Self-oscillating Auxiliary Medium Open Loop Power Supply Deploying Boost EIE Converter

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Abstract: - A new proposal of switched power oscillator with reduced conduction losses, zero voltage and zero current turning on, and zero voltage turning off, is presented in this paper. The proposed topology consists on a Boost EIE converter operating in continuous conduction mode (CCM) associated to a self-oscillating LC series resonant circuit. This new self-oscillating power oscillator can be applied as an inverter stage of electronic Ballast for fluorescent lamps as well as medium open loop power supply. Circuit description, simplified design guide line and experimental results of a 15.7 W self-oscillating auxiliary medium open loop power supply implemented in laboratory are presented.

Key-Words: - Self-Oscillating Auxiliary Power Supply, Power Oscillator.

1 Introduction

Unless someone contradicts, it can be sad that there are only two basic topologies of switched CC-CC converters, the Buck converter and the Boost converter. Combining these two basic topologies, the converters known as Buck-Boost, Cuk, Sepic and Zeta were developed. The Full-Bridge and the isolated converters such as Forward and Push-Pull are results of Buck converter [1].

Focus on the development of new topologies, a new active cell using two switches called EIE (Fig. 1) has been developed and a new family of PWM CC-CC converters has been created [2].

Among those converters, one can outline the Boost EIE converter which is shown in Fig. 2. This topology presents some disadvantages such as highly complex control circuits and it can not be applied to supply loads with ground floating incompatibility. Thus the topology shown in Fig. 3 has been rearranged in order to be improved and it is shown in Fig. 3.

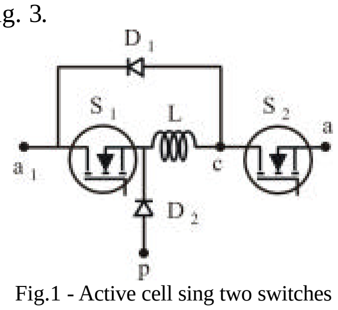

Fig.1 - Active cell sing two switches

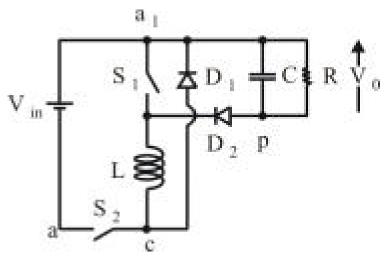

Fig.2 - Boost EIE converter

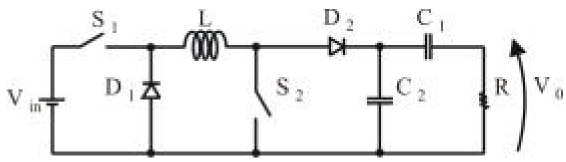

Fig.3 - Rearranged Boost EIE converter

The converter shown in Fig. 3 is the modified Boost EIE converter, although in the literature it has been presented as a power factor correction stage called Buck plus Boost converter [3]. Therefore, when the switches S_1 and S_2 are open and the diodes D_1 and D_2 are forward biased, we have the classic Buck EI. In order to operate as a Boost converter, the classic Boost IE can be noticed when the switches S_1 and S_2 are closed, hence the diodes D_1 and D_2 reverse biased.

The rearranged Boost EIE converter must be shown in order to give a brief outline of the main target of this paper that is to present the self-oscillating Boost EIE converter. This converter is the result of combining the rearranged Boost EIE converter shown in Fig. 3 with a LC series resonant circuit and has a wide variety of applications such as inverter stage of electronic ballast for fluorescent lamps [4] and self-oscillating medium open loop power supply [5].

In this context, it is widely well known that many of the larger power converters require a small amount of auxiliary power supply for the supply of the control circuit and drive circuits. Often the auxiliary requirements are derived from 50/60 Hz line transformers increasing the cost, weight and size of the converters. Therefore, on solution is to use low-power, high frequency converter to supply the auxiliary needs.

