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Robust Fuzzy Gains Scheduling of RST Controller for a WECS Based on a Doubly-Fed Induction Generator

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Original scientific paper

This paper proposes a new robust fuzzy gain scheduling of RST controller for a Wind Energy Conversion System (WECS) based on a doubly fed induction generator (DFIG). First, a designed fuzzy gain scheduling of RST controller is investigated, in which fuzzy rules are utilized on-line to adapt the RST controller parameters based on the error and its first time derivative. The aim of the work is to apply and compare the dynamic performances of two types of controllers (namely, Polynomial RST and Fuzzy-RST) for the WECS. A vector control with stator flux orientation of the DFIG is also presented in order to achieve control of active and reactive power of the wind turbine transmitted to the grid and to make the wind turbine adaptable to different constraints. The results obtained by simulation prove the effectiveness of the proposed controller in terms of decoupling, robustness and dynamic performance for different operating conditions.

Key words: Fuzzy gain scheduling, Wind energy conversion system (WECS), Fuzzy-RST, DFIG, Robustness

Robusno neizrazito prilagođavanje pojačanja RST regulatora za WECS dvostruko napajani asinkroni generator. U radu je predloženo novo robusno prilagođavanje pojačanja RST regulatora za sustav za pretvorbu energije vjetra (WECS) s dvostruko napajanim asinkronim generatorom (DFIG). Prije svega istražena je sinteza neizrazitog prilagođavanja pojačanja RST regulatora u kojem su neizrazita pravila iskorištena on-line za adaptaciju parametara RST regulatora koji koristi signal pogreške i njegovu prvu vremensku derivaciju. Cilj rada primjena je i usporedba dinamičkih svojstava dva tipa regulatora (polinomski RST i neizraziti RST) za WECS. Također je prikazano vektorsko upravljanje s orijentacijom statorskog toka DFIG-a za postizanje upravljanja aktivnom i reaktivnom snagom vjetroagregata koja se predaje mreži te za prilagodbu vjetroagregata za različita ograničenja. Rezultati prikupljeni provedenim simulacijama pokazuju efektivnost predloženog regulatora kroz rasrpegnutost, robusnost i dinamičke performanse za različite uvjete rada.

Ključne riječi: Neizrazito prilagođavanje pojačanja regulatora, sustav za pretvorbu energije vjetra (WECS), neizraziti RST, DFIG, robusnost

1 INTRODUCTION

Wind energy is one of the most important and promising source of renewable energy all over the world, mainly because it is considered to be nonpolluting and economically viable. At the same time there has been a rapid development of related wind energy technology [1].

The controls of wind energy conversion system constitute a vast subject and are more complex than those of DC drives [2]. Furthermore, Vector control obtains very good application in DFIG because it can achieve the decoupling control of the active power and the reactive power. In recent years, many researches of vector control take the following manner to track the largest wind energy under the rated wind speed [1].

Double fed induction generator is widely used for variable-speed generation, and it is one of the most important generators for wind energy conversion systems. Both grid connected and stand-alone operation are feasible [3] through an AC/DC/AC frequency converter [1]. The major advantage of the doubly-fed induction generator, which has made it popular, is that the power electronic equipment only has to handle a fraction (20-30%) of the total system power in order to guarantee the stability of the network in acceptable conditions [4].

The DFIG control is based on a stationary model which is submissive to many constraints, such as parameters uncertainties, (temperature, saturation .....), that might divert the system from its optimal functioning. That is why the regulation should be concerned with the robustness and performances of control techniques [5].

Several techniques of control resulting from the theory of control were established and applied to real systems, especially the RST polynomial control because of their simple structure and good dynamic performances in a wide range of operating conditions. In fixed gain controllers, these parameters are selected by methods such as pole placement [6]. On the other hand, these RST controllers are simple but cannot always effectively control systems with changing parameters or strong nonlinearities. In adaptive RST controllers, the parameters are adapted on-line based on the process parameter estimation.

