FLC and NN Based Alpha Compensation OF Three Phase Controlled Rectifier FED DC-Motor Drive

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***Abstract* -** When a new control strategy of a drive system is formulated, it is often convenient to study the system performance by simulation before building the prototype. The simulation not only validates the system operation, but also permits optimization of the system performance by iteration of its parameters.

Besides control and circuit parameters, the plant parameter variation effect can be studied. Valuable time is thus saved in the development and design of the product and the failure of components of poorly designed systems can be avoided. The simulation program also helps to generate real time controller software codes for downloading to a microprocessor or digital signal processor [2].

Many circuit simulators like PSPICE, EMTP, and MATLAB/SIMULINK incorporated these features. The advantages of simulink over other circuit simulators are the ease in modeling the transients of electrical machines and drives and to include controls in the simulation. To achieve out objectives this efficient simulink software is used. For electrical drives good dynamic performance is mandatory so as to respond to the changes in command speed and torques. So various speed control techniques are being used for real time applications. Here the speed of a dc motor is controlled by using various controllers like PI-controller, Fuzzy controllers. Fuzzy logic and neural network concepts are applied to DC drive system [1].

This project describes application of fuzzy logic controllers for current and speed control loops of DC drive systems. Neural network is employed to linearize the rectifier characteristics in discontinuous conduction mode. Simulation result shows the superiority of proposed controller over fixed parameter PI-controller and best possible fuzzy logic controller can be designed without expert knowledge and extensive tuning of parameters [1].

Keywords: cosine wave crossing method, neural compensation, fuzzy controller, conventional PI- controller, armature reaction, GUI (graphical user interface), feed forward back propagation

1. Introduction

Motion control is required in large number of industrial and domestic application like transportation systems, rolling mills, paper machines, textile mills, machine tools, fans, pumps, robot, washing machines etc. Systems employed for motion control are called drives and may employ any of the prime movers such as, diesel (or) petrol engines, gas or steam turbines, steam engines, hydraulic motor and electric motors for supplying mechanical energy for motion control. Drives employing electric motors are known as electrical drives. The introduction of variable speed drives increases the automation and productivity and in the process, efficiency. Nearly 65 % of total electric energy input increasing the efficiency of the mechanical transmission and process can reduce the energy consumption. The system efficiency can be increased from 15% to 27% by introduction of variable speed drive operation in place of constant speed operation [10].

Attempts to improve its characteristics when used with power electronic devices are most challenging and will lead to beneficial results. With this in view, a three phase fully controlled converter fed dc drive with fuzzy compensation scheme [1] and neural compensation scheme are analyzed in this work. The results obtained are compared to establish their relative merits with different controllers such as PI and fuzzy based systems to establish the most preferable controller among them. Neural network is used for $\Delta\alpha$ compensation scheme. By varying various FLC parameters optimally best possible controllers are designed. Simulation results of proposed controller are compared with PI controller results [2].

2. System Model

A separately excited DC motor fed from a fully controlled rectifier is taken as a model system. The block diagram of the considered system is shown below in figure. The speed loop has an inner current control loop for fast dynamic response. The FLC for speed loop sets the current reference for the current loop considering the error and change in error in speed. The current loop output V_s' is added with the counter emf V_c to get the control signal V_s. Then the control voltage is converted into firing angle α by cosine wave crossing technique. The feed forward addition of counter emf gives fasted loop response [1].

An additional error in firing angle called del-alpha (Δα) is added with the firing angle set by the FLC's. The purpose of Δα and method of finding it are done with fuzzy compensation scheme and neural compensation scheme. The field of the motor is considered to be constant and for simplicity, the three-phase fully controlled rectifier is assumed to work in motoring mode. Here we employ Neural Network as Δα compensator in order to show the superiority to establish non-linear mapping between variables as compared to fuzzy logic system [1].

