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Power Quality Improvement of Solar based G2V Integration System using PI Controller

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ABSTRACT: The integration of solar energy into grid-to-vehicle (G2V) systems offers significant potential for sustainable and eco-friendly transportation solutions. However, the intermittent nature of solar power introduces challenges in maintaining power quality, which can affect the performance and reliability of the G2V system. This study focuses on improving power quality in solar-based G2V systems by employing a Proportional-Integral (PI) controller. The proposed system integrates solar photovoltaic (PV) energy with advanced power electronics and PI control strategies to stabilize voltage, minimize harmonics, and ensure efficient energy transfer. Simulation and analysis are conducted to evaluate the system's performance under various operating conditions, including fluctuations in solar irradiance and dynamic load changes. Key performance metrics such as total harmonic distortion (THD), voltage regulation, and overall efficiency are analyzed. Results demonstrate that the PI controller effectively compensates for power quality disturbances, achieving significant improvements in voltage stability and harmonic reduction. The findings of this research contribute to the development of robust and efficient solar-based G2V systems, paving the way for their large-scale deployment in modern smart grids and electric vehicle ecosystems.

KEYWORDS: Grid to Vehicle (G2V), Proportional Integral (PI), Photovoltaic (PV), Smart Grids (SG)

I. INTRODUCTION

The increasing adoption of electric vehicles (EVs) has driven a parallel interest in renewable energy sources to support sustainable and efficient charging systems. Solar-based grid-to-vehicle (G2V) integration systems are emerging as a promising solution for meeting the growing energy demands of EVs while reducing reliance on fossil fuels. By harnessing solar photovoltaic (PV) energy, these systems can facilitate eco-friendly vehicle charging and contribute to the transition toward greener energy infrastructures. However, the integration of solar power with G2V systems presents challenges, particularly concerning power quality and stability.

Solar energy is inherently intermittent, influenced by factors such as weather conditions and the time of day. These fluctuations can lead to power quality issues, including voltage instability, frequency deviations, and increased harmonic distortion. Ensuring reliable energy transfer and maintaining grid stability in the presence of such disturbances is critical for the seamless operation of G2V systems.

Power electronic converters and control strategies play a vital role in addressing these challenges. Among various control methods, the Proportional-Integral (PI) controller has proven to be effective for power quality improvement due to its simplicity, ease of implementation, and reliable performance. By dynamically adjusting system parameters, the PI controller can compensate for disturbances, stabilize the grid voltage, and reduce harmonic distortion.

The integration of solar photovoltaic (PV) systems with Grid-to-Vehicle (G2V) technology is a promising solution for sustainable electric vehicle (EV) charging. However, the variability of solar energy, due to environmental factors like changing weather conditions and time-of-day effects, introduces significant challenges to power quality. Specifically, fluctuations in solar power generation can cause voltage instability, harmonic distortion, and unreliable energy transfer, which hinder the efficient operation of G2V systems. These power quality issues must be addressed to ensure stable and reliable charging for electric vehicles.

This study investigates the application of a PI controller in a solar-based G2V integration system to enhance power quality. The research focuses on evaluating the controller's effectiveness in mitigating common power quality issues, including voltage fluctuations and total harmonic distortion (THD). Simulation-based analysis is conducted to assess system performance under various operating conditions, such as changes in solar irradiance and dynamic load variations.

The outcomes of this research provide valuable insights into the design and optimization of solar-based G2V systems, ensuring reliable and efficient integration into modern power grids. By addressing power quality concerns, this work contributes to the development of sustainable energy solutions for the expanding electric vehicle ecosystem.

II. PROPOSED METHODOLOGY

A comprehensive appraisal of the writing is given the objective of diminishing the quantity of gadgets expected to help an expanded number of result levels. The thesis's objectives and structure are discussed in depth in this section. These days, interests in new sustainable and economical energy areas are quickly done to lessen CO₂ outflows and address an Earth-wide temperature boost brought about by the utilization of petroleum products.

Solar photovoltaic and wind energy-based power generation systems are largely due to developments in power electronics. in order to connect these sources to either local loads or the distribution grid. Figure 1 depicts the proposed work's fundamental application.

