International Journal for Modern Trends in Science and Technology, 6(11): 157-164, 2020

ISSN: 2455-3778 online
DOI: https://doi.org/10.46501/IJMTST061130
Available online at: http://www.ijmtst.com/vol6issue11.html

Speed Control of DC Motor Using Intelligent Controllers

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To Cite this Article
M. Venkatesh and G. Raja Rao, "Speed Control of DC Motor Using Intelligent Controllers", *International Journal for Modern Trends in Science and Technology*, 6(11): 157-164, 2020.

Article Info
Received on 26-October-2020, Revised on 18-November-2020, Accepted on 25-November-2020, Published on 27-November-2020.

ABSTRACT

DC Motors are broadly utilized in mechanical applications, home appliances and robot controllers on account of their high unwavering quality, adaptability and low cost, where speed and position control of motor are required. The activity of a DC motor is performed by conventional controllers and intelligent controllers in MATLAB environment. The speed control of a dc motor utilizing conventional controllers (PID, IMC) and intelligent controllers (FLC, ANFIS) in view of MATLAB simulation program. A numerical model of the process has been created utilizing genuine plant information and afterward conventional controllers and intelligent controllers has been planned. The outcome acquired as rise time, settling time. Out of these controllers FUZZY can give a superior outcome. Another intelligent controller like ANFIS Controller was created based on Sugeno type FIS along with PID can give a superior performance like quicker settling time, and its sensitivity to applied load. A relative investigation of execution assessment of all controllers has been finished.

KEYWORDS:*DC Motor, PID, IMC, FUZZY, ANFIS, MAMDANI, SUGENO*

I. INTRODUCTION

One of the most broadly utilized modern applications is DC motor as a result of its high dependability, ease and its high adaptability. These DC motors are utilized in robot controllers, home apparatuses, including transports, Cranes, Vacuum cleaner, sewing machine and others for which movable speed and steady or low speed force are required. DC motors convert electrical energy into mechanical energy through the collaboration of two attractive fields, one field is delivered by a magnet of poles gathering, the other field is created by an electrical flowing in the motor windings. These two fields bring about a force which will in general rotate the rotor. The advantage of DC motors is its speed control over a wide reach both or more the rated speed, it has high starting torque and most appropriate for electric traction and free from harmonics. The disadvantage is it has high initial cost, can't operate in explosive and danger conditions.

II. LITERATURE SURVEY

In modern regions, DC motor plays a vital role and are widely utilized, where speed and position control of motor are required. This paper deals the assessment of various conventional controllers like PI, PID, IMC controllers and also Ziegler Nichols frequency response method and intelligent controllers like Fuzzy Logic Controller and ANFIS controller. PID controllers are most commonly used due to basic structure and controlling algorithm for motor control. The parameters of PID controllers are adjust usually by Ziegler-Nichols frequency method, because need to get the system into oscillation mode to realize tuning procedure. In process control, IMC configuration is utilized to get the desired set points and reject small external disturbances then a perfect control can be accomplished. The DC motor control utilizing the conventional PID are inadequate and more effective control approaches are required. These challenges can overcome by IMC. ANFIS controller can give better performance rather than every above controller. In this paper DC shunt motor is used as a result of their automatic speed capabilities, DC shunt motors are ideal for applications where exact speed control is required and that they can't deliver high starting torque, so the load at startup must be little. In this work, DC motor under conventional controllers like PI, PID and IMC tuned PID controllers additionally Ziegler-Nichols technique and intelligent controllers like FLC and ANFIS gives result, for example, settling time, rise time and speed. In this ANFIS in DC motor gives better performance in all parameters.

III. MATHEMATICAL MODELLING OF DC MOTOR

DC motors can undoubtedly changes electrical energy into mechanical energy through the interaction of two magnetic fields, one field is produced by a magnet of poles assembly, the other field is produced by an electrical current in motor windings. These two fields result in a torque which tends to rotate the rotor.