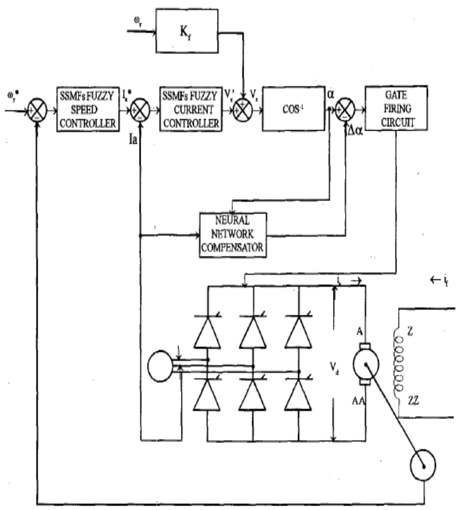


Fig 2.1: SYSTEM BLOCK DIAGRAM

2.2 Mathematical Modeling of a DC Motor:

The resistance of the field winding and its inductance of the motor used in this study are represented R_f and L_f respectively. The resistance of armature and its inductance are shown by effects are ignored in the description model. Armature reaction 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 interpoles or compensating winding. 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 as determined in the following equation.

$$J\ \frac{d\omega_m}{dt} = K_m \phi I_a - B_1.\omega_m - T_1 \qquad \ldots\ldots (2.1)$$

$$L_a\ \frac{dI_a}{dt} = V - R_a.I_a - K_b.\phi.\omega_m \ \ldots \qquad (2.2)$$

Taking Laplace transforms of equations (2.1) ,(2.2) and neglecting initial conditions, we get

$$I_a(s) = \frac{V(s) - K_b W_m(s)}{(R_a + sL_a)} \quad \ldots (2.3)$$

$$W_m(s) = K_b I_a(s) - \frac{T_1(s)}{(B_1 + sJ)} \quad .(2.4) \ \text{[Ref 10]}$$

Fig 2.2 shows the block diagram representation of the DC motor with Laplace transformed equations

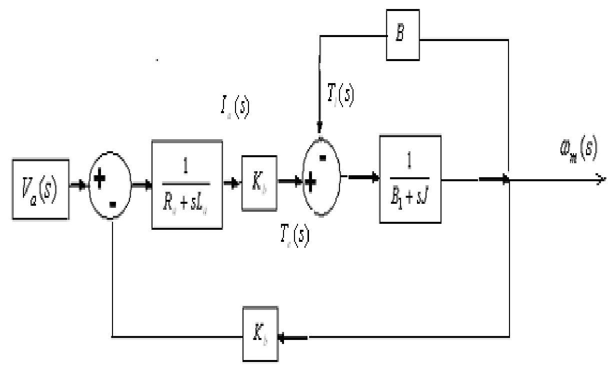


Fig 2.2: Block diagram representation of the DC motor

The dynamic model of the system is formed using theses differential equations and MATLAB simulink block as shown in Fig 2.3

