# Improve the Performance of Control System by using the Second Order Sliding Mode (SMC) Control

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**Abstract** - In this article the second order sliding mode control is proposed for improving the system performance. So that a proportional + integral + derivative sliding surface is used to increase reaching speed. It provides the result with better tracking specifications in case of external disturbances, better behavior of the system output and faster convergence of sliding surface while maintaining the system stability and temperature. The electromechanical plant which shows the suitability and effectiveness of proposed second order sliding mode control and its factors which are involved in design. According to Lyapunov stability criteria and asymptotic stability criteria is theoretically proved.

**IndexTerms** - Sliding mode control (SMC), Proportional integral derivative (PID), Power Rate Reaching Law (PRRL).

## I. INTRODUCTION (HEADING 1)

Now-a-days sliding mode control is the most interesting concept from the technical point of view. Sliding mode control (SMC) is known to be a robust control method appropriate for uncertain systems. High robustness is maintained against various kinds of uncertainties such as external disturbances and measurement error. For good dynamic speed tracking and load regulating response we are using the high performance motor drive. Here DC motor is used whose speed/torque characteristics compatible with mechanical loads. This makes a D.C motor controllable over a wide range of speeds by proper adjustment of its terminal voltage. While using motor practically there are many control issues such as slower speed response, chattering phenomenon, unknown parameters and variable unpredictable input. So the problem of controlling electromechanical systems is very important in many industrial applications. To improve the characteristics of the electric drives and motors various researches are done.

In control system the electromechanical system such as DC motor is used in a wide range, it gives the easy speed or position control. In this control system, second order sliding mode control simulink model is used whose tracking specifications are noted and the required modifications are done to get the faster convergence and better response of the system. To obtain a second-order sliding mode control based on a PID sliding surface with independent gain coefficients and address issues related to sliding mode control. Sliding mode control (SMC) is known to be a robust control method appropriate for uncertain systems. High robustness is maintained against various kinds of uncertainties such as external disturbances and measurement error. Equivalent control approach is used in solution based on the second-order plant. The formal descriptions of traditional SMC, 2-SMC, model description is given with control strategy and results [1].

In recent years, control of such systems has attracted greater search interest. The study of second order sliding mode control is done for an uncertain plant which uses the equivalent approach to show the improved performance of the system. In control system it is well known that it have nonlinear and time varying behavior with various uncertainties and disturbances. Some advantages of SMC method are insensitivity to bounded disturbances, robustness to parameter uncertainties, fast dynamic response are mark able computational simplicity with respect to other robust control approaches.[2,4].

For the robust finite time controller design higher order sliding mode control algorithm is given as: design finite time controller and discontinuous control laws, gives finite time stabilization of the nominal system and rejects the uncertainties of the system respectively [6].

The description of electromechanical plant and its online identification is available in this paper. In short we get the examination of dc motor behavior which constitutes a useful effort for analysis and control of many practical applications [10].

The peculiar focus is to reduce the error to zero, not only the sliding surface, but also its second-order derivative. It means that the second-order sliding mode corresponds to the control acting on the second derivative of the sliding surface [9].

## II. SLIDING MODE CONTROL

*Second-order sliding mode control*

In the 2-SMC the condition is given like this "for any $r^{th}$ order sliding mode, $s(t) = \dot{s}(t)$ …………..= $s^{(r-1)} = 0$.

The purpose of higher order sliding mode control is to enable the error to move on the switching surface s(t) = 0 and the first successive derivative (r-1) null. The PID sliding surface introduced for the second order sliding mode control is give as follow:

$$\dot{s}(t) + \beta s(t) = k_p e(t) + \int_0^t k_i e(\tau)d\tau + k_d \dot{e}(t) \qquad (1)$$

Where kp, ki and kd are the independent positive constants denoting proportional, integral and derivative gains, respectively, all these constants belong to $\mathbb{R}^+$, β is also a positive constant and belongs to $\mathbb{R}^+$. After the sliding mode is enforced it determines the rate of decay for s(t) and contributes in damping too. For the flexibility of the sliding surface the gains are provided in the above equation.

