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Comparison of Speed Control of Dc Servo Motor using Pi, PID, Fuzzy, SMC

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Abstract: DC servo motor is widely used in many applications like Robotics, Conveyor Belts and Camera. In this paper a dc servo motor using MATLAB has been designed whose speed may be investigated using the Proportional, Integral, Derivative (K_P, K_I, K_D) gain of the PID controller. The purpose of this paper is to design a Ziegler-Nichols controller to improve the performance (speed) of the DC motor in order to control the speed of the motor. The results are compared with controller tuned by PI, PID Ziegler- Nichols method. Since, classical controllers like P, PI and PID are failing to control the drive when weight parameters are also changed. The PID controller has some disadvantages like: high overshoot, sensitivity to controller gains and slow response. Fuzzy control and SMC is proposed in this study. In this paper a comparison among PI, PID and fuzzy logic controller, sliding model controller, through MATLAB/Simulink software have been presented the obtained results are promising and is likely to be utilized by the industries.

Keywords: Control System, Proportional-Integral (P-I) controller, Fuzzy logic control, Sliding mode controller Speed control, Modelling of System, D.C. Servo Motor, MATLAB / SIMULINK

1. INTRODUCTION

Electric motors can be classified by their functions as servomotors, gear motors, and so forth, and by their electrical configurations as DC (direct current) and AC (alternating current) motors.

The Automatic systems are common in our daily life, they can be found in almost any electronic devices and appliances we use daily, starting from air conditioning systems automatic doors and automotive cruise control systems to more advanced technologies such as robotic arms, production lines and thousands of industrial and scientific applications.

The development of high performance motor drives is very important in industrial as well as other purpose applications such as steel rolling mills, electric trains and robotics.

DC servomotors are one of the main components of automatic systems; any automatic system should have an actuator module that makes the system to actually perform its function. Generally, a high performance motor drive system must have good dynamic speed command tracking and load regulating response to perform task.

DC drives, because of their simplicity, ease of application, high reliabilities, flexibilities and favorable cost have long been a backbone of industrial applications, robot manipulators and home appliances where speed and position control of motor are required. The control of the speed of a DC motor with high accuracy is required.

2. MODELING OF D.C SERVOMOTOR

A DC motor may be controlled by varying the input voltage or by changing the input current. In this paper, the DC servo motor model is chosen due to its good electrical and mechanical performances compared to other DC motor models. Consider armature controlled dc motor circuit shown below

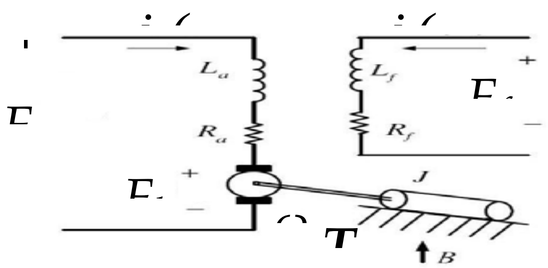

Fig 1 DC servo motor

Where
T or T_m =Torque developed by motor
B =equivalent viscous friction co-efficient of motor
J= equivalent moment of inertia of motor
ω_m =Motor angular velocity
B=Viscous friction coefficient
K_b=Back e.m.f constant
K_T=Torque constant
R or R_a=armature resistance
L or L_a =armature inductance
E_b=back emf of motor
V_a or E_a =armature voltage
I_a=armature current

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The dynamics of a separately excited DC motor may be expressed as:
The air gap flux $\emptyset$ is proportional to the field current

$$\emptyset = K_f I_f \quad (1)$$

Torque developed by motor is proportional to the field current and air gap flux

$$T_m = K_f I_f K_1 I_a \quad (2)$$

In armature controlled dc motor field current is kept constant.

