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Periodic Perturbation Method for Controlling Chaos for a Positive Output DC-DC Luo Converter

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ABSTRACT

A simple, non-feedback method of controlling chaos is implemented for a DC-DC converter. The weak periodic perturbation (WPP) is the control technique applied to stabilize an unstable orbit in a current-mode controlled Positive Output Luo (POL) DC-DC converter operating in a chaotic regime. With WPP, the operation of the converter is limited to stable period-1 orbit that exists in the original chaotic attractor. The proposed control strategy is implemented using simulations and the results are verified with hardware setup. The experimental results of the converter with WPP control are presented which shows the effectiveness of the control strategy.

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1. INTRODUCTION

Power converters find applications in many electronic products and equipment. They are a class of nonlinear systems in real time. The operation of power converters can easily become chaotic when they fail to maintain their normal periodic operation. The normal periodic operation of the converter must be ensured by the control strategies for any converter. To limit the operation of a nonlinear system in normal periodic operation, many techniques have been proposed to control chaotic operation. The control techniques can be classified into two general categories, namely, feedback control methods and non-feedback control methods. Comparing to the feedback type of control, the non-feedback type of control is easier to implement, but it does not always lead to the stabilization of an unstable period-1 orbit that exists in the original chaotic attractor [1]-[3].

Early nonlinear dynamics research in the 1980s focused on identifying systems that display chaos, developing mathematical models to describe them and new nonlinear statistical methods for characterizing chaos, identifying the way in which a nonlinear system goes from simple to chaotic behaviour as a parameter is varied (the so-called “route to chaos”). One outcome of this research was the understanding that the behaviour of nonlinear systems falls into just a few universal categories. A dramatic shift in the focus of research occurred around 1990 when scientists went beyond just characterizing chaos: Ricardo Chacon in his work stated, the non-feedback control techniques may be classified into three broad categories, namely i) the parametric excitation of an experimentally adjustable parameter, ii) entrainment to the target dynamics, iii) the application of a coordinate independent external periodic excitation [4]. There exists, numerical, experimental evidence that the period of the most effective chaos-controlling excitations usually is a rational fraction of a certain period associated with the uncontrolled system [5].

This paper focuses on the application of weak periodic perturbation method is to control the chaotic behaviour of the positive output Luo converter under current controlled mode. The detailed theoretical analysis of occurrence of chaos in hysteretic current programmed Luo converter has been performed using continuous time model [6]. The application of weak periodic perturbation method is to control chaos has been discussed which eliminates the need of feedback control circuitry. The results of simulation and experiments are discussed to show the effectiveness of control technique in limiting the chaos in DC-DC converters [7]-[8].

2. REVIEW OF WEAK PERIODIC PERTURBATION METHOD

Weak periodic perturbation technique is a method, which associates the application of coordinate independent external excitation signal to tame the chaos. It is a periodic parametric excitation technique, in which a low amplitude, low frequency sinusoid is employed as a perturbing signal, which is used to perturb the reference control variable in a physical system. Weak periodic perturbation has been used to suppress, induce and enhance the chaos in some non-linear systems [9]-[10]. It is a simple and a novel method for control which can be implemented for any physical systems with non-linearity. Any parametric variations in the system can drive the system into chaotic regime. But if the perturbations applied at a particular frequency and amplitude can induce the system to stay in periodic regime [11]. The choice of the parameter should be based on its effect on the system's behaviour. Usually a parameter that strongly affects the system can be easily varied is chosen. Suppose this parameter is 'x', then it is perturbed with the Melnikov's function.

$$\ddot{x}+\frac{dU(x)}{dx}=-d(x,\dot{x})+p_c(x,\dot{x})F_c(t)+p_s(x,\dot{x})F_s(t) \tag{1}$$

Where U(x) is the non-linear potential, -d(x,x), a generic dissipative force, which may include constant force terms and time delays, pc(x,x), is the chaos inducing excitation, ps(x,x), is the chaos taming excitation, Fc(t) and Fs(t) are the harmonic functions. The amplitudes of the excitation variables are chosen in such a way to suppress or induce chaos in the non-linear system [12]-[13].

2.1. Positive Output Luo Converter

Positive output Luo (POL) converter is a type of derived DC-DC converter. It finds application in the field of aerospace applications. It has two stages, namely the conversion stage and a filter stage [14]-[15]. The circuit diagram of the POL is shown in Figure 1. The switch is operated periodically with a period of T sec. The switch remains closed for the duration of DT and opened for the time (1-D) T, where D is the duty ratio of the switch S. Continuous conduction mode operation is assumed. Under steady state, the converter operation is divided into two modes for every switching cycle. Mode I when the switch S is closed for the interval ($0 \leq t \leq DT$) and Mode II with the switch S opened for the interval ($DT \leq t \leq T$).

