Journal of Electrical Engineering
The Institution of Engineers, Bangladesh
Vol. EE 31, No. I & II, December 2004

Sliding Mode Speed Controller of a D.C Motor Drive

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ABSTRACT

This paper presents a separately excited DC motor speed control scheme using sliding mode control technique. The mathematical model suitable for sliding mode control is derived. A straight-line switching surface is proposed, and a controller is designed to guarantee that the operation on sliding surface is reached and sustained. The simulation results and experimental results are presented. The performance of the proposed controller is evaluated under various operating conditions and compared with conventional PI controller.

***Keywords* :** sliding mode control, switching surface.

1. INTRODUCTION

Direct current motors have occupied a wide spectrum of applications for variable speed drives, because of their simplicity and versatility of control. In the past three decades, nonlinear and adaptive control methods have been used extensively to control DC and brushless dc motor drives [1-4]. In these methods, the state estimation and parameter identification are based on and limited to linear models. As the model deviates from the physical system, the performance of the control degrades. Sliding mode control is one of the effective and robust means of controlling the nonlinear system. The theory of sliding mode control has been developed for a long time and has recently been applied to the control of a wide range of processes [5-9]. There are many excellent properties in sliding mode control, such as, insensitivity to parameter variations and disturbances, no requirement of the accurate model of the control system, and simple realization of the control algorithm. When a sliding mode is once achieved, the state trajectory slides along a switching hyper surface to the phase space origin.

This paper presents a DC motor speed control using sliding mode control law. A straight-line switching surface is proposed based on the existence of a certain positive define function. The feature of this switching surface is that when the rotor speed response reaches its steady state value, the switching surface become linear.

2. DYNAMIC MODEL OF A SEPARATELY EXCITED DC MOTOR

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

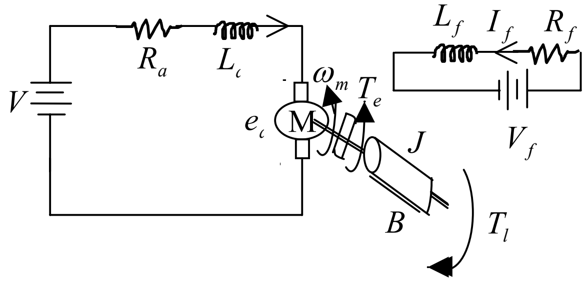


Fig. 1: Schematic diagram of a separately excited dc motor.

The field excitation is normally kept constant to produce rated flux. The armature current is controlled to generate desired electromagnetic torque and the armature voltage is controlled for the load.

Assuming constant field excitation the armature circuit electrical equation is written as

$$V = R_a i_a + L_a \frac{di_a}{dt} + k_b \omega_m . \qquad (1)$$

Where $V =$ Applied Voltage, $R_a =$ Lumped armature resistance, $L_a =$ Equivalent armature inductance, $i_a =$ current flowing through armature circuit, $K_b =$ motor constant and $\omega_m =$ motor speed.

The dynamics of the mechanical system is given by the following torque balance equation

$$T_e = K_t i_a = T_l + J \frac{dw_m}{dt} + B\omega_m . \quad (2)$$

Where $T_e =$ developed torque, $T_l =$ load torque, $J =$ moment of inertia, $B =$ damping constant, and $K_t =$ motor constant.

Equations 1 and 2 are rearranged to obtain

$$\frac{di_a}{dt} = \frac{v}{L_a} - \frac{R_a}{L_a} i_a - \frac{K_b \omega_m}{L_a} , \qquad (3)$$

$$\frac{d\omega_m}{dt} = \frac{K_t i_a}{J} - \frac{T_l}{J} - (\frac{B}{J})\omega_m . \qquad (4)$$

Under steady state condition the speed of the motor is given by

$$\Omega_m = \frac{V - I_a R_a}{K_b} , \qquad (5)$$

$$\Omega_m = \frac{V}{K_b} - \frac{R_a T_e}{K_b K_t} . \qquad (6)$$

Equation 6 indicates that controlling the armature input voltage effectively controls the speed of the motor. It is evident from (3) and (4) that variation of parameters and constants converts the system a nonlinear one.