Fuzzy logic control has been widely used in different control applications. In recent years, some researchers have extensively used the fuzzy logic for modeling, identification, parameter estimation, feedback control of converters, and control of highly nonlinear dynamic systems [7,8,9]. The mathematical tool for the FLC is the fuzzy set theory introduced by Zadeh [7,10,11]. In FLC, the linguistic description of human expertise in controlling a process is represented as fuzzy rules or relations [11,12]. This knowledge base is used by an inference mechanism, in conjunction with some knowledge of the states of the process in order to determine control actions. The controllers based on fuzzy logic (FLC) can be considered as non-linear RST controllers where their parameters are determined online based on an error signal and its derivative. The main advantages of FLC are: a) there is no need for an exact system mathematical model; b) they can handle nonlinearities of arbitrary complexity; and c) they are based on linguistic rules with an IF–THEN general structure, which is the basis of human logic. However, standard FLC cannot react to changes in operating conditions. FLCs need more information to compensate nonlinearities when the operation conditions change. When the number of the fuzzy logic inputs is increased, the dimension of the rule base increases too. Thus, maintenance of the rule base is more time-consuming. Another disadvantage of the FLCs is the lack of systematic, effective and useful design methods and adequate analysis, which can use a priori knowledge of the plant dynamics. Moreover, the application of FLC has faced some disadvantages during hardware and software implementation due to its high computational burden [10]. The earlier reported works for fuzzy-logic applications in generator drives [11,13,14] are mainly theoretical and based on either simulation.

In order to obtain high performance and better control of the active and reactive powers generated by the DFIG, and to overcome the disadvantages of both controllers (RST and FLC), a combination between them is proposed: RST controller parameters are tuned on-line by an adaptive mechanism based on fuzzy logic (adaptive FLC-RST) for doubly-feed induction generator power control. The proposed scheme utilizes fuzzy rules to determine the RST controller parameters, and the RST controller generates the control action signal.

The objective is to show that the proposed technique can improve performances of doubly-fed induction generators in terms of reference tracking, sensibility to perturbations and robustness against machine parameters variations.

A schematic diagram of a DFIG based wind energy generation system is shown in Fig. 1.

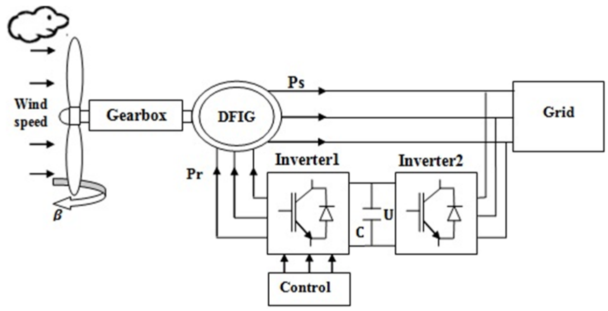

Fig. 1. Configuration of DFIG Wind Turbine

2 WIND TURBINE MODEL

Wind turbines convert mechanical energy produced by the wind to electrical energy. The mechanical power transferred from the wind to the aerodynamic rotor is:

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

The input torque in the transmission mechanical system is given by the following relation:

$$T_m = \frac{P_m}{\Omega_1} = \frac{1}{2\lambda}C_p(\lambda,\beta)\rho\pi R^3 v^2, \quad (2)$$

where λ presents the ratio between the turbine angular speed and the wind speed and is defined by:

$$\lambda = \frac{R\omega_r}{v}, \quad (3)$$

where *R* is the radius of the wind turbine and C_p (λ,β) is the power coefficient, which expresses the effectiveness of the wind turbine in the transformation of kinetic energy of the wind into mechanical energy.

In the model, the $C_p(\lambda,\beta)$ value of the turbine rotor is approximated using a non-linier function according to [1]:

$$C_p(\lambda,\beta) = C_1(\frac{C2}{\lambda_i} - C_3\beta - C_4)e^{(\frac{C_5}{\lambda_i})} + C_6\lambda, \quad (4)$$

with:

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3+1}. \quad (5)$$

$C_1 = 0.5176, C_2 = 116, C_3 = 0.4, C_4 = 5, C_5 = 21, C_6 = 0.0068.$

The characteristic between C_p and λ for various values of the pitch angle β is shown in Fig. 2. Under certain values of v the wind power can be controlled by adjusting either tip speed ratio or pitch angle. The maximum value of C_p, i.e. $C_{pmax} = 0.47$, is achieved for β=0 and $\lambda_{opt} = 8.15$ [1].

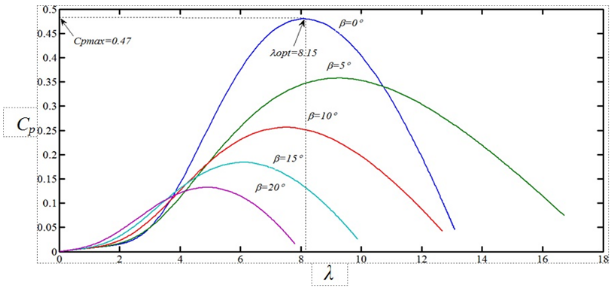

Fig. 2. Evolution of Power coefficient in function of tip speed for different Pitch angle