2.2. Mode I Operation ($0 < t \leq DT$)

This mode starts when the switch S is turned ON. The inductor L1 is charged for the supply and the inductor L2 is charged by both source and capacitor C1. The current in both inductor iL1 and iL2 increases during this mode. The source current Is is the sum of the inductor currents (iL1 + iL2). The equivalent circuit of the converter during Mode I is shown in Figure 2.

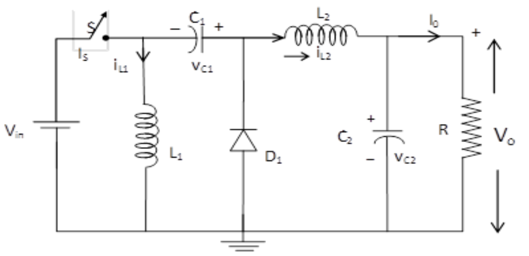


Figure 1. Elementary circuit diagram of POL Converter

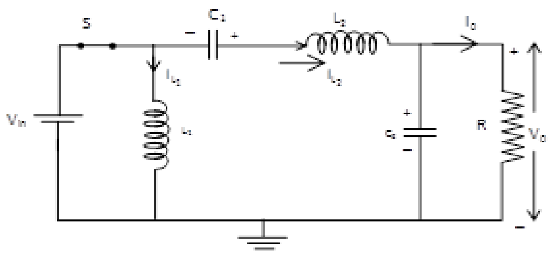


Figure 2. Equivalent circuit diagram of POL converter during Mode 1 operation

2.3. Mode II Operation ($DT < t \leq T$)

In this mode, the switch S is turned off and the inductor L_1 transfers its stored energy to capacitor C_1 through the freewheeling diode D_1. During this interval, the current i_{L2} flows through a capacitor (C_2) and load resistance (R) and freewheeling diode D_1. Both inductor currents i_{L1} and i_{L2} decreases during this mode of operation and the switch current is zero.

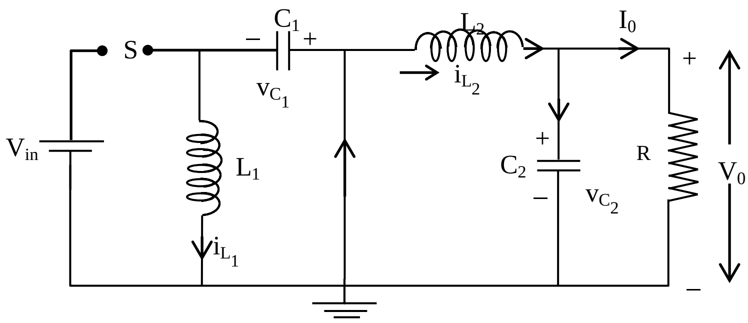


Figure 3. Equivalent circuit diagram of POL converter during Mode 2 operation

The positive output Luo converter offers the flexibility of providing both lower and higher positive polarity DC voltage than the supply voltage. The equivalent circuit of the converter during Mode I is shown in Figure 3.

3. CHAOS IN CURRENT PROGRAMMED POL CONVERTER

The chaotic behaviour in POL converter is analyzed under current mode control. In this strategy, the switch is turned ON periodically by the clock and OFF according to the output of a comparator that compares the inductor current sum (IL1 + IL2) with a current reference Iref [16]-[17]. Specifically, while the switch is on, the current in both inductors ramps up until the inductor current sum (IL1 + IL2) reaches Iref, thereafter the switch is turned off, causing the inductor current to ramp down until the next clock comes [18]. The switching function implemented is given by

$$\partial = I_{ref} - (I_{L1} + I_{L2}) \tag{2}$$

The implementation of the above stated control strategy is shown in the Figure 4. The above strategy is employed to analyze the working of the converter for various reference current values. The converter is operating in continuous conduction mode with the converter parameters are chosen.

Supply Voltage	V_{in} = 12 V
Output Voltage	V_O = 12 V
Inductor	$L_1 = L_2$ = 100μH
Capacitor	$C_1 = C_2$ = 10μF
Load Resistance	R_L = 10Ω
Switching frequency	F_S = 50 kHz
Load Current	I_L = 1.2A
Voltage gain of the converter	$M = V_0/V_{in} = D / (1- D)$

The chaotic behaviour of the converter is examined by varying the current reference Iref, and the results are presented.

