Comparative study of control strategies for the double fed induction generator

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Abstract— **Double Fed Induction Generator (DFIG) had been widely used as a wind turbine generator, due its various advantages especially low generation cost so it becomes the most important and promising sources of renewable energy. This paper presents fuzzy logic control (FLC) of Doubly Fed Induction Generator (DFIG) wind turbine. First, a mathematical model of the doubly fed induction generator written in an appropriate d-q reference frame is established to investigate simulations. In order to control the stator powers of DFIG, a power active and reactive control law is synthesized using PI controllers. Then, the performances of fuzzy logic controller are investigated and compared to those obtained from the PI controller. Simulation results prove the excellent performance of fuzzy control unit as improving power quality and stability.**

Keywords— Fuzzy Logic Controller, Comparative study, Power control , Doubly fed induction generator

I. INTRODUCTION

The modern MW-size wind turbines always use variable speed operation which is achieved by a converter system [1]. These converters are typically associated with individual generators and they contribute significantly to the costs of wind turbines

Variable speed wind turbine topologies include many different generators configurations, based on cost, efficiency, annual energy capturing, and control complexity of the overall system [2].

Due to the fast enhancement and development in manufacture of power electronic converter technology as well as the development of induction machines specially Double Fed Induction Generators and its advantages of small capacity of converters, high energy and flexible power control [3], DFIG has been widely used for large-scale wind power generation systems due to its various advantages, such as variable speed operation, controllable power factor and improved system efficiency, flexibility and robustness. DFIG have windings on both stator and rotor. Through both the windings there is a significant amount of active power transfer between shaft and electrical system.

DFIG wind turbine also improves system efficiency with its optimal rotational speed, reduces noise and mechanical stresses, improves power quality, and compensates for torque and power pulsations [4], power converter only processes slip power therefore it's designed in partial scale and just about 30% of generator rated power which makes it attractive from economical point of view [5][6].

The quality of energy depends not only on the generator type or power converter configuration, but also on the control system. Many different structure and control algorithms can be used for control of power converter. One of the most common control techniques is decoupled PI control of output active and reactive power to improve dynamic behavior of wind turbine.

However, the fixed gain controllers (PI) are very sensitive to parameter variations and cannot usually provide good dynamic performance. So, the controller parameters have to be continually adapted. This problem can be solved by several control techniques such as direct torque control DTC sliding mode control SMC and intelligent techniques like artificial neural networks, genetic algorithms and fuzzy logic FLC...etc [7][8].

In the recent past, several works show that the fuzzy logic controllers (FLC) able to replace the conventional ones[9] [10] Fuzzy control technique does not need accurate system modelling. It employs the strategy adopted by the human operator to control complex processes and gives superior performance than the conventional proportional-integral (PI) control. The fuzzy algorithm is based on human intuition and experience, and can be regarded as a set of heuristic decision rules [11][12].

The components of rotor currents can be related to the real and reactive powers. In this paper, a FLC control strategy is achieved by adjusting rotor currents and using stator voltage vector oriented reference frame. The performances of fuzzy logic controller are investigated and compared to those obtained from the PI controller.

The rest of this work is structured as follows: Section 2 is dedicated to the dynamic modeling of DFIG. Section 3 presents the different strategies adopted to control the DFIG. Section 4 is the simulation results and finally Section 5 represents the conclusion.

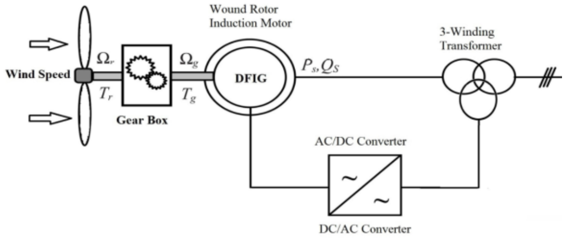

Fig. 1. Doubly fed induction generator-based wind turbine configuration.

II. SYSTEM MODELING

A. Model of the Doubly Fed Induction Generator

As illustrated in Figure 3, DFIG system is a wound rotor induction generator with slip ring, with stator directly connected to the grid and with rotor interfaced through a back to back partial scale power converter. Consequently the DFIG can be regarded as a traditional induction machine with a nonzero rotor voltage.

