Control of chaos in DC-DC positive Output Luo converter using Sliding Mode Control

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Abstract - *This paper deals with the analysis and control of chaos in positive output Luo converter by using sliding mode control. Chaos is a disordered deterministic behavior, which is universally occurring in many systems in all areas of science. In this paper, current controlled positive output Luo converter operating in continuous conduction mode (CCM) is considered. The nominal period -I operation loses its stability through period doubling to Chaos by varying reference current. In power electronics, nonlinear behavior leads to many undesirable effects and so it is of important to control chaos. For controlling chaos, sliding mode control (SMC) has been adopted. Using this method the period doubling and chaotic operation is changed back to stable operation.*

Key Words: *Positive output Luo converter, current mode control, sliding mode control, chaos.*

1. INTRODUCTION

For more than a century the study of presence of non-linear dynamics in all physical systems has been carried out. The history of chaotic behaviour can be done back to the work of Henri Poincare on celestial mechanics around 1900. This non-linear behavior was found to be present in the power electronic converters and the study of such behavioural and its control methods have been carried out for the past five decades. The presence of non-linearity in any physical system is not undesirable and this must be eliminated.

In practice all the power electronic systems are designed to operate at a particular physical condition of the system. Any change in the physical conditions makes the system to behave chaotically.

DC-DC converter is a part of power electronic converters which is found to possess highly nonlinear behaviour. These converters exhibit a rich variety of bifurcations and chaos if the switching action is governed by feedback control as in regulated power supplies.

2. OPERATION OF POSITIVE OUTPUT LUO CONVERTER

The circuit diagram of the positive output Luo converter is shown in Fig 1. The switch S is driven by PWM switching signal with frequency f_s and duty ratio D. In the circuit diode D is the freewheeling diode. The energy storage elements are inductors L_1 and L_2 and capacitors C_1 and C_2 and also R is the load resistance V_{in} and V_o are the input supply and average output voltage.

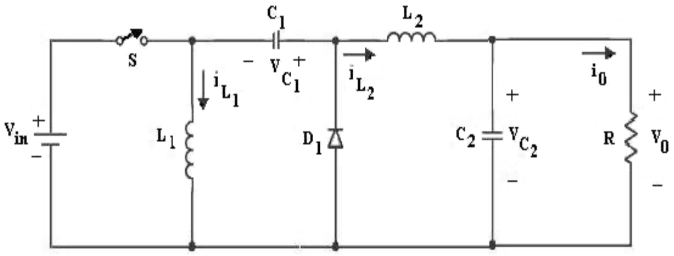

Fig .1: Circuit diagram Positive output Luo Converter

The converter is assumed to be in continuous conduction mode. Operation of positive output Luo converter is explained in two modes of operation.

2.1 Mode -1 Operation

Mode 1 begins when the switch S is closed. The equivalent circuit for mode 1 operation is shown in Fig.2. In this mode, the current in the inductor L_1 increases from i_{L1} to i_{L2} linearly and it charges from the supply voltage. The capacitor C_1 is connected in series with L_2 starts discharging the energy stored in it. Energy stored in the capacitor C_1 is transferred to the load through the inductor L_2. Hence the inductor currents increase until the switch S is turned off.

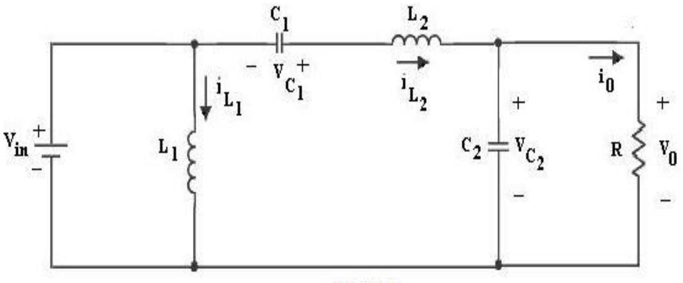

Fig. 2: Equivalent circuit of the positive output Luo Converter in Mode 1 operation.

