SPEED CONTROL OF SEPARATELY EXCITED DC MOTOR BY USING FUZZY LOGIC CONTROLLER

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ABSTRACT

In this paper the various method of speed control of DC motor is available in the literature survey. This dissertation report presents the speed control of a separately excited dc motor varying armature voltage. The speed control of a separately excited DC motor is performed using fuzzy logic controller (FLC) in MATLAB environment. The designed controller is based on the expert knowledge of the system. For the proposed dc motor case, there are fuzzy rules designed for fuzzy logic controller. The output response of the system is obtained by using two types of controllers, namely, PI and Fuzzy Logic Controller. For such applications FLC has been widely used instead of conventional PID controllers. However, size of rule-base of FLC is directly influencing the real time computational burden, which subsequently restricts its application with the processors of limited speed & memory. The number of rule base and performance of drive are inversely related with each other as it is evident that all the rules don't participate equally in the response and can be reduced for simplicity which utilizing less computational resources. In this dissertation the performance of controlled Direct Current (DC) motor drive is presented for three different FLC rule bases namely 49, 25 and 9 rules. The performance of the designed fuzzy controller and classic PI Speed controller is compared and investigated. Finally, the result shows that the fuzzy logic controller approach has minimum overshoot, minimum transient and steady state parameters, which shows more effectiveness and efficiency of FLC than conventional PI Controller. The entire system has been modeled using MATLAB 7.0 toolbox.

Index Terms: Separately Excited DC Motor, Speed Control of Fuzzy Logic Controller, PI, and PID Controller

I. INTRODUCTION

The development of high performance motor drives is very important in industrial as well as other purpose applications such as steel rolling mills, electric trains and robotics. Generally, a high performance motor drive system must have good dynamic speed command tracking and load regulating response to perform task. DC drives, because of their simplicity, ease of application, high reliabilities, flexibilities and favourable cost have long been a backbone of industrial applications, robot manipulators and home appliances where speed and position control of motor are required. DC drives are less complex with a single power conversion from AC to DC [29]. Again the speed torque characteristics of DC motors are much more superior to that of AC motors. A DC motors provide excellent control of speed for acceleration and deceleration. DC drives are normally less expensive for most horse power ratings. DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose.

In these applications, the separately excited direct current motor should be precisely controlled to give the desired performance. The controllers of the speed that are conceived for goal to control the speed of DC motor to execute one variety of tasks, is of several conventional and numeric controller types, the controllers can be: Proportional Integral (PI), Proportional Derivatives (PD) Fuzzy Logic Controller (FLC) or the combination between them: Fuzzy-Neural Networks, Fuzzy-Genetic Algorithm, Fuzzy-Ants Colony, Fuzzy-Swarm[10]. The Proportional, Integral, (PI) controller operates the majority of the control system in the world. It has been reported that more than 95% of the controllers in the industrial process control applications are of PI type as no other controller match the simplicity, clear functionality, applicability and ease of use offered by the PI controller [3], [4]. PI controllers provide robust and reliable performance for most systems if the PI parameters are tuned properly.

The major problems in applying a conventional control algorithm (PI, PD, PID) in a speed controller are the effects of non-linearity in a DC motor. The nonlinear characteristics of a DC motor such as saturation and fiction could degrade the performance of conventional controllers [1],[2]. Generally, an accurate nonlinear model of an actual DC motor is difficult to find and parameter obtained from systems identification may be only approximated values. The field of Fuzzy control has been making rapid progress in recent years. Fuzzy logic control (FLC) is one of the most successful applications of fuzzy set theory, introduced by L.A Zadeh in 1973 and applied (Mamdani 1974) in an attempt to control system that are structurally difficult to model. Since then, FLC has been an extremely active and fruitful research area with many industrial applications reported [5].