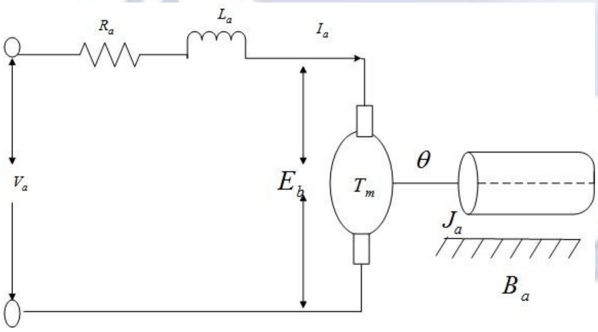

Figure 1. DC shunt motor model

The armature voltage is given by,

$$V_a(t) = R_a.I_a(t) + L_a.\frac{dI_a}{dt} + E_b(t)$$

Equation for back emf of motor will be

$$E_b(t) = K_b\omega(t)$$

Torque of DC motor is proportional to product of flux and current. Since flux is constant so torque equation will be given by

$$T_m(t) = k_t.I_a(t)$$

$$T_m(t) = J\frac{d\omega(t)}{dt} + B\omega(t)$$

Where,

K_t = Torque constant (Nm/A)

K_b = back emf constant (Vs/rad)

Let us combine the above equations, then

$$V_a(t) = R_a.I_a(t) + L_a.\frac{dI_a(t)}{dt} + K_b\omega(t)$$

$$K_t.I_a(t) = J\frac{d\omega(s)}{dt} + B\omega(t)$$

Taking Laplace transformations for above equations with zero initial conditions, we get

$$V_a(s) = R_a.I_a(s) + L_a.I_a(s) + K_b\omega(s)$$

$$K_t.I_a(s) = J\omega(s) + B\omega(s)$$

If current is obtained from above equation then Va(s) becomes as

$$V_a(s) = \frac{\omega(s)}{k_t[L_a.Js^2 + J.R_a + L_a.B(s) + K_b.K_t]}$$

So, the relation between rotor shaft speed and applied armature voltage is represented by transfer function

$$\frac{\omega(s)}{V_a(s)} = \frac{K_t}{(JL_as^2 + (JR_a + BL_a)s + (K_tK_b + BR_a))}$$

This is the transfer function of DC motor.

Consider the following values for the physical parameters

Armature inductance (L_a) = 0.5H

Armature resistance (R_a) = 1 ohm

Armature voltage (V_a) = 200V

Mechanical inertia (J) = 0.01Kg.m2

Friction coefficient (B) = 0.1 N-m/rad/sec

Back emf coefficient K_b = 0.01 V/rad/sec

Motor torque equation K_t = 0.01 N-m/A

Rated speed = 1450rpm

Based on the above values the transfer function is,

$$\frac{\omega(s)}{V_a(s)} = \frac{2}{s^2 + 12s + 20.02}$$

IV. SPEED CONTROL OF DC MOTOR

The purpose of speed control for different drives can be essentially represented high productivity, proper-operations, and high quality products. The desired change in speed is accomplished by acting accordingly on the motor. This might be done physically by the operator (or) by means of some automatic control device. It is found right now that electrical speed-control has many economical as well as engineering advantages over mechanical speed control.

[1] Conventional Controllers

The conventional controllers include Proportional(P),Integral(I),Derivative(D), Proportional-plus-Integral(PI), Proportional-plus-Integral-plus-Derivative(PID) controllers and Internal Modal Controller (IMC).

i. Proportional-integral (PI) Controller

Proportional Integral (PI) controllers are one of the most applicable controllers in various industries. The primary significant need in use of these controllers is their parameters tuning to get the desired result. So an open strategy with high precision and speed must be utilized for assurance of these control parameters.[7]