3 MODELING OF THE DFIG

The modeling of the DFIG is described in the *d-q* Park reference frame. The following equations systems describe the total generator model [15]:

$$\begin{cases} v_{ds} = R_s i_{ds} + \frac{d\varphi_{ds}}{dt} - \omega_s \varphi_{qs} \\ v_{qs} = R_s i_{qs} + \frac{d\varphi_{qs}}{dt} + \omega_s \varphi_{ds} \\ v_{dr} = R_r i_{dr} + \frac{d\varphi_{dr}}{dt} - (\omega_s - \omega_r)\varphi_{qr} \\ v_{qr} = R_r i_{qr} + \frac{d\varphi_{qr}}{dt} + (\omega_s - \omega_r)\varphi_{dr} \end{cases}, \quad (6)$$

$$\begin{cases} \varphi_{ds} = \ell_s i_{ds} + L_m i_{dr} \\ \varphi_{qs} = \ell_s i_{qs} + L_m i_{qr} \\ \varphi_{dr} = \ell_r i_{dr} + L_m i_{ds} \\ \varphi_{qr} = \ell_r i_{qr} + L_m i_{qs} \end{cases}. \quad (7)$$

The stator and rotor angular velocities are linked by the following relation: $\omega_s = \omega + \omega_r$, $\omega = P\Omega$. Equations of electromagnetic and mechanical torques are [15]:

$$C_{em} = P(\varphi_{ds} i_{qs} - \varphi_{qs} i_{ds}), \quad (8)$$

$$C_m = C_{em} + J \cdot \frac{d\Omega}{dt} + f \cdot \Omega. \quad (9)$$

The active and reactive powers at the stator provided to the grid are defined by:

$$\begin{cases} P_s = v_{ds} i_{ds} + v_{qs} i_{qs} \\ Q_s = v_{qs} i_{ds} - v_{ds} i_{qs} \end{cases}, \quad (10)$$

where: R_s is stator resistance, R_r is rotor resistance, ℓ_s and ℓ_r are respectively stator and rotor inductance, L_m: mutual inductance, φ_{ds}, φ_{qs} are respectively direct and quadrature stator flux, φ_{dr}, φ_{qr} are respectively direct and quadrature rotor flux, i_{ds}, i_{qs} are respectively direct and quadrature stator current, i_{dr}, i_{qr} are respectively direct and quadrature rotor current, *P*: number of pair poles, Ω: is mechanical speed, ω_s, ω_r: synchronous and rotor angular frequency, respectively, C_m, C_{em}: mechanical and electromagnetic torque.

4 DFIG FIELD ORIENTATION STRATEGY

For obvious reasons of simplifications, the *d-q* reference frame related to the stator spinning field pattern and a stator flux aligned on the d-axis were adopted. The DFIG is controlled by the rotor voltages. It is an independent control of active and reactive powers [15]. We can write:

$$\begin{cases} \varphi_{ds} = \varphi_s \\ \varphi_{qs} = \frac{d\varphi_{qs}}{dt} = 0 \end{cases}. \quad (11)$$

With these conditions the decoupling of torque and flux is guaranteed in the field oriented control and it can be controlled linearly as in the separate excited DC motor.

If the per-phase stator resistance is neglected, which is a realistic approximation for medium power machines used in wind energy conversion, the stator voltage vector is consequently in quadrature advance in comparison with the stator flux vector. With these assumptions, the new stator voltage, the fluxes and electromagnetic torque expressions can be written as follows [16]:

$$\begin{cases} v_{ds} = 0 \\ v_{qs} = v_s = \omega_s \varphi_s \end{cases}, \quad (12)$$

$$\begin{cases} \varphi_s = \ell_s i_{ds} + L_m i_{dr} \\ 0 = \ell_s i_{qs} + L_m i_{qr} \end{cases}, \quad (13)$$

$$C_{em} = -P\varphi_s \frac{L_m}{\ell_s} i_{qr}. \quad (14)$$

We lead to an uncoupled power control; where, the transversal component i_{qr} of the rotor current controls the active power. The reactive power is imposed by the direct component i_{dr}. The active and reactive powers in the stator and the rotor voltages are given by:

$$\begin{cases} P_s = -v_s \frac{L_m}{\ell_s} i_{qr} \\ Q_s = -v_s \frac{L_m}{\ell_s} i_{dr} + \frac{v_s^2}{\ell_s \omega_s} \end{cases}, \quad (15)$$

$$\begin{cases} v_{dr} = R_r i_{dr} + \ell_r \sigma \frac{di_{dr}}{dt} - g\omega_s \ell_r \sigma i_{qr} \\ v_{qr} = R_r i_{qr} + \ell_r \sigma \frac{di_{qr}}{dt} + g\omega_s \ell_r \sigma i_{dr} + g\frac{L_m v_s}{\ell_s} \end{cases}. \quad (16)$$