$$T_m = K_T I_a \quad (3)$$

The motor back emf being proportional to speed

$$E_b = K_b \frac{d\omega}{dt} \quad (4)$$

The differential equation of armature current is

$$L\frac{dI_a}{dt} + I_a R_a + E_b = E_a \quad (5)$$

The torque equation is given by

$$J\frac{d^2\omega}{dt^2} + B\frac{d\omega}{dt} = T_m = K_T I_a \quad (6)$$

On taking Laplace transforms on both sides with zero initial conditions we get

$$E_b(s) = K_b s\omega(s) \quad (7)$$

$$(Ls+R)\, I_a(s) + E_b(s) = E_a(s) \quad (8)$$

$$(Js^2+Bs)\omega(s) = K_T I_a(s) \quad (9)$$

The transfer function of the system is given by

$$G(s) = \frac{\omega(s)}{E_a(s)}$$

From eqn.(8)

$$(Ls+R)\, I_a(s) + E_b(s) = E_a(s)$$

$$(Ls+R)\, I_a(s) + K_b s\omega(s) = E_a(s)$$

$$(Ls+R)\, I_a(s) + K_b s * \left(\frac{K_T}{(s^2+Bs)}\right) I_a(s) = E_a(s)$$

$$\left[(Ls+R) + \left(\frac{K_b K_T}{(Js+B)}\right)\right] I_a(s) = E_a(s)$$

$$G(s) = \frac{w_a(s)}{E_a(s)} = \frac{\omega(s)}{I_a(s)} * \frac{I_a(s)}{E_a(s)}$$

Therefore the transfer function of motor is given by

$$G(s) = \frac{K_T}{(s[(Ls+R)(Js+B)+K_b K_T])}$$

The armature circuit inductance is generally negligible i.e. L=0

$$\frac{\omega(s)}{E_a(s)} = G(s) = \frac{K_T}{(s[(R)(Js+B)+K_b K_T])} \quad (10)$$

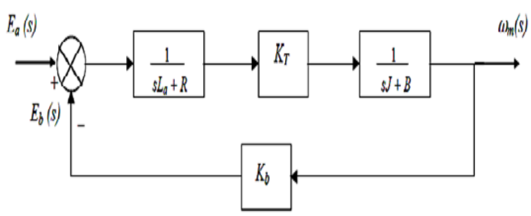

Fig 2 Block diagram of dc servo motor

Transfer function of dc motor is given by

$$\frac{\omega(s)}{E_a(s)} = \frac{0.052}{(0.0002979\, s^2 + 0.01012\, s + 0.092)}$$

3 .PROPORTIONAL PLUS INTEGRAL CONTROLLER DESCRIPTION

The PI controller is standard and proved solution for the most industrial application. The main reason is its relatively simple structure, which can be easily understood and implemented in practice, and that many sophisticated control strategies, such as model predictive control, are based on it. An application with large speed capabilities requires different PI gains than an application which operates at a fixed speed. In addition, industrial equipment that are operating over wide range of speeds, requires different gains at the lower and higher end of the speed range in order to avoid overshoots and oscillations. Generally, tuning the proportional and integral constants for a large speed control process is costly and time consuming. The task is further complicated when incorrect PI constants are sometimes entered due the lack of understanding of the process. The control action of a proportional plus integral controller is defined as by following equation:

$$u(t) = K_p\, e(t) + K_i \int^t e(t)\, dt \quad (11)$$

Where:
u(t) is actuating signal.
e(t) is error signal.
K_p is Proportional gain constant.
K_i is Integral gain constant.

The Laplace transform of the actuating signal incorporating in proportional plus integral control is