In the last three decades, FLC has evolved as an alternative or complementary to the conventional control strategies in various engineering areas. Fuzzy control theory usually provides non-linear controllers that are capable of performing different complex non-linear control action, even for uncertain nonlinear systems. Unlike conventional control, designing a FLC does not require precise knowledge of the system model such as the poles and zeros of the system transfer functions. Imitating the way of human learning, the tracking error and the rate change of the error are two crucial inputs for the design of such a fuzzy control system [6], [7].

II. SEPARATELY EXCITE DC MOTOR

The terms of speed control stand for intentional speed variation carried out manually or automatically DC motors are most suitable for wide range speed control and are there for many adjustable speed drives.

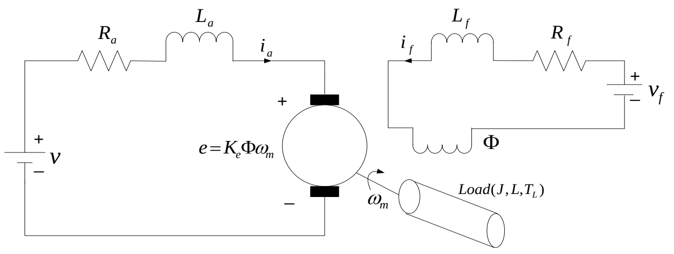

Figure.1 Separately Excited Dc Motor Model.

Where

- V_a Is the armature voltage. (In volt).
- I_a is the armature current (In ampere)
- R_a is the armature resistance (In ohm)

- L_a is the armature inductance (In henry)
- T_m is the mechanical torque developed (In Nm)
- J_m is moment of inertia (In kg/m²)
- B_m is friction coefficient of the motor (In Nm/ (rad/sec))
- ω is angular velocity (In rad/sec)

III. MATHEMATICAL ANALYSIS OF SEPARATELY EXCITED DC MOTOR

This model consists of differential equations for the electrical part, mechanical part and the interconnection between them [14]. The electric circuit of the armature and the free body diagram of the rotor are shown in the Fig.1

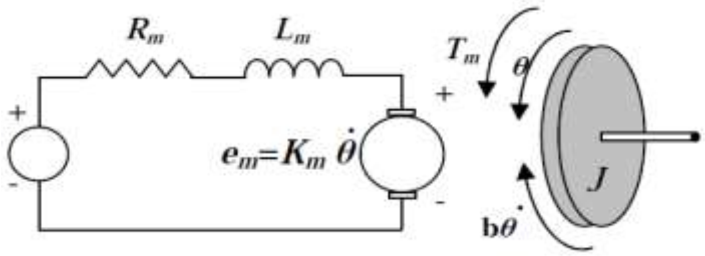

Figure.2 The Electric Circuit of The Armature and The Free Body Diagram of The Rotor For a Direct Current Motor

The armature voltage equation is given by:-

$$V_a = E_b + I_a R_a + I_a (dI_a / dt) \quad (1)$$

Now the torque balance equation will be given by.

$$T_m = J_m d\omega / dt + B_m \omega + T_l \quad (2)$$

Where

$T_L -$ Load torque in Nm.

Friction in rotor of motor is very small (can be neglected), so $B_m = 0$.

Therefore, new torque balance equation will be given by-

$$T_m = J_m d\omega / dt + T_L \quad (3)$$

Taking field flux as Φ and Back EMF Constant as K. Equation for back emf of motor will be

