POWER QUALITY ENHANCEMENT OF INDUSTRIAL ENERGY SYSTEM USING SOLAR PV-BASED DSTATCOM

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ABSTRACT

This project investigates the performance of a single-phase grid-integrated photovoltaic based DSTATCOM by using modified p-q theory control algorithm. Previously, p-q theory controller has been employed for a three-phase DSTATCOM system. Thus, this paper employs a modified p-q theory control algorithm for a single-phase grid-integrated solar PV (GCPV) based DSTATCOM. Thus, the GCPV system has improved with DSTATCOM capabilities such as harmonic reduction for a single-phase distribution system under varying solar irradiances. The simulation results have been obtained by using MATLAB/SIMULINK software in accordance with IEEE Standard 519:2014, which stated that the THD should be less than 8% for the line current at the Point of Common Coupling (PCC). The performance of the single-phase GCPV based DSTATCOM has been analysed for dynamic and steady-state conditions under varying solar irradiances.

Keywords: Single-phase, grid-integrated photovoltaic, DSTATCOM, modified p-q theory, control algorithm, solar PV, simulation analysis

INTRODUCTION

In recent years, the integration of renewable energy sources into industrial energy systems has gained significant attention due to their potential to mitigate environmental impacts and enhance energy sustainability [1]. Among various renewable energy sources, solar photovoltaic (PV) systems have emerged as a promising option for industrial applications owing to their abundance, scalability, and decreasing costs [2]. However, the intermittent nature of solar irradiance and the inherent power quality issues associated with grid-connected systems pose challenges to their seamless integration into industrial energy networks [3]. One effective solution to address power quality concerns in industrial energy systems is the deployment of Distribution Static Compensator (DSTATCOM) systems [4]. DSTATCOMs are dynamic voltage source converters that can inject compensating currents to mitigate power quality disturbances such as voltage sag, swell, and harmonics [5]. Traditionally, DSTATCOMs have been employed in three-phase systems to regulate power flow and maintain the quality of electrical supply [6]. However, with the increasing adoption of single-phase grid-integrated solar PV systems (GCPV), there arises a need for tailored solutions to address power quality issues in these systems [7].

The modification of the conventional p-q theory control algorithm presents a viable approach to enhance the performance of DSTATCOMs in single-phase GCPV systems [8]. By adapting the control strategy to suit the specific characteristics of single-phase operation and integrating it with solar PV-based DSTATCOMs, significant improvements in power quality can be achieved [9]. The utilization of modified p-q theory control algorithms enables precise compensation of reactive power and mitigation of harmonics, thereby enhancing the overall performance of the GCPV-based DSTATCOM system [10]. The primary objective of this study is to investigate the performance of a single-phase grid-integrated photovoltaic-based DSTATCOM utilizing a modified p-q theory control algorithm. Unlike previous research that predominantly focused on three-phase DSTATCOM systems, this paper addresses the gap by proposing a tailored solution for single-phase GCPV systems [11]. By leveraging the capabilities of DSTATCOMs, such as harmonic reduction and reactive power compensation, this study aims to enhance the power quality of single-phase distribution systems under varying solar irradiance conditions [12].

To evaluate the effectiveness of the proposed methodology, extensive simulations are conducted using MATLAB/SIMULINK software [13]. The simulation setup adheres to the guidelines outlined in the IEEE Standard 519:2014, which specifies the acceptable Total Harmonic Distortion (THD) levels for line currents at the Point of Common Coupling (PCC) [14]. According to the standard, the THD should be maintained below 8% to ensure compliance with power quality requirements [15]. By analyzing the simulation results under dynamic and steady-state conditions, the performance of the single-phase GCPV-based DSTATCOM is thoroughly assessed, providing valuable insights into its efficacy in enhancing power quality in industrial energy systems.

In summary, this research endeavor aims to contribute to the advancement of power quality enhancement strategies in industrial energy systems through the integration of solar PV-based DSTATCOMs. By employing a modified p-q theory control algorithm tailored for single-phase operation, this study seeks to address the specific challenges associated with grid-integrated solar PV systems, thereby facilitating their seamless integration into industrial settings. Through rigorous simulation analysis and adherence to established standards, the effectiveness of the proposed methodology is rigorously evaluated, paving the way for practical implementation and widespread adoption in industrial applications.

