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Speed Control of DC Motor Using Fuzzy Logic Controller

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***Abstract*-In this paper , DC motor speed is controlled using PID controller and fuzzy logic controller . PID controller requires a mathematical model of the system while fuzzy logic controller base on experience via rule-based knowledge .**

Design of fuzzy logic controller requires many design decisions , for example rule base and fuzzification. The FLC has two input ,one of these inputs is the speed error and the second is the change in the speed error. There are 49 fuzzy rules which are designed for the fuzzy logic controller. The center of gravity method is used for the defuzzificztion. Fuzzy logic controller uses mamdani system which employs fuzzy sets in consequent part. PID controller chooses its parameters base on trial and error method. PID and FLC are investigated with the help of MATLAB / SIMULINK package program simulation. It is founded that FLC is more difficult in design comparing with PID controller, but it has an advance to be more suitable to satisfy non-linear characteristics of DC motor. The results shows that the fuzzy logic has minimum transient and steady state parameters , which shows that FLC is more efficiency and effectiveness than PID controller.

Keywords- DC motor, PID, FLC, mamdani, SIMULINK.

I.INTRODUCTION

"Almost every mechanical movement that has been noticed around us is accomplished by an electric motor. Electric machines are a means of converting energy. Motors take electrical energy and produce mechanical energy. Electric motors are used to power hundreds of devices we use in everyday life.

Electric motors are broadly classified into two different categories : DC (Direct Current) and AC (Alternating Current). Within these categories are numerous types, each offering unique abilities that suit them well for specific applications. In most cases, regardless of type, electric motors consist of a stator (stationary field) and a rotor (the rotating field or armature) and operate through the interaction of magnetic flux and electric current to produce rotational speed and torque". [1]

"The controllers used to modify the behavior of this system so as it behaves in a specific desirable way over a time. One of these controllers is fuzzy logic controller.

Fuzzy Logic Controller (FLC) which was proved analytically to be equivalent to a nonlinear controller when a nonlinear defuzzification method is used. Also, the results from the comparisons of conventional and fuzzy logic control techniques in the form of the FLC and fuzzy compensator showed that fuzzy logic can reduce the effects of nonlinearity in a DC motor and improve the performance of a controller" .[3]

"For fuzzy controller, the fuzzy logic toolbox is highly impressive in all respect. It makes fuzzy logic an effective tool for the conception and design of intelligent systems. The fuzzy logic toolbox is easy to master and convenient to use. And last, but not least important, it provides a reader-friendly and up-to-date introduction to the methodology of fuzzy logic and its wide-ranging applications". [4]

II.RELATED WORKS

Control of speed can be achieved by use of different methods:

A. Armature voltage control

"In separately excited motors, the voltage applied to the motor can be varied with the field remaining constant. Different voltages then give different intercepts (different no load speeds), and result in a family of parallel (i.e. same slope) mechanical c/s. To obtain variable DC voltage , the simplest method is to use a voltage divider, but this method is impractical and uneconomical; it is used only for testing. In modern applications, variable DC voltage for the armature is often obtained from a solid-state controlled rectifier, with the field fed from an uncontrolled rectifier. Another effective method for obtaining smooth voltage control is the Ward-Leonard system. The dc motor is fed from a dc generator driven by some prime-mover (e.g. ac motor or diesel engine). By varying the field excitation of the generator, the armature voltage of the motor varied (and can be even reserved). The motor field is fed from an exciter (small DC generator) or rectifier at constant voltage. The Ward-Leonard system is generally more expensive than a solid-state drive, but has compensating advantages for certain applications.

B. Field control

If the field circuit resistance is increased, the field current, and hence the main field, will be reduced, and the speed will increase. The higher the field resistance, the higher the intercept and the greater the slope (i.e. the c/s becomes softer). The flux cannot be reduced indefinitely because the speed becomes too high and may damage the motor. Moreover, if the main field becomes too weak, the demagnetizing effect of armature reaction becomes prominent (relatively large) which may lead to instability". [11]

C. Proportional-Integral-Derivative controller (PID controller)

"PID controller is miniature part of embedded system, it operates the majority of the control system on the world, and it's used for wide range of problems like (motor drive, automotive, flight control, instrumentation). Tuning the parameters of the PID controller is very difficult, poor robustness and difficult to achieve optimal state under field condition in the actual production". [2]

III. PROPOSED SOLUTION

The nonlinear characteristics of a DC motor such as saturation and friction could degrade the performance of conventional controllers. In addition , due to the conventional controllers are fixed structure and fixed parameter, expected difficulties in the tuning and optimization of these controllers would happen. So attempts to overcome these limitations using fuzzy controller. The fuzzy logic, unlike conventional logic systems. FLC is able to model inaccurate or imprecise models. The fuzzy logic approach offers a simpler, quicker and more reliable solution that is clear advantages over conventional techniques. Actually fuzzy logic is used mostly to handle high- level control functions that traditional control methods do not address.

