INTELLIGENT CONTROL OF DC MOTOR USING FUZZY LOGIC TECHNIQUE

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ABSTRACT

In this case, fuzzy logic is implemented in a standard microcontroller to regulate the speed of a universal motor by a real time adjustment (every 30 millisecond) of the motor current. This microcontroller directly tunes the motor current by means of a chopper converter. Starting from a basic food-processor application, the paper practically shows how a fuzzy logic approach can be applied to build a closed speed regulation loop from a very low cost tacho-generator. Practical guidelines are successively given from the initial concept analysis phase, up to the final generation of the executable code to be loaded in the microcontroller. The paper also gives the practical procedure to define the input parameters and to build fuzzy logic rules when using the fuzzy logic development tool. Finally, the major benefits of this paper lie in an original approach where fuzzy logic is applied to fast "real-time" regulation loop without requiring any specific expertise in conventional methods of regulation.

1.   INTRODUCTION:

DC motor presents an exciting field of research and is used in many industrial and household applications. DC motors used in many applications such as still rolling mills, electric trains, electric vehicles, electric cranes and robotic manipulators require speed controllers to perform their tasks. The speed of the DC motor varies with the variations in the power supply. Thus the speed control of motor is important to achieve maximum torque and efficiency.

2. MOTOR MODEL

The resistance of the field winding and its inductance of the motor used in this study are represented by Rf and Lf, respectively. The resistance of the armature and its inductance are shown by **Ra,** and La respectively in dynamic model. Armature reactions effects are ignored in the description of the motor. This negligence is justifiable to minimize the effects of armature reaction since the motor used has either inter poles or compensating winding. The fixed voltage **V,** 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 as determined in the following equations:

$$J_m \frac{d\omega_m}{dt} = K_m \cdot \phi \cdot I_a - b \cdot \omega_m - M_{load} \qquad (1)$$

$$L_a \frac{dI_a}{dt} = V_u - R_a \cdot I_a - K_b \cdot \phi \cdot \omega_m \qquad (2)$$

The dynamic model of the system is formed using these differential equations and Matlab Simulink blocks given below:
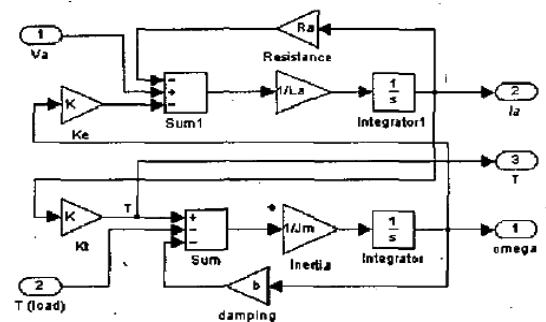

Fig 13:- Matlab Simulink blocks

The various parameters of a DC motor are defined in the table as follows:

Table 1: Parameters of DC Motor

Parameter	Symbol	Value
Field F	Rf	60 Ω
Field Inductance	Lf	80 H
Reference Voltage	Vref	120 V
Amplifier Gain	Ka	2 V/V
Torque Constant	KT	10 Nm/A
Tachometer Constant	Kt	0.1 Vs/rad

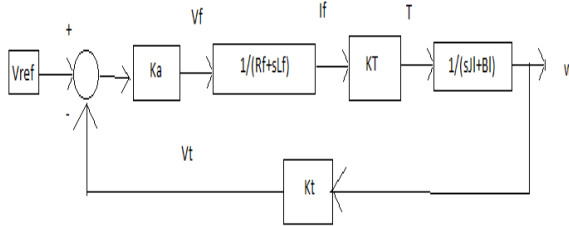| Moment of Inertia of Load	Jl	0.8 kgm²
Friction coefficient of Load	Bl	0.6 Nm/rad/s

The block diagram of a DC motor can be modeled as follows:

Fig 14: Block Diagram of a DC Motor

The equations of the DC motor can be derived from the block diagram as follows [4]:

$$E = V\,ref - Vt$$
$$V_f = Ka*E$$
$$If = V_f / R_f + sLf)$$
$$T = KT*If$$
$$\omega = T/(sJl+Bf)$$
$$Vt = \omega*Kt$$

Based on the values chosen, the measured values of field current, I_f ref and angular speed, ω ref were found to be 3.7895 A and 63.158 rad/s.

