QUID 2017, pp. 1094-1101, Special Issue N°1- ISSN: 1692-343X, Medellín-Colombia

ANALYSIS OF RESONANT BUCK-BOOST CONVERTER WITH THE POSITIVE VOLTAGE

(Recibido el 2-06-2017. Aprobado el 20-9-2017)

Abdolrasool Roostazadeh Sheikh Yousefi
Department of Electrical Engineering,
Department of Electrical, Najaf Abad Branch, Islamic Azad University, Najafabad, Iran
abdolrasool.rst@gmail.com

Masoud Jabbari
Department of Electrical Engineering,
Department of Electrical, Najaf Abad Branch, Islamic Azad University, Najafabad, Iran
jabbari.masoud@gmail.com

Resumen. En este trabajo se proporciona un convertidor resonante de elevación de buck-boost que un tanque resonante LC realiza la transmisión y el control de potencia mediante un inversor de medio puente. Con la utilización de elementos parasitarios y el método de conmutación de conmutadores, la posibilidad de creación de condiciones ZVS se proporcionan al encender y apagar instancia de conmutadores que estas condiciones serán revisadas mediante la comprobación de los diferentes modos de conversión y expresión de relaciones matemáticas. Las ventajas de este convertidor, podemos notar a la protección inherente del cortocircuito de la salida ya la ganancia positiva del voltaje. Al final, después de revisar este convertidor con el uso del software OrCAD, el convertidor resonante de buck-boost ha simulado y los resultados confirman las condiciones de conmutación suave para los interruptores.

Abstract. In this paper, a resonant buck-boost converter is provided that a LC resonant tank does transmission and power control by a half-bridge inverter. With using parasitic elements and switching method of switches, the possibility of creation of ZVS conditions are provided at turning on and off instance of switches that these conditions will be reviewed by checking of the different modes of converter and expression of mathematical relations. The advantages of this converter, we can note to inherent output short circuit protection and the positive voltage gain. In the end, after reviewing of this converter with using OrCAD software, the resonant buck-boost converter has simulated and the results confirm the conditions of soft switching for the switches.

Keywords: Resonator Converter, Soft Switching, Buck-Boost

Citar, estilo APA: Yousefi, A. & Jabbari, M. (2017). Analysis of resonant buck-boost converter with the positive voltage. *Revista QUID (Special Issue).* 1094-1101.

1. INTRODUCTION

Soft switching converters are increasingly attracted to the designers of switching power supplies. In soft switching converter due to the elimination of capacitive losses of switches, is increased the converter frequency. So by increasing the switching frequency, the reactive elements of circuit such as transformers, inductors and capacitors are reduced that the converter in less size and weight will be resulted (Kazimierczuk & Czarkowski, 2012) that it is very suitable for portable applications. This position will be generally created by switching at zero voltage (ZVS) or zero current switching (ZCS) (Mohan, Tore, Undeland & William, 2001).

Zero voltage switching (ZVS) often depends on isolated gate bipolar transistor structure (IGBT), because with this method the losses of the comet current during the off time can be greatly reduced. As well as to reduce the stress current and conduction losses should prevent the unnecessary energy cycle, that for this purpose we can use the Unidirectional switches like RB-IGBT (Jabbari, Hosein & Ghazanfar, 2010), (Jabbari & Hosein, 2010) or a diode in series with the switch. In this paper to get single-way switch, there is a diode in series with a MOSFET.

Resonant converters are a family of soft switching converters that in these converters, resonant tank provides soft switching conditions. One of the benefits of resonant converters is using parasitic elements that in normally may be the parasitic elements cause to disrupt circuit performance (Batarseh, 1994). In the resonant converter, input power is transmitted to the output through the resonant tank, so in these converters the resonance frequency and switching frequency also have an important role in control of power transmission (Deng, Li, Hu, Mi & Ma, 2014).

In general, resonant converters can be configured into three categories (Steigerwald, 1988):

1) Series resonance converters: In these converters are used a series inductor and capacitor and the load is series with the resonant tank too. The converters of this type are known by the names SRC or SLR. Often the soft switching which is used in these types of converters is ZCS and therefore the current waveform of switches is sinusoidal.

