SPEED CONTROL OF A SEPERATELY EXCITED DC MOTOR BY IMPLEMENTING FUZZY LOGIC CONTROLLER

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ABSTRACT-This paper reveals an efficient method for speed control of a separately excited DC motor (SEDC) by using fuzzy logic controller (FLC) in a MATLAB environment and has proved to be a fruitful over conventional techniques. The controller design is wholly based on the expert knowledge of the system taken under the consideration. For the proposed SEDC motor case, seven fuzzy rules are designed for a fuzzy logic controller with two inputs i.e. speed error and change in speed error between the reference and actual speeds. The motor is being modeled and brought to a subsystem in SIMULINK. The PID parameters are being tested with MATLAB/SIMULINK and are directly been applied to the transfer function of the motor. After providing absolute tuning method, proper gain parameter values would be obtained for KP, KI, and KD. The performance of the SEDC motor is being judged by the different types of controllers (PID and FUZZY logic) and it has been found that the FLC performs the best in overshoot, settling time and steady state error.

KEYWORDS: SEDC motor, Fuzzy logic controller, PID control, membership function, fuzzy inference system, MATLAB/SIMULINK.

1. Introduction

Separately excited dc motor as the name implies is an efficient type of DC motor. In this case both the armature winding on the rotor and field windings on the stator got energized with separate supplies, Armature is supplied with a variable voltage source and field winding with an independent source of constant voltage and there are no electrical connections between the two circuits, The effectiveness of this system is that the field current is independent of both load and armature current and thus helps in achieving the better-regulated speed, which is its main characteristics. Main advantages of dc motors are lying in its variable speed changes and control, which makes its way in modern control strategy. This will provide easy controllability and efficient performance. DC motors are almost used in various applications like steel rolling mills, electric vehicles and trains, robotic manipulators and industrial electronics. Speed control in DC motors was obtained by means of voltage control first in 1981 by Ward Leonard [1]. Currently famous and most frequent type of controller used in many industries is PID controller [2,3], but due to some hindrances, they face some complications and don't offer better results when adaptive algorithms are in need.[4]. Due to the various disadvantages of conventional (PI and PID) controllers like delay in response and lack of proper action for error corrections, the Fuzzy Logic Controller makes its way and offers some fruitful solutions. Main advantages of FLC are that it doesn't have a need of constructing a mathematical model of a system [5,6]. The effectiveness of the FLC is manifested by the fact that it puts an effective and simple implementation of human thinking into the actions of controlling algorithm [7]. Main important thing is that the FLC is only based on particular approximation and linguistic information [8]. Basic feedback controller is PID controller which possesses good performance. However is acceptable enough only with flexible and better tunings. In this work, FLC has been proposed for better improvement and analysis of the system functions.

The non-linear attributes of dc motors like saturation and friction may affect the consequences of conventional controllers. Generally, it is very difficult to construct and find a perfect non-linear model for an actual dc motor and various parameter values developed from the system observation may be only approximated values. No doubt, traditional control techniques have proven better enough to handle control tasks on system control; however, this implementation is totally based on an exact mathematical model of the plant and its control variables, The FLC has an ability to model the in- correct and imprecise model, and thus boost its effectiveness; this valuable characteristic is not possible with conventional control techniques. With the Fuzzy Logic study, one can acquire a simpler, better, quicker and reliable result that is the big advantages over conventional techniques.

2. MATHEMATICAL MODELLING OF SEPERATELY EXCITED DC MOTOR

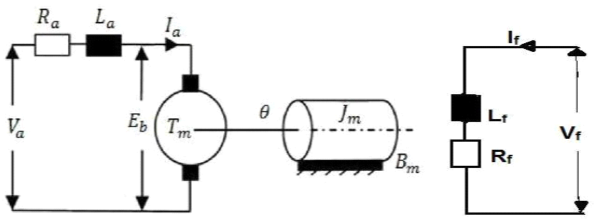


Fig-1: separately excited dc motor model [2]

Speed of a dc motor is given as:

$N \infty (V_a - I_aR_a)/\phi$-------------------------------- (1) $N = (V_a - I_aR_a)/K_a\,\phi$---------------------------- (2)
Where ϕ = Field flux per pole and K_a = Armature constant = $PZ/2\pi a$
Where P = No. of poles, Z = Total no. of armature conductor, a = No. of parallel paths. From the equation (1) it is clear, that speed can be controlled by using any of the following three methods: They are (1) Armature circuit resistance variation. (2) Field flux (3) Armature terminal voltage variations
From fig 3.1, the armature voltage equation is given by:
$V_a = E_b + I_{Ra} + L_a\,(dI_a/dt)$-----------------------(3)
Now the torque balance equation will be given by:
$T_{m=}J_m\,(d\varpi/dt) + B_m\varpi + T_L$-------------------- (4)
As the friction of a rotor is small, neglect it, so $B_{m=}0$, therefore new torque balance equation is given by:
$T_{m=}\,J_m\,(d\varpi/dt) + T_L$----------- ------------- (5)
Set the field flux as Φ and Back EMF Constant as K. Equation for back EMF of motor will be
$E_{b\,=}\,K\phi$--------- -------------------------------- (6) $T_m = K\phi I_a$--------------------------------------- (7)
Laplace transform of the motor's armature voltage equation can be taken as
$I_a(S) = (V_a - E_b)/\,(R_a + L_a)$------------------ (8)
Now, taking equation (6) into deliberation, we have:
$I_a(s) = (\,V_a - K\Phi\omega)/\,Ra\,(1 + \,La\,S/R_a)$----------(9) And $\omega(s) = (T_m - T_L)\,/JS = (K\Phi I_a - T_L)\,/J_mS$----(10)
(Armature Time Constant) $T_a = L_a/R_a$---------------- (11)
By simplifying the above motor model, the overall transfer function be
$\omega\,(\,S)/V_a(S) = K\Phi/L_aJ_mS^{\,2} + R_aJ_mS + K^{\,2}\,\Phi^2$------(12)
The modeling block diagram of a separately excited dc motor is shown as

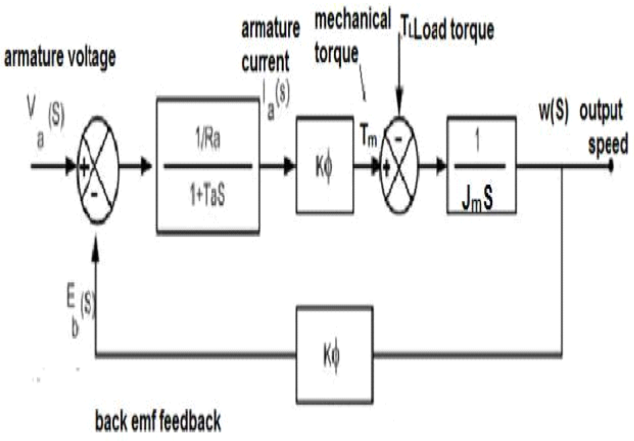


Fig-2: Modeling Block diagram of separately excited DC Motor [2]

2.1 Representation of the considered separately excited dc motor

As the name suggests, separately Excited dc motor mainly consists of two separate supplies one for the field winding and the other for the armature windings. The main differentiate fact in both of these types of dc motor is that the armature current does not flow through the field windings, as the field winding is energized from a separate external source of DC current. Figure 3 shows a separately excited dc motor

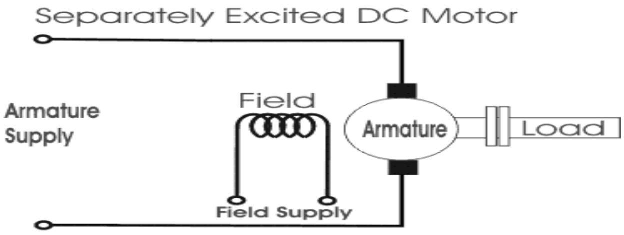


Fig-3: Separately excited dc motor diagram

The rotor and the shaft are presumed to be stiff. The following values for the physical parameters of SEDC motor have been used in this work.

Armature resistance (R_a) = 1.0 ohm Moment of inertia of the rotor (J_m) = 0.01 kg.m^2
Armature inductance (L_a) = 0.5 H Back electromotive force constant (K_e) = 0.01v/rad/sec Motor torque constant (k) =0.5 N.m/A Damping friction of the mech system (K_b) = 0.1 N.M.S

3. PID CONTROLLER

No doubt, Modern control techniques have taken appreciable paid attention from the last few years, but PID controllers have still the best knowing controller capability and are used in the various industrial phenomenon. Their efficient properties such as fast control action and robust performance are among the reasons for their preferences [9]. The design period of a PID controller will involve a crucial and challenging task in that, the three controller parameters i.e. K_P, K_I and K_D having a significant controller success, should be insistent on the proper basis. Practically this determination or say 'tuning process' is executed by an expert operator based on trial and error and Ziegler's method through some practical rules, it is evident that this method is time ingesting. Besides once tuned, controller may later deteriorate because of the non-linearity of the process under control [10]. A Proportional-Integral-Derivative controller (PID Controller) is used in immersive industrial control systems. A PID controller focused to accurate the error between a measured process variable and the desired set point. Figure 4 shows a basic PID controller structure

