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ORIGINAL ARTICLE

Research on Boost Soft-switching Converter

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Abstract: In order to improve the circuit working efficiency of zero-voltage zero-current transition Boost converter, an improved modulation strategy was proposed. The main switch can only achieve zero-current turn-on under traditional modulation strategy. However, the change to the turn-on time of main switch and the turn-off time of auxiliary switch can make the main switch achieve zero-voltage zero-current turn-on and the auxiliary switch realize zero-voltage zero-current turn-off in advance as well. The simulation results show that the main switch can achieve zero-voltage zero-current turn-on and the auxiliary switch could realize zero- voltage zero-current turn-off, the circuit working efficiency was improved.

Keywords: boost converter; zero-current turn-on; zero-voltage zero-current turn-off

Introduction

Whether electric appliances and electronic devices can put on the market is related to their performance, size, cost and power consumption[1-2]. But transformers, inductors, and capacitors can hardly meet the need of volume and weight in practical engineering application. With the increase of switch frequency, the voltage and current cannot be zero at the same time, leading to generate overlapping region[3-4], when the switch is turned on(or turned off). The switch working in hard-switching state produce switch loss. The introduction of soft-switching technology can eliminate the power loss of switch completely by adding small inductors, capacitors and other components in the circuit, whose principle is the resonance between the inductor and capacitor[5-6].

Zero transition PWM circuit, including zero-current transition PWM circuit and zero-voltage transition PWM circuit[7-8], is applied extensively in different circuits. There are two methods to improve circuit working efficiency[9], the first method is to improve the modulation strategy, another method is to improve the circuit working efficiency. This study is based on the second method. In paper[10], a zero-current zero-voltage transition PWM boost converter was put forward, which was formed by the application of zero transition circuit into boost converter and whose main switch can achieve zero-current turn-on under traditional modulation strategy. The change to the modulation strategy can make main switch achieve zero-voltage zero-current turn-on and auxiliary switch achieve zero-voltage zero-current turn-off in advance.

1. Boost soft-switching converter working principle and modeanalysis

1.1 Boost Soft-switching Converter Circuit Working Principle

The boost soft-switching converter in figure 1 is the circuit proposed in paper[9], which contains zero-current transition PWM circuit within the dotted line. The zero-current transition PWM circuit is applied into boost circuit, which can get zero-current turn-on and zero-voltage turn-off of main switch S1 and zero-current turn-on and zero-current zero-voltage

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turn-off of auxiliary switch S2. The input inductor is split into two split inductors L1、L2, while the resonant branch consist of two diodes D1、D3, resonant inductors L1、L2、L3, resonant capacitor C1 and auxiliary switch S2 with anti-parallel diode.

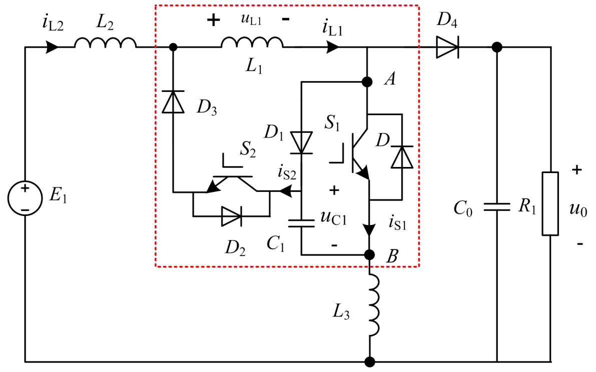


Figure. 1: Boost soft-switching converter

1.2 Mode analysis

The electronic devices in the circuit can be regarded ideally, the photovoltaic arrays are considered as ideal voltage source as well. Resonant inductors L1 and L2 are two split inductors of main inductor of boost converter, with a value of L /2， meanwhile， the value of resonant inductor s L1 and L2 are far more than resonant inductor L3, therefore, the resonant inductors L3 is neglected, the circuit has seven circuit working modes:

（1）working mode 1[t0,t1)：

Figure 2 shows the equivalent circuit of mode 1, the voltage of resonant capacitor C1 reach to its peak value U0 before t0. At t0, the auxiliary switch achieve zero-current turn-on. After t0, the current iS2 flowing through auxiliary switch S2 increase nonlinearly and the current flowing through resonant inductor L1 increase linearly, while the current iL2 flowing through resonant inductor L2 decrease linearly and the voltage of resonant capacitor C1 decrease nonlinearly. All the parameters change as following:

