

The current status and development of DC/AC inverter technology

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Abstract. The advantages, applications, and development trends of DC/AC inverter technology are compared with conventional inverter technology. The traditional DC/AC inverter technology of the low-frequency link inverter process has been gradually replaced by the high-frequency band inverter process. The replacement of the industrial frequency transformer in the low-frequency link inverter process technology with a high-frequency transformer further optimizes and improves the low-frequency link inverter process technology and significantly enhances the characteristics of the inverter. In this paper, some new inverters are highlighted. The focus is on a new high-frequency chain inverter using a unipolar SPWM control method to design different drive logic control switch tubes. A single-stage single-phase high-to-low voltage converter is widely used to interchange solar and wind turbine power supplies. They all belong to PV inverters with high reliability and a wide input voltage range. These completely solve the problems of large size, high ratio, and poor dynamic response of low-frequency transformers. Future trends in inverters at this stage are mainly characterized by high frequency, high performance, and high input power factor.

Keywords: DC/AC inverter, high-frequency chain inverter, unipolar SPWM control method, PV inverter.

1. Introduction

The use of thyristor circuits to convert DC to AC, a process corresponding to the inverse of rectification, is defined as an inverter [1]. For example, an electric locomotive with an inverter application runs the traction motor as an engine when regenerative braking is applied and sends the generated electrical energy back to the AC grid. When traction breaks the inverter, then it provides AC power to drive the motor. Inverting DC power into AC power of a certain frequency to supply the load is called a passive inverter; inverting DC power into AC power to be sent back to the grid is called an active inverter [2]. With the continuous development of science and technology, the requirements of various instruments for inverters are getting higher and higher, and the control requirements of various industries for electrical equipment are getting higher and higher. High-performance inverter circuits are the basic guarantee for industrial development. Inverters span the fields of electricity, electronics, and microprocessors. Currently, IGBT modules form power inverters with the disadvantage of bottom operating voltage. Using a three-level NPC main circuit can reduce the IGBT voltage to about half of the two-level circuit [3]. The development trend of inverters in recent years has focused on the following aspects: (1) new main circuit topology. The most typical example is the multilevel topology, which is usually a set of power semiconductor devices and capacitor voltage source, through the switching of the various switches, so that the capacitor on the various voltages superimposed on each other, the output of high voltage. In contrast, the power semiconductor devices only need to withstand a lower voltage, the output of the inverter to produce a step waveform high voltage [4]. (2) The development of high-voltage and high-current power device technology will promote the development of high-power and high-voltage power conversion

technology. (3) Advances in control strategies and control methods. Increasing main circuit elements in three-level inverters will trigger the diversification of control strategies. Finding simple, reliable, and applicable control strategies is one of the key technologies for medium- and high-voltage inverter technology. In this paper, we introduce the advantages of DC/AC inverter technology, its applications, and future trends in this field to better integrate various inverter-related knowledge, and then finally present some personal views and knowledge about its development.

Nowadays, converters are widely used, but they are flawed to some extent. Shi Shengdan et al. generate a voltage square wave through a full-bridge structure [5]. After a parallel double series-parallel resonant LC network, exchange currents are generated in the series-connected LC branches. The level-clamped network outputs a stable DC voltage, with a wide regulation range under the prerequisite of small switching losses. By limiting the frequency, problems such as energy consumption and excessive temperature rise caused by inconsistent on and off times of the switching input supply are avoided. This interchanger uses two DC-DC transformers, one of which works at positive half-periodicity and the other at negative half-periodicity [6]. This topology requires 4 IGBTs, 8 diodes, 2 inductors, and LC filters and is costly to manufacture.

The DC/AC inverter proposed in this paper is a static variable current device. It converts DC energy into constant voltage and constant frequency AC energy using a power semiconductor device for grid-connected power generation in interchangeable load supply systems or grids [7].

Three different applications of DC/AC inverter technology are written below. The first is a new high-frequency inverter that uses auxiliary switching tubes and designs different drive logic to control the tubes by using a unipolar SPWM control method. It enables soft switching of the inverter, thus reducing the switching losses and solving the electromagnetic interference problem of high-frequency chain inverters. The second is the single-phase voltage converter, which implements a circuit that is highly efficient and reduces the operating costs of the converter circuit to a great extent. It can be fully utilized in photovoltaics. The third type is the photovoltaic inverter, which has the advantage of lower losses, higher power, and higher voltage and frequency than conventional inverters. It is suitable for developing small and medium-sized power applications in the field of power technology. In addition to this, a comparison of the existing high-frequency inverters with conventional DC/AC inverters is presented, which contain square-wave inverters, step-wave compound inverters, and SPWM inverters with sinusoidal pulse-width signal regulation. Finally, at the end of the article, the trends in DC/AC inverter technology are presented, divided into the popularization of “home inverters” and the use of “portable inverters”.

