Design of Soft-Switching Inverter Power Supply Based on PWM In the Microcontroller

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Abstract- In view of the event trend of contemporary power electronic technology towards shrinking and high frequency, the high frequency switch brings the shift loss state of devices. This analysis proposes a load commutation soft- shift electrical converter supported IR2104. The load of the electrical device uses acceptable resonant parts to understand automatic electrical converter shift of the electrical converter power offer to show off the IGBT, that reduces the input and turn-off losses. At the same time, the chip is employed to know the chip of the driving circuit and reduce the scale of the electrical converter. Beneath the operational standing of the circuit via simulation package, the driving signals and also the operating state of the soft-switching tube within the circuit are simulated and analyzed. The experimental results verify that the self-turning-off of the shift tube is achieved beneath the high-frequency soft-switching operating condition. On-off loss is reduced.

Indexed Terms- inverter power supply; high-frequency switch; soft- switching; load commutation; chip drive

I. INTRODUCTION

Inverter power supplies use power electronic devices and use inverter technology in power electronics conversion to convert DC power to AC power. It is generally utilized in different fields of life. With the development of semiconductor technology and commutation technology, the working range and efficiency of varying switching devices have been greatly improved. Among them, the insulated gate bipolar transistor (IGBT) has a high switching frequency, small on-state voltage drop, low driving power, and voltage and current module. The advantages of high grades have become the first choice of small and medium-sized power inverters. High frequency, miniaturization, and lightweight have become the development trend of inverter power supply [1-3].

However, under conditions of high-frequency switching, the on-off loss of the switching devices in the inverter power supply is increased, and the electrical stress of the switching tube is also increased. The application of soft-switching technology in the inverter power supply reduces the on-off loss of the switch in the circuit so that the switching tube can still maintain low loss under high-frequency operation. The use of soft-switching technology in inverter power supplies has become a popular research direction in the field of high- frequency power electronics technology in recent years. The purpose of this technology has enabled the miniaturization of devices and the possibility of high-frequency switching, which has allowed the efficiency of power electronic converters to improve [4].

For overcoming the current problem of significant switching losses in high-frequency switching inverters, this paper studies a full-bridge circuit using a parallel loaded resonant converter. In this transformation process, the inductor and capacitor participate in the process of resonance and the switching tube in the inverter circuit to complete the energy transfer process. In the high-frequency state, the complementary PWM signals driven by the IR2104 are used to switch on and off [5-6]. In actual work, the switching frequency is slightly higher than the resonant frequency of the load, the circuit is capacitive, the load current is ahead of the voltage, and the overlap time of the circuit during commutation to a certain extent alleviates the speed of the current rise when it is turned on, thus achieving soft-switching [7-12].

II. METHOD

- *Analysis of the overall structure of the inverter power supply*

Figure 1 is the principle block diagram of the system. The power supply uses the single-phase AC220V as the input. After the rectification and DC filtering, the AC is converted to DC. Then a parallel resonant full-bridge soft-switching inverter circuit is used to convert DC to AC, and the control signal of the switching device in the inverter circuit is driven by the PWM signal generated within the driving chip.

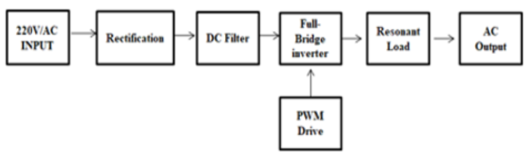

Figure 1. Construction of the inverter power supply

- *DC rectifier circuit*

The uncontrolled rectifier circuit is a rectifier circuit composed of a rectifier diode without a control function. When the input AC voltage is constant, the DC voltage obtained on the load cannot be adjusted. There are four commonly used uncontrolled rectifier circuits. For making the DC voltage ripple smaller and easy to filter, this article uses a single-phase full-bridge rectifier circuit and then uses a large capacitor to screen and stabilize the DC voltage. Considering that the input voltage is AC220V, the diode of the circuit uses 1N4007. This diode has low reverse leakage current, strong forward surge withstand capability [13-14], and the peak reverse voltage reaches 1000V, and the capacitance of the filter capacitor Cd is 2200µf. The simulation circuit is shown in Figure 2.