The total leakage factor σ is given by:

$$\sigma = 1 - \frac{L_m^2}{\ell_s \ell_r}. \tag{17}$$

In steady state, the derivative terms in (16) are zero. We can then write [15]:

$$\begin{cases} v_{dr} = R_r i_{dr} - g\omega_s \ell_r \sigma i_{qr} \\ v_{qr} = R_r i_{qr} + g\omega_s \ell_r \sigma i_{dr} + g\frac{L_m v_s}{\ell_s} \\ g = \frac{\omega_s - \omega_r}{\omega_s} \end{cases}. \tag{18}$$

In the same conditions, it appears that the *vdr* and *vqr* equations are coupled. We have to introduce a decoupling system, by introducing the compensation terms F_{emd} and F_{emq} in which:

$$\begin{cases} F_{emd} = g\omega_s \ell_r \sigma i_{qr} \\ F_{emq} = g\omega_s \ell_r \sigma i_{dr} + g\omega_s \frac{L_m v_s}{\omega_s \ell_s} \end{cases}. \tag{19}$$

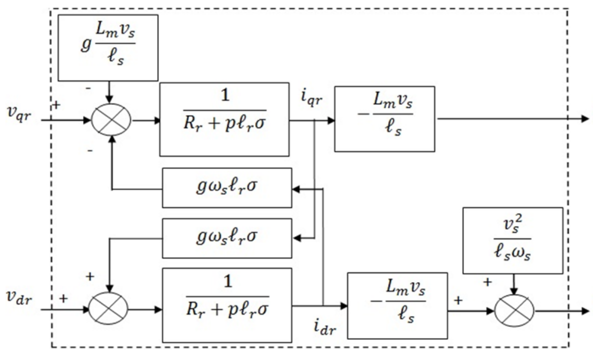

Fig. 3. Block Diagram of simplified DFIG model

From (15) and (16), a block diagram containing the rotor voltages as inputs, and active and reactive stator powers as outputs, is established in Fig. 3.

5 CONTROLLERS SYNTHESIS

This section deals with the synthesis of RST and Fuzzy-RST controllers. Both controllers are designed to obtain high dynamic performances in terms of performing active and reactive power reference tracking, sensitivity to perturbations and parametric robustness [17].

The first objective induces fast dynamics of the transient response but it may lead to few tuning parameters with explicit action on the dynamical response. The second objective takes into account the non-linearity and cross-coupling terms. Finally, the last objective is to give parametric insensibility properties to the closed-loop against over-heating and ageing. And for that, we will synthesize two controllers namely, RST and Fuzzy-RST.

5.1 Design of the control RST

The RST polynomial regulator seems to be an interesting alternative because it permits a best control of the power with acceptable performances. The controller design is based on a robust pole placement theory [16]. The RST controller as its name suggests is a polynomial structure. It consists of three polynomials *R*, *S* and *T*.

with the shaping of the sensitivity functions. This type of controller is a structure with two freedom degrees and compared to a one degree of freedom structure, it has the main advantage that it allows the designer to specify performances independently with reference trajectory tracking and with regulation [18].

The block diagram of a system with its RST controller is presented in Fig. 4. It characterized by the relationship between the input and output of the block and that can be defined by:

$$Y_{mes} = \frac{B}{A}(u + \gamma). \tag{20}$$

The control law is given by:

$$u = \frac{T}{S} Y_{ref} - \frac{R}{S} Y_{mes}, \tag{21}$$

where Y_{ref} is the input signal, Y_{mes} is the output signal, *R*, *S* and *T* define the polynomial controller RST.

The main control objective of the RST control is to maintain the tracking error *E* equal to zero:

$$E = Y_{ref} - Y_{mes}. \tag{22}$$

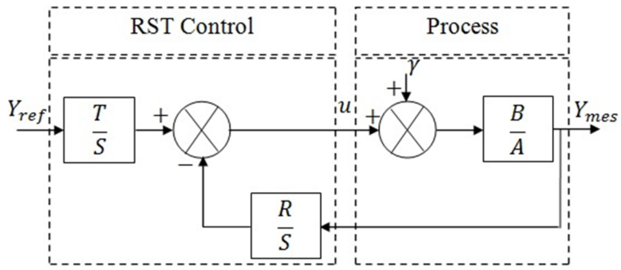

Fig. 4. Block diagram of the RST controller

5.2 Power Control of the DFIG by RST Controller

In our study, the electrical system defined by the transfer-function *B*/*A* has Y_{ref} as a reference and γ as a disturbance. *R*, *S* and T are polynomials which constitute the controller (Fig. 4). Where *A* and *B* are presently defined as follows:

$$A = \ell_s R_r + p\ell_s(\ell_r - \frac{L_m^2}{\ell_s}), \text{ and } B = L_m v_s, \tag{23}$$

where *p* is the Laplace operator.

