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Speed Control of Doubly Fed Induction Motor using Fuzzy Logic Controller

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Abstract **- This paper presents a comparison between a fuzzy logic controller and a conventional PI controller used for speed control with a direct stator flux orientation control of a doubly fed induction motor. The effectiveness of the proposed control strategy is evaluated under different operating conditions such as of reference speed and for load torque step changes at nominal parameters and in the presence of parameter variation. Simulation results show that the fuzzy logic controller is more robust than a conventional PI controller against parameter variation and uncertainty, and is less sensitive to external load torque disturbance with a fast dynamic response.**

Index Terms - direct stator flux orientation control, doubly fed induction motor, fuzzy logic controller, Fuzzy PI controller, conventional PI controller.

I. Introduction

Introduction Due to many freedom degrees, the Doubly Fed Induction Machine (DFIM) presents several advantages as well as motor application in high power applications such as traction, marine propulsion or as generator in wind energy conversion systems like wind turbine, or pumped storage systems [1]. The DFIM has some distinct advantages compared to the conventional squirrel-cage machine. The DFIM can be fed and controlled stator or rotor by various possible combinations. Indeed, the input–commands are done by means of four precise degrees of control freedom relatively to the squirrel cage induction machine where its control appears quite simpler. The flux orientation strategy can transform the non linear and coupled DFIM-mathematical model to a linear model conducting to one attractive solution as well as under generating or motoring operations [2], [3]. Several methods of control are used to control the induction motor among which the vector control or field orientation control that allows a decoupling between the torque and the flux, in order to obtain an independent control of torque and the flux like DC motors [4]. Therefore, decoupling the control scheme is required by compensation of the coupling effect between q-axis and d-axis current dynamics [4].

In this study, we suggest a control scheme to achieve the goal of speed regulation with direct stator flux orientation control DFIM drive and fuzzy logic control (Fuzzy-PI).

1. Machine STATE-EQUATIONS

The electrical model of the DFIM is expressed in a (d-q) synchronous rotating frame. The control is done under the following considerations: An input-output current decoupling is set for all currents; The(d-q) frame is oriented with the stator flux; Due to the large gap between the mechanical and electrical time constants, the speed can be considered as invariant with respect to the state vector. Under these conditions, the electrical equations of the machine are described by a time variant state space system as shown in (1):

$$X = A.X + B.U$$

$$Y = C.X$$

With,

$$X = [i_{sd}\ i_{sq}\ i_{rd}\ i_{rq}]^T$$

$U=[V_{sd}\ V_{sq}\ V_{rd}\ V_{rq}]^T$

$$A=\begin{bmatrix} -a_1 & a\omega+\omega_s & a_3 & a_5\omega \\ -a\omega-\omega_s & -a_1 & -a_5\omega & a_3 \\ a_4 & -a_6\omega & -a_2 & -\frac{\omega}{\sigma}+\omega_s \\ a_6\omega & a_4 & \frac{\omega}{\sigma}-\omega_s & -a_2 \end{bmatrix}, \quad B=\begin{bmatrix} b_1 & 0 & -b_3 & 0 \\ 0 & b_1 & 0 & -b_3 \\ -b_3 & 0 & b_2 & 0 \\ 0 & -b_3 & 0 & b_2 \end{bmatrix},$$

$$C=\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where:

$$a=\frac{1-\sigma}{\sigma}, \quad a_1=\frac{R_s}{\sigma L_s}, \quad a_2=\frac{R_r}{\sigma L_r}, \quad a_3=\frac{R_r M}{\sigma L_s L_r}, \quad a_4=\frac{R_s M}{\sigma L_s L_r}, \quad a_5=\frac{M}{\sigma L_s},$$

$$a_6=\frac{M}{\sigma L_r}, \ b_1=\frac{1}{\sigma L_s}, b_2=\frac{1}{\sigma L_r}, \ b_3=\frac{M}{\sigma L_s L_r}, \ \sigma=1-\frac{M^2}{L_s L_r}$$

The mechanical equation is expressed by (2):

The electromagnetic torque is given by :

$C_e = \quad (\Phi_{sq}.\ i_{rd} - \Phi_{sd}.\ i_{rq})$

$J \ = C_e - C_r - f\,\Omega$

II. Stator Flux Estimator

For the DSFOC of DFIM, accurate knowledge of the magnitude and position of the stator flux vector is necessary. In a DFIM motor mode, as stator and rotor current are measurable, the stator flux can be estimated (calculate). The flux estimator can be obtained by the following equations [10]:

$\Phi_{sd}= L_s\, i_{sd} + M\, i_{rd}$

$\Phi_{sq}= L_s\, i_{sq} + M\, i_{rq}$

The position stator flux is calculated by the following equations:

$\theta_r = \theta_s - \theta$

In which:

$\theta_s \ = \int \omega_s dt\ ,\ \theta = \int \omega dt\ ,\ \omega = P\Omega\ .$

III. Fuzzy logic controller

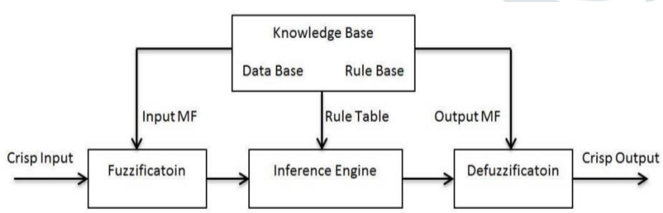

Figure 1: The structure of fuzzy logic controller

Fuzzy logic, FL, is another class of artificial intelligence. Its goal is planting human intelligence in a system so that the system can think intelligently like a human being.

1. Knowledge base

The Knowledge base is composed of data base and rule base. Data base consist of input and output membership functions that provides information for appropriate fuzzification and defuzzification operations.

The rule base contains a set of linguistic rules that provide information for the inference engine. A typical fuzzy rule is given as IF X is SLOW AND/OR Y is MIDDLE THEN Z is Fast 31 Where X and Y are input variable, Z is output variable, SLOW, MIDDLE, and FAST are fuzzy sets, AND and OR are fuzzy operators.

2. Fuzzification

Fuzzification is the process in which the crisp input value is converted into fuzzy number by using the input membership function.

3. Inference engine

Fuzzy inference engine is the process that relates input fuzzy sets to output fuzzy sets using if-then rules and fuzzy operators to drive a reasonable output fuzzy value. There are number of inference systems like Mamdani, Lusing Larson, and Sugeno.

4. Defuzzification

Defuzzification converts the fuzzified output value to crisp control value using the output membership function. The most famous defuzzification methods are Center of area, Height, Mean of maxima, and Sugeno.

IV.Fuzzy Membership Function

Membership function MF is a curve that defines how the values of a fuzzy variable in a certain region are mapped to a membership value μ (degree of membership) between 0 and 1. Membership function can have different shapes such as triangular, 30 trapezoidal, Gaussian, and generalized bell as shown if figure 3.4. The most commonly used MF is the triangular type, which can be symmetrical or asymmetrical in shape.

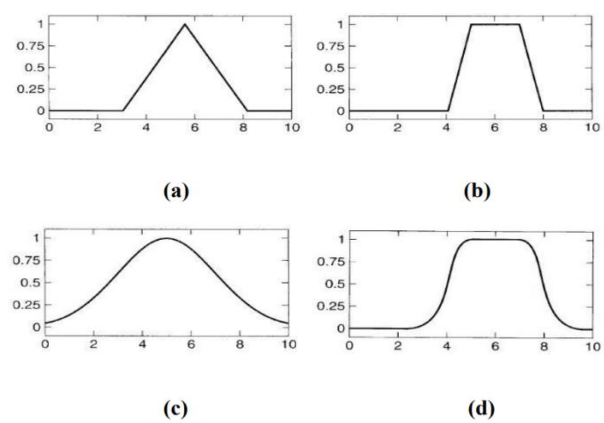

Figure 2: Different types of membership functions (a) triangular (b) trapezoidal (c) Gaussian (d) generalized bell

V.Simulation results

The DFIM used in this work is a 0.8 kW, whose nominal parameters are reported in appendix. The Fuzzy-PI controller in a DSFOC drive system. as presented in Figure 1. The Figure 3 presents the block diagram of fuzzy logic control of the DFIM using MATLAB/SIMULINK.

As shown in this figure, the speed loop uses a fuzzy logic controller (Fuzzy-PI) and the stator flux is controlled by PI controller. The block "command system by PI controller" is the vector control, which to produce the quadrature-axis rotor current reference which controls the motor torque. The motor flux is controlled by direct-axis rotor current reference.

