Bifurcation and Chaos in Current Programmed Positive Output Luo_Converter

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Abstract: The dc-dc converter can be delivers a dc voltage or current at different level to the source, it's like a dc transformers. It also convert unregulated dc voltage into regulated dc voltage under varying load conditions and different voltage conditions. The output voltage of the converter has controlled by using the principle of negative feedback and it exhibit bifurcation and chaos if the switching action is govern by the negative feedback. There are two mode of PWM dc-dc converters they are voltage program mode and current program mode. In this paper, the chaotic behavior is observed in a positive output Elementary Luo_converter in current program mode. The need for chaos analysis is to get the desired regulated voltage and also get better dynamic response. The positive output Elementary Luo_converters has a wide range of industrial application and to control the chaotic behavior of the converter to be a special significance.

Keywords: Bifurcation, Chaos, PWM, Elementary Luo_converter.

1. INTRODUCTION

The dc-dc converters in power electronic circuits which convert electrical voltage from one level into another level by varying switching cycle. It is broadly used in Switch Mode Power Supplies (SMPS) and dc motor drives application. The output of the dc-dc converter should be regulated by varying input voltages at different load conditions. The average output voltage of the dc-dc converter which is controlled by controlling the switching pulses.

The state-space approximation techniques that can be applied to express the input and output relations of a switching converters. Although the original system is linear for any given switch condition, the resulting system is generally nonlinear. To study the behavior of the Elementary Luo_converters to losing its stability when the system at varying load conditions and different voltage conditions.

2. ANALYSIS AND DESIGN OF POSITIVE OUTPUT ELEMENTARY LUO_CONVERTER

Typical Control Strategies

To design and control the dc-dc converters are usually two approaches, they are voltage programmed mode and current programmed mode. In voltage programmed mode, the output voltage is compare with a reference signal that produce control signal and current programmed mode, an inner loop is to force the inductor current based on the reference signal and output voltage feedback. As compare to the voltage programmed mode the current programmed mode is a quicker response.

The positive output Elementary Luo_converter is shown in Fig.1. The Capacitor C_o acts as the primary means of transferring and storing energy from V_{in} to the output load (R) via inductor L_1. At steady state condition, the variation of the voltage across the capacitor V_c can be neglected.

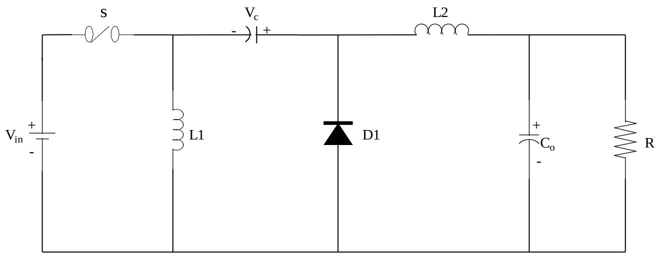

Fig. 1 Positive Output Elementary Luo_converter

$$Output voltage V_o = \left(\frac{\delta}{1-\delta}\right)V_{in}$$

Where $\delta = \frac{t_{on}}{t_{on}+t_{off}}$

When switch (s) is closed the diode D1 act as revered biased condition as shown in Fig 2 and when switch (s) is open the diode D1 act as a forward bias as shown in Fig 3.

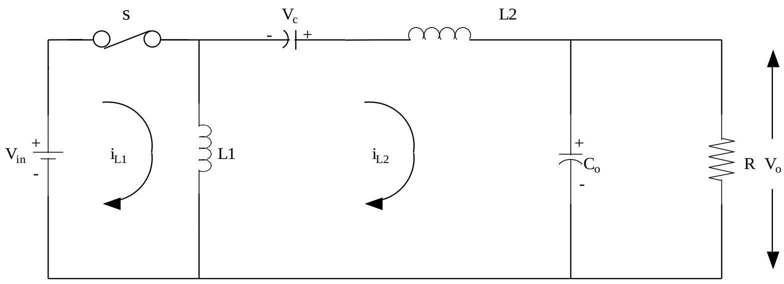

Fig. 2 Equivalent Circuit of Luo_converter when Switch ON

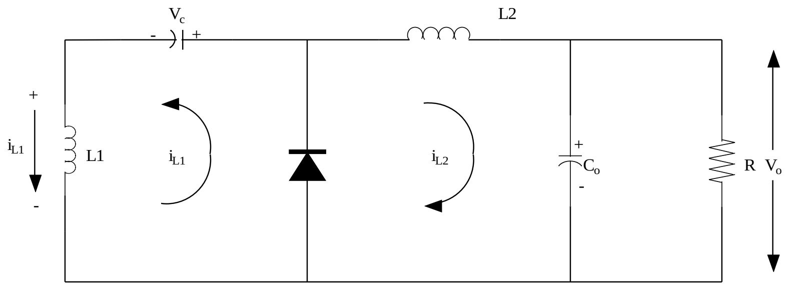

Fig. 3 Equivalent Circuit of Luo_converter when Switch OFF

During switch-ON, the voltage V_1 supply to the circuit, the inductor current i_{L1} increases and capacitor V_c get charged and during switch-OFF the inductor current i_{L1} decreases and capacitor V_c discharged, so the change in inductor current is

