

## Simulation of ZVS Converter and Analysis of Its Switching Loss Based on PSPICE

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### ABSTRACT

The working principle of Zero Voltage Switch (ZVS) inverter is presented in this paper. Simulations of the model are carried out with PSPICE. The loss of the inverter is analyzed with taking the actual situation into consideration. It is worthiness to practical engineering application

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### Keyword:

ZVS inverter  
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## 1. INTRODUCTION

The efficiency of small power soft switching source is about 80%-85% with the development of high frequency inverter. In order to enhance the efficiency and power density, choosing the proper devices and designing the heat dissipation, it is necessary to study the loss of the system[1].

In the part of power devices with IGBT, the loss can be divided into four parts: conduction loss, off-state loss, turn-on loss and turn-off loss. The loss is the conduction loss when switches are in the conduction state. The off-state loss is caused by the leakage current when switches are in the off state.

Zero Voltage Switch (ZVS) inverter is a typical kind of soft switches. PSPICE is powerful software of circuit-simulator. The variables in ZVS circuit can be observed with PSPICE. The series resonance soft switching technology is used ZVS inverter. Since the IGBT is turned off by zero voltage, conduction loss, off-state loss and turn-on loss are only taken into consideration. Mathcad is a interactive numerical calculation system, which is very convenient to solve formulas, equations set and matrixes.

## 2. ZVS INVERTER WORKING PRINCIPLE

ZVS PWM inverter is an excellent soft switch circuit, which can reduce the voltage stress and conduction loss in quasi resonant circuit. It can achieve good performance and stability in high frequency by adjusting the duty circle and optimizing circuit parameters[2]. In ZVS inverter, the zero voltage, which is used to control switches, is implemented through leakage inductance (or series inductance in the primary side) and parasitic capacitance in the power transistors (or external capacitor).

The circuit diagram is shown in Fig. 1. D1~D4 are the internal parasitic diodes of Q1~Q4. C1~C4 are the parasitic capacitances.  $L_r$  is the resonance inductor which includes the leakage inductor of the transformer. The two power transistors in each leg are conducted 180 degrees complementary. The output voltage can be adjusted by change the phase-shift within conducting two legs. The leg with Q1 and Q3 are the leading-leg. The another with Q2 and Q4 is the lagging-leg. The former has a leading angle. When the  $L_f$  is big enough, the filter inductor can be taken as a constant current source which value is equal to the load current.  $R$  is the load and  $C_f$  is the filter capacitor.