The system is initially in the region s(t) > 0 and that input is not sufficient to drive the error towards sliding surface. So that it results in increasing s(t) and error moves far from the sliding surface. To force the error to move towards the sliding surface the integral action is used so that it increase the control action accordingly and it satisfy the condition $\dot{V}$ (t) = 0. Now as the s(t) reaches the sliding surface, the control action gets reduced because s(t) is decreasing. The system is said to be in sliding mode when s(t) is on the sliding surface and so the problem of tracking set point is equivalent to that of remaining on the zero sliding surface for at>0.

The control input is given as , U (t) = ueq(t) + u sw(t)

Where ueq(t) and usw(t) are the equivalent control and the switching control respectively. The equivalent control is given by Ut k in is based on the nominal plant parameters with D (t, u(t)) = 0 and it provides the main control action. And the switching control ensures the discontinuity of the control law across the sliding surface. The controller must be designed such that it can drive the error to sliding surface and when it reach to sliding surface it is said to be the reaching phase.

*Equivalent control equation*

The equivalent control is obtained from the equation, take the second time derivative of the sliding surface as such below,

$\ddot{s}(t) + \beta\, \dot{s}(t) = k_p\, \dot{e}(t) + k_i\, e(t) + k_d\, \ddot{e}(t)$ (2)

The error converges to zero exponetionally if the system trapped on the sliding surface and the coefficients, kp, ki and kd, are selected properly. The plant Eq. satisfies second order mode with respect to the sliding surface s(t) if its error lies on the intersection of s(t) =0 and $\dot{s}$(t) = 0. Now substitute Eq. into Eq. (2), as such,

$\ddot{s}(t) + \beta\, \dot{s}(t) = k_i e(t) + k_p \dot{e}(t) + k_d(\dddot{y}_r(t) + A_n \dot{y}_m(t) + B_n y_m(t) - C_n u(t) - D(t, u(t)))$ (3)

By recognizing $\ddot{s}$(t) = 0 the equivalent control is found and it's the necessary condition for error to stay on sliding surface, D (t, u(t) ) is not taken into account. When $\ddot{s}$(t) =0 we get the equivalent control as,

$u_{eq}(t) = (k_d C_n)^{-1} k_i e(t) + k_p \dot{e}(t) + k_d(\dddot{y}_r(t) + A_n \dot{y}_m(t) + B_b\, y_m(t) - \beta\, \dot{s}(t))$ (4)

The equivalent signal with the uncertainty is given as such below,

$u^* = u + C^{-1} D(t, u(t))$ (5)

Switching control equation

If the switching control is function is introduced directly as,

$U_{sw}(t) = \lambda_1 s(t) + k_s\, \mathrm{sign}(\dot{s}(t))$ (6)

Where $\lambda_1$, $k_s \in \mathbb{R}^+$ with $\lambda_1 > \underline{1}$, $k_s > \underline{D_{max}}$ with $D_{max} = \sup_{\forall t, s, \dot{s}=0} \{D(t,u(t))\}$.If$C_n k_d C_n$

Eqs. (3) and (5) are substituted into Eq.(2) one has

$\ddot{s}(t) = -k_d D(t,u(t)) - k_d C_n \lambda_1 s(t) - k_d C_n k_s\, \mathrm{sign}(\dot{s}(t))$ (7)

The switching controller of the traditional SMC is,

$(t) = \underline{k_{sc}} \tanh(\, s(t)/\Omega_c)$ (8)

The second order sliding mode switching controller using the hyperbolictangent function instead of the sin function can be given as:

$U(t) = \lambda_1\, s(t) + k_s \tanh(\dot{s}(t)/\Omega)$ (9)

## III. REACHING LAW & LYAPUNOV STABILITY

*Sliding Mode Control Based On Reaching law*

Sliding mode control based on reaching law includes reaching phase .The reaching phase drive system is to maintain a stable manifold and the sliding phase drive system ensures slide to equilibrium. Due to the chattering phenomenon the high frequency in the system would be excited easily and the effectiveness of the system also be affected. W.B.Gao, an expert who studied SMC in china has proposed the reaching law approach to reduce or inhibit the chattering of SMC in the premises of ensuring the condition of sliding existence $S\dot{s} < 0$ has been meet. The idea of sliding mode can be describing a follows:

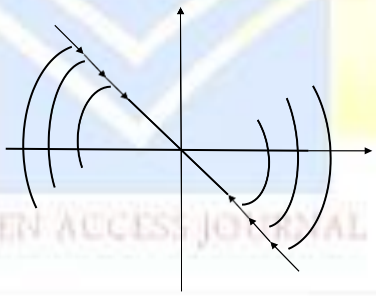

Fig.1 Classic Reaching Law

*Constant Rate Reaching Law*

$\dot{s} = -\varepsilon\, \mathrm{sgn}(s)$ $\varepsilon > 0$ Where ε represent constant rate.

This law constraints switching variable to reach the switching manifold s at a constant rate ε. The merit of this reaching law is its simplicity. But as will be shown later, if ε is too small, the reaching time will be too long. On the other hand, too large ε will cause severe chattering.

*Exponential Reaching Law* is

$\dot{s} = -\varepsilon\, s(t) - ks$ $\varepsilon > 0$ , $k > 0$ Where $\dot{s}$ is exponential term its solution is s = s (0) $e^{ks}$

Clearly by adding the proportional rate term –ks, the state is forced to approach the switching manifold faster when the s is large.

*Power Rate Reaching Law*

$\dot{s} = -k\,|s|^{\alpha}\,\mathrm{sgn}(s) \quad k > 0,\ 1 > \alpha > 0$

This reaching law increases the reaching speed when the state is far away from the switching manifold. However it reduces the rate when the state is near the manifold. The result is fast and the low chattering reaching mode.

*General Reaching Law Is*

$\dot{s} = -\varepsilon\,\mathrm{sgn}(s) - f(s),\ \varepsilon > 0$ Where $f(0) = 0$ and $s\,f(s) > 0$ when $s \neq 0$

It is the evident that above four reaching laws can satisfy the sliding mode arrived condition $S\dot{s} < 0$.

*Equivalent Control Equation*

As we know for the second order sliding mode the condition is $s(t) = \dot{s}(t) = \ldots = s^{(r-1)} = 0$ and in power rate reaching law is used while deriving the equation for equivalent control.

Now use Eq.(2),as given below:

$\ddot{s}(t) + \beta\,\dot{s}(t) = ki\,e(t) + kp\,\dot{e}(t) + kd\,(\ddot{y}r(t) + An\dot{y}m(t) + Bn\,ym(t) - Cn\,u(t) - D(t, u(t))$ (10)

If we substitute the $\ddot{s}(t) = 0$ and the we get,

$\beta\,(-k\,|s|^{\alpha}\,\mathrm{sgn}(s)) = ki\,e(t) + kp\,\dot{e}(t) + kd\,(\ddot{y}r(t) + An\dot{y}m(t) + Bn\,ym(t) - Cn\,u(t) - D(t, u(t))$ (11)

By rearranging the terms we get,

$kd\,Cn\,u(t) = ki\,e(t) + kp\,\dot{e}(t) + kd\,(\ddot{y}r(t) + An\dot{y}m(t)) + \beta\,(k\,|s|^{\alpha}\,\mathrm{sgn}(s))$ (12)

Considering the necessary conditions we kept the error on the sliding surface, D (t, u (t)) is not taken into account so the equivalent control is obtained as follows:

$ueq(t) = (kd\,Cn)^{-1}(ki\,e(t) + kp\,\dot{e}(t) + kd\,(\ddot{y}r(t) + An\dot{y}m(t)) + \beta\,(k\,|s|^{\alpha}\,\mathrm{sgn}(s))$ (13)

*Switching Control Equation*

The equation for the switching control is given as follows:

$usw(t) = \lambda_1\,s(t) + ks\tanh(\dot{s}(t)/\Omega)$

*Lyapunov Stability Analysis*

Lyapunov stability analysis is the most popular approach to prove and evaluate the stable convergence property of nonlinear controllers, e.g. sliding mode control here direct Lyapunov stability approach is employed to investigate the stability property of the proposed second order sliding mode controller.To get stability derivation

