FUZZY CONTROL OF A DOUBLY FED INDUCTION GENERATOR FOR WIND TURBINES

K. MOUILAH*, M. ABID, A.NACERI, M.ALLAM

***IRECOM Laboratory, Electrotechnical Department, Sidi Bel-Abbes University, Algeria**
E-mail_Mouilahkheira@yahoo.fr

Abstract *In this paper, a fuzzy logic control is proposed to control the doubly-fed induction generator (DFIG) widely used as modern large wind turbine generators. This technique finds its strongest justification for the model uncertainties of non-linear systems. The objective is to control of the active and the reactive power generated by the asynchronous machine decoupled by flux orientation. The obtained results show the increasing interest of a such control in electric systems*

Keywords : Doubly fed induction generator, fuzzy logic control, Vector control, wind energy.

1. Introduction

Wind energy is one of the most growing uses of the renewable energy sources since it is clean and available, moreover, because of its reduced cost and improved techniques.

Many different structure and control algorithm can be used to control power converters. One of the most common control techniques is the active and reactive power decoupled by PI control to improve dynamic behavior of wind turbines [1-9]. But uncertainty about the exact model and behavior of some parameters such as wind, wind turbine, and also variation of parameter values, during operation because of the temperature, events or unpredictable wind speed are the main problems in the PI control method.

Using fuzzy control, we can produce controller outputs more reliable because of the effect of other parameters such as noise and events due to wide range of control region; and online changing of the controller parameters can be considered. Moreover without the need of a detailed mathematical model of the system and just using the knowledge of the total operation and behaviour of the system, tuning of parameters can be done more easily [10-12].

In this work, first, a wind turbine system is presented and its characteristics are depicted to estimate its dynamics and performances in different operating conditions. Then, a fuzzy logic control of the DFIG used to control independently the powers is proposed and tested on a wind turbine equipped with a DFIG of 10 kW.

2. Wind Turbine Characteristics

A total scheme of a wind energy conversion system connected to the electrical power grid is shown in Fig. 1.

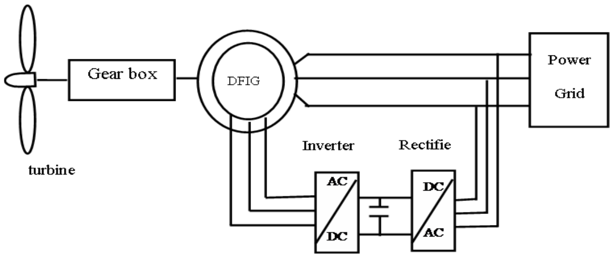

Fig.1 Wind energy conversion system based DFIG.

The power available on the wind turbine is given by [3] [4]:

$$P = \frac{1}{2}\rho C_p S v^3 \qquad (1)$$

where: ρ – air density, S – turbine area, v – wind speed, C_p – power coefficient.

For the wind turbine, the power coefficient C_p, depending on both, the wind speed and the turbine rotating speed, is defined between 0.35 and 0.5.

A wind turbine is dimensioned to develop on its shaft a nominal power p_n obtained from the nominal wind speed v_n. When the wind speed is higher than v_n, the wind turbine parameters must be modified to avoid the mechanics destroy [2, 5-6].

Beside the nominal speed v_n, it is also specified the starting speed v_d where the wind turbine starts producing energy and, the maximum wind speed $v_{\max}$ where the turbine does not convert any more the wind energy. The aerodynamic control principle that limits the power extracted from the turbine at nominal output power value of the generator is based on a “pitch” system [3, 5-6] to adjust the blades lift force at the wind speed, to maintain the power appreciably constant.

2.1 Mathematical Model of the DFIG

The generator chosen for the wind energy conversion is the doubly fed induction generator. Moreover, a DFIG controlled through its rotor is used with a speed variation range limitation of ±30% of the nominal speed. This choice permits the use of only one converter dimensioned for an output power of about 25 to 30% of its nominal output power. It will be thus less bulky, less expensive and will require a less cumbersome cooling system [9].
The DFIG model is described in the d-q Park reference frame, through the following equations [2], [3, 8-9].

