Comparison Between the MIT Rule and Fuzzy Logic Controller to Adapting the Power Generated by a Doubly Fed Induction Generator Integrated in a Wind System.

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***Abstract*—This paper presents the control of the active and reactive power in a wind energy conversion system by using the comparison between a model reference adaptive control (MRAC) basing to the original approach of adaptive reference model control developed at the Instrumentation Laboratory (now Draper Laboratory) at the University of M.I.T. (Massachusetts Institute of Technology) and fuzzy logic controller. The wind energy conversion system is based on a doubly fed induction generator (DFIG) with rotor fed by the electrical network through two converters. Firstly, we present the dynamic model of wind turbine connected to DFIG and grid system, then we present the control strategy. Secondly, we used the MIT rules and fuzzy logic to control the active and reactive power of a doubly fed induction generator (DFIG). The comparison between the MIT rule and fuzzy logic is proposed to proof the adaptation strategy of control. Simulation results illustrate the performances and the feasibility of this control method**

***Keywords*—DFIG, wind turbine, MIT rule, active and reactive power, control strategy, fuzzy logic, MRAC**

I. Introduction

The use of wind energy conversion systems has developed into one of the most important new alternatives to conventional fossil fuels in recent years where most wind turbines currently rely to use double feed induction generator (DFIG) [1]. This is due to many advantages such as variable speed operation of the generator, decoupling between active and reactive powers, maximization of energy generation and competitive price [2]. But, DFIG is subjected to many constraints, such as the effects of parametric variations and the disturbance of the wind speed, which could deviate the system from its optimal operation point.

A control system is a device that regulates or controls the dynamics of any system subject to momentary changes and disturbances of parametric variations. Adaptive control is one of the widely used control strategies to design advanced control systems for better performance and accuracy [3].

Many different structures and control algorithm could be used to control the rotor of DFIG in wind system . One of the most common techniques is by controlling the rotor' voltages [4][5]. This paper presents the modeling and the control of active and reactive power of DFIG . The Model Reference Adaptive Control MRAC-MIT/FUZZY LOGIC inference system is applied as an alternative of the FUZZY LOGIC. The MRAC-MIT/FUZZY LOGIC control has the advantage to be robust and relatively simple to design. The performance of the MIT RULE /FUZZY LOGIC controller is compared with that of the FUZZY LOGIC controller, to shows the dynamic performance of MIT RULE /FUZZY LOGIC controller.

This paper is organized as follows; modelling of the wind energy system in section II. Fuzzy logic controller is presented in section III. The MIT rule control is introduced in section IV. In the section V, the Design of Adaptive MIT rule Gain Scheduling of Fuzzy Logic Controller is presented and the results simulation are presented and discussed in section VI. Finally, a conclusion of the paper is presented in the last section.

II. Modeling of the Wind Energy System

The diagram of a wind energy conversion chain connected to the electrical network is described by figure 2.

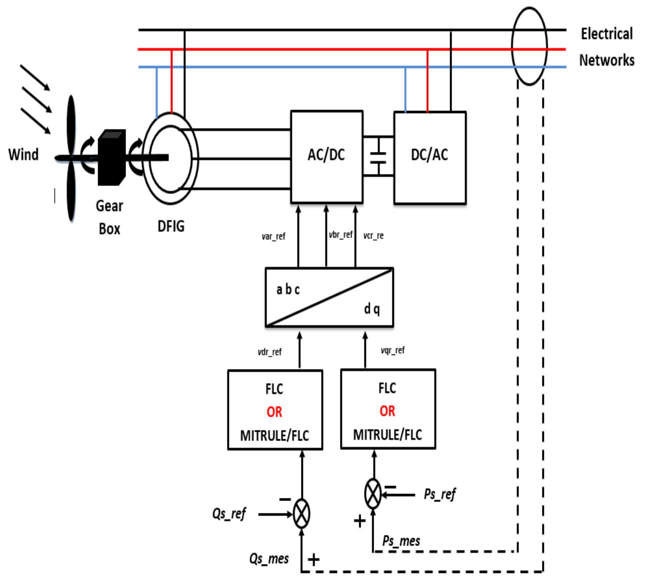

Fig. 1. Diagram blocs of the considered wind system.

