Volume 5, Issue 3, July 2018 ISSN: 2348-8565 (Online)
IJMERT
International Journal of Modern Engineering and Research Technology
Website: http://www.ijmert.org Email: editor.ijmert@gmail.com

Robust Control of DC Motor Using Sliding Mode Control Approach

Mayuri R. Chate
Research Scholar PG)
M. B. E. Society's College of Engineering
Ambajogai(Maharashtra) [INDIA]
Email:mayurichate2894@gmail.com

S. S. Sankeshwari
Professor & Head of the Department
Department of Electrical, Electronics & Power Engg.
M. B. E. Society's College of Engineering
Ambajogai(Maharashtra) [INDIA]
Email: sankeswari@gmail.com

Abstract

The sliding mode controller is used to regulate the speed of direct current (DC) motor based on VSS approach,. DC motors find applications in industrial and domestic equipment. The control of speed of DC motor with high accuracy is required. The speed of a DC motor usually is directly proportional to the supply voltage. The advantages used DC motor is provide excellent speed control for acceleration and deceleration with effective and simple torque control. The Performance Analysis Methods on sliding mode theory is used to improve the dynamical characteristics of DC motor. Sliding mode control method is studied for controlling DC motor because its robustness against model uncertainties and external disturbances..The Performance Analysis Methods improve dynamical characteristics like settling time, steady state error, overshoot. Firstly this paper deals with various conventional controllers (PI, PD, PID) on DC motor to check dynamic characteristics but as controllers have effect of non linearity in dc motor, so sliding mode controller is used to control speed of dc motor. Performance of these controllers has been verified through simulation results using MATLAB/SIMULINK. The simulation results show that sliding mode controller is better than conventional controllers.

Keywords:— *Sliding Mode Controller (SMC), variable structure control(VSS), dc motor, performance analysis methods(PAM).*

I. Introduction

The development of high performance motor drives motor is very important in industrial as well as other purpose. Direct Current motor have occupied wide range of applications for variable speed drives, because of their simplicity [1]. The practical application mainly in field of control of dc motor robotic manipulator [2], pm synchronous motor, induction motor, aircraft control, flexible space structure control [3]. The purpose of speed controller is to drive the motor at desired speed. DC motors generally controlled by conventional Proportional plus Integral controller, since they can be designed easily [4]. 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 [5]. In this SMC controller is designed for dc motor system and its performance is compared with various controllers. The sliding-mode control method, theoretically, is able to reject the matched disturbances and it is able to provide robust control signal under uncertainties [6]. 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 sliding mode technique with various types of controllers. Firstly the paper introduces principle of sliding mode control method. Then design, controller of DC motor and then performances are compared with conventional controllers and sliding mode controller. DC drives are less complex.

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.

DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose. Sliding mode control was performed, as a result, the fast response speed and robust performances can be achieved.

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, that degrade the performance of conventional controllers.

This paper is organized as: brief discussion of the system with mathematical model in Section II. Section III describes various controllers for DC motor system. Section IV describes sliding mode control technique in dc motor system and Section VI with simulation result and conclusion and future scope in section VII.

II. Model 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 Figure 1. Objective here to control the speed of the motor through armature voltage. The field excitation is kept constant to produce rated flux. It is most suitable for wide speed control and for many adjustable speed drives[17].

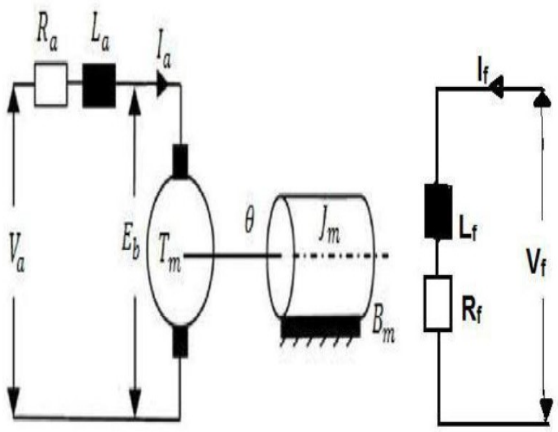

Figure 1: Separately excited DC motor

The equation of motor:

Where, V_a is the Applied Voltage,

R_a is the armature resistance,

L_a is the Equivalent armature inductance,

I_a is current flowing through armature circuit,

E_b is the back emf.