$$E_b = K\Phi\omega \quad (4)$$

Also,

$$T_m = K\Phi I_a \quad (6)$$

Taking Laplace transform of the motor's armature voltage equation I get-

$$I_a(S) = (V_a - E_b) / R_a + I_a S) \quad (7)$$

Now, taking equation (2) into consideration, I have-

$$I_a(S) = (V_a - K\phi\omega) / R_a (1 + L_a S / R_a) \quad (8)$$

And

$$\omega(s) = (T_m - T_L)/JS = K\Phi I_a - T_L)/J_m S \quad (9)$$

(Armature time Constant) $T_a = L_a / R_a$

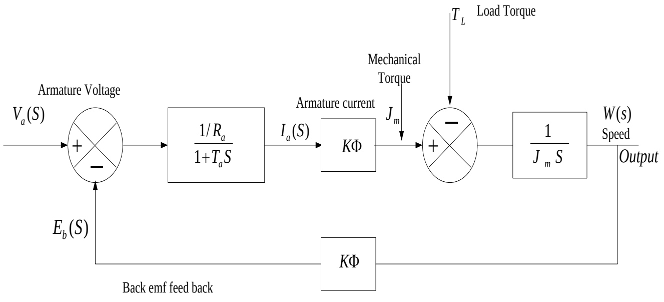

Figure.3 Block Model of Separately Excited DC Motor

After simplifying the above model, the overall transfer function will be ….

Further simplifying the above transfer function

$$\omega(s)/V_a(s) = (1/K\Phi)/\{1+(K^2\Phi^2/R_a)/J_m S(1+T_a S)\} \quad (10)$$

Assuming, $T_{em} = J_m R_a /(K\Phi)^2$ as the electromagnetically time constant

$$\omega(s)/V_a(s) = (1/K\Phi)/[ST_{em}(1+ST_a)+1] \quad (11)$$

Let us assume that during starting of motor, load $T_L = 0$ and applying full voltage V_a Also assuming neglible armature inductance, the basic armature voltage equation can be written as..

$$V_a = K\Phi\omega(t) + I_a R_a \quad (12)$$

At the same time torque equation will be

$$T_m = J_m d\omega/(t) = K\Phi I_a \quad (13)$$

Putting the values of I_a in above armature equation $V_a = K\Phi\omega(t) + (J_m d\omega/dt)R_a / K\Phi$ (14)

Dividing on both sides by K Φ

$$V_a / K\Phi = \omega(t) + J_m R_a (d\omega/dt)/K\Phi)^2 \quad (15)$$

$V_a / K\Phi$ is the value of the motor sped under no load condition therefore?

$$T_{em} = J_m R_a /(K\Phi)^2 - JR_a /(K_m)^2 \quad (16)$$

Therefore,

$$J_m = T_{em}(K_m)^2 / R_a \quad (17)$$

From the motor torque equation, I have:

$$\omega(s) = K_m I_a(s)JS - T_L / J_m S \quad (18)$$

The equation can be written as:

$$\omega(s)/V_a(s) = (1+K_m)/((1+ST_{em})/(1+ST_a)) \quad (19)$$

T_{em} And T_a are the time constants of the above system transfer function that will be determine the response of the system. Hence the Direct Current (DC) Motor can be replaced by the transfer function obtained in equation (19) in the Direct Current Model.

IV. FUZZY LOGIC CONTROLLER

Fuzzy logic control is a control algorithm based on a linguistic control strategy, which is derived from expert knowledge into an automatic control strategy. The operation of a FLC is based on qualitative knowledge about the system being controlled .It doesn't need any difficult mathematical calculation like the others control system. While the others control system use difficult mathematical calculation to provide a model of the controlled plant, it only uses simple mathematical calculation to simulate the expert knowledge [32]. The requirement for the application of a FLC arises mainly in situations where:

- The description of the technological process is available only in word form, not in analytical form.
- It is not possible to identify the parameters of the process with precision.
- The description of the process is too complex and it is more reasonable to express its description in plain language words.
- The controlled technological process has a “fuzzy” character.
- It is not possible to precisely define these conditions.

A fuzzy logic controller has four main components as shown in Figure:

a) Fuzzification.

b) Inference engine.

c) Rule base.

d) Defuzzification.

