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Comparative studies between wind turbine active/reactive power control

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Abstract: -Wind turbines are controlled to provide constant active and reactive power during a certain period for contributing to the service system. In this paper, we present three types separate control of active and reactive power for horizontal axis wind turbine in order to compare their performance: the direct method with a PI and a Fuzzy Logic controller, and also the indirect method control with powers feedback. We aim to obtain the maximum of performance and reducing the controllers number, with taking into consideration the particular wind speed in Algeria. We present also the model of the system to be controlled. A series of simulation results obtained by Matlab / Simulink software are compared and analyzed.

***Keywords*—Wind Turbine, power, modeling, control, simulation, fuzzy, Algeria**

I. INTRODUCTION

Fossil fuel dependency in the global economy and the environmental concerns hold attention for an alternative to current electricity generation methods. However, wind energy has proven the most promising sustainable energy resources [1]. Indeed, progress in wind technology is leading to lower costs compared to conventional methods [2]. In Algeria, more than 80% of the country has a wind speed greater than or equal to 4 m / s [3].

As known, in wind turbine installations, the generator mode of the doubly-fed induction machine (DFIM) attracts particular interest [4]. The wind turbine conversion system based on the doubly-fed induction generator (DFIG) is presented in Figure 1. The stator is directly connected to the grid (fig. 1); it operates synchronously at grid frequency, although the rotor is connected via a static converter that controls the active and reactive power of the generator.

The recent growth in wind power generation has reached a level where the influence of wind turbine dynamics can no longer be neglected. Regulations require normalization to make all stakeholders contribute to service system: control of active power, frequency, reactive power, voltage and tolerance of fault mode [5]. Control of the power quality is required then to reduce the adverse effects on the of WECS integration into the network. Thus, active control has an immediate impact on the cost of wind energy. Moreover, high performance and reliable controllers are essential to enhance the competitiveness of wind technology.

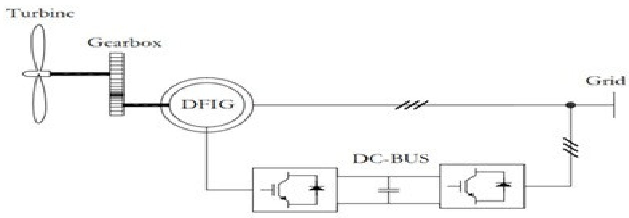

Fig. 1 Chain of conversion

Several active and reactive power control strategies have been the subject of many researches. In the high wind speed range, the pitch control seems more relevant for controlling power margin [6]. To this end, the turbines incorporate either electromechanical or hydraulic devices to rotate the blades, and while in Algeria the low wind speed range makes this type of setting useless viewpoint price /additional needless inertia. The direct and indirect power control method presented in [7] seems to be more effective. The simulation results shown that the indirect control is more efficient than the direct one in terms of dynamics and responses to reactive power levels, but this method is more complicated due to the necessary regulator number and its very high cost.

This paper aims to improve the performance of direct control. To do this, we replace the conventional PI correctors by fuzzy logic controllers. Since the fuzzy logic approach is based on linguistic rules [8], the controller design doesn't require machine parameter to perform adjustment. In terms of robustness, this controller possesses a high robustness [9]. The simulation results obtained by the latter are compared with both direct and indirect methods to analyze the studied system dynamics. In the next section, we briefly describe the mathematical model of wind turbine essential elements.

II. MODELING OF VARIABLE SPEED WIND TURBINE

A. Energy efficiency of a "wind sensor"

We can be found throughout the literature several models for power production capability of wind turbines that have been developed. Power in a wind turbine is proportional to the cube of the wind speed and may be expressed as [10]:

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$P_e = \frac{1}{2}\rho A$ (1)

Where ρ is air density, A is the area swept by blades and V is wind speed. A wind turbine can only extract part of the power from the wind, which is limited by the Betz limit (maximum 59%). This fraction is described by the performance coefficient of the turbine C_p, which is a function of the blade pitch angle and the tip speed ratio.