Thus, focus on the necessity of developing a low-cost converter to provide the auxiliary power, this work proposes a low cost switched power oscillator using self-oscillating techniques, which can be understood as being formed by two stages. The first one stage is a self-oscillating LC series resonant circuit, the second is a soft-commutated Boost EIE converter. The rearranged Boost EIE converter, operating in continuous conduction mode, works like a current source providing the necessary energy to keep the oscillation and supply the load.

The chief advantage of this converter over existing topologies, once that it also presents soft switching, lies in the structure where the oscillation current is diverted from the switches in order to reduce the conduction losses. Moreover, there is no need of auxiliary start device and the proposed topology is self-protected against short-circuit at the load, which guarantees low cost.

2 Power Oscillator Topology

The proposed power oscillator topology shown in Fig. 4 is composed of two switches M_1 and M_2 which are responsible for charging the boost inductor L_b. Two ultra fast diodes D_1 and D_2 when forward biased, provide the energy transference to the load and to the capacitor C_{OS}.

Suitable auxiliary commutation capacitors C_{R1}, C_{R2} are used in parallel to the switches M_1 and M_2 respectively, in order to provide zero voltage and zero current turning on of the switches M_1 and M_2. Hence, the oscillation charge of the capacitors C_{R1} and C_{R2} provides a zero voltage turning off of the.

The gate-to-source voltage of the switches M_1 and M_2 are obtained by using two isolated windings (L_{S1} and L_{S2}) magnetic coupled to the inductor L_{OS}. The L_{S1} and L_{S2} inductance values are selected in order to deliver enough current to turn on a Mosfet gate on relatively rapidly. The capacitor C_f is a single DC filter providing just the high-frequency AC signal to the load R.

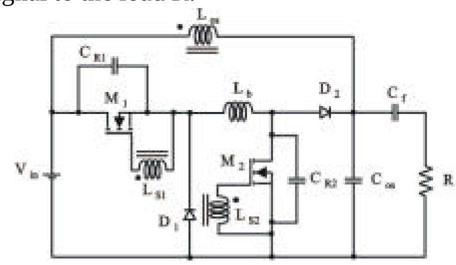

Fig.4 - Power Oscillator topology

3 Principle of Operation

To establish the principle of operation, the following assumptions must be taken into account:

1) The switches M_1 e M_2 operates with a fixed switching frequency and with duty cycle equal to 0,5;

2) The source is considered a single DC source and ripple free.

Based on the above assumptions and considering a single switching period, the proposed circuit can be illustrated by four topological stages in on switching cycle as shown in Figs. 5-9.

First stage - energy storage by the inductor L_b: At initial instant, the inductor current i_{Lb} and the drain-to-source voltage of the switches M_1 and M_2 are equal to zero. When the $L_{OS}C_{OS}$ oscillation begins with frequency f_0, a gate-to-source voltage for M_1 and M_2 is applied simultaneously. Therefore, the switches M_1 and M_2 are zero voltage and zero current turned on and the Boost current i_{Lb} linearly increases by the voltage V_{in} providing the energy transference the from source to the Boost inductor L_b. Figure 5 shows the equivalent circuit.

Second stage - zero voltage turning off of switches M_1 and M_2:

There is a negative derivative of the oscillation current i_{Los}. Therefore, switches M_1 and M_2 are turned off because there is no gate-to-source voltage applied. Hence, the Boost current i_{Lb} is diverted from switches M_1 and M_2 to auxiliary capacitors C_{R1} and C_{R2}, which are charged up with V_{in} and V_{Cos} respectively. Figure 6 shows the equivalent circuit.