It helps to get the output ,where this output is expected to be in short time , with minimal overshoot , little error, minimum settling time and fast rising time are very important and crucial in industrial application.

IV.SEPARATELY EXCITED DC MOTOR MODELING

In modeling, the aim is to find the governing differential equations that relate the applied voltage to the produced torque or speed of the rotor [5]. Fig.1 shows the equivalent circuit with armature voltage control and the model of a general mechanical system that incorporates the mechanical parameters of the motor and the mechanism coupled to it. Armature reactions effects are ignored in the description of the motor. The fixed voltage V_f is applied to the field and the field current settles down to a constant value. A linear model of a simple DC motor consists of a mechanical equation and electrical equation [6].

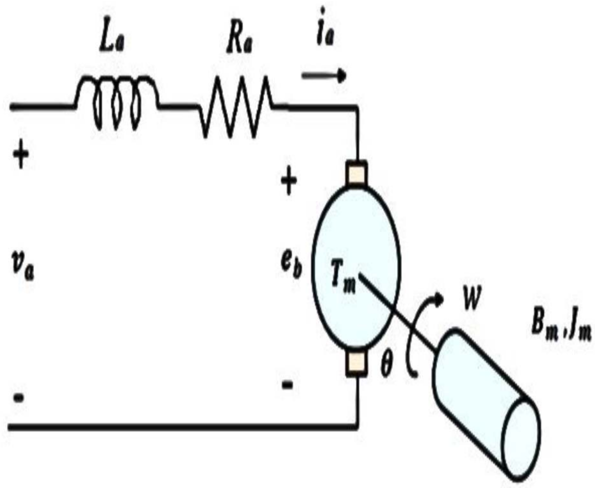

Fig.1 Equivalent circuit of a separately excited DC Motor

From Figure (1), Kirchhoff's Voltage Law (KVL) is applied to the electrical circuit. These can be written

$$E_a\,(t) = R_a\,.I_a + L_a\frac{di_a}{dt} + e_b \qquad (1)$$

Where: E_a is armature voltage (V), I_a is armature current (A), R_a is armature resistance (Ω), L_a is armature inductance (H), e_b is back EMF (V).

Setting e_b(t) in (1) equals to K_b.w(t) the electrical equation in (1)becomes

$$E_a\,(t) = R_a\,.I_a + L_a\frac{di_a}{dt} + K_b.w(t) \qquad (2)$$

For normal operation, the developed torque must be equal to the load torque plus the friction and inertia.

$$T_m(t) = J_m.\frac{dw(t)}{dt} + B_m.w(t) + T_L \qquad (3)$$

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Where: T_m is motor torque (Nm), J_m is rotor inertia ($kg.m^2$), W is angular speed (rad/s), B_m is viscous friction coefficient (Nms/rad), T_L is load torque (Nm).Setting $T_m(t)$ equal to $K_T.I_a$ and $T_L = 0$ yields

$$K_T.I_a(t) = J_m.\frac{dw(t)}{dt} + B_m.w(t) \quad (4)$$

Taking the Laplace transforms for (2) and (4) yields

$$E_a(s) = R_a(s).I_a(s) + L_a.I_a(s).s + K_b.w(s) \quad (5)$$

$$K_T.I_a(s) = J_m.w(s).s + B_m.w(s) \quad (6)$$

Current obtained from (3-4) as

$$I_a(s) = \frac{J_m.w(s).s+B_m.w(s)}{K_T} \quad (7)$$

And then substituted in (5) get

$$E_a(s) = \frac{w(s)}{K_T}[(R_a.J_m.s + R_a.B_m) + (L_a.J_m s^2 + L_a.B_m.s) + K_b.K_T] \quad (8)$$

So the relationship between rotor shaft speed and applied armature voltage is represented by the transfer function and shown in fig.2 .

$$\frac{w(s)}{E_a(s)} = \frac{K_T}{L_a.J_m s^2 + (R_a.J_m + L_a.B_m).s + (R_a.B_m + K_b.K_T)} \quad (9)$$

