A Fuzzy-Based Speed Control of DC Motor Using Combined Armature Voltage and Field Current

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A Fuzzy-Based Speed Control of DC Motor Using Combined Armature Voltage and Field Current

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Abstract: A direct current (DC) motor is supposed to be operated at an accurate and constant speed even if the load on the system is increased or decreased. This paper had controlled the DC motor's speed based on the fuzzy logic methods and simulated the fuzzy rules in Matlab/Simulink environment. Fuzzy Logic Controllers were proposed to achieve the speed control of a DC motor using combined armature voltage and field current by varying the armature voltage in the constant torque region and the field current in the constant power region. The fuzzy logic controllers were designed to be dependent on one another in such a way that the same set of rules were fired at the same time for the two controllers, having the same antecedences but different consequences. Simulation results show the effectiveness of the proposed method.

Keywords**:** Speed, Armature, Field, Combined, Fuzzy Logic Controller, DC motor.

1. INTRODUCTION

The development and applications of power electronics in industry has directly increased the use of direct current (DC) machine. Nowadays, their uses is not limited to the car application (electrics vehicle), but also find applications in weak power using battery system (motor of toy) and for the electric traction in the multi-machine systems. The speed of DC motor can be adjusted or controlled easily to a great extend to provide easy controllability and high performance (Acharya and Agarwala, 2000).

There are three methods of controlling the speed of the shunt and separately excited dc motor, armature voltage speed control, field flux speed control and armature resistance speed control. In this work, armature voltage and field flux control methods were applied independently and finally combined together on a single separately excited DC motor. Different controllers can be used to control the speed of a DC motor, such as PID Controller, Fuzzy Logic Controller; or the combination between them; Fuzzy-Genetic Algorithm, Fuzzy-Neural Networks, Fuzzy-Ants Colony and Fuzzy-Swarm (Prahlad and Nirmal, 2011).

The aim of this work is to control the speed of a separately excited DC motor using combined armature voltage and field current control method with the following objectives:

- To control the speed of a separately excited DC motor using the independent armature voltage and field control methods.
- To design and build an effective Fuzzy logic controller for the DC motor speed control over a wider range (0–2000 rpm)

Many authors have done so much work on DC motor speed control using different types of approaches depending on the application of the motor or purpose of the speed control technique. Some researchers used the convention control methods like the use of proportional-integral-derivative (PID) controller, proportional- integral (PI) controller or non-linear auto-regressive moving average (NARMA) controller (George, 2008). Others used the concept of fuzzy logic technique or the combination of fuzzy and artificial neural network (Neuro-Fuzzy), (Nagendra, 2001).

This work focuses on the combined control method, that is, armature voltage control method and field current control method at the same time on a single separately excited DC motor, using the concept of fuzzy logic technique. Separate fuzzy logic controllers were designed for the armature windings and the field excitation in Matlab/Simulink environment. The speed of the SEDM was successfully controlled from below the rated speed of the motor (1000rpm and 1200rpm), at the motor's rated speed (1750rpm) and above the rated speed (2000rpm). Results obtained for the combined control method were compared to that of the individual armature voltage and field current control method. Simulation results at 1000rpm and 1200rpm reference speed show that the combined control method has faster response than the other two methods with 0.121 seconds and 0.140seconds respectively, while the field control method have the highest overshoot of 17.8% and 6.5% respectively. At the rated speed of 1750rpm and above the rated speed of 2000rpm, field control method settles faster than the combined control with 0.128seconds and 0.116seconds respectively, but the combined control method is better with regards to the overshoot (0.6% and 0.4% respectively).

According to the literature reviewed, most authors controlled the speed of a DC motor using armature voltage control method and used the motor's rated speed as their reference speed. They used the concept of PI or PID controllers, NARMA controllers and fuzzy logic controllers or the combination of any two (El-Kholy, 2007). In this research different reference speeds were chosen, armature voltage and field current methods were carried out separately and finally combined.