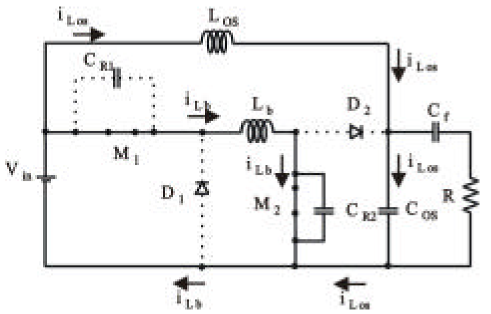

Fig.5 - Operation Stage 1.

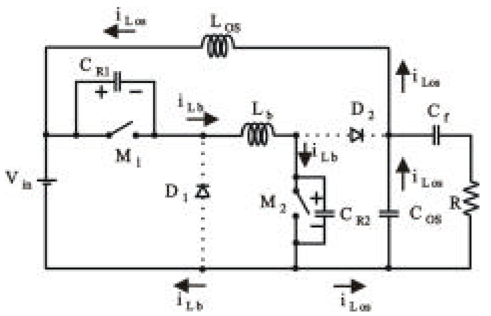

Fig.6 - Operation Stage 2.

Third stage - energy transference:

The third stage begins while the switches M_1 and M_2 are still opened and the diodes D_1 and D_2 are forward biased. Thus, Boost current i_{Lb} starts linearly decreasing and the capacitor C_{OS} and the load R receives the energy that is delivered by Boost inductor L_b through the freewheel diodes D_1 and D2. Therefore, the power which has been stored by the Boost inductor L_b in the first stage is delivered to the load R and to the capacitor C_{OS}.. This stage can be viewed in Fig. 7.

Fourth stage - zero voltage and zero current turning on of switches M_1 and M_2:

This stage begins when Boost current i_{Lb} reaches zero. During this stage, an oscillation among capacitors C_{R1}, C_{R2}, and Boost inductor L_b through V_{in} occurs. Therefore, the capacitors C_{R1} and C_{R2} are completely discharged. Some remainder energy that might be stored in the Boost inductor L_b is discharged through the body diodes D_{S1} and D_{S2}. The end of this stage is reached when the drain-to-source voltage of switches M_1 and M_2 become zero and they are zero voltage and zero current turned on, providing the beginning of a new switching cycle. The discharge of capacitors C_{R1} and C_{R2} through Boost inductor L_b and the DC source V_{in}, provides an oscillation allowing a zero voltage and zero current turning on of the switches M_1 and M_2. The Fig. 9 shows the equivalent circuit.

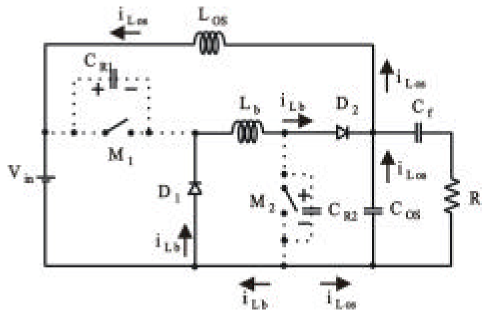

Fig.7 – Operation Stage 3.

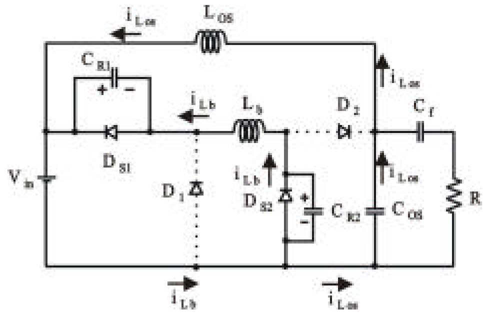

Fig. 8 – Operation Stage 4.

The theoretical Boost current i_{Lb} waveform can be viewed in Fig. 9 providing a better understanding of the topological operation stages.