3. SLIDING MODE CONTROLLER DESIGN

The principle of designing sliding mode control law for arbitrary-order plants is to make the error and derivative of error of a variable is forced to zero [10]. In the DC motor system the speed error and its derivative are the selected coordinate variables those are forced to zero. Switching surface design consists of the construction of the switching function. The transient response of the system is determined by this switching surface if the sliding mode exists. First, the speed error is introduced

$$e(k) = \omega_{ref}(k) - \omega(k) . \qquad (7)$$

Where $\omega_{ref}(k)$ and $\omega(k)$ are the respective responses of the desired reference track and actual rotor speed, at the k th sampling interval and $e(k)$ is the speed error.

A straight-line switching surface σ is introduced in terms of speed error and its derivative is given below [10],

$$\sigma = e(k) + C\frac{de(k)}{dt} . \qquad (8)$$

Where $C > 0$ is a strictly positive real constant and $\frac{de(k)}{dt}$ is the derivative of speed error at k-th sampling interval.

The above equation characterizes the deviations from the desired state. If the sliding surface is reached and sustained, then $\sigma = 0$. The speed error-switching surface is a straight line in the phase plane as shown in Fig 2.

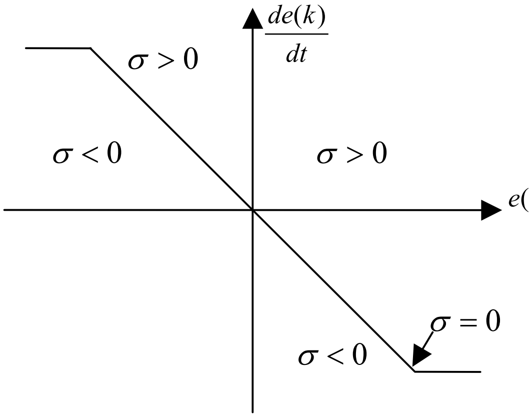


Fig. 2: Switching surface in the phase plane.

For any point at the right side the switching surface $\sigma > 0$ and left side the switching surface $\sigma < 0$, whereas, on the sliding (switching) surface $\sigma = 0$.

The simplest control input to reach $\sigma = 0$ through equivalent control [10] is given by

$$\begin{matrix} u = -1 for \sigma > 0 \\ u = +1 for \sigma < 0 \end{matrix} ,$$

Where u is the equivalent control signal compensating the estimated unknown dynamics.

The complete control circuit block diagram of the proposed system is shown in Fig. 3. Here u is adjusted to positive and negative voltages for -1 and +1 values.

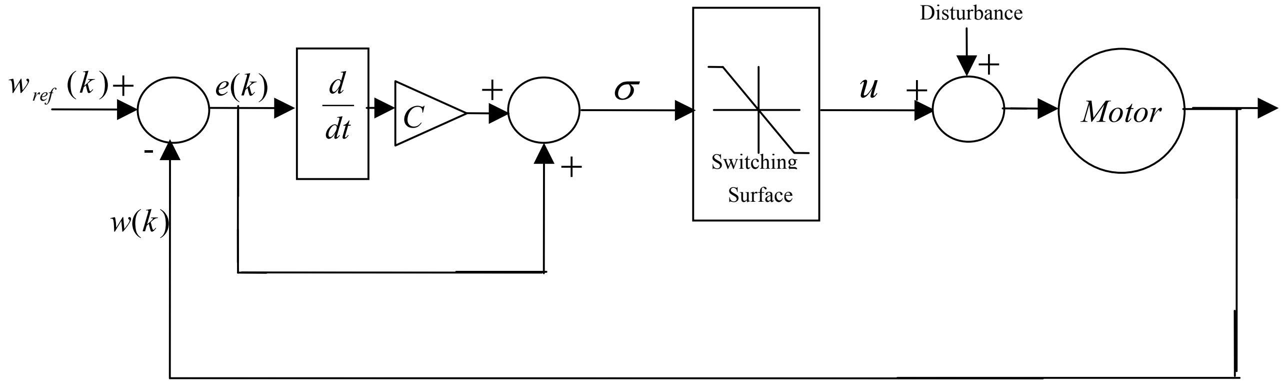


Fig. 3: Block diagram of sliding mode speed control system.

4. SIMULATION RESULTS

The performance evaluation of the proposed speed controller was made by simulation on a digital computer environment. Parameters of the DC motor drive used for simulation are listed below:

Armature resistance,	R_a= 7.56 Ω
Armature reactance,	L_a= 0.055 henry
Moment of inertia,	J = 0.136 Kg-m^2
Damping constant,	B=0.0002 Kg-m^2
Load torque,	T_l= 1 N-m.

