SLIDING MODE SPEED CONTROL OF A DC MOTOR

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ABSTRACT **The main objective of this paper is to control the speed of separately excited DC Motor using a Sliding mode controller based on VSS approach. This controller is based on variable structure systems which aim at reducing the peak overshoot, steady state error and settling time of a DC Motor. In the first stage, PI controller is used to control the speed of DC Motor. A model is developed and simulated using MATLAB/SIMULINK. Later on the same is done with sliding mode controller. The speed control of DC Motor using both PI and Sliding mode controllers is studied and the results are compared. The simulation results show that Sliding mode controller is superior than PI for speed control of DC motor. Since the SMC is robust in presence of disturbances, the desired speed is perfectly tracked.**

KEYWORDS: **Variable structure control, Sliding mode controller, DC motor drives**.

I. INTRODUCTION

Variable structure control (VSC) made its first appearance in early 1950's in Soviet Union. The variable structure systems *(VSS)* consist of a set of continuos subsystems with proper switching logic and, as a result, control actions are discontinuous functions of system states, disturbances and reference inputs. The dominant role in VSS theory is played by sliding modes, and the main idea of designing VSS control algorithms consists of enforcing this type of motion in some manifolds in system state spaces.

When there are disturbances and uncertainties in a system, an appropriate control should be designed so that the system stability and desired system responses are achieved. Sliding mode control (SMC) is insensitive in the presence of external uncertainties and disturbances, particularly, to the so-called matched uncertainties. The robustness properties of SMC have led this approach to be an intensive, popular and suitable method for the control of wide classes of linear and nonlinear systems. Various SMC approaches have been evolved during the last three decades comprising of practical implementation of SMC and theory development of SMC.

PI controllers have a simple control structure, inexpensive cost, many proposed systematic tuning methods, and have been used for more than half a century. However, when the system is nonlinear but known or where there are bounded uncertainties in the system, PI controllers are not perfectly able to stabilise the system, particularly, when the nonlinearity is very high or the bound of uncertainty is large. In many practical problems, almost perfect disturbance rejection or control performance is required. SMCs may be applied to the system to obtain these performances. An SMC enforces the system trajectories to move on a prespecified surface and remain on it thereafter. On the other hand, a discontinuous SMC may be approximated by a continuous control. In fact, the trajectories tend to an equilibrium point within a boundary of the sliding surface. When the trajectories move on the sliding surface, the system is internally controlled by a virtual control, the so-called equivalent control. SMCs are insensitive in the presence of uncertainties and unmodelled dynamics.

II. VariableStructureSystems (VSS)

A *variable structure system* is a dynamical system whose structure changes in accordance with the current value of its state. A variable structure system can be viewed as a system composed of independent structures together with a switching logic between each of the structures. With appropriate switching logic, a variable structure system can exploit the desirable properties of each of the structures the system is composed of. Even more, a variable structure system may have a property that is not a property of any of its structures.

We can illustrate above idea with an example:
We consider a dynamical system model

$$\begin{aligned} \dot{x}_1 &= x_2 \\ \dot{x}_2 &= -U\,x_1 \end{aligned} \qquad -(1)$$

having two structures corresponding to $u = 1/a$ and $u = a$, where a is a positive constant greater than 1; in our

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example we take a = 5. The phase-plane portraits of the structures are shown in figures (a) and (b). The phase-plane portraits of the individual structures are families of ellipses. Neither of the structures is asymptotically stable—they are only stable. However, by choosing a suitable switching logicbetween the structures, we can make the resulting variable structure system asymptotically stable. Indeed, suppose the structure of the system is changed any time the system's trajectory crosses either of the coordinate axes of the state plane, that is,

$$A = \begin{cases} \frac{1}{5}, x_1 x_2 < 0 \\ 5, x_1 x_2 > 0 \end{cases} \qquad -(2)$$

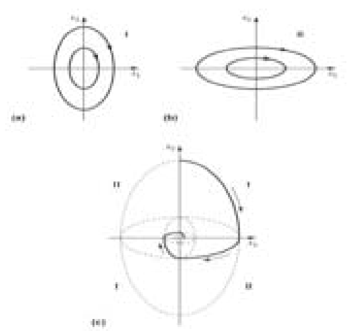

Figure1: Phase Plane Potraits

Here *(*a) and (b) are the phase-plane portraits of structures making up a variable structure system. (c) is phase-plane portrait of the variable structure system itself, where the structure ofthe system is changed any time the system's trajectory crosses either of the coordinate axis.