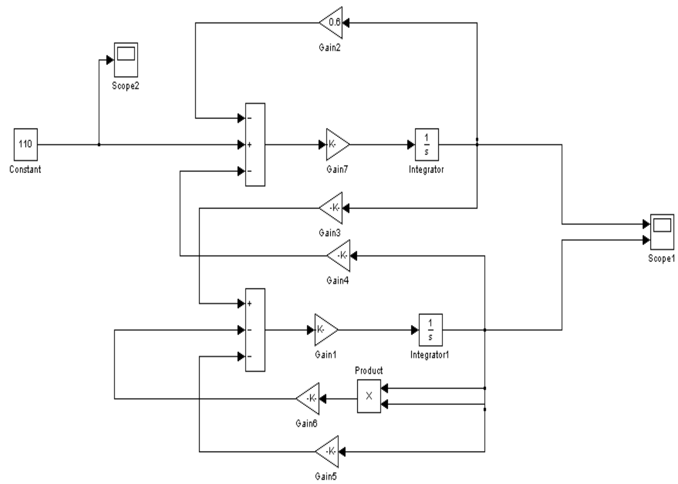


Fig. 2.3: Simulink Model of dc motor

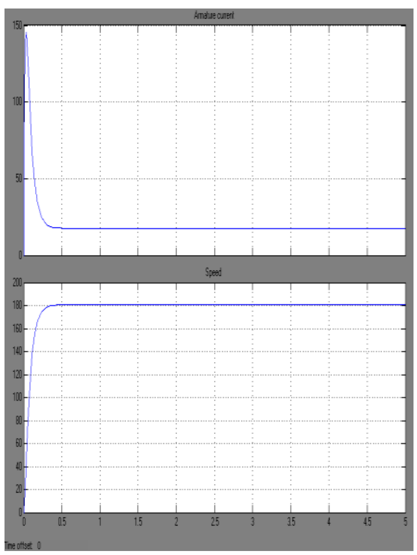


Fig 2.4: Open loop armature current and speed responses of dc motor

2.3 DC Machine Drive with Phase Controlled Converter

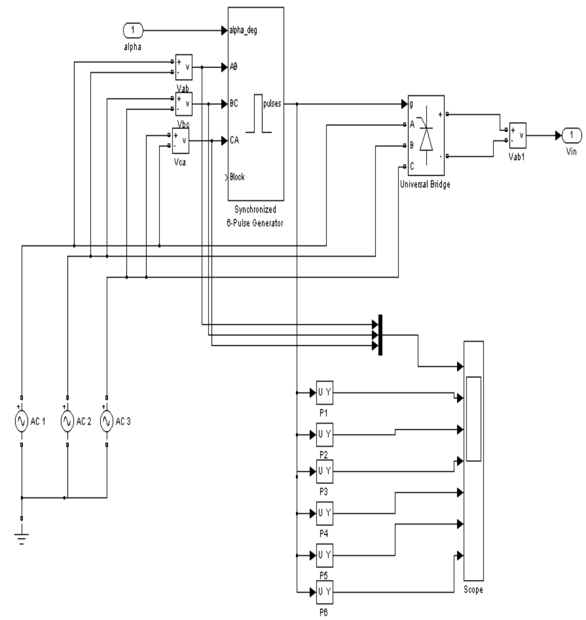
Controlled rectifiers are used to get variable dc voltage from an ac source of fixed voltage. Controlled rectifiers fed dc drives are also known as Static Ward-Leonard system. Controlled rectifiers (Fully-controlled rectifiers) are capable of providing Voltage in two direction and current in one direction which allow the motor control in two quadrant i.e. quadrant I &quadrant IV. For speed control of dc motor there are two types of phase controlled converters are present, they are

I. Three phase full controlled converter

II.Three phase semi controlled converter

2.4. Simulink Implementation of Three –Phase Converter

The block diagram of three phase-controlled bridge converters that drives a separately excited dc motor. For simplicity, the converter is used in motoring mode only with fixed field excitation. The firing angle α, required for the rectifier is generated by cosine wave crossing method [5]



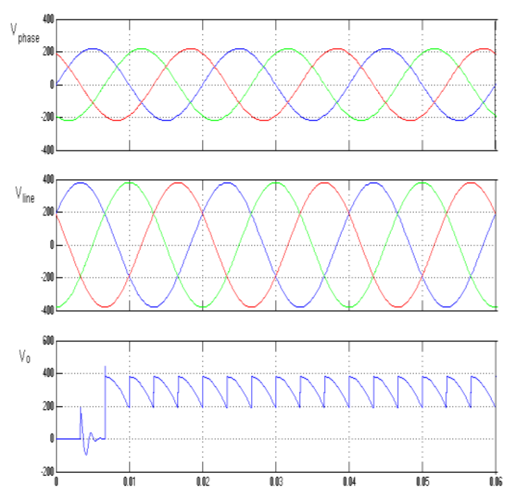


Fig 2.5: Three phase input and output voltage waveforms

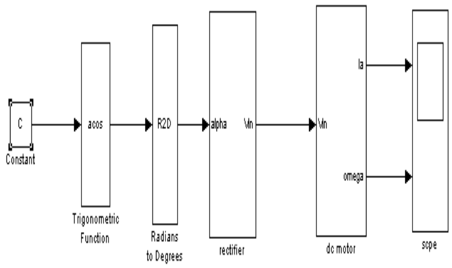


Fig 2.6: Simulink Block Diagram of phase controlled converter fed dc drive

2.4.1 Converter Equations

The converter may operate in either continuous or discontinuous conduction mode. At low speed when the counter e.m.f is small, the conduction will be continuous. However, at high speed, the conduction will tend to be discontinuous. In continuous and discontinuous conduction mode, the normalized armature circuit equations can be given as follows:

The expressions for Rectifier Current and Voltage in Continuous Conduction Mode when supplied to dc motor are

$$I_a(pu) = \frac{I_a}{3V_m / \pi X} = \frac{X}{R}\left[\cos\alpha - \frac{\pi V_c}{3V_m}\right] \quad \text{......... (2.5)}$$

$$V_d(pu) = \frac{V_d}{V_m} = \frac{3}{\pi}\cos\alpha$$

Where

I_a = armature current (average)

V_m = peak ac line voltage

X = armature reactance (ωL)

R = armature resistance

A = converter firing angle

V_c, = armature counter e.m.f

And V_d = converter output voltage (average)

The expressions for Rectifier Current and Voltage in Discontinuous Conduction Mode when supplied to dc motor are

$$I_a(pu) = \frac{I_a}{3V_m / \pi X} = \frac{X}{R}\left[\cos\left(\pi/3+\alpha\right) - \cos\left(\pi/3+\alpha-\theta_1\right) - \frac{V_c}{V_m}\theta_1\right]$$

$$V_d(pu) = \frac{V_d}{V_m} = \frac{3}{\pi}\left[\cos\left(\pi/3+\alpha\right) - \cos\left(\pi/3+\alpha-\theta_1\right) - \frac{V_c}{V_m}\theta_1\right] + \frac{V_c}{V_m}$$

when

$$\frac{V_0}{V_m} = \frac{\sqrt{1+\left(X/R\right)^2}}{1-\exp\left(-R\theta_1/X\right)}\left[\sin\left(\pi/3+\alpha+\theta_1-\varnothing\right) - \sin\left(\pi/3+\alpha-\varnothing_1\right)\exp\left(-R\theta_1/X\right)\right] \quad \text{.........(2.6)}$$

Where

θ_1 = conduction angle of current pulse ($0 < \theta < \pi/3$) and

$\tan\varnothing = X/R$.

For a fixed **X/R** parameter, the equations above are plotted in Fig below for different α angles, which also indicate the boundary between continuous and discontinuous conduction modes[2].