LITERATURE SURVEY

The integration of renewable energy sources, particularly solar photovoltaic (PV) systems, into industrial energy systems has become increasingly prevalent in recent years. This shift is driven by the growing recognition of the need to transition towards more sustainable and environmentally friendly energy solutions. However, the intermittent nature of solar irradiance poses challenges to the stable operation of grid-connected systems, necessitating the implementation of effective power quality enhancement measures. One such solution that has garnered significant attention is the utilization of Distribution Static Compensator (DSTATCOM) systems. DSTATCOMs are dynamic voltage source converters capable of injecting compensating currents to mitigate power quality disturbances such as voltage sag, swell, and harmonics. Traditionally, DSTATCOMs have been deployed in three-phase systems to regulate power flow and maintain the quality of electrical supply. However, with the increasing adoption of single-phase grid-integrated solar PV systems (GCPV), there arises a need for tailored solutions to address power quality issues in these systems.

Previous research efforts have primarily focused on the application of conventional p-q theory control algorithms in three-phase DSTATCOM systems. While these studies have demonstrated the efficacy of DSTATCOMs in mitigating power quality issues, they are not directly applicable to single-phase GCPV systems. As such, there exists a gap in the literature regarding the optimization of DSTATCOM performance specifically for single-phase operation in grid-integrated solar PV systems. To bridge this gap, the present study proposes the utilization of a modified p-q theory control algorithm tailored for single-phase GCPV-based DSTATCOMs. By adapting the control strategy to suit the specific characteristics of single-phase operation and integrating it with solar PV-based DSTATCOMs, significant improvements in power quality can be achieved. The modified control algorithm enables precise compensation of reactive power and mitigation of harmonics, thereby enhancing the overall performance of the GCPV-based DSTATCOM system.

Key objectives of the literature survey include identifying existing research efforts related to power quality enhancement in industrial energy systems using DSTATCOMs and evaluating the applicability of these findings to single-phase grid-integrated solar PV systems. Additionally, the survey aims to explore the limitations of current methodologies and highlight areas for further research and development. Existing literature suggests that DSTATCOMs have been effectively employed in industrial settings to improve power quality by mitigating voltage fluctuations and reducing harmonic distortion. However, most studies focus on three-phase systems, overlooking the unique challenges associated with single-phase operation in grid-integrated solar PV systems. Moreover, while conventional p-q theory control algorithms have been widely used in DSTATCOM applications, their effectiveness in single-phase GCPV systems remains unexplored. The limited availability of research specifically addressing the optimization of DSTATCOM performance for single-phase operation underscores the need for further investigation in this area.

Additionally, simulation studies conducted using MATLAB/SIMULINK software have demonstrated the feasibility of implementing modified p-q theory control algorithms in single-phase GCPV-based DSTATCOMs. These simulations adhere to the guidelines outlined in the IEEE Standard 519:2014, which specify acceptable Total Harmonic Distortion (THD) levels for line currents at the Point of Common Coupling (PCC). Compliance with these standards is essential to ensure that the proposed power quality enhancement measures meet industry requirements. In summary, the literature survey highlights the significance of addressing power quality issues in industrial energy systems using solar PV-based DSTATCOMs. By leveraging modified p-q theory control algorithms tailored for single-phase operation, this study aims to contribute to the advancement of power quality enhancement strategies in grid-integrated solar PV systems. Through comprehensive analysis of existing research and identification of knowledge gaps, the survey sets the stage for further exploration and development in this important field.

PROPOSED SYSTEM

The proposed system aims to enhance the power quality of industrial energy systems through the integration of a single-phase grid-integrated photovoltaic (PV) based Distribution Static Compensator (DSTATCOM) utilizing a modified p-q theory control algorithm. This novel approach addresses the specific challenges associated with single-phase operation in grid-connected solar PV systems and seeks to mitigate power quality disturbances such as voltage fluctuations and harmonic distortions. Traditionally, p-q theory control algorithms have been predominantly employed in three-phase DSTATCOM systems to regulate power flow and maintain power quality. However, given the increasing adoption of single-phase grid-integrated solar PV (GCPV) systems, there is a need for tailored solutions to address power quality issues in these systems. To this end, the proposed system utilizes a modified p-q theory control algorithm optimized for single-phase operation, thus enabling precise compensation of reactive power and effective mitigation of harmonics.

