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An analytical discrete model for evaluation the chaotic behavior of Buck converter under current control mode

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***Abstract*-This paper presents the chaotic behavior of buck converter for switching courses in current control mode by discrete equations. This behavior is demonstrated by presenting a piecewise linear discrete map for this converter and then combining the feedback equation to obtain the overall equation of the converter. After obtaining the overall equation, exact map behavior is then studied. For this purpose, the transition path to chaotic behavior, discrete chaotic time signals, and bifurcation diagram circuit are presented in different conditions, based on various circuit control parameters.**

Keywords: Buck converter; Current control; Saturated feedback; Fuzzy diagram; Bifurcation diagram; Fixed points analysis.

Introduction:

Processing the electrical potential by means of power electronic instruments is the function of power electronic systems[1-3]. The main part of these systems is power converters that transform the electrical energy from one form to other forms. Some of these converters are AC/DC, AC/AC, DC/DC, and DC/AC [4]

Advantages of these converters are their small size, low weight, and high efficiency. In spite of all these advantages, the main problem with them is their nonlinear and varying function with time, which brings complexity to their design and dynamic behavior analysis. Their nonlinearity and variation with time is the result of circuit topology changes because of status changes of switches in the performance period of switching convertors.

Sampling of the continuous behavior of these convertors leads to the discrete behavior model in their switching intervals. Sometimes the behavioral analysis of converters in switching intervals has great complexity such that the order of current or voltage in decreasing or increasing rate in switching intervals seems to be lost. This strange behavior in these intervals is called the chaotic converter behavior. So far, many studies have been carried out to evaluate the chaotic behavior of switching converters [5] .Studies on voltage control mode are carried out in discrete spaces. Study of the chaotic behavior of multilayer converters is possible with higher degree discrete equations [6] However, studying the chaotic behavior of fixed points of converter equations such that the behavior can be followed has not been precisely done in any of the former studies. This paper presents a discrete model of buck converter behavior in current control mode. By presenting an equation for duty cycle and the time when the switch is on, we obtain a final, analyzable equation which is nonlinear and discrete, for the study of chaotic condition of the converter. Finally, an analysis of the equation in the chaotic field and also the converter behavior around the equilibrium point is presented. Evaluation of the chaotic behavior in discrete spaces [7,8], were performed in voltage control mode. However, the circuit behavior of these converters in current control modes were studied by considering various circuits for feedback loops [9,10]. We also intend to study buck converter behavior in current control mode by a saturable function in discrete space, obtained by the subtraction of the circuit current and the reference current.

Studying the buck converter behavior in current control mode:

To study the chaotic behavior of buck converter in current control mode, the converter circuit in Fig. 1 is analyzed. It is presumed that the converter performance is in continuous mode

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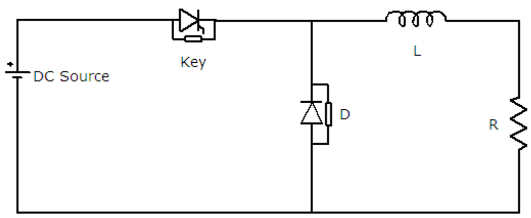


Fig. 1 Circuit buck converter

In the above circuit, we consider the inducer current equations in continuous mode in a switching period. The first interval refers to the time when the switch is on. The time $t_1 = nT$ to $nT + DT$ refers to the time when inducer current increases. The second interval is the time when the switch is off and the inducer current decreases and is shown by $t_2 = nT + DT$ to $(n+1)T$. Circuit equations for inducer current are as follows:

$$E = L\frac{di}{dt} + Ri \qquad (1)$$

The equation solution is as follows:

$$i(t) = Ae^{-\frac{Rt}{L}} + B \qquad (2)$$

Concerning the continuous working condition for the converter and the basic condition $i_0 = i_n$, the solution of the above-mentioned equation will be (3).

$$i(t) = \left(i_n - \frac{E}{R}\right)e^{\frac{-Rt}{L}} + \frac{E}{R} \qquad (3)$$

The current value at the end of this period is considered as the basic condition for the second time interval. This current value is:

$$i(DT) = \left(i_n - \frac{E}{R}\right)e^{\frac{-RDT}{L}} + \frac{E}{R} \qquad for\ t = DT \qquad (4)$$

For the second time interval, the switching frequency of current equation changes as shown in (5).