2.3 MOTOR MODEL IN SIMULINK

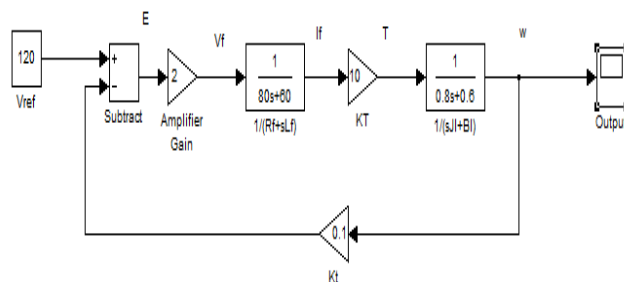The motor model described in the previous section that was implemented in SIMULINK is shown below:

Fig 15: Motor Model in SIMULINK

When the above model is simulated the following graphs are obtained which show clearly that the I_f ref is 3.7895 A (Figure 16) and ω ref is 63.158 rad/s (Figure 17).
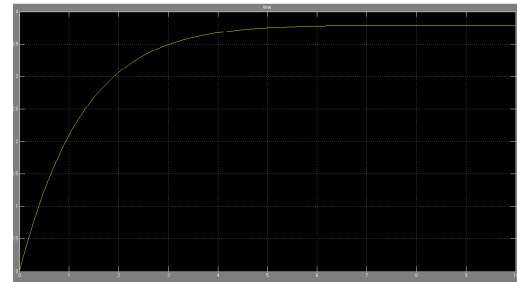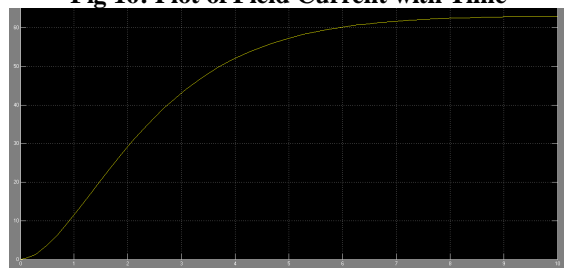

Fig 16: Plot of Field Current with Time

Fig 17: Plot of angular velocity with Time

2.7 FUZZY LOGIC CONTROLLER (FLC) DESCRIPTION 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**.** An expert operator develops flexible control mechanism using words like "suitable, not very suitable, high, little high, much and far too much that are frequently used words in people's life. Fuzzy logic control is constructed on these logical relationships. Fuzzy sets are used to show linguistic variables. There is a strong relationship between fuzzy logic and fuzzy set theory that is similar relationship between Boolean logic and classic set theory. Fig. shows a basic FLC structure.
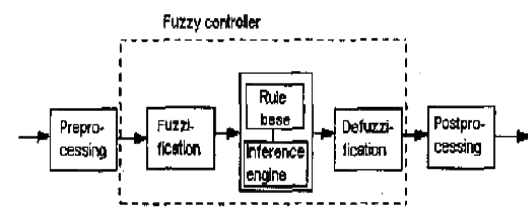

Fig 18:-Block level diagram of a Fuzzy Controller

ii

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. In addition to this, if there is not enough knowledge about control

process, FLC may not give satisfactory results.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 (e) and change of error (ce) for linguistic variables which are generated from the control rules. Equation (3) determines required system equations. The output variable is the change in control variable (cu) of motor driver. cu is integrated to achieve desired alpha value. Here a is a angular value determining duty cycle of DC-DC converter designed in this paper.

$$e(k) = \left[w_r(k) - w_a(k) \right] \times K1_E$$
$$ce(k) = \left[e(k) - e(k-1) \right] \times K2_{CE}$$
$$c\alpha(k) = \left[\alpha(k) - \alpha(k-1) \right] \times K3_{C\alpha}$$

(3)