Under the matrix form, the mathematical model of the DFIG in PARK reference frame is the fifth order model. All the flux dynamics and the important interactions between variables are taken into account. To reduce the complicating features of the machine, some basic assumptions are considered. The air gap is assumed smooth with no slotting effect. The magnetic saturation is neglected and the machine windings are supposed sinusoidally distributed. The electrical magnitudes interactions are described by the following matrix[13].

$$\begin{cases} \dfrac{dI_{sd}}{dt} = -\dfrac{R_s}{L_s} I_{sd} + \dfrac{M}{L_s}\dfrac{dI_{rd}}{dt} + \omega_s I_{sq} - \dfrac{M}{L_s}\omega_s I_{rq} - \dfrac{1}{L_s} V_{sd} \\ \dfrac{dI_{sq}}{dt} = -\dfrac{R_s}{L_s} I_{sq} + \dfrac{M}{L_s}\dfrac{dI_{rq}}{dt} - \omega_s I_{sd} + \dfrac{M}{L_s}\omega_s I_{rd} - \dfrac{1}{L_s} V_{sq} \\ \dfrac{dI_{rd}}{dt} = -\dfrac{R_r}{L_r} I_{rd} + \dfrac{M}{L_r}\dfrac{dI_{sd}}{dt} + \omega I_{rq} - \dfrac{M}{L_r}\omega I_{sq} + \dfrac{1}{L_r} V_{rd} \\ \dfrac{dI_{rq}}{dt} = -\dfrac{R_r}{L_r} I_{rq} + \dfrac{M}{L_r}\dfrac{dI_{sq}}{dt} - \omega I_{rd} + \dfrac{M}{L_r}\omega I_{sd} + \dfrac{1}{L_r} V_{rq} \end{cases} \quad (1)$$

where Φsd,q and Φrd,q are the stator and the rotor fluxes, respectively, Vsd,q and Vrd,q are the stator and rotor voltages, Rs and Rr are the stator and rotor resistances, Ls, Lr, and M are the stator, rotor and magnetizing inductances, σ is the leakage factor, ωg and ωm are the angular frequencies of the stator flux and the rotor shaft.

The electromagnetic torque (Tem) presents the link between mechanical and electrical part of the machine. It can be obtained in terms of fluxes[14]:

$$T_{em} = p.M_{sr}.\left(I_{sq}.I_{rd} - I_{sd}.I_{rq}\right) \quad (2)$$

where J is the system inertia and fv is the viscous friction.

In order to complete the model, the real and reactive power are necessary to be computed. They can be written as:

$$\begin{cases} P_s = -V_{sd}.I_{sd} - V_{sq}.I_{sq} \\ Q_s = -V_{sq}.I_{sd} + V_{sd}.I_{sq} \end{cases} \quad (3)$$

B. Voltage converter modeling

The model of the two level converter with standard IGBTs is defined as[15]:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{V_{dc}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \quad (4)$$

where Sa, Sb, and Sc are the command signals, Van, Vbn, and Vcn are the output voltages and Vdc is DC bus voltage.

III. CONTROL STRATEGIES.

A. PI control of the DFIG

Vector control still the most used control technique for the DFIG[7]. The objective of the Vector control is to regulate stator active power Ps and reactive power Qs independently. In this strategy, the rotor current vector is separated into two elements using synchronously rotating (dq) reference frame. [16]. The direct rotor current is responsible for the control of reactive power and the quadrature current is related to the real power. In this way, the DFIG can closely match the structure of DC machine, which magnitudes controlling the torque and the flux are naturally decoupled. [17].

The relationship between the stator and rotor currents can be derived:

$$\begin{aligned} I_{sd} &= \frac{\phi_s}{L_s} - \frac{M}{L_s}.I_{rd} \\ I_{sq} &= -\frac{M}{L_s} I_{rq} \end{aligned} \quad (5)\,(6)$$

By replacing Equations (5) and (6) in rotor flux expressions, they can be written in terms of rotor currents as follows:

$$\begin{aligned} \phi_{rd} &= \left(L_r - \frac{M^2}{L_s}\right).I_{rd} + \frac{M}{L_s}\phi_s \\ \phi_{rq} &= \left(L_r - \frac{M^2}{L_s}\right)I_{rq} \end{aligned} \quad (7)\,(8)$$

