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Efficiency and Harmonic Analysis of Inverter by Using PV Solar System

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ABSTRACT

The inverter's output impedance can be adjusted to reduce harmonic interference on the grid. Advanced current control strategies like PI and quasi-PR control enable precise control of the inverter's output current, further reducing harmonics. PI control compensates for error signals to eliminate steady-state errors but has limited ability to suppress harmonics in high-frequency ranges. Quasi-PR control combines proportional, integral, and resonance control to suppress specific frequency harmonics. It can also assess the impact of control strategies on harmonic suppression, providing a theoretical basis for optimization. Optimizing grid inverter control strategies is critical for maintaining grid stability and enhancing power quality. Thorough research on grid-connected photovoltaic inverter harmonics and effective control strategies contribute to renewable energy development and green, low-carbon energy systems.

1.INTRODUCTION

In photovoltaic power generation systems, the inverter, as a key component, directly affects the efficiency and electrical quality of the entire system. The use of Pulse Width Modulation (PWM) technology in photovoltaic inverters can improve the quality of output voltage and current. However, due to the non-linear characteristics of electronic devices and dead zone effects, harmonic pollution has become a significant issue. This pollution not only reduces the electrical quality of the grid but may also have negative impacts on grid stability and equipment lifespan.

A comparative analysis of different harmonic analysis methods for photovoltaic inverters is presented, emphasizing the necessity of reasonable control strategies and technological improvements to ensure the harmonious grid connection of photovoltaic power generation systems with the grid.

II. PHOTOVOLTAIC POWER PLANT ELECTRICAL CHARACTERISTICS

The basic principle of grid-connected photovoltaic power plants is to convert the direct current output from the solar cell array into alternating current with the same amplitude, frequency, and phase as the grid voltage, and to transmit the electrical energy to the grid through grid connection[1].

The basic principle of grid connection for photovoltaic power plants is shown in Fig 1. Single-stage non-isolated topologies require the output voltage of the photovoltaic array to be higher than the peak voltage of the grid. In this case, a two-stage circuit may be required. The first stage is a DC/DC converter with an MPPT function. The second stage is an AC/AC device converting DC to AC for grid connection.

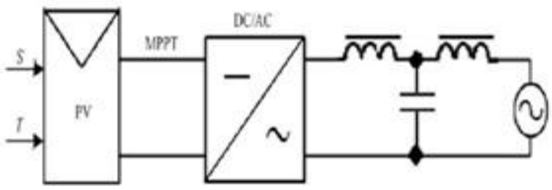

Figure 1. Photovoltaic grid connection topology

The two-stage photovoltaic grid-connected system adds a DC/DC boosting link compared to a single-stage photovoltaic grid-connected system, which means that the direct current energy is boosted through the Boost circuit, then converted into alternating current energy through the photovoltaic inverter, and finally integrated into the distribution grid. The topology of the two-stage photovoltaic gridconnected system is shown in Fig 3.

The comparison between monopole photovoltaic grid-connected system and bipole photovoltaic grid-connected system mainly focuses on aspects such as circuit structure, efficiency, and cost. Bipole systems have two independent power conversion paths, enabling more refined power control and potentially higher efficiency.

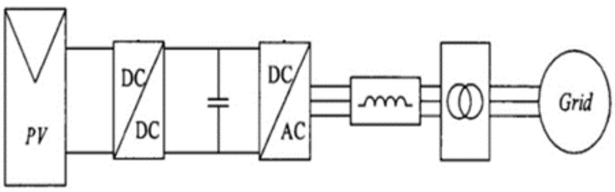

Figure 2 Double-layer structure

III. Grid-connected photovoltaic inverter output characteristics analysis

A. Inverter harmonic component analysis

In recent years, non-isolated photovoltaic grid-connected power generation systems have developed rapidly. In order to suppress the direct current injected into the alternating current grid, a half-bridge inverter circuit is used in the DC/AC link to achieve the method of isolating direct current with a capacitor, resulting in high inverter efficiency. Assuming that the A, B, and C three-phase systems are balanced systems without the interference of unbalanced factors. T1~T6 are IGBT switching devices, which conduct by receiving the SPWM signal, and are connected in reverse with diodes of the same parameters. The output waveform is an SPWM wave with an amplitude of E/2, and after passing through the LCL low-pass filter to filter out high-frequency components, it outputs sinusoidal voltage.

