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DC-motor motion Control (speed &position) using Sliding Mode Control(SMC)

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ABSTRACT: *In industrial, DC motor (speed and position) control is used in many applications ,such as belt drive in factories , elevators ,and others . This paper was focuses on the Sliding Mode Control (SMC) was used to control the speed and position of DC motor. Also PID controller was used to compare the Results between it and SMC for controlling the speed and position of a DC motor.. The motor is modeled and simulated. Moreover, the (PID) controller was designed tuned by using a Matlab/Simulink block instead of conventional tuning methods such as hand-tuning or Ziegler-Nichols method. Then The signal is angle position (θ) was created by Simulink and applied to the input control system. SMC controller succeeded to reduce the error between signal input and signal output is better than conventional tuning methods.*

KEY WARDS: *DC motor, position control, (SMC) control, PID controller.*

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I. INTRODUCTION

In recent years, DC motor control to control the motion (speed and position) has become widespread. The control systems of motors speed and position is very important and necessary because DC motor is widely used in industrial applications, and many other fields of control systems such as industrial homes place and robotics where speed and position control of DC motor are required [1-3].Two major problems encountered in DC motor control are the noise in the system loop and the varying time of the motor parameters under operating conditions. The PID widespread use of control it is highly desirable to have efficient manual and automatic methods of tuning the controllers. A good insight into PID tuning is also useful in developing more schemes for automatic tuning and loop assessment [4]. These methods have successful results but they need more time and effort to get a good system response. The mathematical model to present of DC motor does not give accurate of the real system because approximated it to linear system that is main problem [5]. To avoid this problem, the sliding mode control methodology(SMC) can be used. The sliding mode control methodology has been receiving much more attention from the international control community within the last decade [6].

The major advantage of sliding mode is low sensitivity to plant parameter variations and disturbances which eliminates the necessity of exact modeling. Sliding mode control enables the decoupling of the overall system motion into independent partial components of lower dimension and, as a result, reduces the complexity of feedback design. Sliding mode control implies that control actions are discontinuous state functions which may easily be implemented by conventional power converters with “on-off” as the only admissible operation mode [7]. Due to these properties the intensity of the research at many scientific centers of industry and universities is maintained at high level, and sliding mode control has been proved to be applicable to a wide range of problems in robotics, electric drives and generators, process control, vehicle and motion control [8].sliding mode control (SMC) plays an important role because it not only can stabilize certain and uncertain systems but also provide the capability of disturbance rejection and insensitivity to parameter variations [9]

1.1 DC motor model

In DC motors armature control the voltage was applied to the field winding (separately excited), the voltage applied to the armature of the motor is adjusted without changing the voltage applied to the field. Figure.1 shows a separately excited DC motor equivalent model [3].

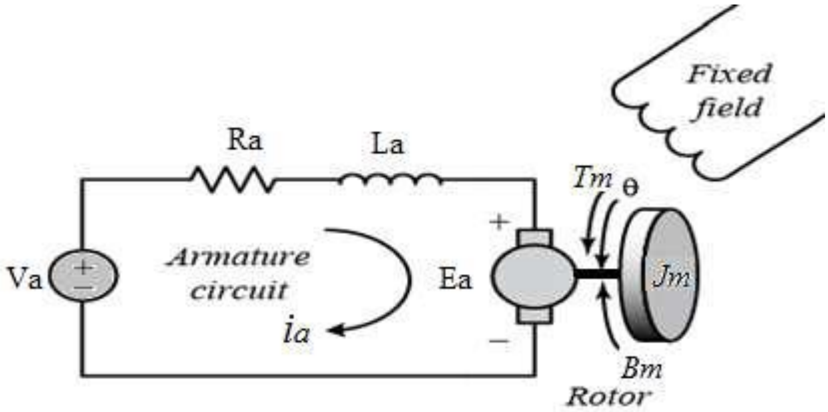

Figure 1:Schematic Diagram of DC Motor

The differential equation of the armature circuit

$$v_a(t) = R_a.i_a(t) + L_a.\frac{di_a(t)}{dt} + e_a(t) \ldots\ldots\ldots (1)$$

$$e_b(t) = K_b.w(t) \ldots\ldots\ldots (2)$$

The torque equation for equilibrium is

$$T_m(t) = K_T.i_a(t) \ldots\ldots\ldots (3)$$

$$T_m(t) = J_m.\frac{dw(t)}{dt} + B_m.w(t) \ldots\ldots\ldots (4)$$

By combining the upper equations together:

