Comparison of Speed Control of DC Motor by Armature Control and Field Control with the Help of Fuzzy Logic Controller

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Abstract: **This paper presents a simulation of the speed control of a separately excited direct current motor (SEDM) using fuzzy logic control (FLC) in Matlab/Simulink environment. A fuzzy logic controller was designed to vary the motor's speed by varying the armature voltage of the separately excited DC motor in the constant torque region (below the rated speed). The simulation results show that the armature voltage control method is better than field control method with regards to delay time and overshoot.**

Keywords: **Speed, DC motor, Matlab, Fuzzy logic, Armature, Field.**

I. INTRODUCTION

Accurate control is critical to every process that leads to various types of controllers which are being widely used in process industries. Tuning methods for these controllers are very important for process industries. The aim of this paper is to design a fuzzy logic controller for speed control of a DC motor. Because of their high reliabilities, flexibilities and low costs, DC motors are widely used in industrial applications, robot manipulators and home appliances where speed and position control of motor are required.

All control systems suffer from problems related to undesirable overshoot, longer settling times and vibrations and stability while going from one state to another state. Real world systems are nonlinear, accurate modelling is difficult, costly and even impossible in most cases conventional PID controllers generally do not work well for non-linear systems. Therefore, more advanced control techniques need to be used which will minimize the noise effects. To overcome these difficulties, there are three basic approaches to intelligent control: knowledge based expert systems, fuzzy logic, and neural networks. All three approaches are interesting and very promising areas of research and development. In this paper, we present only the fuzzy logic approach. Fuzzy logic, proposed by Lotfi A. Zadeh in 1973. Zadeh introduced the concept of linguistic variable. The fuzzy logic, unlike conventional logic system, 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.

Fuzzy Logic has been successfully applied to a large number of control applications. The most commonly used controller is the PID controller, which requires a mathematical model of the system. A fuzzy logic controller provides an alternative to the PID controller. The control action in fuzzy logic controllers can be expressed with simple "if-then" rules. Fuzzy controllers are more sufficient than classical controllers because they can cover a much wider range of operating conditions than classical controllers and can operate with noise and disturbances of a different nature.

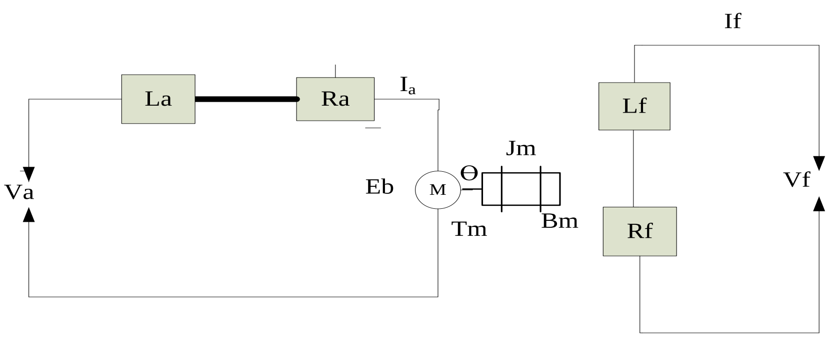

Fig.1. Separately excited DC motor

The armature voltage equation is given by:

$V_t = R_a I_a(t) + L_a \frac{dIa(t)}{dt} + E_b(t)$

$E_b(t) = K_b . w(t)$

Torque equations of DC machine are

$T_m(t) = Kt.i_a(t)$ ….(1)`

$T_m(t) = J_m \frac{dw(t)}{dt} + B_m . w(t) + T_L$ ….(2)

Since friction in motor is very small so B_m can be neglected

Therefore, new torque balance equation will be given by:

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

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

$$E_b = k\phi \quad …..(4)$$

$$T_m = k\phi I_a \quad …..(5)$$

$$I_a(s) = \frac{V_a - E_b}{R_a + L_a s} \quad ……(6)$$

Now, taking equation (6) into consideration, we have

$$I_a = \frac{V_a - K\phi w}{R_a(1 + L_a \frac{s}{R_a})} \quad …..(7)$$

And

$$w(s) = \frac{T_m - T_L}{Js} \quad …..(8)$$

$$= I_a = \frac{k\phi I_a - T_L}{J_m s} \quad …..(9)$$

$$T_a = \frac{L_a}{R_a}$$

After simplifying the above motor model, the overall transfer function will be

$$\frac{\theta(s)}{V_a(s)} = \frac{k\phi}{L_a J_m s^2 + R_a J_m s + k^2 \phi^2} \quad …..(10)$$

