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Design of an Intelligent Controller for Armature Controlled DC Motor using Fuzzy Logic Technique

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***Abstract*—**This paper presents a fuzzy control approach to the speed control of DC shunt motor using armature control. This paper presents concept of development of conventional controller and the design of a fuzzy logic controller applicable to DC Motor Speed Control System (MSCS) with high performance of the FL controller. Since armature voltage supply has a major influence in controlling speed, therefore one of the inputs to the proposed FL Controller will be actual armature voltage supply (Va) while another input will be error (e) in speed. The transfer function model of the DC shunt motor has been obtained via experimentation and calculations and simulated and then as per requirement and specification, the proposed fuzzy logic controller has been designed and simulated using Fuzzy Logic and Simulink Toolboxes of MATLAB 7. Results show robustness against changing loading conditions.

Index Terms*--Causal relationship, conflict resolution, fuzzy logic controller (FLC), linguistic terms, model-based approach (MBA), motor speed control system (MSCS), Proportional, Integral and derivative (PID) controller.*

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I. INTRODUCTION

A large number of DC motors operated at variable speeds are being employed in modern industry. In rolling mills, each shape to be rolled will necessitate an optimum operating speed to get maximum productivity of the mill and a very high quality product [1]. In the application mentioned above as well as in most of the other industrial drives, speed control is necessary to attain high productivity, proper operation and high quality products.Therefore we need fast operating and high performance controllers to control the speed of the motor. The limitations of the conventional controls viz., Proportional, Integral and Derivative (PID) are slow and lack of efficiency in handling system non-linearities [2]. Experience has shown that a fuzzy controller is often more robust than a PID controller in the sense that it is less susceptible to noise and system parameter changes [3]. In our case the problem is to control the speed of DC shunt motor by controlling the input applied armature voltage. By experimentation and calculations we can develop the transfer function model of the motor [7]. But if the applied armature voltage is fluctuating then the output speed of the shaft of the motor will also be unregulated. Also with the variation of the shaft loading, speed of the shaft of the motor will change. So now we can employ subjective information [4] about the system in such a way so that we can achieve our goal and specifications. Example of subjective information is:

If speed is different than the desired speed **then** change the input applied armature voltage (V_a) so that speed comes closer to the desired speed. For example:

. If (speed is higher than the desired) and (V_a is high)
Then (V_a must be decreased)
. If (speed is lower than the desired) and (V_a is low)
Then (V_a must be increased)

The application of fuzzy logic is an effective tool in problems where logical inferences can be derived on the basis of causal relationships. FL attempts to quantify linguistic terms so that the variables thus described can be treated as continuous, allowing the system's characteristics and response to be described without the need for exact mathematical formulations. The attention of the paper is concentrated to the fuzzy logic aspects of the problem rather than upon the complexities of the model.

In the proposed concept, another design strategy for FL Controller applicable to DC Motor control has been presented. Generally for designing FL Controllers for systems the error from the desired output, e and error derivative (de/dt) are taken as inputs to the controller. But in this concept, since armature voltage has a major influence in controlling the speed of the DC shunt motor (Armature Controlled), one of the input to the FL Controller will be actual armature voltage supply (V_a) while another input will be error (e) in speed.

Section II deals with the development and simulation of the transfer function model for DC shunt motor. Section III deals with PID controller, section IV to develop fuzzy logic controller(FLCr). Simulation Results are shown in section V and conclusions are drawn in section VI.

II. DEVELOPMENT AND SIMULATION OF T/F MODEL FOR ARMATURE CONTROLLED DC MOTOR

Schematic diagram of armature controlled DC shunt motor is shown in Fig.1 [7]. The fundamental equations governing the operation of shunt DC motor are as follows:

The voltage equation is

$$V_a = e_b + i_a R_a + L_a.\frac{di_a}{dt} \quad (1)$$

$$e_b = K_a \phi \omega \quad (2)$$

For D.C shunt motor ϕ is constant

$$e_b = K_a \omega \quad (3)$$

The Torque balance equation is

$$T_d = T_L + J.\frac{d\omega}{dt} + f\omega \quad (4)$$

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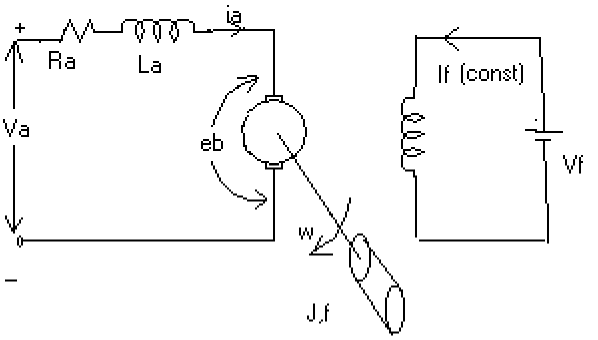

