Speed Control of DC Motor by using Robust SMC Schemes

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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. Due to the robustness of Sliding Mode Control (SMC), especially against parameters variations and external disturbances, and also its ability in controlling linear and nonlinear systems.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 SMC controller for DCmotor 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 .The main result of the paper is the analysis the adaptive sliding mode control. 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 separately excited DC motor.

Keywords—DC motor, PID controller, Sliding mode controller(SMC), Adaptive PID with SMC controller.

I. INTRODUCTION

DC motors have been widely used in many industrial applications such as electric vehicles, steel rolling mills, electric cranes, robotic manipulators, and home appliances due to precise, wide, simple, and continuous control characteristics. The purpose of a speed controller is to drive the motor at desired speed. DC motors are generally controlled by conventional Proportional plus Integral controllers, since they can be designed easily [1]. However the performance of PI controller for speed control degrades under external disturbances and machine parameter variations. Thismakes the use of PI controller a poor choice for variable speed drive applications.

In the past three decades, nonlinear and adaptive control methods have been used extensively to control DC drives. In these methods, the state estimation and parameter identification are based on and limited to linear models. As the model deviates from the dynamics of the physical system, the performance of the control degrades [2]. An intelligent controller of DC Motor drive using hybrid method of optimization for the optimal tuning of proportional-integralderivative (PID) controller parameters is developed by Abhinav, where the parameters of motor, which vary with the operating conditions of the system, are adapted in order to maintain deadbeat response for motor speed [3]. An adaptive control algorithm is developed for the sensor less speed control of a permanent-magnet DC motor directly connected to the hydraulic pump of an antilock brake system [4] by Choi. Performance comparison of sliding mode control and conventional pi controller for speed control of separately excited DC motors is discussed in [1].

Here PID, SMC and Adaptive PID with SMC controller are designed for the DC motor system and their performance is compared. The paper is organized as follows: a description of the system along with the mathematical model is exposed in Section II. Section III describes the PID control technique in DC motor system. Section IV describes the sliding mode control technique in DC motor system and V includes Adaptive PID with Sliding mode controller design for DC motor. Section VI deals with the simulation results and conclusions are drawn in section VII.

II. 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.

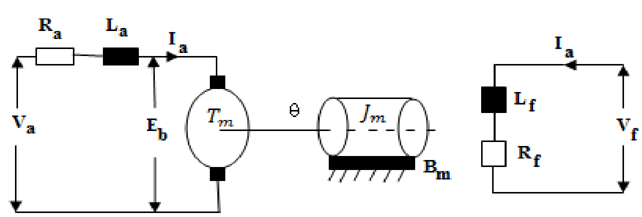

Figure1: A Separately excited DC motor

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 armaturevoltage 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:

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

WhereEa 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 :

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

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. Ebrepresents electromotive force in V given by

$$E_b(t) = K_b \omega(t) \quad (3)$$

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 $x_1 = \theta$

$$x_2 = \dot{x_1} = \dot{\theta} = \omega$$

$$x_3 = I_a$$

$$\dot{x} = \begin{bmatrix} \dot{\omega} \\ \dot{I_a} \end{bmatrix} = Ax + Bu = \begin{bmatrix} -\frac{b}{J} & \frac{k_t}{J} \\ -\frac{k_b}{L_a} & -\frac{R_a}{L_a} \end{bmatrix} \begin{bmatrix} x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{L} \end{bmatrix} u \quad (4)$$

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

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

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

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

(5) in time domain is as follows:

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

However, if the state variables consider$\overline{x_1} = \omega and \quad \overline{x_2} = \dot{\overline{x_1}} = \dot{\omega}$.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,

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

Where

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

$$A_2 = -(\left(\frac{b}{J}\right) + \left(\frac{R}{L}\right)) \quad (10)$$

III. 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

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

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.

IV. SLIDINGMODE CONTROLLER DESIGN

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

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

Where $\in R^n$, $u \in R$, $A\in R^{n*n}$,and $B\in R^n$ 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

$$\dot{\overline{x_1}}= \overline{A_{11}}\overline{x_1} +\overline{A_{12}}\overline{x_2}$$

$$\dot{\overline{x_2}}=\overline{A_{21}}\overline{x_1} +\overline{A_{22}}\overline{x_2}+\overline{B_2}u \quad (15)$$

The switching function in regular form is:

$$\sigma = s_1 \overline{x_1}+s_2 \overline{x_2} \quad (16)$$

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

$$\overline{x_2}= -{s_2}^{-1}s_1 \overline{x_1} \quad (17)$$

From (17) & (15)

$$\dot{\overline{x_1}}= (\overline{A_{11}}-\overline{A_{12}}{s_2}^{-1}s_1)\overline{x_1} \quad (18)$$

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:

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

The control rule is:

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

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

$$u_c = -\widetilde{A_{21}}\ x_1 - \widetilde{A_{22}}\,\sigma \quad (22)$$

$$u_d = -K_s \text{sgn}\ \sigma - K_p\sigma \quad (23)$$

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

$$\sigma = s_1\ \overline{(x_1}\text{-r)}+s_2\ \overline{x_2} \quad (24)$$

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

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

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

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

$$s_2 =\frac{JL}{k_m} \quad (27)$$

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

$$\frac{s_1}{s_2}= -\lambda \quad (28)$$

As (25), (26) and (28) shown $\lambda determines$ 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

$$\sigma =\frac{JL}{k_m}(-\lambda(\omega - r))+\dot{\omega}) \quad (29)$$

B. CONTROLLER DESIGN:

If the equation (8) can be rewritten based on the state variables σ and X_1=$\overline{(x_1}$-r) The following is reached

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

That (30) has the following parameters andvariables.

$$\tilde{A}_{11}= \lambda= -\frac{s_1}{s_2}$$

$$\tilde{A}_{12}=\frac{1}{s_2}$$

$$\tilde{A}_{21}=A_1+A_2\lambda - \lambda^2$$

$$\tilde{A}_{22}= A_2- \lambda$$

$$u_n=s_2{}^{-1}\text{u}+A_1 r \quad (31)$$

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

$$u_n=- \tilde{A}_{21}X_1-\tilde{A}_{22}\sigma -k_s\text{sgn}(\sigma)-k_p\sigma \quad (32)$$

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

$$\text{U}=-s_2 \begin{Bmatrix} [A_1\, \omega + [s_2\, (A_1 + A_2\lambda\, -\, \lambda^2) - \, A_1](\omega - \text{r}) + \\ (A_2 -\, \lambda + k_p)\sigma +\, k_s\text{sgn}(\sigma) \end{Bmatrix} \quad (33)$$

So the sliding mode controller is

$$\text{U}= \frac{JL}{k_m}\left\{\left(\frac{(Rb+k_e k_m)}{JL}\right)\, \omega + [\left(\frac{JL}{k_m}\right)\left(\left(\frac{(Rb+k_e k_m)}{JL}\right) + b/J+RL\lambda+\lambda 2-(Rb+kekm)/JL\right]\omega-\text{r}+(b/J+RL+\lambda- kp)\sigma-ks\text{sgn}(\sigma) \quad (34)$$

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

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

After solving The controller u is given by

$$\text{U}= (.0924*10^{-6})(3675896.1\omega - 3675895.1(\omega - \text{r})+7491.256\sigma \text{-} sgn(\sigma) \quad (36)$$

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

V. ADAPTIVE PID WITH SMC CONTROLLER

The proportional-integral-derivative (PID) controller is extensively used in many control applications because of its simplicity and effectiveness. Though the use of PID control has a long history in control engineering, tuning of the three parameters of controller gain, i.e., proportional gain, K_p , integral gain, K_i , and derivative gain, K_d , was poor. Self tuning these three controller gains has gained interest among the control community recently.

The adaptive PID with sliding mode controller is applied for DC motor to achieve system robustness against parameter variations and external disturbances. The PID parameters can be analytically obtained according to the adaptive law. Three PID control gains, K_p , K_i and K_d are adjusted using an adequate adaptation mechanism to minimize a previously designed sliding condition.

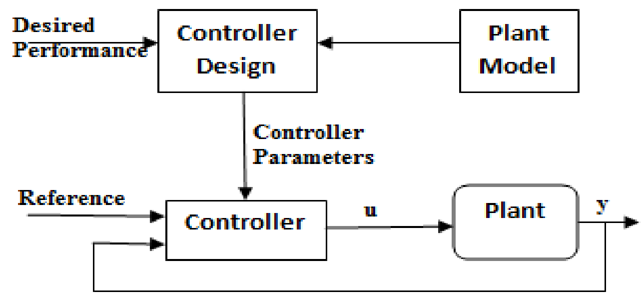

Figure 2: Principles of controller design

A PID controller, with input e(error signal) and output, U_{PID} is

$$U_{PID} =K_p e + K_i\int e + K_d\, \dot{e} \quad (37)$$

The control law for sliding mode control is

$$U_s = U_c + U_{eq}$$

$$U_s= (0.011267)(90\omega - 0.01(\omega - \text{r})\text{-}75\sigma \text{-}sgn(\sigma)) \quad (38)$$

Now the control input U for adaptive PID sliding mode controller is

$$U = U_{PID} + U_S$$

The three PID controller gains, K_p , K_i and K_d can be obtained by adaptive laws as following, and where ρ_1 , ρ_2 and ρ_3 are the learning rates,

$$\dot{K}_p = -\rho\frac{\partial\sigma\dot{\sigma}}{\partial Kp} = -\rho 1\sigma\text{e}$$

$$\dot{K}_i = -\rho \frac{\partial \sigma \dot{\sigma}}{\partial K i} = -\rho_2 \sigma \int e dt \quad \text{and}$$

$$\dot{K}_d = -\rho \frac{\partial \sigma \dot{\sigma}}{\partial K d} = -\rho_3 \sigma \dot{e}$$

VI. RESULTS AND DISCUSSION

The DC motor, a PID controller is attached and the corresponding simulink model and its output for the same reference input of 1000rpm is given below.

