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Stability Analysis and Control of DC Motor using Fuzzy Logic and Genetic Algorithm.

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***Abstract*— The main focus of this paper is to do stability analysis of a DC Motor (Field controlled and armature controlled). The stability analysis includes time domain analysis, frequency domain analysis and pole-zero domain analysis using state space averaging technique. The simulation and study is done using Matlab from its respective graphs obtained from above mentioned domains. Later the control of this motor is done using advanced controllers such as Fuzzy and Genetic algorithm optimization techniques.**

***Index Terms*—DC-Motor, Field controlled, Armature controlled Stability analysis, frequency domain, pole-zero, time domain, state space averaging, Fuzzy logic, Genetic Algorithm**

I. INTRODUCTION *(DC MOTOR)*

DC motor is an electromechanical energy conversion device that converts electrical energy into mechanical energy. The main aim of this paper is to control the angular speed of the motor by varying armature voltage (armature controlled) or by varying field flux (field flux controlled) method. The modeling of DC motor is first done and for various parameters of the motor the stability analysis is done. The speed control of DC motor is done using two classical techniques i.e. Field flux control and armature voltage control method. The modeling of both techniques are done using State space averaging method and their stability analysis is done using Step response, bode plot, polar plot and pole zero plot. The output speed response of the DC motor is observed using three optimization techniques i.e. PID control technique and its tuning, Fuzzy logic and Genetic Algorithm [1]. The response steady state error reduces on application of Fuzzy logic controller (Human experience added) and eventually, the best response with minimum overshoot and small steady state error is obtained using Genetic Algorithm which is based upon natural genetics and selection method. This paper also reveals the fact that on application of intelligent controllers like Fuzzy logic and Genetic algorithm perfect control is obtained.

II. ARMATURE CONTROLLED DC MOTOR

The circuit diagram of armature controlled dc motor is shown in figure 1 below.

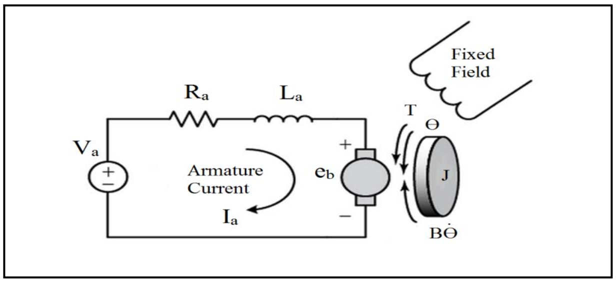

Fig.1.Armature Controlled DC Motor

Where, Ra=Resistance of armature,(ohm), La=Inductance of armature winding, (henry),I_a = Armature current, (ampere), I_f= Field current, (ampere), V_a = Applied armature voltage, e_b = back emf, (volt), T_m=Torque developed by the motor(N.m),□=Angular displacement of motor-shaft, (radian), ω= Angular velocity of motor-shaft, J= Equivalent moment of inertia of motor and load referred to motor shaft, (Kg.m^2), B=Equivalent viscous-friction coefficient of the motor and load referred to the motor shaft, (Nm/rad/sec).The armature voltage V_a is usually supplied by a generator, which in turn may be supplied by an amplifier. The voltage V_b is the back e.m.f. induced by the rotation of the armature windings in the magnetic field. The transfer function of the DC motor will be developed for a linear approximation to an actual motor, and second-order effects, such as hysteresis and the voltage drop across the brushes, is neglected. The input voltage may be applied to the field or armature terminals. The air-gap flux of the motor is proportional to the field current. Here the field current is held constant and the armature current is controlled by varying armature voltage.

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The motor transfer function of armature control from applied terminal voltage $V_a(s)$ (input) to position angular displacement $\theta(s)$ (output) without load ($T_d(s)=0$) is given by:

$$\square(s) / V_a(s) = K_m / ((s\,(Js+B)\,(sL_a+R_a)) + K_m K_b s) \qquad (1)$$

$$\omega(s) / V_a(s) = K_m / (((Js+B)\,(sL_a+R_a)) + K_m K_b) \qquad (2)$$

Where,
$\tau_a = L_a/R_a$ = Time constant of armature circuit.

