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Performance Evaluation of Multiquadrant DC Drive Using Fuzzy-Genetic Approach

This paper presents the simulation of multiquadrant DC drive using Fuzzy Logic Control (FLC) for various operating conditions. Genetic Algorithm (GA) has been used in the design of membership functions and rule sets for eliminating the need of human input in the design loop. Performance analysis is performed through mathematical simulation for the stable operation of the drive. Simulated results validate the proposed control technique.

Keywords: Multiquadrant DC Drive, Fuzzy Logic, Genetic Algorithm, PI Controller.

1. NOMENCLATURE

Bf viscous friction coefficient

E_a armature voltage

N_{fb} feedback speed

I_{ref} current reference for current loop

i_a armature current

ii r eference current command

iii reference control command

IN moment of inertia

t_{tacho} tacho generator time constant

K_p speed controller gain

K_{pi} current controller gain

k_{tacho} gain of tachogenerator

l_a armature inductance

N_a actual speed

r_a armature resistance

N_{ref} reference input to drive

T torque of motor

2. Introduction

It is easy to run the DC drive in motoring as well as in the braking mode. According to the direction of speed and torque, the multiquadrant DC drive can be operated in all four quadrants in open or closed loop mode [1]. It is used in closed loop if steady - state and dynamic performance of the drive in open loop is not acceptable. In closed - loop control scheme, an inner current loop and outer speed loop are incorporated to achieve the desired performance. The overall performance of the drive in closed loop is dependent mainly upon the nature of the controllers used for both loops. PI controller combines the desirable transient characteristics of a “P controller” and the feature of no steady - state error of an “I controller” and in addition provides a quick response.

The development of fuzzy theory came from the inability to describe some physical phenomenon with the exact mathematical models dictated by more conventional BOOLEAN models. Fuzziness describes event ambiguity. It measures the degree, to which an event occurs, not whether it occurs. Fuzzy set theory is first introduced in 1965 by Zadeh

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to express and process fuzzy knowledge [2], [3]. Fuzzy logic control has been applied to a wide variety of motion control applications [3]-[6]. With non-linearity, parameter variation, and load disturbance effects, Fuzzy Logic Controllers provides fast and robust control for DC drive. A vital region of interest concerns the implementation of the fuzzy controller. Several approaches have been proposed to construct the membership functions and the fuzzy rule base [7]-[9].

It has been observed that the major drawback of most fuzzy controllers is the need to predefine membership functions and fuzzy rules. The application of genetic algorithms to fuzzy logic controllers holds a great deal of promise in overcoming two of the major problems in fuzzy controller design, design time and design optimality [10]-[12]. Previous work has been done mainly in two areas: learning the fuzzy rules and learning membership functions. Genetic algorithm [13],[14] robustness enables it to cover a complex search space in a relatively short period of time while ensuring an optimal or near optimal solution and because of this capability; it is natural match for fuzzy controllers. The present paper describes a new technique for the stable operation of the drive where the fuzzy controller of the type PI is employed. Only inertial load has been considered in this work. Here genetic algorithm is used to determine the base lengths of the triangular fuzzy sets. An integral performance criterion is used to evaluate the best solution [15], [16]. It has been shown that proposed approach settles the drive in a very less time as compared to other approaches.

3. SYNTHESIS OF FUZZY CONTROL MATRIX USING GENETIC ALGORITHM

The method which is used in this paper is described as follows:

First, the numbers of alleles (individual locations which make up the strings) have been determined from the size of the rule set plus the number of fuzzy sets used to partition the space of the input and output variables. In this method, the bases of the triangles which formed the output space are fixed to ease the computational burden (reduction of string length and simplification of the defuzzification process), while the input variable (x-error and v-delerror) base lengths, have been determined by the GA. Five triangular fuzzy sets which have been used to partition the input and output spaces are: negative medium (NM), negative small (NS), zero (ZE), positive small (PS), and positive medium (PM). The rule set then, contains twenty-five (5x5) rules to account for every possible combination of input fuzzy sets. The rules are of the form, IF (x is {NM, NS, ZE, PS or PM} AND (v is {NM, NS, ZE, PS or PM}) THEN (output), where output is one of the fuzzy sets used to partition the output space. The two input spaces use a total of ten triangles with the speed controller gain Kp is taken into account, the string to represent a given rule set and membership function combination would have thirty-six alleles (25+10+1). No additional alleles are needed for the output triangles because their base lengths are fixed. Note that the term alleles is used instead of bits, because the value of each location in the string contains either the number of the output fuzzy set to be use for a given rule (the first twenty-five alleles where NM=1, NS=2), etc. or the value which will be converted to the length of base of the triangles which make up the input spaces (the last eleven alleles). The calculation of the triangle bases from the allele values were done as follows:

a) Multiply the allele value by 0.05.

b) Subtract this value from one, which is the fixed distance between the peaks of each triangle.

c) Doubling this value gives the base length for each particular triangle.