The closed-loop transfer-function of the controlled system is:

$$Y = \frac{BT}{AS+BR} Y_{ref} + \frac{BS}{AS+BR} \gamma. \tag{24}$$

By applying the Bezout equation, we have:

$$D = AS + BR = CF, \tag{25}$$

where *C* is the command polynomial and *F* is the filtering polynomial. In order to have good adjustment accuracy, we choose a strictly proper regulator. So if *A* is a polynomial of *n* degree (deg (*A*) =*n*) we must have:

$$\deg(D) = 2n + 1, \tag{26}$$

$$\deg(S) = \deg(A) + 1, \tag{27}$$

$$\deg(R) = \deg(A). \tag{28}$$

In our case:

$$\begin{cases} A = a_1 p + a_0 \\ B = b_0 \\ R = r_1 p + r_0 \\ S = s_2 p^2 + s_1 p + s_0 \\ D = d_3 p^3 + d_2 p^2 + d_1 p + d_0 \end{cases}. \tag{29}$$

To find the coefficients of polynomials *R* and *S*, the robust pole placement method is adopted with T_c as control horizon and T_f as filtering horizon. We have:

$$P_c = -\frac{1}{T_c} \text{ and } P_f = -\frac{1}{T_f}, \tag{30}$$

where P_c is the pole of *C* and P_f the double pole of *F*. The pole P_c must accelerate the system and is generally chosen 2–5 times greater than the pole of *A*, P_a and P_f is generally chosen 3–5 times smaller than P_c. In our case:

$$T_c = \frac{1}{4} T_f = -\frac{1}{4P_a} = \frac{\ell_s(\ell_r - \frac{L_m^2}{\ell_s})}{4\ell_s R_r}. \tag{31}$$

Perturbations are generally considered as piecewise constant. γ can then be modeled by a step input. To obtain good disturbance rejections, the final value theorem indicates that the term $BS/(AS+BR)$ must tend to zero:

$$\lim_{p \to 0} p \frac{S}{D} \frac{\gamma}{p} = 0. \tag{32}$$

To obtain a good stability in steady state, we must have $D(0) \neq 0$ and respect relation (32). The Bezout equation leads to four equations with four unknown terms where the coefficients of *D* are related to the coefficients of the polynomials *R* and *S* by the Sylvester Matrix [16]:

$$\begin{pmatrix} d_3 \\ d_2 \\ d_1 \\ d_0 \end{pmatrix} = \begin{pmatrix} a_1 & 0 & 0 & 0 \\ 0 & a_1 & 0 & 0 \\ 0 & a_0 & b_0 & 0 \\ 0 & 0 & 0 & b_0 \end{pmatrix} \begin{pmatrix} s_2 \\ s_1 \\ r_1 \\ r_0 \end{pmatrix}. \tag{33}$$

In order to determine the coefficients of *T*, we consider that *Y* must be equal to Y_{ref} in steady state. In consequence,

$$\lim_{p \to 0} \frac{BT}{AS+BR} = 1. \tag{34}$$

Because of *S(0)*=0, we can conclude that *T=R(0)*. In order to separate regulation and reference tracking, we try to make the term $BT/(AS+BR)$ only dependent on *C*.

We then consider *T* = *hF* (where *h* is real) and we can write:

$$\frac{BT}{AS+BR} = \frac{BT}{D} = \frac{BhF}{CF} = \frac{Bh}{C}. \tag{35}$$

As $T = R(0)$, we conclude that $h = R(0)/F(0)$.

5.3 Power Control of the DFIG by an Adaptive FLC-RST Controller

To overcome the disadvantages of RST controllers and FLC, we propose a hybrid controller, in which the RST controller parameters are adjusted by an adaptive mechanism based on fuzzy inference (adaptive FLC-RST). In what follows we show how the two types of controllers are combined.

5.4 Fuzzy gain scheduling of RST controller

Gain scheduling means a technique where RST controller parameters (r_0, r_1, s_1, and s_2) are tuned during control of the system in a predefined way [10]; it enlarges the operation area of linear controller (RST) to perform well also with a nonlinear system. The diagram of this technique is illustrated in Fig. 5. The fuzzy inference mechanism adjusts the RST parameters and generates new parameters during process control, so that the FLC adapts the RST parameters to operating conditions based on the error and its first time derivative.