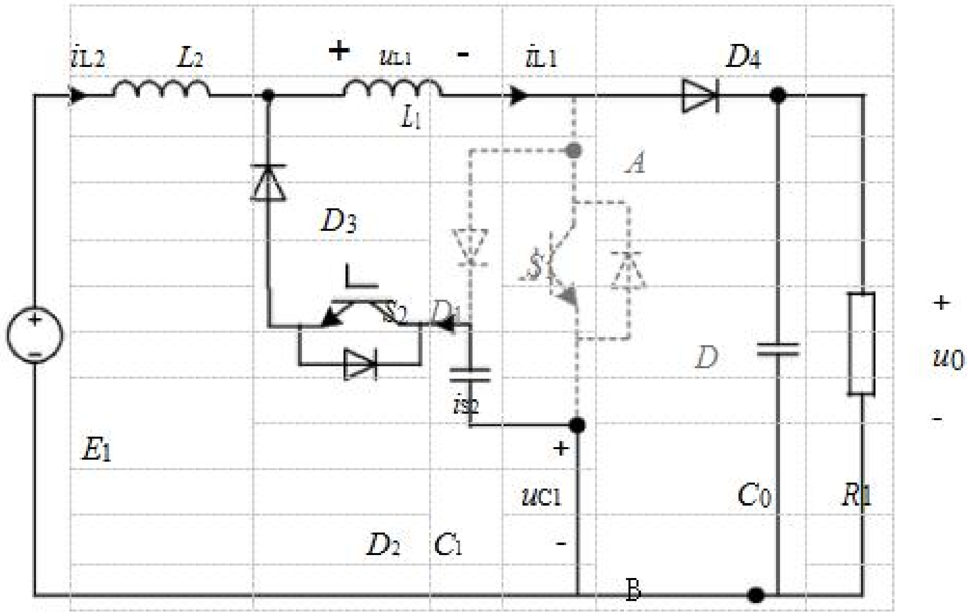
$$u_{L1} = u_{C1} - u_0 \tag{1}$$

$$u_{L1} = L_1 \frac{di_{L1}}{dt} \tag{2}$$

$$i_{L1} = C_0 \frac{du_{C0}}{dt} + \frac{u_0}{R_1} \tag{3}$$

The followings can be obtained from the formulas (1)、(2)、(3)：

$$\frac{di_{L1}}{dt} = \frac{2u_{L1}}{L} \tag{4}$$



$$\frac{du_{C0}}{dt}=\frac{1}{C_0}i_{L1}-\frac{u_{C0}}{R_1C_0} \tag{5}$$

Figure. 2: Boostsoft-switching converter

（2）working mode 2[t1,t2)：

At t1, the main switch S1 achieve zero- current turn-on. After t1, the current iS1 flowing through main switch S1 increase linearly and the diode D4 cut off. The resonant capacitor C1 continues to discharge to inductors L1 and L2, the current iL1 flowing through resonant inductor L1 increase linearly, while the current iL2 flowing through resonant inductor L2 decrease slowly. The voltage of resonant capacitor C1 decrease nonlinearly till t2, at which the voltage uC1 of resonant capacitor C1 reach to zero and the current iS1 flowing through main switch S1 reach its maximum. The variation of some parameters change as following formulas:

$$L_2\frac{di_{L2}}{dt}+L_1\frac{di_{L1}}{dt}=E_1 \tag{6}$$

$$\frac{du_{C0}}{dt}=\frac{1}{C_0}i_{L1}-\frac{u_{C0}}{R_1C_0} \tag{7}$$

（3）working mode 3[t2]：

The voltage uC1 of resonant capacitor C1 become zero at t2, the diode D1 is on conduction.

（4）working mode 4(t2,t3)：

After t2, resonant inductor L1 start to charge to resonant capacitor C1, the voltage between diode and resonant capacitor C1 is zero. According to Kirchhoff laws, the current iS1 flowing through main switch S1 decrease rapidly, while the current iS2 flowing through auxiliary switch S2 decrease gradually. In addition, the current of resonant inductor L1 keep constant, the current flowing through resonant inductor L2 increase until t3, when the current of two resonant inductors are same, the circuit turns into next working mode.

