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Research Article

Modeling And Adaptive Fuzzy Logic Control Of A Wind Power System Based On DFIG For Power Supply To Electrical Grid

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Abstract: In this article, we will focus on the study of a system consisting of a wind turbine operating at variable wind speed, an asynchronous machine with dual power supply (DFIG) connected to the network by a stator and supplied by a transducer of the side of the rotor. The conductors are separately controlled for the flow of active and reactive power between the stator (DFIG) and the grid, which is achieved in this article using fuzzy logic and AI-based adaptive control to improve the efficiency of the system and optimize performance to ensure that the active and reactive power reach the required reference values and extract energy. Maximum variable wind speeds (MPPT) and electric current are pumped into the network while maintaining a very good power factor. Our results show that the proposed adaptive controller offers improved power response time, overshoot and stabilization time compared to conventional PI and fuzzy control. The proposed control has been demonstrated by simulation using Matlab / Simulink.

Keywords: Doubly Fed Induction Generator (DFIG), Variable Wind Speed, Active and Reactive Power, Maximum Power Point Tracking (MPPT), Fuzzy Control , Adaptive Controller, Adaptive Fuzzy Logic Control ,Proportional Integral (PI).

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1. Introduction

Variable-speed wind turbines are more popular than fixed-speed systems because of their flexibility. of their efficiency and the quality of their power output. In addition to optimization as well as dynamic performance in case of network errors. In the modern era, the majority of wind diversion systems are equipped with DFIG (Mossa, 2021). Under ideal control conditions, at different wind speeds, the system can extract the maximum value of energy. Several control technologies have been developed for turbines to improve their power output for a given wind speed. Some of these variable-speed approaches need a wind speed estimate strategy, which is challenging to implement in variable-speed high wind circumstances (Alhato, 2019) . Much research has been done on the control of wind turbines. Thanks to them, the latest generations of wind turbines operate at variable speeds and have pitch regulation (Benamor, 2019). This allows we may vary the rotational speed and angle of inclination of each of the blades, allowing us to increase the wind's efficiency turbine. However, there is still a need to bring more intelligence into the operation of wind turbines, and the aim of this article is to provide robust generator control that can increase wind turbine efficiency, the quality of energy generated and energy efficiency(Sun, 2015) .In addition, to reduce mechanical stress, which can make it possible to manufacture lighter wind turbines, thus improving productivity. Therefore, you must take into account the control behavior of the system as a whole. Likewise, wind disturbances must also be taken into account. Kinetic energy is transformed into mechanical power. The fast movement is transferred to the generator's output shaft, which transforms the rotating movement's mechanical energy into electrical energy before injecting the energy into the grid (Osmic, 2016).The generator is linked to transformers. The DC bus voltage and power factor are monitored by the grid-side transformer. Furthermore, the generator side transducer regulates the active and reactive power generated by the generator DFIG (Mostefa, 2021).This article presents a method of controlling an asynchronous generator with two power supplies. An adaptive fuzzy logic controller for DFIG speed control is presented in this study for maximum operating point power tracking for a wide range of wind speeds and improved power gain (Guediri, 2017) . We have made improvements to the wind bypass system using intelligent controllers The AI-based module is used to govern the active and reactive power of the system. DFIG connected to the grid through the stator. Where we have conducted many experiments and achieved the best results in terms of accuracy and improvement over results previously published in articles and books (Song, 2017). Where we are always looking for the best.In the beginning, the basic structure of the ambiguous MPPT command was discussed, then the rotary current prediction is the prediction, then the description of the system, then the adaptive fuzzy logic control, then the modification of the rotary currents of DFIG, then the experimental process is described, and finally we concluded the simulation and discussion results by Matlab / Simulink.

2. Basic Structure Of A Fuzzy MPPT Command

Using fuzzy logic is just an extension of the perturbation and observation method. The main objective of this work is to use the MPPT fuzzy control to improve the extraction of electrical energy in the wind energy conversion chain (Wiktorowicz, 2015). The proposed fuzzy controller (CF) structure is shown in Figure 1.

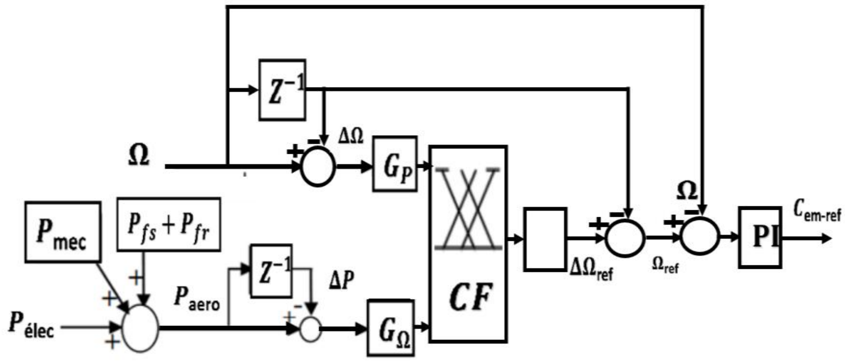

Figure 1. Structure of the fuzzy MPPT controller

We neglect all the losses in the transformer and in the filter and do not take into account the mechanical losses and the joule losses in the stator and the rotor of the machine. In this case, we can write (Kharchouf, 2020):