Fuzzy controllers have been widely applied to industrial processes. They are effective techniques especially when the mathematical model of the system is nonlinear or when there is no mathematical model.

The structure of the fuzzy control system consists of the following main parts: Fuzzification, Knowledge base, Inference engine, Defuzzification [19].

The schematic diagram of a complete fuzzy control system is given in Fig. 6. The outputs value of the fuzzy

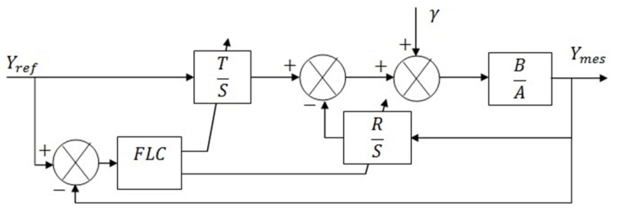

Fig. 5. Fuzzy RST Adaptive Controller

(r_0, r_1, s_1, and s_2) is inferred from the two state variables, error (*E*) and change in error (*CE*).

The values of the actual inputs (*E*) and (*CE*) are mapped onto [-1,1] by the input Scaling Factors (SF's) F_E and F_{CE}, respectively. Selection of suitable values inside of fuzzy control system (F_E, F_{CE} and F_{CU}) are made based on the knowledge about the process to be controlled and sometimes through trial and error to achieve the best possible control performance, depending on the trend of the controlled process output.

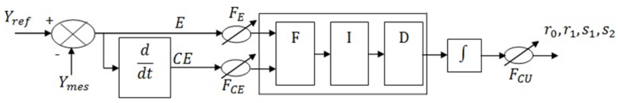

Fig. 6. Basic structure of fuzzy control system

The two input variables *E*(t_s) and *CE*(t_s) are calculated at every sampling time as:

$$E\left(t_s\right) = Y_{ref}\left(t_s\right) - Y_{mes}\left(t_s - 1\right), \quad (36)$$

$$CE\left(t_s\right) = E\left(t_s\right) - E\left(t_s - 1\right). \quad (37)$$

The output of the FLC model (r_0, r_1, s_1, and s_2) is calculated by:

$$\left(r_0, r_1, s_1, s_2\right) = U\left(t_s\right) = U\left(t_s - 1\right) + CU\left(t_s\right). \quad (38)$$

To synthesize the fuzzy controller of two variables (active and reactive powers), the new parameters of the RST are obtained for each set of input parameters using fuzzy logic control. The fuzzy rules may be extracted from operator's expertise or based on the step response of the process [10]. The tuning rules for (r_0, r_1, s_1, and s_2), used in our system are given in Tables 1. The rows represent the rate of the error change (*CE*) and the columns represent the error (*E*). Each pair (*E*, *CE*) determines the output level corresponding to (r_0, r_1, s_1, and s_2).

Here NB is negative big, NS is negative small, ZR is zero, PS is positive small medium and PB is positive big, are labels of fuzzy sets and their corresponding membership functions are depicted in Fig. 7.

Table 1. Rules Base for Fuzzy Controller

r_0,r_1,s_1,s_2		***CE***				
		NB	NS	ZR	PS	PB
E	NB	ZR	ZR	PB	PB	PB
	NS	ZR	ZR	PS	PS	PS
	ZR	PS	ZR	ZR	ZR	NS
	PS	NS	NS	NS	ZR	ZR
	PB	NB	NB	NB	ZR	ZR

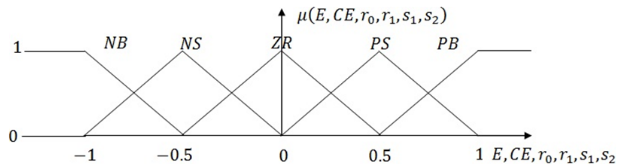

Fig. 7. Fuzzy memberships used for simulation

The error signal of the controlled variable was the single variable used as an input to the fuzzy system. In the above-mentioned applications, the design of the fuzzy inference system was completely based on the knowledge and experience of the designer, and on methods for tuning the membership functions (MFs) so as to minimize the output error [12].

In this paper, the triangular membership function, the max-min reasoning method, and the center of gravity defuzzification method are used, as those methods are most frequently used in many literatures [20].

The Fig. 8 represents the output surface of the fuzzy inference system of the inputs (*E* and *CE*) and the output (r_0, r_1, s_1, and s_2).