$$\Delta i_{L1} = \frac{kTV_1}{L_1}, \Delta i_{12} = \frac{kTV_1}{L_2}$$

The variation ratio inductor current i_{L1} and i_{L2} it become

$$\xi_1 = \frac{\Delta i_{L1}/2}{I_{L1}} = \frac{kTV}{2L_1 I_1} = \frac{1-k}{2M_E}\frac{R}{fL_1}$$

$$\xi_2 = \frac{\Delta i_{12}/2}{I_{L2}} = \frac{kTV_1}{2L_2 I_o} = \frac{k}{2M_E}\frac{R}{fL_2}$$

When switch-off, the diode current is $i_D = i_{L1} + i_{L2}$ and change in inductor current is

$$\Delta i_D = \Delta i_{L1} + \Delta i_{L2} = \frac{kTV_1}{L_1} + \frac{kTV_1}{L_2} = \frac{kTV_1}{L} = \frac{(1-k)TVo}{L}$$

The variation voltage V_c is

$$\Delta v_C = \frac{Q}{C}$$

The ratio of V_C is

$$\rho = \frac{\Delta v_C/2}{V_C} = \frac{(1-k)TI_I}{2CV_o} = \frac{k}{2}\frac{1}{fCR}$$

The charge variation ΔQ

$$\Delta Q = C_O \Delta V_O$$

The half variation of output voltage V_o and V_{co} is

$$\frac{\Delta v_o}{2} = \frac{\Delta Q}{C_o}$$

The variation ratio of output voltage V_o is

$$\varepsilon = \frac{\Delta v_o/2}{V_o}$$

State Space Model

The state space equations during ON and OFF conditions have been written from the mode-1 and mode-2 operation of the positive output elementary Luo_converter.

Applying Kirchhoff's voltage law for mode-1

$$\frac{di_{L1}}{dt} = \frac{v_{in}}{L1}, \quad \frac{dv_C}{dt} = -\frac{i_{L2}}{C}$$

$$\frac{di_{L2}}{dt} = \frac{v_{IN}}{L2} + \frac{v_c}{L2} - \frac{v_{co}}{L2}$$

$$\frac{dv_{co}}{dt} = -\frac{v_{co}}{RC_O} + \frac{i_{L2}}{C_O}$$

Assume the state variables

$$x_1 = i_{L1} ;\ x_2 = V_c ;\ x_3 = i_{L2} ;\ x_4 = V_{co}$$

$$\dot{x}_1 = \frac{1}{L1}V_{in}, \quad \dot{x}_2 = -\frac{1}{C}x_3$$

$$\dot{x}_3 = \frac{1}{L2}V_{in} + \frac{1}{L2}x_2 - \frac{1}{L2}x_4$$

$$\dot{x}_4 = -\frac{1}{RCo}x_4 + \frac{1}{Co}x_3$$

The equation can be written in universal form

$$\dot{x} = A_1 x + B_1 u$$

$$y = C_1 x + D_1 u$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{-1}{C} & 0 \\ 0 & \frac{1}{L2} & 0 & \frac{-1}{L2} \\ 0 & 0 & \frac{1}{C_0} & \frac{-1}{RC_0} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} \frac{1}{L1} \\ 0 \\ \frac{1}{L2} \\ 0 \end{bmatrix} V_{in}$$

State coefficient matrix Source coefficient matrix

$$A_1 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{-1}{C} & 0 \\ 0 & \frac{1}{L2} & 0 & \frac{-1}{L2} \\ 0 & 0 & \frac{1}{C_0} & \frac{-1}{RC_0} \end{bmatrix} \qquad B_1 = \begin{bmatrix} \frac{1}{L1} \\ 0 \\ \frac{1}{L2} \\ 0 \end{bmatrix}$$

Applying Kirchoff's voltage law for mode-2

$$\frac{di_{L1}}{dt} = -\frac{v_c}{L1}, \quad \frac{dv_c}{dt} = \frac{i_{L1}}{C}, \quad \frac{dv_{co}}{dt} = -\frac{v_{co}}{RC_o} + \frac{i_{L2}}{C_o}$$

Assigning the state equation we get

$$\dot{x}_1 = -\frac{1}{L1} x_2, \quad \dot{x}_2 = \frac{1}{C} x_1$$

$$\dot{x}_3 = -\frac{1}{L2} x_4, \quad \dot{x}_4 = -\frac{1}{RC_o} x_4 + \frac{1}{C_o} x_3$$

The equation can be written in universal form as:

$$\dot{x} = A_2 x + B_2 u$$

$$y = C_2 x + D_2 u$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L1} & 0 & 0 \\ \frac{1}{c} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{L2} \\ 0 & 0 & \frac{1}{C_o} & \frac{-1}{RC_o} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} V_{in}$$