The output voltage in Figure 2 passes the filter capacitor, the formula is [15]

$$U_d = \sqrt{2}U_{in} \quad (1)$$

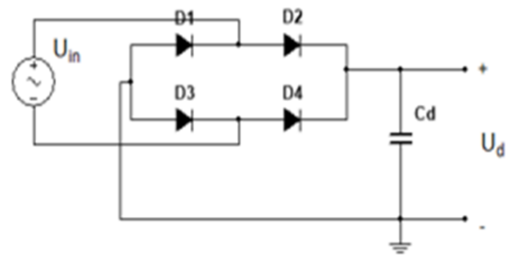

Figure 2. DC rectifier circuit

- *A parallel resonant soft-switching inverter circuit*

The parallel resonant soft-switching circuit used in this paper is a current source inverter circuit [9, 16-17]. As shown in Figure 3, an enormous value of filter inductor L1 is connected in series on the side of DC input, which is ideally equivalent to a current source. Thereby it is formed a current source inverter circuit. The inverter circuit consists of four switching devices to build an H-bridge structure. Because its operating frequency is relatively high, four IGBTs are used as conversion devices. L2~L5 are four small-value inductors, which are used to limit the rising rate of IGBT current. The load is a compensation capacitor C1 in parallel with an inductor L6 and a resistor R1, forming a parallel resonant circuit. Because this circuit is the current source inverter circuit, the waveform of the output AC current of the circuit is close to a rectangular wave, which includes the fundamental wave and each harmonic. When the circuit is operating, the frequency at which the IGBT alternately turns on is slightly higher than the resonant frequency of the load. The load is capacitive, so the load presents high impedance to the fundamental wave and low impedance to the harmonics. Harmonics hardly generate the voltage on the load. Thus, the waveform for the load voltage is the sine wave. Because the load is capacitive, the output current is ahead of the output voltage by a certain angle, and the purpose of automatic commutation to turn off the IGBT is achieved. At the same time, the overlap time of the circuit during commutation, to a certain extent, eases the speed of the current rise when it is turned on and realizes soft-switching.

When the circuit is operating, Q1 and Q4 are steady on, the current on the input side flows from Q1 to load to Q4 in sequence, and the polarity of the voltage on capacitor C1 is positive on the left and negative on the right. When Q2 and Q3 are triggered, the circuit starts to commutate. When Q2 and Q3 are turned on, the voltage across the load is added to both ends of Q1 and Q4 to make it withstand the negative voltage. Because the small-value inductors L2 ~ L5 limit the rate of current rise, Q1 and Q4 cannot be turned off immediately, and the currents in Q2 and Q3 cannot quickly rise to the steady-state value. Therefore, during commutation, all four IGBTs are turned on. Due to the short time and the effect of the extensive filtering inductance Ld, the power source is not short-circuited. When the currents of Q1 and Q4 are reduced to zero and turned off, the input current Id is transferred to Q2 and Q3. At this time, the direction of the current flow is from Q2 to load to Q3 in sequence, and the commutation process ends at this point.

After the Fourier transform of the output current, the practical value of the fundamental wave is [18]:

$$I_{01} = \frac{4I_d}{\sqrt{2}\pi} . \qquad (2)$$

The root mean square (RMS) value Uo of the load voltage is equal to the output power by the input power. It is expressed as follows:

$$U_d I_d = U_0 I_{01} \cos \varphi . \qquad (3)$$

Putting equation (2) into equation (3) gives

$$U_0 = \frac{\pi U_d}{2\sqrt{2}\cos\varphi} \qquad (4)$$

Where φ is the power factor of the load.

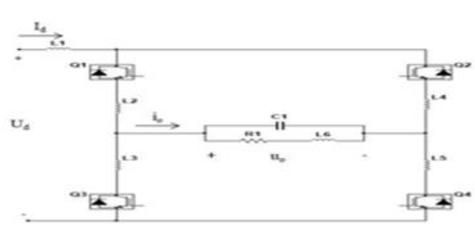

Figure 3. The parallel resonant soft-switching inverter circuit

- *IR2104-based drive circuit*

The output PWM signal from the digital signal generator is generally small, and the driving signal of the IGBT needs to reach 10~20V to be fully turned on, and the upper and lower arm switch tubes of the H-bridge structure inverter circuit are painful to be driven by one power source at the same time. Additional power supply or bootstrap circuits are added, causing more losses. The chip, IR2104 half-bridge driver, drives the IGBT for the system. The chip comes with a bootstrap floating power supply, the hardware circuit is simple to connect, and only one power supply can drive the upper and lower bridge arms at the same time. With the dead-time control, its working voltage can reach 500V, the drive is stable, and the gate drive voltage is in the range of 10 to 20V. It can simultaneously output two complementary PWM signals, and the circuit operates stably. The driving circuit diagram is shown in Figure 4.