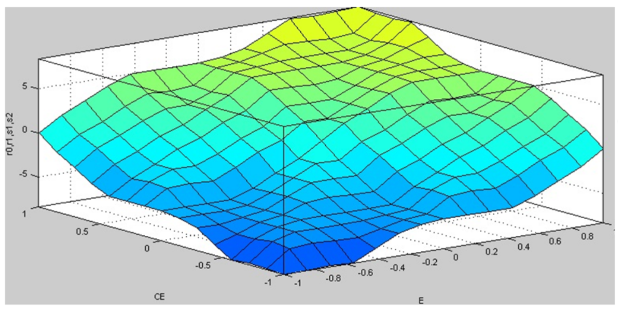

Fig. 8. The output surface of the fuzzy inference system

6 RESULTS AND DISCUSSION

Simulation is done to illustrate the performances of the RST and FLC-RST controllers applied to the DFIG. A bloc diagram is proposed in Fig. 9 to control the whole system.

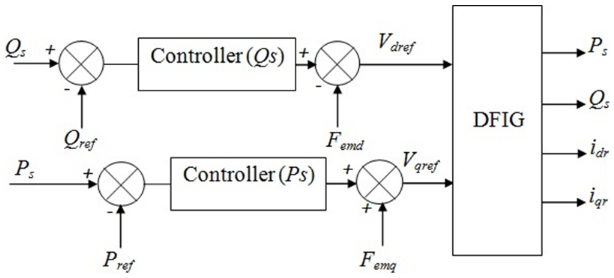

Fig. 9. Block diagram of the whole system

In this section simulation results are obtained by using the MATLAB/Simulink platform and are presented to show dynamic performances of the control system described above. Controllers will be tested in reference tracking and robustness against parameter variations.

The values of RST have been optimized in order to have the best compromise between response time and overshoot. The initial values are given in Appendix.

6.1 Reference tracking

The active-reactive stator power and its reference are reported in Fig. 10 and Fig. 11. These figures represent a good pursuit, and a perfect decoupling between them is assured, the static error goes to zero, and the time of transient state is so short. Therefore we can consider that the fuzzy-RST controller has a very good performance for this test.

6.2 Robustness

In order to test the robustness of the two controllers, the value of rotor resistance R_{rn} is doubled from its nominal value. Fig. 12 and Fig. 13 show the effect of parameter variations on the active and reactive power response for the two controllers.

These results show that parameters variations of the DFIG don't have an observable effect on the powers curves. This result enables us to conclude that in term of robustness, the FLC-RST control type is more robust.

6.3 Comparison of classical RST and adaptive RST

The comparison of both controllers has been shown in Table 2.

From Table 2 we can say that convergence speed in fuzzy-RST controller is an excellent than that of RST controller. The best performance in terms of settling time and overshoot has been given by fuzzy-RST.

From the simulation results, it can be concluded that fuzzy-RST controller has most satisfied performance compared with the RST controllers.

Table 2. Comparison of both controllers (RST and FLC-RST)

Controller Type		Time response parameters			
		Convergence speed	***Settling time (sec)***	***Peak time(sec)***	***Overshoot (%)***
P_s	RST	Medium	0.06	0.0699	0.2
	FLC-RST	High	0.01	0.0141	0.02
Q_s	RST	Medium	0.025	0.032	0.56
	FLC-RST	High	0.012	0.028	0.01

7 CONCLUSION

In this work, we proposed a method of combination between the fuzzy controller and conventional RST controller in order to overcome the disadvantages of RST controllers and FLC, this combination gave us an adaptive RST controller which presented satisfactory performances (no overshoot, minimal rise time, and best disturbance rejection). The major drawback of the fuzzy controller is the insufficient analytical design technique (choice of the rules, the membership functions and the scaling factors).

The main objective of the proposed control method Fuzzy-RST of active and reactive powers generated by the WECS based on double fed induction generator, in order to ensure of the high performance and a better execution of the DFIG, and to make the system insensible with the external disturbances and the parametric variations. We have described a model of the DFIG and established a model of the control strategy based on vector control.

In term of power reference tracking with the DFIG in ideal conditions, the performances of the proposed strategy Fuzzy-RST have better energy quality compared with the RST regulator. Additionally, the proposed strategy shows a good dynamic performance and ability to reduce the effect of the robustness and hence it is called as Robust Fuzzy-RST Control (FLC-RST).

APPENDIX A APPENDIX SECTION

Rated data of the simulated doubly fed induction generator: 7.5 kW, $v_s = 220$V, $F_s = 50$Hz, P=3, $J = 0.1\text{Kg/m}^2$, $f = 0.06$N.m.s./rad, $R_s = 0.95\Omega$, $R_r = 1.8\Omega$, $L_m = 0.082$H, $\ell_s = 0.094$H, $\ell_r = 0.088$H.