State coefficient matrix Source coefficient matrix

$$A_2 = \begin{bmatrix} 0 & \frac{-1}{L1} & 0 & 0 \\ \frac{1}{C} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{L2} \\ 0 & 0 & \frac{1}{C_o} & \frac{-1}{RC_o} \end{bmatrix} \qquad B_2 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Design Parameters

Input Voltage	V_{in} = 10V
Switching frequency	fs = 20 KHz
Load Resistance	R = 60 Ω

Inductance	L_1 = 1 mH
	L_2 = 1 mH
Capacitance	C_0 = 20 μF
	C_1 = 20 μF

3. BIFURCATION AND CHAOS IN POSITIVE OUTPUT ELEMENTARY LUO_CONVERTER

In most of the power electronics circuits that exhibits deterministic chaos, so it necessary to understand the behavior of the parameters variations and route to chaos. The behavior of the Elementary Luo_converter has non-linear in nature, so it become necessary to develop a state-space averaging model.

Current Programmed Mode Elementary Luo Converter

The schematic diagram of current mode Elementary Luo_converter as shown in Fig.4.

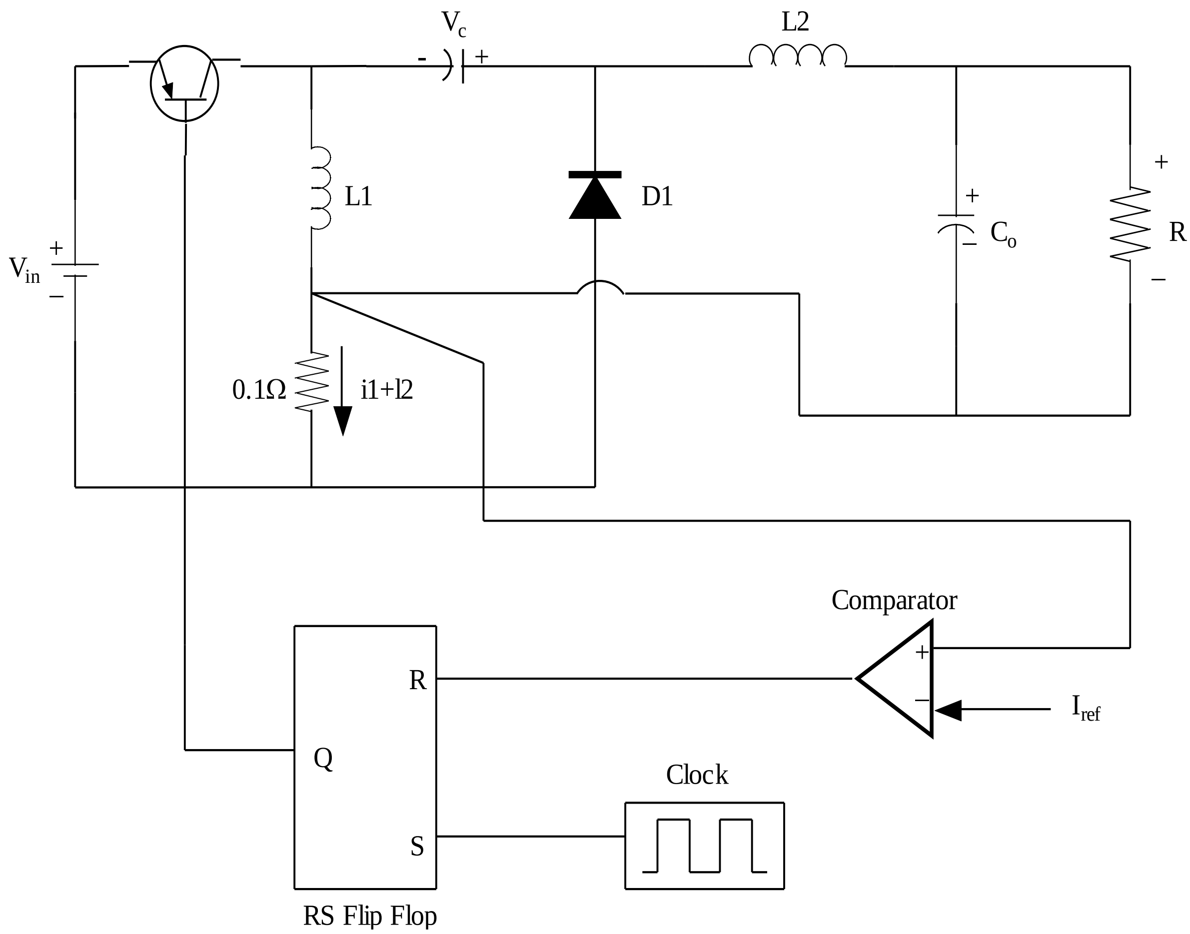

Fig. 4 Circuit of Current Mode Controlled Elementary Luo_converter

The RS flip-flop generate the pulse based on the reference current and feedback current that is operated to the transistor T_1, which act as a switch. When the switch (s) is turned ON at sampling time t=nT, the inductor current increases and decreases when switch (s) is turned OFF until the next cycle begins. The output waveform of the inductor current and capacitor voltage as shown in Fig.5 and the corresponding input and output waveform of RS flip-flop as shown in Fig.6.