$\tau_m = J/B$ = mechanical time constant

The block diagram of armature controlled DC motor is shown in figure below:

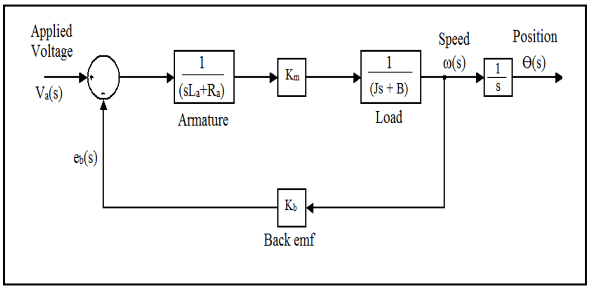


Fig.2. Block diagram of armature controlled DC motor

III. FIELD CONTROLLED DC MOTOR

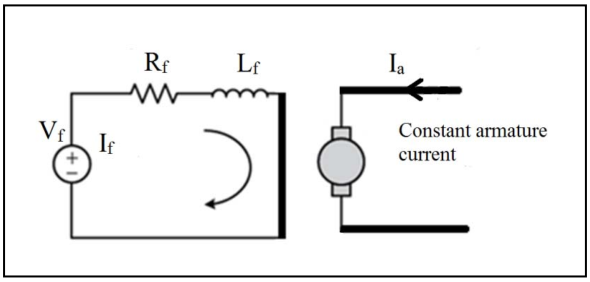


Fig.3. Field controlled dc motor.

The DC motor transfer function of field controlled from the Field voltage (input voltage) $V_f(s)$, to the position (Angular displacement) $\theta(s)$ without load which ($Td(s)=0$) is given by

$$\square(s) / V_f(s) = K_m/(s\,(Js + B)\,(sL_f + R_f)) \qquad (3)$$
$$\omega(s) / V_f(s) = K_m/((Js + B)(sL_f + R_f)) \qquad (4)$$

The block diagram of Field controlled dc motor without load is shown below:

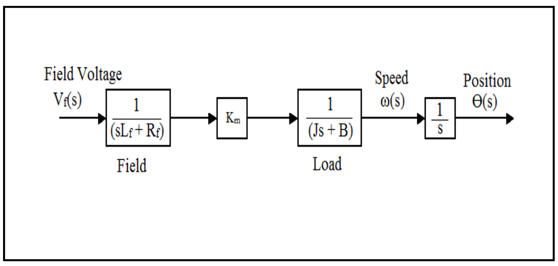


Fig.4.Block diagram of field controlled dc motor without load

IV. STABILITY ANALYSIS OF ARMATURE CONTROLLED AND FIELD CONTROLLED DC MOTOR

1) Routh –Hurwitz criteria:

For armature controlled dc motor we will chose the parameters as:
$R_a = R_f = 2\Omega$
$L_a = L_f = 0.5H$
$K_m = 0.01$, $K_b = 0.1$
$J = 0.02kgm^2/s^2$
$B = 0.2$
Therefore, the transfer function will be:
$\omega(s) / V_a(s) = 0.01/ (((0.02s+0.2)\,(0.5s+2)) + 0.001)$

The characteristics equation is given by
$(0.02s+0.2)(0.5s+2) + 0.001=0$
$0.01s^2+0.14s+0.401=0$

s^2	0.01	0.401
s^1	0.14	0
s^0	0.401	

Similarly, for field controlled dc motor,
$\omega(s) / V_f(s) = 0.01/ ((0.02s+0.2)\,(0.5s + 2))$

The characteristics equation is given by:
$(0.02s+0.2)(0.5s+2)=0$
$0.1s^2+0.14s+0.4=0$

s^2	0.1	0.4
s^1	0.14	0
s^0	0.4	

If it is found that all the elements of the first column of the array are positive which indicates both the system are stable, and all the roots of the characteristic equations lies in the left half of s-plane.

2) State space averaging technique:

2.1. Armature controlled DC motor:

The state space model equation for armature controlled dc motor is given below:

$$\begin{bmatrix} dx_1/dt \\ dx_2/dt \\ dx_3/dt \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -B/J & -K_m/J \\ 0 & -K_b/L_a & -L_a/R_a \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1/L_f \end{bmatrix} e(t)$$

From the transfer function of dc motor, the step response is plotted and to support the stability check of the system bode plot, pole zero plot and root locus plots are done In Matlab.[2]

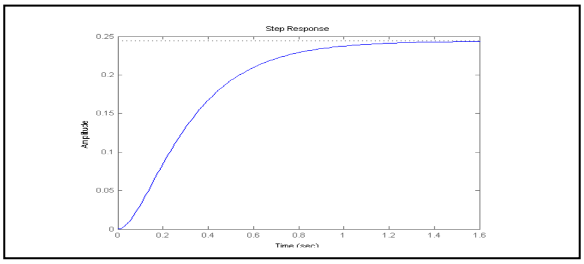


Fig.5. Step response of Armature controlled DC motor.

