Speed Control of Induction Motors using GA based PI Controller

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ABSTRACT

This paper deals with speed control of induction motors with a gain tuning based on simple Genetic Algorithms, which are search algorithms based on the mechanics of natual selection and genetics. Based on the designed control system structure, the indirect vector control system of induction motors is simulated. The simulation results show that the system has a strong robust to the parameter variation and is insensitive to the load disturbance. Thus, the proposed PI controller based on genetic algorithms is superior to manually tuned classical PI controller in improving the speed control performance of induction motors.

1. INTRODUCTION

The PI controller has been widely used in industrial application due to the simple control algorithm. But, a classical PI controller should produce a suitble PI gains according to the operating conditions, parameter changes, disturbance and loads. Therefore, it is very difficult and complex to optimize the PI controller gains. In this paper, we applied Genetic Algorithms to cope with this problem. We employed Genetic Algorithms to the classical PI controllers. The approach having ability for global optimization and with good robustness, is expected to overcome some weakness of conventional approaches and to be more acceptable for industrial applications.

This paper deals with speed control of induction motors with a gain tuning based on simple Genetic Algorithms, which are search algorithms based on the mechanics of natural selection and genetics. Simulations are carried out to verify the feasibility of this speed control of induction motors under vector control conditions. The Simulation results show that the speed control system of induction motors has a strong robust to the parameter variation and is insensitive to the load disturbance. The control performance of this PI controller is evaluated by simulation for different GA's parameters and comparing with the results of the classical PI controller using the Integral of Time by Absolute Error (ITAE) critérion. Thus, the proposed PI controller based on Genetic Algorithms is superior to manually tuned PI controller in improving the speed control performance of an induction motor and GAs based approach is really an alternative and potential method for induction motor drive system. This paper is organized as follows. Section2 describes dynamics and mathematical model of induction motor. Section3 provides basic information on Genetic Algorithms and details of the controller design. In section 4 simulation results and control performance analyses are given.

2. INDUCTION MOTOR DYNAMICS AND CONTROL STRUCTURE

The state equations of a squirrel-cage induction motor drive in a synchronously rotating frame can be expressed as follows (1):

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s+SL_s & \omega_e L_s & SL_m & \omega_e L_m \\ -\omega_e L_s & R_s+SL_s & -\omega_e L_m & SL_m \\ SL_m & (\omega_r-\omega_e)L_m & R_r+SL_r & (\omega_e-\omega_r)L_r \\ -(\omega_e-\omega_r)L_m & SL_m & -(\omega_e-\omega_r)L_r & R_r+SL_r \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \quad (1)$$

where S is the Laplace operator. If the speed ω_r is considered as constant, then knowing the inputs V_{qs}, V_{ds}, and ω_e, the currents i_{qs}, i_{ds}, i_{qr}, and i_{dr} can be solved from equation (1).

The torque equation as a function of stator curmets and stator fluxes is

$$T_e = \frac{3}{4} P \frac{L_m}{L_r} (i_{qs}\lambda_{dr} - i_{ds}\lambda_{qr}) = T_L + B\omega_r + Jp\omega_r \quad (2)$$