$$v_a(t) = R_a.i_a(t) + L_a.\frac{di_a(t)}{dt} + K_b.w(t) \ldots\ldots\ldots (5)$$

$$K_T.i_a(t) = J_m.\frac{dw(t)}{dt} + B_m.w(t) \ldots\ldots\ldots (6)$$

By using Laplace transforms role to (5) and (6) are:

$$V_a(s) = R_a.I_a(s) + L_a.I_a(s).(s) + K_b w(s) \ldots\ldots\ldots (7)$$

$$K_T.I_a(s) = J_m.W(s).s + B_m.W(s) \ldots\ldots\ldots (8)$$

The armature voltage is

$$V_a(s) = W(s).\frac{1}{K_T}.[L_a.J_m s^2 + (R_a.J_m + L_a.B_m).s + (R_a.B_m + K_b.K_T)] \ldots\ldots,,,\ldots (9)$$

Then the relation between armature voltage and angular speed of the shaft can be presented by transfer function as:

$$\frac{W(s)}{V_a(s)} = \frac{K_T}{L_a.J_m s^2 + (R_a.J_m + L_a.B_m).s + (R_a.B_m + K_b.K_T)} \ldots\ldots\ldots (10)$$

The position can be found as:

$$\theta(s) = \frac{W(s)}{s} \ldots\ldots\ldots (11)$$

The transfer function between armature voltage as input and the position of the shaft as output when the motor without load is:

$$\frac{\theta(s)}{V_a(s)} = \frac{K_T}{L_a.J_m s^3 + (R_a.J_m + L_a.B_m)s^2 + (R_a.B_m + K_b.K_T)s} \ldots\ldots\ldots (12)$$

The DC motor model is built in Simulink/MATLAB as shown in figure.2, the inputs are armature voltage (Va) and load torque (T_{load}).The outputs are angular speed in (ω) and position (θ).

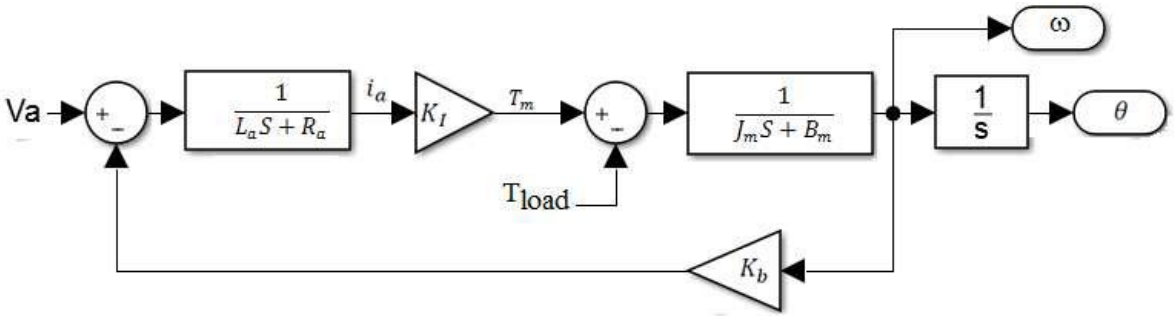

Figure 2. DC motor model in Simulink/MATLAB

The following characteristic of the DC motor was used:.
Performance specifications:
Torque continuous = 0.95 N-m
Peak torque =5.22 N-m
Maximum speed =5000 rpm
Rated power =200 w
Electrical specification
Torque constant = 0.17 N-m/ Amp
Terminal resistance = 1.4 Ohms
BEMF constant = 18.2 V/krpm
Armature inductance = 4.9 m-H
Moment of inertia = 0.00092 kg/m²
Recommended Bus Voltage = 80 VDC
Maximum Terminal voltage =104 VDC

1.2Proportional-integral-derivative (PID) controller

The PID controllers are used essentially in industrial control applications due to their simple structures, completely
control algorithms and low costs. Figure.3 shows the schematic model of a control system with a PID controller[1].

