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SOFT SWITCHING ANALYSIS IN DC-DC BOOST CONVERTERS

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Abstract- The boost topology is the most popular topology used in power factor correction circuits. The efficiency and performance of the boost converter depends on the switching frequency affecting the switching losses. At high frequency operations the switching losses of the converter is considerable and decreases the efficiency of the converter. To remove this problem the converter is designed to operate at soft switching mode operation. Soft switching mode operation also removes the problem of EMI which is a result of high frequency operation operating at hard switching. In this study, there are given five different topologies of DC-DC boost converters operating at soft switching. The hard switching operation of the corresponding converters are also given for the same load and operating conditions and the effect of the soft switching in increasing the efficiency of the converter is investigated. The given converters are analyzed and their efficiencies are compared. Auxiliary switches are also used in most soft switching DC-DC boost converter. Though these switches make the converter design a rather complicate they have considerable effects on the performance of boost converters.

Keywords: DC-DC Converters, Soft Switching, Efficiency, Losses.

I. INTRODUCTION

The boost converter topology has been extensively used in various AC-DC and DC-DC applications. Also, the boost topology is used in numerous applications with battery-powered input to generate a high output voltage from a relatively low battery voltage. In modern AC-DC power supplies utilize power factor correction in order to minimize the harmonics in the input current drawn from the utility.

The Boost topology is the most popular topology for power factor correction today but it has some disadvantages like high EMI due to reverse recovery of the boost diode and high switching losses caused by hard switching of the boost switch. Many variations of the original boost topology have been suggested to overcome these problems [5, 9].

The boost converter used for power factor correction operates at two different two operating modes of CCM and DCM depending on the operating frequency and the load conditions. Conventional hard switching pulse width modulation (PWM) converters, have disadvantages like high stress on device and objectionable EMI [7, 8, 11,12]. Increasing the switching frequency will reduce the volume and weight of switching mode power supplies. By increasing the operating frequency the power losses and EMI level of switch will increase too [1]. In modern switching mode power supplies the soft switching techniques are used to minimize the power losses of switches. These techniques have the advantages of high frequency operation with high efficiency and large power to volume ratio [2, 3, 6, 10].

New soft switching DC-DC converter uses a auxiliary circuit to compensate the power loss of hard switching converter. At soft switching method the properties of resonance operation are used. This is achieved using capacitors and inductors in the auxiliary circuits. At soft switching operations the devices of the converter change their on and off states either the voltage across them is zero (zero voltage switching ZVS) or when the current through them is zero (zero current switching ZCS) [2, 4]. Also, there are two techniques which are used in soft switching of DC-DC converters, ZVT and ZCT. The ZVT has often used in low and medium power applications [3, 8].

II. CONVENTIONAL DC-DC BOOST CONVERTER

A boost converter has a step-up conversion ratio; hence the output voltage is always higher than the amplitude of the input voltage. The boost converter can be supplied from any suitable DC sources, such as fuel cell, photovoltaic cell, rectifiers and DC generators [2, 5, 10]. Figure 1 Show a typically classic DC-DC boost converter.

The boost type topology is the most popular configuration because; the input current is the inductor current and is therefore easily programmed by current mode control. The boost inductor is in series with the ac power line so that the input current has smooth waveform especially at CCM resulting in much less EMI and reduced input filtering requirements.

Another advantage of this converter is the driving of the switch which has a common ground connection. Due to these advantages, the boost type topology has mostly been proposed in the literature for PFC applications [5, 8, 9]. The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. In a boost converter, the output voltage is higher than the input voltage. When the switch is turned-on, the current flows through the inductor and energy is stored in it. When the switch is turned-off, the stored energy in the inductor tends to collapse and its polarity changes such that it adds to the input voltage. Thus, the voltage across the inductor and the input voltage are in series and together charge the output capacitor to a voltage higher than the input voltage. When a boost converter operates in continuous mode, the current through the inductor (I_L) never falls to zero.