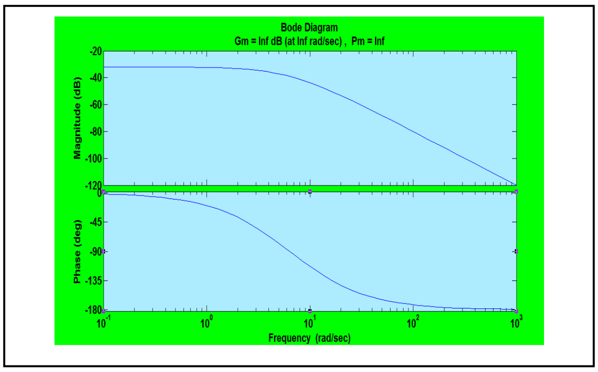


Fig.6.Bode plot of Armature controlled DC motor

In the above plot, the gain margin and phase margin both are infinity and it indicates that the system is totally stable and the gain value can be increased to a large value before the system becomes unstable. Similarly in the polar plot if the locus of the plot crosses the negative real axis then the system becomes unstable and in pole zero plot if the roots of the characteristics equation lies in right hand side of s plane then the system becomes unstable.

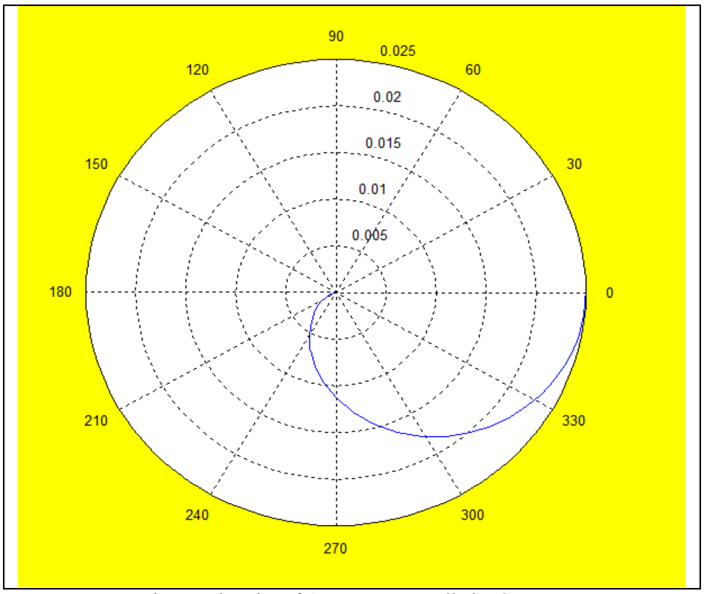


Fig 7. Polar plot of Armature controlled DC motor

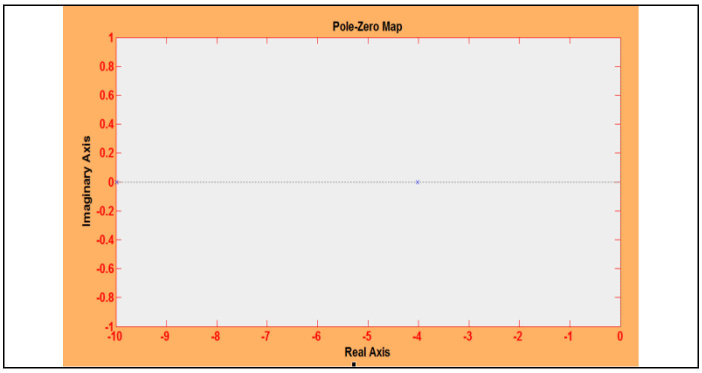


Fig.8.Pole zero plot of Armature controlled DC motor

2.2. Field controlled DC motor:

Similarly, the state space model equation for field controlled dc motor is given as:

$$\begin{bmatrix} dx_1/dt \\ dx_2/dt \\ dx_3/dt \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -B/J & K_m/B \\ 0 & 0 & -R_f/L_f \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1/L_f \end{bmatrix} e(t)$$

From the transfer function of dc motor, the step response is plotted and to support the stability check of the system bode plot, pole zero plot and root locus plots are done using MATLAB.

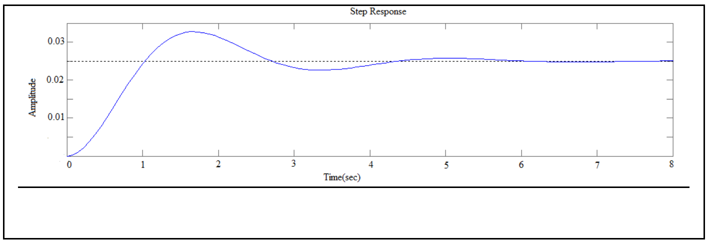


Fig.9. Step response of Field controlled DC motor.

