SPEED CONTROL OF DC MOTOR USING ADAPTIVE PID WITH SMC SCHEME

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Abstract - *Direct Current (DC) motors have been used extensively in industry mainly because of the simple strategies required to achieve good performance in speed or position Control applications. The sliding mode control approach is recognised as an efficient tool to design robust controllers for complex high-order nonlinear dynamic plant operating under uncertain conditions. The research in this area initiated in the former Soviet Union about 40 years ago, and the sliding mode control methodology has subsequently received much more attention from the international control community within the last two decades. Due to the robustness of Sliding Mode Control (SMC), especially against parameters variations and external disturbances, and its ability in controlling linear and nonlinear systems. This thesis deals with the Adaptive PID with sliding mode control adjustment of a speed control for DC motor. Firstly, the thesis introduces the principle of sliding mode control method. Then, design SMC controller for DC motor after that design Adaptive PID with SMC controller then the performance of dc motor with adaptive PID with SMC is compared with SMC and PID controllers is made on the real model of the DC motor. After obtaining the entire model of speed control system, Performance of these controllers has been verified through simulation results using MATLAB/SIMULINK software. The simulation results shows that Adaptive PID with SMC controller was a superior controller than SMC and PID controllers for speed control of a separately excited DC motor. The performance of DC motor with these controllers, clearly observe Settling time, Rise time and Overshoot. Adaptiv*e PID SMC controller gives best results considering above three conditions and also this controller is very robust controller. That is irrespective of any disturbances Adaptive PID SMC produce the same output.*

1.INTRODUCTION

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. 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.

DC drives are less complex with a single power conversion from AC to DC. Again the speed torque characteristics of DC motors are much more superior to That of AC motors. A DC motors provide excellent control of speed for acceleration and deceleration. DC drives are normally less expensive for most horsepower ratings. DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose. In these applications, the motor should be precisely controlled to give the desired performance. The controllers of the speed that are conceived for goal to control the speed of DC motor to execute one variety of tasks, is of several conventional and numeric controller types, the controllers can be: proportional integral (PI), proportional integral derivative (PID),sliding mode controller etc…The proportional –integral – derivative (PID) controller operates the majority of the control system in the world. It has been reported that more than 95% of the controllers in the industrial process control applications are of PID type as no other controller match the simplicity, clear functionality, applicability and ease of use offered by the PID controller. PID controllers provide robust and reliable performance for most systems if the PID parameters are tuned properly. The major problems in applying a conventional control algorithm (PI, PD, PID) in a speed controller are the effects of non-linearity in a DC motor. The nonlinear characteristics of a DC motor such as saturation and fiction could degrade the performance of conventional controllers. Generally, an accurate nonlinear model of an actual DC motor is difficult to find and parameter obtained from systems identification may be only approximated values. The field of sliding mode control has been making rapid progress in recent years. Interests in the application of sliding mode control technique in variable speed drives have increased in recent years. It is well known that a distinguished property of a sliding mode control technique is its insensitivity to system uncertainties and external disturbances. Compared to the conventional PI controller, the system is sensitive to the parameter variations and inadequate rejection of external disturbances or load variations. Furthermore in order to design PI controller, the challenge faced by the researchers due to multi loop system structure and trial and error design approach which make the control design time consuming and expensive. This has lead to the development of the sliding modes control technique, which is very attractive for its excellent performance, easy to implement with simple control algorithm. It is desirable to achieve robust performance against external disturbances especially sudden or step load applications.

This paper deals with the Adaptive PID with sliding mode control adjustment of a speed control for DC motor. Firstly, the paper introduces the principle of sliding mode control method. Then, design controller for DC motor after that the performance is compared with the performance of PID and SMC is made on the real model of the DC motor .The main result of the paper is the analysis the adaptive sliding mode control. After obtaining the entire model of speed control system, the model is utilized with MATLAB (SIMULINK). The simulations of the performance comparisons between Adaptive PID with sliding mode control and PID control show that variable structure system with sliding mode control approach is less sensitive to parameter variations, produce faster dynamic response, eliminate overshoot and performs better in rejecting disturbance. The excellent features of the sliding mode control based on variable structure system are mainly due to the high gain effect, which suppresses influence of disturbances and uncertainties in system behavior.