2. Application of DC/AC inverter technology

2.1. New high-frequency chain inverter

With the development of power electronics, DC/AC inverters are becoming more and more lightweight, high frequency, and high power. The high-frequency chain inverter uses a high-frequency transformer instead of the traditional inverter used in the industrial frequency transformer. It solves the defects of the low-frequency inverter, such as high volume and ratio and poor dynamic response, and significantly improves the characteristics of the inverter. However, the high switching power frequency band also causes power consumption and electrical effects.

A new high-frequency chain inverter (Figure 1) is proposed to achieve soft switching of the inverter and to solve the problems of high switching losses and electromagnetic interference in high-frequency chain inverters [8]. The topology of this new high-frequency chain inverter has a full-wave circumferential converter on the secondary side of the transformer. Compared to the conventional push-pull circuit structure, the front end of the inverter only requires adding an auxiliary switching tube between the input power supply and the middle tap of the high-frequency transformer. Using the unipolar SPWM control method and the designed drive logic to control the switching tubes, the soft switching of the inverter's switching tubes can be realized, and the switching tube losses are reduced.

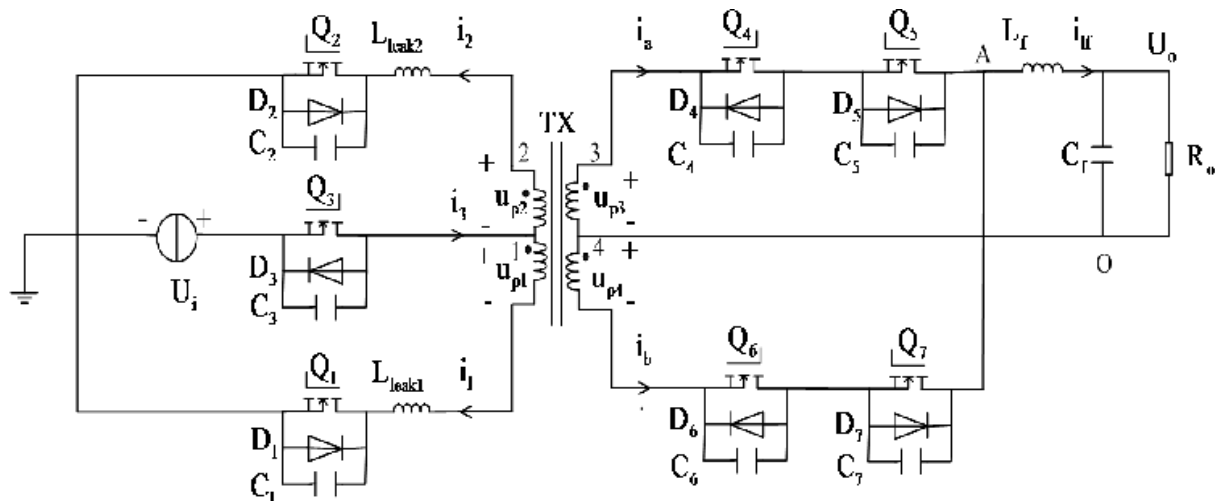


Figure 1. High-frequency link inverter circuit topology

2.2. Single-phase boost converters

An innovative and unique single-stage, single-phase high- and low-voltage converter for the interchange of solar and wind turbine power sources has been introduced (Figure 2). The converter implementation circuit is efficient and significantly reduces the operating costs of the converter circuit [9]. The basic theoretical analysis and modeling of the given converter have been carried out, and the IC design theory has proven its desirability and practical economic value in photovoltaic applications [10, 11].