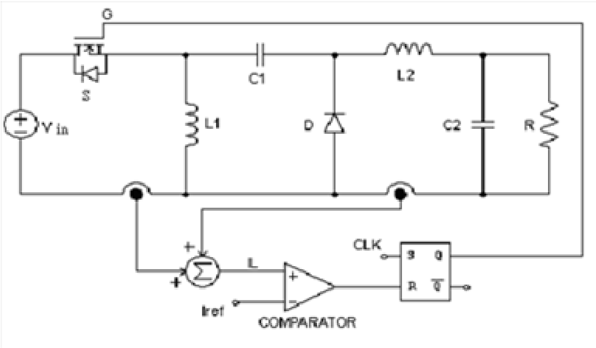


Figure 4. Circuit diagram of Current mode controlled POL converter.

4. HARDWARE IMPLEMENTATION OF CURRENT PROGRAMMED POL CONVERTER

The hardware circuit diagram of the POL is shown in the Figure 5. The switch S in realizing using MOSFET IRF540N. The freewheeling diode D1 is realized using IR306 fast recovery diode. The load is a 10Ω, 20W resistor. The DC supply voltage for the converter is obtained from a diode bridge rectifier comprising of four 1N5408 diodes through a 230V/15V step down transformer from the AC supply mains [19].

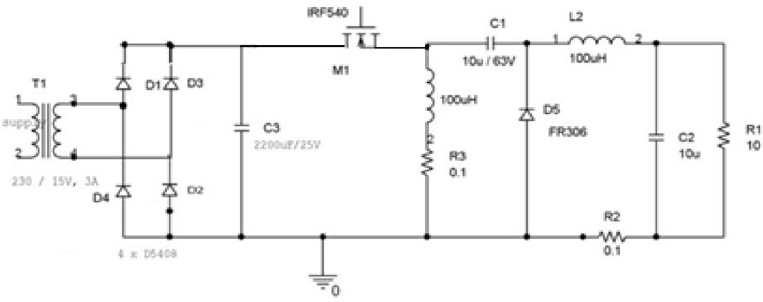


Figure 5. Hardware circuit of Positive Output Luo Converter.

The complete circuit of current programmed POL is shown in Figure 6. The essential gating for the MOSFET is generated using NE555 timer operating in astable mode. The pulse generated by the timer is applied to the MOSFET through CD4013 latch and an IR2125 MOS driver. The pulse from the timer is applied to the set input (Pin 6) of CD4013.

The inductor currents of the power circuit are sensed using current sensing resistors placed at appropriate locations in the circuit. The sensed current is summed up and compared with a constant reference current using TL082 high frequency Op-amp comparator. The output of the comparator is then applied to the reset input (Pin 4) of CD4013. The experimental setup of the current programmed POL is shown in Appendix A.1.

5. HARDWARE RESULTS OF CURRENT PROGRAMMED POL CONVERTER

The hardware results of the converter exhibiting chaos for variation in current references are presented in this section.

5.1. Period I Operation

The fundamental period operation of the converter is obtained for a reference current setting of 2.5A. The simulated results of output voltage, inductor current waveforms and phase portrait of the converter for the period I operation is shown in Figure 7 for Iref = 2.5A. The experimental results of output voltage, inductor current and phase portrait are shown in Figure 8 (a) to Figure 8(c) under period I operation for Iref = 2.5 A.

5.2. Period II Operation

As the current reference is increased to 3A, the period of the converter doubles. The simulated output voltage, inductor current waveforms and phase portrait of the converter of the period doubling operation is shown in Figure 9. The experimental results of output voltage, inductor current and phase portrait are shown in Figure 8 (a)-(b) under period II operation for I_{ref} = 3 A.

5.3. Chaotic Operation

As the reference current is increased further to 3.6A, the converter operates in the chaotic regime. The corresponding simulated waveform and the phase portrait for the converter are shown in Figure 11. The experimental results of output voltage, inductor current and phase portrait are shown in Figure 8 (a) to Figure 8(c) under Chaotic Operation of the converter for Iref = 3.6A.