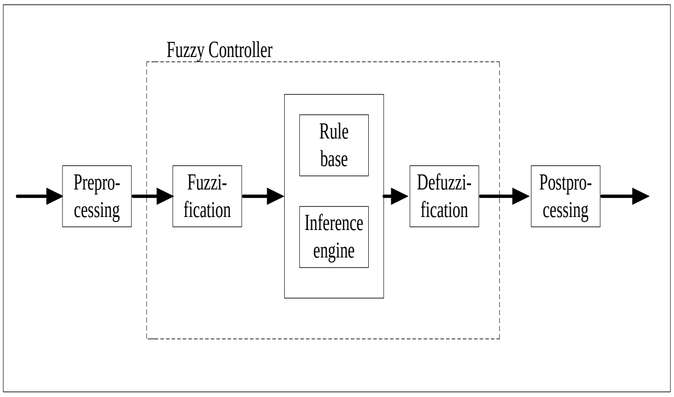

Figure.4 Structure of Fuzzy Logic Controller.

V. FUZZY CONTROLLER DESIGN

The input to the Self-tuning Fuzzy PI Controller is speed error "e (t)" and Change-in-speed error "de (t)". The inputs shown in figure are described [16] to [24]. By

$$e(t) = W_r(t) - W_a(t)$$

$$de(t) = e(t) = e(t-1)$$

Using fuzzy control rules on-line, PID parameters “K_P ",” K_I " are adjusted, which constitute a self-tuning fuzzy PI controller as shown in Figure.

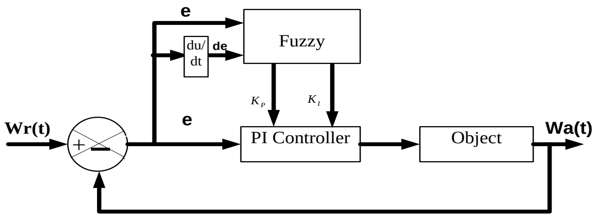

Figure.5 The structure of self-tuning fuzzy PI controller.

PI parameters fuzzy self-tuning is to find the fuzzy relationship between the three parameters of PI and "e" and "de", and according to the principle of fuzzy control, to modify the three parameters in order to meet different requirements for control parameters when "e" and "de" are different, and to make the control object a good dynamic and static performance [12].

VI. FUZZY MEMBERSHIP FUNCTIONS AND RULES

In order to improve the performance of FLC, the rules and membership functions are adjusted. The membership functions are adjusted by making the area of membership functions near ZE region narrower to produce finer control resolution. On the other hand, making the area far from ZE region wider gives faster control response. Also the performance can be improved by changing the severity of rules [15]. An experiment to study the effect of rise time (T_r), maximum overshoot (M_r) and steady-state error (SSE).

VII. RULE BASE DESIGNING

The FLC’s with different Rule base sizes the rule base with the sizes of 49, 25 and 9 rules are designed for speed control of Separately Excited Direct Current Motor’s drive. I have the use the rule base size of 49 tables in this Fuzzy Logic Controllers. The Rule base is basically a matrix used for determining the controller output from their input(s) as it holds the input/output relationships. The rules used in the rule base of 49, 25 and 9 rules with the different FLC’s are given in tables shown in Tab. I, II, and III respectively. The linguistic terms used for input and output variables are described as: “Z” is “Zero”; “N” is “Negative”; and “P” is “Positive”, NL is Negative Large, NM is Negative Medium, NS is Negative Small, PL is Positive Large, PM is Positive Medium and PS is Positive Small. The rules are in general format of “*if* anticedent1 *and* antecedent2 *then* consequent”.

VIII. RULE BASE ARRAY FOR FLC (49)

Table: 1. Rule Base Array For FLC (49).

SE/CSE	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NM	NM	NS	Z
MN	NL	NL	NM	NM	NS	Z	PS
NS	NL	NM	NM	NS	Z	PS	PM
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PM	PM	PL
PM	NS	Z	PS	PM	PM	PL	PL
PL	Z	PS	PM	PM	PM	PL	PL

IX. FUZZY RULES SYSTEM

The Fuzzy Rules Editor contains a large editable text field for displaying and editing rules. It also has some by now familiar landmarks similar to those in the FIS Editor and the Membership Function Editor, including the menu bar and the status line. A format pop-up menu is the only window specific control is used to set the format for the display.

