Control of Chaos in Positive Output Luo Converter by means of Time Delay Feedback

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Abstract—Faster development in Dc to Dc converter techniques are undergoing very drastic changes due to that major advancements like low voltage, high power density in electronic industry. Chaos is a kind of quasi-stochastic behaviors of determinate nonlinear system. It is a non-linear phenomenon specifically found in all non-linear systems. The dc-dc converters exhibit a wide range of bifurcation and chaotic behavior under certain operating conditions. This paper analyses the behavior of Luo converter under current control mode. As the reference current is increased, the system becomes unstable to chaos. This is shown by means of bifurcation diagram. This is stabilized by means of time delayed feedback control method. The simulation is done using PSIM.

Index Terms—Chaos, Bifurcation, Positive Output Luo Converter, Time Delayed Feedback Control

I. INTRODUCTION

Switched dynamical systems such as dc-dc converters are known to exhibit non-linear behavior such as bifurcation and chaos due to cyclic switching of circuit topology [1]. Chaotic motion occurs frequently in the DC-DC converters, for the performance of the harsh electromagnetic noise, the control system of the intermittent unstable and critical operation of the collapse, and so on. Chaos movement studies have identified in the DC-DC converters, most of them because of bifurcation and chaos caused in the system [2]. In most practical situations, required stable operation is a period-1 operation. Thus, any effective design automatically has to avoid the occurrence of chaos for the range of variations of the parameters.

II. BASIC OPERATION OF POSITIVE OUTPUT LUO CONVERTER

The Basic Circuit Diagram of Positive Output Luo Converter is shown in Figure below. The MOSFET is driven by PWM signal with frequency $f_s$ and duty ratio $D$. The converter is assumed to be operated in continuous conduction mode. Analysis of positive output Luo Converter is explained below.

A. Mode 1 Operation: ($0 \leq t \leq DT$)

When switch is ON, the inductor $L_1$ absorbs energy from source and inductor $L_2$ absorbs energy from both source and capacitor. Both $i_{L1}$ and $i_{L2}$ increases during this mode and source current is sum of inductor currents.
Equations governing Mode 1 operation are:

\[
\frac{di_{L1}}{dt} = \frac{E}{L_1} \quad (1)
\]
\[
\frac{dV_c}{dt} = -iL_2 \quad (2)
\]
\[
\frac{di_{L2}}{dt} = \frac{E + V_{C1} - V_{C2}}{L_2} \quad (3)
\]
\[
\frac{dV_{C2}}{dt} = \frac{i_{L2} - V_{C2}}{C_2} \quad (4)
\]

**B. Mode 2 Operation: (0 \leq t \leq DT)**

When the switch S is turned off, inductor L1 transfers stored energy to capacitor C1 through freewheeling diode D. At the same time current iL2 flows through C2-R-D. Both currents iL1 and iL2 decreases during this mode of operation and the switch current is zero.

The equations governing this mode of operation are:

\[
\frac{dV_{C1}}{dt} = \frac{i_{L1}}{C_1} \quad (5)
\]
\[
\frac{dV_{C2}}{dt} = \frac{i_{L2} - V_{C2}}{C_2} \quad (6)
\]

Here the converter is assumed to operate in continuous conduction mode. The waveforms for voltage across two inductors and current passing through both inductors are shown below:

**III. CHAOTIC BEHAVIOR**

Current mode control is considered here to analyze the chaotic behavior in positive output LVO converter. Here the switch is turned ON periodically by the clock and OFF according to the output of a comparator that compares the inductor current IL with a current reference \(I_{ref}\).

When the switch is on, the inductor current climbs up and as it reaches \(I_{ref}\), the switch is turned off, thereby causing the inductor current to ramp down until the next clock comes. To analyze the chaotic behavior in positive output LVO converter, current mode control is considered.

For this analysis the converter parameters are chosen as follows.