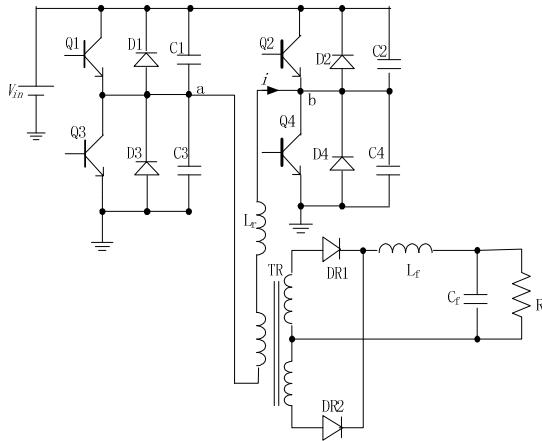


Fig. 1 Circuit diagram of ZVS inverter

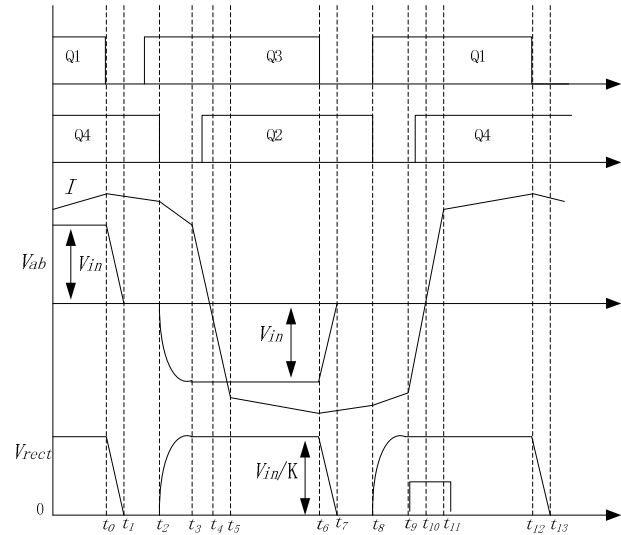


Fig. 2 Main waveform of the circuit simulation

The simulation waveform in circuit is shown in Fig. 2. Q1 is turned off when time is  $t_0$ . The primary current transfers from Q1 to the branch of C3 and C1 in the period of  $t_0$ — $t_1$ . C3 is discharged when C1 is charged. Q1 is the zero-voltage turn-off under the influence of C1 and C3. The voltage of C3 drops to zero when time is  $t_1$ . At the same time, D3 and Q3 are turned on. Q3 is zero-voltage turn-on. The primary current flows from the D3. There is no current in Q3[3].

### 3. RESULTS AND ANALYSIS

#### 3.1. Simulation of the ZVS inverter with PSPICE

In order to verify work principle of the ZVS inverter and make the analysis of inverter losses convenient, the inverter circuit is simulated and analyzed with PSPICE. Simulation model is shown as Fig. 3. Main data used in the simulation are as following:

Input DC voltage: 48V	Output DC voltage: 22V
Output Current: 2.75A	Filter inductance: 60μH
Resonant inductor: 2.7μH	Filter capacitor: 10μF
Resonant capacitor: 650pF	switching frequency: 1MHz

The simulation waveform is shown in Fig.4. This is the stable waveform. When switch S1 is turn off, the resonant capacitor limits its voltage rate of rise. The zero-voltage turn-off of Q1 is achieved[5]. When the resonant capacitor voltage is declined to zero, the anti-parallel diode of S1 is turn on. The voltage of Q1 is limited to zero. The opening of S1 is zero-voltage too. The different output voltage is get by changing the duty cycle.

The simulation waveform of ZVS inverter power is shown in Figure 5. The blue line is output power, and the red and yellow one are output power of the two switch tube. As the switching frequency is 1MHz, the cycle is 1μs. It is helpful for loss calculation to analyze the two switching tube efficiency.

As the switching speed of diode is slower than switching tube, most of the inverter switching loss is the tube switching loss. The main reason for the switch loss is the positive and reverse recovery process of diode. The diode which has better recovery performance is chosen generally to reduce the switch loss, such as schottky diodes.