A. Model of the wind turbine

The total power of wind turbine is given by [6] :

$$P = \frac{1}{2}\rho S v^3 \tag{1}$$

but, only part of the available energy can be captured by the wind turbine

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$$P=\frac{1}{2}\rho C_P S v^3 \tag{2}$$

For wind turbines, the energy extraction coefficient *Cp* which depends on both the wind speed and the speed of rotation of the turbine is generally defined in the interval 0.35-0.5.

The dynamic equation of the wind turbine is given by:

$$\Gamma_{m}=\Gamma_{em}+f\Omega+J\frac{d\Omega}{dt} \tag{3}$$

Where, J is the wind system inertia and d is the friction coefficient.

B. Model of DFIG

In the Park model, the mathematical model of a doubly-fed induction generator chosen for the conversion of the wind power energy is described by the following equations: [7]

$$\begin{cases} v_{ds}=R_s i_{ds}+\dfrac{d}{dt}\phi_{ds}-\omega_s\phi_{qs} \\ v_{qs}=R_s i_{qs}+\dfrac{d}{dt}\phi_{qs}+\omega_s\phi_{ds} \\ v_{dr}=R_r i_{dr}+\dfrac{d}{dt}\phi_{dr}-(\omega_s-\omega_r)\phi_{qr} \\ v_{qr}=R_r i_{qr}+\dfrac{d}{dt}\phi_{qr}+(\omega_s-\omega_r)\phi_{dr} \end{cases} \tag{4}$$

$$\begin{cases} \phi_{ds}=L_s i_{ds}+M_{sr} i_{dr} \\ \phi_{qs}=L_s i_{qs}+M_{sr} i_{qr} \\ \phi_{dr}=L_r i_{dr}+M_{sr} i_{ds} \\ \phi_{qr}=L_r i_{qr}+M_{sr} i_{qs} \end{cases} \tag{5}$$

$$C_{em}=p\frac{M_{sr}}{L_s}\left(\phi_{qs} i_{dr}-\phi_{ds} i_{qr}\right) \tag{6}$$

Where: R_s is the stator resistance, R_r is the rotor resistance, L_s is the stator inductance, M_{sr} is mutual inductance, ϕ_{ds} , ϕ_{qs} are the direct and quadrature fluxes of the stator respectively, ϕ_{dr}, ϕ_{qr} are the direct and quadrature fluxes of the rotor respectively, i_{ds}, i_{qs} are respectively direct and quadrature stator currents, i_{dr}, i_{qr} are the direct and quadrature rotor currents, respectively, p is number of even poles, ω_r, ω_s are the angular speeds of the rotor and stator, respectively.

C. Control strategy

in the Park model, the active and reactive powers are written as follows [8]:

$$\begin{cases} P_s=V_{ds} i_{ds}+V_{qs} i_{qs} \\ Q_s=V_{qs} i_{ds}-V_{ds} i_{qs} \end{cases} \tag{7}$$

The stator flux is set aligned with the d axis. So we can write:

$$\begin{cases} \phi_{qs}=0 \ ; \ \phi_{ds}=\phi_s \\ V_{qs}=V_s \ ; \ V_{ds}=0 \end{cases} \tag{8}$$

The equation (7) becomes:

$$\begin{cases} P_s=V_{qs} i_{qs} \\ Q_s=V_{qs} i_{ds} \end{cases} \tag{9}$$

By combining (4), (5), and (9), equation (9) becomes:

$$\begin{cases} P_s=-V_s\dfrac{M}{L_s} i_{qr} \\ Q_s=-V_s\dfrac{M}{L_s} i_{dr}+\dfrac{V_s^2}{L_s\omega_s} \end{cases} \tag{10}$$

III. Fuzzy Logic Controller

In this section, we have used the fuzzy logic controller with following IF-THEN rule:

$Rule(i)$: if S is F_S^i, then u_f is $F_{u_f}^i$, $i=1,\dots..5$

Table 1 shows one of possible control rules based on five membership functions, where: NB is negative big, NS is negative small, ZE is zero, PS is positive small and PB is positive big. These acronyms are labels of fuzzy sets and their corresponding membership functions are depicted in Fig.2, [9]

TABLE I. ONE OF POSSIBLE CONTROL RULES BASED ON FIVE MEMBERSHIP FUNCTIONS.

