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Modeling and control of Doubly-fed Induction Generator for Wind Energy Conversion System Using two different controllers

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***Abstract*— This paper presents a study analysis of a wind energy conversion system (WECS) based on a doubly fed induction generator (DFIG) connected to the electric power grid. The aim of this paper is to propose a control method for a doubly-fed induction generator used in wind energy conversion systems. The active and reactive powers exchanged between the generator and the grid is controlled by the way of the generator inverter with the algorithm of control based on vector control c with stator flux orientation, with two different controllers: classical IP controller (integral-proportional), Sliding Mode Controller (SMC). Finally the Simulations results are presented and discussed. Therefore, we conclude which is a suitable controller of DFIG in Wind Energy Conversion System.**

***Keywords*— Doubly fed induction generator, Power control, Integral Proportional controller, Sliding Mode Controller.**

I. Introduction

Because of the concern about the environmental pollution and a possible energy crisis, there has been a rapid increase in renewable energy sources worldwide. Among various renewable energy sources, wind energy is one of the most important and promising renewable energy resources in the world, because it is considered to be non polluting and economically viable [1] .The capacity has grown rapidly over the past decades, the wind generation is estimated to be 10% of the world's total electricity by the year 2020 and is expected to be double or more by the year 2040 [2], [3].

The variable-speed wind turbine operation has been used for several reasons such as ability to get the maximum active power of the wind speed and possibility to control reactive power independently [4-5]. Nowadays the doubly fed induction machine (DFIMs) is widely used as a generator, particularly in variable-speed wind energy application [6].

The DFIG has recently received much attention as one of preferred technology for wind power generation because of their advantages such as: act for any angular wind speed, small power converters to control it, low-converter cost, lower requirement of maintenance and speed control with improved power quality, and reduced mechanical stress and also has an ability to decoupled control of active and reactive power in the four-quadrant, furthermore the power-factor control can be implemented at lower cost [1], [4], [6-8].

Additionally, with the power electronics development, there is appearing a back-to-back converter technique, which consist of two bidirectional converters and a dc-link (AC/DC/AC) [9]. Consequently when use this technique with DFIG in the WECS, the powers can be generated both from the stator and the rotor [4-5], [8], [10] this technique permits to the DFIG to operate at super and sub-synchronous speed. Furthermore, the power electronic converters are only rated at about 25% to 30% of the total generator rating, to achieve full control of the generator. To ensure good connectivity of the DFIG with the grid, the control system is suitable for this application and is extensively investigated. In literature [5], [6], [8], [11], were study the power control strategy of the DFIG with decupled control of active and reactive powers. These control schemes are generally based on vector control concept (with stator flux or voltage orientation) associated with classical controllers. There are different approaches to control the DFIG, all these approaches are based on the stator or rotor flux orientation with conventional controllers [12-14]. Newly, these controllers are replaced by fuzzy logic and sliding mode methods [15-17].

This paper presents a control method based on oriented field control with active and reactive powers as variables to be controlled in a WECS using three different controllers (IP, SMC). Such an approach does not manage easily the compromise between dynamic performances and robustness or between dynamic performances and the generator energy cost.

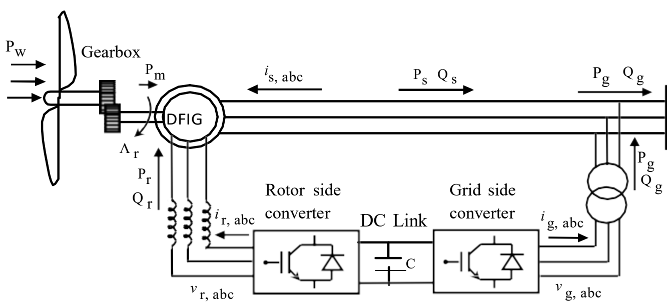

Fig. 1 Scheme of a DFIG equipped wind turbine.

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II. MATHEMATICAL MODEL OF THE GENERATOR

The Generator converts energy derived from the wind into electrical energy. The DFIG based a wound rotor and an AC/DC/AC based PWM converter (back-to-back converter with capacitor dc-link), the stator windings is directly connected to the grid while the rotor winding is interfaced through a power electronic converter (AC/DC/AC) [9].

