# Mitigating PCC Harmonic Distortion in Solar-Grid EV Charging Systems with Closed-Loop Control

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***Abstract---*** Power quality at the Point of Common Coupling (PCC) and harmonic distortion are major concerns as EVs become more embedded in power systems. A closed-loop PI-controlled Buck Converter is suggested in this work as a means to manage the charging process and reduce harmonic injection in a hybrid solar-grid electric vehicle charging system. The suggested method optimises power distribution across solar PV, the grid, and the electric vehicle charger by continuously modifying the charging settings to reduce voltage and current distortions. The results show that the closed-loop control stabilizes power flow, improves grid performance overall, and decreases Total Harmonic Distortion (THD). The suggested approach greatly enhances PCC power quality in comparison to conventional open-loop EV charging techniques, rendering it a practical and eco-friendly option for a future EV charging infrastructure.

**Keywords**: Electric vehicle charging, harmonics, power quality, power system, PI Controller.

## I. INTRODUCTION

The transportation sector is the principal pollutant, accounting for 21% of global $CO_2$ emissions [1]. As a result, there is heightened awareness of the dangers of greenhouse gas emissions and the need to address these issues. Thus, a number of international governments have recognized the widespread adoption of electric vehicles (EVs) as a viable solution to meet the urgent global objectives related to air quality and climate change, as well as the reduction of emissions outlined in the Paris Agreement [2] – [5]. Due to their shorter range compared to gas-powered cars, electric vehicles need to be recharged more often and take longer to reach full capacity [6]. Concerns regarding load profile, voltage drop, phase unbalance, power loss, increased power demand, system components (distribution transformer and transmission cable), system stability and resilience, and harmonic issues caused by power electronic equipment are among those that might arise as a result of connecting numerous electric vehicles to the power grid for charging purposes [7]. Researchers in [8] looked at the effects of rapid electric vehicle charging on total current and harmonic distortion, taking into account the literature on the topic. They found that the total harmonic order values in their simulations adhered to the IEEE 519 and 61000-3-12/2-4 standard limits. According to an analysis of the effects of voltage harmonics on electric vehicle charging in [9], the 3rd and 9th harmonics are the most significant in their model, and charging at specific times is the best way to prevent overloading. In distribution grids, the harmonic spectra of voltage and current were examined in [10]. The results showed that voltage distortion had no noticeable impact on the grid, however current distortions were connected with larger Total Harmonic Distortion (THD) values. In addition, Total Demand Distortion (TDD) was shown to be a more accurate measure of current harmonic distortions than THD (as mentioned in reference 11). According to research on the impact of vehicle-to-grid (V2G) technology on voltage harmonics, published in [14], voltage total harmonic distortion (THD) is greater during the summer and falls below the IEEE standard limit, enabling bidirectional power transmission. Unbalanced EV charging produces harmonics, yet the simulation by [12] showed that transformer losses are not much affected. The research also found that the distribution transformer might have serious issues due to the neutral line's high current flow and associated current harmonics. As the principal superharmonic source, the superharmonic of the electric vehicle's battery was studied in [13]. The results showed that the power grid was negatively affected by most EVs due to the high current superharmonic or high TDD values created by others. Compared to a golf cart, contemporary EVs produced higher voltage THD and lower current THD, according to the study by [14]. It is possible to deduce the charging station's architecture and the power conversion technology that connects to the utility grid from the power quality at the Point of Common Coupling (PCC). A comprehensive analysis of potential topologies for power conversion is offered in [15]. Instead, a comprehensive state-of-the-art presentation on on-board charging topologies is available in [16]. According to research in [17], power transformers are negatively impacted by current harmonics injected at the PCC, leading to an increase in hot-spot temperature and a decrease in transformer life-expectancy [18]. This paper's key contribution is an in-depth investigation of the real-world voltage and current harmonic spectra obtained from the PCC described in [19] – [24]. The third harmonic of the current is examined using the percentiles of the charging active power level. In addition, we compare the power usage over a year to the seasonal TDDs of the current. Following this introduction, Section II details the methodology and results, including voltage and current harmonics as well as seasonal TDD. Section III explains the potential power conversion topology and how the data is fitted into this model. Finally, Section IV summarizes and concludes the study.

## II. METHODOLOGY

This section describes the systematic procedure adopted to design, model, and evaluate the proposed solar–grid integrated EV charging system with harmonic mitigation at the Point of Common Coupling (PCC). The overall methodology is divided into system modeling, control design, simulation setup, and performance evaluation.