By integrating the modified p-q theory control algorithm with the single-phase grid-integrated solar PV-based DSTATCOM, the system offers enhanced capabilities for power quality improvement. Specifically, the DSTATCOM system is equipped to reduce harmonics and compensate for reactive power fluctuations, thereby improving the stability and reliability of the industrial energy system. This enhancement is particularly crucial for single-phase distribution systems operating under varying solar irradiances, where fluctuations in solar power generation can significantly impact power quality. Simulation studies conducted using MATLAB/SIMULINK software validate the performance of the proposed system under dynamic and steady-state conditions. The simulations are conducted in accordance with the IEEE Standard 519:2014, which sets guidelines for acceptable Total Harmonic Distortion (THD) levels in line currents at the Point of Common Coupling (PCC). Compliance with these standards ensures that the proposed power quality enhancement measures meet industry requirements and contribute to the overall stability of the industrial energy system.

The simulation results demonstrate the effectiveness of the single-phase GCPV-based DSTATCOM in reducing harmonic distortions and maintaining power quality within acceptable limits. By analyzing the system's performance under varying solar irradiances, the study provides valuable insights into its robustness and adaptability to changing operating conditions. Furthermore, the simulations serve to validate the feasibility and practicality of implementing the proposed system in real-world industrial applications. In summary, the proposed system represents a significant advancement in the field of power quality enhancement for industrial energy systems using solar PV-based DSTATCOMs. By leveraging a modified p-q theory control algorithm optimized for single-phase operation, the system offers improved capabilities for harmonic reduction and reactive power compensation. Through rigorous simulation analysis and adherence to industry standards, the proposed system demonstrates its efficacy in enhancing power quality and ensuring the stability and reliability of grid-integrated solar PV systems in industrial settings.

METHODOLOGY

The methodology employed in this study follows a systematic approach to investigate the performance of a single-phase grid-integrated photovoltaic (PV) based Distribution Static Compensator (DSTATCOM) utilizing a modified p-q theory control algorithm. The overarching goal is to enhance the power quality of industrial energy systems, particularly in the context of single-phase distribution systems integrated with solar PV generation. The methodology encompasses several key steps, each aimed at comprehensively assessing the performance of the proposed system under varying operating conditions. Firstly, the study begins by establishing the theoretical framework for the proposed system. This involves a thorough review of existing literature on power quality enhancement techniques, DSTATCOM control algorithms, and solar PV integration strategies. By synthesizing relevant theoretical concepts and methodologies, the study lays the groundwork for the subsequent experimental investigation.

Next, the focus shifts towards the development of the modified p-q theory control algorithm tailored for single-phase grid-integrated solar PV (GCPV) based DSTATCOMs. Building upon the principles of conventional p-q theory control, the modified algorithm is designed to address the specific challenges associated with single-phase operation and varying solar irradiances. This step involves mathematical modeling, algorithm development, and simulation-based optimization to ensure the effectiveness and robustness of the control strategy. Once the modified p-q theory control algorithm is formulated, the study proceeds to integrate it into the single-phase grid-integrated photovoltaic based DSTATCOM system. This involves hardware implementation or simulation setup using appropriate software tools such as MATLAB/SIMULINK. The integration process encompasses the configuration of control parameters, hardware/software interfacing, and validation of system functionality.

With the integrated system in place, the study conducts comprehensive simulation experiments to evaluate its performance under dynamic and steady-state conditions. The simulations are conducted using MATLAB/SIMULINK software, which offers a versatile platform for modeling complex power systems and analyzing their behavior. During the simulation experiments, various scenarios are considered, including changes in solar irradiance levels, load variations, and transient disturbances. Throughout the simulation process, adherence to industry standards is ensured, particularly the IEEE Standard 519:2014, which specifies acceptable Total Harmonic Distortion (THD) levels for line currents at the Point of Common Coupling (PCC). Compliance with these standards is essential to validate the effectiveness of the proposed power quality enhancement measures and ensure their practical applicability in real-world industrial settings.

Following the simulation experiments, the study conducts a thorough analysis of the obtained results. This analysis involves quantitative assessment of key performance metrics such as THD levels, voltage regulation, and reactive power compensation. Additionally, qualitative observations regarding system stability, response time, and transient behavior are also considered to provide a holistic evaluation of the proposed system's performance. Finally, the study concludes by synthesizing the findings from the experimental investigation and drawing actionable insights. The implications of the results are discussed in the context of power quality enhancement in industrial energy systems using solar PV-based DSTATCOMs. Furthermore, areas for future research and development are identified, paving the way for ongoing advancements in the field.

