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COMMUNICATIONS

A TORQUE TRACKING CONTROL ALGORITHM FOR DOUBLY–FED INDUCTION GENERATOR

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In this paper a torque tracking control algorithm for doubly-fed induction generator (DFIG) is proposed. First, a mathematical model of the doubly-fed induction generator written in an appropriate d-q reference frame is established to investigate simulations. In order to control the rotor currents of DFIG, a torque tracking control law is synthesized using PI controllers, while the stator side power factor is controlled at unity level. Results obtained in Matlab/Simulink environment are presented illustrating good control system performance.

K e y w o r d s: doubly-fed induction generator, wound rotor, power factor, torque tracking control

1 INTRODUCTION

A doubly-fed induction generator is an electrical asynchronous three-phase machine with open rotor windings which can be fed by external voltages. The typical connection scheme of this generator is reported in Fig. 1. The stator windings are directly connected to the line grid, while the rotor windings are controlled by means of a PWM inverter [1]. This solution is very attractive for all applications where limited speed variations around the synchronous velocity are present since the power handled by the converter at the rotor side will be a small fraction (depending on the slip) of the overall system power. In particular, for electric energy generation applications, it is important to note that the asynchronous nature of the DFIG allows to produce constant-frequency electric power with a variable mechanical speed and to reduce copper losses [2].

Different strategies were proposed in the literature to solve the DFIG control problem. A vector controlled doubly fed induction generator is an attractive solution for high performance restricted speed-range electric drives and energy generation application [1,2].

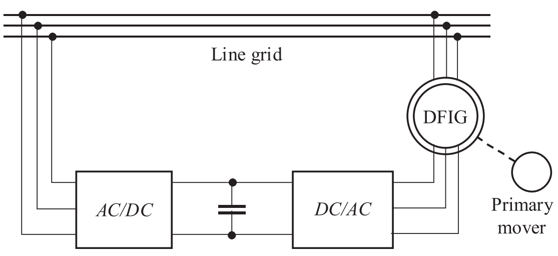

Fig. 1. The typical connection scheme of DFIG

In this paper, the torque tracking control strategy is achieved by adjusting rotor the currents and using a stator voltage vector oriented reference frame. Simulation is investigated with PI regulators under condition of unity stator side power factor. Simulation results present a high dynamic performance vector controlled doubly-fed induction generator.

2 MATHEMATICAL MODEL OF THE DFIG

The equivalent two-phase model of the symmetrical DFIG represented in the stator voltage-vector oriented frame (d-q) is [3]:

$$J\frac{\mathrm{d}\omega}{\mathrm{d}t} = \big[p\mu\big(\Psi_{qs} i_{dr} - \Psi_{ds} i_{qr}\big) - T_L - f\omega\big] \,, \tag{1}$$

$$\frac{\mathrm{d}Psi_{ds}}{\mathrm{d}t} = -\alpha_s\Psi_{ds} + \omega_s\Psi_{qs} + \alpha_s M i_{dr} + V_{ds} \,, \tag{2}$$

$$\frac{\mathrm{d}Psi_{qs}}{\mathrm{d}t} = -\alpha_s\Psi_{qs} + \omega_s\Psi_{ds} + \alpha_s M i_{qr} + V_{qs} \,, \tag{3}$$

$$\begin{aligned}\frac{\mathrm{d}i_{dr}}{\mathrm{d}t} &= -\gamma_r i_{dr} + \omega_r i_{qr} + \alpha_s\beta\Psi_{ds} \\ &\quad - \beta p\omega\Psi_{qs} - \beta V_{ds} + \frac{1}{\sigma_r}V_{dr},\end{aligned} \tag{4}$$

$$\begin{aligned}\frac{\mathrm{d}i_{qr}}{\mathrm{d}t} &= -\gamma_r i_{qr} - \omega_r i_{dr} + \alpha_s\beta\Psi_{qs} \\ &\quad + \beta p\omega\Psi_{ds} - \beta V_{qs} + \frac{1}{\sigma_r}V_{qr},\end{aligned} \tag{5}$$

$$\dot{\Theta} = \omega \,, \tag{6}$$

where: V_{dr}, V_{qr}, V_{ir}, i_{qr}, Ψ_{ds}, Ψ_{qs} are rotor voltages, rotor currents and stator fluxes, T_L is the moving torque generated by the primary mover, U_m and ω_s are stator (line) voltage amplitude and angular frequency, Θ and ω are angular position and rotor speed, $\omega_r = \omega_s - \omega$ is the sleep angular frequency, p is the number of pole pairs. Positive constants related to DFIG electrical parameters are defined as:

$$\alpha_s = R_s/L_s \,; \quad \gamma_r = L_r\big(1 - M^2/L_2L_r\big) \,; \; \beta = M/(L_s\sigma_r) \,;$$
$$\mu = 3M/2L_s \,; \gamma_r = R_r/\sigma_r + \big(R_sM^2\big)/L_s^2\sigma_r \,,$$

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where: R_s, R_r, I_s, I_r are the resistances and inductances of the stator and rotor respectively, M is the mutual inductance.

