GFPID 제어기에 의한 Pseudo-on-line Method를 이용한 유도전동기의 구동

권양원, *윤양웅, **강학수, *안태천
원광대학교 공과대학 전기·전자공학부

Drive of Induction Motors using Pseudo-on-line Method Based on Genetic Algorithms for Fuzzy-PID Controller(GFPID)

Yangwon Kwon, *Yangwoong Yoon, **Haksu Kang, *Taechon AHN
*School of Electrical & Electronics Eng., Wonkwang University, Iksan, Chonbuk
**Electrical Eng., Jeonju Technical College, Jeonju, Chonbuk

Abstract - This paper proposes a novel method with pseudo-on-line scheme using look-up table based on the genetic algorithm. The technique is a pseudo-on-line method that optimally estimate the parameters of fuzzy PID(FPID) controller for systems with non-linearity using the genetic algorithm which does not use the gradient and finds the global optimum of an un-constraint optimization problem. The proposed controller(GFPID) 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 than 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]. Use of these conventional controllers is often adequate when the non-linearities of process are mild and plant operations are constrained to small region at a nominal steady-state. Model-based nonlinear control techniques can be used when high performance is required over a broader range of operating conditions.

The design of discrete-time FPID controllers in various combinations results in a new 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, namely, the proportional, integral, and derivative gains are nonlinear functions of the input signals. The FPID controllers thus preserve the simple linear structure of the conventional controllers, yet enhance the self-tuning control capability for non- linearity.

In this paper, a pseudo-on-line method (GFPID) is proposed that auto-tunes the parameters of controller by the genetic algorithm[4] for the improvement and optimization of systems. This method is applied to FPID controller of the drive system of induction motor. The proposed GFPID controller with the auto-tuning function executes the speed control of the system. Authors divide the region of errors that have influence on the system parameters, into several error levels and then make each level the optimized look-up table using the genetic algorithm.

Computer simulations would show that the proposed controller has high performance better than conventional FPID and PID controllers.

2. Induction Motor Modeling

As the stator or rotor is assumed to have symmetrical air gap, it is possible to express its voltage equations of the three-phase induction motor in stationary coordinates a_s, b_s and c_s, as follows [5],[6] :

$$v_{abcs} = R_s i_{abcs} + \frac{d\lambda_{abcs}}{dt} \quad (1)$$

$$v_{abcr} = R_r i_{abcr} + \frac{d\lambda_{abcr}}{dt} \quad (2)$$

where v_{abc*}, i_{abc*} and λ_{abc*} are instantaneous voltages, currents and flux linkage vectors of the rotor and stator, respectively, in the stationary frame.

The $d-q$ reference frames are usually selected on the basis of convenience or compatibility with the representations of other network components.

The stator and rotor flux linkage expressions in terms of the currents can be written compactly as follows [6]:

$$\begin{aligned}
\lambda_{qs} &= L_{ls} i_{qs} + L_m(i_{qs} + i_{qr}) \\
\lambda_{ds} &= L_{ls} i_{ds} + L_m(i_{ds} + i_{dr}) \\
\lambda_{qr} &= L_{lr} i_{qr} + L_m(i_{qs} + i_{qr}) \\
\lambda_{dr} &= L_{lr} i_{dr} + L_m(i_{ds} + i_{dr})
\end{aligned} \quad (3)$$

where, L_{ls} is stator leakage inductance, L_{lr} is rotor leakage inductance and L_m is mutual inductance.

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

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

The vector control of the induction motor[2] 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. The torque equation becomes as follows:

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}(i_{qs}\lambda_{dr} - i_{ds}\lambda_{qr}) \quad (5)$$

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

As the λ_{qr} is set to zero, the torque is as follows:

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

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

$$i_{qs} = \frac{2}{3}\frac{2}{P}\frac{L_r}{L_m}\frac{1}{\lambda_{dr}}T_e \quad (7)$$

The scheme of control system considered is like Fig. 1.

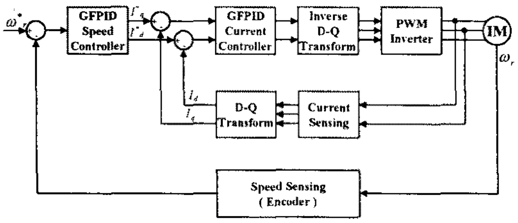

Fig. 1. The Scheme of Control System Considered

3. Fuzzy-PID Control Algorithm

In general, the control input $\boldsymbol{u}$ of the fuzzy controllers is decided by the proportional combination of error term and derivative term of error as eqn.(8). It corresponds to the PD of conventional PID as eqn.(9).

$$\boldsymbol{u} = \sum_{i=1}^{k}(\mu(e_i)\cap\mu(de_i)) \quad \langle Fuzzy \rangle \quad (8)$$

$$\boldsymbol{u}(t) = k_p e(t) + k_d\frac{de(t)}{dt} \quad \langle PD \rangle \quad (9)$$

In this paper, to remove defects of the fuzzy controller, the direct FPID controllers are designed by using the conventional PD+I controller design method. To obtain the increment of fuzzy control input, this method directly applies the control gains to PID control input concept. The fuzzy reasoning is executed using the eqn.(10).

$$\boldsymbol{du} = k_p \cdot e + k_i \cdot ie + k_d \cdot de \quad (10)$$

where e_m, de_m and ie_m are the maximum values of error, derivative of error and integral of error and e_o, de_0 and ie_o, the minimum values of error, derivative of error and integral of error.

The fuzzy sets of e, de and ie are described as Fig. 2:

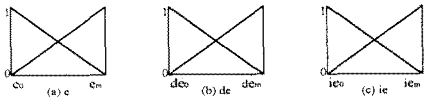

Fig. 2. Fuzzy sets of e, de, ie

Each fuzzy rule can be described as follows by simpled fuzzy reasoning method.