$$u(s) = kp\, e(s) + ki\, e(s) \quad (12)$$

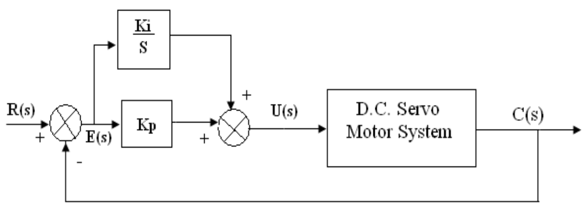

Fig 3 Block diagram of PI Controller

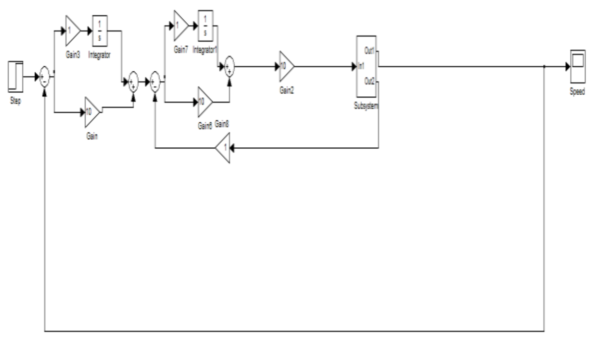

Fig 4 Simulink Model of D.C. Servo Motor Using Pi Controller

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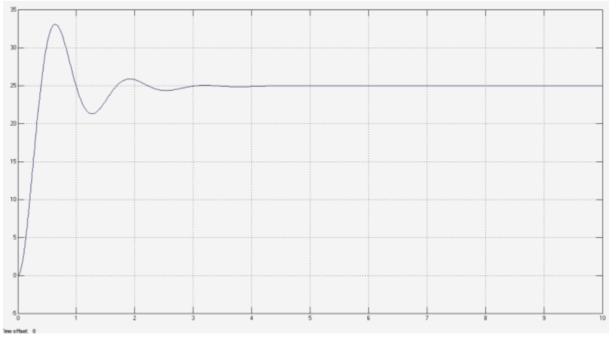

Fig 5 Simulation output of pi controller

4. PROPORTIONAL-INTEGRAL-DERIVATIVE (PID) CONTROLLER

PID controllers are widely used in industrial control applications due to their simple structures, comprehensible control algorithms and low costs. Below figure shows the schematic model of a control system with a PID.P-I-D controller has the optimum control dynamics including zero steady state error, fast response (short rise time), no oscillations and higher stability. The necessity of using a derivative gain component in addition to the PI controller is to eliminate the overshoot and the oscillations occurring in the output response of the system. One of the main advantages of the P-I-D controller is that it can be used with higher order processes including more than single energy storage.

$$u(t) = Kp\; e(t) + Ki \int^{t} e(t)\, dt \quad + k_d\, dt \qquad (13)$$

4.1 ZIEGLER-NICHOLS METHOD

More than six decades ago, P-I controllers were more widely used than P-I-D controllers. Despite the fact that P-I-D controller is faster and has no oscillation, it tends to be unstable in the condition of even small changes in the input set point or any disturbances to the process than P-I controllers. Ziegler-Nichols Method is one of the most effective methods that increase the usage of P-I-D controllers

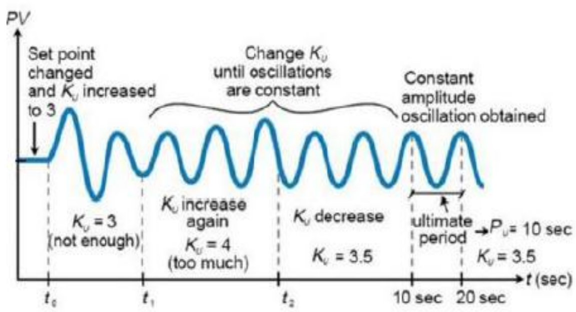

Fig 6 Ziegler-Nichols P-I-D controller tuning method

The logic comes from the neutral heuristic principle. Firstly, it is checked that whether the desired proportional control gain is positive or negative. For this, step input is manually increased a little, if the steady state output increases as well it is positive, otherwise; it is negative. Then, K_i and K_d are set to zero and only K_p value is increased until it creates a periodic oscillation at the output response. This critical K_p value is attained to be "ultimate gain", K_c and the period where the oscillation occurs is named as Pc "ultimate period". As a result, the whole process depends on two variables and the other control parameters are calculated according to the table.

Type of controller	K_p	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	$\frac{1}{1.2}P_{cr}$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

