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Controlling the Speed of Induction Motor Using Imperialist Competitive Algorithm (ICA) Based on FLC

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Abstract— **This paper presents a method for optimizing Fuzzy Logic Controller (FLC) using Imperialist Competitive Algorithm (ICA) in order to control the speed of an induction motor (IM) in the Indirect Field-Oriented Control (IFOC) method. So as to achieve a better control performance, the ICA optimizes the parameters of the FLC, which are input membership functions (MFs) and normalization factors. The ICA-optimized FLC discussed in this study has only a few rules and consequently requires less computation. This makes the FLC more suitable for real-time implementation, particularly at high speeds. Simulation results show that optimizing the fuzzy logic speed controller of IM through ICA is the best performance compared to FLC-based drive.**

Keywords- Induction Motor (IM); Indirect Field-Oriented Control (IFOC); Fuzzy Logic Controller (FLC); Imperialist Competitive Algorithm (ICA)

I. INTRODUCTION

Induction motors (IMs) are generally used in the industry because they are simple, cheap, robust, and easy to maintain [1]. Since, the IM is a complex nonlinear system, the time-varying parameters entail an additional difficulty during the controller design [2-4]. For this reason, various field-oriented control (FOC) methods have been proposed to simplify the design of IM speed controllers [5-7]. As a torque-flux decoupling technique, the FOC makes control an IM like a separately excited DC motor [3, 6].

The control of IM has attracted much attention over the past few decades [2, 7]. The authors of [3, 8] controlled the speed of IMs using conventional control systems and FOC methods.

However, due to their nonlinearity, IMs may not be appropriately controlled by conventional methods. Another problem is that such control methods are based on sophisticated mathematical modeling of IMs [9, 10]. Moreover, such factors as load disturbance, motor saturation, and thermal change machine parameters and consequently disrupt the performance of the conventional controller [11, 12].

To avoid these problems, advantage can be taken of artificial intelligence techniques [10, 13, 14]. An intelligent but computationally simple controller is the nonlinear Fuzzy Logic Controller (FLC), which successfully executes fuzzy logic in order to solve practical control problems [15].

The FLC has the following advantages over conventional controllers: its design is independent of machine parameters, it can handle complex nonlinear functions, and its performance is more robust [16, 17].

However, there is no systematic method for designing and optimizing the FLC. It is time-consuming and requires experience and skills on the part of the designer [18]. This has led many researchers to work on the optimization of the FLC [19-21].

In this paper, a new computationally simple FLC is proposed as a speed controller. To avoid the lengthy computation, the Imperialist Competitive Algorithm (ICA) is employed to optimize the parameters of the FLC: MFs and normalization factors.

II. MODEL OF IM

The electrical dynamics of an IM in the synchronous coordinate system (d- and q-axis) can be expressed as follow:

$$\begin{bmatrix} v_{ds} \\ v_{qs} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + L_s p & -\omega_e L_s & L_m p & -\omega_e L_m \\ \omega_e L_s & R_s + L_s p & \omega_e L_m & L_m p \\ L_m p & -\omega_{sl} L_m & R_s + L_r p & -\omega_{sl} L_r \\ \omega_{sl} L_m & L_m p & \omega_{sl} L_r & R_r + L_s p \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} \quad (1)$$

The electromagnetic torque in an IM can be expressed as:
Mechanical equation of IM is given by

$$T_e = J\frac{d\omega_r}{dt} + B\omega_r + T_L \quad (2)$$

The generation torque is given by

$$T_e = \frac{3PL_m}{4}\left(i_{dr} i_{qs} - i_{qr} i_{ds}\right) \quad (3)$$

Where

ω_e, ω_r	electrical and rotor angular frequency
ω_{sl}	slip angular frequency $(\omega_e - \omega_r)$
i_{ds}, i_{qs}	d- and q-axis current
v_{ds}, v_{qs}	d- and q-axis stator voltage
R_s, R_r	Stator and rotor resistant
L_s, L_r, L_m	Stator, rotor, and mutual inductance
p	differential operator
P	number of poles
T_e	electromagnetic torque
T_l	load torque

