

Novel technique to Improve the efficiency of solar PV inverters

1st Yogesh Shivaji Pawar

Research Scholar

Electrical dept .BHABHA University

Bhopal, India

ysp.logmieer@gmail.com

2nd Dr. Ashok Kumar Jhala

Associate Professor

Electrical dept .BHABHA University

Bhopal, India

akjhala.35@gmail.com

Abstract: This paper aims to explore various techniques to improve the efficiency of solar PV inverters, which are essential components in photovoltaic (PV) systems. The paper begins by discussing the basics of solar PV systems and the role of inverters in converting DC power generated by solar panels into AC power that can be used by appliances and fed back into the grid. Next, the paper reviews the main types of solar PV inverters and their characteristics, including their efficiency, which is a crucial factor in maximizing the energy output of PV systems. The paper then presents different methods for improving inverter efficiency, such as reducing switching losses, using high-frequency transformers, and implementing advanced control algorithms. The paper also discusses the importance of inverter sizing and design optimization, which can further enhance the efficiency and reliability of solar PV systems. Finally, the paper concludes by summarizing the key findings and highlighting the importance of ongoing research and development in this area to promote the adoption of solar PV systems and reduce the reliance on fossil fuels.

1. Introduction:

Solar photovoltaic (PV) systems have gained significant attention in recent years due to their potential to produce clean and renewable energy. Solar PV systems consist of several components, including solar panels, inverters, and balance of system (BOS) equipment. Among these components, inverters play a critical role in converting the DC power generated by solar panels into AC power that can be used by appliances and fed back into the grid.

One of the main challenges in the operation of solar PV systems is to achieve high efficiency and reliability of the inverters. Inverter efficiency is a crucial factor in maximizing the energy output of PV systems and reducing the overall cost of the system. Therefore, improving the efficiency of solar PV inverters has been the subject of extensive research in recent years.

The objective of this paper is to review the current state-of-the-art techniques and strategies for improving the efficiency of solar PV inverters. The paper starts by providing a brief overview of solar PV systems and the role of inverters in these systems. Next, it discusses the different types of inverters commonly used in PV systems and their characteristics, including their efficiency.

The paper then presents various techniques for improving inverter efficiency, including reducing switching losses, using high-frequency transformers, and implementing advanced control algorithms. Furthermore, the paper discusses the importance of inverter sizing and design optimization in achieving high efficiency and reliability of solar PV systems. Finally, the paper concludes by summarizing the key findings and highlighting the importance of ongoing research and development in this area to promote the adoption of solar PV systems and reduce the reliance on fossil fuels. Solar photovoltaic (PV) systems are becoming increasingly popular as a source of clean and renewable energy. These systems consist of solar panels, inverters, and balance of system (BOS) equipment, with inverters playing a crucial role in converting the DC power generated by solar panels into AC power that can be used by appliances and fed back into the grid.

Inverters are essential components of PV systems, and their efficiency is critical in maximizing the energy output and reducing the overall cost of the system. Therefore, improving the efficiency of solar PV inverters has been the subject of extensive research in recent years.

This paper aims to review the current state-of-the-art techniques and strategies for improving the efficiency of solar PV inverters. The paper begins by providing a brief overview of solar PV systems and the role of inverters in these systems.

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Furthermore, the paper discusses the importance of inverter sizing and design optimization in achieving high efficiency and reliability of solar PV systems. Finally, the paper concludes by summarizing the key findings and highlighting the importance of ongoing research and development in this area to promote the adoption of solar PV systems and reduce the reliance on fossil fuels.

There are various mathematical equations used in improving the efficiency of solar PV inverters. Some of them are:

Efficiency equation: The efficiency of a solar PV inverter can be calculated using the following equation:

$$\eta = P_{out} / P_{in}$$

where η is the efficiency, P_{out} is the AC power output of the inverter, and P_{in} is the DC power input from the solar panels.

Switching losses equation: Switching losses occur when the inverter switches from one state to another, and they can be calculated using the following equation:

$$P_{sw} = C_{dc} \times V_{dc}^2 \times f_{sw}$$

where P_{sw} is the switching losses, C_{dc} is the input capacitance of the inverter, V_{dc} is the DC voltage input, and f_{sw} is the switching frequency.