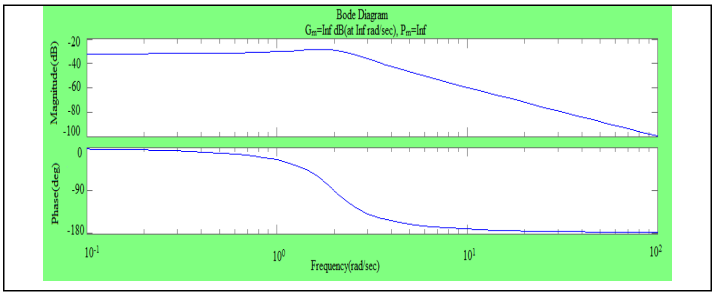


Fig.10..Bode plot of Field controlled DC motor

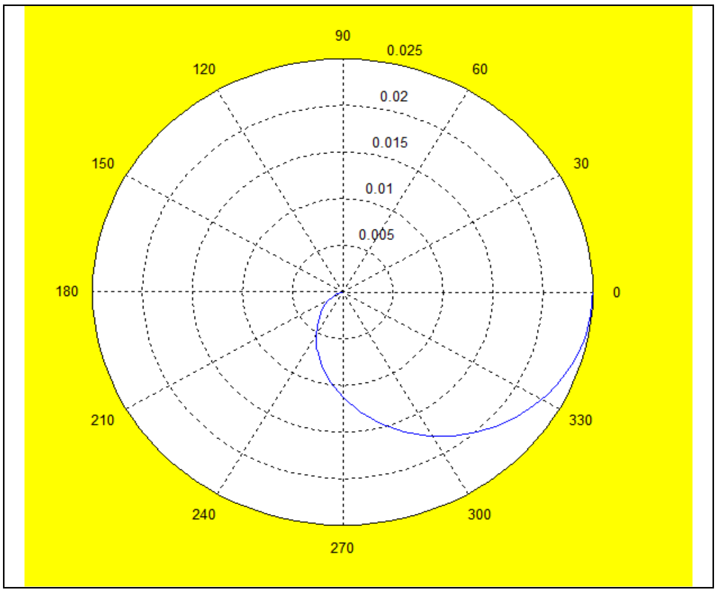


Fig.11.Polar Plot of Field controlled DC motor

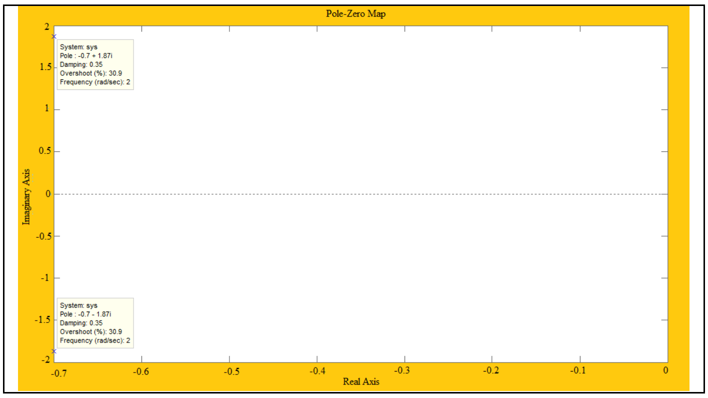


Fig.12.Pole zero plot of Field controlled DC motor

For, both the cases the gain margin and phase margin both are infinite, it indicates that the system is Robust and has minimal overshoot.

From the above polar plot, the poles lie in left hand side of s plane. So, the system is stable.

V. Fuzzy logic control of DC motor

In the experimental approach, the speed control of a DC motor using armature voltage control and field flux control was done and the following data's were obtained:[3]

TABLE I. Experimental Readings

Armature voltage (V)	Field current (A)	Angular speed (rpm)
190	0.50	1320
200	0.40	1515
195	0.35	1573
190	0.40	1442
190	0.45	1403
190	0.30	1622
180	0.40	1430
190	0.40	1442
185	0.45	1365
185	0.35	1535
195	0.45	1420
190	0.40	1466
195	0.45	1420