Fig **7** Estimation value for gain, reset and derivative

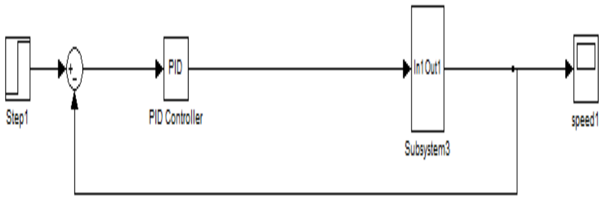

Fig 8 Simulink Model of D.C. Servo Motor using pid controller

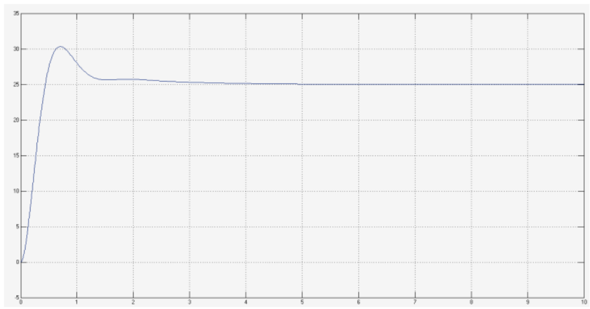

Fig 9 simulation output of pid

5. FUZZY LOGIC CONTROLLER DESCRIPTION

Fuzzy logic control is a control algorithm based on a linguistic control strategy, which is derived from expert knowledge into an automatic control strategy. Fuzzy logic control doesn't need any difficult mathematical calculation like the others control system. While the others control system use difficult mathematical calculation to provide a model of the controlled plant, it only uses simple mathematical calculation to simulate the expert knowledge. Although it doesn't need any difficult mathematical calculation, but it can give good performance in a control system Thus, it can be one of the best available answers today for a broad class of challenging controls problems. A fuzzy logic control usually consists of the following:

FUZZIFICATION

This process converts or transforms the measured inputs called crisp values, into the fuzzy linguistic values used by the fuzzy reasoning mechanism.

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KNOWLEDGE BASE
A collection of the expert control rules (knowledge) needed to achieve the control goal.

FUZZY REASONING MECHANISM
This process will perform fuzzy logic operations and result the control action according to the fuzzy inputs.

DEFUZZIFICATION UNIT
This process converts the result of fuzzy reasoning mechanism into the required crisp value.

FUZZY CONTROLLER DESIGN
The most important things in fuzzy logic control system designs are the process design of membership functions for inputs, outputs and the process design of fuzzy if-then rule knowledge base. They are very important in fuzzy logic control. The basic structure of Fuzzy Logic Controller is given in the D.C drive, speed error (E) and change in speed error (CE) are taken as the two inputs for the fuzzy controller and one output control input (CI). For this, a three-member as well as a seven-member rule base is devised. The rule base for seven membership functions is shown in Table

CE	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NM	NS	NS	Z
NM	NL	NL	NM	NS	NS	Z	PS
NS	NL	NM	NS	NS	Z	PS	PM
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PS	PM	PL
PM	NS	Z	PS	PS	PM	PL	PL
PL	Z	PS	PS	PM	PL	PL	PL