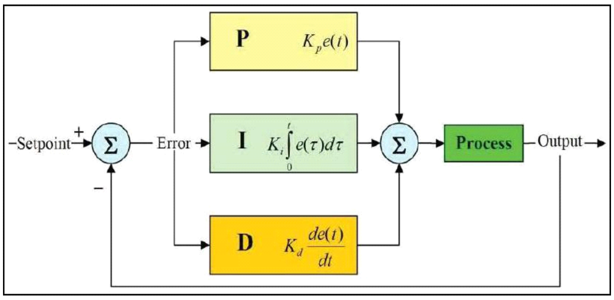


Fig-4: Basic PID controller structure

PID got its name from the three inter-related terms whose quantity constitutes the manipulated variable. The three terms are summed to calculate the PID controllers output. (1) **P** is denoted for the current values of the error. For example, if the error is substantial and positive, the control output will also be monstrous and positive. The proportional gain (K_p) is obviously the most eminent tuning parameter. A low gain will make the system inactive and unresponsive. Larger values are meant for faster responses since larger the error, greater will be the Proportional term compensation. A gain that is excessively high will makes the axis oscillate or vibrate, so the proper tuning proportional gain is used. (2) **I** is denoted for the past values of the error e.g. if the prevalent output is not enough powerful, the integral of the error will assemble over time. Larger values implicit steady state errors are rectified more quickly (3) **D** is denoted for possible upcoming drifts of the error; depend on its current rate of change. Derivative controller and gain (K_d) should not be used alone; it should be used in combinations with other modes of controllers owing to its few drawbacks. Larger values may degrade overshoot.

3.1 PID Controller Modelling Systems and design

This can be modeled in various ways, so as to control the process efficiently. Proper selection of the gain values must be done to fit and cope with the necessitate transfer function of a system under the control.

The designing procedures for a desired response of a PID controller meant for a particular problem mainly accompanies.(1) Select an open-loop or closed loop response and the needs to be improved.(2) Boost a rise time; overshoot by adding proportional and integral controls (3) The steady-state error can by eliminated by adding derivative control (4) Proper values for Kp, Ki, and Kd are adapted until we obtain a desired overall response. The best combinations of gain value are when the system can run with less overshoot and steady state error. The input- output relation of a PID controller is:

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_p \frac{de}{dt} \qquad \text{.....................(1)}$$

4. FUZZY LOGIC CONTROLLER

The Fuzzy Logic is a form of a systematic reasoning that can be integrated into automation systems with classical human reasoning schemes. Fuzzy theory was first suggested and probed by Prof Zadeh in 1965 [11] Fuzzy systems are apprehension based or rule based systems. The heart of a fuzzy system is a knowledge base inherent of the so-called If-Then rules. After allocating the fuzzy sets and their membership functions, rules must be noted to place an action to be taken for each combination of control variables. These rules will correlate the input and output variable by using IF-Then statements.

In a fuzzy logic system, the inference structure resolve upon the type of rules which are to be supplied for the corresponding inputs by coupling the Fuzzified inputs to the premises of the rules in the rule base. The defuzzification is meant to change the fuzzy set constructed by the inference into a crisp output to be used by the plant. The main components of Fuzzy logic controller are shown in Fig: 4.5 [2].

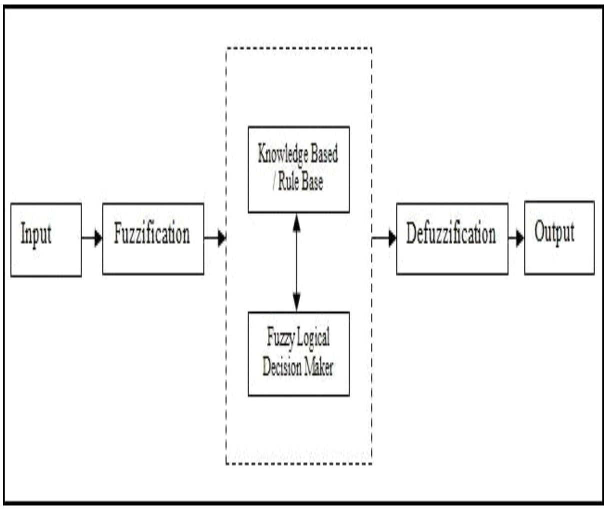


Fig- 5: Structure of the fuzzy logic controller

(1) Fuzzy Input the inputs are mainly hard or crisp measurements acquired from some calculated equipment and are converted into fuzzy values for every input fuzzy set with the fuzzification block. These crisp measurements can be obtained from an expert knowledge of the system. **(2) Fuzzification** it is generally the process of altering a real scalar value into a fuzzy value. This can be achieved by the different type of fuzzifies or membership functions. In this phase, the crisp variables eω (k) and deω (k) are transformed in to fuzzy variables *e* ω (error) and *de* ω (change in error) respectively. Each fuzzy variable is an associate of the subsets with a level of either membership μ varying between 0 (non-member) and 1 (full-member). The Fuzzification block Computes the values of input variables.**(3) Fuzzy Inference engine** Fuzzy inference system (FIS) employs a fuzzy set theory for portraying of the inputs with the outputs. Mamdani type of inference system is used in this method. In this stage, the variables error and change in error are processed by an inference engine that accomplished 7 RULES. These rules are confirmed using the knowledge of the system performance by the control engineers. Each rule is manifested in the form of the following example: IF (Error is Negative Large) THEN