2.2 Mode- 2 Operation

Mode 2 begins when the switch S is turned off. The equivalent circuit for this mode is shown in Fig.3

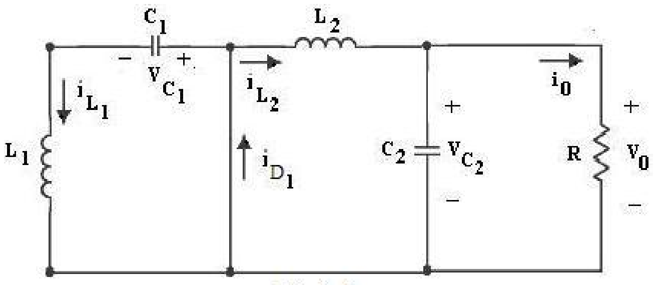

Fig. 3: Equivalent Circuit of the positive output Luo Converter in Mode -2 operation

In this mode, the energy stored in the inductor L1 is transferred to the capacitor C_1. The energy stored in the inductor L_2 is transferred to the capacitor C_2 through D_1. This energy supplies the load current and restores the charge drained away from the output capacitor C_2 when it is alone was supplying the load current during the on time. Hence the inductor currents decrease until the switch S is turned on again for the next cycle. The converter will operate in discontinuous mode if the switching frequency is small, for low values of D, low values of L, and high values of load current.

The theoretical waveforms for the voltage across the switch V_S, current through the diode i_{D1}, inductor currents i_{L1} and i_{L2} and voltage through capacitor V_{C2} of the Luo converter are shown in Fig .4

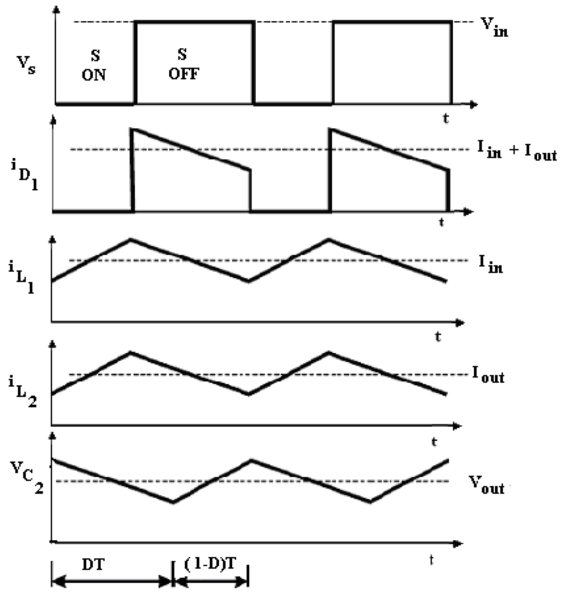

Fig. 4: Theoretical Waveforms of Positive output Luo converter

The average DC output voltage is given by

$$V_0 = \frac{D}{1-D} V_{in}$$

The average DC input current is given by

$$I_{in} = \frac{D}{1-D} I_0$$

Voltage transfer gain is

$$M_E = \frac{D}{1-D}$$

3. CURRENT MODE CONTROL OF POSITIVE OUTPUT LUO CONVERTER

To analyze the chaotic behavior of positive output Luo converter operating in CCM, the following parameters are chosen as follows

Supply Voltage	V_{in}	=12 V
Switching frequency	f_s	=50 KHz
Load resistance	R	=10 Ω
Output voltage	V_o	=12 V
Load current	I_o	=0-2 A
Duty cycle	D	=0.5
Inductor values	L_1, L_2	=100 µH
Capacitor Value	C_1, C_2	=10 µF

The Fig. 5. shows the current mode control in positive output Luo converter. If any one of the parameter changes, the system loses its stability. Here the bifurcation parameter is reference current. When the sum of the inductor currents excedes the reference current, output from the flipflop will be high, that will turn off the switch and when the sum of the inductor currents less than the reference current the output of the flipflop will be low and the switch condition