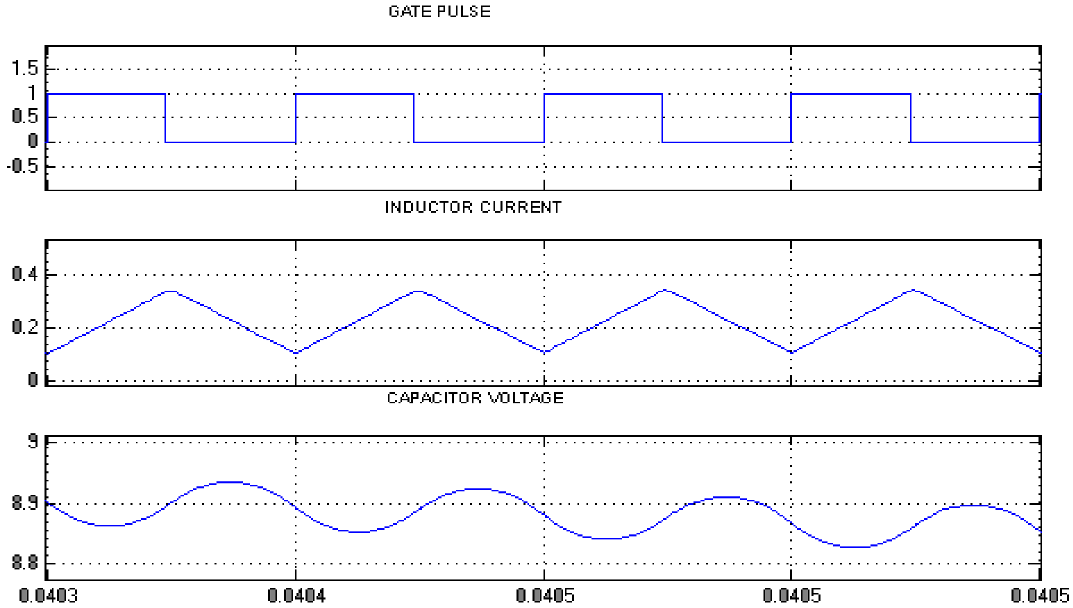

Fig. 5 Wave forms of Inductor Current and Capacitor Voltage

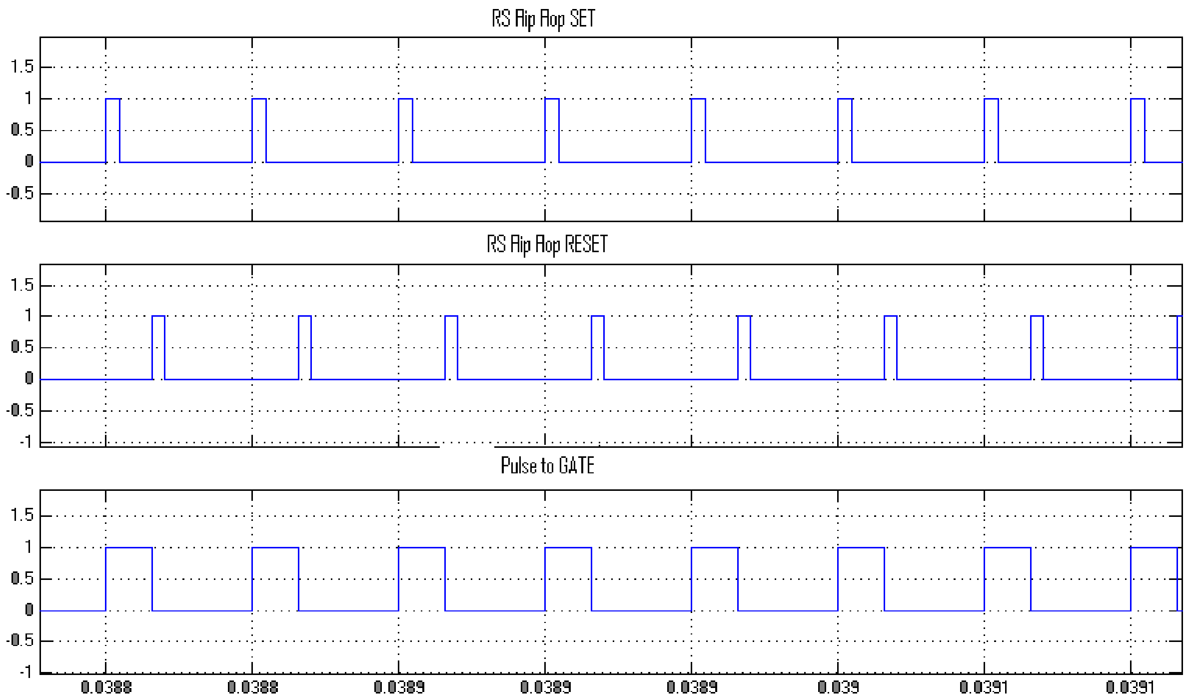

Fig. 6 Input and Output Wave forms of RS Flip Flop

Derivation of Discrete-Time Model

- Introduction

To study the stability of the system accurately, first to build discrete-time model. In this work, to derive the discrete-time model for Elementary Luo_converter in current program mode and also derive by a stroboscopic map. In stroboscopic mapping is a function of voltage and current vector (V_n, i_n) at sampling instant nT, and the next sampling instant (n+1)T voltage and current vector be the (v_{n+1}, i_{n+1}), where T is the switching period.

$$X_{n+1} = \phi_2(T - t_n)(\phi_1(t_n)X_n + \Psi_1(t_n) + \Psi_1(T - t_n)$$

Where,

$$\Psi_1(\xi) = A_i^{-1}\,\phi_i(\xi)t_n - I)\,B_i$$

$$X_{n+1} = \phi_2(T - d_nT)\phi_1(d_nT)\left[X_n + \int_{nT}^{nT+d_nT} \phi_1(nT - \tau)\,B_1 V_{in}\,d\tau\right]$$

$$+\phi_2(T - d_nT)\int_{nT+d_nT}^{(n+1)T+d_nT} \phi_2(nT + d_nT - \tau)\,B_2 V_{in}\,d\tau$$

where, $\phi_j(\xi) = 1 + \sum_{k=1}^{\alpha} \frac{1}{k!} A_j^{k1} \xi^k \qquad for\ \ k = 1,2......$

The mapping can be derived based on the above equation, hence the system matrix of the Elementary Luo_converter is non-invertible and the mapping function f_x is obtained in the form f_{ij}'s and g_i's are given by

$$\begin{bmatrix} i_{L1,n+1} \\ v_{c,n+1} \\ i_{L2,n+1} \\ v_{co,\,n+1} \end{bmatrix} = \begin{bmatrix} f_{11} & f_{12} & f_{13} & f_{14} \\ f_{21} & f_{22} & f_{23} & f_{24} \\ f_{31} & f_{32} & f_{33} & f_{34} \\ f_{41} & f_{42} & f_{43} & f_{44} \end{bmatrix} \begin{bmatrix} i_{L1,n} \\ v_{c,n} \\ i_{L2,n} \\ v_{co,n} \end{bmatrix} + \begin{bmatrix} g_1 \\ g_2 \\ g_3 \\ g_4 \end{bmatrix} V_{in}$$