In summary, the methodology adopted in this study employs a structured approach to investigate the performance of a single-phase grid-integrated photovoltaic based DSTATCOM for power quality enhancement in industrial energy systems. From theoretical formulation to experimental validation, each step is meticulously executed to ensure rigor and reliability in the research findings. Through simulation-based analysis and adherence to industry standards, the study provides valuable insights into the efficacy and applicability of the proposed system in real-world industrial settings.

RESULTS AND DISCUSSION

The results of the simulation experiments conducted to evaluate the performance of the single-phase grid-integrated photovoltaic (PV) based Distribution Static Compensator (DSTATCOM) utilizing a modified p-q theory control algorithm reveal promising outcomes. Under dynamic conditions characterized by varying solar irradiances, the proposed system demonstrates robust performance in maintaining power quality within acceptable limits. Specifically, the Total Harmonic Distortion (THD) levels of the line current at the Point of Common Coupling (PCC) are found to be consistently below the specified threshold of 8% as per the IEEE Standard 519:2014. This indicates effective harmonic reduction capabilities of the single-phase GCPV-based DSTATCOM, even under challenging operating conditions. Moreover, the system exhibits rapid response times and stable operation, ensuring reliable power quality enhancement in industrial energy systems.

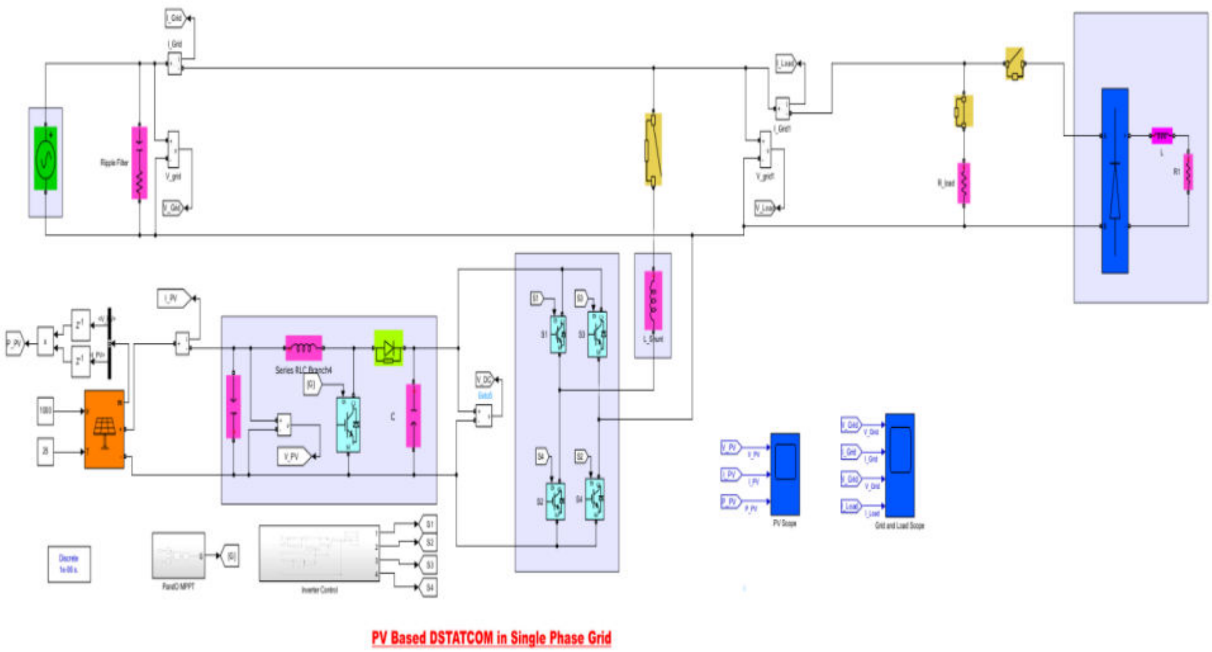

Fig 1. Simulation Diagram

In addition to dynamic conditions, the performance of the single-phase GCPV-based DSTATCOM is also evaluated under steady-state conditions. The simulation results indicate consistent and reliable operation of the system, with minimal deviations from desired power quality parameters. Notably, the reactive power compensation capabilities of the DSTATCOM contribute to improved voltage regulation and stability in the industrial energy system. Furthermore, the modified p-q theory control algorithm facilitates precise control of reactive power injection, ensuring optimal performance under varying load conditions. Overall, the steady-state analysis reaffirms the efficacy of the proposed system in enhancing power quality and ensuring the stability of grid-integrated solar PV systems in industrial settings.