$$\begin{cases} \hat{P}_{\text{aéro}} = P_{\text{élec}} + \Delta p \\ \hat{P}_{\text{aéro}} = P_{\text{élec}} + p_{\text{frot}} + p_{Js} + p_{Jr} \end{cases} \tag{1}$$

$$p_{Js} = 3R_s I_s^2 = 3R_s\left(i_{ds}^2 + i_{qs}^2\right) \tag{2}$$

$$p_{Js} = 3R_r I_r^2 = 3R_r\left(i_{dr}^2 + i_{qr}^2\right) \tag{3}$$

$$P_{\text{mec}} = f\Omega^2$$

(4)

3. Rotor Current Prediction The Prediction

Of the direct and quadrature components of the rotor current is necessary to exploit it in the function as follows (Trong, 2013):

$$\begin{cases} i_{dri}(k+1) = \frac{T}{\sigma L_r}\left(V_{dri}(k) - r_r i_{dri}(\mathrm{k}) + s_i \omega_{si} \sigma\, L_r i_{qri}(k)\right) + i_{dri}(k) \\ i_{qri}(k+1) = \frac{T}{\sigma L_r}\left(V_{qri}(k) - r_r i_{qri}(k) - s_i \omega_{si} \sigma L_r i_{dri}(k) - s_i \frac{MV_s}{L_s}\right) + i_{qri}(k) \end{cases}$$

(5)

Also, the prediction of the active and reactive stator powers are given by :

$$\begin{cases} P_{si}(k+1) = -V_s \cdot \frac{\mathrm{M}}{L_s} \cdot i_{qri}(k+1) \\ Q_{si}(k+1) = \frac{V_S \cdot \phi_S}{L_s} - \frac{V_S \cdot L_m}{L_s} \cdot i_{dri}(k+1) \end{cases}$$

(6)

4. System Description

The number one DFIG configuration used in this paper is confirmed in Figure 2 by means of a gearbox and a coupling shaft mechanism, the wind turbine being mechanically connected to the dual feed induction generator . The wound rotor induction generator is powered by each of the elements. The stator is immediately connected to the mains, while the moving part is fed from the lower back to other four-wheel drive PWM transducers (RSC and GSC) connected using a battery inside the capacitor. direct current link (Naik, 2018).

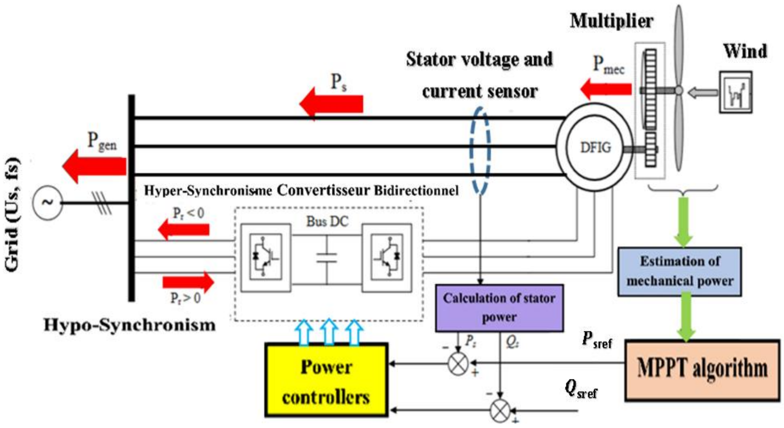

Figure 2. Configuration of a controlled wind power system connected to the grid.

Figure 2 shows a schematic diagram of a normal computer for switching powers between DFIG, switches and the grid. The rotor side transducer provides dynamic and reactive control of the separate stator power, Ps and Qs, consistent with the reference torque provided by the MPPT (Maximum Power Point Tracking) control (Monda, 2015). The grid face transformer handles the electricity drift trade with the grid through it. The rotor, by keeping the DC vector in a constant voltage phase and using the use of reactive power QL by charging at zero. The DC vector voltage in Figure 3, which is represented as a harmonic spectrum:

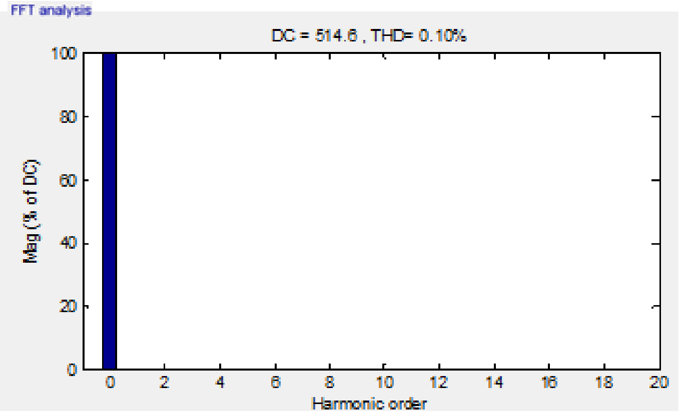

Figure 3. DC bus voltage control harmonics spectrum.

