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Imperialist Competitive Algorithm (ICA)-Optimized PI Speed Control in the Indirect Field-Oriented Control of an IM Drive

*Farzad Razavi and *Beitollah Ghadiri
*Azad University, Qazvin Branch, Electrical Engineering Department, Qazvin, Iran
farzad.razavi@qiau.ac.ir, b.ghadiri@qiau.ac.ir,

Abstract— **In this paper, Imperialist Competitive Algorithm (ICA) and Genetic Algorithm (GA) is applied to optimize the proportional and integral gains of PI speed controller in the Indirect Field Oriented Control (IFOC) of an Induction Motor (IM) drive. The control performance of the ICA-optimized PI speed controller and the GA-optimized PI speed controller is evaluated by analysis for various operating conditions. Simulation results show that optimizing the PI speed controller of IM through ICA is the best performance compared to GA-optimized PI speed controller of IM.**

Keywords- Induction Motor (IM); Indirect Field-Oriented Control (IFOC); Imperialist Competitive Algorithm (ICA); PI controller

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, 3]. For this reason, various field-oriented control (FOC) methods have been proposed to simplify the design of IM speed controllers [4, 5]. As a torque-flux decoupling technique, the FOC makes control an IM like a separately excited DC motor [3, 4].

However, conventional controllers like PI, PID are still extensively used in the industry; this is due to their simplicity and high stability. But, the performance of conventional controllers is dependent on the exact machine model and accurate gains [6]. Moreover, tuning these controllers are rather difficult and can be a time consuming and tedious process. [7]. On the other hand, with the development of artificial intelligence several optimization algorithms are presented to design the PI and PID controllers, which could obtain optimal gains to given objects control, especially to those with time-variance and nonlinearity [8-11].

In this paper, a PI controller is proposed for controlling the speed of an IM. The Imperialist Competitive Algorithm (ICA) and Genetic Algorithm (GA) are employed to optimize the gains of the PI speed controller. Also, evaluation of simulation results obtained using the ICA-optimized PI in comparison with GA-optimized PI is presented.

II. MODEL OF IM

The electrical dynamics of an IM in the synchronous coordinate system (d- and q-axis) can be expressed as equation (1):

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

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) of IM drive. 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 [12].

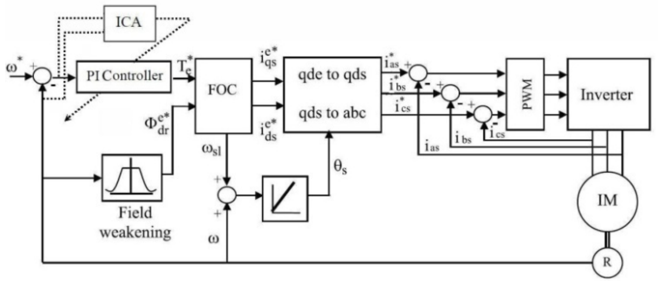

Fig. 1.IFOC of an IM using ICA-optimized PI controller

IV. IMPERIALIST COMPETITIVE ALGORITHM (ICA)

ICA is a recently introduced optimization algorithm. Optimization through this algorithm has basis on the concept of imperialistic competition. Fig. 2 portrays the flowchart of ICA. ICA takes advantage of the assimilation policy adopted by imperialistic countries since the 19th century.

