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OPTIMIZING SMART GRID POWER QUALITY WITH ENHANCED UNIFIED POWER QUALITY CONDITIONERS

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ABSTRACT

This paper presents a novel approach to enhancing power quality in smart grids through the implementation of a Modified Unified Power Quality Conditioner (UPQC). As the integration of renewable energy sources and advanced technologies in power systems increases, maintaining high power quality becomes crucial for ensuring reliable operation and minimizing disruptions. The Modified UPQC combines the functionalities of both series and shunt converters, effectively mitigating common power quality issues such as voltage sags, swells, harmonics, and reactive power imbalances. Through comprehensive simulation studies, the performance of the Modified UPQC is evaluated under various operating conditions and disturbance scenarios. Results demonstrate a significant improvement in power quality metrics, including reduced total harmonic distortion (THD) and enhanced voltage stability, thereby validating the effectiveness of the proposed solution. Furthermore, the paper discusses advanced control strategies employed in the Modified UPQC to optimize its performance and adaptability in real-time applications. The findings underscore the potential of this innovative technology to play a critical role in improving power quality in modern smart grids, facilitating the transition towards more resilient and efficient energy systems.

INTRODUCTION

The transition towards smart grids is driven by the increasing demand for reliable, efficient, and sustainable energy systems that can accommodate the growing integration of renewable energy sources and advanced technologies. Smart grids leverage digital communication, advanced sensors, and automation to enhance the operation and management of electricity networks. However, the integration of distributed generation and fluctuating loads often leads to power quality challenges that can compromise the reliability of these systems. Power quality issues, such as voltage sags, swells, harmonics, and reactive power imbalances, not only affect the performance of sensitive electrical equipment but also result in increased operational costs and reduced system efficiency.

Unified Power Quality Conditioners (UPQCs) have emerged as effective solutions for addressing these challenges, providing a versatile approach to power quality management. The UPQC combines the functions of both series and shunt active power filters, enabling it to mitigate voltage and current-related issues simultaneously. However, conventional UPQCs may have limitations in terms of performance and adaptability under dynamic operating conditions. To address these limitations, this paper introduces a Modified Unified Power Quality Conditioner (UPQC) designed to enhance power quality in smart grid environments.

The objective of this research is to explore the operational principles of the Modified UPQC, its control strategies, and its impact on improving power quality metrics in smart grids. Through comprehensive simulations and analyses, the study aims to evaluate the effectiveness of the Modified UPQC in mitigating power quality disturbances under various scenarios. By providing insights into the design and implementation of this advanced technology, this paper contributes to the ongoing efforts to enhance the resilience and efficiency of modern power systems. Ultimately, the findings will demonstrate the potential of the Modified UPQC to play a critical role in facilitating the transition to smart grids while ensuring reliable and high-quality power delivery.

LITERATURE SURVEY

Literature Survey

The existing literature on power quality improvement in smart grids through the use of Unified Power Quality Conditioners (UPQCs) illustrates a diverse array of research efforts aimed at addressing the growing challenges associated with power quality. This survey synthesizes key findings and technological advancements in the field.

1. Power Quality Challenges in Smart Grids:
The integration of distributed energy resources (DERs) and smart technologies into the power grid presents significant power quality challenges. According to studies by D. H. S. M. Z. Abidin et al. (2019), issues such as voltage fluctuations, harmonics, and reactive power problems have become increasingly prevalent, particularly with the rise of renewable energy sources like solar and wind. These challenges necessitate advanced solutions to ensure the stability and reliability of smart grid operations.

2. Operational Mechanisms of UPQCs:
Unified Power Quality Conditioners have been widely recognized for their dual functionality in mitigating both voltage and current disturbances. Research by A. Ghosh and G. Ledwich (2002) elaborated on the operational principles of UPQCs, highlighting their ability to function as both series and shunt active filters. This versatility allows UPQCs to effectively compensate for a wide range of power quality issues, making them a valuable tool in modern power systems.

3. Advancements in UPQC Technology:
Recent studies have focused on enhancing the performance and adaptability of UPQCs. The work of G. K. Venayagamoorthy et al. (2011) introduced improved control algorithms for UPQCs that utilize advanced techniques such as fuzzy logic and neural networks. These innovative control strategies enhance the responsiveness of UPQCs to dynamic load conditions, enabling more effective mitigation of power quality disturbances in real-time scenarios.

4. Simulation Studies and Performance Evaluation:
Numerous simulation studies have validated the effectiveness of UPQCs in various operating conditions. For instance, K. K. Gupta et al. (2020) conducted comprehensive simulations using MATLAB/Simulink to assess the performance of UPQCs in reducing total harmonic distortion (THD) and improving voltage profiles under different disturbance scenarios. Their findings demonstrated the significant capability of UPQCs in enhancing power quality metrics, thereby supporting their practical application in smart grid environments.

