An Electrolytic Capacitorless Bidirectional EV Charger for V2G and V2H Applications

Submitted By

Fayyaz Ahmed (244102502)

Vinay Pandey (244102115)

Under the Guidance of

Dr. Chandan Kumar

Department of Electronics and Electrical Engineering

Indian Institute of Technology Guwahati

North Guwahati, Assam - 781039, India

Contents

Abstract

In this paper, a bidirectional battery charger is proposed for grid-to-vehicle (G2V), vehicle-to-grid (V2G), and vehicle-to-home (V2H) operations of electric vehicles. The proposed charger adopts sinusoidal charging to eliminate the use of electrolytic capacitors. A nonregulating series resonant converter (SRC) is employed for isolation, thereby minimizing the ratings of the components and achieving zero-current switching (ZCS) turn ON and OFF of switches. Meanwhile, an AC–DC converter is employed to control each mode and their mode changes, making the whole control scheme simple and the transitions seamless.

keywords

Bidirectional electric vehicle (EV) charger, electrolytic capacitorless, on-board charger (OBC), seamless, vehicle-to-grid (V2G), vehicle-to-home (V2H).

1 Introduction

Recently, electric vehicles (EVs) and plug-in hybrid EVs (PHEVs) have been recognized as promising transportation options to reduce fossil fuel usage and greenhouse gas emissions. Key power conditioning units in EVs include electric motors, inverters, DC–DC converters, and on-board battery chargers (OBCs). Among these, the OBC allows the EV battery to be charged using standard outlets at homes and offices.

The basic functions of an OBC include battery charging, power factor correction (PFC), and galvanic isolation. Challenges include improving power density, efficiency, reliability, and lifetime—areas where power electronics are crucial.

The primary operation, grid-to-vehicle (G2V), charges the traction battery. With vehicle-to-grid (V2G) technology, the stored energy can be returned to the grid on demand. Additionally, vehicle-to-home (V2H) enables the EV battery to power home loads during a grid outage.

Conventional bidirectional chargers use two-stage topologies, typically an AC–DC converter followed by an isolated DC–DC converter such as a dual-active bridge (DAB). However, DAB converters suffer from high circulating currents and a narrow range of zero-voltage switching (ZVS), especially under varying voltage conditions.

To address these issues, frequency-controlled resonant converters were introduced. These offer high efficiency and low EMI but struggle to maintain continuous power flow when power direction changes.

Moreover, most topologies require bulky electrolytic capacitors to handle low-frequency ripple in the DC link, limiting power density and system life. Replacing them with film capacitors is possible using active power filters, but this increases cost and control complexity.

Sinusoidal charging is a viable alternative. It permits ripple current to pass to the battery using smaller film capacitors, with minimal impact on battery health.

Some systems regulate both AC–DC and DC–DC converters in sinusoidal charging mode using DABs. Others use unregulated LLC converters, but with slow control response and limited V2H capability due to lack of AC output control.

2 Proposed Bidirectional Charger Overview

This paper presents a bidirectional EV charger supporting G2V, V2G, and V2H operations. Sinusoidal charging eliminates bulky electrolytic capacitors and improves efficiency. A series resonant converter ensures ZCS at all loads, reducing losses. The AC–DC converter manages PFC and all operating modes, resulting in a simple, seamless control system.

3 Circuit Configuration

Figure 1 shows the proposed bidirectional EV charger. It consists of two stages: a single-phase full-bridge inverter with an LCL filter, and a nonregulating half-bridge series resonant converter (SRC) with an LC filter.

Capacitors C_{d1} and C_{d2} absorb only high-frequency switching ripples. Low-frequency components are passed to the battery via the SRC. The LC filter on the battery side prevents HF ripple from entering the battery, but allows low-frequency ripple for sinusoidal charging. Film capacitors are used throughout due to this filtering strategy.