II. CONCEPT OF FUZZY LOGIC CONTROLLER (FLC)

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. Fuzzy logic, unlike the crispy logic in Boolean theory, deals with uncertain or imprecise situations. A variable in fuzzy logic has sets of values which are characterized by linguistic expressions, such as SMALL, MEDIUM, LARGE, etc.(Mendel, 1995). Figure 1 shows the internal structure of a fuzzy logic controller. Triangular membership distribution is used in the analysis and defuzzification is carried out by center of gravity method [Mendel, 1995]. Generally, the number of rules in a fuzzy logic controller depends on the number of input and output variables and the number of membership functions [Zadeh, 1996]. If all the premise terms are used in every rule and the rule is formed for each possible combination of premise elements, then the number of rules is defined as in equation

$$N_r = \pi_{i=1}^{n} N_i$$

Where, Nr is the total number of rules, n is the number of input variables and Ni is the number of membership functions on each universe of discourse, [Passino and Yurkovich, 1997].

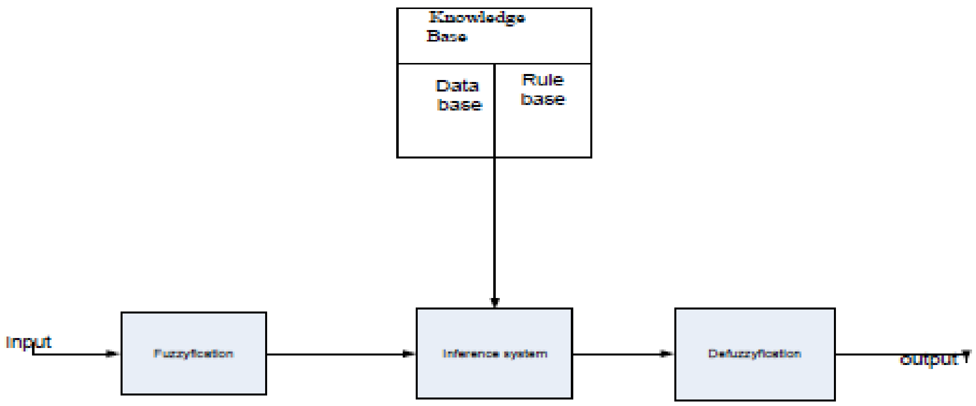

Fig.2. Fuzzy logic controller

Fuzzy logic model is a logical-mathematical procedure based on an “IF-THEN” rule system that mimics the human way if thinking in computational form.

Generally, a fuzzy rule system has four modules.

- Fuzzification
- Fuzzy Inference
- Rule base
- Defuzzification

Fuzzification

The process of converting a numerical variable (real number or crisp variables) into a linguistic variable (fuzzy number) is called Fuzzification. In others words, means the assigning of linguistic value, defined by relative small number of membership functions to variable

Fuzzy inference

Under inference, the truth value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule. Mostly MIN or PRODUCT is used as inference rules. In MIN inference, the output membership function is clipped off at a height corresponding to the rule premise's computed degree of truth (fuzzy logic AND). In PRODUCT inference, the output membership function is scaled by the rule premise's computed degree of truth *Rule base* for the rule bases a classic interpretation of Mandani was used. Under rule base, rules are constructed for outputs. The rules are in “If Then” format and formally the If side is called the conditions and the Then side is called the conclusion. 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.

Defuzzification

Defuzzification is a process in which crisp output is obtained by the fuzzy output. In other words, process of converting fuzzy output to crisp number. There is more Defuzzification methods in which two of the more common techniques are the CENTROID and MAXIMUM methods. In the CENTROID method, the crisp value of the output variable is computed by finding the variable value of the centre of gravity of the membership function for the fuzzy value. In the MAXIMUM method, one of the variable values at which the fuzzy subset has its maximum truth value is chosen as crisp value for the output variable

III. METHODOLOGY

In armature voltage control method, the field current, If is constant (and hence the flux density B is constant), and the armature voltage is varied. A constant field current is obtained by separately exciting the field from a fixed dc source. The flux is directly proportional to the field current. Thus, the torque is proportional only to the armature current. Figure 7 shows how the armature voltage control method was realized. The reference speed was set to a particular value and the output of the fuzzy logic controller is fed to the armature winding of the separately excited dc motor while the field winding are supplied with a constant rated DC source.