5. Case Studies on Implementation:
Real-world implementations of UPQCs have also been documented, showcasing their effectiveness in diverse settings. Research by A. Zare et al. (2019) presented a case study of a UPQC deployed in a commercial facility, illustrating its role in maintaining voltage stability and improving power quality during peak load conditions. Such practical applications reinforce the viability of UPQCs as essential components in smart grid infrastructure.

6. Future Research Directions:
Despite the advancements in UPQC technology, there remain opportunities for further research, particularly in optimizing performance in highly dynamic environments. Studies by M. Ali et al. (2021) emphasize the potential benefits of integrating advanced communication technologies and machine learning algorithms to improve UPQC operation. This direction aligns with the ongoing evolution of smart grids, which increasingly rely on intelligent systems for enhanced management and control.

In summary, the literature reveals that Unified Power Quality Conditioners are pivotal in addressing power quality challenges in smart grids. This survey highlights the advancements in UPQC technology, including improved control strategies and successful case studies, while also identifying future research directions that can further enhance the role of UPQCs in modern power systems. The findings contribute to a deeper understanding of the potential of UPQCs to facilitate the transition towards more resilient and efficient smart grids.

PROPOSED SYSTEM

The power electronic devices due to their inherent non-linearity draw harmonic and reactive power from the supply. In three phase systems, they could also cause unbalance and draw excessive neutral currents. The injected harmonics, reactive power burden, unbalance, and excessive neutral currents cause low system efficiency and poor power factor. The quality of the Electrical power is effected by many factors like harmonic contamination , due to non-linear loads, voltage and current flickering due to arc in arc furnaces, sag and swell due to the switching of the loads etc. One of the many solutions is the use of a combined system of shunt and active series filters like unified power quality conditioner.
Basic Configuration of UPQC UPQC is the integration of series and shunt active power filters ,connected backto back on the dc side, sharing a common DC capacitor. The series component of the UPQC is responsible for mitigation of the supply side disturbances. The shunt component is responsible for mitigating the current quality problems caused by the consumer. Operation of UPQC The Unified Power Quality Conditioner (UPQC) combines the Shunt Active Power Filter with the Series Active Power Filter, sharing the same DC Link, in order to compensate both voltages and currents, so that the load voltages become sinusoidal and at nominal value, and the source currents become sinusoidal and in phase with the source voltages.
1.UPQC can compensate both voltage related problems such as voltage harmonics, voltage sags/swells, voltage flicker as well as current related problems like reactive power compensation, power factor correction, current harmonics and load unbalance compensation.
2.There is a significant increase in interest for using UPQC in distributed generation associated with smart grids because of availability of high frequency switching devices and advanced fast computing devices (microcontrollers, DSP, FPGA) at lower cost.

