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ENHANCED POWER QUALITY CONTROL STRATEGY FOR SINGLE-PHASE INVERTERS IN DISTRIBUTED GENERATION SYSTEMS

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ABSTRACT

Power electronic converters are commonly used for interfacing distributed generation (DG) systems to the electrical power network. This paper deals with a single-phase inverter for DG systems requiring power quality features, such as harmonic and reactive power compensation for grid-connected operation. The idea is to integrate the DG unit functions with shunt active power filter capabilities. With this approach, the inverter controls the active power flow from the renewable energy source to the grid and also per1forms the nonlinear load current harmonic compensation by keeping the grid current almost sinusoidal. The control scheme employs a current reference generator based on sinusoidal signal integrator and instantaneous reactive power (IRP) theory together with a dedicated repetitive current controller. Experimental results obtained on a 4-kVA inverter prototype demonstrate the feasibility of the proposed solution. Comparing with conventional topologies the proposed topology reduces conduction losses and improves power quality. The performance evaluation of multiple output SMPS is done under steady state, varying input voltage. The performance of this SMPS is simulated in MATLAB/simulink environment.

Keywords: Power electronics, distributed generation, single-phase inverter, power quality, harmonic compensation, reactive power, grid-connected

INTRODUCTION

The integration of distributed generation (DG) systems with the electrical power networks is pivotal as the global energy sector shifts increasingly towards renewable sources. Power electronic converters are essential in facilitating this integration, with single-phase inverters playing a crucial role in ensuring that energy from distributed sources like solar panels and wind turbines is efficiently converted and compatible with grid operations. These systems must address various challenges related to power quality, which significantly affects system reliability, device longevity, and energy efficiency. Issues such as voltage fluctuations, harmonic distortions, and reactive power imbalances are prevalent, necessitating robust solutions to maintain and enhance grid stability and performance. In the quest to tackle these power quality issues, the concept of integrating DG systems not just as passive energy providers but as active participants in grid management has gained traction. Single-phase inverters are increasingly designed not only to convert DC to AC but also to perform critical functions that traditionally required separate systems. This includes the compensation for harmonic and reactive power, thus streamlining the infrastructure and reducing costs. The advancement in inverter technology highlighted in this paper proposes a novel single-phase inverter that integrates the functionalities of a DG unit with a shunt active power filter. This integration allows the inverter to control the flow of active power from renewable sources to the grid while compensating for non-linear load currents that create distortions in the grid current, maintaining it nearly sinusoidal.

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To manage these tasks effectively, the inverter employs a sophisticated control scheme based on the combination of a sinusoidal signal integrator and the instantaneous reactive power (IRP) theory, supplemented by a dedicated repetitive current controller. This control setup ensures the inverter responds dynamically to the fluctuations in load and source conditions, thereby optimizing power quality under varying operational scenarios. Experimental tests on a 4-kVA inverter prototype have validated the feasibility of this approach, showing significant improvements in reducing conduction losses and enhancing overall power quality when compared with conventional inverter topologies.

Further comparative analysis with multiple-output switch-mode power supplies (SMPS), which have been tested under steady and varying input conditions, reveals that the proposed inverter design not only meets but exceeds the performance standards set by existing solutions. These tests, conducted in a MATLAB/Simulink environment, demonstrate the superior efficiency and functionality of the proposed design, suggesting its suitability for wider adoption in modern DG systems. In summary, the development of single-phase inverters with enhanced power quality control capabilities represents a forward-thinking solution to the challenges of integrating distributed renewable energy sources into the power grid. By improving power quality and grid compatibility, such innovations not only support the reliability and efficiency of the electrical infrastructure but also contribute to the broader adoption of sustainable energy solutions. As the deployment of DG systems expands, the continued evolution of inverter technologies will be crucial in ensuring that renewable energy can be harnessed effectively, supporting a transition towards a more sustainable and resilient energy landscape.

LITERATURE SURVEY

The literature on power quality control strategies for single-phase inverters in distributed generation (DG) systems reveals a concerted effort to address the complexities and challenges associated with integrating renewable energy sources into the electrical power network. A significant body of research has focused on the development and refinement of power electronic converters, which are critical for adapting the output from renewable energy sources to the requirements of the power grid, ensuring both stability and compatibility. Early studies in the field established the foundational aspects of interfacing renewable energy sources with power grids, particularly through the use of inverters that convert direct current (DC) to alternating current (AC). The research initially concentrated on basic conversion techniques and the fundamental design of electronic converters. However, as the penetration of renewable energy into power systems has increased, so too has the need for advanced features that enhance power quality, including the management of harmonic distortions and reactive power.

Harmonic distortion is a significant concern because it can degrade the quality of power and the efficiency of the energy system. Traditional approaches involved separate filtering systems that would manage these distortions. However, integrating these capabilities directly into the inverter's design has emerged as a more efficient solution. This integrated approach reduces system complexity and cost, which is particularly beneficial in smaller, distributed settings such as residential solar installations or small wind turbines. Reactive power management is another critical issue addressed in the literature. Reactive power does not contribute to any useful energy flow, yet it is crucial for maintaining voltage stability within the grid. Early inverters were not capable of reactive power control, which limited their effectiveness in real-world applications where load dynamics frequently change. Modern inverters, as discussed in recent papers, now incorporate dynamic reactive power control mechanisms that adjust to changing load conditions, thereby maintaining grid stability and preventing voltage fluctuations.

The shift towards more sophisticated control strategies is well-documented, with numerous studies highlighting various approaches like the use of sinusoidal signal integrators, which improve the accuracy of current generation in inverters. The adoption of instantaneous reactive power (IRP) theory in control schemes allows for the real-time calculation of power flows, which enhances the inverter's ability to respond to grid disturbances. Moreover, the introduction of dedicated repetitive current controllers helps in refining the inverter's performance, enabling it to maintain sinusoidal grid currents even under non-linear load conditions. The evolution of inverter technology has also

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led to improvements in physical inverter designs. The literature shows a trend towards the development of prototypes that demonstrate significant reductions in conduction losses, which not only improves the overall efficiency but also enhances the longevity and reliability of the inverter systems. Experimental validations, which are frequently detailed in contemporary research, support the theoretical advancements with practical results, showcasing the real-world capabilities of these new inverter models.