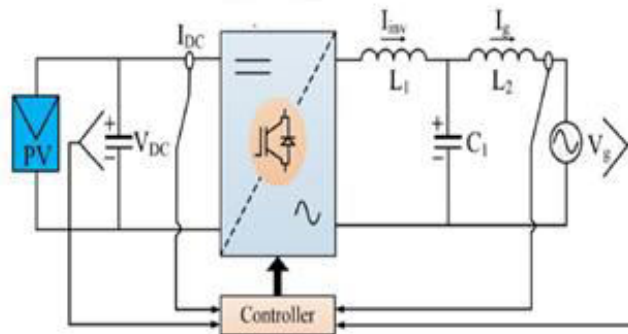


Figure 1: Proposed Work Fundamental Application

2.1 PI Controller

The Proportional-Integral (PI) controller is a widely used feedback control mechanism in electrical engineering applications due to its simplicity, efficiency, and ability to address both transient and steady-state errors in a system. The PI controller combines two control actions: (a) Proportional (P) Control and (b) Integral (I) Control

Application of PI Controller in Power Quality Improvement

In the context of the **solar-based G2V integration system**, the PI controller plays a crucial role in regulating power quality by stabilizing the system's voltage and reducing harmonic distortion. Here's how the PI controller addresses the primary concerns:

1. Voltage Regulation:

- a. The PI controller adjusts the duty cycle of the power electronic converter (e.g., DC-DC or AC-DC converter) based on the measured voltage deviation from the desired setpoint. The proportional term adjusts the output to correct the immediate error, while the integral term ensures that any small voltage deviation that persists over time is eliminated, bringing the voltage back to the desired level.

2. Harmonic Reduction:

- a. Harmonic distortion is often introduced by power converters. The PI controller can be tuned to minimize the harmonic content by adjusting the switching characteristics of the power converters. This helps in reducing the total harmonic distortion (THD) in the output, improving the overall power quality.

3. Dynamic Load Handling:

- a. The PI controller is adaptive to changes in load, ensuring that the system can maintain stable voltage levels and efficient energy transfer, even as the charging demand for the EV fluctuates. By continuously adjusting the converter's operation, the controller ensures the system responds promptly to sudden changes in load or solar irradiance.

Advantages of PI Controller in Solar-based G2V Integration:

- **Simplicity:** The PI controller is relatively simple to implement, making it an attractive solution for real-time applications.
- **Steady-State Error Elimination:** The integral action effectively eliminates steady-state errors, ensuring accurate voltage regulation over time.
- **Robustness:** The PI controller is robust and can adapt to changes in system dynamics, such as varying solar irradiance or load fluctuations.
- **Cost-Effective:** Due to its simplicity, the PI controller does not require complex algorithms or additional sensors, reducing the cost of the system.

III. RESULT AND DISCUSSION

The transition to sustainable energy systems has accelerated the adoption of electric vehicles (EVs) as a viable alternative to traditional fossil-fuel-based transportation. The integration of EVs with the power grid, known as Grid-to-Vehicle (G2V) systems, has emerged as a crucial component in this transformation. G2V systems enable the efficient transfer of electricity from the grid to EV batteries, supporting the dual objectives of meeting transportation energy demands and optimizing grid operations.

As the penetration of EVs continues to rise, their charging infrastructure introduces both opportunities and challenges for power grid stability and efficiency. A G2V system facilitates the seamless charging of EVs, leveraging smart grid technologies to ensure efficient energy management. However, challenges such as grid overloading, voltage fluctuations, and harmonic distortion must be addressed to prevent adverse impacts on power quality.

To overcome these challenges, advanced control mechanisms and intelligent energy management strategies are essential. Fuzzy logic controllers (FLCs) and other optimization techniques have proven effective in addressing the dynamic and nonlinear nature of G2V systems. By managing real-time charging demands, minimizing grid disturbances, and integrating renewable energy sources, G2V systems can contribute to building a resilient and sustainable energy ecosystem.

This research explores the design and optimization of Grid-to-Vehicle integration systems, focusing on their role in improving power quality, enhancing grid efficiency, and enabling the widespread adoption of EVs. By examining the interplay between advanced control systems and power electronics, this study aims to propose innovative solutions that align with the goals of smart grids and sustainable transportation.

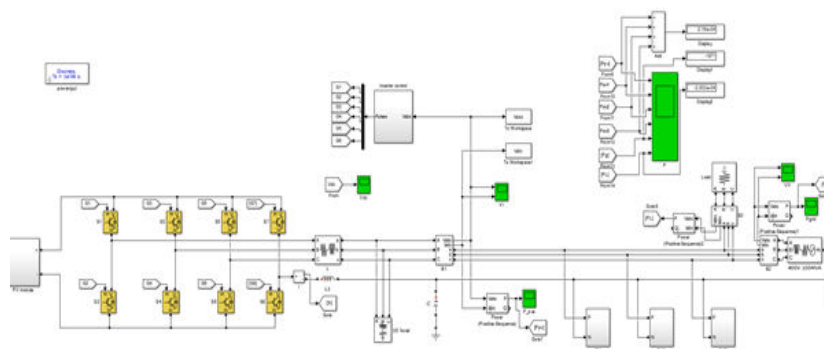


Figure 2: Simulation Model of Smart Grid and EV integration system with controllers and loads

The Electric Vehicle (EV) Circuit Structure with MOSFET Switch is commonly used in the power electronics system of EVs, particularly in battery charging circuits, inverters, and motor controllers. MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors) are preferred in these applications due to their high efficiency, fast switching capabilities, and ability to handle high currents and voltages.

