A Comparative Study of High Efficiency DC/DC Boost Converters for Medium Power Applications

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Abstract – Switching Converters commonly known as DC/DC Converters have gained tremendous popularity due to their use in variety of applications such as hybrid energy systems, hybrid vehicles, satellite applications and portable electronic devices to name a few. The main positives of using high step up converters include improving voltage gain, reduction of voltage stress and current ripple. But these converters seem to have some disadvantages like very high EMI due to reverse recovery of the boost diode and considerable amount of losses which occur due to hard switching of the boost switch. Many variations of the original boost circuit schematic have been suggested to overcome these problems. The Zero Voltage Transition (ZVT) Boost converter and Zero Current Transition (ZCT) Boost converter are such solutions. These soft switching topologies employ an auxiliary resonant circuit which affects the working only when the boost switch is turning on or off. Employing the auxi1iary circuit allows the boost switch to turn on and off under zero voltage and zero current conditions respectively thus reducing the switching losses. The aim of this review is focused on high step-up voltage and high efficiency DC/DC Boost converters with high voltage gain. This paper presents the comparison across number of parameters of the various soft switching Boost topologies.

Index Terms – DC-DC converter, High Step-up, High Efficiency, Soft Switching, Zero Voltage Switching (ZVS), Zero Current Switching (ZCS).

1. INTRODUCTION

Switching converters commonly known as the DC/DC Converters are widely used circuits in many industrial applications They convert a fixed-voltage dc source into a variable-voltage dc source. DC/DC Converters are usually used to obtain an output voltage which is: i) higher in magnitude (Boost) than the input voltage or ii) lower in magnitude (Buck) than the input voltage or iii) Both higher and lower (Buck Boost) than the input voltage. This survey is related only with the PWM Boost Convertors.

When Boost converters, are being operated at high frequencies, these converters suffer from significant reverse recovery related losses which become more prominent when the converter is switched under hard switching conditions. As a consequence, the Boost Converters need to be operated at low switching frequencies in order to achieve higher conversion efficiencies. Thus by introducing the concept of soft switching, will significantly enhance the switching frequency and therefore the power density of the Boost Converters.

Till date, a significant number of soft switched boost converters have been proposed [1] – [20]. In order to control the turn-off di/dt rate of the rectifier, Soft switching converters employ various additional components such as inductor and capacitor thus forming a snubber circuit. By implementing various soft switching techniques, the switch will make a transition from its on-state to its off state and from its off state to its on state at the instant when the switch voltage or the switch current is zero.

This will prevent the occurrence of the switching losses. Soft Switching techniques are mainly categorized as: i) Zero Voltage Switching (ZVS) and ii) Zero Current Switching (ZCS). During switching period when either voltage or current is zero, then the product of voltage and current becomes zero which in turn means that there is ideally no power loss in the device. Thus Soft Switching results in enhanced system efficiency.

In [7], a new class of resonant converters commonly known as Quasi resonant convertors (QRC) were introduced. These resonant converters provided Zero Voltage Switching (ZVS) for active switch and zero current switching for rectifier diode. However, in QRC switches have to withstand high voltage stress and high current stress. This was one of the primary drawbacks of these resonant converter topologies.

In [8], [9], [17], [18] a new class of Boost converters referred to as Novel ZVT-ZCT-PWM Boost converters were introduced with a new kind of an active snubber cell. This approach is fairly effective in reducing the switching losses as it mainly focusses to modify the control technique used in the earlier ZCT-PWM converters [1]. In novel ZVT-ZCT Boost converter [18], ZVT turn on and ZCT turn off of the main switch is ensured. The main devices are subjected to minimal voltage as well as minimal current stresses.

In addition, the stresses on the auxiliary devices are very low in the proposed new converter. This novel ZVT-ZCT structure has an advantage of providing desirable results at light load conditions as well as at very high frequencies. The simplicity of the structure as well as minimum cost of the overall structure are the additional benefits of this soft switching topology. Thus this soft switching topology was extensively used for various high efficiency applications due to its numerous benefits.

2. OPERATIONAL DESCRIPTION OF BOOST CONVERTER TOPOLOGIES

A. CASE A

One of the first soft switching topologies, was the ZCT-PWM [1], the schematic of which is shown in figure (1). In addition to the components used in the normal Boost topology, the circuit consists of an auxiliary circuit composed of a semiconductor switch (S2) referred to as the auxiliary switch, a capacitor (Cr), auxiliary diode (Daux) and an inductor (Lr). The operation of the proposed converter shown in figure (1) proceeds as follows: When the main switch (S1) is in the “ON” state, the converter operates as traditional PWM boost converter as all the input current flows through the main switch. Turning “ON” the auxiliary switch (S2), just before the main switch (S1) is turned “OFF”, ensures that the current which earlier was flowing through the main switch (S1), now flows through the auxiliary circuit thereby providing the ZCS turn “OFF”, of the main switch (S1). The auxiliary switch (S2) turns off shortly afterwards and the current will be directed to the output through the auxiliary diode (Daux).

The capacitor (Cr) of the auxiliary circuit discharges through the body diode of the auxiliary switch (S2). The next switching cycle begins when the main switch (S1) is turned “ON” and the next switching cycle begins. Due to the main switch turn “ON”, there is a resonant interaction between the resonant inductor (Lr) and the resonant capacitor (Cr). The efficiency of this converter topology is around 97% but the major drawback of this topology is that the auxiliary switch (S2) has hard turn-off which results in significant switching losses and which to a certain extent offset the minimizing of turn-off losses in the main switch. Although this topology provided a significant improvement in the efficiency of the boost converter topologies by utilizing the concept of soft switching there was a scope to further enhance the efficiency by providing the soft switching of both the main as well as the auxiliary switch.

