A new lossless passive snubber with simple structure for pulse width modulation DC-DC converters

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***Abstract*— A new lossless passive snubber for pulse width modulation converters is introduced in this paper. This snubber is established zero current switching condition for main switch in the converters for turning on distance. This snubber does not impose any additional current stress on the switch. The snubber can be applied to all single-switch DC-DC converters. A boost converter with the proposed snubber is analyzed and to verify theoretical analysis a 200 W sample is implemented and tested, also the experimental results are presented. In order to investigate the effect of snubber circuit in the converter in terms of efficiency, the boost converter with the proposed snubber has been compared in terms of efficiency with the conventional boost converter and the results show that the efficiency has increases by about 7% despite the snubber.**

Keywords*— *DC-DC converters, lossless snubber, passive snubber, efficiency.

I. INTRODUCTION

DC-DC converters are wide used in industry because of high efficiency and simple structure [1-6]. Hard switching converters has low efficiency and it is necessary to increase efficiency with soft switching techniques. These techniques eliminate voltage and current jumps and reduce their overlap, thus reduces switching losses. One way to reduce losses on the switches in DC-DC converter is used of snubber circuits. One type of snubber is losses snubbers [7], which by elements such as R, L and C, the energy due to sudden jump on the voltage or current of the switch is lost in a resistor. These snubbers, as is clear from their behavior, waste energy, which does not increase the efficiency of the converters. These circuits only solve the problem of sudden change in voltage and current so as not to damage the switch, but waste energy, which may also reduce efficiency. Therefore, in recent years, lossless snubbers have become particularly important [8-11]. These types of snubbers are divided to active [12] and passive [13] snubbers. In the active type, the circuit also includes an auxiliary switch that is activated at certain times to provide soft switching conditions [14]. Due to the addition of a switch and the timing of its activation, these circuits are complex and difficult to control [15]. In the passive type, the auxiliary switch is not added to the circuit and only with the inductor and capacitor or coupled inductors soft switching condition is created [16]. Since there are no additional switches in these converters, the control of these converters is no different from the base converter and does not require a new control circuit [17].

In [18] a new active snubber is proposed. With this snubber zero voltage switching (ZVS) condition is achieved for turn on and turn off on the switch, but the active snubber circuit is complicate and the auxiliary switch has a very special tuning that makes the control circuit very complex. [19] Proposes a family of zero voltage transition (ZVT) converter with active snubber. The structure of this auxiliary circuit is simple, but control of the converter is complicated. These conditions are also present for the converter introduced in [20], which is an interleaved converter with active snubber introduced. The converter has a simple snubber but the snubber control circuit is very complex. Also, the snubber introduced in [20] is only for the same converter and is not used for other converters. A new converter with high voltage gain is introduced in [21]. It uses an auxiliary circuit with two switches to create soft switching condition. Although the control of switches in this converter is simple, but the converter has many elements and is not suitable in terms of structure, volume and cost.

A new passive snubber is presented in [22], which by two capacitors, five diodes and one coupled inductor, soft switching condition is provided. The converter has simple structure and easy to design, but with the addition of this snubber, the voltage and current stress of the switch is greatly increased. Also, the presence of 5 diodes in the snubber circuit, has increased the conduction losses, which reduces the efficiency. In [23] a new snubber is introduced, which is created ZCS condition for switch. The snubber circuit has simple structure and low number of elements, but the snubber circuit imposes current stress on the switch. Also, the introduced snubber is only for boost converters and cannot be used for other converters. [24] proposes a snubber for bidirectional converter, which this snubber has low number of elements, but the snubber is imposed current and voltage stresses on the switch, and only used for bidirectional converter. These conditions also exist for the converter introduced in [25], which have voltage and current stresses on the switch. A new LED drive with simple snubber circuit is introduced in [26], which by only two diodes, one capacitor and one coupled inductor, soft switching condition is provided. Although the

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circuit introduced is simple, it has high voltage and current stress on the switch and also has a low efficiency.