2. CONCEPT OF FUZZY LOGIC CONTROLLER

Fuzzy logic control (FLC) 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 set of values which are characterized by linguistic expressions, such as SMALL, MEDIUM, LARGE, etc (Zadeh, 1996). These linguistic expressions are represented numerically by fuzzy sets (sometimes referred to as fuzzy subsets). Every fuzzy set is characterized by a membership function, which varies from 0 to 1 (unlike 0 and 1 of a Boolean set). A fuzzy set has a distinct feature of allowing partial membership. In fact, a given element can be a member of a fuzzy set, with degree of membership varying from 0 (non-member) to 1 (full member), in contrast to a "crisp" or conventional set, where an element can either be or not be part of the set. Although fuzzy theory deals with imprecise information, it is based on sound quantitative mathematical theory (Seda, 2004).

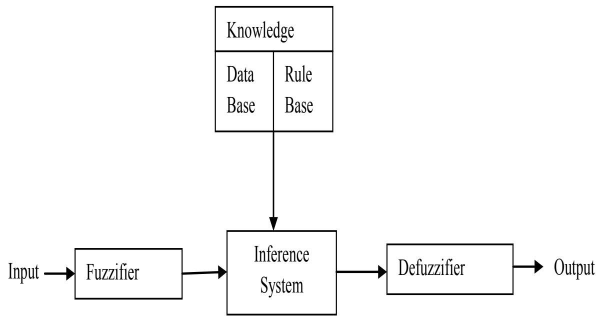

Figure 1: Structure of Fuzzy Logic Controller

The internal structure of the fuzzy logic speed controller comprises three functional blocks namely – the fuzzifier, the inference engine and the defuzzifier (Mendel, 1995). This is as shown in Figure 1. The fuzzifier converts crisp data into linguistic format. The decision maker decides in linguistic format with the help of logical linguistic rules supplied by the rule base and relevant data supplied by the data base. The output of the decision maker passes through the Defuzzifier wherein the linguistic format signal is converted back into the numeric form or crisp form. The inputs are categorized as various linguistics variables with their corresponding membership values. 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. 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 (1) (Hussain, 2001).

$$N_r = \prod_{i=1}^{n} Ni \quad (1)$$

Where, N_r is the total number of rules, n is the number of input variables and N_i is the number of membership functions on each universe of discourse, (Passino and Yurkovich, 1997).
In centre of gravity (COG) method, the output value is computed using the relation (Passino and Yurkovich, 1997).

$$u = \frac{\sum_i b_i A_i}{\sum_i A_i} \quad (2)$$

Where, $A_i = \int u_i$ is the area under the membership function u_i and b_i is the centre of membership function of the consequent i^{th} rule.

3. METHODOLOGY

3.1 Introduction

The speed of a separately excited DC motor (SEDM) can be controlled, either by varying the voltage applied to the field winding or by varying the voltage applied to the armature (Astha and Dubey, 2011). This is given by equation 3.

$$\omega = (V_a - I_a R_a)/K\varphi \quad (3)$$

Where V_a is the armature voltage, I_a is the armature current, R_a is the armature resistance, K is the armature constant and $\varphi$is the field flux.

Speed of the motor can be controlled by varying V_a and holding V_f constant at its rated value. Then as the voltage applied to the armature is increased, the armature current increases first. As the armature current increases, the torque developed by the motor increases and hence speeds of the motor increases. According to Ansu and Deep (2008), the drop across the armature resistance tends to be small and hence the motor speed rises almost proportionately with the voltage applied to the armature. But there is a limit to the voltage that can be applied to the armature and that limit is the rated armature voltage.

The speed of the motor corresponding to the rated armature voltage and the rated field voltage is its rated speed. Thus the speed of the motor was varied below its rated speed by controlling the armature voltage. It would be desirable that the motor should be able to develop as high as a torque as possible and hence the rated voltage applied to the field is held at its rated value. Therefore, the speed of SEDM was varied at three different levels, using the armature voltage control method (AVCM), field current control method (FCCM) and the combined armature voltage and field current control method (CAFCM):

- Below the motor's rated speed

- At the rated speed
- Above the rated speed

Speed below the rated speed was achieved using armature voltage control method by varying the armature voltage in the constant torque region, whereas speed above the rated speed was achieved using the field current control method by varying the field voltage in the constant power region and the combined control method was used to achieve both.

