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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 11 (3): 359-363, 2012
ISSN 1812-5638 / DOI: 10.3923/itj.2012.359.363

Optimization of Nine-point Five-state Speed Controller for Asynchronous Motor Based on Intelligent Genetic Algorithm

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Abstract: Considering multivariable and close coupling of asynchronous motor vector control system, an intelligent control strategy named nine-point five-state controller was adopted as speed controller. The intelligent genetic algorithm (IGA for short) was applied to optimize the controller parameters, which used orthogonal experiment and intelligent mating operations to improve the optimization performance. The detailed optimization method and process were given. Simulation results have indicated that this kind of strategy can not only improve system dynamics and steady-state behavior but can also achieve relatively strong anti-disturbance performance.

Key words: Phase plane, IGA, speed controller, nine-point five-state

INTRODUCTION

Asynchronous motor AC drive system is a complex nonlinear system. However, different kinds of decoupling control methods like slip frequency vector control, scalar decoupling vector control and stator flux field-oriented vector control etc., all work under the prerequisite of accurate motor parameters and accurate observer of flux. So the conventional PID control can't meet the high accuracy, fast response and good robustness.

Nine-point five-state controller is a new intelligent control strategy based on pan-boolean algebra (Nanlun, 2005). Currently, great progress has been made in its research and applications (Siyun and Jianzhong, 2003; Nanlun *et al*., 2004; Qian *et al*., 2010). However, nine-point five-state controller is based on phase plane analysis method. Nine control parameters acquired from phase plane division have obvious effect on control performance. Thus, it is necessary to do some setting on given values of nine-point five-state controller. Over the last several years, neural network or fuzzy control algorithm is usually used to set the parameters.

Huang and Nelson (1999) designed an adaptive fuzzy controller using phase plane analysis method. This method can obtain relatively good control performance but from its design and adjustment processes, it is easy to know that this method is complex and takes up large memory space with much time loss. Shujun and Xiaohu (2006) have integrated online learning ability of neural network, adaptive regulatory function and logical judgment of phase plane division to propose a new intelligent controller-neural network phase plane division controller. This controller built a real-time correspondent relationship on phase plane between system response basic performance and division of control forces and effective strength of different working conditions. Liu *et al.* (2005) introduced genetic algorithms (GA for short) to estimate nonlinear system model varying parameters and set parameters for nine-point five-state controller. However, traditional GA may converge on local minimum point and suffer premature convergence under the condition of too many parameters and too long GA encoding. To obtain best performance, this paper has employed IGA (Ho *et al*., 2004) to optimize parameters of nine-point five-state controller and design the speed controller to improve control performance of asynchronous motor.

THEORY OF NINE-POINT FIVE-STATE CONTROLLER

Structure of nine-point five-state controller is shown in Fig. 1. There into, r is the set value of system, c is the output of system, u_c is output of controller, deviation e = r-c, deviation variance ratio $\ddot{e} = (e_i-e_{i-1})/T$ (T is sampling period, i and i-l are i-th sampling point and the next sampling point).

Nine-point five-state controller embodies significance of all parameters of fuzzy control and divides them into nine control effects like positive or negative, strong or

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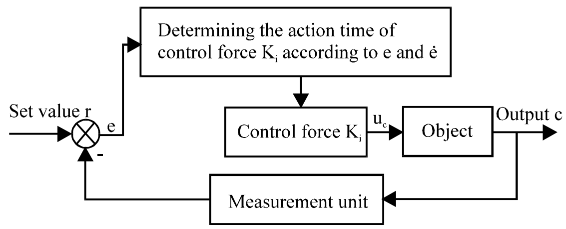

Fig. 1: Structure of nine-point five-state controller

Table 1: Control strategy of nine-point five-state controller

	Error variance ratio		
Error	$\dot{e}<-\dot{e}_0$	$\lvert\dot{e}\rvert\le\dot{e}_0$	$\dot{e}>\dot{e}_0$
$e<-e_0$	Reduce a lot (K_{4-})	Reduce slightly (K_{2-})	Reduce slightly (K_{2-})
$\lvert e\rvert\le e_0$	Reduce a lot (K_{4-})	Hold (K_0)	Increase a lot (K_{4+})
$e>e_0$	Increase slightly (K_{2+})	Increase slightly (K_{2+})	Increase a lot (K_{4+})

weak. It determines action time and switching time of the nine control effects according to variety of system error e and its variance ratio ë. It works like this: when the controlled object deviates from set values, the controller will add a reacting force automatically to make system response return to the vicinity of set values. Controller keeps switching among nine effects until the system can be controlled under the set conditions according to real-time varying logical relationship of e and ë. Nine-point five-state controller has nine divisions corresponding to plane made up of e and ë. It is easy to get a plane having five divisions after combination and simplification of those nine divisions shown in Fig. 2 (where $\pm e_0$ and $\pm\ddot{e}_0$ represent system allowable error and allowable error variance ratio, respectively (Li *et al*., 2004).

