Designing a Buck Converter with a New Switching Technique at Zero Current

[1]S. M. Shariatmadar
Dep. Electrical Engineering,
Naraghbranch,Islamic Azad
University,Naragh, Iran

[2]A. Aliabbasi Jazi
Dep. Electrical Engineering,
IslamicAzad University,
Naraghbranch,Naragh, Iran

[3]S. M. Athari Esfahani
Dep. Electrical Engineering,
IslamicAzad University,
Naraghbranch,Naragh, Iran

***Abstract*—In this paper, an active auxiliary circuit is suggested to apply the minimum possible elements and having easy performance for the buck converter. By adding this circuit to the main converter, zero current transition (ZCT) is provided, and it will increase the efficiency of the converter and reduce the losses due to switching and also conduction losses. By adding an auxiliary circuit to the converter control it will remain as the pulse width modulation (PWM).Different circuit and functional states of the converter will be simulated and analyzed. Converter efficiency in various performance capacities will be measured and compared with hard switching mode.**

Keyword*—*Switching at* zero current transition *(*ZCT*), zero current switching (ZCS), zero voltage switching (ZVS),* zero voltage switching *(*ZVS*)

I. INTRODUCTION

DC / DC Buck (decreasing) Converters with pulse width modulation (PWM) are widely used in radio systems [1], battery chargers, telecommunication equipment [2], computers, fuel cells, televisions and many other industrial and telecommunication and military applications[3]. To reduce the size and weight of the converters, we are forced to increase their operating frequency and this problem can increase the switching losses and also electromagnetic interferences [1-12]. Furthermore, the use of semiconductor switches, for high power applications may arise issues such as limiting the operating frequency of converters and increasing stress as well as switching losses. In general, an auxiliary circuit can decrease conduction and switching losses by adding to main convertor [4].Switching at zero-current transition (ZCT) techniques and zero voltage techniques (ZVT) provide good performance at converters with a pulse width modulation (PWM) and this reduces the switching losses in the converter [5]. In some of the convertors an auxiliary circuit including a resonant switching element is added to the main convertor and this collection provides soft switching conditions for the main switch of the convertor at the collection and soft switching conditions for the main switch of the converter at the switching moments [4]. Recently, many techniques for improving the performance of DC / DC converters have been introduced such as ZVS, ZCS techniques [1-6]. ZCZVT, ZVT, ZCT are placed in other circuits and resonant elements in series arrangement with the main power circuits except circuits with ZVT and ZCT techniques. Thus, the voltage and current stress and circular energy will increase in all of them and the circuit is incapable of detecting a soft switching at wide input and output ranges. However, in zero-current transition (ZCT) converters, resonant elements are placed in parallel with the main power circuit and in addition to solving the above problem; soft shutdown conditions at zero moment for the main key and also auxiliary key will be provided [7].Choosing the soft switching method depends on the type of applied semiconductor element. MOSFET switches usually have a better performance on ZVT converters because the capacitive losses caused by turning on the key have been removed. IGBTs have a better efficiency in ZCT convertors because outage losses caused by the sequence current have been removed in them [8]. In ZCT converters with pulse width modulation, auxiliary circuit consists of an active circuit and a number of passive elements that are placed in parallel with the main switch. The duty of active circuit is turning off the main switch softly and passing the current synchronously, after doing this duty and turning off the main switch, it will turn off quickly. [9]. A ZCT PWM circuit has been suggested in [10] in which the main and auxiliary switches are turned on and off under soft switching conditions. However, over time the auxiliary switch is turned on, the current rises because of the resulting resonance and the excessive current is transmitted to the main switch rotatory and this increases the peak current of the main switch and increases the current stress and therefore conduction losses are increased after turning the key on. On the other hand the applied stress to the proposed converter diode, is double the output voltage that is considered a large and significant value.