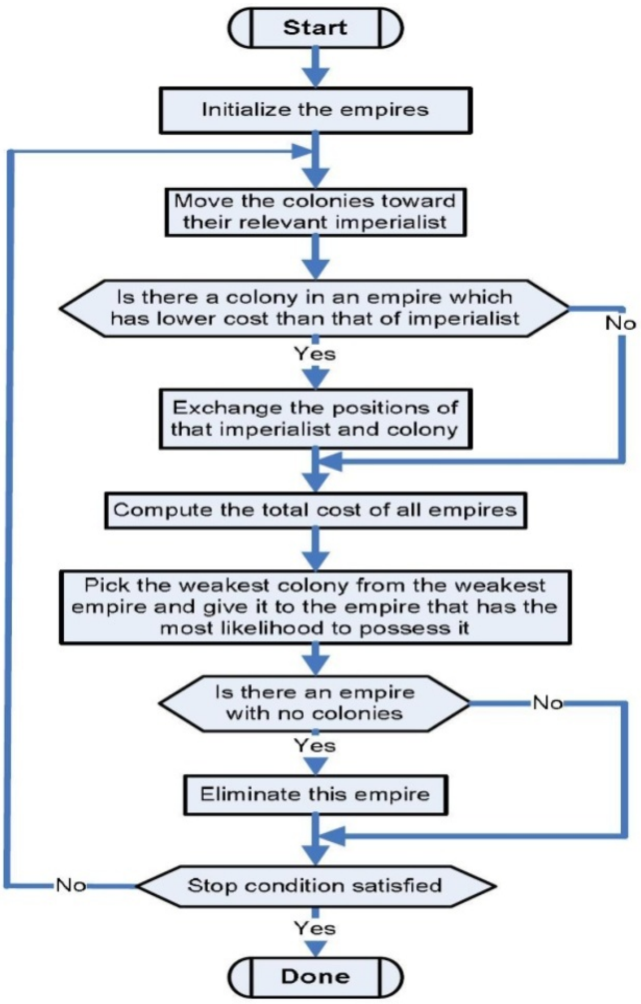

Fig. 2. Flowchart of Imperialist Competitive Algorithm

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. 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. 3 shows the movement of a colony towards the imperialist.

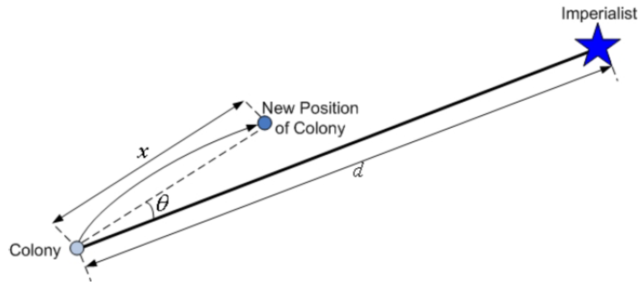

Fig. 3. Motion of colonies toward their relevant imperialist

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.

$$x \sim U(0, \beta \times d) \tag{4}$$

$$\theta \sim U(-\gamma, \gamma) \tag{5}$$

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 [13].

V. ICA-OPTIMIZED PI CONTROLLER

To utilize the ICA and GA in optimizing the proportional and integral gains of PI speed controller, the gains in the ICA are coded in the form of the array country and in the GA are coded into a chromosome. Additionally, a cost function is defined so as to minimize it with the purpose of satisfying the design criteria.

To optimize the PI controller through ICA, the proportional and integral gains of PI controller are specified by means of two points P1 and P2, respectively.

Thus, the problem of finding the parameters of PI controller is reduced to the problem of determining 2 points (Pi, $1 \leq i \leq 2$).The two points are placed together to form the array country.

$$Country = [P1, P2] \tag{6}$$

The performance of the designed PI controller is evaluated on the basis of the transient and steady-state responses. In this paper, the transient characteristics of the output Settling Time (ts), Rise Time (tr), Overshoot (Ov) along with the Steady State

Error (*ess*) are used to evaluate the designed controller. A good controller causes the output to have low values for ts, tr, Ov, and ess. By considering a combination of all criteria, the multi-objective design problem is reduced to a problem of a single objective [14]. Therefore the cost function is chosen as follow:

$$Cost\ Function = (1 - e^{-w}) * (ov + ess) + e^{-w} * (t_s + t_r) \quad (7)$$

where w is the weight which must be determined by the designer. The ICA looks for the best array Country (i.e. the array of Pi's) with a minimal cost function. In this paper the weight is set at w=0.6.

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.

Also, in GA the initial number of populations is set at 100. Crossover is set at two points while elitism and number of generations are set at 2 and 50, respectively.

VI. SIMULATION RESULTS

For evaluation purposes, the proposed PI speed controller of IM optimized through ICA is compared with the GA-optimized PI speed controller in MATLAB toolbox. The performance of the motor was evaluated for a period of 4 s against a reference speed of 150 Rad/s.