J	inertia moment
B	friction coefficient

III. THE PROPOSED CONTROL SCHEME

Fig. 1 shows the schematic representation of the way the proposed speed control method is applied to an Indirect Field-Oriented Control (IFOC) IM. The figure gives the block diagram of a current-controlled Pulse With Modulation (PWM) IM controlled using the IFOC method. The FOC block receives the computed torque from the speed controller and the flux from the field weakening block. In the look-up table used for field weakening, as far as the motor operates below the rated speed, the flux is assumed to be constant. Also, when the motor operates faster than rated speed, the product of the flux and the motor speed is held constant [22]. As can be seen, the reference electromagnetic torque T_e^* and consequently reference current i_{qs}^{e*} is generated by the ICA-optimized FLC.

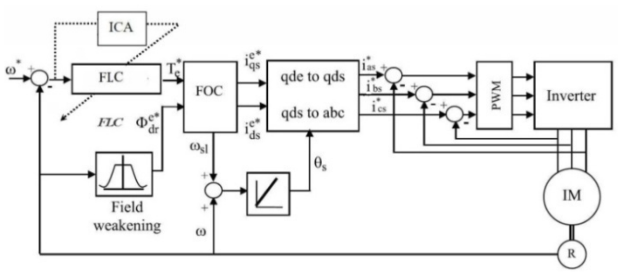

Fig. 1.IFOC of an IM using ICA-FLC

A. FLC

Fig. 2 shows a proposed configuration of a simple FLC. FLC takes in the speed error e and the derivative of the error signal e. Then these have to be fuzzified. Since the plant cannot respond directly to fuzzy control sets, these control sets have to be defuzzified. The fuzzy control algorithm consists of a set of fuzzy control rules that are related through the concept of MFs and the composition rule of inference. On the other hand, the controller output ΔU is summed or integrated in order to generate the actual control signal U as current i_{qs}^*. Also, K_e, $K_{\Delta e}$, and $K_{\Delta u}$ are normalization factors. Input variables require to be normalized over a range specified for MFs and also, output variable requires to be normalized over a range specified for plant. a Suitable normalization has a direct impact on optimizing the performance and response speed of the controller [23, 24]. In line with this, the ICA was used to optimize the normalization factors.

The performance of a FLC depends on the selection of the MFs and control rules. To account for this, we developed a new FLC using ICA.

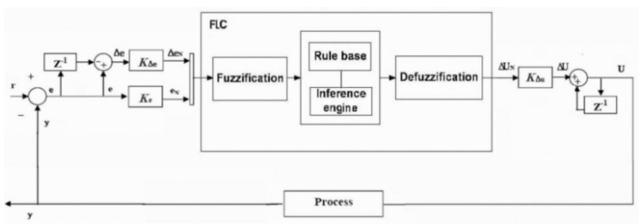

Fig. 2. FLC

B. Imperialist Competitive Algorithm (ICA)

ICA is a recently introduced optimization algorithm. Optimization through this algorithm has basis on the concept of imperialistic competition. Fig. 3 portrays the flowchart of ICA. ICA takes advantage of the assimilation policy adopted by imperialistic countries since the 19th century. According to this policy, the imperialists seek to improve the economical, cultural, and political situation of their respective colonies so as to win their loyalty.