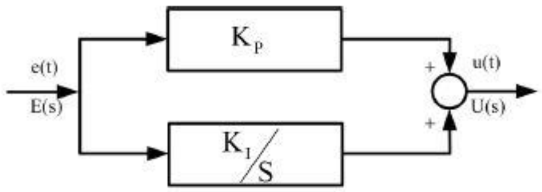

Figure 2. Block diagram of PI controller

The transfer function is given as

$$K(s) = K_p\left[1 + \frac{1}{T_i(s)}\right]$$

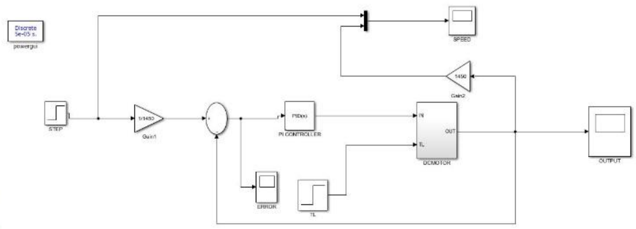

Figure 3. PI controller Simulink model

ii. proportional-integral-derivative(PID) Controller

Proportional Integral Derivative controllers are broadly utilized in modern control frameworks due to the reduced number of parameters to be tuned[4]. They give control signals that are corresponding to the error between the reference signal and the actual output to integral of error and to the derivative of the error[6].

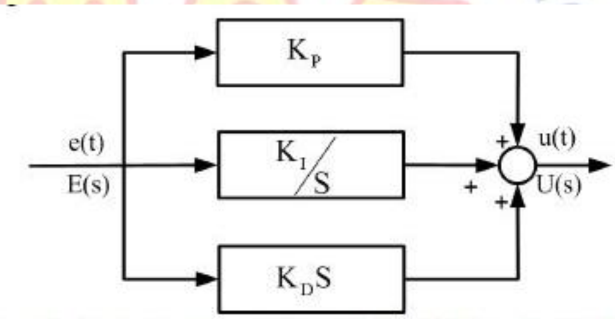

Figure 4. Block diagram of PID controller

The transfer function is given as

$$K(s) = K_p\left[1 + \frac{1}{T_i(s)} + T_d(s)\right]$$

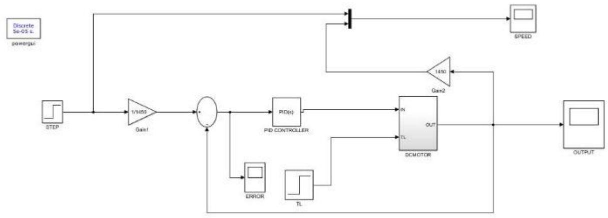

Figure 5. PID controller Simulink model

Ziegler-Nichols rule is a heuristic PID tuning method that attempts to produce good values for PID gain parameters.

It is performed by setting the I(integral) and D (derivative) gains to zero. The P (proportional) gain, K_p is then increased from zero until it arrives ultimate gain K_u, which is the largest gain at which the output of control loop has stable and consistent oscillations; higher gains than a ultimate gain K_u have diverging oscillations and oscillation period T_u and then used to set the P, I, D gains relying upon type of controller.

From the outcome, the total process relies upon two variables and the other systematize parameters are resolved according to the table.

Type of controller	*Kp*	*Ti*	*Td*
P	0.5*Kc*	∞	0
PI	0.45Kc	0.83T	0
PID	0.6*Kc*	0.5T	0.125T

Table 1. Closed loop oscillation based tuning methods

iii. *Internal mode control (IMC)*

The theory of IMC states that "control can be accomplished only if the control system encapsulates, either implicitly or explicitly, some representation of the process to be controlled".[2,9]

The IMC controller depends on the inverse of the process model and the gain becomes utility and have an ideal set-point tracking.[10] The main feature of internal model controller is that the process model is in parallel with the actual process.