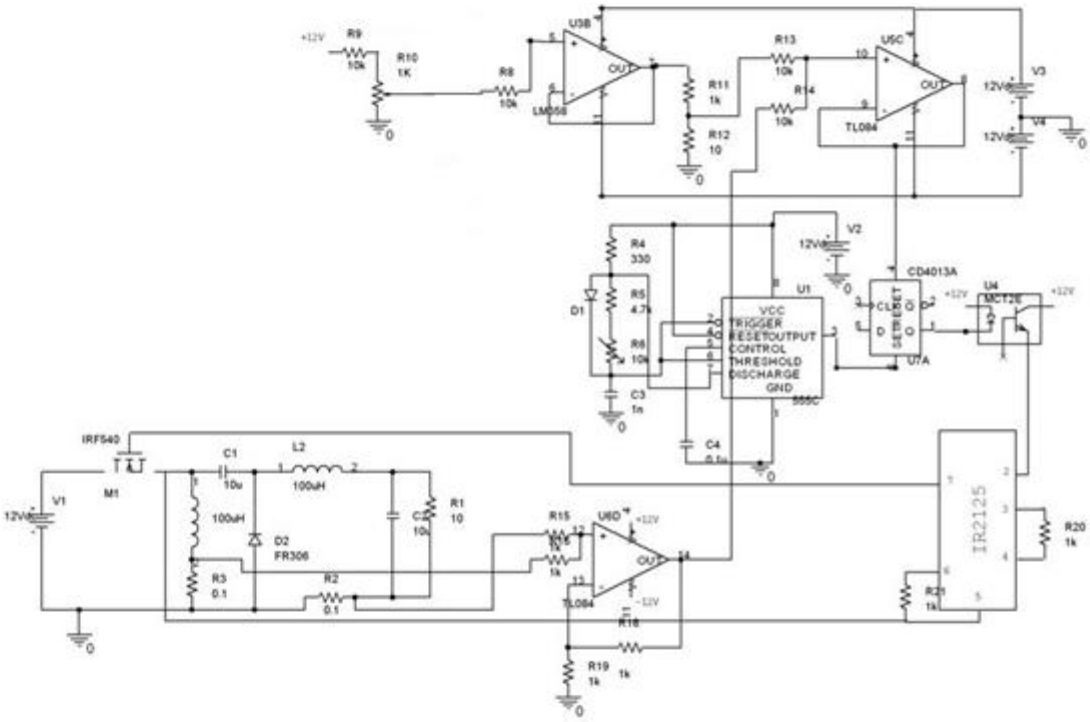


Figure 6. Circuit Diagram of Current programmed POL Converter.

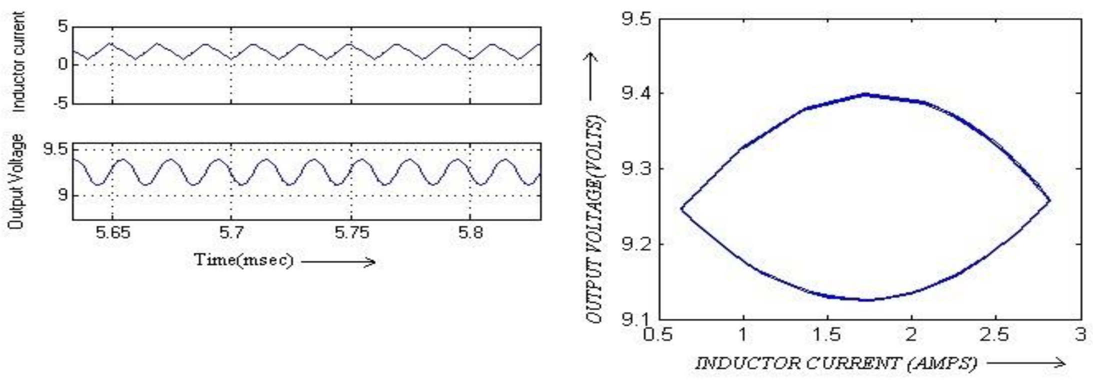
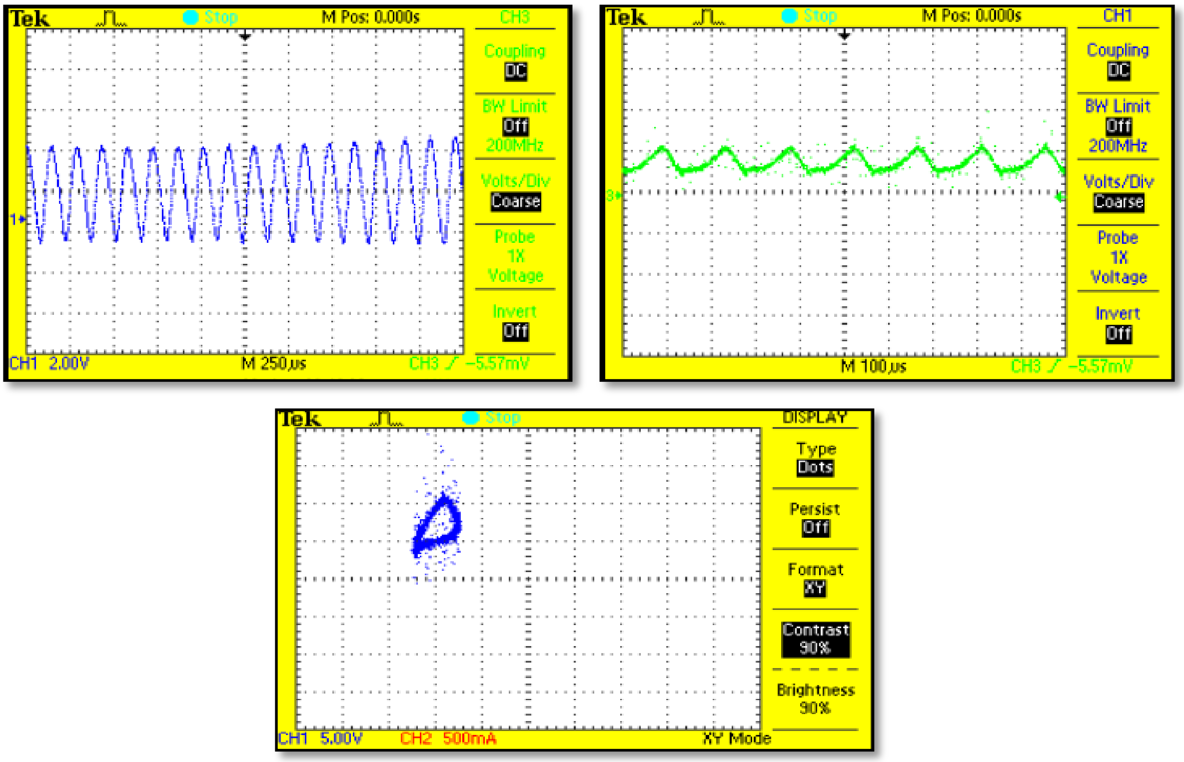