2) Parallel resonance converters: In these kinds of converters, resonance tank is parallel and the load is parallel with the tank too. Basis converters of this type are known by the names of the PRC and PLR. Often in these types of converters, the ZVS soft switching are used and therefore voltage waveform across the switches is sinusoidal (lu, Liu, Liang, Lee, & van Wyk, 2006).

3) Series-parallel resonance converters: In these converters the complex resonance circuits is used. The simplest case is being both series and parallel tanks. Analysis of these converters is often very difficult. In naming of theses converters, the number of inductors and capacitors generally are referred for example we can note to resonant LLC or LCC converters (Choi, 2007).

In this paper, a Gm buck-boost converter is provided which is similar to SCR converter and includes Passive elements, a high frequency resonant tank, half-bridge converter, output one-sided switches and capacitor filter. Switches of half-bridge converter provide on and off ZVS conditions in switching times without depending on the load current and operational voltage; Output diode operates under ZVS operation too and the converter in output short circuit will be automatically stopped.

2. PROPOSED BUCK-BOOST CONVERTER

Figure 1 shows the proposed converter topology. In this converter, three MOSFET is used that Q_1 and Q_2 are half-bridge branch MOSFETs and Q_2 and Q_3 are turned off and on simultaneously. Diode in series with the MOSFET Q_3 is used for doing one-way switch Q_3. To evaluate the performance of the converter, different modes of circuit and mathematical relationships have described.

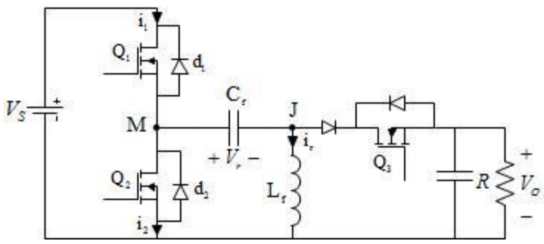


Figure 1. Proposed resonant buck-boost converter

2.1 Performance of proposed converter

To simplify the analysis, we assume that the converter is in steady-state and all circuit elements are ideal. The output capacitor has suggested too large to remain the output voltage constant at a switching period.

$$\omega_r = \frac{1}{\sqrt{L_r . C_r}} \tag{1}$$

$$f_r = \frac{1}{T} = \frac{\omega_r}{2\pi} \tag{2}$$

$$r = \frac{R}{Z_r} \tag{3}$$

$$A = V_O / V_S \tag{4}$$

$$Z_r = \sqrt{\frac{L_r}{C_r}} \tag{5}$$

Suppose that before the first case, the voltage resonance (V_r), is $-V_O$ and the resonance current (i_r), is zero and turned off Q_1 and Q_2 and Q_3 .

The converter operation can be checked in seven states under review.

Mode 1($t_1 - t_2$):

In the beginning of this mode (the moments between t_6' to t_0) the parallel-reverse diode of switch Q_1 conducts. So if in this interval from the moment of t_6' to t_0 , has been commanded to Q_1 to be turning on, this switch is turned on under ZVS. At the moment of t_0 , the current through of Q_1 will be positive and the switch starts to conduct and the capacitor C_r resonances with inductor Lr. At the end of this mode, before the i_r being zero, the Q_1 is turned off. The capacitor C_1 , almost keeps constant the voltage of switch Q_1 during its turning-off and therefore, Q_1 is turned off under ZVS. Figure 2 shows the equivalency circuit of this mode.