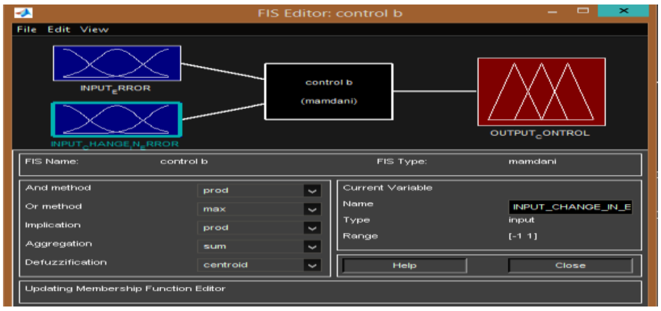
(Control signal provided will also be a negative large to compensate the Error). (**4) Knowledge Based / Rule Based** A decision building logic replicating a human decision ideology reduces the fuzzy control effort from the command of the control rules and linguistic variable meanings. The rules are in "IF-THEN" structure and basically the IF side is known as the conditions and the THEN side is called the closure. The computer has got the ability to perform the rules and calculate a control signal hinged on the rhythmic inputs error (e) and change in error (de). **(6) Defuzzification** The Reverse of Fuzzification is called Defuzzification. According to the real world requirements, the linguistic variables obtained have to be modified back into crisp output. Normally four types of membership functions are commonly used, based on their experience, knowledge and preference i.e (1) Trapezoidal MF (2) Triangular MF (3) Gaussian MF (4) Generalized bell MF **(7) Fuzzy Output** generally, the outcome is the output gain which is being tuned and also acts as an integrator. The output crisp value can be deliberated by the center of gravity or with the weighted average

4.1 Meaning of the linguistic variables in the fuzzy Inference system

ENL	Error negative large	CPL	Control positive large	CEP	Change of error positive
ENM	Error negative medium	CNL	Control negative large	CEN	Change of error negative
EZ	Error zero	CNM	Control negative medium	CEZ	Change in error zero
EPM	Error positive medium	CZ	Control zero		
EPL	Error positive large			CPM	Control positive medium

4.2 Fuzzy Logic Controller Designing procedure/methodology

This paper presents a methodology for rule base fuzzy logic controller (FLC) applying to the system under control. Before starting the simulation in MATLAB/SIMULINK, the FLC is to be constructed, but this may involve the use of various steps, first fuzzy inference system (FIS) Editor is opened and this file is being created using the fuzzy logic toolbox. The construction of a FLC requires the selection of proper membership functions. After the appropriate membership functions are chosen rule base is generated. The set of linguistic rules is the key part of a fuzzy controller. Different linguistic variables used in the design of a rule base for output of the FLC are enlisted in Table 1; the response of the FLC is being acquired by using in SIMULINK/MATLAB. Normally two inputs, one is the speed error having the 5 membership functions, two trapezoidal and three triangular and the other is the change in error having 3 membership functions, two trapezoidal, one triangular. Also have one output change in control having 5 membership functions and all are triangular in shape. When the membership functions and Fuzzy rules are resolute, the Surface viewer is developed showing the correlation among the inputs and outputs, thus a properly controlled control output signal is obtained with the use of FLC. Membership function for inputs is as shown in Fig 6(a) and 6(b) respectively while the membership function for output is shown in Fig 6(c) Mamdani type of inference system with Centroid method for fuzzification are being implemented, 7 rules are being used in this methodology, below figure shows a basic FIS Editor.



FIS Name: control b
FIS Type: mamdani
And method: prod
Or method: max
Implication: prod
Aggregation: sum
Defuzzification: centroid
Current Variable
Name: INPUT_CHANGE_IN_E
Type: input
Range: [-1 1]
Updating Membership Function Editor

Fig-6(a): Basic FIS editor

4.3 Input variables (Fuzzy sets of error variable)

These are the input variables given to the fuzzy inference system. These are two in number, one is the error generated due to the speed difference between the reference and actual speed of the motor, the other is the change in error. The Table-4.1 show the input variable error fuzzy sets with description and parameter values and Figure 6 (b) show the input error membership functions respectively:

Table 4.1: Membership function of input variable error

Fuzzy set(label)	Description	Membership type	Parameter values
Negative ERROR large(NEL)	Large speed difference in negative direction	Trapezoidal	[-1 -1 -0.9 -0.2]
Negative ERROR Medium(NEM)	Medium speed difference in negative large	Triangular	[-0.4 -0.2 -0]
Zero	Speed difference is zero	Triangular	[-0.01 0 0.01]
Positive ERROR Medium(PEM)	Medium speed difference in positive	Triangular	[0.2 0.4 0]
Positive ERROR Large(PEL)	Large speed difference in positive	Trapezoidal	[0.2 0.9 1 1]

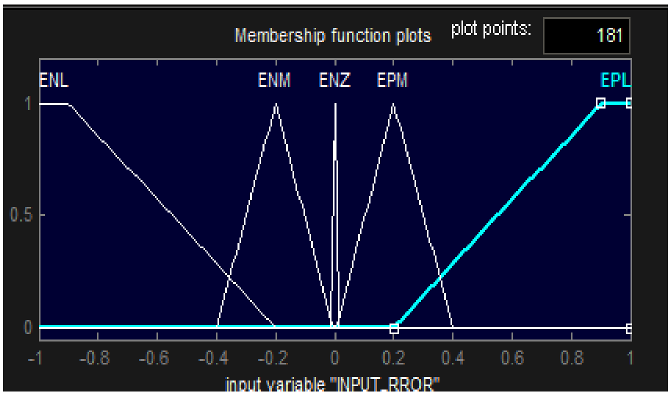


Fig 6(b) : Fuzzy Error input variable membership functions

4.4 Fuzzy sets of change in speed error (de)

The following table-4.2 show a change in error values with description and parameter and the figure 6(c) show membership function values with change in error.