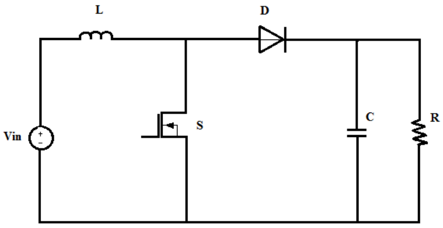

Figure 1. A conventional boost converter

III. SOFT SWITCHING DC-DC BOOST CONVERTERS

This paper studies soft switching in DC-DC boost converters to analyze the effects of soft switching in converters. In this study, five different kinds of DC-DC boost converter are simulated and the power loss on the switches and the voltage and current of switches are concerned and compared. Beside these, the power efficiency of the converters is important. By reducing the power loss of switches, the power efficiency increases [1, 3, 5, 10].

A. Zero Voltage Transition (ZVT) in On-State

Figure 2 shows the zero voltage transition on On-State technique. In this circuit the main switch turns on, at zero voltage switching condition and the auxiliary switch turns off at zero voltage switching. The advantage of this circuit is that the auxiliary switch under ZVS condition which leads to less power loss [1]. In this circuit, L=560μH, C=15μF, R=266Ω, V_i=150V, V_o=400V, f_{PWM}=30kHz.

The simulation results of Figure 2 are given in Figure 3. In this figure the voltage and current waveforms of the main and auxiliary switches and also the power losses of the main switch are given.

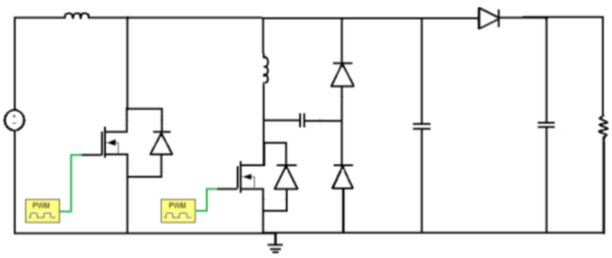

Figure 2. Zero voltage transition (ZVT) in on-state circuit

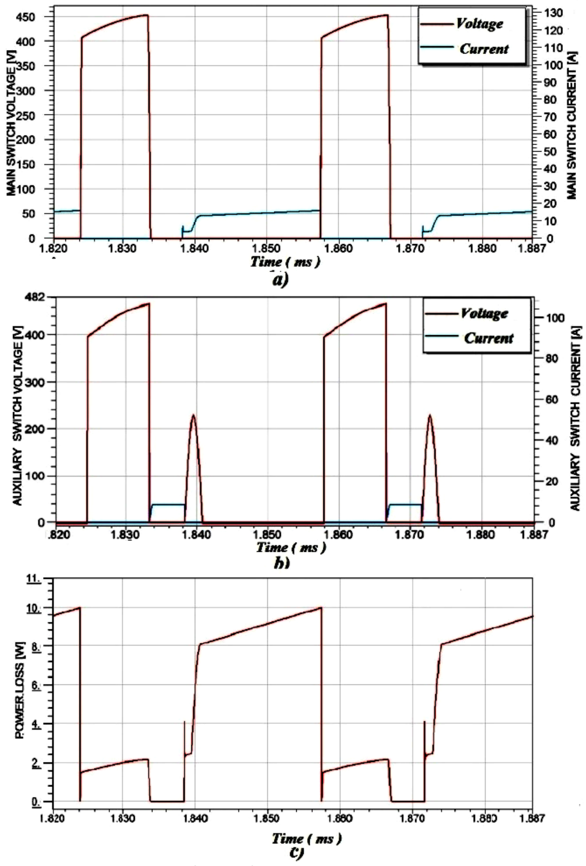

Figure 3. Output wave form of zero voltage transition (ZVT) in on-state technique, (a) Voltage and current of main switch, (b) Voltage and current of auxiliary switch, (c) Power loss on main switch

Figure 4 shows the power loss of switch at hard switching technique. Table 1 shows the power efficiency of the circuit in different load current.