In this paper a new lossless snubber for DC-DC converter is introduced. The proposed snubber has simple structure and does not impose any extra current stress on the switch. Also, voltage stress that impose on the switch is very small. The snubber is created ZCS condition for switch, which decreases losses and increases efficiency. A boost converter with proposed snubber is analyzed and its operation modes presented in section II. Also, the design procedure is presented. To verify theoretical analysis, in section III, the experimental results is presented, and in this section, a comparison between proposed converters with other converters is illustrated. Finally, the conclusion of the paper is presented in section IV.

II. METHODS

A. Circuit description and operation

The boost converter with the proposed snubber is shown in Fig. 1. The circuit is included of a boost converter with the proposed lossless snubber consist of L_1, L_2, D_1, which L_1 and L_2 are coupled. L_1 is element that create ZCS condition, and D_1, L_2, are circuit that transfer L_1 energy to the output. To simplify analysis, all semiconductors are assumed ideal, also input inductor and output capacitor are large enough, which I_{in} and V_O are fixed in one switching cycle.

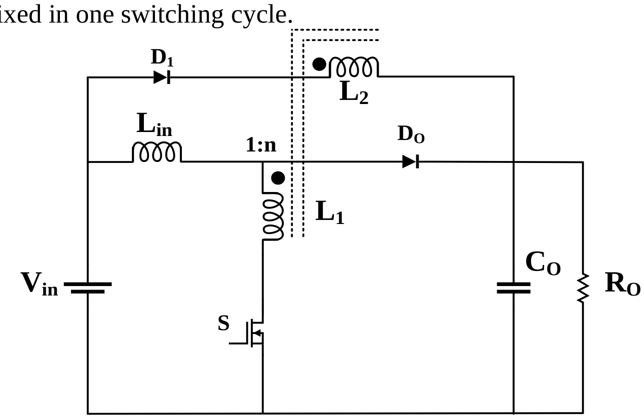

Fig.1. Boost converter with the proposed lossless passive snubber

The converter has four modes at one switching cycle, which described at below completely. The key waveform of the proposed converter is shown in Fig 2.

Mode 1 (t_0-t_1): When the switch is turned on this mode begins. Due to existence of L_1, the current is increased with sloe and ZCS condition is provided. In this mode the current of D_O decreases with same slope, therefore this diode turns off under ZCS condition. The slope of increase current in this paper is shown at below.

$$\alpha_1 = \frac{V_0}{L_1} \tag{1}$$

Where α_1 is slope of current increase. Also, the relationship in this mode is shown at below.

$$I_{L1} = \frac{V_0}{L_1}(t - t_0) \tag{2}$$

At t_1, I_{L1} reach to I_{in}, therefore the duration of this mode is:

$$\Delta_{t1} = (t_1 - t_0) = \frac{L_1 I_{in}}{V_O} \tag{3}$$

Mode 2 (t_1-t_2): This mode begins when reach to Iin, which DO turns off IS and the converter is worked like conventional boost converter when switch on, and L_{in} is charged. In this mode the C_O provides output power.

Mode 3 (t_2-t_3): This mode starts with turning off the switch. Due to the current of main inductor, D_O turns on immediately. Also because of coupling on L_1 and L_2, the current on L_1 cause to L_2 current is flowed and D_1 conducts. Therefore, the energy of L_1 is transferred to the output by this coupling path. This mode continues until the energy of L_1 over. The current of D_1 decreases with slope and slowly, which the slope is shown in below.

$$\alpha_2 = \frac{V_0 - V_{in}}{L_2} \tag{4}$$

Where α2 is current slope decrease of D_1. In the beginning of this mode the current of D_1 is:

$$I_{L2} = \frac{I_{in}}{n} \tag{5}$$

After the beginning of this mode, the current decreases linearly, therefore the equation of the current is as below