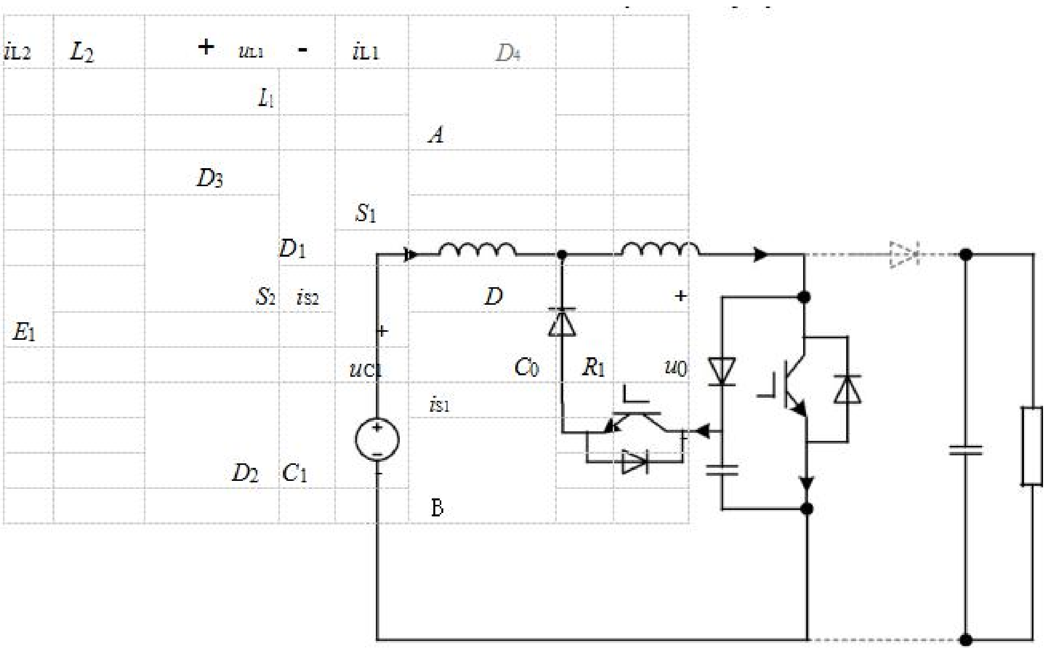


Figure. 3: Working mode 2[t1,t2)

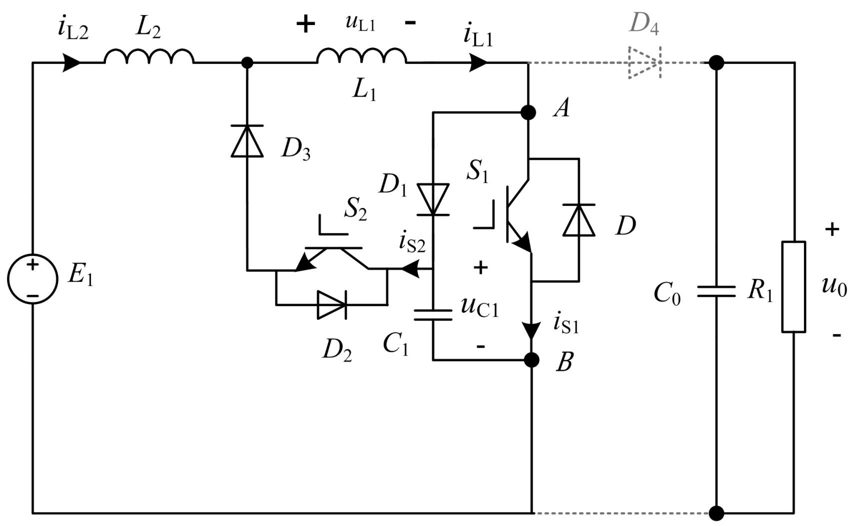


Figure. 4 Working mode 3[t2]

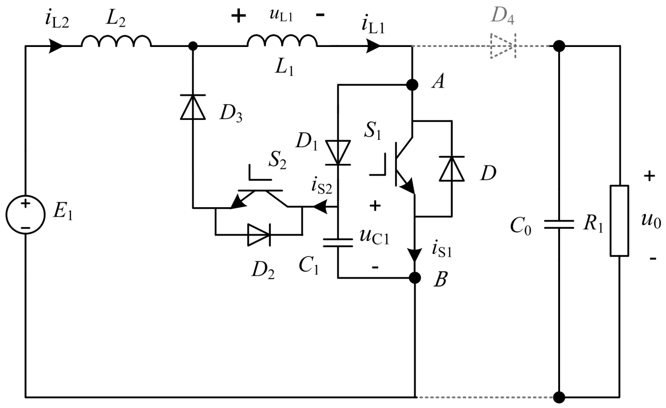


Figure. 5 Working mode 4(t2,t3)

（5）working mode 5[t3,t4)：

At t3, the current iL2 flowing through resonant inductor L2 equals the current iL1 flowing through resonant inductor L1, the diodes D1 and D2 cut off, so the current iS2 of auxiliary switch S2 become zero. After t3, the current of resonant inductors L1 and L2 increase gradually.

