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Application of Fuzzy-PID Controller Based on Genetic Algorithm for Speed Control of Induction Motors

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Abstract

This paper proposed a novel method for pseudo-on-line scheme using look-up table based on the genetic algorithm. The technique is an pseudo-on-line method that optimally estimate the parameters of FPID controller for systems with non-linearity using the genetic algorithm which does not use the gradient and finds the global optimum of an unconstraint optimization problem. The proposed controller is applied to speed control of 3-phase induction motor and its computer simulation is carried out. Simulation results show that the proposed method is more excellent then conventional FPID and PID controllers.

1. Introduction

The induction motor control problem has been widely studied with the objectives of obtaining better results in terms of stability, robustness to parameters variation and disturbances rejection. The voltage or current and frequency are the basic control variables of the induction motor. Many algorithms have been employed to improve the performance of the induction motor control[1].

The 3-phase induction motor is a representative plant, and the conventional PID controllers are used extensively in its control[2]. Model-based nonlinear control techniques can be used when high performance is required over a broader range of operating conditions. However, this approach requires an accurate model of the process. A simpler alternative, although with some loss in performance, is to use linear controllers with gain scheduling.

The design of the fuzzy PID controllers in various combinations result in a discrete-time fuzzy version of the result of the conventional PID controllers[3]. These controllers have the same linear structure as the conventional PID controllers in the proportional, integral and derivative parts, but has non-constant gains. The fuzzy PID(FPID) controllers thus preserve the simple linear structure of the conventional controllers, yet enhance the self-tuning control capability[4].

In this paper, an pseudo-on-line method is proposed that auto-tunes the parameters of controller by GAs[5] and the fuzzy clustering technique[2], for the improvement and optimization of the systems. This method is applied to fuzzy PID controller of the drive system of induction motor. The proposed FPID controller with the auto-tuning function executes the speed control of the system. Authors define the division concept of level to divide into region of errors that haveinfluence on the system parameters and make the optimized lookup table using genetic algorithm in the each level. This makes on-line and real-time control of the system possible. Computer simulations show that the proposed controller has high performance better than conventional FPID and PID controllers.

2. Induction Motor Modeling

The idealized three-phase induction machines are assumed to have symmetrical air gap. Using the coupled circuit approach and motor notation, the voltage equations of the magnetically coupled and rotor circuits can be written as follow[6][7]:

$$v_{abcs} = R_s i_{abcs} + \frac{d\lambda_{abcs}}{dt} \tag{1}$$

$$v_{abcr} = R_r i_{abcr} + \frac{d\lambda_{abcr}}{dt} \tag{2}$$

where $(f_{abcs})^T = [f_{as}\ f_{bs}\ f_{cs}]$, $(f_{abcr})^T = [f_{ar}\ f_{br}\ f_{cr}]$

The dq reference frames are usually selected on the basis of convenience or compatibility with the representations of other network components. Those of the induction machine in the stationary reference frame can be obtained by setting.

The induction motor state space modeling, which describes its electric behavior in dq synchronously rotating reference frame, is written below in a standard notation.

$$\begin{bmatrix} v_{qs} \\ v_{ds} \\ v_{qr} \\ v_{dr} \end{bmatrix} = \begin{bmatrix} R_s + L_s\frac{d}{dt} & \omega_e L_s & L_m\frac{d}{dt} & \omega_e L_m \\ -\omega_e L_s & R_s + L_s\frac{d}{dt} & -\omega_e L_m & L_m\frac{d}{dt} \\ RL_m\frac{d}{dt} & \omega_{sl} L_m & R_r + L_r\frac{d}{dt} & \omega_{sl} L_r \\ \omega_{sl} L_m & L_m\frac{d}{dt} & \omega_{sl} L_r & R_r + L_r\frac{d}{dt} \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \tag{3}$$

where ω_e is the stator angular frequency, ω_r is the rotor electrical speed in angular frequency, $\omega_{sl} = (\omega_e - \omega_r)$ is the slip angular frequency, L_m is mutual inductances and L_{lr} is leakage inductances of rotor.

The expression for the electromagnetic torque in terms of current as:

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\frac{L_m}{L_r}\left(i_{qs}\lambda_{dr} - i_{ds}\lambda_{qr}\right) \tag{4}$$

where L_r is $L_{lr}+L_m$ and P is the number of poles.

The vector control of the induction motor[8] is a very accepted method when high performance of the system response is required. It is based on the decoupling of the magnetizing and torque producing components of the stator current. Under this condition, the q-axis component of the rotor flux is set to zero while the d-axis reaches the nominal value of the magnetizing flux.