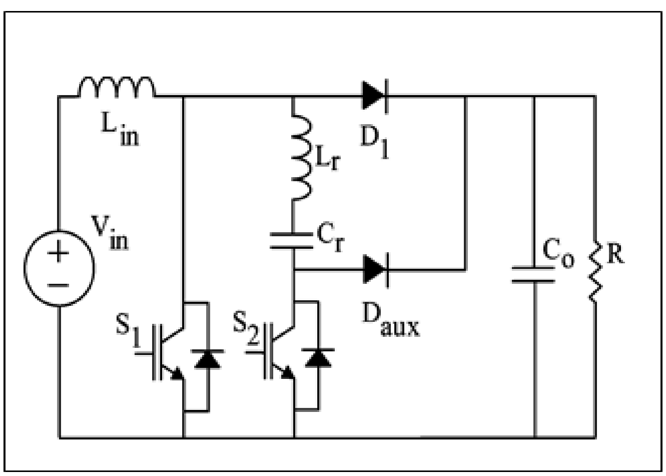

Fig. 1. Converter with hard switching auxiliary circuit [1]

A. CASE B

In fig (2), is shown another schematic of soft switching boost converter circuit that ensures the main switch (S1) is turned “off” under zero current conditions thus achieving Zero Current Switching (ZCS), and also it is helps in reducing: i) the conduction losses and ii) the current stress in the boost converters. This topology **[13]** consists of an auxiliary circuit composed of a single switch (S2), a diode (Da), resonant inductor (Lr) and a resonant capacitor (Cr). One switching cycle of the proposed soft switching boost converter is completed in eight operational modes. When the switch “S1” is turned “ON”, the current which flows through the resonant inductor(Lr) and the main diode (Df) linearly reduces to zero, thus the main diode (Df) is turned “off” softly. When the diode (Df) is turned “off”, the auxiliary switch (S2) turns “on” at the same time under ZCS condition and as such the voltage of the resonant capacitor reverses its polarity after half of the resonating period due to the resonance between the resonant inductor(Lr) and the resonant capacitor (Cr). Thus the auxiliary diode (Da) conducts and as such the current flows through the resonant inductor in the opposite direction.

The value of the main switch current is reduced to zero due to the negative inductor current, as a result the body diode (anti parallel diode) of the main switch “S1”, starts to conduct. The voltage is charged to the value of output voltage across the resonant capacitor and as such the main diode (Df) turns “ON” under Zero Voltage Switching (ZVS) condition. However, the main switch “S1” and auxiliary switch “S2” are both turned “off” at the same time under Zero Current Switching(ZCS) conditions. This ensures simplicity in the control design. The switching cycle repeats after the main diode (Df) turns “ON”.

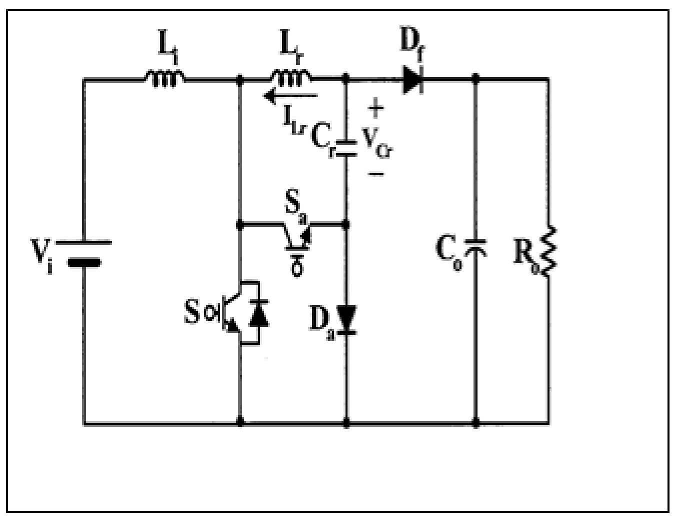

Fig. 2. Schematic of ZCT Boost Converter [13]

In this Soft Switching Boost Converter topology both the switches S1 and S2 are controlled by same PWM signal, this accounts for the ease of control of the proposed soft switching converter., The proposed ZCT Boost converter has an efficiency of about 95.2% at full load. However, efficiency decreases as we go on decreasing the loads due to the fact that in case of the resonant process the circulating energy is constant and not dependent on load.

B. CASE C

In fig (3) is shown the schematic of the ZCT-PWM boost converter with output resonance as proposed in [2]. This boost topology was one among the various topologies wherein the peak current of the main switch does not increase due to the introduction of the auxiliary circuit in the conventional Boost topology. The auxiliary circuit of this ZCT-PWM boost topology is composed of: i) diode (Daux), ii) two inductors (Lr1 and Lr2), iii) a capacitor(Cr), and iv) switch (S2). In order to ensure ZCS turn “ON” of the main switch (S1), the inductor (Lr1) is connected in series with the main switch (S1). This is primarily useful in minimizing the reverse recovery current of the diodes Daux and D1. One switching cycle of the proposed converter has nine operational modes. The working of the circuit is explained as follows: When the switch (S1) turns “ON”, the current through the switch) (S1) and the inductor (Lr1) begins to increase linearly. The output diode is in the “OFF” state and the voltage across the resonant capacitor is clamped to the value of the output voltage. Now turning “ON” of the switch “S2”, causes the resonant capacitor (Cr) to discharge towards zero, turning on diode (Daux). As a result, the resonance starts between inductor (Lr2) and capacitor (Cr). When the voltage across the resonant capacitor (Cr) becomes negative, the current flowing through the main switch (S) is diverted into the auxiliary circuit, turning “OFF” the switch (S1) under zero current conditions, thus achieving Zero Current Switching (ZCS) of the main switch.

