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# Heuristic Technique of DC Motor Speed Control Using PI & Fuzzy Controller

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## ABSTRACT
*In this work proposed a new study of application of Fuzzy logic controller. It is used for the governing of speed of separately excited DC motor on various load condition. Many industries like paper mill, steel rolling mill etc. required very smooth and constant speed of operation of motor, since classical controller like PI, PD, and PID are fail to operate the system when load parameters are changed. Fuzzy logic controller is given better speed control solution at such situation. Here we are discussed about PID controller as well as Fuzzy logic controller. The simulation results obtained by Fuzzy logic controller are better than the PID controller.*

***Keywords: - DC motor, speed control, Chopper, PID and Fuzzy-logic controllers.***

## 1. INTRODUCTION
Direct current motors have been widely used in many industrial applications such as electric vehicles, steel rolling mills, electric cranes, and robotic manipulators due to precise, wide, simple, and continuous control characteristics. For such application DC motor operate on various mode of Speed. For the operation on wide range of speed it requires a controller, to control the speed of motor to perform desired task. The major problems in applying the conventional control algorithms 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 friction could degrade the performance of conventional controllers. Many advanced model-based control methods have been developed to reduce nonlinearity effects, such as proportional-integral-derivative (PID) control, classical control, State-space methods: state feedback, optimal control, robust control: $H_2$ or $H_\infty$ methods, Nonlinear methods sliding mode control, Adaptive control, Self-tuning regulators, Nonlinear Adaptive control, Stochastic control(Minimum variance control, Linear quadratic Gaussian (LQG) Control), Discrete event systems. These control methods depends on the accurate system models and parameters. The main problem of using these controllers is the effect acquired as a result of disturbances and environmental conditions on the structure of the system, adding complexity to the controller's design. Much of the interest in fuzzy control system has arises due to potential of handling uncertainty and impression in design of system. In general they improve machine IQ. The biggest advantage of fuzzy based system is a model free approach for design. Most often an appropriate mathematical model of the dynamical system is not available and information access from human expert knowledge about plan operation. The fuzzy logic approach do not required a fix model of DC motor and its results are also not affected by parameter variation. Fuzzy logic offers a simpler, quicker and more reliable solution that is clear advantages over conventional techniques. Fuzzy control is more robust control method than usual conventional control to variation of system parameter. In this paper proposed a Fuzzy logic controller and it is tested for various load torque. The deigned Simulink model of Fuzzy logic controller for the speed control of DC motor are also tested for 3,5 and seven membership number of fuzzy system. And it is found that for all membership numbers fuzzy controller operate efficiently and gives better results than PID controller.

## 2. SYSTEM DESCRIPTIONS
### 2.1 Motor Model
A linear model of a simple DC motor consists of a mechanical equation and electrical equation as described here. Air gap flux given as

$$\phi = K_f\, I_f \qquad (1)$$

*The torque developed by the motor is given as*

$$T_m = K_T\, I_a \phi \qquad (2)$$

*Back emf of the motor*

$$e_b = K_b\, \omega_m \qquad (3)$$

*Taking Laplace transform we get*

$$E_b(s) = K_b\, s\theta(s) \qquad (4)$$

*General equation of SEDCM is given as*

$$V_a = R_a I_a + L_a \frac{dI_a}{dt} + e_b \quad (5)$$

*Taking Laplace transform on both sides we get*

$$V_a(s) = R_a\, I_a(s) + s\, L_a I_a(s) + E_b(s) \qquad (6)$$

*Now by equation (4) & (6) get,*

$$V_a(s) = R_a\, I_a(s) + s\, L_a I_a(s) + K_b\, s\theta(s) \qquad (7)$$

$$I_a(s)(Ra + sLa) = V_a(s) - K_b\, s\theta(s) \qquad (8)$$

*The load torque equation is given as,*

$$J\frac{d^2\theta}{dt^2} + f\frac{d\theta}{dt} = T_m = K_T I_a \qquad (9)$$

*Taking Laplace transform on both sides of eq. (9), we get*

$$(js^2 + fs)\theta(s) = T_m(s) = K_T I_a(s) \quad (10)$$

*So armature current of the dc motor from eq. (10) is given as*

$$I_a(s) = \frac{T_m}{K_T} = \frac{Js^2+fs}{K_T}\ \theta(s) \qquad (11)$$

*Now by eq. (8) & (11) we get,*

$$\frac{(Js^2+fs)(Ra+sLa)}{K_T}.\theta(s) = V_a(s) - K_b\, s\theta(s) \quad (12)$$