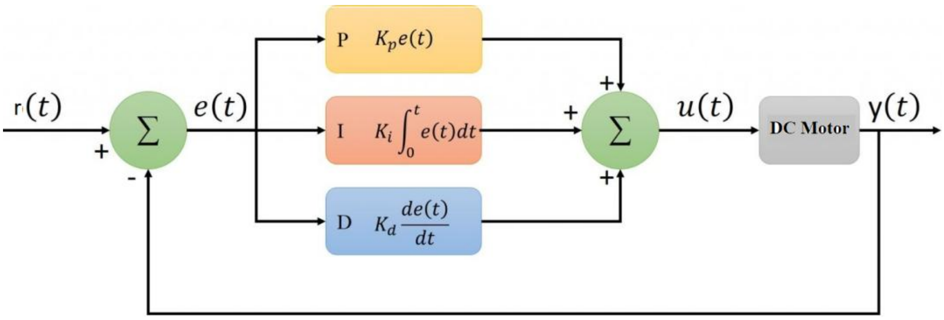

Figure 3.PID controllers system

Where
K_P = proportional gain
K_I = integral gain
K_D = derivative gain

1.3MATLAB/Simulink

The simulation was performed by using Simulink to present the model as shown in figure.4, the simulation begins with the motor at the zero degree position. The desired position was 45^o degree. There is deferent between input and output signal without any controller as shown in figure 5.