- Stability Analysis

Using Jacobean matrix, the stability analysis of the Elementary Luo_converter is derived from its discrete-time model with respect to the state variables. The stability of the systems can be determined by the characteristic multipliers Mi should be less than unity.

The Eigen values of J(X) can be obtained by solving the following characteristic equation

$$\det\ [\lambda I\ -\ J(X)]\ =\ 0$$

4. SIMULATION RESULTS

The chaotic behavior of current programmed mode positive output Elementary Luo_converter is studied using MATLAB/SIMULINK software. The way system loses its stability has been observed using this software. Eigen values are computed from the Jacobean matrix and the Lyapunov exponents are calculated and also study and evaluated all the characteristic multipliers lie within the unit circle in the complex plane at each time the reference current i_{ref} may be vary.

Route to Chaos by Varying Reference Current I_{REF}

The output of the Elementary Luo_converter behave from period one to chaos at which to increase the external reference current from 0.5A to 1.2A. The inductor current waveform for the various values of I_{ref} is shown below.

- Fundamental Operation

The fundamental operation for I_{ref} is set to 0.5A and the input voltage is fixed at 10V which is shown in fig. 7.

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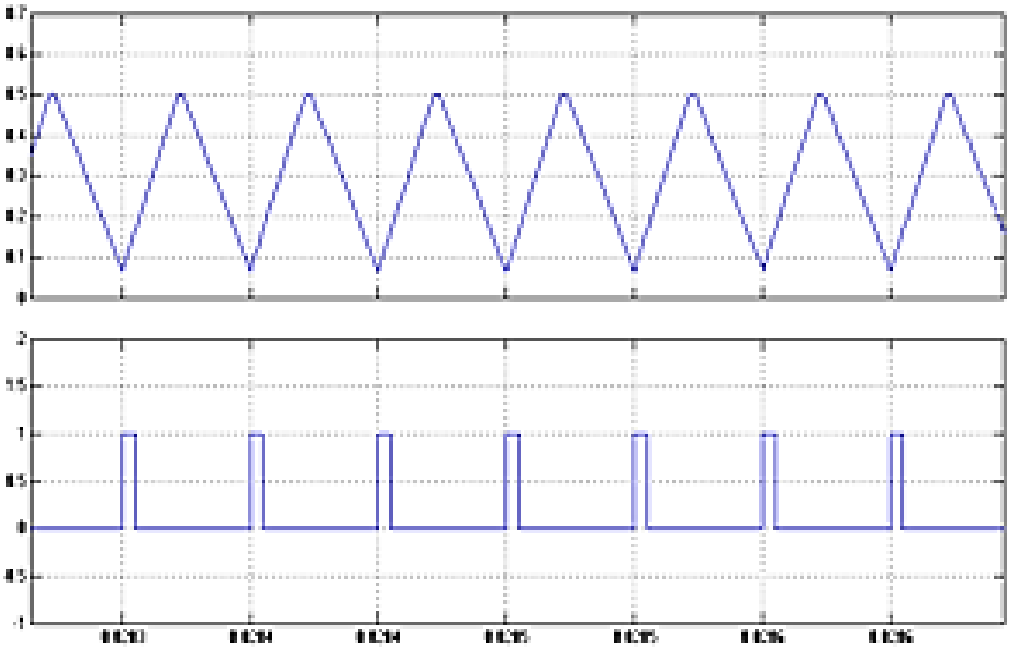