3.2 Combined Armature and Field Control of SEDM

The speed of a separately excited dc motor can be varied from zero to rated speed mainly by varying armature voltage in the constant torque region. Whereas in the constant power region, field flux should be reduced to achieve speed above the rated speed (Mustapha, 2005)

Figure 2 shows how the two fuzzy logic controllers are connected to the armature and field windings of the DC motor. Unlike in the individual armature voltage control and the field current control methods, in the combined armature voltage and field current control method the armature voltage, V_a and the field voltage V_f are varied simultaneously.

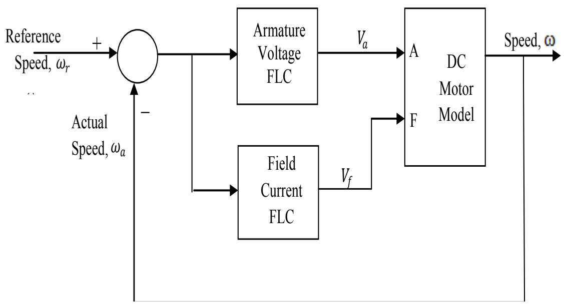

Figure 2: Combined Armature and Field Control of SEDM

3.3 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 are described by equations 4 and 5.

$$e(t) = \omega_r(t) - \omega_a(t) \tag{4}$$

$$\Delta e(t) = e(t) - e(t-1) \tag{5}$$

where; e(t) is the error signal, e(t-1) is the previous error signal, Δe(t) is the change in error signal, $\omega_r(t)$ is the reference speed, and $\omega_a(t)$ is the actual speed.

A Mamdani type FLC was used in this work 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).

3.4 Realization of Combined FLC

In the combined control method, two separate fuzzy logic controllers were designed for the armature voltage control and the field current control. The two controllers have similar characteristics to that of the individual armature/field controllers. Speed below and above the rated speed were maintained at different levels.

The combined control method is implemented as shown in Figure 3. Two separate fuzzy logic controllers were connected to the armature and field circuits respectively. The actual speed of the motor is then fed back to the input. The difference between the reference speed and the actual speed gives the error signal and the rate of change in error signal, which are the two inputs to the fuzzy logic controller. The motor output comprises the speed, armature current, field current and the developed torque were analyzed in Matlab.

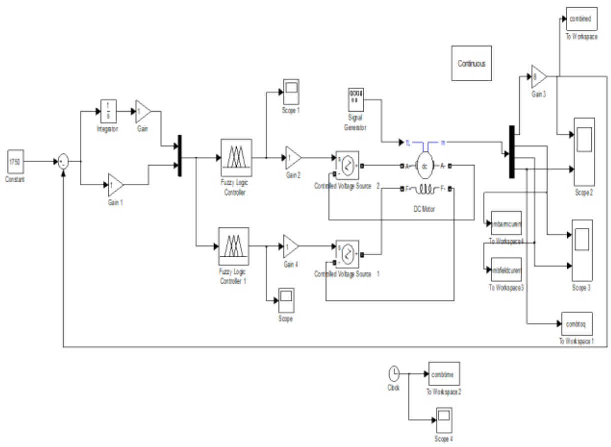

Figure 3: Simulink model for combined control method

Table 1 shows the corresponding rule base for the speed controller. The top row and left column of the matrix indicate the fuzzy sets of the variable Δe and e respectively and the membership function of the body of the matrix (Mohammed, 2008).
There are 5 × 5 = 25 possible rules in the matrix, where a typical rule reads as:
If e = PS and Δe = NS then output is = ZERO

Table1: Fuzzy logic controller rule base

Δe

e	NL	NS	ZERO	PS	PL
PL	PL	PL	ZERO	NL	NL
PS	PS	ZERO	NS	NL	NL
ZERO	PL	PS	ZERO	NS	NL
NS	PL	PL	PS	ZERO	NS
NL	PL	PL	PL	PS	PL

4. RESULTS AND DISCUSSION

Results of simulations done at various speed references are hereby presented. The simulations were done at 0.6 second time intervals to enable the transient regions to be properly captured. Matlab/Simulink software was used to run the simulation models for the three different methods of speed control used in the course of this research. These include; Armature Voltage Control method (AVCM), Field Current Control Method (FCCM) and the Combined Armature and Field Control Method (CAFCM) Fuzzy logic controllers were designed for each of the three different approaches, which controlled the motor's speed to the desired or reference speed.