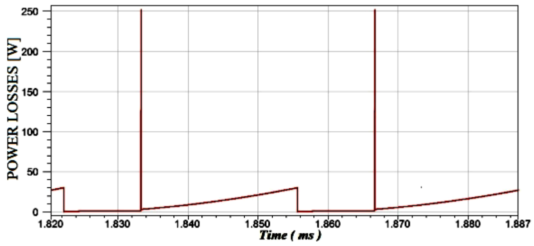

Figure 4. Power loss on main switch (hard switching)

Table 1. Power efficiency of zero voltage transition in on-state circuit

Load (Ω)	Load Voltage (V)	Input Power-SS (W)	Input Power-HS (W)	Output Power (W)	Power Eff-SS (%)	Power Eff-HS (%)
1000	400	169.725	171.5	160	94.2	93.29
500	400	336.25	338.1	320	95.1	94.64
333	400	486.00	492.2	480	98.7	97.52
266	400	609.65	614.5	600	98.4	97.64

A. B. Bidirectional Boost Converter

In this circuit by using a resonant inductor and capacitors parallel with the switches, the ZVS technique is applied to switches and the main and auxiliary switches turns on and off on ZVS condition [2]. In this circuit, L=1mH, C_{o1}=10μF, C_{o2}=5μF, R= 53Ω, V_i=200V, V_o=400V, f_{PWM}=30kHz.

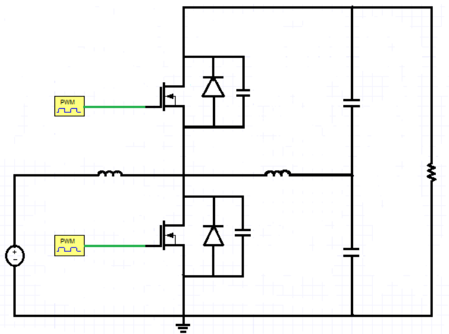

Figure 5. Bidirectional boost converter

The simulation results of Figure 5 are given in figure 6. In this figure the voltage and current waveforms of the main and auxiliary switches and also the power losses of the main switch are given. Power loss of the Bidirectional boost converter in hard switching technique is like the Figure 7. Table 2 shows the power efficiency of Bidirectional boost converter for different load resistance.

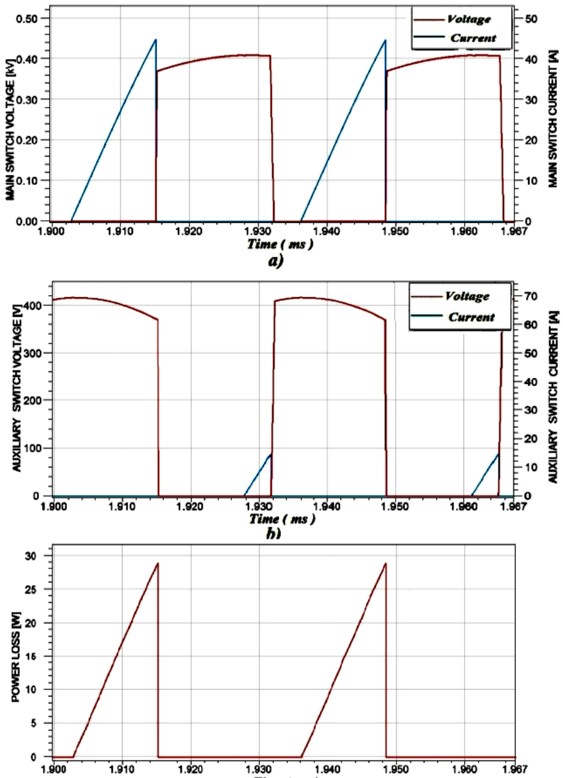

Figure 6. Output wave form of bidirectional boost converter technique, (a) Voltage and current of main switch, (b) Voltage and current of auxiliary switch, (c) Power loss on main switch

