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European Journal of Advances in Engineering and Technology, 2015, 2(10): 12-16

Research Article ISSN: 2394 - 658X

Chattering Reduction in Sliding Mode Controlled DC-DC Buck Converter Based on a New Novel Reaching Law

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ABSTRACT

In this paper presents a new novel reaching law for sliding mode controlled DC-DC buck converter. The proposed novel reaching law can dynamically adapt to the parameter variations of the controlled system, which allows chattering reduction on control input while maintain high tracking performance of the controller. Chattering analysis presented for both traditional and proposed reaching law. The simulation results are presented to show the better performances of the proposed reaching law and regarding particularly the chattering reduction and high convergence speed on control input in steady state regime.

Key words: Buck Converter, Chattering, Novel Reaching Law, Sliding Mode Control

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INTRODUCTION

Sliding mode control is applied to DC-DC Buck converter for its good dynamic response and robustness. But in SMC the chattering is severe problem, which causes power losses in switching devices. Hence a proposed a new novel reaching law reduces a chattering near sliding surface of system. The SMC based reaching law was proposed and output voltage to reach steady state taken more time [1]. The SMC based on reaching low as proposed to eliminate chattering and reaching phase has taken more time [2]. Research of new SMC based converter was proposed and eliminates the chattering and taken more time to reach the sliding plane to compare previous work [3].In most system, chattering phenomena is undesirable because it can excite high frequency dynamics which could be in proposed to overcome this phenomenon. An interesting approach for chattering reduction is to change the reaching law by making the discontinuous gain 'k' a function of 's', Gao [7], one of the reaching they studies based on Constant Plus proportional rate reaching strategy and use the following reaching law.

$$\dot{S} = -\varepsilon sgn(S) - kf(S) \quad k>0, \epsilon>0 \tag{1}$$

However in aforementioned reaching law the terms 'ε', and 'k', thus reducing the robustness of the controller near the sliding surface and also increasing the reaching time.

In order to propose a solution aforementioned problems, this paper introduces a new reaching law containing an exponential term functions of the sliding surface 'S'. This reaching law is able to deal with chattering performance phenomena. The exponential form smooth by adopts variation of 'S'. [5-6]

In order to have a faster reaching time a good robustness as tracking performance 'k' must be increased. However this will directly increase the chattering level on the control input in order to solve the problem, the interdependence between reaching times and chattering level should removed.

PROPOSED NEW NOVEL REACHING LAW

The reaching law proposed in this paper is based on the choice of exponential term that adapts to the variation of switching function; this reaching law is given by.

$$\dot{S} = \frac{-Ksgn(S)}{\left(\varepsilon + \left(|X1| - \varepsilon\right) e^{-\alpha|s|^{p}}\right)} \tag{2}$$

Where α is a positive offset (α>1), ε is positive constant (ε>1), p is positive constant (p>1) and k is a constant (k>1)

The derivation of new novel reaching law is as given follows -Integrate between zero and tr'

$$tr' = \frac{\left(\varepsilon|S(0)+(|X1|-\varepsilon|)\int_0^{s(0)} sgn(s)e^{-\alpha|s|^p} ds\right)}{k} \tag{3}$$

If S≤0 for $t \le t_r$' than

$$\int_0^{s(0)} \mathrm{sgn}(s)e^{-\alpha|s|^p}ds = -\int_0^{s(0)} e^{-\alpha|s|^p}ds = \int_0^{-s(0)} e^{-\alpha|s|^p}ds \tag{4}$$

On other hand, if S ≥ 0 for $t \le t_r$'

$$\int_0^{s(0)} \mathrm{sgn}(S)e^{-\alpha|s|^p}ds = \int_0^{s(0)} e^{-\alpha|s|^p}ds \tag{5}$$

Therefore, one can combine the eqn. (4) and eqn.(5) gives the following,

$$tr' = \frac{1}{k}\left(\varepsilon|S(0)|+(|X1|-\varepsilon\right)\int_0^{|s(0)|} e^{-\alpha|s|^p} ds \tag{6}$$

$$tr' = \frac{1}{k}\left(\varepsilon|S(0)| + \frac{(|X1|-\varepsilon)}{\alpha}\right)\left(1-e^{-\alpha|s|^p}\right) \tag{7}$$

Eqn.(7)shows the reaching time of sliding function while keeping the same gain 'k' needed for the reaching law eqn. (2) is smallest than the needed for eqn.(1)[4].

