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Indirect rotor field oriented control based on fuzzy logic controlled double star induction machine

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ABSTRACT

The difficulty of control in the induction machine is due to the coupling of the torque and flux since the load torque change induces unavoidably the flux variation. So, to ensure separately the control of these two variables, the field oriented control is often used. Also, the efficiency of the latter technique is closely related to the conventional proportional integral controller parameters. Evidently, it is suitable to use controllers which are independent of the parameters variations as an alternative solution. For this purpose, fuzzy logic controllers associated to the indirect field oriented control (IFOC) of a double star induction machine (DSIM) are then used and the performance of the system is finally tested under different operating conditions. The results obtained in MatLab/Simulink environment are presented and show that the proposed structure of control is more robust and non-sensitive versus the rotor resistance variation of the machine.

1. Introduction

The field oriented control (FOC) has been widely used for the electrical variable speed drive. The use of an FOC aims to ensure a decoupling control of the flux and the torque in order to obtain an independent control like DC motors [1,2]. However, the efficiency of control depends on the variation of motor parameters [3]. This kind of control has been used to three-phase induction machine for a long time. Nevertheless, multiphase machines are very suitable for high power systems because of their several advantages [4–6]. The multi-phase machines could be an interesting alternative for variable speed control drive because they possess several advantages over three phase machine. In the multiphase machine windings are housed in the same stator and the current per phase is thereby reduced. The double star induction motor (DSIM) is a typical example of the above mentioned machines. It has two windings whose phases are spatially shifted by $\alpha = 30$ electrical degrees with isolated neutrals [7]. These windings are generally fed by two voltage source inverters (VSI) in variable speed drive.

The indirect field oriented control (IFOC) method is the most commonly used because of its relative simplicity and low cost of implementation. But, this control is influenced by the motor parameters variations, essentially the rotor resistance of the machine [8,9]. In fact, the main drawback of the classical PI controllers is the sensitivity of their performance versus the parameters variations of the system and their usability to reject the internal disturbances.

Recently, fuzzy logic controller (FLC) has been successfully used for a few number of non-linear and complex processes [10,11]. In the design of FLC, the mathematical model is not necessary. Consequently, they are robust and their efficiencies are not sensitive to the parameter variations compared to the conventional controllers. So, in this study, a robust control method based on fuzzy logic is proposed. For this reason, the fuzzy logic controllers have been suggested to obtain robust performance of indirect field oriented control.

This work presents a comparative study between a conventional PI controllers and fuzzy logic controllers used in the associated to the indirect field oriented control. The results obtained by MatLab/Simulink are discussed. The simulation results show that the proposed method can yields very satisfactory performances.

The rest of this paper is organized as follows. In Section 2, modeling of de machine is given. Sections 3 present the field control. The structure proposed is given in Section 4, and the results are presented and discussion in Section 5. Finally, conclusion is presented in Section 6.

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2. Double star induction machine modeling

Each winding of a double star induction motor contains three phases distributed and their magnetic axes are displaced by 120° apart. In the synchronous reference frame $(d,\ q)$, the electrical equations of DSIM are given by following system [7,12,13].

$$\begin{cases} \dfrac{d}{dt}\Phi_{ds1} = V_{ds1} - R_{s1} i_{ds1} + \omega_s \Phi_{qs1} \\ \dfrac{d}{dt}\Phi_{qs1} = V_{qs1} - R_{s1} i_{qs1} - \omega_s \Phi_{ds1} \\ \dfrac{d}{dt}\Phi_{ds2} = V_{ds2} - R_{s2} i_{ds2} + \omega_s \Phi_{qs2} \\ \dfrac{d}{dt}\Phi_{qs2} = V_{qs2} - R_{s2} i_{qs2} - \omega_s \Phi_{ds2} \\ \dfrac{d}{dt}\Phi_{dr} = V_{dr} - R_r i_{dr} + \omega_a \Phi_{qr} \\ \dfrac{d}{dt}\Phi_{qr} = V_{qr} - R_r i_{qr} - \omega_a \Phi_{dr} \end{cases} \tag{1}$$

Where the expressions for stator and rotor flux are:

$$\begin{cases} \Phi_{ds1} = L_{s1} i_{ds1} + L_m i_D \\ \Phi_{qs1} = L_{s1} i_{qs1} + L_m i_Q \\ \Phi_{ds2} = L_{s2} i_{ds2} + L_m i_D \\ \Phi_{qs2} = L_{s2} i_{qs2} + L_m i_Q \\ \Phi_{dr} = L_r i_{dr} + L_m i_D \\ \Phi_{qr} = L_r i_{qr} + L_m i_Q \end{cases} \tag{2}$$

With

$$i_D = i_{ds1} + i_{ds2} + i_{dr}; \quad i_Q = i_{qs1} + i_{qs2} + i_{qr} \quad \text{and} \quad \boldsymbol{\omega_a = \omega_s - \omega_r}$$

The mechanical equation is expressed by (3), where the equation of the electromagnetic torque is given by (4):

$$J\frac{d}{dt}\Omega = T_{em} - T_l - k_f \Omega \tag{3}$$

$$T_{em} = \frac{pL_m}{L_r + L_m}[\Phi_{dr}(i_{qs1} + i_{qs2}) - \Phi_{qr}(i_{ds1} + i_{ds2})] \tag{4}$$

3. Field oriented control

The objective of space vector control is to assimilate the operating mode of the induction machine at the one of a DC machine with separated excitation, by decoupling the torque and the flux control. Therefore, decoupling the control scheme is required by compensation of the coupling effect between d and q axis current dynamic. The indirect field oriented control (IRFOC) [3,14,15] consists in making $\Phi_{qr} = 0$ while the rotor direct flux (Φ_{dr}) converges to the reference flux (Φ_r).