Here **K1E, K2CE** and **K3Cα** are each gaincoefficients and k is a time index.
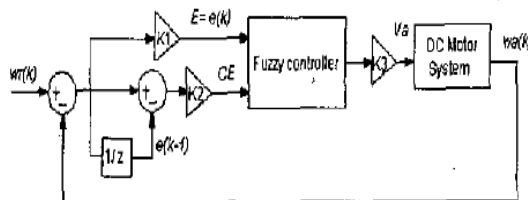

Fig 19:- Block diagram of the DC motor control
2.8 MOTOR MODEL WITH FUZZY CONTROLLER
The model presented thus far is a very ideal case. In the real world situation, due to variations in the power supply voltages and other disturbances, there may be random variations in the angular speed which may affect the performance of DC motor. So a controller is required which would track these changes in angular speed. The following diagram shows the basic mechanism of a fuzzy controller [5].
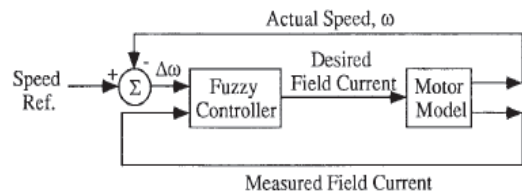

Fig 20: Basic Simulation Model
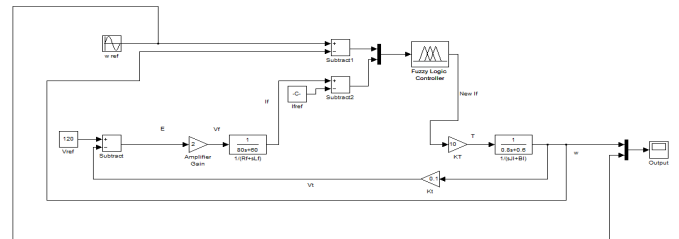The following model using Fuzzy Controller was implemented in SIMULINK.

Fig 21:- Motor Model with Fuzzy Controller in SIMULINK

2.9 Inputs & Outputs of Fuzzy Logic Controller
A lot of research work has been done using different models to control the speed of DC Motor. These models use suitable input combinations based on their models[6]. There are two inputs given to the Fuzzy Logic Controller in our model. These are the change in angular velocity (defined as Error) and the change in the field current (defined as FieldCurrentError). The output of the Fuzzy Logic Controller is new value of field current based on the fuzzy rule base (defined as NewFieldCurrent).
Our model is designed for particular ranges of inputs where it gives best possible results. The input variable Error lies in the range [-35, 35] while the variable FieldCurrentError lies in the range [-3.5, 3.5]. The output NewFieldCurrent lies in the range [0.2895, 7.2895]. The window where the variables are specified is shown below.
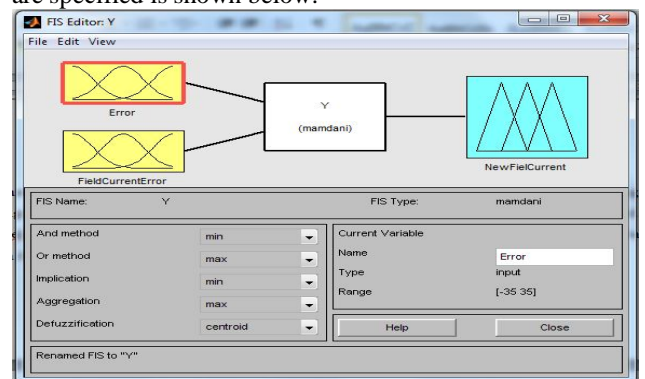

Fig 22: Defining Input & Output Variables

iii

2.10 Defining Membership Functions

The range of input and output variables was fuzzified using membership functions. The following tables show the association of the linguistic variables used for the various ranges of the Input and the output.

