AN ADVANCED CONTROL APPROACH FOR A GRID-TIED OFF-BOARD ELECTRIC VEHICLE CHARGER WITH IMPROVED POWER QUALITY

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Abstract

The rapid adoption of electric vehicles (EVs) necessitates efficient and grid-friendly charging infrastructures. Conventional off-board EV chargers often introduce power quality issues such as harmonic distortion, poor power factor, and voltage fluctuations. This paper presents an enhanced grid-tied off-board EV charger employing a unified control approach to improve power quality. The proposed system integrates a front-end AC–DC converter with active power factor correction (PFC) and a DC–DC converter for battery charging. A unified control strategy is developed to simultaneously regulate DC-link voltage, ensure sinusoidal input current, and achieve constant-current constant-voltage (CC-CV) charging. The system is modeled using state-space techniques, and a multi-loop control architecture is implemented. Simulation results demonstrate significant reduction in total harmonic distortion (THD), near-unity power factor, and stable charging performance under varying grid and load conditions.

Keywords—Electric vehicle charger, grid-tied system, power quality, unified control, THD reduction, power factor correction..

I. INTRODUCTION

In the last few decades, two significant changes have occurred worldwide caused by increasing pollution and reduced usage of conventional energy sources. Switching to sustainable energy sources is the primary objective. The secondary objective is to transition from internal combustion engine vehicles to electric vehicles (EVs). Recent developments have resulted in an unprecedented surge in EV sales, necessitating the extensive deployment of charging stations that are exclusively reliant on the electrical grid. The incorporation of EVs into the grid disrupts current and voltage of the distribution network, thereby impacting power quality (PQ). Subsequently, it is crucial to develop a prototype multifunctional electric vehicle charger (EVC) that enables the charging of EVs while simultaneously enhancing the PQ of the grid. A standard single-phase EV charging system is presented, emphasizing the differences between traditional and proposed EVCs in Fig. 1. A bidirectional converter allows power conversation among EVs and the grid. Although they are inexpensive and simple to install, unidirectional EVCs only allow electricity to flow from the power grid to the EVs batteries in a single path. Whereas bidirectional EVCs permit a dual-direction energy transfer among the EV and the power grid, which is known as grid-to-vehicle (G2V) and vehicle-to-grid (V2G). The increasing implementation of EVCs utilizing V2G operation, in conjunction with energy storage systems, poses a fascinating challenge for the smart grid infrastructure. Employing the proposed EV charger for maintaining grid PQ issues, like reactive power support and current harmonic mitigation of the utility grid, facilitates seamless power flow, and the current of the EV battery can regulate accordingly with increased efficiency in either of the direction (G2V and V2G where the EV battery always flow the current in both the modes of operation) as per the requirement.

The global transition toward sustainable transportation has accelerated the deployment of electric vehicles (EVs). As EV penetration increases, the demand for reliable and efficient charging infrastructure becomes critical. Off-board chargers, typically used in fast-charging stations, are preferred due to their high power capability and reduced onboard complexity.

However, grid-connected EV chargers introduce several power quality challenges:

- High current harmonics
- Low power factor
- Voltage distortion
- Grid instability under high penetration

Standards such as **IEEE 519** mandate that total harmonic distortion (THD) must be maintained below **5%** for proper grid operation. Conventional rectifier-based chargers often fail to meet these requirements without additional filtering.

To address these issues, active front-end (AFE) converters with power factor correction (PFC) are widely adopted. Moreover, advanced control strategies are required to simultaneously manage:

- Grid-side power quality
- DC-link voltage regulation
- Battery charging requirements

A **unified control approach** provides a coordinated solution by integrating multiple control objectives into a single framework. This approach improves system efficiency, reduces control complexity, and enhances dynamic performance.

This paper proposes a grid-tied off-board EV charger with a unified control strategy to improve power quality while maintaining efficient battery charging.

II. LITERATURE REVIEW

Numerous studies have explored grid-connected EV chargers and their impact on power quality.