Figure 7. Simulated Period-I Waveforms for Control Signal (I_l) and Output Voltage (V_{c2}) a) Time Domain Waveform b) Phase Portrait.



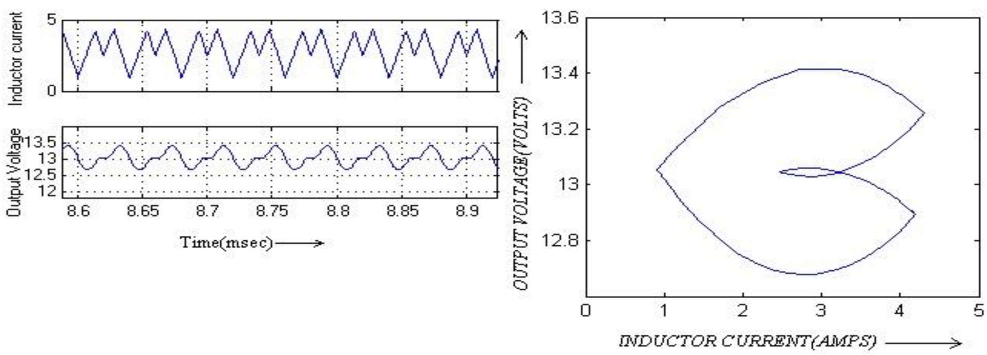


Figure 9. Simulated Period-II Waveforms for Control Signal (I_s) and Output Voltage (V_{c2}) when $I_{ref} = 3$ A. a) Time Domain Waveform b) Phase Portrait.