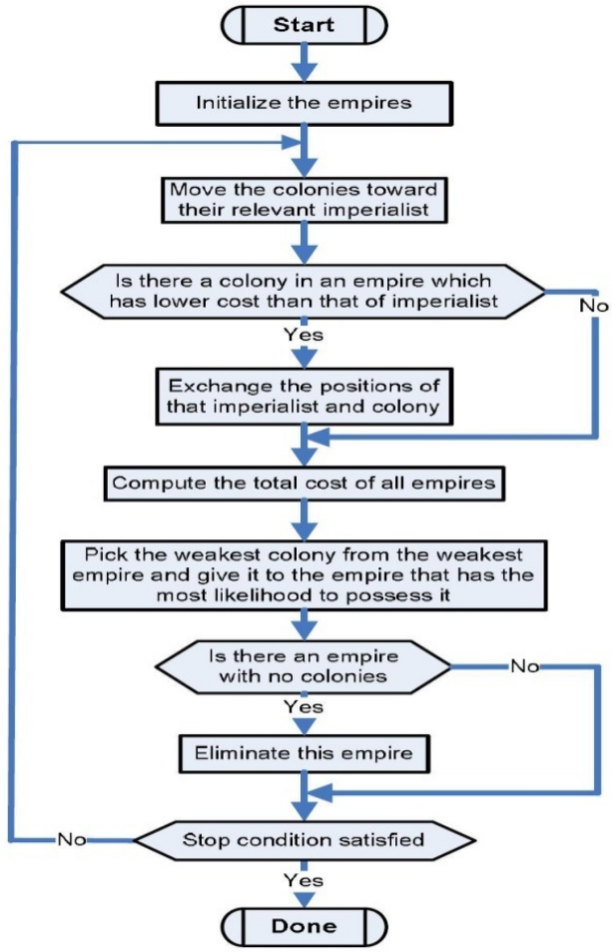

Fig. 3. Flowchart of Imperialist Competitive Algorithm

This theory uses the term “empire” to refer an imperialist and its colonies. The power of an empire depends on the power of its imperialist and its colonies. In imperialistic competitions, weaker imperialists lose their colonies to more powerful empires. After dividing all colonies among imperialists and creating the initial empires, these colonies start moving toward their relevant imperialist state. This movement is a simple model of assimilation policy that was pursued by some imperialist states. Fig. 4 shows the movement of a colony towards the imperialist.

In this movement, x and θ are random numbers with uniform distribution as shown in equations (4) and (5), respectively, and d is the distance between a colony and its imperialist.

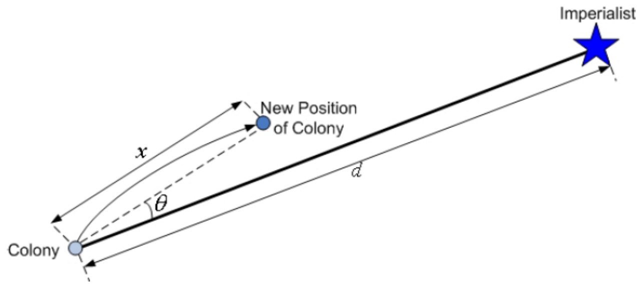

Fig. 4. Motion of colonies toward their relevant imperialist

$$x \sim U(0, \beta \times d) \quad (4)$$

$$\theta \sim U(-\gamma, \gamma) \quad (5)$$

where β and γ are arbitrary numbers that modify the area around the imperialist which colonies randomly search.

The weak empires, once they lose all their colonies, will be the colonies of other empires. Eventually, all the weak empires will collapse, leaving only one powerful empire. Fig. 5 portrays the flowchart of ICA [25].

IV. Designing FLC Using ICA

Depending on the operation of the system, nine control rules can be written in fuzzy logic. To design such a controller, the input variables of speed error e and derivative of speed error Δe are considered to have three MFs: N (Negative), ZE (Zero), and P (Positive) as shown in Fig. 5 and Fig. 6, respectively. The MFs of the output are NB (Negative Big), N, ZE, P, and PB (Positive Big) are shown in Fig. 7. Also, Table I shows the nine fuzzy if-then rules of FLC.

TABLE I. DECISION TABLE OF FLC

Δe \ e (output)	N	ZE	p
N	NB	N	N
ZE	N	ZE	P
P	ZE	P	PB

To utilize the ICA to optimize the FLC, the parameters of the FLC in the ICA are coded in the form of the array country. Additionally, a cost function is defined so as to minimize it with the purpose of satisfying the design criteria.

To optimize the parameters of FLC using ICA, the parameters are coded as below:

The MFs of the input variable of speed error e can be specified by means of three points P1, P2, and P3 as shown in Fig. 5. Similarly, for the other input variable, derivative of speed error (Δe), three points P4, P5, and P6 are used as shown in Fig. 6.