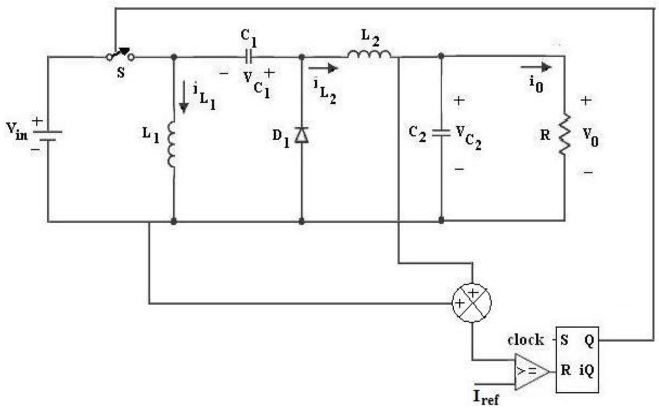

Fig. 5: Circuit diagram of current controlled mode in positive output Luo converter

4. ROUTE TO CHAOS BY VARYING THE REFERENCE CURRENT I_{ref}

4.1 Period – I operation

When $i_{L1}+i_{L2}$ attains the value of I_{ref}, the switch goes to off condition and remains off condition until the next cycle starts. For the reference current of 3.2 A, the fundamental wave forms are shown in the Fig 6.

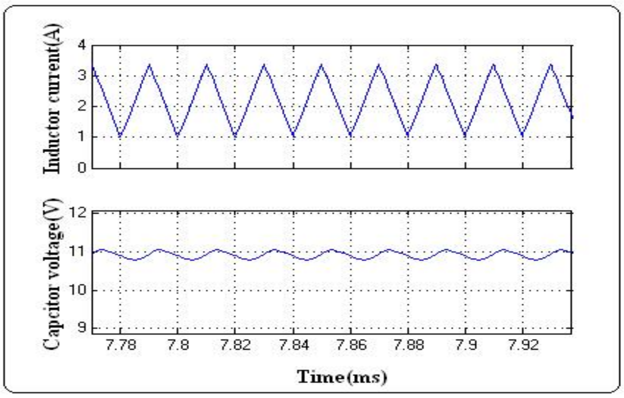

Fig.6: Simulated fundamental waveforms for inductor current and capacitor voltage when $I_{ref} =$ 3.2A

4.2 Phase trajectory of period-I operation

Phase trajectory which is drawn between the output voltage and the inductor current when $I_{ref} =$ 3.2A. The phase trajectory of period-I operation is shown in the Fig .7

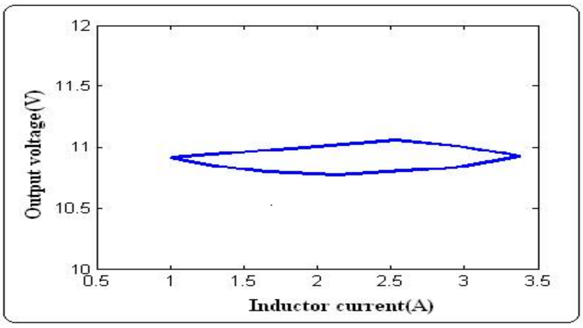

Fig 7: Phase trajectory of period-I operation

4.3 Period – II operation

When the value of reference current I_{ref} is increased, period doubling regime is obtained. For I_{ref} = 4A, the simulated waveforms for inductor current and capacitor voltage waveform for period -II operation are shown in the Fig. 8.

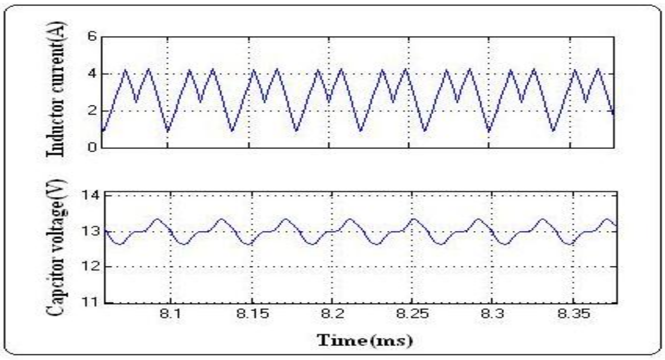

Fig .8: Simulated Waveforms for inductor current and capacitor voltage when $I_{ref} =$ 4A