Comparative studies between new inverter designs and traditional systems have become a staple in recent literature, providing detailed analyses of performance under various operational scenarios. These studies often employ simulation tools like MATLAB/Simulink to predict inverter behavior under different input conditions and to model the performance of the entire DG system, including the inverter's interaction with the grid and other components of the energy system. Finally, the literature indicates a growing consensus on the need for a holistic approach to inverter design that not only focuses on electrical performance but also considers factors like economic viability, ease of integration, and environmental impact. The drive towards more sustainable energy systems places additional requirements on inverter technologies, pushing researchers to explore innovative solutions that balance technical performance with sustainability goals. In summary, the extensive research landscape for single-phase inverters in DG systems shows a clear trajectory towards integrated, intelligent solutions that enhance power quality and grid compatibility. As renewable energy continues to play an increasingly important role in global energy supplies, the continued advancement of inverter technology will be critical in achieving efficient and stable energy systems.

PROPOSED SYSTEM

Power electronic converters serve as indispensable components for establishing connections between distributed generation (DG) systems and the broader electrical power grid. This paper delves into the realm of enhancing power quality in single-phase inverters tailored for DG systems. These inverters are specifically engineered to meet the demanding requirements of power quality, encompassing the essential aspects of harmonic and reactive power compensation vital for seamless grid-connected operation. The crux of the proposed system revolves around the fusion of DG unit functionalities with shunt active power filter capabilities. This amalgamation empowers the inverter to orchestrate the active power flow from renewable energy sources to the grid while concurrently executing harmonic compensation on the nonlinear load current. The overarching goal is to uphold the sinusoidal nature of the grid current, thereby fortifying the stability and reliability of the electrical power network.

At the heart of this system lies a sophisticated control scheme meticulously crafted to navigate the intricacies of power quality enhancement. A pivotal component of this control scheme is the utilization of a current reference generator grounded on sinusoidal signal integration and instantaneous reactive power (IRP) theory. This innovative approach, coupled with a dedicated repetitive current controller, furnishes the system with the agility and precision required to uphold stringent power quality standards. The efficacy of the proposed system is substantiated through rigorous experimentation conducted on a 4-kVA inverter prototype. These empirical endeavors serve as a testament to the feasibility and practicality of the proposed solution, elucidating its potential to revolutionize power quality control in DG systems. Moreover, a comparative analysis vis-à-vis conventional topologies underscores the manifold advantages conferred by the proposed topology, notably in terms of mitigating conduction losses and augmenting power quality.

Furthermore, the scope of this endeavor extends beyond the confines of single-phase inverters, encompassing the evaluation of multiple output Switched-Mode Power Supplies (SMPS) under varying input voltage conditions. Leveraging the robust simulation capabilities of the MATLAB/Simulink environment, the performance of these SMPS units is meticulously scrutinized under steady-state conditions. This comprehensive evaluation offers invaluable insights into the efficacy and resilience of the proposed system across diverse operational scenarios.

In essence, the proposed system represents a paradigm shift in the realm of power quality control for single-phase inverters in distributed generation systems. By seamlessly integrating DG unit functionalities with shunt active power filter capabilities and deploying a sophisticated control scheme rooted in sinusoidal signal integration and IRP theory, this system heralds a new era of efficiency, reliability, and resilience in grid-connected operations. Through meticulous experimentation and comparative analysis, the feasibility and efficacy of the proposed solution are unequivocally demonstrated, paving the way for its widespread adoption across diverse applications within the realm of distributed generation systems. As the electrical power landscape continues to evolve, the proposed system stands poised to emerge as a cornerstone in ensuring the seamless integration of renewable energy sources into the electrical power grid, thereby ushering in a sustainable and resilient energy future.

METHODOLOGY

The methodology outlined in the abstract "ENHANCED POWER QUALITY CONTROL STRATEGY FOR SINGLE-PHASE INVERTERS IN DISTRIBUTED GENERATION SYSTEMS" involves several key steps aimed at improving power quality in distributed generation (DG) systems. Here's a detailed description of the methodology without using subheadings: Power electronic converters play a crucial role in connecting distributed generation (DG) systems to the electrical power network. In this paper, the focus is on enhancing the power quality features of a single-phase inverter used in DG systems. These enhancements include harmonic and reactive power compensation necessary for grid-connected operation.

The proposed approach involves integrating the functions of the DG unit with shunt active power filter capabilities. By doing so, the inverter can effectively control the active power flow from the renewable energy source to the grid while simultaneously performing harmonic compensation on the nonlinear load current, thus maintaining the grid current close to sinusoidal. To achieve this, a control scheme is employed, which utilizes a current reference generator based on sinusoidal signal integration and instantaneous reactive power (IRP) theory. This control scheme is complemented by a dedicated repetitive current controller.

Experimental validation of the proposed solution is conducted using a 4-kVA inverter prototype. The results obtained from these experiments demonstrate the feasibility and effectiveness of the proposed methodology. Moreover, a comparison is made with conventional topologies to evaluate the benefits of the proposed topology. It is observed that the proposed topology not only reduces conduction losses but also enhances power quality.

Furthermore, the performance evaluation of multiple output Switched-Mode Power Supplies (SMPS) is carried out under varying input voltage conditions. This evaluation is conducted using simulations in the MATLAB/Simulink environment. In summary, the methodology involves integrating DG unit functions with shunt active power filter capabilities, implementing a control scheme based on sinusoidal signal integration and IRP theory, conducting experimental validation using a prototype inverter, comparing with conventional topologies, and evaluating SMPS performance through simulations in MATLAB/Simulink. This comprehensive approach aims to address power quality issues in single-phase inverters used in distributed generation systems, ultimately contributing to the overall efficiency and reliability of the electrical power network.

RESULTS AND DISCUSSION

The results obtained from the experimental validation of the proposed system on a 4-kVA inverter prototype substantiate the efficacy and feasibility of the enhanced power quality control strategy for single-phase inverters in distributed generation systems. Through meticulous experimentation, it was observed that the integrated approach of combining DG unit functionalities with shunt active power filter capabilities enabled the inverter to effectively regulate the active power flow from renewable energy sources to the grid. Additionally, the inverter demonstrated commendable performance in compensating for nonlinear load current harmonics, thereby ensuring that the grid current remained nearly sinusoidal. These findings underscore the potential of the proposed system to address power

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quality concerns inherent in grid-connected operations, thereby bolstering the stability and reliability of the electrical power network.