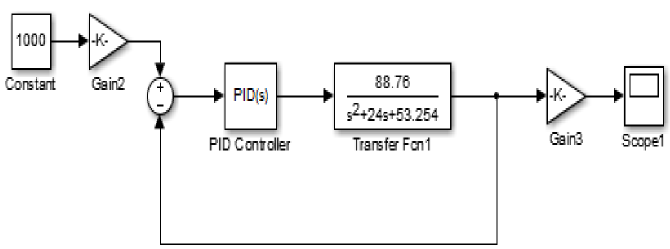

Figure 3:simulink model of dc motor with PID controller

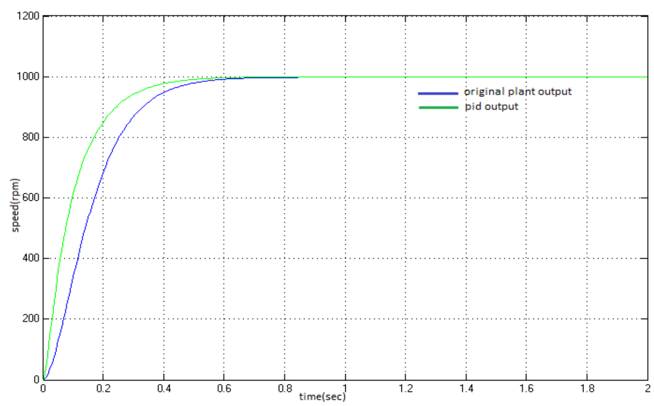

Figure 4: Speed response of DC motor with combined Original plant and PID

The DC motor, a SMC controller is attached and the corresponding simulink model and its output for the same reference input of 1000rpm is given below.

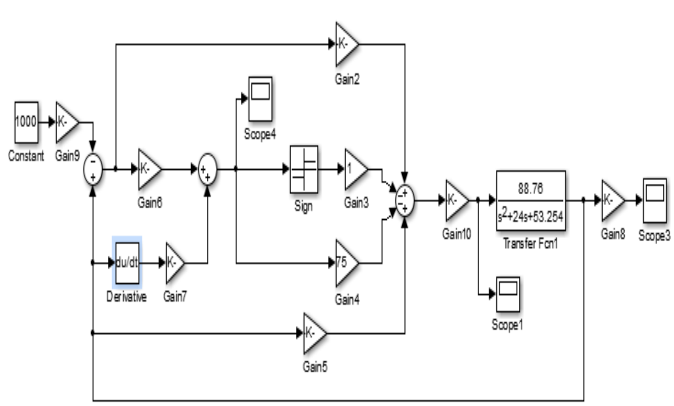

Figure 5:simulink model of dc motor with SMC controller

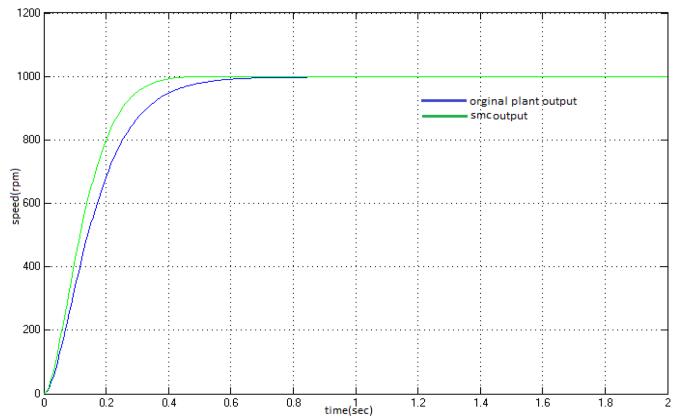

Figure 6: Speed response of DC motor of combined Original plant and SMC

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.