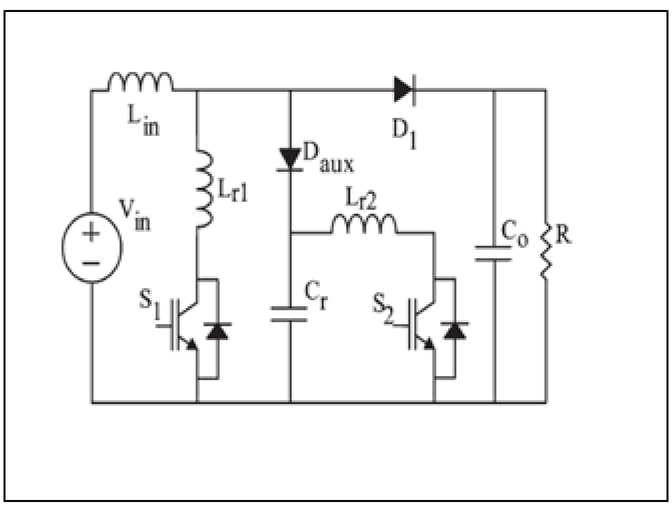

Fig. 3. Schematic of ZCT Boost with parallel auxiliary circuit [2]

Again as a result of the resonance between the inductor (Lr2) and the capacitor (Cr), the current which was earlier flowing through the auxiliary switch (S2) reverses its direction to flow through the body diode i.e. antiparallel diode across S2, thus allowing auxiliary switch (S2) to be softly turned off. Thus the resonant capacitor (Cr) charges to the output voltage and the boost diode (D1 conducts. The major advantage of this topology is that it helps in reducing conduction losses by providing soft turn-on as well as turn-off of the auxiliary switch however the limitation of this topology is that the peak voltage across the boost diode is nearly twice as that of the output voltage. The topology presented has a maximum efficiency of about 97.8%.

C. CASE D

The schematic of soft switching boost converter employing HI-bridge auxiliary resonant circuit [12] is shown in Fig. (4). As can be seen from the schematic, the HI-bridge auxiliary resonant circuit in the proposed soft switching topology employs a resonant inductor (Lr), two resonant capacitors (Cr and Cr2), two diodes (D1 and D2), and an auxiliary switch (S2).The proposed converter with the help of a resonant circuit is able to perform soft switching under zero voltage condition. The proposed converter operation proceeds in the nine modes. When the auxiliary switch (S2) is turned “ON”, the current through the resonant inductor (Lr), begins to increase linearly whereas current through the main inductor (L) decreases. As soon as the resonant inductor current and the current flowing through the main inductor become equal, the main diode is turned “OFF” as a result of which there is resonance between the resonant inductor (Lr) and resonant capacitor (Cr). Due to the effect of resonance, the voltage across the resonant capacitor “Cr” becomes zero, this turns “ON” the anti-parallel diode of the main switch (S1) under zero voltage condition and the auxiliary switch (S2) turns “OFF”.

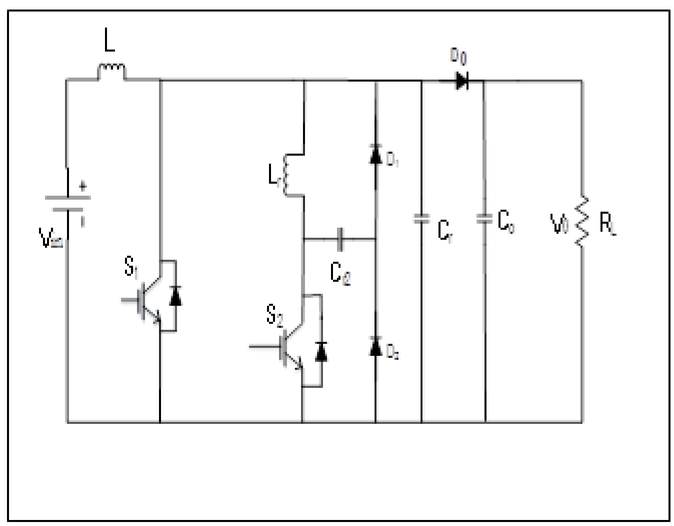

Fig. 4. Schematic of soft switching topology [12]

Thus there is a resonant interaction between the main inductor(L) and the other resonant capacitor (Cr2). Again due to the effect of resonance, the voltage the voltage across the resonant capacitor “Cr2” becomes zero which turns “ON” the body diode i.e. anti parallel of the auxiliary switch “S2” and the main switch “S1” turns “OFF” under zero voltage condition. It must be noted that the resonant capacitor “Cr” has been charged to output voltage by the sum of the currents flowing through the inductor during the two resonance cycles. The converter discussed above is used in numerous applications such as photovoltaic dc/dc converters, power-factor correction circuits and battery chargers. The efficiency of the proposed converter is about 96% at full load.

D. CASE E

In fig (5) is shown the schematic of a ZVT-PWM boost converter [3] employing a dual auxiliary circuit. The auxiliary circuit in the proposed converter topology has two parallel branches: i) resonant branch consisting of components Lr2, Cr, D4 and ii) non resonant branch consisting of components Lr1, Lr2, D3, D4. One switching cycle of the proposed converter topology is completed in nine operational modes. The auxiliary switch (S2) turn “ON”, causes the current flow to increase through the components Lr1, Lr2 and Cr whereas the current flowing through the boost diode (D1) decreases. The current flowing through the inductor (Lr2) increases until it reaches its maximum value and then eventually decreases, thus the body diode of the main switch (S1) conducts.

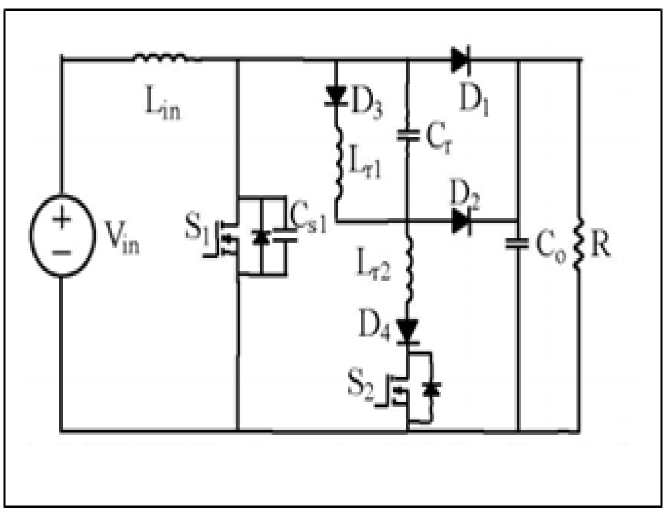

Fig. 5. Schematic of ZVT-PWM Boost with dual auxiliary circuit [3]

The current flowing through the resonant inductor (Lr2) and the resonant capacitor (Cr) decrease due to the resonance in the resonant branch (Cr, Lr2, D4) and as such the switch (S1) can be turned “ON” with ZVS. The resonance continues and the currents flowing through Lr2 and Cr continue to decrease till the ZCs of the auxiliary switch (S2) is achieved. The diode (D3) does not allow the current to reverse the direction. Now the main switch (S1) turns off with ZCS and the diode (D2) begins to conduct, this forces the voltage to drop across the resonant capacitor (Cr) and the voltage across the main switch capacitor (Cs1) rises. This continues till the voltage across the main switch capacitor (Cs1) rises to the value of the output voltage and the voltage across the resonant capacitor rises to zero. At this point, the input current starts flowing through the boost diode (D1) and this completes one switching cycle of the converter. The efficiency of the converter was found to be about around 95.7.7%.