III. <u>Sliding Mode Control (SMC)</u>

The Sliding mode control is one way of approach to **Variable Structure Control**.

In many practical problems, almost perfect disturbance rejection and set point tracking are required. SMC may be applied to such systems to obtain these performances. VSC has non-linear feedback, which is discontinuous in the nature. The control is called non-linear because the control input switches rapidly between two or more control limits. Using this control as a feedback the structure of the system can be altered or switched as its state crosses each discontinuity surface. This closed loop system is described as Variable Structure Control System or Variable Structure System. The state crosses and re-crosses the surface, called switching surface or sliding surface and then continuously lies on the switching surface, when error and rate of change of error become zero. This type of motion is called Sliding Motion. To emphasize the importance of the sliding motion, the control is often called as Sliding Mode Control. When the trajectory moves on the sliding surface, the system is internally controlled by the so called equivalent control.

DC motors are extensively used in robotics and electrical equipments. Therefore, the control of the speed of the DC motor is very important and has been studied since the early decades in the last century. Generally, the DC motor systems have uncertain and nonlinear characteristics which degrade performance of controllers. Based on these reasons, Sliding Mode Control (SMC) is one of the popular control strategies and powerful control technology to deal with thenonlinear uncertain system. It is often used to handleany worst-case control environment such as parametric perturbations with lower and upper bounds, externaldisturbances, stick-slip friction, and etc. Precise dynamic models are not required and its control algorithms can be easily implemented. However, the robustness of the slidingcontrol strongly depends on specified parameters in designing of the sliding function.

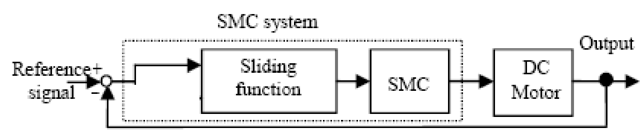

Figure2: Block diagram of a DC motor with SMC system

IV. <u>Generation of the control signal for SMC</u>

DC motors are widely used for industrial and domestic applications. Examples are as robotic and actuator for automation process, mechanical motion, and others. Accurate speed control of the motor is the basic requirement in such applications. The electric circuit of the DC motor is shown in Fig. 4. Objective is to control the speed of the motor by armature voltage control. The reference signal determines the desired speed. For simplicity, a constant value as a reference signal is given to the system to obtain desired speed.

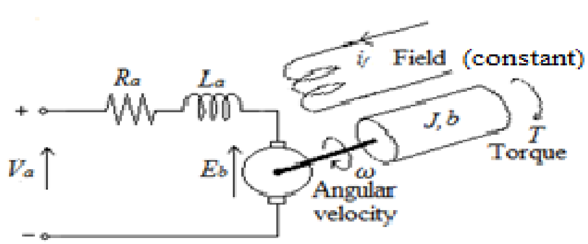

Figure 3: The structure of DC Motor

The differential equations governing the dynamics of the system is given by

$$T(t) = J\frac{d\omega}{dt} + B\,\omega(t) \quad -(3)$$

Where represents angular velocity in rad/s, J represents the moment of inertia in Kgm^2/s^2 and b is the coefficient of viscous friction which opposes the direction of motion in Nms. The torque T generated by the armature current in Nm is given by

$$T(t) = K_t\, i_a(t) \quad -(4)$$

Where $i_a(t)$ is the armature current in Amp and Kt is torque factor constant in Nm/Amp. This in turn is assumed to satisfy Kirchhoff's voltage law

$$V_a(t) - E_b(t) = R_a\, i_a(t) + L_a \frac{d\, i_a}{dt} \quad -(5)$$

Where R_a and L_a are the armature inductance in H and resistance in ohm respectively and E_b represents electromotive force in V given by

$$E_b(t) = K_b(t)\,\omega(t) \quad -(6)$$

Where K_b is the back emf constant in Vs/rad . The input terminal voltage V_a is taken to be the controlling variable.

