Sliding Mode Controlled Step down Converter using Reaching law Technique

Tanuja.T[1] , Nandini .G.R [1], Farzana Parveen B.A[1], Roopa .S[1] , Noor Fathima[1]

[1] Sri Jagadguru Murugharajendra Institute of Technology Chitradurga 577502, Karnataka, India

Department of Electronics and Communication Engineering

ABSTRACT

The 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 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 sliding surface, in another way they decline the chattering effectively, even unmatched certainties and disturbances. A proposed reaching law is analyzed mathematically and applied to SMC step down converter to lessen the chattering, because switching devices are existing in the model, it reduces effectively in the switching losses in the switching devices. MATLAB/Simulink results gives significant decline of chattering and switching losses in the step down converter.

Keyword : *- Key word Step down converter,reachinglaw,Chatterig,Reaching law,Conventional reaching law,Sliding mode control*

I. INTRODUCTION

Sliding Mode Control (SMC) is a nonlinear control systems design technique which is robust adjacent to parameter variations and matched uncertainties. It evolved from the Variable Structure Control (VSC) and is established in the field of nonlinear control. Details of sliding mode control can be obtained in [1]- [3]. In the Sliding Mode Control a reaching law takes the system states in the sliding surface at limited time interval. Once the condition of the system reaches the sliding line the switching control causes chattering. The chattering regularity is infinite and its amplitude towards zero. However, in realistic systems due to the dynamics of the Electronics sensors and actuators etc., the chattering frequency is finite and also has some amplitude [4]. In mechanical systems this can result in high bear and losses, as an effect becoming infeasible for use in such systems, on the other hand 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 explanatory the chattering effect. In [5], VSC along with non sliding methods were used for eliminate the high frequencies by achieving the elimination of chattering. In6], tuned sigmoid functions were implemented to weaken the chattering. In [7], power rate reaching law was implemented for the alleviation of chattering. Higher order sliding mode wakened the chattering [8]-[9]. Smooth Sliding Mode [10]-[12].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[13]-[14].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 [15]. Another method of restraining chattering is higher order sliding mode control, which can eliminate the discontinuous term in control input [16]. In this reaching law technique which is used to chattering mitigation can obtain the control law easily [17]-[19]. 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. Hence the reaching law plays key role for reduction of losses and bringing the states on to the phase of sliding mode.

2. METHOD: MATHEMATICALANALYSIS OF SLIDING MODE REACHING LAW (SMRL)

A new RL, called Sliding mode Reaching Law, is described in this section. The proposed RRL is described in vector format as

$$\dot{s} = -\rho(s,\mu,\sigma)\operatorname{sign}(s) \tag{1}$$

Where σ isa positive integer ,0< σ <1; μ isaconstant, 0< μ <1

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

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

Integrating with respect to time, reaching time can be calaculated as follows.

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

When si (t)>0, for negative values

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

When si (t) <0, positive values

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

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

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

As a final point, we get

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

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 parameters of reaching law are bring the stability of the system on the switching surface. [21]-[22].

A. ***SMC with Reaching Law***

Sliding mode control with Robust reaching law is given by,

State variable equation is given by

$$X_1 = V_{ref} - \beta V_o$$
$$X_2 = -\frac{\beta i_c}{C}$$
$$X_3 = \int X_1 \qquad (9)$$

Where X_1 X_2 X_3 are state variables.[20]-[22]

B. ***The conventional reaching law :***

$$\dot{S} = -Q\,\text{sgn}(s) - Ks \qquad (10)$$

Q > 0 AND K> 0 ARE POSITIVE CONSTANTS

$$\dot{s} = -\rho(s,\mu,\sigma)\text{sign}(s) = \dot{S} = \alpha_1\dot{X}_1 + \alpha_2\dot{X}_2 + \alpha_3\dot{X}_3 = 0 \qquad (11)$$

Using equation (1) and (11), we get (Using Control Law)

$$\dot{s} = \mathbf{U(X)} = -\,\partial S/\partial X\ \mathbf{B}\ [\ \partial S/\partial X\ \mathbf{Ax} + \rho(s,\mu,\sigma)\text{sign}(s)\,] \qquad (12)$$

Where A and B are matrix coefficients of the step down converter parameters equation (12) represents the control

$$-\rho(s,\mu,\sigma)\text{sign}(s) = \alpha 1\dot{X}1 + \alpha 2\dot{X}2 + \alpha 3\dot{X}3 = 0$$

law $-\rho(s,\mu,\sigma)\text{sign}(s) = \alpha 1\left(-\frac{\beta}{C}\right)ic + \alpha 2\frac{\beta ic}{RC^2} - \alpha 2\frac{UVin\beta}{LC} + \alpha 2\frac{\beta V0}{LC} + \alpha 3\left(Vref - \beta Vo\right)$ Equations (1) and (12) gives the equivalent

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

values of input and it is implemented using Simulink.