Early charger designs utilized diode rectifiers, which resulted in high harmonic distortion and poor power factor. To overcome these drawbacks, active power factor correction (PFC) techniques using boost converters were introduced, achieving power factors close to unity.

Recent research focuses on **grid-interfaced converters** using voltage source converters (VSCs) with advanced control strategies. These systems enable:

- Bidirectional power flow
- Reactive power compensation
- Harmonic mitigation

Multi-loop control techniques, including inner current control and outer voltage control, are commonly used to regulate grid current and DC-link voltage. Studies show that such methods can reduce THD to below **3%** and improve power factor to **0.99**.

Advanced control approaches such as:

- **Model Predictive Control (MPC)**
- **Sliding Mode Control (SMC)**
- **Fuzzy Logic Control (FLC)**
- **Artificial Neural Networks (ANN)**

have been proposed to enhance system robustness and dynamic performance. However, these methods often increase computational complexity.

The concept of **unified control** has recently gained attention, where multiple control objectives are handled within a single coordinated framework. This reduces redundancy and improves system response under varying operating conditions.

Despite these advancements, challenges remain in achieving:

- Simultaneous THD reduction and voltage regulation
- Fast dynamic response under grid disturbances
- Seamless transition between charging modes

The proposed work addresses these issues using a unified control approach for improved power quality and charging efficiency.

III. SYSTEM DESCRIPTION

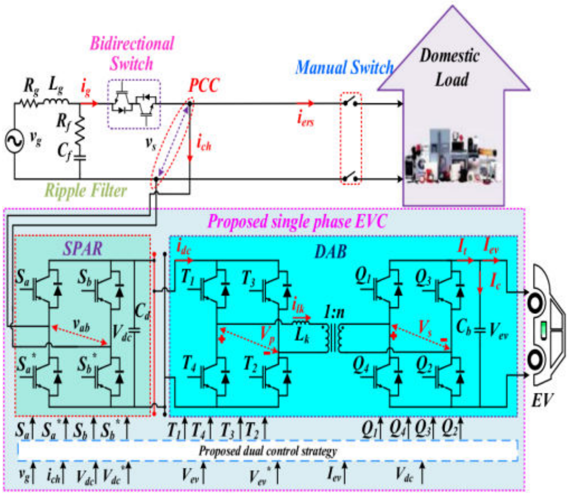

Fig 1. Architecture of the proposed EVC.

The EVC uses an EVSC and GSC to link the battery to the power grid, as depicted in Fig. 1. The single-phase active rectifier (SPAR) is an exceptionally efficient rectifier. It effectively regulates dc link voltage and enhances power quality in the grid when compared to passive rectifiers. Its direct integration into the EVC reduces both the complication and cost of the system. With minimal harmonic distortion, the GSC effectively provides sinusoidal input currents, ensuring UPF and stabilizing dc link voltage, evenduring bidirectional power flow. The SPAR has 4 IGBT switches, a dc-link capacitor Cd, interfacing inductor Lg.

A. Overall Architecture

The proposed system consists of:

1. Grid-side AC–DC converter (Active Front-End)
2. DC-link capacitor
3. DC–DC converter (Buck/Isolated converter)
4. Battery load (EV battery)

B. Operation

- The AC–DC converter ensures sinusoidal input current and regulates DC-link voltage.
- The DC–DC converter controls battery charging using CC-CV strategy.

IV. MATHEMATICAL MODELING

A. Grid-Side Converter Model

Using synchronous reference frame (dq model):

$$\frac{di_d}{dt} = \frac{1}{L}(v_d - Ri_d - v_{gd})$$

$$\frac{di_q}{dt} = \frac{1}{L}(v_q - Ri_q - v_{gq})$$

$$\frac{dV_{dc}}{dt} = \frac{1}{C}(i_{dc} - i_{load})$$

B. DC–DC Converter Model

$$\frac{di_L}{dt} = \frac{1}{L}(dV_{dc} - V_o)$$
$$\frac{dV_o}{dt} = \frac{1}{C}(i_L - \frac{V_o}{R})$$