Equations (3) and (4) are solved simultaneously using the Runge-Kutta-Gill method. Sampling time of the speed controller is 5 ms. The performance of proposed controller was compared with conventional PI controller.

Figure 4 shows the output voltage and speed of PI controller for a random disturbance in speed measurement (output) of ± 3%.

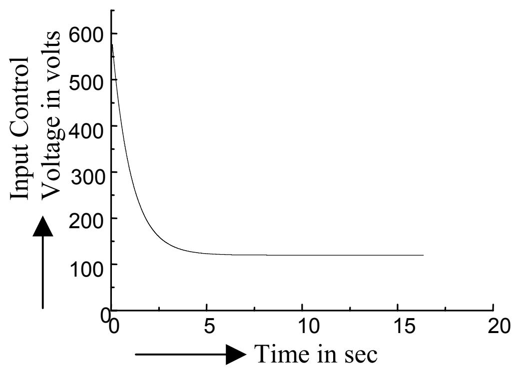


Fig. 4(a): Control signal voltage of the PI controller for a disturbance in speed of ± 3%.

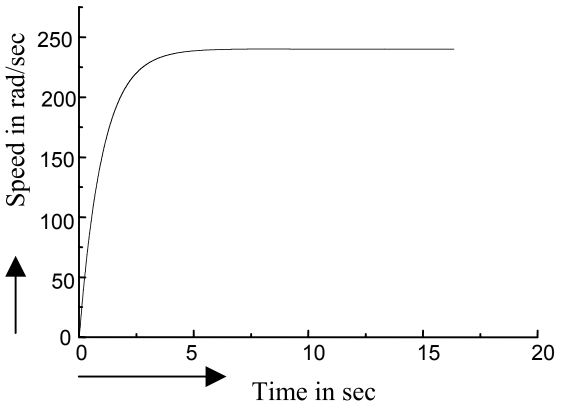


Fig. 4(b): speed of the PI controller for a disturbance in speed of ± 3%.

Figure 5 shows the output voltage and speed of sliding mode controller for a random disturbance in speed measurement (output) of ± 3%.

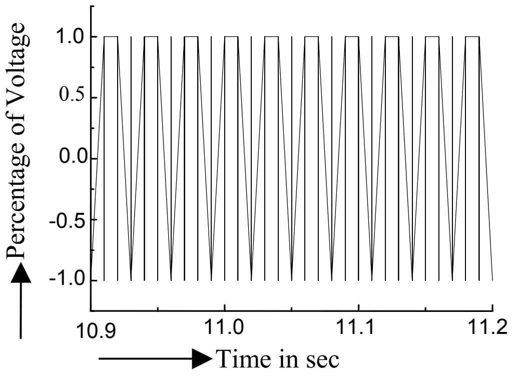


Fig. 5(a): Percentage of voltage of the Sliding Mode Controller for a disturbance in speed of ± 3 % (Base value of voltage= 220 volts).

The steady state speed of sliding mode controller is very close to reference speed as compared to PI controller. The sliding mode controller shows better performance.

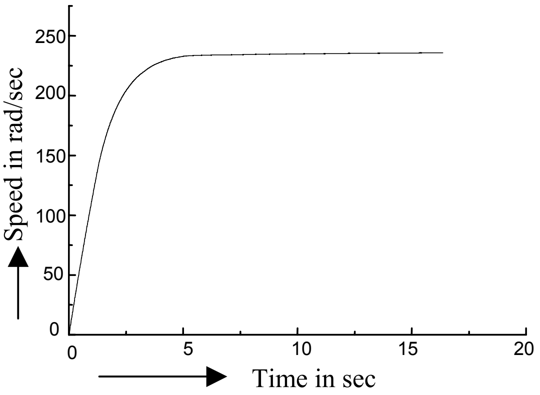
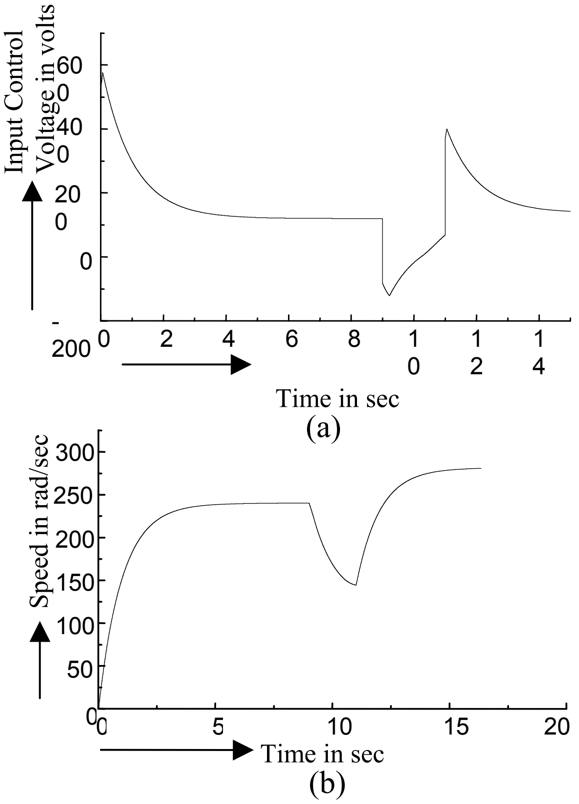


