Application of Hyper-Fuzzy Logic Type -2 in Field Oriented Control of Induction Motor with Broken Bars

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Abstract: The aim for this paper is a proportional and integral (PI) controller and fuzzy logic type-2 (FLCT2) controller devoted to improve the performance of Indirect field orient control (IFOC) strategy of induction motor with broken bars. In addition, the paper describes a model of induction motor in d-q reference frame theory and its computer simulation in MATLAB/SIMULINK®, fed by Pulse Width Modulation (PWM) inverter to be studied. The performance of the Indirect Field orientated control with a PI and FLCT2 is tested under different speed command and load disturbances. And also show a better robustness beside the parametric variations of the motor. Type 2 fuzzy logic systems have recently been utilized in many control processes due to their ability to model uncertainty, so we are concerned with the use of a new fuzzy logic type-2 controller to improve the performance of conventional PI controller.

Key words: induction motor, fuzzy logic type-2, Indirect field orient control, Robustness, Rotor fault.

I. INTRODUCTION

The induction motor (IM) has great variety of applications in industrial process when is used as fans or pumps, heating and air conditioning. Its design simplicity, reliability, absence of collector is the main reasons for its success. But its mathematical model is complex, multi-variable or linear, with a strong coupling between the variables, input, and output and internal, which has long delayed the onset of effective; appropriate controls this type of engine [1]. Although the induction motor is well constructed and robust, the possibility of faults is inherent due to stresses involved in the conversion of electrical to mechanical energy and vice verse. For productivity and safety reason, there has been an increasing demand for automated preventive maintenance and fault diagnostic system.

In the recent years, the reliability of the electric machine drives, particularly in some critical applications has become a very interesting research topic. In the literature, many researches have been presented on the fault-tolerant control strategies of electric machine drives [12-13]. In [12-14], some methods to control a 3-phase IM under speed-sensor fault, in [10-14], different methods to control a 3-phase motor under open-circuit fault and in [10-13], some techniques to control an IM under inverter faults have been proposed.

In this manner, over the past 30 years, several artificial intelligence techniques have been developed and applied in the monitoring processes of faults, among them, the Artificial Neural Networks (ANNs), Fuzzy Logic (FL) [2-3]. The most commonly used controller for the speed control of Induction motor is Proportional plus Integral (PI) controller However, the PI controller has some demerits such as: the high starting overshoot, sensitivity to controller gains and sluggish response due to sudden disturbance. To overcome these problems, replacement of PI controller by an intelligent controller based on Fuzzy set theory is proposed in this work.

Field Oriented Control (FOC) is theoretically a onlinear control technique that linearizes the complex dynamics of the induction motor. Rotor flux indirect FOC, which is the more simplest decoupling scheme, is widely used in many industrial applications. This paper deals with fuzzy based fault detection and control of an induction motor. As an intelligent control technology the FLC type-2 has the potential to accommodate an improved method of determining nonlinear models which are complementary to conventional techniques [16]. The fuzzy algorithm is based on intuition and experience and can be regarded as a set of heuristic decision rules. This concept of fault diagnosis consists of two steps. First, the parameters which reflect faults in the process behavior are measured. In the second step, a decision is made by determining the type of faults from the change in parameters. This paper is used to comparing between these methods of control (FOC and FLCT2). This occurs through the simulation theses controls with using the MATLAB program. The rest of the paper is divided into five sections, Field Oriented Control is presented in Section 2. Fuzzy logic type-2 system is dealt in Section 3. In Section 4 the fault diagnosis concept and its simulation using fuzzy logic type-2 is explained. Section 5 concludes the paper.