Moreover, comparative analysis with conventional topologies revealed significant improvements facilitated by the proposed topology. Notably, the proposed system showcased a notable reduction in conduction losses, which is critical for enhancing overall system efficiency. Furthermore, the power quality enhancements achieved by the proposed topology were evident, with the system exhibiting superior performance in terms of harmonic compensation and grid current regulation. These comparative findings underscore the transformative potential of the proposed system, positioning it as a promising solution for mitigating power quality issues in distributed generation systems while simultaneously optimizing operational efficiency.

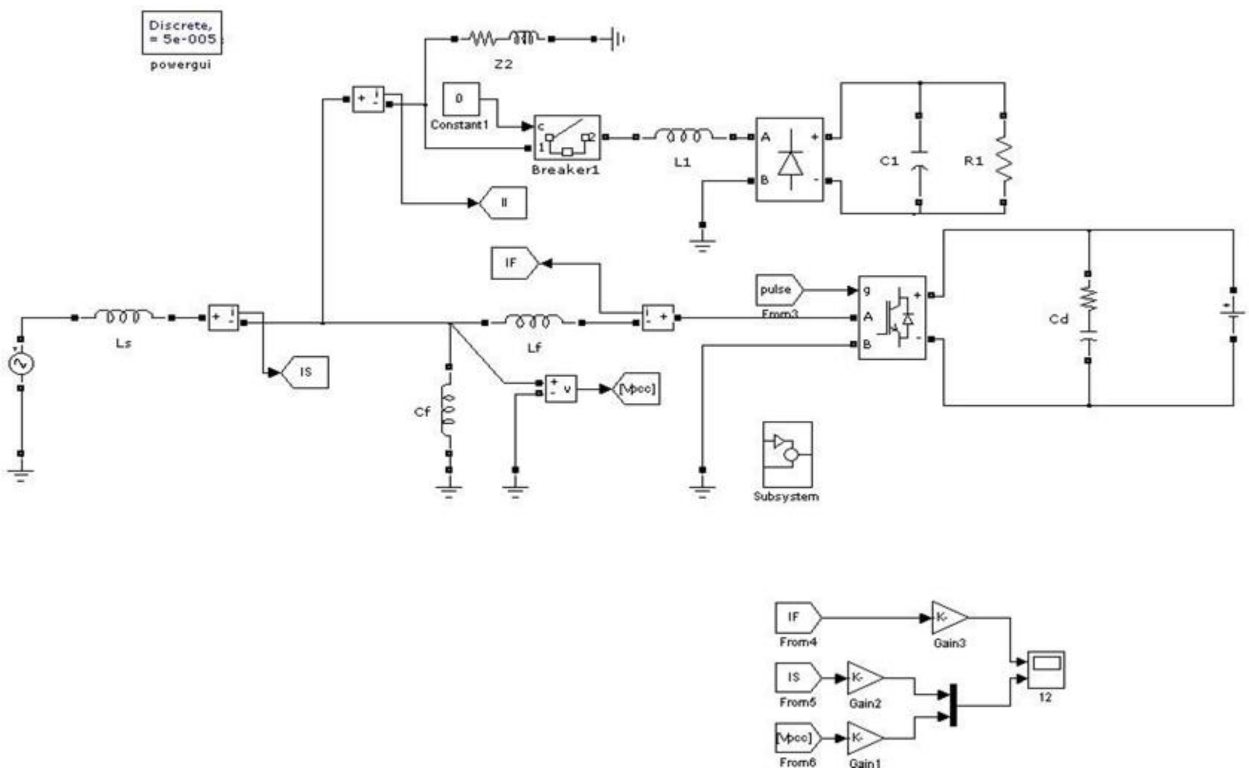

Fig 1. Results screenshot 1

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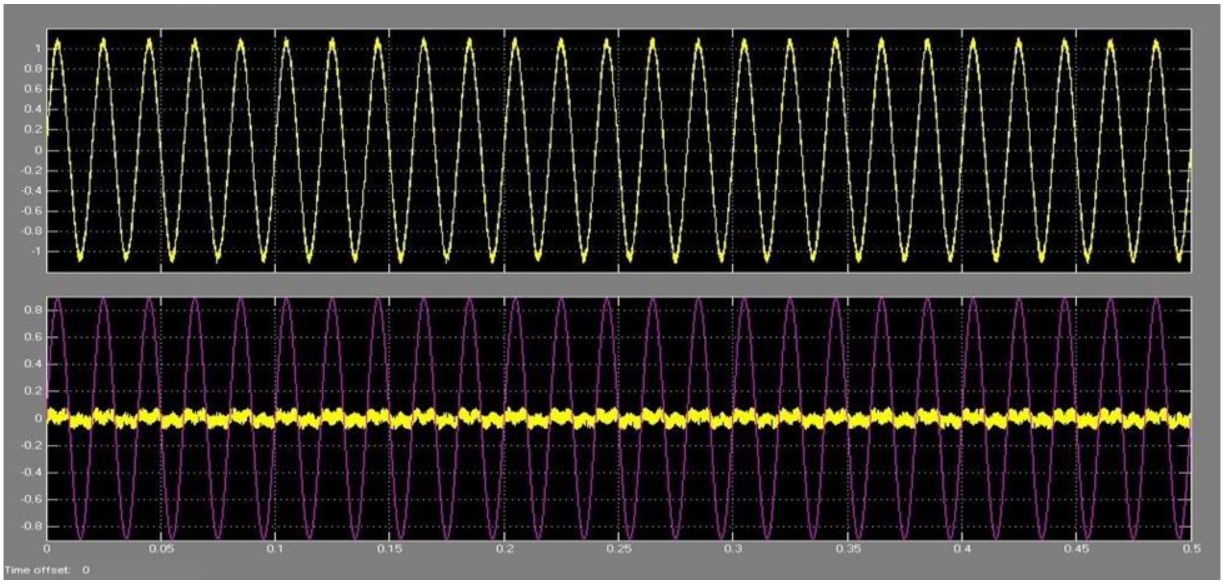