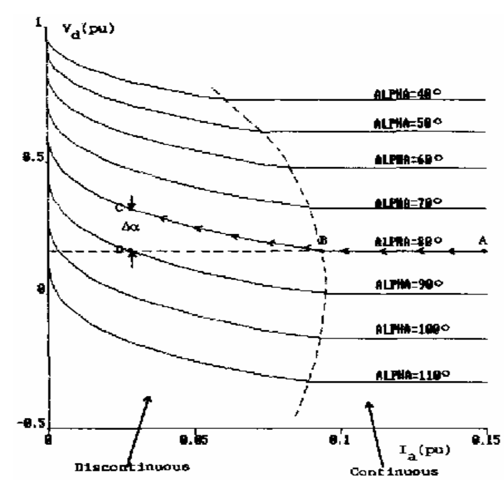


Fig 2.7: V_d-I_d Transfer Characteristics of phase controlled converter

For example at α = 80, the conduction

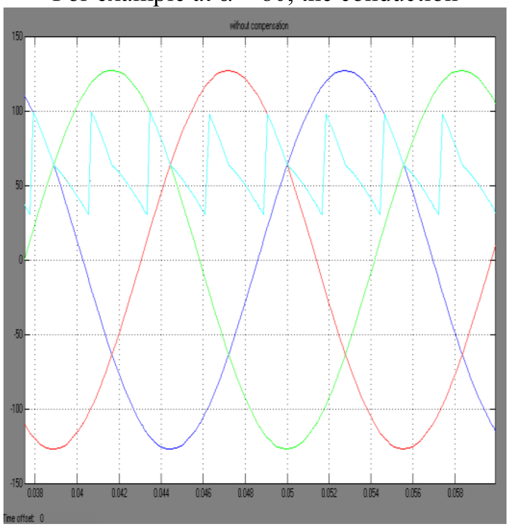


Fig 2.8: Response of the converter for firing angle of α = 80 degrees

3. Fuzzy speed and current controller

The fuzzy linearization of converter at discontinuous conduction mode the fuzzy control is well suited in a nonlinear system especially where parameter variation problem exist. In addition to converter linearization, fuzzy logic control was applied to the speed and current loops. The objective was to explore the control robustness in the presence of parameter variation and load disturbance effect. However, both loops must satisfy the needs of fast transient response with minimum overshoot with converter linearization, both speed and current loops have essentially fist order characteristics. Therefore, intuitively the same fuzzy control strategy should be valid for both loops .The fuzzy speed and current controllers are equally effective in ac drives with vector control, since the transient response is similar to that of a dc machine [4] .

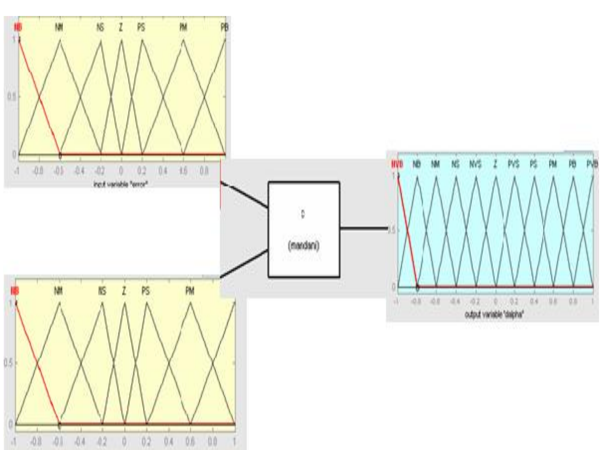


Fig 3.1: Membership functions for error, change in error and dalpha

Table1

Ia \ α	NB	NS	Z	PS	PB
NVB	NVB	PB	PB	PB	PB
NB	NVB	Z	Z	Z	Z
NM	NVB	NS	NVS	NVS	NVS
NS	NVB	NM	NS	NS	NS
Z	NVB	NB	NM	NM	NS
PS	NVB	NVB	NB	NM	NM
PM	NVB	NVB	NB	NB	NB
PB	NVB	NVB	NVB	NB	NB
PVB	NVB	NVB	NVB	NVB	NB

Rule base matrix [2]

3.1 Fuzzy compensation

The converter which drives the separately excited dc motor may operate in either continuous (or) discontinuous mode. At low speed when the counter emf is small, the conduction will be continuous. However, at high speed, the conduction will tend to be discontinuous. Here the line voltage (V_m) can essentially be considered at constant, and therefore, V_d can be controlled linearly by V with cosine wave crossing technique [3]

Fuzzy linearization of converter at discontinuous conduction mode the fuzzy compensation was implemented in mamdani type and it is a two input and single output fuzzy system The input of the fuzzy system are Ia and α and the output of the network is Δα.. It involves three steps (i) Fuzzification (ii) Inference engine (iii) Defuzzification