Therefore the mechanical power of the wind turbine extracted from the wind is:

$$P_m = \frac{1}{2} C_p(\lambda, \beta) \rho \pi R^2 V^3 \quad (2)$$

The performance coefficient depends on both the pitch angle (β) and the tip speed ratio (λ). The tip speed ratio is calculated by using blade tip speed and wind speed upstream of the rotor, as in the following formula [11]:

$$\lambda = \frac{R n}{V} \quad (3)$$

The relationship between performance coefficient (c_p), pitch angle (β) and tip speed ratio (λ) is established by the $c_p - \lambda$ approximation (3) for different blade pitch angle, as shows the simulation result obtained by MATLAB / SIMULINK software.

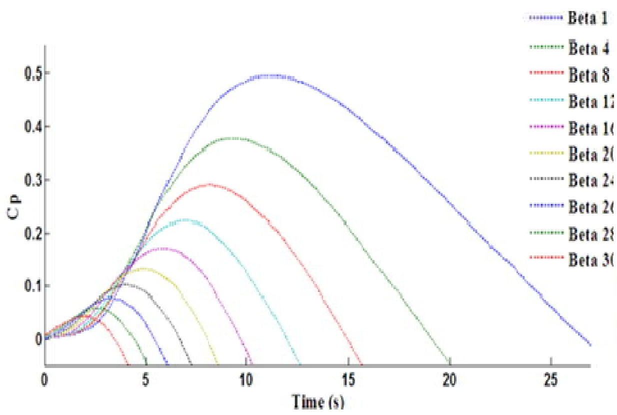

Fig. 2 performance coefficient (c_p)

B. Model of the wind

The model of the wind is essential to obtain realistic simulations for the wind turbines power control. The model includes wind turbulence. But to exploit this energy, we must consider the following constraints [12]:

- The wind speed may fluctuate by ± 25% over a several minutes period.

-The regularity of the wind direction and speed depends on the site. To determine the best wind resource, we must conduct surveys of speed and wind direction over a period of at least one year.

The measurement of wind speed is generally carried out at 10 meters above the ground. However, it is often useful to be able to measure at interest altitudes such as the heights of wind turbines.

Several empirical formulas allowing the vertical extrapolation of wind speed [4,13]. Speed V_1 is extrapolated from an altitude above sea level to a $z_1 z_2$, according to the formula (4)

$$V_2 = V_1 \left[\frac{Z_2}{Z_1}\right]^{\alpha_1} \quad (4)$$

With

$$\alpha_1 = \frac{1}{\ln \frac{Z}{Z_0}} - \left\{\frac{0.0881}{1 - 0.0881 \ln \frac{Z_1}{10}}\right\} \ln\left(\frac{V_1}{6}\right) \quad (5)$$

Where

$$Z = \exp[\ln(Z_1) + \ln(Z_2)]/2 \quad (6)$$

Z: the roughness of the ground.

Wind speeds, the roughness of the place is available, were extrapolated at 10 meters height, and at 25 meters altitude. Table 1, defines the values of and according several surfaces type [14].

TABLE I

VALUES OF Z_0 AND A_1 ACCORDING SEVERAL SURFACES TYPE

Surface type	Z0 (mm)	$\alpha 1$
sand	0.2 to 0.3	0.10
mown grass	1 to 10	0.13
high grass	40 to 100	0.19
suburb	1000 to 2000	0.32

Figure 3 shows a realistic sample of variable wind speed simulated in 100s.