- Serves as the primary switching device for power conversion.
- Operates in various configurations, such as high-side, low-side, or as part of an H-bridge.
- Controls the flow of current between the battery, inverter, and load (e.g., motor).

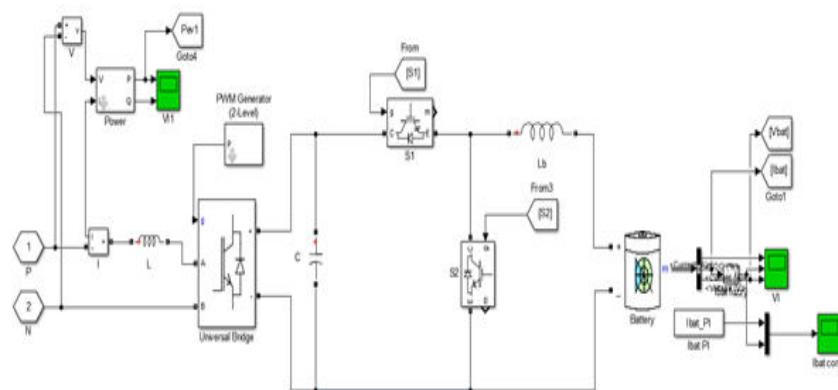


Figure 3: EV circuit structure with MOSFET Switch

The above figure 4 are the modeling of the complete proposed system with PV array module connected to grid along with EV charging units. All the devices are connected to a common point named as Point of Common Coupling (PCC). The characteristics of the PV array for the given solar irradiation can be observed in figure 5.

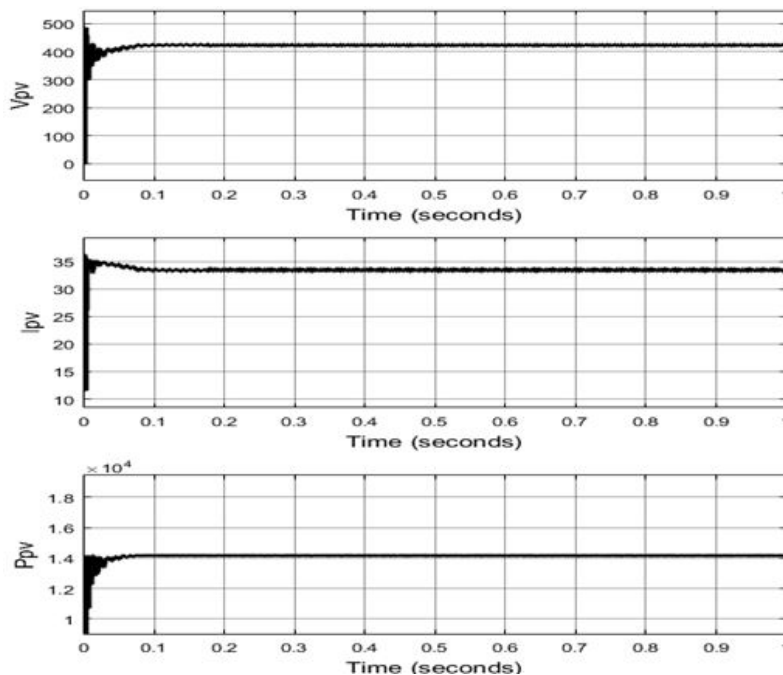


Figure 4: PV characteristics

The DC link voltage at the output of the PV array module before the three phase four legged inverter. The value of the DC link voltage is noted to be 830V which is generated as per the requirement of the grid voltage of 440Vrms line voltage.