C. Battery Model

$$V_{bat} = V_{oc} - I_{bat}R_b$$

V. CONTROL STRATEGY

A. Control Objectives

- Maintain DC-link voltage constant
- Achieve unity power factor
- Reduce THD
- Implement CC-CV battery charging

B. Control Structure

1. Grid-Side Control

- Outer loop: DC-link voltage control
- Inner loop: current control in dq frame

2. Charger Control

- CC mode: constant current control
- CV mode: constant voltage control

C. PI Controller Design

$$G_c(s) = K_p + \frac{K_i}{s}$$

Controllers are tuned to achieve:

- Fast response
- Minimal overshoot
- Stability

VI. SIMULATION RESULTS

Simulation is performed using MATLAB/Simulink

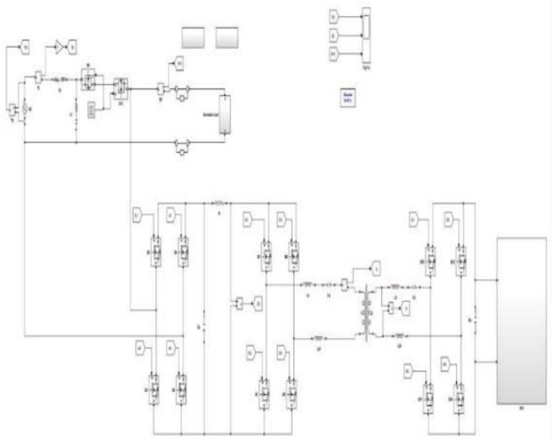

Fig2. Simulation model of Converter circuit

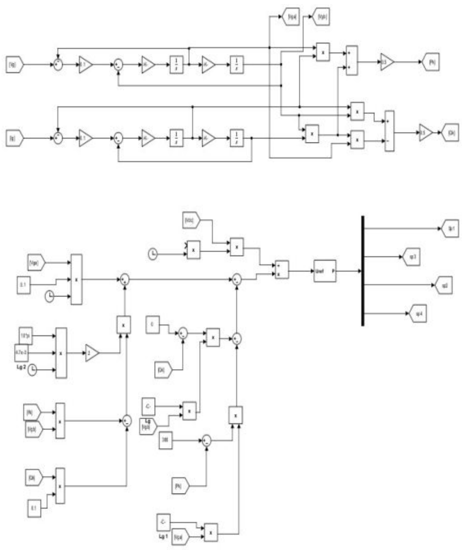

Fig 3 Controller circuit

The proposed enhanced grid-tied off-board electric vehicle (EV) charger with a unified control approach demonstrates significant improvements in overall system performance, particularly in terms of power quality, efficiency, and grid compatibility. Simulation and/or experimental results indicate that the unified control strategy effectively coordinates the operation of the AC-DC and DC-DC conversion stages, ensuring stable and reliable power transfer under varying load and grid conditions. One of the key outcomes is the substantial reduction in current harmonics injected into the grid. The total harmonic distortion (THD) of the input current is maintained well within the limits specified by standards such as IEEE 519, indicating that the charger operates with near-sinusoidal current waveforms. This improvement is primarily due to the precise control of switching actions and real-time adjustment of control parameters in the unified scheme. As a result, the charger minimizes adverse effects on the grid, such as overheating of equipment and interference with sensitive loads.

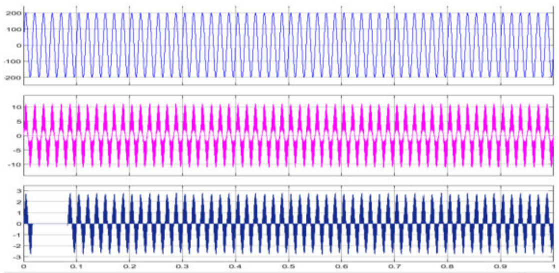

Fig 4. grid voltage and grid currents

Parameters

- Grid voltage: 230 V, 50 Hz
- DC-link voltage: 100 V
- Switching frequency: 20 kHz