II. FIELD ORIENTED CONTROL

The field oriented control introduced for the first time at the hands of Blashka in 1971 as an alternative to bring the induction motor instead of the DC motor in industrial applications that required high dynamic performance [5]. In FOC, the space phasor of the stator current is decoupled into two components torque current component and flux current component. To implement that, the position and magnitude of the rotor flux are required and this can be done directly by using sensor to measure the rotor flux or indirectly by estimating the rotor flux. In this paper the rotor flux is estimated by indirect method [6-8]. This means that, the d-axis rotor flux is equal to the rotor flux and the q-axis rotor flux becomes zero so the rotor flux can be calculated as[7-15].

$$\Phi_r = \frac{M}{1 + s T_r} I_{ds}$$

(1)

$$\omega_r = \frac{M}{T_r \Phi_r} I_{qs}$$

The electromagnetic torque is found as:

$$C_e = \frac{3}{2} p \cdot \left(\Phi_{ds} \cdot I_{qs} - \Phi_{qs} \cdot I_{ds} \right)$$

(2)

The equations tension of the machine is written to the system related to the rotating field configuration as follows:

$$
\begin{cases}
V_{ds} = R_s \cdot I_{ds} + \frac{d\Phi_{ds}}{dt} - \omega_s \Phi_{qs} \\
V_{qs} = R_s \cdot I_{qs} + \frac{d\Phi_{qs}}{dt} + \omega_s \Phi_{ds} \\
0 = R_r \cdot I_{dr} + \frac{d\Phi_{dr}}{dt} - \omega_r \Phi_{qr} \\
0 = R_r \cdot I_{qr} + \frac{d\Phi_{qr}}{dt} + \omega_r \Phi_{dr}
\end{cases}
$$

(3)

The main objective of the vector control of induction motors is, as in DC machines, to independently control the torque and the flux; this is done by using a d-q rotating reference frame synchronously with the rotor flux space vector . In ideally field-oriented control, the rotor flux linkage axis is forced to align with the d-axes, and it follows that [6].

$$
\begin{cases}
\Phi_{dr} = \Phi_r = \text{constant} \\
\Phi_{qr} = 0
\end{cases}
$$

(4)

Applying the result of (4) and (5), namely field-oriented control, the torque equation becomes analogous to the DC machine and can be described as follows:

$$C_e = \frac{3}{2} p \cdot \frac{M}{L_{rc}} \Phi_r I_{qs}$$

(5)

Consequently, the dynamic equations (3) yield:

$$V_{ds} = \left(R_s + s \cdot \sigma \cdot L_{sc} \right) I_{ds} - \omega_s \cdot \sigma \cdot L_{sc} \cdot I_{qs}$$

$$V_{qs} = \left(R_s + s \cdot \sigma \cdot L_{sc} \right) I_{qs} + \omega_s \frac{M}{L_{rc}} \Phi_r + \omega_s \sigma \cdot L_{sc} \cdot I_{ds}$$

(6)

III. MODELING AND DESIGN OF FLCT2 SYSTEM

The structure of a type-2 FLS is shown in figure 1. It is similar to its type-1 counterpart, the major difference being that at least one of the fuzzy sets in the rule base is type-2. Hence, the output of the inference engine is type- 2 sets and a type-reducer is needed to convert them into type-1 sets before defuzzification can be carried out.

