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Designing a FFOPID controller based on genetic algorithm for speed control of induction motor drive system

Mohamadmahdi Shahbazi [1], **Farhad Amiri**[2]

[1]Department of Electrical Engineering, Bu-Ali SinaUniversity, Hamedan/Iran; m.shahbazi@basu.ac.ir
[2] Department of Electrical Engineering, Bu-Ali SinaUniversity, Hamedan/Iran; f.amiri94@basu.ac.ir

Abstract
In this paper, an indirect vector control is presented for a three-phase induction motor drive system. Fuzzy fractional order PID controller has a robust and simple structure and a precise induction motor model is not needed for its design. Genetic algorithm is used to determine the parameters of fuzzy fractional order PID controller. In order to investigate the performance of the proposed controller, simulations are carried out with the fuzzy PI controller in several scenarios, and the results show the suitable performance of the proposed controller. Simulations are performed using the MATLAB software.

Keywords: Indirect vector control, FFOPID, Genetic algorithm, Induction motor, Fuzzy PI

Introduction

Nowadays, the application of three-phase AC machines has increased. However, these machines also face limitations, such as speed control problem, harmonic generation and overconsumption of reactive power compared to DC machines [1]. Numerous studies have been conducted on the AC machine. The induction motor (AC machine) is used in various industries for its low cost, high robustness, and less maintenance requirements. The main problem in controlling three-phase induction motors is that the torque producing current and flux producing current are not decoupled. This problem is solved by the vector control method [2-4]. Vector control is based on the components being separate and the independent control of each component, similar to an independent excitation dc motor. Therefore, a drive system with suitable dynamic response can be developed to respond to changes in load or the reference speed. Usually, a normal PI controller is used in the design of speed control of an induction motor drive [1-4]. The use of this type of controller also poses many issues, such as speed and torque fluctuations due to external factors and sudden changes of the load. Moreover, this type of controller is weak against the uncertainty of the parameters. Different methods have been used to control the induction motor drive system [5-9]. In [5], the design of a self-tuning fuzzy controller for an induction motor drive system is discussed. In [6], the design of a GPC controller for an induction motor drive system is discussed. In [7,8], the design of a nonlinear controller for a five-phase induction motor drive system in the laboratory is discussed. In [9], a fuzzy PI controller is designed for controlling the induction motor drive system. Smart control methods are better than conventional adaptive controls (such as PI) (Smart controls function much better than the conventional controls). Fuzzy logic technique could be viewed as the visualization of human thinking for a control system. Fuzzy logic control is highly effective and suitable for induction motor speed drives and does not require precise mathematical modeling of the motor. Also, the fractional order PID control is more robust and has a simple structure and better control due to its higher degrees of freedom. In this paper, a smart speed control of induction motor drive system based on FFOPID controller is proposed whose coefficients are optimized by using genetic algorithm. The results of the proposed controller are compared with the fuzzy PI controller and the suitable performance of the proposed controller is shown. The simulations are carried out using the MATLAB software. The paper includes the equations of induction motor, FFOPID controller design whose coefficients are optimized using genetic algorithm, the simulation, and the results.

The Equations of Induction Motors

The direction of the field is determined by the rotor flux vector. The rotor flux is obtained through a flux observer. The rotor field frequency in the induction motor is not calculated. The rotor field frequency depends on the load torque value [9]. For instance, the slip frequency is combined and the rotor flux position (θ_r) is obtained. The velocity of the rotating field is shown by Eq. (1). In Eq. (1), ω_e is the rotating field velocity, ω_r the rotor field velocity, and ω_{sl} the slip velocity of induction motor. The equations of the induction motor are shown by Eqs. (2) to (8). According to Eqs. (2) and (3), for separate control, the the stator current flux component (i_{ds}) must be on the middle of the d axis, and the torque current

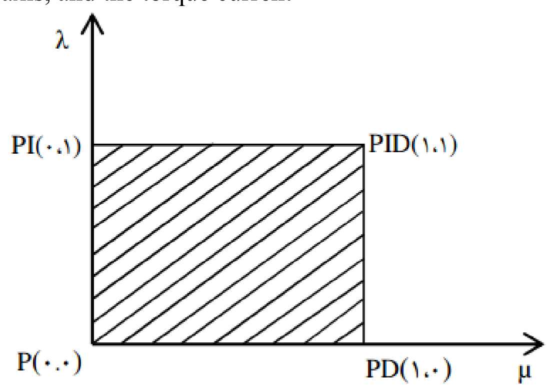

Figure 1.. Fractional order controller [10]