Table 4.2: Membership function of input variable change in error

Fuzzy set(label)	Description	Membership type	Parameter values
(Change in error large negative)	Error difference in negative direction	Trapezoidal	[-1 -1 -0.2]
(change in error large negative	Error difference in positive direction	Trapezoidal	[0.2 1 1]
Central error zero	Error difference zero	Triangular	[0.001 0 0.001]

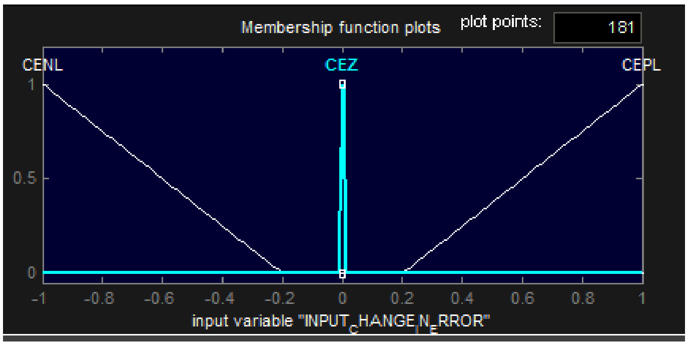


Fig 6(c): Change in error input variable Membership functions

4.5 Output variables

The Table-4.3 represents the control output variable 5 in number with description and parameter values, and the Fig 6(d) represents output control membership functions.

Table 4.3: Membership functions of output variable control

Fuzzy set(label)	**Description**	**Membership type**	**Parameter values**
Negative large (CNL)	Control in negative large	Triangular	[-30 -25 -20]
Negative medium (CNM)	Control in negative medium	Triangular	[-15 -10 -5]
Zero (CZ)	Control zero	Triangular	[-0.01 0 0.01]
Positive medium (CPM)	Control in positive medium	Triangular	[5 10 15]
Positive large (CPL)	Control in positive large	Triangular	[20 25 30]

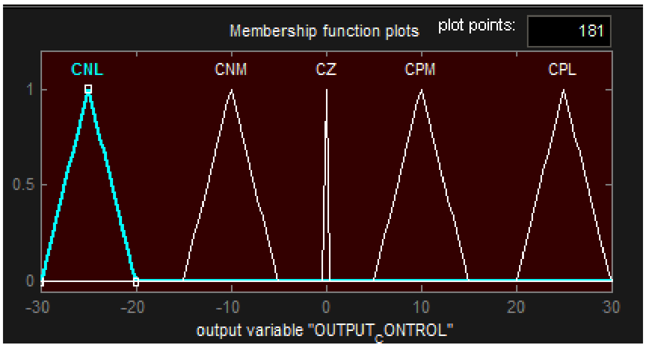
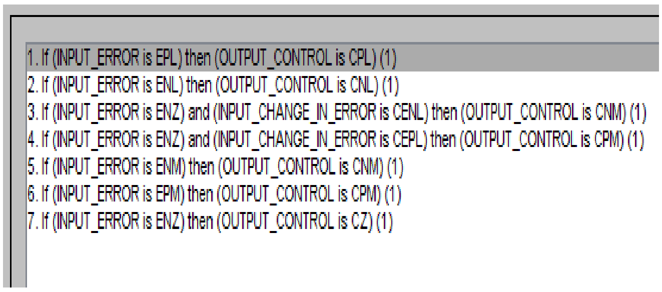


Figure 6(d): Output controls Membership functions

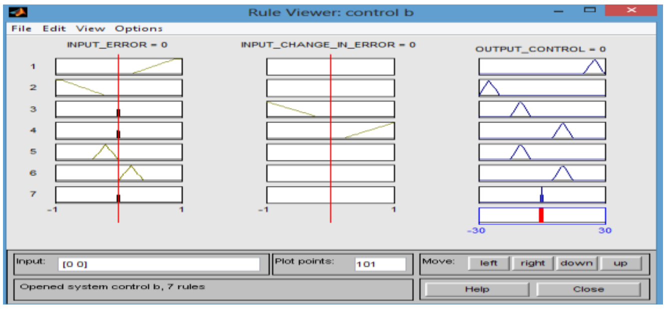
4.6 Construction of rules and rule viewer

The rules are the main building blocks of a fuzzy logic controller; generally seven rules are used in this system. The below Figures 6(e) and 6(f) shows a rule FIS editor and rule viewer respectively, these are actually used to represent the rules and their values. The rules are in IF-THEN statements:



1. If (INPUT_ERROR is EPL) then (OUTPUT_CONTROL is CPL) (1)
2. If (INPUT_ERROR is ENL) then (OUTPUT_CONTROL is CNL) (1)
3. If (INPUT_ERROR is ENZ) and (INPUT_CHANGE_IN_ERROR is CENL) then (OUTPUT_CONTROL is CNM) (1)
4. If (INPUT_ERROR is ENZ) and (INPUT_CHANGE_IN_ERROR is CEPL) then (OUTPUT_CONTROL is CPM) (1)
5. If (INPUT_ERROR is ENM) then (OUTPUT_CONTROL is CNM) (1)
6. If (INPUT_ERROR is EPM) then (OUTPUT_CONTROL is CPM) (1)
7. If (INPUT_ERROR is ENZ) then (OUTPUT_CONTROL is CZ) (1)

Fig 6(e); Assigning of If -then fuzzy rules

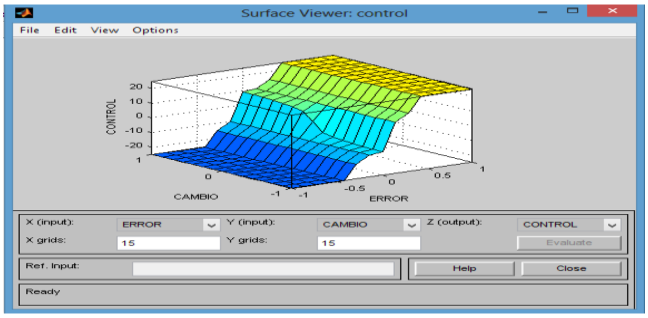


Input: [0 0]
Plot points: 101
Opened system control b, 7 rules

Fig 6 (f): Rule viewer

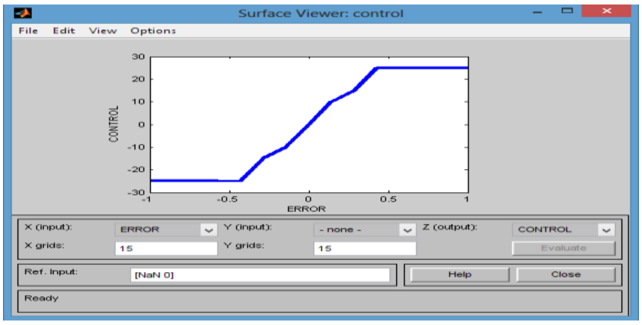
4.7 Surface Viewer

This represents a three-dimensional graph between the inputs and the outputs; this has proven helpful in designing a controller and it shows that how output control is being changed by varying the inputs. Figure 6(g) and 6(h) shows the surface viewer between the two inputs that is error and change in error with the output control and the surface viewer between the input error and output control respectively. This figure represents that how control signal is applied in sequence to the input error.



X (input): ERROR
X grids: 15
Y (input): CAMBIO
Y grids: 15
Z (output): CONTROL
Ref. Input:
Ready

Fig 6(g): Surface viewer between inputs and output variables



X (input): ERROR
X grids: 15
Y (input): - none -
Y grids: 15
Z (output): CONTROL
Ref. Input: [NaN 0]
Ready

Fig 6(h): Surface view Graph between input error and output control

5. RESULTS AND DISCUSSIONS

Parameters used in simulation Dc motor

Armature resistance=1.0, Armature inductance=0.5, Damping=0.1 Inertia=0.01

Step signal and step torque signal

Step time=7 Initial value=0.001 Final value=0.02 sample time=0

PID controller

Proportional gain=200, Integral gain=150, Derivative gain=08**,** Step signal (800 to 1450) rpm of a motor

5.1 SIMULINK PID controller model

Fig 7 (a) shows a SIMULINK model of PID controller, the basic blocks required for a specific task are used therein. The model is used to control the speed of a SEDC motor by adjusting first its proper gain values Kp,Ki,Kd . Basically in this work analysis first the motors speed is being set in between 800 to 1450 rpm, the calculated speed of a motor tends to track the reference speed of a motor and hence this may develop the control mechanism. The reference speed shown in fig 7 (b) is a common reference speed of both the controllers analyzed in this work. Fig 7 (c), (d) shows the calculated speed of a SEDC motor controlled by PID and the output response between a reference and the actual speeds of a SEDC motor with the use of a PID controller respectively.