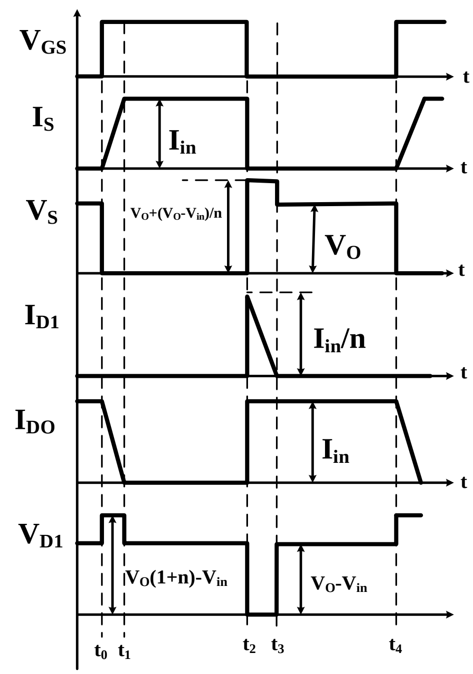

Fig. 2. The key waveform of the proposed converter

$$I_{L2}(t) = I_{L2} - \frac{V_O - V_{in}}{L_2}(t - t_2) \tag{6}$$

At t3, the current reach to zero and diode turns of under ZCS condition, hence duration of this mode is:

$$\Delta_{t3} = (t_3 - t_2) = \frac{I_{L2} L_2}{V_O - V_{in}} \tag{7}$$

Mode 4 (t_3-t_4): When the energy of L_1 is covered, L_2 current reach to zero and D_1 turns off. Due to existence of L_2 in D_1 path, D_1 turns off under ZCS condition. In this mode the lossless snubber is cut off from the converter and the converter works like conventional boost converter when switch is turned off and energy of main inductor transfers to the output. Duration of this mode is:

$$\Delta_{t4} = (1-D)T_S - \Delta_{t3} \quad (8)$$

The equivalent circuits of these modes are shown in Fig 3.