In addition, the ripples of this voltage are very weak, its harmonic spectrum being a very low THD, which is 0.10%, as shown in Figure 3. In addition, over the entire range of variation of the wind profile, this DC voltage remains stable. And thus, a constant flow of power is ensured between the rotor of the generator and the grid.

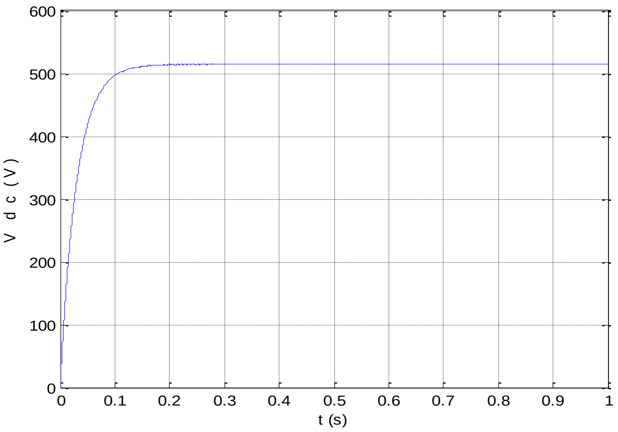

Figure 4. DC bus voltage (V)

Figure 4 represents the evolution of the continuous vector voltage, which shows the following:

- The DC bus voltage reaches the set point, which is 514.6 V in a shorter response time, with no overshoot.
- The shape of the DC vector voltage is smoother, which has the advantage of changing the wind speed.

5. Adaptive Fuzzy Logic Control

To date, conventional regulators are the most widely used in industrial applications. About 90% of industrial controllers are PID controllers. The others are custom control systems based on various modern control techniques. The simplicity of the PI controller, its ease of use, its good performance under certain conditions and its rather low cost are the main reasons for this success (Benamor, 2019). It is known that the fuzzy regulator offers surprising solutions to the problems of regulation in transient conditions, faced with the evolution of the parameters of the system and in the event of nonlinear dynamics of the system. However, there is always a risk of low amplitude oscillations in steady state, which is not the case for a conventional PI regulator. The mathematical precision and simplicity of the regulator's algorithm are its strong qualities, but it has certain drawbacks in the face of system parametric changes and non-linear dynamics(Guediri, 2017) .

6. Population And Sample Description Of The Aadaptation Mechanism Of a Classical Regulator By Fuzzy Logic

PI-fuzzy hybrid regulators can be thought of as non-linear PI and their parameters change during operation. In our case, we use the error and its derivatives to adjust these parameters (gains). This approach, which combines a PI regulator and a moderator The fuzzy linguistic formalism, which is made up of fuzzy grammar, allows you to combine the mathematical precision of the PI algorithm with the adaptability, flexibility, and simplicity of the fuzzy linguistic formalism (Ardjoun, 2015). This type of control, called adaptive, makes it possible to exploit the advantages offered by PI controllers and those of fuzzy logic. The objective of the adaptive law is to improve the control performance of complex and nonlinear systems . We propose a moderator whose inputs (the error and its variability), and the outputs are two fuzzy matrices allowing the signal generation, which will be applied to each gain of PI (Kp, Ki) (Benkahla, 2016).The fuzzy system makes it possible to modify the parameters according to the behavior of the process. In our case, the order gains will be adapted in real time. It is calculated by (Boussairi, 2015):

$$\begin{cases} k_p = k_{p0} + G_p \Delta k_p(E, \Delta E) \\ k_i = k_{i0} + G_i \Delta k_i(E, \Delta E) \end{cases} \tag{7}$$

The error and the derivative of the error are the inputs to the adaptive fuzzy logic control.The outputs are the relative action's normalized value. Δkp and the normal value of the integral action ki. These two order quantities are normalized in the interval [-1, 1] .Figure 5 Kp0 and ki0 are the initial state control parameters. It is determined by the method of ziegler and nichols. The extent of the change for each of these parameters (Δkp, Δki) was determined from simulation tests and on this basis, the gain values Gp and Gi were determined (Du, 2014).

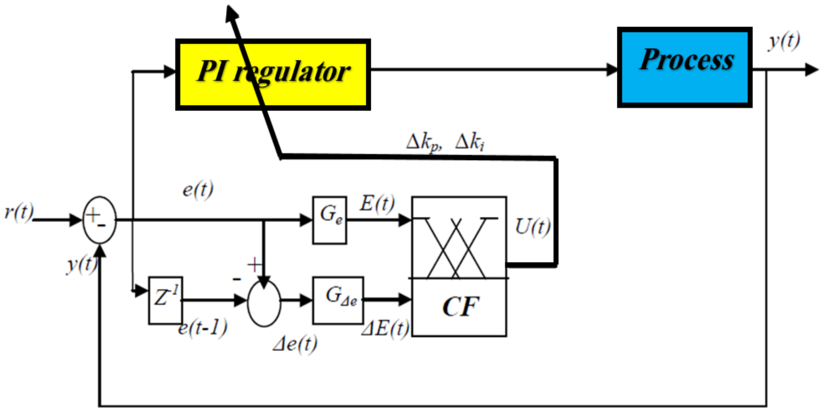

Figure 5. Principle of adaptation of the PI by fuzzy logic

The membership functions for input E and ΔE are specified in the interval [-1, 1].Figure 6 the fuzzy console inputs are the error and the derivative of the error. The outputs are the relative action normal Δkp and the integral action normal Δki(Belabbas, 2017) . The quantities of these two commands are normalized in the interval [-1, 1]. Kp0 and ki0 are the initial state control parameters. It is determined by the method of ziegler and nichols. The extent of the change for each of these parameters (Δkp, Δki) was determined from simulation tests and based on this, the gain values Gp and Gi were determined(Hamane, 2016) .