These five conditions represent all operational modes of system and make the system work approaching to perfect curve when different divisions have different control effects (namely control force K_{4+}, K_{2+}, K_0, K_{2-}, K_{4-}). The control strategy is shown in Table 1.

Research shows K_0 controls steady-state error, K_{4-} can inhibit overshoot, K_{4+} can inhibit undershoot, K_{2-} accelerates response speed and forces deviation to come back to set value, K_{2+} influences the rising time of system, the bigger K_{2+} is, the less rising time is. So the system will meet the requirement of steady-state, accuracy and rapidity if all the K values are set reasonably.

PRINCIPLE OF IGA

IGA's main advantage is high stability. It mainly designs an effective GA chromosome and an intelligent crossover operation to improve its search speed. This paper applies it to optimize parameters of nine-point five-state controller like K_{4+}, K_{2+}, K_0, K_{2-}, K_{4-}, every individual is a real number accurate to 3 decimal places.

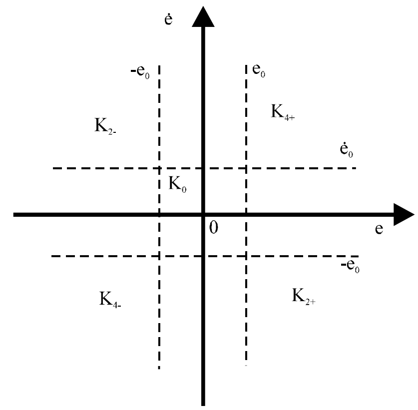

Fig. 2: The phase plane of nine-point five-state controller

Intelligent crossover and gene selection: Intelligent crossover operation is based on orthogonal experiment design. This method can reduce the number of experiments in gene combination of conventional GA and makes the experiments representative. Also, gene combination can be distributed evenly in the room for all the gene combinations. As a result, the acquired orthogonal gene combination experiments can be very representative and the evaluation on value of contribution of the fitness of every gene calculated from gene evaluation function can be credible. If the evaluation of quality of every gene is assured, desirable genes can be gained from every gene of chromosome. Then, desirable genes of their paternal chromosome will unite to realize intelligent crossover.

Orthogonal experiment design: Orthogonal experiment design has both merits of orthogonal array and factor analysis. It uses superb performance of part factor experiment to select optimal combination and can obtain relatively good results through less experiments and simpler analysis methods.

If the paternal binary coding chromosome has 7 genes, it is easy to build an orthogonal table of $L_8(2^7)$ according to gene numbers of chromosome to be crossover and two possible values of each gene. The orthogonal table is obvious comparability, every row has the same possibility to be 1 or 2 (4 times). If two random rows of one line can be considered as order pair (1,1), (1,2), (2,1) and (2,2), then every kind of pair will appear at the same rate (collocation). So this orthogonal experiment can make gene value distributed evenly in the space for all possible solutions. Eight times experiments will meet the requirement of comparability and collocation. After these 8 times experiments, Gene values will be distributed evenly in the space for solutions. And the number of gene

Table 2: $L_8(2^7)$ orthogonal experiment arrays

	Gene							
Trial No.	1	2	3	4	5	6	7	Fitness value
1	1	0	0	1	0	1	0	f_1
2	1	0	0	1	0	0	1	f_2
3	1	1	0	1	0	0	1	f_3
4	1	1	0	1	0	1	0	f_4
5	0	0	0	1	0	1	1	f_5
6	0	0	0	1	0	0	0	f_6
7	0	1	0	1	0	0	0	f_7
8	0	1	0	1	0	1	1	f_8
Y_{j1}	Y_{11}	Y_{21}	Y_{31}	Y_{41}	Y_{51}	Y_{61}	Y_{71}	
Y_{j2}	Y_{21}	Y_{22}	Y_{32}	Y_{42}	Y_{52}	Y_{62}	Y_{72}	

combination will be reduced from 64 (method of exhaustion) to 8, thus, calculation times can be cut down greatly.