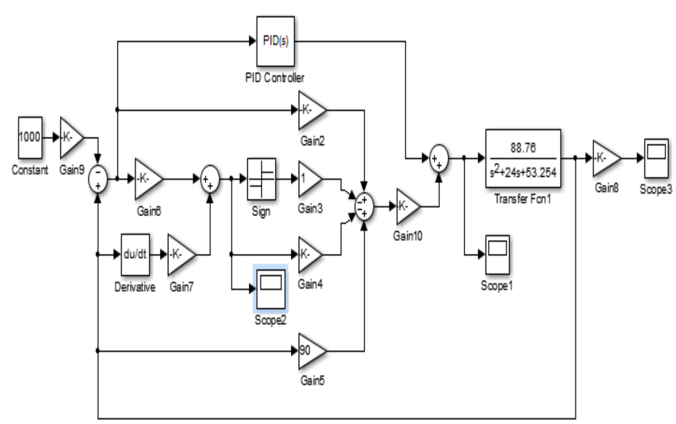

Figure 7:simulink model of dc motor with Adaptive PID with SMC controller

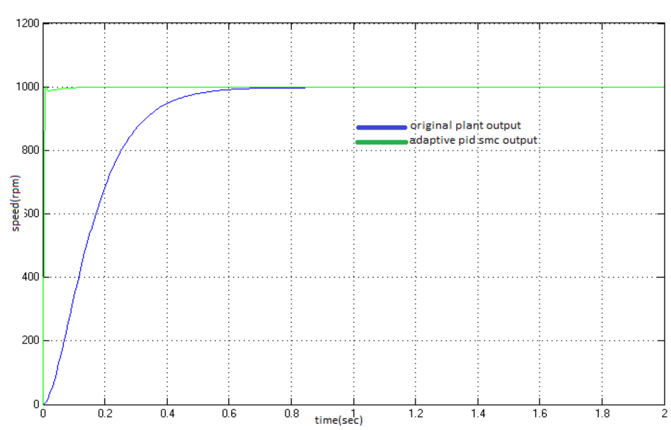

Figure 8: Speed response of DC motor of Original plant and Adaptive PID with SMC

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

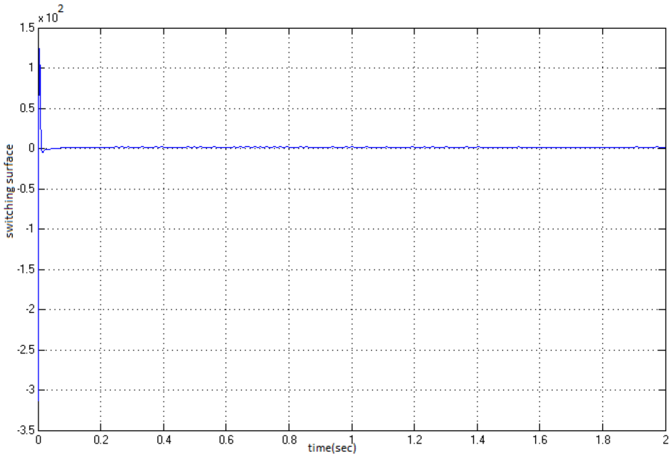

Figure. 9: switching function

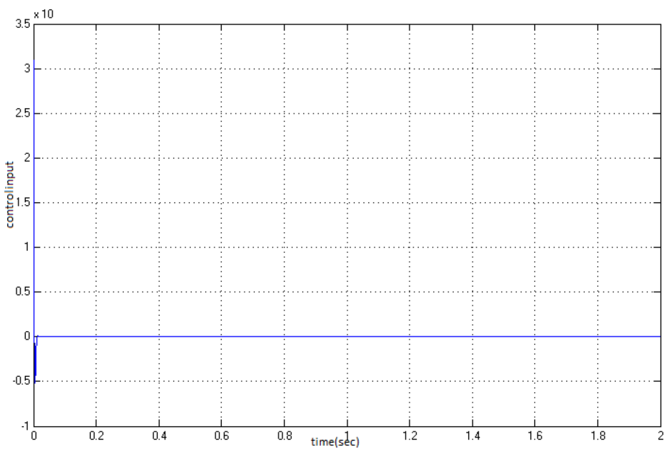

Figure. 10: control input

The comparison of performance of all the designed controllers is given in table 2.

Controller	Settling time (sec)	Overshoot	Disturbance rejection	Rise time (sec)
PID	0.68	nil	poor	Nil
SMC	0.45	nil	good	Yes
Adaptive PID with SMC	0.12	nil	good	Small

Table 2: comparisons between SMC, PID and PIDSMC controllers

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 DC motor is improved by using an adaptivePID with sliding mode controller compared to other control techniques.

VII. CONCLUSIONS

In this paper adaptive PID with sliding mode control Proposed to speed control of DC motor. At first for controlling speed of DC motor a simplified closed loop is utilized. Then DC motor is modeled after that speed controller is designed. As adaptive PID SMC is based on the system Dynamic characteristics also it took a lack of influence of external disturbances from user as result it worked more useful and results confirms that used adaptive PID with sliding mode control for speed control is more efficient in comparison with SMC and PID controllers. And also the designed PIDSMC is robust controller shown by varying the different parameters of the motor.

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