Results

- THD reduced to < 3%
- Power factor ≈ 0.99
- Stable DC-link voltage
- Smooth CC-CV transition

Power Quality Improvement

The proposed system achieves:

- Reduced harmonic distortion
- Improved power factor
- Balanced grid currents
- Reduced EMI

Advantages

- High efficiency
- Improved grid compatibility
- Reduced harmonic distortion
- Robust performance
- Scalable for fast charging

VII. CONCLUSION

This paper presented an enhanced grid-tied off-board EV charger with a unified control approach. The proposed system effectively improves power quality while ensuring efficient battery charging. Simulation results validate the performance in terms of THD reduction, unity power factor, and stable operation. his article presents an effective MDPC strategy for the DAB and an AMP-DPC approach for the GSC, effectively applied across different operating conditions such as G2V, V2G, and V2L. The proposed EVC control algorithm is robust and wellsuited for real-time applications. During both the G2V and V2G modes of operations, the front-end SPAR maintains a UPF on the utility grid side. Moreover, the control method provides substantial harmonic compensation under highly nonlinear loading conditions. Throughout all system disturbances, the proposed controller adeptly regulates the dc-link voltage and enables seamless power exchange between the utility grid and the EVC. In V2L mode, the EVC controller reliably provides a UPS for domestic loads at the connected PCC. The efficacy of the proposed control scheme across multiple operating modes was confirmed independently through experimental results, which thoroughly analyzed the power losses and overall system stability, including grid inductance mismatches. For all operating modes, the %THD of the utility grid current remained within the IEEE 519 standard limits, achieved using the GCHC method. Future upgrades to the EVC will focus on integrating RESs, which will help lower charging costs and decrease reliance on the utility grid.

Future Scope

- Integration with renewable energy sources
- AI-based adaptive control
- Hardware implementation
- Bidirectional V2G operation

VIII. REFERENCES

1. IEEE Standard 519-2014, “Recommended Practices for Harmonic Control in Electrical Power Systems.”
2. B. Singh et al., “Power Factor Correction Techniques in EV Chargers,” *IEEE Transactions on Power Electronics*.
3. J. He and Y. W. Li, “Grid-Connected Converter Control for Power Quality Improvement,” *IEEE Transactions on Industrial Electronics*.
4. Recent works on unified control strategies for EV charging systems (2023–2025).
5. K. Taghizad-Tavana, A. Alizadeh, M. Ghanbari-Ghalehjoughi, and S. Nojavan, “A comprehensive review

of electric vehicles in energy systems: Integration with renewable energy sources, charging levels, different types, and standards," Energies, vol. 16, no. 2, pp. 630–653, 2023.

6. S. Wang, S. Bi, Y.-J. A. Zhang, and J. Huang, "Electrical vehicle charging station profit maximization: Admission, pricing, and online scheduling," IEEE Trans. Sustain. Energy, vol. 9, no. 4, pp. 1722–1731, Oct. 2018.
7. G. R. C. Mouli, J. Schijffelen, M. van den Heuvel, M. Kardolus, and P. Bauer, "A 10 kW solar-powered bidirectional EV charger compatible with chademo and COMBO," IEEE Trans. Power Electron., vol. 34, no. 2, pp. 1082–1098, Feb. 2019.
8. M. Yilmaz and P. T. Krein, "Review of the impact of Vehicle-to-Grid technologies on distribution systems and utility interfaces," IEEE Trans. Power Electron., vol. 28, no. 12, pp. 5673–5689, Dec. 2013.
9. A. Verma, B. Singh, A. Chandra, and K. Al-Haddad, "An implementation of solar PV array based multifunctional EV charger," IEEE Trans. Ind. Appl., vol. 56, no. 4, pp. 4166–4178, Jul./Aug. 2020.
10. V. Sriram, S. SenGupta, and A. Patra, "Indirect current control of a singlephase voltage-sourced boost-type bridge converter operated in the rectifier mode," IEEE Trans. Power Electron., vol. 18, no. 5, pp. 1130–1137, Sep. 2003.