A ZCT PWM converter has been suggested in [11] and the preponderance of this converter is also turning on and off the main and the auxiliary switch softly. Despite the above one, this circuit is not carrier of the rotary current transferred from the auxiliary switch to the main one. As a result, the peak switch current and conduction losses will not increase in this circuit. But the biggest disadvantage of this circuit is passing the input current of two diodes, instead of passing it through one of them and this will increase the conduction losses. A ZCT PWM converter has been proposed in [12], with the advantages such as creating the soft switching conditions for the main and the auxiliary switch, and lessening the rotational current of the converter, which reduces the peak current in the main key. The biggest disadvantage of this circuit is that the negative side of the resonance current of auxiliary key will increase due to the use of a big inductor and this question limits the application of the switch where the narrow duty cycle is required. However, given that the passing rotational current is still entering through the main switch increasing the stress of the current on the main switch will be observed that will increase losses. In [13] a Buck converter with an active auxiliary circuit is proposed in which the main and auxiliary switches of the circuit are turned on and off softly and the converters are also highly efficient, but due to the current flowing through the body diode of the main converter, the current stress is high. On the other hand, three switches are used in this circuit and this subject makes the synchronization of drivers and control structure of the circuit difficult and these cases are among the disadvantages of the proposed converter. Given that buck converter is the basis of other converters like Half-Bridge, All-Bridge, and Flay back and forward. Therefore, in this paper, a PWM Buck Converter with soft switching is recommended that has advantages and disadvantages compared to the converters mentioned at above references: In the proposed converter, because the diode is in series arrangement with auxiliary switch no current passes through the body diode and this reduces the stress on the auxiliary switch. While the converters proposed in [6] and [7], are under the current stress on the auxiliary switch. The number of elements of the proposed circuit is less than the number of elements in [7] and [13] and this will lead to simpler circuit structure and less cost than the cases referred. In the circuit presented in [7] driver pulses of the auxiliary circuit have been set up to be applied to it at the moment the main switch is turned on and off. The driver pulses of the auxiliary circuit are applied to the main switch at the rising and falling edges of the auxiliary circuit and this will lead to the complexity of the driver structure and the control circuit of the auxiliary switch while at the proposed circuit of this paper, the auxiliary circuit driver pulses are applied only at the rising edge of the main switch pulse i.e. only at the switching-on moments and to create a soft shutdown condition, Asnabr circuits are designed to help. Adding the current stress on the switch and main diode of the converter at the peak current times and applying a voltage equal to twice the input voltage on the capacitor C1 are the disadvantages of the proposed converter.

II. PROPOSED CONVERTER

A. Description of the proposed converter:

The proposed Buck converter is presented in Figure 1.In this converter, s1 and s2 are the main and auxiliary switches respectively. Auxiliary switch s2 is turns on prior to turning on key s2 and provides zero current soft switching conditions. Diodes D1 and D2 are the auxiliary diodes of the converter and diode D3 is the original diode of the converter. During conducting the current, Diode D2 provides the charging condition of the capacitor C1 that is an auxiliary capacitor. This capacitor will be charged as much as $_{2Vin\ when}$ the auxiliary switch is turned on. Inductors L1 and L2 and capacitor C1 are responsible to create resonance.

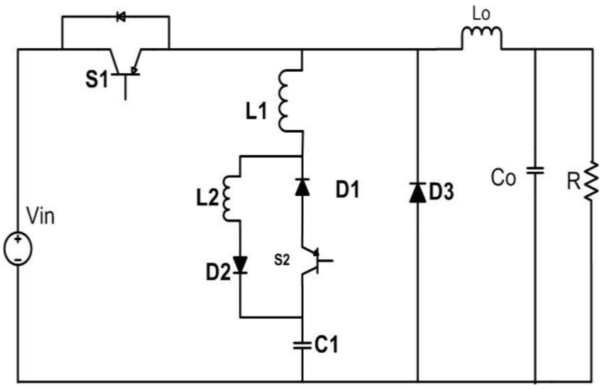


Figure 1.Proposed Buck Converter

Using the above method, the auxiliary circuit conduction losses of the added auxiliary circuit will reduce, and this will be very little impact on the main performance of the converter.

B. Analyzing the proposed circuit and reviewing its performance

Before examining the different modes of operation of the circuit, we assume that the size of the capacitor C1 is charged 2Vin.