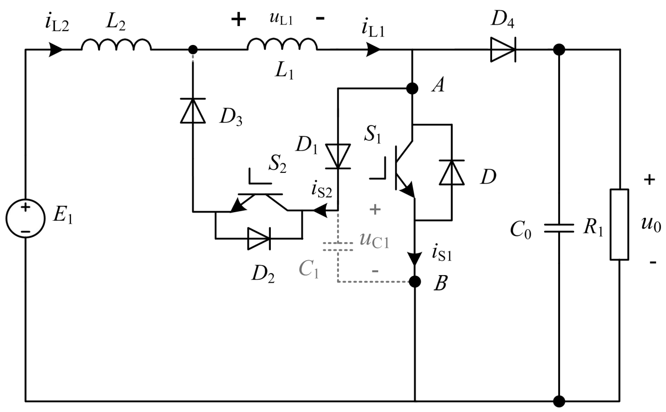


Figure. 6 Working mode 5[t3,t4)

（6）working mode 6[t4,t5)：

At t4, the current flowing through main switch S1 reach its maximum value, but the current flowing through auxiliary switch S2 become zero, which achieve zero-current turn-off, and the main switch turn off. After t4, the diode D1 is on conduction. The resonance among resonant inductors L1、L2 and resonant capacitor C1 make the voltage uC1 of resonant capacitor C1 increase gradually and the current of resonant inductors L1、L2 decrease slowly till t5, when the voltage uC1 of resonant capacitor C1 reach its peak value U0. All the parameters change as following:

$$\frac{di_{L1}}{dt} = -\frac{1}{L}u_0 + \frac{E_1}{L} \tag{10}$$

$$\frac{du_0}{dt} = -\frac{1}{C_0}i_{L1} - \frac{1}{C_0 R_1}u_0 \tag{11}$$

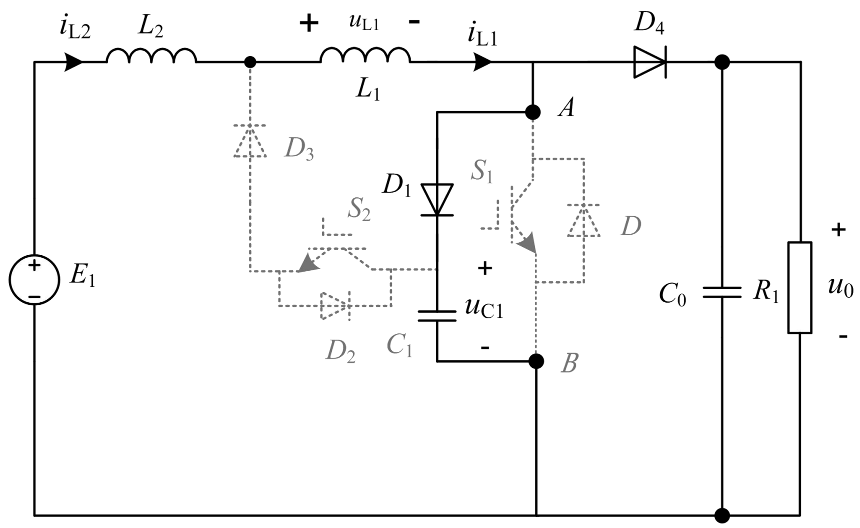


Figure. 7 Working mode 6[t4,t5)

（7）working mode 7[t5,t6)：

At t5, the voltage uC1 of resonant capacitor C1 become maximum, resonant capacitor C1 and direct power supply charge to resonant inductors L1 and L2 until t6. The circuit is equivalent to boost converter, releasing energy in this process. and the circuit turn into next working cycle.

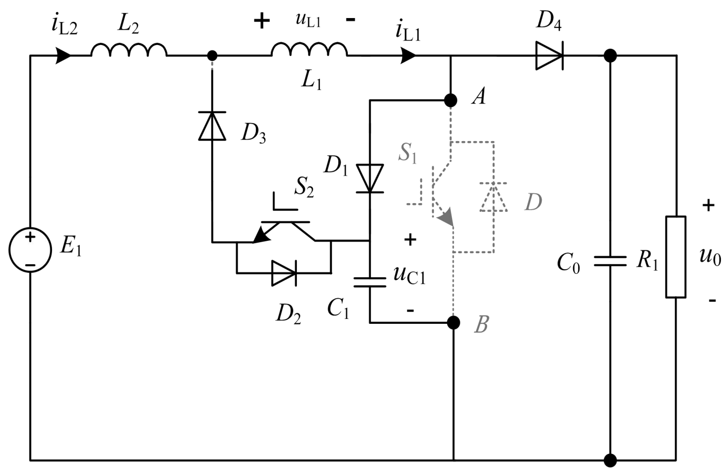


Figure.8 Working mode 6[t5,t6)

2. Traditional modulation strategy

The main switch S1 can only achieve zero-current turn-on at t1 from mode 3, but both of the current and the voltage of main switch S1 are zero, so it can achieve zero-current zero-voltage turn-on at t2. The current and voltage of auxiliary switch S2 are zero at t3 from mode 5, so it can achieve zero-current zero-voltage turn-off. Figure 9 illustrates traditional modulation strategy, whose solid arrow indicates the turn-on time of main switch and the turn-off time of auxiliary switch needed to improve. Furthermore, the dotted line shows the direction needed to change.