Realization of a Fuzzy Logic Controller based DC motor Speed Control

The inputs to the Fuzzy Logic Controller are speed error "e(t)" and change-in-speed error "Δe(t)". The inputs as shown in Figure 3 are described by equations 11 and 12

$e(t) = \omega r(t) - \omega a(t)$ 11

$\Delta e(t) = e(t) - e(t-1)$ 12

Where;

e(t) is the error signal

$(t-1)$ is the previous error signal

Δe(t) is the change in error signal

ωr(t) is the reference speed

ωa(t) is the actual speed

A Mamdani type FLC is used in this research with triangular membership functions. They are faster than many types of membership functions and can easily be embedded into a microcontroller. More number of fuzzy membership functions will lead to more rules and will require more computations in obtaining the defuzzification. Hence a set of five membership functions with twenty-five rules were chosen [Singh and Ahmed, 1996].

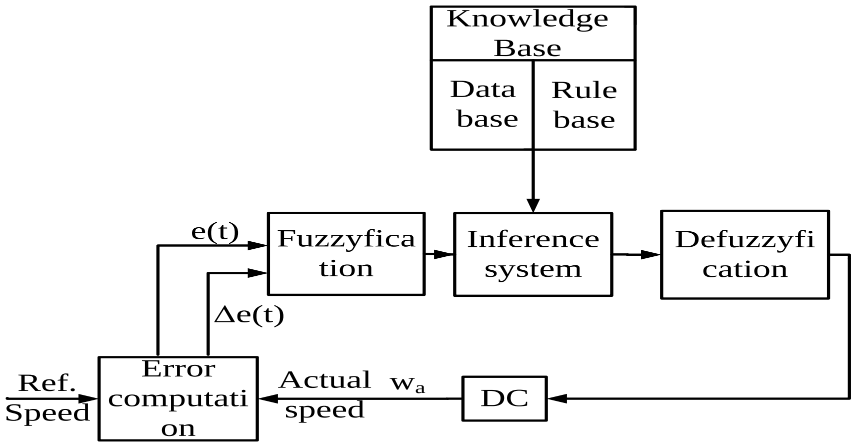

Fig.3. A Fuzzy Based DC Motor Speed Controller Design

Armature voltage control method FLC design

Here, the FLC designed has two inputs which are the speed error (e) and the change in the speed error (Δe). These two inputs are speed in revolutions per minute (rpm) and the output of the FLC is voltage (V). The range chosen for both the speed error and the change in speed error is 1600 rpm (just below the motor rated speed) so as to achieve armature voltage speed control method. Figure shows the Simulink model realization for armature voltage control method, where the output of the fuzzy logic controller is connected to the variable voltage source and then to the armature windings of the separately excited DC motor. The field windings are supplied with the rated field voltage of 300V. The outputs of the DC motor are the speed, armature current, armature voltage and the developed torque