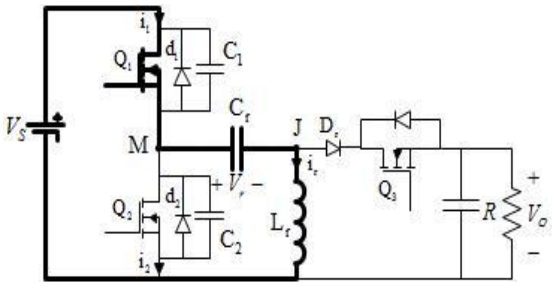


Figure 2. Equivalent circuit mode 1

The initial conditions and circuit relations of this mode are as follows:

$$\begin{cases} i_r(t_0) = 0 \\ v_r(t_0) = -V_7 \times V_S \end{cases} \tag{6}$$

$$I(t) = (1 + V_7).\sin(\omega_r(t - t_0)) \tag{7}$$

$$\Rightarrow V_1 = V(t_1) = 1 - (1 + V_7)\cos(\omega_r(t_1 - t_0)) \tag{8}$$

$$T_1 = t_1 - t_0 = \frac{\varphi_1}{\omega_r} \tag{9}$$

Mode 2($t_1 - t_2$):

This mode that is started at the moment t_1 , has a resonance current that is greater than zero. The remaining current after the second t_1 , continues to flow through the C_1 and C_2 , and the voltage V_M is slowly decreased to zero from V_S . Figure 3 shows the equivalent circuit of this mode.

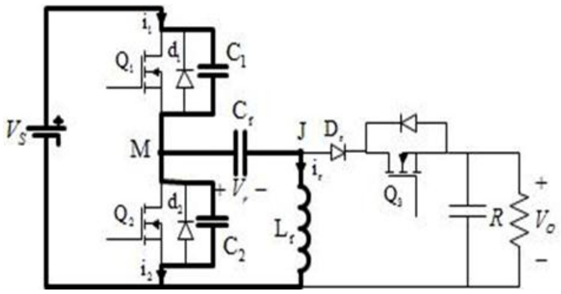


Figure 3. Equivalent circuit mode 2

The initial conditions and circuit relations of this mode are as follows:

$$\begin{cases} I_1 = (1+V_7)\sin\varphi_1 \\ V_1 = 1-(1+V_7)\cos\varphi_1 \end{cases} \tag{10}$$

$$I_r(t) = \frac{(1+V_7)\cos\varphi_1}{\sqrt{1+\alpha}}\sin(\sqrt{1+\alpha}.\omega_r(t-t_1)) + (1+V_7)\sin\varphi_1\cos(\sqrt{1+\alpha}.\omega_r(t-t_1)) \tag{11}$$

$$V_r(t) = \left(-\frac{(1+V_7)\cos\varphi_1}{1+\alpha}\right)\cos(\omega_\alpha(t-t_1)) + \left(\frac{(1+V_7)\sin\varphi_1}{\sqrt{1+\alpha}}\right)\sin(\omega_\alpha(t-t_1)) + \left(\frac{(1+V_7)\cos\varphi_1}{1+\alpha}\right) + V_7 - (1+V_7)\cos\varphi_1 \tag{12}$$

$$\Rightarrow T_2 = t_2 - t_1 = \frac{1}{\omega_\alpha}\cos^{-1}\left(\frac{(1-V_1)\left(\frac{(1+2\alpha)V_1-\alpha}{\alpha(1+\alpha)}\right) - I_1\sqrt{\frac{(1-V_1)^2}{1+\alpha} - \frac{(1+2\alpha)V_1-\alpha}{\alpha^2(1+\alpha)} + I_1^2}}{\frac{(1-V_1)^2}{1+\alpha} + I_1^2}\right) \tag{13}$$

Mode 3($t_2 - t_3$):

When the voltage of M point get to zero, at the moment t_2, the parallel-reverse diode of switch Q_2, is placed forward biased and the inductor current of L_r after passes through the parallel-reverse diode, continues to charge the capacitor C_r, so at the end of this mode, the capacitor C_r will have maximum voltage. In this mode switch Q_2 must be turned on so that it has been turned on under ZVS. Although in this mode any current does not pass of switch Q_2. The current of i_r will be zero at the moment t_3 and direction of current in the next mode will be reversed and will pass of switch Q_2. Figure 4 shows the equivalent circuit of this mode.