A. Inference
An interval type-2 FLS is employed [10-11]. "Interval" means that the input/output domains are characterized by interval type-2 sets [3-8].
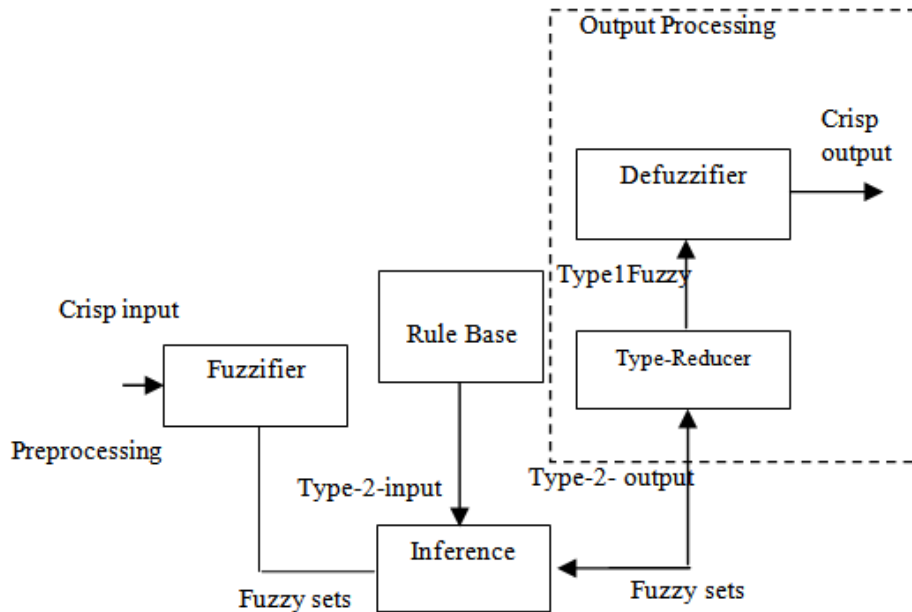
Figure 1. Structure of a type-2 FLS.

Of all elements in the FOU (secondary membership grades) area nifty. The inference engine then matches the fuzzy rules in the rule base. To compute unions and intersections of type-2 sets, compositions of type-2 relations are needed. Just as the sup-star composition is the backbone computation for a type-1 FLC, the extended sup-star composition is the backbone for a type-2 FLC [4-9].
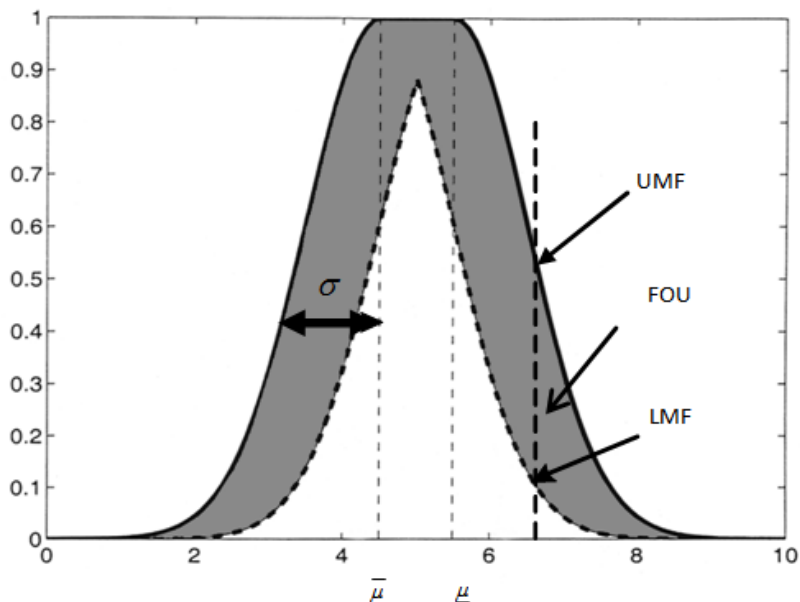

Figure 2. Membership Function Interval Type-2 Fuzzy Logic Set.

B. Type-Reduction and Defuzzification

The output of the inference engine is a type-2 fuzzy; it must be type-reduced before the defuzzifier can be used to generate a crisp output. This is the main structural difference between type-1 and type-2 FLC. The most commonly used type-reduction method is the center-of-sets type-reducer, which may be expressed as [12-13]. The footprint of uncertainty (FOU) of the membership function (MSF) in the IT2FLS is the area which limited by two MSF, the overhead limitation is the upper membership function UMSF and the down limitation is the lower membership function (LMSF), as shown in figure 2[15].

C. Rules

linguistic variable exists. This output variable is the α ($\alpha \in$ [-10; 10]). Each linguistic variable possesses seven linguistic values: NB, NM,NS, ZE, PS, PM,PB [7].