Fig 10.Fuzzy rules table

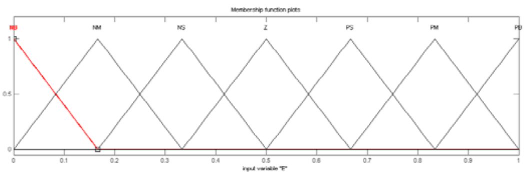

Fig 11 Error

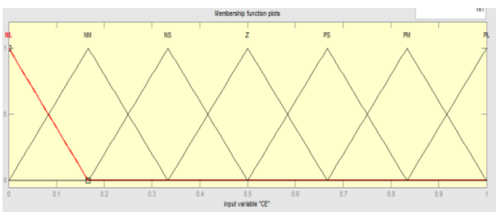

Fig 12 Change in error

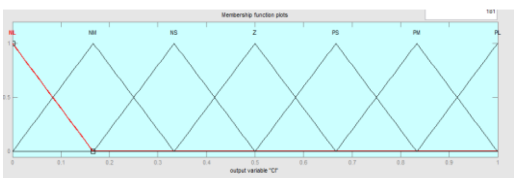

Fig 13 Change in input

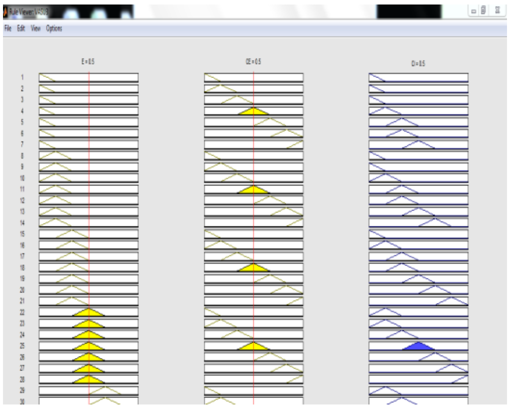

Fig 14 Rule View of FLC

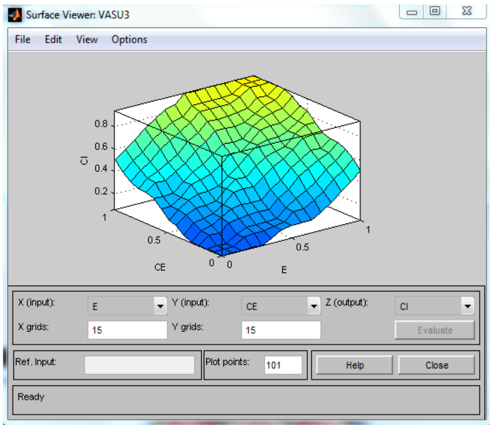

Fig 15 Surface View of FLC Block diagram

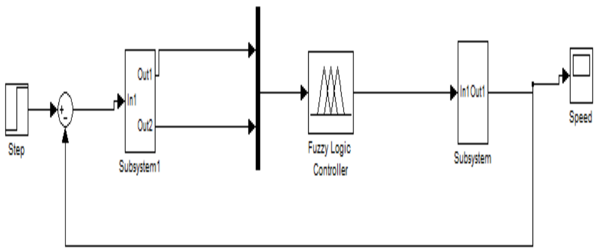

Fig 16 Simulink Model of D.C. Servo Motor using fuzzy logic controller

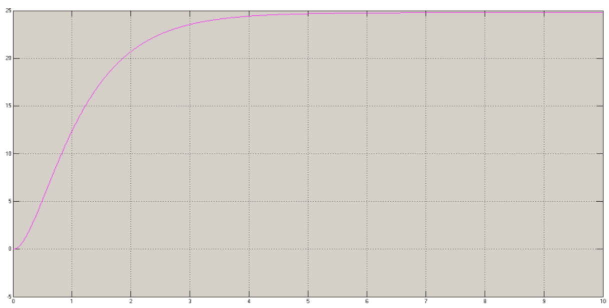

Fig.17 simulation output fuzzy logic controller

6. SLIDING MODE CONTROLLER

VSS (variable structure system) is well known as special class of nonlinear systems for solving several specific control tasks in second order linear and nonlinear systems.

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However VSS did not receive wide acceptance among engineering professionals until the first survey paper that is IEEE Transactions on Automatic Control in 1977 was published by Utkin. The most interesting fact is that robustness has becomes a major requirement in modern control application.

The most distinguishing property of VSS is its ability to result in very robust control systems. In other words, the system is completely insensitive to parametric uncertainty and external disturbances. Due to its excellent invariance and robustness properties, the VSS concepts have been developed into practical application mainly in the field of control of DC servo motors, robotic manipulators, PM synchronous servomotors, induction motors, aircraft control, spacecraft control and flexible space structure control. These experiments confirm the theoretical results regarding robustness of VSS with sliding modes. However, in some of these experimental results, it was found that the resulting control is discontinuous and the chattering phenomenon which can leads to low accuracy in control system.

These problems can be solved by replacing a continuous control into the computation of the control input (a sign function). As a result, the large error behaviour of a system is identical to that with discontinuous control. It can be assumed that, the behaviour of the system in small error region as a high gain system and this is similar to that of system with discontinuous control. Hence, this high gain effect of sliding mode control based on VSS, suppressed the uncertainties due to parametric variations, external disturbances and variable payloads.

Besides that the proper selection of the switching functions will avoid chattering problem in the DC drive systems, hence result in high accuracy control. The choice of switching functions to control the system states, such that current, speed or position has been discussed and examined in detail in literature under this control strategy, the dynamic performance of the system can be shaped according to the system specification by an appropriate choice of switching function.

