

High-Efficiency Inverter Circuit Applied to Solar Power Generation

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Abstract. As a clean and renewable energy, solar energy's photovoltaic power generation market has developed rapidly under the impetus of "carbon peak, carbon neutrality" and has become the main force. This article first introduces the basic principle and process of solar power generation and analyses the principle of inverter circuit. Then five ways to improve the efficiency of the inverter circuit are summarized including: designed a high-efficiency rooftop photovoltaic power generation system; designed SiC devices to replace traditional Si devices to improve performance; proposed a new PWM strategy and improve transmission efficiency by reducing the loss of low-frequency switching bridge arms; generated SPWM modulation control signals. These methods can effectively improve the efficiency of the inverter circuit. But for solar photovoltaic power generation, there are still many practical problems to be solved. For example: the cost of photovoltaic power generation materials, natural weather conditions and other reasons have reduced power generation efficiency.

Keywords: List the; keywords covered; in your paper.

1. Introduction

At present, the energy used by human beings mainly includes fossil fuels, nuclear energy, solar energy, water energy, biomass energy, wind energy, etc. According to statistics, in 2016, fossil fuel utilization accounted for about 85% of global energy consumption, and nuclear energy utilization accounted for about 4.5% of global energy consumption [1].

However, the large-scale use of fossil fuels will produce a large number of harmful substances and greenhouse gases, and during nuclear fusion and fission, there will be "mass losses" and release huge energy. Therefore, in the process of achieving the goal of "carbon peak, carbon neutrality", the utilization of renewable energy is of great significance, among which the solar energy resources are the largest, about 170 million tce/a, which has great utilization potential [2].

In order to effectively use photovoltaic power generation technology and improve the utilization rate of solar energy, it is significant to further optimize the control technology of photovoltaic power generation system, which can be achieved by improving the efficiency of photovoltaic inverter circuits.

2. Theoretical basis

2.1. Solar power generation

2.1.1 Working principle

The primary components of solar power generation systems include solar cell modules, controllers, batteries, inverters, and loads. Within this system, the power supply is managed by solar cell modules and batteries, while the controller and inverter handle control and protection. The load functions as the terminal element of the system.

At the heart of this system lies the solar cell module, which is essential for converting the sun's radiant energy directly into direct current. This electricity is either used immediately by the load or stored in batteries for later use. Solar cell modules are typically created by arranging several solar panels in a specific configuration to form a solar cell array. This array is then outfitted with suitable mounting brackets and junction boxes. The fundamental structure of a solar cell encompasses five

key components: the substrate, p-n diode, anti-reflective layer, textured surface structure, and metal electrode.

When the photovoltaic cell works, there are three parts of the current: the photoelectric current I_L , the p-n junction forward current I_F under the action of the photoelectric voltage V , and the current flowing through the external circuit I . The equivalent circuit of the ideal solar cell is shown in the figure 1.

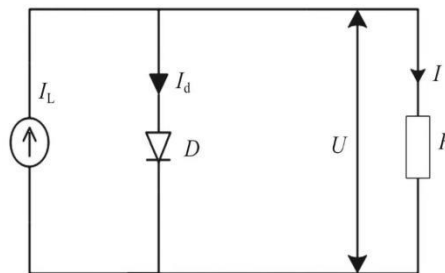


Fig. 1 equivalent circuit of the ideal solar cell (Photo/Picture credit: Original)

The charging controller optimizes the charging process by delivering the ideal current and voltage to the battery. This facilitates a quicker, more stable, and efficient charging experience, thereby minimizing losses and maximizing the battery's operational lifespan. At the same time, it protects the battery and avoids the occurrence of overcharging and over-discharge.

In the photovoltaic power generation system, the battery serves to store DC electricity generated by the solar cell array for later use by the load. The battery alternates between two modes: floating charging and discharging. During the day, the solar cell array not only charges the battery but also powers the load directly. At night, the load is powered by the stored energy in the battery. Additionally, the inverter plays a crucial role by converting direct current into alternating current and features an automatic voltage stabilization function, which enhances the quality of the power supply from the photovoltaic system.