Δe / *e*	*NB*	*NS*	*ZE*	*PS*	*PB*
NB	*ZE*	*ZE*	*PB*	*PB*	*PB*
NS	*ZE*	*ZE*	*PS*	*PS*	*PS*
ZE	*PS*	*ZE*	*ZE*	*ZE*	*NS*
PS	*NS*	*NS*	*NS*	*ZE*	*ZE*
PB	*NB*	*NB*	*NB*	*ZE*	*ZE*

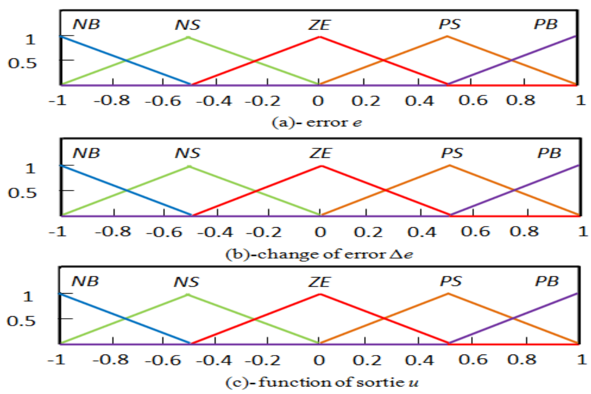

Fig. 2. Membership functions of: (a) error e; (b) change of error Δe; (c) function of sortie u

IV. THE MIT RULE CONTROL

In the MRAC strategy, the difference between the plant output and the reference model output is used to tracking error, *e:*

$$e = y - y_m \tag{11}$$

From this error, the cost function is [10]:

$$J(\theta) = \frac{1}{2}e^2(\theta) \tag{12}$$

To update the parameter θ, an equation must be formed for the change of θ. So, the objective is to minimize this cost linked to the error. The cost function is represented by [10]:

$$\frac{d\theta}{dt} = -\gamma\frac{\partial J}{\partial\theta} = -\gamma e\frac{\partial e}{\partial\theta} \tag{13}$$

There are many alternatives for the cost function given by equation (11). If we choose:

$$J(\theta) = |e| \tag{14}$$

So, the gradient method gives by [11]:

$$\frac{d\theta}{dt} = -\gamma\left(\frac{\partial e}{\partial\theta}\right)sign(e) \tag{15}$$

Where:

$$sign(e) = \begin{cases} 1 & \text{if } e > 0 \\ 0 & \text{if } e = 0 \\ -1 & \text{if } e < 0 \end{cases}$$

To see how the MIT rule can be used to form an adaptive controller, consider a system with an adaptive feed forward gain. The block diagram is given below:

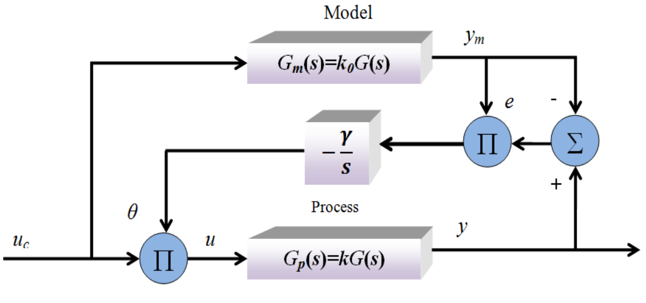

Fig. 3. Block diagram of gain in anticipation adaptation [10] [12].