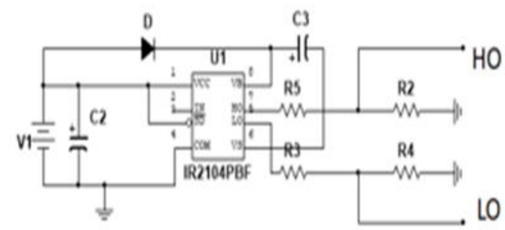

Figure 4. Diagram of the IR2104 drive circuit

- *Total harmonic distortion (THD) and Fourier transform*

A harmonic refers to the amount of electricity contained in the output voltage at a recurrence that is a number numerous of the fundamental wave, that is, the Fourier series decomposition of the periodic non-sinusoidal wave that is greater than the power generated by the voltage at the frequency of the fundamental wave. The total harmonic coefficient characterizes the closeness of an actual waveform through its fundamental wave [14], and its definition is calculated as:

$$THD = \frac{1}{U_1}\left(\sum_{n=2}^{\infty} U_n^2\right)^{1/2} \qquad (5)$$

In equation (1), n = 1, 2, 3, represents the order of harmonics, and n = 1 is the fundamental wave;

III. RESULTS

Based on the above method, this part is used simulation software (Multi-SIM) for the inverter power supply, and by comparing it with the typical current source inverter, the simulation results show that the power supply to achieve soft- switching technology, reduces the loss of switching, improves efficiency.

In the simulation software, the parallel resonant inverse soft-switching inverter power supply is simulated. The driving signal in the circuit is set as a complementary PWM square wave with an amplitude of 20V, and the switching frequency is chosen to be 20 kHz. This design can reduce the IGBT's turn-off loss on the one hand, and can also take into account the high frequency so that the size of the power transformer and the output filtering is reduced. Also, to ensure the rapid and complete saturation of the IGBT, it selects AUIRGP4063D of IR Company. The output resistance R1 is 1Ω, the inductance L6 is 140μH, the capacitance C1 is 0.5μH,

The inductance of phase shift reactors L2 to L5 is 1.5mH, and the filter inductance Ld. is 50mH.

- *A.A waveform of IGBT drive pulse*

The waveform diagram of the simulation result that after the PWM signal generated by the digital generator passes the IR2104 drive circuit, the value of the PWM square wave rises to 20V compared to the value of the original square wave, which is enough to make the IGBT enter the state of the saturation conduction quickly. The bootstrap function makes the IGBT of the upper arm usually work. The simulation waveform diagram is shown in Figures 5 and 6. The complementary upper and lower bridge arms are obtained from Figure 7, and there is a stable dead time.

