$v_r = R_r i_r + \frac{d\Psi_r}{dt} + j\left(\omega_p - p_p \omega_r\right)\Psi_r \tag{5}$$

$$\Psi_r = L_r i_r + L_{mc} i_r + L_{mp} i_p \tag{6}$$

$$T_{em} = \frac{3}{2} p_p Im[\Psi_p^* i_p] + \frac{3}{2} p_c Im[\Psi_c^* i_c^*] \tag{7}$$

This model is similar to the well-known vector model of a standard induction machine. In the rotor flux equation, the two stator currents influence is represented. In the CW, the factor

$\omega_p - (p_p + p_c)\omega_r$ represents the relative angular speed between the reference frames dq and $\alpha\beta_c$ [13].

Eqs. 1, 3 and 5 refer to the power and control machines, respectively. Due to the pole pair difference between the two stators, there exists such relations between the electrical speeds of the rotor and stators for the 50 Hz system, which are given in

$$\omega_p = 2\pi 50 \tag{8}$$

$$\omega_r = \omega_p - \omega_m P_p \tag{9}$$

$$\omega_c = \omega_p - \omega_m (P_p + P_c) \tag{10}$$

There are three initial reference frames (shown in Fig. 2):

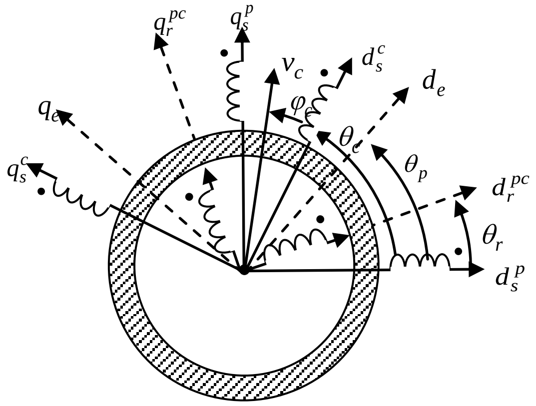

Fig. 2. Three-phase. BDFM model in d-q reference frame

In a standard practice, the dynamic equations in 1-6 are usually represented in the selected d-q reference frame. With the assumption of a stiff grid connection, the synchronous reference frame is selected. The stator frame rotates at the speed ω_e which is shown in Fig. 2. Moreover, Fig. 2 also shows the angle relationship of power machine stator, power and control machine rotors and control machine stator to the selected reference frame.

III. BDFG Controller Design

The developed control strategy is based on a loops control as shown in Fig. 3. Two regulation paths are implemented as in the classical vector control schemes: one control path regulates the d magnetizing currents and the other one is dedicated to control the q active currents. In order to obtain a good decoupled control, the power machine flux orientation has been selected ($\psi_{sp}^d = |\psi_{sp}|$ and $\psi_{sp}^q = 0$). The obtained control strategy for the BDFM is similar to the well-known stator field orientation control used in the DFIM. [9]

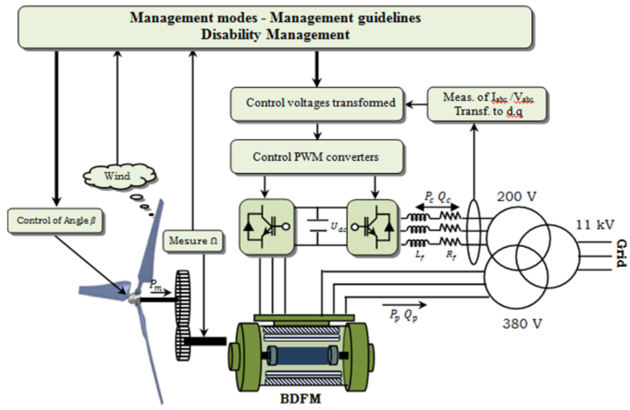

Fig. 3. Block diagram of BDFM power control system.

IV. Simulation Results And Discussion

The brushless doubly fed Machine parameters used in the simulation are given in appendix A.

The switches of inverters are considered as ideal, and their states are given by logical functions that take 1 the component is closed and 0 when it is open.