$$\frac{Y(s)}{U(s)} = kG(s) \tag{16}$$

The constant k for this plant is unknown. However, a reference model can be formed with a desired value of k, and through adaptation of a feed forward gain, the response of the plant can be made to match this model. The reference model is therefore chosen as the plant multiplied by a desired constant k_0:

$$\frac{Y(s)}{U_c(s)} = k_0G(s) \tag{17}$$

The same cost function as above is chosen and the derivative is represented by:

$$J(\theta) = \frac{1}{2}e^2(\theta) \rightarrow \frac{d\theta}{dt} = -\gamma e\frac{\partial e}{\partial\theta} \tag{18}$$

The error is then reformulated in terms of transfer functions multiplied by their inputs.

$$e = y - y_m = kGU - G_mU_c = kG\theta U_c - k_0GU_c \tag{19}$$

As we can see, this expression of the error contains the parameter θ, which must be updated. To determine the update rule, the sensitivity derivative is calculated and updated in terms of the model output:

$$\frac{\partial e}{\partial\theta} = kGU_c = \frac{k}{k_0}y_m \tag{20}$$

Finally, the MIT rule is applied to give an expression for updating t θ. The constants k and k_0 are combined into γ [13].

$$\frac{d\theta}{dt} = -\gamma\frac{k}{k_0}y_me = -\gamma' y_me \tag{21}$$

V. DESIGN OF ADAPTIVE MIT RULE GAIN SCHEDULING OF FUZZY LOGIC CONTROLLER

In this section we have improved the performances of our system. To answer these requires, we are interested to develop a control strategy based on the online adaptation of the MIT rule controller parameters by the fuzzy logic technique.

To control the stator power in a DFIG we have using the block diagram of Fig. 4.

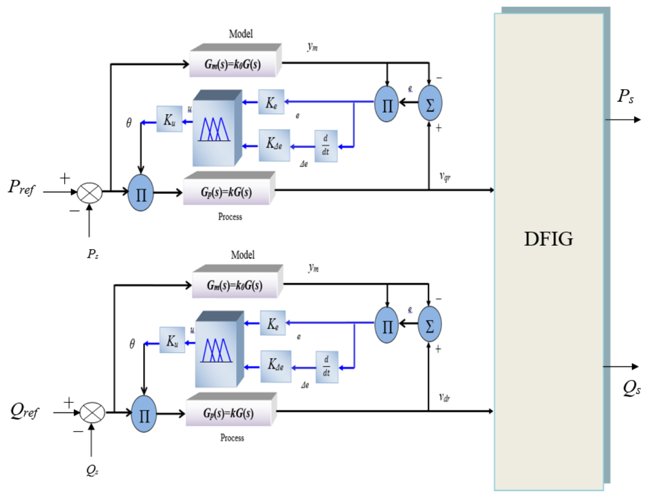

Fig. 4. Block diagram of active and reactive power control by MIT rule / fuzzy logic

VI. SIMULATIONS AND RESULTS

In this section, we will have the results of control simulation to active and reactive powers generated by doubly fed induction generator DFIG in wind energy system, by using MRAC-MIT rule /Fuzzy logic controller, whose objective is to compare the responses powers active and reactive compared to desired reference. A comparison is done with Fuzzy logic controller to show the robustness of the MRAC-MIT rule /Fuzzy logic controllers.

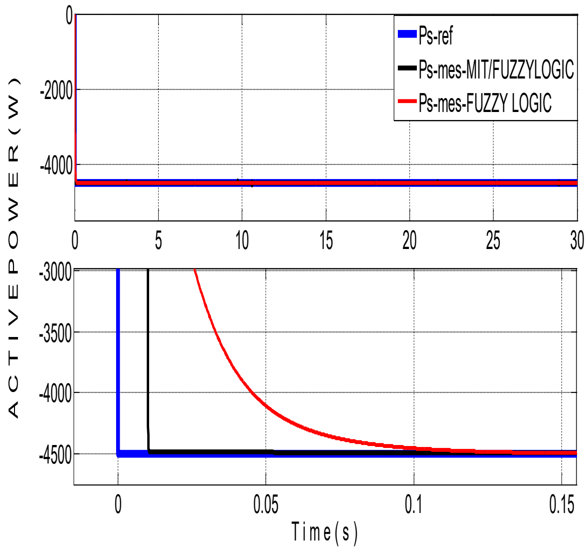

Fig. 5. Block diagram of active and reactive power control by MIT rule / fuzzy logic