component (i_{qs}) must be on the q axis, leading to $\psi_{qr} = 0$ and $\psi_{dr} = \psi_r$. Then, Eq. (4) is obtained. The slip frequency in the induction motor is calculated by Eq. (5) [6-8]. If a high slip angular velocity is used to generate the field direction, decoupling will be resulted. The control of the rotor flux ψ_r and its derivative with respect to time $\frac{d\psi_r}{dr} = 0$ can be substituted in Eq. (4) and the rotor flux is then adjusted according to Eq. (6). The electromagnetic torque is obtained by Eq. (7). By substituting $\psi_{dr} = L_m \bullet i_{ds}$ in Eq. (7), the electromagnetic torque is obtained by Eq. (8). According to Eq. (8), iqs is the stator current torque component and ids is the stator current flux component. Therefore, flux linkage is not affected by the change in i_{qs} and the control of the stator flux and torque is achieved separately [6-9].

$$\theta_e = \int \omega_e = \int (\omega_r + \omega_{sl}) = \theta_r + \theta_{sl} \tag{1}$$

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r}\psi_{dr} - \frac{L_m}{L_r} R_r \bullet i_{ds} - \omega_{sl} \bullet \psi_{qr} = 0 \tag{2}$$

$$\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r}\psi_{qr} - \frac{L_m}{L_r} R_r \bullet i_{qs} - \omega_{sl} \bullet \psi_{dr} = 0 \tag{3}$$

$$\frac{L_r}{R_r} \bullet \frac{d\psi_r}{dt} + \psi_r = L_m \bullet i_{ds} \tag{4}$$

$$\omega_{sl} = \frac{L_m \bullet R_r}{\psi_r \bullet L_r} i_{qs} \tag{5}$$

$$\psi_r = L_m \bullet i_{ds} \tag{6}$$

$$T_e = \frac{3}{2} \bullet \frac{P}{2} \bullet \frac{L_m}{L_r} (i_{qs} \bullet \psi_{dr}) \tag{7}$$

$$T_e = \frac{3}{2} \bullet \frac{P}{2} \bullet \frac{L_m^2}{L_r} (i_{qs} \bullet i_{ds}) \tag{8}$$

Design of a FFOPID Controller with Optimized Coefficient, Using Genetic Algorithm

A. *Fractional-order PID Controller*

$PI^{\lambda}D^{\mu}$ is the most common type of fractional order controller. Eq. (9) shows the transfer function of fractional order PID controller which includes a proportional gain, an integral gain with an integrator of order λ, and a derivative gain with a differentiator of order μ $(\lambda, \mu > 0)$ [10]. Obviously, by choosing λ=1,λ=1 , we will have a classic PID control. Selecting $\lambda = 1, \mu = 0$ and $\lambda = 0, \mu = 1$ corresponds to conventional PI and PD controllers, respectively. All these classical types of PID controllers are special cases of the $PI^{\lambda}D^{\mu}$ (FOPID) controller given in Eq. (9). The FOPID controller is generalization of the classical PID controller and expands it from point to plane form. Fig. 1 shows a fractional order PID controller [10].

One of the most important advantages of $PI^{\lambda}D^{\mu}$ controller is better control of fractional order dynamic systems. Another advantage is that $PI^{\lambda}D^{\mu}$ controllers are less sensitive to changes in the parameters of the controlled system, which is due to having two more degrees of freedom for better adjustment of the dynamic properties of a fractional order control system [10].