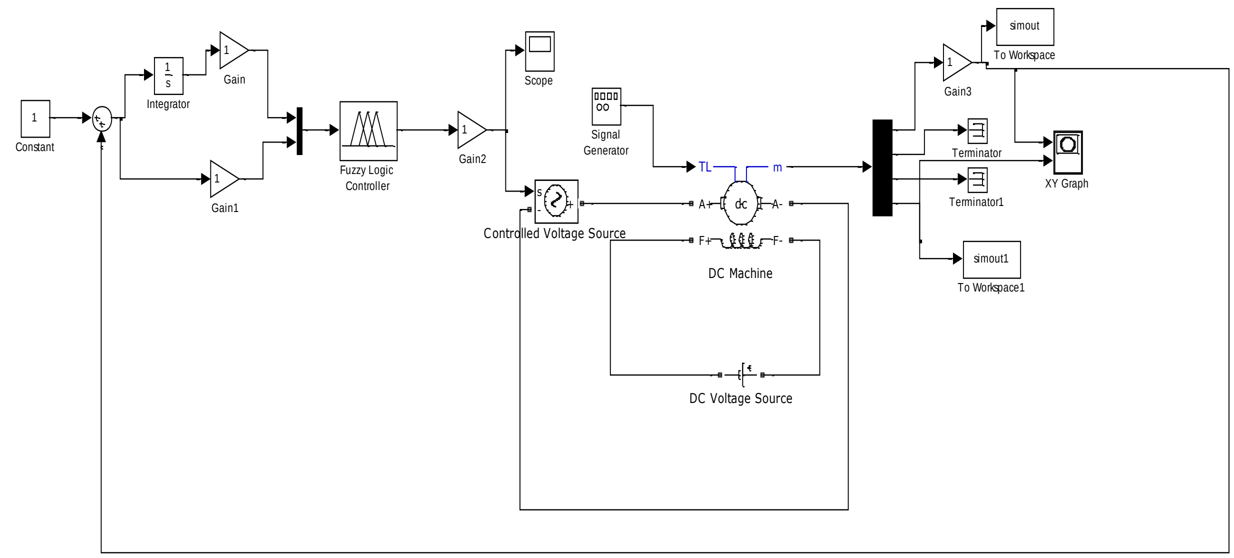

Fig.4. Simulink diagram

In armature voltage control method, the field current, If is constant (and hence the flux density B is constant), and the armature voltage is varied. A constant field current is obtained by separately exciting the field from a fixed dc source. The flux is directly proportional to the field current. Thus, the torque is proportional only to the armature current. Figure 7 shows how the armature voltage control method was realized. The reference speed was set to a particular value and the output of the fuzzy logic controller is fed to the armature winding of the separately excited dc motor while the field winding are supplied with a constant rated DC source.

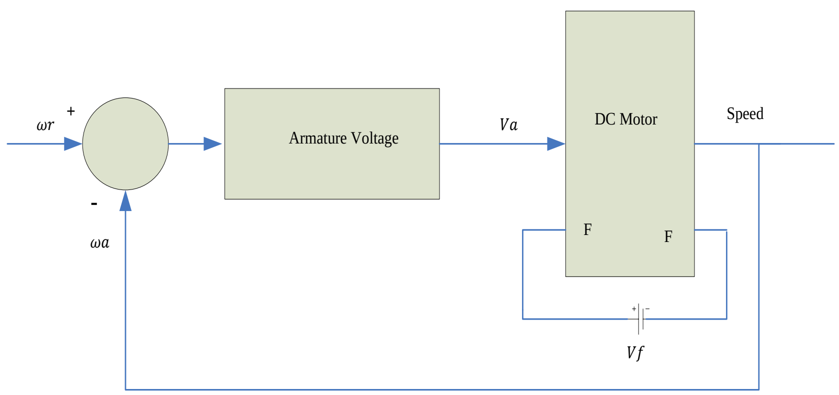

Fig.5.

Armature voltage control method FLC design

Here, the FLC designed has two inputs which are the speed error (e) and the change in the speed error (Δe). These two inputs are speed in revolutions per minute (rpm) and the output of the FLC is voltage (V). The range chosen for both the speed error and the change in speed error is 1600 rpm (just below the motor rated speed) so as to achieve armature voltage speed control method.

Figure 4 shows the Simulink model realization for armature voltage control method, where the output of the fuzzy logic controller is connected to the variable voltage source and then to the armature windings of the separately excited DC motor. The field windings are supplied with the rated field voltage of 300V. The outputs of the DC motor are the speed, armature current, armature voltage and the developed torque.

IV. RESULTS AND DISCUSSION

Results of simulations done at various speed references are hereby presented. The reference speed levels of the SEDM chosen are as follows;

- 1000 rpm and 1200 rpm were chosen as reference speed below the rated speed. This is because DC motors are usually operated at speed below their rated speed.
- 1750 rpm which is the rated speed of the motor

The speed of the SEDM was varied and maintained at 1000rpm using armature voltage control method. Figures 5 show the SEDM transient responses at 1000rpm as reference speed. It settles after 0.150 seconds and has an overshoot of 4.1%. The reference speed was then increased to 1200rpm as shown figure 6. In this case, it settles faster than at 1000rpm after 0.160 seconds with a small overshoot of 0.8%. It can be seen that as the speed of the motor is increased the overshoot decreases, this shows the effectiveness of the fuzzy logic controller [Nagrath and Gopal, 2009). Other transient response characteristics are summarized in Table 1. It can be seen from Table 1 that the armature voltage control method has less settling time at 1000rpm but with a higher overshoot. The reverse is the case for 1200rpm.