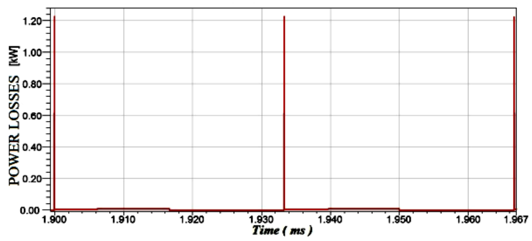

Figure 7. Power loss of main switch (hard switching) in bidirectional boost converter

Table 2. Power efficiency of bidirectional boost converter

Load (Ω)	Load Voltage (V)	Input Power-SS (W)	Input Power-HS (W)	Output Power (W)	Power Eff-SS (%)	Power Eff-HS (%)
76	400	2114.9	2136.5	2100	99.28	98.29
67	400	2416.4	2438.6	2400	99.32	98.41
59	400	2717.0	2741.8	2700	99.37	98.47
53	400	3018.1	3045.0	3000	99.40	98.52

C. Efficient Soft Switched Boost Converter

This circuit uses either ZVS and ZCS in both switches. The efficient soft switched boost converter's nominal output power is 110 watt [3]. In this circuit, L=200μH, C_o=3μF, R=110Ω, V_i=30V, V_o=110V, f_{PWM}=100kHz.

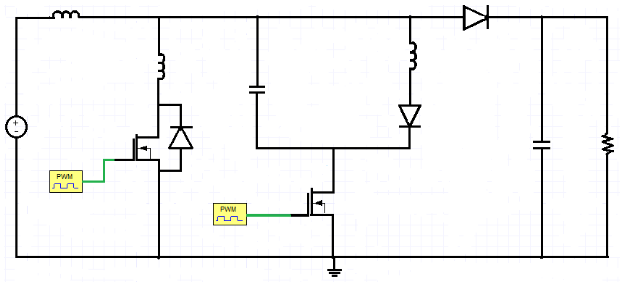

Figure 8. Efficient soft switched boost converter

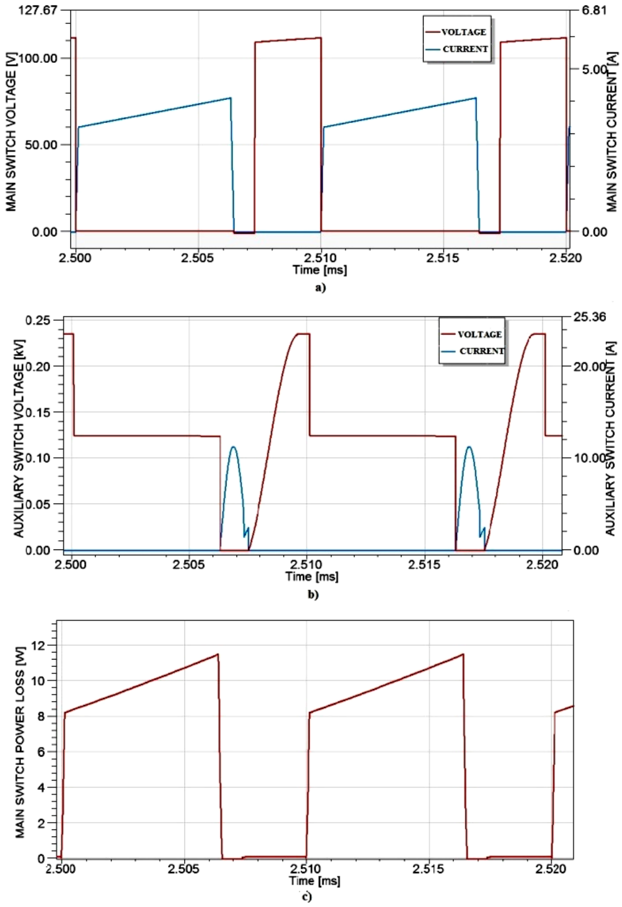

Figure 9. Output wave form of efficient soft switched boost converter technique, (a) Voltage and current of main switch, (b) Voltage and current of auxiliary switch, (c) Power loss on main switch