$\dot{v}(t) < 0,\ s(t) \neq 0,\ \dot{s}(t) \neq 0.$

$\dot{v}(t) = s(t)\,\dot{s}(t) + \dot{s}(t)\,\ddot{s}(t) = s(t)\dot{s}(t) + \dot{s}(t)(-k_dD(t,u(t)) - k_dC_n\lambda_1\,s(t)k_dC_nk_s\mathrm{sign}(\dot{s}(t)) = s(t)\dot{s}(t) - k_dC_n\lambda_1\,s(t)\,\dot{s}(t) - \dot{s}(t)\,k_dD(t,u(t)) - k_dC_nk_s|\dot{s}(t)|$

$\leq |\dot{s}(t)|(s(t) - k_dC_n\lambda_1\,s(t) - k_dD(t,u(t)) - k_dC_nk_s)$

$\leq |\dot{s}(t)|(|s(t)| - k_dC_n\lambda_1|s(t)| - k_dD(t,u(t)) - k_dC_nk_s)$

$\leq |\dot{s}(t)|(|s(t)| - k_dC_n\lambda_1|s(t)| + k_dD_{max} - k_dC_nk_s)$

$= -|\dot{s}(t)|(|s(t)|(k_dC_n\lambda_1 - 1) + k_dC_nk_s - k_dD_{max}) < 0$

In control theory a control-Lyapunov function V(x) is a Lyapunov function for a system with control inputs. The ordinary Lyapunov function is used to test whether a dynamical system is stable (more restrictively, asymptotically stable). That whether the system starting in a state $x \neq 0$ in some domain D will remain in D, or for asymptotic stability will eventually return to $x = 0$. The control-Lyapunov function is used to test whether a system is feedback stabilizable, that is whether for any state x there exists a control u (x, t) such that the system can be brought to the zero state by applying the control u.

## IV. Simulink Results And Discussion

*SOSMC combined model with PRRL*

The speed response and associated control efforts of the proposed SOSMC and the PRRL based SOSMC is shown in the results. The performance specification of the PRRL based SOSMC is much better than the SOSMC. Such that smaller rise time, settling time and smaller output deviation in magnitude is seen in the PRRL. The performance specifications of the 2-SMC system are much better than that of the first-order SMC system such that the smaller rise time, settling time and the