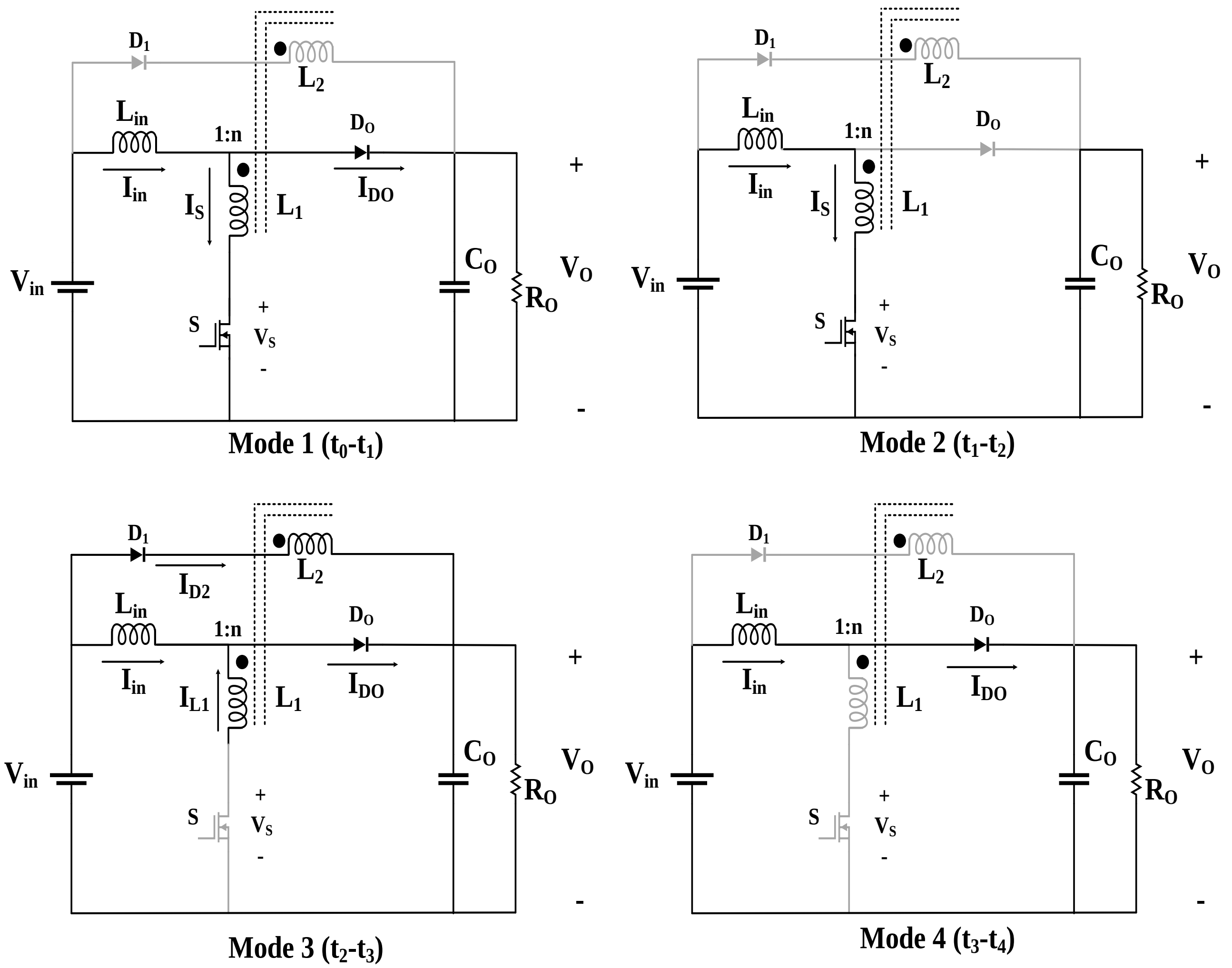

Fig. 3. The equivalent circuits of the proposed converter

B. Design procedure

L_{in} and C_O should be design like a conventional boost converter, also the switch and diodes (D_1, D_O) should be selected according to power of the converter, which defines voltage and current of switch and diodes. Therefore, the proposed snubber elements consist of L_1 and L_2 and related equations should be designed.

When the switch is turned on, ZCS condition is created by L_1. This inductor can be design according to [31] as below.

$$L_1 > L_{min} = \frac{V_S t_r}{I_S} \quad (9)$$

Where t_r is rise time of switch current. To fully reach ZCS condition, L_1 is considered larger than L_{min}, but it is important to note that the existence of L_1 limits it to at least duty cycle. So that the duty cycle must be larger than duration of mode 1, which the converter can be reach the mode 2. Therefore, minimum duty cycle can be obtained from equation below.

$$D_{min} T > \frac{L_1 I_{in}}{V_O} \quad (10)$$

Therefore;

$$L_1 < \frac{D_{min} V_O}{f_{SW} I_{in}} \quad (11)$$

Or

$$D_{min} > \frac{f_{SW} L_1 I_{in}}{V_O} \quad (12)$$

According to modes of the proposed converter, the larger n, the lower voltage stress of switch, but the higher voltage stress of D_1. Therefore, n should be selected with suitable value. Also, the duration of mode 3, depends on the values of L_2 and n, which must be short to discharge the inductor energy before the switch is turned on again.

Therefore, a maximum limit of duty cycle is obtained according to the following.

$$(1 - D_{max})f_{SW} > \frac{I_{L2}L_2}{V_O - V_{in}} \quad (13)$$

Therefore;

$$(1 - D_{max}) > \frac{f_{SW}I_{in}L_2}{n(V_O - V_{in})} \quad (14)$$

Or;

$$D_{max} < 1 - \frac{f_{SW}I_{in}L_2}{n(V_O - V_{in})} \quad (15)$$

The equation above can be given L_2 limitation as below.

$$L_2 < \frac{n(1 - D_{max})(V_O - V_{in})}{f_{sw}I_{in}} \quad (16)$$

According to (12) Fig .4 is drawn, which show relationship between D_{min} and L_1 with several of power in the converter.