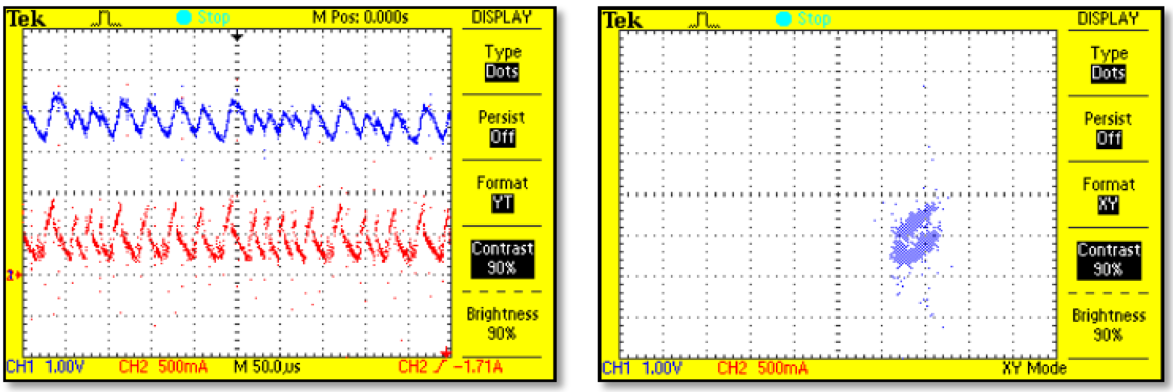


Figure 10. Experimental Results voltage under Period II Operation of the converter for $I_{ref} = 3$A.

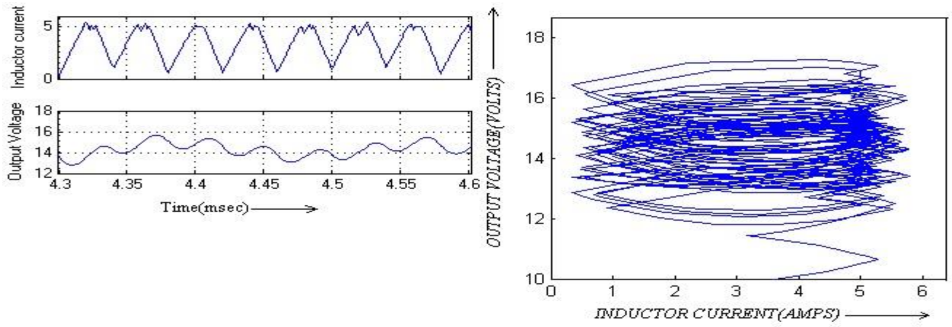


Figure 11. Simulated Chaotic Waveforms for Control Signal (I_s) and Output Voltage (V_{c2}) When I_{ref} = 3.6 A. a) Time Domain Waveform b) Phase Portrait

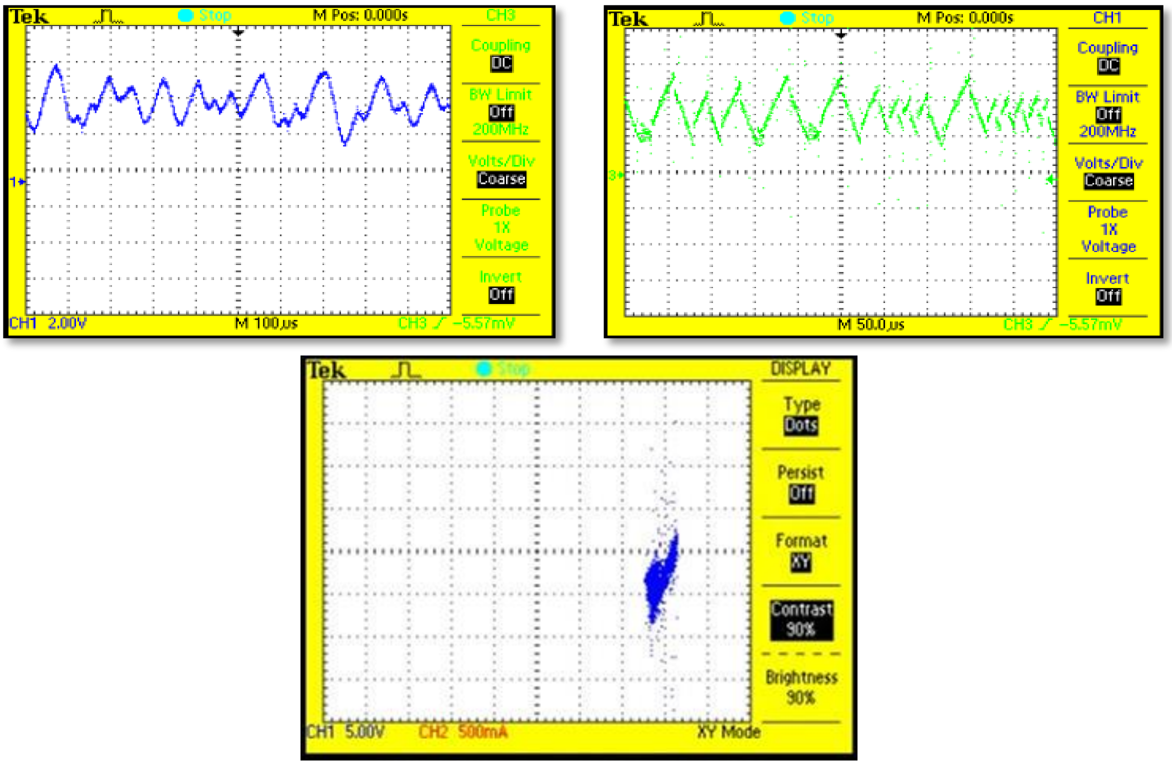


Figure 12. Experimental Results under Chaotic Operation of the converter for I_{ref} = 3.6A.