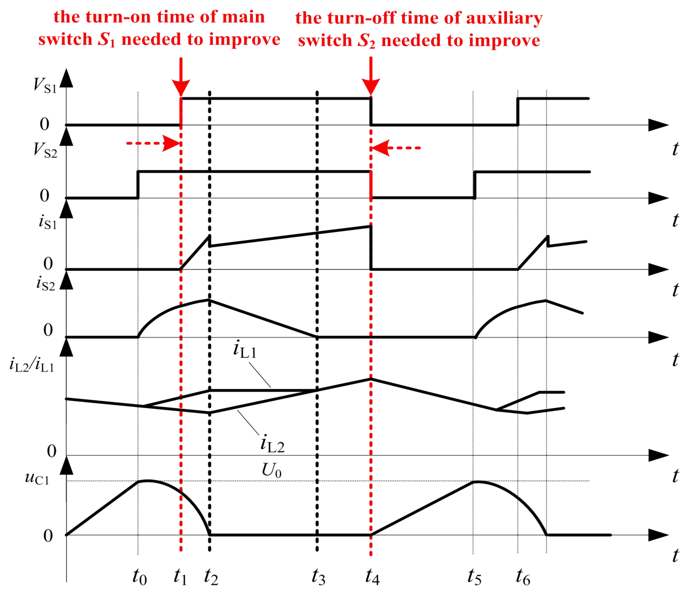


Figure. 9 Traditional modulation strategy

3. Improved modulation strategy

The main switch S1 in figure 9 can only achieve zero-current turn-on at t1, however, the improved modulation strategy in figure 10, whose turn-on time of main switch S1 is moved to the right along the abscissa, can make main switch S1 achieve zero-current zero-voltage turn-on. The auxiliary switch S2 in figure 9 can turn off at t4, while the turn-off time of auxiliary switch S2 in figure 10 moves from t4 to t3, with zero-current zero-voltage turn-off. The improved modesare as following：

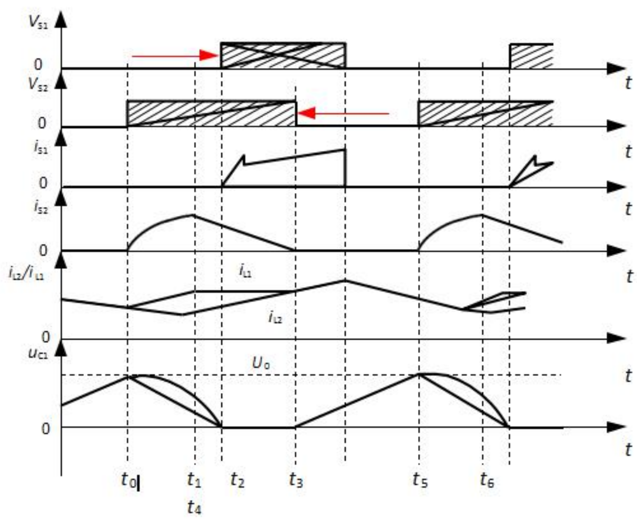


Figure. 10: Improved modulation strategy

（1）working mode 3[t2]：

As the voltage uC1 of resonant capacitor C1 is zero and the diode D1 is on conduction, the voltage between diode D1 and resonant capacitor C1 is zero, meanwhile, the current flowing through the main switch S1 is zero, so it is easily for the main switch S1 to achieve zero-current zero-voltage turn-on.

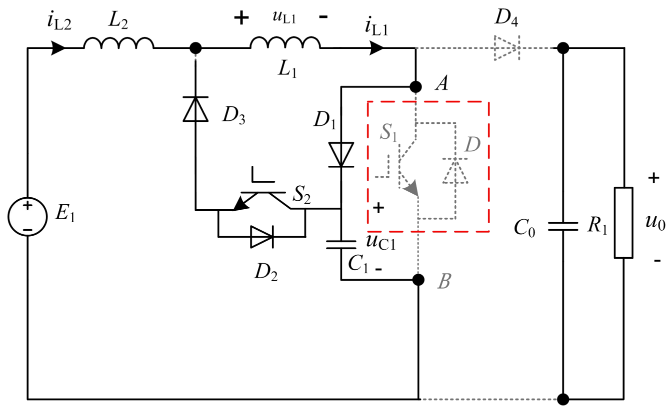


Figure. 11: Working mode 3[t2]

（2）working mode 5[t3,t4)：

At t3, the current flowing through resonant inductor L2 equals the current flowing through resonant inductor L1, so the current of auxiliary switch S2 is zero according to Kirchhoff laws.

In addition, the current flowing through resonant inductor L1 stay constant from t2 to t3, leading to the voltage of auxiliary switch S2 become zero, therefore, the auxiliary switch S2 can achieve zero- current zero-voltage turn-off. After t3, the circuit is equivalent to energy storage process of boost.