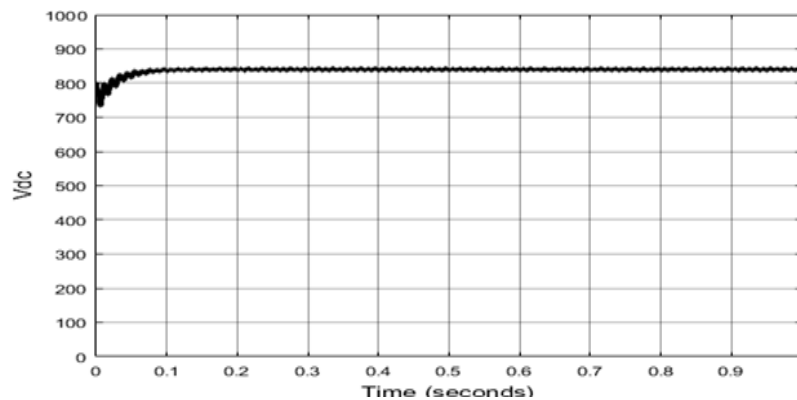


Figure 5: DC link voltage

The DC Link voltage is seen to be constant throughout the simulation of 1sec which reduced ripple content. The below figure 6 are the three phase voltages and currents of the PV inverter after the LC filter.

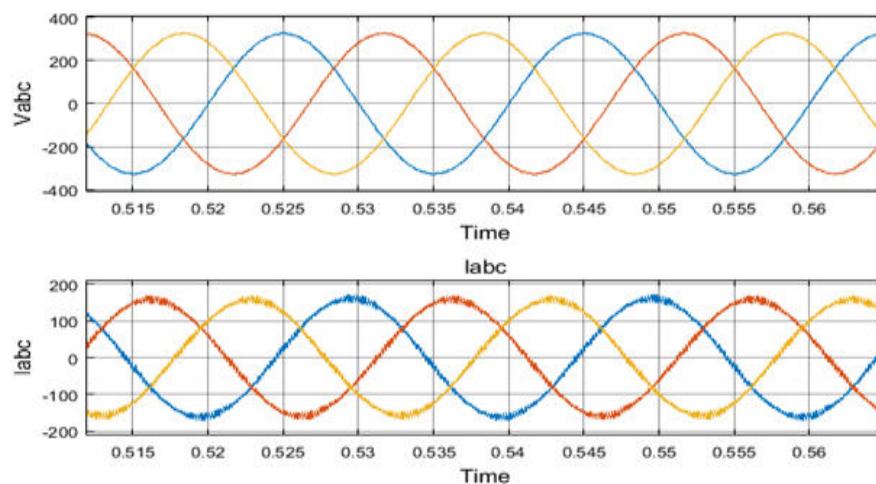


Figure 6: PV inverter three phase voltages and currents

The figure 7 and 8 are the THDs of the PCC voltage and PV inverter current noted to be 0.75% and 3.63% respectively. These harmonics are very low and are maintained below 5% as per IEEE standard.

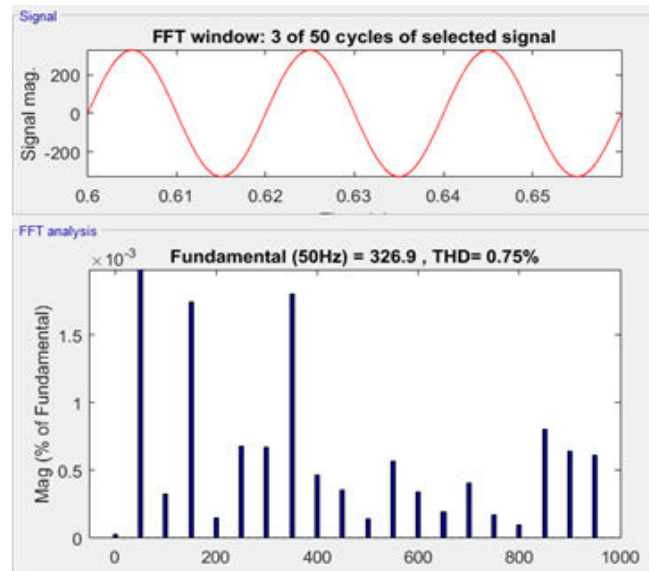


Figure 7: THD of PCC voltage

IV. CONCLUSION

This research has focused on the application of a Proportional-Integral (PI) controller to enhance the power quality of a solar-based Grid-to-Vehicle (G2V) integration system. Solar energy, while a sustainable and eco-friendly power source, introduces variability and intermittency, which can significantly affect the performance of G2V systems. Voltage fluctuations, harmonic distortions, and inefficiencies in energy transfer are some of the key challenges that must be addressed to ensure stable and reliable EV charging. Through the use of the PI controller, this study demonstrated the ability to stabilize the output voltage, minimize harmonic distortion, and improve overall power quality in the system. The proportional action ensured immediate correction of voltage deviations, while the integral action eliminated steady-state errors, contributing to a stable and efficient system operation. Simulation results confirmed the effectiveness of the PI controller in maintaining voltage stability, reducing total harmonic distortion (THD), and ensuring efficient energy transfer between the solar PV system and the electric vehicle.

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