The armature voltage equation is given by,

$$V_a(t) = Ra.\, I_a(t) + L_a \frac{dIa}{dt} + E_b(t) \quad (1)$$

And back emf equation,

$$E_b(t) = K_b(t)\,\omega(t) \quad (2)$$

Torque balance equation of system as,

$$Tm(t) = J\frac{d\omega}{dt} + B\ \omega(t) \qquad (3)$$

Where T is developed torque, J is moment of inertia, B is damping constant, ω is angular velocity, Kt is torque constant(Nm/A).

$$T_m\ (t) = K_t .\ I_a\ (t) \qquad (4)$$

From above equations we get,

$$V_a\ (t) = Ra.\ I_a\ (t) + L_a \frac{dIa}{dt} + K_b\ (t)\ \omega(t) \qquad (5)$$

$$K_t .\ I_a\ (t) = J\frac{d\omega}{dt} + B\ \omega(t) \qquad (6)$$

By taking Laplace equation, rearranging them as,

$$V_a(s) = \omega(s)\frac{1}{Kt}[L_a.Js^2 + Ra.J + L_a.B(s) + K_b\ K_t] \qquad (7)$$

$$\frac{\omega(s)}{Va(s)} = \frac{Kt}{(JLa\ s^2 + (JRa + BLa)s + (KtKb + BRa))} \qquad (8)$$

This is transfer function of DC motor. The input terminal V_a is taken to be the controlling variable.

Table 1 : DC Motor Specifications

Parameter	**Value**
Armature resistance (Ra)	1.5 Ω
Armature inductance (La)	0.05 mH
Torque constant	24.5 mNm/A
Rotor inertia	82.5 ms
Starting current	10 A
Nominal voltage	12 V
No load speed	1200 rpm
No load current	151 mA

III. Performance Analysis

1. P Controller

P controller is mostly used in first order processes to stabilize the unstable system. It is mainly used to decrease steady state error of system. If gain K increases, the system steady state error decreases. P controller decreases rise time after some decreasing steady state error. Due to p controller causes oscillation.

- Increasing K_p will reduce steady state error.
- After certain limit, increasing K_p only causes overshoot.
- Increasing K_p reduces rise time

2. PI Controller

PI controller is mainly used to eliminate steady state error formed from P controller. But overall stability and speed response of system it has negative impact. And also controller cannot decrease rise time and eliminate oscillations. And if applied guarantees overshoot rises.

- Integral control eliminates steady state error.
- After certain limit, increasing K_i only increases overshoot.
- Increasing K_i reduces rise time a little.

3. PD Controller

PD controller predicts the future error by improving the controlling. D is derivative mode, for sudden change in output by change in error signal. It not used as it amplify the noise.

- Increasing K_d decreases overshoot.
- Increasing K_d reduces the settling time

4. PID Controller

PID controller optimizes all dynamics of the system with higher stability. PI controller with the derivative component eliminate overshoot and oscillations occurring in output response. Main feature of PID controller is used with higher order processes.

$$C_{pid}(s) = K_p\left(1+\frac{1}{T_r(s)}+T_d(s)\right) \qquad (9)$$

In order to achieve optimum solution K_p, K_i and K_d gains are arranged according to system characteristics.