Condition (1) the time interval [t_0-t_1]:

This time interval will begin with turning on the auxiliary switch and after that the resonance between the inductor L1 and capacitor C_1 will start, and this makes the diode D_4 to be turned off under zero voltage (ZV) conditions and the inductor L1 current to increase from zero. At the end of this interval, the inductor L1 current will be equal to the output current I_o.

$$I_{L1} = \frac{2V_{in} - V_o}{Z_1} \sin(\omega(t - t_0)) \quad (1)$$

$$V_{C1} = 2V_{in} \cos(\omega(t - t_0)) \quad (2)$$

$$Z_1 = \sqrt{\frac{L_1}{C_1}} \quad (3)$$

$$\omega = 1/\sqrt{L_1 C_1} \quad (4)$$

Condition (2) the time interval [t_1-t_2]:

In this time interval, the resonance between L1 and C_1 will continue to the point where inductor L1 current exceeds I_o. In this case, given that the output current I_0 is constant the additional current created through the body diode of main switch returns to input source. So in this situation the body diode is turned on. When the body diode is on, the main key under zero voltage (ZV) conditions is about to be on, but no current passes through it. Reducing the inductor L1 current, and reaching again to the current Io, the body diode turns off.

$$V_{C1} = V_{in} \quad (5)$$

$$\omega = 1/\sqrt{L_1 C_1} \quad (6)$$

Condition (3) the time interval [t_2-t_3]:

In this time interval after the transition from the body diode to the main switch, the switch is turned on under zero voltage (ZV) conditions and the inductor L1 current is reduced linearly. The main switch current increases gradually and reaches to zero output current I_0. Increasing the output current of main switch, the inductor L1 current and capacitor C_1 voltage are reduced so that at the end of this interval are both zero.

$$I_o = \frac{V_{in} - V_o}{Z_1} \quad (7)$$

$$\omega = 1/\sqrt{L_1 C_1} Z_1 = \sqrt{\frac{L_1}{C_1}} \quad (8)$$

Condition (4) the time interval [t_3-t_4]:

This time interval begins with zero inductor L_1 current and thereby switching off the auxiliary key under ZC conditions. In this situation, due to the created resonance between the capacitors C_1 and Inductors L_1 and L_2, the current to the main key will increase and will exceed Io and this will lead that diode D2 to be turned on and thereby capacitor C_1 voltage which was zero already begins to rise and correspondingly after that capacitor C1 voltage reached to the value 2Vin this time interval will end.

$$\omega = 1/\sqrt{(L_1 + L_2) C_1} \quad (9)$$

$$Z_3 = \sqrt{\frac{(L_1 + L_2)}{C_1}} \quad (10)$$

$$I_{L1} = I_{L2} = \frac{V_{in}}{Z_3} \sin\big(\omega(t - t_3)\big) \quad (11)$$

$$V_{C1} = V_{in}(1 - \cos(\omega(t - t_0))) \quad (12)$$

Condition (5) the time interval [t_4-t_5]:

After the termination of resonance between Inductors L_1 and L_2 and reaching the capacitor voltage C_1 to $_{2Vin}$ this time interval begins. The diode D2 turns off under ZC conditions and the main key current will equal to output current I_0. In this situation the converter acts like a PWM Buck Converters in this situation and the output current is supplied through it. This situation will continue as long as the main switch is turned on.

Condition (6) the time interval [t_5-t_6-T]:

This situation starts with the main switch reduction and thus turning off under ZC conditions. In this situation, the main diode of the converter will turn on under ZC conditions and close the output current loop. This time interval will be terminated with re-switching on the auxiliary key.In this situation, the main diode current slope of the converter will be the reverse of the main switch current slope and because the switch current does not decrease immediately, Diode current is also increased softly, and the diode will turn on under ZC conditions. In Figure 2, the waveforms associated with gate – source voltage of the main and auxiliary key and also the inductor current L_1 and the voltage waveforms and the main and auxiliary key current are represented. Also, In Figure 3 the six-form states of the performance of the proposed converter are shown. In figures related to the functional states of the converter, the elements involved in each time interval are displayed as bold and other elements as dotted-line.

III. SIMULATION AND PRESENTATION OF ITS RESULTS

In this section, the proposed converter is simulated using software PSPICE and the simulation results are presented. In the simulation carried out, the operating frequency for both the main and auxiliary keys is considered 100 kHz. Considering that the selectedconverter is a buck type the duty time should be considered for less than 50 percent. Here to start the operation of converter the amount of 45% has been considered.