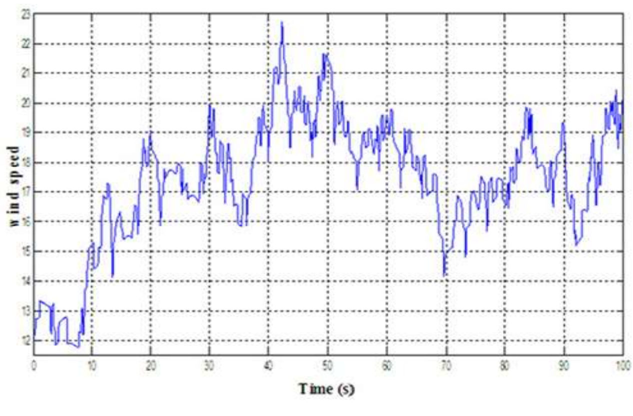

Fig. 3 Wind speed sample (100s)

C. DFIG Modeling

As cited before, we use in this study the DFIG, nowadays, most of the installed wind turbines are based on a doubly fed induction generator (DFIG), sharing the place with the wound rotor synchronous generators (WRSGs) and the permanent magnet synchronous generators (PMSGs) [15]. These generator choices allow variable speed generation.

The DFIG is operableas a motor or generator independently from the rotation speed [16]. It allows access to the rotor voltages and currents [17]. The rotor voltages control gives the machine the ability to operate

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in super or sub synchronism of both motor and generator mode [18].

The general equations of the DFIG can be written in a three-phase landmark as a result [19] [20].The generalized reduced order machine modelwas developedbased on conditions and assumptions cited in [19].

$$\begin{bmatrix}[V_s]\\ [V_r]\end{bmatrix} = \begin{bmatrix}[R_s][I_s]\\ [R_R][I_r]\end{bmatrix} + \frac{d}{dt}\begin{bmatrix}[\phi_s]\\ [\phi_r]\end{bmatrix} \quad (7)$$

And the flux ;

$$\begin{cases}[\phi_s] = L_s[I_s] + M[I_r]\\ [\phi_r] = M[I_s] + L_r[I_r]\end{cases} \quad (8)$$

$$L_s = l_s - M \; ; \; L_r = l_r - M \; ; \; M = \frac{3M_{sr}}{2} \quad (9)$$

Taking into account (8), Park transformations applied to (7) provide:

$$\begin{cases}V_{sd} = R_s I_{sd} + \frac{d\phi_{sd}}{dt} - \theta_s \phi_{sq}\\ V_{sq} = R_s I_{sq} + \frac{d\phi_{sq}}{dt} - \theta_s \phi_{sd}\\ V_{rd} = R_r I_{rd} + \frac{d\phi_{rd}}{dt} - \theta_r \phi_{rq}\\ V_{rq} = R_r I_{rq} + \frac{d\phi_{rq}}{dt} - \theta_r \phi_{rd}\end{cases} \quad (4)$$

$$\begin{cases}\phi_{sd} = L_s I_{sd} + M I_{rq}\\ \phi_{sq} = L_s I_{sq} + M I_{rq}\\ \phi_{rd} = L_r I_{rd} + M I_{sd}\\ \phi_{rq} = L_r I_{rq} + M I_{sq}\end{cases} \quad (10)$$

Power expression can be rewritten as follows:

$$\begin{cases}P = -V_s \frac{M}{L_s} I_{rq}\\ Q = -V_s \frac{M}{L_s} I_{rd} + \frac{V_s^2}{L_s \omega_s}\end{cases} \quad (11)$$

Figure 4, presents the block diagram of DFIG used in simulation. The input are rotor voltages ($V_{rd}$and V_{rq}) however, the outputs are the stator active and reactive power ($P_s$and Q_s).

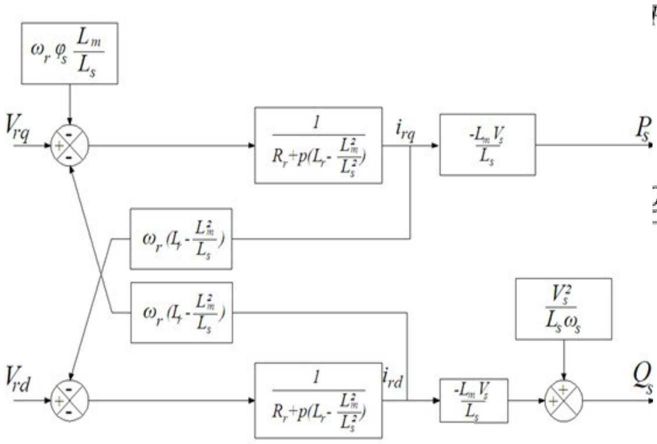

Fig. 4 DFIG bock diagram

Table 2, shows the main parameters of the induction generator which is used in this study.