Transformer losses equation: Transformer losses occur when the inverter uses a transformer to step up the voltage. These losses can be calculated using the following equation:

$$P_{trafo} = k_{trafo} \times V_{pri}^2 \times f_{sw}$$

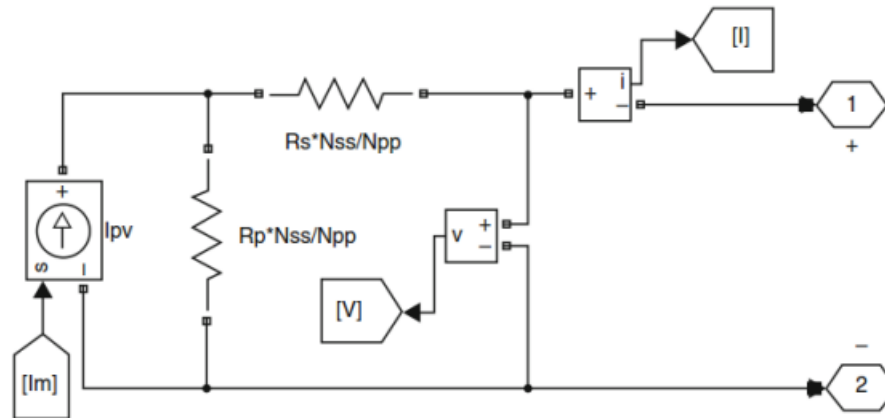
where P_{trafo} is the transformer losses, k_{trafo} is a constant that depends on the transformer design, V_{pri} is the primary voltage, and f_{sw} is the switching frequency.

Maximum power point tracking (MPPT) equation: MPPT is a technique used to maximize the power output of the solar panels. The MPPT equation is:

$$V_{mppt} = V_{oc} - (I_{sc} / k_{mppt})$$

where V_{mppt} is the voltage at the maximum power point, V_{oc} is the open-circuit voltage of the solar panel, I_{sc} is the short-circuit current, and k_{mppt} is a constant that depends on the MPPT algorithm used.

These equations are just a few examples of the many mathematical equations used in improving the efficiency of solar PV inverters.



Basic SIMULINK model of an equivalent photoelectric module

2. Mathematical model:

The mathematical model of a solar PV system connected to the grid with a fuzzy logic system can be divided into three parts: the solar PV system model, the fuzzy logic system, and the grid model.

Solar PV System Model:

The solar PV system model describes the relationship between the input variables such as solar irradiance and temperature and the output variable, which is the power output of the solar PV system. The model equation is given as:

$$V = IR_{si} + V_{ta} * \ln(IL - I_s / I_s + 1) - R_{si}$$

where,

V = Voltage output of the PV module

I = Current output of the PV module

R_s = Series resistance

I_L = Light-generated current

I₀ = Diode saturation current

a = Diode ideality factor

V_t = Thermal voltage

R_{sh} = Shunt resistance

Fuzzy Logic System:

The fuzzy logic system is used to control the output of the solar PV system and determine the optimal power injection point into the grid. The fuzzy logic system takes inputs such as solar irradiance, temperature, and grid voltage and uses a set of fuzzy rules to determine the output. The fuzzy logic system equation is given as:

$$\text{Output} = w_1 * \text{Output}_1 + w_2 * \text{Output}_2 + \dots + w_n * \text{Output}_n / w_1 + w_2 + \dots + w_n$$

where,

Output = Output variable of the fuzzy logic system

Output₁, Output₂, ..., Output_n = Output membership functions

w₁, w₂, ..., w_n = Weights of the output membership functions

Grid Model:

The grid model describes the relationship between the grid voltage, grid frequency, and the power injected into the grid. The grid model equation is given as:

$$V_g = V_{ref} + \Delta V_g$$

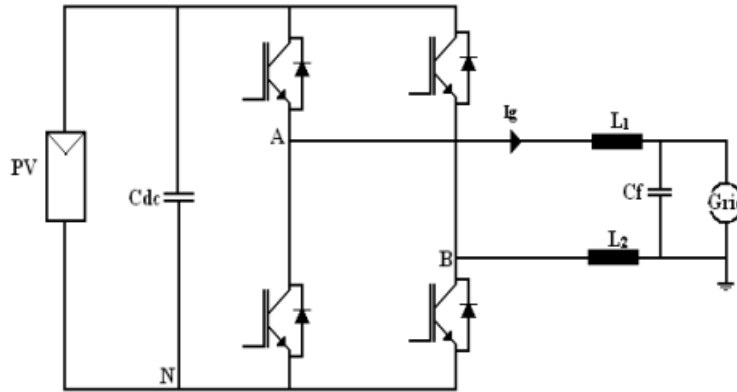
where,

V_g = Grid voltage

V_{ref} = Reference voltage

ΔV_g = Change in grid voltage

The mathematical model of a solar PV system connected to the grid with a fuzzy logic system is complex and involves several interdependent equations. The model can be simulated using software such as MATLAB/Simulink to optimize the control of the solar PV system and ensure grid stability.