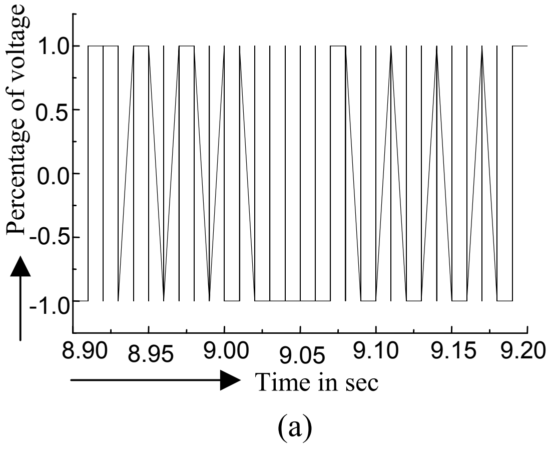
Fig. 5(b): Speed of the Sliding Mode Controller for a disturbance in speed of ± 3%.



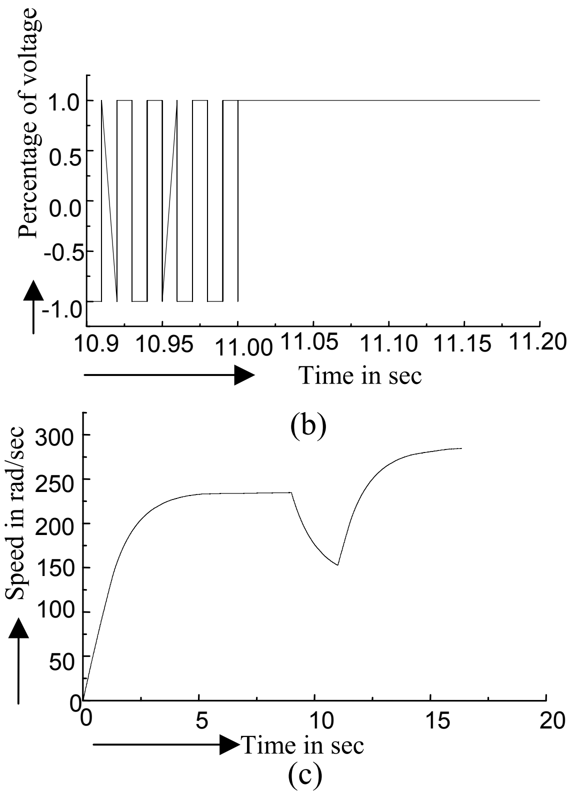
(a)

(b)

Fig. 6: (a) Control signal voltage and (b) speed of the PI controller for different set speeds.