IV. Sliding Mode Control

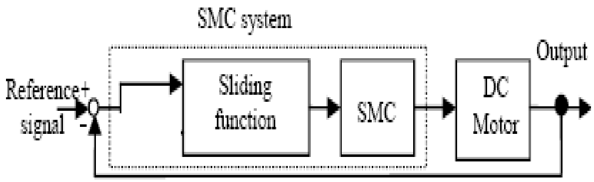

Figure 2: DC Motor with SMC System

Sliding Mode Control is a technique derived from variable structure control (VSC) which was originally studied by [1]. The controller is based on SMC method as it deals with liner as well as non-linear system, time varying system [3]. The robustness to uncertainties is mainly considered in designing the system. The structure of controller is intentionally altered as its state crosses the surface as described in control law. The first step in sliding mode control is defining the sliding surface.

Features

- Robustness of sliding mode controller.
- Used for systems with uncertainties.
- Dynamic behavior of the system may be tailored by the particular choice of switching functions.
- Closed-loop response becomes totally insensitive to a particular class of uncertainty.

V. Controller Design

We write system in state space model,

$$\dot{x} = f + gu + hd \qquad (10)$$

$$\dot{x} = \begin{bmatrix} a & 0 \\ 1 & 0 \end{bmatrix} x + \begin{bmatrix} b \\ 0 \end{bmatrix} u + \begin{bmatrix} 1 \\ 0 \end{bmatrix} d \qquad (11)$$

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}, f = \begin{bmatrix} a & 0 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} ax_1 \\ x_2 \end{bmatrix}, \; g = \begin{bmatrix} b \\ 0 \end{bmatrix}, \; h = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \qquad (12)$$

The switching surface is defined by,

$$\sigma(x) = C_1 x_1 + C_2 x_2 = p^T x \qquad (13)$$

$p^T = [c_1 \; c_2]$, to determine control law that keeps the system on $\sigma(x) = 0$, where p introduce the Lyapunov function,

$$V(x) = \frac{\sigma^2(x)}{2} \qquad (14)$$

The following control law design will ensure that $V(x) < 0$ for all 't' except when $\sigma(x) = 0$.

VI. Simulation and Simulation Result

The DC motor with sliding mode controller is attached by the corresponding simulink model and its outputs are given below.