$$G_c(s) = K_P + \frac{K_I}{S^{\lambda}} + K_D S^{\mu} \tag{9}$$

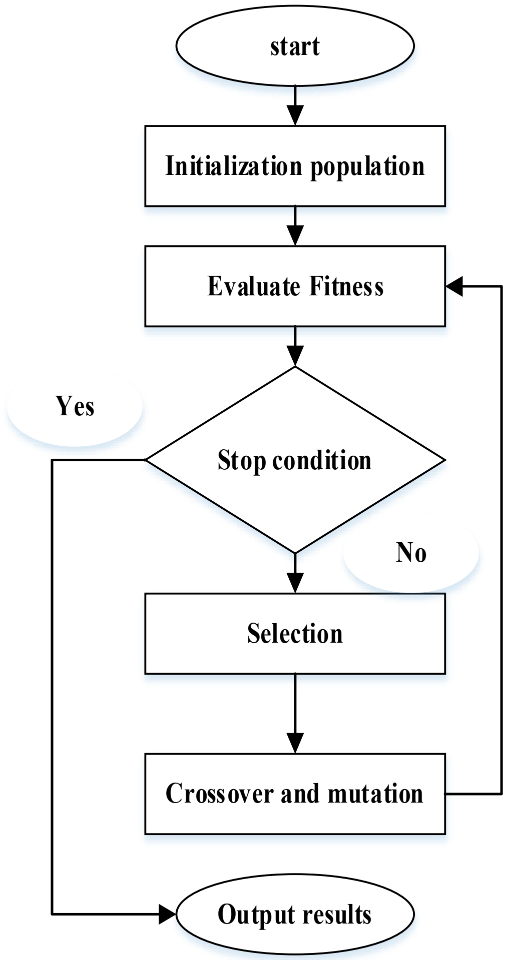

Figure. 2: The flowchart of the genetic algorithm [11]

B. *Genetic Algorithm*

Genetic algorithm is an algorithm that is based on iteration, and its basics are derived from the natural genetics. This algorithm randomly selects a set of candidate solutions, called population, and modifies them in an iterative cycle. At each step, the algorithm selects individuals as parents from the population and uses them to produce offspring for the next generation [11]. The steps of the genetic algorithm are shown below:

1) Each member of the population is evaluated using the objective function.
2) One or more parents are selected randomly. However, chromosomes (solutions) with high fitness are more likely to be selected for reproduction.
3) Genetic operators, including mutation and reproduction, are applied to parents to produce offspring.

4) The offspring are added to the population and the process is repeated

The flowchart of the genetic algorithm is shown in Figure.2.

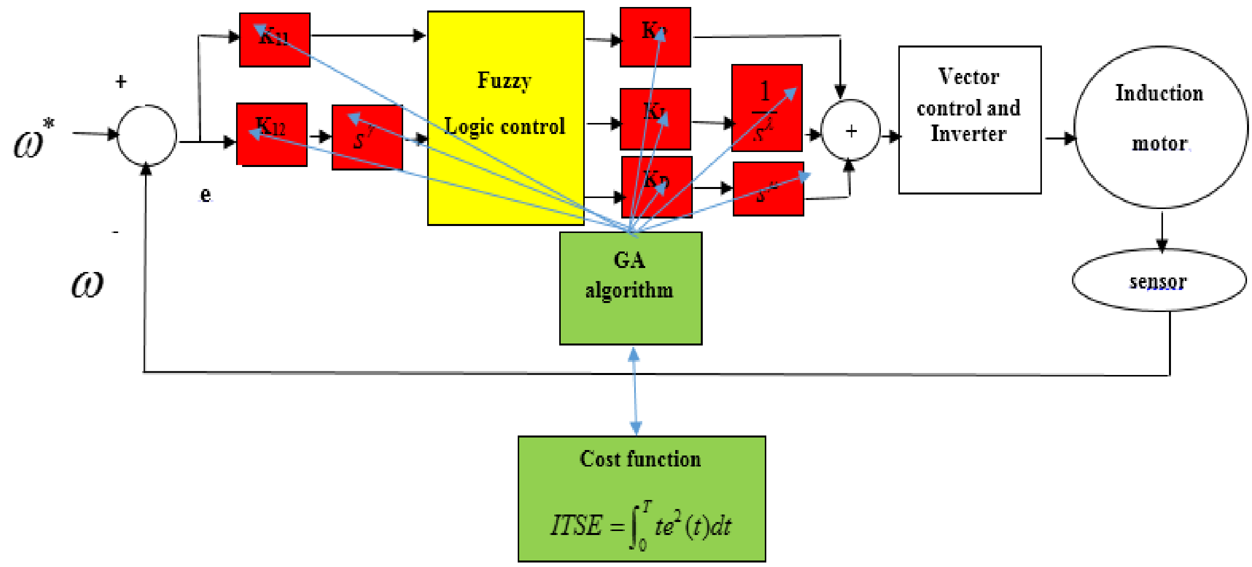

Figure. 3. Structure of the proposed controller for induction motor speed control

C. Design of FFOPID controller optimized by genetic algorithm

The structure of the optimized fuzzy fractional order PID controller for speed control of the induction motor is shown in Figure. 3.