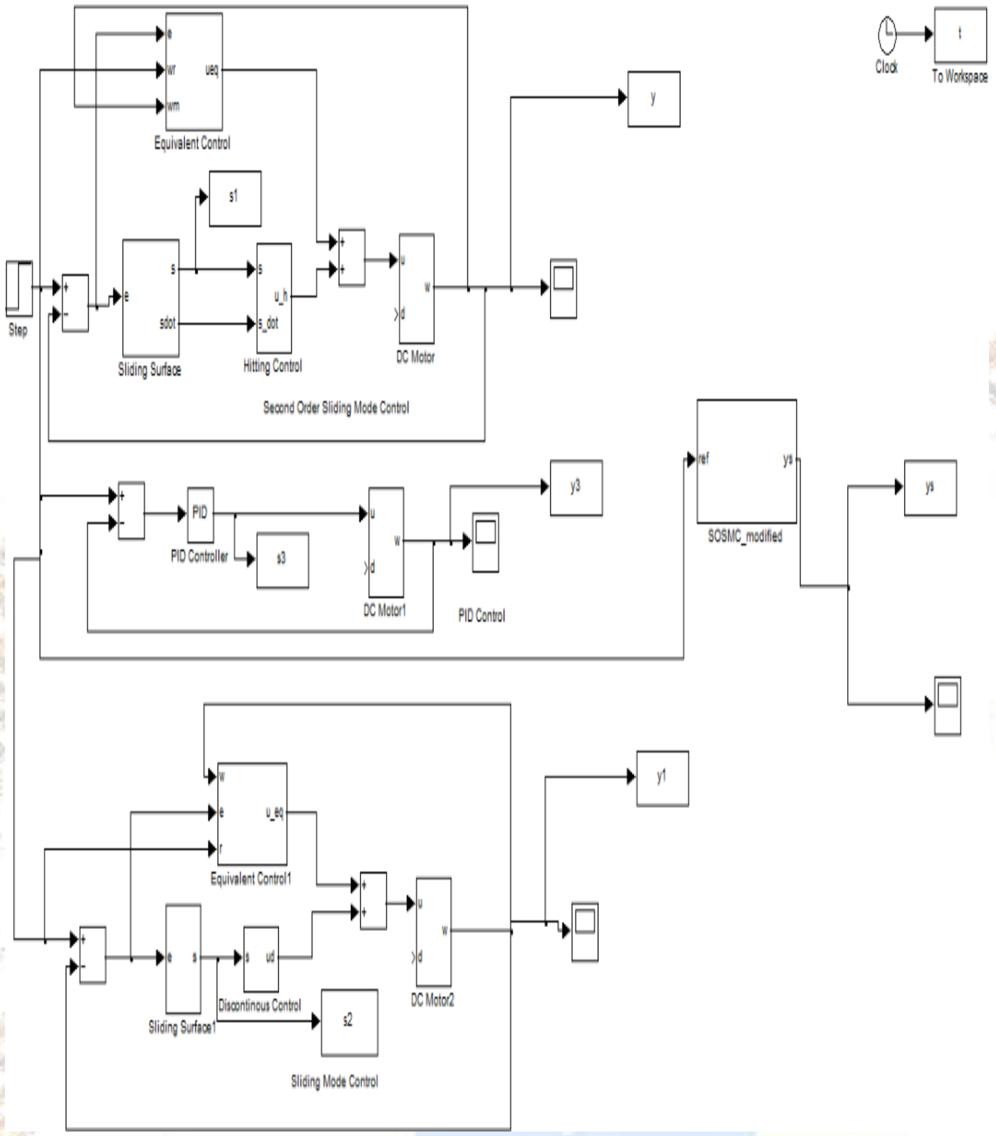


Fig.2 Combined Simulink Model



smaller output deviations in magnitude were obtained from the proposed 2-SMC system. The large overshoot (57.8%) is obtained from the PID control system that is unacceptable. The responses in smaller time range, in 0.20 s, are illustrated to check transient performance specifications. The 2-SMC input converges faster and the variations are smaller in steady-state conditions. Traditional sliding mode control input converges more slowly and the PID control input has larger variations in magnitude at the transient and steady-state conditions. Larger variations in the control effort are not desired. The steady-state variations are smaller in the 2-SMC system with faster convergence. It can be noted that the sliding surface is not zero, $s(t) \neq 0$ when the error signal is not zero. This means that the sliding mode is in the reaching phase up to 0.1 s and then arrives sliding phase. The surface s(t) is near to zero when the error signal is very small or motor speed is trying to reach the command speed. Theoretically the sliding function is expected to be zero at steady-state conditions, but there are always unmatched uncertainties ad disturbances, frictions and nonlinearities. The system is in the sliding phase since the steady state (average) value of the sliding function is zero. The system trajectories are plotted in the phase plane, $e(t)$ and $\dot{e}(t)$ of the traditional SMC algorithm, respectively.

The tracking of the SOSMC control system is show in the fig.6.3.1[11] and fig.6.4.1[11] shows the tracking of PRRL based SOSMC. With the help of this result we can analyze the difference in the result of SOSMC and PRRL based SOSMC. To test the tracking of the system, the closed-loop system is tested at 1500 rpm of speed such that a square wave set-point change corresponding to 1500 - 100 rpm is applied to the system. The figures confirm the fact that the system with the second-order sliding mode controller has a better tracking performance than the system with the traditional sliding mode controller and PID controller. Smaller speed variations, ±7 rpm in magnitude were obtained in the 2-SMC system. The control effort of the SOSMC is shown in the fig.6.3.2 [11] and fig.6.4.8 [11]show the control efforts of the PRRL. The response to speed change of the dc motor is shown in the fig.6.3.6 [11]for the SOSMC and the fig.6.4.7 [11]shows speed change response of the PRRL. The control signal for the SOSMC is shown in the fig.6.3.7[11] and for the PRRL is shown in the fig.6.4.8 [11]Now the phase plane trajectory of the SOSMC system is shown in the fig.6.3.5[11] and the phase plane trajectory of PRRL is shown in the fig.6.4.10[11] The sliding surface s(t) of the SOSMC is shown in the fig.6.3.4 [11]and the fig.6.4.9[11] shows sliding surface s(t) for the PRRL