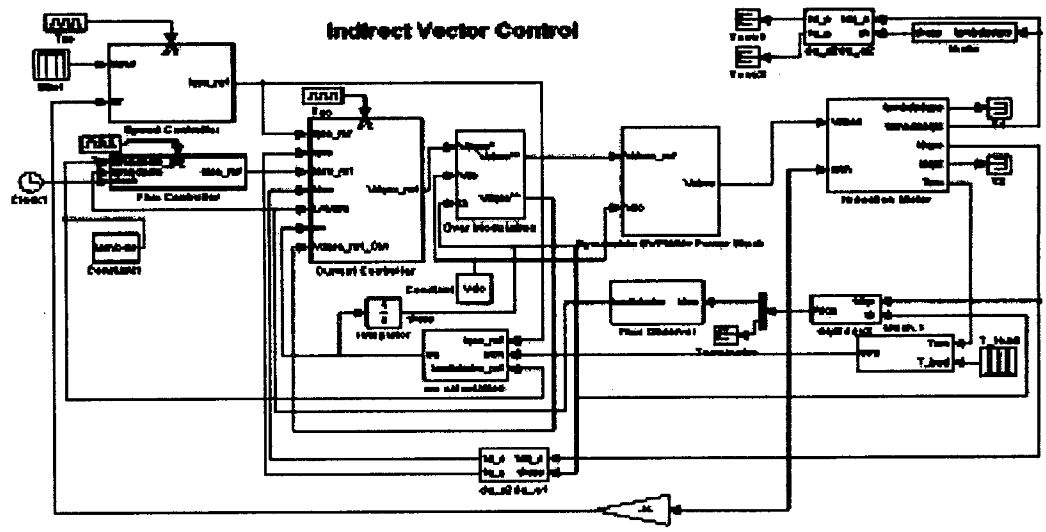

Figure 1. SIMULINK Block of Induction Motor Drive

where, $p \cong \frac{d}{dt}$, $\sigma \cong L_s - \frac{L_m^2}{L_r}$,

J=total machnical inertia, B=total damping coefficient

Basically, the indirect field-oriented for an induction motor drive can be regarded as one of predictive control. It is found that the ideal decouling can be achieved if the following slip angular speed command is used for making field-orientation:

$$\omega_{sl}^* = \frac{R_r}{L_r}\frac{i_{qs}^*}{i_{ds}^*} \cong \frac{1}{T_r^*}\frac{i_{qs}^*}{i_{ds}^*} \quad (3)$$

where, T_r^* denotes the actual rotor time constant, i_{ds}^* and i_{qs}^* are the d- and q-axes stator current commands set by the field and speed controllers. In this case, it can lead to the following three phenomena:

1) $\lambda_{qr} = 0$ and $\frac{d\lambda_{qr}}{dt} = 0$

2) the rotor flux can be set as

$$\lambda_r^* = \lambda_{dr}^* = (L_m i_{ds}^*)(1 + T_r^*) \cong L_m i_{ds}^*$$

since normally, $T_r^* << (J/B)$

3) the motor developed torque is directly related to i_{qs}^* by

4) $T_e = (\frac{3}{4}P\frac{L_m}{L_r}\lambda_{dr}^*)i_{qs}^* = (\frac{3}{4}P\frac{L_m^2}{L_r}i_{ds}^*)i_{qs}^* \cong k_t^* i_{qs}^*$ (4)

The control schematic of an indirect field-oriented induction motor with proposed speed controller is shown in Fig.1. The vector rotate transforms the currents in the synchronously rotating reference frame to three-phase reference currents in stationary reference frame. The reference currents are compared with the actual currents to switch the current-controlled voltage source inverter.

3. DESIGN OF GA BASED PI CONTROLLER

3.1. Genetic Algorithm Overview

Genetic algorithms are a numerical optimization technique. More specially they are parameter search procedures based upon the machnics and natural genetics. They combine a Darwinian survival-of-the fittness strategy with a random yet structured information exchange among a population of artificial "choromosomes". Genetic Algorithms in general require the parameter set of an optimization problem to be coded as a finite length string(called chorosomomes, individuals, or population members). A Genetic Algorithm wil typically employ three "operators" in a simple genetic Algorithms: reproduction, crossover, and mutation. These operators work with a number of artificial creatures called a generation. By exchanging information from each individual in a population, GAs preserve a better individual and yield higher fitness generation by generation such that the performance can be improved. The flow chart of simple Genetic Algorithm is shown in Fig.2. Next, we will briefly describe the basic operators in a GA.

3.1.1. Reproduction

The underlying criterion of reproduction is the Darwinian survival of the fittest theory. In a population, individuals with higher fitness values will be selected and copied to a new population with higher porbabilities. In other words, the strings which have better fitness than the others contribute a larger number of offspring in a new generation.