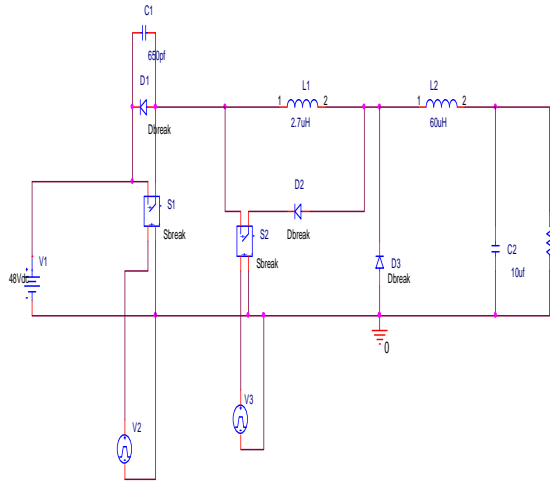


Fig. 3 The simulation model of ZVS inverter

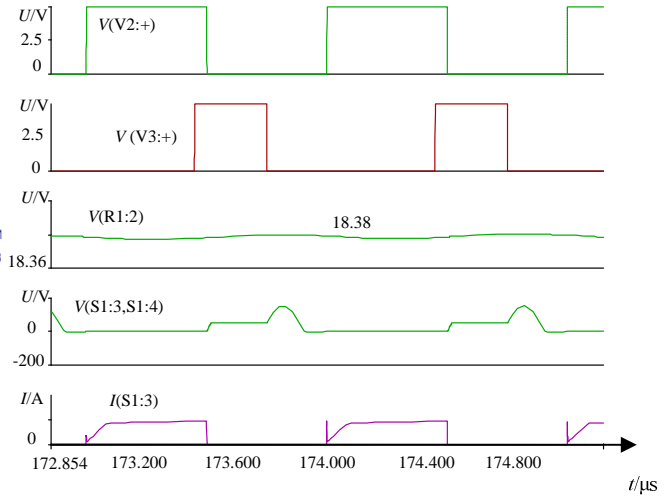


Fig. 4 Simulation waveform of ZVS inverter

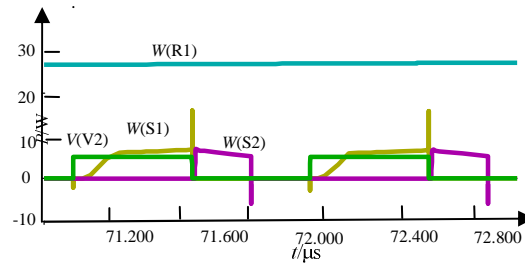


Fig. 5 Power simulation waveform

### 3.2. Calculations of IGBT losses with Mathcad

In order to study the inverter losses, it is necessary to calculate the losses of IGBT with Mathcad. It has some reference value to choose appropriate IGBT and cooling system of inverter. The characteristics curves of IGBT and diode are shown as Fig.6 and Fig.7. When junction temperature is higher, the forward characteristic curve goes to left. The forward voltage drop gets smaller. The influence of temperature on the parameters of devices is not discussed in this paper.

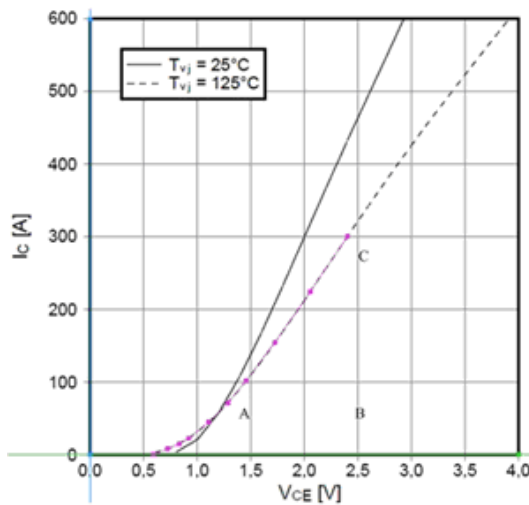


Fig. 6 Forward characteristic curve of IGBT

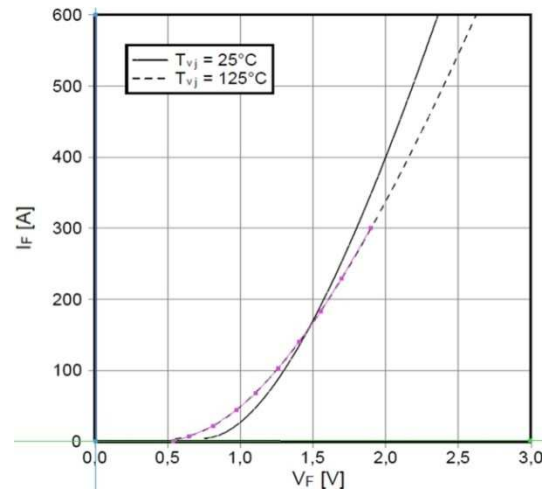


Fig. 7 Forward characteristic curve of diode

FF300R17KE3 diode is selected. The junction temperature is set  $T_{vj}=125$  . To make the calculated losses value more accurately, the curves of  $V_{ce\_igbt}$  and  $I_{igbt}$  are obtained by using the software of GetData Graph. The curve data is displayed in table 1.