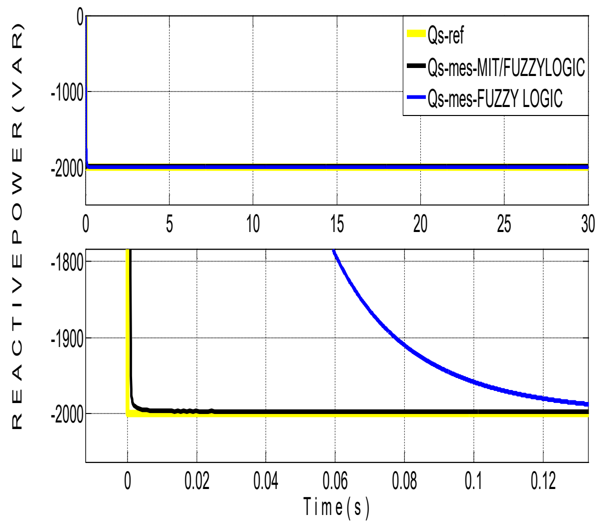

Fig. 6. Block diagram of active and reactive power control by MIT rule / fuzzy logic

Firstly, the MRAC-MIT rule/Fuzzy logic and Fuzzy logic controller is used to control the active and reactive stator powers in a fixe speed system. Fig. 5 and Fig. 6 show that the control of the active and reactive powers by MRAC-MIT rule/Fuzzy logic technique is very fast compared to the Fuzzy logic technique with more precision.

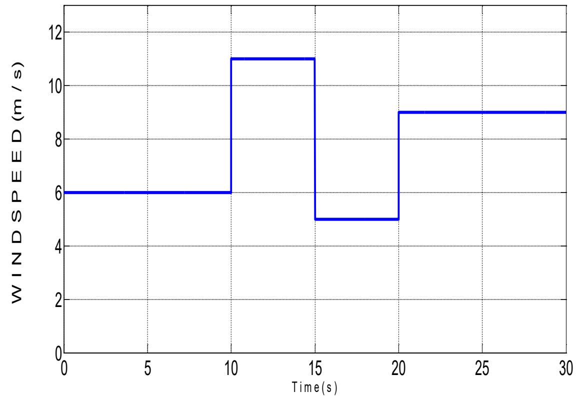

Fig. 7. Wind speed variation

Secondly, a variable wind speed are chosen to prove the stability of the system, as shown in Fig. 7. We therefore have a different speed like 6m / s, 11m / s, 5m / s and 9m / s at period [0 10] s , period [10 15], period [15 20] and [20 30], respectively (treatment of different changes in wind speed: increase, decrease and stability).