DESIGN OF SM CONTROLLED DC-DC BUCK CONVERTER WITH NOVEL REACHING LAW

The state equations are

$$X1 = Vref - \beta Vo \qquad X2 = -\frac{\beta ic}{C} \qquad X3 = \int X1 \tag{8}$$

The derivative of the state variables

$$\dot{X}1 = -\beta\frac{dVo}{dt} = -\beta\frac{ic}{C} = \frac{\beta}{C}[io - iL] \qquad \dot{X}2 = \frac{\beta}{C}\left[\frac{1}{R}\frac{dVo}{dt} - \int\frac{UVi+Vo}{L}\right] \qquad \dot{X}2 = \frac{\beta}{C}\left[\frac{1}{R}\frac{ic}{C} - \frac{UVi+Vo}{L}\right] \qquad \dot{X}3 = X1$$

The sliding surface is given by

$$S = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 \tag{9}$$

The derivative of the sliding surface is given by

$$\dot{S} = \alpha_1\dot{X}_1 + \alpha_2\dot{X}_2 + \alpha_3\dot{X}_3 = 0 \tag{10}$$

The proposed new novel reaching law is given by

$$\dot{S} = \frac{-K\mathrm{sgn}(S)}{\left(\varepsilon + (|X1|-\varepsilon)e^{-\alpha|s|^p}\right)}$$

$$\dot{S} = \frac{-K\mathrm{sgn}(S)}{\left(\varepsilon + (|X1|-\varepsilon)e^{-\alpha|s|^p}\right)} = \alpha_1\dot{X}_1 + \alpha_2\dot{X}_2 + \alpha_3\dot{X}_3 = 0 \tag{11}$$

$$\frac{-K\mathrm{sgn}(S)}{\left(\varepsilon + (|X1|-\varepsilon)e^{-\alpha|s|^p}\right)} = \alpha 1\left(-\frac{\beta}{C}\right)ic + \alpha 2\frac{\beta ic}{RC^2} - \alpha 2\frac{UVin\beta}{LC} + \alpha 2\frac{\beta V0}{LC} + \alpha 3(Vref - \beta Vo) \tag{12}$$

$$Ueq = \frac{LC}{\alpha 2 Vin\beta}\left[\frac{-K\mathrm{sgn}(S)}{\left(\varepsilon + (|X1|-\varepsilon)e^{-\alpha|s|^p}\right)} - \frac{\alpha 1 ic\beta}{C} + \alpha 2\frac{\beta ic}{RC^2} + \alpha 2\frac{\beta Vo}{LC} + \alpha 3(Vref - \beta Vo)\right] \tag{13}$$

$$Ueq=d \qquad d=\frac{Vc}{Vramp} \qquad Vc=d*Vramp \qquad Vramp=\beta Vin$$

$$Vc=\frac{LC}{\alpha 2}\left[\frac{-Ksgn(S)}{\left(\varepsilon+\left(|X1|-\varepsilon\right)e^{-\alpha|s|^{p}}\right)}-\frac{\alpha 1ic\beta}{C}+\alpha 2\frac{\beta ic}{RC^{2}}+\alpha 2\frac{\beta Vo}{LC}+\alpha 3\left(Vref-\beta Vo\right)\right] \qquad (14)$$

The control law for the above equation is obtained through a exponential reaching law and automatically reads to free order switching scheme [7].