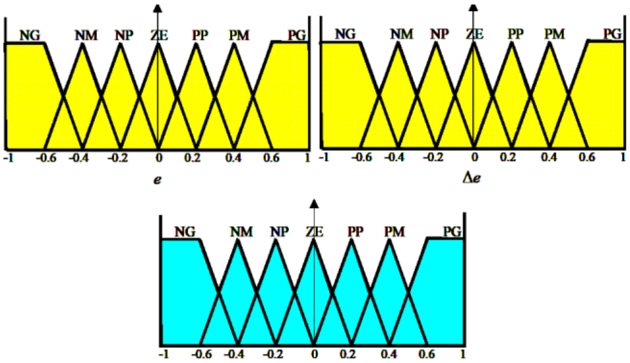

Figure 6. Shape of the membership function for the following quantities: E, ΔE, ΔKp, Δki

7. Links Between Changes in PI Parameters And Desired Performance

PI parameters are tuned for faster response, with reduced overshoot and short-term damping. The differences in relative and integrative gains affect the dynamics of the system, which differ in the same direction, depending on the position in the error phase plane and its variability. The temporal description of the control signal is given as follows (Guediri, 2021) :

$$\begin{cases} \boldsymbol{u(t)} = & \boldsymbol{k_p E(t) + k_i \int_0^t E(\tau)d\tau} \\ \quad\;\; = & \boldsymbol{\left[k_{p0}E(t) + k_{i0}\int_0^t E(\tau)d\tau\right]} \\ & \quad + \boldsymbol{\left[G_p \Delta k_p(E,\Delta E)E(t) + G_i \Delta k_i(E,\Delta E)\int_0^t E(\tau)d\tau\right]} \\ \quad\;\; = & \boldsymbol{u(t) + \Delta u(t)(E,\Delta E)} \end{cases} \tag{8}$$

When the error is large, Kp should be large and Ki small and when the error is small, Kp should be small and Ki large, because Kp provides fast dynamic response and Ki eliminates static error and ensures system stability. During the operation of the in-line regulator, the fuzzy matrix makes it possible to adapt the gains in order to improve the temporal response properties (Ebrahimkhani, 2016) . This table shows the inference matrix for CF for a section of fuzzy combinations at 7 cents for each input variable E (t) and ΔE (t) (Guo, 2014).

Table.1. Rules of inference to adjust the two proportional and integral parameters of PI

E ΔE	NG	NM	NP	EZ	PP	PM
	ΔK_p	ΔK_i	ΔK_p	ΔK_i	ΔK_p	ΔK_i
NG	NG	NG	NG	NM	NP	NP
NM	NG	NM	NM	NM	NP	EZ
NP	NG	NM	NP	NP	EZ	PP
EZ	NG	NM	NP	EZ	PP	PM
PP	NM	NP	EZ	PP	PP	PM
PM	NP	EZ	PP	PM	PM	PM
PG	EZ	PP	PP	PM	PG	PG

Linguistic variables are noted as follows: **NG** for large negative, **NP** for small negative, **EZ** for approximately zero, **PP** for small positive, and **PG** for large positive. **NM** for mean negative, **PM** for mean positive

8. Adjustment Of The Rotor Currents Of The DFIG

We will now use the same diagram of the vector control except that this time the rotor current regulators are fuzzy adaptive regulators Figure 7.

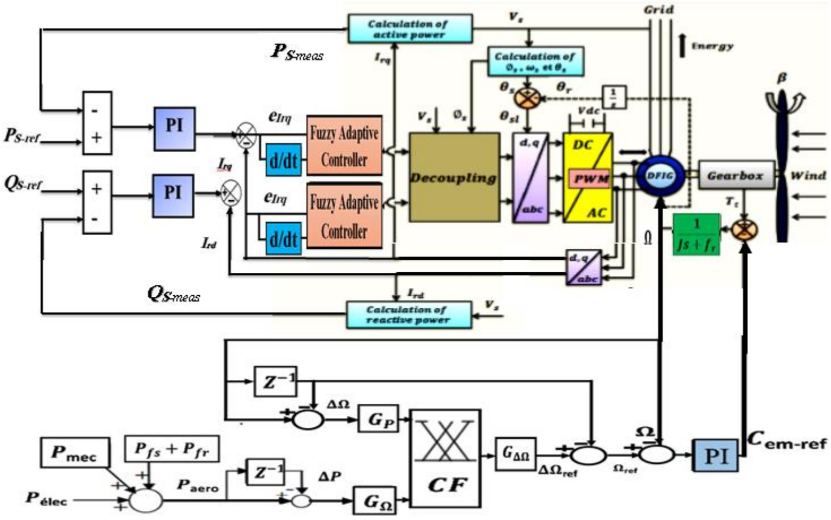

Figure 7. Block diagram of the DFIG Adaptive fuzzy -PI regulators of speed for supply of power to the electrical grid.