The proposed controller uses following linguistic labels NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), PB (positive big). Each of the   inputs and output contain membership function with all these seven linguistics.

Table 1 shows one of possible control rules based on seven membership functions [15].

<p align="center">Table 1 : The fuzzy control rule bases</p>

Δe \ e	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

For indirect field orientation (Fig.3), the control variables are I_{ds}^{*} and I_{qs}^{*} which represent respectively the desired rotor flux component and torque Component. These components can be generated from a flux control loop (for I_{qs}^{*}), and from a speed control loop (for I_{ds}^{*}).
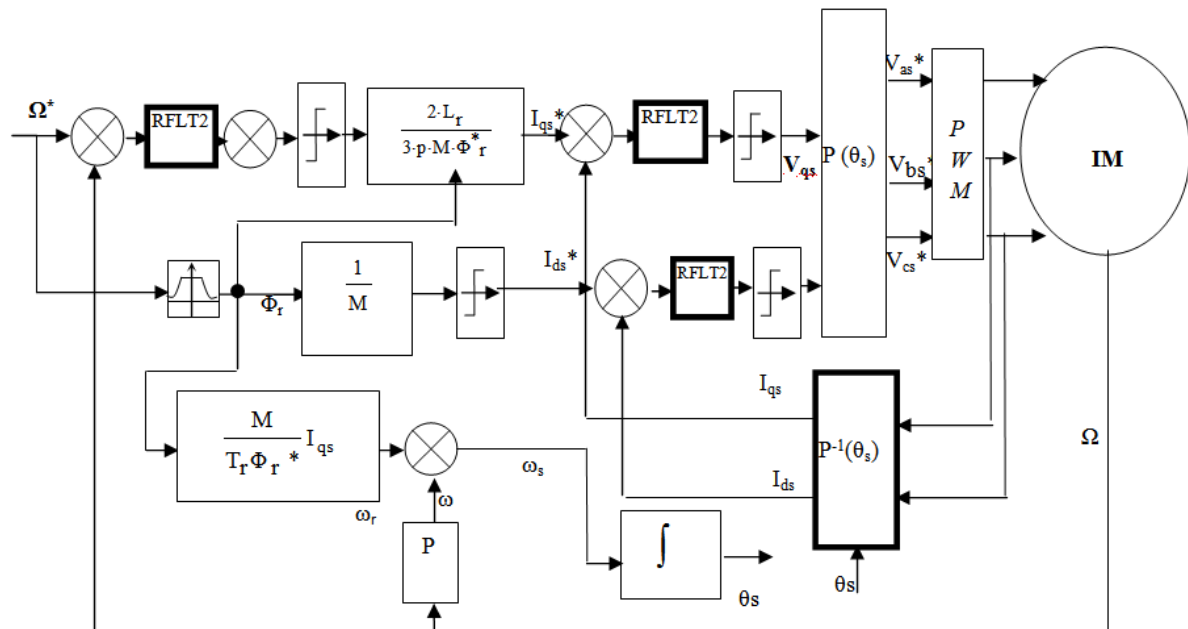

Figure.3: Indirect Vector Controlled induction motor block diagram with the Fuzzy Logic Controller type-2 [6]

IV. RESULT AND DISCUSSION

The simulation results for FOC and FLT2 are discussed here, the case of study is for induction motor which has the data in Appendix. In order to analyze the drive system performance for speed and torque responses, with Healthy case, the above-presented system has been simulated using MATLAB/SIMULINK software. A squirrel cage induction motor with a rated power of 1.1 kW has been used. In this section, simulation results are presented to show the performance of the proposed Fuzzy Controller, meanwhile, the proposed control method has been compared with the PI control method.