X. FUZZY RULES VIEWERS

The Rule Viewer displays a roadmap of the whole fuzzy inference process. It's based on the fuzzy inference diagram described in the previous section. You'll see a single figure window with seven small plots nested in it. In addition there are the now familiar items like the status line and the menu bar. In the lower right there is a text field where you can enter a specific input value.

XI. SIMULATION RESULTS

Recently, the best performance of speed control separately excited direct current motor has been interesting to the researchers industry, because the direct current motor is the most commonly used and it advances in power electronic and electric drives have possible new methods. The numerical simulation is very important to decide whether the control design processes are valid and to avoid the mistakes early in the simulations before actual real implementations. SIMULINK have been a very powerful tool to model the electrical and the mechanical systems because its simplicity. In this chapter, the dynamic simulation of separately excited direct current motor is first performed employing the MATLAB/ SIMULINK. Proportional Integral (PI) and Fuzzy Logic Controller (FLC) methods are used to speed control the separately excited direct current motors follows.

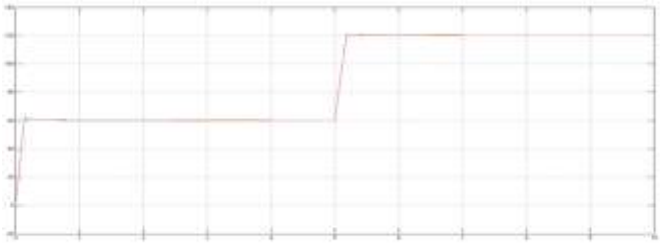

Figure:1 The Speed of Separately Excited Direct Current Motor From Initial Speed Zero To Start 60 Rad/Sec After 5 Second The Speed Reach To 60 T0 120 Rad/Sec.

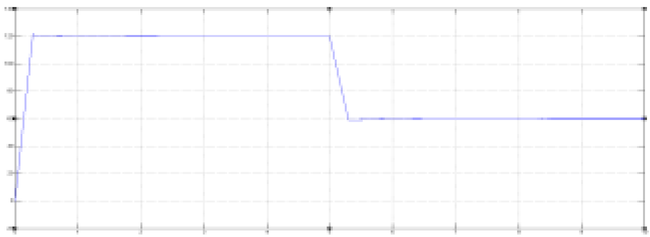

Figure.2The Speed of Separately Excited Direct Current Motor From Initial Speed Zero To Start 120 Rad/Sec After 5 Second The Speed Reach To120 To 60 Rad/Sec.

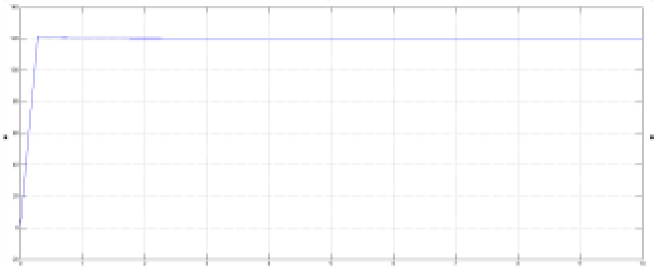

Figure 3. The Speed Control of Separately Excited Direct Current Motor From Initial Speed Zero To Start 120 Rad/Sec

XII. SIMULINK/ MATLAB MODEL RESULTS OF SEPARATELY EXCITED DC MOTOR WITH PROPORTIONAL INTEGRAL CONTROLLR METHOD

Figure: 4. SEDC Motor Using The (PI) Controller Speeds From Start 60 To 120 Rad/Sec.

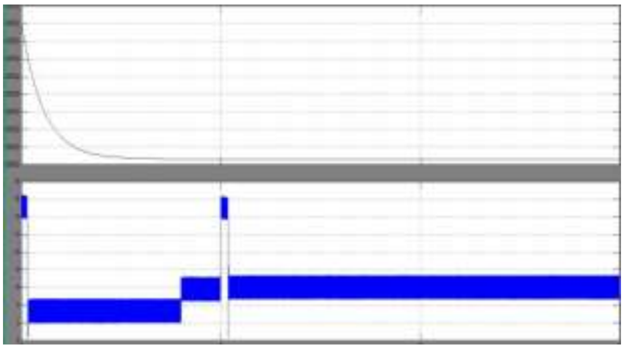

Figure: 5. Sedc Motor Controlled Speed of Field Current And Armature Current.