Making the following assumptions before the losses of inverter is analyzed[6]:

- not discuss the influence of leakage inductance and other parasitic parameters;
- not discuss the influence of temperature on various parameters of the device;
- ignoring the input voltage ripple and fluctuations.

The calculated formula of  $\phi_b$  is followed like this:

$$\phi_b = \arctan \left( \frac{0.000982 \cdot \pi \cdot f_0 \cdot \frac{I}{\sqrt{2}}}{U} \right) \cdot \frac{180}{\pi} \quad (1)$$

Table 1. The Curve Data of  $V_{ce\_igbt}$  and  $I_{igbt}$

$V_{ce\_igbt}$	$I_{igbt}$
2.401 712 857 1	22.423 982 502
2.055 715 714 2	15.302 194 856
1.749 839 230 4	10.739 204 852
1.439 294 021 1	7.129 240 318 7
1.284 920 342 1	4.483 920 452 2
1.012 948 274 2	2.247 382 944 5
0.923 910 384 8	1.450 294 853 2
0.837 849 321 3	7.934 021 375 4
0.593 802 313 4	5.385 394 857 3

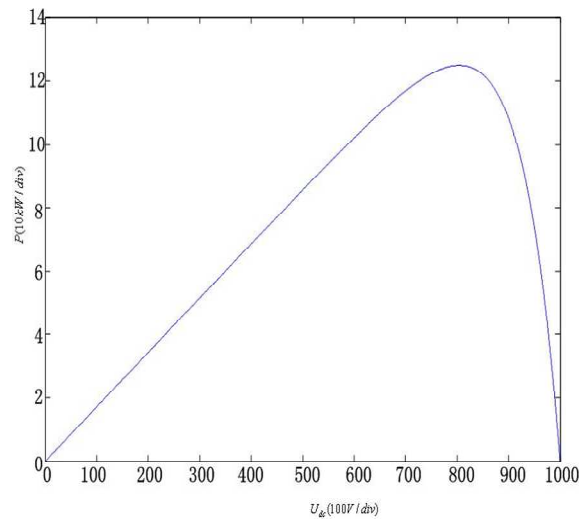


Fig. 8 Characteristic curve of power and voltage

Fig. 8 is the curve of output power. The curve is changed with the voltage. The table 2 can be get by the software of GetData Graph.

Table 2 The Curve Data of  $U_{de}$  and  $P$

$U_{dc}$	$P$
500.000 000 00	859.443 865 89
550.138 294 74	942.845 930 28
603.886 086 34	103.895 478 24
645.573 854 52	110.028 942 09
698.362 137 85	117.149 227 83
753.459 024 21	122.608 490 32
802.472 598 46	125.109 285 74
909.345 728 20	121.938 572 93
923.568 294 23	101.302 983 01
942.648 294 37	942.049 282 93
974.428 476 20	739.102 732 13
993.472 804 38	428.492 109 34
995.382 749 24	298.209 378 00
1 039.847 524 65	106.392 845 03

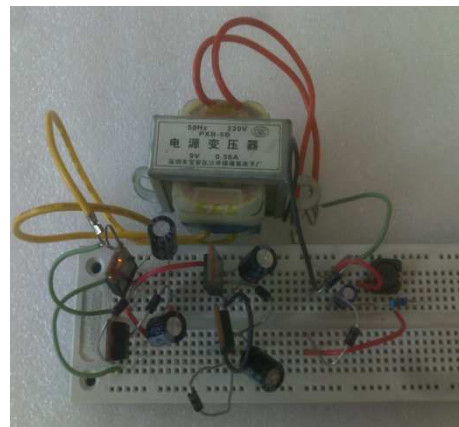


Fig. 9 Figure of experiment equipment

The required parameters can be calculated through the appropriate formula. The formula (2) and (3) are the loss formulas of IGBT and diode[7]. The relevant loss can be calculated and compared with the parameters given by the mill. It is helpful to analyze the loss of ZVS inverter.