The two current regulators are of the same type (a seven-class Mamdani regulator) and have the same membership functions.

9. Description Of The Experimental Process

The experimental setup shown in Figure 8 consists of a wind turbine (simulated with a DC motor), a rotary wound induction machine representing DFIG, a grid-connected stator (simulated with a three-phase resistive load), and a DSPACE digital modelling system. The proposed generation of control as well as control pulses of the rotary lateral converter (CCR) was produced using the DSPACE digital system linked to Matlab/Simulink instruments by a real-time interface block (RTI)

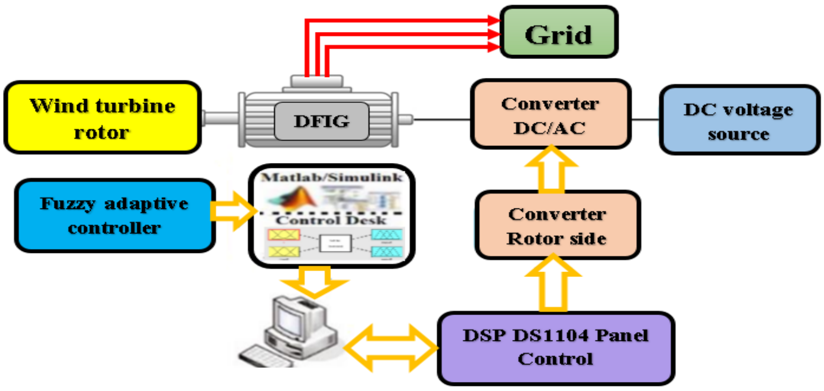

Figure 8. Presentation of the experimental stage

10. Results and discussion

Results of our simulation of a wind system (Turbine + DFIG) controlled by fuzzy logic adaptable controllers. Following load shedding, an active reference power is applied.

- ❖ Active power:
  - (Pref = 0W); so that t ∈ [0;0.2] s .
  - (Pref = -20000W) negative scale; so that t ∈[0.2;0.6] s .
  - (Pref = - 10000W); so that t ∈ [0.6;1] s .
- ❖ Reactive power:
  - (Qref = 0 VAR); so that t ∈[0;0.2] s .
  - (Qref = -5000 VAR) negative scale; so that t ∈[0;0.6] s .
  - (Qref = 0 VAR); so that t ∈[0.6;1] s .

The Figures below show the performance of reactive and active stator power PI-Adaptive fuzzy logic control applied to DFIG. Figures 9 and 10 illustrate the system responses with the adaptive fuzzy logic controller. In general, it can be seen that power steps are followed by the generator for active and reactive power. However, it is observed that the effect of the coupling appears on one of the two powers when changing the setpoint of the other power. We can perform the transient and steady state performance of these regulators using the following criteria:

- ❖ Maximum error (overshoot).
- ❖ Recovery or stabilization time (response time).
- ❖ Residual error (static error).

The direct and quadratic components of the rotor current are shown in Figure 11 illustrates the control error of ird and irq. From these curves, we see that:

- ❖ Regulating the stator voltage forces the PI regulators to maintain the rotor currents at their respective references.
- ❖ A reduction in the load leads to a reduction in the rotor current.
- ❖ The verification error of ird and irq is practically zero.

The direct and quadrature components of the stator currents follow their reference values in Figure 12 These results indicate that the fuzzy controller outperforms the PI controller in terms of tracking. Overshoot is not produced by floating regulators, especially during transients. For the other representations, they look almost exactly like those of the PI controller.

The results obtained are illustrated in Figures 13 and 14 and 15 respectively show that the rotor flux and the electromagnetic couple perfectly follow its reference with good dynamic performance, less oscillations and less overshoot, Figure 16 illustrates the stator voltage and current waveforms. It should be noted that static voltage is equal to grid voltage, while current waveform is related to active and reactive power. Moreover, the results of Figures 17 and 18 show that the three-phase stator and rotor currents generated by DFIG are proportional to the supplied active power. The shape of the current waveform is almost sinusoidal for both stator and rotor currents, indicating high quality of power delivered to the grid. Adaptive audio regulators produce no overshoot, especially in transit. For the other performances, they are almost similar to that of the PI regulator. Shows regulation by excellence of adaptive fuzzy logic control by the effective rejection of the effects of disturbances from which authorities completely trace their reference.