Lastly, the five MFs of output variable can be represented by means of five points P_7, P_8, P_9, P_{10}, and P_{11}. Also, the normalization factors K_e, $K_{\Delta e}$, and $K_{\Delta u}$ can be specified by P12, P13, and P14. Thus, the problem of finding the MFs and the normalization factors is reduced to the problem of determining 14 points (Pi, $1 \leq i \leq 14$).The 14 points are placed together to form the array country.

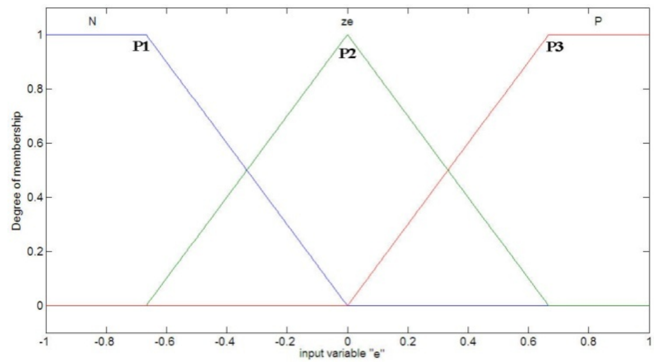

Fig. 5. MFs of speed error before optimization

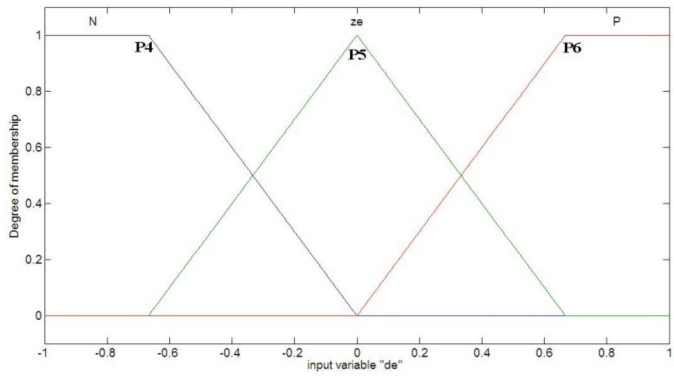

Fig. 6. MFs of derivative of speed error before optimization

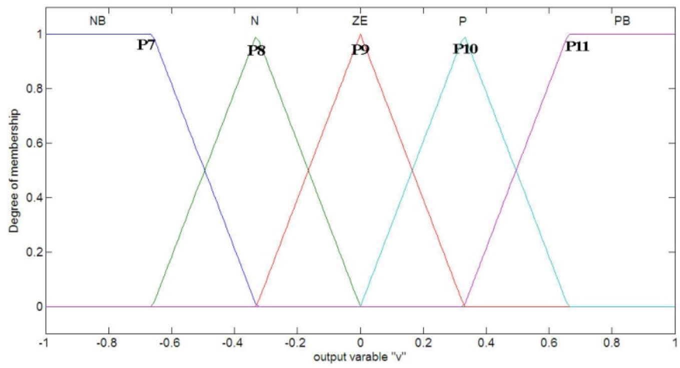

Fig. 7. MFs of output before optimization

Country = [P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8, P_9, P_{10}, P_{11}, P_{12}, P_{13}, P_{14}]

The performance of the designed FLC is evaluated on the basis of the Integral of Absolute Error (*IAE*). So as to minimize this cost function, the ICA looks for the best array country (i.e., the array of Pi's).

In ICA, initial number of countries is set at 100, fifteen of which are chosen as the initial imperialists. Also, β and γ are set at 2 and 0.5 Rad, respectively. The maximum number of iterations of the ICA is set at 50.

V. SIMULATION RESULTS

The fuzzy MFs optimized by ICA are shown in Figures 8 to 10.