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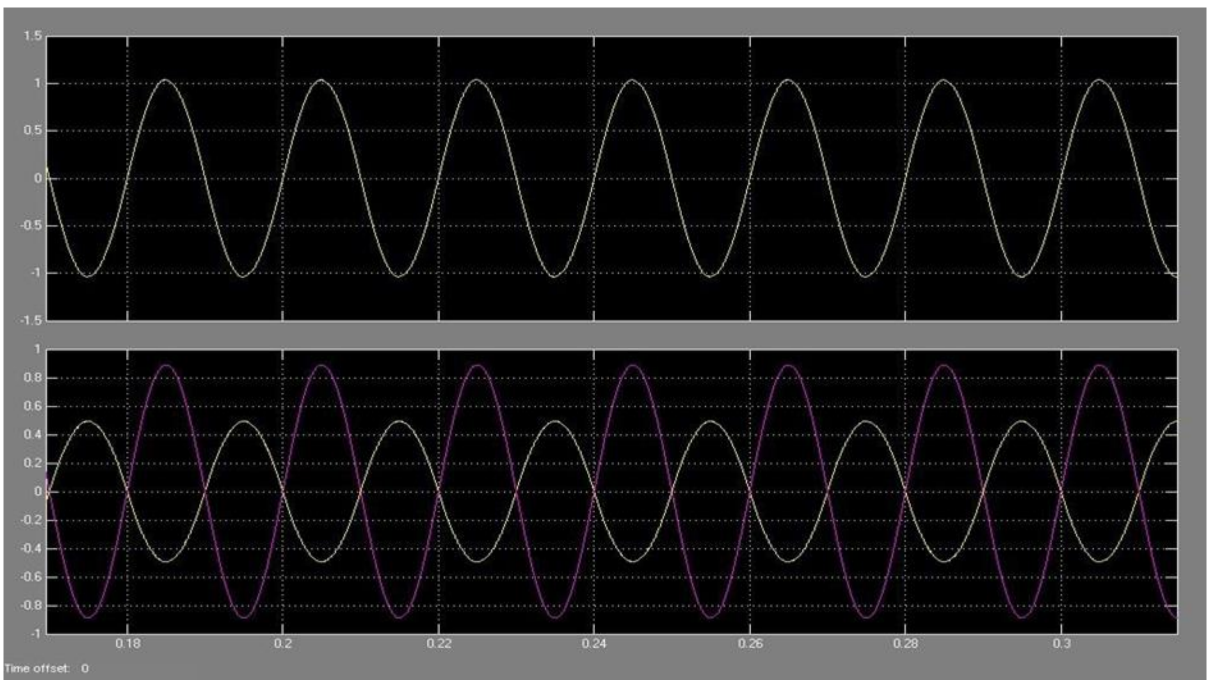

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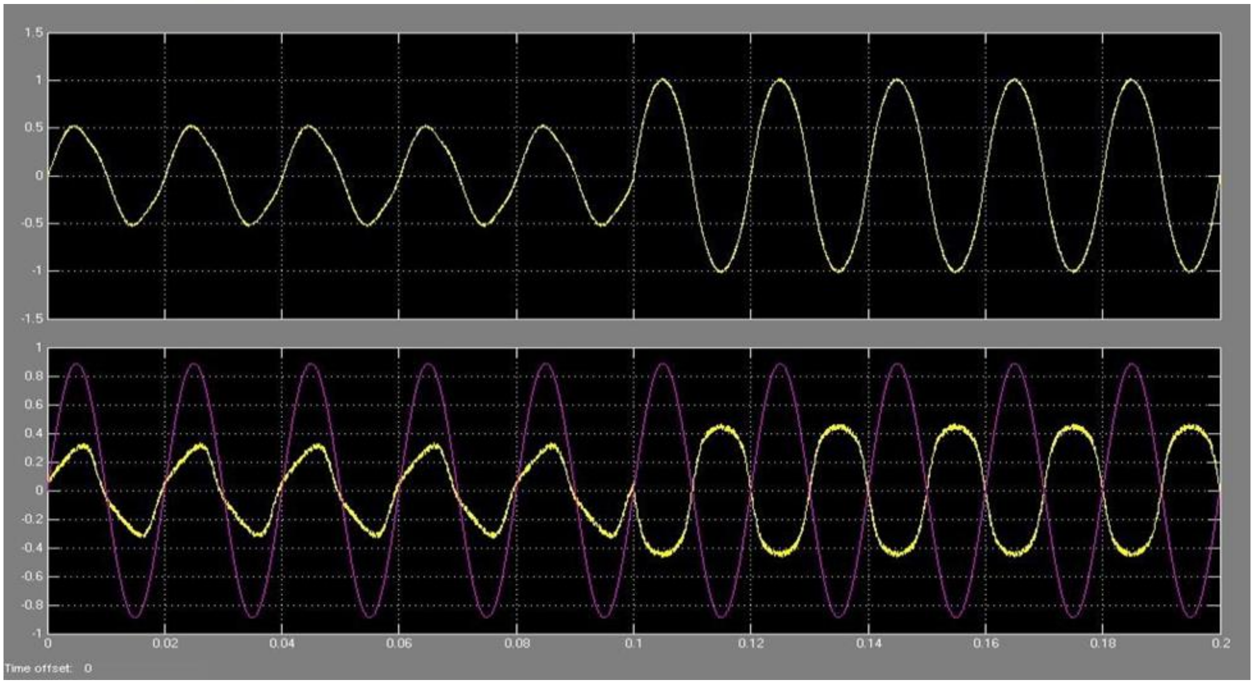

