Fuzzy Logic Controller Design Based on Genetic Algorithm for DC Motor

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Abstract—**This paper propose a genetic based fuzzy logic controller to regulate the speed of separately excited DC motor. The fuzzy membership function and rules are optimized based on genetic algorithm. The DC motor speed control system is modeled and simulated in MATLAB/SIMULINK. Simulation results show that the optimized fuzzy logic controller not only has no overshoot, minimum settling times and vibrations, but also demonstrate high performance for real-time control over a wide range of operating conditions.**

Keywords-***DC motor drive; Fuzzy logic controller; Genetic algorithm; Simulation***

I. INTRODUCTION

In spite of the development of power electronics resources, the direct current machine became more and more useful.[1]. The speed control of DC motor is the main issue associated to DC motor application and the non-linear characteristics of a DC motor is still degrading the performance of traditional speed control methods. Basically, these traditional methods all depend on the accuracy of system models and parameters. Yet, an accurate non-linear model of an actual DC motor is difficult to find.

Recently, there are more and more discussions on fuzzy controller used in DC motor drive system. Although the mathematical model is not necessary in designing fuzzy logic controller, the expert experiences and knowledge database are still necessary for the rules and ranges of membership functions. To enhance the adaptability of the controller, genetic algorithm is applied to search the globally optimal parameters of fuzzy logic controller. Computer simulation results are a direct demonstration of the effectiveness and robustness of the optimal design.

II. MODEL OF SEPARATELY EXCITED DC MOTOR

A separately excited DC motor is a motor in which the field and armature circuit has independent voltage sources. This means that the armature and the field voltage can be controlled separately, which give it the advantage of better electrical and mechanical performances than the other DC motor configuration. The equivalent circuit of a separate excited DC motor is shown in Figure 1.

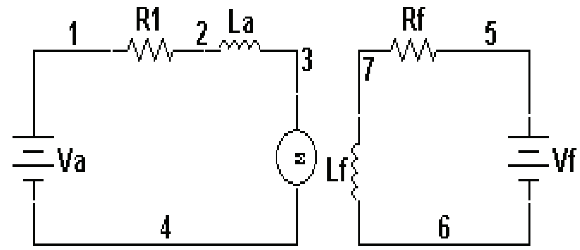

Figure 1. Separately excited DC motor

The characteristic equations of the DC motor are represented as[2]:

$$\frac{di_a}{dt} = \frac{1}{L_a}(V_a - R_a i_a - E_a) \tag{1}$$

$$\frac{di_f}{dt} = \frac{1}{L_f}(V_f - R_f i_f) \tag{2}$$

$$\frac{d\omega}{dt} = \frac{1}{J}(T_e - T_L - B\omega) \tag{3}$$

Where the T_e is the development electrical torque, E_a is the back EMF, B denotes the viscous friction coefficient, and J is the moment of inertial.

The torque developed by the motor is:

$$Te = K_t * i_f * i_a \tag{4}$$

Where K_t is torque constant in V/A-rad/sec.

From the above equations, the DC model is constructed with MATLAB R2009b, in Simulink version 7.4, and is shown in Figure 2.

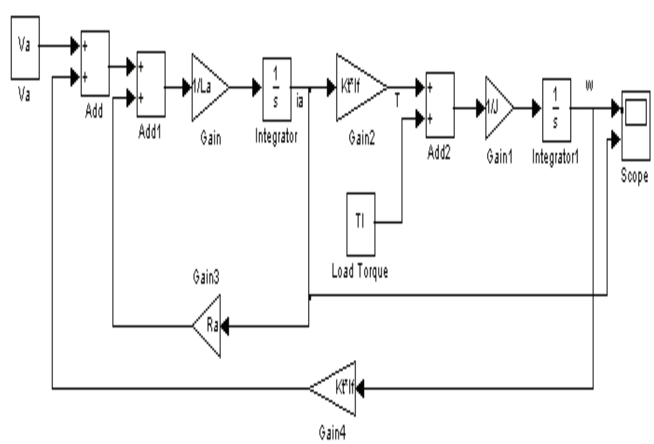

Figure 2. The model of the DC motor in Simulink

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III. GENETIC BASED FUZZY LOGIC CONTROLLER

Fuzzy logic is a technology based on engineering experience and observations[3]. Constructing membership functions and fuzzy rules, which is based on experts' experience, is the key problem of a fuzzy controller design. Genetic algorithms, which are adopted from the principle of biological evolution, are efficient search techniques. Hence by strengthening fuzzy logic controllers with genetic algorithms the searching and attainment of optimal fuzzy logic rules and high-performance membership functions will be easier and faster[4]. The fuzzy logic controller with genetic algorithms is shown in Figure 3.

