Direct Active and Reactive Power Regulation of DFIG Using Fuzzy Adaptive PI Controller

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***Abstract* — Classic control of grid-connected DFIGs is usually based on either stator voltage oriented, or stator-flux-oriented vector control. Control of instantaneous stator active and reactive powers is then achieved by regulating the decoupled rotor currents, using PI controllers. One main drawback for this control scheme is that the performance highly relies on the tuning of the PI parameters and accurate machine parameters such as stator and rotor inductances and resistances. Thus, performance may degrade when actual machine parameters deviate from values used in the control system.**

In this paper, a novel controller is known as adaptive FLC-PI, where the fuzzy logic controller is used online to adjust the PI parameters.

***Keywords* —** DFIG - PI - FLC - Direct Power Control - Adaptive.

I. Introduction

Wind energy is one of the most important and promising sources 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 turbine technology.

Compared with other wind farm technologies DFIG offers several advantages such as lower converter cost, lower power losses, variable speed and four quadrants active and reactive power operation capabilities compared with the fixed-speed induction generators or synchronous generators with full sized converters. [1]

The Direct Power Control (DP) method directly controls the stator-side active and reactiveC powers by selecting voltage vectors from a lookup table using the information about the active and reactive powers of the stator. DPC of the DFIG is able to produce fast active and reactive power control with the hysteresis band and is robust with respect to the change of machine parameters and to perturbations. [1]

Our contribution consists of using a novel controller known as adaptive FLC-PI controller, where the fuzzy logic controller is used online to adjust the PI parameters.

This paper aims to show the techniques followed to control a DFIG power factor. Several significant simulation results, obtained after modeling the wind turbine, the generator and their overall control system in MATLAB/SIMULINK.

II. Modeling of Wind Turbine

A variable-speed wind turbine generally consists of an aeroturbine, a gearbox and a generator as shown in Fig. 1.

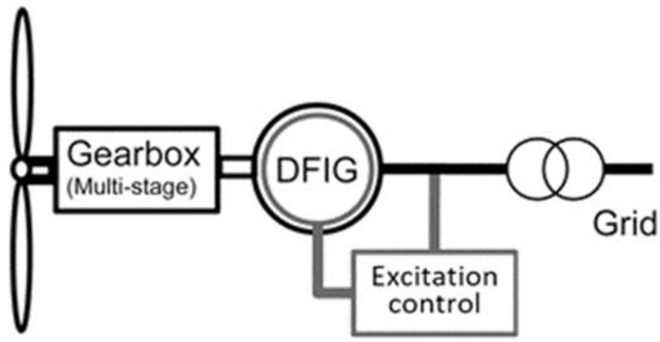

Fig. 1 The basic configuration of a DFIG wind turbine.

The aerodynamic power captured by the rotor is given by the following nonlinear expression: [2]

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

Where:

P_{mec}	power extracted from the wind
ρ	air density
R	radius of the turbine
v	wind speed

C_p power conversion coefficient

The power conversion coefficient C_p is expressed as follows:

$$C_p(\lambda,\ \beta) = c_1\left(c_2\frac{1}{\lambda_i} - c_3\beta - c_4\beta^x - c_5\right) exp\left(-c_6\frac{1}{\lambda}\right) \quad (2)$$

Where:

$$\frac{1}{\lambda_i} = \frac{1}{\lambda+0{,}08\beta} - \frac{0{,}035}{1+\beta^3} \quad (3)$$

and $c_1 = 0{,}5,\ c_2 = 116,\ c_3 = 0{,}4,\ c_4 = 0,\ c_5 = 5,\ c_6 = 21,\ x = 0.$

III. Modeling of DFIG

The most significant feature of this kind of wound-rotor machine is that it has to be fed from both stator and rotor side.

Normally, the stator is directly connected to the grid and the rotor is interfaced through a variable frequency power converter.

The operating principle of a DFIG can be analyzed using the classic theory of rotating fields and the well-known model, as well as both three-to-two and two-to-three axes transformations.