It is well known, that the sliding mode control is a popular robust control Method. However it has a reaching phase problem and an input chattering problem (as discussed above). These problems cause the sliding mode control (SMC) is very conservative to be used with other controller design methods because the state trajectory of the sliding mode control system is determined by sliding mode dynamics, which cannot have the same order dynamics of the original system.

This leads to the introduction of robust controller design with novel sliding surface. To overcome the conservatism of the SMC, the novel sliding surface has been used which the same dynamics of the nominal original system has controlled by a nominal controller. The reaching phase problem can be eliminated, by using an initial virtual state that makes the initial sliding function equal to zero. Therefore, it is possible to use the SMC technique with various types of controller.

A linear system can be described in the state space as follows

$$\dot{x} = Ax+Bu \quad (14)$$

Where $x \in R^n$, u ∈ R, A ∈ R^{n*n}, and B∈ R^{n} and B is full rank matrix. A and B are controllable matrixes. The functions of state variables are known as switching function

$$\sigma = sx \quad (15)$$

The main idea in sliding mode control is to Design the switching function so that $\sigma = 0$ (sliding mode) provide the desired dynamic.

Finding a controller ensuring sliding mode of the system occurs in finite time First of all, the system should be converted to its regular form

$$\bar{x} = T_x \quad (16)$$

T is the matrix that brings the system to its regular form

$$\dot{\bar{x}}_1 = \bar{A}_{11}\bar{x}_1 + \bar{A}_{12}\bar{x}_2$$
$$\dot{\bar{x}}_2 = \bar{A}_{21}\bar{x}_1 + \bar{A}_{22}\bar{x}_2 + \bar{B}_2 \quad (17)$$

The switching function in regular form

$$\sigma = s_1\bar{x}_1 + s_2\bar{x}_2 \quad (18)$$

on the sliding mode manifold ($\sigma = 0$)

$$0 = s_1\bar{x}_1 + s_2\bar{x}_2$$
$$\bar{x}_2 = -s_2^{-1}s_1\bar{x}_1 \quad (19)$$

From (16) &(19)

$$\dot{\bar{x}}_1 = \bar{A}_{11}\bar{x}_1 - \bar{A}_{12}s_2^{-1}s_1$$
$$\dot{\bar{x}}_1 = (\bar{A}_{11} - \bar{A}_{12}s_2^{-1}s_1)\bar{x}_1 \quad (20)$$

One of matrixes in product: $s_2^{-1}s_1$ should be chosen arbitrary. Usually (21) is used to ensure that s_2 is invertible

$$s_2 = \bar{B}_2^{-1} \quad (21)$$

s_1 can be calculated by assigning the Eigen value of (20) by pole placement method. Hence, switching function will be obtained as follows

$$S = [\,s_1 \quad s_2\,]\,T \quad (22)$$

The control rule is

$$u = u_c + u_d \quad (23)$$

Where u_c and u_d are continuous and discrete parts, respectively and can be calculated as follows

$$u_c = -\widetilde{A}_{21}\,x_1 - \widetilde{A}_{22}\sigma \quad (24)$$
$$u_d = -K_s \operatorname{sgn}\sigma - K_p \quad (25)$$

where sgn is sign function. K_s, and K_p are constants calculated regarding to lyapunov stability function.

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6.2 MODELLING OF DC SERVO MOTOR

The state space model of DC motor is as follows
The modelling and state space model of dc motor is already discussed

$$\dot{x} = Ax + Bu = \begin{bmatrix} -\frac{b}{J} & \frac{k_m}{J} \\ -\frac{k_e}{L} & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{L} \end{bmatrix} u \qquad (26)$$

In this equation x is two dimensional vector

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

Where
x_1= angular velocity of shaft.
x_2= armature current.
u is the armature voltage.
R= resistance of armature coil.
L= inductance of the armature coil.
k_e = velocity constant.
k_m = torque constant.