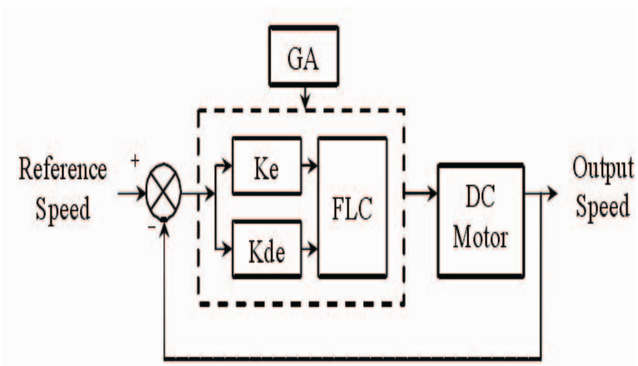

Figure 3. The fuzzy logic controller with genetic algorithms

A. *Fuzzy Logic Controller Design*

Fuzzy logic uses membership functions to define the degree to which crisp physical values belong to a certain term in a linguistic variable set. The fuzzy logic controller mainly includes three components, namely the fuzzification, the rule base and defuzzification. The fuzzification converts real input values into fuzzy values, the fuzzy inference engine processes the input data and computes the control outputs using IF and THEN rules. These fuzzy value outputs are then converted into a crisp real number in the defuzzification stage.

a) *Fuzzyfication* : The error e(k) and the variation of error de(k) of the angular velocity are two input variables of the fuzzy controller, which are determined by formula (5) and (6). The control voltage u(k) is the output variable of the fuzzy logic controller.

$$e(k)=w^*(k)-w(k) \tag{5}$$

$$de(k)=e(k)-e(k-1) \tag{6}$$

Where $w^*(k)$ is the set speed at the kth sampling, and the w(k) is the actual speed at the kth sampling. e(k) and e(k-1) are present and previous error respectively.

The fuzzification procedure uses triangular membership function, due to its simplicity of calculation. The error and variation-in-errors are designed to only operate within the universe of discourse between [-1,1]. The membership functions used in this study are shown in Figure 4, of which (a),(b),(c) are memberships function of error , variation of error and control voltage respectively.

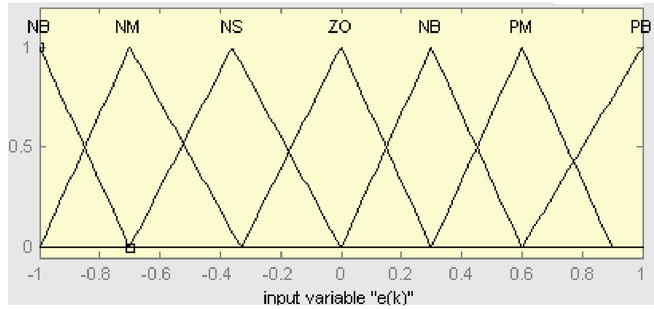

Figure 4. (a)

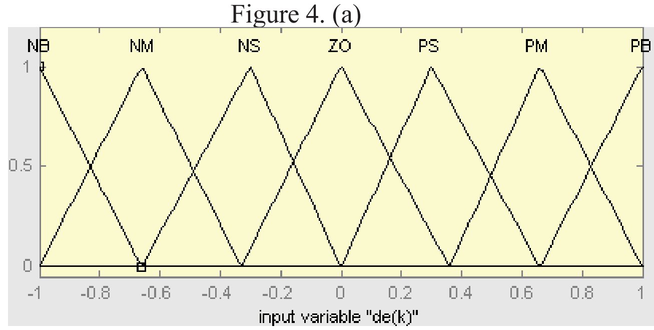

Figure 4. (b)

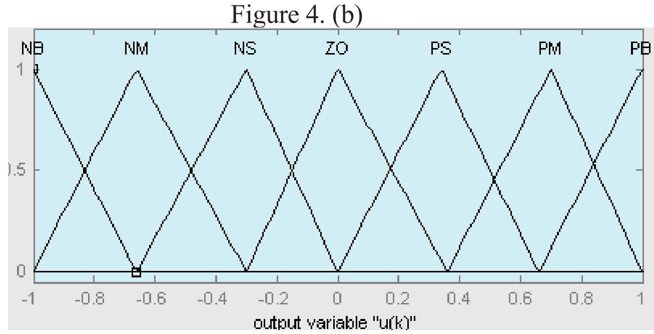

Figure 4.(c)

Figure 4. Membership functions of the fuzzy logic controller

b) *Rule Base*: The fuzzy linguistic variables are defined as: NB: Negative Big, NM: Negative Medium, NS: Negative Small, ZO: Zero, PS: Positive Small, PM: Positive Medium, PB: Positive Big. Meanwhile, the 49 fuzzy rules are summarized in Table 1.

c) *defuzzifacation*: Defuzzification is the reverse of fuzzification. Fuzzy Logic Controller produces output in linguistic variables, which have to be transformed to crisp output. In this study, the defuzzification procedure applies the weighted average method, which is the best well-known defuzzification method.