**System Modeling**

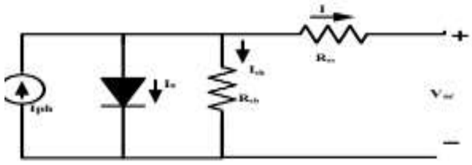
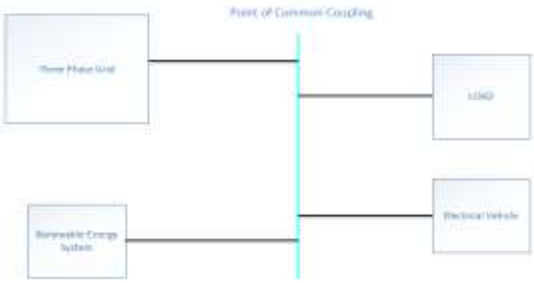


Fig: Modeling of PV cell

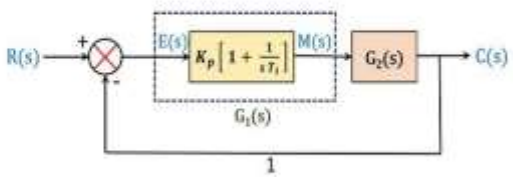
The complete system is modeled in MATLAB/Simulink and consists of a solar photovoltaic (PV) source, a three-phase utility grid, an EV charging unit, and a linear load interconnected at the PCC. The solar PV array is represented using a single-diode equivalent model to accurately capture its nonlinear voltage–current characteristics under varying irradiance and temperature conditions. A DC–DC converter and grid-connected inverter are used to interface the PV system with the AC grid.



The EV charging unit is modeled using a DC–DC buck converter supplying a battery load. The buck converter represents the nonlinear behavior of EV chargers, which is a major source of harmonic distortion in the system. The three-phase grid is modeled as a stiff voltage source with standard distribution parameters to analyze realistic grid interaction.

**B. Control Strategy Implementation**

A closed-loop proportional–integral (PI) control strategy is implemented to regulate the EV charging process and reduce harmonic injection at the PCC. The PI controller continuously compares the reference charging voltage/current with the actual measured values and generates an appropriate duty cycle for the buck converter.




This closed-loop operation ensures smooth current draw, reduced ripple, and improved dynamic response compared to open-loop charging.

In the PV subsystem, a maximum power point tracking (MPPT) algorithm is employed to extract maximum available solar power. The inverter control regulates active and reactive power exchange with the grid, maintaining voltage stability and synchronization while minimizing harmonic contribution.

**C. Harmonic Measurement at PCC**

The Point of Common Coupling is selected as the critical monitoring location for power quality assessment. Voltage and current signals at the PCC are measured and processed using Fast Fourier Transform (FFT) analysis to extract harmonic components. Total Harmonic Distortion (THD) is calculated for both voltage and current in accordance with IEEE 519 standards.

**D. Simulation Scenarios**

To validate the effectiveness of the proposed methodology, two simulation scenarios are considered:

System operation without EV charging, to establish baseline power quality conditions.

System operation with EV charging using closed-loop PI control, to evaluate harmonic mitigation performance.

Each scenario is analyzed under steady-state operating conditions, and the corresponding voltage and current waveforms, as well as THD values, are recorded.

**E. Performance Evaluation**

The effectiveness of the proposed methodology is evaluated by comparing THD levels, waveform quality, and system stability at the PCC for both scenarios. Reduced harmonic distortion, improved sinusoidal waveforms, and enhanced power quality indicate the successful

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implementation of the closed-loop controlled EV charging strategy.

## III. RESULTS

**CASE 1**: Simulation without EV

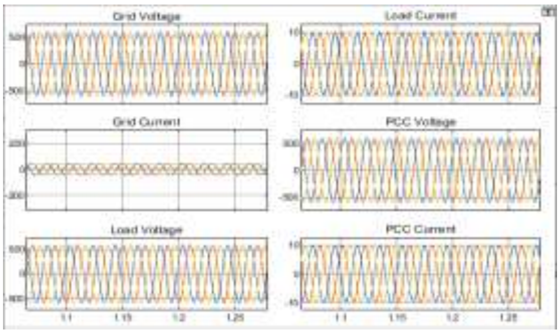
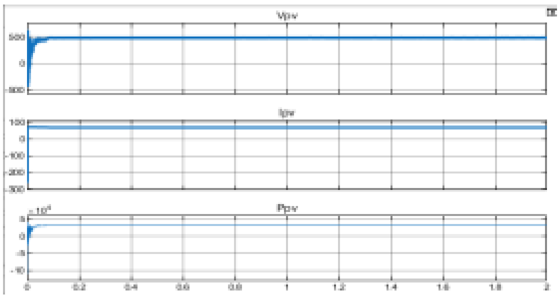