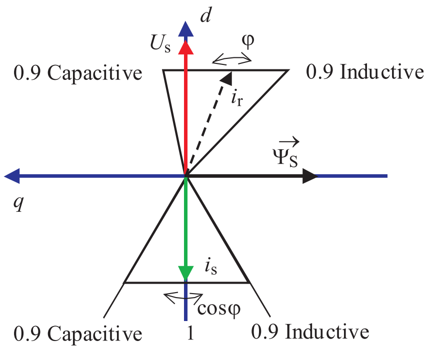

Fig. 2. Diagram control of power factor.

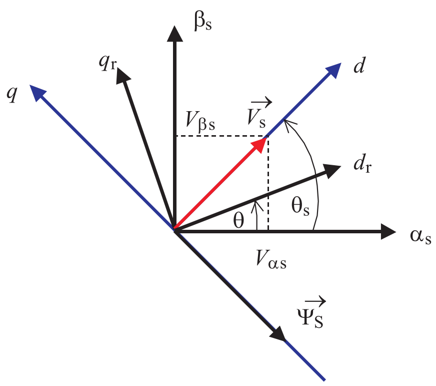

Fig. 3. Setting of vectors oriented and transformation angles.

3 VECTOR CONTROL ALGORITHM FOR DFIG

Conditions of the stator flux field orientation and line voltage orientation are equivalent if the stator side power factor is controlled at unity level [4]. Under such a condition the stator flux modulus is not a free output variable but it is a function of the produced electromagnetic torque. The reactive component of the stator current is practically equal to zero as it is the given working condition of DFIG control algorithm. Figure 2 shows the diagram control of the power factor. The setting of different vectors and transformation angles is represented in Fig. 3.

Using this reference frame, the flux errors are defined as

$$\tilde{\Psi}_{ds} = \Psi_{ds}\,, \quad \tilde{\Psi}_{qs} = \Psi_{qs} - \Psi^*, \quad i_{qs} = 0\,.$$

where Ψ^* is the flux level reference trajectory.

The complete equations of the vector control of the doubly-fed induction machine are given by:

Stator flux vector controller:

$$i^*_{qr} = \frac{1}{\sigma_s M}\left(\alpha_s \Psi^* + \dot{\Psi}^*\right), \tag{7}$$

$$\Psi^* = \frac{-U_m - \left(U_m^2 - 4(2/3)\omega_s R_s T^*_g\right)}{2\omega_s}\,. \tag{8}$$

Torque controller:

$$i^*_{dr} = \frac{T^*_g}{\mu \Psi^*_{qs}}\,. \tag{9}$$

Rotor current controller:

$$\begin{aligned} U_{dr} &= \sigma_r\Big[Y_r i^*_{dr} - \omega_r i^*_{qr} + \beta\omega\Psi^* + \beta U_m + \frac{\mathrm{d}i^*_{dr}}{\mathrm{d}t} + k_p \tilde{i}_{dr} + x_d\Big], \\ U_{qr} &= \sigma_r\Big[Y_r i^*_{qr} + \omega_r i^*_{dr} - \beta\omega_s\Psi^* - \frac{\mathrm{d}i^*_{qr}}{\mathrm{d}t} - k_p \tilde{i}_{qr} + x_q\Big], \end{aligned} \tag{10}$$

$$\dot{x}_d = -k_i \tilde{i}_{dr}\,, \tag{11}$$

$$\dot{x}_q = -k_i \tilde{i}_{qr}\,, \tag{12}$$

$$\tilde{i}_{dr} = i_{dr} - i^*_{dr}\,, \tag{13}$$

$$\tilde{i}_{qr} = i_{qr} - i^*_{qr}\,, \tag{14}$$

here i^*_{dr}, i^*_{qr} are rotor currents reference in $(d\text{-}q)$ reference frame, k_p and k_i are positive proportional and integral gains of rotor current controllers; Ψ^* is the stator flux reference, x_d, x_q are integral components of current controllers.