3. .Results And Discussions

Table 1: Specifications of step down converter and proposed reaching law

Sl.No.	Parameter	Symbol	Value
1	Input voltage	Vi	24Volts
2	Capacitance	C	220μF
3	Inductance	L	69μH
4	Switching Frequency	fs	200KHz
5	Minimum load resistance	R_L(min)	6 Ohm
6	Maximum load resistance	R_L(max)	10 Ohm
7	Desired Output voltage	Vod	12V
8	Reference voltage	Vref	12V
9	m1 &m2 (Parameters)		2,3
10	k_1 and k_2(Parameters)		1, 0.5
11	Feedback factor	β	0.99
12	sliding coefficients,	α_1 α_2 α3	3 25 2000
13	Duty cycle	α	0.5
14	Efficiency of the Converter	η	0.91

Table 2: comparison of reaching law with traditional reaching law

Parameters	Proposed reaching law	Conventional reaching law
Settling time	0.2msecs	0.7msecs
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	0.00025Secs	0.0085Secs

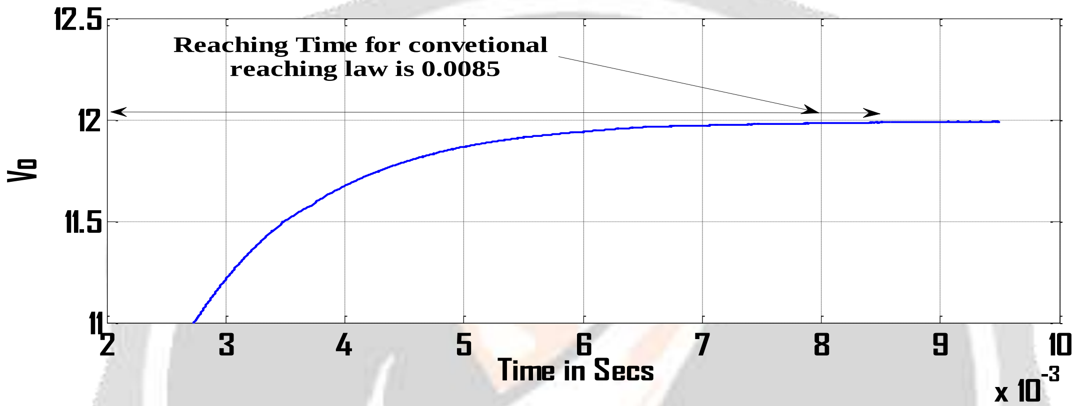

Figure 1 .Output voltage of Traditional reaching law

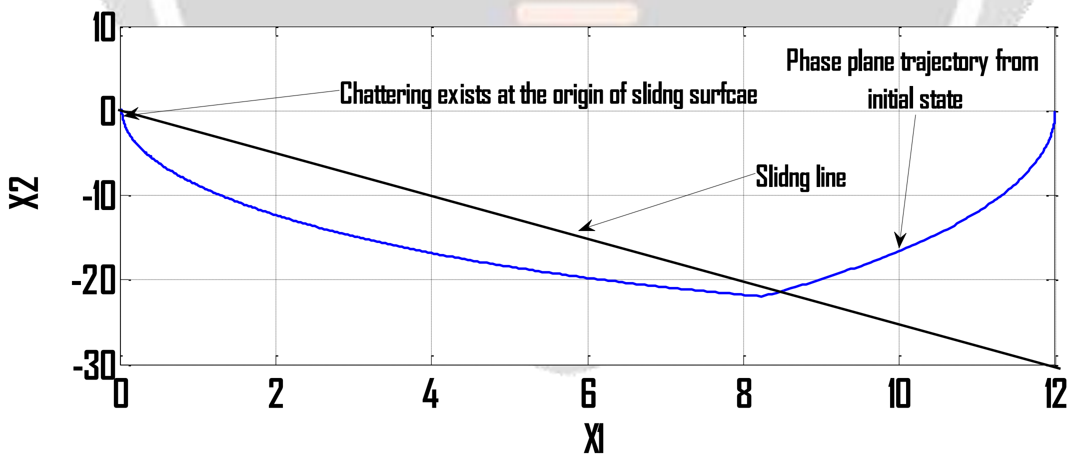

Figure 2. Chattering of reaching law

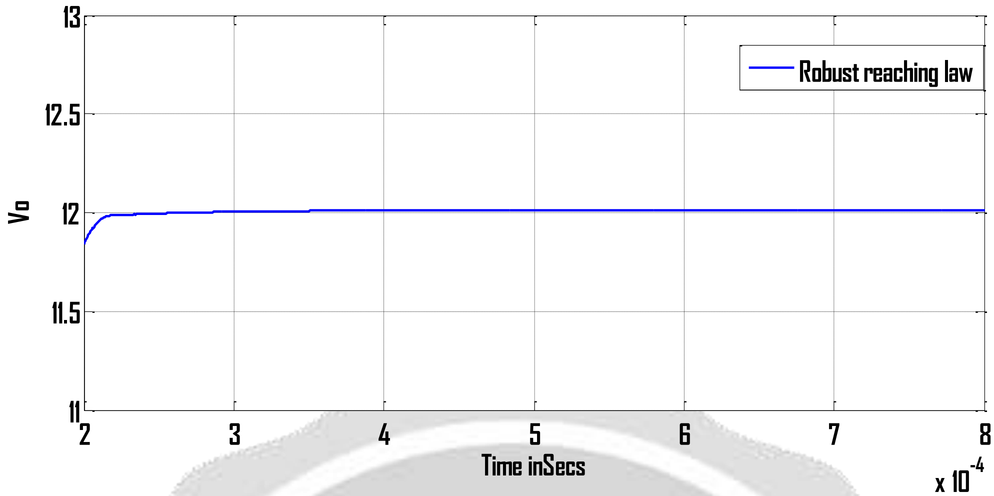

Figure 3. Output voltage of reaching law

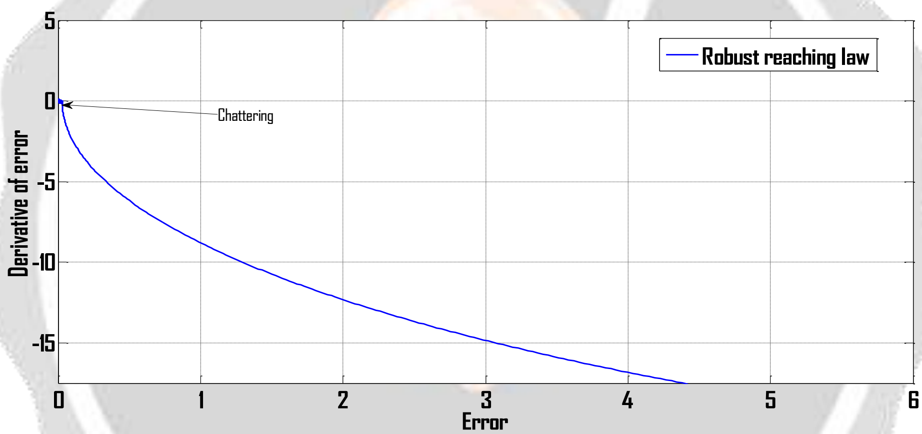

Figure 4. Chattering of reaching law.

The table 1 shows the specification of the reaching law and buck 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 sliding mode reaching law, the reaching law obeys close up to the rule of the sliding surface. Figure 4. Represents the output voltage of the 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 sliding mode reaching law reaches to earlier than the traditional reaching law. Table 2 represents the settling time, amplitude and reaching time of the reaching law and traditional reaching law. A proposed sliding mode reaching law gives more dynamic in reaching time, losses and mitigates the chattering effectively than the traditional reaching law.