2.MODELLING OF DC MOTOR

A separately excited dc motor has the simplest decoupled electromagnetic structure. A schematic diagram of the separately excited DC motor is shown in Fig.1.

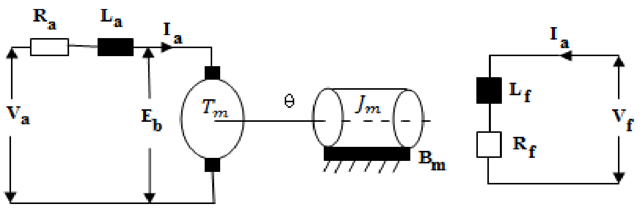

Figure 2.1: A Separately excited DC motor

The armature controlled method for speed control of DC motor is considered here. The armature current is controlled to generate desired electromagnetic torque and the armature voltage is controlled for the load. The field excitation is kept constant to produce rated flux. For a constant field excitation the armature circuit electrical equation of a separately excited
DC motor is written as:

$$L_a \frac{dI_a}{dt} + I_a R_a + E_b = E_a \qquad (1)$$

where E_a is the Applied Voltage, R_a is the armature resistance, L_a is the Equivalent armature inductance, Ia current flowing through armature circuit, Eb is the back emf and. The dynamics of the mechanical system is given by the torque balance equation :

$$J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} + T_l = T_m = K_t I_a \qquad (2)$$

where T_m is the developed torque, T_l is the load torque, J is the moment of inertia, B is the damping constant, and K_t = Torque constant. E_b represents electromotive force in V given by

$$E_b(t) = K_b\, \omega(t) \qquad (3)$$

Where K_b is the back emf constant in Vs/rad. The input terminal voltage V_a is taken to be the controlling variable. one can write state model with the ω and I_a as state variables and V_a as manipulating variable, as given below

Let

$$x_1 = \theta$$

$$\dot{x}_1 = x_2 = \dot{\theta} = \omega$$

$$x_3 = I_a$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ A_1 & A_2 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{K_m}{JL} \end{bmatrix} u \qquad (4)$$

$R_a = 1.2\ ohm$	$K_b = 0.6\ V\ s/rad$
$L_a = 0.05\ H$	$J = 0.1352\ Kg\ m^2/s^2$
$K_t = 0.6\ Nm/Amp$	$b = 0\ Nms$

Table. 1 : Parameters of DC motor

$$\frac{\omega(s)}{U(s)} = \frac{\frac{k_m}{JL}}{\left(\left[S^2 + \left(\left(\frac{b}{J}\right)+\left(\frac{R}{L}\right)\right)S + \frac{(Rb + K_g k_m)}{JL}\right]\right)} \qquad (5)$$

Using the parameters given in Table 1, transfer function of the DC motor with angular velocity as controlled variable and input terminal voltage as manipulating variable is determined as given below

$$\frac{\omega(s)}{V_a(s)} = \frac{88.76}{S^2 + 24S + 53.25} \qquad (6)$$

(5) in time domain is as follows:

$$\frac{d^2\omega}{dt^2} + \left(\left(\frac{b}{J}\right)+\left(\frac{R}{L}\right)\right)\frac{d\omega}{dt} + \frac{(Rb + K_g K_m)}{JL}\omega = \frac{K_m}{JL}u \qquad (7)$$

However, if the state variables consider $\overline{x_1} = \omega$ and $\overline{x_2} = \dot{\overline{x_1}} = \dot{\omega}$ .The system described by equation (4) by equation (8) will be expressed, Where the only variable is the angular velocity and derivative.

Therefore the state space model is,

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ A_1 & A_2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{K_m}{JL} \end{bmatrix} u \quad (8)$$

Where

$$A_1 = -\left(\frac{(Rb + K_g K_m)}{JL} \right) \quad (9)$$

$$A_1 = -\left(\left(\frac{b}{J} \right) + \left(\frac{R}{L} \right) \right) \quad (10)$$

3.PID CONTROLLER

Proportional, integral and derivative are the basic modes of PID controller. Proportional mode provides a rapid adjustment of the manipulating variable reduces error and speeds up dynamic response. Integral mode achieves zero offset. Derivative mode provides rapid correction based on the rate of change of controlled variable. The controller transfer function is given by

$$C_{PID}(s) = K_p \left(1 + \frac{1}{T_\tau s} + T_d s \right) \quad (11)$$

where, K_p, T_i and T_d are the proportional, integral and derivative constants of PID controller respectively. PID controller tuning algorithm is based on Ziegler-Nichols open loop method. And the preference is given to the load disturbance rejection.