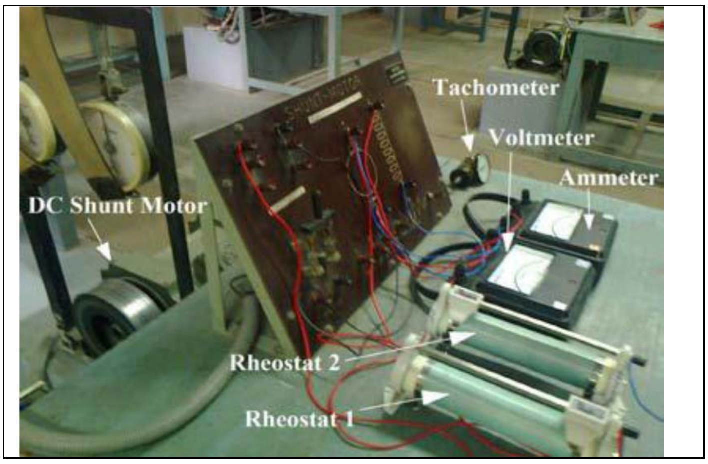


Fig.13 .Experimental setup of speed control of DC motor.

Using fuzzy Mamdani's approach, the following plots for input and output were done.

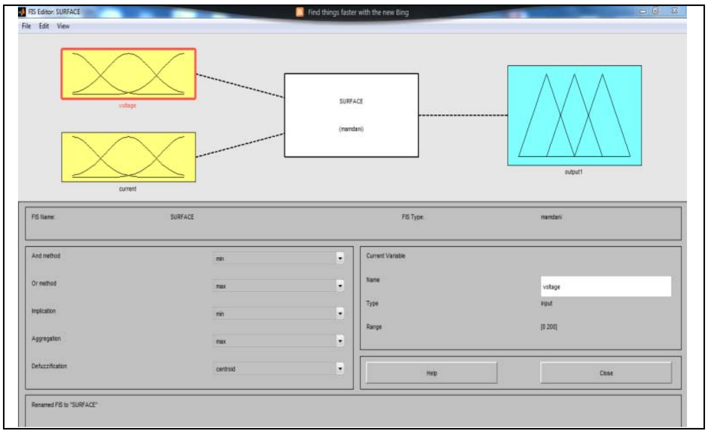


Fig.14.Input –Output fuzzy logic plots

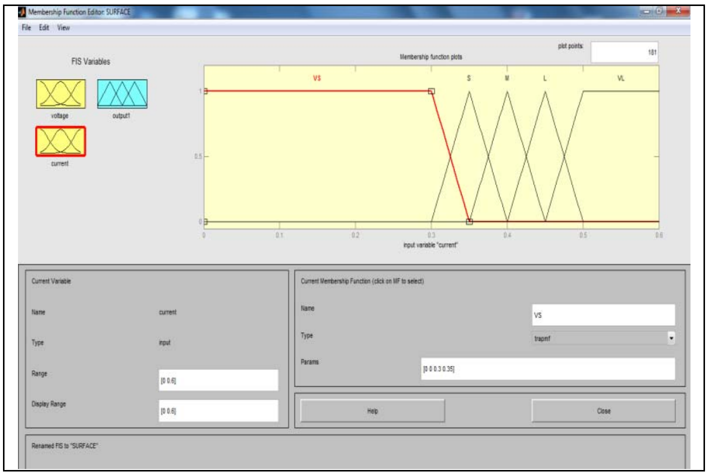


Fig.15.Current variable membership plot

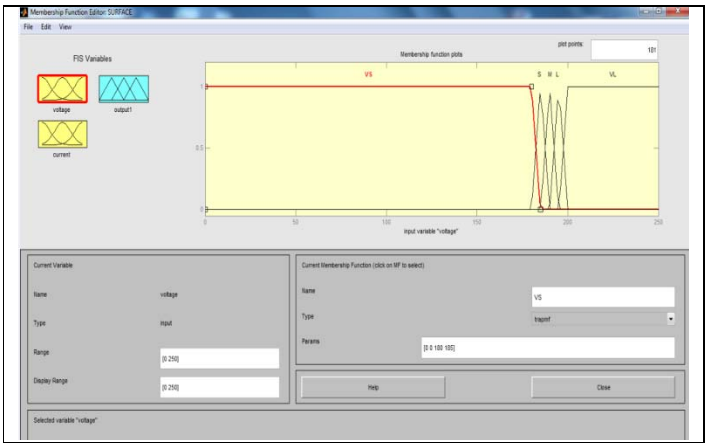


Fig.16.Voltage variable membership plot

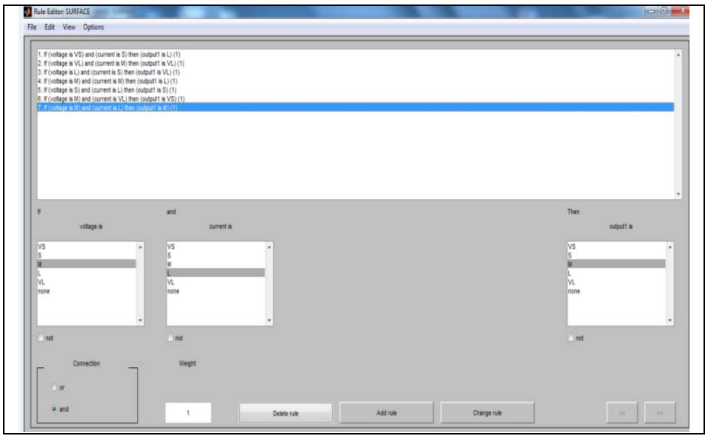


Fig.17. Fuzzy logic Rules.

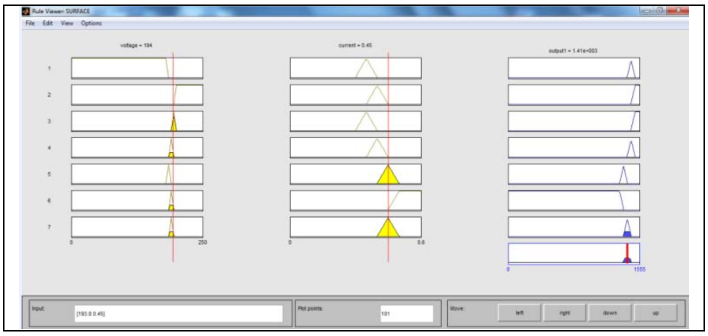


Fig.18.Armaturevoltage=194V, Field-current=0.45A, Speed=1410Rpm

