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Real Time Simulation of Doubly-Fed Induction Machine IGBT Drive on a PC-Cluster

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***Abstract* - This paper has presented a device intended to fit in a wind mill based on a Doubly Fed Induction Generator connected to the grid. After a description of this device and its connection procedure, we have established a two-phase mathematical model of the DFIG. In order to control statoric active and reactive power exchanged between the DFIG and the grid, a vector-control strategy has been presented. Simulations have been investigated with two types of regulators: classical proportional-integral and polynomial RST based on pole-placement theory. The synthesis of the RST controller has been detailed. Simulations results have shown that performances are equivalent for the two controllers under ideal conditions (no perturbations and no parameters variations). The RST controller is more efficient when the speed is suddenly changed (which happens frequently in wind energy conversion systems) and is more robust under parameters variations of the DFIG (for example rotoric resistance in our study).**

***Keywords:* Doubly Fed Induction Generators, Active and Reactive Power, RST Controller**

I. INTRODUCTION

The electromagnetic conversion is usually achieved by induction machines or synchronous and permanent magnet generators. Squirrel cage induction generators are widely used because of their lower cost, reliability, construction and simplicity of maintenance [1]. But when it is directly connected to a power network, which imposes the frequency, the speed must be set to a constant value by a mechanical device on the wind turbine. Then, for a high value of wind speed, the totality of the theoretical power can not be extracted. To overcome this problem, a converter, which must be dimensioned for the totality of the power exchanged, can be placed between the stator and the network. In order to enable variable speed operations with a lower rated power converter, doubly fed induction generator (DFIG) can be used as shown on Fig. 1. The stator is directly connected to the grid and the rotor is fed to magnetize the machine. In this paper, the control of electrical power exchanged between the stator of the DFIG and the power network by controlling independently the torque (consequently the active power) and the reactive power is presented [2]. Several investigations have been developed in this direction using cycloconverters as converters and classical proportional-integral regulators [3-5]. In our case, after modeling the DFIG and choosing the appropriate d-q reference frame, active and reactive powers are controlled using respectively Integral-Proportional (PI) and an RST controller based on pole placement theory. Their performances are compared in terms of reference tracking, sensitivity to perturbations and robustness against machine's parameters variations.

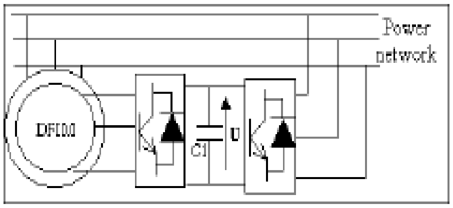

Fig. 1 Doubly-fed induction generator

II. MATHEMATICAL MODEL OF THE DFIG

For a doubly fed induction machine, the Concordia and Park transformation's application to the traditional a,b,c model allows to write a dynamic model in a d-q reference frame as follows:

$$\left\{\begin{bmatrix} V_{ds} = R_s I_{ds} + \dfrac{d}{dt}\psi_{ds} - \dot{\theta}_s \psi_{qs} \\ V_{qs} = R_s I_{qs} + \dfrac{d}{dt}\psi_{qs} + \dot{\theta}_s \psi_{ds} \\ V_{dr} = R_r I_{dr} + \dfrac{d}{dt}\psi_{dr} - \dot{\theta}_r \psi_{qr} \\ V_{qr} = R_s I_{qr} + \dfrac{d}{dt}\psi_{qr} + \dot{\theta}_r \psi_{dr} \end{bmatrix}\right\} \qquad (2.1)$$

$$\left\{\begin{bmatrix} \psi_{ds} = L_s I_{ds} + M I_{dr} \\ \psi_{qs} = L_s I_{qs} + M I_{qr} \\ \psi_{dr} = L_r I_{dr} + M I_{ds} \\ \psi_{qr} = L_r I_{qr} + M I_{qs} \end{bmatrix}\right\} \qquad (2.2)$$

$$\Gamma_m = \Gamma_e + J\frac{d\Omega}{dt} + f\Omega \qquad (2.3)$$

$$\Gamma_e = -P\frac{M}{L_s}(\psi_{qs} I_{dr} - \psi_{ds} I_{qr}) \qquad (2.4)$$

III. DFIG CONTROL

A. Aim of the Control

When the DFIG is connected to an existing network, this connection must be done in three steps which are presented below [6]. The first step is the regulation of the statoric voltages with the network voltages as reference (fig. 2). The second step is the stator connection to this network. As the voltages of the two devices are synchronized, this connection can be done without problem. Once this connection is achieved, the third step, which constitutes the topic of this paper, is the power regulation between the stator and the network. (Fig. 3).