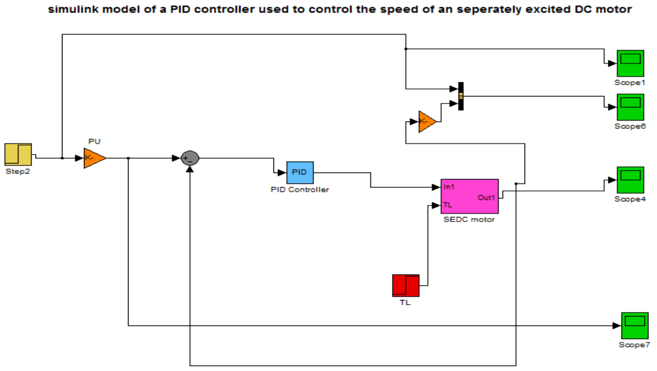

simulink model of a PID controller used to control the speed of an seperately excited DC motor
Scope1
Scope5
Scope4
Scope7
Step2
PU
PID
PID Controller
In1
Out1
TL
SEDC motor
TL

Fig 7(a): SIMULINK PID controller model

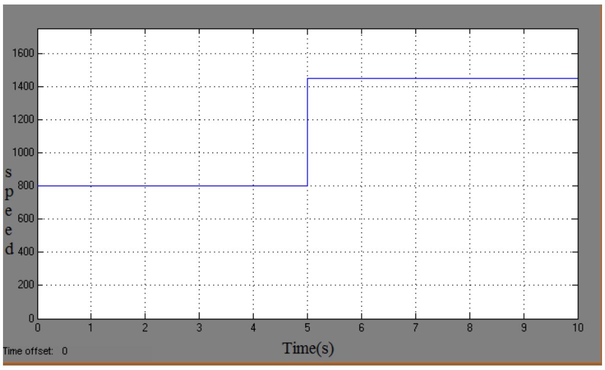


Fig 7 (b): Reference speeds (R.P.M) vs. time graph of separately excited motor

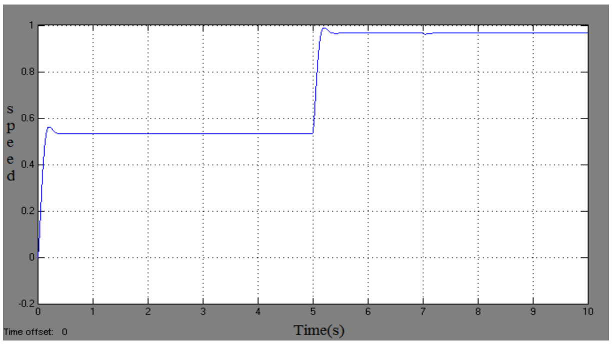


Fig 7 (c): Speed (P.U) vs. time(s) graph of the SEDC motor using PID controller

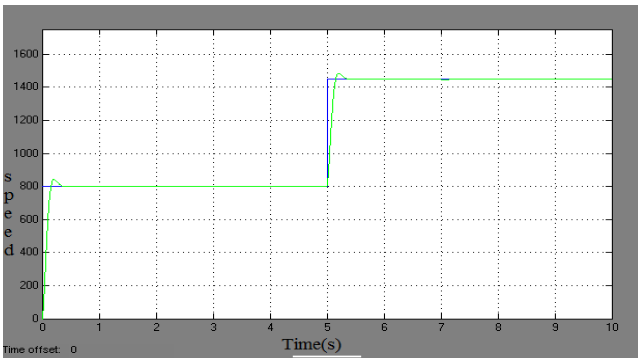


Fig 7 (d): Output response of: Speed (R.P.M) vs. time (s) graph for PID controller

From this figure, it is almost clear that an actual speed of SEDC motor tends to track the reference speed of a SEDC motor and hence develops a speed control mechanism for controlling speed of a SEDC motor.

5.2 SIMULINK FLC (Fuzzy logic controller model)

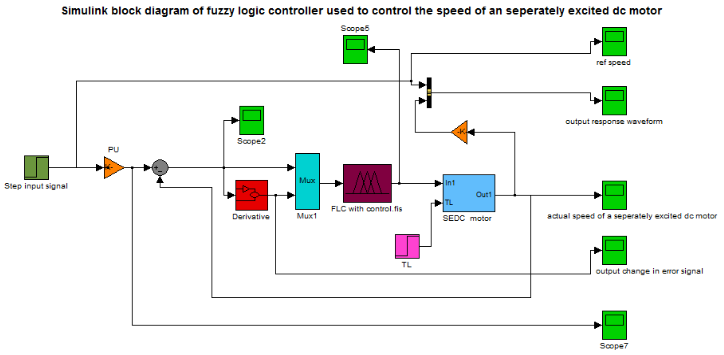

Simulink block diagram of fuzzy logic controller used to control the speed of an seperately excited dc motor
Scope5
ref speed
output response waveform
Scope2
PU
K-
-K-
Step input signal
Mux
Derivative
Mux1
FLC with control.fis
In1
TL
Out1
SEDC motor
actual speed of a seperately excited dc motor
TL
output change in error signal
Scope7

Fig. 8 (a): MATLAB/SIMULIK model of a separately excited dc motor using fuzzy logic controller

The developed MATLAB model in Fig 8(a) provides the speed control strategy to a separately excited dc motor by using a Fuzzy logic controller. The simulation results develop the necessary waveforms for the analysis of speed control of a separately excited dc motor. Reference speed of a SEDC motor is set in between 800 to 1450 rpm

The implemented fuzzy logic develops an output control correction free voltage signal, which is then given to the armature circuit of an SEDC motor and hence help in controlling the speed of an SEDC motor. Fig 8(b), Fig 8(c) and Fig 8(d),actual speed of a dc motor, error correction signal from FLC output, output response signal of speed vs. time graph between reference and actual speeds of motor respectively. From Fig 8(e) it has been analyzed that an actual speed waveform of an SEDC motor tends to track the reference waveform, thus developing a control mechanism for speed control of a SEDC motor.