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

As the results of fuzzy reasoning, the output of fuzzy controller is described as follows:

$$f = \boldsymbol{du} = k_p \cdot e + k_d \cdot de + k_i \cdot ie \quad (11)$$

The output of fuzzy controller, that is, eqn. (11) is used as the control input of induction motor.

4. Auto-Tuning by Genetic Algorithm

Genetic algorithms (GAs) [4] are directed to random search techniques, which can find the global optimal solution in complex multidimensional search spaces. GAs employ different genetic operators to manipulate individuals in a population of solution over several generations to improve their fitness, gradually. Normally, the parameters to be optimized are represented in a binary string.

In this paper, to easily conduct the crossover operator, input variables are multiplied by 1000, roundoff the fractions, transformed into integer and converted to binary digital system. This integers become new input variables. Takagi's formula[7] is used as the objective function that defined by function of input variables like eqn.(23).

$$\boldsymbol{F}(\boldsymbol{k}) = \sqrt{(e(k)^2 + de(k)^2 + ie(k)^2)} \quad (12)$$

where, $e(k)$, $de(k)$ and $ie(k)$ is error, derivative of error and integral of error as input variables, respectively. The number of populations use 10 and the number of chromosomes gain 20 through the conversion of five decimal places to binary. Selection of genetics uses probability theory and random variable. The crossover and mutation rates also use random variable. The algorithm is repeated until a predefined result has 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, that is, $e(k)$, $de(k)$ 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 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 increasing levels cause that the performance is getting bad, owing to large computer capability and the low access speed. Therefore it is to be suitable to select levels between 30 to 100.

Heuristic algorithm that changes fuzzy control rule to the experience knowledge, have good performance in the steady-state error, but do not give so good performance in the transient-state error. This method provides good performances in the steady-state and transient-state errors.

5.Simulation

Several simulations have been carried out to examine the feasibility of the proposed pseudo-on-line 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.

$$\frac{d}{dt} i_{qs} = \frac{-1}{L_sL_r - L_m^2}(R_sL_ri_{qs} + \omega_rL_m^2i_{ds} - R_rL_mi_{qr} + \omega_rL_rL_mi_{dr} - L_rV_{qs})$$

$$\frac{d}{dt} i_{ds} = \frac{-1}{L_sL_r - L_m^2}(-\omega_rL_m^2i_{qs} + R_sL_ri_{ds} - \omega_rL_rL_mi_{qr} + R_rL_mi_{dr} - L_rV_{ds})$$

$$\frac{d}{dt} i_{qr} = \frac{-1}{L_sL_r - L_m^2}(R_sL_mi_{qs} - \omega_rL_sL_mi_{ds} + R_rL_si_{qr} - \omega_rL_rL_si_{dr} - L_rV_{qs})$$

$$\frac{d}{dt} i_{dr} = \frac{-1}{L_sL_r - L_m^2}(-\omega_rL_sL_mi_{qs} - R_sL_mi_{ds} + \omega_rL_rL_si_{qr} + R_rL_si_{dr} - L_rV_{ds})$$

$$\frac{d}{dt} \omega_r = \frac{3L_m}{2J}(i_{qs}i_{dr} - i_{ds}i_{qr})\frac{-B}{J}\omega_r - \frac{1}{J}T_i \tag{13}$$

Torque equation can be as follows[8]:

$$T_e = \frac{3}{2}\frac{P}{2}\frac{1}{\omega_b}(\phi_{qr}i_{dr} - \phi_{dr}i_{qr}) \tag{14}$$

where $\phi = \omega_b\lambda$, $\omega_b = 2\pi f_{rated}$ electric radians per second and f_{rated} being the rated frequency in Hertz of the machine.

Voltage source frequency ω can be related to the rotor frequency ω_r as follows:

$$\omega_e = \frac{R_rL_m}{\phi_{dr}L_r} \cdot i_{qs} + \omega_r \tag{15}$$

Table 3 shows the rated values and the nominal parameters of a tested machine. Simulation results are depicted in Fig. 8 ~ 13, when the motor speed is changed from -600[rpm] to 600[rpm], applied the control techniques proposed in the previous section. In these figures, 30 levels case is compared for the given method in viewpoint of motor speed and torque component current. We use also eqn.(16) as performance index (PI) of induction motor.

$$PI = \int\sqrt{e^2} \tag{16}$$

where, e is error of motor speed.

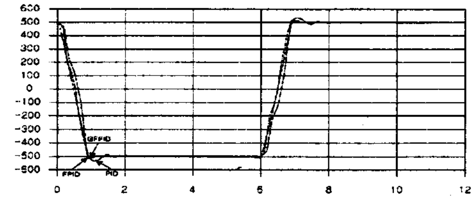

Fig. 2. Motor Speed (x-sec., y-rpm, No Load)

As shown in Fig. 2 with no load, the proposed controller reduces the rise time and improves maximum overshoot.

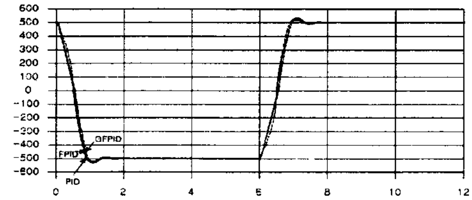

Fig. 3. Motor Speed (x-sec., y-rpm, Load)

As shown in Fig. 3 with load, the proposed controller has the same performance for the rise time and the performance index. But this method improves maximum overshoot and settling time.

6. Conclusions

This paper proposed a novel method with on-line scheme using look-up table based on the genetic algorithm. This technique is an pseudo-on-line method (GFPID) that optimally estimate the parameters of FPID 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.

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