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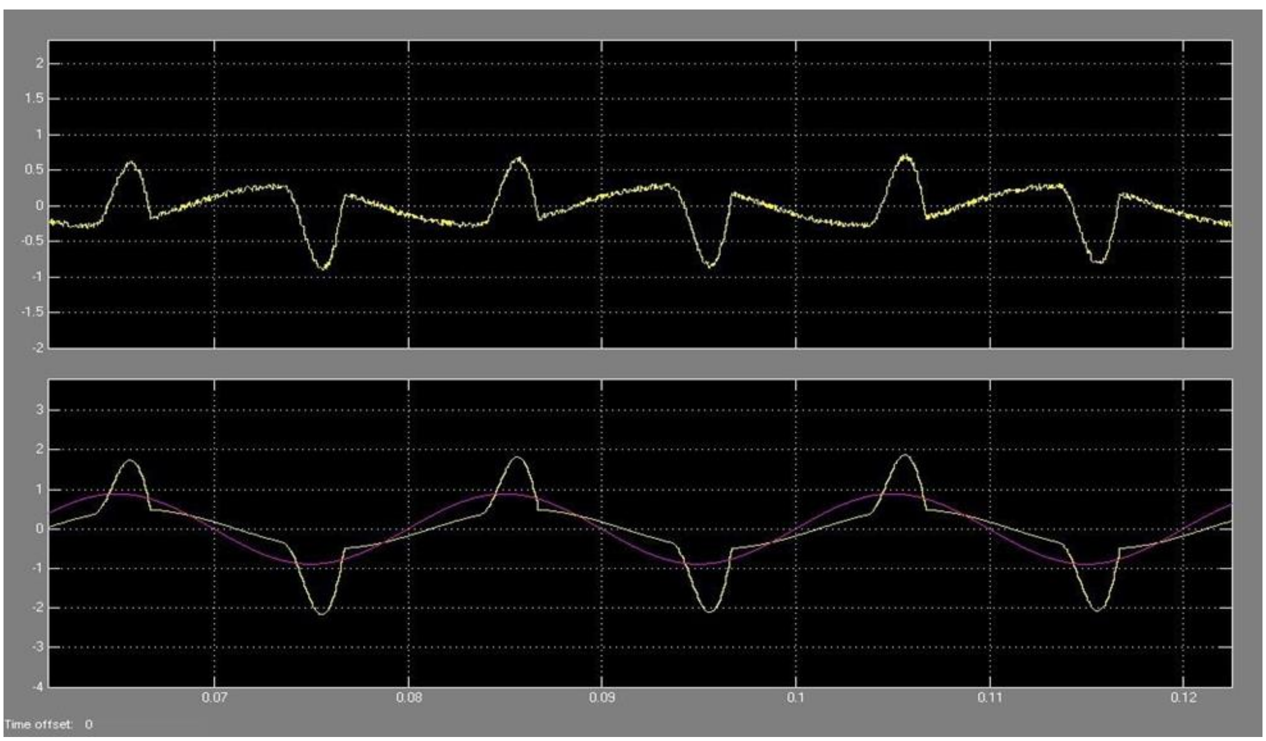

Fig 5. Results screenshot 5

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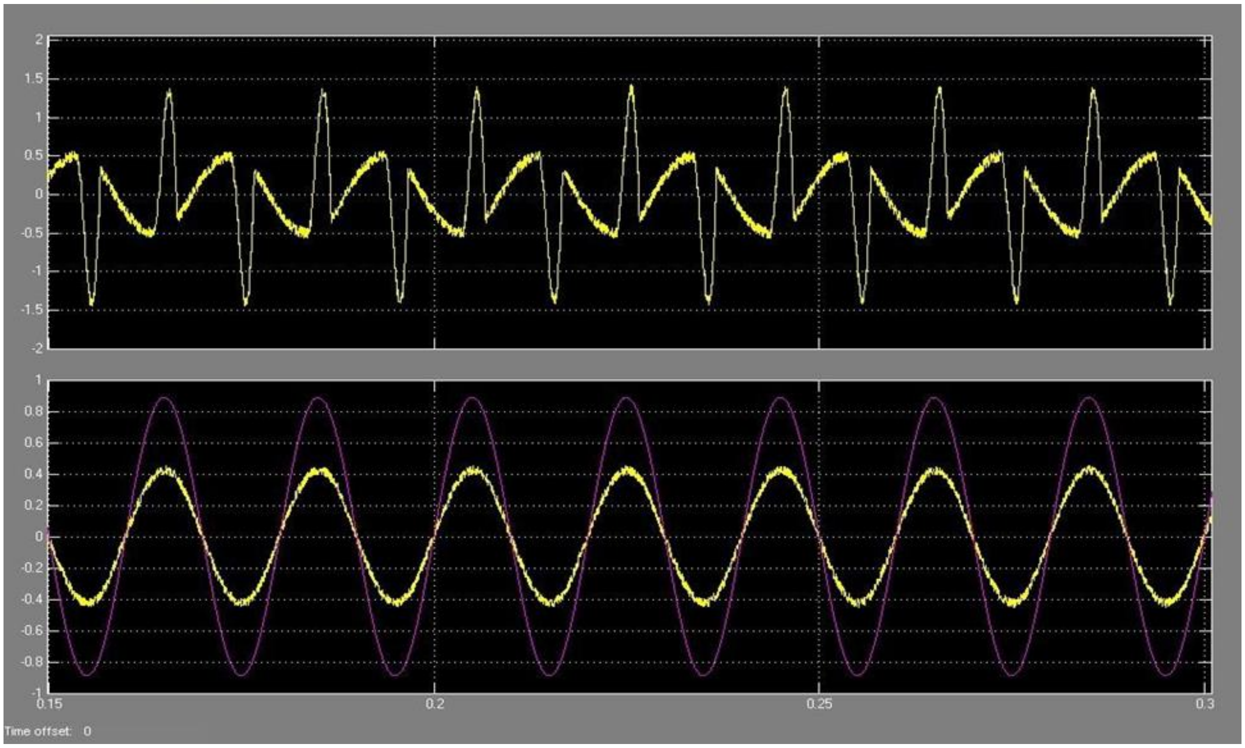
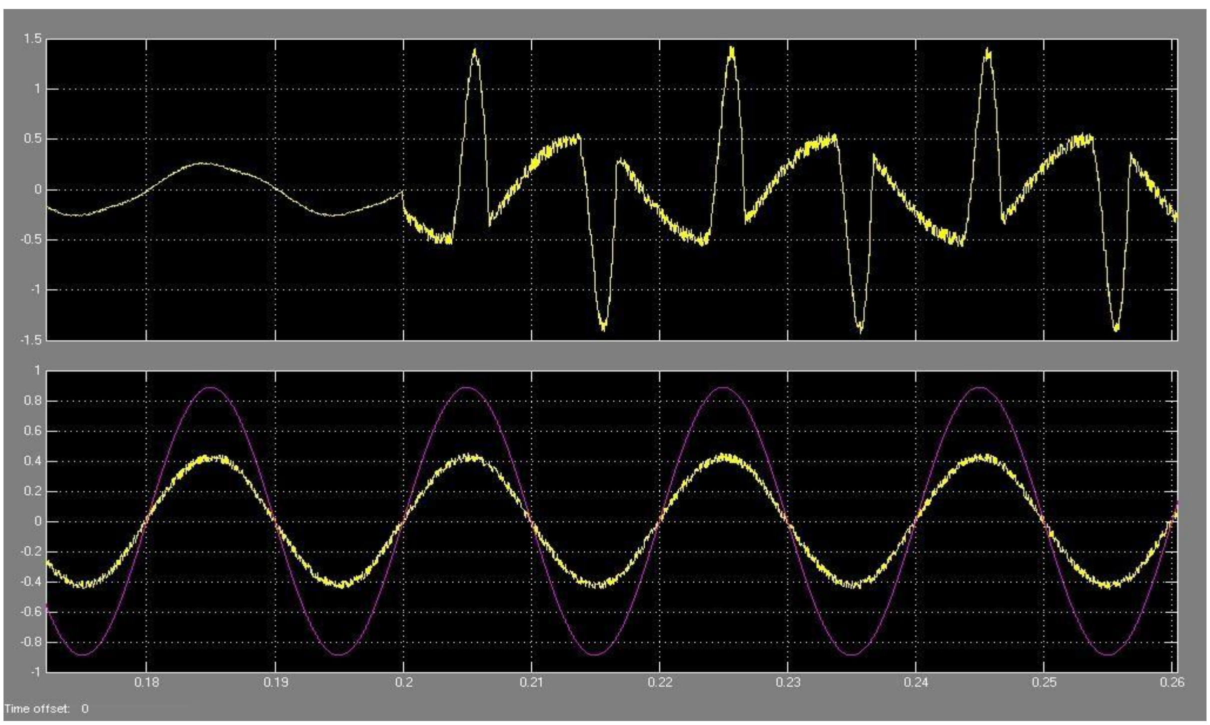