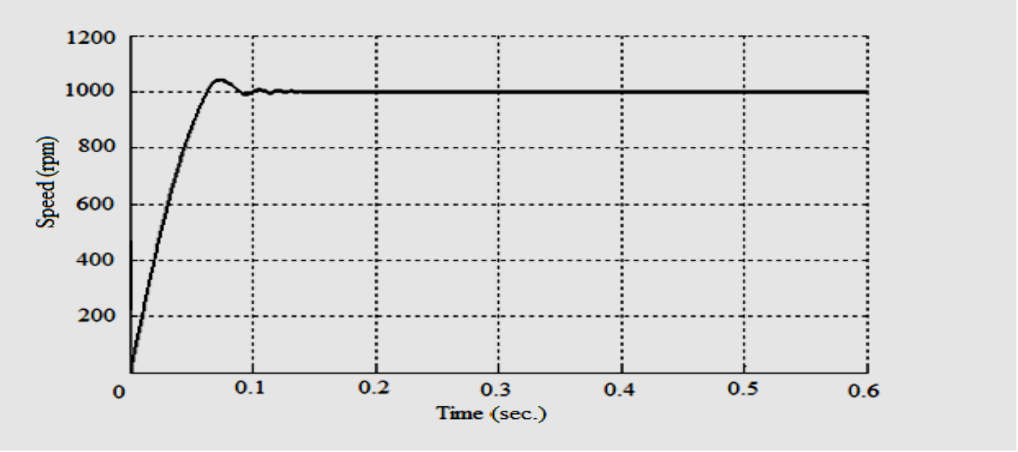

Fig.6. Armature Voltage Control Method (1000 rpm)

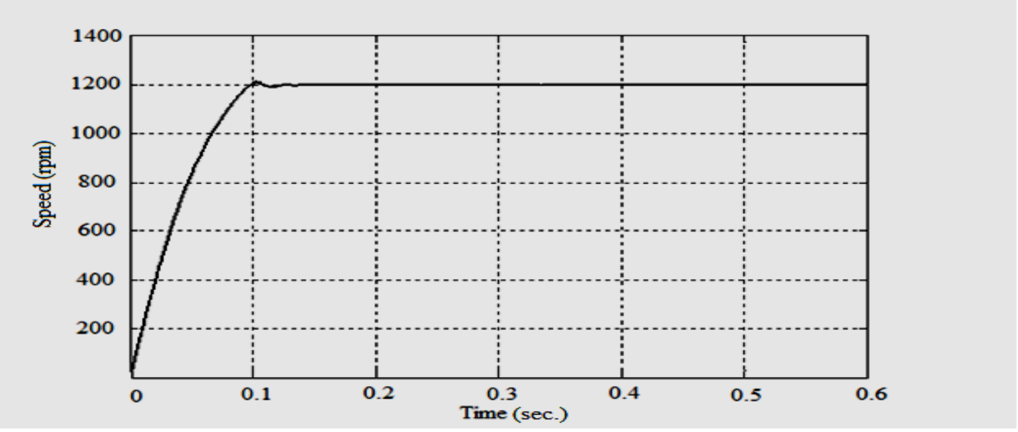

Fig.7. Armature Voltage Control Method (1200 rpm)

Table 1

Armature Voltage Control Method	**Delay Time, Td (sec.)**	**Rise Time, Tr (sec.)**	**Peak Time, Tp (sec.)**	**Settling Time,Ts (sec.)**	**Overshoot, Mp (%)**
1000rpm	0.025	0.052	0.073	0.150	4.1
1200rpm	0.032	0.072	0.103	0.160	0.8

The reference speed was then increased to the rated speed of the motor, which is 1750rpm. At this reference speed armature voltage control method and field control method were used to compare the transient characteristics of the motor. Results obtained are presented in figure 7 and 8. It can be seen from figure 7 that the speed settles after 0.156 seconds with an overshoot of 0.6% using armature voltage control method whereas figure 8 shows that using field control method which settles after 0.128 seconds with an overshoot of 10.1%. See table 2 for other transient characteristics. It can be seen from table 2 that the field control method settles faster than the armature voltage control method but with a higher overshoot. The separately excited DC motor used in the course of this research work has the following parameters as shown in Table2.

Table 2

Control method	**Delay Time, Td (sec.)**	**Rise Time, Tr (sec.)**	**Peak Time, Tp (sec.)**	**Settling Time,Ts (sec.)**	**Overshoot, Mp (%)**
Armature control	0.033	0.077	0.101	0.156	0.6
Field control	0.08	0.017	0.027	0.128	10.1

V. CONCLUSION

The speed of a separately excited DC motor has been efficiently controlled using the armature voltage control method. Independent armature voltage control method and the field current control method have been achieved in controlling the speed of the SEDM. Effective fuzzy logic controllers were designed and built for the armature and field control methods. In view of the above, it can be concluded that the aim and objective of the research have been achieved. The speed of SEDM has been successfully controlled by using Fuzzy logic controller technique in Matlab/Simulink. Triangular membership functions were used due to their computational efficiency and simplicity. The concept of FLC has simplified the control technique by making it robust, cheap and can easily be embedded into a microcontroller. Unlike using conventional and other types of controllers that require the linearized model of the DC motor, fuzzy logic controller can be designed using linguistic rules without knowing the exact mathematical model of the motor.

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