2.1.2 Method of Photovoltaic power generation

Solar power generation mainly includes two power generation methods: photothermal and photovoltaic. In order to balance the quality of solar energy production and cut down on the cost of power generation, at present, in photovoltaic additional power generation, energy is fully allocated through photovoltaic and photothermal power stations [3]. The method of ensuring efficiency is a complementary method with the highest utilization rate and commercialization at present. The research of photovoltaic photothermal complementary power generation system mainly focusses on capacity configuration optimization and operation scheduling optimization, and also includes the study of photovoltaic photothermal fusion ratio [4]. The latter uses the photovoltaic-volt effect of semiconductor materials to directly convert light energy (solar radiation) into electrical energy. Relevant data show that the highest photovoltaic conversion efficiency has reached 93% [5].

The photovoltaic effect is the underlying mechanism of solar cells. When light strikes solar cells, photons possessing energy exceeding the semiconductor material's bandgap penetrate the p-n junction and reach deeper into the semiconductor. This excitation causes the valence electrons to jump, creating electron-hole pairs near the p-n junction. Due to the internal electric field present, these electrons and holes are quickly separated before they can recombine. Electrons are drawn towards the n-zone, which is positively charged, while holes move towards the p-zone, which is negatively charged. When the p-n junction is linked to an external circuit, this movement generates an electrical current, known as the photovoltaic phenomenon.

2.2. Invert circuit

Turning direct current into alternating current is called inverter. According to the structural characteristics of the circuit, the inverter circuit includes half-bridge inverter circuit and full-bridge inverter circuit, etc. U_d is the input DC voltage, and R is the output load of the inverter. When the switch T_1 and T_4 are closed and T_2 and T_3 are disconnected, the output voltage of the inverter is $u_0 = U_d$; when the switch T_1 and T_4 is disconnected and T_2 and T_3 are closed, the output voltage is $u_0 = -U_d$.

When switching switches T_1 , T_4 , T_2 and T_3 alternately with frequency f_s , the alternating voltage waveform shown in the figure 2 is obtained on the resistance R , with a period of $T=1/f_s$, so that the DC voltage E is turned into an AC voltage u_0 , which contains various spectral waves. If you want to get the sine wave voltage, you can filter it through the filter. Wave obtained.

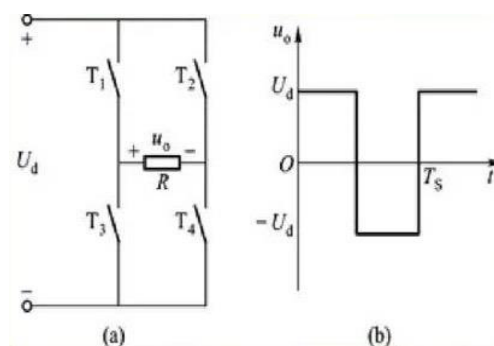


Fig. 2 the alternating voltage waveform (Photo/Picture credit: Original)

The half-bridge inverter circuit of the voltage-type inverter includes two conducting arms, each made up of a fully controlled device coupled with a parallel anti-parallel diode. On the DC side, two sufficiently large capacitors, C_1 and C_2 , are connected in series and are equal in value, satisfying the condition $C_1=C_2$. An inductive load is then connected between points A and O . The voltage-type inverter circuit half-bridge inverter circuit is shown in figure 3.

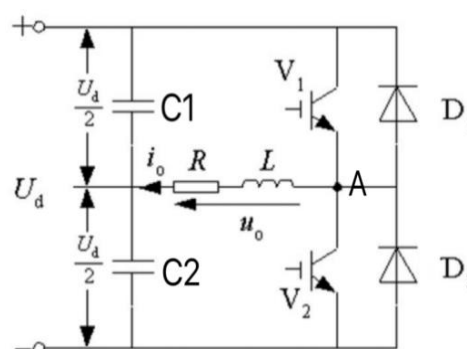


Fig. 3 The voltage-type inverter circuit half-bridge inverter circuit (Photo/Picture credit: Original)

The fully controlled switching devices T_1 and T_4 together create one pair of bridge arms, while T_2 and T_3 form another pair. T_1 and T_4 are switched on and off simultaneously, as are T_2 and T_3 . The driving signals for T_1 and T_4 are complementary to those for T_2 and T_3 ; thus, when T_1 and T_4 are activated, T_2 and T_3 are inactive, and the reverse is also true. These two pairs of bridge arms conduct alternately at 180° phases. This arrangement is depicted in the voltage-type single-phase full-bridge inverter circuit illustrated in figure 4.