Fig. 7 Fundamental Waveform of $i_{L1}+i_{L2}$ for I_{ref} = 0.5 A

- Period 2T Operation

When i_{ref} increased to 0.8A and the input voltage is fixed at 10V, period 2T operation is found in Fig. 8.

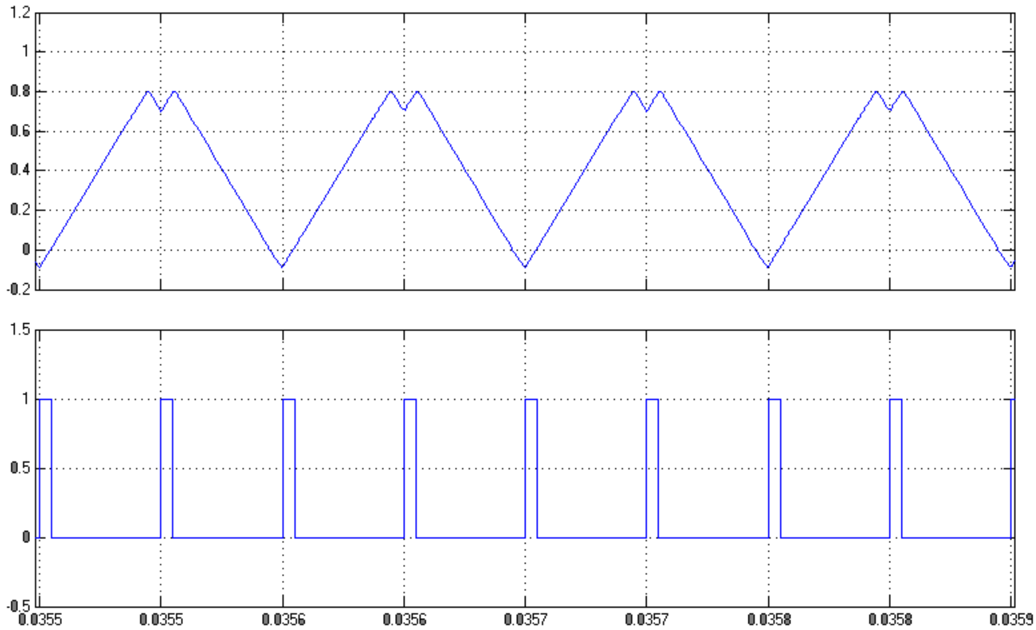

Fig. 8 Period 2T Waveform of i_{L1} + i_{L2} for I_{ref} = 0.8 A

- Chaotic Operation

When i_{ref} increased further at 1.2A and the input voltage is fixed at 10V, the chaotic operation regime is obtained as shown in Fig. 9.