Table 2: Fuzzy Variable Associations & Numerical Ranges

Fuzzy Variable 1: Error		
Fuzzy Association	Variable	Range
LN	Large Negative	[-52.5, -17.5]
MN	Medium Negative	[-26.25,-8.75]
SN	Small Negative	[-17.5 ,0]
Z	Zero	[-8.75,8.75]
SP	Small Positive	[0 ,17.5]
MP	Medium Positive	[8.75 ,26.25]
LP	Large Positive	[17.5 ,52.5]

Fuzzy Variable 2: Field Current Error		
Fuzzy Association	Variable	Range
LN	Large Negative	[-5.25, -1.75]
MN	Medium Negative	[-2.625,-.875]
SN	Small Negative	[-1.75 ,0]
Z	Zero	[-.875,.875]
SP	Small Positive	[0 ,1.75]
MP	Medium Positive	[.875 ,2.625]
LP	Large Positive	[1.75 ,5.25]

Fuzzy Variable 3 : New Field Current		
Fuzzy Association	Variable	Range
FBN	Far Below Normal	[-1.443 , 2.072]
BN	Below Normal	[1.157 ,2.919]
JBN	Just Below Normal	[2.053 ,3.789]
N	Normal	[2.938 ,4.679]
JAN	Just Above Normal	[3.789 ,5.526]
AN	Above Normal	[4.66 ,6.42]
FAN	Far Above Normal	[5.526 ,9.041]

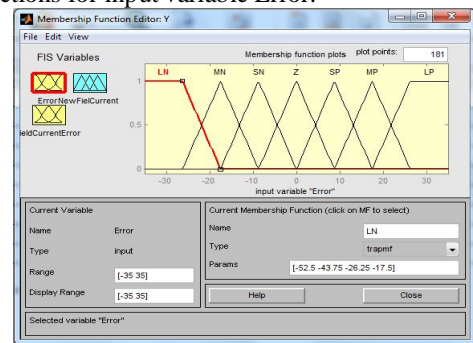The following figure shows the membership functions for input variable Error.

Fig 23: Defining Membership Functions

2.11 Fuzzy Rule Base

The following Fuzzy Rules were used for our model.

		Field Current Error						
		LN	MN	SN	Z	SP	MP	LP
	LN	LN	LN	LN	MN	MN	SN	Z
	MN	LN	MN	MN	MN	SN	Z	SP

iv

Error	SN	LN	MN	SN	SN	Z	SP	MP
	Z	LN	MN	SN	Z	SP	MP	LP
	SP	MN	SN	Z	SP	SP	MP	LP
	MP	SN	Z	SP	MP	MP	MP	LP
	LP	Z	SP	MP	MP	LP	LP	LP

The following snapshot show how the fuzzy rule surface looks in SIMULINK.
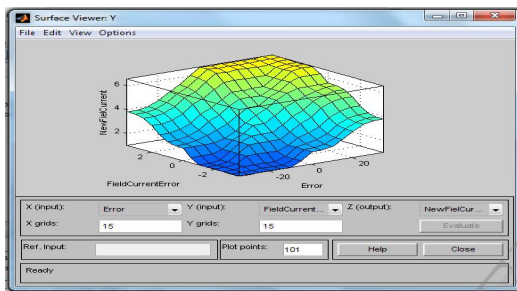
Fig 24: Fuzzy Rule Surface

2.12 Simulink modeling of Fuzzy Control System

Motor Model:- The motor model developed is shown below. On simulation the full load (120 V) rated speed of the motor was found to be 480 rad/s as shown in Fig 25.
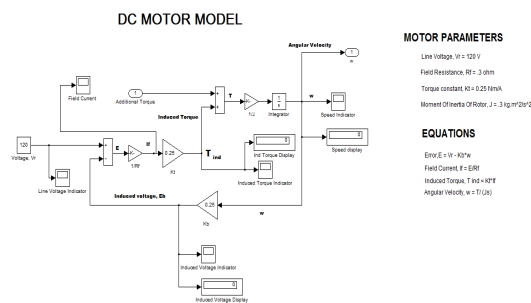
Fig 25:- DC Motor Model
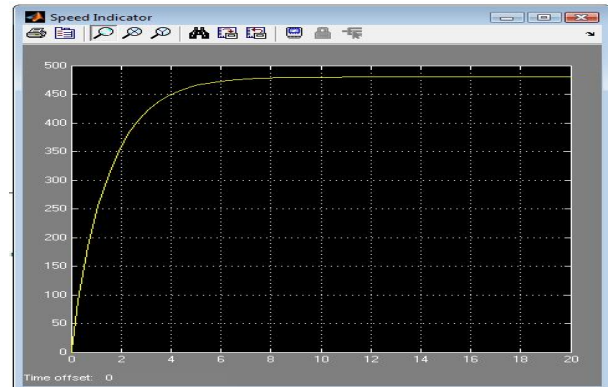
Fig 26:- DC motor Speed