For constitute the method (4), control the voltage source frequency. The λ_{qr} is zero,

$$T_e=(\frac{3}{2})(\frac{P}{2})\frac{L_m}{L_r}(i_{qs}\lambda_{dr}) \tag{5}$$

Then the torque component current i_{qs} is follows:

$$i_{qs}=(\frac{2}{3})(\frac{2}{P})L_m(\frac{1}{\lambda_{dr}})T_e \tag{6}$$

The block diagram of control system is follows:

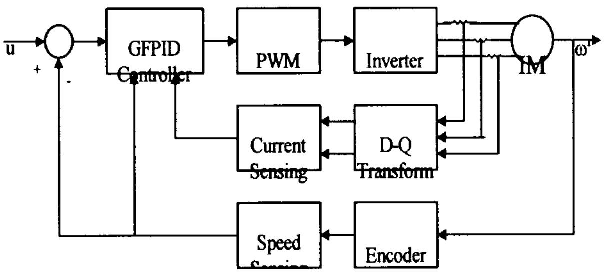


Fig. 1. The Functional Diagram of Control System

3. The PID Control Algorithm by The Fuzzy Reasoning

In the design and analysis of a PID controller, the determination of the control gain parameters that gave acceptable outputs was done by manually tuning these gains until a set that satisfactory outputs were obtained.

Its control strategy is more complex, when induction motor can be dealt with mathematically. In this situation, fuzzy control[4][9] can be developed easily, provided a body of knowledge about the control process exists, and is formed into a number of fuzzy rules.

In this paper, The design of the fuzzy PID controllers are not followed by the practical approach of the conventional PD+I controller[10] design method. For remove the defect of the fuzzy control, apply to the PID control concept by fuzzy reasoning.

$$du=k_p\cdot e+k_i\cdot ie+k_d\cdot de \tag{7}$$

If the maximum value of error, derivative of error and integral of error are e_m, de_m and ie_m and minimum value of error, derivative of error and integral of error are e_0, de_0 and ie_o.

The value of e, de and ie are described as follows:

$$e_0\leq e\leq e_m \tag{8}$$

$$de_0\leq de\leq de_m \tag{9}$$

$$ie_0\leq ie\leq ie_m \tag{10}$$

Fuzzy rules can be expressed as PID control rules:

Rule 1 : e_0 *AND* de_0 *AND* $ie_0 \Rightarrow f_1$
Rule 2 : e_0 *AND* de_0 *AND* $ie_m \Rightarrow f_2$
Rule 3 : e_0 *AND* de_m *AND* $ie_0 \Rightarrow f_3$
Rule 4 : e_0 *AND* de_m *AND* $ie_m \Rightarrow f_4$
Rule 5 : e_m *AND* de_0 *AND* $ie_0 \Rightarrow f_5$
Rule 6 : e_m *AND* de_0 *AND* $ie_m \Rightarrow f_6$
Rule 7 : e_m *AND* de_m *AND* $ie_0 \Rightarrow f_7$
Rule 8 : e_m *AND* de_m *AND* $ie_m \Rightarrow f_8$
Fact : e de ie

Each term of fuzzy inference is used to describe the process of determining the weighting of each of the rules and its consequence.

The results of fuzzy reasoning are described as follows:

$$f=k_p\cdot e+k_d\cdot de+k_i\cdot ie \tag{11}$$

4. Auto-Tuning Method OF Fuzzy PID Controller

4.1 Heuristic Algorithm

Fuzzy controllers achieve fuzzification of the control inputs using triangular membership functions. Recent literature has suggested that other forms of input membership function can be used to provide different properties for the controller. However, the triangular membership functions provide an idal means of developing control capability and so are used in general:

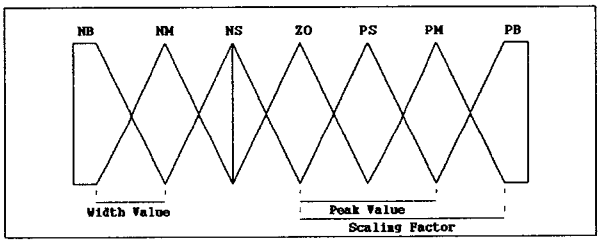


Fig. 2. Scaling Factors of Membership Function

Define the objective function to appreciate the fitness of induction motor as follows[11]:

$$F=s(k)+\frac{1}{2}r(k)+10\frac{v_p(k)-v_{ref}(k)}{v_{ref}(k)} \tag{12}$$

where, $s(k)$ is settling, $r(k)$ is rise time, $v_p(k)$ is maximum overshoot and $v_{ref}(k)$ is reference speed.

