Sliding mode control technique of step down converter using reaching law

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ABSTRACT

The robust reaching law based sliding mode control is used for chattering suppression, minimization of steady state error and reaching speed kept minimized. With fine tuning of parameters of robust reaching law, the sliding mode reaches the equilibrium point at the earliest. The stability of the proposed reaching law is analyzed. In one hand, they guarantee the system reach the sliding face rapidly and stay on it, in another way they decline the chattering effectively, even unmatched certainties and disturbances. Such that the system response can better realize the unification of rapidity. A proposed reaching law ia analyzed mathematically and applied to SMC DC-DC buck converter to lessen the chattering, because switching devices are existing in the model, it reduces effectively in the switching losses in the switching devices of the dc-dc converter. In turn effectiveness of the efficiency increases. MATLAB/Simulink results give significant decline of chattering and switching losses in the buck converter.

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1. INTRODUCTION

Sliding mode control (SMC) is a nonlinear control system design technique that is robust to parameter variations and matched uncertainties [1]–[8]. It evolved from variable structure control (VSC) and is established in the field of nonlinear control [1], [2], [9]–[13]. In [14]–[16] provide more information on sliding mode control. A reaching law in the SMC takes the system states into the sliding surface at a fixed time interval. Once the condition of the system reaches the sliding line, the switching control causes chattering. The regularity of the chattering is infinite, and its amplitude is decreasing. However, in realistic systems, due to the dynamics of the electronics sensors and actuators. The chattering frequency is finite and also has some amplitude [17]. In mechanical systems, this can result in high losses, making such systems unusable; in high-speed electronics, it can result in enormous variations in the fixed state presentation, resulting in unacceptable systems. A number of methods have been proposed in various research works for explaining the chattering effect.

Young *et al.* [18] proposed VSC along with non sliding methods were used for eliminate the high frequencies by achieving the elimination of chattering. Camacho *et al.* [19] introduced tuned sigmoid functions were implemented to weaken the chattering. Gao and Hung [20], power rate reaching law was implemented for the alleviation of chattering. Higher order sliding mode wakened the chattering [21], [22] and smooth sliding mode [23]–[25] suppressed the chattering. However, it was not considered robust against the parameter variations and matched uncertainties, which increased the complexity of the smooth sliding mode control.

The different reaching law structures explained that chattering alleviation and convergence speed, minimization of steady sate errors, robustness explained [26], [27]. However, the further application of SMC is limited because of the chattering phenomenon, which can excite high frequency dynamics. Thus, some approaches have been proposed to overcome this problem. Continuation control method can solve this problem effectively. Though this method could restraint the high-frequency chattering, it also destroys the sliding mode [28]. Another method of restraining chattering is higher order sliding mode control, which can eliminate the discontinuous term in control input [29]. In this reaching law technique which is used to chattering mitigation can obtain the control law easily [30], [31]. The problem identified that in the proposed work is chattering in SMC, due to chattering, more switching losses in the step-down converter and not obeying portion of the sliding mode. The sliding mode and switching losses are coincide with control techniques. Hence the reaching law plays key role for reduction of losses and bringing the states on to the phase of sliding mode.

2. METHOD: MATHEMATICAL ANALYSIS OF ROBUST REACHING LAW (RRL)

A new RL, called robust reaching law, is described in this section. The proposed RRL is described in vector format as (1).

$$s^{\cdot} \quad = -\rho(s, \mu, \sigma) sign(s) \tag{1}$$

Where σ is a positive integer, $0 < \sigma < 1$; μ is a constant, $0 < \mu < 1$.

$$\rho(s, \mu, \sigma) = \left(1 - \mu e^{\frac{-abs(si)}{\sigma i}}\right) \tag{2}$$

$$\dot{si}\left(1 - \mu e^{\frac{-abs(si)}{\sigma i}}\right)^{-1} = -sgn(si(t) \tag{3}$$

Integrating with respect to time, reaching time can be calculated as (4).

$$treach = -\int_0^{Si(0)} \left(1 - \mu e^{\frac{-abs(si)}{\sigma i}}\right)^{-1} ds \tag{4}$$

When si (t)>0, for negative values

$$treach = -\int_0^{-Si(0)} \left(1 - \mu e^{\frac{-abs(si)}{\sigma i}}\right)^{-1} ds \tag{5}$$

When si (t) <0, positive values

$$treach = -\int_0^{Si(0)} \left(1 - \mu e^{\frac{-abs(si)}{\sigma i}}\right)^{-1} ds \tag{6}$$

When combined both (5) and (6) the reaching time,

$$treach = -\int_0^{abs(Si(0))} \left(1 - \mu e^{\frac{-abs(si)}{\sigma i}}\right)^{-1} ds \tag{7}$$

As a final point, we get

$$treach = \frac{\sigma i}{ki} ln \left| e^{\frac{abs(si(0))}{\sigma i}} - \frac{\mu i}{1} - \mu i \right| \tag{8}$$

The proposed reaching laws μ bring the system on to the sliding line, by decreasing the value of μ, causes a delay in approaching on to the sliding line, if μ value increases the speed of the system states on the trajectory path, wherever the initial conditions of states. σ makes the states to fast speed kept. If the value of σ reduces, the chattering effect can be minimized and the reaching time kept fast by appropriate selection of σ and μ values, and reduces the chattering at the origin of the sliding surface. The absolute values of the‘s’ bring the stability of the system on the switching surface [32], [33].