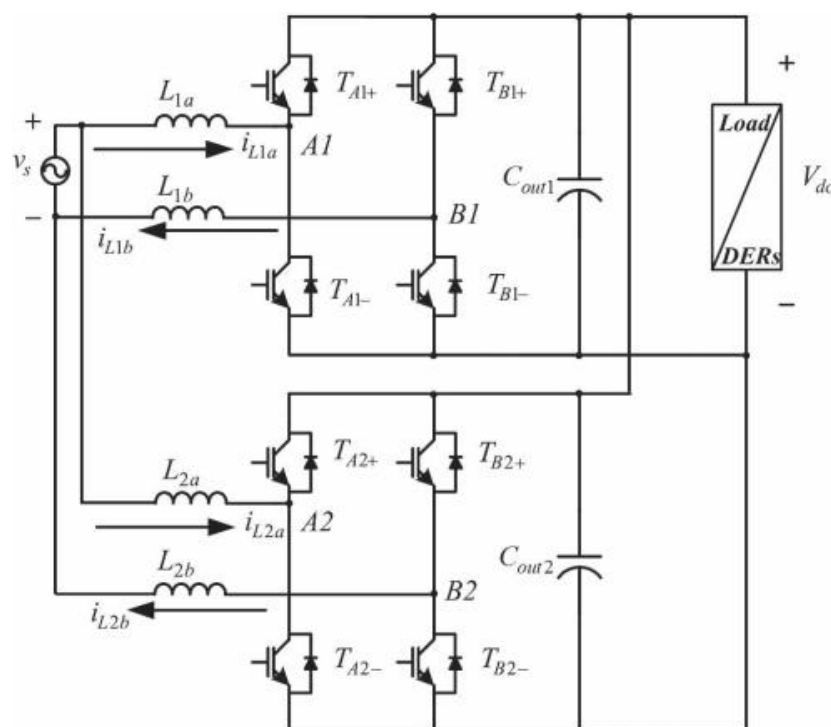


Figure 2. Single-phase boost converters

2.3. Photovoltaic Inverter

As an important part of the PV power generation system, the PV inverter not only features high reliability, wide input voltage range, low distortion, reliable communication, and high efficiency, but also has the functions of parameter monitoring, over-voltage protection, output control, short-circuit protection, and overload protection. For example, when the input voltage fluctuates within a certain range, the inverter can ensure the relative stability of the output voltage. Applying PV inverters

significantly improves the conversion efficiency and the output power quality, providing higher-quality power to the consumer. With the development of electronic technology, the new PV inverters are developing in the direction of intelligence, integration, and information technology, with lower losses, higher power, and higher voltage and frequency than traditional inverters. PV inverters can be classified into single-ended flyback, double-ended flyback, centralized, string, distributed, microinverters, etc. These types of inverters have their own characteristics, among which double-ended flyback inverters (Figure 3) have the advantages of simple topology, high reliability, and high-frequency isolation [12] and are suitable for small and medium power applications, especially in the field of power technology.

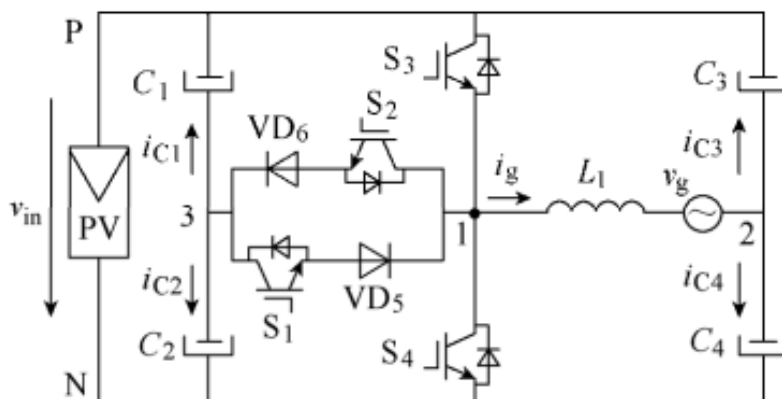


Figure 3. Photovoltaic Inverter topology

2.4. The comparison of inverter and converter

Table 1. The comparison of inverter and converter

	Principle	Application Scenarios	Advantages	Disadvantages
New high-frequency chain inverter	Unipolar SPWM control mode	Vehicle mounted inverter, uninterruptible power supply (UPS)	Low loss, reduce electromagnetic interference	Duty cycle loss of secondary voltage
Single-phase boost converter	Simplified pulse modulation strategy	Microgrid	Eliminate the DC loop and control the AC loop	Line current distortion
Photovoltaic Inverter	Add relevant capacitors and inductors	Low power photovoltaic grid-connected system	Small output ripple, high efficiency	DC offset problem

The table focuses on the three applications presented in sections 2.1-2.3, comparing, and analyzing their respective principles, application scenarios, and advantages and disadvantages. Section 2.1 of the article proposes a new type of high-frequency chain inverter that achieves soft switching of the inverter front-end supervisor by controlling the drive logic of the power switch, which greatly reduces the switching losses and improves the efficiency of the inverter. A unipolar SPWM wave controls the inverter, but some key factors can have some effects, including the transformer's secondary duty cycle loss phenomenon, the conditions for the inverter to achieve soft switching, and the DC bias problem of the high-frequency transformer. Section 2.2 of the article presents a single-phase boost converter with a simplified pulse-width modulation strategy. It is designed to eliminate the dc-loop and reduce switching losses to reduce common mode and differential mode loops in parallel systems with different power-sharing rectifier and inverter modes in microgrid applications. A single-phase PV inverter is proposed in section 2.3 of the article. This inverter has a low output ripple and high frequency, making it suitable for transformer less single-phase PV grid-connected systems. However, the devices used in the detection and control chain have a DC offset problem that leads to the presence

of DC components in the grid, and to reduce the DC component due to device offset, a low offset device must be used.