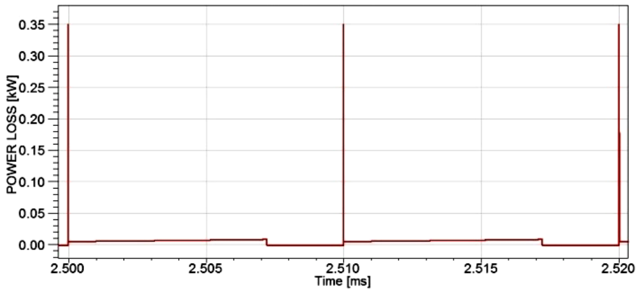

Figure 10. Power loss on hard switching converter

Figure 10 shows the power loss of switch in hard switching technique. The simulation results of figure 8 are given in Figure 9. In this figure the voltage and current waveforms of the main and auxiliary switches and also the power losses of the main switch are given. Power efficiency of the efficient soft switched boost converter is shown below. As the load resistance becomes small in value the power efficiency reaches to high values.

Table 3. Power efficiency of efficient soft switched boost converter

Load (Ω)	Load Voltage (V)	Input Power-SS (W)	Input Power-HS (W)	Output Power (W)	Power Eff-SS (%)	Power Eff-HS (%)
242	110	51.60	52.10	50	96.89	95.96
173	110	72.10	72.88	70	97.10	96.04
135	110	92.50	93.00	90	97.29	96.77
110	110	112.95	113.60	110	97.36	96.83

D. ZVT PWM Boost Converter

Figure 11 show a novel family of zero voltage transition boost converter that uses a resonant source to apply ZVT for switches [4]. In this circuit, L=0.91mH, C=5μF, R=160Ω, V_i=150V, V_o=400V and f_{PWM}=100kHz.

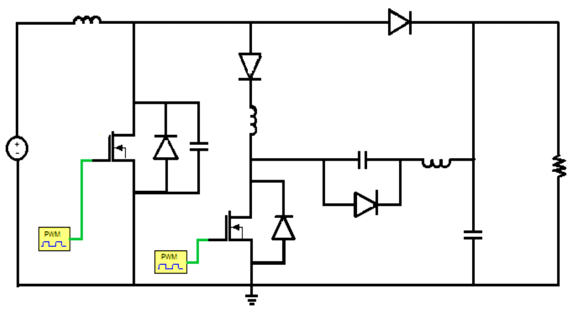

Figure 11. ZVT PWM boost converter

Figure 13 shows the power loss of switch in hard switching technique. Table 4 illustrates power efficiency of converter in different load resistance.

The simulation results of Figure 11 are given in Figure 12. In this figure the voltage and current waveforms of the main and auxiliary switches and also the power losses of the main switch are given.

E. Zero Voltage Transition (ZVT) in On-State Circuit with PID Controller

Fifth boost converter topology, similar to case A. is "Zero voltage transition (ZVT) in on-state with PID controller" (Figure 14) [1]. In this circuit, L=560μH, C=15μF, R=266Ω, V_i =150V, V_o=400V, f_{PWM}=30kHz.