2.1. SMC with robust reaching law

Sliding mode control with robust reaching law is given by state variable equation. The state variable equation is given by (9):

$$X1 = Vref - \beta Vo$$
$$X2 = -\frac{\beta ic}{C}$$
$$\text{X3} = \int \tag{9}$$

where X1 X2 and X3 are state variables [32]–[34].

2.2. The constant plus proportional rate reaching law or traditional reaching law

$$\dot{S} = -Qsgn(s) - Ks \tag{10}$$

Q > 0 and K> 0 are positive constants

$$s^{\cdot} = -\rho(s, \mu, \sigma)sign(s) = \dot{S} = \alpha 1\dot{X}1 + \alpha 2\dot{X}2 + \alpha 3\dot{X}3 = 0 \tag{11}$$

Using (1) and (11), we get (using control law)

$$s^{\cdot} = U(X) = -\frac{\partial s}{\partial X}\text{B}\left[\frac{\partial s}{\partial X}\text{Ax} + \rho(s, \mu, \sigma)\text{sign}(s)\right] \tag{12}$$

Where A and B are matrix coefficients of the step-down converter parameters. The (12) represents the control law.

$$-\rho(s, \mu, \sigma)sign(s) = \alpha 1\dot{X}1 + \alpha 2\dot{X}2 + \alpha 3\dot{X}3 = 0$$
$$-\rho(s, \mu, \sigma)sign(s) = \alpha 1\left(-\frac{\beta}{C}\right)ic + \alpha 2\frac{\beta ic}{RC^2} - \alpha 2\frac{UVin\beta}{LC} + \alpha 2\frac{\beta V0}{LC} + \alpha 3(Vref - \beta Vo)$$
$$Ueq = \frac{LC}{\alpha 2Vin\beta}\left[\rho(s, \mu, \sigma)sign(s) - \frac{\alpha 1ic\beta}{C} + \alpha 2\frac{\beta ic}{RC^2} + \alpha 2\frac{\beta Vo}{LC} + \alpha 3(Vref - \beta Vo)\right] \tag{13}$$

The (1) and (12) gives the equivalent value of the input and it's implemented using Simulink.

2.3. Chattering

The chattering is tearness and wearness of the system, it reduces the efficiency of the step -down converter and also makes more noises and switching losses in the system. The effect of chattering in the step-down converter is that more deviated in the output voltage and loss of trajectory path. Figure 1 shows the chattering in SMC. Chattering phenomena is unwanted possessions of variable structure system. The main grounds of chattering a phenomenon are the existence of sign function in control inputs. The chattering has more oscillation at the origin, this causes a more heat losses in system, the sliding line should end with the origin of the system. The chattering is the main drawback of the sliding mode control systems [32], [33]. The trajectory is the path in which sliding line passed through it. If the sliding line curve is not passed through the switching surface, effects that more power losses in the system.

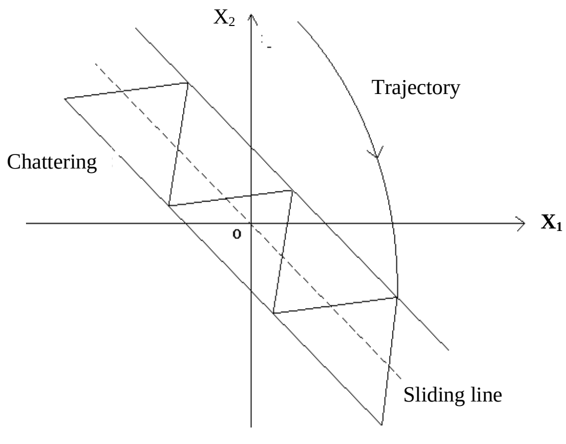

Figure 1. Chattering

3. RESULTS AND DISCUSSIONS

The Table 1 gives the specification of the reaching law and step-down converter. Figure 2 represents the output voltage of the traditional reaching law, it takes the long time to reach the desired output voltage, due to the effect of chattering. Figure 3 represents the chattering of robust reaching law; the Robust reaching law obeys close up to the rule of the sliding surface.

Figure 4 represents the output voltage of the Robust reaching law. The proposed robust reaching law brings the output voltage nearby the origin at minimum time. Figure 5 represents the chattering at the origin of a robust reaching law. Overall performance of the step-down converter is improved. The proposed reaching law is reaches to early than the traditional etching law. From Table 2 represents the settling time, amplitude and reaching time and switching losses of the Robust reaching law and traditional reaching law. A proposed robust reaching law gives more dynamic in reaching time, losses and mitigates the chattering effectively than the traditional reaching law.