SIMULATION RESULTS AND DISCUSSIONS

From the Table-2 it's observed that the proposed reaching law gives less chattering, which exists from 0 to 0.03 and the magnitude is one milli sec. Traditional reaching law gives more chattering, which exists from 0 to 0.25 and the magnitude is one milli sec. Fig.1 shows the graph of proposed and traditional reaching laws, the proposed reaching law gives very less chattering than conventional reaching law. Fig. 2 shows the graph of line variation from 24V to 15V and then 15V to 24V. Which results very less variation in the output voltage.Fig.3 shows the graph of load variation from 10Ω to 3.75Ω and 3.75Ω to 10Ω, which results very less variation in output voltage. Fig. 4 shows the graph of sliding surface of proposed reaching law. Fig. 5 shows the graph of Error of proposed reaching law.

Table-1 Specification of Buck Converter

Parameter	Symbol	Value
Input voltage	Vi	24Volts
Capacitance	C	220μF
Inductance	L	69μH
Switching Frequency	fs	200KHz
Minimum load resistance	R_L(min)	6 Ohm
Maximum load resistance	R_L(max)	10 Ohm
Desired Output voltage	V_{od}	12V

Table-2 Chattering Analysis of Proposed and Traditional Reaching Law

Reaching laws	Traditional reaching law	Proposed reaching law
Chattering existence on error axis	0 to 0.25	0 to 0.03
Chattering existence on Derivative of error axis(magnitude)	1e-03	1e-03
Chattering	More	Less