TABLE II

DFIG PARAMETERS

Components	Rating Values
R_s	0.455 Ω
L_s	0.07H
R_r	0.19Ω
L_r	0.0213H
M	0.034H
P	2Polepair

III. Methods Presentation

In this section, first, we describe two existed types for separate control of both active and reactive power: Direct/Indirect control methods using PI controllers, then in the end we present our proposed combined method by using FL-controller with a proper Fuzzy rules Inputs and outputs. In real installation, these methods are implemented to control the rotor/generator side converter as described in figure.1.

A. Direct control with PI

Considering the block diagram of the system to be controlled "Fig. 5 ". Taking into account the relation between the rotor currents and stator powers, we see the appearance of the $\frac{MV_s}{L_s}$ term. Since the wind turbine is considered connected to a high power and stable network, this term is constant and therefore there is no necessary regulator between the rotor currents and powers is needed. But we provide a control loop for each power with an independent regulator by compensating the perturbation terms shown in the block diagram "Fig. 5, [21] [22] [23].

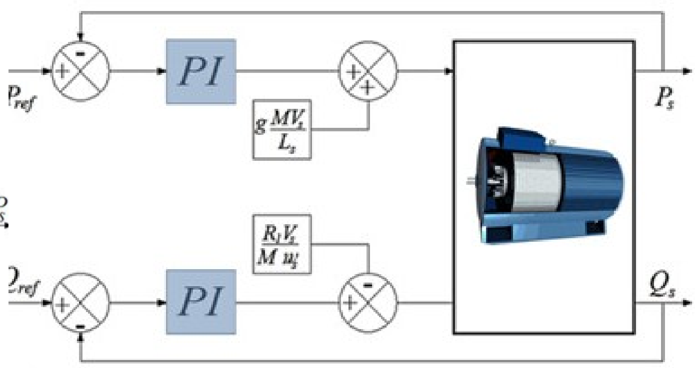

Fig. 5 Direct control block diagram

As shown it is clear that this method simple to implement

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B. *Indirect control with power-loop*

The basic principle of the indirect method is to replicate the block diagram of the control system in the opposite direction [25] [26]. We reach a block diagram to express voltages according powers. Indirect control will therefore contain all the elements in the DFIG block diagram.

To enhance indirect control, we insert anadditional power loop to eliminate the static error while preserving the system dynamics. Thus, we obtain the block diagram shown in "Fig. 6 ", we distinguish the two control loops for each axis, one to control the current and another one for the power.

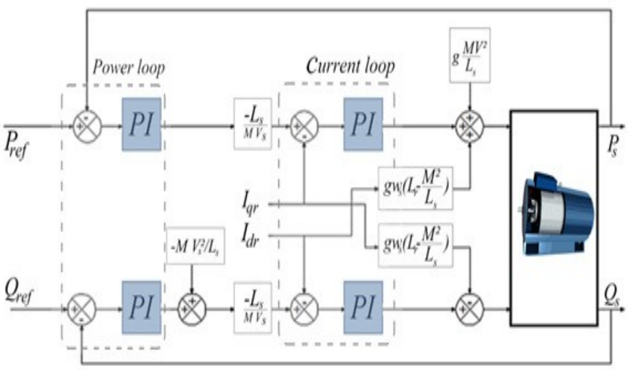

Fig. 6 Indirect control with the power-loop

C. *Direct Control With Fuzzy Logic Controller*

As explained in the fuzzy control block diagram "Fig. 7 ", have two inputs (the error (e), and its derivatives (de)) and an output (of the order (cde)).