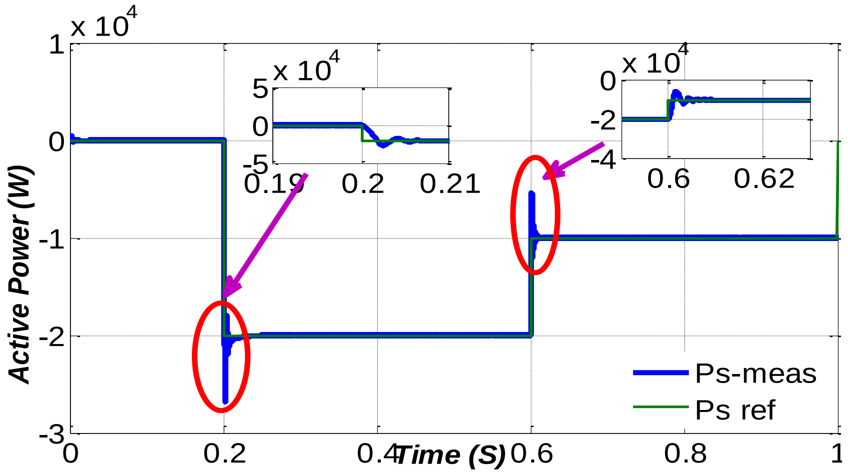

Figure 9. Active power stator

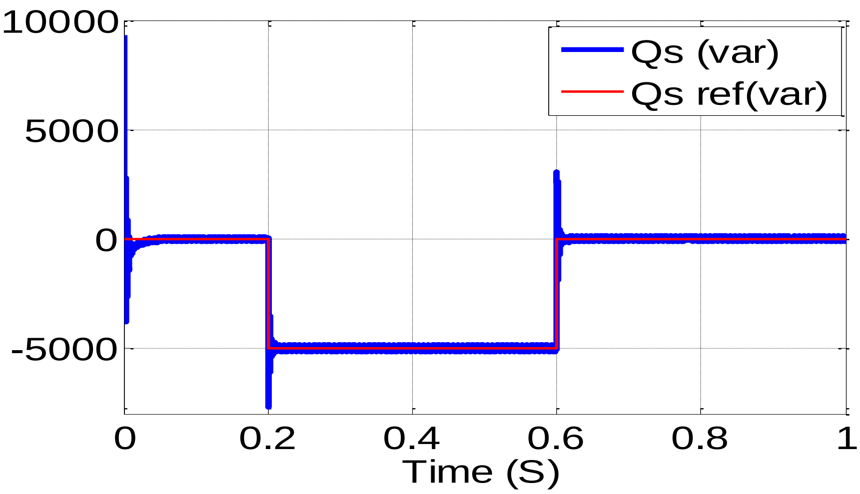

Figure 10. Reactive power stator

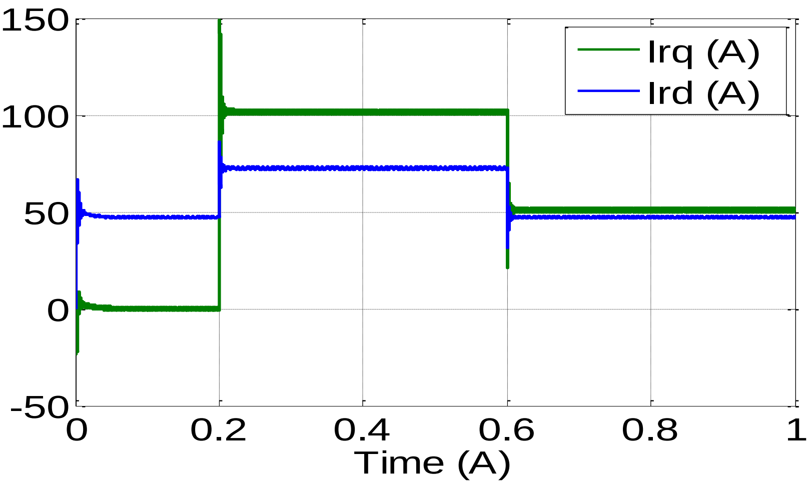

Figure 11. Direct currents and rotor quadrature.