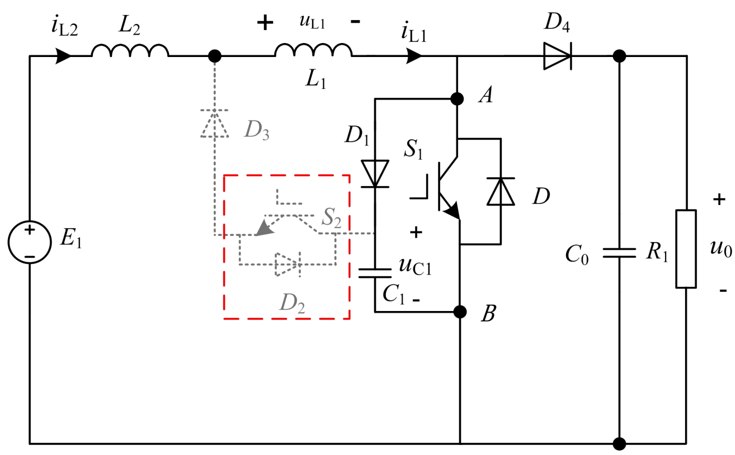


Figure. 12: Working mode 3[t3,t4)

4. Simulation verification：

4.1 Parameter settings

Table 1 is the parameter settings of circuit, whose resonant inductors L1 and L2 are equivalent.

Table 1: Parameter settings

Input Voltage E_1	200V	Resonant Inductor L_3	0.8mH
Ouput Voltage u_0	400V	Resonant Capacitor C_1	0.33uF
Resonant Inductors L_1、L_2	10mH	Frequency f_k	25kHz

4.2 Parameter settings

Figure 13 illustrates main switch and auxiliary switch driving signals of primary circuit, the voltage VP1 and the current I1 of main switch, the main switch S1 can only achieve zero-current turn-on.

Figure 14 illustrates main switch and auxiliary switch driving signals of improved circuit, the voltage VP1 and the current I1 of main switch, the main switch S1 can achieve zero-current zero-voltage turn-on at t2.

Figure 15 shows main switch and auxiliary switch driving signals of primary circuit, the voltage VP2 and the current I2 of auxiliary switch, the auxiliary switch S2 can achieve zero-current zero-voltage turn- off at t4.

Figure 16 shows main switch and auxiliary switch driving signals of improved circuit, the voltage VP2 and the current I2 of auxiliary switch. Compared to figure 15, the auxiliary switch S2 in figure 16 can achieve zero-current zero-voltage turn-off before t4.

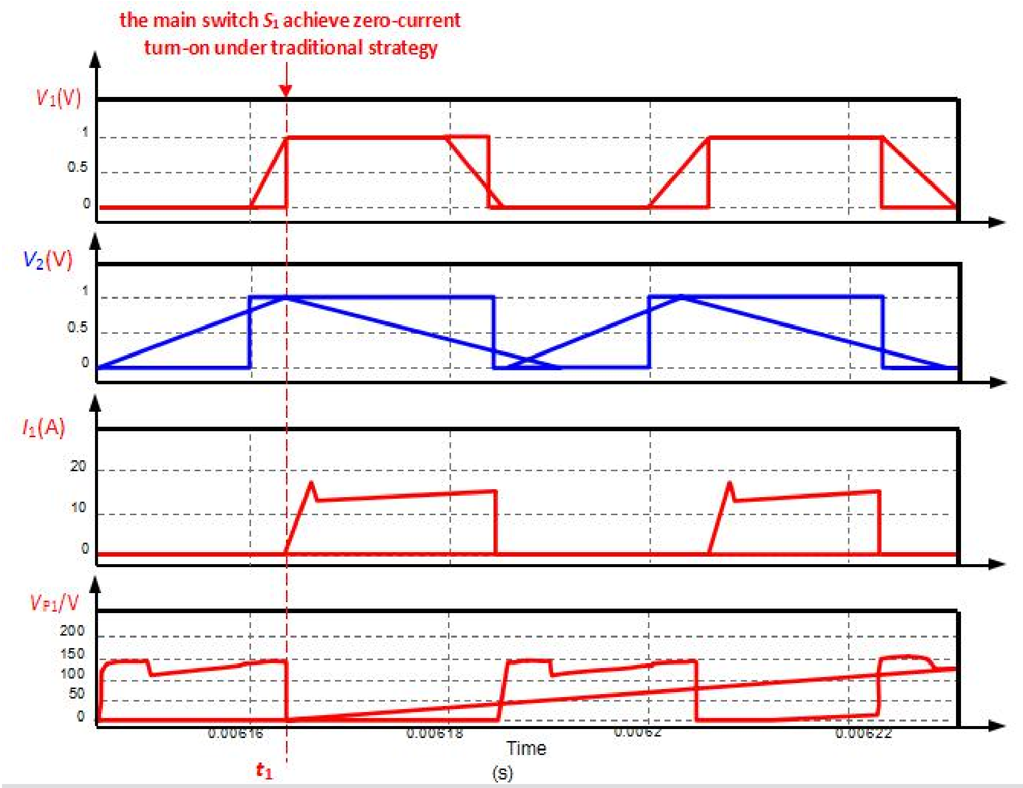


Figure. 13: Driving signals of primary circuit and the voltage and current of main switch