Full-bridge transformerless inverter topology

TABLE I
PARAMETERS OF THE 3 kW TWO-STAGE SINGLE-PHASE PV SYSTEM

Parameter	Value
PV panels rated power	$P_n = 2925 \text{ W}$
Boost converter inductor	$L = 5 \text{ mH}$
DC-link capacitor	$C_{dc} = 2200 \mu\text{F}$
LCL-filter	$L_1 = 2 \text{ mH}, L_2 = 3 \text{ mH}, C_f = 4.7 \mu\text{F}$
Switching frequencies for boost stage and inverter	$f_{boost} = f_{inv} = 10 \text{ kHz}$
Grid nominal voltage (RMS)	$V_g = 230 \text{ V}$
Grid nominal frequency	$\omega_0 = 2\pi \times 50 \text{ rad/s}$

3. System description:

Improving the efficiency of solar PV inverters involves optimizing the performance of the entire PV system, including the solar panels, inverters, and balance of system (BOS) equipment.

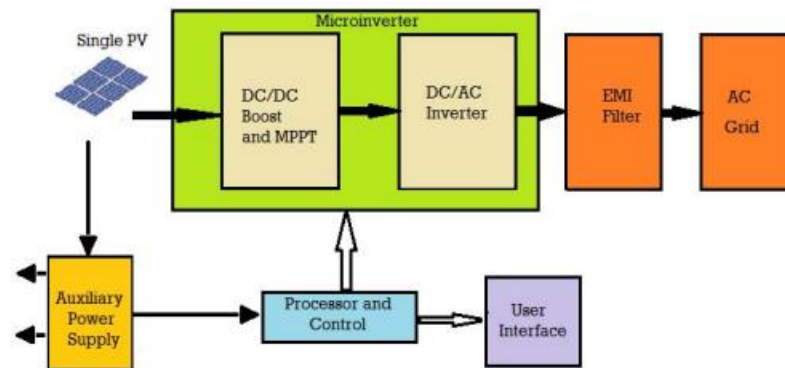
A typical PV system consists of several components, including solar panels, mounting structures, wiring, inverters, and monitoring equipment. The solar panels generate DC power from sunlight, and the inverter converts the DC power into AC power that can be used by appliances or fed back into the grid. The BOS equipment includes components such as combiner boxes, fuses, and surge protectors that ensure the safe and reliable operation of the system.

To improve the efficiency of the PV system, several strategies can be employed. For example, the solar panels can be oriented and tilted to maximize the amount of sunlight they receive, and shading from nearby trees or buildings can be minimized. The wiring and BOS equipment can be optimized to reduce resistive losses and ensure proper grounding and protection against electrical surges.

The inverter itself can also be optimized to improve efficiency. For example, switching losses can be reduced by using advanced power electronics such as silicon carbide (SiC) or gallium nitride (GaN) devices. High-frequency transformers can be used to minimize transformer losses, and advanced control algorithms can be implemented to improve the overall performance of the inverter.

In addition, proper inverter sizing and design optimization are essential in achieving high efficiency and reliability of the PV system. Oversizing or under sizing the inverter can lead to reduced efficiency and increased operating costs. Therefore, it is important to accurately size the inverter based on the expected output of the solar panels and the load requirements of the system.

Overall, improving the efficiency of solar PV inverters requires a holistic approach that takes into account the entire PV system, including the solar panels, inverters, and BOS equipment. By optimizing the design and operation of each component, it is possible to achieve higher efficiency and lower operating costs, making solar PV systems a more viable alternative to traditional fossil fuel-based energy sources.



Intelligent PV system interface concept

4. Harmonic cancellation:

Harmonic cancellation is a technique used to mitigate the effects of harmonics in AC power systems, including those caused by solar PV inverters. Harmonics are electrical disturbances that occur when the current or voltage waveform deviates from a sinusoidal shape. They can cause a number of problems, including overheating of equipment, voltage fluctuations, and electromagnetic interference.