The modeling of the DFIG is described in the d-q Park reference frame. The mathematical representation of the DFIG can be described by the equations below [2], [5] and [10].

The stator and rotor voltages:

$$\begin{cases} v_{ds} = R_s i_{ds} + \frac{d}{dt}\phi_{ds} - \omega_s \phi_{qs} \\ v_{qs} = R_s i_{qs} + \frac{d}{dt}\phi_{qs} + \omega_s \phi_{ds} \end{cases} \quad (1)$$

$$\begin{cases} v_{dr} = R_r i_{dr} + \frac{d}{dt}\phi_{dr} - \omega_r \phi_{qr} \\ v_{qr} = R_r i_{qr} + \frac{d}{dt}\phi_{qr} + \omega_r \phi_{dr} \end{cases} \quad (2)$$

Where R_s and R_r are, respectively, the stator and rotor phase resistances. $\omega = p \cdot \Lambda_{mec}$ is the electrical speed and p is the pair pole number.

The flux linkages equations can be expressed as:

$$\begin{cases} \phi_{ds} = L_s i_{ds} + M i_{dr} \\ \phi_{qs} = L_s i_{qs} + M i_{qr} \end{cases} \quad (3)$$

$$\begin{cases} \phi_{dr} = L_r i_{dr} + M i_{ds} \\ \phi_{qr} = L_r i_{qr} + M i_{qs} \end{cases} \quad (4)$$

Where i_{ds}, i_{qs}, and i_{dr}, i_{qr} are, respectively, the direct and quadrate stator and rotor currents.

The DFIG electromagnetic torque is given as:

$$T_{em} = p(\phi_{ds} i_{qs} - \phi_{qs} i_{ds}) \quad (5)$$

The stator active and reactive powers are defined as:

$$\begin{cases} P_s = v_{ds} \cdot i_{ds} + v_{qs} \cdot i_{qs} \\ Q_s = v_{qs} \cdot i_{ds} - v_{ds} \cdot i_{qs} \end{cases} \quad (6)$$

III. CONTROL STRATEGY OF THE DFIG

A. Decoupled Control of the active and reactive powers

The function of the rotor circuit power electronic converter is to control the DFIG active and reactive powers [9], [7], since the DFIG is connected to the utility grid, the power produced by the (generator) must be controlled independently. Accordingly, we align the d-axis along the stator flux vector position, as shown in Fig.2.

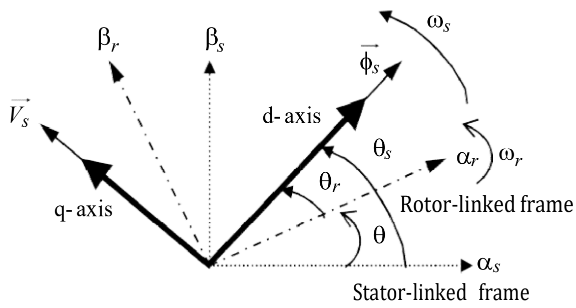

Fig.2 Orientation of the stator flux

Which is the principle of the stator-flux-oriented vector control approach, this approach is regarded by the WECS as a natural application and the most commonly utilized frame for the design and analysis of control strategy for the DFIG [5], and it allows to the DFIG to regulate separately the stator active and reactive powers by means of rotor current regulation [5], [7], [15].

So, under this assumption we can write:

$$\phi_{ds} = \phi_s \Rightarrow \phi_{qs} = 0 \quad (7)$$

Using the condition above, supposing that the grid system is steady, having a single voltage V_s that leads to stator's constant flux ϕ_s, we can easily deduce the voltages as:

$$\begin{cases} v_{ds} = 0 \\ v_{qs} = \omega_s \cdot \phi_s = V_s \end{cases} \quad (8)$$

If per phase stator resistance is neglected, which is a realistic approximation for medium power machines used in WECS, the stator voltage vector is consequently in quadrate advance in comparison with the stator flux vector.