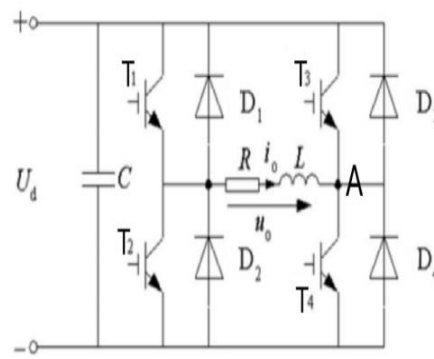


Fig. 4 Voltage-type single-phase full-bridge inverter circuit (Photo/Picture credit: Original)

3. High-efficiency inverter circuit

At this stage, the conversion efficiency of common photovoltaic cells is generally 15% to 25%, and conventional crystalline silicon solar cells cannot completely convert solar rays. Moreover, the conversion efficiency of photovoltaic cells will also be affected by factors such as temperature, light intensity and spectral distribution. At certain times and locations, the photovoltaic power generation system may not deliver a consistent and reliable power supply. This instability is often due to variations in sunshine availability or shifts in weather conditions, including cloud cover and fluctuations in light intensity. There are intermittent situations in the output. These changes will cause fluctuations in power generation, which will lead to unstable power output and affect the continuity and reliability of energy supply. And when the power output is unstable and cannot meet the power demand, it will be replenished by the public grid, which will affect the energy supply and demand balance, increase the scheduling and management difficulty of the grid, and then affect the economic benefits.

Dong Jianhui designed a high-efficiency rooftop photovoltaic power generation system, applied the maximum power point tracking algorithm, and maximized the output power of the system by adjusting the working point of the photovoltaic array voltage and current. Ensure that the photovoltaic power generation system achieves efficient grid-connected operation and stable performance, so as to maximize the power control of the power generation efficiency of the system [6]. In the high-efficiency rooftop photovoltaic power generation system, the power control can be achieved by adjusting the output voltage and frequency of the DC/AC inverter. Power control can also realize the load management of the system, dynamically adjust the transmission power of the system according to the needs of the power grid and improve the availability and flexibility of the photovoltaic power generation system. In addition, reactive power compensation is also required. The main purpose is to adjust the power factor and voltage quality of the system to meet the requirements of the power grid. And use PID control to effectively improve power generation efficiency and optimize system performance.

Apply it to a wharf in Hainan Province which has long lighting time, unobstructed surroundings, average solar radiation of 4150~5000 MJ/m², rich solar energy resources (B) level) adopts a group series inverter, 225KW inverter, and roof photovoltaic is selected. The brand 450W monocrystalline silicon solar cells are all installed by fixed installation. In this case, the roof photovoltaic power station equipment has been put into operation since 2021. It is operating normally and in good condition without equipment failure. At present, the maximum recorded photovoltaic power generation power is 3700KW, exceeding the rated power generation power 3477KW223K [7].

Through the use of rooftop space for photovoltaic power generation, we can effectively utilise renewable energy, reduce dependence on traditional fossil energy, and reduce environmental pollution.

Zeng Zheng designed SiC devices to replace traditional Si devices to improve performance. The high energy gap of SiC devices means that the leakage current of the devices is small, and the high

temperature tolerance of SiC devices adopts a simpler cooling method and reduces dispersion. The volume and weight of the heater increase the power density and reduce the cost of the inverter. Using SiC material, the voltage resistance of MOSFET devices can reach 1200V or even 1700V, which can meet the needs of photovoltaic inverters. SiC IGBT devices can reach a voltage resistance level of 10kV and above, which can simplify the topology of high-voltage converters [8]. In addition, the high critical field strength means that under the same voltage resistance, the size of the chip can be made smaller, the on-resistance is reduced, and the size of the junction capacitance can be reduced, which can improve the switching speed. Therefore, in the application of photovoltaic inverters, using SiC MOSFET to replace Si IGBT. we can see decline in the loss and it can improve the efficiency of the inverter. Besides, it can also increase the switching frequency, reduce the volume and weight of passive components such as DC bus capacitance and output filter inductor, reduce system cost, and improve power density. In addition, low loss can also reduce temperature cycle stress and improve the reliability and life of devices and inverters.