Fig.19.Armaturevoltage=194V, Field-current=0.38A, Speed=1500Rpm

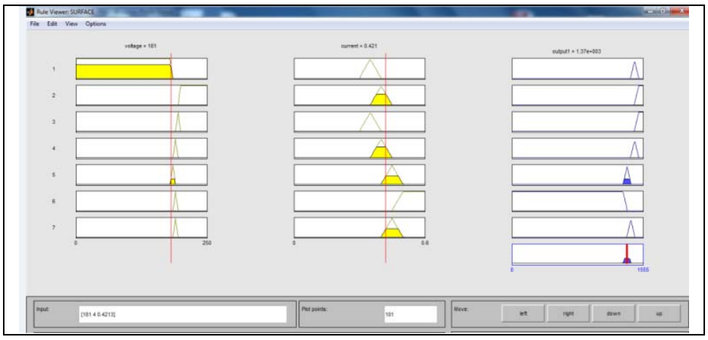


Fig.20. Armature voltage=181V, Field-current=0.42A, Speed=1370rpm

From Fig no.18 and 19 it is clear that for constant armature voltage, on decreasing the field current it will increase the motor speed which proves that speed of motor is inversely proportional to the field current and from figure no.18 and 20 it is clear that on decreasing armature voltage, the speed of the motor also decreases .Hence, speed of the motor is directly proportional to the armature voltage.[8]