Rotor voltages can be expressed by:

$$\begin{cases} v_{dr} = \sigma L_r \frac{di_{dr}}{dt} + R_r i_{dr} - \sigma L_r \omega_r i_{qr} + \frac{M}{L_s}\frac{d\phi_{ds}}{dt} \\ v_{qr} = \sigma L_r \frac{di_{qr}}{dt} + R_r i_{qr} + \sigma L_r \omega_r i_{dr} + s\frac{M}{L_s} V_s \end{cases} \quad (9)$$

Where V_s is the stator voltage magnitude assumed to be constant and s is the slip range, we can rewrite the rotor voltages as follows:

$$\begin{cases} v_{dr} = \sigma L_r \frac{di_{dr}}{dt} + R_r i_{dr} + fem_d \\ v_{qr} = \sigma L_r \frac{di_{qr}}{dt} + R_r i_{qr} + fem_q \end{cases} \quad (10)$$

With fem_d and fem_q are the crosses coupling terms between the $d-$axis and $q-$axis:

$$\begin{cases} fem_d = -\sigma L_r \omega_r i_{qr} \\ fem_q = \sigma L_r \omega_r i_{dr} + s\frac{M}{L_s} V_s \end{cases} \quad (11)$$

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The active and reactive power can then be expressed only versus these rotor currents as:

$$\begin{cases} P_s = V_s I_{qs} = -V_s \dfrac{M}{L_s} I_{qr} \\ Q_s = V_s I_{ds} = \dfrac{V_s \phi_s}{L_s} - \dfrac{V_s M}{L_s} I_{dr} \end{cases} \quad (12)$$

Field oriented control of the DFIG can then be applied with the active and reactive power considered as variables to be controlled. And, we consequently the bloc diagram is presented in Fig. 3.

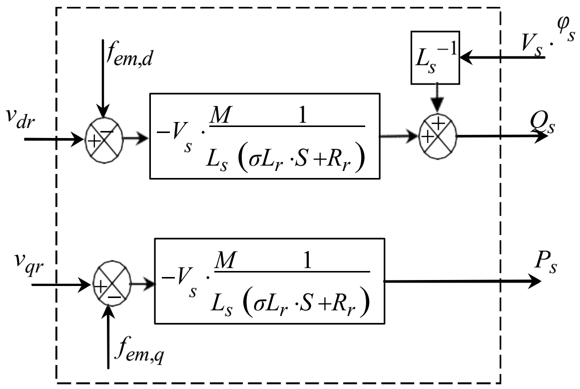

Fig. 2 The coupled model of active and reactive stator powers.

B. Controllers synthesis

1) IP controller synthesis

Fig.5 shows the structure of IP controller, it has some clear differences with PI controller. In the case of IP is an association of an internal loop provided with the regulator proportional and of an external loop ordered by an integrating regulator.

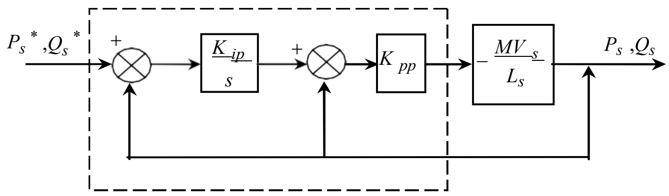

Fig. 4 Structure of IP controller

2) Sliding Mode Controller (SMC)

The rotor currents (which are linked to active and reactive powers by equation (12), quadrate rotor current i_{qr} linked to stator active power P_s and direct rotor current i_{dr} linked to stator reactive power Q_s have to track appropriate current references, so, a sliding mode control based on the above Park reference frame is used.

The sliding surfaces representing the error between the measured and references rotor currents are given by this relation:

$$\begin{cases} S_d = \lambda\left(i^*_{dr} - i_{dr}\right) \\ S_q = \lambda\left(i^*_{qr} - i_{qr}\right) \end{cases} \quad (13)$$

V_{dr} and V_{qr} will be the two components of the control vector used to constraint the system to converge to $S_{dq} = 0$.