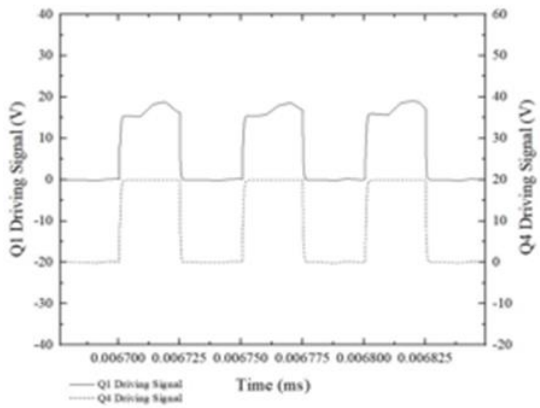

Figure 5. Q1 and Q4 driving signals

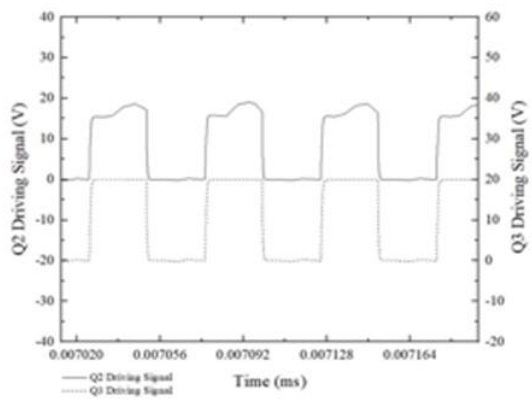

Figure 6. Q2 and Q3 driving signals

B. Implementation of the soft-switching inverter circuit

The input of the inverter circuit is simulated by a DC source. As one can see from Figure 8, the output voltage by the inverter circuit is the sine wave, and the output current is close to the rectangular wave. Because the load is capacitive, the output current is ahead of the output voltage by the particular phase.

Figure 9 shows the relationship between the current of the parallel resonant inverse soft-switching IGBT tube and the driving voltage. When a group of IGBTs receives the signal for turning on, the current slowly rises from zero to the steady- State value, and then gradually decreases. When another group of IGBTs turns on, the previous group of IGBTs receives a negative voltage, and the current gradually decreases to zero and turns off. When the IGBT is on, the current flowing through the IGBT slowly rises, reducing the overlap of current and voltage at the off-time, and reducing losses. Compared with the conventional current-type inverter circuit shown in Figure 10, the overlap area of current and voltage is significantly reduced.

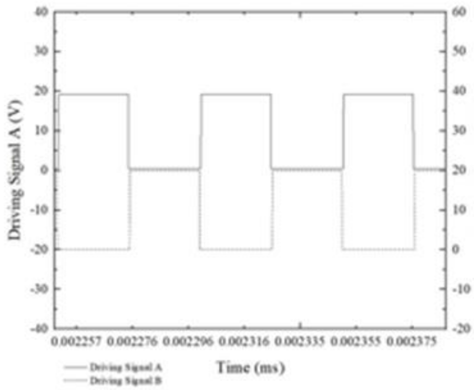

Figure 7. Complementary PWM driving signal

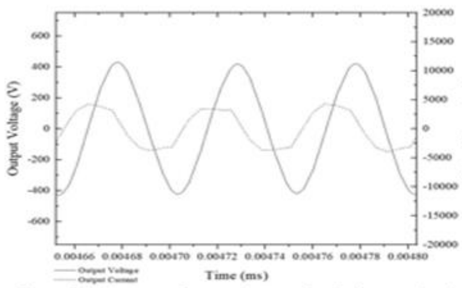

Figure 8. The output voltage and current for the inverter circuit

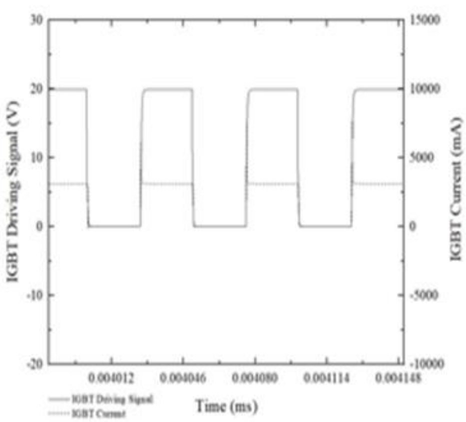

Figure 10. The waveform of IGBT current and driving voltage for the typical inverter circuit