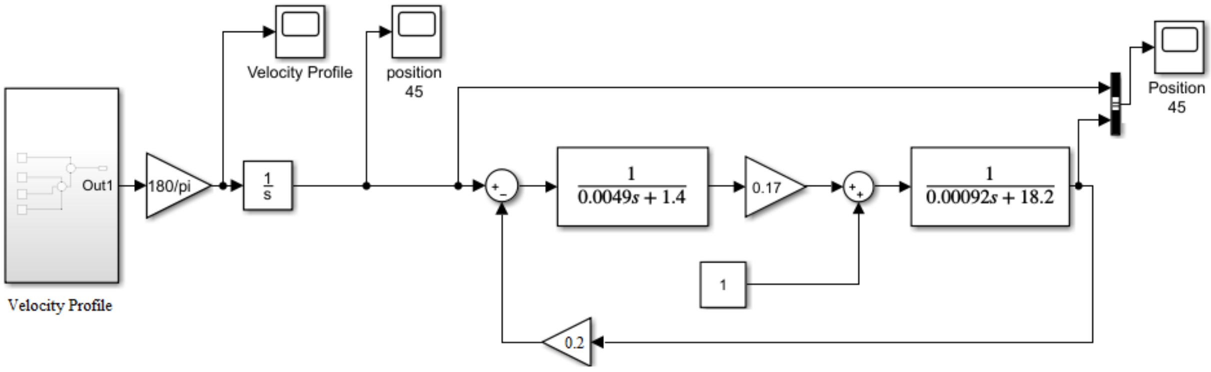

Figure. 4 Simulink Model of dc Motor without any controller

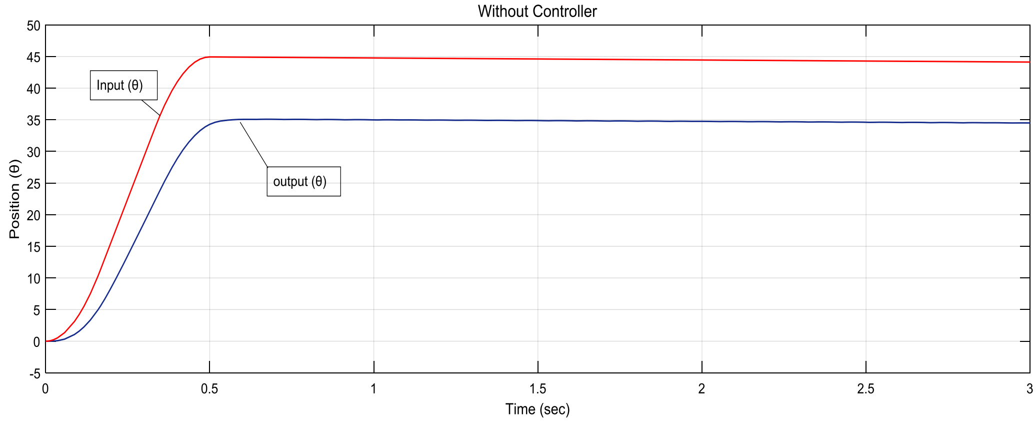

Figure 5 .Input and output signal without controller

To reduce this deferent, the PID controller was used as shown in Figure.6. By using Hand Tuning, the parameters was done to reduce the deferent between input signal (position 45^o) and output signal (position). The values of the parameters which gated the best results as shown in figure.7 are:
Kp = 1.7 Ki = 0.4 Kd =0.45

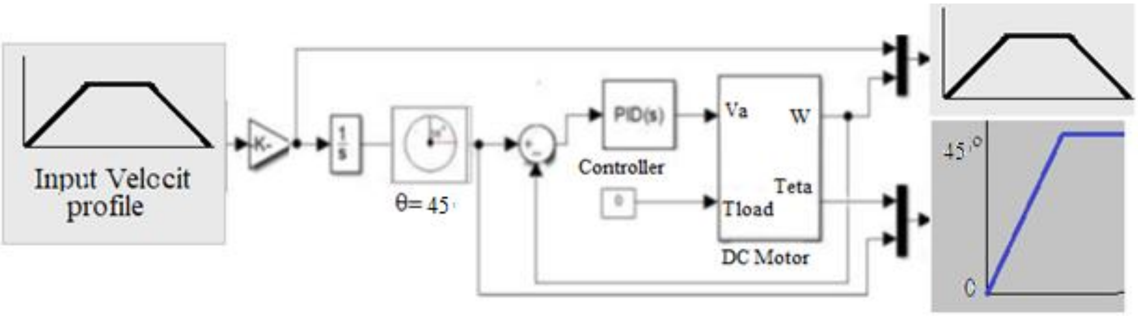

Figure.6.Simulink Block Diagram of DC Motor with PID controller

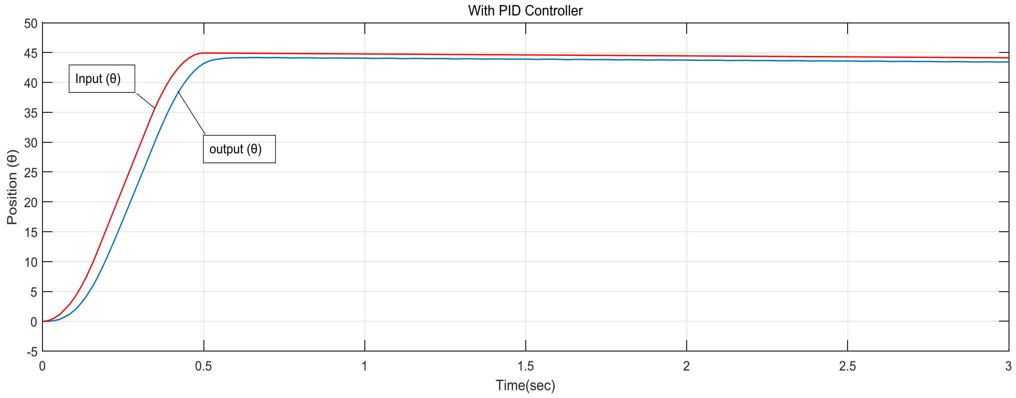

Figure 7. The output response with PID controller

II. SLIDING MODE DESIGN

recently , uncertain dynamical systems have the dispute of controlling in increasingly form. Often, there is a difference in the actual plant and its mathematical model used for the controller design in the practical control problem. The mismatches are come from unknown external noise or disturbances, parameters of the plant and unmolded dynamics. Law of the control was designed which provides the desired performance to the control system in presence of these disturbances is a very challenging task for a control engineer. This has produced to an intense interest in the development of so called robust control methods which are supposed to find solution this problem. One particular approach to robust controller design is called sliding mode control technique[10]. Sliding mode control (SMC) is a non-linear control method which modify the dynamics of a non-linear system by the application of an irregular control signal that forces the system to 'slide' along a cross-section of the system usual behavior in control theory. The state feedback control law is not a continuous function of time rather it can switch from one continuous structure to another based on the current position in the state space. so, sliding mode control is a form of variable structure control[10-11].