$$\begin{cases} V_{ds} = R_s I_{ds} + \dfrac{d\varphi_{ds}}{dt} - \omega_s \varphi_{qs} \\ V_{qs} = R_s I_{qs} + \dfrac{d\varphi_{qs}}{dt} + \omega_s \varphi_{ds} \\ V_{dr} = R_r I_{dr} + \dfrac{d\varphi_{dr}}{dt} - (\omega_s - \omega_r)\varphi_{qr} \\ V_{qr} = R_r I_{qr} + \dfrac{d\varphi_{qr}}{dt} + (\omega_s - \omega_r)\varphi_{dr} \end{cases} \quad (2)$$

$$\begin{cases} \varphi_{ds} = L_s I_{ds} + L_m I_{dr} \\ \varphi_{qs} = L_s I_{qs} + L_m I_{qr} \\ \varphi_{dr} = L_r I_{dr} + L_m I_{ds} \\ \varphi_{qr} = L_r I_{qr} + L_m I_{qs} \end{cases} \quad (3)$$

Where: s/r are stator/rotor subscript; V/I – voltage/current; φ –flux; R – resistance; L_m – mutual inductance; σ – leakage coefficient, $\left(\sigma = 1 - L_m^2 / L_s L_r\right)$; L_r / L_s – rotor/stator leakage inductance; ω_r / ω_s – rotor/stator pulsation.

3. Control Strategy of the Doubly Fed Induction Generator

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. Moreover, the stator resistance can be neglected since it is a realistic assumption for the generators used in the wind turbine.
The DFIG is controlled by the rotor voltages via an inverter. It is an independent control of active and reactive powers. In the d-q reference frame and in an asynchronous generator stator, the active power P_s and reactive power Q_s are:

$$P_s = (V_{ds} I_{ds} - V_{qs} I_{qs}) \quad (4)$$

$$Q_s = (V_{qs} I_{ds} - V_{ds} I_{sq}) \quad (5)$$

The adaptation of these equations to the simplifying assumptions gives

$$P_s = -V_s \frac{L_m}{L_s} I_{qr} \quad (6)$$

$$Q_s = -V_s \frac{L_m}{L_s} I_{dr} + \frac{V_s^2}{L_s \omega_s} \quad (7)$$

$L_s \omega_s$ is the stator reactance. Equations showing the relationship between the rotor currents and voltages are established and will be applied to control the generator

$$V_{dr} = R_r I_{dr} + \left(L_r - \frac{L_m^2}{L_s}\right) \frac{dI_{dr}}{dt} - g\left(L_r - \frac{L_m^2}{L_s}\right)\omega_s I_{qr} \quad (8)$$

$$V_{qr} = R_r I_{qr} + \left(L_r - \frac{L_m^2}{L_s}\right) \frac{dI_{qr}}{dt} + g\left(L_r - \frac{L_m^2}{L_s}\right)\omega_s I_{dr} + g \frac{L_m V_s}{L_s} \quad (9)$$

Since the power grid frequency is imposed, $\dot{\theta}_r = g\omega_s$, $\dot{\theta}_r / \dot{\theta}_s$ – rotor/stator electrical speed, g is the DFIG slip. From equations (6), (7), (8) and (9), a block diagram containing the rotorique voltages as inputs and active and reactive statorique powers as outputs, is established in Fig. 2.

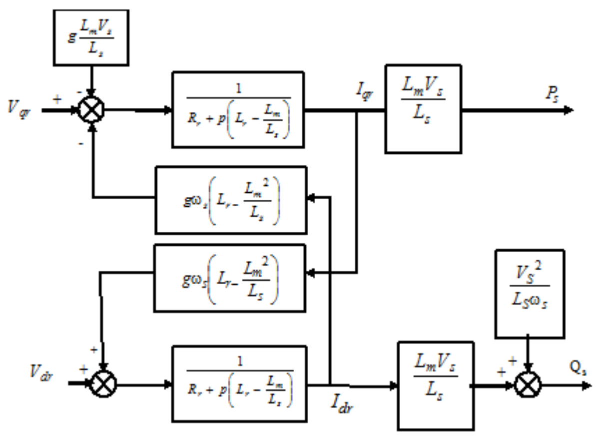

Fig. 2 Block diagram of the generator.

The powers and the voltages are linked by a first order transfer function. Since the slip value is weak, it is possible to establish a vectoriel control, because the influence of the coupling will remain weak and the d and q axes can be controlled separately by their own regulators.

4. Fuzzy Control

The control system is based on fuzzy logic. This type of control, approaching the human reasoning, making use of tolerance, uncertainty, imprecision and fuzziness in the decision-making process, managed to offer a very satisfactory performance, with no need of a detailed mathematical model of the system, but just incorporating the expert 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 operating conditions where linear control techniques fail (i.e., large parameter variations) [10-16].