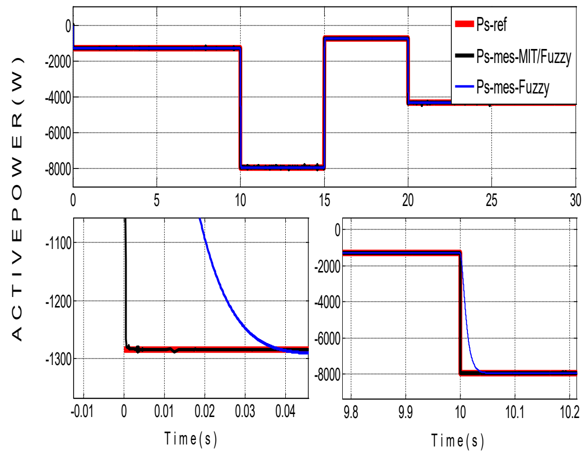

Fig. 8. Stator-active power after control and regulation

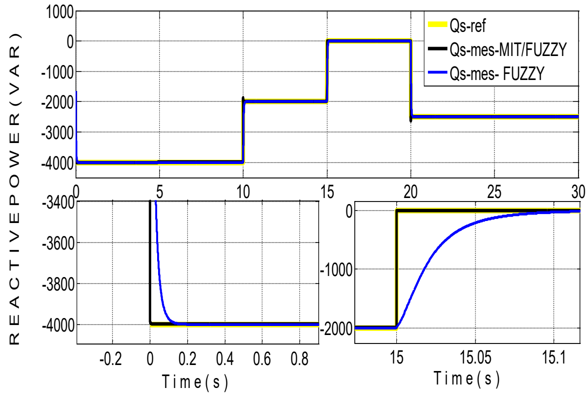

Fig. 9. Stator-reactive power after control and regulation

Fig. 8 and Fig.9 show the regulation of the active and reactive stator power as a function of time. At time t = 10s, the active and reactive power where adapted to the values of 1,28kW and 4 kvar, respectively. At the period [10 15] s: the active power was adapted to the value 8 kW, the reactive power to the value 2 kvar and at the period [15 20] s: the active and reactive power was adapted to the value 0.8 kW and 0 kvar, respectively(changement of power value in different changes in wind speed) . So, the active and reactive powers perfectly pursue the desired variables in all time of simulation (different changes in wind speed: increase, decrease and stability)

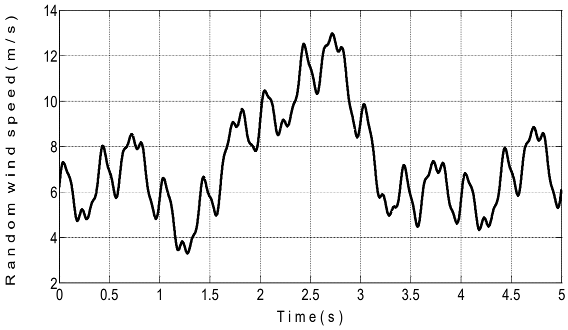

Fig. 10. Random wind speed

In Fig. 10, we proposed a random wind speed to follow the reaction of our system and their response time. (rapid and instantaneous variation of wind speed condition)

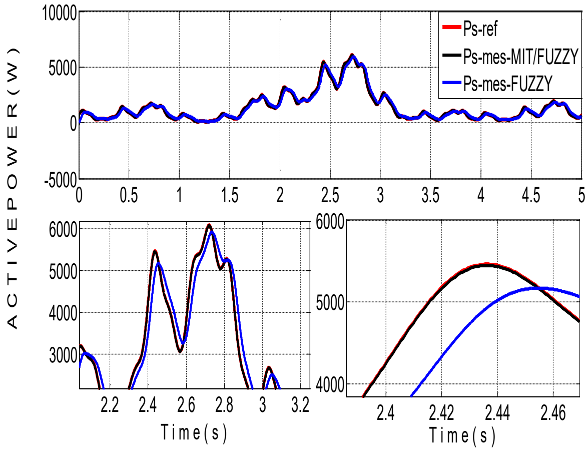

Fig. 11. Stator-active power in random wind speed

In Fig. 11, the active power perfectly pursues the desired variables. In MIT rule / fuzzy logic control, the responses are without overshoot, fast in transient conditions and the static error tends to zero.

So, the Fig. 11 shows the response of the system with a controller by MRAC-MIT rule / fuzzy logic with random variation of wind parameter. The controller acts quickly and efficiently and follows the desired path. From these results, we see the dynamic performance and robustness of the control by using MRAC-MIT rule/ Fuzzy logic controller in random variation of system parameter.

VII. CONCLUSION

In this paper we were able to establish a decoupled and robust control of the active and reactive powers generated by a DFIG. The work carried out is a numerical simulation of the adaptive control MRAC of an asynchronous wind generator with double fed integrated in a wind system. In the proposed adaptive control MRAC, we used the MIT rule / fuzzy logic for the design of the adaptation mechanism and the regulator of the internal loop where the performance of the adaptive regulator by MIT rule / fuzzy logic has been tested. The results obtained by simulation show that the MRAC-MIT/FUZZY LOGIC controller is very robust to the Fuzzy logic controller in the disturbances due to parametric variations of system. The power response correctly pursues the reference model chosen despite the disturbances in the system parameters.

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