3. Existing high-frequency inverter technology versus conventional DC/AC inverter technology

Traditional DC/AC inverters use low-frequency link inverter technology, mainly square wave inverters, step wave composite inverters, and sine pulse width signal-regulated SPWM inverters.

3.1. Square wave inverters

Square wave inverters are mainly available in push-pull and full-bridge circuit configurations. It consists of a push-pull inverter, an AC voltage regulation controller, and an inlet output filter, as represented in Figure 4. The push-pull square wave inverter is mainly used to achieve the voltage regulation management function by adjusting the inverter outlet voltage input pulse width. This regulating method is to adjust the input-output power S_1 , and S_2 drive signal duty cycle and thus the pulse width of the input-output current. However, there are obvious problems with this type of regulation, that is, inductive load storage back to the grid, the transformer T secondary winding inductance has a shadow part of the current. This part of the voltage with the inductive load inductance component increases and widens, pure inductive load effective pulse width adjustment range of $0 \sim T_s/4$, and a purely resistive load effective pulse width adjustment range of $0 \sim T_s/2$. Another regulation method is the transformer secondary. Another regulating method is to add an AC voltage controller S_3 between the input and output AC filters and adjust the output power controller S_3 to drive the signal duty cycle. It can adjust the output rectangular wave pulse width. AC switching input power will be square wave current into the pulse width adjustable rectangular wave current.[13]

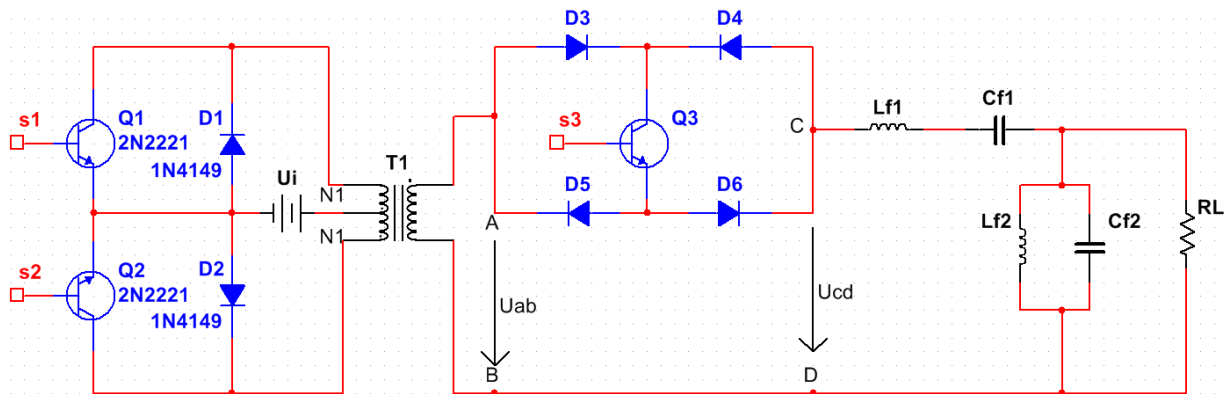


Figure 4. Push-pull inverter circuit topology

At present, in the industrial production of electronic equipment heating process, high frequency, ultra-high frequency technology switching power supply is increasingly widely used. The rapid development of power semiconductor electronics and high-speed integrated wafers has had a major impact on the development and widespread use of high-frequency, high-output power inverter technology. Various new types of high-frequency, high-power inverter power supplies have been launched. Among them, in 1975, Sokal proposed a high-frequency, high-efficiency class E amplifier, with its high inverter operating frequency, and the efficiency of theoretical values up to 100% of the optimized characteristics of the huge boom [14]. However, the actual operation of these inverters is limited by the fact that the switching tubes are subjected to 3-5 times the voltage stress of the dc bus, thus limiting the dc-side input current, and limiting the export power of the entire inverter.

The circuit topology and Bridge square wave inverters' principal waveforms are represented in Figure 5. By varying the phase of the power switch drive signal, rectangular waveforms can be obtained to generate current, and the stability of the generated current can be achieved by adjusting the angle appropriately.