The control vector U_{dqeq} is obtained by imposing $\dot{S}_{dq} = 0$ so the equivalent control components are given by the following relation:

$$U_{eqdq} = \begin{bmatrix} -R_r b L_r \sigma I_{dr} + \dfrac{M}{L_s \omega_s} V_{qs} \\ + R_r c \phi_{ds} + \omega_r \left(L_r \sigma I_{qr} + \dfrac{M}{L_s \omega_s} V_{ds}\right) \\ -R_r b L_r \sigma I_{qr} + \dfrac{M}{L_s \omega_s} V_{qs} \\ + R_r c \phi_{qs} - \omega_r \left(L_r \sigma I_{dr} + \dfrac{M}{L_s \omega_s} V_{qs}\right) \end{bmatrix} \quad (14)$$

To obtain good performances, dynamic and commutations around the surfaces, the control vector is imposed as follows:

$$U_{dq} = U_{eqdq} + K.sign\left(S_{dq}\right) \quad (15)$$

The sliding mode will exist only if the following condition is met:

$$S(x,t) \cdot \dot{S}(x,t) < 0 \quad (16)$$

The block-diagram of the variable structure control of the DFIG is presented on Fig.5. The stator active and reactive powers are controlled.

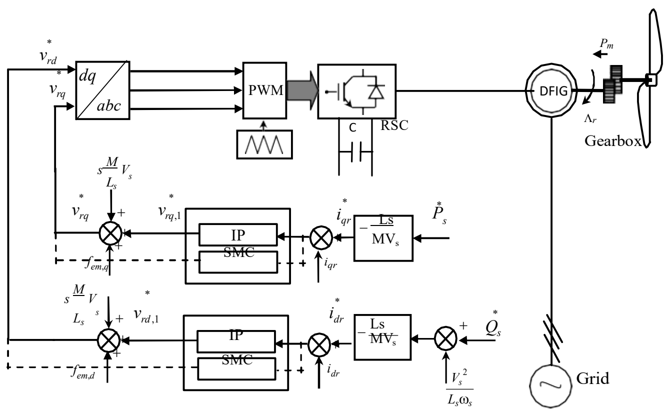

Fig.5 Overall oriented field control of DFIG in WECS with different controllers.

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IV. Results and Discussion

In this section, simulations are investigated with a 7.5kW generator connected to a 220V/50Hz grid. The machine's parameters are presented below:

Three pole pairs, Rs = 0.455Ω, Ls = 0.084 H, M = 0.078 H, Rr = 0.62 Ω, Lr = 0.081 H

The simulations are done in purpose to study the responses of wind turbine and its control with different controllers to analyze the influence of a speed variation of the DFIG on active and reactive powers. The active and reactive power references are maintained to $5\,kW$ and $-5\,kVAR$ and at $t = 0.5\ s$ the speed varies from 1350 rpm to 1450 rpm. At time= 1.5 s the speed varies also from 1450 rpm to1300 rpm. A variable step solver is used with an automatic step size and with a relative tolerance of 1e-3.

We notice that, those figures represent a good tracking and performances in terms of dynamics and responses. The classical IP controller is limited, which is only based on the machine's parameters and their eventual variations are not taken into account. In fact, for this controller, a speed variation induces an important peak value of the active and reactive powers. The Sliding Mode Controller contains the presence of perturbations in its synthesis, so it shows better disturbance rejection than IP controller. This rejection is still imperfect because the synthesis of the controller includes parameters, which have an influence on its performance.

V. Conclusion

The doubly fed induction generator is receiving increasing attention for wind energy conversion system.

In this paper, we have presented Wind Energy Conversion System based Double Fed Induction Generator. The control of the generator inverter has been presented in order to control the active and reactive powers exchanged between the generator and the grid. Field oriented control is applied, is based on the calculated rotor currents from the active and reactive powers and measuring the rotor currents (Indirect Power Control). Two different controllers are synthesized and compared. Under the simulation results we conclude that the impact on the active and reactive powers values is important for the booth controllers (IP, SMC) which in only based on the machine's parameters. In fact for these controllers a speed variation induces an important peak value of the active and reactive powers. However the SMC controller presents a problem of charting in the current which is limited to use.

References

[1] A.Tapia, G.Tapia, J. Xabier Ostolaza, and J. Ramón Sáenz, "Modeling and Control of a Wind Turbine Driven oubly Fed Induction Generator ", IEEE Transaction on energy conversion, Vol. 18, No 2, June 2003, pp. 194-204.