Using above equations, one can write state model with the ω and i_a as state variables and V_a as manipulating variable, as given below

$$\begin{bmatrix} \frac{d\omega(t)}{dt} \\ \frac{di_a(t)}{dt} \end{bmatrix} = \begin{bmatrix} \frac{-b}{J} & \frac{K_t}{J} \\ \frac{-K_b}{L_a} & \frac{-R_a}{L_a} \end{bmatrix} \begin{bmatrix} \omega(t) \\ i_a(t) \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{L_a} \end{bmatrix} V_a(t)$$

Table 1

Parameters of DC Motor

$R_a = 0.6\,\Omega$	$K_b = 0.8\,Vs/rad$
$L_a = 0.012H$	$J = 0.0167\ kg\ m^2/s^2$
$K_t = 0.8\,Nm/A$	$b = 0.0167$

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

$$\frac{\omega(s)}{v_{a(s)}} = \frac{3992.015}{s^2 + 51\,s + 51.39} \quad -(7)$$

In time domain the above equation can be

$$\ddot{\omega}(t) + 51\dot{\omega}(t) + 51.39\,\omega(t) = 3992.015\,v_a(t) \quad -(8)$$

Now consider

$$x_1 = \omega(t) \text{ and } u = V_a(t) \quad -(9)$$

Then the system can be converted in the following canonical form

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

$$\dot{x}_2 = -51.39\,x_1 - 51\,x_2 + 3992.015\,U \quad -(10)$$

$$y = x_1$$

Now select the sliding surface

$$\sigma = c\,(r - x_1) + x_2 \quad -(11)$$

Where c is the constant of sliding matrix $C_\sigma \in R^{m*n}$ such that $c < 0$. The total control law is then given by

$$U = U_l + U_{nl} \quad -(12)$$

$$U = \frac{-1}{3992.015}\left((-51.39\,x_1 + (c-51)x_2) + k\,\frac{\sigma}{\sigma+\delta}\right) \quad -(13)$$

Where $K > 0$ is selected sufficiently large. Larger the value of K the faster the trajectory converges to the sliding surface.

This function is given as control input to the DC motor model to control the speed of it.

V. Simulink idea for Sliding Mode Control

In order to control the speed of DC motor using sliding mode control we need to design the motor as per our convenience to give our sliding mode control signal which is derived above as input.

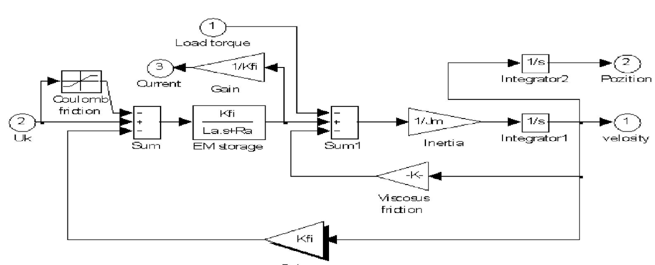

Figure 4: Simulink Model Of DC Motor for SMC

We need to place this dc motor block in the below model of SMC to control the speed as per our requirement.

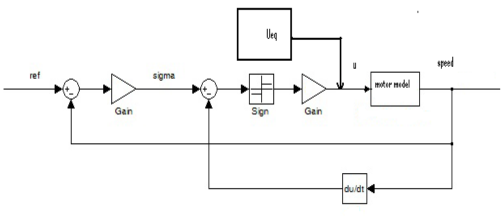

Figure 5: Control Model for SMC

VI. SIMULATION RESULTS

Case I: The load torque is subjected to change from 10N-m to 25N-m t 0.8 sec and constant reference speed of 100 rad/sec.