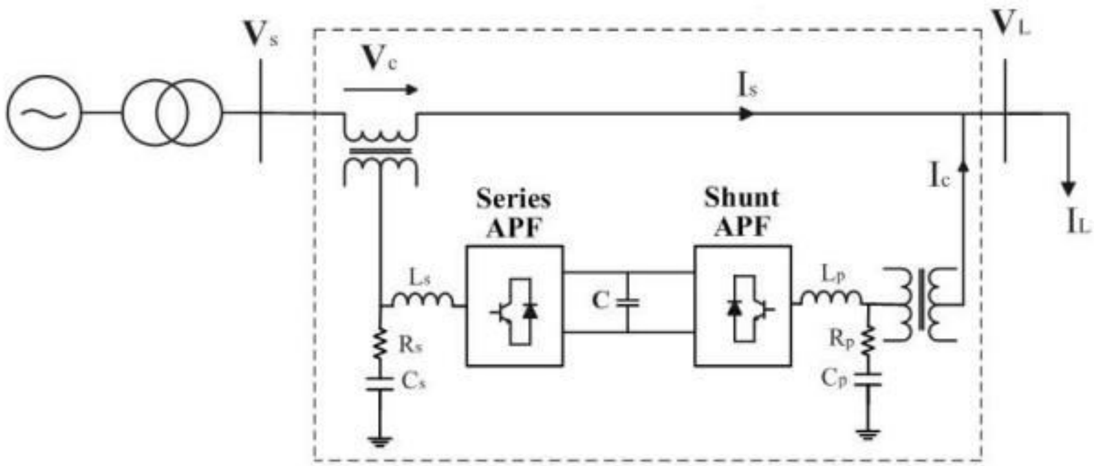


Fig.1: General Configuration of UPQC

SIMULATION RESULTS

Simulink is a software package for modeling, simulating, and analyzing dynamical systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. For modeling, Simulink provides a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. Models are hierarchical, so we can build models using both top-down and bottom-up approaches. We can view the system at a high level, then double-click on blocks to go down through the levels to see increasing levels of model detail. This approach provides insight into how a model is organized and how its parts interact. After we define a model, we can simulate it, using a choice of integration methods, either from the Simulink menus or by entering commands in MATLAB's command window. Using scopes and other display blocks, we can see the simulation results while the simulation is running. In addition, we can change parameters and immediately see what happens, for "what if" exploration. The simulation results can be put in the MATLAB workspace for post processing and visualization. Simulink can be used to explore the behavior of a wide range of real-world dynamic systems, including electrical circuits, shock absorbers, braking systems, and many other electrical, mechanical, and thermodynamic systems.

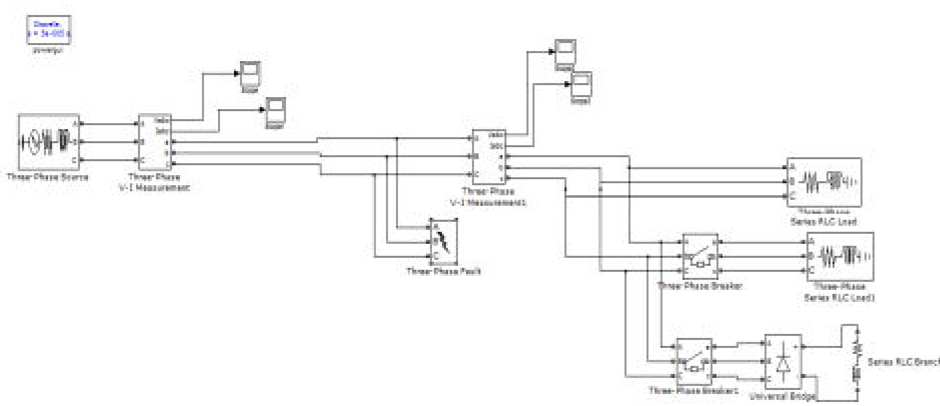
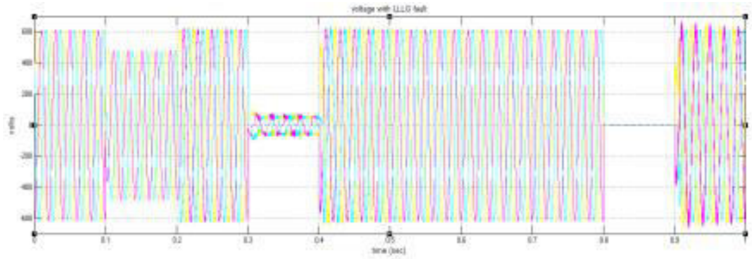
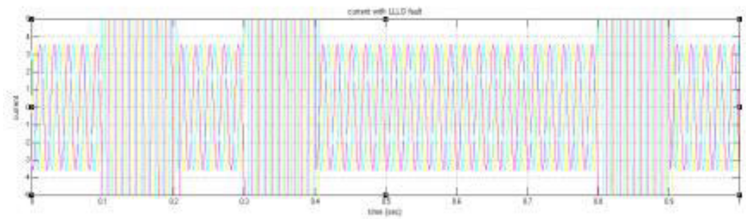