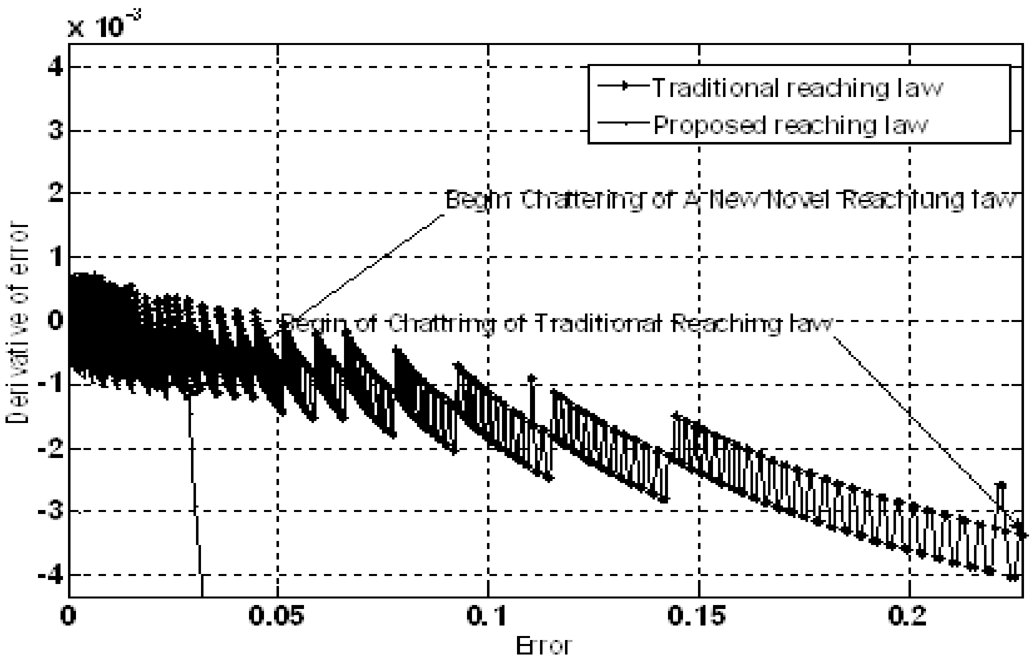

Fig. 1 Chattering analysis of reaching laws

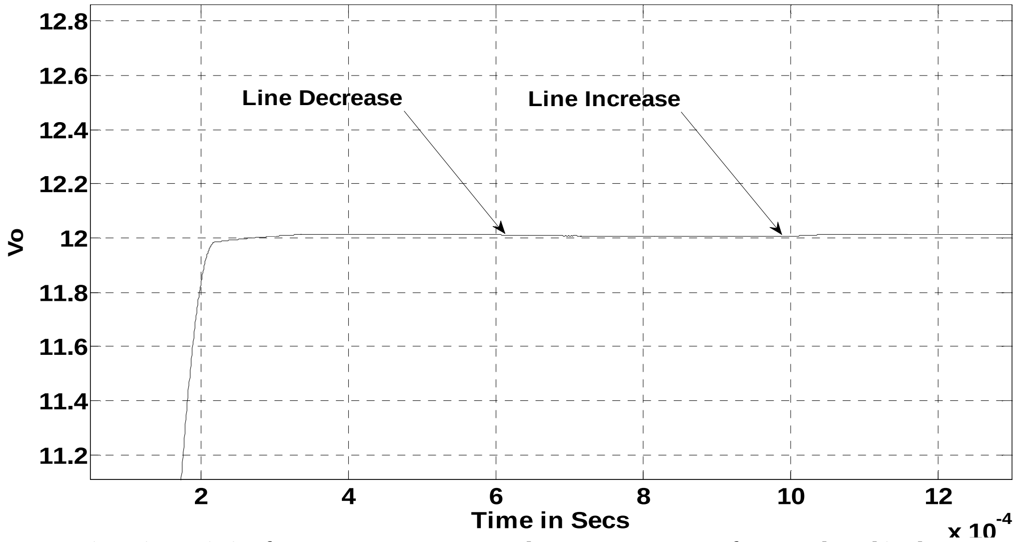

Fig 2 Line variation from 24V to 15Vat 0.6ms and 15V to 24V at 1ms of proposed reaching law

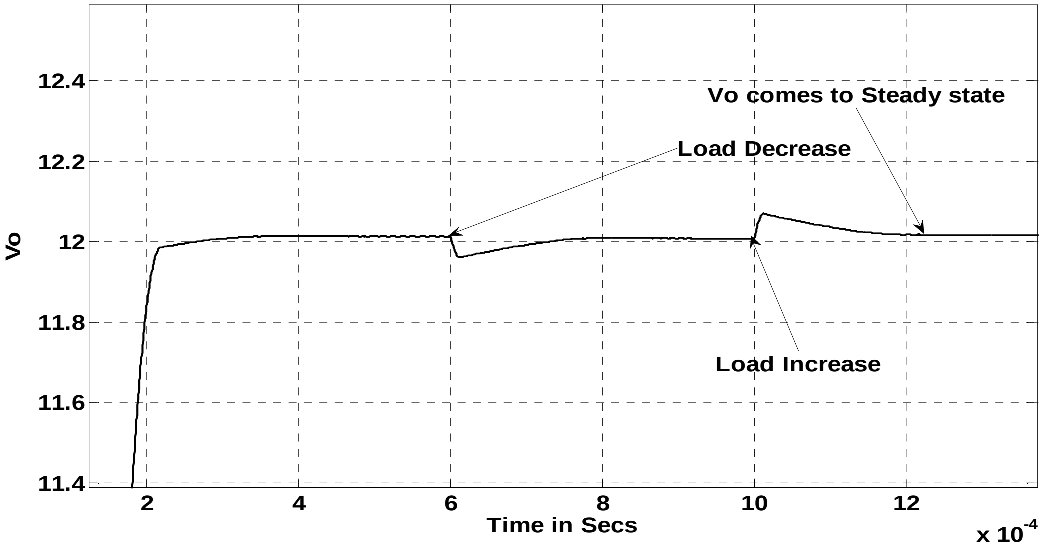

Fig. 3 Load variation from at 10Ω to3.75Ω at 0.6ms and 3.75Ω to 10Ω at 1ms of proposed reaching law