Following this method, the string representing the controller is integer-based [14] instead of binary based. This change in structure does not change the basic functioning of the GA. In fact, the only difference occurs within mutation, since an allele was allowed to change into any value other than its present value. How each string broken down is shown in Table I.

Table I. Representation of controller as a string

String : 1 4 3 2 1 5 2 4 3 2 1 2 4 5 1 4 3 1 2 2 1 1 3 4 5 4 5 2 5 2 3 4 1 2 4

String : | 1 4 3 2 1 5 2 4 3 2 1 2 4 5 1 4 3 1 2 2 1 1 3 4 5 | 4 5 2 5 2 | 3 4 1 2 4 |

rule set — **x** - error — **v** - delerror

x/v	NM	NS	ZE	PS	PM
NM	1	4	3	2	1
NS	5	2	4	3	2
ZE	1	2	4	5	1
PS	4	3	1	2	2
PM	1	1	3	4	5

Thus when fuzzy controller is used for both loops (inner current and outer speed), string represents seventy-two alleles ((25+10+1)+(25+10+1)).

4. SIMULATION OF DC DRIVE

4.1. Basic Structure

In order to determine the actual speed and actual current for speed and current error processing, machine dynamics is solved by numerical method in each iteration. The two basic equations for the machine will be,

$$E_a = k_b N_a + r_a i_a + l_a \frac{di_a}{dt} \tag{1}$$

$$T = IN \frac{dN_a}{dt} + Bf * N_a \tag{2}$$

Where the term $IN \frac{dN_a}{dt}$ is due to the moment of inertia and $Bf * N_a$ is due to viscous friction of machine.

$$pN_{fb} = (k_{tacho} * N_a - N_{fb}) / t_{tacho} \tag{3}$$

$$N_{fb}(s)(1 + st_{tacho}) = k_{tacho} * N_a(s) \tag{4}$$

$$I_{ref} = ii + K_p * (N_{ref} - N_{fb}) \quad (5)$$

$$E_a = iii + K_{pi} * (I_{ref} - I_{fb}) \quad (6)$$

Where ii and iii are the reference current and control commands respectively. Machine dynamics is solved by using Runga-Kutta fourth order method.

A number of performance indices are used in practice [15]. The most common being the integral square error (ISE). Here integral of the absolute magnitude of error (IAE) performance index is used, which in the proposed system is written as;

$$IAE = \int_0^T 5\left|E_{ref} - n_a\right|dt + 50\left|E_i - i_a\right|dt \quad (7)$$

This performance index gives slightly better results when compared with ISE in the proposed system. It is used in objective function in genetic algorithm where all the parameters are optimized according to their fitness values calculated by this performance index.

4.2. Developed Algorithm

In order to validate the control strategy of DC drive using fuzzy PI controllers, simulation studies of DC drive were made according to the algorithms as follows:

i Initialization

After initializing the various parameters and completing necessary preliminaries, in rapid succession, the generation counter is incremented, generate a new generation and calculate new generation statistics. All this continues step after step, until the generation counter exceeds the maximum. After that, temporary results are stored and necessary control actions are derived. Values are printed lastly to see the transient response.

ii Speed error processing loop

Here actual and reference speed is measured after initializing the local variables and then speed error and change in speed error is evaluated. A fuzzy partition of input space i.e. speed and change in speed error for speed error processing is shown in the Fig. 1

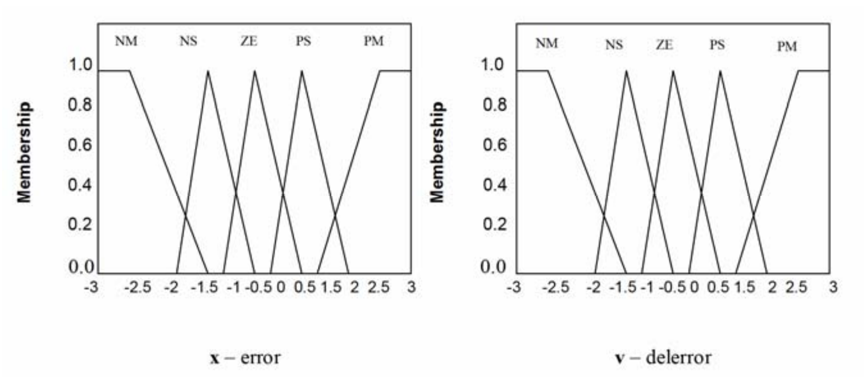

Fig 1 Fuzzy partition of input space.