The initial values of RST:

$$\begin{cases} R = 5.2980\text{e}+003p + 6.5147\text{e}+005 \\ S = 645.9948p^2 + 4.9426\text{e}+005p \\ T = 6.5147\text{e}+005 \end{cases} . \tag{39}$$

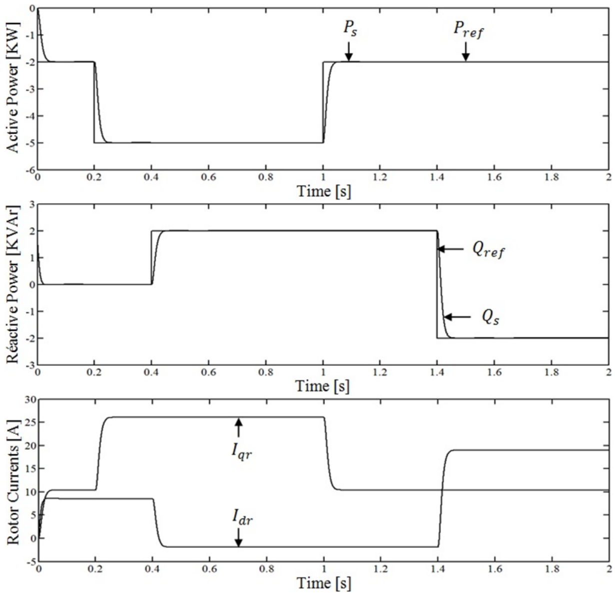

Fig. 10. Dynamic Responses to the active and reactive power tracking change using RST controllers

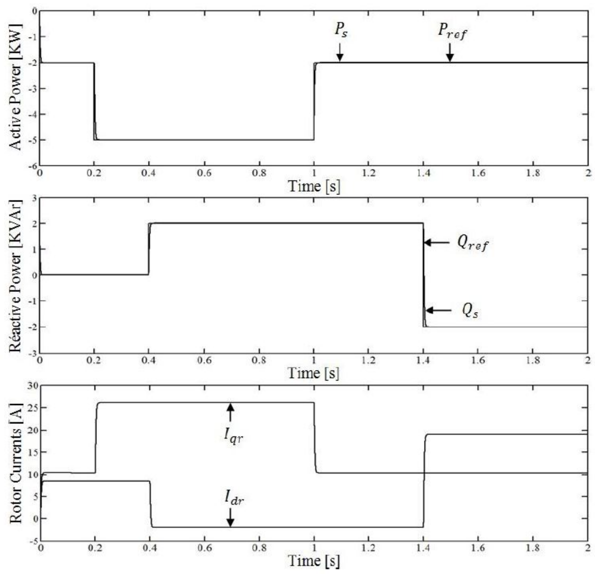

Fig. 11. Dynamic Responses to the active and reactive power tracking change using FLC-RST controllers

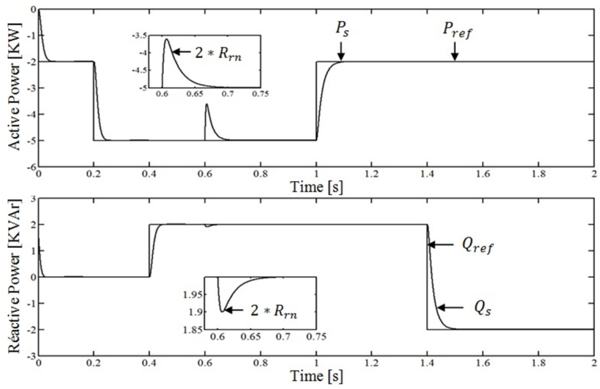

Fig. 12. Test of robustness of rotor resistance variation +100% R_{rn} using RST controllers

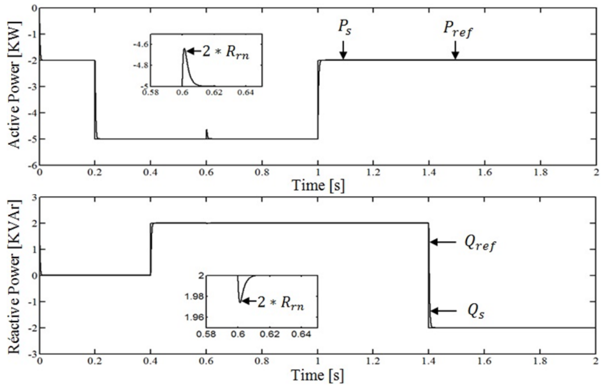

Fig. 13. Test of robustness of rotor resistance variation +100% R_{rn} using FLC-RST controllers

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