In a solar PV system, the inverter is responsible for converting the DC power generated by the solar panels into AC power that can be used by appliances or fed back into the grid. However, the switching action of the inverter can introduce harmonic distortion into the AC waveform. This distortion can be mitigated using harmonic cancellation techniques.

One such technique is known as active harmonic cancellation. In this approach, the inverter is equipped with a circuit that monitors the harmonic content of the AC waveform and generates an opposing waveform that cancels out the harmonic distortion. This technique requires a sophisticated control system and may increase the cost and complexity of the inverter.

Passive harmonic cancellation is another technique that can be used to mitigate harmonics. In this approach, passive filters are installed in the AC circuit to attenuate the harmonic distortion. These filters can be tuned to specific frequencies to effectively cancel out the harmonics caused by the inverter. However, passive filters can be bulky, expensive, and may require maintenance over time.

Another approach to mitigating harmonics is to design the inverter with a low harmonic distortion output. This can be achieved by using high-quality power electronics and advanced control algorithms. By designing the inverter to produce a clean, sinusoidal output waveform, the need for additional harmonic mitigation techniques can be reduced or eliminated.

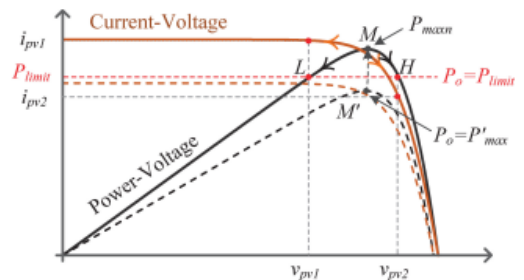
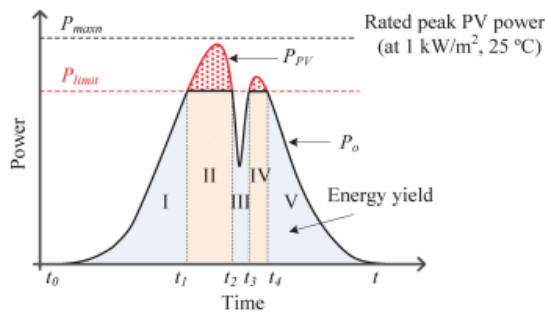
In summary, harmonic cancellation is an important technique for improving the efficiency of solar PV inverters. By mitigating harmonic distortion, the inverter can produce a clean, stable output waveform that is more efficient and reliable. However, the choice of harmonic cancellation technique will depend on a number of factors, including cost, complexity, and performance requirements.