Intelligent mating operation: Mating is the most important step of GA. It can generate new individuals from ancestor genes by gene recombination and decides the global search capability of GA. IGA makes use of even mating operation and intelligent mating operation. Even mating operation will generate two chromosomes to be compared with paternal chromosomes so as to choose two chromosomes with best fitness value. This can make the algorithm converge fast at the beginning. Assuming that two selected chromosomes are P_1 [1001010] and P_2 [0101001] in the intelligent mating operation, both including 7 genes, the intelligent mating operation can be conducted as following:

Step 1: Do the orthogonal experiment, assume that level 1 and level 2 of gene j represent j th parameter from paternal chromosomes P_1 and P_2, then orthogonal experiment is shown in Table 2

Step 2: Analyze the data of orthogonal experiment by using main effect, which can make contribution value of every gene expressed in quantification. If f_t is the fitness value of t th trial, main effect Y_{jk} of level k of j th gene is:

$$Y_{jk} = \sum_{t=1}^{M} f_t \cdot F_k \quad j=1,2,...,N, k=\{1,2\} \tag{1}$$

where, F_k=1 means that the level of j th gene in the t th experiment is k, otherwise F_k = 0. Larger main effect means better contribution to fitness function.

Step 3: Determine the best level according to every parameter. When $Y_{j1}>Y_{j2,}$ gene j chooses level 1, otherwise level 2

Step 4: Choose the best parameter combination as filial generation individual S_1 after main effect analysis

Step 5: Find the largest fitness function value among all the experiments as filial generation individual S_2

Step 6: Complete the intelligent mating

Uniform mutation: In order to expand the IGA search range in solution space and improve the diversity of population, this paper has employed relatively big mutation ratio and uniform mutation strategy with the same operation of traditional GA while best individual in population does not mutate.

OPTIMIZATION OF NINE-POINT FIVE-STATE CONTROLLER BASED ON IGA

Fitness function selection: Chromosome coding is binary coding. Mean-square error is often considered as performance index of system according to minimum of target function and system time domain specification. In phase plane, better performance can be obtained when the area of phase path is becoming smaller. Therefore, fitness function chooses integrated time and absolute error (ITAE for short) performance index function in order to make controller parameters more selective, define:

$$f = \delta\int e^2\,dt + \beta\int|\dot{e}|\,de \tag{2}$$

where, $\int e^2$ dt reflects requirement on error and it is a widely-used performance index. $\int|\dot{e}|de=\int\dot{e}^2dt$ represents area of phase path, it corresponds to the mean-square value of time domain error variance ratio and reflects system requirement on error variance.

The above mentioned performance indices integrate information of time domain and phase plane and demand much on error and error variance ratio. Using these indices to evaluate system performance will be more reasonable and comprehensive when compared with the method using only error as performance index. Selection of δ and β reflects system requirement on error and its variance ratio.

Optimization procedure based on IGA: The specific procedure based on IGA is:

Step 1: Define the control parameter. Set the population size at 40, mutation rate at 0.02, crossover rate at 0.92, maximum iteration at 30 and convergence of IGA requirement is to keep maximum fitness of 5 generations in succession constant

Step 2: Initialize the population. Generate initial population randomly according to pre-set population size

Step 3: Intelligent crossover. Select those chromosome to be crossover from the population according to pre-set crossover rate, then do the intelligent crossover and choose the desirable genes to attain their filial generations

Step 4: Mutation. Apply the even mutation to selected individuals according to pre-set mutation rate

Step 5: Judge if the convergence requirement has been met, otherwise repeat step 3)

SIMULATION EXPERIMENTS

In order to test the system control performances based on IGA, this paper chooses MATLAB as simulation platform. Set motor parameters: U_N=460V, p = 4, f = 60Hz, R_s = 0.087Ω, L_{1s} = 0.8 mH, L_m = 34.6 mH, R_r = 0.228Ω, L_{1r} = 0.8 mH.

Figure 5-7 represent a-phase current, torque, stator voltage response curves under the given load disturbance shown in Fig. 3 and the given rotate speed shown in Fig. 4. Figure 8 provides the comparison curves between speed response of nine-point five-state controller optimized by IGA, PID controller and fuzzy controller.