It is evident that membership functions are taken to vary as triangular function and overlap in adjacent fuzzy subsets is taken, hence for particular value of speed error and change in speed error, four rules are possible and membership function for output of each rule is calculated using SUP-MIN [2] method.

According to the values of speed error and change in speed error regions of both error and change in error are decided by comparison methods, then four rules are fired and output change in current and its membership function for each rule is calculated. Sum of output change in current for all four rules is then divided by accumulated sum of membership function to obtain change reference current command. It is then added algebraically to the previous reference current command to get final reference current command.

iii Current error processing loop

Now current error processing loop is processed in the same way as speed loop proceeds. The partition of input space i.e. current and change in current error is shown in Fig. 1. The basic structure for this simulated drive [16] is shown in Fig. 2.

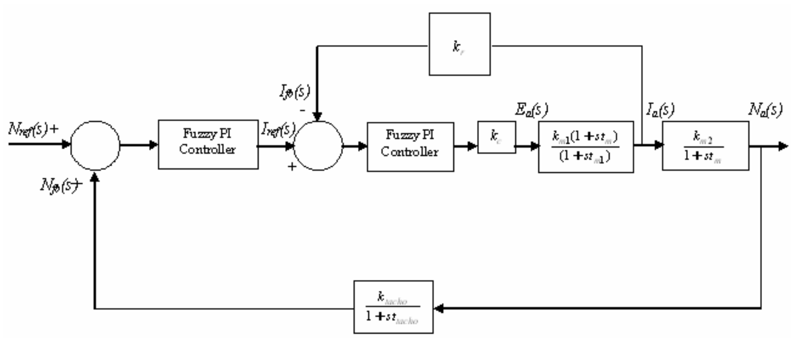

Figure 2 Block diagram of DC drive.

5. RESULTS AND DISCUSSIONS

Fig. 3 (a-e) shows the speed and current responses of DC drive at various reference speeds and different loading conditions respectively. By these results, performance of artificial intelligent dc drive system has been evaluated.

Fig. 3 (a, b, d) shows the current and speed response of DC drive under variable speed conditions. Current is settled earlier than the speed. It validates that the electrical time constant of the drive is small as compared to the mechanical time constant. From Fig. 3(a), it is clear that as compared to Fig. 4(b, d), settling time is less in current as well as in speed. It also shows that to make these changes, peak overshoot is large. Thus there is need to fine tune the controller parameters such that settling time as well as peak overshoot must be reduced simultaneously. It is also evident that in the starting, current shoots up to about maximum value and then settles down to steady state value. This is because in the starting, errors and change in errors are maximum.

Fig. 3(c) shows that if the speed is suddenly reduced and reversed, the drive may become unstable. Thus proper arrangements must be taken into account for reversible drives.

Fig. 3(e, f) shows the drive performance under loading and unloading conditions. Fig. 3(e) shows that during speed reversal if load is applied, settling time can be increased. Thus there is more need to study the drive performance under loading and unloading conditions. Further it is also seen from Fig. 3(f) that if heavy load is applied at the starting, drive can be unstable.

Thus as dc drive settles down very quickly at the desired speed under various conditions of loading and unloading with very small overshoot in most of the cases, the proposed control technique can be validated.

Table II shows comparison of various approaches for proposed drive. It is seen that fuzzy genetic approach gives best results as compared to other approaches. This also proves the validity of the proposed approach.

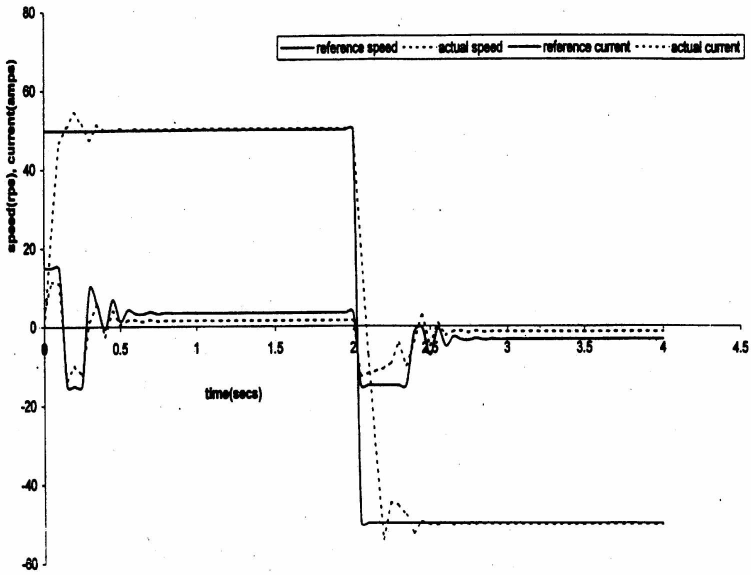

Figure 3(a) Time response of multiquadrant DC Drive (when reference speed is 50 rps).