$$V_a(s) = \frac{(Js^2+fs)(Ra+sLa)}{K_T}.\theta(s) + K_b\, s\theta(s) \quad (13)$$

$$V_a(s) = \frac{[(Js^2+fs)(Ra+sLa)+s\,K_b\,K_T]}{K_T}.\theta(s) \quad (14)$$

*Eq. (15) gives the transfer function of the separately excited dc motor*

$$\frac{\theta(s)}{V_a(s)} = \frac{K_T}{[(Js^2+fs)(Ra+sLa)+s\,K_b\,K_T]} \qquad (15)$$

Where, $R_a$= Armature Resistance (Ω).
$L_a$ =Armature Inductance (H).
$j_m$=Motor of inertia (kg.m² /S²).

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Kb =Motor Constant
f=Damping friction coefficient

The dynamic model of the DC Motor connected with dynamic load is shown in fig.1.

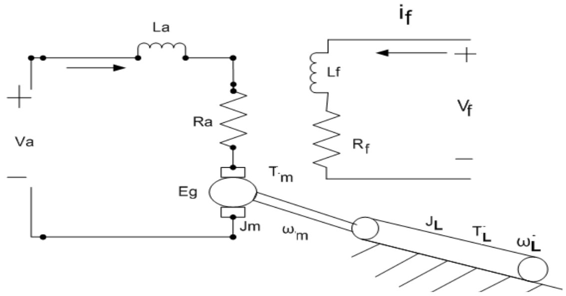

Fig.1 Dynamic model of separately excited DC

### 2.2 Driver Circuit

Choppers are used to get variable DC voltage from a DC source of fixed voltage. The speed control of DC motor with power electronic systems is obtained generally by changing its terminal voltage. A chopper fed DC motor circuit diagram is shown in fig. 2.

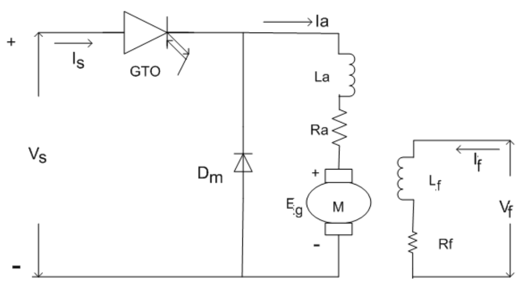

Fig.2 Chopper fed SEDC motor

Armature (DC) current is given as:

$$I_a = \frac{V_a - E_g}{R_a} \qquad (16)$$

The average output voltage of chopper fed DC motor is calculated from:

$$V_{avg} = \frac{1}{T}\int_0^T V(t)dt = KV_m \qquad (17)$$

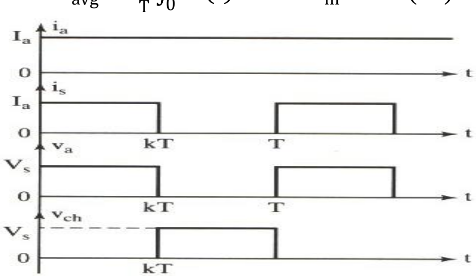

Fig.3 V-I characteristic of chopper fed DC motor

The average output armature voltage can be calculated as

$$Vavg = \frac{Ton}{Ton + Toff}.Vs$$

Or

$$V_{avg} = KV_s \qquad (18)$$

Where K is the duty cycle,

## 3 FUZZY LOGIC CONTROLLER (FLC) DESCRIPTIONS AND DESIGN

The fuzzy logic foundation is based on the simulation of people's opinions and perceptions to control any system. One of the methods to simplify complex systems is to tolerate to imprecision, vagueness and uncertainty up to some extent. Fuzzy logic control is constructed on logical relationships. Fuzzy Sets Theory is first introduced in 1965 by Zadeh to express and process fuzzy knowledge. There is a strong relationship between fuzzy logic and fuzzy set theory that is similar relationship between Boolean logic and classic set theory. Fig 4 shows a basic FLC structure.