The relationship between the rotor voltages and the rotor currents can be established by substituting Equations (7) and (8) into Vrd and Vrq expressions[18]:

$$\begin{cases} V_{rd} = R_r I_{rd} + (L_r - \dfrac{M^2}{L_s})\dfrac{dI_{rd}}{dt} \\ \quad -g\,\omega_s (L_r - \dfrac{M^2}{L_s}) I_{rq} \\ V_{rq} = R_r I_{rq} + (L_r - \dfrac{M^2}{L_s})\dfrac{dI_{rq}}{dt} \\ \quad +g\,\omega_s (L_r - \dfrac{M^2}{L_s}) I_{rd} + g\,\dfrac{MV_s}{L_s} \end{cases} \quad (9)$$

The vector control scheme consists of the real and reactive power can be rewritten in terms of rotor currents as follows:

$$\begin{cases} P_s = -V_s \dfrac{M}{L_s} I_{rq} \\ \varphi_s = \dfrac{V_s^{\,2}}{\omega_s L_s} - V_s \dfrac{M}{L_s} I_{rd} \end{cases} \tag{4}$$

Two series of two PI controllers. The active and reactive power error signals are given to the two different PI controller which gives direct rotor current Ird* and quadrature current Irq* respectively. These two signals are compared with the generator currents, Ird and Irq and the error signal is given to the other two PI controllers. The outputof these controllers is rotor voltage Vrd and Vrq respectively

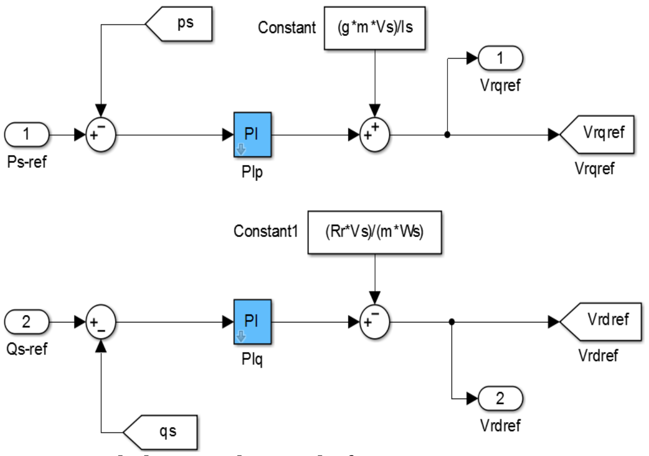

Fig. 2. Filed oriented control of DFIG.

The rotor current references can be estimated from the desired powers. Then, the control loops are utilized to ensure that these references are followed by the measured currents [19]

B. *Fuzzy control of the DFIG*

Fuzzy logic control, approaching the human reasoning that makes use of the tolerance, imprecision, and fuzziness in the decision-making process, manages to offer a very satisfactory performance, without the need of a detailed mathematical model of the system, 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 [20] [21].

The four main components of fuzzy logic controller are fuzzification, fuzzy inference engine, rule base and defuzzification. Inputs are fuzzified, then based on rule base and inference system, outputs are produced and finally the fuzzy outputs are defuzzified and applied to the main control system. Error of inputs from their references and error deviations are chosen as inputs[22].

The problem of selecting the suitable fuzzy controller rules remain relying on expert knowledge and try and error tuning methods. Rule bases are shown in Table 3 and 4. NB, N, ZE, P and PB represents negative big, negative, zero, positive and positive big respectively.

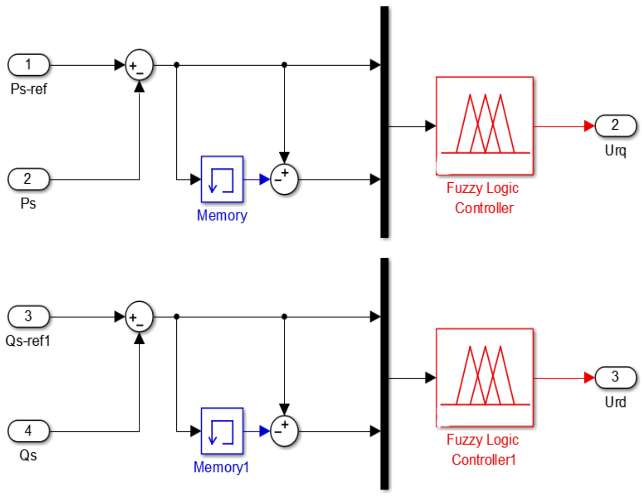

Fig. 3. Block diagram of fuzzy controller.