Fig.1. Schematic diagram: Armature Controlled shunt DC Motor

By taking Laplace transforms of these equations (2) and (4) and manipulating, we get the transfer function of the motor

$G(s) = \omega(s)/V_a(s) = K_a/((R_a + sL_a)(f + s J) + K_a\text{^}2)$

The block diagram representation of T/F is as shown in Fig.2.

From experimentation, DC test and AC test we get Ra=1.32 ohms, L_a=0.046 H

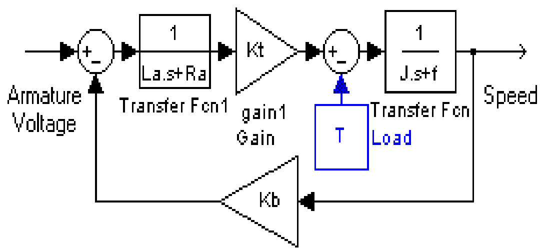

Fig.2. Block Diagram T/F Model

Using retardation test and following equations

$E_b = K_a . \omega$, $e_b . i_a = T_d . \omega = (f. \omega).\omega$ and $e_b . i_a = J. \omega . d\omega/dt$, we have got K_a=1.41 , J=0.0772 , f=0.00381. Using these data, simulation of the T/F model has been developed. From simulation we get information and data about the system given in Table 1.

TABLE 1 EFFECT OF CHANGING LOAD

Va (volts)	Load (N-m)	Speed (rad/s)	Error (e)	V_{ad} (volts) so that Speed matches the set speed (Desired voltage)
214.8	0	152	0	214.8
214.8	1	151.3	0.7	215.79
214.8	2	150.8	1.2	216.5
214.8	3	149.9	2.1	217.8
214.8	4	149.4	2.6	218.5
214.8	5	148.7	3.3	219.5
214.8	6	148	4	220.45
214.8	7	147.3	4.7	221.4
214.8	8	146.6	5.4	222.4
214.8	9	146	6	223.3
214.8	10	145.3	6.7	224.3
214.8	11	144.7	7.3	225.12
214.8	12	144	8	226.11
214.8	13	143.3	8.7	227.10
214.8	14	142.7	9.3	227.94
214.8	15	142.1	9.9	228.79
214.8	16	141.3	10.7	229.92
214.8	17	140.7	11.3	230.77
214.8	18	140	12	231.76
214.8	19	139.4	12.6	232.61
214.8	20	138.7	13.3+	233.6

The basic structure of the PID controller is first described in the following equation,

$$U^{PID} = K_p e + K_I \int e dt + K_D \frac{de(t)}{dt} \quad .... (5)$$

Where e is the tracking error, conventional PID control is a sum of three different control actions. The proportional gain

K_p, integral gain K_I, and derivative gain K_D, represent the strengths of different control action can reduce the steady state

error, but too much of it can cause the stability to deteriorate. Integral action will eliminate the steady-state. Derivative action will improve the closed loop stability. The relationship between the control parameters are:

$$K_I = \frac{K_P}{T_I}$$

$$K_D = K_P * T_D$$

Where T_I and T_D are integral and derivative time respectively.

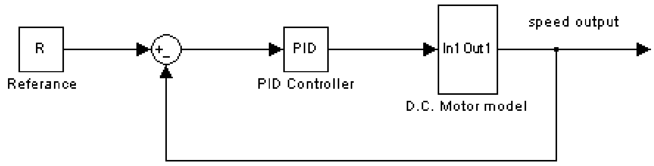

Fig.3. D.C. Motor with PID controller

IV. FLC DESIGN AND DEVELOPMENT

Knowledge base has been formed by considering 230 V motor (Line voltage=230V) with rated speed of 1450 RPM (151.84 rad/sec). Since increasing shaft loading condition results in decreased shaft speed. At armature voltage V_a = 214.8 volts, with various shaft load from 0-20 N-m, we get different speeds (Table 1). Set speed is 152 rad/sec, which we want to maintain. To get the set speed at these various loading conditions, V_a has to be modified to as in the last column of Table 1.