**Fig:** Simulation Results of a) Solar Voltage b) Solar Current C) Solar Power




**CASE 2**: Simulation with EV

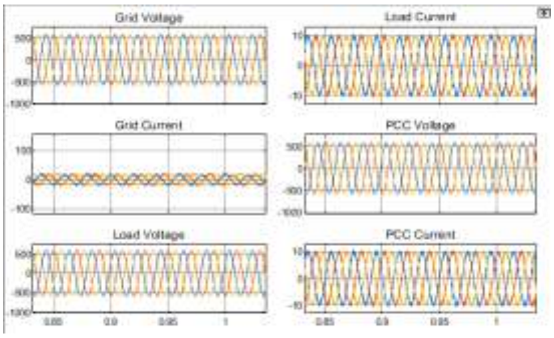



**Fig:** Simulation Results of a) Solar Voltage b) Solar Current C) Solar Power

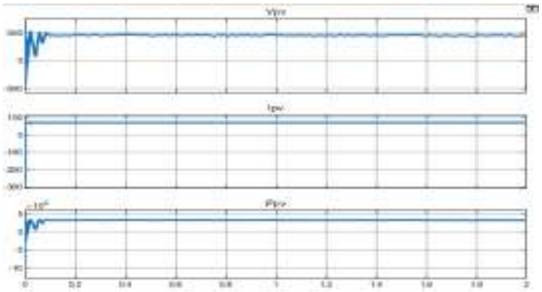
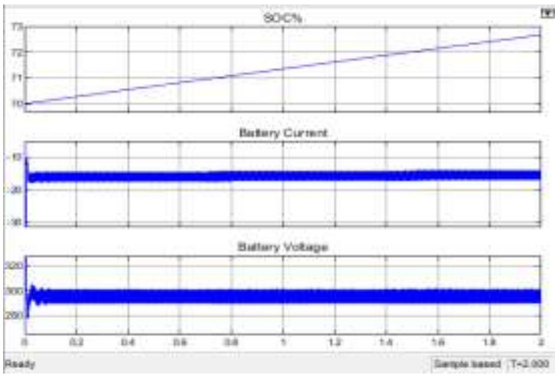



**Fig:** Simulation Results of Electrical Vehicle a) Battery SOC% b) Battery Voltage c) Battery Current.




**CASE 3**: Simulation Results with EV with PI Controller a) Grid Voltage b) Grid Current c) Load Voltage d) LoadCurrent e) PCC Voltage f) PCC Current

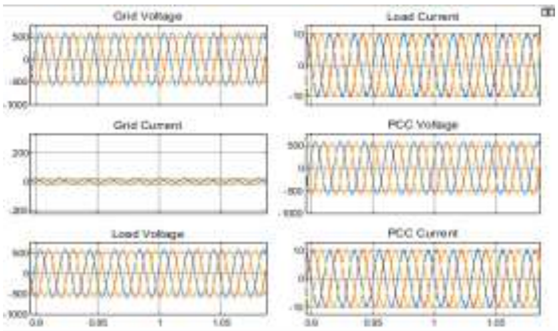



**Fig:** Simulation Results of a) Solar Voltage b) Solar Current
C) Solar Power

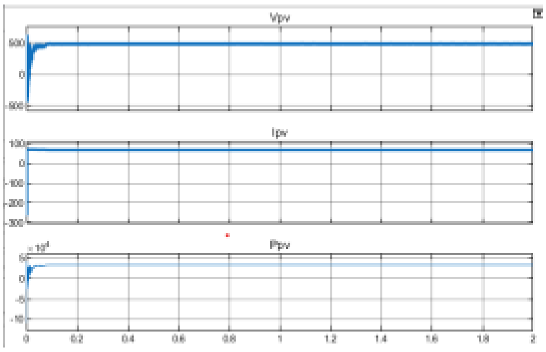
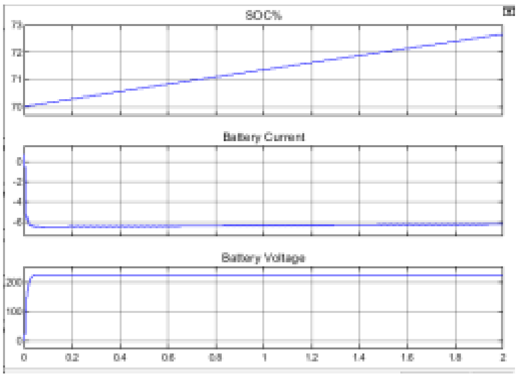


**Fig:** Simulation Results of Electrical Vehicle with PI Controller




## IV. CONCLUSION

The implementation of a closed-loop PI-controlled Buck Converter for EV charging has proven to be highly effective in mitigating the impact of EV integration on the power system. By dynamically regulating the charging process, the PI controller minimizes voltage and current distortions, reducing THD levels across key system parameters. As a result, the power quality at the Point of Common Coupling (PCC) is significantly improved, ensuring stable grid operation even with EV charging. The simulation results confirm that the closed-loop PI control enables EV charging without adversely affecting the grid or connected loads. The improved regulation of battery voltage and current ensures optimal charging performance, preventing excessive power fluctuations while maintaining system stability. Additionally, the reduction in THD values demonstrates the controller's ability to suppress harmonic injection, making the system more reliable and grid-friendly.

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