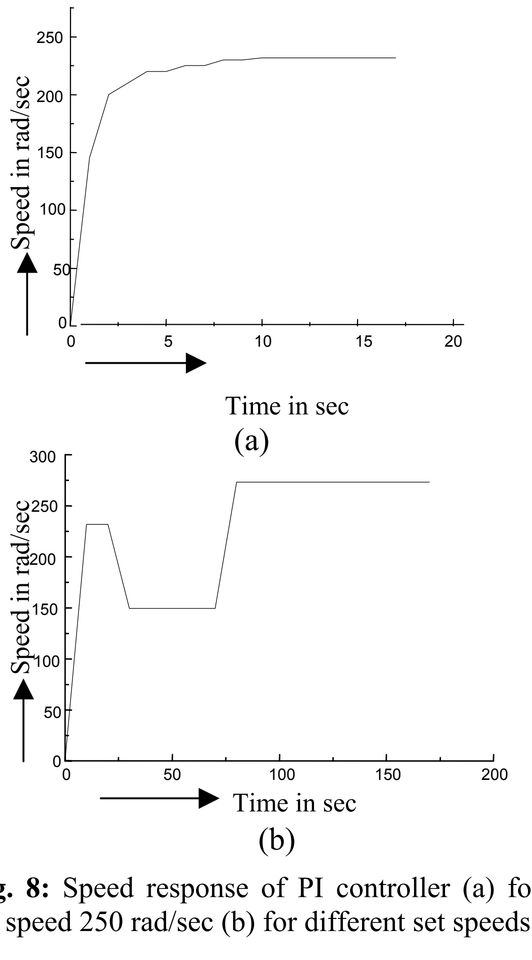
(a)



(b)

(c)

Fig.7: (a), (b) Control signal voltage, (c) speed of the Sliding Mode Controller for different set speeds.



(a)

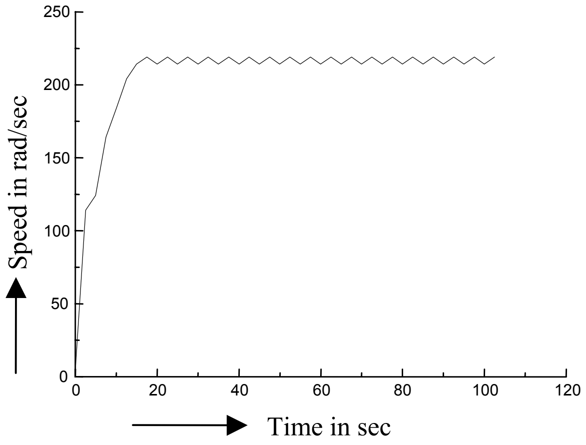
(b)

Fig. 8: Speed response of PI controller (a) for set speed 250 rad/sec (b) for different set speeds.

Figures (6) and (7) show the controller performance for different set speeds. Initially the reference speed was 250 rad/sec. After 09 seconds the reference speed was set at 150 rad/sec. When the motor speed reaches to set speed, the reference speed was set at new value of 300 rad/sec. For both controllers, speed is changed gradually with change in reference speed.

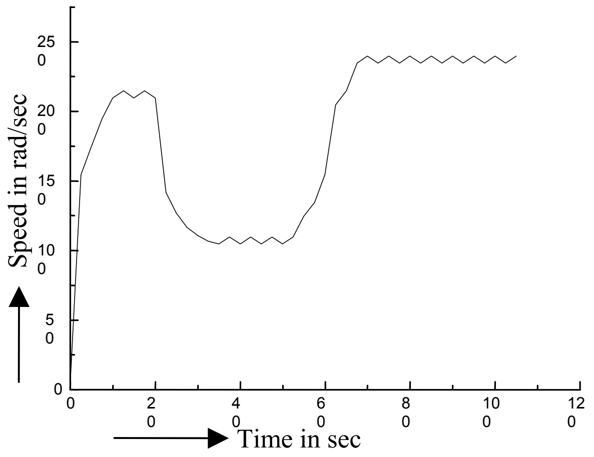
5. EXPERIMENTAL RESULTS

To verify the proposed concept a laboratory setup was made with a DC motor drive. Figures (8) and (9) show the speed response of PI controller and sliding mode controller respectively. It was found that step changes of speed for PI controller where speed change gradually for sliding mode controller.



(a)

Fig. 9(a): Speed response of Sliding Mode Controller for set speed 250 rad/sec.



(b)

Fig. 9(b): Speed response of Sliding Mode Controller for different set speeds.

6. CONCLUSIONS

A new switching surface is proposed for a DC motor speed control system. The simulation and experimental results show that the sliding mode controller has the fast speed response, determined by the switching surface, and is obtained without overshoot. By applying random speed disturbance up to ± 3%, the speed response of PI controller is slightly oscillatory, whereas the speed response of sliding mode controller is perfectly smooth. The control system is insensitive to the motor parameter variation and load torque disturbances.

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