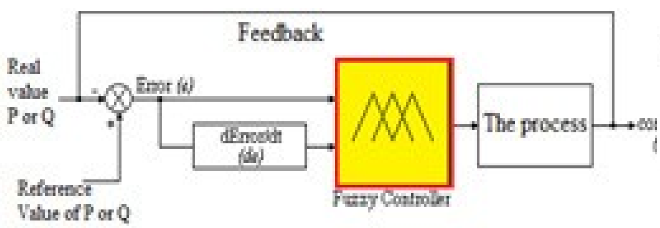

Fig. 7 Fuzzy Control Synoptic Schema

The fuzzy controller inputs are the active and reactive power errors, the error rate of change in a time interval. Linguistic variables and terms are shown in Table 3.

As described in Figure 6 , this paper focuses on fuzzy logic control based on mamdani's system[24]. This system has four main parts. First, using input membership functions, inputs are fuzzified then based on rule bases and inference system, outputs are produced and finally the fuzzy outputs are defuzzified and applied to the main control system. The membership functions used for the input and output variables are shown in fig8 and fig9.

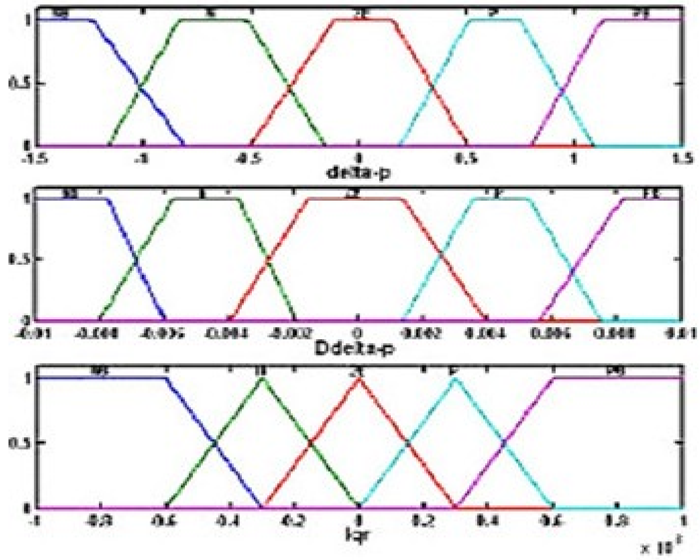

Fig. 8 Inputs and outputs of the active power controller

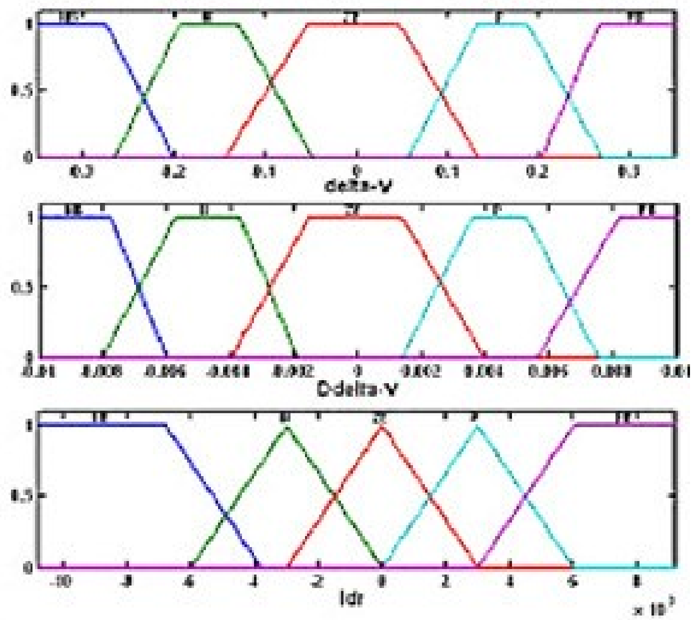

Fig. 9 Input and output of the reactive power controller.

TABLE III

FUZZY RULES

Errour (e)	**Error derivative (de)**				
	NB	**N**	**ZE**	**P**	**PB**
NB	NB	NB	N	N	ZE
N	NB	N	N	ZE	P
ZE	N	N	ZE	P	P

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P	N	ZE	P	P	PB
PB	ZE	P	P	PB	PB

IV. SIMULATION AND DISCUSSION

Direct control with PI and fuzzy correctors and indirect control with the power loop were implemented in MATLAB / SIMULINK software for testing. We applied to the system levels of active and reactive power in order to observe the control behavior.