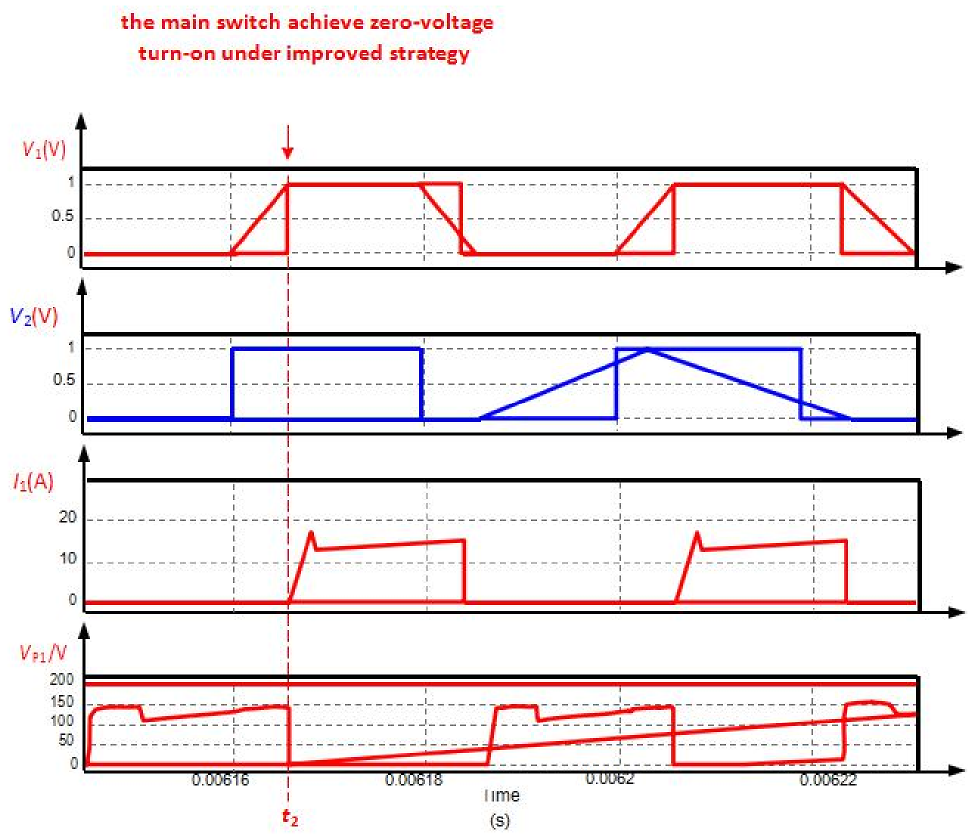


Figure. 14: Driving signals of improved circuit and the voltage and current of main switch