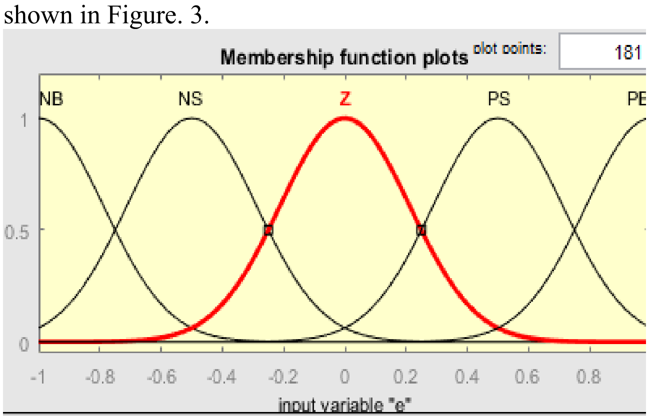

Figure 4. Membership functions of input and output variables

considered to be the controller input [12]. The Mamdani fuzzy method is used. The membership functions of all input and output variables are defined to be Gaussian, as shown in Fig. 4. Each membership function includes 5 linguistic variables. The fuzzy rules related to the FFOPID controller optimized with the genetic algorithm are shown in Table. 1. The intersection is performed with the min operator, union is performed with the max operator, and defuzzification is achieved using the center of gravity method. The objective function is defined as Eq. (10), whose minimization by the genetic algorithm adjusts the input and output parameters of the FFOPID controller.

$$\min ITSE = \int_0^T te^2(t)dt \tag{10}$$

Table 1. GA-FFOPID fuzzy controller rules

		$K_{12}\dfrac{d^\gamma e}{dt^\gamma}$				
		NB	NS	Z	PS	PB
$K_{11}e$	NB	NB	NB	NB	NS	Z
	NS	NB	NS	NS	Z	PS
	Z	NB	NS	Z	PS	PB
	PS	NS	Z	PS	PS	PB
	PB	Z	PS	PB	PB	PB

Table 2. Induction motor specifications

HP	10
Supply voltage,V_s	460
Poles,P	4
Frequency,f	60
Stator resistance,R_s	0.6837
Stator Inductance,$L1_s$	0.004152
Rotor resistance,R_r	0.451
Rotor Inductance,$L1_r$	0.00415
Mutual Inductance,L_m	0.1486
Inertia	0.05
RPM	1760

Friction factor	0.00814

Simulation Results

Induction motor parameters are as in Table.2. In order to investigate the performance, the FFOPID controller optimized by genetic algorithm is compared with fuzzy PI controller.

A. *Scenario. 1*

the line to line voltage, three phase induction motor current, rotor speed and torque using the proposed controller and the fuzzy PI controller are shown under no-load conditions and a reference speed of 120 rad/sec. Figure. 5 shows the results of the proposed controller (GA-FFOPID) and Figure. 6 shows the results of fuzzy PI controller at no-load condition with a reference speed of 120 rad/sec. the results of the proposed controller (GA-FFOPID) and Figure. 6 shows the results of fuzzy PI controller at no-load condition with a reference speed of 120 rad/sec.

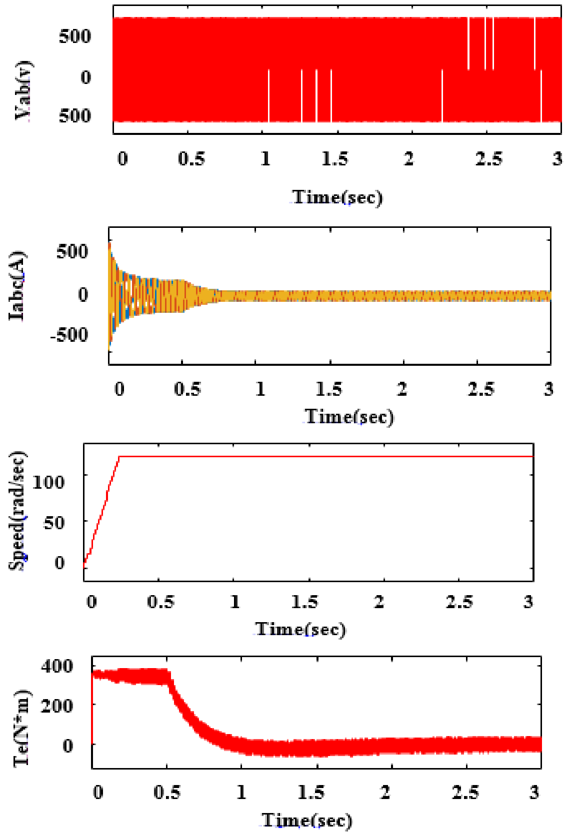

Figure. 5. Results of the proposed controller (GA-FFOPID)

B. *Scenario. 2*

In this scenario, the reference speed of the induction motor is 120 rad/sec without load. According to Figure. 7, the GA-FFOPID controller has shorter settling time and rise time than the fuzzy PI controller, indicating the suitable performance of the proposed controller.