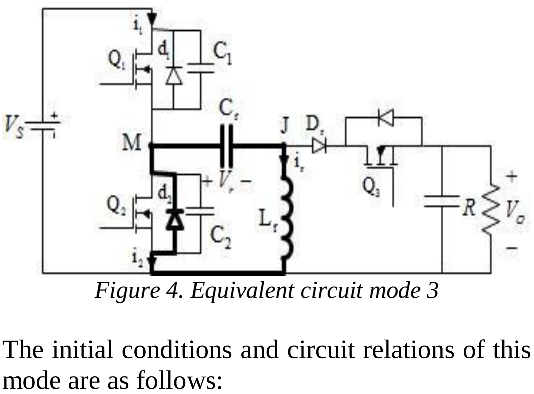


Figure 4. Equivalent circuit mode 3

The initial conditions and circuit relations of this mode are as follows:

$$\begin{cases} I_2 = \frac{(1+V_7)\cos\varphi_1}{\sqrt{1+\alpha}}\sin(\sqrt{1+\alpha}.\varphi_2) + (1+V_7)\sin\varphi_1\cos(\sqrt{1+\alpha}.\varphi_2) \\ V_2 = \frac{(1+\alpha)V_1}{\alpha} \end{cases} \tag{14}$$

$$I(t) = I_2\cos(\omega_r(t-t_2)) - V_2\sin(\omega_r(t-t_2)) \tag{15}$$

$$V(t) = \frac{v_r(t)}{V_S} = I_2\sin(\omega_r(t-t_2)) + V_2\cos(\omega_r(t-t_2)) \tag{17}$$

$$(57-4) \Rightarrow T_3 = t_3 - t_2 = \frac{1}{\omega_r}\tan^{-1}\frac{I_2}{V_2} \tag{18}$$

Mode 4($t_3 - t_4$):

At the moment t_3 the switch Q_2 is turned on under ZVS. The voltage polarity of C_r through of resonance with L_r will start to reverse until the amount of V_r get to $-V_O$ at the moment t_4. So we can say that the stored energy of C_r and L_r are transmitted to the output at the moment t_4. Although in this mode the switch Q_3 is turned on simultaneously with Q_2, but because of the diode D_r is reverse biased, does not pass any current of that branch. Duration of this mode are defined $\frac{\varphi_d}{\omega_r}$. Figure 5 shows the equivalent circuit of this mode.

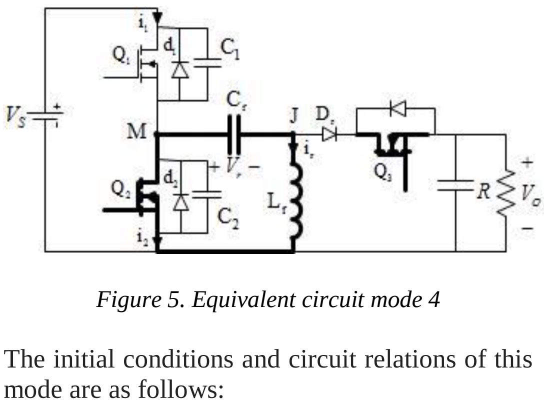


Figure 5. Equivalent circuit mode 4

The initial conditions and circuit relations of this mode are as follows:

$$\begin{cases} I_3 = 0 \\ V_3 = \gamma \end{cases}$$

(18)

$$V(t) = V_3 \cos(\omega_r (t - t_3))$$

(19)

$$I(t) = -V_3 \sin(\omega_r (t - t_3))$$

(20)

$$T_4 = \frac{\varphi_d}{\omega_r}$$

(21)

Mode 5($t_4 - t_5$):

When the voltage of resonant capacitor (according to the polarity shown on the fig), is $-V_o$ at the moment t_4, the diode D_r is placed forward biased, and because the switch Q_3 was already on in before mode, power transmission to the load is occurred. So, V_{Lr} and V_r in the amounts of V_O and $-V_O$, have respectively clamped and stored magnetic energy of L_r is transferred to output. The current of i_r has decreased in linear form, but it will not be zero until the end of this mode. The switch Q_2 will be off at the end of this mode and because the capacitor C_2, fix the voltage across of switch Q_2 during its turning on, the switch Q_2 is turned off under ZVS. The duration of this mode is defined φ_3 / ω_r . Figure 6 shows the equivalent circuit of this mode.