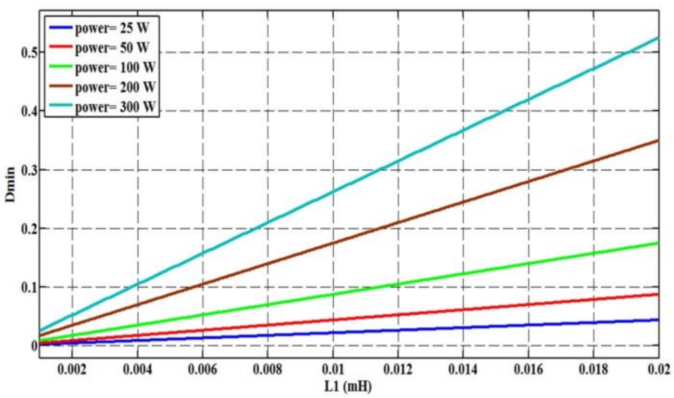

Fig. 4. The relationship between L_1 and D_{min} with various of power.

Fig .5 is based on equation (15). Which show that in low values of L_2, there is a limit of D_{max}.

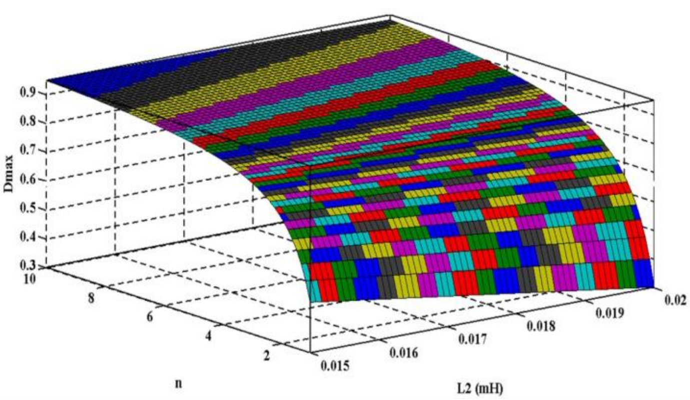

Fig. 5. The relationship between L_2, D_{max} and n.

Using Equation (15), the curves of Fig .6 are plotted. In these curves, the selection limit of D_{max} and L_2 is clearly defined. As can be seen from this figure, in large quantities L_2, D_{max} has become negative, which is not rational. But this shows that if large amounts of inductors are selected, the duration time of the mode 3 in the converter converters is so small that the maximum duty cycle is no longer limited. Therefore, in large values of L_2, limitation of D_{max} is not considered.

III. Results and Discussion

A. Experimental results

To verify theoretical analysis, a prototype of the proposed boost converter with 24 volts input voltage and 48 volts output voltage in 200W power is implemented. Given the relationships and curves of the previous section, L_1 is selected 15 µH and n is selected 3, which makes the value of L_2 equal to 135 µH. IRF640 is selected for switch and MUR1020 is selected for D_O and D_1. The switching frequency to test is 100 kHz. Fig .7 shows the experimental prototype of the proposed converter that implemented. This converter is tested and experimental results are shown in Fig .8. As can be seen from Fig .8 the current of switch is increased with slope, which ZCS condition is achieved. Also, for turns off instant at D_O and D_1, ZCS condition cleared from figure.