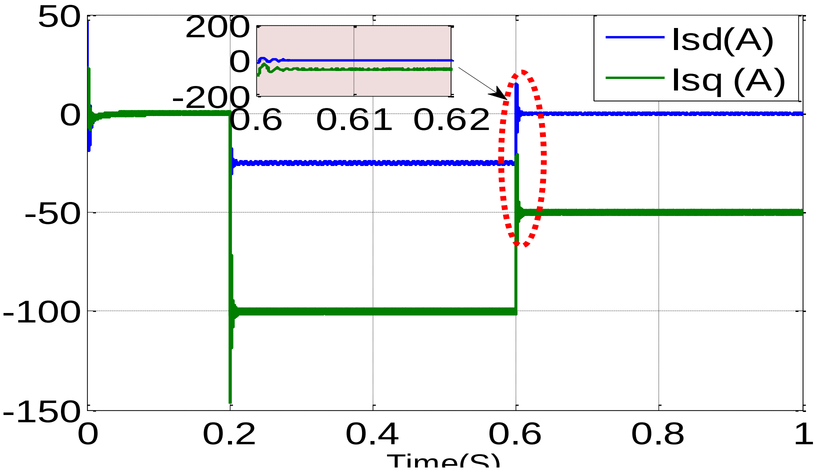

Figure 12. Direct currents and stator quadrature

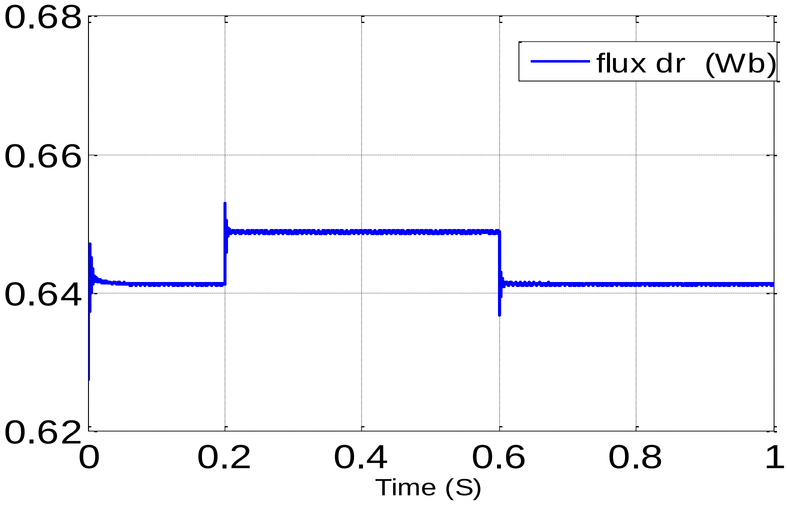

Figure 13. Direct rotor flux

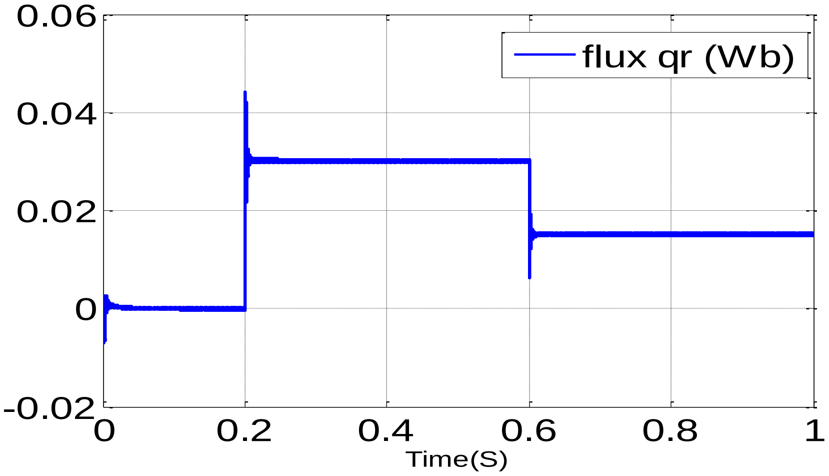

Figure 14. Quadrature rotor flux.