By using the Laplace transform of (26), the transfer functions of system according to angular speed of shaft (ω (s)) and armature voltage (U(s)) can be calculated

Take $\dot{\theta}$(s)= ω (s) and $E_a(s)$=U(s) from motor model we have

$$\frac{\omega(s)}{U(s)} = \frac{k_m}{([(Ls+R)(Js+B)+k_e k_m])}$$

Therefore the state space model is

$$\begin{bmatrix} \dot{x_1} \\ \dot{x_2} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ A_1 & A_2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{k_m}{JL} \end{bmatrix} u \qquad (27)$$

Where $A_1 = -\left(\frac{(Rb + k_e k_m)}{JL}\right)$ (28)

$A_2 = -\left(\left(\frac{b}{J}\right) + \left(\frac{R}{L}\right)\right)$ (29)

The methodology to design switching function is
U=$-s_2$ [A_1 ω- A_1 (ω-r) +s_2 (A_1+$A_2\lambda$ - λ^2) (ω-r) + (A_2- λ) σ +$k_s$sgn(σ)+ k_p σ]
U=1/174.5((33.97 e(t))-(c-30.8)e(t)+k sign(s)

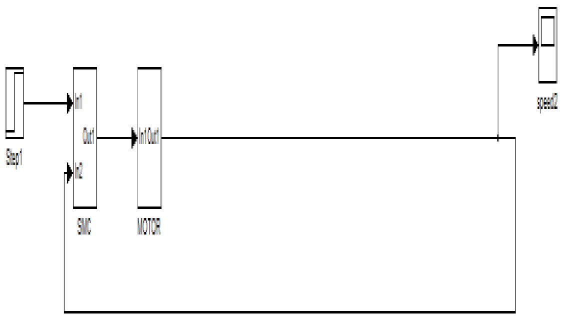

Fig 18 Simulink Model of D.C. Servo Motor using sliding mode controller

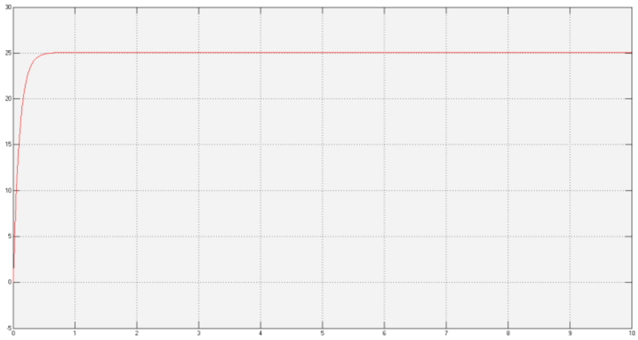

Fig 19 Simulink output of sliding mode controller

7. D.C. SERVO MOTOR PARAMETER

The motor used in this experiment is a 25V D.C. motor with no load speed of 4050 rpm
R-resistance 1 Ω
L-inductance 29.79 mH
J-moment of inertia 0.01 kg.m^2
K_t -torque constant 0.052 Nm/A
K_b-electromotive force constant 0.1 V/rad/s
B-viscous friction coefficient 0.004 N.m/rad/s

8. CONCLUSION

For the speed control of dcservo motor drives, it is observed that Sliding mode controller gives a better response compared than other controllers.

REFERENCES

[1] "SIMULINK User's Guide", The Math Works Inc. 1992.
[2] E.H. Mamdani, "Application of Fuzzy Algorithm for Control of Simple Dynamic Plant", Proc. IEE121 (12), pp.1585-1588, 1974.
[3] V M Venkateswara Rao , "Performance Analysis Of Speed Control Of Dc Motor Using P, PI, PD And PID Controllers" International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 5, May - 2013 ISSN: 2278-0181.
[4] Gopal K. Dubey, "Fundamental of electrical Drives", Narosa Publication 2009.
[5] Stephen, J.2005, "Electric Machinery Fundamentals", Hand Book, Fourth Edition, McGraw Hill, Higher Education, Australia.
[6] Khuntia, K.B. Mohanty, S. Panda and C. Ardil, "A Comparative Study of P-I, I-P, Fuzzy and Neuro-Fuzzy Controllers for Speed Control of DC Motor Drive", International Journal of Electrical and Computer.
[7] I. H. Altas and A .M. Sharaf, "A Generalized Direct Approach for Designing Fuzzy Logic Controllers in Matlab/ Simulink GUI environment", International Journal of Information Technology and Intelligent Computing, Int.J. IT&IC no.4 vol.1, 2007.