$$0 = L\frac{di}{dt} + Ri \ \ for \ \ nT + DT < t_1 < (n+1)T \qquad (5)$$

The overall solution of this first degree equation is (5).

$$i(\acute{t}) = Ke^{-\frac{R\acute{t}}{L}} \qquad (6)$$

Regarding the above equation and the basic condition for the previous part, the overall solution of inductance current in a switching period is (7).

$$i_{n+1} = \left(\left(i_n - \frac{E}{R}\right)e^{-\frac{RDT}{L}} + \frac{E}{R}\right)e^{-\frac{RT(1-D)}{L}} \qquad (7)$$

The current feedback equation function

To solve equation (7), it is required to define variable D in terms of currents. To do this, the duty cycle amount (D) is obtained from the feedback equation. Regarding this, the control algorithm causes an ϵ_n difference between the reference I and the sampled load current. This controller also includes a rectification coefficient K that increases the error by the factor of K and produces the control voltage u_n.

Block diagram of current controller is shown in

Fig. 2

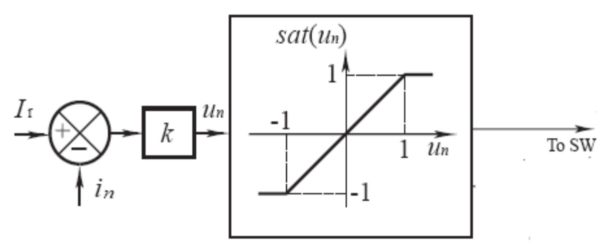


Fig .2 Bolock diagram of current controller

and its equation is:

$$u_n = k(I - i_n) \qquad (8)$$

Duty cycle (D) is defined in terms of difference voltage as follow:

$$D_n = .5 + Sat(u_n)/2 \qquad (9)$$

Combining this equation and the map current equation, the overall current equation (10) is obtained.

$$i_{n+1} = \left(\left(i_n - \frac{E}{R}\right)e^{-\frac{R(.5+\frac{Sat(k(I-i_n))}{2})\ T}{L}} + \frac{E}{R}\right)e^{-\frac{RT\left(1-(.5+\frac{Sat(k(I-i_n))}{2})\right)}{L}} \qquad (10)$$

Concerning the feedback function behavior; this map is defined as a three ply function that consists of two saturated regions and a linear distance of saturated function.

$$i_{n+1} = \begin{cases} \left(\left(i_n - \frac{E}{R}\right) e^{-\frac{R\,T}{L}} + \frac{E}{R}\right) & for \quad i_n < I - 1/K \\ \left(\left(i_n - \frac{E}{R}\right) e^{-\frac{R(.5+\frac{Sat(k(I-i_n))}{2})\,T}{L}} + \frac{E}{R}\right) e^{-\frac{RT\left(1-(.5+\frac{Sat(k(I-i_n))}{2})\right)}{L}} & for\ I + \frac{1}{K} < i_n < I - \frac{1}{K} \\ \left(\left(i_n - \frac{E}{R}\right) e^{\frac{R\,T}{L}} + \frac{E}{R}\right) e^{-\frac{RT2}{L}} & for\ i_n > I + 1/K \end{cases} \qquad (11)$$

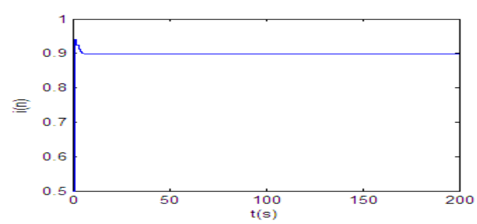
Simulation results:

To simulate the above-mentioned equation and show the outputs of the converter, the parameters in Table (1) were used.

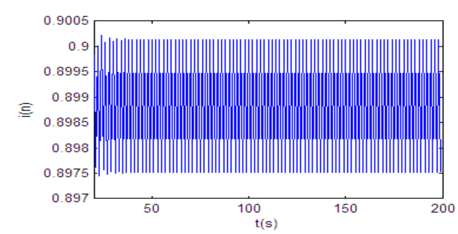
Parameter	Value
E(v)	20
L(H)	.0116
R(ohm)	10
T(s)	.0005

Table.1 parameter buck converter

Setting the parameters of Table (1) in the discrete dynamic equations of the converter, different output signal behavior is obtained for various values. Figs. 3, 4, show the time discrete signals for converter function periods at different feedback gains. By selecting the basic condition for the converter current that performs in the continuous condition, time behavior of the signal is obtained.