In this way, taking the general three-phase model of the electric machine dynamic performance as starting point, the "Quadrature-Phase Slip-Ring" model for the DFIG might be expressed through the following matrix equation: [3]

$$\begin{bmatrix} v_{sD} \\ v_{sQ} \\ v_{r\alpha} \\ v_{r\beta} \end{bmatrix} = \begin{bmatrix} R_s + sL_s & 0 & sL_m\cos\theta_r & -sL_m\sin\theta_r \\ 0 & R_s + sL_s & sL_m\sin\theta_r & sL_m\cos\theta_r \\ sL_m\cos\theta_r & sL_m\sin\theta_r & R_r + sL_r & 0 \\ -sL_m\sin\theta_r & sL_m\cos\theta_r & 0 & R_r + sL_r \end{bmatrix} \begin{bmatrix} i_{sD} \\ i_{sQ} \\ i_{r\alpha} \\ i_{r\beta} \end{bmatrix} \quad (4)$$

Where $s = d/dt$ represents the Laplace differential operator.

And:

v_{sD}, v_{sQ} Direct- and quadrature-axis stator voltage components, respectively, expressed in the stationary reference frame.

$v_{r\alpha}, v_{r\beta}$ Direct- and quadrature-axis rotor voltage components respectively, expressed in the rotor natural reference frame.

R_s, R_r Stator and rotor phase winding resistances, respectively.

L_s, L_r Rotor and stator inductances, respectively.

L_m Magnetizing inductance.

θ_r Rotor electrical angle.

i_{sD}, i_{sQ} Direct- and quadrature-axis stator current components respectively, expressed in the stationary reference frame.

$i_{r\alpha}, i_{r\beta}$ Direct- and quadrature-axis rotor current components respectively, expressed in the rotor natural reference frame.

IV. Fuzzy Adaptive PI control

The concept of fuzzy logic was introduced by Professor Lofti A. Zadeh to present vagueness in linguistic terms and express human knowledge in a natural way. Fuzzy systems use IF-THEN rules, where the IF part is called "antecedent" and the THEN part is called "consequent". The basic configuration of a pure fuzzy system is shown in Fig. 2. A fuzzy inference mechanism maps fuzzy IF-THEN rules from input space to output space by using fuzzy logic methods. [4]

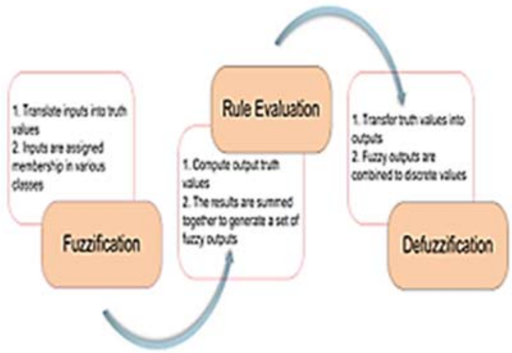

Fig. 2 Fuzzy system configuration.

In this paper, fuzzy logic approach is used to adjust K_P and K_I PI controller parameters online, using error e and the derivative of error as inputs for direct active and reactive power control of DFIG wind turbine as shown in Fig. 3

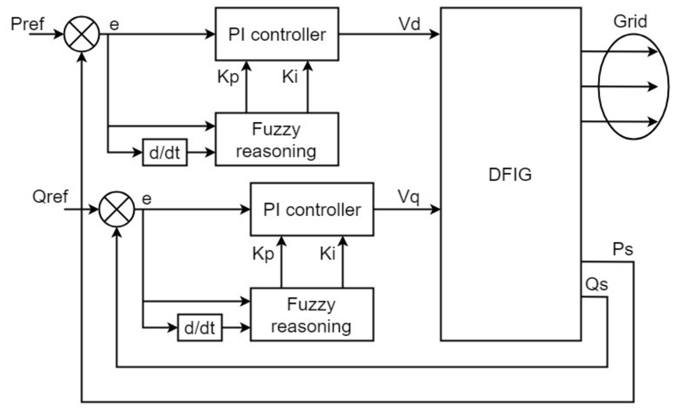

Fig. 3 DPC of a DFIG using adaptive FLC-PI controller.

V. Simulation and Results

The simulation for the proposed control strategy is

performed with Matlab/Simulink. Fig. 4 bellow show the realized model.