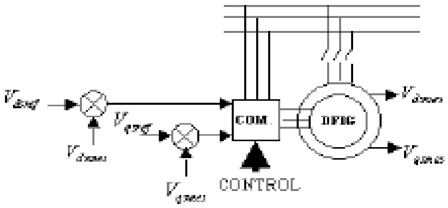

Fig. 2 First step of the DFIG connection

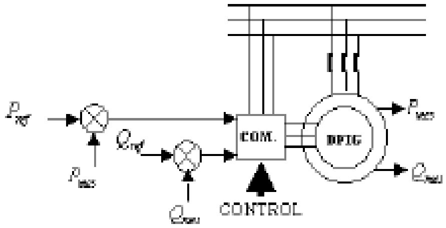

Fig. 3 Third step of the DFIG connection

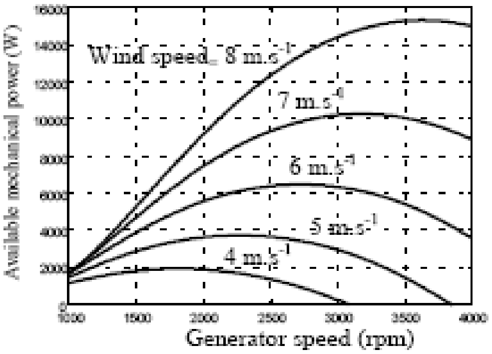

Fig. 4 Example of wind-turbine power-curves

For a given wind turbine, some relations exist between the wind speed, the generator's rotating speed and the available mechanical power (fig. 4). If the wind speed is measured and the mechanical characteristics of the wind turbine are known, it is possible to deduce in real-time the theoretical electrical power which can be generated. It is then possible to control the generator using this power as reference.

B. Establishment of the Control Strategy

To achieve a stator active and reactive power vector control as shown on figure 3, we choose a d-q reference-frame synchronized with the stator flux. By setting the statoric flux vector aligned with d-axis, we have:

$$\psi_{ds} = \psi_s \text{ and } \psi_{qs} = 0 \qquad (3.1)$$

$$\Gamma_e = -p\frac{M}{L_s} I_{qr}\psi_{ds} \qquad (3.2)$$

The electromagnetic torque and then the active power will only depend on the q-axis rotoric current. Neglecting the per phase statoric resistance Rs (that's the case for medium power machines used in wind energy conversion systems), the statoric voltage of the phase number n of the DFIG can be written as follows:

$$V_{sn} = \frac{d\psi_{sn}}{dt} \quad ; \quad n=a, b \text{ or } c. \qquad (3.3)$$

The statoric voltage vector is consequently in quadrature advance in comparison with the statoric flux vector. Then we can write:

$$V_{ds} = 0 \text{ and } V_{qs} = V_s \qquad (3.4)$$

C. Sensitivity to Perturbations

The generator is now driven at 3500 rpm with a constant reference of active power of –5 kW and a reactive power reference set to zero. At t=3s, the speed suddenly varies from 3500 to 3100 rpm. This speed impact can be compared to a wind gust in a real wind energy system. The effect of this speed step on the behavior of the power generated is shown on fig. 5 and 6 for the two controllers.