The circuit shown in Fig 4 is a modulation circuit. Assuming the carrier to be a triangular wave u，The angular frequency is ω， with a peak value of U; Modulation Wave u is sine wave， with an angular frequency of ω， with a peak value of U ;setting modulation ratio M = U / U≤1， carrier ratio N = ω /ω， and dead time is Δt; applying a dual Fourier transform decomposition to the inverter output waveform, the output waveform contains modulated stage high frequency harmonics u,and dead time effect additional harmonics u,[2].

B. Impact of dead-time effect on photovoltaic grid-connected output

The impact of the dead-time effect on photovoltaic grid-connected output manifests in several aspects.

Firstly, the dead-time effect can lead to distortion in the inverter output voltage, not only reducing the fundamental value of the output voltage but also altering its phase.. Additionally, the dead-time effect may affect the stability of the system. Since the dead-time effect changes the system's equivalent open-loop transfer function, the system may exhibit resonance at certain frequencies, thus impacting its stability. Lastly, the dead-time effect may also influence the system's dynamic performance. As the dead-time effect introduces nonlinearity to the system, it may take longer for the system to return to a stable state after being disturbed [3].

IV. Grid-connected photovoltaic inverter current control strategy and inverter output impedance

A. Current control strategy

In the harmonic analysis of photovoltaic inverters, the new current control strategies mainly include maximum power point tracking outer loop based on perturbation observation method and grid-connected current PI decoupling control. This method achieves maximum power point tracking through perturbation observation and uses PI decoupling control in gridconnected mode to ensure system stability

Maximum power point tracking outer loop based on disturbance observer and gridconnected current PI decoupling control. This method achieves maximum power point tracking through a disturbance observer and utilizes PI decoupling control in grid-connected mode to ensure system stability. However, it may increase system complexity and cost [4].

Regarding the third strategy of grid-connected current direct control loop based on quasiproportional resonance. However, this approach requires accurate measurement and analysis of various harmonic components in the grid, posing high demands on the system [5].

Based on the above two equations, it can be seen that as the gain at the fundamental frequency tends to infinity, the system is able to achieve zero steady-state error tracking for a fixed-frequency sine signal [6]. To increase the phase margin and bandwidth, a low-pass filter with higher gain can be added to realize proportional resonant (PR) control, thus constituting a quasi-proportional resonant controller [7].

In the middle formal:K ， K ， ω is the controller parameter.,ω=314 rad/s。The frequency characteristics of PI control, PR control, and quasi-PR control are shown in

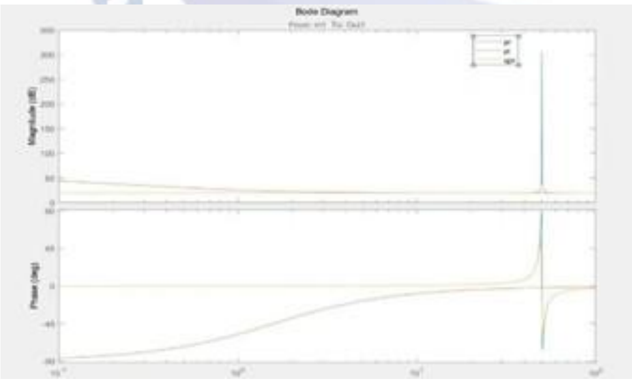

Figure 3 Frequency characteristics comparison[7].

Fig 5. In the diagram, the gain of the PI controller at the fundamental frequency is almost zero, whereas the gains of the PR controller and the quasi-PR controller at the fundamental frequency are significant and exhibit similar frequency characteristics [8].This enables effective elimination of steady-state errors at specified frequencies.

B. Inverter output impedance

The suitable value of the inverter output impedance depends on the specific requirements and application scenarios of the system. Generally, the inverter output impedance should meet the following criteria[9]. It should be easy to control and adjust. The inverter output impedance should be easy to control and adjust to facilitate the implementation of various control strategies and optimize system performance. [10].

The design and analysis of inverter output impedance play a crucial role in ensuring system stability, grid-connected power quality, and system expansion. Existing technologies and research achievements have made some progress in the design of inverter output impedance.. These methods provide a theoretical basis and guidance for the design of photovoltaic power generation systems[11][12].

V. Conclusion

This paper first introduces the basic principles and operation of photovoltaic power generation systems and their key component, the inverter. It summarizes the current research status of harmonic issues in photovoltaic inverters, including theoretical analysis, experimental research, and control strategies. Furthermore, the paper discusses how effective current control strategies and the rational design of inverter output impedance can reduce harmonic interference and improve the power quality of the grid. Finally, this paper compared and analyzed different harmonic analysis methods, pointing out the importance of studying and developing more efficient control techniques to achieve the harmonious grid connection of photovoltaic power systems with the electricity grid.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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