How to get that desired armature voltage (V_{ad}) when input supply to the armature is varying in a wide range? It necessitates introduction of a controller, whose input will be the input supply to the armature and output will be the desired armature voltage. Another input to the controller will be the error in speed $e=\omega_{sp}-\omega$. The Block diagram of the proposed FL Controller is shown in Fig.4.

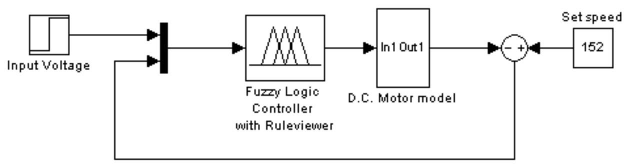

Fig.4. Block Diagram ofProposed FLC

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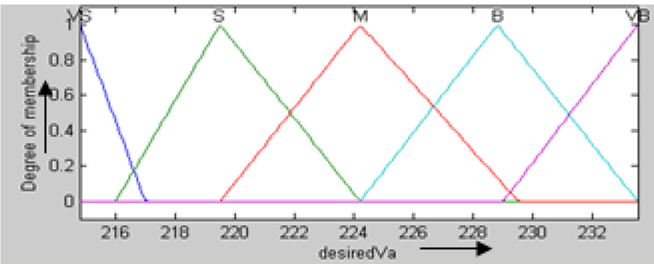

Let us say that applied armature voltage varies by 50 volts each side of Va=214.8 volts then the range of applied armature voltage Va is [164.8 264.8]. From T/F simulation, error in speed ranges [-35.3 35.4], when applied armature voltage Va varies [164.8 264.8] volts. Output of fuzzy controller desired armature voltage Vad ranges [314.8 233.5] volts (from Table 3 last column). Fuzzy variable associations and numerical ranges for both input variables of the controller, Va and error in speed(e) and for the output variable V_{ad} are defined in Table 2. Using the notation of Table 2, the fuzzy sets required for the controller are depicted in Fig.4

TABLE 2(a).
FUZZY INPUT VARIABLE 1 :
V_a (APPLIED ARMATURE VOLTAGE)

Range	Description	Fuzzy Association
164.8-195	Very Low	VL
185-215	Low	L
205-235	Medium	M
225-255	High	H
245-264.8	Very High	VH

TABLE 2(b).
FUZZY INPUT VARIABLE 2:ERROR (e) IN SPEED

Range	Description	Fuzzy Association
-35.3 : -20	Negative Very Big	NVB
-25 : -10	Negative Big	NB
-15 : -3	Negative Small	NS
-5 : 5	Moderate	M
3 : 15	Positive Small	PS
10 : 25	Positive Big	PB
20 : 35.4	Positive Very Big	PVB

TABLE 2(c).
FUZZY OUTPUT VARIABLE 1:
V_{ad} (DESIRED ARMATURE VOLTAGE)

Range	Description	Fuzzy Association
214.8-219.8	Very Small	VS
218.3-222.3	Small	S
221.8-226.8	Medium	M
225.3-229.3	Big	B
228.8-233.5	Very Big	VB