Rule of the designated area in the fuzzy rule table is to influence the performance of control system. Therefore, the use of the estimated control rule obtains better results in terms of stability, robustness to parameters variation and disturbances rejection.

A fuzzy model[9] of a system consists of a finite number of fuzzy implication rules. The modelling aspects are related to the construction of a fuzzy rule basis based on a set of input reference command signal and output measurement.

Based on this input-output data set, fuzzy clustering distills this data set into several local groups so that it provides an accurate representation of the system's behavior. Fuzzy clustering method, a batch-mode unsupervised classification scheme, provides a constructive way of delineating and composing the structure of the fuzzy model.

This method shows that the control system not only have a good response but also keep the stability.

4. 2. GENETIC ALGORITHMS

Genetic algorithms(GAs) are directed to random search techniques, which can find the global optimal solution in complex multidimensional search spaces.

To start the optimization, GAs use randomly produced initial solutions created by random number generator. This method is preferred when a priori knowledge about the problem is not available.

In this paper, to easily conduct the crossover operator, input variables are 1000 times, transformed into integer and converted to binary. The objective function is chosen as Takagi's formula[9] that is determined by function of input variables.

$$F(k) = \sqrt{(e(k) + de(k) + ie(k))} \tag{13}$$

The number of populations have 10 and the number of chromosomes use 20 from five unit decimal. Selection of genetics uses probability and random variable. The crossover and mutation rates also use random variable. The algorithm is repeated until a predefined number of generations have been produced.

Through the genetic algorithm, a Look-up table is made of the optimized results and it is used to the On-line system. Each table consists of 125, 17000 and 1000000 databases that is divided into 5, 30 and 100 levels for each of input variables, $e(k)$, $de(k)$ and $ie(k)$. Each level is divided by proportion to the square of error for steady state. The scope of $e(k)$ is chosen to set the difference between reference speed and initial speed. Such as, initial speed as -100% and 100% overshoot as 100%. The scope of $de(k)$ is chosen to set 1000 as 100% and -1000 as -100%, because $de(k)$ approaches to infinity. The scope of $ie(k)$ is chosen to set 1 as 100% and -1 as -100%, because $de(k)$ is limited from -1 to 1.

When the number of levels increases, the excellent result can be obtained. But it caused that the performance is getting bad, because of the low access speed. Therefore it is to be suitable to select levels between 30 to 100.

5. SIMULATIONS

Several simulations have been carried out to examine the feasibility of the proposed tuning algorithm for induction motor system that is described as the type of fifth-order nonlinear differential equation. Using the Runge-Kutta method, the numerical solution was obtained.

$$\frac{d}{dt} i_{qs} = \frac{-1}{L_s L_r - L_m^2} (R_s L_r i_{qs} + \omega_r L_m^2 i_{ds} - R_r L_m i_{qr} + \omega_r L_r L_m i_{dr} - L_r V_{qs})$$

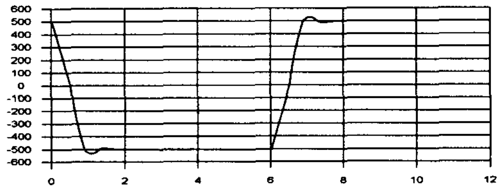
$$\frac{d}{dt} i_{ds} = \frac{-1}{L_s L_r - L_m^2} (-\omega_r L_m^2 i_{qs} + R_s L_r i_{ds} - \omega_r L_r L_m i_{qr} + R_r L_m i_{dr} - L_r V_{ds})$$

$$\frac{d}{dt} i_{qr} = \frac{-1}{L_s L_r - L_m^2} (R_s L_m i_{qs} - \omega_r L_s L_m i_{ds} + R_r L_s i_{qr} - \omega_r L_r L_s i_{dr} - L_r V_{qs})$$

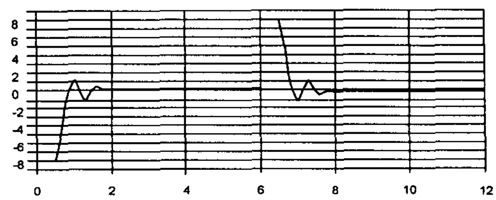
$$\frac{d}{dt} i_{dr} = \frac{-1}{L_s L_r - L_m^2} (-\omega_r L_s L_m i_{qs} - R_s L_m i_{ds} + \omega_r L_r L_s i_{qr} + R_r L_s i_{dr} - L_r V_{ds})$$

$$\frac{d}{dt} \omega_r = \frac{3L_m}{2J} (i_{qs} i_{dr} - i_{ds} i_{qr}) \frac{-B}{J} \omega_r - \frac{1}{J} T_i \tag{14}$$

Simulation results are depicted in Fig. 3, 4, 5 using the control techniques proposed in the previous section.