2.13 Servo Control

The servo control model is shown in Fig 27. Different types of input waveforms are given as reference speed and the response of the controller is shown by comparing the output speed of the motor model with the reference speed.
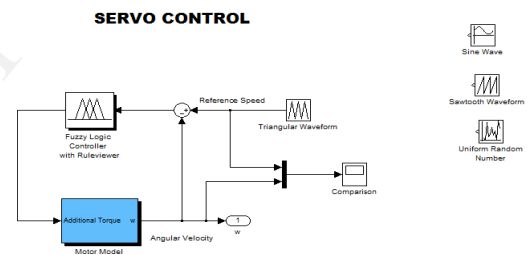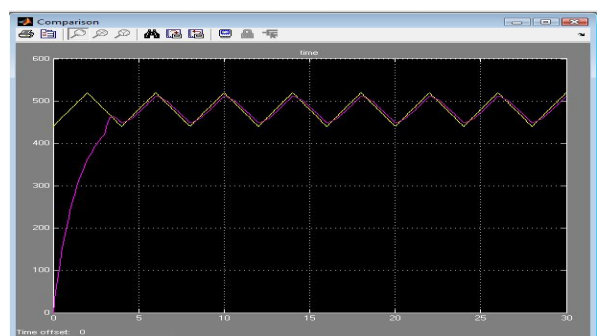

Fig 27:-Servo Control

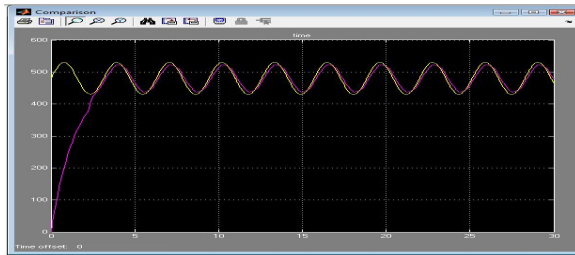**Fig 29:-Triangular Waveform response of controller**

Fig 30:- Sine Wave response of controller

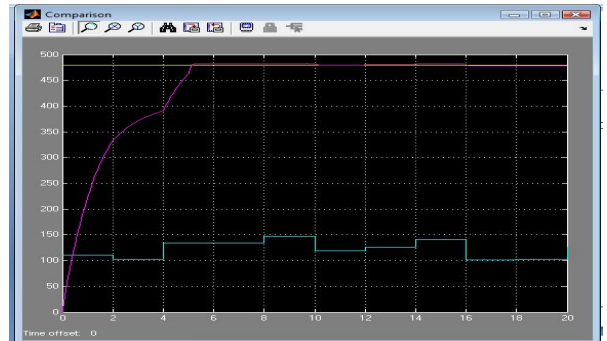**Fig 31: Saw tooth Waveform response of controller**
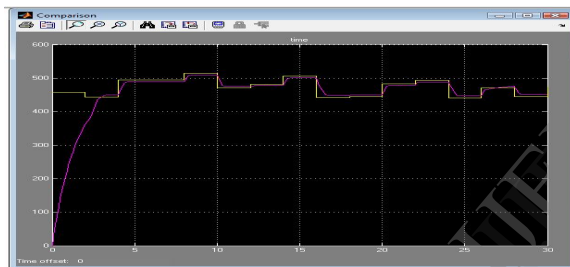