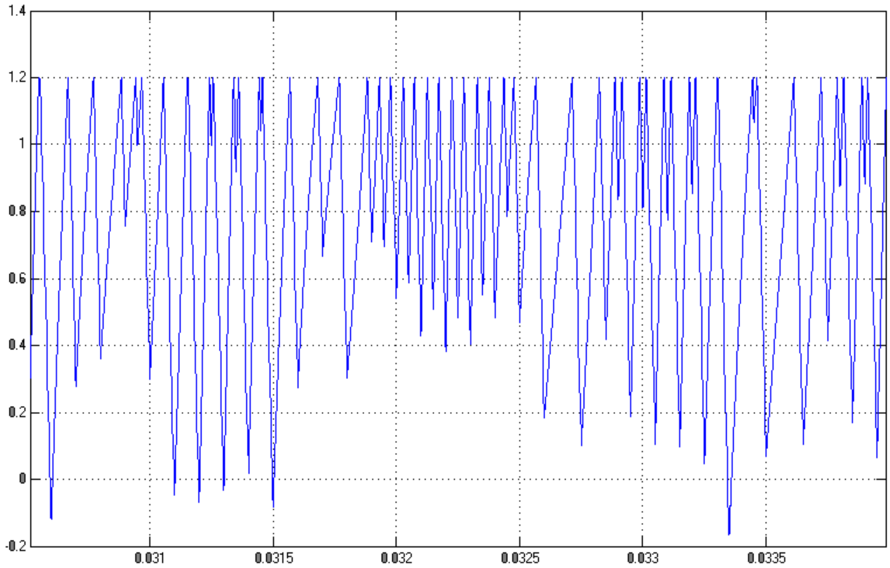

Fig. 9 Chaotic Waveform of $i_{L1} + i_{L2}$ for $I_{ref} = 1.2$ A

Supply Voltage Variations

The reference current is fixed at 0.6A and the load Resistance is 60Ω, when the supply voltage is varying to the Elementary Luo_converter. The stable, period 2T and chaotic regions are also obtained as shown in below.

- Period 2T Operation

As the input voltage is reduced from 10V to 8V, the period 2T operation is found as shown in Fig.10.

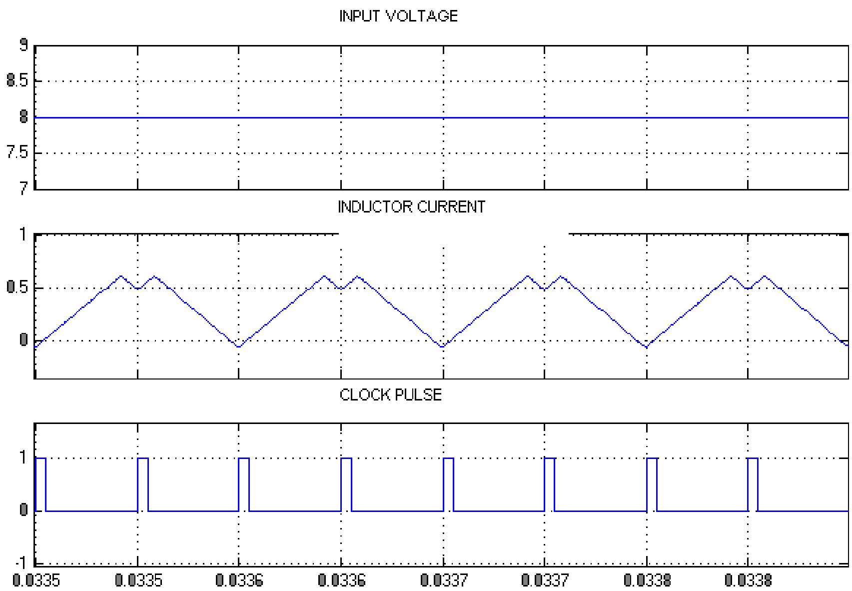

Fig. 10 Period 2T Waveform of $i_{L1} + i_{L2}$ for $V_{in} = 8$ V

- Chaotic Operation

As the input voltage is further decreased from 8V to 5V, keeping the reference current and load resistance fixed, the system enters into chaos as shown in Fig.11.

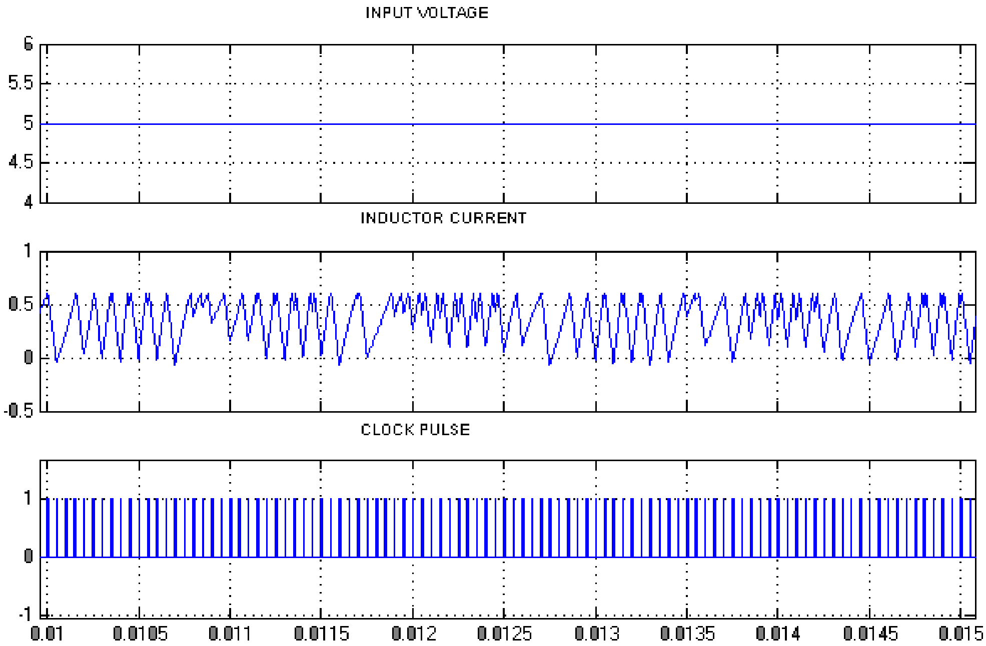

Fig. 11 Chaotic Waveform of i_{L1} + i_{L2} for V_{in} = 5 V

Load Resistance Variations

The reference current is fixed at 0.6A, input voltage at 10V and the load resistance is varying to the Elementary Luo_converter. The system way to chaos from stable, period 2T as shown below.