4.SLIDINGMODE CONTROLLER DESIGN

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

$$\dot{x} = Ax + Bu \quad (12)$$

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

$$\sigma = sx \quad (13)$$

The main idea in sliding mode control is

- Designing the switching function so that $\sigma = 0$ manifold (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:

$$\bar{x} = Tx \quad (14)$$

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

$$\begin{aligned} \bar{x}_1 &= \bar{A}_{11}\bar{x}_1 + \bar{A}_{12}\bar{x}_2 \\ \bar{x}_2 &= \bar{A}_{21}\bar{x}_1 + \bar{A}_{22}\bar{x}_2 + \bar{B}_2 u \end{aligned} \quad (15)$$

The switching function in regular form is:

$$\sigma = s_1\bar{x}_1 + s_2\bar{x}_2 \quad (16)$$

On the sliding mode manifold ($\sigma = 0$):

$$\bar{x}_2 = -s_2^{-1}s_1\bar{x}_1 \quad (17)$$

From (17) & (15)

$$\bar{x}_1 = \left(\bar{A}_{11} - \bar{A}_{12}s_2^{-1}s_1 \right)\bar{x}_1 \quad (18)$$

One of matrixes in product: $s_2^{-1}s_1$ should be chosen arbitrary. Usually (19) is used to ensure that S_2 is invertible

$$s_2 = B_2^{-1} \quad (19)$$

s_1 can be calculated by assigning the Eigen value of (18) by pole placement method. Hence, switching function will be obtained as follows:

$$s = [s_1 \quad s_2]T \quad (20)$$

The control rule is:

$$u = u_c + u_d \quad (21)$$

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

$$u_c = -\tilde{A}_{21}x_1 - \tilde{A}_{22}\sigma \quad (22)$$

$$u_d = -K_{ssgn}\sigma - K_p\sigma \quad (23)$$

Where sgn is sign function. K_s , and K_p are constants calculated regarding to lyapunov stability function.
We are going to set the angular velocity over a certain value *r*, so switching function is

$$\sigma = s_1\left(\bar{x}_{1-r}\right) + s_2\bar{x}_2 \quad (24)$$

If the controller switching function is designed to be placed on the surface $\sigma = 0$ then Solving equations (24) assume $\sigma = 0$, ω and $\dot{\omega}$ are obtained by

$$\omega = r - e^{-\frac{s_1}{s_2}t} \quad (25)$$

$$\dot{\omega} = \frac{s_1}{s_2} e^{-\frac{s_1}{s_2}t} \quad (26)$$

As equation (8) it is regular form, so the transformation matrix is equal to the unit matrix Factor s_2 according to equation (19) must be calculated

$$s_2 = \frac{JL}{K_m} \tag{27}$$

Also according to (12-19) 1 s calculated and w Pole placement method using (12-21) .Suppose we have to placed system poles in λ so we have

$$\frac{s_1}{s_2} = -\lambda \tag{28}$$

As (25), (26) and (28) shown λ determines the speed of convergence of the system output So it is better to choose a small negative value Thus, the switching function was designed as follows

$$\sigma = \frac{JL}{K_m}\left(\lambda(\omega - r) + \dot{\omega}\right) \tag{29}$$

B. Controller design:

If the equation (8) can be rewritten based on the state variables σ and $X_1 = (\bar{x}_1 - r)$ The following is reached

$$\begin{bmatrix} \dot{X}_1 \\ \dot{\sigma} \end{bmatrix} = \begin{bmatrix} \tilde{A}_{11} & \tilde{A}_{12} \\ \tilde{A}_{21} & \tilde{A}_{22} \end{bmatrix} \begin{bmatrix} X_1 \\ \sigma \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u_n \tag{30}$$

That (30) has the following parameters and variables.