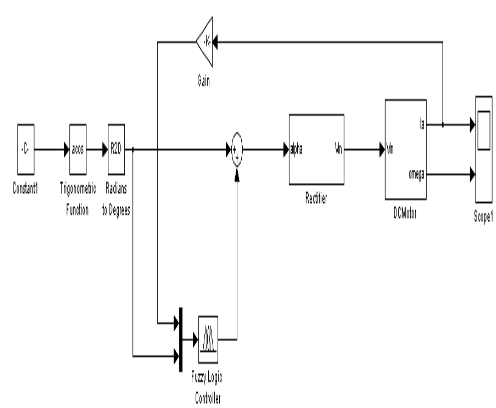


Fig 3.2: Block diagram of Fuzzy Compensation

3.2 SIMULINK IMPLEMENTATION OF FUZZY COMPENSATION

3.2.1 Neural compensation

The required data to train the neural network are obtained by plotting the relationship between rectifier output voltage and current given by the expressions (equations 3.1 and 3.2). The input of the neural network are I_a and α and the output of the network is Δα[1]. A two layer network is chosen to do this operation. The Neural Network is trained using back-propagation by neural network training tool GUI. A GUI Network/Data Manager window has its own work area, separate from the more familiar command-line workspace. Thus, when running a GUI Network, you can create a network, view it, train it, simulate it, and export the final results to the workspace. Similarly you can import data from the work space for use in the GUI.Generally here the problem is the compensation of alpha of phase controlled rectifier fed dc drive. Here in this compensation of alpha the GUI tool used is nn tool.

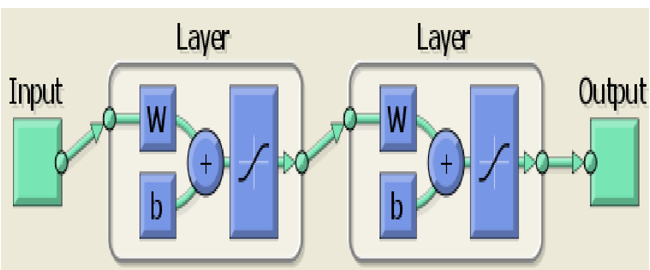


Fig 3.3: Neural block diagram

3.2.2 Simulation study

Here we have to create a network and perform compensation of del-alpha. Now give the input vector containing the different values of I_a , alpha. Once the network is created, train it and can save the network, its output, etc., by exporting it to workspace. To start type nn tool in the command window. Now import data from the workspace and select the given data for input and target . Now create a network and call it delalpha. And set the network type feed forward back propagation and press creates. Network is created and delalpha is added to network manager. Now select the network delalpha and train the network. After the training finished generate a simulink block by giving the network descriptions place that block used for the compensation.

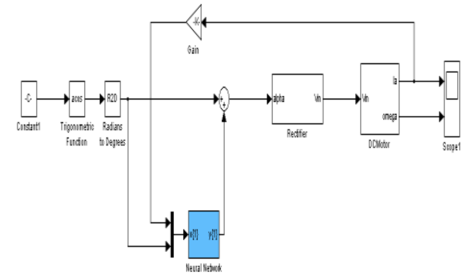


Fig 3.4: Block diagram for neural compensation

4 SIMULINK IMPLEMENTATION OF NEURAL COMPENSATION

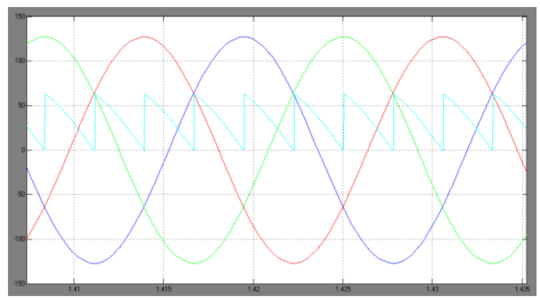
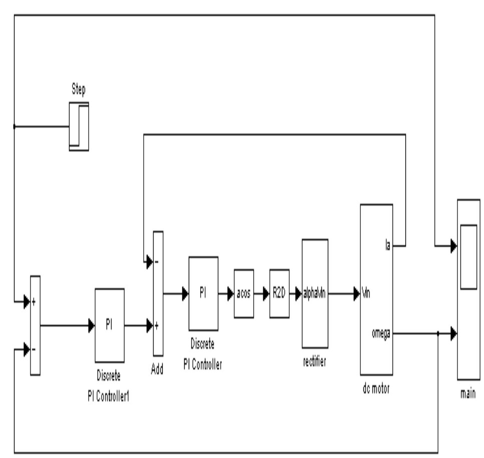


Fig 4 .1: Linearization of rectifier characteristics

4.1 SIMULINK IMPLEMENTATION OF CLOSED LOOP SPEED CONTROL

The PI- controller was designed for controlling the speed of the dc motor. The three phase controlled converter fed with PI controller was implemented in simulink and output waveforms was observed for a command speed of step change in speed [12] .