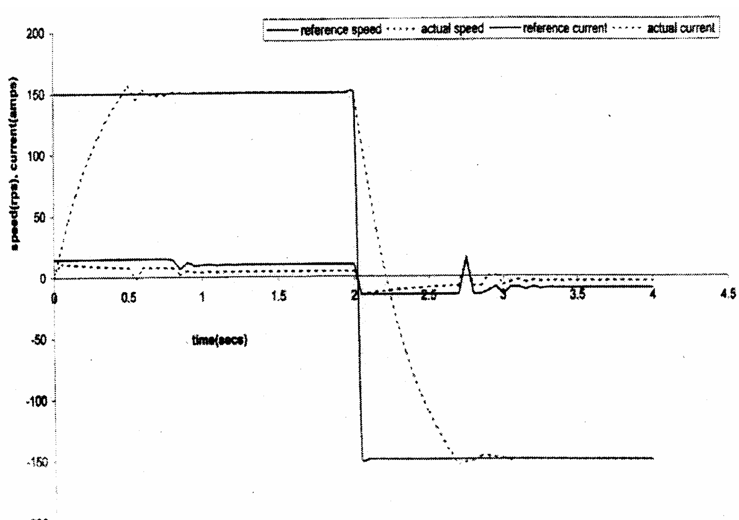

Figure 3(b) Time response of multiquadrant DC Drive (when reference speed is 150 rps).

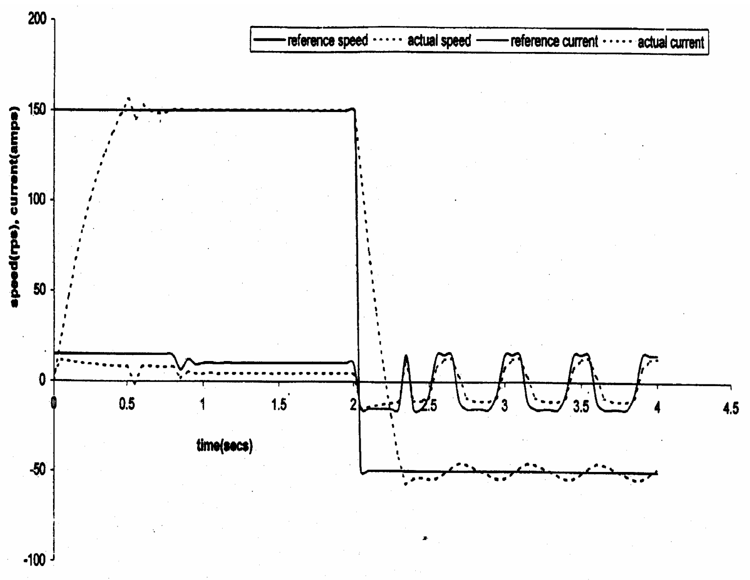

Figure 3(c) Time response of multiquadrant DC Drive (when reference speed is changed suddenly from 150 rps to 50 rps after 2.0 secs).

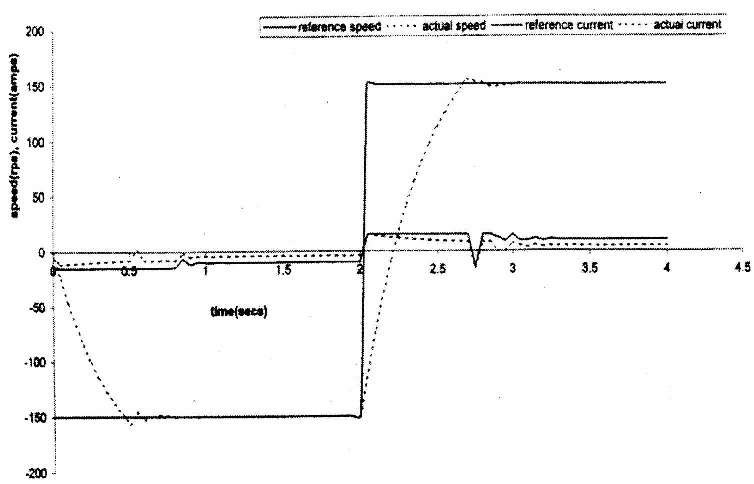

Figure 3(d) Time response of multiquadrant DC Drive (when reference speed is changed suddenly from 150 rps in backward direction to the 150 rps in forward direction after 2.0 secs).