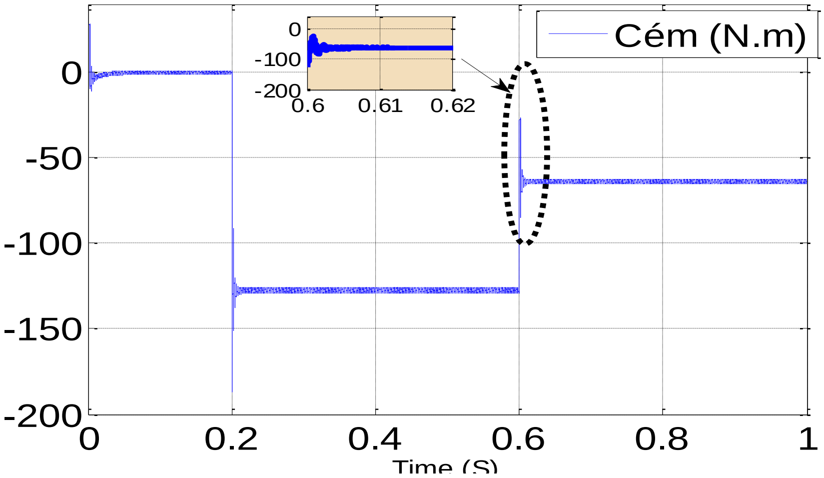

Figure 15. Electromagnetic torque

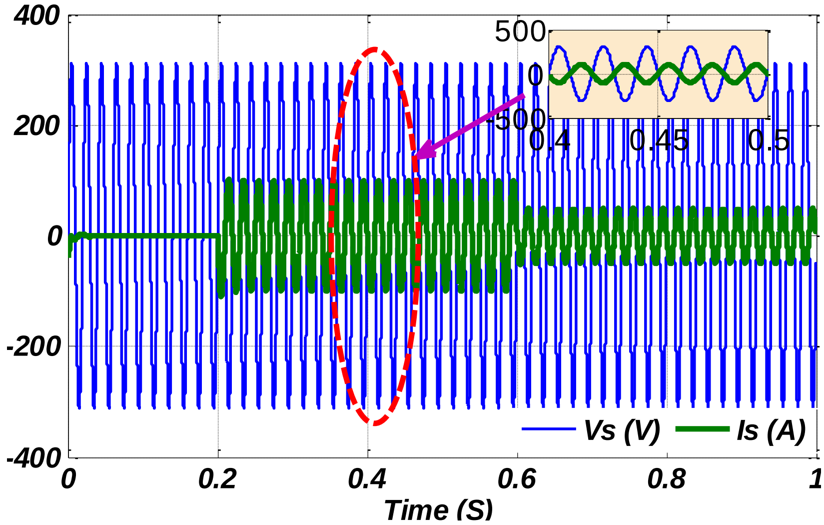

Figure 16. The stator current and voltage

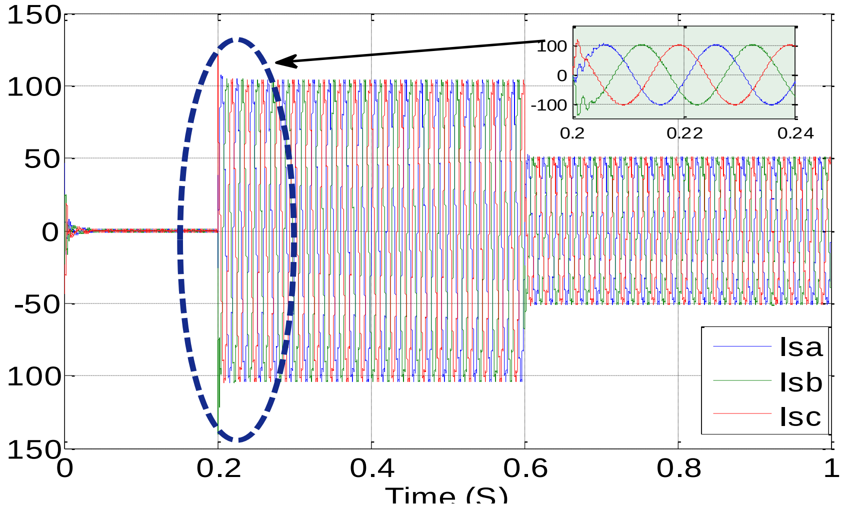

Figure 17. stator three-phase currents (A)

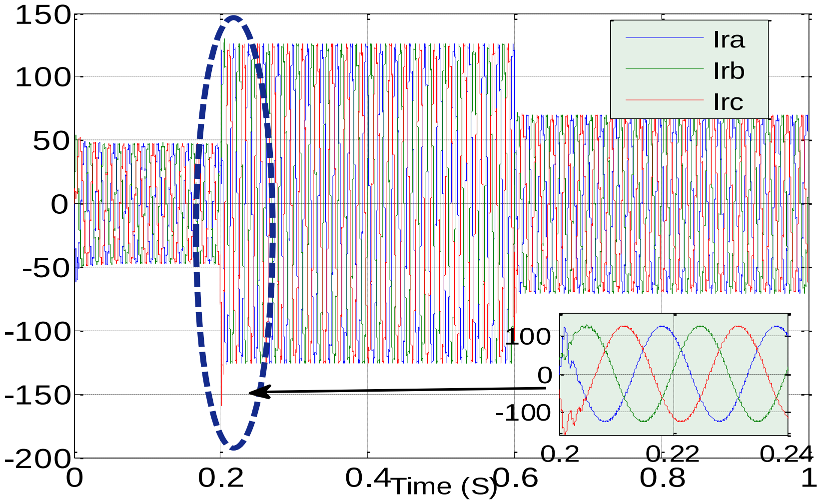

Figure 18. Rotary three-phase currents (A)

11. Appendix

Table 2. Parameters of 1.5 MW DFIG

Symbol	Parameters	Value
Pn	Rated Power	1.5 MW
Vs	Stator Voltage	300 V
Fs	Stator Frequency	50 Hz
Rs	Stator Resistance	0.012 Ω
Ls	Stator Leackage Inductance	0.0205H
Rr	Rotor Resistance	0.021Ω
Lr	Rotor Leakage Inductance	0.0204H
M	Mutual Inductance	0.0169H
P	Pairs of poles number	2
J	Rotor inertia	1000 Kg.m^2

Table 3. Parameters of Turbine

Symbol	Parameters	Value
R	Blade radius	35.25m
N	Number of blades	3
G	Gearbox ratio	90
J	Moment of inertia	1000 Kg.m^2
f_v	Viscous friction coefficient	0.0024 N.m.s^{-1}
V	Nominal wind speed	16 m/s
V_d	Cut-in wind speed	4 m/s
V_m	Cut-out wind speed	25 m/s

12. Conclusion

In this article, the control of a wind power conversion system equipped with a dual asynchronous power generator is presented. After modelling the system, we developed two controllers, one for active power and one for reactive power, using adaptive fuzzy logic control. With a good selection of the controller parameters, the results we have obtained are interesting for wind applications to ensure the durability and quality of the energy produced. In addition, this command has a simple and powerful control algorithm, easy to implement in the computer. The simulation results confirm the effectiveness of the adaptive fuzzy logic control system. Its superiority is especially evident compared to performance of a conventional control system. However, we can note the appearance of a small error in the response of the system controlled by this type of regulator. The reason for this error is that the adaptation law is not fast enough to detect sudden changes in wind speed. This drawback can be limited by a short sampling time. However, this choice can increase the calculation time. In practice, good continuity of control allows us to save energy (increase energy efficiency) and increase the service life of the elements.

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