4.2 Speed control of separately excited dc motor drive with Proportional and Integral (PI)control



<u>Output waveform</u>

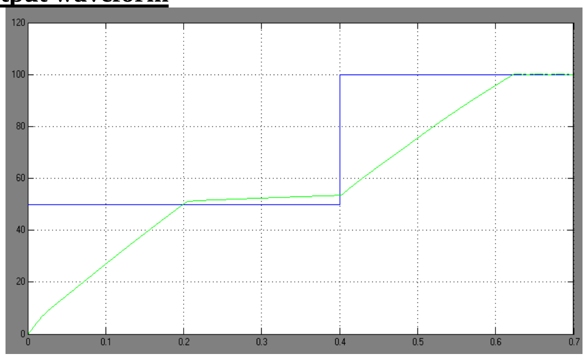
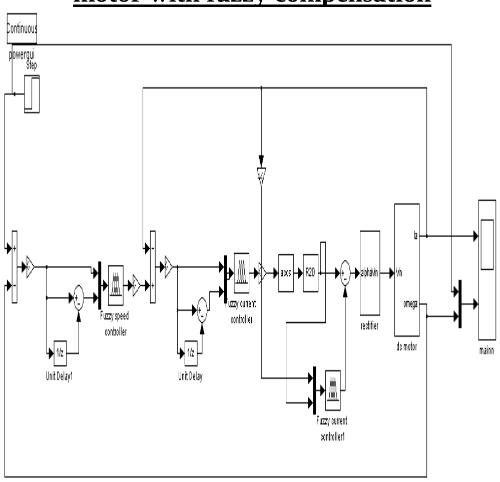


Fig 4.2 output characteristics of neural compensation of closed loop speed control

<u>4.3 Simulink model of fuzzy logic speed control of dc motor with fuzzy compensation</u>



<u>Output waveform</u>

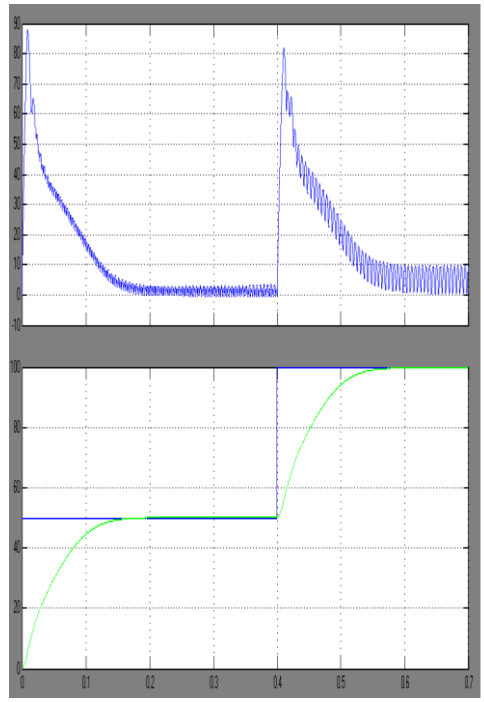
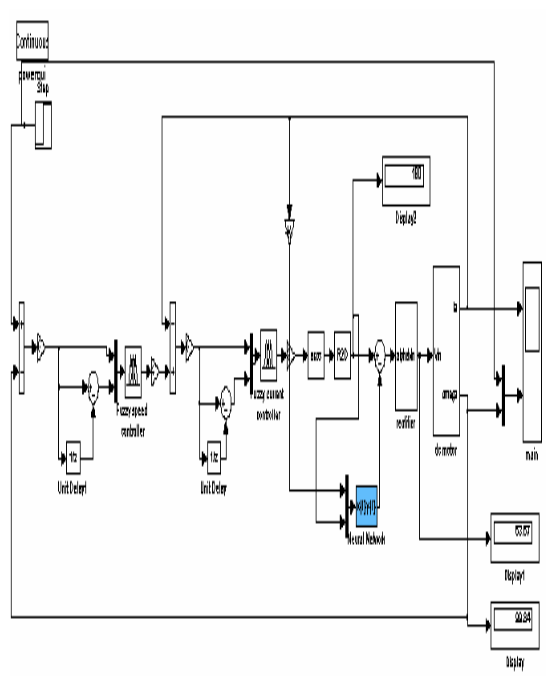