Fig 6. Results screenshot 6



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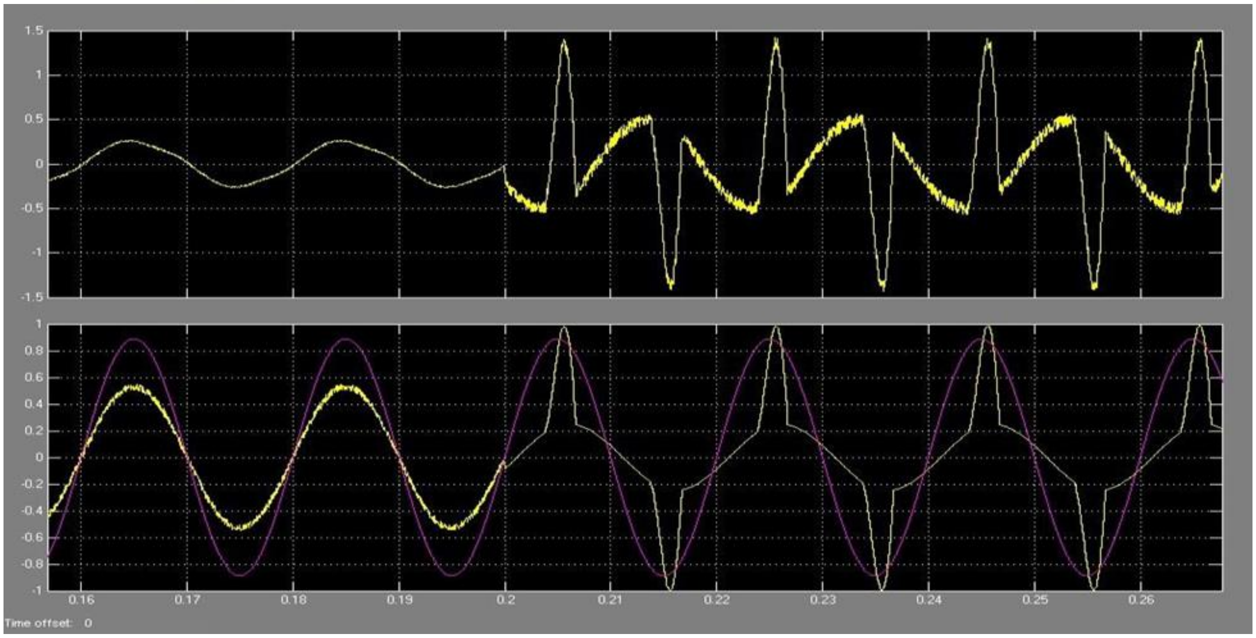

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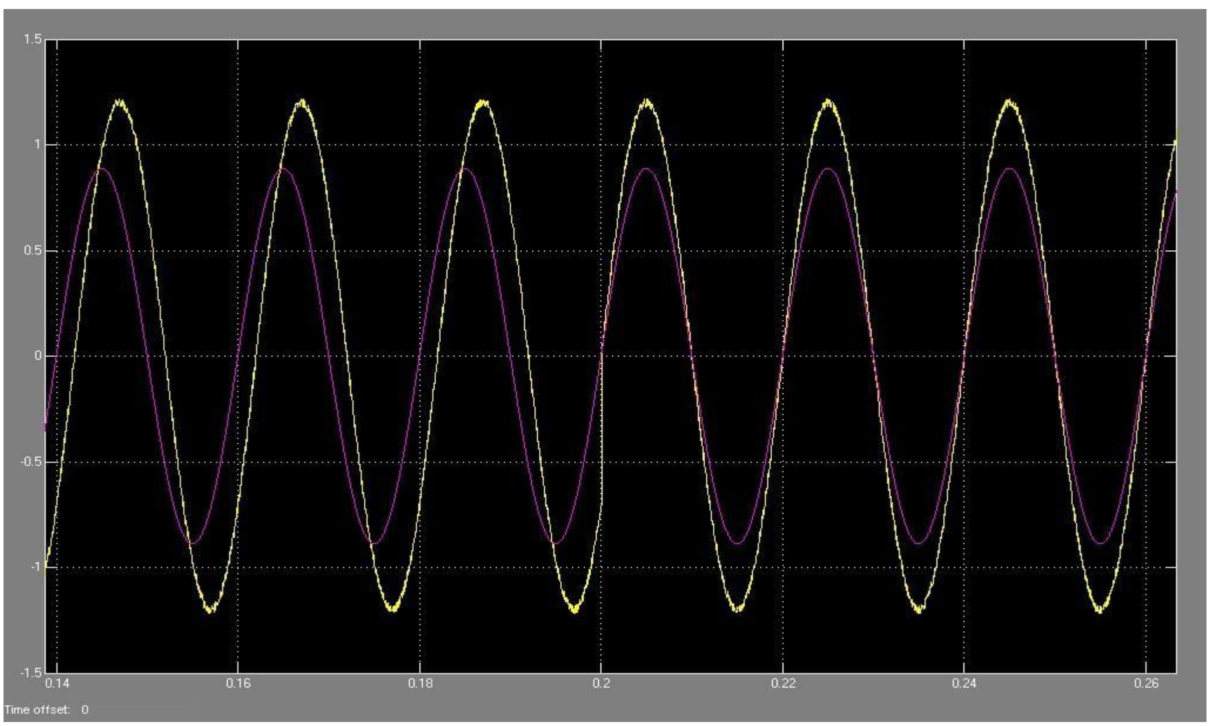