- Supply Voltage \(E = 12\) V
- Output Voltage \(V_o = 12\) V
- Inductor Current \(L = 100\mu\)H
- Capacitor \(C = 10\mu\)F
- Load Resistance \(R = 10\) W
- Switching frequency \(F_s = 50\) KHz
- Load Current \(I_L = 1.2\) A
- DC Voltage conversion M Ratio = \(V_0/V_{in} = d/(1-d)\)

PSIM circuit diagram of Current Mode Control in Positive Output Luo Converter is shown below.

**Fig 2. Waveforms of Luo Converter**

**Fig 3. PSIM Circuit Diagram of Current Mode Control in Positive Output Luo Converter**

The route to chaos can be observed by varying reference current in the range of (3-5) A. For values of reference current lower than 3 A, the system is periodic. As reference increases above 3 A, system enters chaotic region.

**A. Phase-1 Operation**

By the principle operation of current mode controlled positive Luo converter as iL1+ iL2 approaches the value of \(I_{ref}\), the switch is turned off, and remains off until the next cycle begins. For the reference current of 3A, the fundamental waveform is shown in Figure 4.
B. Phase Operation of Period-1

The phase portrait drawn between inductor current and capacitor voltage when the reference current is about 3 A. The portrait diagram of period-1 operation is shown in Fig. 5.

C. Phase-2 Operation

If $I_{ref}$ is further increase beyond 3A, the period doubling stage is reached. For the reference current of 4A the inductor current waveform and capacitor voltage waveform is as shown:

D. Phase Operation of Phase-2

The phase portrait drawn between inductor current and capacitor voltage when the reference current is about 4 A. The portrait diagram of period-2 operation is shown in Fig. 7.

E. Chaos Operation

Chaos is nothing but transition from period to aperiodic state. Chaos occurs when reference current increases to 5A. Simulation waveform of inductor current and capacitor voltage is shown in Fig. 8.

F. Phase Operation of Chaos Operation

The phase plot drawn between inductor current and capacitor voltage when the reference current is about 5 A. The portrait diagram of chaotic operation is shown in Fig 9.
IV. CHAOS CONTROL BY TIME DELAYED FEEDBACK CONTROL

Time Delayed feedback control (DFC), proposed by Pyragis[10] is one of useful method for chaotic systems. Here the reference current is calculated using the formula,
\[ I_{ref} = I_c + k(i(t) - i(t-T)) \] (9)

The control input \( I_{ref} \) is fed by the difference between the current state and the delayed state. The delay time is determined as the period of the unstable periodic orbit to be stabilized. Hence the control input vanishes when the unstable periodic orbit is stabilized. In addition this method requires no preliminary calculations of the unstable periodic orbit. Hence it is simple and convenient for controlling chaos. The use of TDF control technique increases operating region of current controlled Luo converter.

Without TDF control Luo converter goes into unstable periodic orbits, when \( I_{ref} \) is above 3 A. After applying TDF control, results will be periodic one operation for the same \( I_{ref} \) of period doubling and chaos. The circuit of TDFC is shown in Fig. 10.

The most common, only acceptable operating regime employed in practical power supplies is the fundamental operating regime, which demonstrates the stable and periodic nature of the system. With \( I_{ref}=4A \) and \( I_{ref}=5A \), it was observed that the system enters in to period doubling operation without TDFC. With TDFC for the same \( I_{ref} \), result will be period 1 operation and is shown in Fig.11 and Fig 12.

V. CONCLUSION

In this work, the analysis of chaos of a current mode controlled Luo converter has been performed. It was shown that as the reference current is varied, the nominal periodic orbit undergoes a flip bifurcation and finally enters into the chaotic regime. The simulated results using PSIM is presented. The results obtained reveals that the current mode controlled Luo converter becomes unstable, when \( I_{ref} \) is increased beyond 3 A. By using Time Delayed Feedback Control, results will be period one operation for the same \( I_{ref} \) of period doubling and chaos.

REFERENCES

[4] Chaos in power electronics: An overview, Mario di Bernardo and Chi.k