Figure 3 shows the block diagram of rotor side converter to which fuzzy controllers are applied. The main objectives of this part are active power and reactive power control.

IV. RESULTS AND DISCUSSION

The simulation is presented to investigation of dynamic behavior and the performances of proposed system with fuzzy logic and PI controller.

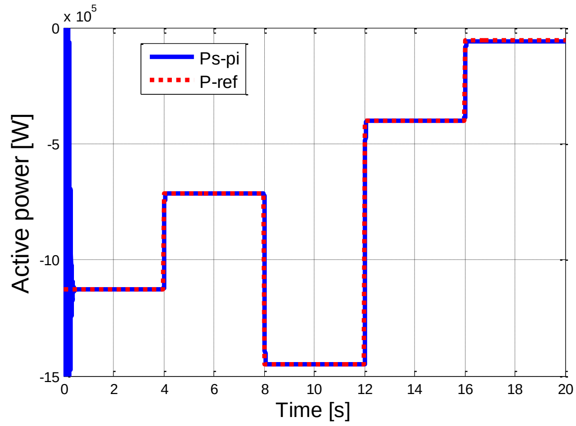

Fig. 4. Stator active power using PI controller

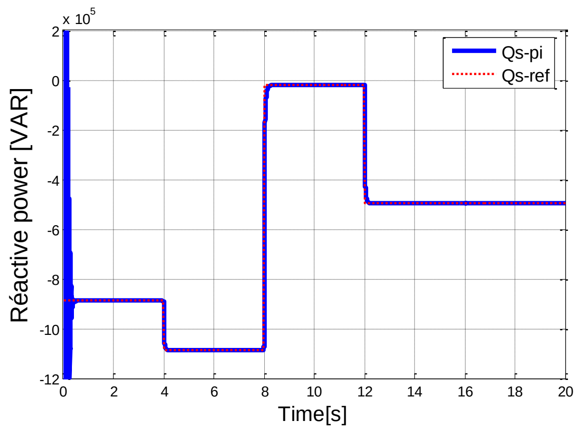

Fig. 5. Stator reactive power using PI controller

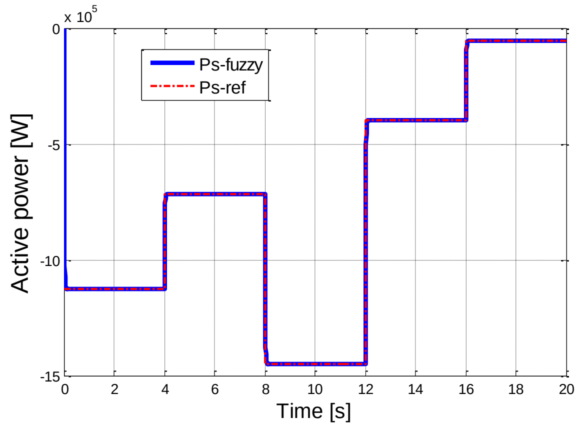

Fig. 6. Stator active power using FLC controller

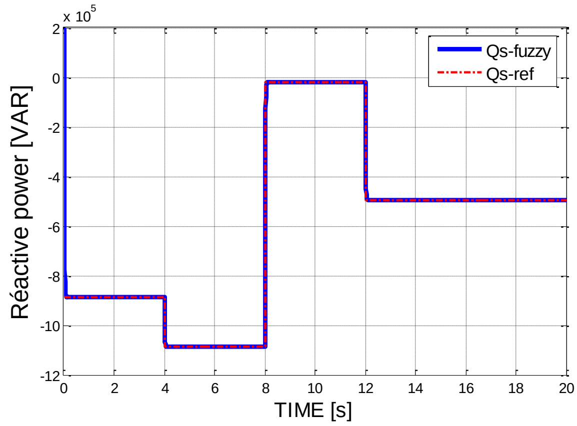

Fig. 7. Stator reactive power using FLC controller

V. ROBUSTNESS TESTSN

To test the robustness of the controllers used, parameters of the machine have been modified: the values of the stator and the rotor resistances are multiplied by 1.5, while the values of inductances Lr , Ls and M are divided by 1.5. The machine is running at its nominal speed. The results presented in Fig. 10 show that parameter variations of the DFIG present a clear effect on the power curves (their errors curves) and that the effect appears more significant for PI and controller than that with FLC one. Thus it can be concluded that this last is the most robust controller used in this work.