VI. Simulink Model and Results

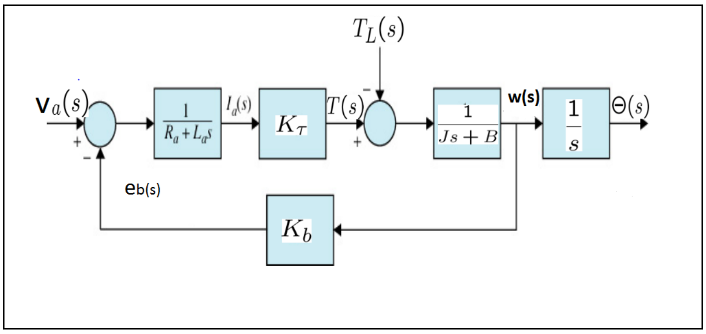


Fig.21. Simulink model of a simple DC motor

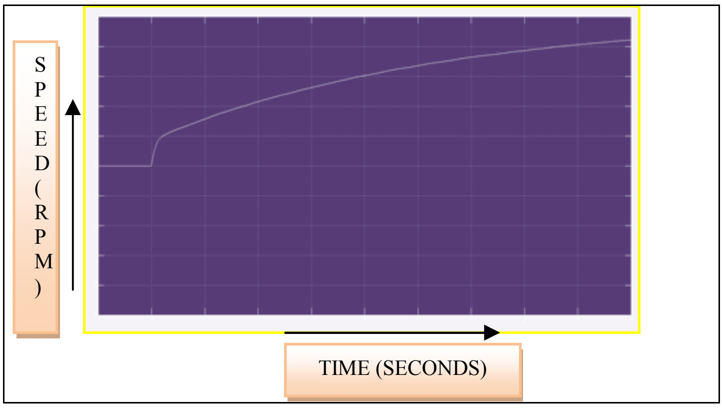


Fig.22.Simulation graph of DC motor using PI controller

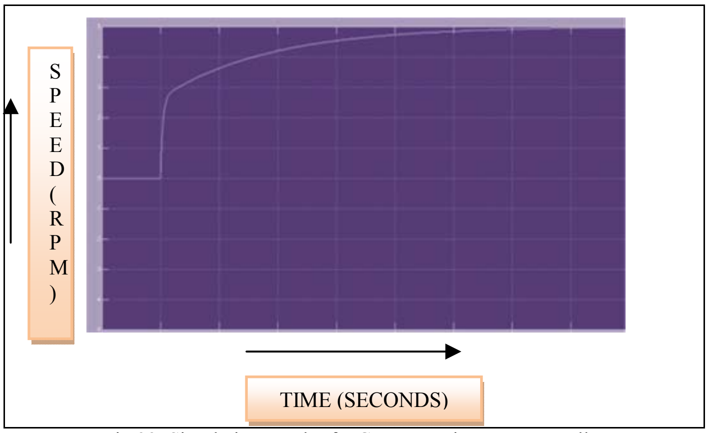
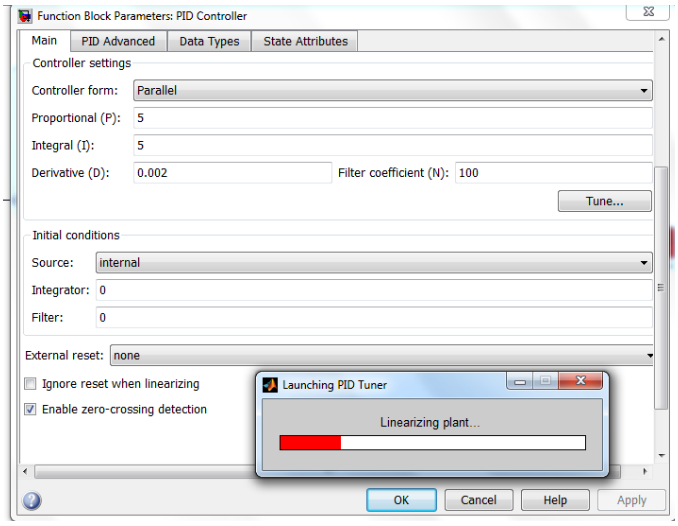


Fig 23. Simulation graph of DC Motor using PID controller

VII. Tuning of PID Controller Using Genetic Algorithm



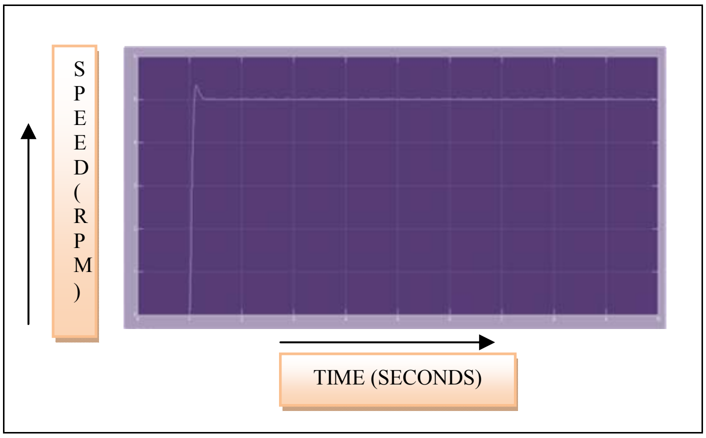


Fig. 24 Simulation graph of DC motor using PID Tuned controller

GA is a stochastic global adaptive search optimization technique based on the mechanisms of natural selection.

[4]]Recently, GA has been recognized as an effective and efficient technique to solve optimization problems compared to other optimization techniques. GA starts with an initial population containing a number of chromosomes where each one represents a solution of the problem which performance is evaluated by a fitness function. Basically, GA consists of three main stages: Selection, Crossover and Mutation. The application of these three basic operations allows the creation of new individuals which may be better than their parents. This algorithm is repeated for many generations and finally stops when reaching individuals that represent the optimum solution to the problem.