Table 1. Specifications of step-down converter and proposed reaching law

Sl. No.	Parameter	Symbol	Value	Sl. No.	Parameter	Symbol	Value
1	Input voltage	Vi	24 volts	11	Feedback factor	β	0.99
2	Capacitance	C	220µF	12	sliding coefficients,	α_1	3
3	Inductance	L	69µH			α_2	25
4	Switching frequency	fs	200 KHz			α3	2000
5	Minimum load resistance	R_L(min)	6 Ohm	13	Duty cycle	α	0.5
6	Maximum load resistance	R_L(max)	10 Ohm	14	Efficiency of the Converter	η	0.91
7	Desired output voltage	Vod	12V	15	Input Power	Pi	14.2 W
8	Reference voltage	Vref	12V	16	Output Power	Po	12.9 W
9	m_1 and m_2 (parameters)		2 and 3				
10	k_1 and k_2 (parameters)		1 and 0.5				

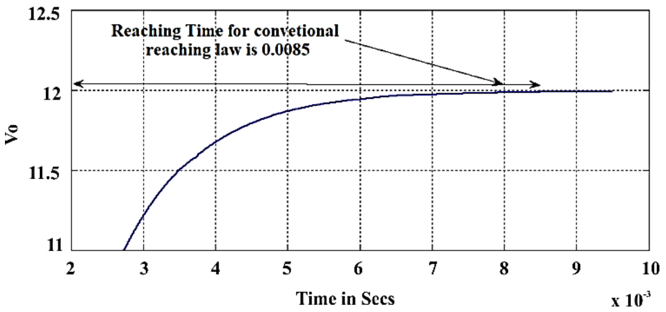

Figure 2. Output voltage of traditional reaching law

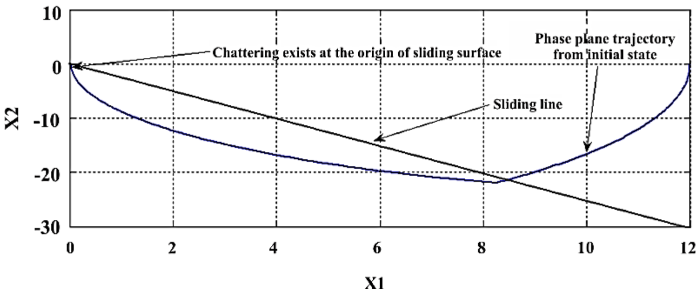

Figure 3. Chattering of robust reaching law

Table 2. Comparison of reaching law with traditional reaching law

Parameters	Proposed robust reaching law	Constant plus proportional rate reaching law
Settling time	0.2 msecs	0.7 msecs
Chattering Amplitude	0n x-axis 0 to 0.03 On y-axis -0.08 to 0.085	0n x-axis 2.5 to 0 On y-axis -0.25 to 0.25
Reaching time To steady state	0.00025 secs	0.0085 secs
Switching losses	0.982 W	0.45 W

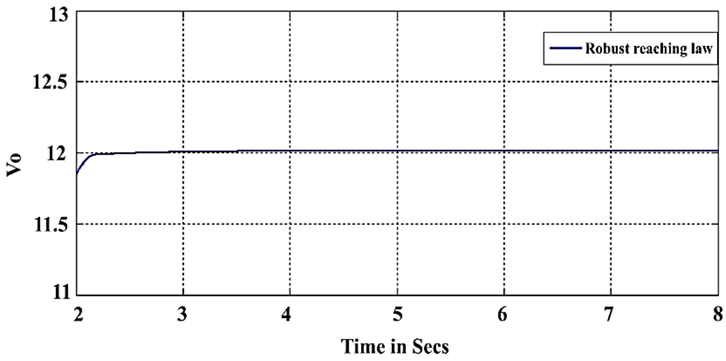

Figure 4. Output voltage of robust reaching law

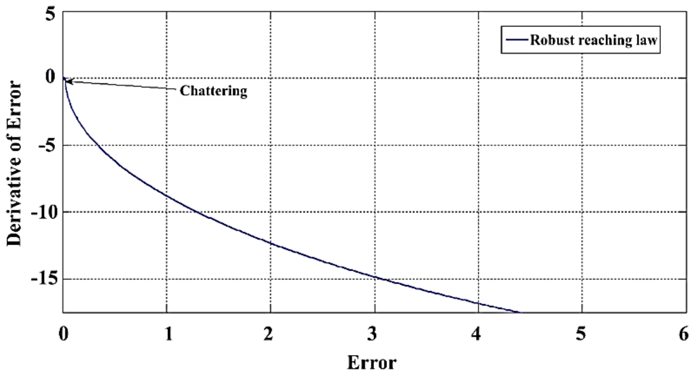

Figure 5. Chattering of robust reaching law

4. CONCLUSION

In this paper we discussed the robust reaching law with conventional reaching law about the chattering mitigation and newly designed robust reaching law effectively reduces the chattering and system remains on sliding surfaces. Both reaching laws are applied to DC-DC step down converter. The dynamic performance of the system can be effectively improved by changing the value of the reaching law parameters. Switching losses can be minimized in the step-down converter. The simulation results show that the proposed robust reaching law exhibits superior static and dynamic properties than the constant plus proportional rate reaching law with respect to losses and reaching time.

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