[2] J. Liang, W. Qiao, and Ronald G. Harley, "Direct Transient Control of Wind Turbine Driven DFIG for Low Voltage Ride-Through", IEEE Proceeding, Lincoln, NE, June 24-26, 2009 pp. 1-7.

[3] A.A. El-Sattar, N.H. Saad, M.Z. Shams El-Dein, "Dynamic response of doubly fed induction generator variable speed wind turbine under fault", Elsevier Electric Power Systems Research, Vol. 78, No. 7, Jul. 2008, pp. 1240-1246.

[4] J. Zhao, X. Li, J. Hao, J. Lu, "Reactive power control of wind farm made up with doubly fed induction generators in distribution system", Elsevier Electric Power Systems Research, Vol. 80, No. 6, June 2010, pp. 698-706.

[5] R. Pena, J. C. Clare, and G. M. Asher, "Doubly fed induction generator using back-to-back PWM converter and is application to variable-speed wind–energy generation", Proc. IEE B Electr. Power Appl, Vol. 143, No. 3, May 1996, pp. 231–241.

[6] S. Muller, M. Deicke, and R. W. De Doncker, "Doubly fed induction generator systems for wind turbines ", IEEE Industry Applications Magazine, Vol. 8, No. 3, May/Jun 2002, pp. 26–33.

[7] R. Cárdenas, R. Pena, S. Alepuz, G. Asher, " Overview of Control Systems for the Operation of DFIGs in Wind Energy Applications ", IEEE Trans. Industrial Electronics, Vol. 60, No. 7, July 2013.

[8] M. Moghbel, H. Tari Mokui , M. A.S. Masoum, M. Mohseni, "Reactive Power Control of DFIG Wind Power System Connected to IEEE 14 Bus Distribution Network ", 22nd Australasian Conference , Bali September 26-29, 2012, pp. 1–7.

[9] M. Ghofrani, and A. Arabali, , M. Etezadi-Amoli, "Modeling and Simulation of a DFIG-Based Wind-Power System for Stability Analysis", Power and Energy Society General Meeting; San Diego, CA, July 22-26, 2012, pp. 1-8.

[10] B.Singh, S. Kumar Aggarwal, and T. Chandra Kandpal, "Performance of Wind Energy Conversion System using a Doubly Fed Induction Generator for Maximum Power Point tacking", Industry Applications Society Annual Meeting (IAS), Houston, Oct 3-7, 2010, pp. 1-7.

[11] L. M Fernandez, C.A. Garcia, F. Jurado, "Comparative study on the performance of control systems for doubly fed induction generator (DFIG) wind turbines operating with power regulation", Energy, Vol. 33, 2008, pp. 1438-1452.

[12] P.C Krause, O.Wasynczuk and S. D.Sudhoff, Analysis of electrical machinery and drive system ,IEEE .Press :2002.

[13] A. Boyette, S.Saadate, P. Poure, " Direct and indirect control of a Doubly Fed Induction Generator wind turbine including a storage unit", 32nd Annual Conference On IEEE Industrial Electronics; Paris , Nov 06-10,2006, pp. 2517-2522.

[14] A. Dekhane, S. Lekhchine, T. Bahi, S. Ghoudelbourg, H. Merabet, " DFIG Modeling and Control in a Wind Energy Conversion System", 1st International Conference on Renewable Energies and Vehicular Technology, Hammamet, March 26-28, 2012, pp. 287-292.

[15] K.Belmokhtar, M.L Doumbia and K. Agbossou, " Modelling and Fuzzy Logic Control of DFIG Based Wind EnergyConversion Systems" IEEE International Symposium on Industrial Electronics Hangzhou;May 28-31;2012;pp.1888-1893.

[16] Munteanu, Bacha S, Bratcu A, Guiraud J, Roye D. "Energy reliability optimization of wind energy conversion systems by sliding mode control", IEEE Trans Energy Convers, 2008, pp. 975–85.