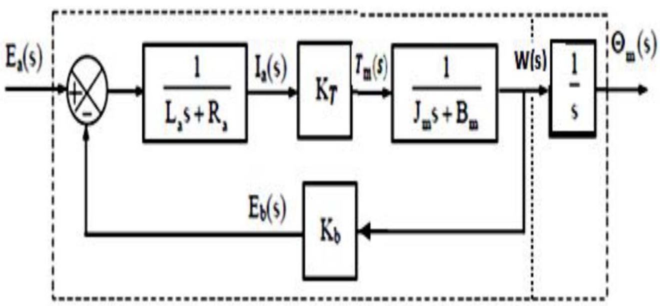

Fig.2 separately excited DC motor

❖ Specification of the separately excited DC motor

Separately excited DC motor with the below parameters were used in table.1. [7]

TABLE I
Parameters used in DC motor

Parameter	Its value
(armature resistance) R_a	11.2 Ω
(armature inductance)L_a	0.1215 H
(rotor inertia)J_m	0.02215 kgm
(viscous friction coefficient)B_m	0.002953Nms/rad
(torque constant)K_T	1.28 Nm/A
(back emf constant)K_b	1.28 Vs/rad

V.FUZZY INFERENCE SYSTEM

"Fuzzy Inference System (FIS) is the process of formulating the mapping from a given input to an output using fuzzy logic. Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision. There are two types of fuzzy inference systems that can be implemented Mamdani-type and Sugeno-type.

These two types of inference systems vary somewhat in the way outputs are determined. Mamdani-style inference requires finding the centroid of a two-dimensional shape by integrating across a continuously varying function.

Michio Sugeno suggested to use a single spike, a singleton, as the membership function of the rule consequent. A singleton, or more precisely a fuzzy singleton, is a fuzzy set with a membership function that is unity at a single particular point on the universe of discourse and zero everywhere else".[4]

"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." .[8]

- **Fuzzy 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 .
A block diagram for a fuzzy control system is given in Fig.3 . The fuzzy controller consists of the following four components:

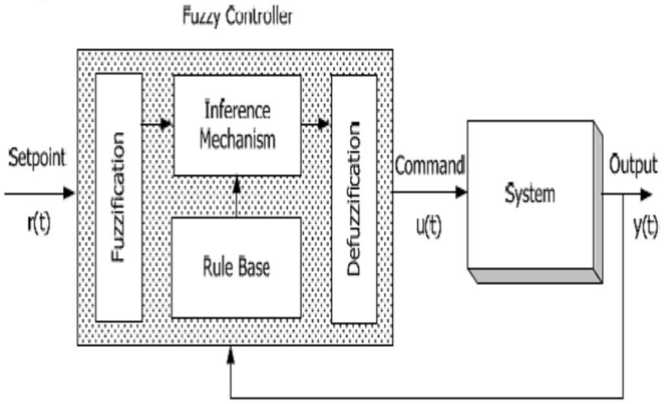

Fig.3 Structure of Fuzzy Logic controller

A. Fuzzification

The first step in designing a fuzzy controller is to decide which state variables represent the system dynamic performance must be taken as the input signal to the controller. Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting a numerical variable (real number or crisp variables) into a linguistic variable (fuzzy number) is called fuzzification. This is achieved with the different types of fuzzifiers. There are generally three types of fuzzifiers, which are used for the fuzzification process; they are

1) *Singleton fuzzifier.*
2) *Gaussian fuzzifier.*
3) *Trapezoidal or triangular fuzzifier.*

Here there are two inputs (speed error and change in the speed error) where the speed error has a range from -4.75 to 4.75 and the change in the speed error is from -1.65 to 1.65 which are shown in figures 4,5.The Gaussian fuzzifies has been used for the input and the triangular has been used for the output , the output is the control action which has a range from -7 to 7 which is shown in fig.6.