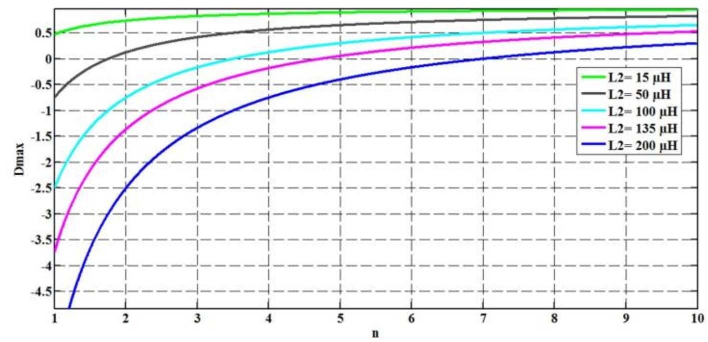

Fig. 6. The relationship between n and D_{max} with various of L_2.

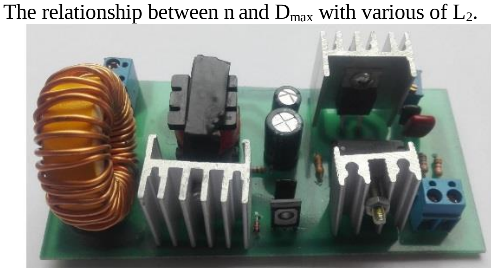
Fig. 7. The prototype of the proposed converter.

B. Comparison

The proposed converter is compared with conventional boost converter according to efficiency and the results are presented as curves in Fig .9. The efficiency has been obtained by simulation in PSPICE software on the proposed converter and the converter with hard switching in different powers. This figure shows that the efficiency increases due to soft switching condition. A comparison is also made between the important parameters between the proposed converter and four newly introduced converters, which the results are given in Table I. The converter in [26] has simple structure, but this converter has high voltage and current stresses on the switch. Also, the converter has low efficiency. [27] Introduces new snubber for non-isolated converter with simple structure, but this snubber, impose extra current stress on the switch. This condition also exists for [28]. In [29], the current stress is almost low, but the voltage stress is high and also the converter is very complex and voluminous. Converter in [30] has low voltage stress and no additional stress is imposed on the switch. But the converter has a complex structure and additional current stress is imposed on the switch.

As it is known, the efficiency of the proposed converter is still lower than converters in [27], [28] and [29]. One of the important reasons for this difference is the difference in the switching frequency, the lower the frequency, the lower the switching losses, thus increasing the efficiency. Also, the snubber placed in this article establishes soft switching conditions only at the turn-on moments, which losses still exist at the turn-off moments.

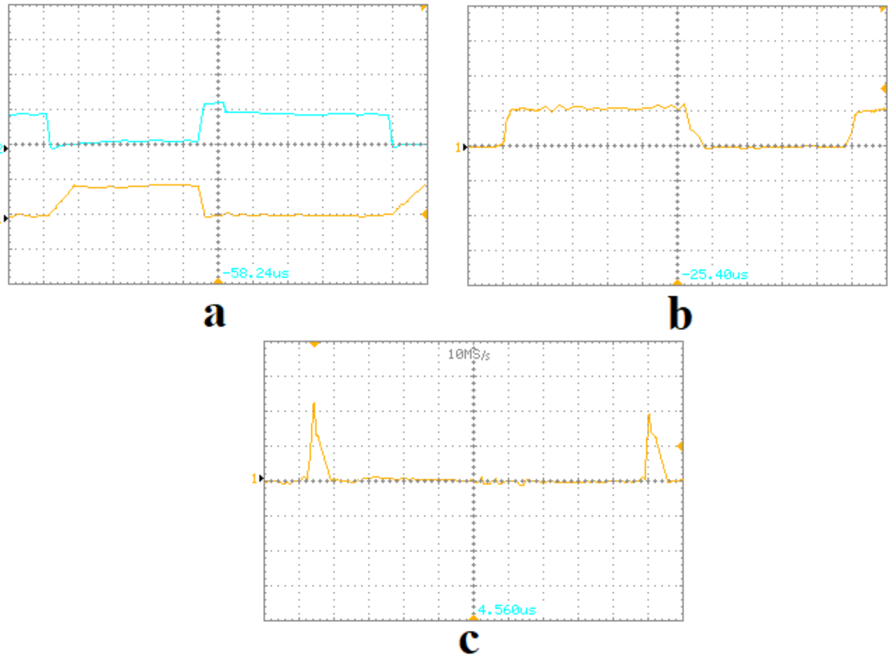

Fig. 8. The experimental results of the proposed converter.