The reference speed is 120 rad/sec. it is observed that motor pick up the reference speed at t = 0.4 sec figure.4 shows the performance characteristic of motor. This is due to the facts that the fuzzy control is a

nonlinear control and the IM motor mathematical model is also non-linear and complex**.** The FLCT2 controller performed better performance with respect to rise time and steady state error, we perform a simulation of a first broken rotor bar at t = 2s increasing resistance 11fois the resistance of the bar, the second adjacent broken rotor bar at t = 3 s. In bars break during we note that the speed remains constant insensitive broken the bars, demonstrating the robustness of the order by fuzzy logic type-2. There is a small fracture strain of the bar. In fact, it is on (Figure 4b) which cancels the loads instructions FLCT2 effects perturbations applied at time t = 0.8s, so also we see in this figure that the electromagnetic torque following these instructions without causing overflows considered moments and with less vibration. We also note the increase in the amplitude modulation of the stator current during the second broken rotor bar. The control input (u) has chattering in IFOC, but is free of chattering in FLCT-2. The field orientation is obvious, as the d-axis stator current and rotor flux remain constant. The speed response is shown in Figure.5.a. It can be seen clearly that the FLCT-2 provides a minimum response time and robust speed response compared to the traditional PI controller.
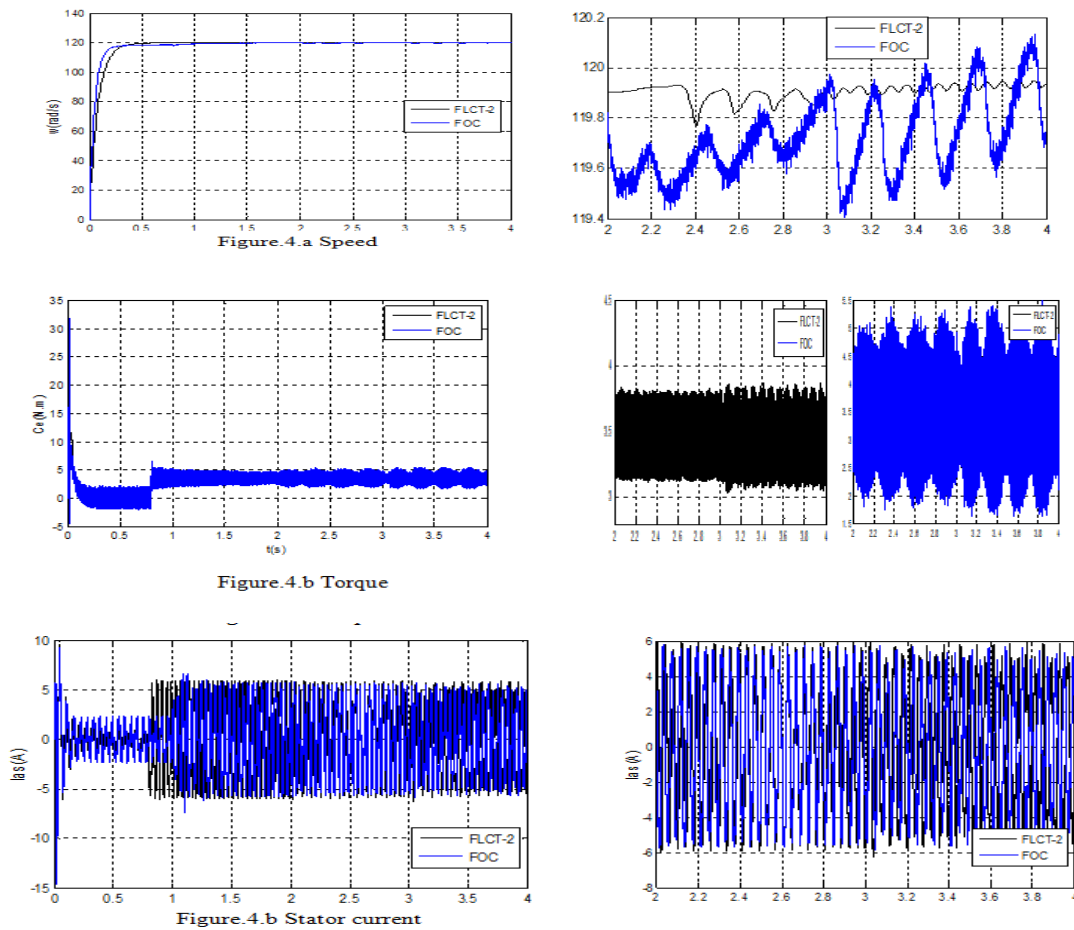
Figure.4: Simulated results of the comparison between the PI and FLCT-2 of Induction Motor