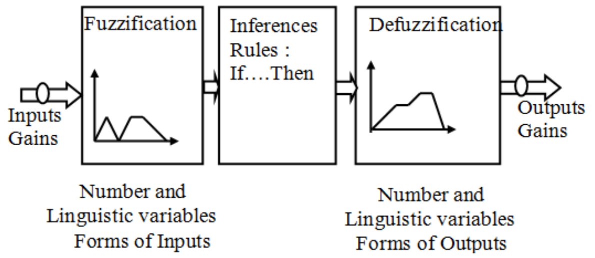

Fig. 3 Block diagram of fuzzy control.

As illustrated in Fig. 3, this paper focuses on fuzzy logic control based on mamdani's system. This system has three main parts. First, using input membership functions, the 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. In any time interval,the error and the error change rate are chosen as inputs.

Fig.4 shows the block diagram where fuzzy controllers are integrated to the rotor side converter to control the DFIG. The main objective of this part is the active power control and the reactive power control. As illustrated rotor side converter manages to follow reference active power and reactive power separately using fuzzy controllers. Based on equations (5) and (6), inputs of the fuzzy controller are the active and reactive power error and the error change rate in any time interval.

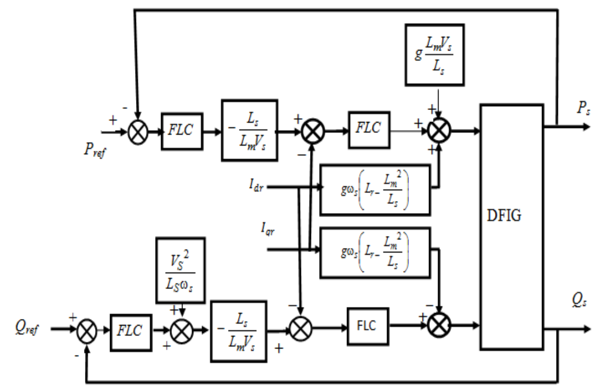

Fig. 4 Control scheme of DFIG.

5. FLC design

The inputs of the fuzzy controller are error (e) and error change rate (Δe). The output of the fuzzy controller is (Δu). The universe of (e), (Δe), and (Δu) are partitioned into three fuzzy sets. N (negative), Z (zero), P (positive). Each fuzzy set is represented by either triangular membership function or trapezoidal membership function.

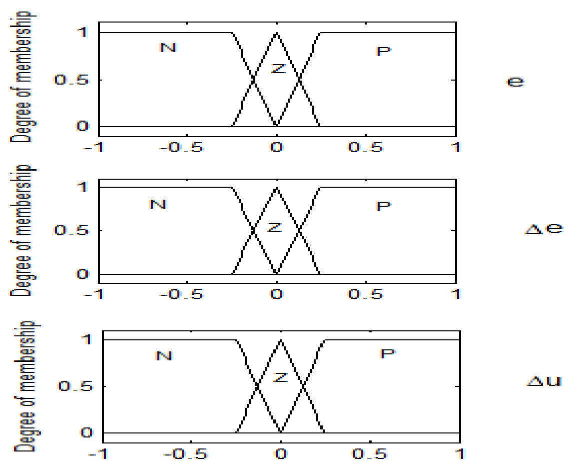

Fig.5 Membership functions.

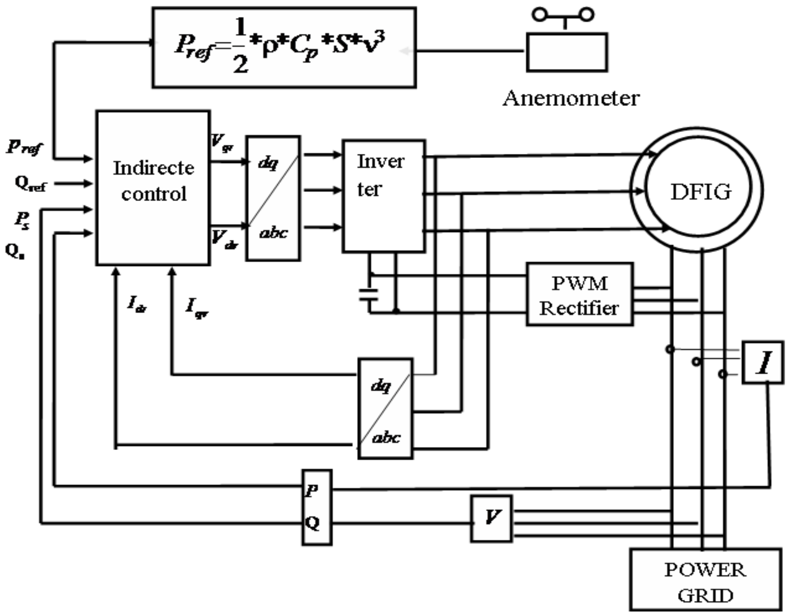

Fig.6 Blok diagram of the whole system

The rule base of the FLC contains nine rules based on the IF-THEN structure which are tabulated in Table1