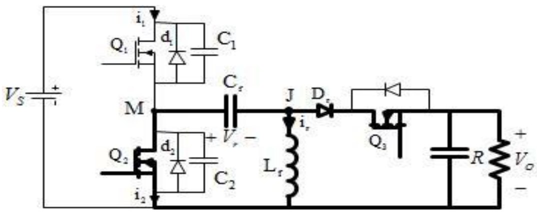


Figure 6. Equivalent circuit mode 5

The initial conditions and circuit relations of this mode are as follows:

$$\begin{cases} I_4 = -V_3 \sqrt{1 - \dfrac{A^2}{V_3^2}} \\ V_4 = -A \end{cases}$$

(22)

$$I(t) = I_4 + A\omega_r (t - t_4)$$

(23)

$$T_5 = \frac{\varphi_2 - \varphi_d}{\omega_r} = \frac{\varphi_3}{\omega_r}$$

(24)

$$V_{L_r}(t) = V_O$$
$$V_r(t) = -V_O$$

(25)

Mode 6($t_5 - t_6$):

At the moment t_5, the switches Q2 and Q3 are turned off and the remaining current of ir, will flow to C1 and C2. Figure 7 shows the equivalent circuit of this mode.

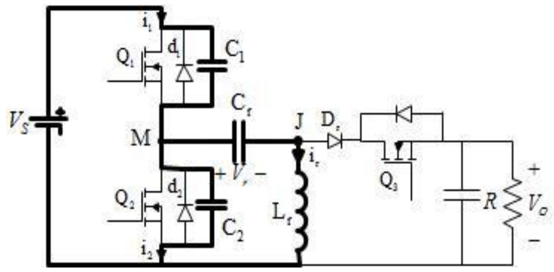


Figure 7. Equivalent circuit mode 6

The initial conditions and circuit relations of this mode are as follows:

$$\begin{cases} I_5 = I_4 + A\varphi_3 \\ V_5 = -A \end{cases}$$

(26)

$$\Rightarrow \; I(t) = \frac{A}{\sqrt{1+\alpha}} \sin(\sqrt{1+\alpha}.\omega_r (t - t_5)) + I_5 \cos(\sqrt{1+\alpha}.\omega_r (t - t_5))$$

(27)

$$\Rightarrow T_6 = \frac{1}{\omega_\alpha} \cos^{-1}\left(\frac{\alpha A(\alpha A + \alpha + 1) - \alpha(1+\alpha) I_5 \sqrt{\alpha^2 I_5^2 - (2\alpha A + \alpha + 1)}}{(\alpha.A)^2 + \alpha^2 (1+\alpha) I_5^2} \right)$$

(28)

$$V_{C_r}(t) = \frac{A}{1+\alpha}(1 - \cos(\omega_\alpha (t - t_5)) + \frac{I_5}{\sqrt{1+\alpha}} \sin(\omega_\alpha (t - t_5)) - A$$

(29)

Mode 7($t_6 - t_7$):

At the moment $t = t_6$ the M point voltage reaches to Vs and the parallel-reverse diode of switch Q1 is forward biased and the resonant current is reduced Sinusoidal, until at the moment t_7, the resonance current will be zero. So if the switch Q_1 has been turned on during this mode, the switch has turned on under ZVS. Figure 8 shows the equivalent circuit of this mode.

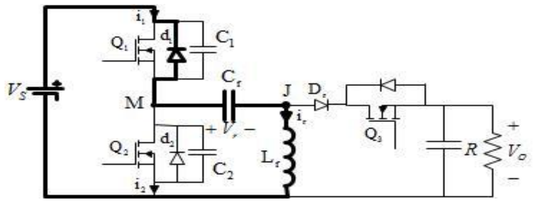


Figure 8. Equivalent circuit mode 7

The initial conditions and circuit relations of this mode are as follows:

$$\begin{cases} I_6 = \dfrac{A}{\sqrt{1+\alpha}}\sin(\varphi_6) + I_5\cos(\varphi_6) \\ V_6 = \dfrac{A}{1+\alpha}(1-\cos(\varphi_6)) + \dfrac{I_5}{\sqrt{1+\alpha}}\sin(\varphi_6) - A \end{cases} \quad (30)$$