Fig 9. Results screenshot 9

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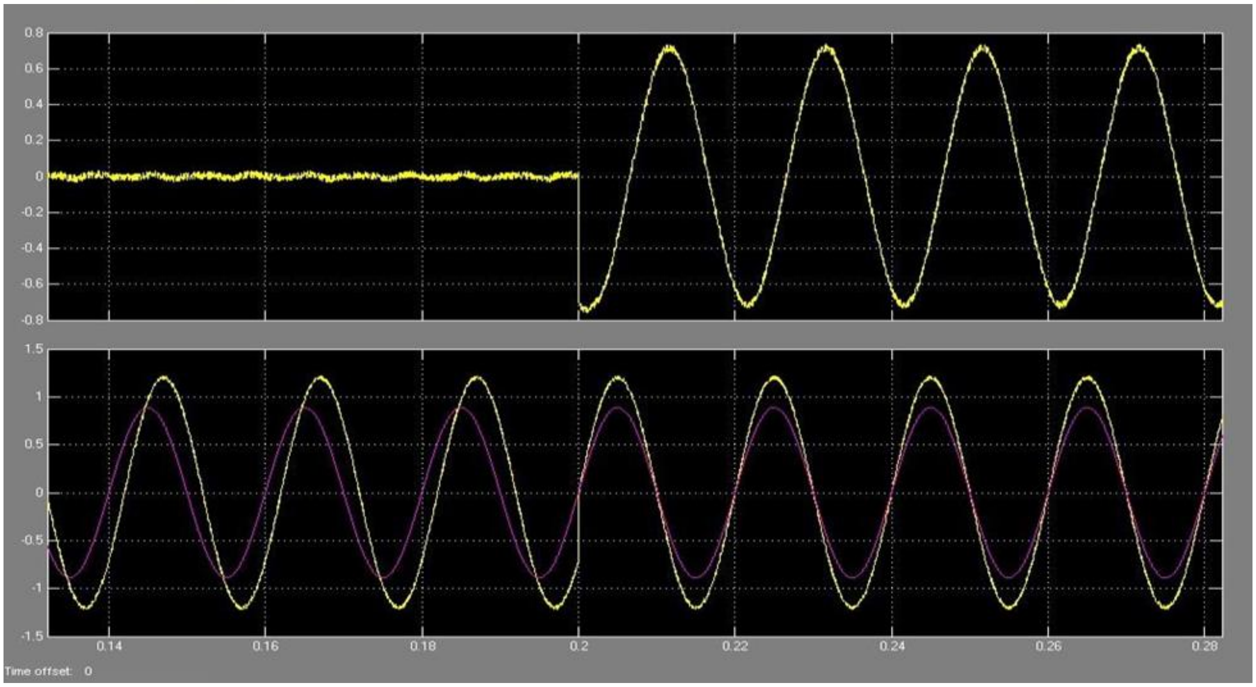