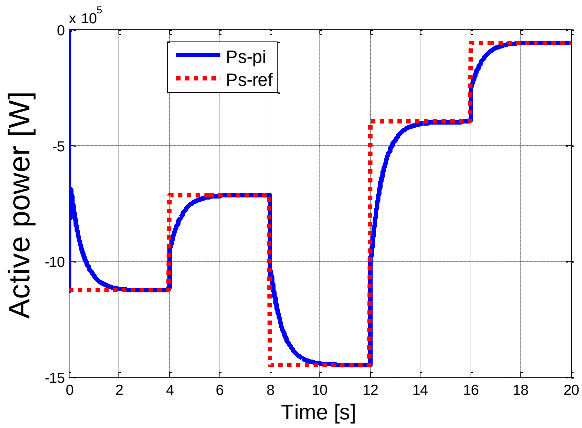

Fig. 8. Stator active power using PI controller

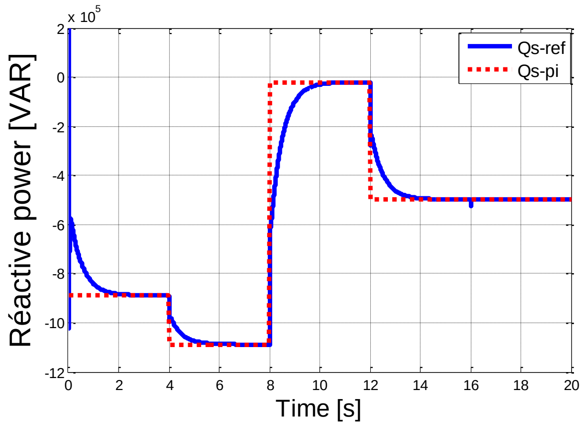

Fig. 9. Stator reactive power using PI controller

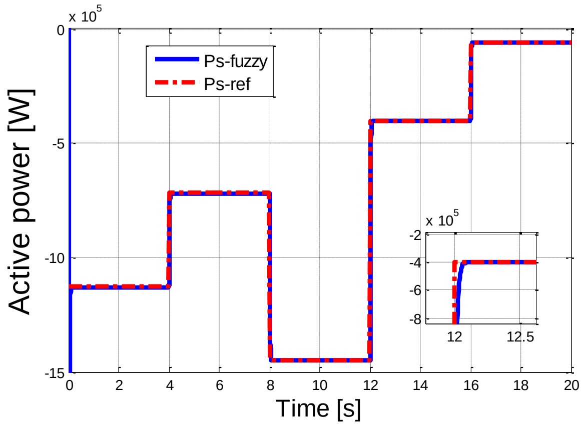

Fig. 10. Stator active power using FLC controller

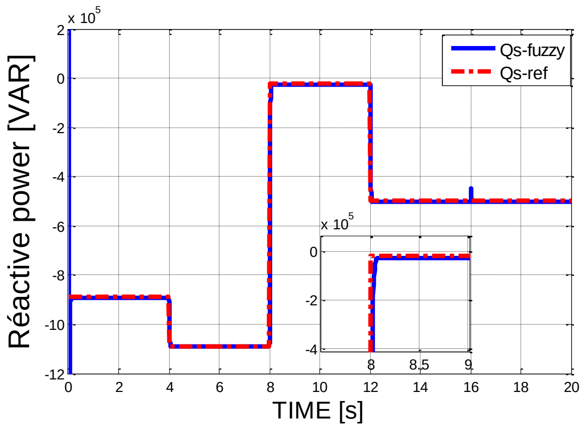

Fig. 11. Stator reactive power using FLC controller

VI. CONCLUSIONS

The modeling, the control and the simulation of a doubly fed induction generator has been described in this paper. At first, a model of the turbine and the generator are proposed. Then, a control strategy based on fuzzy logic and PI controllers allowing independent control of power has been presented. The objective was the implementation of a robust decoupled control the system of active and reactive powers generated by the side stator of the DFIG, 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.

Through the response characteristics obtained by the simulation results, the good performance is observed even in the presence of variations of targets. Moreover, by comparing the controller PI and fuzzy, it is clear that the fuzzy control is robust against parametric variations of the machine, provides fast convergence.

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