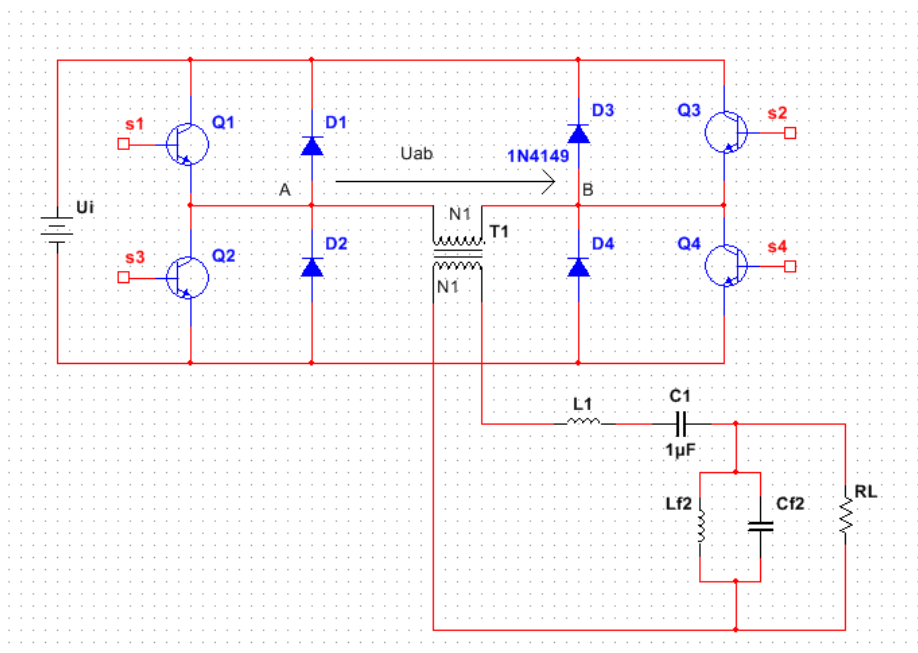


Figure 5. Bridge-type square wave inverter circuit topology

3.2. Stepped wave synthesis inverters

To reduce the harmonic concentration of the waveform generated by the square wave inverter, a DC/AC switcher and a cascade of combined step wave inverters can be used to realize the circuit composition, as listed in Figure 6. If the number of steps in each cycle of the step wave is $2N$, N single-phase inverters or $N/3$ three-phase inverters are required. Each single-phase working power circuit is identical and can be used as a push-pull, bridge, or three-phase bridge circuit. The phase-shifted iterative method is a common way of combining step waves in high-power inverters. Here, N square or rectangular waves with different amplitudes are combined in a sequential phase-shifted π/N iterative manner to maximize the resistance of certain low harmonics to each other and to minimize the harmonic concentration of the synthesized waves. For this reason, step-wave compound inverters are also known as inverters with “harmonic offset”.