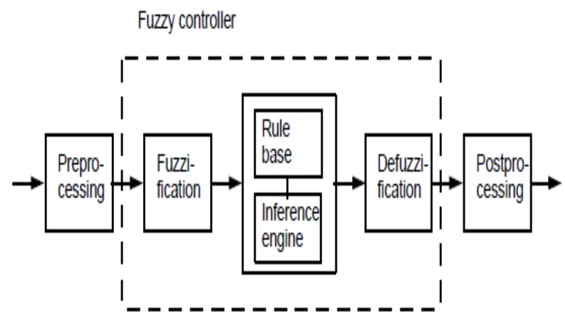

Fig.4 Structure of Fuzzy Controller.

Although the classic controllers depend on the accuracy of the system model and parameters, FLC uses different strategies for motor speed control. Basically, FLC process is based on experiences and Linguistic definitions instead of system model. It is not required to know exact system model to design FLC. A defining Input and Output: The goal of designed FLC in this study is to minimize speed error. The bigger speed error the bigger controller input is expected. In addition, the change of error plays an important role to define controller input. Consequently FLC uses error and change of error for linguistic variables which are generated from the control rules.

## 4 MATLAB/SIMPOWER SYSTEMS MODEL OF DC MOTOR FOR PID CONTROLLER

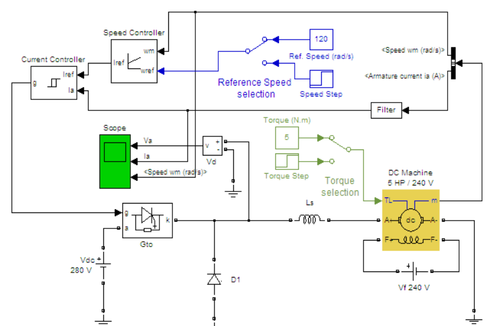

Fig.5 Matlab/Simulink model of SEDCM for PID controller

Fig.5 shows simulink model of controlled separately excited dc motor using chopper circuit with PID controller for the speed control of DC motor. It consists of a separately excited

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dc motor fed by a dc source through a chopper circuit. A single GTO thyristor with its control circuit and a free-wheeling diode form the chopper circuit. The motor drives a mechanical load characterized by inertia J, friction coefficient f, and load torque $T_L$. The control circuit consists of a speed control loop and a current control loop. A proportional-integral-derivative (PID) controlled speed control loop senses the actual speed of the motor and compares it with the reference speed to determine the reference armature current required by the motor.

### 4.1Matlab/Simpower Systems Model of Dc Motor for Fuzzy Logic Controller

The Matlab/simulink model of SEDCM for fuzzy logic controller is shown in fig 6. Its have same dc motor, chopper circuit and current controller as taken in fig 5. Only PID controller replaced by fuzzy logic controller.

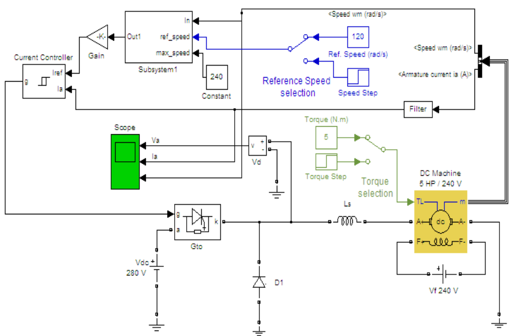


Fig.6 Matlab/Simulink model of SEDCM for Fuzzy logic controller

### 4.2 SOFTWARE DESIGN

FLC designed is based on Mamdani fuzzy type. The details of the designed controller are,

```
        type: 'mamdani'
   andMethod: 'min'
    orMethod: 'max'
defuzzMethod: 'centroid'
   impMethod: 'min'
   aggMethod: 'max'
       input: [1x2 struct]
      output: [1x1 struct]
        rule: [1x49 struct]
```