4.4 Phase trajectory of period-II operation

Phase trajectory which is drawn between the output voltage and the inductor current when $I_{ref} =$ 4A. The phase trajectory of period-II operation is shown in the Fig .9

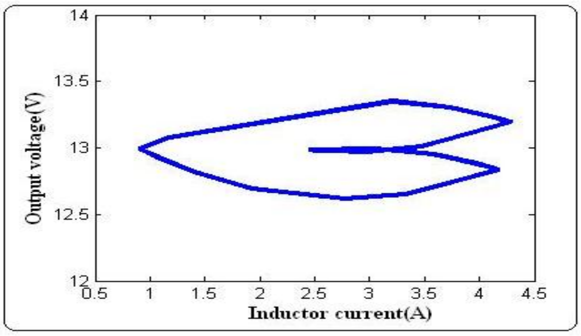

Fig. 9: Phase trajectory of period-II operation

4.5 Chaotic operation

When the value of the reference current I_{ref} is increased, the chaotic regime is obtained. For I_{ref} = 5A the simulated inductor current and capacitor voltage waveforms for the chaotic operation are shown in the Fig .10.

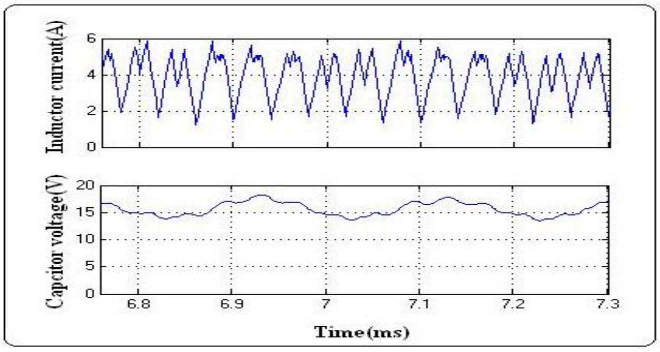

Fig. 10: Simulated waveforms for inductor current and capacitor voltage when I_{ref} = 5A

4.5 Phase trajectory of chaotic operation

Phase trajectory which is drawn between the output voltage and the inductor current when I_{ref} = 5A. The phase trajectory of period-1 operation is shown in the Fig .11

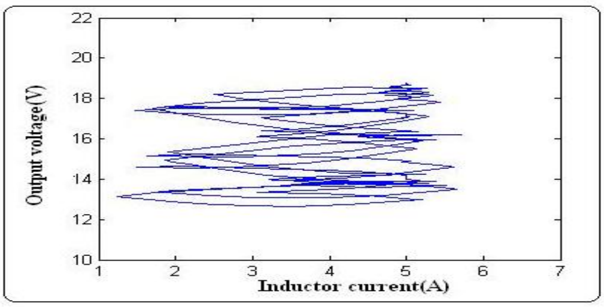

Fig.11: Phase trajectory of chaotic operation

5. SLIDING MODE CONTROL OF CHAOS IN POSITIVE OUTPUT LUO CONVERTER

Sliding mode control is a type of variable structure control in which specific state dynamic behavior is imposed on a structure in the state space on which the switching occurs at infinite frequency. Sliding mode control can be characterized with a switching surface along which the state action is to be contrived. State dependent switch action is given using switching surface in state-space. It was shown that the use of the sliding mode control can lead to enhanced robustness in providing consistent transient response over a wide range of operating conditions.