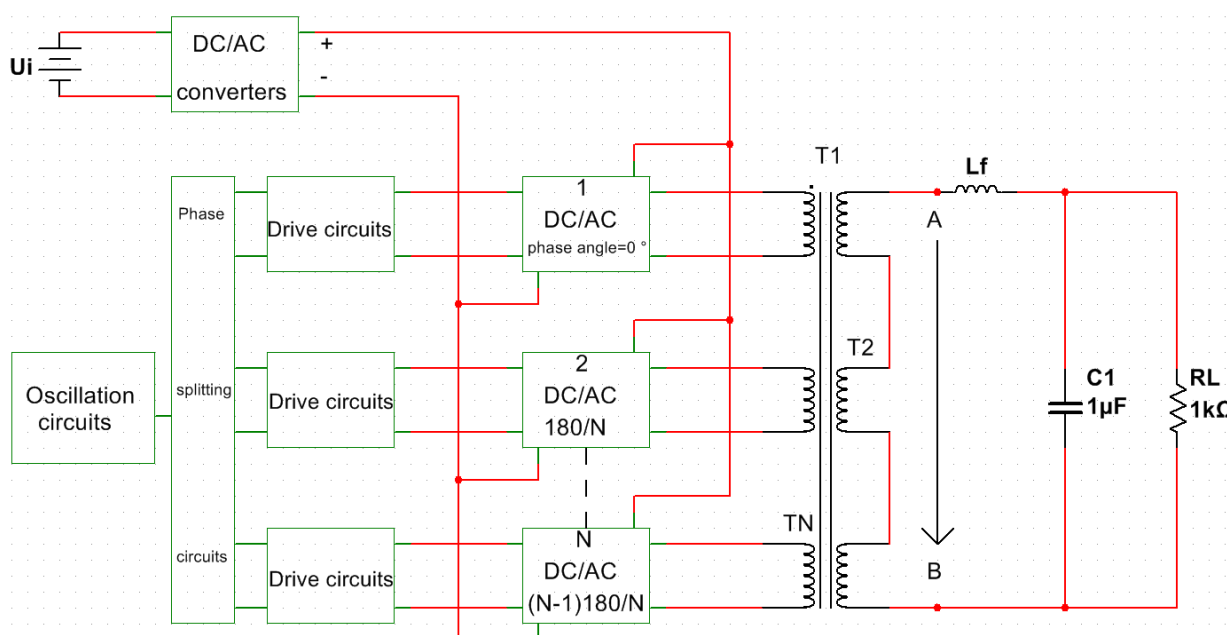


Figure 6. Stepped wave synthesis inverter circuit structure

3.3. Sine pulse width modulated SPWM inverters

The so-called sine pulse width modulation (SPWM) waveform is a series of rectangular pulse waveforms of equal amplitude and unequal width to replace the corresponding sinusoidal waveform under certain conditions to make it equivalent. As seen in Figure 7 the sine half wave is divided into an equal part, each equal part of the sine curve, and with the same area.[15] The amplitude of the rectangular pulsation remains unchanged. The midpoint of each rectangular pulse wave coincides with the midpoint of the first part of the sine wave. This waveform is composed of a sequence of an equal amplitude rectangular pulses of different widths which is like the sine wave's half circumference and is called the SPWM waveform (Figure 8).

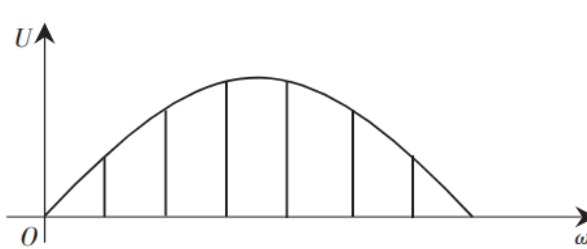


Figure 7. Sine wave

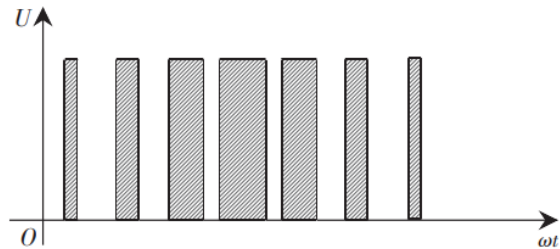


Figure 8. Equivalent SPWM waveform

When modulating the SPWM inverter, a sine wave is usually used as the modulating wave and an isosceles triangle as the carrier wave, and the intersection of the modulating wave and the carrier wave is used as the on/off moment of the SPWM inverter switching device (Figure 9). When the frequency spectrum and amplitude of the modulating waveform change, the frequency spectrum and amplitude of the resulting voltage base waveform also change. When the modulating wave amplitude decreases, the diameter of each rectangular pulse wave becomes narrower, and the distance between rectangular pulse waves increases, so that the amplitude of the input and output current fundamental wave is also correspondingly smaller. Currently, the harmonic amplitude becomes correspondingly larger, the degree of harmonic influence increases significantly, and the negative impact on the load motor is also very large. When the modulating wave amplitude increases, the distance of each rectangular pulse wave becomes wider, and the distance between rectangular pulse waves decreases. When the amplitude of the modulating wave is increased, the distance between the rectangular pulses becomes wider. The spacing between the rectangular pulses is reduced. The amplitude of the fundamental wave of the output voltage also increases accordingly. The amplitude of the harmonics decreases accordingly (Figure 10).