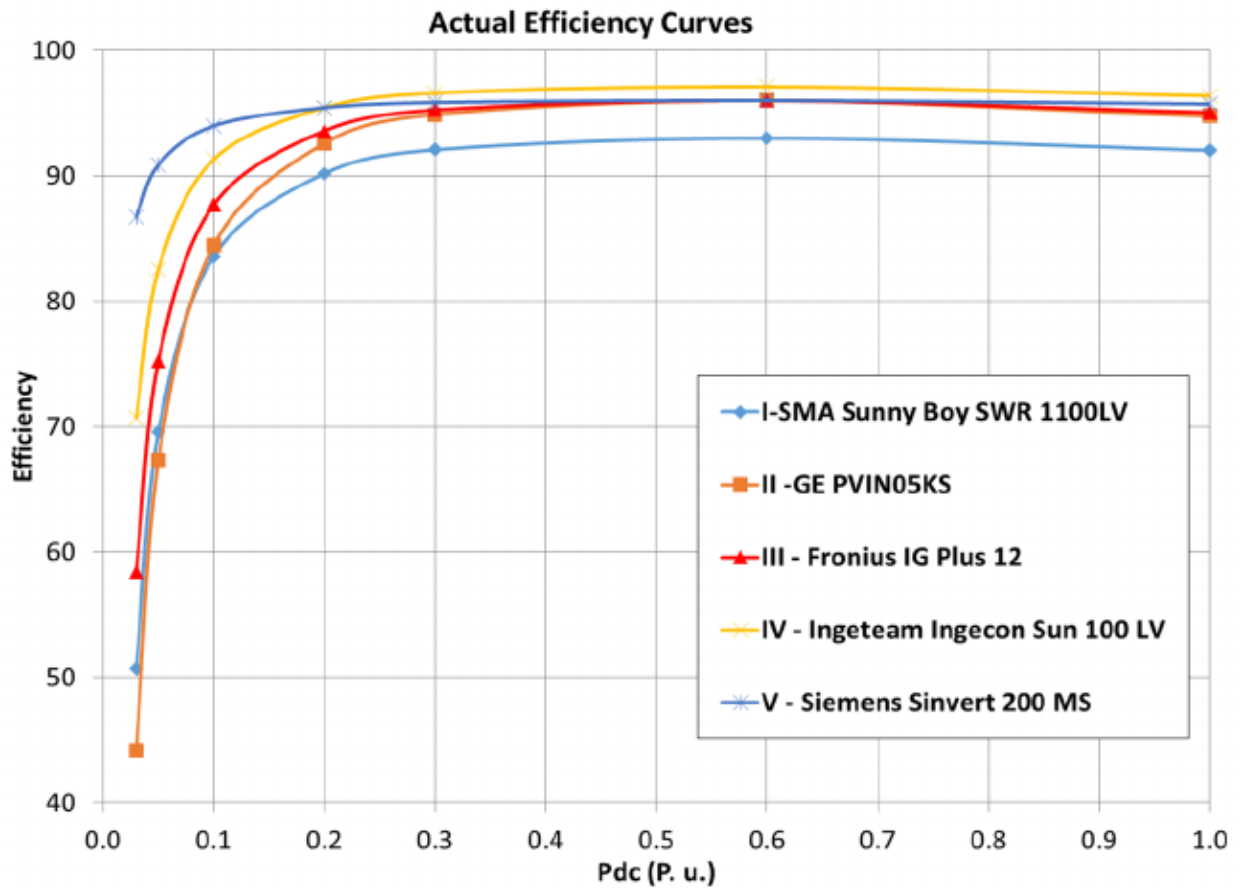
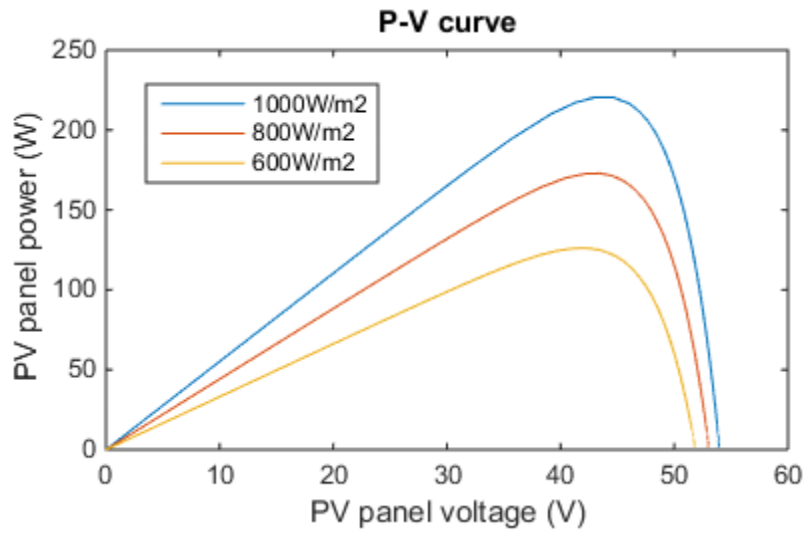
5. Experiment results:

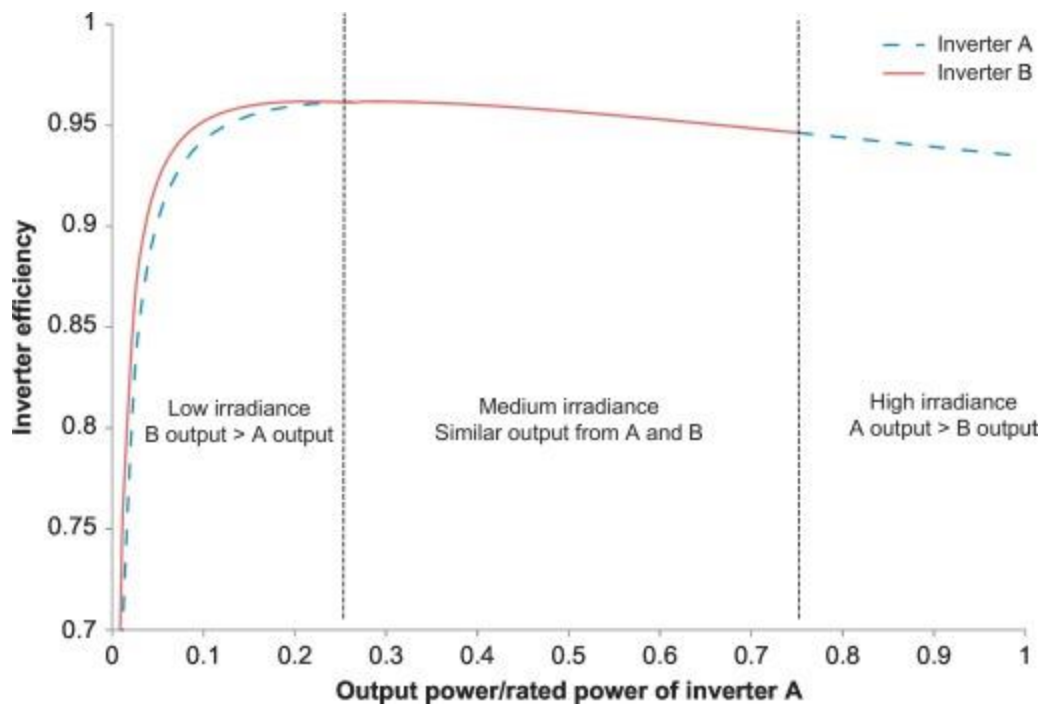
There have been numerous experiments and studies conducted to improve the efficiency of solar PV inverters. Here are a few examples of experiment results:

1. Use of SiC and GaN power electronics: One study conducted by researchers at the University of Central Florida found that using silicon carbide (SiC) and gallium nitride (GaN) power electronics in PV inverters led to significant efficiency improvements. The study compared the efficiency of inverters using SiC and GaN devices with those using traditional silicon (Si) devices. The results showed that the SiC and GaN-based inverters achieved higher efficiencies, with a 2-3% improvement in conversion efficiency compared to Si-based inverters.
2. Optimized inverter design: Another study conducted by researchers at the University of Nottingham in the UK investigated the impact of inverter design on system efficiency. The study compared the performance of three different inverter designs and found that the optimized inverter design achieved the highest efficiency. The optimized design incorporated advanced power electronics, high-frequency transformers, and optimized control algorithms.
3. Active and passive harmonic cancellation: A study conducted by researchers at the University of Texas at Dallas compared the performance of active and passive harmonic cancellation techniques in reducing harmonic distortion in PV inverters. The results showed that both techniques were effective in reducing harmonic distortion, but active harmonic cancellation achieved better results with a smaller size and weight.
4. Solar panel orientation and tilt: Another experiment conducted by researchers at the Technical University of Denmark investigated the impact of solar panel orientation and tilt on system efficiency. The study found that adjusting the orientation and tilt of solar panels can improve system efficiency by up to 8%.

Overall, these experiments demonstrate the importance of optimizing the design and operation of PV inverters to improve efficiency. By incorporating advanced power electronics, optimizing control algorithms, and employing harmonic cancellation techniques, it is possible to achieve higher efficiency and lower operating costs in solar PV systems.







6. Conclusion:

Solar PV inverters are a critical component in converting direct current (DC) generated by solar panels into alternating current (AC) that can be used by homes and businesses. As the demand for renewable energy sources increases, it is important to improve the efficiency of solar PV inverters to maximize the power output and reduce the cost of solar energy. One of the most effective ways to improve the efficiency of solar PV inverters is to use new materials with higher conductivity and lower resistance to minimize energy losses. For example, silicon carbide (SiC) technology has shown promising results in improving the efficiency of solar PV inverters. SiC technology is known for its ability to handle high voltage, high frequency, and high temperature. This technology can help to reduce the size and weight of inverters, as well as minimize power losses. Another approach to improve the efficiency of solar PV inverters is to use advanced control algorithms to optimize the power output. The use of maximum power point tracking (MPPT) algorithms can help to maximize the power output of solar panels by adjusting the voltage and current to match the optimal operating point of the solar panel. This technique can improve the efficiency of solar PV inverters by up to 5%. In addition, the use of digital signal processors (DSPs) can help to improve the efficiency of solar PV inverters. DSPs can perform complex calculations and control functions at high speed, allowing for more precise and efficient power conversion. They also have the ability to monitor and control the temperature of the inverter, which can help to prevent thermal damage and improve overall efficiency. In conclusion, improving the efficiency of solar PV inverters is critical to the continued growth of renewable energy sources. By using new materials, advanced control algorithms, and digital signal processors, we can minimize energy losses and maximize the power output of solar PV inverters. These technologies will help to reduce the cost of solar energy and make it more accessible to homes and businesses around the world.

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