$$\tilde{A}_{11} = \lambda = -\frac{s_1}{s_2}$$
$$\tilde{A}_{12} = \frac{1}{s_2}$$
$$\tilde{A}_{21} = A_1 + A_2\lambda - \lambda^2$$
$$\tilde{A}_{22} = A_2 - \lambda$$
$$u_n = s_2^{-1}u + A_1 r \tag{31}$$

Thus the relations (21), (22) and (23) controller for the system (30) is designed as follows.

$$u_n = \tilde{A}_{21}X_1 - \tilde{A}_{22}\sigma - K_s \operatorname{sgn}(\sigma) - K_p\sigma \tag{32}$$

The below equation Sets armature voltage feedback based on the derivative of the angular velocity for motor.

$$U = s_2 \left\{ \begin{array}{l} A_1\omega + \left[s_2\left(A_1 + A_2\lambda - \lambda^2\right) - A_1 \right](\omega - r) \\ + \left(A_2 - \lambda + K_p\right)\sigma + K_s \operatorname{sgn}(\sigma) \end{array} \right\} \tag{33}$$

So the sliding mode controller is

$$U = \frac{JL}{K_m} \left\{ \begin{array}{l} \left(\frac{(Rb + K_g K_m)}{JL} \right)\omega + [\left(\frac{JL}{K_m}\right)\left(\left(\frac{(Rb + K_g K_m)}{JL}\right) + \left(\left(\frac{b}{J}\right) + \left(\frac{R}{L}\right)\right)\lambda + \lambda^2\right) \\ -\left(\frac{(Rb + K_g K_m)}{JL}\right)](\omega - r) + \left(\left(\frac{b}{J}\right) + \left(\frac{R}{L}\right) + \lambda - K_p\right)\sigma - K_s \operatorname{sgn}(\sigma) \end{array} \right\} \tag{34}$$

Switching function of sliding mode controller for DC motor control method according to the relations (34) and (33) are designed.If the motor parameters like table (1),then the controller we will numerically designed as follows

$$\sigma = .0924 * 10^{-4}(\omega - r) + .0924 * 10^{-6}\dot{\omega} \tag{35}$$

After solving The controller u is given by

$$U = \left\{ \begin{array}{l} (.0924 * 10^{-6})(3675896.1\omega - 3675896.1(\omega - r)) \\ +7491.256\sigma - \operatorname{sgn}(\sigma) \end{array} \right\} \tag{36}$$

Where λ, k_s and k_p parameters are -100, 1 and 0 respectively.

5.RESULTS

In this thesis work firstly simulink model of sliding mode controller was introduced and then the SMC is attached with the real model of dc motor i.e. for dc motor. The figure below gives the sliding mode controller and controller equation obtained to control the speed of dc motor which was designed with help of state space model of dc motor.

For third order transfer function

The mat lab model and response of the real plant is given below

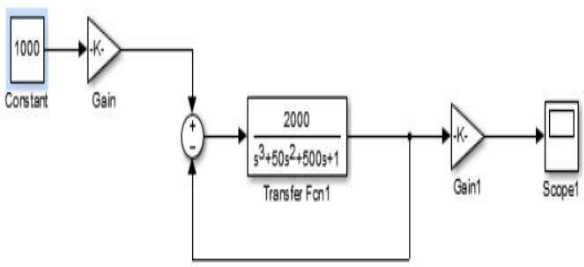

Figure1 original system simulink model

The corresponding output is shown in fig2

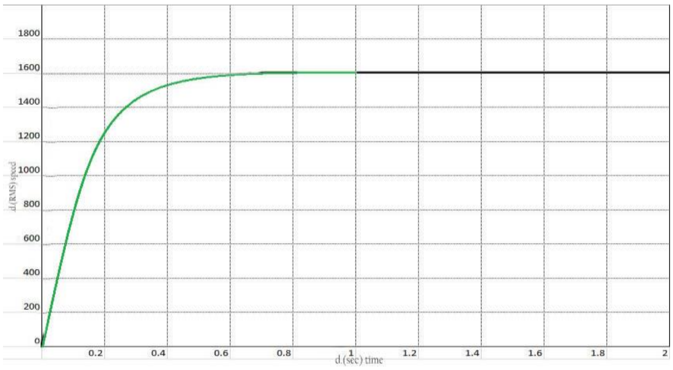

Figure2 Speed response of DC motor original system

Now for the same DC motor a Adaptive PID with Sliding mode controller is attached and the corresponding simulink model and its output for the same reference input of 1000rpm is given below