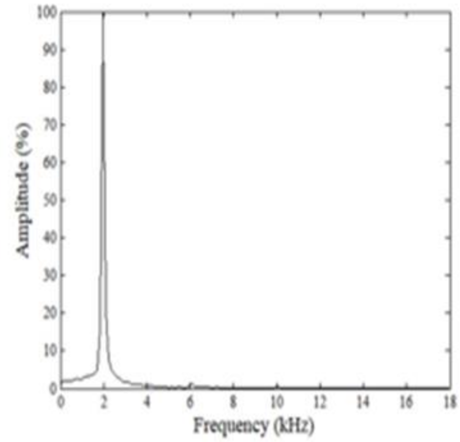

Figure 11. Fourier analysis of the output voltage of the inverter circuit

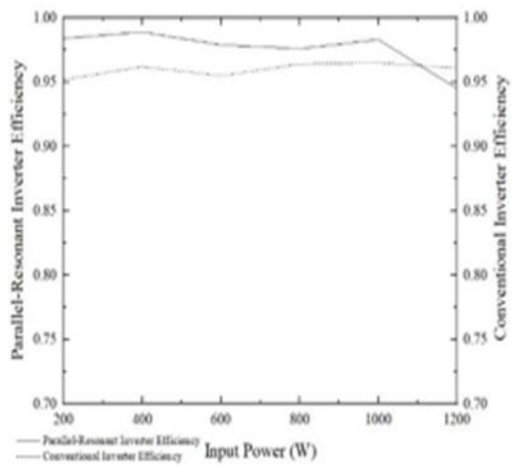

Figure 12. Comparison of conversion efficiency

C. Analysis of THD and conversion efficiency

Fourier analysis of the output voltage waveform of the inverter circuit by simulation software is shown in Figure 11. The value for the THD of the output voltage of the inverter is 1.26%. Figure 12 shows the conversion efficiency between parallel resonance inverters and ordinary inverters for the input power. From this figure, the designed inverter in this paper has an average conversion efficiency of about 97.89%. The data collected by software simulation results show that the designed inverter has the characteristics of low switching loss, high conversion efficiency, and strong output stability in the operating window.

IV. DISCUSSION

It is known from Figure 5 and Figure 6 that the voltage of the driving switch can be increased to 20V by the IR2104- based drive circuit. As a result, the switch on the upper arm also has a sufficient driving force to be driven. Also, two IGBTs connected by push-pull are turned on and off alternately to change the direction of the current in the coil. For avoiding unnecessary current surges caused by the two transistors being turned on at the same time, the control circuit introduces a dead-time characteristic in the switching action. Because the IR2104 chip comes with the dead time to ensure the safety of the two complementary switches of upper and lower outputs, it is known from Figure 7 that the dead time is measured at 382ns, which accounts for 0.76% of the entire cycle and is stable for multiple consecutive times.

Because the parallel resonant inverter circuit is a current type, the output current waveform is similar to the square wave, which includes the fundamental wave and each harmonic. Since the switching frequency of the switching tube is close to the resonance frequency of the load circuit, the load shows high impedance to the fundamental wave and low impedance to the harmonic wave so that the output voltage is similar to the sine wave. The set output is an inductive load. One can see from Figure 8 that the current waveform is somewhat distorted, but the voltage part is very close to the sine wave. This result is consistent with the theory. It is verified by Figure 11 that the harmonic is very small, and the value of THD is only THD = 1.26%.

Soft-switching technology is mainly based on zero voltage switch (ZVS) off or zero current switch (ZCS) on, thereby reducing losses at high-frequency switching. In this study, the resonant flow of the compensation capacitor and the inductive load is used to complete the ZVS turn-on and automatic commutation to turn off the switch. Figure 9 shows the switching range of ZVS and ZCS. Besides, the operational window is limited by the size of the compensation capacitor, because an excessively large-value capacitor is still likely to cause substantial losses. When the input power is lower than 1kW, the average power conversion efficiency is about 97.89%, which indicates that the soft-switching circuit is effectively reduced the loss during the conversion.

Fourier analysis for the output voltage waveform of the inverter circuit by simulation software is shown in Figure 11. The value for the THD of the output voltage of the inverter power supply is 1.26%. Figure 12 shows the input power diagrams of designed inverters and ordinary inverters. From this figure, the inverter intended in this paper has an average inverter efficiency of about 97.89%. The data of these simulation results show the designed inverter has the characteristics of low switching loss, high conversion efficiency, and strong output stability in the operational window.

CONCLUSION

The simulation results and the elaboration of the soft-switching inverter power supply are explained. It is verified that the parallel resonant soft-switching inverter power supply using IR2104 as the driving circuit proposed in this paper is feasible. Under the switching frequency at 20 kHz of this circuit, the THD value of the output voltage is 1.26%, and the conversion efficiency reaches 97.89%. Also, the circuit realizes the advantages of turning on the switch at zero voltage and turning off the switch by automatic commutation to reduce the on-off switching loss under high-frequency operation. Besides, the use of the half-bridge driving chip minimizes the complexity of the hardware circuit, improves the stability of the driving signal, and reduces the size of the overall inverter power supply.

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