E. CASE F

Fig (6) shows the schematic of a novel ZCS-PWM Boost converter **[4].**This novel topology has an auxiliary circuit composed of a single switch (S2), two diodes (Daux1 and Daux2),a capacitor (Cr) and an inductor (Lr).In order to allow the switch (S1) to be turned “ON” with Zero Current Switching (ZCS), the inductor (Lr) is placed between the boost diode (D1) and the output capacitor (Co). The working is explained as follows:

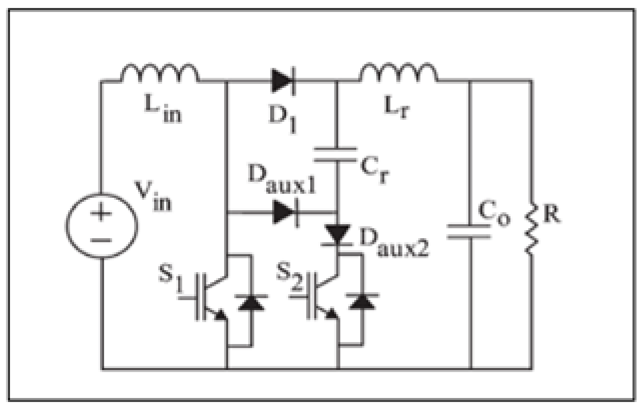

Fig. 6. Schematic of a novel ZCS-PWM Boost Converter [4]

The switch (S2) is turned “ON” just before the main switch (S1) is to be turned “OFF”, this initiates the resonant interaction between the inductor (Lr) and the capacitor (Cr).The blocking diode (Daux2) prevents the current flow through (S2) in the negative direction and as such the current that flows through (S1) constitutes the negative portion of the resonant cycle. Now this current drops to zero eventually and flows through the body diode i.e. anti parallel diode connected across the switch (S1) thus allowing it to turn off softly. The resonant capacitor (Cr) discharges fully allowing the input current to flow through the boost diode. The main advantage of this topology is that no energy is trapped in the circuit as direct path exists from the auxiliary circuit to the output thus minimizing the losses. However, the drawback of this topology is that the voltage stress on the boost diode is twice as high as the output voltage. The efficiency of the ZCS-PWM Boost converter is about 97.3%.

F. CASE G

In fig (7),is shown circuit scheme of the Zero Voltage Transition Pulse Width Modulated (ZVT-PWM) Boost Converter [17].As seen the topology of the ZVT-PWM Boost converter consists of an active snubber cell which has the following components: resonant inductor (Lr), resonant capacitor (Cb), two auxiliary diodes (D1 and D2) and an auxiliary switch (T2).The capacitor (Cr) in parallel with the main switch (S1) is not required. The steady state operation of the proposed ZVT-PWM Boost Converter consists of seven stages over one switching cycle. Turning "ON", the auxiliary switch "T2" results in increase in current through the resonant inductor(Lr). At the same time the current which flows through the main diode (Df) decreases and eventually falls to zero. Thus the main diode (Df) is turned "OFF" under zero voltage condition. When the main diode (Df) turns "OFF", the parallel resonance between the inductor(Lr) and the capacitor (Cr) starts. Due to this resonant interaction, the voltage across the resonant capacitor (Cr) becomes zero, thus forcing the anti-parallel diode of the main switch (T1) to turn "ON" under Zero Voltage conditions. The diodes Dr and D1 are turned off under near Zero Current condition. This primarily happens due to the fall in the value of the resonant inductor current to zero. This ensures ZVS turn "OFF" of the main switch (T1). In addition, the auxiliary diode (D2) turns "ON" with ZVS. During this period, the voltage across the resonant capacitor (Cr) reaches the value of the output voltage (Vo) and at the same time, the voltage across the auxiliary resonant capacitor (Cb) falls to zero. Thus the main diode (Df) is turned "ON" with Zero Voltage Switching(ZVS) conditions and the diode (D2) is turned "OFF" under near Zero Voltage condition.

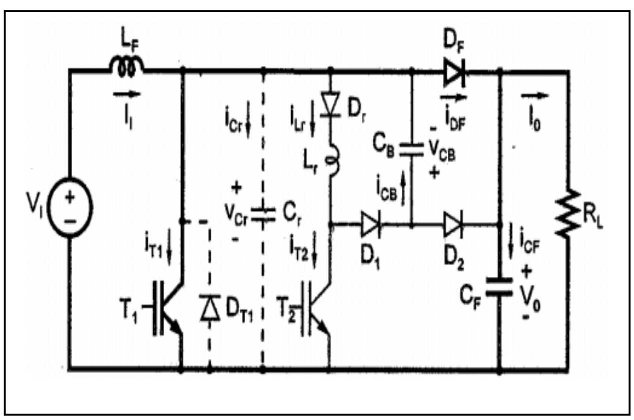

Fig (7). Schematic of a novel ZVT-PWM Boost Converter [17]

In ZVT-PWM Boost converter topology, the main distinguishing features include the simplicity of the structure, high efficiency as well as the ease of control.