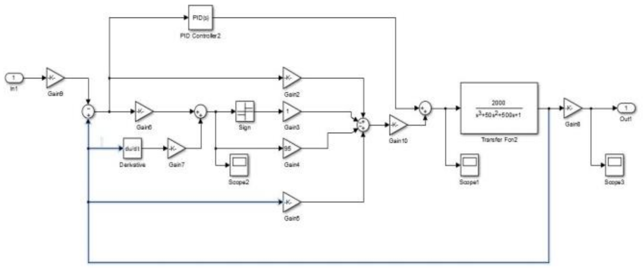

Figure3 simulink model of dc motor with Adaptive PID with SMC controller

The speed response of the DC motor with Adaptive PID with sliding mode controller is shown in figure4

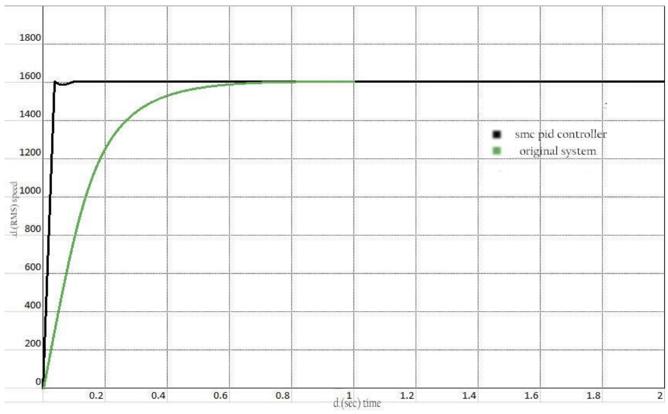

Figure 4 Speed responses of DC motor Original plant and Adaptive PID with SMC

The control input and switching function in adaptive PID SMC are given in below figure.

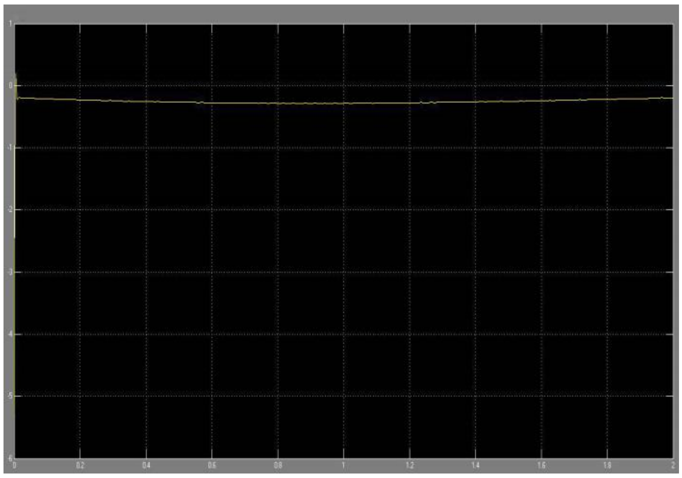

Figure. 5 switching function

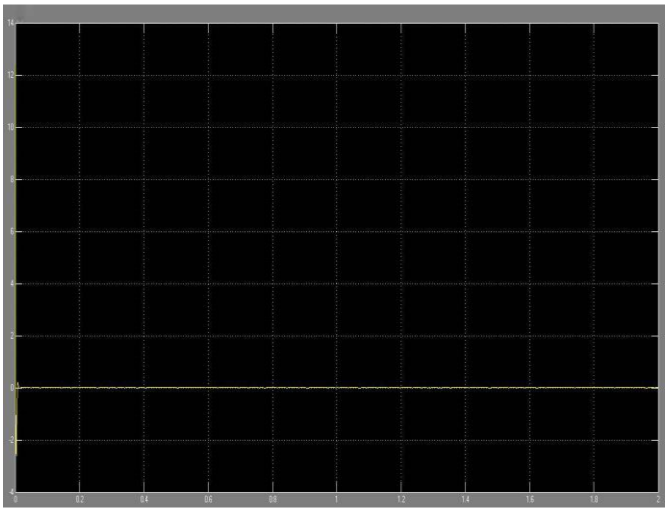

Figure. 6 control input

The combined simulation block diagram of DC motor with PID , SMC , Adaptive PID with SMC controller for the same reference input of 1000rpm is given below