Having the best performance for the auxiliary key it should be noted that the auxiliary key must be turned on in a very short time before turning on the main key, and turned off immediately after turning on the main key.

ISSN: 2278-0181
Vol. 3 Issue 8, August - 2014

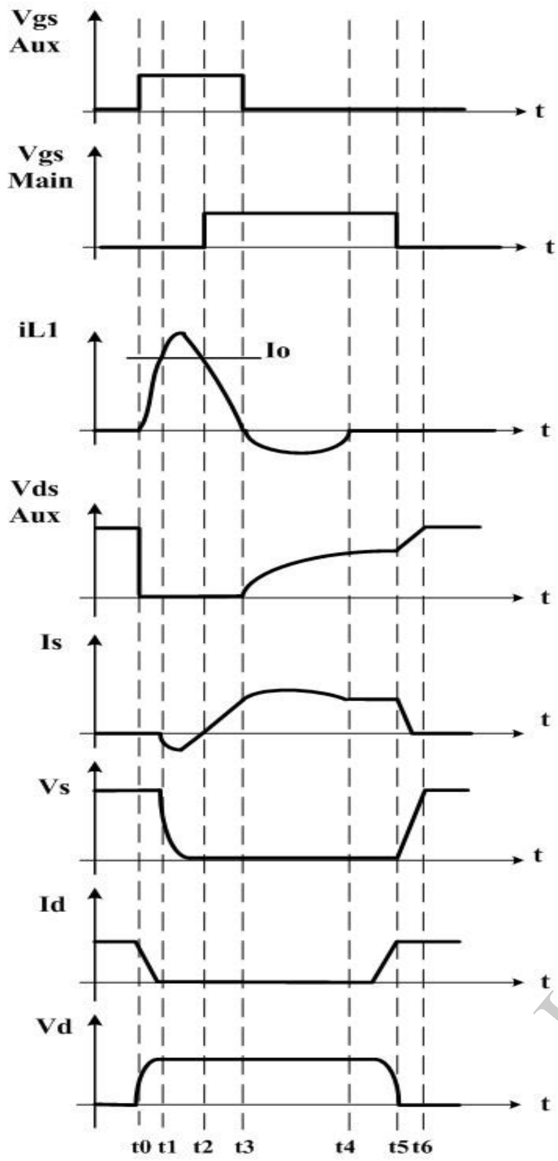
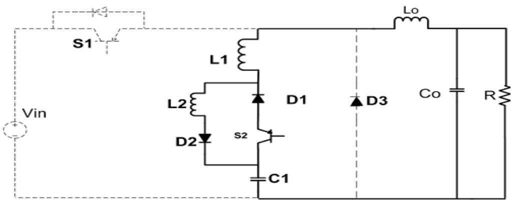
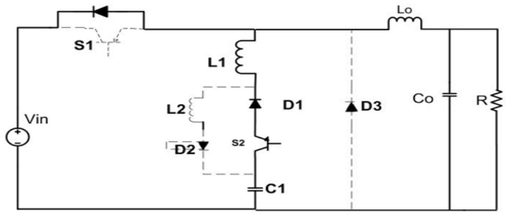


Figure 2.Proposed converter Waveforms

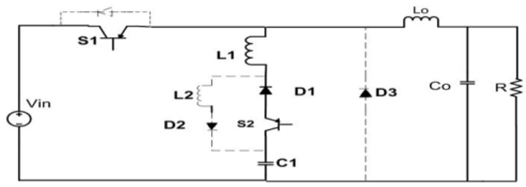
For this purpose, the duty time of the main key may be considered as short as possible. Therefore, in the proposed converter the period of the main and auxiliary keys is considered 10 microseconds equivalent to about 100 kHz. In the main key of the converter TD =0, PW = 10us and in the auxiliary key TD = 9.6us and W = 1.2us are considered.