a) Voltage (up) and current (down) of S (vertical scale is 50 volts/div or 10 A/div and horizontal scale is 1 µs/div)

b) The current of D_O (vertical scale is 10 A/div and horizontal scale is 1 µs/div)

c) The current of D_1 (vertical scale is 2 A/div and horizontal scale is 1 µs/div)

Table. I. Comparison with the proposed converter with other converters

converter / parameters	**[26]**	**[27]**	**[28]**	**[29]**	**[30]**	**proposed**
Number of switches	1	1	1	1	3	1
Number of diodes	3	4	4	6	7	2
Current stress on the switch	(n+1) I_{in}	$\frac{V_{in}}{L_{r2}}\left(\frac{\pi\sqrt{L_{r1}C_r}}{2}\right) + \sqrt{\frac{L_{r2}}{L_{r1}}}I_O$	$\left(\frac{2+2n}{1-D} + \frac{(1+n)\pi}{2D}\right)I_O$	$I_{Lr1} + I_{in}$	(n+1) I_{in}	I_{in}
Voltage stress on the switch	$V_{in} + \frac{V_O}{(n-1)}$	$V_{in} + \sqrt{\frac{L_{r2}}{C_r}}I_O$	$\frac{V_O}{2+n+nD}$	$\frac{V_{in}}{(1-D)^2}$	V_O	$V_O + \frac{V_O - V_{in}}{n}$
Soft switching condition	ZCS	ZCS	ZCS	does not have	ZCS	ZCS
Number of coupled inductors	1	0	1	2	2	1
efficiency	91%	96%	96.5%	96%	94.2%	94%
topology	BUCK	BUCK	BOOST	BOOST	BOOST	BOOST
Input voltage	12 V	48 V	20 V	24 V	48 V	24 V

Output voltage	10 V	24 V	200 V	310 V	400 V	48 V
Switching frequency	200 kHz	50 kHz	50 kHz	50 kHz	100 kHz	100 kHz

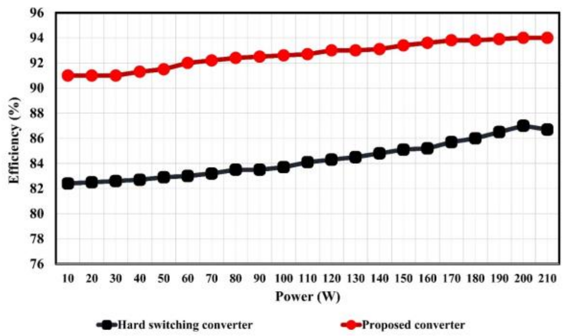

Fig. 9. Comparison between the proposed converters with conventional converter according to efficiency.

C. Other converters with the proposed snubber

As mentioned earlier, the proposed snubber can work on other single-switch converters and it provides soft switching condition. The different topologies with the proposed snubber are shown in Fig .10 and 11. In these figures, it is clear that the proposed snubber can be applied to all isolated and non-isolated single-switch converters. The modes and analysis of all converters in this figure is similar to the boost converter with the proposed snubber described in Section 2. It is noted that the proposed snubber can be applied on all single switch converters. Therefore, any proposed single-switch converter can use this snubber.

It is true that the introduced snubber is simple and can be used on all converters, but the introduced snubber does not provide soft switching for turning off moments, also this snubber is designed with coupled inductors, which makes the design a bit complicated.