It also provides the benefit of both ZVS and ZCS turn off/on of various devices used in the topology. As shown in fig (8), efficiency of the ZVT-PWM Boost converter is higher than that of the conventional hard switching converter. At full output power, the total circuit loss is about 36% of that of the hard switching Boost Converter topology. Also the overall efficiency increases to about 97 % as compared to 91 % in the hard switching case.

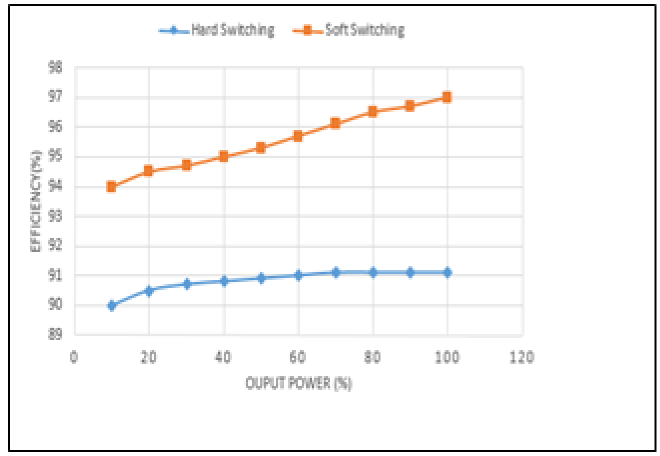

Fig (8) Overall Efficiency Curve of the hard switching and proposed ZVT- PWM Boost Converter.

G. CASE H

The circuit scheme of a new kind of a soft switching topology referred to as Novel ZVT-ZCT-PWM Boost Converter [18] is shown in the fig (9). In this novel Boost topology, a new kind of an active snubber cell is proposed. This active snubber cell consists of a snubber inductor (Ls), a snubber capacitor (Cs) and an auxiliary switch (S2) which consists of a transistor (T2) along with its body diode. In addition to the active snubber cell, the circuit consists of an input voltage source (Vin), main inductor (Lf), output filter capacitor (Cf), main switch (S1) composed of a transistor T1 along with its body diode. The circuit also consists of main diode (Df). The switching cycle of the proposed novel ZVT-ZCT-PWM boost converter consists of eleven modes.

Initially both the transistors "T1" and "T2" are in the "OFF" state, however The main diode (Df) is in the ON state and conducts the input current. Due to the auxiliary transistor (T2) turn "ON', the resonant interaction between the snubber inductor (Ls) and snubber capacitor (Cs) starts and as such the current flow through the resonant inductor (Ls) increases and at the same time the current which flows through the main diode (Df) decreases. As a result, the auxiliary transistor (T2) is turned "ON" with ZCS and the main diode (Df) is turned "OFF" with nearly ZCS and ZCS. The transfer of energy from parasitic capacitor (Cr) to the resonant circuit (Ls and Cs) is completed as a result of resonance between parasitic capacitor (Cr), snubber inductor (Ls) and snubber capacitor (Cs). At this stage, the body diode of the transistor (T1) is turned "ON" with nearly ZVS because the voltage across the resonant capacitor (Cr) becomes zero. The application of control signal to the gate of the transistor (T1) provides ZVT turn "ON" of transistor (T1), while fall in the value of current flowing through the snubber inductance (Ls) ensures that the body diode of transistor (T1) is turned "OFF" under ZCS. As the main transistor (T1) is in "ON" state, the current flowing through it increases and the resonance between the snubber inductor (Ls) and snubber capacitor (Cs) continues. The current flowing through the transistor (T2) becomes zero so that it is perfectly turned "OFF" under ZCT.

At the same time, body diode of the auxiliary transistor (T2) is turned "ON" with ZCS and its current starts to rise. The resonance between the Ls and Cs still continues and current flowing through the main transistor (T1) decreases to the input current level and thus the transistor (T1) is turned "OFF" under ZCS. The transistor (T2) is turned "ON" with ZCS when the control signal is applied to its gate, thus the current flow through the inductor (Ls) increases whereas the current through the main transistor to its gate, thus the current flow through the inductor (Ls) increases whereas the current through the main transistor drops to zero. At that instant, the anti-parallel diode of the transistor (T1) is turned "ON" with Zero current switching (ZCS). The transistor (T2) is turned "OFF" with ZCS due to the removal of the control signal. The capacitor (Cr) charges linearly to the value of the output voltage (V0) and the main diode (Df) is turned "ON" with ZVS.This completes one switching cycle and the other switching cycle starts.

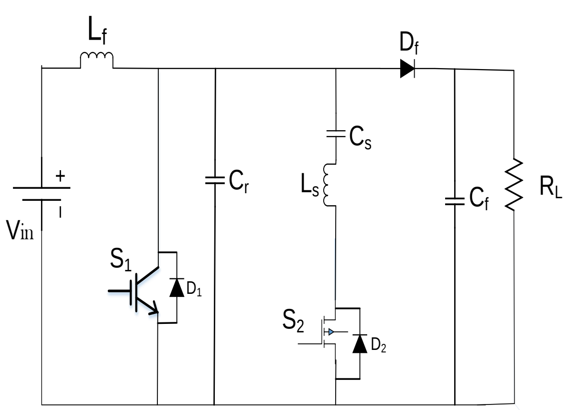

Fig (9) Schematic of Novel ZVT-ZCT-PWM Boost Converter [18]

In the proposed Novel ZVT-ZCT-PWM Boost converter, all of the semiconductor devices are switched under soft switching conditions. One of the main features of this soft switching topology is that the converter can operate at considerably higher switching frequencies and the soft switching conditions are maintained at very wide line and load ranges. Both the switches S1 and S2 have a common ground and this provides simplicity in the control. The efficiency of this soft switching topology is also higher than the other topologies which have been discussed so far. Thus, it is evident that this topology has numerous advantages over the other topologies discussed in this paper and as such is preferred choice for applications requiring higher efficiency.