4. CONCLUSION

In this paper the sliding mode reaching law and conventional reaching law is used for chattering mitigation. Newly designed sliding mode reaching law optimally reduces the chattering and system remains on sliding surfaces. Both reaching laws are applied to step down converter. The system can be effectively improved by altering the value of the reaching law parameters. The simulation results show that the proposed sliding mode reaching law exhibits static and dynamic properties than the conventional reaching law with respect to reaching time, settling time and chattering amplitude.

REFERENCES

[1] V. Utkin, “Sliding Modes in Control and Optimization”, Berlin: Springer, 1992.
[2] John **Y.** Hung, Weibing Gao, and James C. Hung, “Variable Structure Control: **A** Survey”IEEE Transactions OnIndustrial
Electronics**,** Vol. 40, No. 1, Feb 1993
[3] V. Utkin, J. Guldner and J. Shi, “Sliding Mode Control in Electromechanical Systems”, Taylor & Francis, 1999.
[4] C. Edwards and S. K. Spurgeon, “Sliding Mode Control Theoryand Applications”, Taylor & Francis, 1998.
[5] K. David Young, Vadmin I. Utkin,Umit Ozguner “Guide to Sliding Mode Control”, IEEE Transactions on Control Systems
Technology, vol. 7, no. 3, May 1999.[6] J. T. Moura and N. Olgac, “Robust Lyapunov control with perturbation estimation”, IEE
Proceedings - Control Theory and Applications, vol. 145, pp. 307-315, May 1998.
[6] O. Camacho, R. Rojas and W. García, “Variable structure control applied to chemical processes”, ISA Transactions,vol. 38, pp. 55-72, 1999.