As shown in Figure 6, the speed of the DFIM is controlled even though the torque is varied. The controlling is done by varying the phase current which is done through Fuzzy logic controller. Hence, Fuzzy logic controller attains to steady state when compared to other type of Controllers.

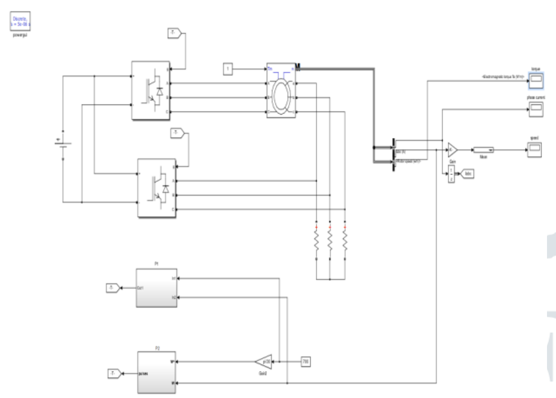

Figure 3: Simulink model of Doubly fed Induction motor

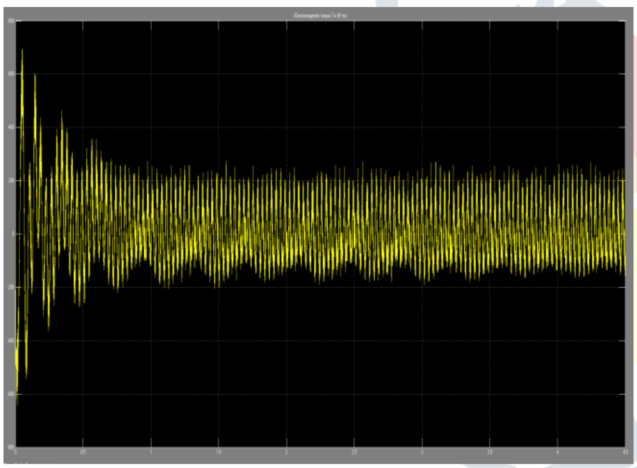

Figure 4: Torque V/S Time plot

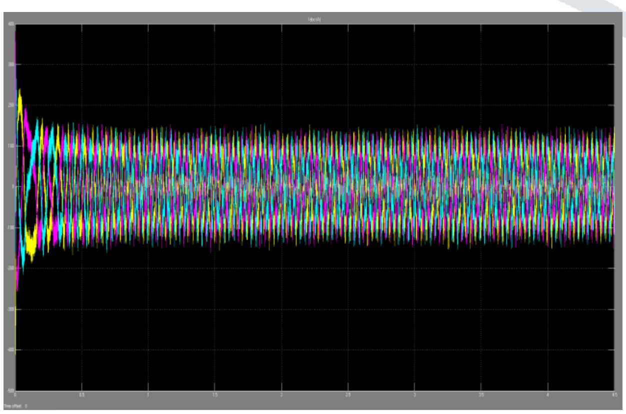

Figure 5: Phase current V/S Time plot

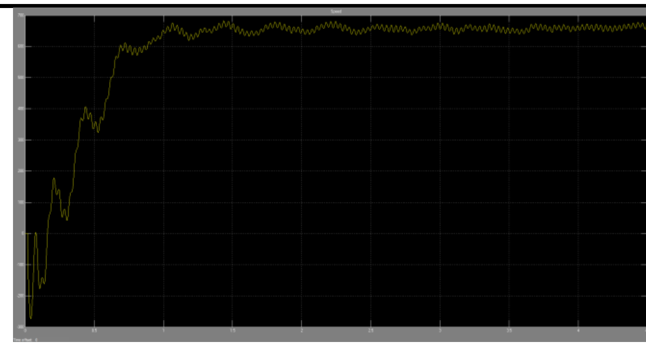

Figure 6: Speed controlled waveform

1. Conclusion

In this paper, we have proposed a fuzzy logic controller for the speed control of doubly fed induction motor with a direct stator flux orientation control. The effectiveness of the proposed controller has been tested on DFIM in comparison with conventional IP controller under different operating conditions. The fuzzy PI regulator proves robustness against rotor resistance variation and insensitivity to load torque disturbance as well as faster dynamics with negligible steady state error at all dynamic operating conditions. Simulation results have shown correct stator flux oriented control behavior and speed tracking performances.

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