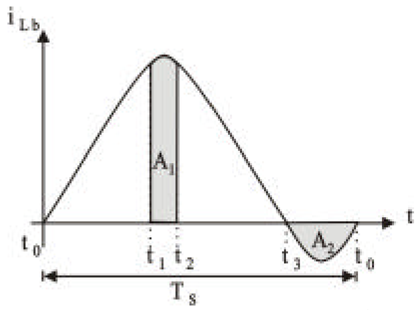

Fig. 10 - Theoretical Boost current waveform.

Figure 10, where T_S is the switching period, can be understood as it follows:

$[t_0,t_1]$- Linear increasing of Boost current i_{Lb} through switches M_1 and M_2;
$[t_1,t_2]$- Meanwhile the first oscillation among capacitors C_{R1}, C_{R2} and Boost inductor L_b occurs, the switches M_1 and M_2 are turned off;
$[t_2,t_3]$- Linear decreasing of Boost current i_{Lb} through freewheel diodes D_1 and D_2;
$[t_3,t_0]$- Before switches M_1 and M_2 being turned on, the second oscillation among capacitors C_{R1}, C_{R2} and Boost inductor L_b occurs.

4 Simplified Design Guide Line

The following theoretical analysis could be understood as an approximated design guideline of the proposed converter. During the simplified mathematical analysis of this new switched power oscillator, an input power equal to the output power has been considered. Thus, the output power is going to be mathematically described based on the input current value and also. A symmetrical oscillation current through the inductor L_{OS} must be considered, which guarantees duty cycle equal to 0,5. Therefore we have Eqs. 1 and 2.

$$P_{in} = P_{out} \tag{1}$$

$$P_{in} = V_{in} \times I_{in} \tag{2}$$

As it has been described, the Boost inductor L_b is responsible for energy storage. Note that the oscillation among capacitors C_{R1}, C_{R2} and Boost inductor L_b can be neglected in this simplified analysis since it just provides the soft-commutation of the switches M_1 and M_2 and there is no significant influence on the power processing. That being so, as Boost inductor L_b is the only one that is responsible for energy transference, it is possible to select the output power by the average Boost current i_{Lb}. Then

$$I_{Lb(avg)} = \frac{1}{T_S} \times \left(\frac{I_P \times T_S}{2} \right) \tag{3}$$

where T_S is the switching period and I_P is the peak value of the current trough Boost inductor L_b.

Note that the average oscillation current i_{Los} must be considered. Thus, it is possible to consider the average input current equal to half the average Boost current i_{Lb} because it just delivers energy during a half period of current conduction. Then

$$I_{in} = \frac{1}{T_S} \times \left(\frac{I_P \times T_S}{2} \right) - I_{Los(avg)} \tag{4}$$

Considering a suitable choice of capacitor C_{OS}, inductor L_{OS} and the load, the switching period (T_S) can be set as it follows,

$$T_S = 2 \times p \times \sqrt{L_{os} \times C_{os}} \tag{5}$$

The Boost current peak value (I_P) is

$$I_P = \frac{V_{in} \times T_S}{L_b \times 2} \tag{6}$$

where

$$V_{in} = L_b \times \frac{\Delta i}{\Delta t} \tag{7}$$

$$\Delta t = \frac{T_S}{2}; \Delta i = I_P \tag{8}$$

Thus, from Eqs. [4] and [6] the output power can be set as it follows:

$$P_{out} = V_{in} \times \left[\left\{ \left(\frac{V_{in}}{L_b \times 2} \right) \times \frac{T_S}{4} \right\} - I_{Los(avg)} \right] \tag{9}$$

$$P_{out} = V_{in} \times \left[\left(\frac{V_{in} \times T_S}{L_b \times 8} \right) - I_{Los(avg)} \right] \tag{10}$$

Since the Boost inductor L_b processes all the energy that is delivered to the load, it means that the best way to select the output power is by changing the Boost inductor value. It can also be done by changing the oscillation frequency or switching frequency, however, it is not advisable.