The results of simulations are obtained for reactive power Q=0 and DC link voltage U_{dc}= 330 V:

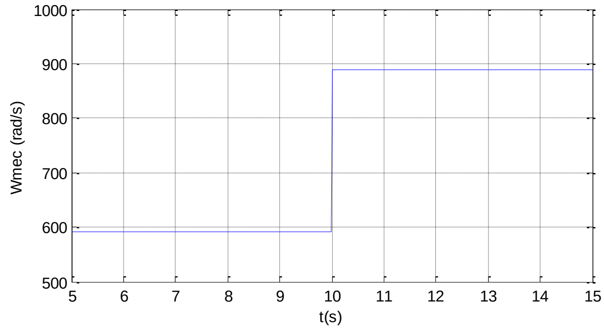

Fig. 4. Step of BDFG rotor speed.

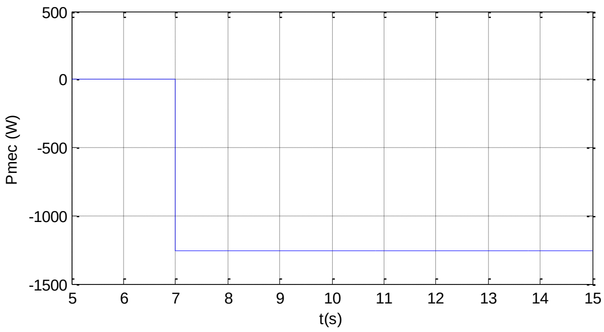

Fig. 5. Wind generator mechanical power.

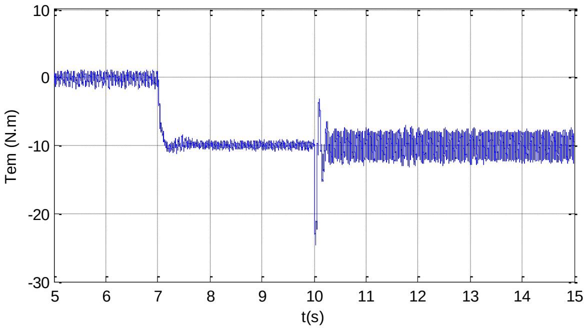

Fig. 6. Generator torque.

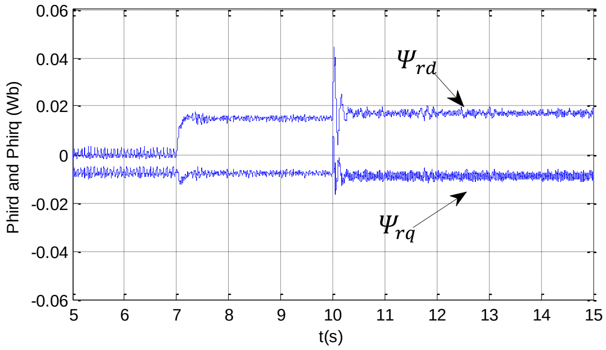

Fig. 7. Direct and quadratic rotor flux.

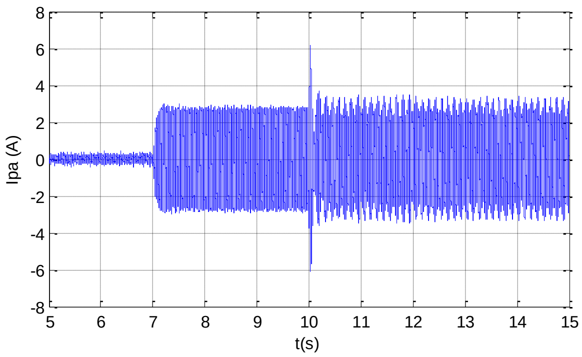

Fig. 8a. Stator current (phase Pa).

p

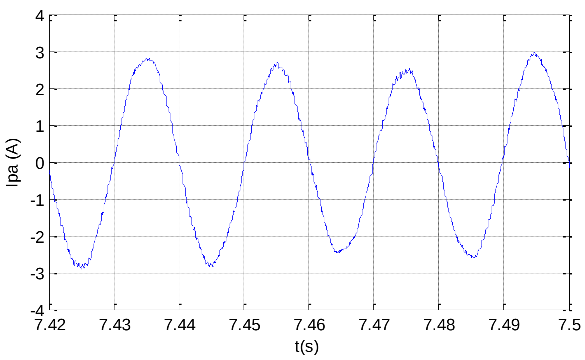

Fig. 8b. Zoom of Stator current (phase Pa).