"Fig. 10 ", presents the results of simulations with the direct control of PI.

There is a reactive power error when active power is low. By cons, it shows a static error at the active and reactive power mainly due to the methodology of this regulation. There is only one current-loop, and powers are thus remained inopen loops.

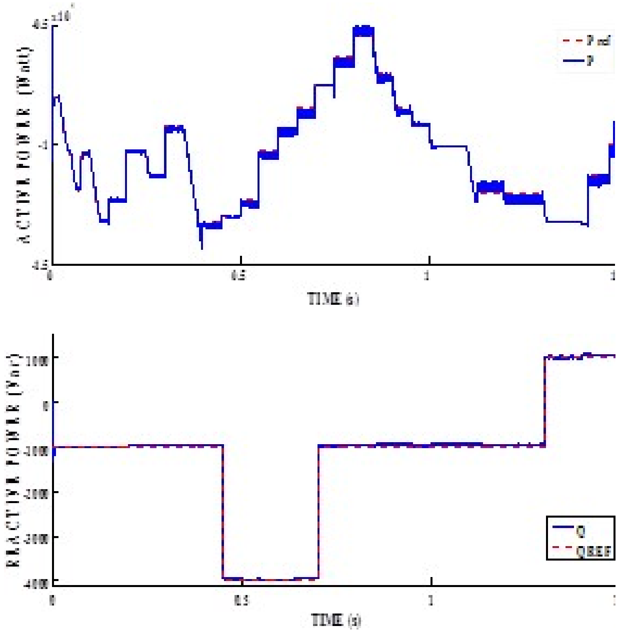
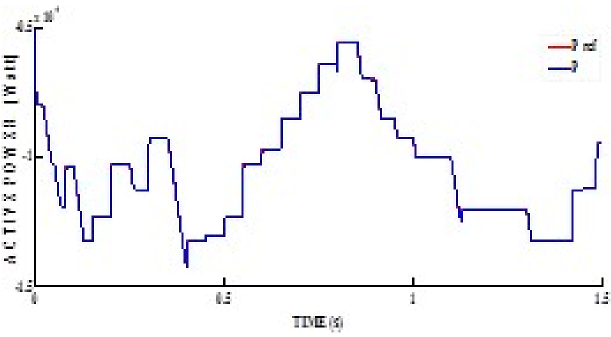


Fig. 10 Active and reactive power control (direct PI)

"Fig. 11 ", presents the simulation resultsof the direct control with fuzzy regulators.



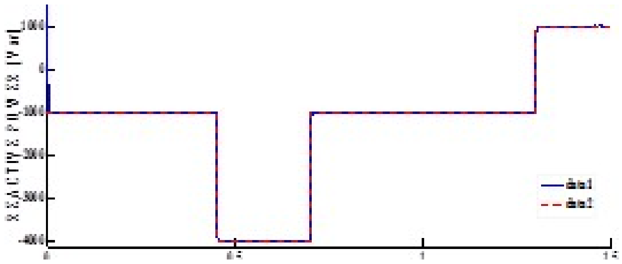


Fig. 11 Active and reactive power control (Fuzzy regulators).

We notice that the system has a satisfactory dynamic and null static error. For both active and reactive powers, there is a dynamic that reacts quickly and without overshoot. Levels are properly monitored and there are no more power errors. The coupling between the two powers is very small and hardly noticeable. It should not be a problem for the future machine model operation.

"Fig. 12 ", presents the results of simulations of indirect control with the power loop.