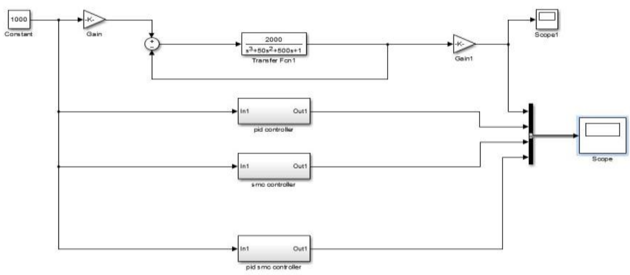

Figure 7 simulink model of dc motor with PID, SMC and Adaptive PID with SMC

The speed response of DC motor for above simulation diagram is shown in below figure 8

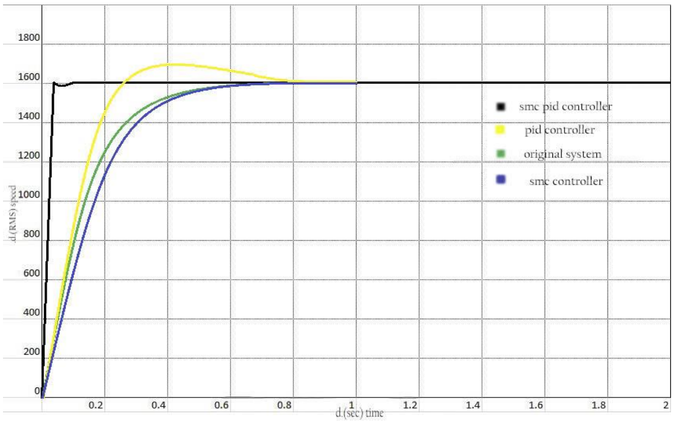

Figure8 Speed response of DC motor with all controllers

d its simulink models and corresponding outputs are given below.

If we observe the outputs of the above figures PID, SMC and Adaptive PID with SMC controllers, this reveals that SMC is a robust controller i.e. irrespective of any disturbances Adaptive PID SMC produce the same output where as for the same motor and same reference speed PID produces oscillations for which the system parameters are disturbed. Settling time is also reduced very well in case of Adaptive PID with SMC when compared with PID and SMC controllers.

Table 2 comparisons between SMC, PID and PIDSMC controllers

CONTROLLER	SETTLING TIME (SEC)	OVERSHOOT	DISTURBANCE REJECTION	RISE TIME (SEC)
PID	0.68	moderate	poor	0.29
SMC	0.45	nil	good	0.23
Adaptive PID with SMC	0.12	nil	good	0.025

For fifth order transfer function

The mat lab model and response of the real plant is given below

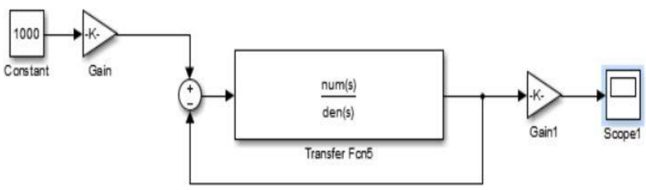

Figure 9 original system simulink model

The corresponding output is shown in fig 10

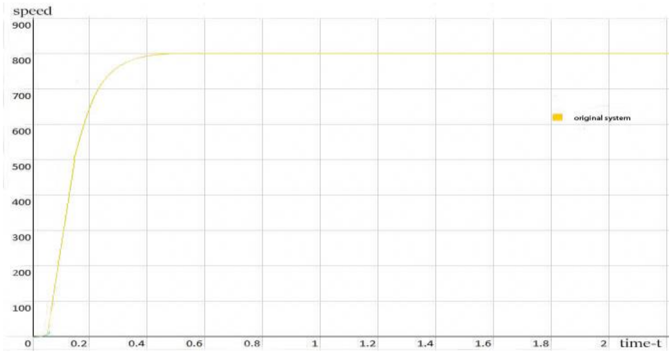

Figure10 Speed response of DC motor original system

Now for the same DC motor a Adaptive PID with Sliding mode controller is attached and the corresponding simulink model and its output for the same reference input of 800rpm is given below