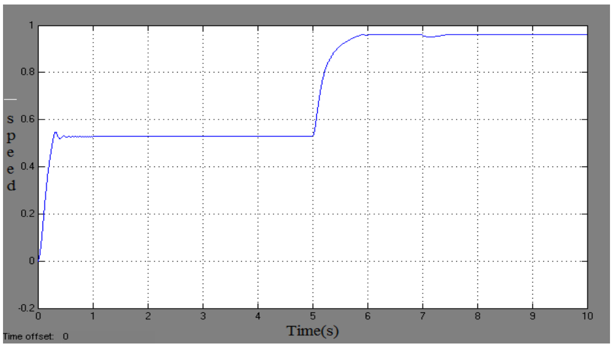


Fig 8(b): Speed (P.U) vs. time graph of the SEDC motor using fuzzy logic controller

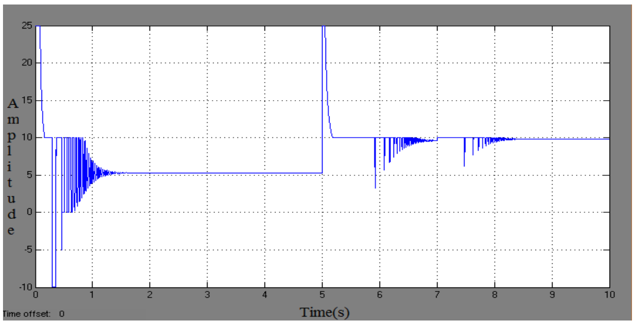


Fig 8 (c): FLC output error correction signal (amp vs. time)

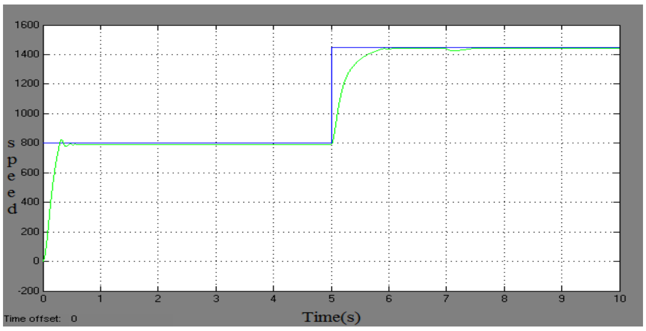


Fig 8(d): Speed (R.P.M) vs. time (s) graph of a Step response of the system using FLC

The results obtained in Fig 8(d) shows that the actual speed of an SEDC motor is almost tracking the reference speed with less overshoot and disturbances, thus the speed of an SEDC motor is best controlled by the use of a fuzzy logic controller, thus an efficient speed control is achieved and it proves that FLC is better than other conventional control methods.

COMPARATIVE ANALYSIS BETWEEN FLC AND PID

- From the waveforms it is clear that FLC has better performance than PID controller in settling time, overshoot, steady state and transient response.
- Unlike conventional PID, fuzzy logic is a self tuning controller so manual tuning is being circumvent while intelligent self-tuning is being done by the computer itself.
- The main problem in PID controller is its tuning. And the parameters like Kp, Ki and Kd needs to be persistently adjusted in order to acquire better control performance making system less robust

Table 5.1: Comparison between the output responses of controllers

Controller type	Rise time	Overshoot %	Settling time required	Steady state error
PID	0.15	4.8%	low	low
FLC	0.28	2.5%	Very Low	Very low

6. CONCLUSIONS

This approach manages the speed control of a SEDC motor using FL and PID controller. The simulation results are acquired using MATLAB/SIMULINK .The fuzzy logic response is contrasted with that of the conventional controller. The results show that overshoots, settling time, and control performance has been enhanced effectively by the use of a FLC. Hence a fuzzy logic system is being suggested, developed and actually implemented in hardware to observe its main feasibility. It is clear that fuzzy logic can be used in countless applications. It can appear almost in any place where computers and modern control theory are unduly accurate as well as in tasks requiring exquisite human intuition and experience based knowledge. This paper introduces a design procedure of two inputs and one outputs for self-tuning FLC and makes use of M ATLAB fuzzy toolbox for its design. From the simulation results it is concluded that , compared with the conventional PID controller, self-tuning FLC is more effective.

FUTURE SCOPE

It has been found and strongly viewed that the FLC acting as the smart intelligent controller in various control processes is believed to be used in various aircraft techniques, it can make its way in various fields, Ranging from the small real problems up to the weather forecasting and robotic manipulators.

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