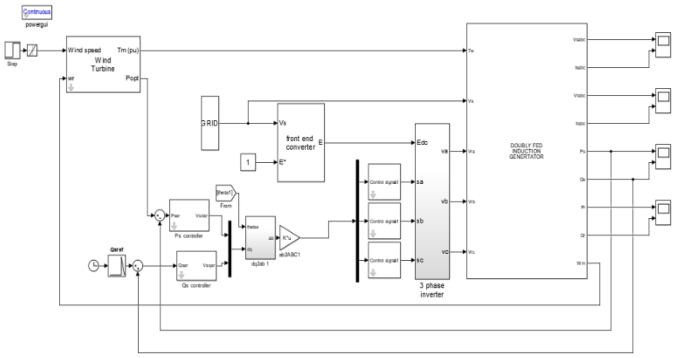

Fig. 4 MATLAB/SIMULINK model.

Where the following Fig. 5 and Fig.6 present Ps controller and Qs controller blocs respectively.

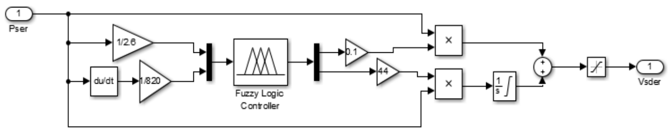

Fig. 5 Ps controller bloc.

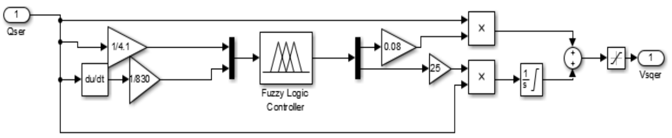

Fig. 6 Qs controller bloc.

The Fuzzy Inference System properties used to estimate the PI parameters is depicted on the fig. 7.

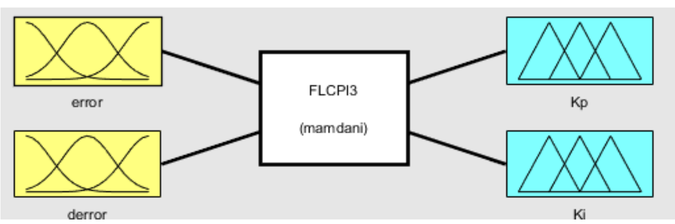

Fig. 7 FIS properties.

Where,

And method=min; Or method=max; Implication=min

Aggregation= max; Defuzzification=Centroid.

The centroid defuzzification returns the center of the area under the curve according to the equation below:

$$z_o = \frac{\int \mu_i(x) x dx}{\int \mu_i(x) dx} \quad (5)$$

The figures below show respectively the membership functions of the two inputs (error, derror) and the two outputs (Kp, Ki) which are the proportional and integral parameters of the PI controller. [5]

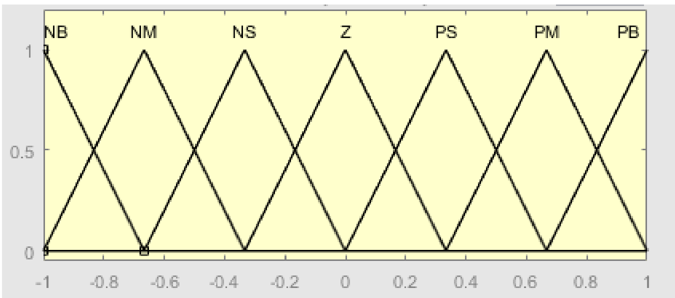

Fig. 8 Membership functions of the input error.

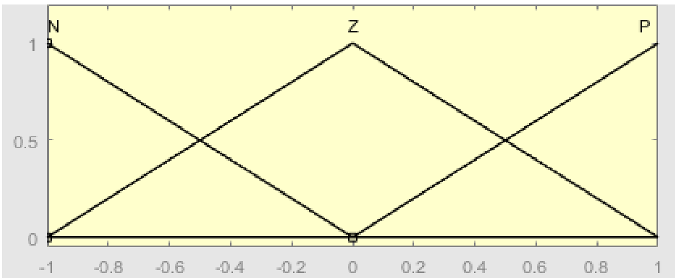

Fig. 9 Membership functions of the input derror.

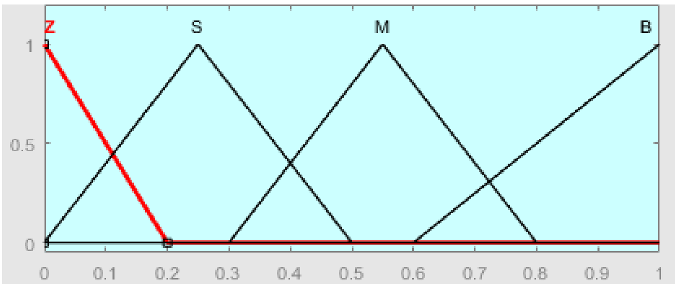

Fig. 10 Membership functions of the outputs Kp and Ki.