[17] J. Hu, H. Nian, B. Hu, Y. He, and Z. Zhu, "Direct active and reactive power regulation of DFIG using sliding-mode control approach", IEEE Trans. Energy Convers, vol. 25, Dec. 2010, pp.1028-1039.

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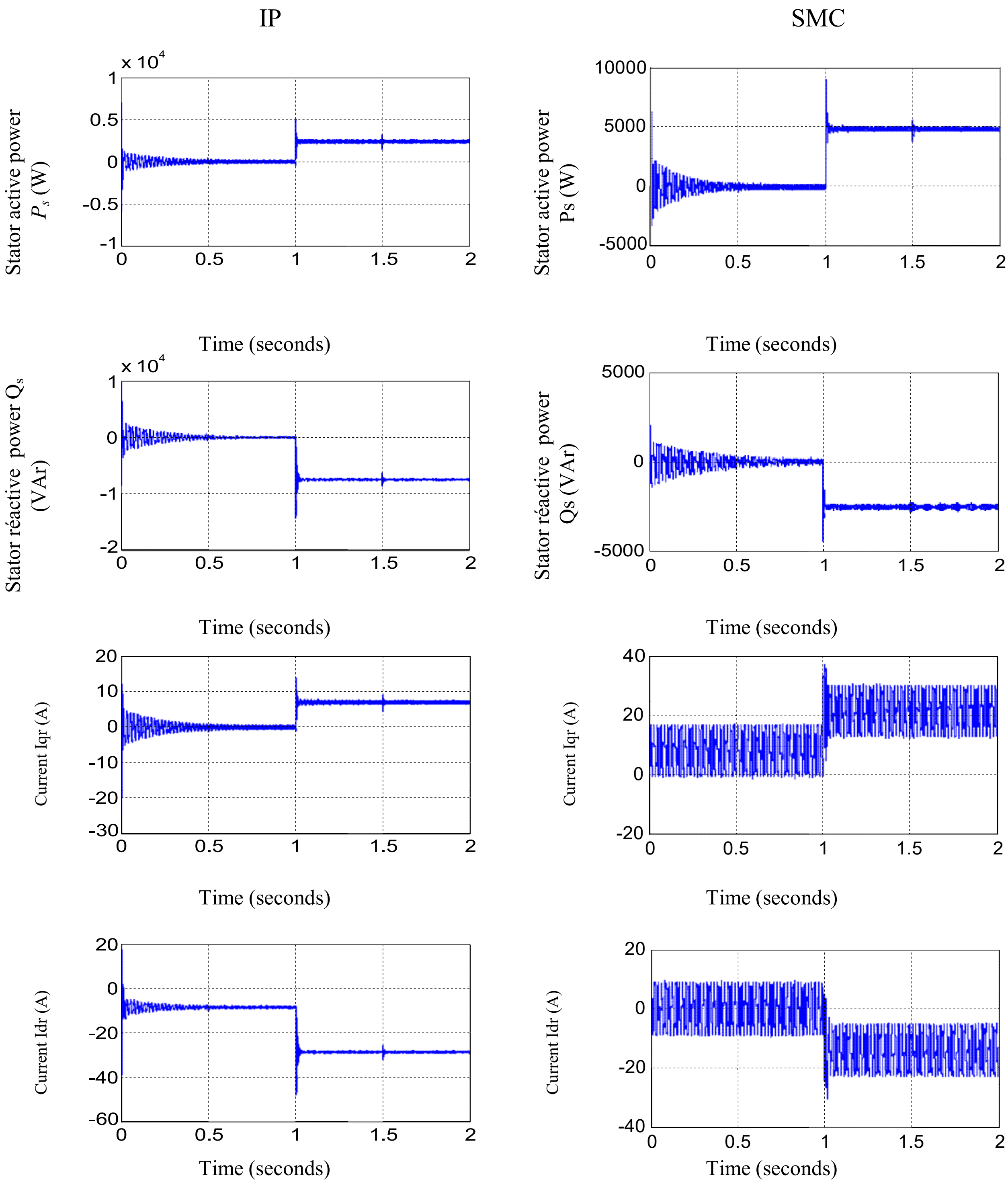

Fig.6 Effect of a speed variation (indirect control) equipped with IP and SMC controllers.

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