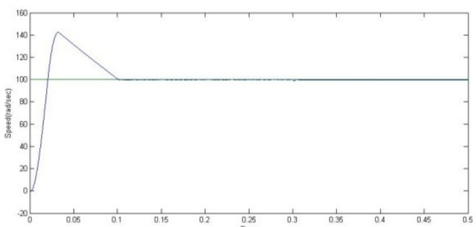

Figure 6: Output Waveform using PI control

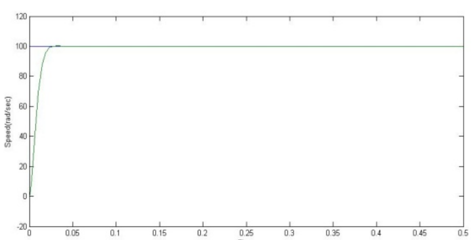

Figure 7: Output Waveform using SMC

	M_p	SettlingTime	SteadyState Error
PI	0.15	0.005	0.04
SMC	0.001	0.001	-0.002

Case II: The reference speed is subjected to change from 100rad/sec to150 rad/sec at 0.8 sec and constant load torque of 25 N-m.

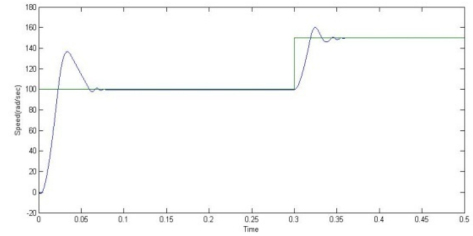

Figure 8: Output Waveform using PI control

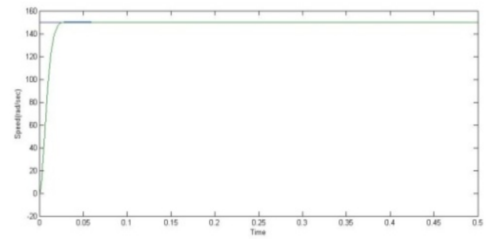

Figure 9: Output Waveform using SMC

	M_p	SettlingTime	SteadyState Error
PI	4.33	0.025	0.22
SMC	0.0667	0.0023	-0.012

Case III: The reference speed is subjected to change from 100rad/sec to150 rad/sec and step load torque of 10N-m to 25 N-m at 0.8sec.

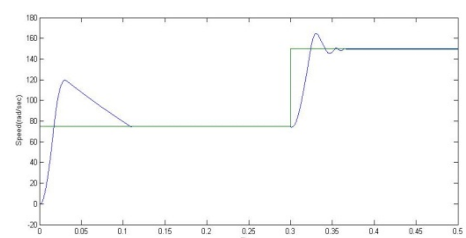

Figure 10: Output Waveform using PI control

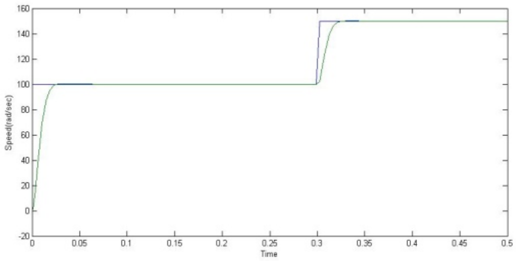

Figure 11: Output Waveform using SMC

	M_p	SettlingTime	SteadyState Error
PI	4.3	0.035	0.3
SMC	0.073	0.0067	-0.02

VII. CONCLUSIONS

In this paper PI controller and SMCare applied for the speed control of DC motor .Performance of both controllers are evaluated at different step load torques and different step reference changes in speed and it is observed that performance of Sliding Mode controller is better over PI controller when settling time, peak overshoot, and steady state error are considered. It would be possible to get better performance of PI controller by increasing proportional and integral coefficients but it will be a problem in real time implementation of PI controller for changes in the parameters of plant.

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