5 Self-oscillating Auxiliary Medium Open Loop Power Supply

The circuit shown in Fig. 11 illustrates the proposed converter applied as a self-oscillating auxiliary medium open loop power supply with four outputs set as shown in table 1. Experimental results of a 15.7 W laboratory prototype are shown in Figs. 12, 13, 14, and 15 which illustrates the operation conditions of the switches M_1 and M_2, the transformer voltages and the output voltages respectively.

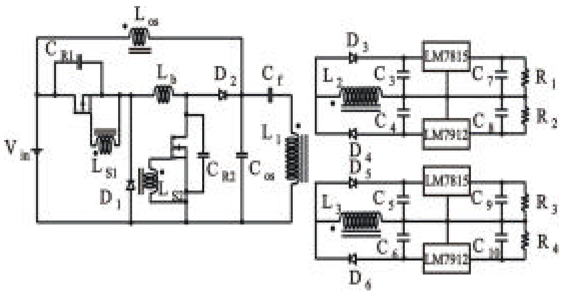

Fig. 11 - Proposed Self-oscillating Auxiliary Medium Open Loop Power Supply

Table 1
Parameters set

Data Specifications	
Input voltage, V_{in}	127 V
Output power, P_{out}	15.7 W
Switching frequency, f_0	40.0 kHz
Output voltage, V_1	+15.0 V
Output voltage, V_2	-12.0 V
Self-oscillating Auxiliary Power Supply	
Boost inductor, L_b	580 uH
Oscillation inductor, L_{OS}	440 uH
Oscillation capacitor, C_{OS}	56 nF
Capacitor, C_{R1}	9.4 nF
Capacitor, C_{R2}	2.2 nF
Capacitors, C_3-C_{10}	47 uF
Series capacitor, C_f	1 uF
Switches, M_1 and M_2	IRF740
Resistive load, R_0-R_4	47O
Diodes, D_1 and D_2	UF4007

The output voltages V_1 and V_2 are not perfectly symmetrical because the current source (rearranged Boost EIE converter) just delivers power to the capacitor C_{OS} during the positive half-cycle of its voltage, so that the positive peak value of the primary winding voltage is higher than the negative peak value, as it can be seen in Figs. 14.

Since this power supply does not use a 60 Hz transformer and there is not any chip, it has been demonstrated itself as a low cost self-oscillating auxiliary power supply with reduced weight and size, which means it is perfectly able for being coupled to other converters in order to supply the auxiliary needs.

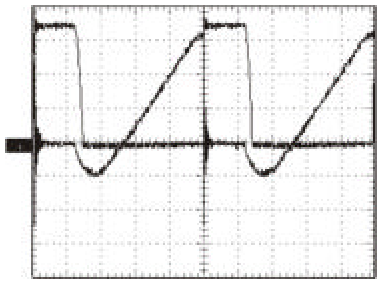

Fig. 12 - Switch M_1 - Experimental result (50V/div, (1A/div) - Time:5us/div

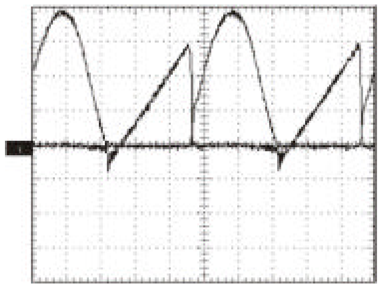

Fig. 13 - Switch M_2 - Experimental result (100V/div, (1A/div) - Time:5us/div

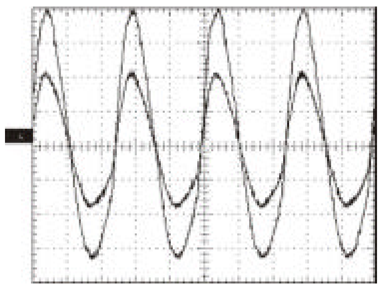

Fig. 14 - Primary and secondary windings voltages of the transformer - Experimental - (50V/div), (10V/div) -Time: 5us/div result