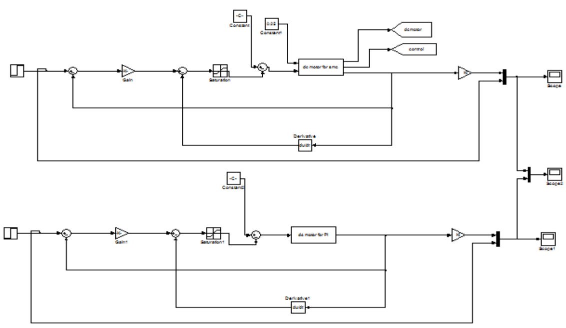

Figure 3: With PID and SMC

Results

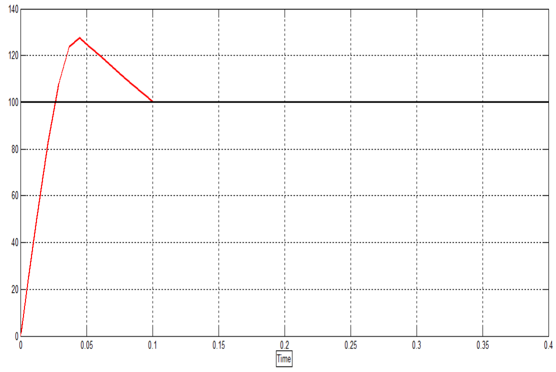

Figure 4: Output of sliding mode controller

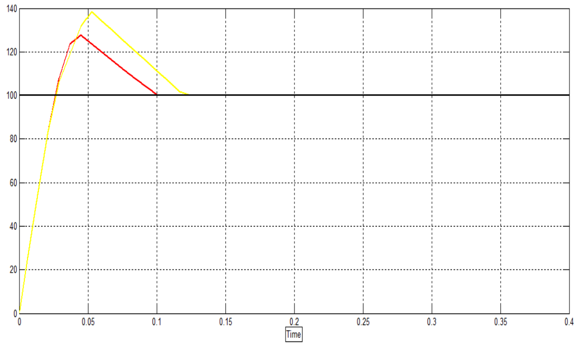

Figure 5: Comparing with PI and sliding mode controller

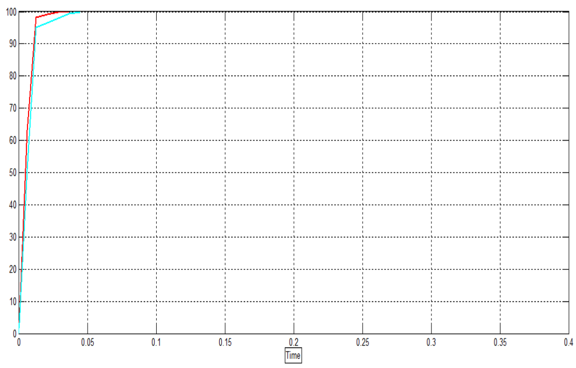

Figure 6: Output waveform with constant speed

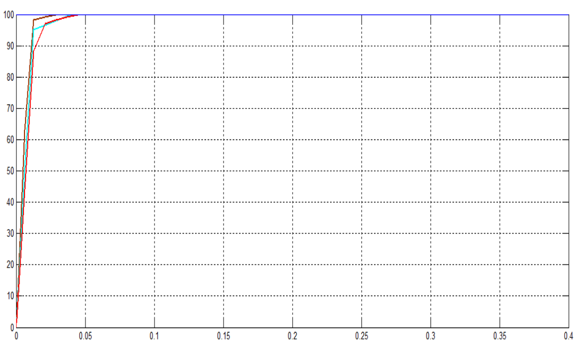

Figure 7: Waveforms comparing PI, PID and SMC

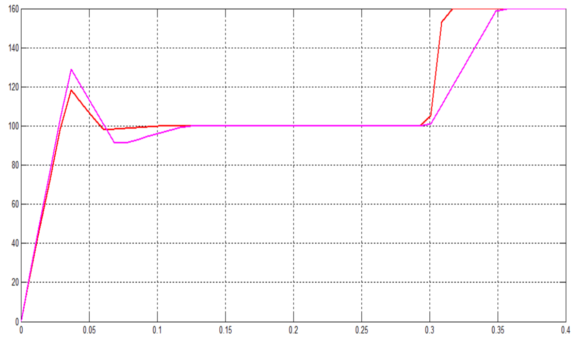

Figure 8: Output waveform by changing speed and load torque

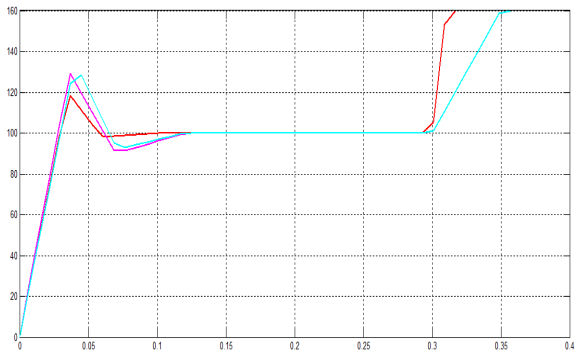

Figure 9: Waveforms of PI, PID and SMC

Speed response of DC motor is done by using PID, PD and SMC controllers, the response due to SMC is better compared to PID controller.

VII. CONCLUSION

In this paper, Sliding Mode Controller is used for speed control of DC motor. It reveals that speed control of dc motor with sliding mode control produces smaller overshoot and oscillations, than the measure value. The SMC is proven to be robust to the parameters variations like order reduction, fast response and robustness to disturbances. Simulation result from the sliding mode controller, provides high performance, Dynamic characteristics and are robust with regard to DC motor parameter variations and external load disturbances. In addition to this is performance analysis is used to reduce settling time, over shoot, steady state error of DC motor.

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