Under such a condition, the stator side active and reactive powers are given by

$$P = -\frac{3}{2} U_m i_{ds}\,, \tag{15}$$

$$Q = \frac{3}{2} U_m i_{qs}\,, \tag{16}$$

The study that we present consists in using a machine where the rotor is supplied through a converter. This converter is based on PWM control algorithm [8] operating at 2 KHz switching frequency.

The proportional and integral gains of the rotor current controllers have been set at $k_p = 500$, $k_i = 62040$. All programs for controller implementation have been written using Matlab/Simulink environment. The block diagram of the proposed controller is shown in Fig. 4.

4 SIMULATION RESULTS

The results reported in Figs. 5 to 14 show the system behaviour during torque tracking. The sequence of operation during this test is shown in Fig. 5. The DFIG, already connected to the line grid, is required to track a trapezoidal torque reference which starts at $t = 0.2$ s from zero initial value and reaches the rated value of -10 Nm.

Note that flux value required to track the torque trajectory with unity power factor at the stator side is not a constant. The rotor current i_{as} is sinusoidal as shown in Fig. 12. Waveforms of the rotor reference currents i^*_{dr} and i^*_{qr} are shown in Fig. 6. The stator power follows the current i^*_{qr} as shown in Fig. 10. This results in unity power factor on the grid as the stator reactive power is zero. Rotor current errors are controlled at zero level. The reactive component of the stator current i_{qs} is almost equal to zero during all the time. As a result, the stator phase current reported in Fig. 11 has a phase angle opposite to the line voltage one and shows a low content of high order harmonics.