Simulation results show that conventional PID controller needs more time to recover when added a pop in-load and may encounter bigger overshoot and oscillation during recovery time. Fuzzy control works better than PID controller in dynamic performance, anti-load-disturbance and parameter robustness of small range, yet it has comparatively worse steady-state performance. The control system with nine-point five-state controller optimized by IGA has relatively fast rising time, shortest setting time and least error, which also can reduce system error apparently and improve the anti-load-disturbance ability.

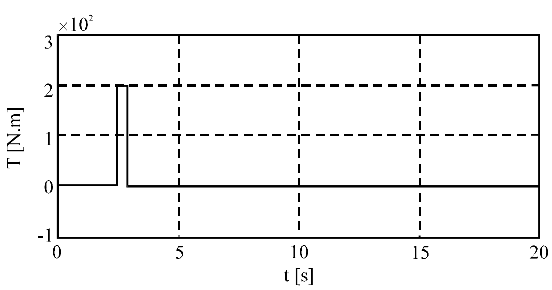

Fig. 3: Load disturbance curve

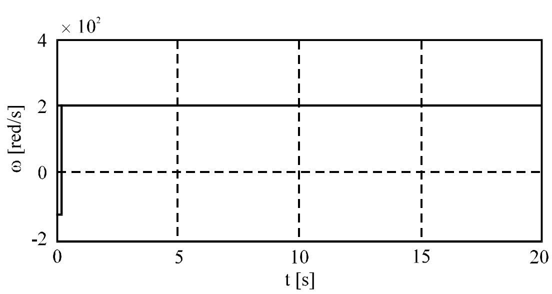

Fig. 4: System setting rotate speed curve

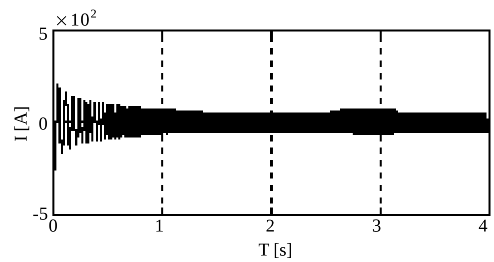

Fig. 5: A-Phase current response curve

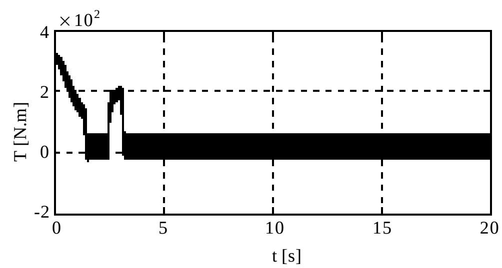

Fig. 6: Torque response curve

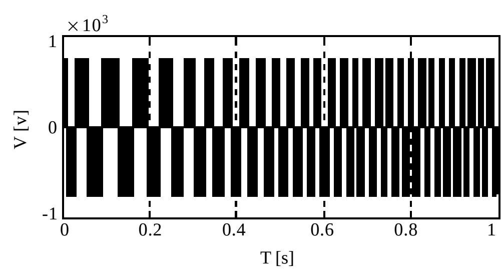

Fig. 7: Stator voltage response curve

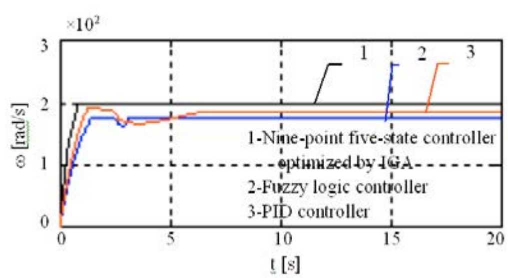

Fig. 8: Speed response curves under 3 controllers

CONCLUSION

Nine-point five-state controller optimized by IGA has advantages of both IGA and phase plane division control. IGA carries out intelligent mating on the basis of orthogonal experiment design to make chromosome converge fast and accelerate system response with no overshoot. Nine-point five-state speed controller has built corresponding relationship among basic system performance, optimization of division of control force under corresponding work conditions and their effect strength. All these forces can have more definite performance indices of system in their phase plane and can work more effectively during the entire system response time. Therefore, using IGA to optimize nine-point five-state speed controller of asynchronous motor is an effective method to improve speed adjusting performance.

ACKNOWLEDGMENT

This study thanks the Natural Science Key Foundation of Anhui Provincial Education Department (No.KJ2010A041) and the Science and Technology Development Funds of Wuhu City(2009-190).

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