Fig 4.3 output characteristics of fuzzy logic speed control of dc motor with fuzzy compensation

<u>Simulink model of fuzzy logic speed control of dc motor with neural compensation</u>



<u>Output waveform</u>

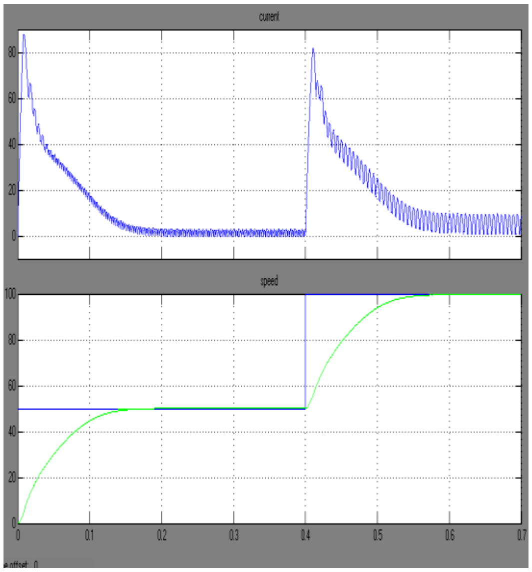


Fig 4.4 output characteristics of fuzzy logic speed control of dc motor with neural compensation

Table-2 : Drive Parameters

Supply voltage (V) -110 volts
Rated motor current (I_a) - 20A
Speed of the motor (r.p.s) – 1800
Armature resistance (Ra) – 0.6 ohms
Armature Inductance (La) – 8mH
Moment of Inertia (J) – 0.0465 Kg-m^2
Friction Coefficient (B) – 0.004N.m sec/rad
Line voltage (VL) – 90 volts
Shaft power – 2.5hp
Load Torque (TL) – 2.78*10^(-4) *W^2

5 Results:

In this project the neural and fuzzy compensation has been implemented to linearize the transfer characteristics of dc motor at discontinuous mode which occurs at light load(or) high speed. The fuzzy control is then extended to the current and speed control loops, replacing the conventional PI- controller method. The simulation study indicates the superiority of fuzzy control over conventional control methods. The controllers designed have been simulated for command speed of step change form 50 rad/sec top 100 rad/sec. Then percentage overshoot (%Mp) and steady state error (e_{ss}) and rise time have been measured

Table-3

Parameter	PI Controller	Fuzzy Logic Controller and Compensation	FLC and Neural Network Compensation
Setting Time Ts	0.2sec	0.17sec	0.15sec
Over shoot(%)	6%	0 rad/sec	0rad/sec
Rise time tr	0.17 sec	0.1 sec	0.08sec
Steady State Error	0 rad/sec	0 rad/sec	0 rad/sec

6 Conclusions:

- Neural network compensation has been implemented and compared with fuzzy logic compensation implementation.
- Separately excited dc motor speed has been controlled with classical PI and FLC.
- Simulation results shows that neural network compensation with FLC gives better performance in respect of rise time, percentage overshoot and steady state error in comparison of PI and Fuzzy logic compensation.
- It would be possible to get better PI controller performance by increasing proportional and integral coefficient but it will be a problem in real time applications of PI controller.

7 Future Scope

- Till now the speed of dc motor is controlled using PI, Fuzzy controllers.
- The next approach is to control the speed using a neural network controller and neuro fuzzy control.
- Another new approach is using a DSP controller. With the DSP controller an intelligent control approach is possible to reduce the overall system cost and to improve the reliability of the drive performance.

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