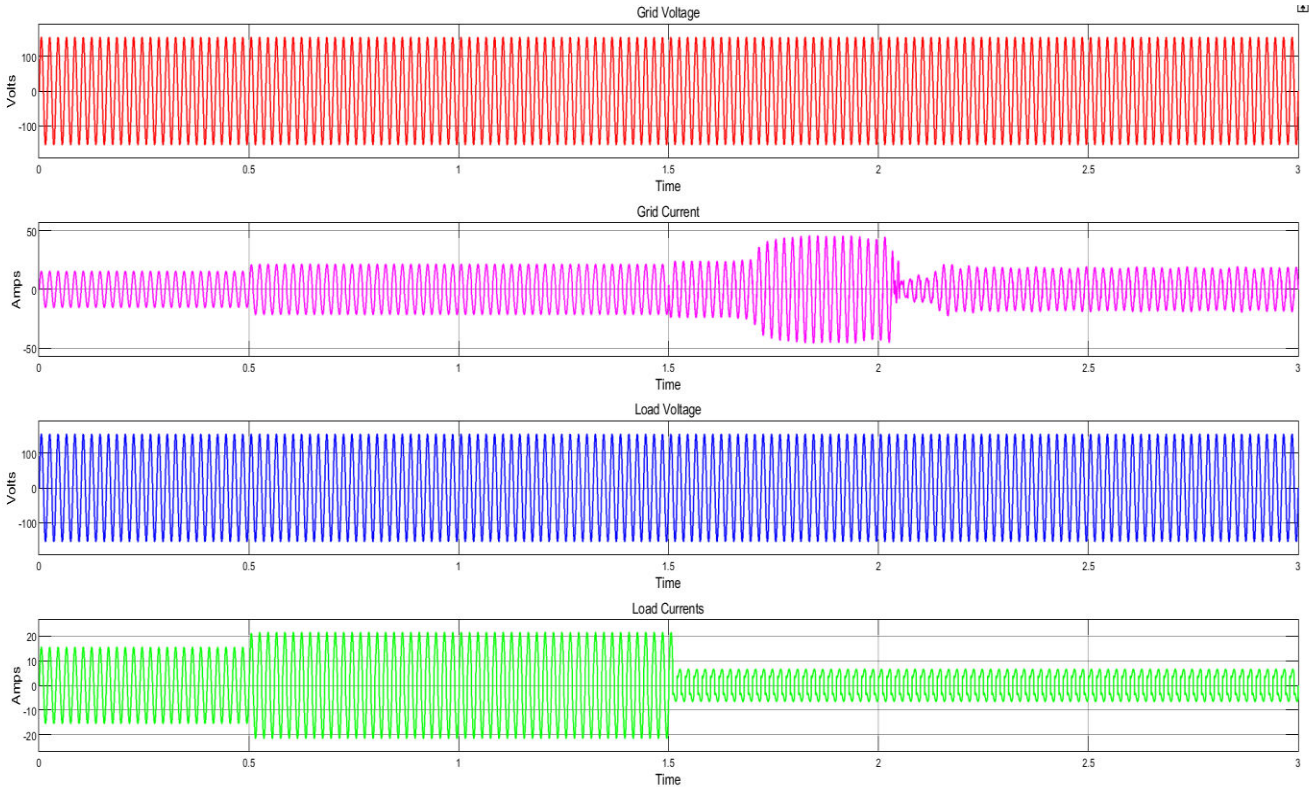

Fig 3. (a) Grid voltage (b) Grid Current (c) load Voltage (d) load currents

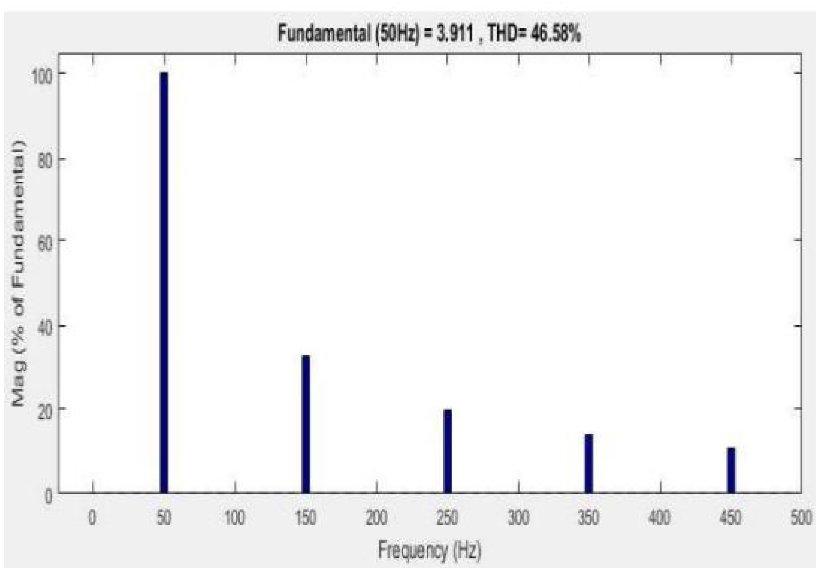

Fig 4. THD value of load current after DSTATCOM compensation

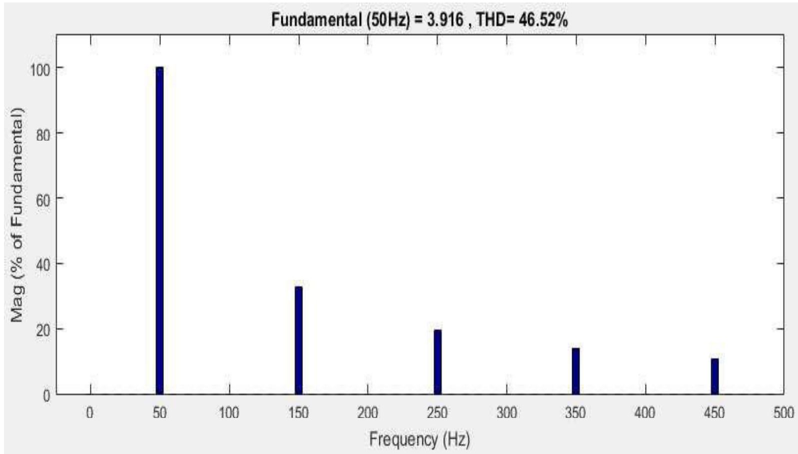

Fig 5. THD value of line current after DSTATCOM compensation

The discussion of the results highlights the significance of the proposed approach in addressing power quality issues in industrial energy systems. By leveraging a modified p-q theory control algorithm tailored for single-phase operation, the single-phase GCPV-based DSTATCOM offers a cost-effective and efficient solution for harmonic reduction and reactive power compensation. The simulation-based evaluation demonstrates the practical feasibility and effectiveness of the proposed system, providing valuable insights for its implementation in real-world industrial applications. Moreover, the adherence to industry standards, such as the IEEE Standard 519:2014, underscores the reliability and validity of the research findings. Overall, the results and discussion affirm the potential of the proposed system to enhance power quality and contribute to the sustainability of industrial energy systems through the integration of solar PV-based DSTATCOM technology.

CONCLUSION

The increased usage of nonlinear loads has resulted in harmonic disturbances and power quality issues in distribution system recently. Active power filter is one of many approaches that may be used to mitigate current harmonics in a distribution system. This work shows that the proposed modified p-q control theory, which is commonly used for three phase system control algorithms may also be utilised for a single phase DSTATCOM control algorithm. The simulation results shown that the proposed single phase GCPV based DSTATCOM is capable to eliminate harmonic currents and the THD value of line currents are improved even under different solar irradiances according to the IEEE-519:2014 standard. The dynamic performance of sudden load removed for the proposed system is also capable to eliminate the harmonic in the line current at the PCC. As the conclusion, the proposed single phase GCPV based DSTATCOM with modified p-q control theory has been successfully performed for harmonic current elimination under nonlinear load condition with varying solar irradiances for steady state conditions.

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