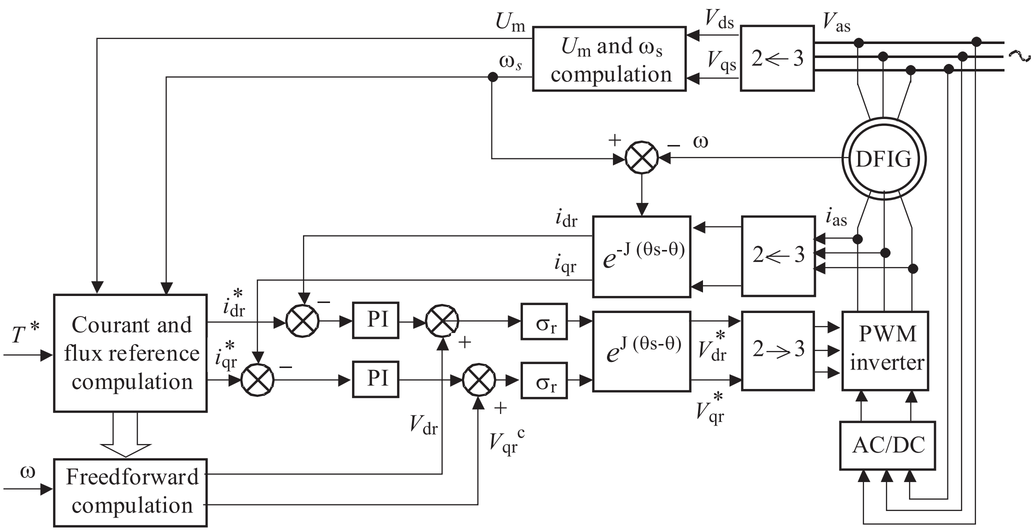

Fig. 4. Block diagram of the DFIG vector control

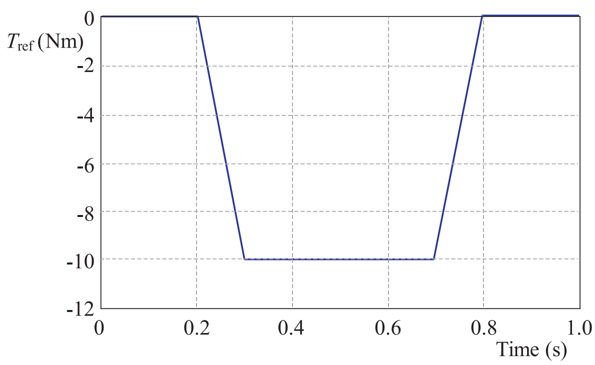

Fig. 5. Torque reference

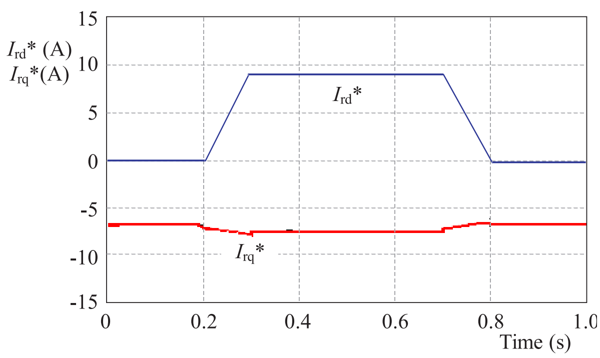

Fig. 6. Rotor reference currents $I_{rd}*$ and $I_{rq}*$

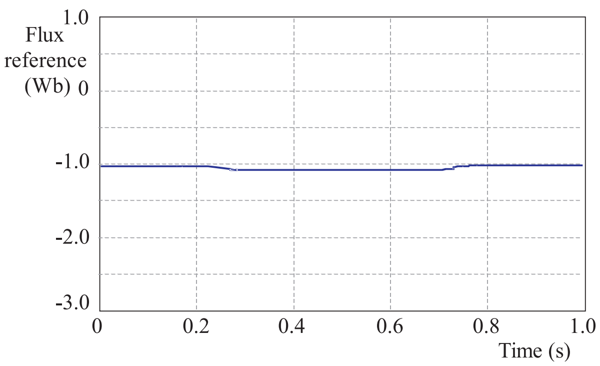

Fig. 7. Flux reference

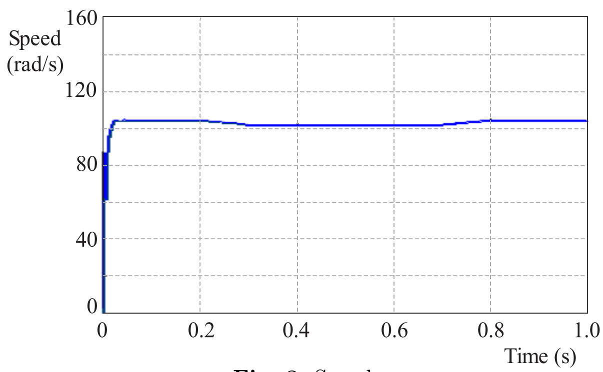

Fig. 8. Speed

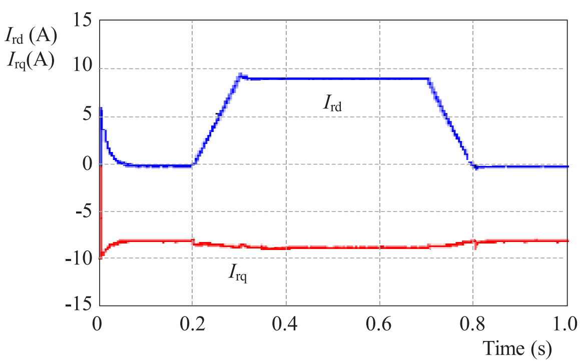

Fig. 9. Rotor Currents responses I_{rd} and I_{rq}

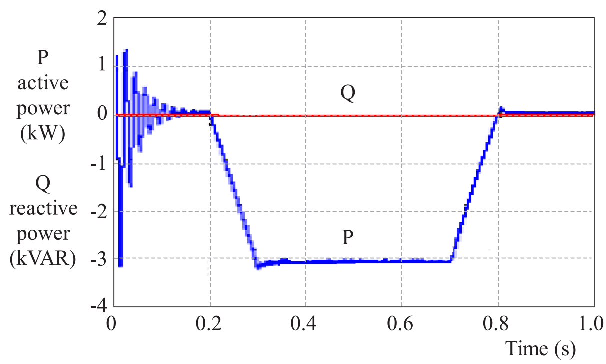

Fig. 10. Stator active power P and reactive power Q.