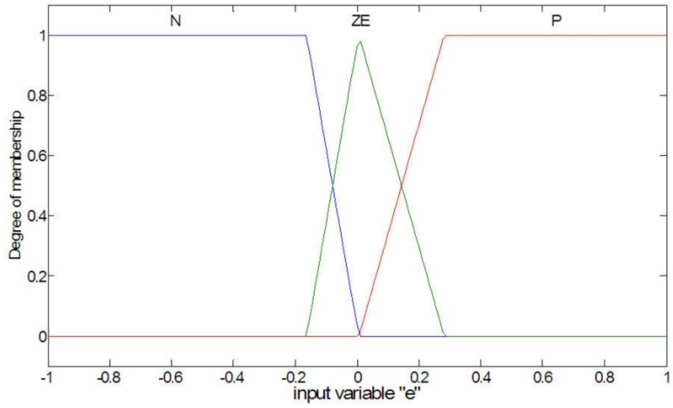

Fig. 8. MFs of speed error after optimization

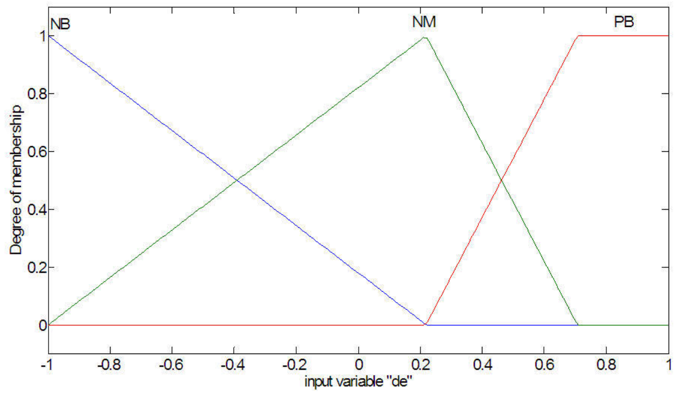

Fig. 9. MFs of derivative of speed error after optimization

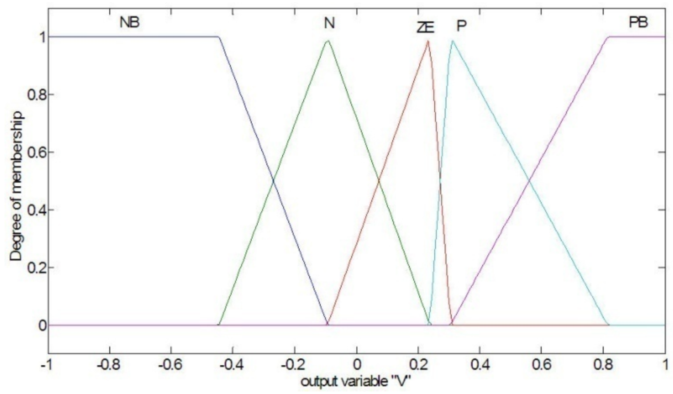

Fig. 10. MFs of the output after optimization

For evaluation purposes, the proposed ICA-optimized controller is compared with the FLC in MATLAB toolbox. The performance of the motor was evaluated for a period of 1s against a reference speed of 150 rad/s.

In addition, the ICA-optimized FLC and the FLC were subjected to full load torque TL=200 N.m at t=0.45 s in order to verify their validity. The simulation results of the FLC and the ICA-optimized FLC are plotted as shown in Fig. 11 and Fig. 12, respectively.