V. COMPARISON BETWEEN IFOC AND FLCT-2

For a comparative analysis of IFOC and FLCT-2, the performance of both methods in transients and steady-state operation must be studied; there are usually performance criteria such as: Square Error (ISE), the Integrated Absolute Error (IAE) and integral time-weighted absolute error (ITAE). That can be evaluated logically in frequency domain. These performance criteria are including the overshoot, rise time, settling time and steady-state error. In addition, it has been indicated the robust of the drive system.

In this study are utilized to judge the performance of the controllers. ISE, IAE and ITAE criterion is widely adopted to evaluate the dynamic performance of the control system.
The index ISE, IAE and ITAE is articulated as follows [18]:

$$ISE = \int_{0}^{T} e^2(t)dt \qquad (7)$$

$$IAE = \int_{0}^{T} |e(t)|dt \qquad (8)$$

$$ITAE = \int_{0}^{T} t|e(t)|dt \qquad (9)$$

ISE: integral squared error, IAE: integral absolute error,
ITAE: integral time-weighted absolute error.

For quantitative comparison between two methods, ISE, IAE and ITAE are used as the criterion. Table.2 shows the ISE, IAE and ITAE values of the simulation results of Indirect Field oriented control and Indirect Field oriented control using the FLCT-2 controller (FLCT-2, IFOC). Actually these performances index are obtained at the end of the simulation time (t=4 sec) with a sampling period h=1*e-5.

Table 2.Quantitative comparison between the FLCT-2 and IFOC

Index	Controllers	IFOC FLCT-2	IFOC PI
ISE	Speed	3.009	10.01
	Flux rotor	1.464	2.563
IAE	Speed	2.668	3.948
	Flux rotor	2.419	3.2
ITAE	Speed	4.444	6.59
	Flux rotor	4.485	6.401

VI. CONCLUSION

In this paper, we proposed a hybrid control of an induction motor with broken bars. This command combines the advantages of two techniques considered robust and which are the control by PI and the fuzzy control type-2. This structure aims to exploit the robustness and the speed of the fuzzy logic type-2 during the transient regime and the flexibility of the fuzzy controller during the steady state. The simulation results show that the hybrid control by PI and fuzzy logic gives better results compared to the other commands studied previously. The criterions for a fair comparison between FLCT-2 and IFOC have been established and the results of simulation tests have been presented to show the performance of both methods in various conditions and new comparison between the two methods (FLCT-2) and (IFOC) under the influence of new factors (ISE, IAE, ITAE) that have not been used before judging one of these two methods in terms Performance and control.

- **Appendix**

The parameters of the machine used for simulation are listed below [7]:

parameter	value
Stator resistance	R_s=7.58(Ω)
Rotor resistance	R_r=6.3(Ω)
Resistance of a rotor bar	R_b=0.00015(Ω)
Inertia	J=0.0054(Kgm^2)
Number of turns per stator phase	N_s=160
Number of rotor bars	N_r=16
Poles number	p=2
Leakage inductance of end ring	L_e=0.1e-6(H)
Rotor bar inductance	L_b= 0.1e-6H
Output power	P=1.1(kW)
Air-gap mean diameter	E=25(mm)
Length of the rotor	L=65(mm)
Mutual inductance	L_{1s}=0.0265(H)

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