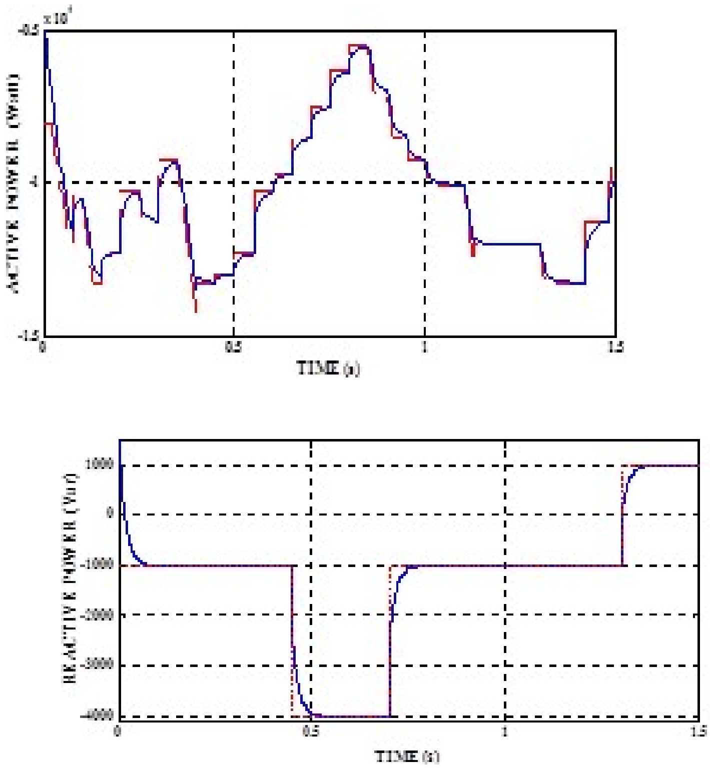


Fig. 12 Active and reactive power (Indirect Control with feedback).

Simulation results of indirect control with the closure of the powers really shows a null static error but a little big response time, which makes this control slow, and this is mainly due to the incorporation of two control loops, one of the currents and the other of the powers.

It is clearly that the proposed method very easy to implement and present a very satisfaction performance comparing to the Indirect control with power-loop method.

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V. Conclusion

Simulation results already presented have shown that the indirect control with the power loop gives a better performance than the direct method using the power loop. This eliminates the static error, there's a outstanding time response (0.08s) however the control with a power loop is complicated to implement regarding the required regulators, that's why the use of fuzzy regulators, which seem difficult to adjust, is less complex than the four regulators and therefore the cost will be lower. We have proven by the presented simulation results that the static error is zero and that the response time is faster. The FLC, offer a very satisfactory performance without the need of a detailed mathematical model of our system, we just by incorporating the experts' knowledge into fuzzy rules. In addition, it has inherent abilities to deal with imprecise or noisy data; thus, it is able to extend its control capability even to those operating conditions where linear control techniques fail (i.e., large parameter variations) which it is a future perspective of this work.

References

[1] Ammonit. MesstechnikfürKlimaforschung und Windenergie (Measuring equipment for climatic research and wind energy). AmmonitGesellschaftfürMesstechnikmbH, 2006.

[2] Global Wind Energy Council, Global Wind Statistics 2010, consulter en juin 2012.

[3] Cheggaga. N, Ettoumi, F.Y., " A neural network solution for extrapolation of wind speeds at heights ranging for improving the estimation of wind producible", Wind Engineering, Volume 35, Issue 1, 1 February 2011, Pages 33-53.

[4] N. KasbadjiMerzouk, " Carte des Vents de l'Algérie - Résultats Préliminaires - " Laboratoire dévaluation du Potentiel Énergétique, Centre de Développement des Énergies Renouvelables B.P. 62, Route de l'Observatoire, Bouzaréah, Alger.

[5] A. Gaillard: Wind System based on a DFIM: contribution to the study of the quality of electric power and continuity of service, University Henri Poincaré, Nancy I, 2010.

[6] Fernando D. Bianchi, Hernán De Battista and Ricardo J. Mantz, "Wind turbine control systems. Principles, modelling and gain scheduling design", Springer, London, 2006, ISBN-13: 978-1846284922.

[7] N.A,Janssens, G. Lambin, N Bragard, Active Power Control Strategies of DFIG Wind Turbines, Power Tech, 2007 IEEE Lausanne, Page(s): 516 – 521.