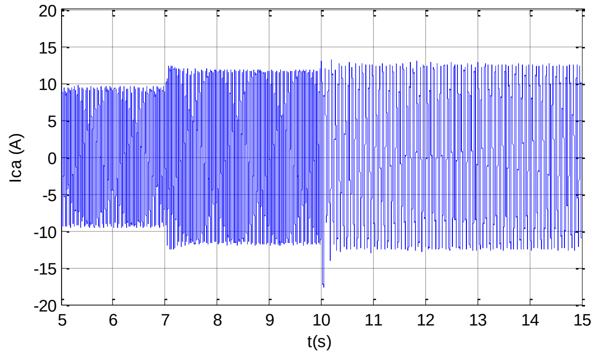

Fig. 9a. Stator current (phase Ca).

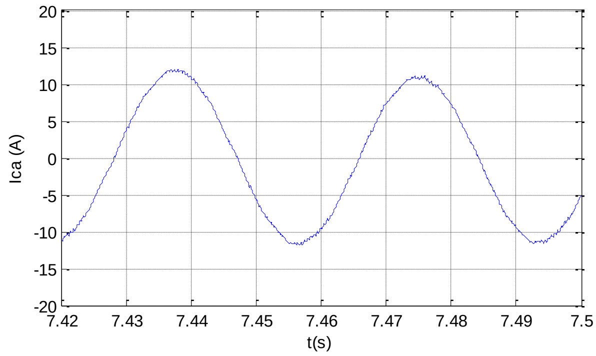

Fig. 9b. Zoom of Stator current (phase Ca).

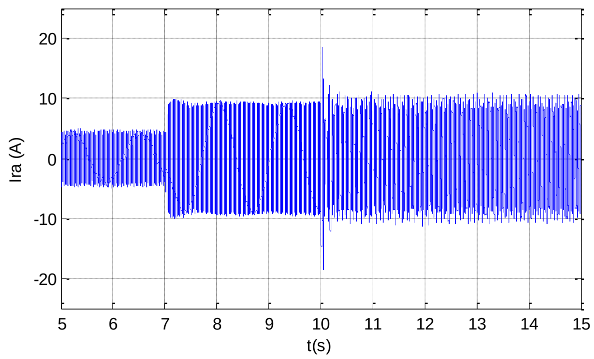

Fig. 10. Rotor current (phase Ra).

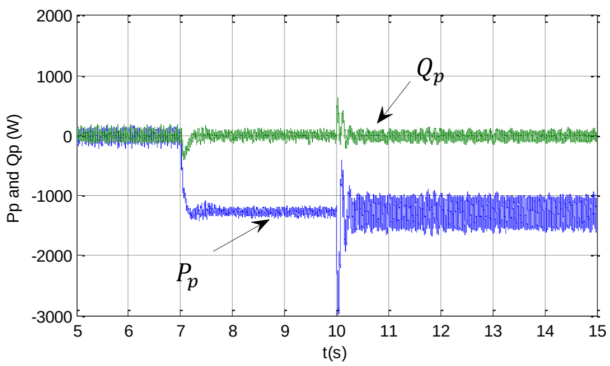

Fig. 11. Stator active and reactive powers.

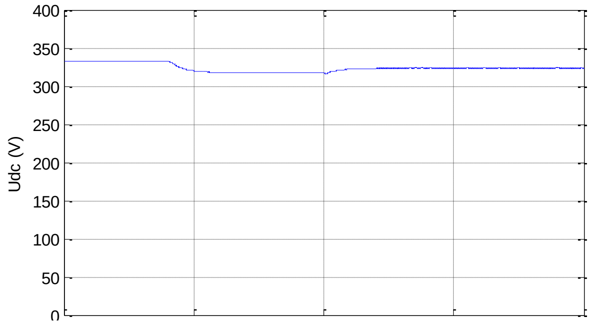

Fig. 12a. DC link voltage.