3.1.2. Crossover

This operator provides a mechanism for individual to exchange information via a probabilistic process. It is proceeded in two steps. First, members of the newly reproduced strings in the mating pool are mated at random. Second, each pair to strings exchange information by selecting a position

3.1.3. Mutation

The machanics of reproduction and crossover are surprisingly simple. Reproduction preserves the elitist part of the old generation, and crossover combines the elite of different individuals to obtain a new individual with higher fitness values. However, no matter how many generations have been processed, reproduction and crossover cnanot produce the features that are not contained in the initial population. Consequently, mutation is needed for overcoming shortage. The operation of muatation is to replace the value of a fixed position in a string by another value.

3.2. GA Tuning PI Controller Design

The focus of this paper is the optimization of a PI speed controller for a indirect vector-controlled induction motors.

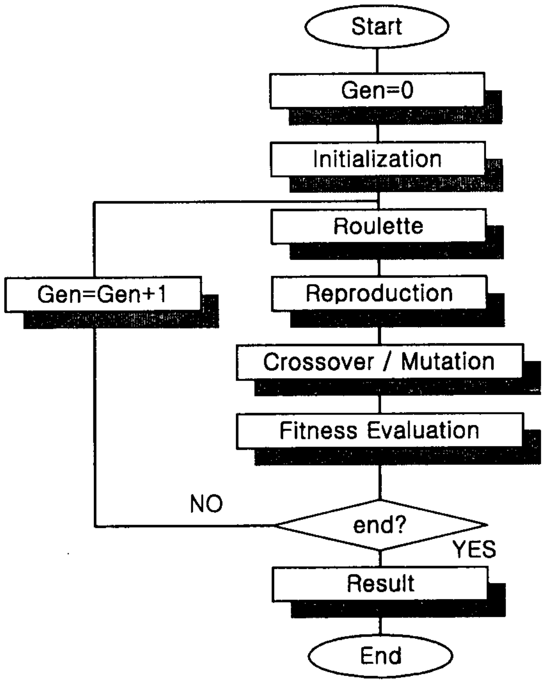

Figure2. Flow Chart of simple GA

The PI controller for speed control of induction motordrive is given by equation (5) and (6).

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt \tag{5}$$

$$e(t) = y(t) - y(t-1) \tag{6}$$

For the purpose of tuning the PI speed controller, the proportional(Kp), integral(Ki) gains have to adjusted. So the genes of the chromosomes are possible gain values for the controller as follow :

$$\text{Chromosome} = \lfloor K_p, K_i \rfloor \tag{7}$$

The selection of an appropriate criterion to evaluate the fitness of each chromosome is minimized the Integral with Respect to Time of Absolute Speed Error(ITAE) which tuned the speed controller.

$$ITAE = \int_0^t t|e(t)|dt \tag{8}$$

A performance index (ITAE) reduces the contribution of the large initial error to the value of the performance integral , as well as to emphasize errors occurring later in the response. The PI controller proposed in this paper employs simple Genetic Algorithms which is developed with Matlab/Simulink. Fig.3 is SIMULINK block of PI controller for speed control of induction motor drive.

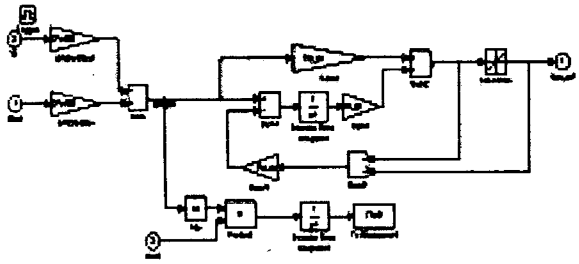

Figure3. SIMULINK Block of PI Controller

4. SIMULATION RESULTS

In this paper, the impacts of the generation number and mutation probability are investigated when using a genetic algorithm for the tuning of PI speed controller in induction motor drive. This paper employs the fittness function to minimize ITAE for the high control performance. Fig.4 shows the ITAE means of 10, 20, 30 and 50 generations, respectively.

Considering the searching time, 10 generations are chosen as a generation number in this paper.