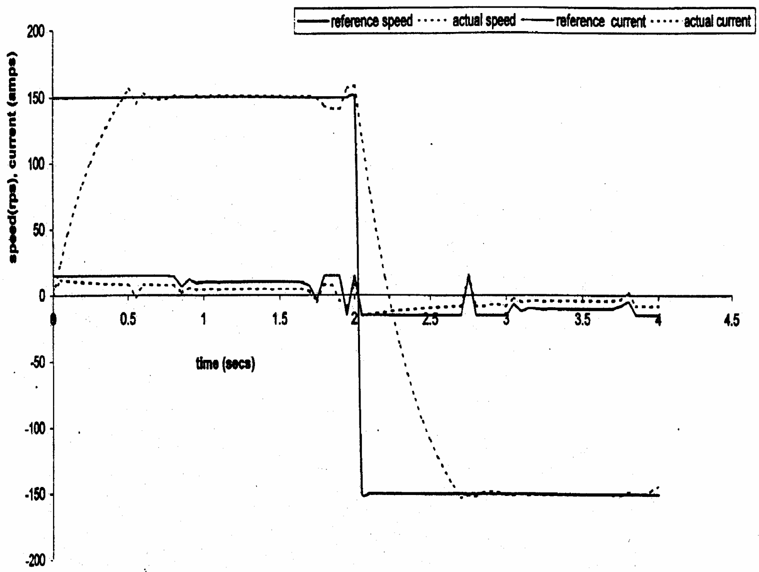

Figure 3(e) Time response of multiquadrant DC Drive (when load is applied suddenly at 1.75 secs and then removed from 2.0 to 3.8 secs. In the backward direction, machine is loaded again after 3.8 secs).

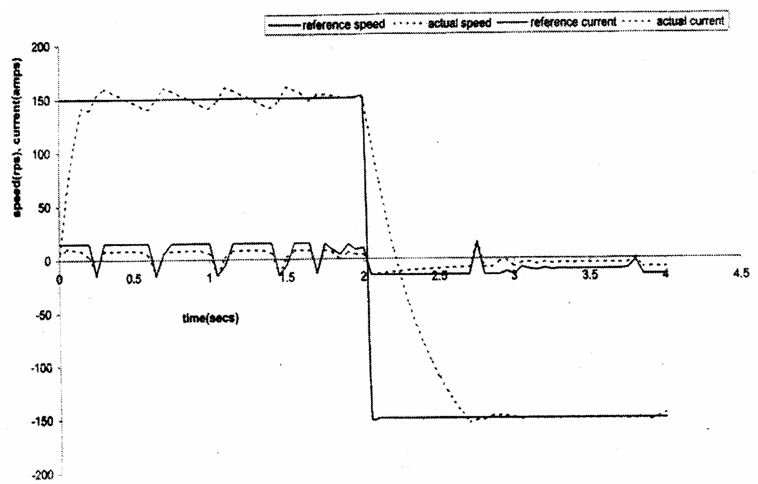

Figure 3(f) Time response of multiquadrant DC Drive (when load is applied in forward direction from start upto 1.6 secs and after 3.8 secs load is applied again in the backward direction.

Table II Comparison of various approaches

Approach	Settling Time	Peak Overshoot	Steady State Error
Classical Approach	4.3	0	0
D-Partition Approach	4.5	0	0
Genetic Algorithm Approach	1.7	0	0
Fuzzy Genetic Approach (Fuzzy Controller in Speed Loop)	2.54	13.33	9.52
Fuzzy Genetic Approach (Fuzzy Controller in Speed Loop and Current Loop)	0.69	0	0

6. CONCLUSIONS

Fuzzy PI controller (using genetic algorithm) is used here for performance evaluation of dc drive in closed loop mode. Comparison with other approaches proves the validity of the proposed approach. In spite of the advantage in fuzzy control, the main limitation is the lack of systematic procedure for design, analysis, and calibration of the drive. As the heuristic and interactive approach to fine-tune the rule base and membership function can be very time consuming, genetic algorithm technique is used here. It is shown that by using GA's, fuzzy controller can be fully integrated to deliver a more finely tuned, high performance controller and thus drive is settled quickly.

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