Fig 32: Controller response to random speed reference

2.14 Regulatory Control

The regulatory control model is shown in Fig 13. Different types of input waveforms are given as line voltage and the response of the controller is shown by comparing the output speed of the motor model with the reference speed.
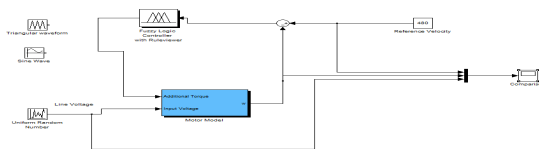

Fig 33:- Regulatory Control

Fig 34:- Controller response to random load

Fig 35:- Figure showing variations in detail

Results and Discussions

When a sinusoidal input of mean value of ωref(63.158) and amplitude 20 was given to the system, the following output was obtained. The output very closely tracks the input sinusoid which is required. The graph in yellow color is the output.
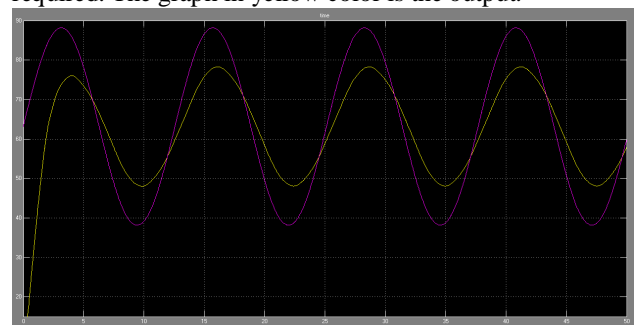

Fig 36:- Output for Sinusoidal Input

vi

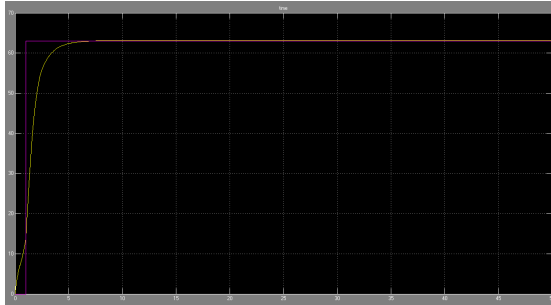The switching on of the motor can be modeled by applying a step input to the motor, which is done below:

Fig 37: Output for Step Input

In practice, the load on the motor does not remain constant. It fluctuates about the mean value, which is modeled below by a pulse wave:
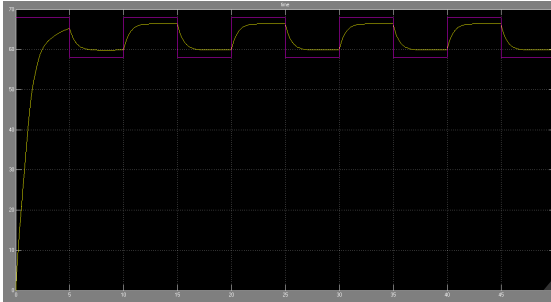

Fig 38:- Output for Pulse Input

The system is observed to produce most accurate results when simulated around the speed for which it was designed. Variations to a certain extent from the designated speed are tolerated well.

Conclusions

A DC Motor model was designed in SIMULINK. Fuzzy Logic Controller was used to control its speed. Various inputs were given to the system. The output waveform closely tracks the input waveform in the results, thereby indicating that the controller designed is quite efficient.

The small error is due to the fact that our design is valid for a particular range of inputs.

Hence it is seen that the response of a fuzzy logic controller is much better and faster than a simple feedback control system. The results indicate superior controllability over conventional controllers and it is less sensitive to noise and parameter changes.

Fuzzy systems are indicating good promise in consumer products, industrial and commercial systems, and decision support systems. Instead of using complex mathematical equations, fuzzy logic uses linguistic descriptions to define the relationship between the input information and the output action.

In engineering systems, fuzzy logic provides a convenient and user-friendly front-end to develop control programs, helping designers to concentrate on the functional objectives, not on the mathematics.

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by MEHMET AKAR İSMAİL TEMİZ, Tokat Vocational High School Electrical Education Gaziosmanpaşa University, Marmara University.
Issue 4, Volume 1, 2007