The multiple control structures are designed in such a way that the trajectory always move towards a switching condition so that system does not remain confined within one system structure, instead it slides along the boundary of different control structures. The motion of the system as it slides along the boundary of these systems is sliding mode and the geometrical locus consisting of these boundaries is called the sliding surface [9]. Consider a linear time invariant n[th] order plant with scalar control as

$$\dot{x} = Ax(t) + Bu(t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

where, matrix A of size n × n is the system transformation matrix and vector B of size n × 1 as input vector. The sliding surface is defined as

$$s = [c_1 c_2 c_3][x_1 x_2 x_3] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

The vector C, (C>0) consist of coefficients which describe the sliding surface in terms of the state vector x. The sliding surface 's' is defined such a way called a hype surface, it is one dimension lesser than the system order. The surface need not be a plane (or line in case of second order system) always, the surface can be of any shape. If the sliding surface is a plane then the gradient of the matrix is the matrix itself. The value of 's' specifies the distance of the point from the sliding surface. Hence s = 0 implies the point is on the sliding surface. Differentiating Eq. (14) and the substituting in equation (13),

$$\dot{S} = CAx(t) + CBu(t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

The sliding to exist when s = 0, this gives us the equivalent input. Assuming that CB is invertible we get

$$u_{eq} = (CB)^{-1} CAx(t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Depending on to concept of equivalent control, substituting the equivalent input into the system equation (5,6), and we get an autonomous system that describes the motion of the describing point on the sliding surface.

$$\dot{X} = \{I - B(CB) - 1\}Ax(t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

To check the stability of the sliding surface, the Lyapunov second method can be used of determining stability is commonly taken. In order to provide the asymptotic stability of Eq. (12) about the equilibrium point s=0.

$$V = \frac{1}{2} S^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

The next conditions should be satisfied.

$(a)\ V < 0$ $\qquad$ $(b)\ \lim_{|s| \to \infty} V = \infty$

The condition (b) is clearly satisfied. To approve finite time convergence, condition (a) can be modified to be

$$V \le -\alpha V^{\frac{1}{2}} \quad , \quad \alpha > 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

Integrating inequality of Eq. (19), over the time interval $0 \le \tau \le t$

$$V^{1/2}(t) \le -\frac{1}{2}\alpha t + V^{1/2}(0) \ldots\ldots (20)$$

Thus, V(t) arrive zero in a finite time tr that can be bounded by

$$t_r \le \frac{2V^{\frac{1}{2}}(0)}{\alpha} \ldots\ldots (21)$$

When derivative of V we get

$$\dot{V} = S\dot{S} = S(Cx_2 + f(x_1, x_2, t) + u) \ldots\ldots (22)$$

Assuming

$u = -cx2 + v$, substituting it into Eq. (22). Therefore

$$\dot{V} = s(f(x_1, x_2, t) + v) = sf(x_1, x_2, t) + sv \le sL + sv \ldots\ldots (23)$$

Selecting $v = -\rho sign(s), \rho > 0$ and substituting into Eq. (23)

$$V \le |s|\ L|s|\ \rho = -|s|(\rho - L) \ldots\ldots (24)$$

Taking Eq. (24) in Eq. (19), condition Eq. (22) can be rewritten as-

$$V \le \alpha V^{\frac{1}{2}} = -\frac{\alpha}{\sqrt{2}}|s|\ , \alpha > 0 \ldots\ldots (25)$$

Combining of Eqs. (24) and (25)

$$V \le -|s|(\rho - L)\ = -\frac{\alpha}{\sqrt{2}}|s| \ldots\ldots (26)$$

Finally, the control gain ρ is

$$\rho = L + \frac{\alpha}{\sqrt{2}} \ldots\ldots (27)$$

Thus a control law u that drives s to zero in finite time of Eq. (13) is

$$u = -cx2 - \rho\ sign(s) \ldots\ldots (28)$$

$s\dot{s} \le -\frac{\alpha}{\sqrt{2}}|s|$ is named as reachability condition and can be used for sliding mode controller design.