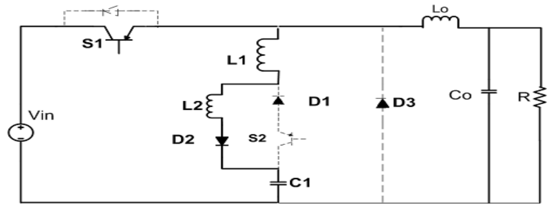
Condition (1) the time interval [t_0-t_1]



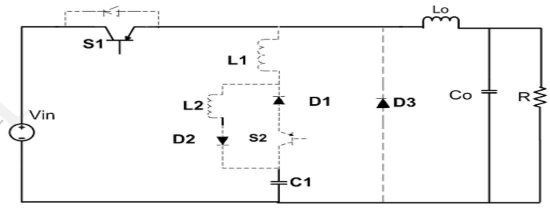
Condition (2) the time interval [t_1-t_2]:



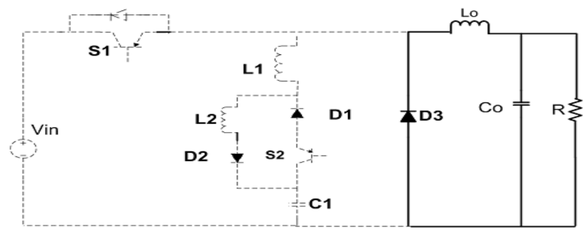
Condition (3) the time interval [t_2-t_3]:



Condition (4) the time interval [t_3-t_4]:



Condition (5) the time interval [t_4-t_5]



Condition (6) the time interval [t_5-t_6-T]

Figure 3. Different condition modes of the proposed converter

As mentioned at the beginning, the purpose of this circuit was applying the lowest element in creating soft switching conditions for the converter. To make better the performance of the converter and lack of use of non-polarity capacitor in the circuit, we can add a part to it a diode for example can be put in parallel with the capacitor C_1 to force charging and discharging the capacitor to happen at the positive section and prevent it to become negative. In the following circuit schematic and simulation results are shown. It is observed in Figure 4 that when the body diode of the main key has conducted (the current) it has become negative. Simulation results conducted are consistent with the presented theory at the previous sections and the theoretical accuracy of the circuit performance is confirmed. As indicated in the following simulations, all the elements involved in the operation of

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 8, August - 2014

the switching are switched on and off softly and as it is shown in Figure 8-7-6-5 in the states of operation of the circuit, switching conditions at zero current and zero voltage are provided for them. In Figures 6-5-4 bold lines represent the voltage and dotted-lines indicate the current.