Table1. Rules bases

Δu		Δe		
		N	Z	P
e	N	N	N	Z
	Z	N	Z	P
	P	Z	P	P

6. Simulation Results

Simulation is done to illustrate the fuzzy control performances applied to the DFIG. A bloc diagram is proposed in Fig. 6 to control the whole system

The parameters of the DFIG are:

$R_s = 0.455\ \Omega$, $L_s = 0.07\ H$, $R_r = 0.19\ \Omega$, $L_r = 0.0213\ H$, $L_m = 0.034\ H$, $V_s = 230\ V$.

The results plotted in the following figures show the powers generated when reference signals are applied. Fig.7 shows the answers with fuzzy controller. Whereas fig.8 shows the Effect the wind of a speed variation on the active power and reactive power, on the test of robustness of the proposed controller are represented on fig.9.

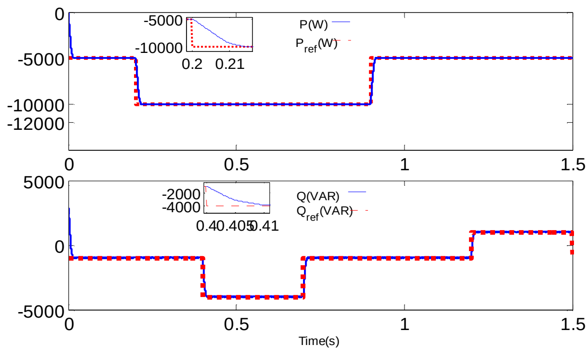

Fig.7 System responses with fuzzy controller.

The active and reactive powers follow the desired variables. In fuzzy logic control, the answers are without overshoots, no coupling effect; the static error goes to zero, rapid in transient state.

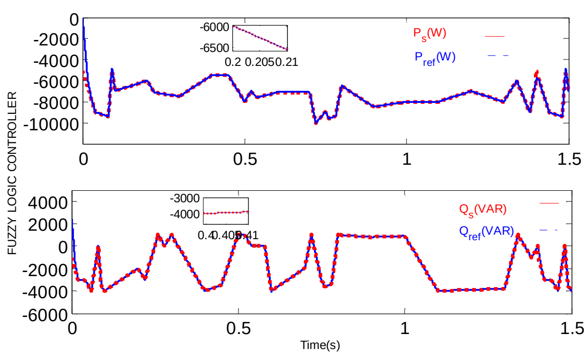

Fig.8 Effect the wind of a speed variation on the active power and reactive power.

In the wind power generation system, the DFIG is required to operate at variable speed and, meanwhile, the required active and reactive power references may also be variable.

Under this circumstance, the active power and reactive power of the DFIG follows the power reference calculated from the wind speed. this active power is limited by the generator nominal power (10kW).

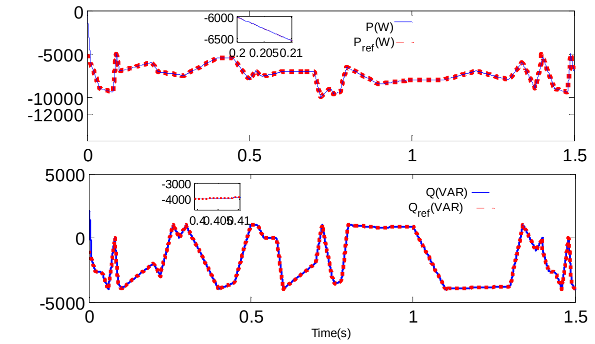

Fig.9 Reponse of system with (0.8*Lm, 0.8*Ls, 0.8*Lr).

A robustness test of the proposed controller was realised by a decrease of 20% in the rotor, stator and mutual inductances. The Fig.9 shows that the fuzzy controller gives satisfactory performances of robustness against parameters changes of the DFIG.

7. Conclusion

A complete fuzzy logic control based on wind generation system has been described in the paper. First, a generator model is proposed; then, a control strategy using fuzzy logic of the DFIG allowing an independent control of the powers is also proposed. The results show the improved quality of the control when using the fuzzy logic controller.

Through the response Characteristics, good performances are observed even in the reference signal variations. The output power follows the reference signal without overshoots.

The advantages of the fuzzy control are that it is parameter insensitive, provides fast convergence, and accepts noisy and inaccurate signals. The fuzzy algorithms are universal and can be applied retroactively in any system. System performance, both in steady state and dynamic conditions, is excellent.

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