[7] W. Gao and J. C. Hung, “Variable structure control of nonlinear systems”, IEEE Transactions on Industrial Electronics,vol. 40, no. 1, pp. 45-55, Feb 1993.

[8] T. Floquet, J.-P. Barbot and W. Perruquetti, “Higher-order sliding mode stabilization for a class of nonholonomic perturbed systems”Automatica, Science directpp. 1077-1083, June 2003.

[9] A. Levant, "Higher order sliding modes and arbitrary-order exact robust differentiation," in Proc. of the European Control Conference (ECC'01), 2001.

[10] Y. B. Shtessel, I. A. Shkolnikov and A. Levant, "An Asymptotic Second-Order Smooth Sliding Mode Control" Asian Journal of Control,vol. 5, no. 4, pp. 498-504, 2003.

[11]Siew-Chong Tan, Y. M. Lai, and Chi K. Tse “An Evaluation of the Practicality of Sliding Mode Controllers in DC–DC Converters and Their General Design Issues”37th IEEE Power Electronics Specialists Conference/ June 18 - 22, 2006, Jeju, Korea
[12]Yu-Xin Zhao, TianWu, and Yan Ma “Double Power Reaching Law of Sliding Mode Control Based on Neural Network”Hindawi
Publishing CorporationMathematical Problems in Enginereng Volume 2013, Article ID 408272, 9 pages
[13]Hongtao Ye,Mengmeng Li,Wenguang Luo, “A novel reaching law of sliding mode control design and analysis” 20-22 Oct. 2017, Pages 1803 – 1807,2017 Chinese Automation Congress (CAC).Jinan, China.
[14] K. B. Devika, Susy Thomas“Improved sliding mode controller performance through power rate exponential reaching law” Second International Conference on Electrical, Computer and Communication Technologies .1 - 7 (ICECCT)22-24 Feb. 2017 ,Pages 1 – 7, 23 November 2017 Coimbatore, India.
[15]Bing Li,Kai SuContour control for direct drive X-Y table based on a new exponential reaching law”Chinese Automation Congress(CAC), 2017, 20-22 Oct. 2017, Jinan, China.
[16] H. Wang, H. Zhang, Y. Liang and W. Xiong,” Reducing chattering using Adaptive Exponential Reaching Law”, in Sixth international conference on Natural Computation (ICNC), 2010.
[17] C. J. Fallaha, M. Saad, H. Y. Kanaan and K. Al-Haddad, "Sliding-Mode Robot Control using exponential Reaching Law," IEEE Transactions on Industrial Electronics, vol. 58, no. 2, pp. 600-610, Feb 2011.
[18] Burton, J. A. and, Zinober, A. S. I., “Continuous approximation of variable structure control”, Int. J. Syst. Sci., Vol. 17, No. 6, pp. 875-885,1986.
[19] Fallaha, Charles J. Maarouf Saad, Hadi Youssef Kanaan and Kamal Al-Haddad, “Sliding-mode tobot control with exponential reaching law”,IEEE Trans. Ind. Electron., Vol. 58, No. 2, pp. 600-610, 2011
[20] K.B. Siddesh , B. Basavaraj “Chattering Analysis In Sliding Mode Controlled Dc-Dc Buck Converter Using New Novel Reaching Law Method” Journal On Electrical Engineering ISSN : 0973-8835 Volume 10. No. 4 April - June 2017I-Manager Publications 2017.

[21].Liang Tao, Qiang Chen, Yurong Nan, And Chun W "double Hyperbolic Reaching Law With Chattering-Free And Fast Convergence"IEEE Access Multidisciplary journal digital Object Identifier 0.1109/ACCESS.2017.DOI,
[22] Wang, Y.; Feng, Y. Zhang, X. Liang, J. "A new reaching law for antidisturbance sliding-mode control of PMSM speed regulation system". IEEE Trans. Power Electron. 2020, 35, 4117–4126.

	Tanuja T Assistant professor, Electronics and Communication Engineering Department
	Nandini G R Assistant professor, Electronics and Communication Engineering Department
	Farzana Parveen B A Assistant professor, Electronics and Communication Engineering Department
	Roopa S Assistant professor, Electronics and Communication Engineering Department
	Noor Fathima Assistant professor, Electronics and Communication Engineering Department