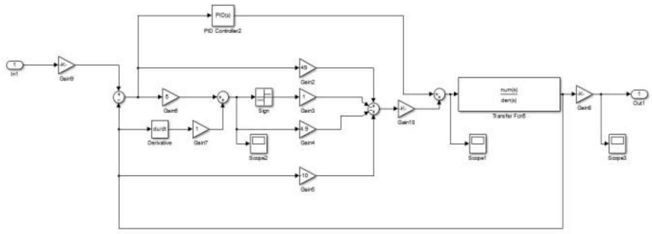

Figure11 simulink model of dc motor with Adaptive PID with SMC controller

The speed response of the DC motor with Adaptive PID with sliding mode controller is shown in figure 12

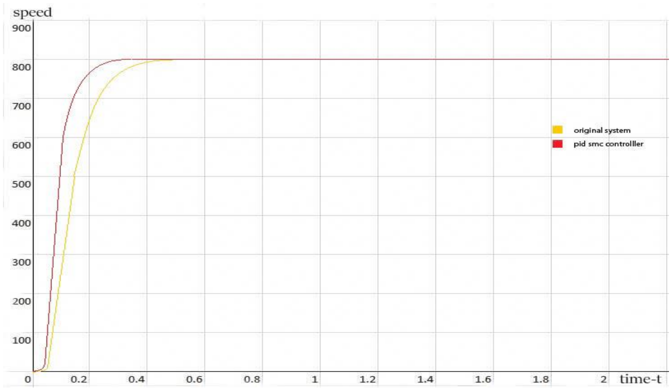

Figure.12 Speed responses of DC motor Original plant and Adaptive PID with SMC

The control input and switching function in adaptive PID SMC are given in below figure.

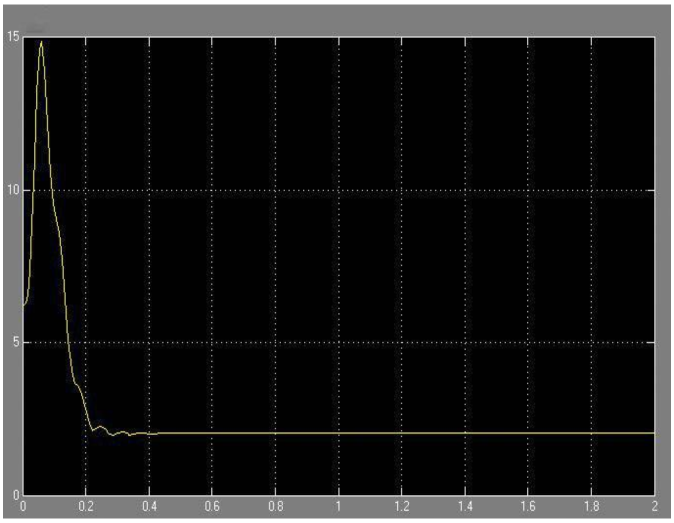

Figure. 13 switching function

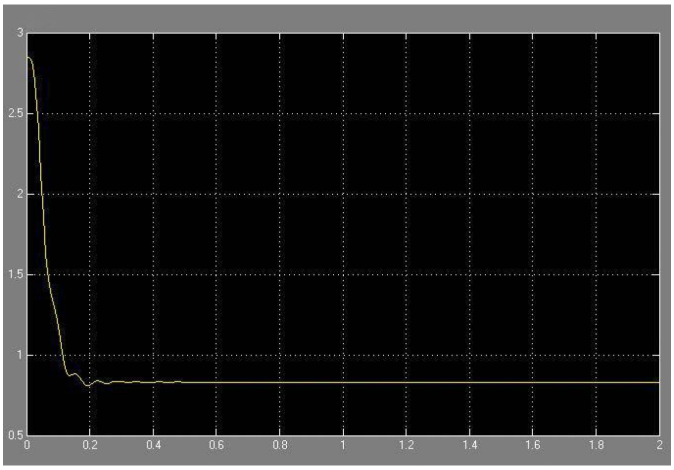

Figure.14 control input

The combined simulation block diagram of DC motor with PID , SMC , Adaptive PID with SMC controller for the same reference input of 800rpm is given below