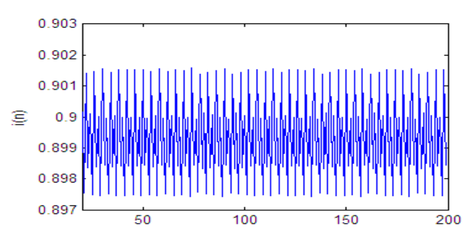


a

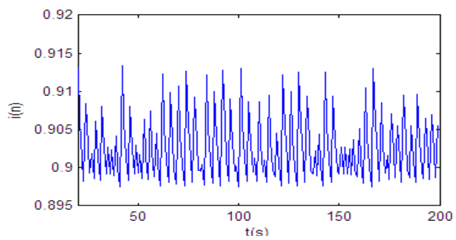


b

Fig.3:a ,Period -1 b,priod-4



a



b

Fig.4 : a. period 8 b .chaotic behavior

It was observed that although the input improves as the negative feedback increases, the convertor leaves single frequency and moves toward chaos.

Fig. 5 demonstrates an example of the fuzzy behavior of these converters. In this figure, there is only one stable point in the system and the behavior path of the signal around that point is stable and Node .

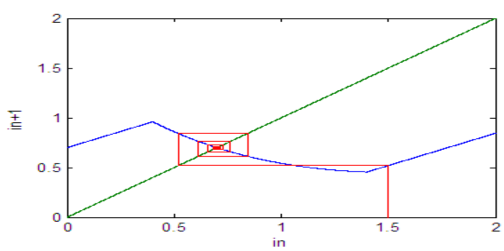


Fig .5 Phase plane diagram for k=2&Iref=.9

Fig. 6, 7, show incurring instability in the afore-mentioned stable point and producing new stable points by increasing the domain of controller gain feedback on the map which leads to, four, and eight frequencies, respectively.

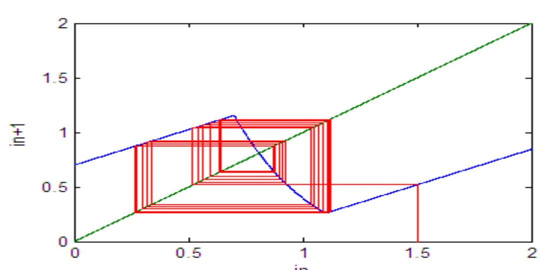


Fig .6 Phase plane diagram for k=5&Iref=.9

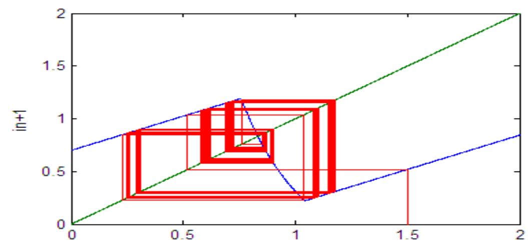


Fig .7 Phase plane diagram for k=7&Iref=.9

But Fig. 8 demonstrates the state in which the system undergoes a strange attractor series and chaos.

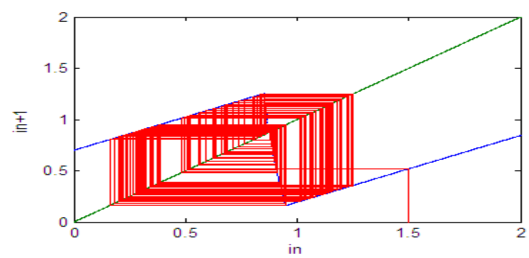


Fig .8 Phase plane diagram for k=12&Iref=.9

Concerning the time and fuzzy signal behavior of current, it seems that the system underwent chaos based on local bifurcation logic. This behavior is shown in bifurcation diagrams for various system parameters in Fig. 9, 10, 11, and 12. In Fig. 9, the converter bifurcation diagram is shown in terms of gain feedback of current control. It is obvious in the figures that the converter undergoes chaos for gains higher than eight.

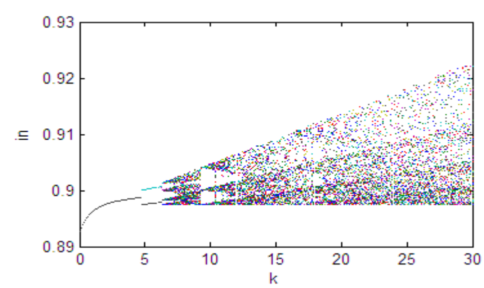


Fig .9 Bifurcation diagram for Iref=.9&K is variable

In Fig.10, the bifurcation diagram map is demonstrated in terms of reference current. By selecting high feedback gain in this diagram, a chaotic behavior at the beginning and end, as well as in the inputs is observed as the reference current increases.