- Fundamental Operation

The reference current and the input voltage are fixed at 0.6A and 10V respectively and the fundamental periodic operation is found with the load resistance R = 60Ω.

- Period 2T Operation

The Fig.12 shows the load resistance is increased from 60Ω to 70Ω and it is seen that the system exhibits period 2T operation.

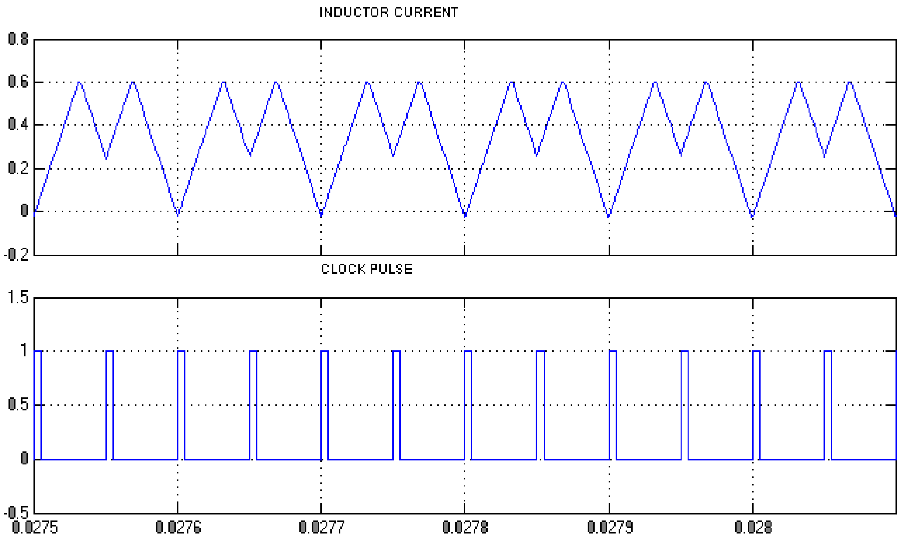

Fig. 12 Period 2T Waveform of i_{L1} + i_{L2} for R_L = 70 Ω

- Chaotic Operation

When the load resistance is further increased from 70Ω to 100Ω, the system enters into chaotic region as shown in Fig.13.

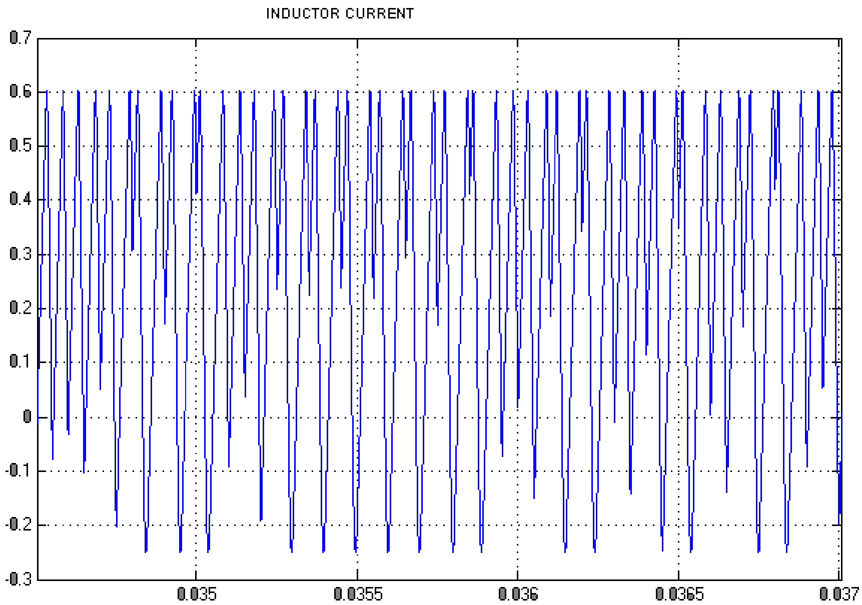

Fig. 13 Chaotic Waveform of $i_{L1} + i_{L2}$ for $R_L = 100\ \Omega$

5. CONCLUSION

The higher order free running switching converters exhibit nonlinearities such as bifurcation, quasi-periodicity and chaos. The chaotic behavior of the positive output Elementary Luo_converter is analyzed operation based on a free-running hysteretic current-mode control. The state space averaged model is derived and Jacobean matrix has been formed by using dimensionless variables. The Control parameters used in the control law are varied to determine the Hopf bifurcation point. The detailed simulation results are presented to support the concept.

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