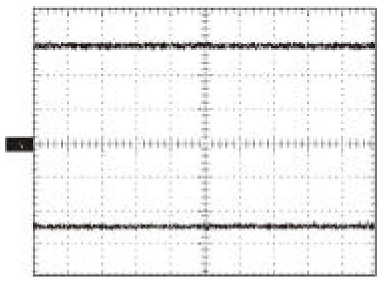

Fig. 15 - Output voltages V_1 and V_2 – Experim ental Result (5V/div)

2.1.1 Gate Drive Circuit

The switching frequency f_0 is defined by the L_{OS} and C_{OS} parameters. The inductors L_{S1} and L_{S2} are magnetic coupled to the oscillation inductor L_{OS} and therefore, when the oscillation starts, there is positive derivative of the oscillation current providing a gate-source signal applied to switches M_1 and M_2, as depicted in Fig. 16.

It must be emphasized that there is no problem in obtaining a low rising time because when the gate-to-source voltage are applied to the switches M_1 and M_2, the body diodes are forward biased providing a zero voltage switching.

The inductor L_{S3} is magnetic coupled to the oscillation inductor, however, its polarity is inverted in relation to the inductors L_{S1} and L_{S2}. Therefore, during the negative derivative of the oscillation current, there is a voltage signal applied to the base of the transistor Q_1, hence, the transistor Q_1 saturates providing a path for the discharge of the gate-to-source capacitance. The experimental results illustrating the gate-to-source signal is portrayed in Fig. 17.

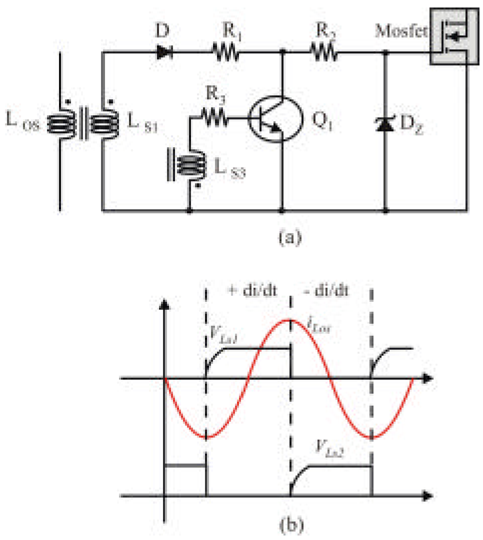

Fig. 16 – (a) Gate-drive circuit (b) Theoretical gate-to-source signal and oscillation current waveforms.

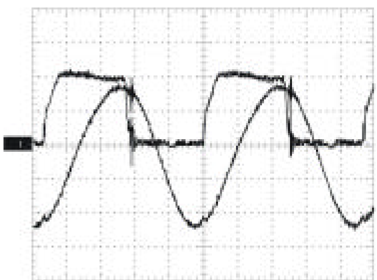

Fig. 17 - Gate-to-source signal and oscillation current – Experimental Result (10V/div,1A/div) – Time: 5us.

4 Conclusion

This paper presented a new soft-switched power oscillator operating in continuous conduction mode called Self-oscillating Boost EIE converter. From the simplified analysis, it was possible to describe the principle of operation with special emphasis on self-oscillation techniques and reduced conduction losses.

A soft-commutation could be achieved using suitable auxiliary capacitors in parallel to the active switches. More over, there is no need of auxiliary start device and the proposed topology is self-protected against short-circuit on the load, which guarantee low cost. On the other hand, a simplified protection device against load voltage increasing is needed.

A simplified mathematical analysis, which can be understood as a simplified design guide line, has been presented. Simulation and experimental results from a 15.7 W laboratory prototype of a self-oscillating auxiliary medium open loop power supply switching at 40 kHz has been shown. This converter has shown great results with reduced cost, weight, and size which means it is perfectly able for being coupled to other converters in order to supply the auxiliary needs.

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