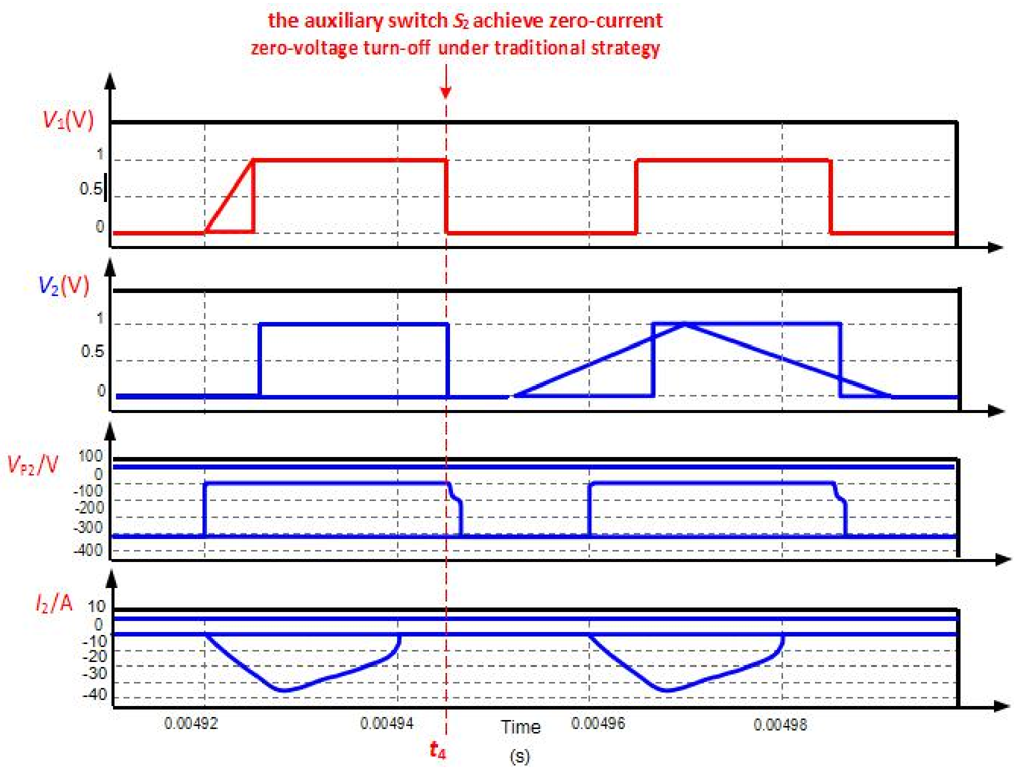


Figure. 15: Driving signals of primary circuit and the voltage and current of auxiliary switch

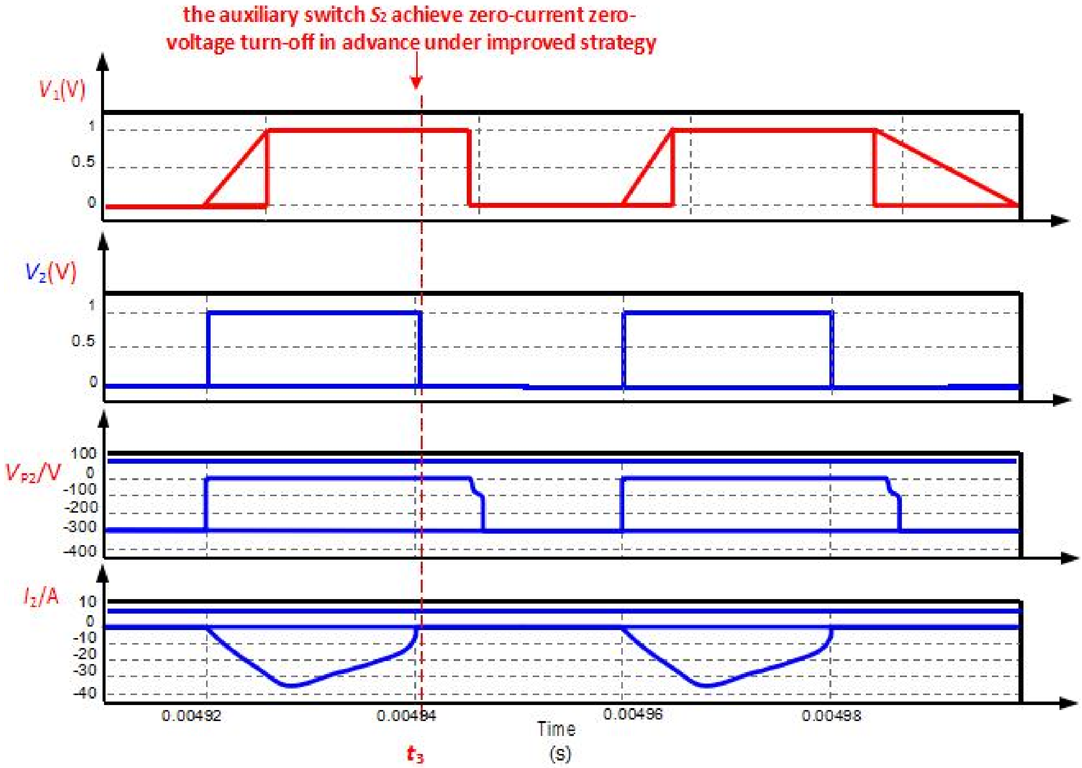


Figure. 16: Driving signals of improved circuit and the voltage and current of auxiliary switch

Compare figure 13 with figure 14, it is obvious that the energy stored in resonant capacitor C1 is transferred to resonant inductor completely at t2. The voltage between diode D1 and resonant capacitor C1 is zero, while the current flowing through main switch S1 is zero.Therefore, it is easily for the main switch S1 achieve zero-current zero-voltage turn-on. Compare figure 14 with figure 15, it is apparent that the auxiliary switch S2 achieve zero-current zero-voltage turn-off at t3 under the improved driving signals of main switch and auxiliary switch.

At t3, the current of resonant inductor L2 is equivalent to the current of resonant inductor L1 and the current flowing through auxiliary switch S2 is zero. As the current flowing through resonant inductor L1 stay constant from t2 to t3, so the voltage of auxiliary switch S2 is zero, which can achieve zero-current zero-voltage turn-off at t3.

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