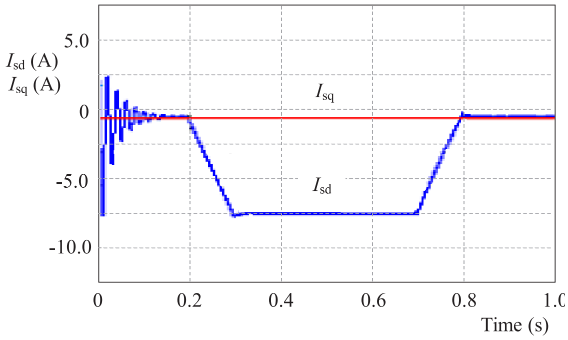

Fig. 11. Stator currents responses I_{sd} and I_{sq}

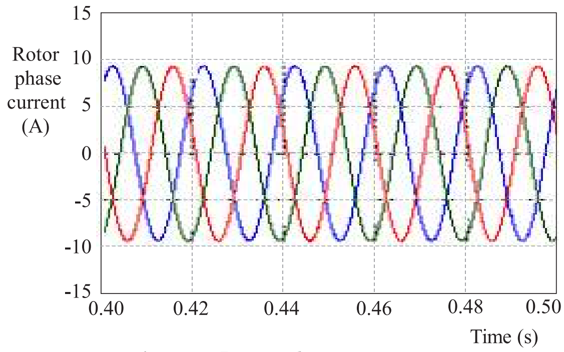

Fig. 12. Rotor phases currents

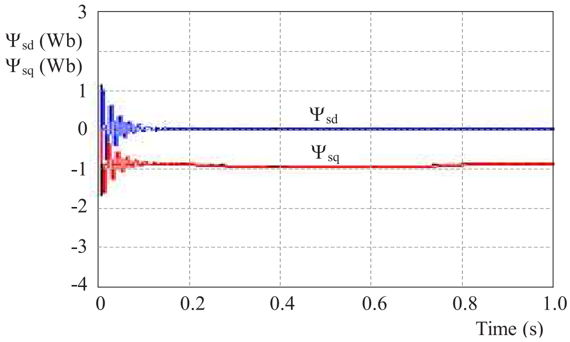

Fig. 13. Stator flux Φ_{sd} and Φ_{sq}

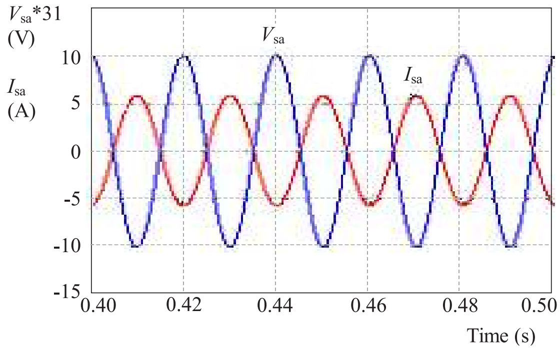

Fig. 14. Stator voltage and current

5 CONCLUSION

In this paper, a torque tracking control algorithm for doubly-fed induction generator has been proposed. Torque tracking control strategy has been achieved by adjusting the rotor currents and using a stator voltage vector oriented reference frame. Simulations have been investigated with PI regulators. Results show high performance torque tracking under condition of a unity stator side power factor.

Appendix

Rotor resistance	$R_r = 5.3\,\Omega$
Rated current	5.2 A
Stator inductance	$L_s = 0.161$ H
Rated voltage	220/380 V
Rotor inductance	$Lr = 0.161$ H
Rated torque	15 Nm
Mutual inductance	$M = 0.138$ H
Rated speed	880 rev/min
Number of pole pair	$p = 3$,
Stator resistance	$R_s = 4.7\,\Omega$
Friction coefficient	$f = 0.45$

References

[1] PETERSSON, A.: Analysis, Modeling and Control of Doubly-Fed Induction Machine for Wind Turbines, tutorial's thesis, Chalmers university of technology, Göteborg, Sweden, 2003.

[2] BOSE, B. K.: Power Electronics and Variable Frequency Drives: Technology and Applications, IEEE Press, N.Y., 1996.

[3] LEONHARD, W.: Control of Electric Drives, Springer-Verlag, Berlin, 1995.

[4] PERESADA, S.—CHEKHET, E.—SHAPOVAL, I.: Asymptotic Control of Torque and Unity Stator Side Power Factor of the Doubly-Fed Induction Machine, in Proceedings. Intern. Conf. Problems of Electrical Drives, Alushta, 1998, pp. 81–86.

[5] TAPIA, A.—TAPIA, G.—OSTOLAZA, J. X.—SAENZ, J. R.: Modiling and Control of a Wind Turbine Driven Doubly Fed Induction Generator, IEEE Transactions on Energy Conversion **18** No. 2 (June 2003), 194–204.

[6] PENA, R.—CLARE, J. C.—ASHER, G. M.: Doubly Fed Induction Generator Using Back-to-Back PWM Converters and its Application to Variable-Speed Wind-Energy Generation, IEE Proc Part B **143** No. 3 (May 1996), 231–241.

[7] XU, L.—CHENG, W.: Torque and Reactive Power Control of a Doubly-Fed Induction Machine by Position Sensorless Scheme, IEEE Transactions on Industry Applications **31** No. 3 (May/June 1995), 636–642.

[8] ZHANG, L.—WATTHANASARN, C.: A Matrix Converter Excited Doubly-Fed Induction Machine as a Wind Power Generator, IEE conference Publication N456, Power Electronics and variable speed drives, Sept. 1998, pp. 532–537.

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