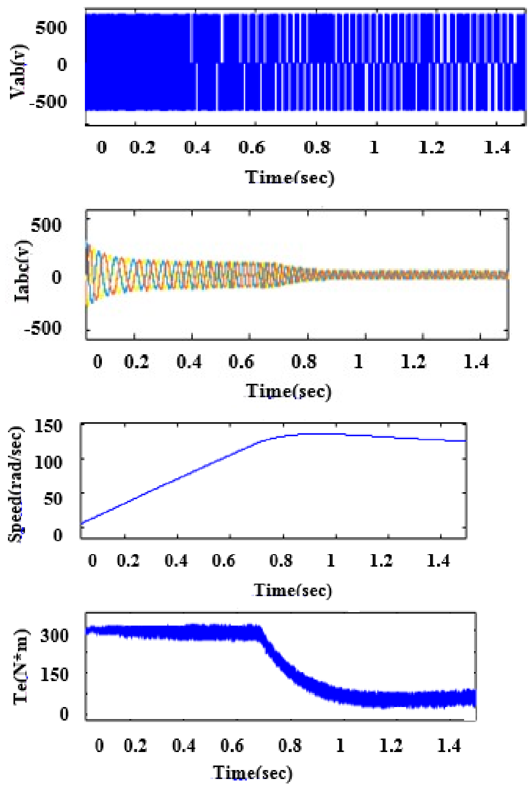

Figure. 6. Results of the fuzzy PI controller

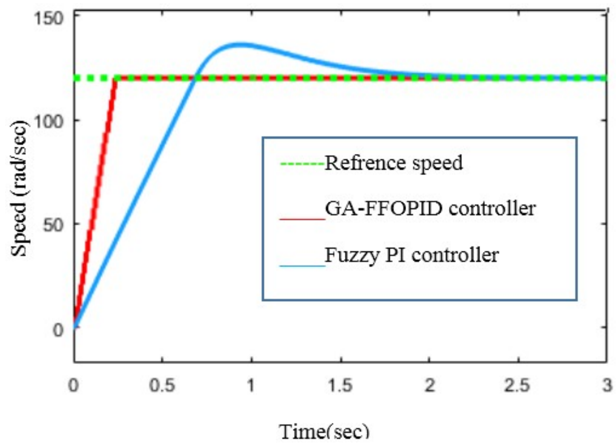

Figure. 7: Results of the controllers in following the reference speed(second scenario)

C. *Scenario. 3*

In this scenario, the reference speed of the induction motor is 120 rad/sec without load in the period between 0 and 2 sec. At 2 sec, the reference speed changes to 160 rad/sec. According to Figure. 8, the GA-FFOPID controller has shorter settling time and rise time than the fuzzy PI controller, indicating the suitable performance of the proposed controller with respect to the changes in reference speed.

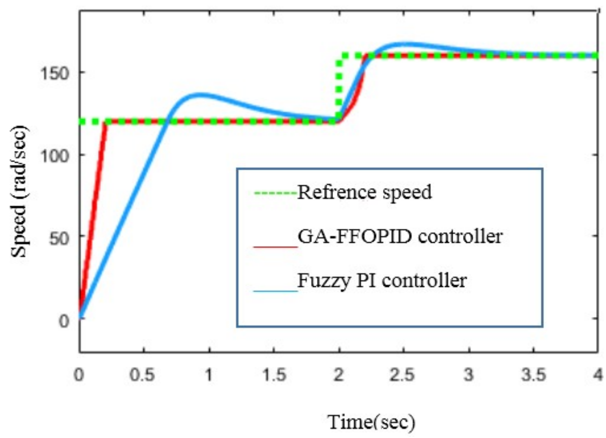

Figure. 8. Results of the controllers in following the reference speed(third scenario with step reference change)

Conclusion

Induction motors have found wide applications in industries nowadays. In this paper, an indirect vector control method is discussed for a three-phase induction motor drive system. The fuzzy fractional order PID controller has a robust and simple structure and does not require a precise model of the induction motor for its design. The genetic algorithm is used to determine the parameters of the fuzzy fractional order PID controller. In order to investigate the performance of the proposed controller, simulations are carried out in several scenarios with fuzzy PI controller. According to results, the desired performance of the proposed controller is observed. The simulations are performed using MATLAB software.

REFRENCE

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