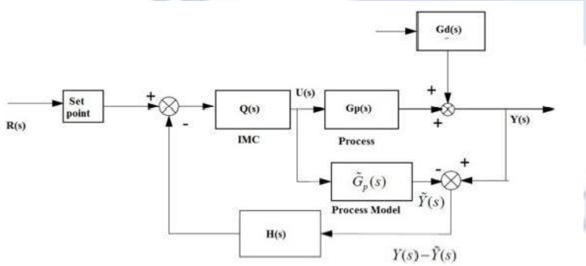

Figure 6. IMC module control scheme

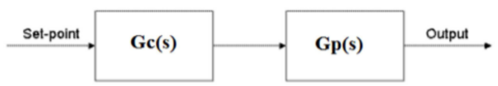

Figure 7. Equivalent block diagram of IMC

A controller $G_c(s)$ has been used to control the process $G_p(s)$

$$G_c(s) = \frac{Q(s)}{1-\tilde{G}_p(s).Q(s)}$$

And if

$$G_p(s) = \tilde{G}_p(s)$$

The model is an exact representation of process, at that point obviously the yield will consistently equivalent to set point. Notice that this is an ideal control performance accomplished without feedback[11,12]

Designed the IMC controller as

$$G_{IMC)} = Q(s) = [\tilde{G}_p(s)]^{-1} G_f(s)$$

Where $G_f(s)$ is a low pass function defined as

$$G_f(s) = \frac{1}{(1+\lambda s)^n}$$

Here we consider second order low pass filter (n=2)

Thus $G_f(s) = \dfrac{1}{(1+\lambda s)^2}$

Now,

$$G_p(s) = \frac{K_t}{J_m L_a S^2 + (J_m R_a + B_m L_a)s + (K_t K_b + B_m R_a)}$$

After substituting all given data

$$G_p(s) = \frac{2}{s^2 + 12s + 20.02}$$

A good rule of thumb is to choose λ to be twice fast as open loop response.

λ =0.9, Then $G_f(s) = \dfrac{1}{(1+0.9s)^2}$

Thus,

$Q(s) = [\tilde{G}_p(s)]^{-1} G_f(s)$ becomes,

$$Q(s) = \frac{S^2 + 12s + 20.02}{1.62S^2 + 3.6s + 2}$$

Hence

$$G_c(s) = \frac{Q(s)}{1-\tilde{G}_p(s).Q(s)}$$

Implies

$$G_c(s) = \frac{S^2 + 12s + 20.02}{1.62S^2 + 3.6s + 0}$$

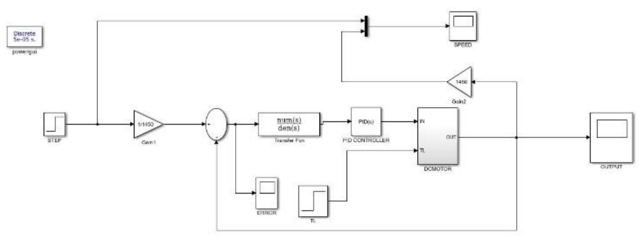

Figure 8. IMC controller Simulink model

[2] Intelligent Controllers

Intelligent control is a class of control procedures that utilization different man-made reasoning processing approaches like neural organizations, Bayesian probability, fuzzy logic, reinforcement learning, evolutionary computation and genetic algorithms

1. Fuzzy logic controller (FLC)

In recent years, the number and variety of applications of fuzzy logic have increased significantly. Fuzzy theory was first proposed and researched by Prof Zadeh in 1965.

A typical fuzzy controller infers the consequence of more or less large simple rules, this process of reasoning can be performed in parallel, yielding the result with a simple logical sum[1,3].

The defuzzification is utilized to change fuzzy set created by the inference mechanism into a crisp output to be utilized by the plant.

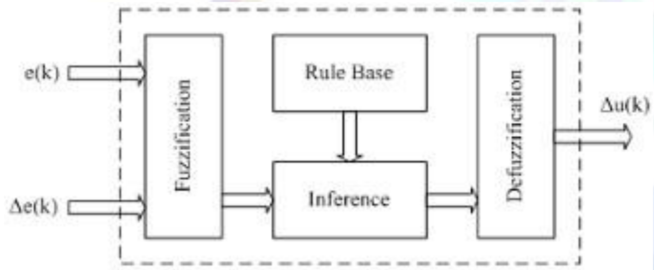

Figure 9. structure of Fuzzy Logic Controller

The system utilizes measured variables as inputs to describe the error from the DC motor. These inputs are then "fuzzified" using membership function provided by a specialist operator to decide the degree of membership in each input class[8,13]. The resulting fuzzy inputs are evaluated utilizing a linguistic rule base and fuzzy logic operation to yield a proper yield and an appropriate output and an associated level of membership.[5]