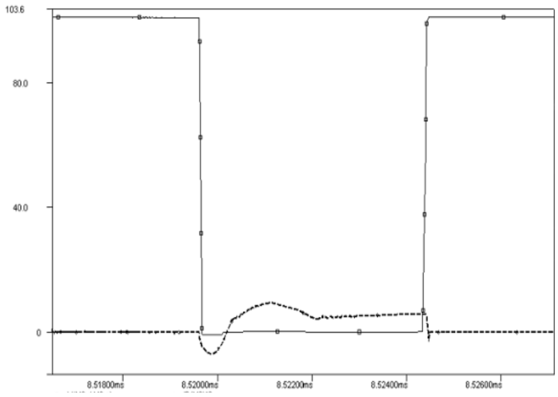


Figure 4. Main switch Current and voltage

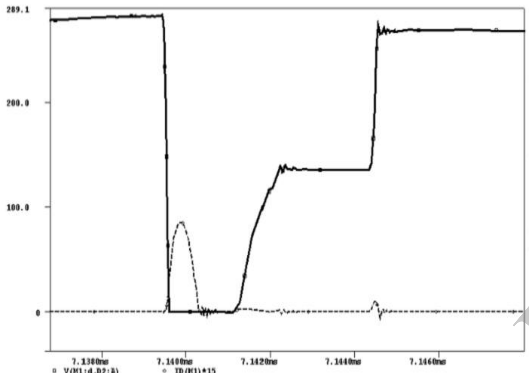


Figure 5. Auxiliary switch Current and voltage

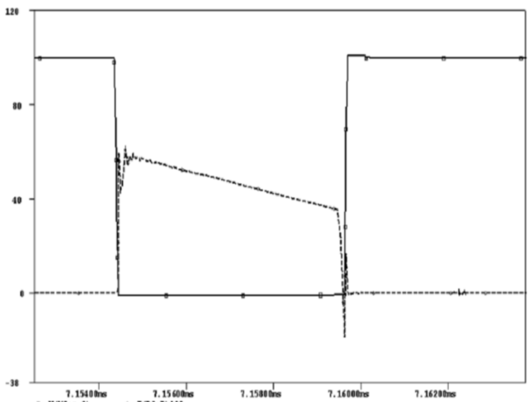


Figure 6. Main diode Current and voltage

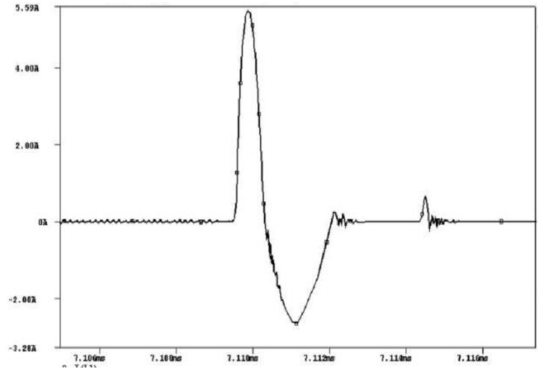


Figure 7. L1 Current

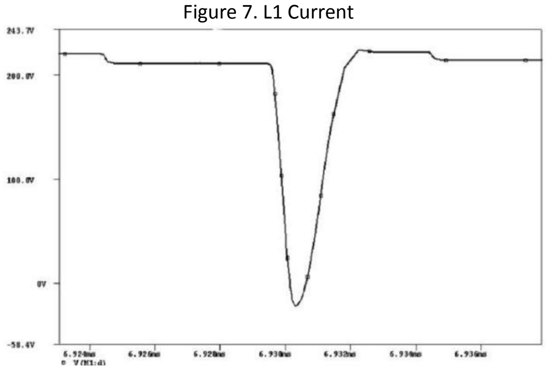


Figure 8. C1 voltage

The circuit schematic is shown in Figure 9 and components and elements used in the proposed converter are listed in Table 1.

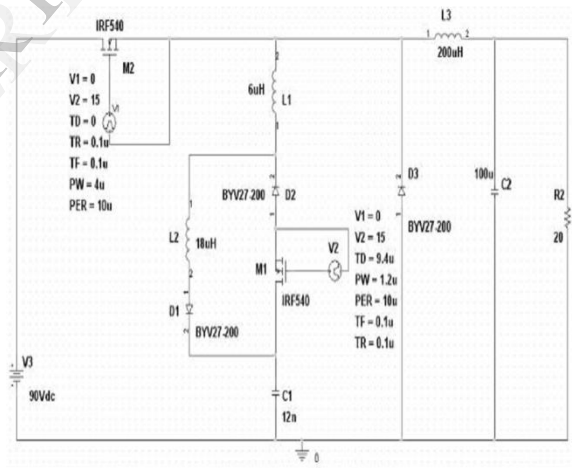


Figure 9. Schematic of the simulated converter circuit

Table 1.Components and elements Converter

Component	Part name/value
S1-S2	IRF540
D1-D2-D3	BYV27-200
C1	12nf
C2	100nf
L1	6uH
L2	18uH
Input voltage	90v
Output voltage	40v
Output power	800w
Frequency	100KHz

IV. CONVERTER EFFICIENCY

In this section, the comparative graph regarding the efficiency of the converter using the auxiliary circuit described in this paper, and normal mode is presented. In order to obtain the converter efficiency at different loads, load power and input power should be achieved and then we can calculate the converter efficiency. It is noteworthy that the proposed converter in this paper is designed for an 80-watt converter and a 20-ohm load. Note that in this converter, due to the output constant current after the load changing the duty time should be set in such a way that the efficiency to become the best. As shown in the graph, the efficiency of the proposed converter, based on its output power, is indicated with bold lines and the conventional Buck converter efficiency is shown as dotted-line.