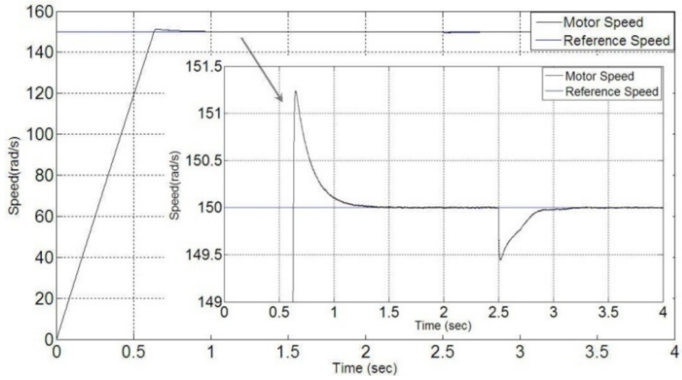

Fig. 4. Speed response of IM using GA-optimized PI controller

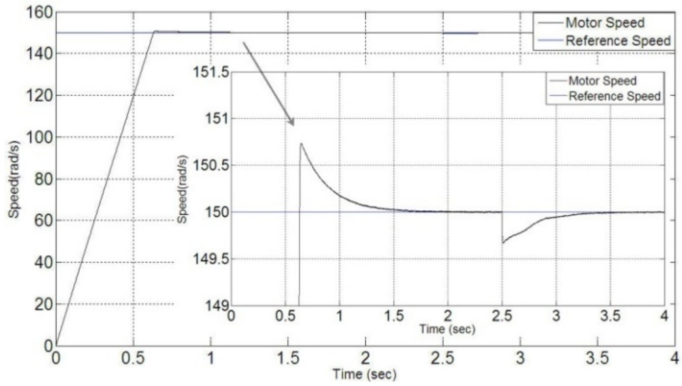

Fig. 5. Speed response of IM using ICA-optimized PI controller

In addition, the GA-optimized PI controller and the ICA-optimized PI controller were subjected to full load torque TL=200 N.m at t=2.5 s in order to verify their validity. The simulation results of the both optimized controllers are plotted as shown in Fig. 4 and Fig. 5, respectively.

The control criteria of the GA-optimized PI speed controller (codenamed GA-PI) and the ICA-optimized PI speed controller (codenamed ICA-PI) are compared in Table I. The control criteria used were Settling Time (ts), Overshoot (Ov), Steady State Error (*ess*), and Cost Function (codenamed CF). As shown in this table, almost the PI speed controller of IM optimized by ICA has a better performance than the GA-optimized PI-based drive.

TABLE I. SIMULATION PERFORMANCE COMPARISON

Criteria / controller	*ts(s)*	*Ov(%)*	*ess*	*CF*
GA-PI	0.6	0.8	0	0.54
ICA-PI	0.6	0.4	0	0.31

In another test, the two controllers were compared in terms of their responses 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=3 s and to 50 rad/s at t=6 s. Also, the full load torque TL=200 N.m was applied at t=2 s. As shown in Fig. 6 the ICA-PI showed a better performance. This means that it had a more optimum response to the abrupt speed changes with full load torque.

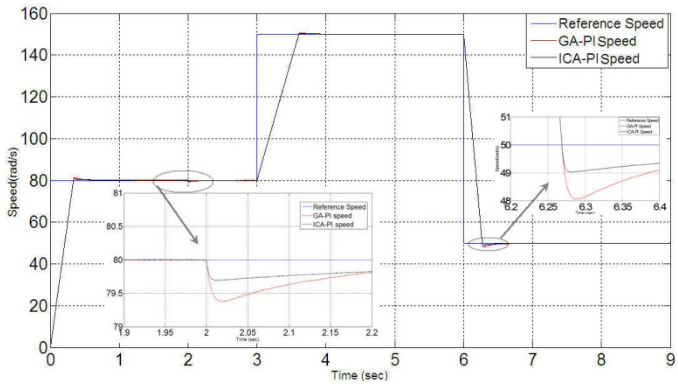

Fig. 6. Speed response of IM using GA-PI and ICA-PI to abrupt changes in the reference speed with full load torque

VII. CONCLUSION

In this paper, a PI controller 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 GA-optimized PI speed controller has also been provided. The two optimized controllers compared in terms of their responses to abrupt changes in the reference speed and variation of load torque. Comparative simulation results indicate the better response of the PI speed controller of the IM optimized through ICA over the GA-optimized PI-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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