$$I_r(t) = -(1+V_6).\sin(\omega_r(t-t_6)) + I_6\cos(\omega_r(t-t_6)) \quad (31)$$

$$V_C(t) = (1+V_6).\cos(\omega_r(t-t_6)) + I_6\sin(\omega_r(t-t_6)) - 1 \quad (32)$$

$$\Rightarrow T_7 = (t_7 - t_6) = \frac{1}{\omega_r}\tan^{-1}\left(\frac{I_6}{1+V_6}\right) \quad (33)$$

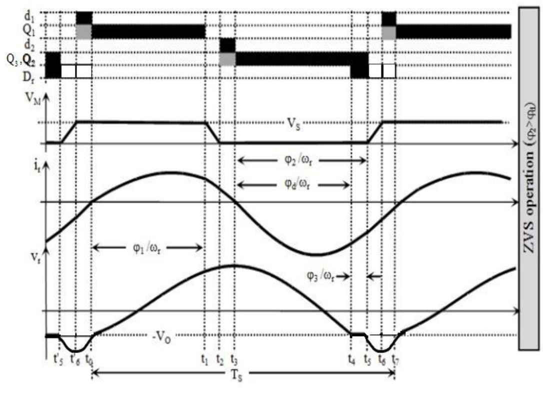


Figure 9. Buck-boost Gm resonant converter steady-state Waveforms

3. THE PROPOSED CONVERTER SIMULATION

Figure 10 shows the schematic simulation of the proposed resonant converter in the OrCAD software. In this application due to considering the elements with real models the results will be very similar to practical results. The following tables (1) and (2), respectively express the considering specifications for designing and the elements used in simulation.

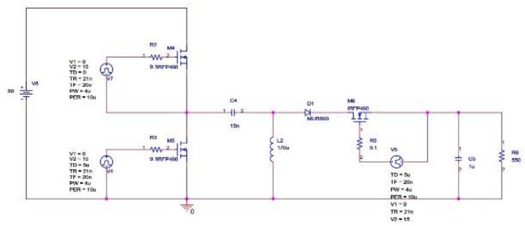


Figure 10. Schematic of the proposed resonant converter in the OrCAD software

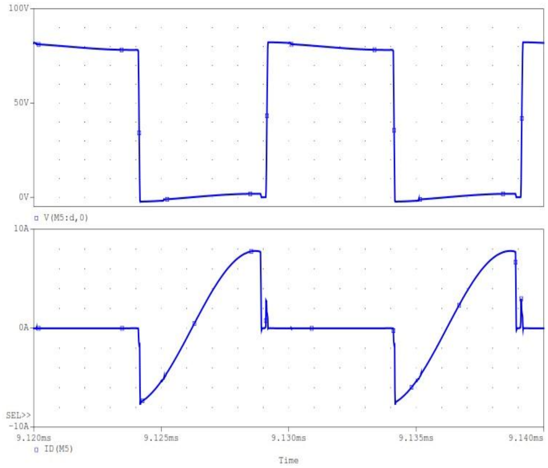
Wanting specification	Amounts
Input voltage V_S	80 V
Output voltage V_O	100 V
Switching frequenc f_S	100 KHz
Resonant frequency f_r	100 KHz
Output power P_O	40 W

Table 1. Designing specifications.

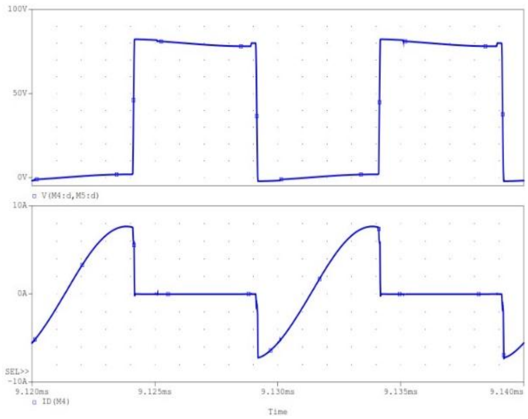
Designing elements	Amounts
Mosfet	IRFP460
Diode	MUR860
Resonant capacitor	15 Nf
Resonant inductor	170 Uf
Output filter capacitor	1 uF