In Fig.5, the same initial population was created and evolved through 10 generations with 0%, 1%, 5% and 10% mutation probabilities. For the higher mutation probability, the convergence of the genetic algorithm towards the optimum solution was faster compared to those cases where the probability was 0%, 1% and 5%. The reason is that higher mutation probability produces more changes in the population between generations. Therefore, by simulation results shown in Fig.5. 5% is determined as a mutation probability for induction motor drive in this paper. Fig.6 is the searching process of best PI gains when generation number and mutation probability is 10 and 5%. After evolution through 10 generations, the best PI gains are achieved as shown in Fig.6(d).

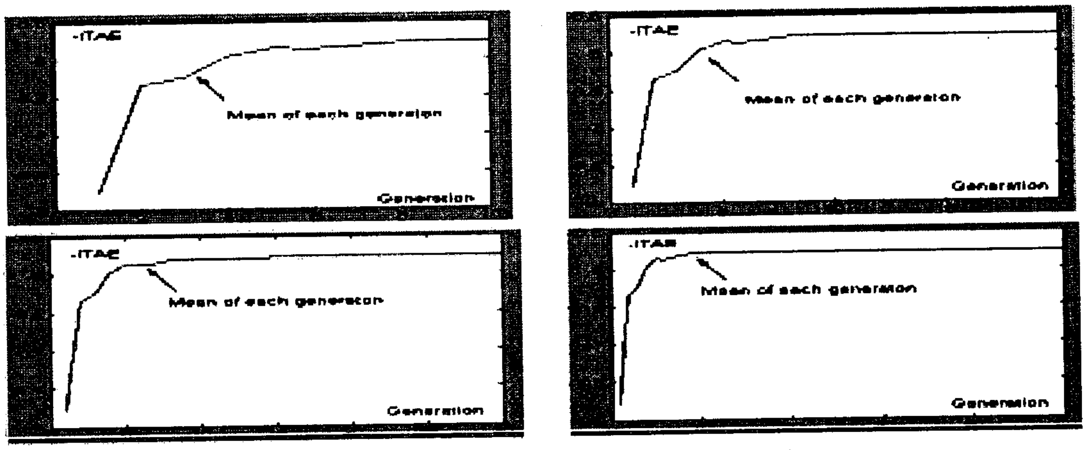

Figure 4. –ITAE Mean Values of Each Generation Numbers

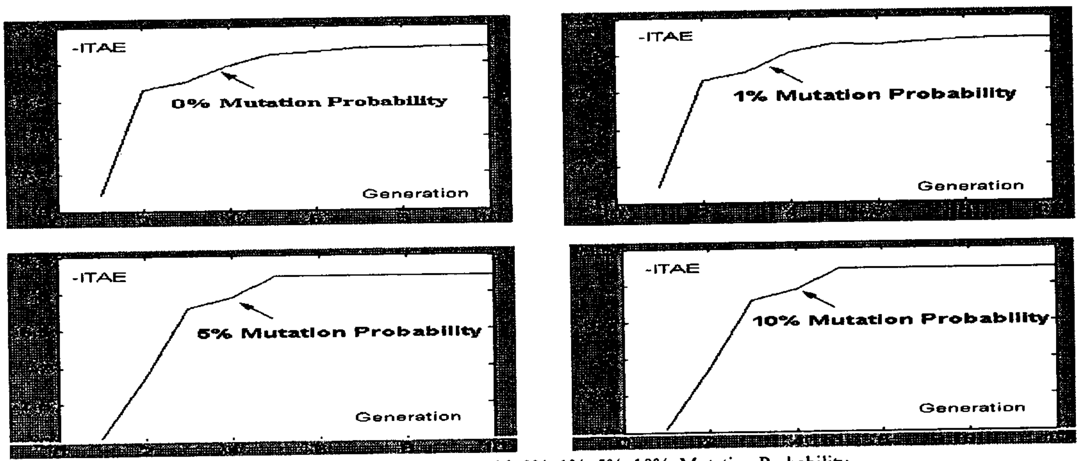

Figure 5. 10 Generations with 0%, 1%, 5%, 10% Mutation Probability

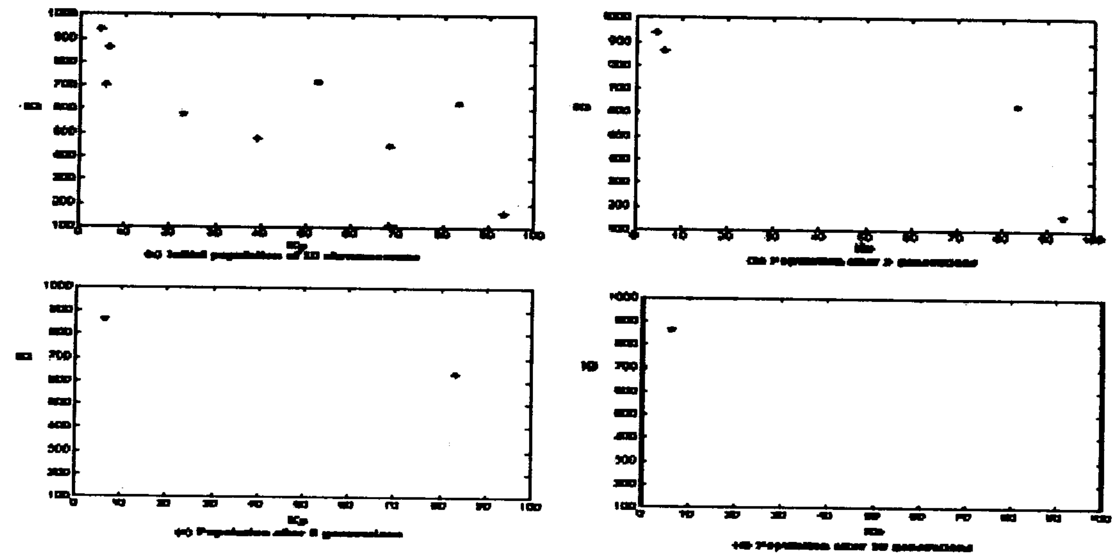

Figure 6. Population after Initial, 3, 5, 10 Generations

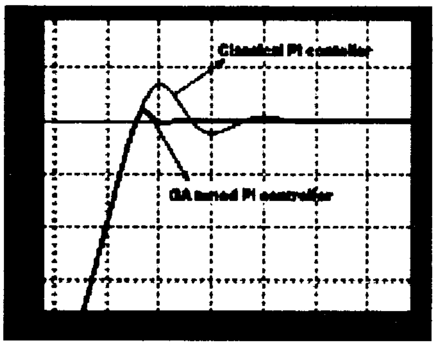

Figure7. Speed Responses of IM

Fig.7 is the speed responses of induction motor drive with the best PI gains. This simulation result shows that genetic algorithm based PI controller is superior to classical PI controller with improving the control performance. The summarized simulation results of this paper are presented in table 1.

Generations	Kp	Ki	-ITAE
10	6.9270	861.5507	-5.779021
20	7.8282	816.8838	-5.773063
30	9.3751	830.9463	-5.771425
50	9.4068	887.2512	-5.771305

Table 1. Summary of Results

5. CONCLUSION

The speed controller of induction motor drive using a genetic algorithm has been studied and investigated the impacts of the generation number and mutation probability. By evolution with 10 generations, the best Kp, Ki gains are obtained 6.927, 861.25 respectively, when -ITAE is –5.779. This paper shows that GAs could become more effective optimization technique in induction motor drive.

6. REFERENCES

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APPENDIX

Rated Power	3.75 [KW]	Rs	0.6992 [Ω]
Rated Speed	1730 [rpm]	Rr	0.3552 [Ω]
Rated Voltage	220 [V]	Ls	0.0661 [H]
Rated Current	12.6 [A]	Lm	0.0632 [H]
Poles	4	J	0.0918 [kg.m^2]

Table 2. Motor Parameters