Figure: 6. SEDC Motor Controlled The Speed of Electric Torque And Load Torque.

Figure: 7. Shows The Result of SEDC Motor Using The (PI) From 120 To 60 Rad/Sec.

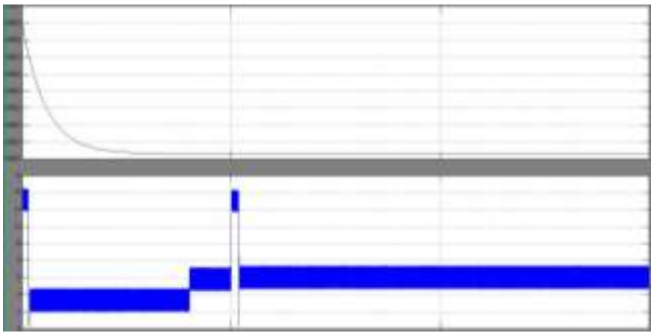

Figure: 8. Field Current And Armature Current Speed Control By (PI) In Separately Excited DC Motor 120 To 60 Rad/Sec.

Figure: 9. SEDC Motor Controlled The Speed of Electric Torque And Load Torque.

Figure: 10. The Separately Excited DC Motor From The 0 To 120 Rad/ Sec..

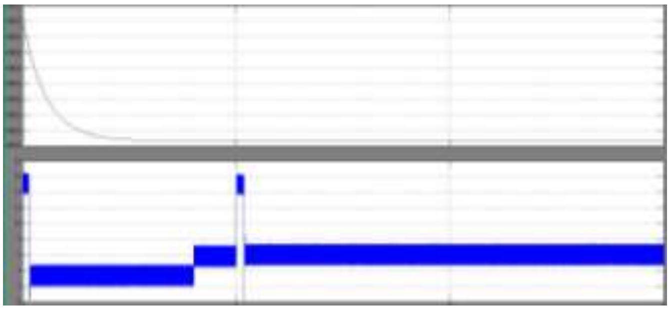

Figure: 11. Field Current And Armature Current Speed Control By (PI) Controller In Separately Excited DC Motor 0 To 120 Rad/Sec.

Figure: 12. The Speed Controlled The Speed of Electric Torque And The Load Torque From The 0 To 120 Rad/Sec Speed of SEDC Motor Using The Proportional Integral (PID) Controller.

XIII. CONCLUSION

In this paper I have studies about different methods for speed of separately excited direct current motor. The steady state operations and its various speeds, the armature resistance control, field resistance control and voltage control characteristics of separately excited direct current motor are studied. I have also studied the basic definition and terminology of fuzzy logic, fuzzy set and fuzzy logic control. This project introduces a design method of one input and one outputs fuzzy logic control and makes use of MATLAB fuzzy toolbox to design fuzzy logic controller. The fuzzy controller adjust proportional integral and fuzzy logic controller according to state error and change state error. From simulation results it is concluded that compared with the PI controller and fuzzy logic controller has better performance in transient, steady state response state error and change state error. The Fuzzy logic Controller has better dynamic response curve, shorter response time, steady state error (SSE) and high steady precision compared to the conventional PI controller. The fuzzy logic controller is that type of controller which could be use everywhere in the research field and the latest technologies in industries and other fields

XIV. FUTURE WORK

MATLAB Simulation for speed control of separately excited DC motor has been done which can be implemented in hardware to observe actual feasibility of the approach applied in this dissertation. This technique can be extended to other types of motors. The parameters of fuzzy logic controller can also be tuned Artificial Neural Networks (ANN) and Genetic Algorithm (GA) in Separately Excited Direct Current Motor.

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