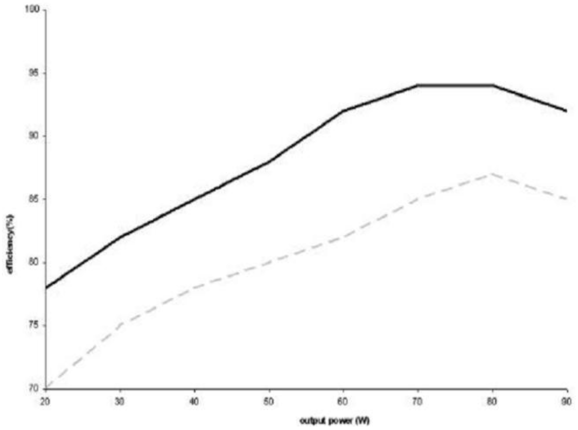


Figure 10.Efficiency compared of conventional Buck converter and the proposed converter

V. CONCLUSION

In this paper, a Buck converter was introduced using an active auxiliary circuit. The use of this auxiliary circuit caused the key converter diode and also main and auxiliary keys to be turned on at zero current and soft switching conditions to be created for them. Noting that switching occurs at zero current conditions the current stress on the main switch is reduced and the efficiency of the converter increases. Low number of elements of the circuit compared with other proposed converters and subsequently lower cost and on the other hand having a simple control structure and lack of current stress on the auxiliary switch are among the advantages of the converter. But still, the current stress on the main switch of the circuit is high in the proposed converter which is suggested to improve the condition of the mentioned converter the diodes applied in this converter to be replaced with MOSFET. This reduces the conduction losses and the stress of the current and also increases the efficiency of the converter. Different conditions of the circuit were simulated and compared with the theoretical results and the simulations verify the theoretical results.

REFERENCES

[1] Mishima, T.; Nakaoka, M, “A new family of soft switching PWM non-isolated DC-DC converters with Active auxiliary Edge-Resonant Cell,” IEEE Conferences, Power Electronics Conference (IPEC), pp.2804 – 2809, 2010.

[2] Anup Kumar Panda, SwapnajitPattnaik, andK. K. Mohapatra, “ A Novel Soft-Switching Synchronous Buck Converter for Portable Applications,” International Journal of Power Management Electronics, Article ID 862510,2007.

[3] S. -Y. Tseng, Y. –J. Li and, Y. –J. Wu, “Buck converter Associated with Active clamp Flyback converter for PV Power System,” Green Power Evolution Applied Research Lab (G-PEARL), ICSET 2008.

[4] E.Adib and H. Farzanehfard, “New zero current transition PWMconverters,” in Proc. IEEE ICIT Conf., 2006, pp. 2131–2136.

[5] E. Adib and H. Farzanehfard, “Family of zerocurrent transition PWM converters,” IEEE Trans. Ind. Electron., vol. 55, no. 8, pp. 3055–3063, Aug. 2008

[6] E. Adib and H. Farzanehfard, “Family of Isolated Zero Current Transition PWM converters,” journal of power Electronics, vol. 9, No. 2,March 2009.

[7] Jiuchun Jiang; Weige Zhang; Bo Shen, “Analysis and design of a novel ZCT-PWM converter,” IEEE PEDS Conf , Vol.1,pp. 126 – 130, 2003.

[8] E. Adib and H. Farzanehfard, “Family of zero current zero voltage transitionPWM converters,”.IET Power Electron, Vol. 1, No. 2, pp. 214–223, 2008.

[9] Pritam Das, Gerry Moschopoulos, “A Comparative Study of Zero-Current TransitionPWM Converters,” Power Electronics Conference and Exposition, 2006.

[10] G. Ivensky, D. Sidi, and S. B. Yaakov, “A softswitcher optimized for IGBTs in PWM topologies,” in Proc . IEEE APEC, 1995, pp. 900-906.

[11] R. C. Fuentes and H. L. Hey, “A comparative analysis of the behavior and of the switching losses for a group of ZCS-PWM converters using IGBTs,” in Proc. IEEE PESC, 1997, pp. 972–977.

[12] Fuentes, R.C.; Hey, H.L, “An improved ZCSPWM commutation cell for IGBT’s application,” IEEE Trans. Power Electron., vol. 14, no. 5, pp. 939–948, Sep. 1999.

[13] A. K. Panda and Aroul. K; “A Novel Technique to Reduce the Switching Losses in a Synchronous Buck Converter”.International conference on power electronics, Drivers and energy systems, PEDES,2006, P1-5.