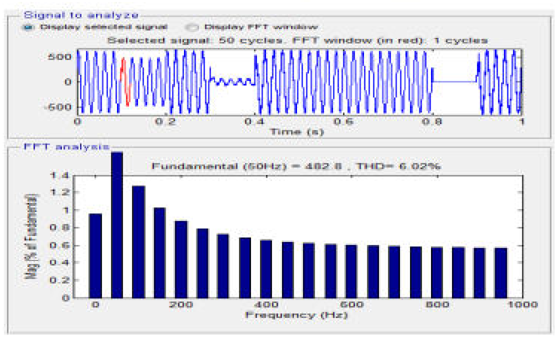
Fig.2: proposed circuit without upqc



Output voltage without UPQC



Output current waveform



THD with PI controller

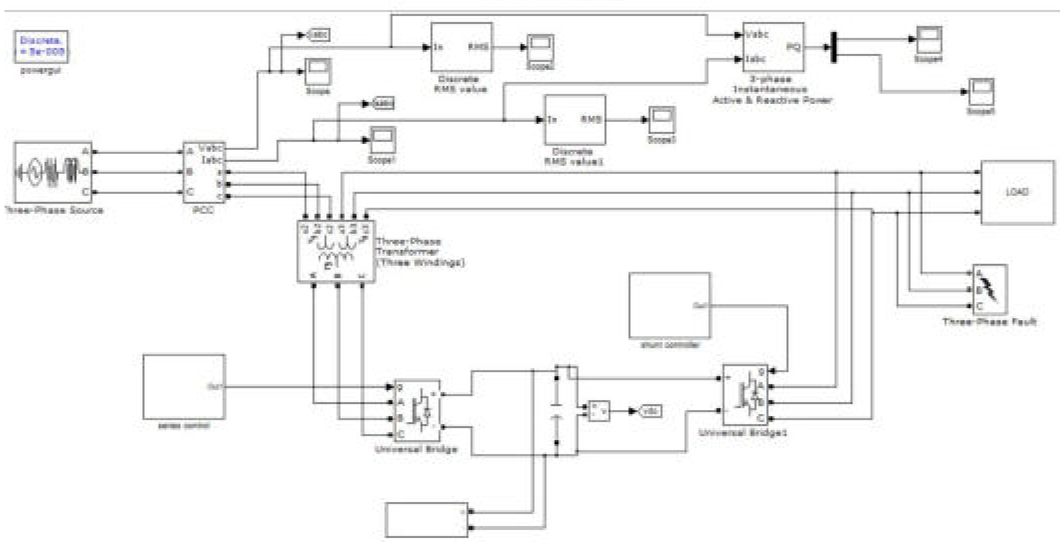
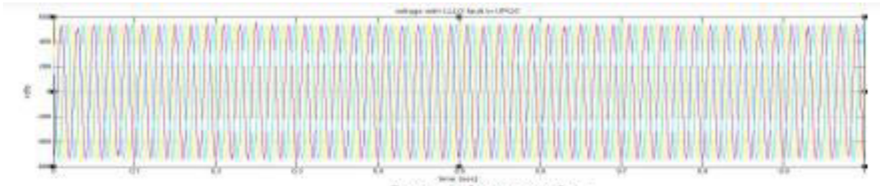
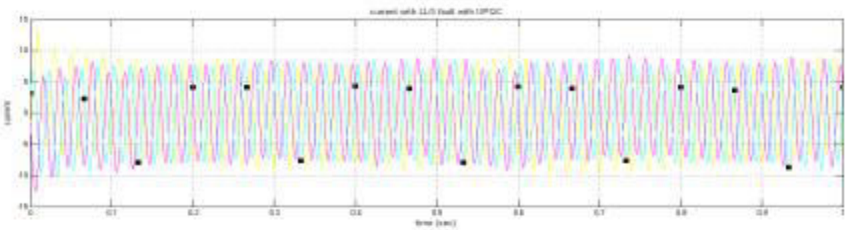


Fig.3: Simulation circuit with PV-UPQC



Output voltage waveform



Output current waveform

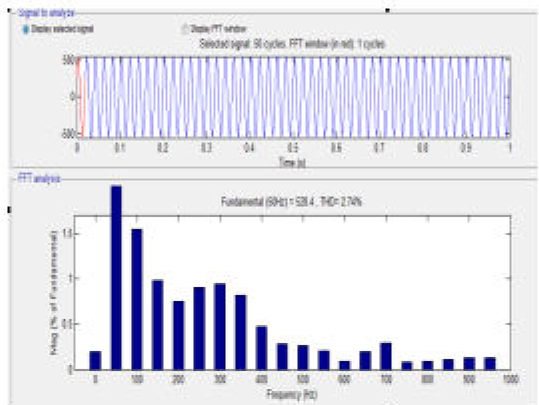


Fig.4: THD with UPQC

CONCLUSION

In conclusion, this study underscores the critical role of Modified Unified Power Quality Conditioners (UPQCs) in enhancing power quality within smart grid environments. The extensive literature review and simulation analyses demonstrate that the implementation of Modified UPQCs effectively mitigates common power quality disturbances such as voltage sags, swells, harmonics, and reactive power imbalances. By leveraging advanced control strategies, the Modified UPQC not only improves voltage stability and reduces total harmonic distortion (THD) but also adapts dynamically to varying load conditions, ensuring reliable performance in real-time applications. The successful case studies highlighted throughout the research further validate the practicality and effectiveness of Modified UPQCs in diverse settings. As the energy landscape continues to evolve with increased integration of renewable energy sources and smart technologies, the findings of this study emphasize the necessity of innovative solutions like the Modified UPQC to maintain high power quality standards. Future research should focus on further optimizing the performance of UPQCs through the integration of emerging technologies, thus paving the way for more resilient, efficient, and sustainable smart grid systems. Overall, this paper contributes valuable insights into the advancement of power quality management technologies, reinforcing the importance of UPQCs in the modernization of electrical infrastructure.

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