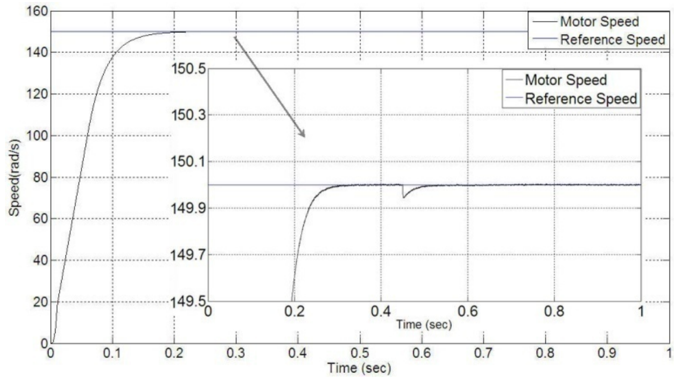

Fig. 11. Speed response of IM using FLC

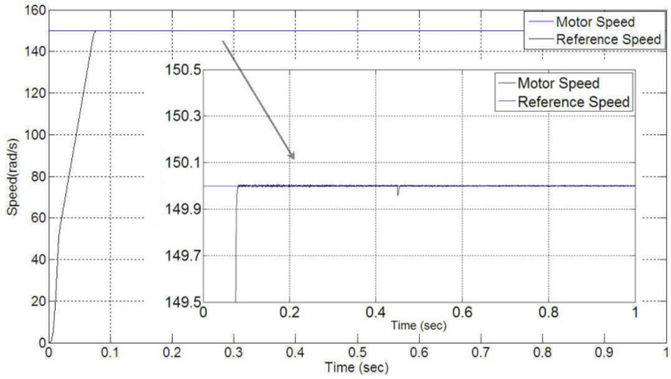

Fig. 12. Speed response of IM using ICA-optimized FLC

The control criteria of the FLC and the ICA-optimized FLC (codenamed ICA-FLC) are compared in Table II. The control criteria used were Settling Time (ts), Rise Time (tr), Overshoot (Ov), and Integral of Absolute Error (IAE). It is clear from this table that the fuzzy logic speed controller of IM optimized by ICA has a better performance in all criteria than the FLC-based drive.

TABLE II. SIMULATION PERFORMANCE COMPARISON

Criteria / **Method**	*ts(s)*	*tr(s)*	*Ov(%)*	*IAE*
FLC	0.11	0.31	0	0.56
ICA-FLC	0.06	0.08	0	0.24

In another test, the two controllers were compared in terms of their response to abrupt changes in the reference speed. The reference speed was 80 rad/s at the start. Then, it was changed to 150 rad/s at t=1 s and to 50 rad/s at t=2 s. The full load torque TL=200 N.m was applied at t=0.45s. As shown in Fig.

13 the ICA-FLC showed a better performance. This means that it had a more optimum rise time, settling time, at each change of speed and there was no overshoot in the responses.

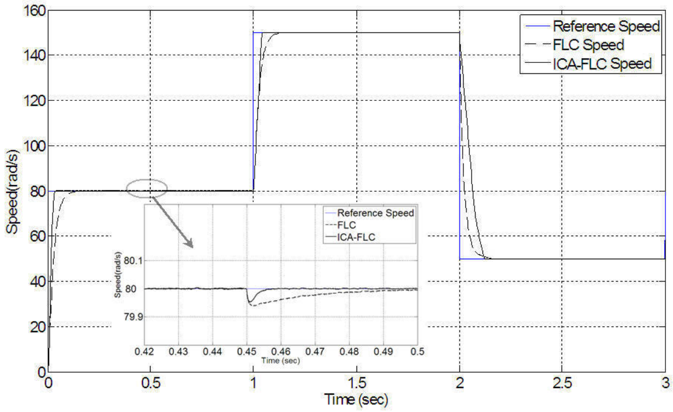

Fig. 13. Speed response of IM using FLC and ICA-FLC to abrupt changes in the reference speed

VI. CONCLUSION

In this paper, a new unsophisticated FLC optimization using ICA was proposed for the purpose of controlling the speed of an IM. In order to evaluate the proposed controller, a performance comparison with FLC has also been provided. Comparative simulation results indicate the higher efficiency of an IM speed controller based on the ICA-optimized FLC over the FLC-based drive.

APPENDIX

The specifications of the IM chosen for simulation are as follows:

Electrical power:	$P = 7\text{HP}$
Stator voltage:	$V = 4600\text{V}$
Rated speed:	$w = 1800\text{Rpm}$
Frequency:	$f = 60\text{HZ}$
Number of Poles:	$p = 4$
Stator resistant:	$R_s = 0.08\Omega$
Rotor resistant:	$R_r = 0.6\Omega$
Stator inductance:	$L_s = 0.005974\text{H}$
Rotor inductance:	$L_r = 0.005974\text{H}$
Mutual inductance:	$L_m = 0.2037\text{H}$
Moment of inertia:	$J = 0.02\text{Kg.m}^2$
Coefficient of friction:	$B = 0.02\text{N.m.s}$

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