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
- 2000 rpm was chosen because running the motor above its rated speed affects the performance of the motor and may even damage the motor.

The separately excited DC motor used in this work has the following parameters as shown in Table 2.

Table 2: Separately excited DC motor parameters

Parameter (Unit)	Value
Rated power (hp)	5
Armature resistance, R_a (Ω)	2.581
Armature inductance, L_a (H)	0.0281
Armature voltage, V_a (V)	240
Field resistance, R_f (Ω)	281.3
Field inductance, L_f (H)	156
Field voltage, V_f (V)	300
Mechanical inertia, J_m (kg.m^2)	0.0221
Friction coefficient, B_m (N.m.s)	0.002953
Back emf constant, K_v (V/rad/sec)	1.25
Motor torque constant, K_m (N.m/A)	0.516
Rated speed, ω_r (rpm)	1750

Source: (www.directindustry.com, 2011)

Figures 4 to 7 shows the various speed responses of the motor obtained at different desired reference speed values. Figure 4 shows the transient response of the motor at 1000rpm reference speed using the three methods. It can be seen that the combined control method has small settling time (0.12seconds) and minimum overshoot (3.6%) compared to the armature and field control methods. This shows that the combined control method has faster response than the other two methods. The transient response of the motor at 1200rpm reference speed is shown in Figure 5. Field control method still exhibits high overshoot of 6.5% but has the least delay, peak and rise time.

Combined control method in this case has the fastest settling time and minimum overshoot of 0.8%. This shows a slight advantage of the combined control method over the two other methods.

The rated speed of the SEDM is 1750 rpm. This is the speed which corresponds to the rated armature voltage V_a, rated armature current I_a and rated field current I_f. Field control method and the combined control method were used to maintain the speed of the motor at the rated speed and above the rated speed. Armature voltage control is used to achieve speed below the rated speed that is why it is not being considered in this case. Field control and the combined control methods were used to achieve speed at the rated speed and above the rated speed. Figure 6 show the responses of the dc motor maintained at its rated speed of 1750 rpm. As it can be seen from the responses of the motor at rated speed, field control method has higher overshoot than the combined control method but settles faster than the combined control method.

The speed of the SEDM was then increased to 2000 rpm, slightly above the rated speed so as not to overrun the motor. Field control and the combined control methods were used to achieve this by keeping the armature terminal voltage at its rated value and decreasing field current in the constant power region. Figure 7 show the transient responses of the motor obtained at 2000 rpm reference speed. Figure 7 show the transient response of the motor at 2000 rpm as the reference speed using field control method and the combined control method. It can be seen that the field control method has the better response with faster settling time, delay time, rise time and smaller peak time. The combined control method has little of 0.4% as compared to 2.4% of the field control method.