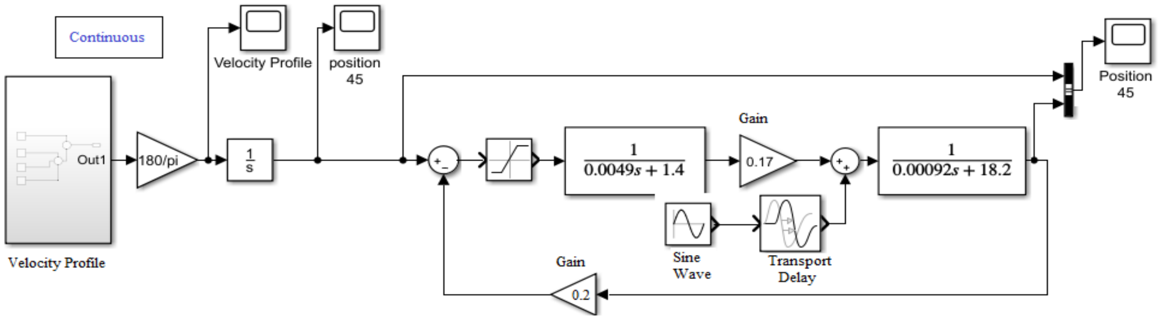

Figure 8 : Simulink Model of dc Motor with SMC Controller

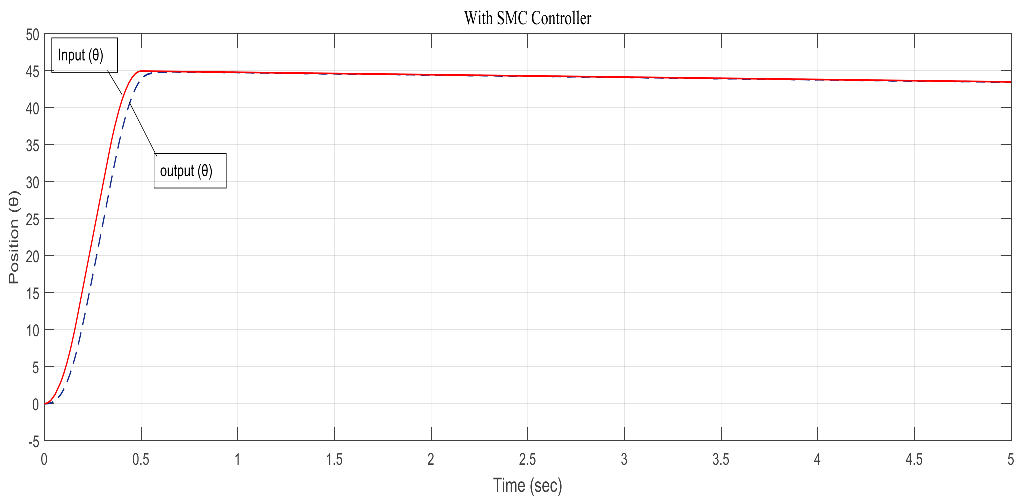

Figure 9. The output response with SMC controller

In figure 9 can be noted that, the deferent between input signal (position 45o) and output signal (position) was reduced . So the sliding mode controller gives better performance than the PID controller against parameter variations.

III. CONCLUSION

In this paper, we have considered the PID controller and sliding mode control (SMC) for controlling the angle, speed and position of a separately excited dc motor. The performance of the controllers was validated through simulations. From the comparative simulation results, one can conclude that the two controllers demonstrated nearly the same dynamic behavior under nominal condition. However, simulation results show that the sliding mode controller realized a good dynamic behavior of the motor with a rapid rise time and settling time and had better performance than the PID controller. But the comparison between the speed control of a separately excited dc motor by the sliding mode controller (SMC) showed clearly that ,the sliding mode controller gives better performance than the PID controller against parameter variations.

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