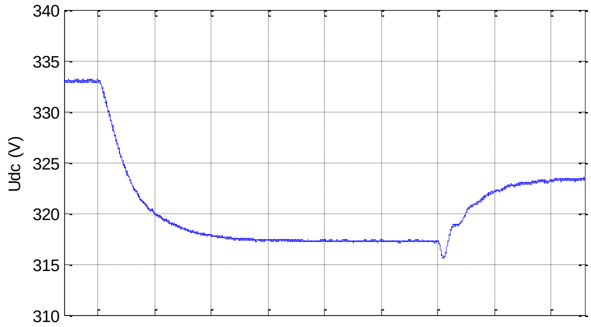

Fig. 12b. Zoom of DC link voltage.

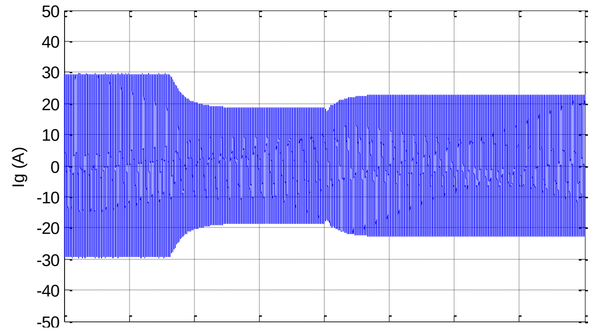

Fig. 13a. Current at the output of grid inverter.

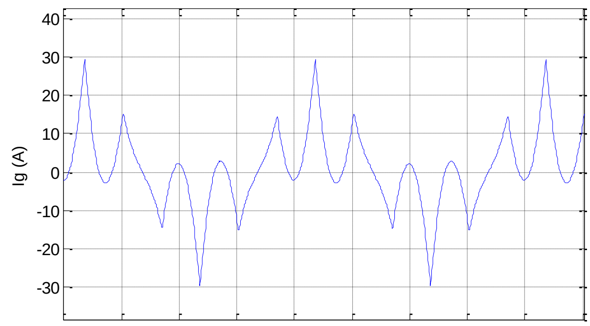

Fig. 13b. Zoom of Current at the output of grid inverter.

Fig. 4 shows the angular speed random of the BDFG. Fig. 5 presents the wind generator mechanical power. Fig. 6 shows the generator torque. The decoupling effect of the between the direct and quadratic rotor flux of the BDFG is illustrated in Fig. 7. The stator currents and voltages waveforms of the BGFG and the related expended plots are shown, respectively, in Figs. 8a and 9b (phase V_{ap}). The PWM inverters are operated at 5 kHz; hence, the currents are almost sinusoidal. The stator currents (winding set I and II) waveforms and these zoom are presented, correspondingly, in Figs. 10a and 10b. Fig. 11 gives the rotor current of the BDFG. The stator active and reactive powers are plotted in Fig. 12. Figs. 13a and 13b show the regulation of the DC link voltage. It is maintained at a constant level (330 V). The current and voltage at the output of the grid inverter waveforms and these zoom are given, respectively, in Figs. 14a and 14b. The line side converter (rectifier) supplies real power to the utility grid. Fig. 15, in turn, gives the grid active and reactive powers. Finally, the grid current and voltage (phase a) and the related expended plots are shown, in that order, in Figs. 16a and 16b.

V. Conclusions

Owing to its great reliability, BDFIG is an interesting solution for wind energy applications. It has been also shown in this paper that using an appropriate modeling approach based on dynamical equivalent circuit representation; a theoretical and simulation study of the BDFG dynamic performance in closed loop control of the generator active and reactive powers has been presented. The control system is based on the field orientation principle and the orientation of the power machine stator flux with two PI controllers placed in the power stator field coordinates, where a back-to-back voltage source converter was employed. Moreover, the proposed modeling approach allows the study of power flow.

The effectiveness of the proposed controllers has been demon strated by simulation and successfully implemented in a wind driven dual-stator induction generator system.

VI. References

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