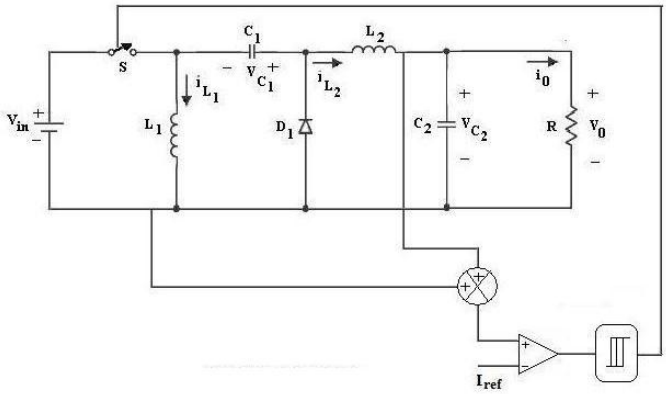

Fig.12: Circuit for current programmed positive output Luo converter with sliding mode control

The positive output Luo consists of switch S, a diode D_1, inductors L_1 and L_2, capacitors C_1 and C_2 and a resistive load R. All the elements are considered to be ideal. Output voltage Vc_2 is the control target. It will not possible for the closed loop controlled system to reach stable motion on the sliding surface, if it is chosen as the control variable. Thus the sum of the inductor currents ($i_{L1}+i_{L2}$) is chosen as the control target, which can lead to sliding motion.

The sliding surface can be written as

$$S=i_{L1}+i_{L2}-I_{ref}=0$$

Where I_{ref} is the reference current

6. CONTROLLED OUTPUT VOLTAGE WITH SLIDING MODE CONTROL

The most common, only acceptable operating region employed in practical power supplies is the fundamental operating region, which shows the stable and periodic nature of the system. Before, without SMC for I_{ref}=4A resulting is period-II operation now for the same I_{ref} result will be period-I operation with the use of SMC is shown in Fig. 13

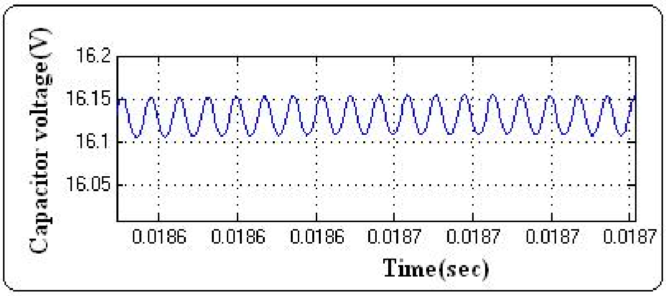

Fig.13: Simulated waveform of capacitor voltage with I_{ref}=4A

Without SMC for I_{ref} =5A, resulting chaotic operation now for the same I_{ref}, result will be period-I operation with the use of SMC is shown in Fig. 14

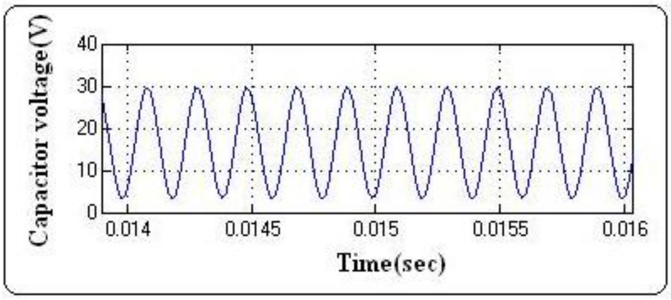

Fig.14: Simulated waveform of capacitor voltage with I_{ref}=5A

The chaotic behavior of the current controlled Luo converter has been controlled by using feedback control namely sliding mode control. The simulation results for period-II to period-I and chaotic to period-I have been presented for the same reference current where period-II and chaotic operation are resulting.

7. CONCLUSION

In this work, control of chaos in the current mode controlled positive output Luo converter has been performed. It was shown that as the reference current is changed the nominal periodic orbit undergoes a flip bifurcation and finally enters into the chaotic regime. The simulated results using MATLAB have been presented. The results obtained reveal that the current mode controlled positive output Luo converter becomes unstable when the load is increased beyond the rated value. In order to control the chaos of the converter, sliding mode control method is proposed and it is implemented for the converter. The results obtained by using MATLAB/ SIMULINK shows that this type of control change the behavior of the converter from chaotic to periodic regime.

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