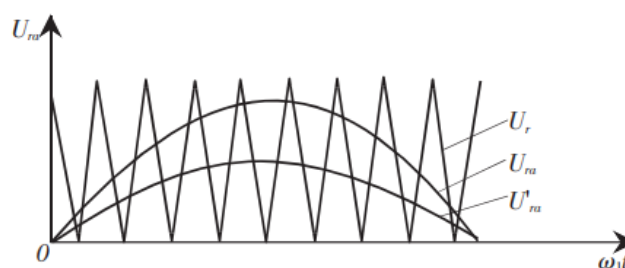


Figure 9. Sine modulated waveform and triangular carrier waveform

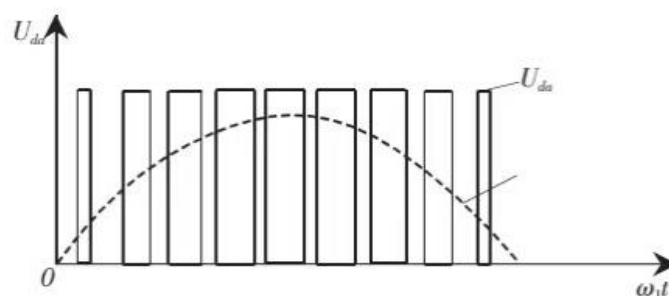


Figure 10. Output SPWM waveform

4. Trends in DC/AC inverter technology

4.1. Popularization of the home inverter

The car battery has recovered its normal capacity after cyclic discharge and fluid exchange, so I wanted to make full use of it, with an inverter to change the DC to 220 V AC, to facilitate the use in power outages [16]. As a result, an inverter board was made, but the power test did not output properly. VT3 and VT5 currents were measured. VT3 was found to be much larger than VT5. And the components and wiring were carefully checked to be correct. The original diagram is analyzed as follows (Figure 11), IC ③ pin output is about 50 Hz standard square wave, in 3-pin output for high level, D4 cut off, VT4, VT5 is off, D3, VT2, VT3 conductive, L1 have current through. When the 3-pin output is low level, the current through L2, VT4, D4, R6 to IC ③ foot, but there is still a part of the current through D3, VT2, VT3 to the power ground, resulting in L2, L1 is current through, and cannot output 220V AC. LED1, D1, LED2 can increase VT1. VT2 conduction potential to prevent misconduct at a low level. With an oscilloscope to observe the output waveform found that, because it is a square wave drive, in VT4, VT5 cycle on, the primary and secondary ends of the transformer will produce a very high spike pulse, thus connecting DW1, DW2 to clamping. According to the diagram, the inverter can stable output 220 - 250 V between the more standard square wave voltage, whether connected to fluorescent lamps, incandescent lamps, televisions, and other loads can work reliably.

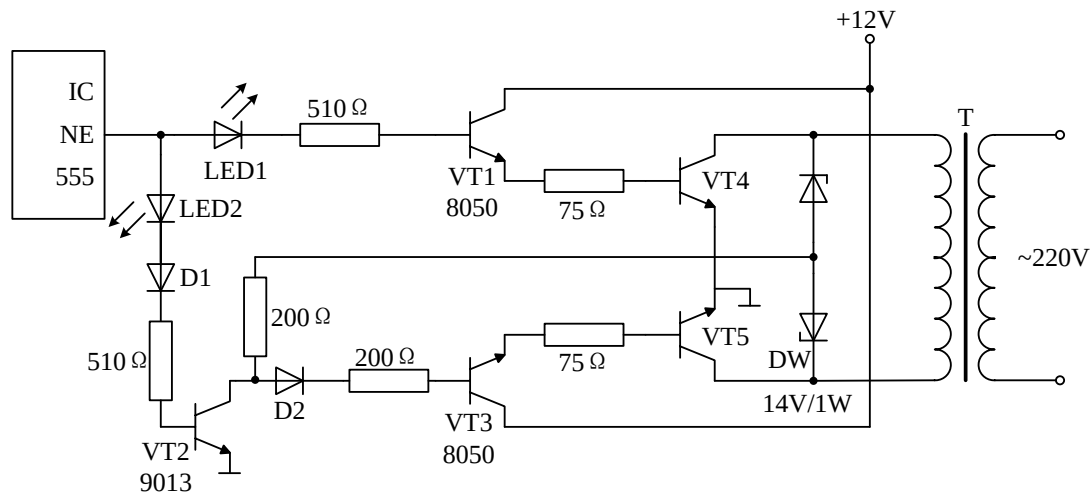


Figure 11. Principle diagram

4.2. Applications for “portable inverters

A new type of inverter based on a Class E diffuser. In contrast to conventional Class E diffusers, this push-pull inverter (referred to as a dual Class E inverter) has a switching tube S1 (MOSFET). Together with S2, it takes the peak-to-peak of the input voltage and provides the load circuit with a high-frequency voltage, in turn, making it possible to increase the input and output operating power by a factor of four. In addition, this inverter maintains the simplified construction of a Class E amplifier and is called a portable inverter because of its small size.

4.2.1. S1 from off to on, S2 from on to off

As shown in figure 12, the voltage I_e starts to flow through the electric gate tube S1, and the voltage i_{s1} on the electric gate tube starts to rise, that is, $i_{s1} = I_e - i_0$, because I_e is constant, the voltage i_0 flowing through the load starts to fall. As the switching tube S2 is turned off, the voltage flowing through S2 becomes flowing through C2. That is, the load current i_0 and I_2 flow through the capacitor C, to the capacitor C2 to make up for the current $i_{C2} = i_0 + I_2$. And the voltage on the capacitor C2 begins to rise. In this period, the load current i_0 gradually becomes smaller until the load current drops to zero and enters the next stage. The load current i_0 starts to change direction, part of the current I_2

is charged to capacitor C2 and the other part flows to the load. At this point, the load current i_o rises in the opposite direction (the load current is specified as positive from left to right). As the current I_2 is constant ($I_2 = i_{C2} + i_o$), the charging current of capacitor C2 decreases continuously until it is reduced to zero. At this moment, the current I_2 is all turned to the load.

