Bulletin of Electrical Engineering and Informatics
Vol. 11, No. 3, June 2022, pp. 1735~1741
ISSN: 2302-9285, DOI: 10.11591/eei.v11i3.3790

Chattering reduction in step down converter using robust reaching law

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Article Info

Article history:

Received Mar 12, 2022
Revised Apr 22, 2022
Accepted May 24, 2022

Keywords:

Chattering
Reaching law
Robust reaching law
Sliding mode control

ABSTRACT

The proposed robust reaching law for sliding mode control is used for chattering suppression, minimization of steady state error and reaching speed kept fast. With fine tuning parameters of robust reaching law, the system state reaches the sliding mode at the earliest. The mathematical analysis of the proposed reaching law is verifed. In one hand, they guarantee the system states reaches the sliding surface quickly and remain on it, in another way it deteriorate the chattering effectively, even unmatched certainties and disturbances. Such that the system response can better realize the unification of rapidity. A proposed reaching law applied to SMC DC-DC step down converter to analyse the chattering, it reduces the switching losses in the switching devices of the step down converter. In turn efficiency of the buck converter increases. MATLAB/Simulink results gives significant turn down of chattering and dynamic response of the system. This research work effectively improves the performance of the system.

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1. 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 SMC 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 countless and its amplitude reaching towards zero. However, in realistic systems due to the dynamics of the electronics sensors and actuators, 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. Research by Young *et al.* [5] VSC along with non sliding methods were used for eliminate the high frequencies by achieving the elimination of chattering. Research by Moura and Olgac [6], tuned sigmoid functions were implemented to weaken the chattering. Research by Camacho *et al.* [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 swirtching losses in the step down converter and not maintaining the the sliding mode condition rule. Some previous work did not mention the losses in the buck converter and chattering [20], presently this work very effectively applicable to computer hardware sets and hardware sectors, hence this research work very effectively reduces the chattering and usefull to the electronic gadjets.

2. METHOD

2.1. Robust reaching law

A new RL called review of related literature (RRL) is described in this section. The proposed RRL is described in vector format as:

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

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

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

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

Integrating with respect to time, reaching time can be calaculated as (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,

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

The proposed reaching laws μ bring the system on to the slidng line by dereasing 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, whereeever the intial 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 on the sliding path. The value of ‘s’ bring the stabilty of the system on the switching surface [20]-[22].

2.1.1. SMC with robust reaching law

Slidng mode control with robust reaching law is given by. State variable eqaution is given by.

$$X1 = Vref - \beta Vo$$
$$X2 = -\frac{\beta ic}{C} \quad (9)$$
$$X3 = \int X1$$

Where X_1, X_2, and X_3 are state variables.

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

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

Q > 0 and K> 0 are positive constants.

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

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

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

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

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

In (1) and (12) gives the equivalent value of the input and it's implemented using Simulink. In (13) gives the mathematical modeling of the step-down converter.

2.2. Chattering

The chattering is tearness and wearness of the system, it reduces the effieiciency of the buck converter and also makes more noises in the system. The effect of chattering in the step down converter is that more deviated in the output voltage. Figure 1 shows the chattering in SMC. Chattering phenomena is unwanted possessions of variable structure system. The main grounds of chattering a phenomenon is 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 shoud end with the origin of the system. The chattering is the main drawback of the sliding mode control systems [21]-[25]. The trajectory is the path in which slidng line passed through it. Figure 1 represents the chattering on the switching surface. From Figure 1 X1 and X2 represents the state variables of the system and their deeds on sliding line.

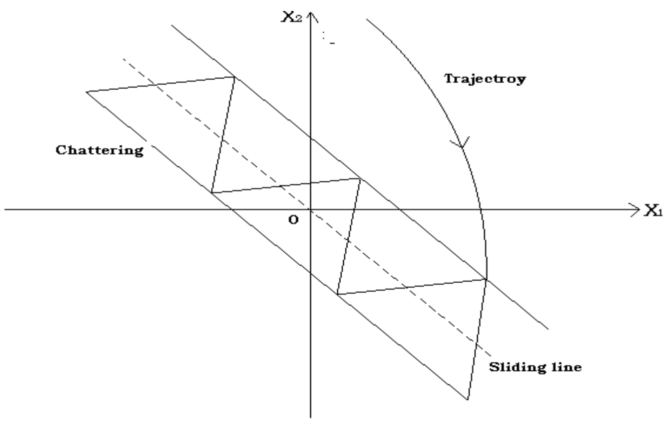

Figure 1. Chattering

3. RESULT AND DISCUSSION

The simulation has been done via MATLAB/Simulink. The Table 1 gives the specifiaction 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 effect of chattering. Figure 3 represents the chattering of robust reaching law, the robust reaching law agrees the rule of the sliding switching surface. Figure 4. Represents the ouput voltage of the robust reaching law. The proposed 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 performanace of the step down converter is improved. From Table 2 represents the settlimng time, amplitude and reaching time of the robust reaching law and traiditional reaching law. A proposed robust reaching law gives dynamic and mitigates the chattering effectively than the the traditional reaching law.