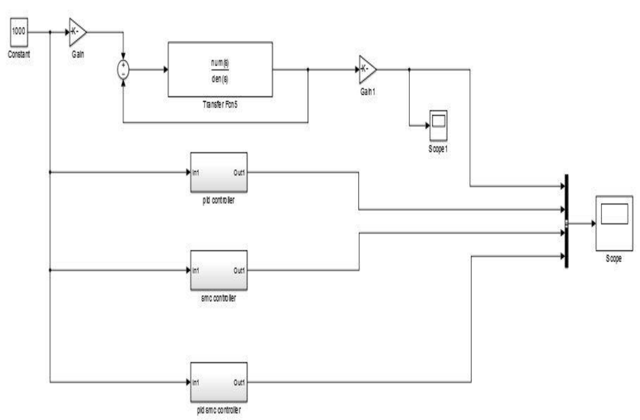

Figure15 simulink model of dc motor with PID, SMC and Adaptive PID with SMC

The speed response of DC motor for above simulation diagram is shown in below figure 16

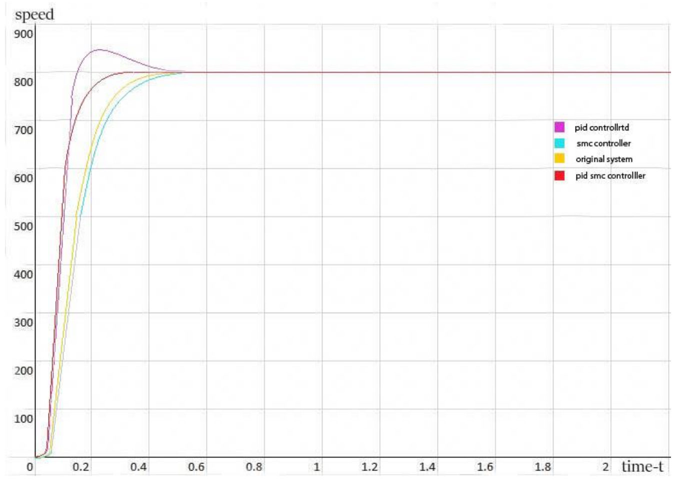

Figure16 Speed response of DC motor with all controllers

If we observe the outputs of the above figures PID, SMC and Adaptive PID with SMC controllers, this reveals that SMC is a robust controller i.e. irrespective of any disturbances Adaptive PID SMC produce the same output where as for the same motor and same reference speed PID produces oscillations for which the system parameters are disturbed. Settling time is also reduced very well in case of Adaptive PID with SMC when compared with PID and SMC controllers.

Table 3 comparisons between SMC, PID and PIDSMC controllers

CONTROLLER	SETTLING TIME (SEC)	OVERSHOOT	DISTURBANCE REJECTION	RISE TIME (SEC)
PID	0.48	moderate	poor	0.29
SMC	0.45	nil	good	0.23
Adaptive PID with SMC	0.22	nil	good	0.11

Sliding mode control (SMC) and Adaptive PID with sliding mode control techniques are used to control the speed of DC motor. The chattering problem in SMC is avoided by using Adaptive PID with sliding mode controller and the performance of the SMC is improved by using an adaptive PID with sliding mode controller.

6. CONCLUSIONS

After obtaining the entire model of speed control system, Performance of these controllers has been verified through simulation results using MATLAB/SIMULINK software. The simulation results showed that Adaptive PID with SMC controller was a superior controller than SMC and PID controllers for speed control of a DC motor. Also, this controller is very robust and is irrespective of any disturbances Adaptive PID SMC produce the same output.

7. SCOPE FOR FUTURE STUDY

(1) Besides being simple to construct and to implement; it has a very fast response and less sensitive to parameter variation and external disturbances. But the performance of dc motor further improved if it is possible to design better controllers than this controller.

(2) The DC motor is a linear system model, so this controller is extended to design for nonlinear systems like Induction motor and robotics.

8. REFERENCES

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