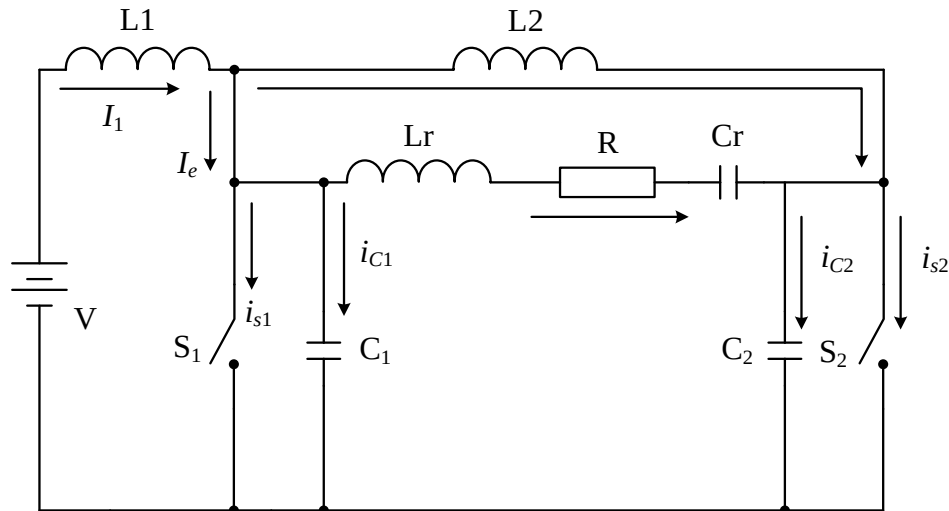


Figure 12. Principle diagram

4.2.2. S1 from on to off, S2 from off to on

The current flowing to the switching tube S1 is transferred to the bypass capacitor C1 and starts to build up a voltage in the capacitor C1. At this point, as the switching tube S2 opens, the current I_2 is diverted to the switching tube S2 and the load, respectively. The capacitor C2 is discharged through the switching tube S2, and the current i_{S2} of the switching tube S2 gradually increases. Because I_2 is constant, the load current gradually decreases until it decreases to zero. And the load current begins to change direction into the next stage. At this point, $I_2 = i_{S2}$.

The load current starts to turn to the switching tube S2, at this time $i_{S2} = I_2 + i_o$, the current of the switching tube S2 continues to increase, at this time the switching tube S1 is off, I_0 is increasing, i_{C1} is decreasing, until reduced to zero, the voltage of capacitor C1 reaches the peak. Capacitor C1 begins to discharge. The load current continues to rise, and the current on the switching tube S2 is the sum of the load current i_o and I_2 , that is, the current on the switching tube S2 increases the load current and increases.

As seen from the operating principle, two filter inductors and two MOSFET bypass capacitors provide resonant current to the load in succession, producing twice the load current and four times the output power compared to a conventional Class E amplifier.

5. Conclusion

In this paper, we summarize and sort out the previous research on inverters by combining various literature and comprehensively explaining the basic knowledge of inverters around the advantages of the inverter. This paper focuses on the application of inverter technology, comparing the existing high-frequency and traditional inverter technology and the future development trend of inverters.

First, this paper describes the use of high-frequency chain inverters to address the high loss and electromagnetic interference drawbacks of high-frequency chain inverter switching and single-phase boost converters to reduce circuit costs at the same efficiency. Then, this paper introduces three types of inverters, including push-pull square-wave inverters that can manage voltage regulation by adjusting the outlet voltage input pulse width, and step-wave synthesis inverters that can reduce the harmonic concentration in square-wave inverters. SPWM inverters can be used to increase the voltage fundamental amplitude and reduce the harmonic amplitude. Using these three types of transformers

can reduce the interference of harmonics to the load motor. Finally, the paper discusses the principle of differentiating between home inverters and portable inverters.

At this stage, although inverter-related industries and technologies have made certain applications and research results, there is still a broad space for development. The potential problems are: solving the poor overload capacity of high-frequency inverters, the inability to connect full negative inductive loads, the safety hazards caused by DC branch fuses of PV inverters, and the harmonic suppression of string inverters. Based on the effective use of existing technologies, electricity should be further utilized safely and efficiently.

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