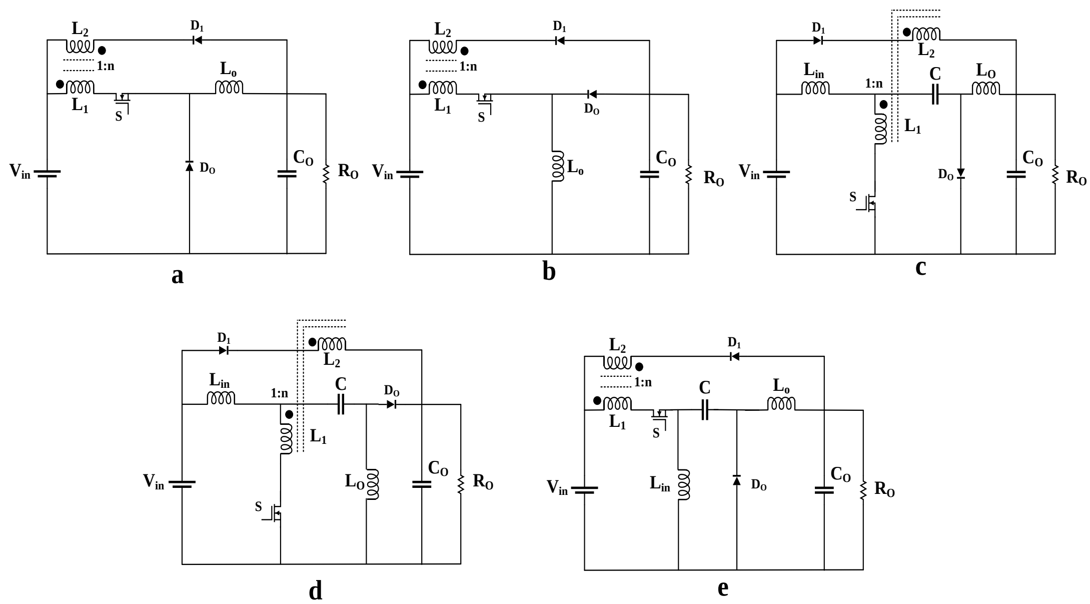

Fig. 10. Different non isolated topologies with the proposed snubber: a buck, b buck-boost, c CUK, d SEPIC, e ZETA

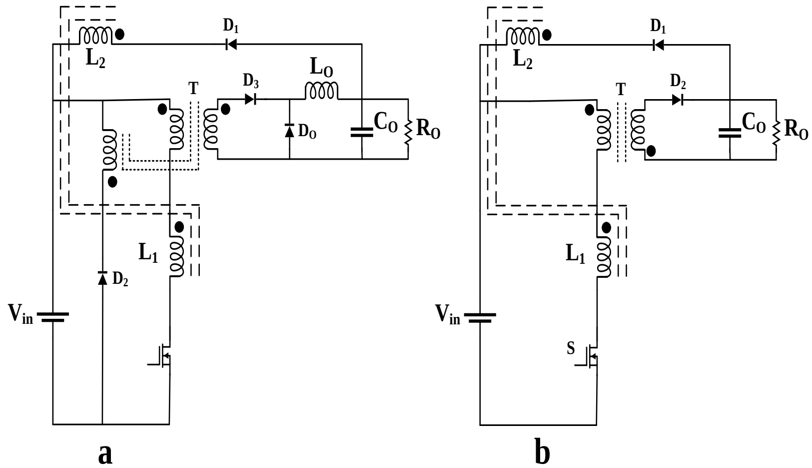

Fig. 11. Different isolated topologies with the proposed snubber: a forward, b flyback

IV. CONCLUSION

A new lossless snubber with simple structure and easy to design is proposed in this study. The snubber is worked on all single-switch DC-DC converters and created ZCS condition for switch in turning on distance. The proposed snubber does not impose any extra current stress on the switch. This snubber, impose voltage stress on the switch, but this stress is low with comparison by other references. Since this snubber has only one coupled inductor and a diode, it has a very simple design and can be easily used on converters. To verify the theoretical analysis, a sample of the boost converter with the proposed snubber is implemented and the results are show that the snubber is created ZCS condition on switch.

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