3. DISCUSSION AND COMPARISON OF VARIOUS BOOST CONVERTER TOPOLOGIES

Now we analyze the various soft switching converters discussed in this paper. The comparison is on the basis of various parameters shown in TABLE1. As it is evident, we can see the efficiency values of each of the Boost Converter topology already discussed. From these efficiency values, we observe that the efficiency of Zero Current Transition (ZCT) Pulse Width Modulated converters (as shown in serial no.2) of the comparison table is the lowest at around 95.2% whereas the efficiency of the novel ZVT-ZCT PWM Boost converter(serial no.9) and that of the ZCT Boost converter employing a parallel auxiliary circuit (as shown in serial no.3) is the highest at around 97.8%.So considering the fact that the efficiency of the novel ZVT-ZCT PWM Boost converter and ZCT Boost converter employing an auxiliary resonant circuit is the highest, hence both these topologies are desirable for use in photovoltaic(PV) applications where efficiency is a major concern.

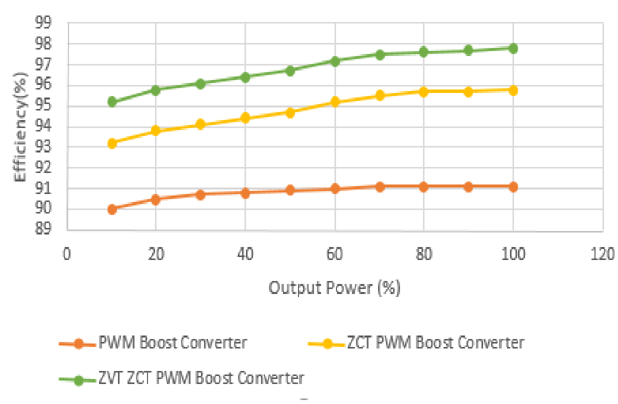

Fig 10. Efficiency Comparison of various Boost Converter Topologies

Table1 also shows the comparison among the number of components used in the auxiliary resonant circuits of the various boost converter topologies. The cost of the converter depends upon the number of components used in a particular topology so ideally the number of components should be as minimum as possible. From the table we observe that the topology mentioned in serial no. 9 i.e. a novel ZVT-ZCT-PWM Boost topology [18] has the minimum number of components whereas the topology mentioned in serial no.5 i.e. ZVT-PWM Boost [3] employing dual auxiliary circuit has the maximum number of components in the auxiliary circuit. Therefore, a novel ZVT-ZCT-PWM Boost converter is also more attractive as it offers minimum cost compared to the other soft switching topologies. The comparison of the various soft switching Boost Converter topologies is also made on the basis of the frequency of operation as shown in Table 1. All these converters operate at different frequencies. The converters mentioned in serial no's 1,5,9 are operated at maximum frequency of 100khz whereas the converter mentioned in serial no.3 operates at a minimum frequency of 30khz.

The operating frequency ranges of other topologies are mentioned in the comparison table 1. The output power ranges of the various soft-switching converters are also listed in the table I. Among various kinds of soft switching topologies discussed in this paper, the ZCT-PWM Boost with parallel auxiliary circuit listed in serial no.3 of the table1. has the maximum output power of around 2500W whereas the the topology mentioned in serial no.5 i.e. ZVT-PWM Boost with dual auxiliary circuit has the minimum output power of around 500W.In the comparison table, is also the mention of the number of various components such as the number of diodes, inductors, capacitors and switches used in the various converter topologies.

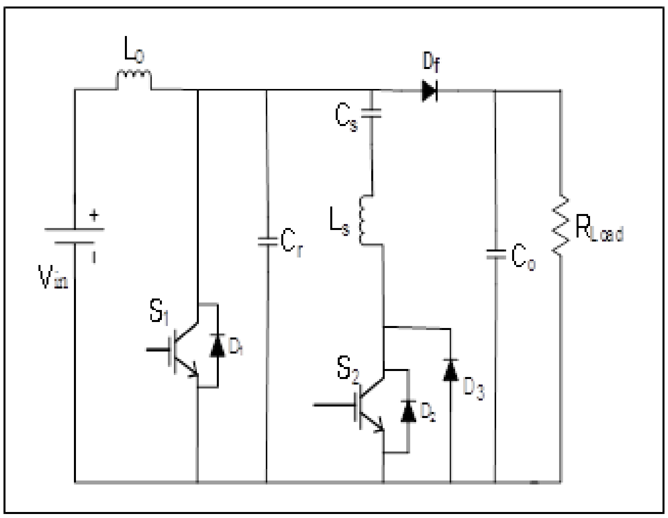

Fig 11. Block diagram of the proposed ZCT-PWM Boost Converter

4. PROPOSED ZCT-PWM BOOST CONVERTER

In this section, a new ZCT-PWM boost converter is proposed that is an improvement over other previously proposed ZCT-PWM boost converters, including the ones discussed in this paper. The circuit diagram of the proposed ZCT-PWM Boost Converter is shown in fig (11). The proposed converter is a boost converter with an auxiliary circuit, that consists of a switch (S2), a resonant capacitor(Cs) and a resonant inductor(Ls). In addition, the circuit consists of an anti-parallel diode "D3" which is connected across the switch "S2". In our design, we input inductor(Lr) is assumed to be large enough to be considered as a constant current source whereas the output capacitor is large enough to be depicted as a voltage source "Vo" with a voltage equal to the output voltage.

The converters operation can be described as follows: Initially prior to the time t=T0, the input current Iin is flowing through the diode Df as both the switches (S1 and S2) are in the "OFF" state. At t = T0 (Mode 1), the auxiliary switch (S2) turns "ON"., due to which a resonance starts between the inductor(Ls) and capacitor(Cs). Therefore, the current through the auxiliary circuit increases whereas the current through the auxiliary circuit increases whereas the current through diode (Df) falls simultaneously.

Thus, the diode (Df) turns off with Zero Current Switching (ZCS) conditions. At t = T1(Mode 2), the capacitor "Cr" discharges due to the previously started resonance, this forces the body diode "D1" to turn on with Zero Voltage Switching (ZVS). At t=T2 (Mode 3), the main switch (S1) is turned "ON" with ZVS and as such the current through the main switch "S1" continues to increases. At t=T3 (Mode 4), the current through the switch "S2" becomes zero and as such switch "S2" is turned "OFF" with ZCS. At t=T4 (Mode 5), as the current through the switch "S2" goes zero, the diode "D3" connected antiparallel to auxiliary switch(S2) conducts rather than the body diode (D2) of the switch "S2" which is a slow recovery diode.