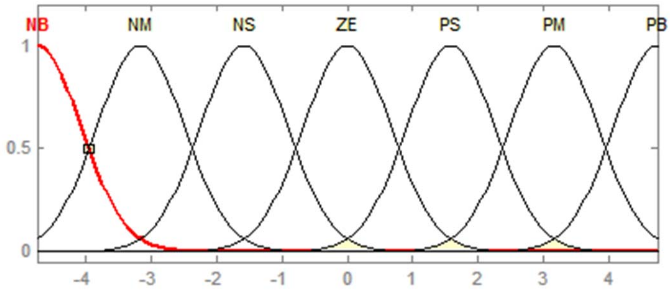

Fig.4 Speed error variable

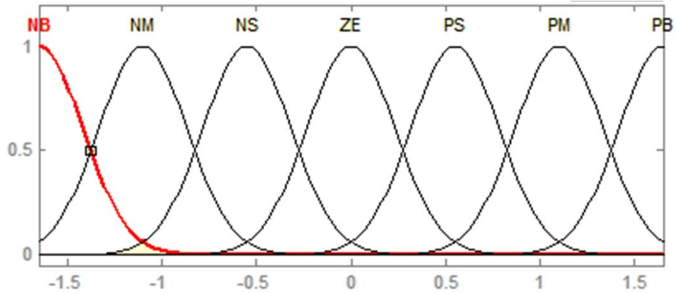

Fig.5 Change in speed error variable

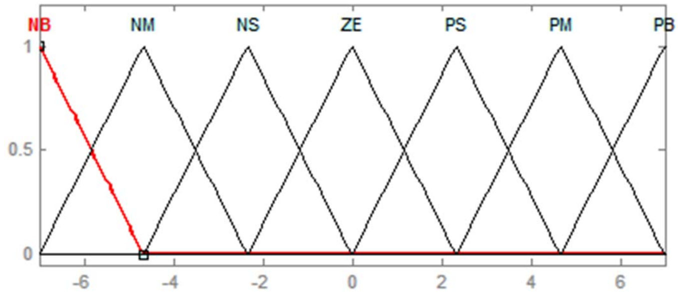

Fig.6 Output variable

B. Rule base

A decision making logic which is, simulating a human decision process, inters fuzzy control action from the knowledge of the control rules and linguistic variable definitions [9]. The rules are in the “If Then” format and formally the If side is called the conditions and the Then side is called the conclusion. The computer is able to execute the rules and compute a control signal depending on the measured inputs error (e) “difference between the output speed and the set point” and error variation as inputs to the fuzzy controller and control function as the output which it will be the armature voltage. In a rule based controller the control strategy is stored in a more or less natural language. A rule base controller is easy to understand and easy to maintain for a non- specialist end user and an equivalent controller could be implemented using conventional techniques[12]. The rules are illustrated in table.2 (7*7=49) .The linguistic variables that is used in the rules are :

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1) LN Large Negative

2) MN Medium Negative

3) SN Small Negative

4) ZE Zero

5) SP Small Positive

6) MP Medium Positive

7) LP Large Positive

TABLE II.
Rule base for separated excited DC motor speed control

E \ CE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

C. Inference engine

Inference engine is defined as the Software code which processes the rules, cases, objects or other type of knowledge and expertise based on the facts of a given situation. When there is a problem to be solved that involves logic rather than fencing skills, we take a series of inference steps that may include deduction, association, recognition, and decision making. An inference engine is an information processing system (such as a computer program) that systematically employs inference steps similar to that of a human brain. There are two popular methods(max-min and max-product), in this paper the max-min has been used.

D. Defuzzification

The reverse of Fuzzification is called Defuzzification. The use of Fuzzy Logic Controller (FLC) produces required output in a linguistic variable (fuzzy number). According to real world requirements, the linguistic variables have to be transformed to crisp output. There are many defuzzification methods but the most common method is as follows [10]:
Center of gravity (COG) :

For discrete sets COG is called center of gravity for singletons (COGS) where the crisp control value is the abscissa of the center of gravity of the fuzzy set is calculated as follows:

$$u_{COGS} = \frac{\sum_i \mu_c(x_i) x_i}{\sum_i \mu_c(x_i)}$$

Where xi is a point in the universe of the conclusion (i=1, 2, 3…) and μc (xi) is the membership value of the resulting conclusion set. For continuous sets summations are replaced by integrals.

- *Controller design*

Simulation is an inexpensive and safe way to experiment with the system model. However, the simulation results depend entirely on the quality of the system model. It is a powerful technique for solving a wide variety of problems.
The MATLAB will be used as a simulation tool. The figures (7,8) below show the separately excited DC motor at full load with PID and FLC . To control separately excited DC motor with fuzzy controller the parameters are tuned using trial and error. The parameter values are: Gain_1=20 , Gain_7 =10 , Gain_6=0.08 , Gain_4=10 , Gain_5=1.5