However, the switching process of SiC MOSFET will produce strong voltage and current over surge, endangering the safety of the device, so that the device can only operate at a reduced rate, increasing the cost of the device and inverter. Therefore, the SiC device package of low parasitic inductance, the busbar and capacitance design scheme of low parasitic inductance are a major challenge; due to the reliability of SiC MOSFET gate oxygen, the minimum value of negative bias is limited, usually -5V, and the minimum cannot be lower than -9V; in terms of driving, three degrees of freedom The control amount also needs to be optimized collaboratively; in terms of packaging process, it is mainly welding process [9]. Ensure that the solder and the connecting layer establish sufficient strength bonding force; and in order to overcome the problem of uneven thermal stress of multi-chip parallel power, countermeasures should be taken.

The input end of the inverter circuit is high-voltage direct current, and its output result is an AC power signal, so the inverter circuit is very critical. Wang Xu adopts the SPWM modulation signal in the photovoltaic inverter mode. In order to drive the IGBT, the circuit design adopts the optocoupler element, and finally realizes the purpose of weak level driving the strong current element.

Gong Renxi proposed a new PWM strategy to make the two switching bridge arms work in high-frequency and low-frequency states respectively and improve transmission efficiency by reducing the loss of low-frequency switching bridge arms. And alternately appear in regions 1 and 3. At this time, the PWM index range is $0 < m < 0.5$, and the range of the inverter u_{ab} is $0 < U_{ab} < U_{dc}/2$. N_2 and N_3 alternately appear in interval 2, the PWM index range is $0.5 < m < 1$, the range of the inverter U_{ab} is $U_{dc}/2 < U_{ab} < U_{dc}$, N_4 and N_5 alternate between interval 4 and interval 6, the PWM index range is $-0.5 < m < 0$, and the paradigm of the inverter U_{ab} The circumference is $-U_{dc}/2 < U_{ab} < 0$, N_5 and N_6 alternate in interval 5, the exponential range of PWM is $-1 < m < -0.5$, and the range of inverter U_{ab} is $-U_{dc} < U_{ab} < -U_{dc}/2$ [5]. By operating one of the switch bridge arms at power frequency, the system can minimize switching losses, thereby enhancing the overall transmission efficiency. Experimental findings indicate that the implemented PWM strategy successfully boosts the inverter's transmission efficiency, leading to a higher power density.

Sun Xingyi generated SPWM modulation control signals through the 51 single-chip microcomputer system through a timer, and then controlled the opening and shutdown of IGBT devices in the inverter circuit through the IR2110 drive circuit and reversed the DC into alternating current. Finally, the LC low-pass filter was used to eliminate the multiple harmonic problems in the transformation process of DC-AC, and basically realized the conversion of DC to AC generated by light energy [10].

4. Summary

Solar photovoltaic power generation technology has made great progress. In the future, with the continuous innovation of photovoltaic materials, photovoltaic cells and solar grid technology, the efficiency of solar photovoltaics will continue to improve, and the cost will be greatly reduced. With the increasing demand for renewable energy, the solar photovoltaic market will maintain a good development momentum. At present, many countries and regions around the world have introduced various forms of solar energy policies to encourage and support the development and application of solar energy. At the same time, efforts to strengthen international cooperation and standardization will also contribute to the globalization of the solar photovoltaic industry. With the increasing global requirements for sustainable development, solar photovoltaics will be more widely used as a clean and renewable energy form. Moreover, solar photovoltaic is expected to become the leading force in the energy field, replacing the traditional fossil energy. However, in practical application, solar energy technology also faces some challenges. For example, solar power generation is greatly affected by weather conditions, which is also one of the important factors restricting the further development of solar energy technology. It also needs to make efforts on how to reduce the impact of weather on solar power generation and how to meet more demand more efficiently.

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