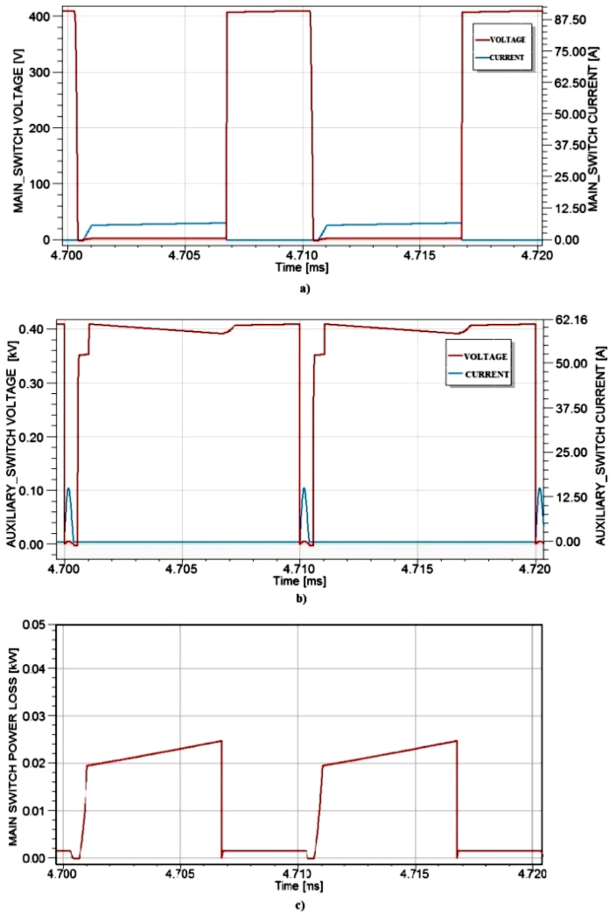

Figure 12. Output wave form of ZVT PWM boost converter technique, (a) Voltage and current of main switch, (b) Voltage and current of auxiliary switch, (c) Power loss on main switch

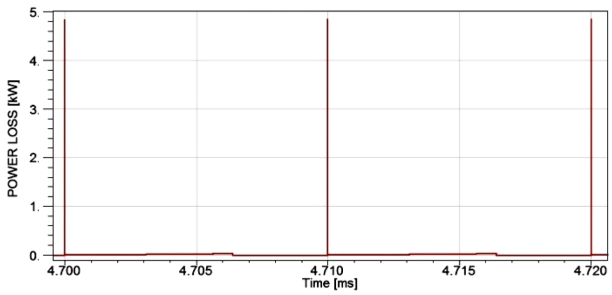

Figure 13. Power loss in main switch (hard switching)

Table 4 . Power efficiency of ZVT PWM boost converter

Load (Ω)	Load Voltage (V)	Input Power-SS (W)	Input Power-HS (W)	Output Power (W)	Power Eff-SS (%)	Power Eff-HS (%)
230	400	716.8	726.5	700	97.65	96.35
200	400	818.3	828.0	800	97.73	96.66
178	400	920.0	928.2	900	97.82	96.95
160	400	1021.4	1030.0	1000	97.91	97.04

The Figure 15 shows the wave forms of zero voltage transition (ZVT) in on- statewith control boost converter topology. In this figure the voltage and current waveforms of the main and auxiliary switches and also the power losses of the main switch are given. Hard switching power loss is illustrated in Figure 16. Table 5 illustrates power efficiency of converter in different load resistance.