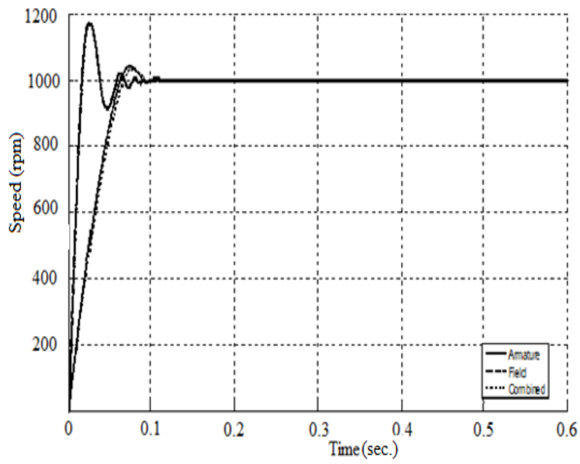

Figure 4: 1000rpm reference speed response

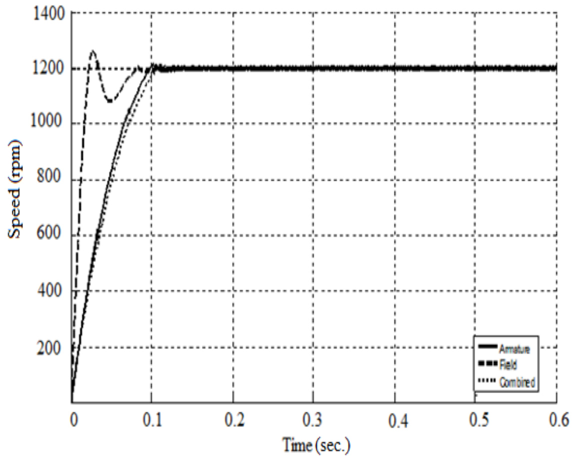

Figure 5: 1200rpm reference speed response

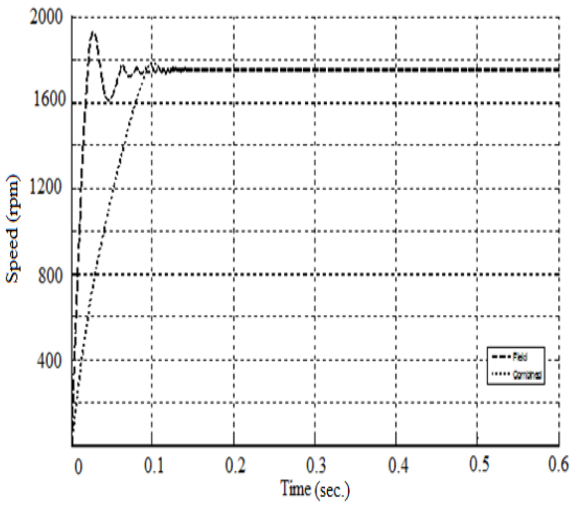

Figure 6: 1750rpm reference speed response

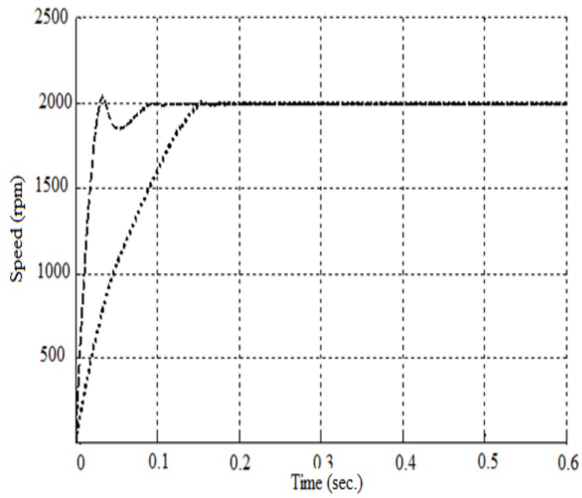

Figure 7: 2000rpm reference speed response

4.2 Summary

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 simulation results clearly revealed that although the armature voltage control and the field current control methods were equally accurate and acceptable, only the combined armature voltage and field current control method is capable of an accurate description of the combined effects of the armature and field excitation to the motor. The advantage of the combined armature voltage and field current control method is that wide range of speed control has been achieved from below the rated speed to above the motor's rated speed. The performances of the CAFCM have been compared to that of the independent AVCM and the FCCM. From the results obtained, it can be seen that the armature voltage control method (AVCM) is closer to the combined armature and field control method (CAFCM) with respect to the delay time T_d, rise time T_r and settling time T_s. Field current control method (FCCM) has the highest overshoot in all cases and for different reference speed values.

These observations clearly show the ability of the fuzzy logic controller in appropriately selecting the desired output (voltage) to maintain the motor speed at a constant reference value. Application of the proposed FLC will reduce the time of implementation.

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