### 4.3 FUZZY RULES

In the present work we developing Fuzzy rule for seven membership Function, as shown in fig.7

## 5. RESULTS & ANALYSIS

We have taken a PID controller used for separately excited DC motor, from Matlab simulink model as reference [12] model and find out Simulink responses for various load torque. After that we replace PID controller by Fuzzy logic controller for same motor and Parameters and find out simulink response for constant and variable load torque is shown below;

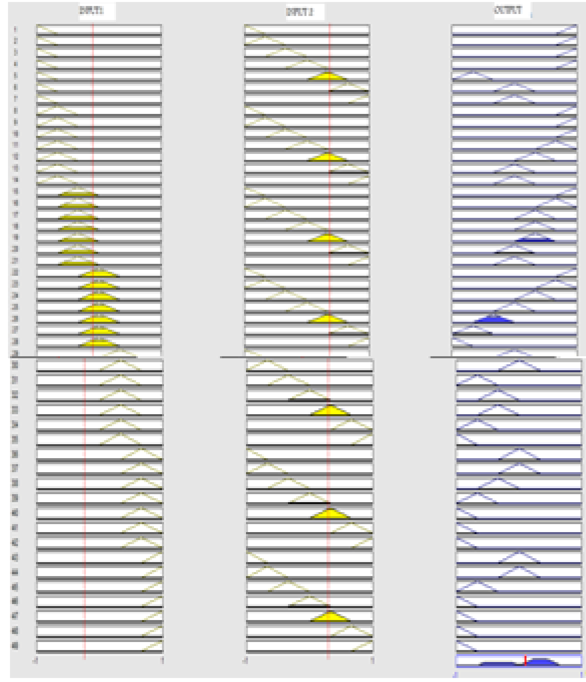

Fig.7 Fuzzy rules for seven membership function

Surface Structure of rules is given in fig 8

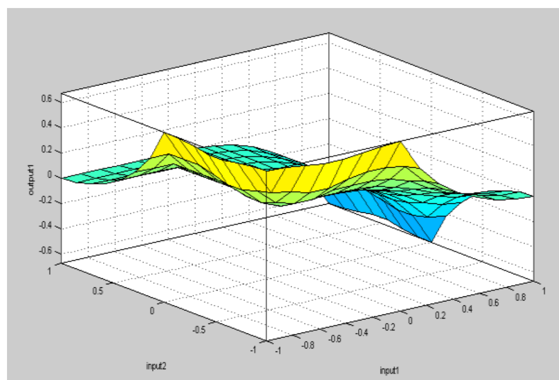


Fig.8 surface structure of fuzzy rules

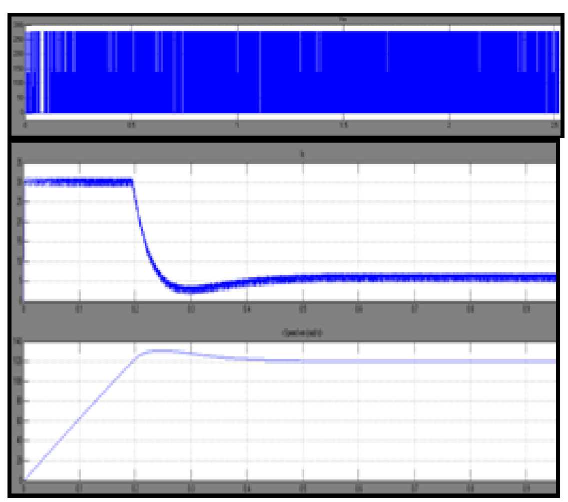

Fig.8 Simulink response of PID controller (arm. voltage, arm. current and speed)