Table 1. Fuzzy inference rules.

de(k)	e(k)						
	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	NS	ZO
NM	NB	NM	NM	NS	NS	ZO	PS
NS	NM	NM	NS	NS	ZO	PS	PS
ZO	NM	NS	NS	ZO	PS	PS	PM
PS	NS	NS	ZO	PS	PS	PM	PM
PM	NS	ZO	PS	PS	PM	PM	PB
PB	ZO	PS	PS	PM	PM	PB	PB

B. *Optimal Fuzzy Controller Design*

Genetic algorithms are intelligent optimization technique that relies on the parallelism found in nature; in particular its searching procedures are based on the mechanics of natural selection and genetics[6].In this study, genetic algorithm is used to optimize the shapes of membership functions and the inference rules. The evolution procedure of genetic algorithm is shown in Figure 5.

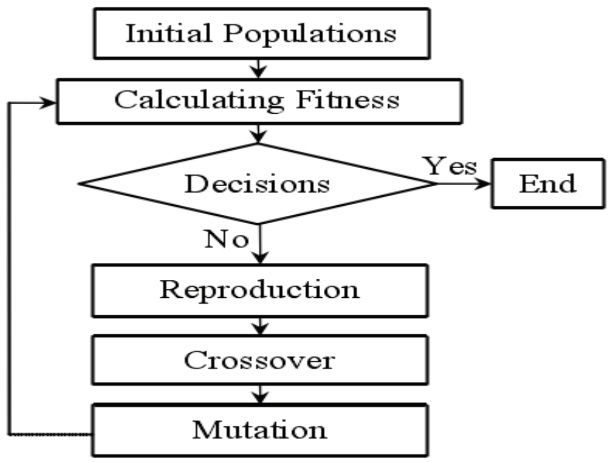

Figure 5. The evolution procedure of genetic algorithm.

First, the initial population of the genetic algorithm has to be produced. The population is composed of binary coded string chromosomes. Second, fitness function has to be determined to evaluate the fitness of each chromosome in the population. Third , a new set of chromosomes is created at each generation, by the process of selecting individual chromosomes according to their level of fitness in the specific problem domain and breeding them using the operators: selection, crossover and mutation. The fitness function is defined as the following equation:

$$FN=MIN\_offset-\sum|e| \tag{7}$$

Where "FN" is the fitness value, e is the speed error and "MIN_offset" is a constant.

After calculate the fitness function, the fitness value and the number of the generation determine whether the evolution procedure should continue or not. New chromosomes are generated using the crossover operation. The equations to generate the new populations with crossover are:

$$x_1=(1-\beta)x_{p1}+\beta x_{p2} \tag{8}$$

$$x_2=\beta x_{p1}+(1-\beta)x_{p2} \tag{9}$$

Where x_{p1} and x_{p2} are the old chromosomes, β is the random value from 0 to 1, x_1 and x_2 are the new chromosomes. In this paper, the chromosomes of the genetic algorithms include three parts: the range of the membership functions (Ke and Kde), the shape of the membership functions (e1~e7, de1~de7 and u1~u7) and the fuzzy inference rules (r1~r49).

Table 2 the parameters of genetic algorithms.

population	72
generation	100
crossover	0.8
Mutation	0.04
MIN_offset-	200
Ke and Kde	[0.001, 0.005]

IV. SIMULATION AND RESULTS

The optimal fuzzy controller is designed based on the genetic algorithms to search the optimal range of the membership functions, the optimal shape of the membership functions and the optimal fuzzy inference rules. The optimal membership functions of error, variation of error and control voltage are shown in Figure 6. The optimal fuzzy inference rules are listed in Table 3. Specifications of the separately excited DC Motor are listed in table 4. Let the input signal be the speed of the DC motor at 256Rad/Sec. The speed response of the optimal fuzzy controller is shown in Figure 7, which demonstrate zero steady state error and overtaking.