At t=T5 (Mode 6) the main switch "S1" continues to conduct the input current. The switch "S1" can be turned "OFF" at some time when the current flowing through it reaches its peak value and at that instant the switch "S2" can be turned ON. Thus, the current which flows through the switch main switch (S1) reduces. At t = T6 (Mode7), the current through the main transistor falls to zero and this turns "ON" the body diode of the main switch(S1) with ZCS. Also, the control signal of the switch auxiliary switch(S2) is removed. At t = T7 i.e At the beginning of Mode8, the capacitor "Cr" is charged linearly under the input current. The main diode(Df) turns "ON" with ZVS and this mode finishes. This completes one switching cycle and another switching cycle starts.

5. CONCLUSION

In this review paper we have presented the operational details, properties and the schematic of various soft switching boost converter topologies. In various kinds of Converter Topologies, reviewed in this paper, all of the semiconductor devices perform soft switching under zero voltage or the zero current conditions. The gain of the converter depends upon the design and the components used in the circuit. The Boost converter circuits implemented using various soft switching topologies offer numerous benefits in terms of: i) simplicity of control, ii) higher efficiency and iii) more affordability i.e. lower cost. All of the soft switching boost converter topologies discussed in this paper, have an efficiency of greater than 95%. Among the various topologies discussed in this paper, almost all of them seem to have one of the following drawbacks such as high peak current of the main switch, very high voltage stress of the boost diode and significant switching losses of the auxiliary switch. But the most appropriate choice amongst all the discussed converter topologies seems to be the Boost converter topology proposed in serial no.4 of the comparison table 1. This novel ZVT-ZCT converter offers the significant advantage of efficiency and lesser number of components, thus making it suitable for use in medium/high power applications such as photovoltaic generation. However, the proposed topology as shown in figure (11) aims to have the much higher efficiency levels as compared to all the existing topologies in this paper by having minimum switching losses in the auxiliary switch in addition to the lower main switch peak current and the voltage stress. Furthermore, the ZCT operation in the proposed topology is expected to be independent of line and load conditions. All these features make this novel ZCT-PWM Boost technique attractive for high power applications where the minority carrier devices such as IGBT'S are employed.

Serial no.	Topology	No. of auxiliary switches	No. of auxiliary diodes	No. of resonant inductors	No. of resonant capacitors	Frequency (KHZ)	Max. Output Power (W)	Efficiency (%)
1.	Figure (1)	1	1	1	1	100	1000	97
2.	Figure (2)	1	1	1	1	50	1001.8	95.2
3.	Figure (3)	1	1	1	1	40	2500	97.8
4.	Figure (4)	1	2	1	1	30	600	96
5.	Figure (5)	1	3	2	1	100	500	95.8
6.	Figure (6)	1	2	1	1	50	1000	97.3
7.	Figure (7)	1	3	1	1	50	2000	97
8.	Figure (9)	1	0	1	1	100	1000	97.8

Table 1. Comparison of Various Topologies

REFERENCES

[1] Hua, G.; Yang, E.X.; Yimin Jiang; Lee, F.C., "Novel zero-current-transition PWM converters," in Power Electronics, IEEE Transactions on, vol.9, no.6, pp.601-606, Nov 1994.

[2] Hang-Seok Choi; Cho, B.H., "Novel zero-current-switching (ZCS) PWM switch cell minimizing additional conduction loss," in Power Electronics Specialists Conference, 2001. PESC. 2001 IEEE 32nd Annual, vol.2, no., pp.872-877 vol.2, 2001

[3] Xing Gao; Moschopoulos, G.; Bassan, S., "A New ZVT-PWM Converter with Reduced Circulating Current Losses," in Telecommunications Energy Conference, 2006. INTELEC '06. 28th Annual International, vol., no., pp.1-5, Sept. 2006

[4] Chien-Ming Wang, "A novel ZCS-PWM power-factor preregulator with reduced conduction losses," in Industrial Electronics, IEEE Transactions on , vol.52, no.3, pp.689-700, June 2005.

[5] Ching-Jung Tseng; Chen, Chern-Lin, "Novel ZVT-PWM converters with active snubbers," in Power Electronics, IEEE Transactions on, vol.13, no.5, pp.861-869, Sep 1998

[6] Mirsamadi, M.; Taherbaneh, M.; Rezaie, A.H., "Efficiency improvement of a DC-DC converter used in Series-Connected Boost Converters," in Electric Power and Energy Conference (EPEC), 2010 IEEE, vol., no., pp.1-4, 25-27 Aug. 2010.

[7] Taufik; Luther, P.; Anwari, M., "Digitally controlled ZVS quasi-resonant boost converter with M-type switch," in Intelligent and Advanced Systems, 2007.ICIAS 2007. International Conference on, vol., no., pp.823-828, 25-28 Nov. 2007.

[8] Bodur, H.; Bakan, A.F., "A new ZVT-ZCTPWM DC-DC converter," in Power Electronics, IEEE Transactions on , vol.19, no.3, pp.676-684, May 2004

[9] Aksoy, I.; Bodur, H.; Bakan, A.F., "A New ZVT-ZCT-PWM DC–DC Converter," in Power Electronics, IEEE Transactions on, vol.25, no.8, pp.2093-2105, Aug. 2010

[10] Soong, T.; Lehn, P., "A transformerless high boost DC-DC converter for use in medium / high voltage applications," in IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society, vol., no., pp.174-179, 25-28 Oct. 2012.

[11] Abdel-Rahim, O.; Orabi, M.; Abdelkarim, E.; Ahmed, M.; Youssef, M.Z., "Switched inductor boost converter for PV applications," in Applied Power Electronics Conference and Exposition (APEC), 2012 Twenty-Seventh Annual IEEE, vol., no., pp.2100-2106, 5-9 Feb. 2012.