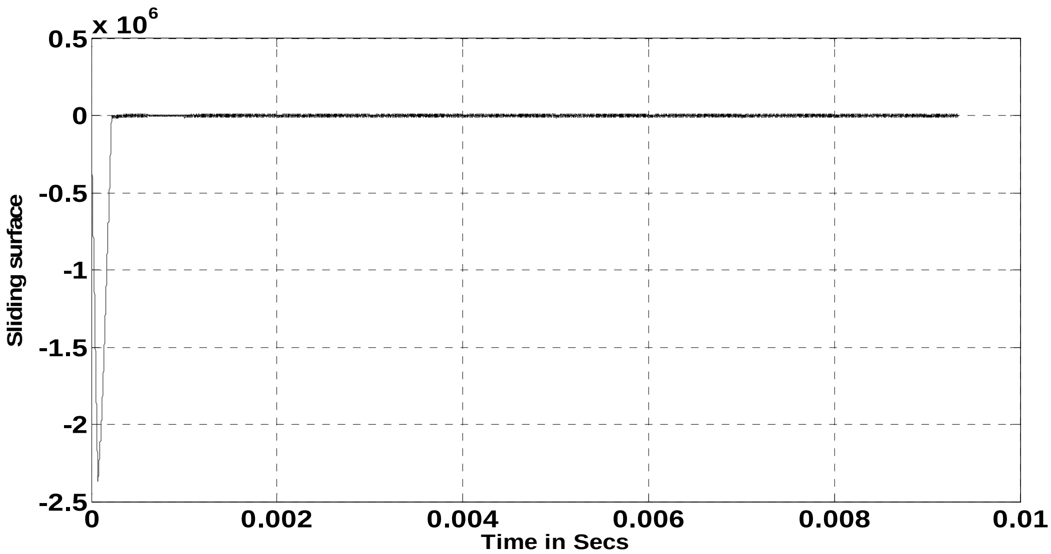

Fig. 4 Sliding surface of proposed reaching law

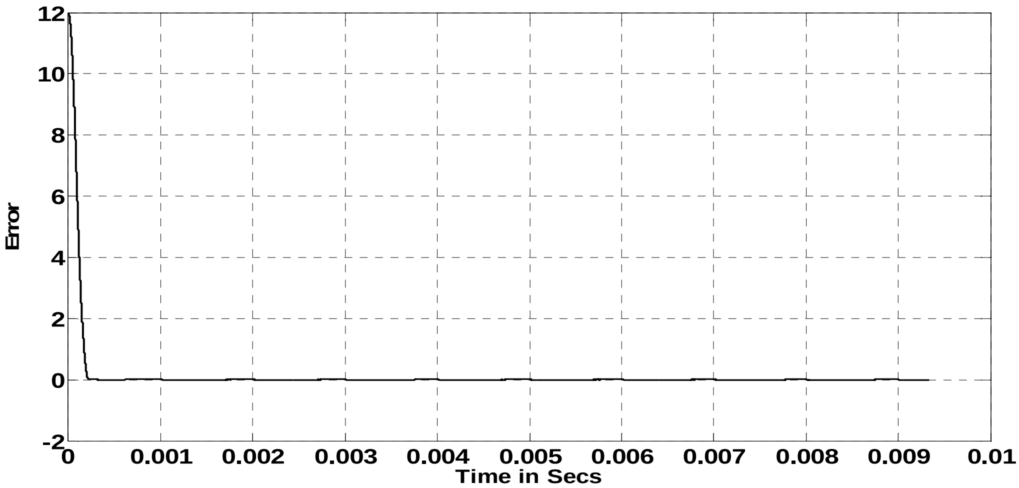

Fig. 5 Error of proposed reaching law

CONCLUSION

In this paper conventional and exponential reaching law applied to SMC DC-DC buck converter. The Proposed new novel reaching law reduces the chattering and increase tracking performance of steady state output voltage. Simulation results of the proposed reaching law are better performance than conventional reaching laws. Especially regarding the reduction of chattering in turn reduces the switching losses.

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