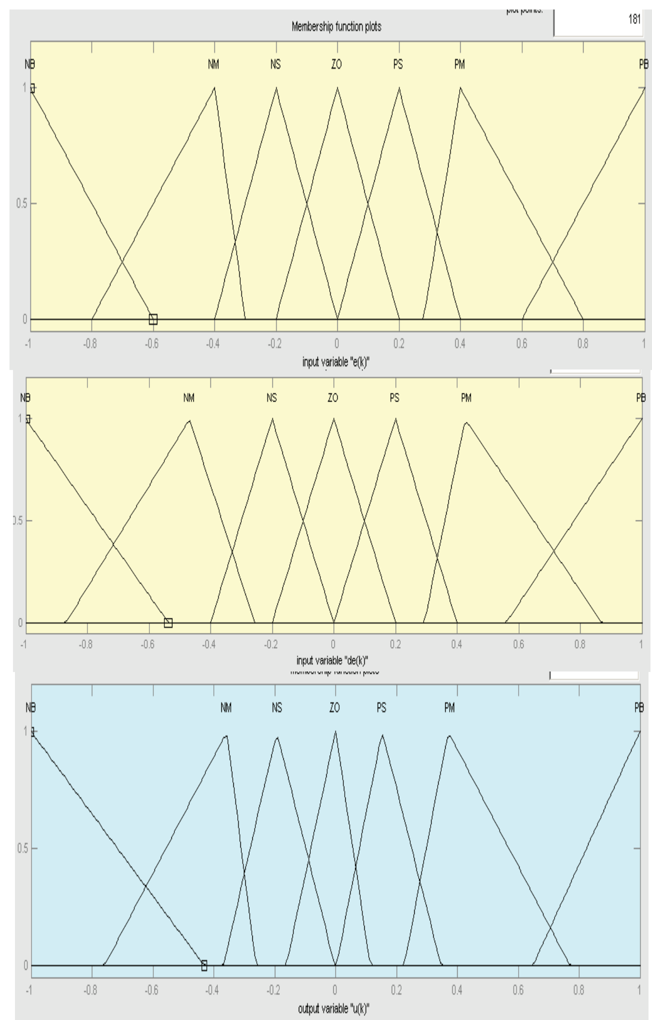

Figure 6. The optimal membership functions

Table 3 The optimal fuzzy rules

de(k)	e(k)						
	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	NS	ZO
NM	NB	NM	NM	NS	NS	ZO	PS
NS	NM	NM	NS	ZO	ZO	PS	PS
ZO	NM	NS	ZO	ZO	ZO	PS	PM
PS	NS	NS	ZO	PS	PS	PM	PM
PM	NS	ZO	PS	PS	PM	PM	PB
PB	ZO	PS	PS	PM	PM	PB	PB

Table 4 Specification of the separately excited DC Motor:

Motor parameters	value
Armature resistance(R_a)	0.5Ω
Armature inductance(L_a)	0.012 H
Armature voltage(V_a)	220 V
Mechanical inertia(J)	0.15 $Kg.m^2$
Friction coefficient(B)	0.008 N.m/rad/sec
Back EMF constant(kt)	1.8 V/rad/sec
Rated speed	2100 r.p.m

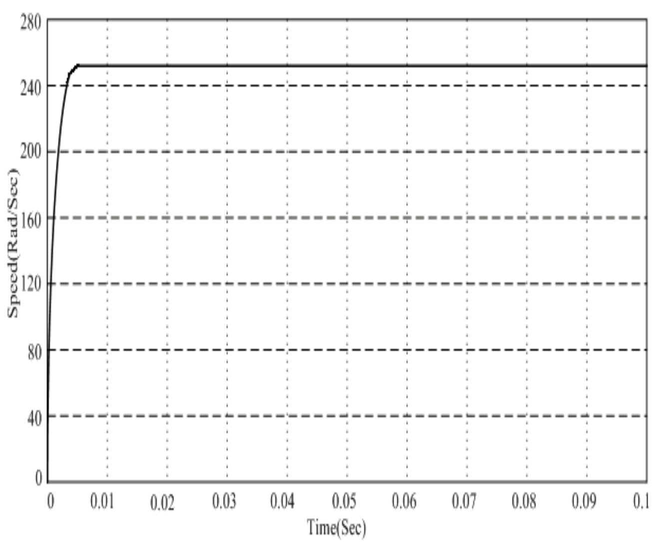

Figure 7. The speed response of fuzzy controller with GAs

V. CONCLUSION

In this paper, a genetic based fuzzy controller is designed to regulate the speed of a separately excited DC motor drive. The fuzzy membership function and rules were optimized based on genetic algorithm. The DC motor model is constructed to evaluate the performance of the fuzzy controller. According to simulation results, the presented fuzzy logic controller optimized with genetic algorithm demonstrated satisfactory performances and good robustness.

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