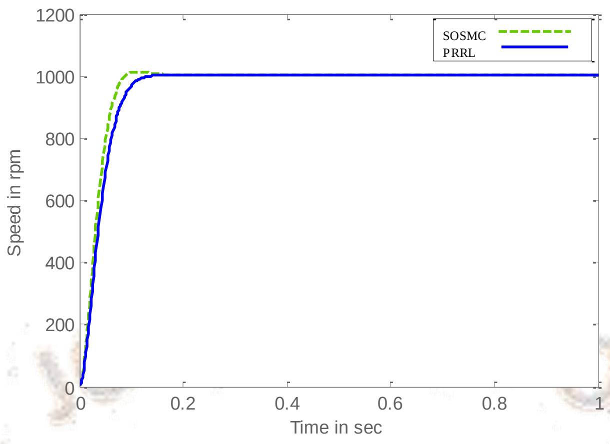


Fig. 3 Combined result of SOSMC & PRRL for speed

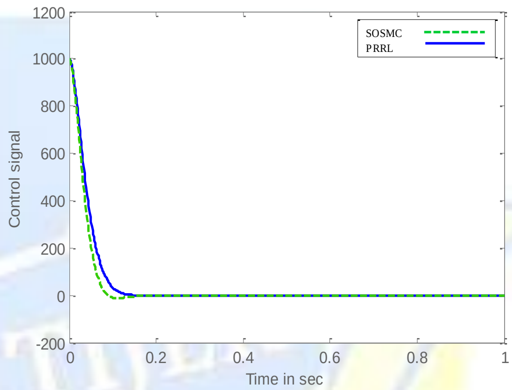


Fig. 4 Combined result of SOSMC & PRRL for control signal

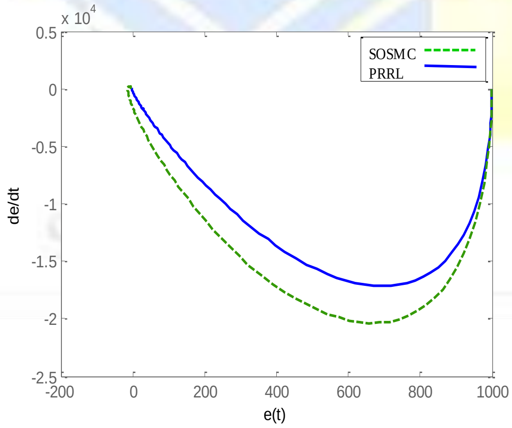


Fig.5 Combined result OF SOSMC & PRRL for phase trajectory

The speed responses and the associated control efforts of the proposed PRRL system, the 2-SMC system to a step command change (0_1000 rpm speed change) are illustrated. The performance specifications of the 2-SMC system are much better than that of the first-order SMC system such that the smaller rise time, settling time and the smaller output deviations in magnitude were obtained from the proposed 2-SMC system. The large overshoot (57.8%) is obtained from the PID control system & SMC that is unacceptable. Moreover, the switching control should be minimized to provide a reasonable control activity in practical implementation not to hurt actuators.The figures below confirm the fact that the proposed PRRL control system provides better the transient and the steady-state performance specifications. These verify that the proposed PRRL system provides better performance specifications of the closed-loop system, a faster convergence of the sliding surface and better behavior of the output in case of external disturbances. At last the comparison of the speed, the control signal and the phase trajectory are given in the figures below. The Fig.3 shows the comparison for speed of SOSMC and PRRL. The Fig.4 shows the comparison for control signal of SOSMC and PRRL. The Fig.5shows the phase trajectory comparison of SOSMC and PRRL.

## V. CONCLUSIONS

In the study of article to improve the performance of control system we proposed the second order sliding mode control. The power rate reaching law is used in order to get the better tracking performance of the control system. In second order sliding mode control system the tracking error converges to zero under the existence of parameter uncertainties and disturbances. This system provides better performance specifications, a faster convergence of the sliding surface and better behaviour of the output. Here we get the better behaviour of the system output and good stability response.

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