[8]Dekhane, S. Lekhchine, T. Bahi, S. Ghoudelbourg , H. Merabet, « DFIG Modeling and Control in a Wind Energy Conversion System", First international conference on renewable Energies and Vehicular Technologies, 2012.

[9] Elmer P. Dadiosin : Fuzzy Logic – Controls, Concepts, Theories and Applications, ISBN 978-953-51-0396-7.

[10]HosseinMadadiKojabadi, Liuchen Chang, "Development of a Novel Wind Turbine Simulator for Wind Energy Conversion Systems Using an Inverter-Controlled Induction Motor", IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 19, NO. 3, SEPTEMBER 2004.

[11] B.H. Chowdhury, S. Chellapilla, "Double-fed induction generator control for variable speed wind power generation", Electric Power Systems Research 76 (2006) 786–800.

[12]Wildi. Sybille "Électrotechnique "4th Edition.

[13]Quanhua Liu, Qinxian Miao, Jue J. Liu, and Wenli Yang, Solar and wind energy resources and prediction, Journal of Renewable and Sustainable Energy / Volume 1 / Issue 4.

[14] Wu, F. (2001). A generalized LPV system analysis and control synthesis framework. International Journal of Control 74(7), 745–759.

[15] A. Hansen and L. Hansen, \Market penetration of wind turbine concepts over the years," in Proc. European Wind Energy Conference and Exhibition 2007 (EWEC2007), Milan, Italy, May 2007.

[16] W. Li, Design of a hybrid fuzzy logic proportional plus conventional integralderivative controller. IEEE. Trans. Fuzzy Syst., Vol. 6, no. 4, pp 449-463.

[17] A. Boyette, ShahrokhSaadat : Wind turbine generator with dual power supplies and storage unit of energy for electricity generation," EPF Grenoble (CD rom S7-2) in July 2006.

[18] F. Poitiers : Study and control of induction generators for the use of wind energy, Thèse de Doctorat en Polytechnic University of Nantes, 2003.

[19] Janaka B. Elkanayake, Lee Holdsworth, XueGuang Wu, and Nicholas Jenkins : Dynamic Modeling of Doubly Fed Induction Generator Wind Turbine, IEEE Transactions on Power Systems, Vol. 18, NO. 2, May 2003.

[20] Wu Dingguo, Wang Zhixin, "Modeling and Design of Control System for Variable Speed Wind Turbine in All Operating Region," WSEAS Transactions on Circuits and Systems, pp. 438-443, May 2008.

[21] G. Abad, J. Lo´pez, M. A. Rodr_ıguez, L. Marroyo, and G. Iwanski in Doubly Fed Induction Machine: Modeling and Control for Wind Energy Generation, First Edition..2011 the Institute of Electrical and Electronic Engineers, Inc. Published 2011 by John Wiley &Sons, Inc.

[22] D. Hansen, P. Sorensen, "Grid support of a wind farm with active stall wind turbines and AC grid connection", Wind energy, Wiley, vol. 9 pp 341-359, 2005.

[23] H. Akagi, S. Ogasawara, H. Kim : The Theory of Instantaneous Power in Three Phase kiln wire systems and its applications, Electrical Engineering in Japan, ol.135, Issue 3, pp.74-86, 2001.

[24]Cordón, O. , A historical review of evolutionary learning methods for Mamdani-type fuzzy rule-based systems: Designing interpretable genetic fuzzy systems, International Journal of Approximate Reasoning, Volume 52, Issue 6, September 2011, Pages 894-913

[25] Armand Boyette, Philips and SharokhSaadat: direct and Indirect control of a doubly Fed Induction Generator Wind Turbine Including a storage unit, IECON'06, Paris (CD ROM ISBN 1-4544-0136-4). November, 2006.

[26] Hans ØversethRØstØen, Tore M. Undeland, TrjeGjengedal, " Doubly fed induction generator in a wind turbine ". Wind power and the impacts on power systems : workshop, Oslo, Norway, 17-18 June 2002.

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