The rules of fuzzy control are shown in Table 1 bellow. [5]

TABLE I

FUZZY RULES TABLE FOR COMPUTING K_P AND K_I

Kp, Ki	**error**						
	NB	NM	NS	Z	PS	PM	PB

derror	N	B, Z	M, S	S, M	M, B	S, M	M, S	B, Z
	Z	B, Z	M, S	B, M	Z, B	B, M	M, S	B, Z
	P	B, Z	M, M	B, B	Z, B	B, B	M, M	B, Z

The simulation results are presented in the figures below:

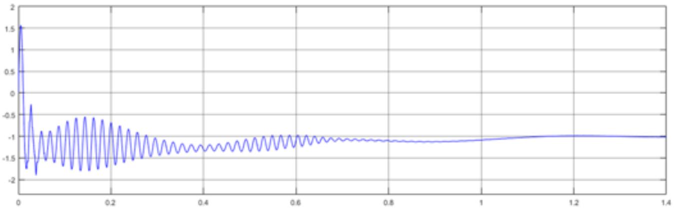

Fig. 11 Ps variations using PI controller

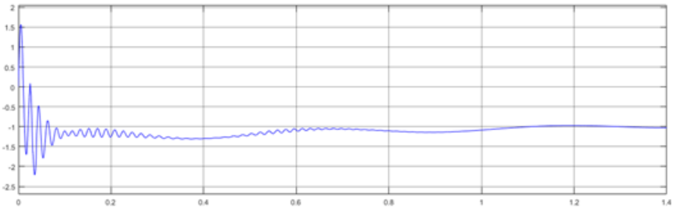

Fig. 12 Ps variations using FLC-PI controller

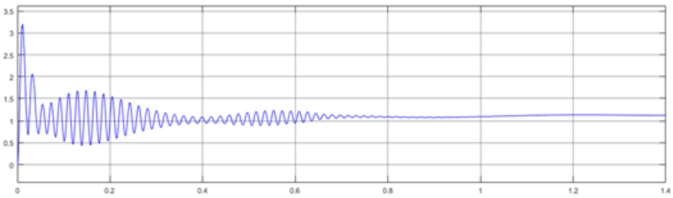

Fig. 13 Qs variations using PI controller

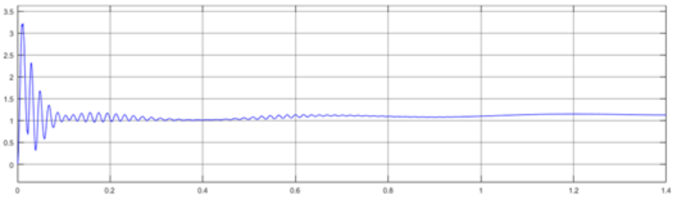

Fig. 14 Qs variations using FLC-PI controller

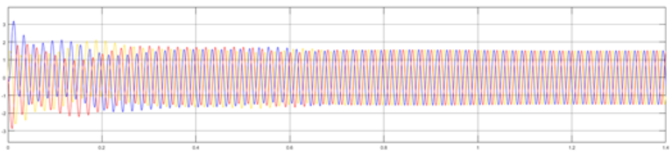

Fig. 15 Is variations when PI controller is used

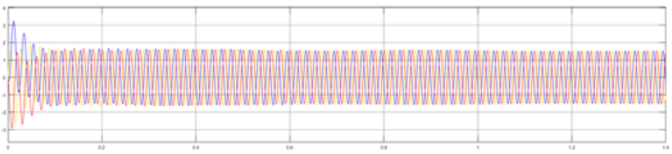

Fig. 15 Is variations when FLC-PI controller is used

VI. Conclusion

This paper proposes a new direct active and reactive power control (DPC) of grid-connected doubly fed induction generator (DFIG)-based wind turbine systems. The proposed DPC strategy employs a nonlinear fuzzy adaptive PI control scheme to directly calculate the required rotor control voltage so as to eliminate the instantaneous errors of active and reactive powers,

A comparative study between PI direct stator active and reactive powers control and proposed fuzzy adaptive PI, shows that not only the active and reactive power responses precision have been improved, but also the stator current ripples have been effectively decreased, and the robustness of the whole system has been enhanced.

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