Fig 10. Results screenshot 10

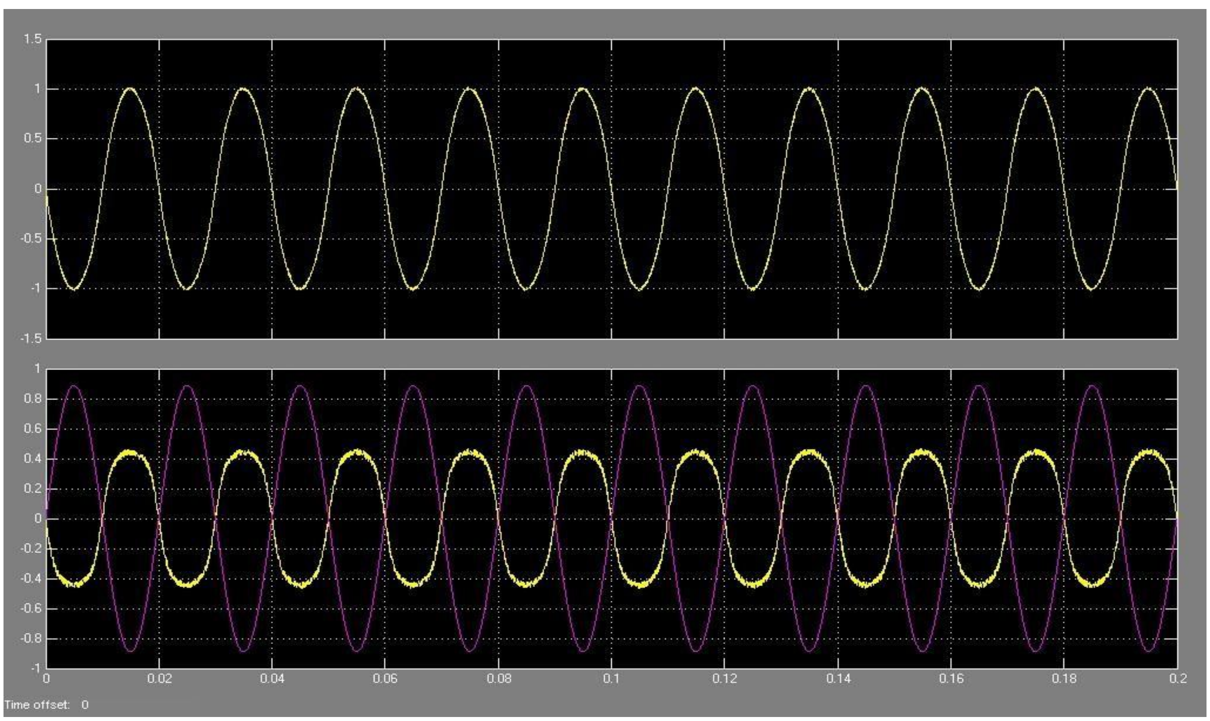

Fig 11. Results screenshot 11

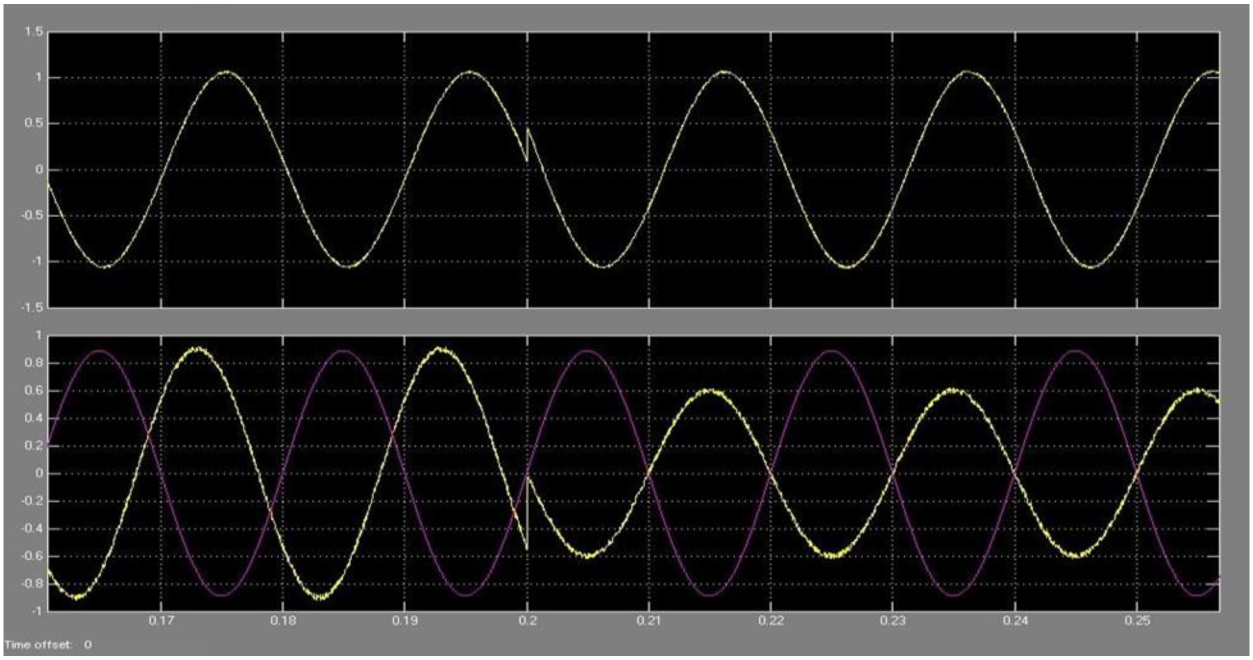

Fig 12. Results screenshot 12

Furthermore, the performance evaluation of multiple output Switched-Mode Power Supplies (SMPS) under varying input voltage conditions provided valuable insights into the resilience and adaptability of the proposed system across diverse operational scenarios. Leveraging the simulation capabilities of the MATLAB/Simulink environment, the SMPS units demonstrated robust performance under steady-state conditions, underscoring the versatility and scalability of the proposed system. These findings not only validate the efficacy of the proposed power quality control strategy but also highlight its applicability across a broad spectrum of applications within the realm of distributed generation systems. Overall, the results and discussions presented affirm the viability and effectiveness of the enhanced power quality control strategy for single-phase inverters in distributed generation systems, paving the way for its widespread adoption and implementation in real-world applications.

CONCLUSION

In conclusion, the proposed enhanced power quality control strategy for single-phase inverters in distributed generation systems represents a significant advancement in addressing power quality challenges inherent in grid-connected operations. Through the integration of distributed generation unit functionalities with shunt active power filter capabilities, the system demonstrated remarkable efficacy in regulating active power flow from renewable energy sources to the grid while simultaneously compensating for nonlinear load current harmonics. The utilization of a current reference generator based on sinusoidal signal integration and instantaneous reactive power (IRP) theory, coupled with a dedicated repetitive current controller, proved instrumental in achieving these objectives. Experimental validation conducted on a 4-kVA inverter prototype corroborated the feasibility and practicality of the proposed solution. Comparative analysis with conventional topologies further accentuated the superiority of the proposed topology, showcasing notable reductions in conduction losses and tangible improvements in power quality. These findings underscore the transformative potential of the proposed system in enhancing the efficiency, stability, and reliability of distributed generation systems. Furthermore, the comprehensive performance evaluation of multiple output Switched-Mode Power Supplies (SMPS) under varying input voltage conditions elucidated the robustness and adaptability of the proposed system across diverse operational scenarios. Leveraging advanced simulation techniques in the MATLAB/Simulink environment, the SMPS units exhibited commendable performance under steady-state conditions, reaffirming the versatility and scalability of the proposed solution. In summary, the proposed enhanced power quality control strategy holds immense promise for addressing power quality concerns in single-phase inverters deployed in distributed generation systems. By leveraging innovative integration techniques and advanced control schemes, the system not only mitigates power quality issues but also enhances overall system efficiency and reliability. Moving forward, further research and development efforts are warranted to refine and optimize the proposed strategy for broader deployment and adoption in real-world applications, ultimately contributing to the advancement of sustainable and resilient electrical power networks.

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