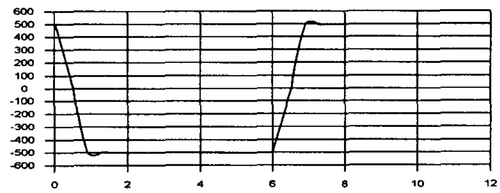


(a) Motor speed (rpm)

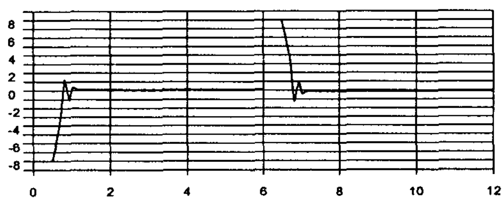


(b) Torque component current (mA)

Fig. 3. Fuzzy-PID Controller(No Load)



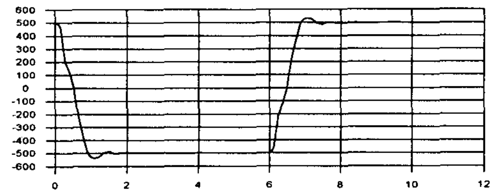
(a) Motor speed (rpm)



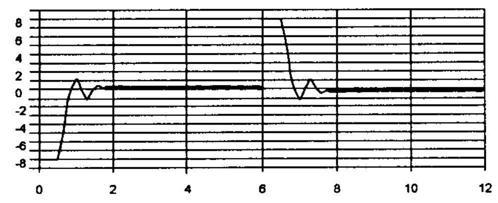
(b) Torque component current (mA)

Fig. 4. Proposed Controller (No Load, 30 Level)

As shown, we know that the proposed controller reduced the rise time and improved maximum overshoot. But the torque component current have a little non-linearity

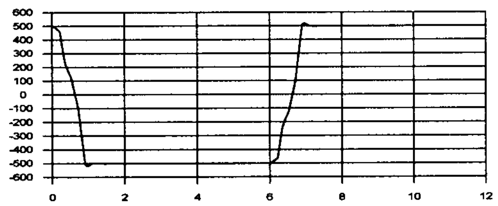


(a) Motor speed (rpm)

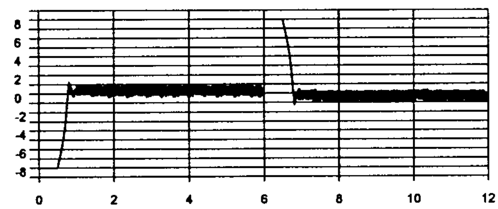


(b) Torque component current (mA)

Fig. 5. Fuzzy-PID Controller(Load)



(a) Motor speed (rpm)



(b) Torque component current (mA)

Fig. 11. Proposed Controller(Load, 30 Level)

To compare with no-load, the induction motor showed almost same performance. But torque component current had amplitude of vibration that becomes wide.

Finally, the torque component current oscillate in the steady state. This is a general characteristic of powerful controller like fuzzy controller that the small errors occur the large reactions.

Table 2. Ability of each controller for no load

	Estimated Value (PI)	Rise Time (s)	Maximum Overshoot(%)	Settling Time(s)
PID	13.577	0.640	4.4	1.844
Fuzzy-PID	12.425	0.639	4.3	1.728
GFPID	11.532	0.634	1.9	1.324

Table 3. Ability of each controller for no load

	Estimated Value (PI)	Rise Time (s)	Maximum Overshoot (%)	Settling Time (s)
PID	13.834	0.641	4.5	3.557
Fuzzy-PID	12.664	0.639	4.4	1.794
GFPID	11.624	0.635	1.9	1.328

6. CONCLUSIONS

This paper proposed a novel method for On-Line scheme using look-up table based on the genetic algorithm. This technique is an On-Line method that optimally estimate the parameters of Fuzzy-PID controller for speed control of induction motors with nonlinear plant using the genetic algorithm.

To prove the high performance, the proposed controller is applied to the induction motor for the speed control and its computer simulation is carried out.

The results of the controller are as follows:

1. The speed control of induction motor showed that the proposed controller gains optimal performance at load or loadless.
2. Through the division of input parameter region and optimal look-up table, On-line real time control with off-line performance was possible based on genetic algorithm.
3. The proposed controller achieved high performance better than conventional PID controllers. Especially, It obtain the high performance of rising time, overshoot and settling time at transient state when the level of input variable increased.
4. The proposed controller with auto-tuning method proved that it is possible to control the speed for electric vehicles with drive system of induction motor.

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