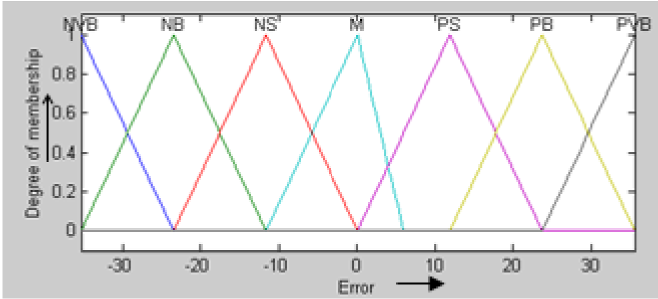

Fig.4 (a).Membership Function plot for error, e

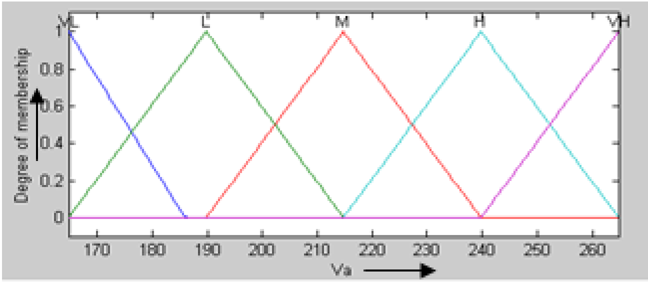

Fig.4 (b).Membership Function plot for input applied armature voltage

Fig.4(c).Membership Function plot for output desired armature voltage

The purpose of fuzzy logic controller is to maintain a fairly constant speed of the motor as load is varied. Speed control is accomplished by adjusting the armature voltage. A fuzzy rule for this problem appears in the form: -

If (V_a is L_1 and e is L_2)**then** V_{ad} is L_3 where L_1,L_2 and L_3 are linguistic terms.

The fuzzy inference system is represented by a Fuzzy Association Memory (**FAM**) mapping that associates the Input variables to the output variables as shown in Table 5.

TABLE 5
FUZZY ASSOCIATION MEMORY**(**FAM) TABLE

e / Va	NVB	NB	NS	M	PS	PB	PVB
VL				**VS**	**B**	**VB**	**VB**
L				**S**	**M**	**B**	**VB**
M		**VS**	**VS**	**VS**	**M**	**B**	**VB**
H	**VS**	**VS**	**S**	**B**	**S**	**M**	**B**
VH	**VS**	**S**	**M**	**VB**	**VS**	**S**	**M**

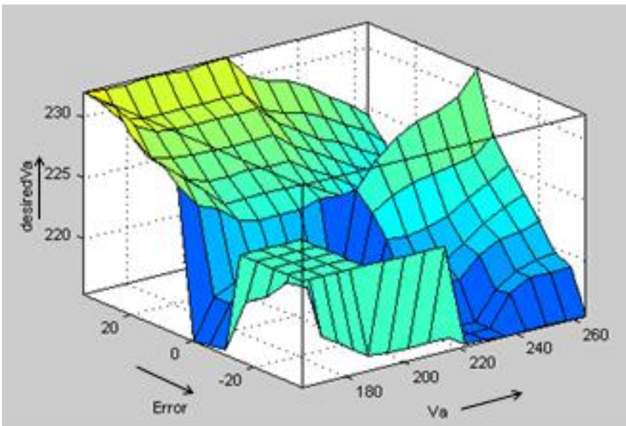

Fig.4(d).Surface plot of V_a, error and desired output(V_a)

Based on the relationship between input and output variables a total of 28 rules (corresponding to the 28 meaningful states in the FAM table) are composed from the FAM table. There is a reason for 'missing' rules in the FAM table and this should be pointed out. For example: If V_a is VL and error is NVB then error, e = ω_{sp}-ω→ω>ω_{sp}→ω has to be reduced →V_a has to be reduced. But V_a is already in lowest state i.e. VL, so no further reduction is possible. Such deletion of rules from the FAM table allows the designer to eliminate the conflicting or noncausal relationships. In classical expert systems theory, this is often referred to as 'conflict resolution'.
Some examples of the use of FAM table

. If e→ PVB **&** V_a→VL **Then** V_{ad}→VB

e→PVB means ω is very much less than set speed, so V_a has to be increased very much. Therefore when V_a is VL then V_{ad} must be set to VB.

. If e→ NVB **&** V_a→ H **Then** V_{ad}→VS

e→NVB means, the motor is running in over speed, so to bring the speed to normal position, V_a should be lowered therefore V_{ad} is set to VS.

In the design of fuzzy logic controller membership functions are of triangular type and the defuzzification method used is of centroid type.

V. SIMULATION RESULTS

Simulation of system using fuzzy logic controller has been developed. For the uncompensated MSCS, the response characteristics are shown in Fig.5 for load 2 N-m, while response characteristics using proposed FLC and PID are shown in Fig.6 and Fig.7 respectively. Fig.8 presents the characteristics of combined response of load 2 N-m.