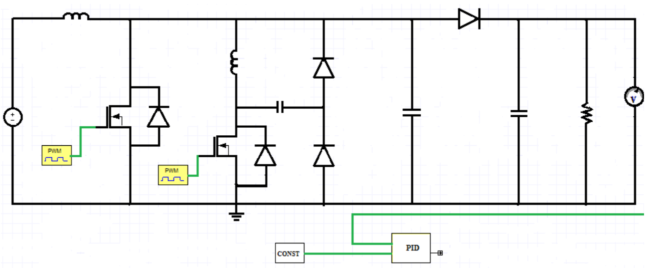

Figure 14. Zero voltage transition (ZVT) in on-State circuit with PID controller

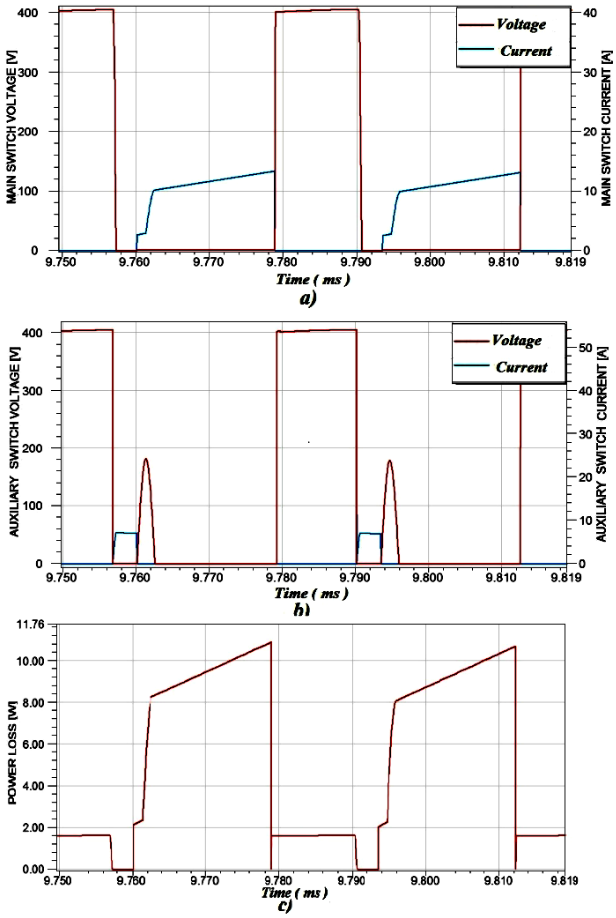

Figure 15. Output wave form of zero voltage transition on On-state circuit with control boost converter technique, (a) Voltage and current of main switch, (b) Voltage and current of auxiliary switch, (c) Power loss on main switch

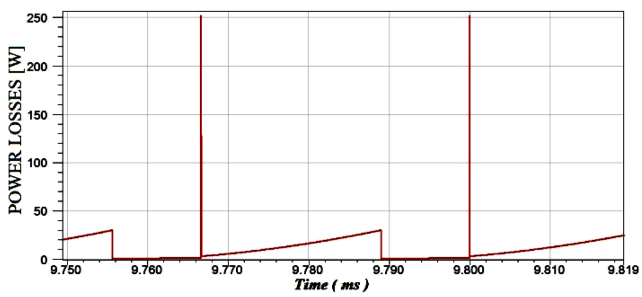

Figure 16. Power loss of main switch (hard switching)

Table 5. Power efficiency of zero voltage transition in on-state circuit with control boost converter

Load (Ω)	Load Voltage (V)	Input Power-SS (W)	Input Power-HS (W)	Output Power (W)	Power Eff-SS (%)	Power Eff-HS (%)
1000	400	169.72	171.5	160	94.2	93.29
500	400	336.25	338.1	320	95.1	94.64
333	400	486.00	492.2	480	98.7	97.52
266	400	609.65	614.5	600	98.4	97.64

IV. CONCLUSIONS

The purpose of using soft switching techniques in DC-DC converter is to reduce the power loss of switches in converters. The simulation results verify the effect of the soft switching in reducing the switching losses. Among the different configurations of soft switching boost converters given in this study, the second type has the highest rate of power efficiency, the first and the fifth types have the lowest power efficiency. The number of elements used in converters is also important. This is due to the fact that using more elements makes the circuit design more complex and directly reduces the power efficiency. The number of elements also affects negatively the cost and the volume of the converter.

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Ires Iskender received B.Sc. degree in Electrical Engineering from Gazi University, Ankara, Turkey in 1989. He received the M.Sc. and Ph.D. degrees in Electrical Engineering from Middle East Technical University, Ankara, Turkey in 1991 and 1996, respectively. From 1989 to 1996 he worked as a Research Assistant in Electrical and Electronics Engineering Department, Middle East Technical University, Ankara, Turkey. Since 1996 he has been with Department of Electrical Engineering, Gazi University, where he is currently an Associate Professor. His interests include renewable energy sources, energy conversion systems, power electronics and electrical machines.

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