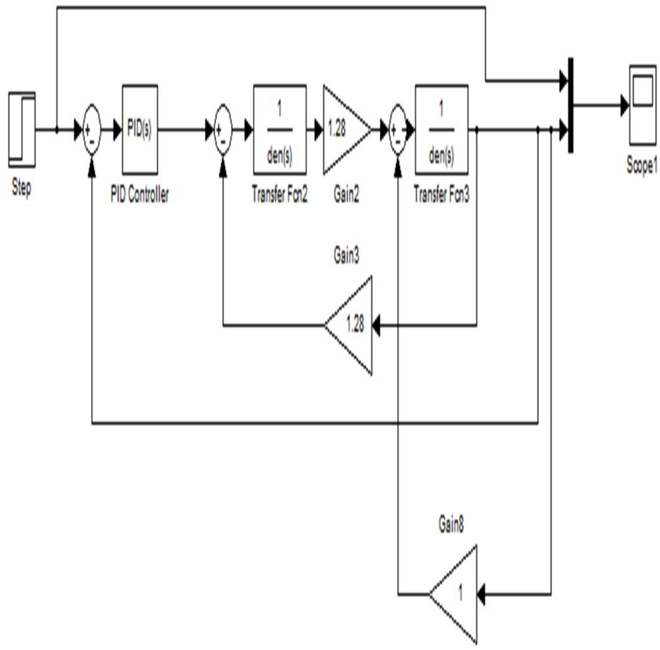

Fig.7 DC motor at full load with PID controller

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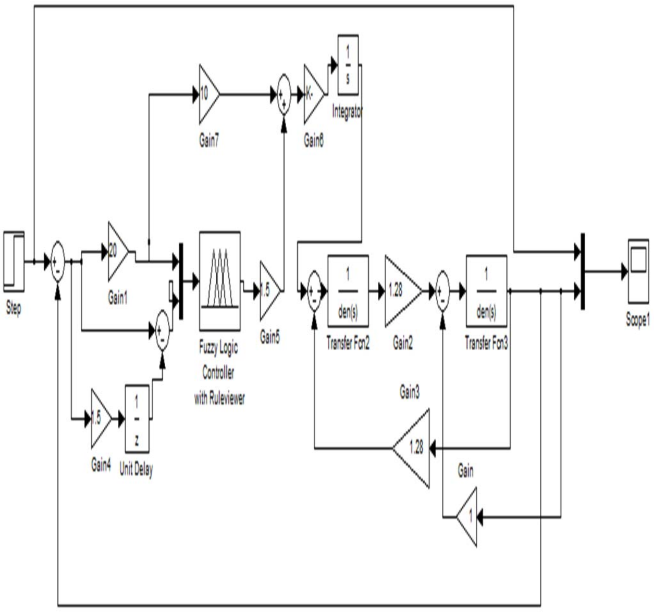

Fig.8 DC motor at full load with FLC

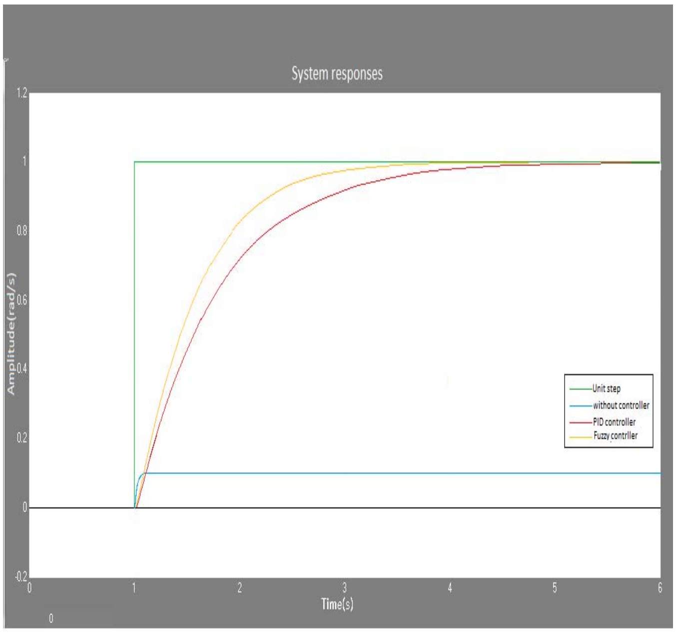

Fig.9 Unit step response of the system

VI.RESULTS AND DISCUSSION

To achieve the desired goal of this study which is the speed control of DC motor, DC motor system was converted into its equivalent mathematical model and applied control system to it through the MATLAB program. Fig.9 shows the comparison of system responses using PID, FLC and without controller , also table.3 shows the numerical comparison.

TABLE III.
Comparison results between PID and fuzzy controller

Controller / Time Characteristics	PID	Fuzzy controller
Rise time	0.8727	0.7600
Settling time	2.9782	2.6200
Overshoot	0.120000%	0.008264%
Peak time	1	2

VII.CONCLUSION

The PID controller and fuzzy controller for separately excited DC motor speed controller have been designed using MATLAB software. When applied PID controller and fuzzy controller , the system performance has been improved. It concluded that when compared fuzzy controller with the conventional PID controller, fuzzy controller has better

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performance in both transient and steady state response, it also has better dynamic response curve, shorter response time, small steady state error (SSE) and high precision compare to the conventional PID controller.

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