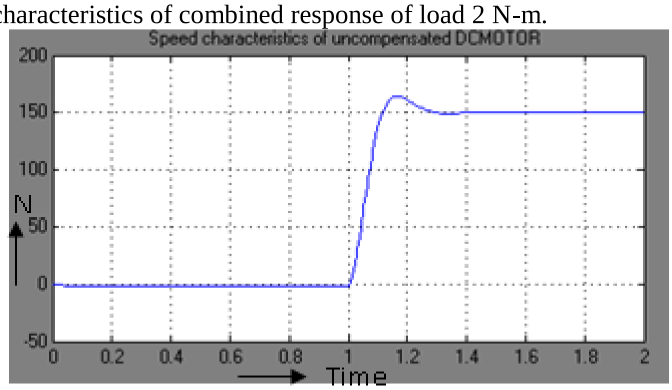

Fig. 5. Speed Characteristic for Uncompensated System for Load=2 N-m

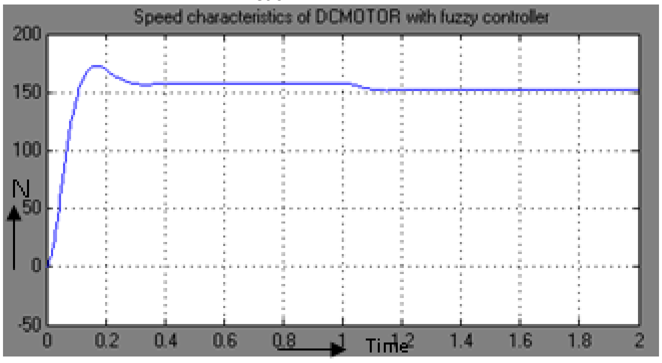

Fig.6.Speed Characteristic of MSCS using Proposed FLC for Load=2 N-m

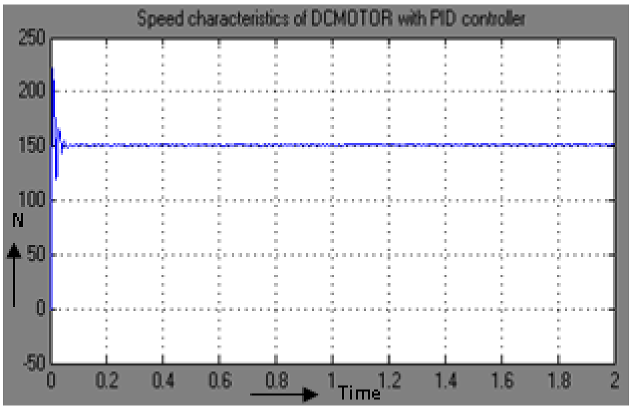

Fig.7. Speed Characteristic of MSCS using PID for Load=2 N-m

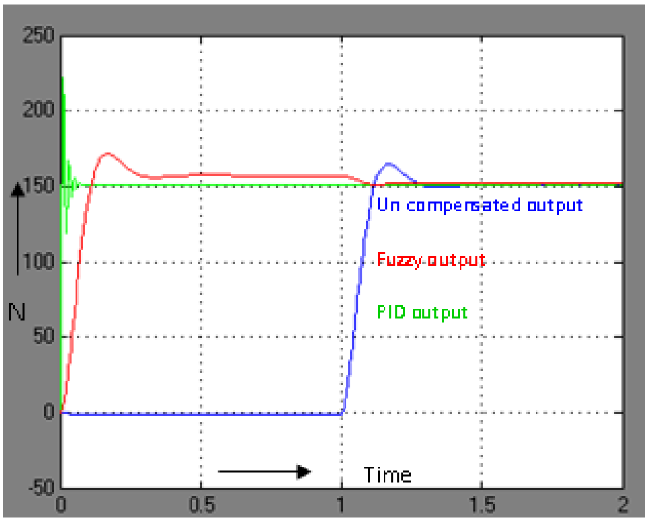

Fig.8.Combinedoutput response for load = 2 N-m

VI. CONCLUSION

A design concept of fuzzy logic controller and PID controller applicable to DC Motor Speed Control System (MSCS) has been shown in this paper. In the proposed controller inputs to the controller were taken V_a and e, rather than usual, error e and error derivative de/dt. Fuzzy logic toolbox, Simulink toolbox of MATLAB and a program in MATLAB programming language are used to simulate and demonstrate the controller. The numerical results from the Results are seen to be robust against varying loading conditions.

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