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
11	Sliding coefficients,	α_1 α_2 α3	3 25 2000
12	Duty cycle	α	0.5
13	Efficiency of the converter	η	0.91
14	Input power	Pi	14.2W
15	Output power	Po	12.9W

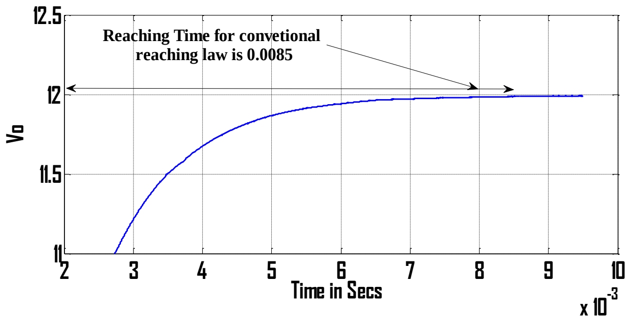

Figure 2. Output voltage of traditional reaching law

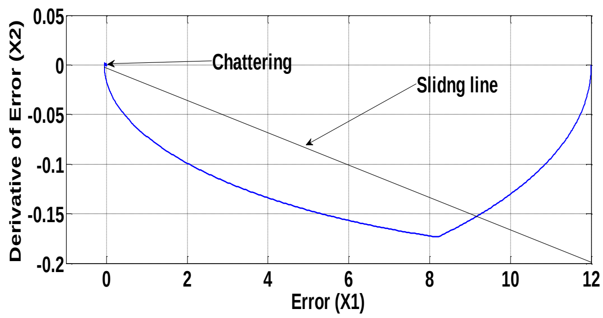

Figure 3. Chattering of robust reaching law

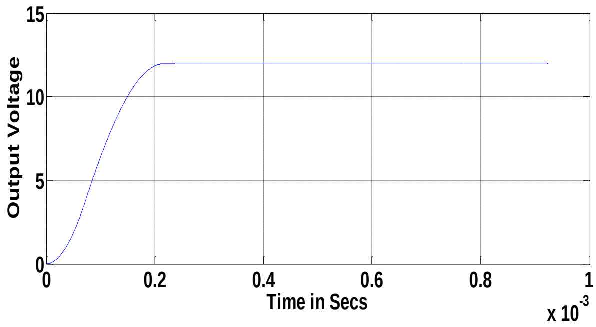

Figure 4. Output voltage of robust reaching law

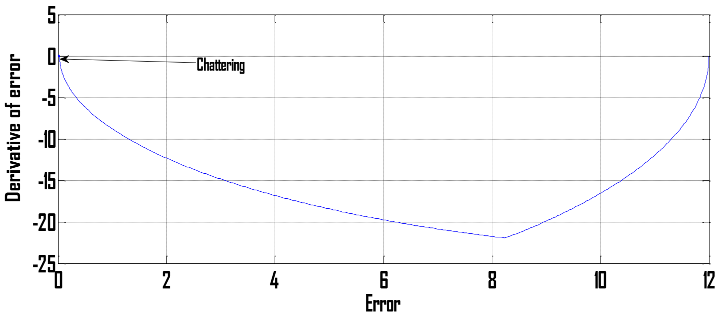

Figure 5. Chattering of Robust reaching law

Table 2. Comparison of robust 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	On x-axis 0 to 0.03 On y-axis -0.08 to 0.085	On 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

4. CONCLUSION

The traditional reaching law fails to satisfy the attribute of close to chattering free operation, sliding mode portion and reaching time to steady state. In this work the proposed robust reaching 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 minimsed in the step down converter. The simulation results show that the proposed robust reaching law exhibits superior static and and improves the performance of SMC. This research work improves overall efficiency of the buck converter and least losses in the buck converter when compared to other previous research works.

REFERENCES

[1] V. I. Utkin, "*Sliding Modes in Control and Optimization*," Springer Science & Business Media, 2013.

[2] J. Y. Hung, W. Gao, and J. C. Hung, "Variable structure control: a survey," in *IEEE Transactions on Industrial Electronics*, vol. 40, no. 1, pp. 2-22, Feb. 1993, doi: 10.1109/41.184817.

[3] V. Utkin, J. Guldner, and J. Shi, "*Sliding mode control in electro-mechanical systems*," CRC press, 2017.

[4] C. Edwards and S. Spurgeon, "*Sliding mode control: theory and applications*," Crc Press, 1998.

[5] K. D. Young, V. I. Utkin, and U. Ozguner, "A control engineer's guide to sliding mode control," in *IEEE Transactions on Control Systems Technology*, vol. 7, no. 3, pp. 328-342, May 1999, doi: 10.1109/87.761053.

[6] J. T. Moura and N. Olgac, "Robust Lyapunov control with perturbation estimation," *IEE Proceedings-Control Theory and Applications*, vol. 145, no. 3, pp. 307-315, May 1998, doi: 10.1049/ip-cta:19982047.

[7] O. Camacho, R. Rojas, and W. García, "Variable structure control applied to chemical processes," *ISA Transactions*, vol. 38, no. 1, pp. 55-72, Jan. 1999, doi: 10.1016/S0019-0578(99)00005-1.