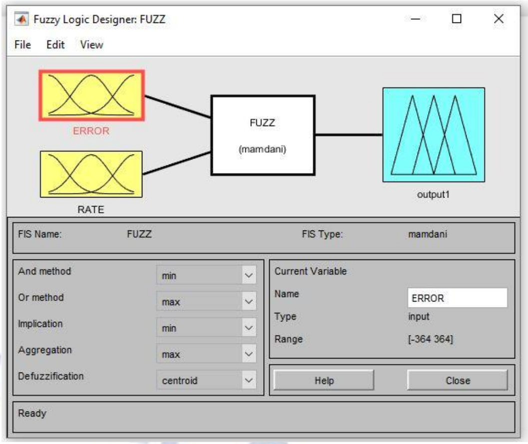

Figure 10. FLC designer

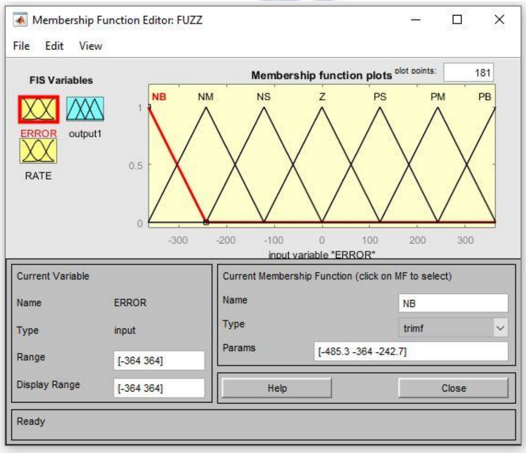

Figure 11. Membership function editor

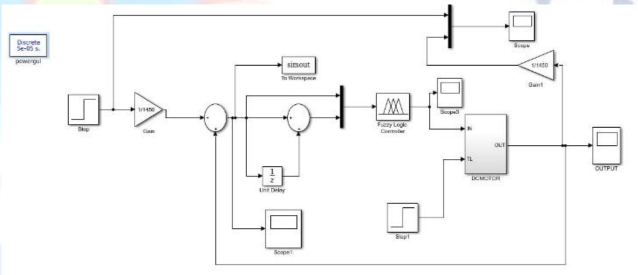

Figure 12. FLC controller Simulink model

2. Adaptive neuro fuzzy inference system (ANFIS)

ANFIS is a hybrid network which consists of a combination of two controllers; Fuzzy logic and neural network.

These both controllers result in a single entity which enhances the features of controlling machine than using a single controller alone[14].

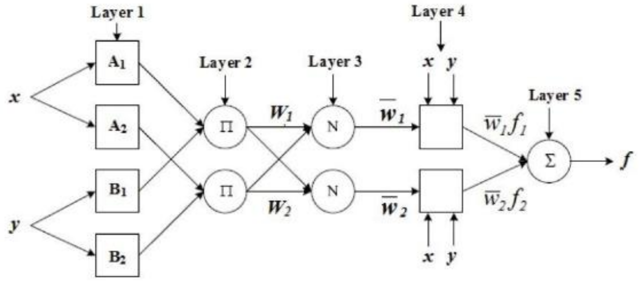

Figure 13. First order Sugeno ANFIS architecture

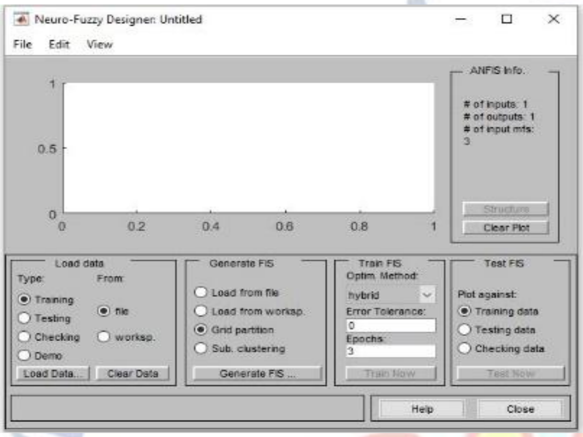

Figure 14. Neuro fuzzy designer

ANFIS editor window will open by typing "anfisedit" in MATLAB command window.