[12] Sang-Hoon Park; So-Ri Park; Jae-Sung Yu; Yong-Chae Jung; Chung-Yuen Won, "Analysis and Design of a Soft-Switching Boost Converter

with an HI-Bridge Auxiliary Resonant Circuit," in Power Electronics, IEEE Transactions on, vol.25, no.8, pp.2142-2149, Aug. 2010

[13] Dong-Yun Lee; Min-Kwang Lee; Dong-Seok Hyun; Choy, I., "New zero-current-transition PWM DC/DC converters without current stress," in Power Electronics, IEEE Transactions on, vol.18, no.1, pp.95-104, Jan 2003

[14] Hua, G.; Lee, F.C., "Soft-switching techniques in PWM converters," in Industrial Electronics, IEEE Transactions on , vol.42, no.6, pp.595-603, Dec 1995.

[15] D. Y. Jung and C. Y. Won, "Soft Switching Boost Converter for Photovoltaic Power Generation System," International Power Electronics and motion control Conference, pp.1929-1933, 2008

[16] Min-Kwang Lee; Dong-Yun Lee; Dong-Seok Hyun, "New zero-current-transition PWM DC/DC converters without current stress," in Power Electronics Specialists Conference, 2001. PESC. 2001 IEEE 32nd Annual, vol.2, no., pp.1069-1074 vol.2, 2001.

[17] Bodur, H.; Bakan, A.F., "A new ZVT-PWM DC-DC converter," in Power Electronics, IEEE Transactions on, vol.17, no.1, pp.40-47, Jan 2002

[18] Altintas, N.; Bakan, A.F.; Aksoy, I., "A Novel ZVT-ZCT-PWM Boost Converter," in Power Electronics, IEEE Transactions on, vol.29, no.1, pp.256-265, Jan. 2014

[19] Yingqi Zhang; Sen, P.C., "A new soft-switching technique for buck, boost, and buck-boost converters," in Industry Applications, IEEE Transactions on, vol.39, no.6, pp.1775-1782, Nov.-Dec. 2003

[20] B. Abdi, Member, IACSIT, A. Safaei, J. S. Moghani, and H. Askarian Abyaneh, "An Overview to Soft-Switching Boost Converters for Photovoltaic", International Journal of Computer and Electrical Engineering, Vol. 5, No. 1, February 2013

[21] Gang Yao; Alian Chen; Xiangning He, "Soft Switching Circuit for Interleaved Boost Converters," in Power Electronics, IEEE Transactions on , vol.22, no.1, pp.80-86, Jan. 2007.

[22] Wuhua Li; Xiangning He, "Review of Nonisolated High-Step-Up DC/DC Converters in Photovoltaic Grid-Connected Applications," in Industrial Electronics, IEEE Transactions on , vol.58, no.4, pp.1239-1250, April 2011.

[23] Chien-Ming Wang, "Novel zero-Voltage-transition PWM DC-DC converters," in Industrial Electronics, IEEE Transactions on , vol.53, no.1, pp.254-262, Feb. 2006

[24] Das, P.; Moschopoulos, G., "A comparative study of zero-current transition PWM converters," in Applied Power Electronics Conference and Exposition, 2006. APEC '06. Twenty-First Annual IEEE , vol., no., pp.6 pp.-, 19-23 March 2006

[25] T. W. Kim, H. S. Kim, and H. W. Ahn, "An improved ZVT PWM boost converter," in Proc. 31th Power Electron. Spec. Conf.(PESC2000),Galway, Ireland, vol. 2, pp. 615–619.

[26] Das, P.; Moschopoulos, G., "A Comparative Study of Zero-Current-Transition PWM Converters," in Industrial Electronics, IEEE Transactions on , vol.54, no.3, pp.1319-1328, June 2007.

[27] Chok You Chan, "Comparative study of current-mode controllers for a high-order boost dc-dc converter," in Power Electronics, IET , vol.7, no.1, pp.237-243, January 2014.

[28] Chongming Qiao; Smedley, K.M., "A topology survey of single-stage power factor corrector with a boost type input-current-shaper," in Power Electronics, IEEE Transactions on , vol.16, no.3, pp.360-368, May 2001.

[29] Kui-Jun Lee; Byoung-Gun Park; Rae-young Kim; Dong-Seok Hyun, "Nonisolated ZVT Two-Inductor Boost Converter With a Single Resonant Inductor for High Step-Up Applications," in Power Electronics, IEEE Transactions on , vol.27, no.4, pp.1966-1973, April 2012.

[30] Lessa Tofoli, F.; De Castro Pereira, D.; Josias de Paula, W.; De Sousa Oliveira Júnior, D., "Survey on non-isolated high-voltage step-up dc–dc topologies based on the boost converter," in Power Electronics, IET, vol.8, no.10, pp.2044-2057, 10 2015.

[31] Jianbing Li; Yujie Shi; Zhongxia Niu; Dongfang Zhou, "Active Clamp ZVT Boost Converter," in Industrial Electronics and Applications, 2006 1ST IEEE Conference on , vol., no., pp.1-3, 24-26 May 2006.

[32] Li, W.; He, X., "ZVT interleaved boost converters for high-efficiency, high step-up DC-DC conversion," in Electric Power Applications, IET , vol.1, no.2, pp.284-290, March 2007.

[33] Trip, N.D.; Schiop, A.; Tomse, M., "Increase of the Efficiency for a Solar Renewable Source Using a Soft Switched DC-DC Boost Converter," in Signals, Circuits and Systems, 2007. ISSCS 2007. International Symposium on , vol.2, no., pp.1-4, 13-14 July 2007.

[34] Wuhua Li; Jun Liu; Jiande Wu; Xiangning He, "Design and Analysis of Isolated ZVT Boost Converters for High-Efficiency and High-Step-Up Applications," in Power Electronics, IEEE Transactions on , vol.22, no.6, pp.2363-2374, Nov. 2007.

[35] Furqan Zahoor, Swastik Gupta and Vipan Kakkar, "High Efficiency DC DC Boost Converters for Medium/High Power Applications" International Journal of Hybrid Information Technology Vol.9,No.11 (2016), pp.67-78.