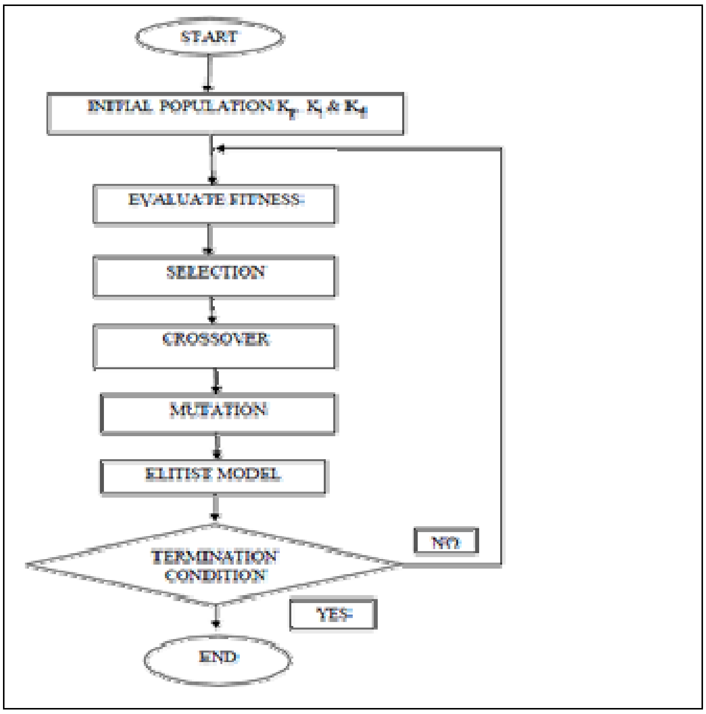


Fig 25. Genetic Algorithm Flowchart

TABLE II. G.A PARAMETERS

Parameter	*Value*
Population size	20
Iteration	05
Crossover Probability	> 0.8
Mutation Probability	< 0.05

In the proposed work a DC Motor model is called by a program which is coded in Matlab for fitness function i.e. cost function. In order to use GA to tune the PID controller for DC motor[6]. Variables Kp, Ki, & Kd are coded to solve string structures. Binary coded string having 1's & 0's are mostly used. The length of string is usually determined according to the desired solution accuracy [9]. Here 10 bits are used to code each variable. We can use 8 bit & 4 bit also. Thereafter select the random strings from the population to form the mating pool. In order to use roulette-wheel selection procedure, we calculate the average fitness of the population. Then the mating pool strings are used in the crossover operation. The next step is to perform mutation on strings in the intermediate population. The resulting population becomes the new population. The whole process is coded in Matlab & after running the program we get the optimized values of Kp, Ki & Kd. The simulation model for the entire system is given below and also the genetic algorithm parameters are chosen for the optimization.[5]

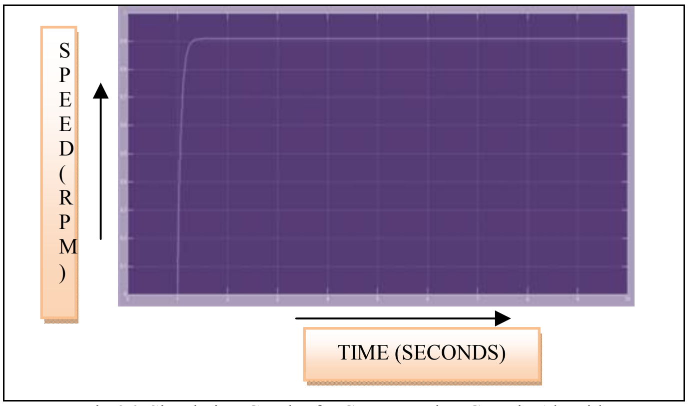


Fig 26. Simulation Graph of DC motor using Genetic Algorithm

TABLE III.PARAMETERS OF A SECOND ORDER SYSTEM

Parameter	**Kp**	**Ki**	**Kd**	**Tr**	**Ts**	**Mp**	**ess**
Without GA	1	1	0.100	1.0603	8.66	3.13	0.09
With GA	6.520	0.008	0.303	0.3773	0.943	0.004	0.02

VIII. CONCLUSION

We can conclude that the speed control of DC motor is stable which is proved by Routh Hurwitz Criteria, Bode plot, Polar plot and pole-zero analysis. Further through fuzzy logic controller applied to the experimental data has proved that on increasing armature voltage, motor speed increases and on increasing field current, motor speed decreases[10].

Through the simulation output of the Simulink model we can see that the steady state error of the output graph was improved by replacing PI controller with PID and on further tuning the controller results in better steady state plot. Genetic algorithm Based on natural genetics and natural selection has proved to be the best controller as the steady state error is minimum in this case.[7]

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