$$P_{igbt} = \left( \frac{1}{2 \cdot \pi} + m_b \cdot \frac{\cos(\phi_b)}{8} \right) \cdot V_{ce} \cdot I_m + \left( \frac{1}{8} + m_b \cdot \frac{\cos(\phi_b)}{3 \cdot \pi} \right) \cdot R_{ce} \cdot (I_m)^2 \quad (2)$$

$$P_{diode} = \left( \frac{1}{2 \pi} - m_b \cdot \frac{\cos(\phi_b)}{8} \right) V_f I_m + \left( \frac{1}{8} - m_b \cdot \frac{\cos(\phi_b)}{3 \cdot \pi} \right) R_f (I_m)^2 \quad (3)$$

In the expression,  $m_b$  is the model index for different points, and  $\phi_b$  is the phase angl.

### 3.3. Experiment and analysis

The experiment equipment can be get on the basis of principium of inverter as in Fig.9. It is controlled by PWM pattern. The controlled pulse is showed as Fig.10. There is dead-time in the Figure. In order to avoid the H bridge to turn on at the same time, a guard period must be set. It can effectively avoid the delay effect. The effect can cause that an arm of the bridge do not completely shut off. But another bridge arm is in conducting state. The module cannot be damaged with the guard period. The output voltage is showed as Fig. 11.

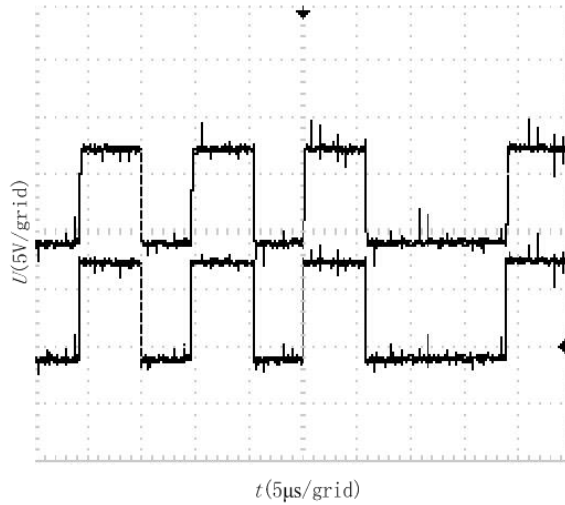


Fig.10 Trigger pulse

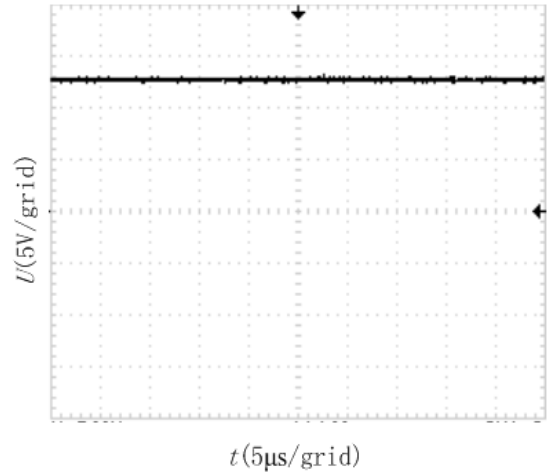


Fig.11 Output voltage

## 4. Conclusion

In this paper, the main study point is the switching loss of inverter. It is apparent to get the voltage, current and power waveforms with the software of Mathcad and PSPICE. It is helpful to understand the working principle of ZVS. It is easy to get the power loss efficiency of switch and it is useful to analyze the inverter loss, compared with the data given by the mill.

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