By applying this principle $(\Phi_{qr} = 0$ and $\Phi_{dr} = \Phi_r^*)$ into (1), (2), and (4) equations, the finals expressions of the electromagnetic torque and slip speed are respectively:

$$T_{em} = pL\Phi_r^*(i_{qs1}^* + i_{qs2}^*) \tag{5}$$

$$\omega_{sr}^* = \frac{LR_r(i_{qs1}^* + i_{qs2}^*)}{\Phi_r^*} \tag{6}$$

With

$$L = \frac{L_m}{L_r + L_m}$$

The voltage stators compensation are expressed by the following equations:

$$\begin{cases} V_{ds1}^* = R_{s1} i_{ds1} + L_{s1}\frac{di_{ds1}}{dt} - \omega_s^*(L_{s1} i_{qs1} + T_r \Phi_r^* \omega_{sl}^*) \\ V_{qs1}^* = R_{s1} i_{qs1} + L_{s1}\frac{di_{qs1}}{dt} + \omega_s^*(L_{s1} i_{ds1} + \Phi_r^*) \\ V_{ds2}^* = R_{s2} i_{ds2} + L_{s2}\frac{di_{ds2}}{dt} - \omega_s^*(L_{s2} i_{qs2} + T_r \Phi_r^* \omega_{sl}^*) \\ V_{qs2}^* = R_{s2} i_{qs2} + L_{s2}\frac{di_{qs2}}{dt} + \omega_s^*(L_{s2} i_{ds2} + \Phi_r^*) \end{cases} \tag{7}$$

The torque expression shows that the reference flux and stator currents in quadrate are not perfectly independents, for this, it is necessary to decouple torque and flux control of this machine by introducing new variables:

$$\begin{cases} V_{ds1} = R_{s1} i_{ds1} + L_{s1}\frac{di_{ds1}}{dt} \\ V_{qs1} = R_{s1} i_{qs1} + L_{s1}\frac{di_{qs1}}{dt} \\ V_{ds2} = R_{s2} i_{ds2} + L_{s2}\frac{di_{ds2}}{dt} \\ V_{qs2} = R_{s2} i_{qs2} + L_{s2}\frac{di_{qs2}}{dt} \end{cases} \tag{8}$$

To compensate the error introduced at decoupling time, the voltage references $(V_{ds1}^*,\ V_{ds2}^*,\ V_{ds1}^*,\ V_{ds2}^*)$ at constant flux are given by:

$$\begin{cases} V_{ds1}^* = V_{ds1} - V_{ds1c} \\ V_{qs1}^* = V_{qs1} + V_{qs1c} \\ V_{ds2}^* = V_{ds2} - V_{ds2c} \\ V_{qs2}^* = V_{qs2} - V_{qs2c} \end{cases} \tag{9}$$

With

$$\begin{cases} V_{ds1c} = \omega_s^*(L_{s1} i_{qs1} + T_r \Phi_r^* \omega_{sr}^*) \\ V_{qs1c} = \omega_s^*(L_{s1} i_{ds1} + \Phi_r^*) \\ V_{ds2c} = \omega_s^*(L_{s2} i_{qs2} + T_r \Phi_r^* \omega_{sr}^*) \\ V_{qs2c} = \omega_s^*(L_{s2} i_{ds2} + \Phi_r^*) \end{cases} \tag{10}$$

$$\text{Accepting that}: i_{ds1}^* = i_{ds2}^* \quad \text{and} \quad i_{qs1}^* = i_{qs2}^* \tag{11}$$

In order to obtain a perfect decoupling, stator currents regulation loops are added and at their respective output, stator voltages are obtained. Fig. 1 shows internal structure of the IFOC bloc. The control scheme consists mainly of four fuzzy logic controllers. The actual currents i_{ds1}, i_{qs1}, i_{ds2} and i_{qs2} are compared with their reference currents i_{ds1}^*, i_{qs1}^*, i_{ds2}^* and i_{qs2}^* respectively. The resulting error and error variation for each current are the inputs variables of FLC. Furthermore, the outputs of these controllers are V_{ds1}, V_{qs1}, V_{ds2} and V_{qs2}.

4. Fuzzy logic controller

In this section, the principles of fuzzy controllers, their design and their use in indirect field oriented control of the DSIM are illustrated. The fuzzy logic theory is based on the techniques of artificial intelligence and was first proposed and investigated by Zedeh [16]. Fuzzy logic controller (FLC) is an appropriate method for designing nonlinear controllers via the use uf heuristic information and operates in know ledge-based way and is expressed by means of roles with human language know ledge relies on a set of linguistic *if…then* rules. The bloc diagram of FLC is shown in Fig. 2. It is composed from the following blocs: fuzzification interface, knowledge base, inference. The fuzzification module converts the crisp values of the control inputs into fuzzy values. The data base and the rules the knowledge base which is used to obtain the inference relation. The data base contains a description of input and output variables using fuzzy set. The rule base is essentially the control strategy of the system. The mathematical procedure of converting fuzzy values into crisp value is known as defuzzification [17–19].