[8] W. Gao and J. C. Hung, "Variable structure control of nonlinear systems: a new approach," in *IEEE Transactions on Industrial Electronics*, vol. 40, no. 1, pp. 45-55, Feb. 1993, doi: 10.1109/41.184820.

[9] T. Floquet, J.-P. Barbot, and W. Perruquetti, "Higher-order sliding mode stabilization for a class of nonholonomic perturbed system," *Automatica*, vol. 39, no. 6, pp. 1077-1083, Jun. 2003, doi: 10.1016/S0005-1098(03)00076-1.
[10] A. Levant, "Higher order sliding modes and arbitrary-order exact robust differentiation," *2001 European Control Conference (ECC)*, 2001, pp. 996-1001, doi: 10.23919/ECC.2001.7076043.
[11] Y. B. Shtessel, I. A. Shkolnikov, and M. D. J. Brown, "An Asymptotic Second-Order Smooth Sliding Mode Control," *Asian Journal of Control*, vol. 5, no. 4, pp. 498-504, Oct. 2008, doi: 10.1111/j.1934-6093.2003.tb00167.x.
[12] S. -C. Tan, Y. M. Lai, and C. K. Tse, "An evaluation of the practicality of sliding mode controllers in DC-DC converters and their general design issues," *2006 37th IEEE Power Electronics Specialists Conference*, 2006, pp. 1-7, doi: 10.1109/pesc.2006.1711761.
[13] Yu-Xin Zhao, T. Wu, and Y. Ma, "Double Power Reaching Law of Sliding Mode Control Based on Neural Network," *Mathematical Problems in Engineering*, vol. 2013, 2013, doi: 10.1155/2013/408272.
[14] H. Ye, M. Li, and W. Luo, "A novel reaching law of sliding mode control design and analysis," *2017 Chinese Automation Congress (CAC)*, 2017, pp. 1803-1807, doi: 10.1109/CAC.2017.8243060.
[15] K. B. Devika and S. Thomas, "Improved sliding mode controller performance through power rate exponential reaching law," *2017 Second International Conference on Electrical, Computer and Communication Technologies (ICECCT)*, 2017, pp. 1-7, doi: 10.1109/ICECCT.2017.8117984.
[16] B. Li and K. Su, "Contour control for direct drive X-Y table based on a new exponential reaching law," *2017 Chinese Automation Congress (CAC)*, 2017, pp. 1816-1821, doi: 10.1109/CAC.2017.8243063.
[17] S. Su, H. Wang, H. Zhang, Y. Liang, and W. Xiong, "Reducing chattering using Adaptive Exponential Reaching Law," *2010 Sixth International Conference on Natural Computation*, 2010, pp. 3213-3216, doi: 10.1109/ICNC.2010.5582697.
[18] C. J. Fallaha, M. Saad, H. Y. Kanaan, and K. Al-Haddad, "Sliding-Mode Robot Control with Exponential Reaching Law," in *IEEE Transactions on Industrial Electronics*, vol. 58, no. 2, pp. 600-610, Feb. 2011, doi: 10.1109/TIE.2010.2045995.
[19] J. A. Burton and A. S. I. Zinober, "Continuous approximation of variable structure control," *International Journal of Systems Science*, vol. 17, no. 6, pp. 875-885, 1986, doi: 10.1080/00207728608926853.
[20] S. Yu, X. Yu, B. Shirinzadeh, and Z. Man, "Continuous finitetime control for robotic manipulators with terminal sliding mode," *Automatica*, vol. 41, no. 11, pp. 1957-1964, 2005, doi: 10.1016/j.automatica.2005.07.001.
[21] K. B. Siddesh and B. Basavaraj, "Chattering Analysis in Sliding Mode Controlled DC-DC Buck Converter Using New Novel Reaching Law Method," *Journal on Electrical Engineering*, vol. 10, no. 4, pp. 22-27, Apr.-Jun. 2017.
[22] L. Tao, Q. Chen, Y. Nan, and C. Wu, "Double Hyperbolic Reaching Law with Chattering-Free and Fast Convergence," in *IEEE Access*, vol. 6, pp. 27717-27725, 2018, doi: 10.1109/ACCESS.2018.2838127.
[23] Z. Chen and J. Huang, "Attitude Tracking and Disturbance Rejection of Rigid Spacecraft by Adaptive Control," in *IEEE Transactions on Automatic Control*, vol. 54, no. 3, pp. 600-605, March 2009, doi: 10.1109/TAC.2008.2008350.
[24] Quanmin Zhu and Lingzhong Guo, "Stable adaptive neurocontrol for nonlinear discrete-time systems," in *IEEE Transactions on Neural Networks*, vol. 15, no. 3, pp. 653-662, May 2004, doi: 10.1109/TNN.2004.826131.
[25] W. Xiao and B. Zhang, "Switching rule based on min-projection strategy for single phase DC-AC converter," *2015 IEEE Applied Power Electronics Conference and Exposition (APEC)*, 2015, pp. 2394-2398, doi: 10.1109/APEC.2015.7104683.

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