ANFIS GUI involves following steps:

1. *Load data:* This will load previously saved data from .dat extension file.
2. *Generate FIS:* FIS model had generated by using Grid partititon.
3. *Training and validation of FIS:* This process trains FIS model generated and repeat itself until the required number of epoch is reached and goal of training error is attained. By considering epochs=50 and click on "train now". Here "train now" shows the value of Epochs error.

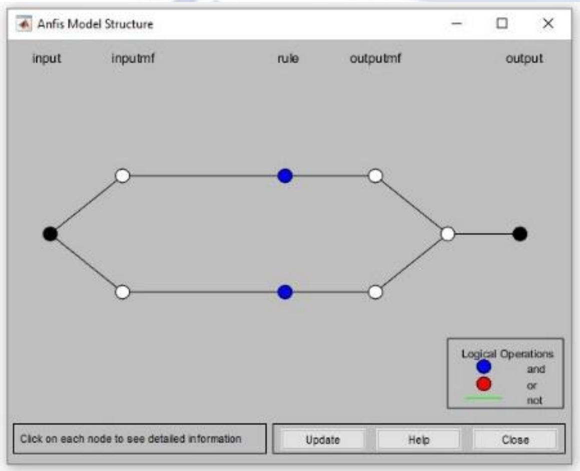

Figure 15. ANFIS model structure

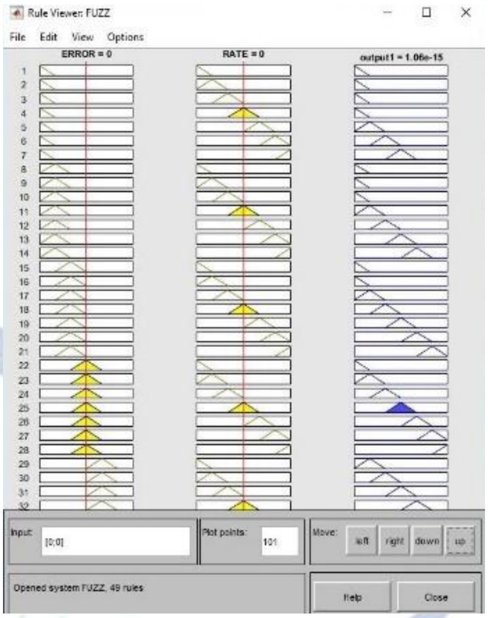

Figure16.Rules view

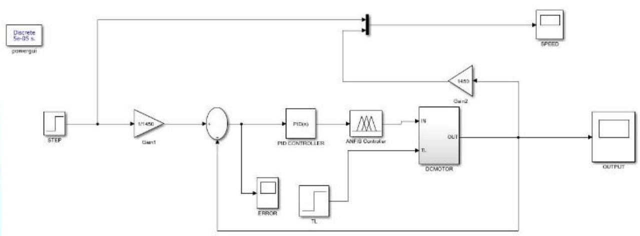

Figure 17. ANFIS controller Simulink model

V. SIMULATION RESULTS AND DISCUSSIONS

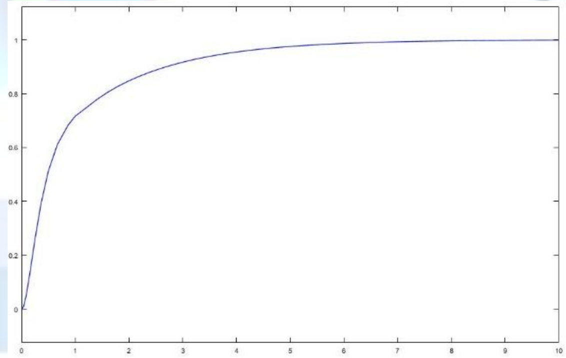

Figure 18. Unit step response of PI controller

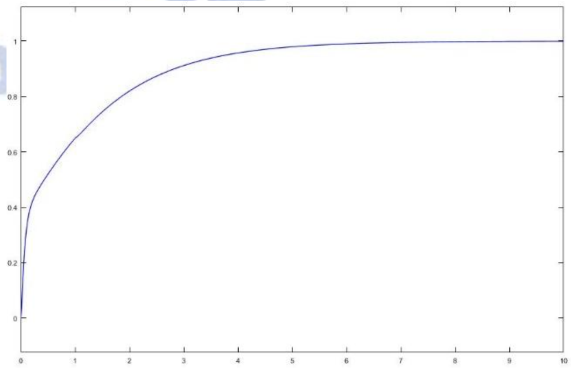

Figure 19. Unit step response of PID controller

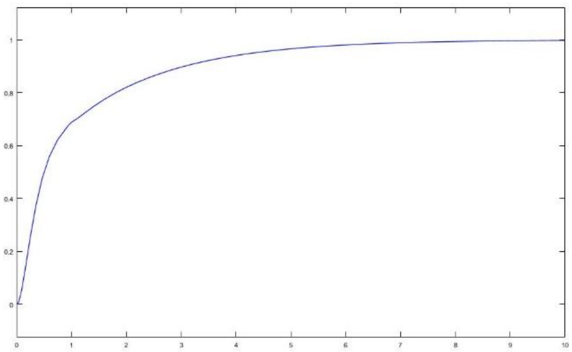

Figure 20. Unit step response of IMC controller

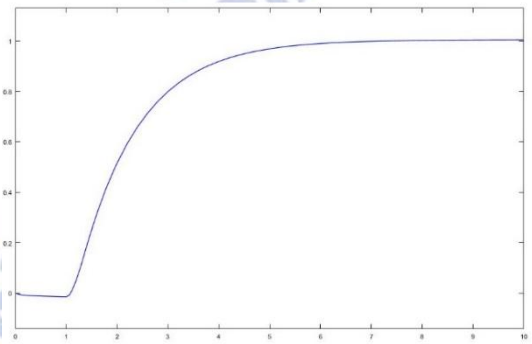

Figure21. Unit step response of FLC controller

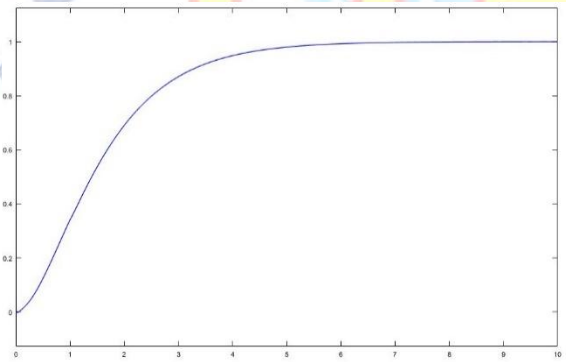

Figure 22. Unit step response of ANFIS controller

To accomplish the ideal objective of speed control of DC motor, DC motor was converted into its equivalent mathematic model and applied control system to it through MATLAB program. As we know, rise time is the time required to reach 90% of the final value and settling time is known as the time required for the response to reach the steady state and stay within the specified tolerance band. Based on the above definitions, rise time and settling time are calculated here.Tabular result shows the numerical comparison of conventional and intelligent controllers.

Tabular Result

Type of the Controller	Rise Time(t_r) sec	Settling Time(t_s) sec	Oscillation
PI	3.5	9.26	NO
PID	3	8.18	NO
IMC-PID	3.12	7.98	NO
FLC	3.77	6.69	NO
ANFIS	3.44	6.41	NO

VI. CONCLUSION

In this paper, comparative studies of performance of different conventional and intelligent controllers has been studied. According to the simulation results it is found that intelligent controllers are better than conventional controllers.

Hence it is concluded that proposed ANFIS controller provides better performance characteristics and improve the control of DC motor.

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