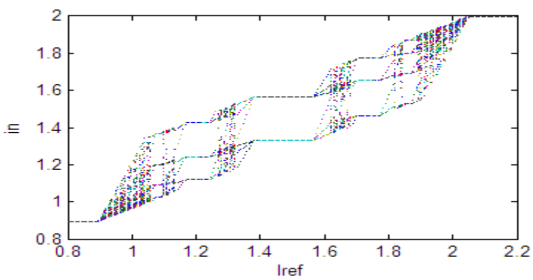


Fig .10 Bifurcation diagram for K=15& Iref is variable

Moreover, Fig. 11 shows the bifurcation diagram in terms of input source and Fig. 12 shows the chaotic logic of the system in terms of duty cycle constant term.

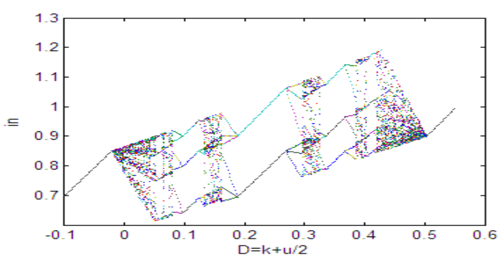


Fig .11 Bifurcation diagram for Iref=.9&K =15and D is variable

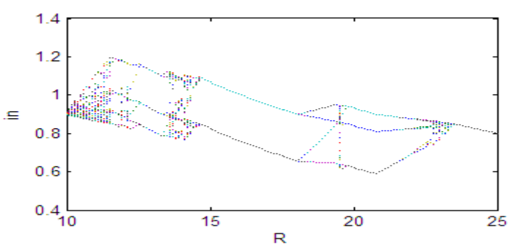


Fig .12 Bifurcation diagram for Iref=.9&K =15and Resistance is variable

conclusion:

Using converter discrete model and combining it with feedback control, a three-ply equation for the converter in control behavior in the current mode is obtained. Analyzing these equations can explain how this chaotic behavior occurs. Finally, discrete time signals in converter map and fuzzy diagram among the current parameters in terms of other parameter, as well as the bifurcation diagrams in terms of various control parameters as defined for the circuit current equations were drawn.

REFERENCES

[1]:M.H.Rashid, power electronics: circuit,devices and application,pearson/prentice hall 2003

[2]:D.A bradly ,power electronics crc press 1995

[3]:N.mohan,T.undeland W.P robin, power electronics: converters,application and design,wiley 1989

[4]: G.seguuir,power electronic converter: AC-DC convertion,Mc Graw –Hill ,1986

[5]:C.K Tse,chaos from a buck switching regulator in discontinuous mode, internation journal of circuit theory and applications,vol.22,No.4 ,pp.263-278,july 1994

[6]: S. Banerjee, G. C. Verghese ed., "Nonlinear Phenomena in Power Electronics: Attractors, Bifurcations, Chaos, and Nonlinear Control," Wiley-IEEE Press, 2001.

[7]: S. Banerjee, M. S. Karthik, G. Yuan. and James A. Yorke, "Bifurcations in One-Dimensional Piecewise Smooth Maps – Theory and Applications in Switching Circuits," IEEE Trans. Circuits and Syst. part I, Vol. 47, No. 3, pp. 389–394, 2000.

[8]: T. Kousaka, T. Ueta, Y. Ma, and H. Kawakami, "Bifurcation Analysis of a Piecewise Smooth System with Nonlinear Characteristics," International Journal of Circuit Theory and Applications , 2005.(In press)

[9]: S. Banerjee, P. Ranjan and C. Grebogi, "Bifurcation in Two-Dimensional Piecewise Smooth Maps - Theory and Applications in Switching Circuits," IEEE Trans. Circuits and Syst. part I, Vol. 47, No. 5, pp. 633–643, 2000.

[10]: S. Banerjee, S. Parui, and A. Gupta, "Dynamical Effects of Missed Switching in Current-Mode Controlled dc-dc Converters," IEEE Trans. Circuits and Syst. part II, Vol.51, No.12, pp.649 – 654, 2004.

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