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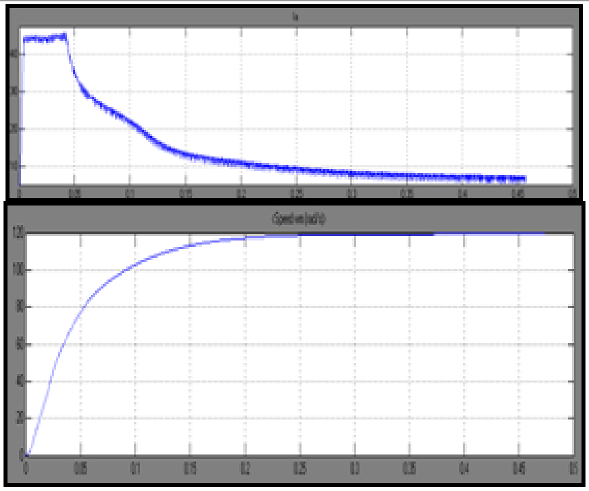

Fig.9 Simulink response of fuzzy controller for seven membership function (arm. Current & speed)

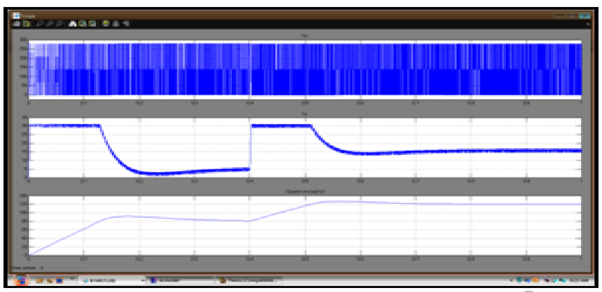

Fig10. Simulink response of PID controller for $T_L$ = 5 to 17 Nm and speed (80 & 120 rad/sec)

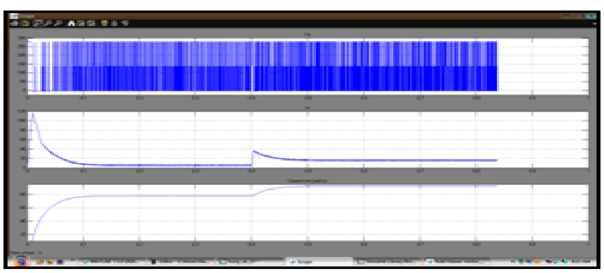

Fig.11 Simulink response of FLC for 7- membership function ($T_L$ = 5 to 17 Nm) and speed (80 to 120 rad/sec)

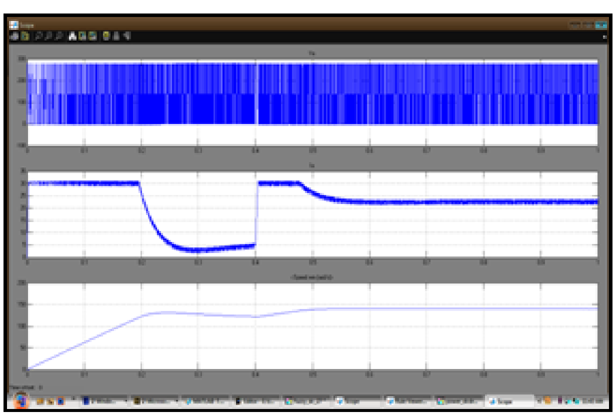

Fig.12 Simulink response of PID controller for TL (5 to 25 Nm) and speed (120 to 140 rad/sec)

Simulink response of PID controller for constant torque (25Nm) and constant speed (120 rad/sec) is shown in fig8,its shows that rise time of response is about 0.2sec.its have maximum overshoot at t= 0.24sec. After t=0.421sec its give steady state response. The response of the Fuzzy controller for the given Fuzzy rules is shown in fig.9, its shows that rise time of response is about 0.23 sec. and it is free from maximum overshoot. After t=0.25sec its give steady state response. For the validity of the results we find out the simulink response of the PID and fuzzy logic controller for different load torque and speeds as shown in fig (10-13) It is seen that The fuzzy controller can be adjusting the fuzzy rules according to the change of error and change in error and It is concluded that the fuzzy controller as compared. With the conventional PID controller, it provides improvement performance in both transient and the steady states response, fuzzy controller has no overshoot and gives steady state operation.

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