Table 2. Designing elements

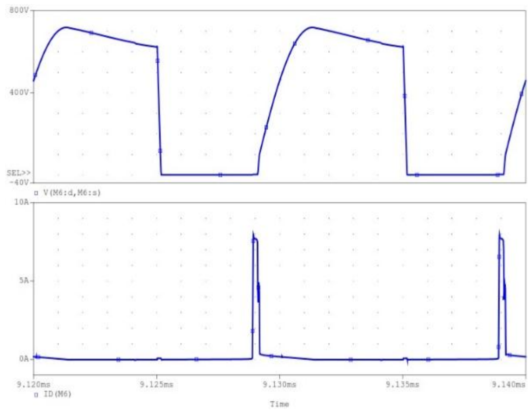
3.1 Results of simulation



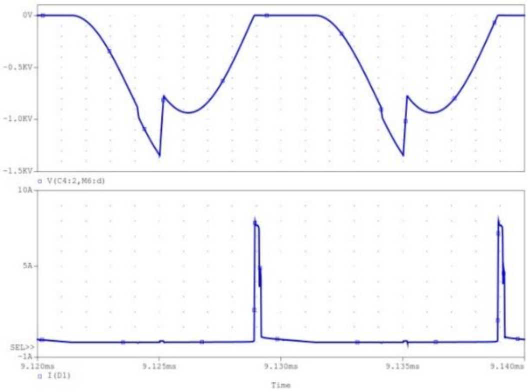
A. *Voltage stress and current of switch* Q_1



B. *Voltage stress and current of switch* Q_2



C. *Voltage stress and current of switch* Q_3



D. *Voltage and current of output diode*

Figure 11. Waveforms of simulation

As you can see in Figures, the switches of half-bridge converter branch, and the output diode and switch have ZVS condition in turning off and on.

4. CONCLUSION

In this paper, a resonant buck-boost converter with the positive voltage has expressed which using a resonant LC tank, a soft switching conditions has been created. All switches are under ZVS at the moment of turning on and off that it has been caused that the switching frequency of converter has been greatly increased. Another advantage of this converter is inherent short-circuit protection. Finally, with simulation of this converter in OrCAD software, the expressed relations have been confirmed.

REFERENCES

Kazimierczuk, M. K. & Czarkowski, D. (2012). *Resonant power converters.* John Wiley & Sons.

Mohan, N., Tore, M. Undeland & William P. Robins. Power electronic. (2001). Grigore, Vlad. Topological issues in single-phase power factor correction. Helsinki University of Technology,

Jabbari, M., Hosein, F. & Ghazanfar, S. (2010). Isolated topologies of switched-resonator converters. *Journal of Power Electronics*, 10(2), 125-131.

Jabbari, M., & Hosein, F. (2010). New resonant step-down/up converters. *IEEE Transactions on Power Electronics* 25(1), 249-256.

Batarseh, I. (1994). Resonant converter topologies with three and four energy storage elements. *Power Electronics, IEEE Transactions*, 9(1), 64-73.

Deng, J., Li, S., Hu, S., Mi, C. C., & Ma, R. (2014). Design methodology of LLC resonant converters for electric vehicle battery chargers. *IEEE Transactions on Vehicular Technology*, 63(4), 1581-1592.

Steigerwald, R. L. (1988). A comparison of half-bridge resonant converter topologies. *Power Electronics, IEEE Transactions*, 3(2), 174-182.

lu, B., Liu, W., Liang, Y., Lee, F. C. Y., & van Wyk, J. D. (2006). Optimal design methodology for LLC resonant converter. *In Applied Power Electronics Conference and Exposition, 2006. APEC'06. Twenty-First Annual IEEE*, pp. 6.

Choi, H. (2007). Analysis and design of LLC resonant converter with integrated transformer. In Applied Power Electronics Conference, APEC 2007-Twenty Second Annual IEEE, pp. 1630-1635.