6. WEAK PERIODIC PERTURBATION TO CONTROL CHAOS IN CURRENT PROGRAMMED POL CONVERTER

Weak periodic perturbation method of controlling chaos is employed for the converter. This method is a classical approach that can eliminate the chaotic behaviour of any physical system. It is a non-feedback method of control, which can easily be implemented in any physical systems.

The use of WPP extends the operating region of the converter by modulating the reference signal with a low frequency low amplitude sinusoid. Without the control, the converter bifurcates from its periodic nature to period doubling and to chaotic region beyond 4A. After applying the control, the converter operates in periodic regime for wide ranges of reference current settings. The implementation of WPP to the POL is shown in the Figure 13. According to this control method, the Iref is added a weak periodic perturbation as in Equation (3) and is applied to the converter as a reference. Hence the modified Iref is given by

$$\tilde{I}_{ref} = (1-\eta)I_{ref} + \eta(1+\sin(2\Pi ft)) \quad (3)$$

Where, η is the perturbation amplitude and ‘f’ is the perturbation frequency.

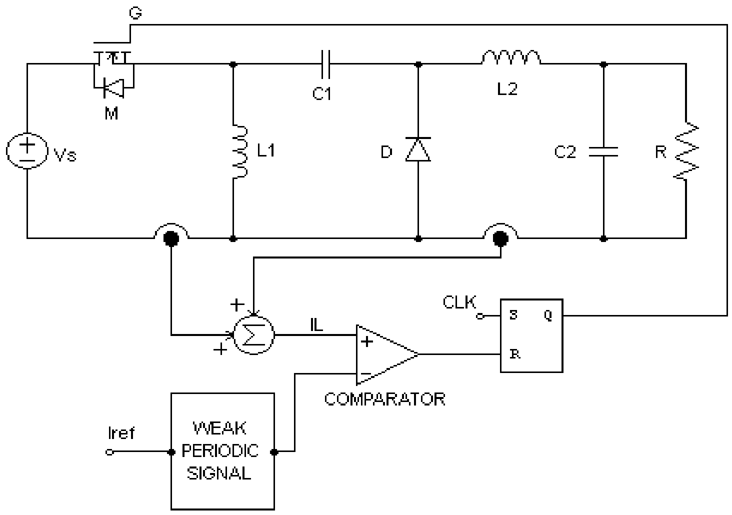


Figure 13. Circuit of Current mode controlled Positive Output Luo converter with Weak Periodic Perturbation Control.

With this controlled reference, the working of the converter in the chaotic regime is shifted to periodic UPO. The proposed control scheme is implemented in the hardware using ICL8038 function generator and op-amp LM358 buffer and a simple voltage divider network.

The ICL8038 is a function generator IC capable of generating standard wave shapes of adjustable frequency and duty cycles. It is a simple, versatile device that depends simply on the external resistors and capacitors for the frequency of the output wave. A low frequency sine wave is generated using ICL8038 (at pin 2) is used as the perturbation signal for the converter. This is shown if Figure 14.

The perturbation amplitude is introduced by a simple potential divider network. Using op-amp LM358, the constant Iref is added to the perturbation signal. Now this periodically perturbed signal is used as the reference current signal to the converter. The controlled waveforms of the converter with various reference current settings are shown in Figure 15 (a) to Figure 15 (b) for period II operation and chaotic regime. From the results, it is clear that the POL under current control mode work under the periodic regime for wide ranges of reference currents.