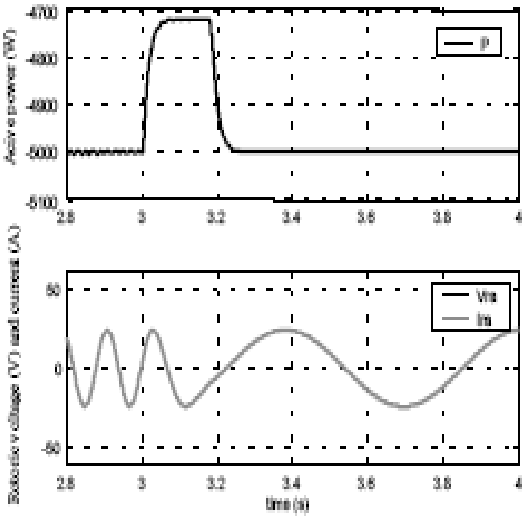

Fig. 5 Response to a speed impact (PI controller)

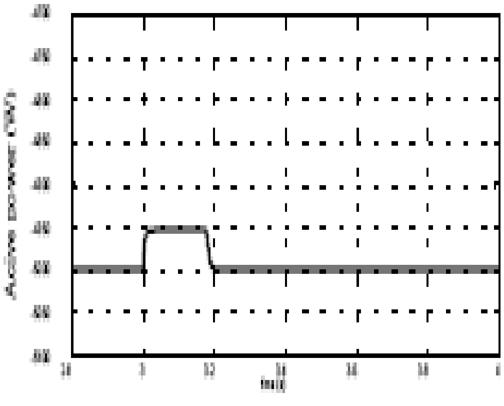

Fig. 6 Response to a speed impact (RST controller)

These results permit to verify that the RST controller has better performances than PI to reject speed perturbation. As a matter of fact, the variation of active power is about 80 per cent smaller with the RST than with the PI controller. We also show the waveforms of rotoric voltage and current on figure 5. The variation of frequency is naturally related to the speed variation.

D. Robustness

In order to test the robustness of the two controllers, the value of the rotoric resistance Rr is doubled (from 0.38W to 0.76W). The generator is driven to 3500 rpm and we impose an active power reference of -5kW. Fig. 7 and 8 shows the effect of rotoric resistance variation on the generator response for the two controllers.

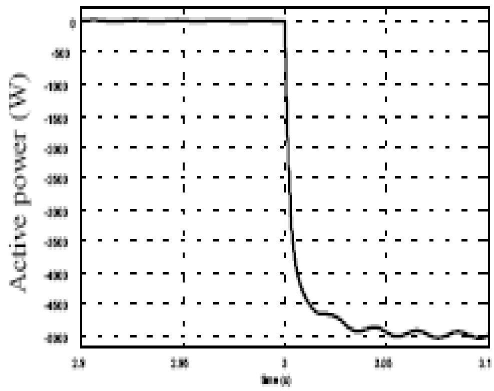

Fig. 7 Response to a rotoric resistance variation (PI controller)

This robustness test shows that in the case of a PI regulator, the time response is strongly altered whereas it remains unmodified when the RST controller is used.

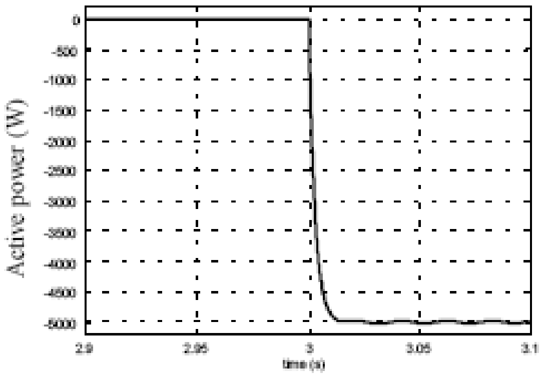

Fig. 8 Response to a rotoric resistance variation (RST controller)

IV. CONCLUSION

The controllability analysis of the inverter fed induction machine among other things showed that the process has large RGA elements for large operating point stator frequencies, which causes problems with cross-coupling at flux control. If possible, the controller bandwidths should be set higher than the operating point stator frequency to avoid problems. This may not be possible for higher stator frequencies due to for example long time delays. In this case at least the change rate of the flux reference should be limited to avoid exciting the critical frequencies around the operating point stator frequency. It was also shown that the DC-link voltage disturbance enters the system in a direction giving large gain around the resonance frequency.

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