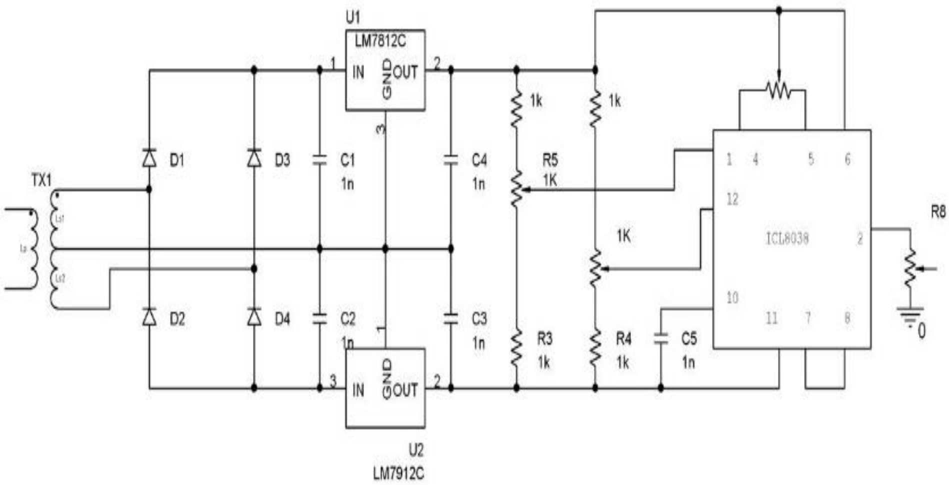


Figure 14. Generation of low frequency sinusoid using ICL8038 function generator.

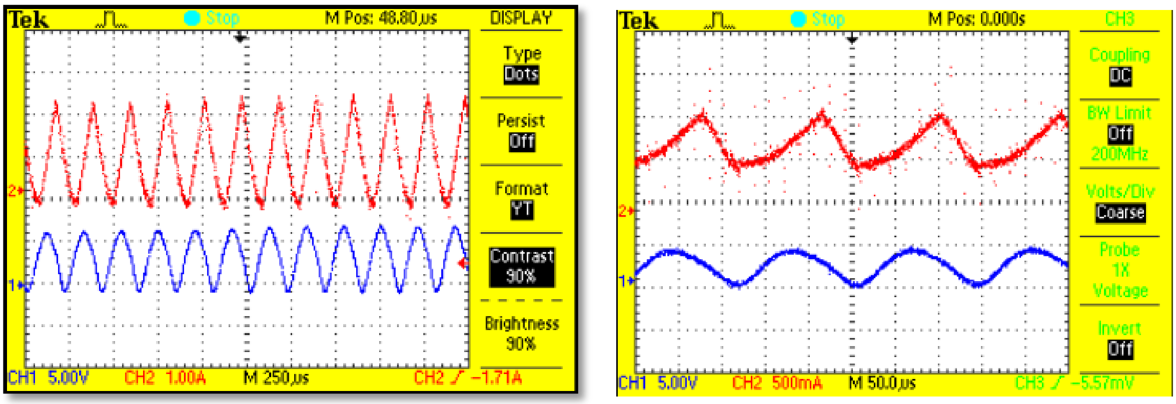


Figure 15. Controlled output of the converter from (a) period II operation (b) chaotic regime.

7. CONCLUSION

In this work, the operation the current mode controlled positive output Luo DC-DC converter has been considered to demonstrate the chaotic operation of the converter. It was proved that as the reference current is varied the nominal periodic orbit undergoes a flip bifurcation and finally enters into the chaotic regime. The results obtained by emulation reveal that the current mode controlled Luo converter becomes unstable, when Iref is increased beyond 4A. By applying the Weak Periodic Perturbation Control, to the converter the operating regime of the converter is limited in the periodic regime over a wide range of current references. The analog implementation of the control strategy makes the control simpler compared to other digital controllers. Also the control is simple and effective. The experimental results also prove the effectiveness of the control method that can be applied for controlling the chaotic behaviour in POL converter. The control strategy can be extended for other classes of DC – DC converters to maintain the stability under the conditions of parametric changes.

APPENDIX-I

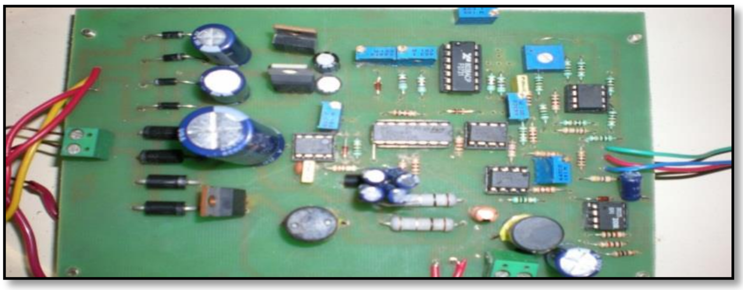


Figure A.1 Experimental Setup.

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