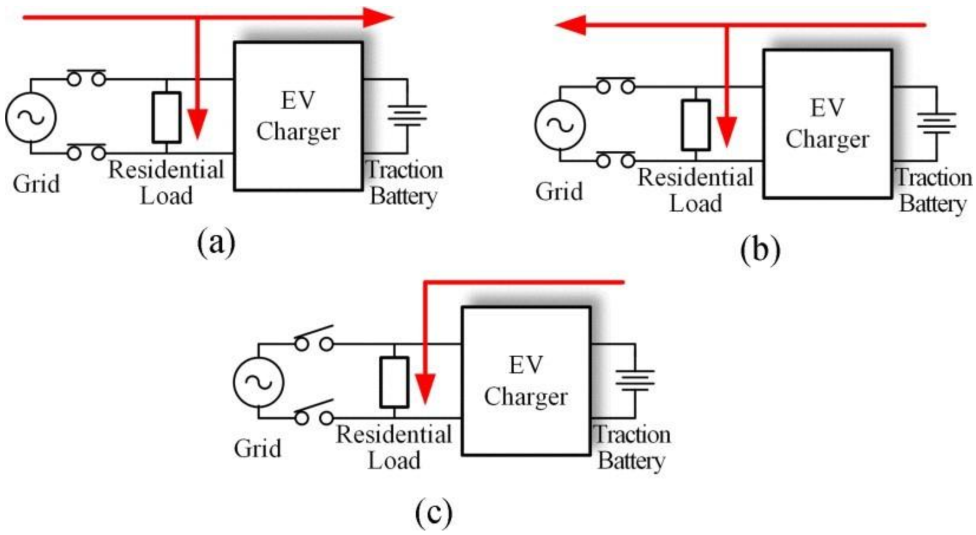

Figure 1: Operating modes of the bidirectional EV charger: (a) G2V mode, (b) V2G mode, (c) V2H mode.

4 Operation Analysis

Resonant capacitors C_{r1} and C_{r2} resonate with transformer leakage inductance L_k. The resonant frequency is:

$$\omega_r = \frac{1}{\sqrt{L_k(C_{r1} + C_{r2})}}. \tag{1}$$

Using the fundamental harmonic approximation, the voltage gain of the SRC is:

$$G_{SRC} = n \cdot \frac{1}{1 + j\frac{\pi^2}{8} \cdot Q \left(\frac{\omega_s}{\omega_r} - \frac{\omega_r}{\omega_s}\right)} \tag{2}$$

where n is the transformer turn ratio, and ω_s is the switching frequency. Q is the quality factor of the SRC.

At $\omega_s = \omega_r$, the gain becomes load-independent, allowing all switches to achieve ZCS regardless of load. The SRC operates at fixed frequency with a half-duty cycle.

5 Analysis on Half Bridge Resonant DC–DC Converter

PWM converters switch at high di/dt and dv/dt, causing EMI, voltage stress, and switching losses. Resonant converters mitigate these by ensuring zero-voltage or zero-current switching via LC resonance.

Series resonant inverters place switching devices in series with resonant components, forming underdamped circuits where current naturally falls to zero, enabling soft switching.

A half-bridge resonant converter inverts the 1500 V DC link voltage into 8 kHz high-frequency AC using a transformer, then rectifies it to supply the battery.

6 Bidirectional Charger Architecture and Operation

A battery charger for electric vehicles (EVs) can be implemented as either an on-board or off-board system. On-board chargers are compact and typically support slow charging, making them suitable for residential and portable applications. In contrast, off-board chargers are larger, stationary systems that enable faster charging due to their higher power capacity.

In this work, the proposed EV battery charger is designed as a bidirectional V2G (Vehicle-to-Grid) charger capable of operating in multiple modes: slow charging, fast charging, slow discharging, and fast discharging.

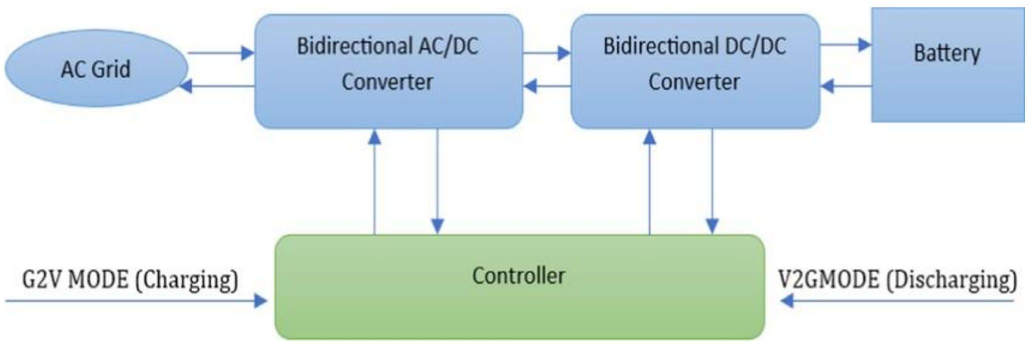

Figure 2: Basic structure of grid to vehicle (G2V) and vehicle to grid (V2G).

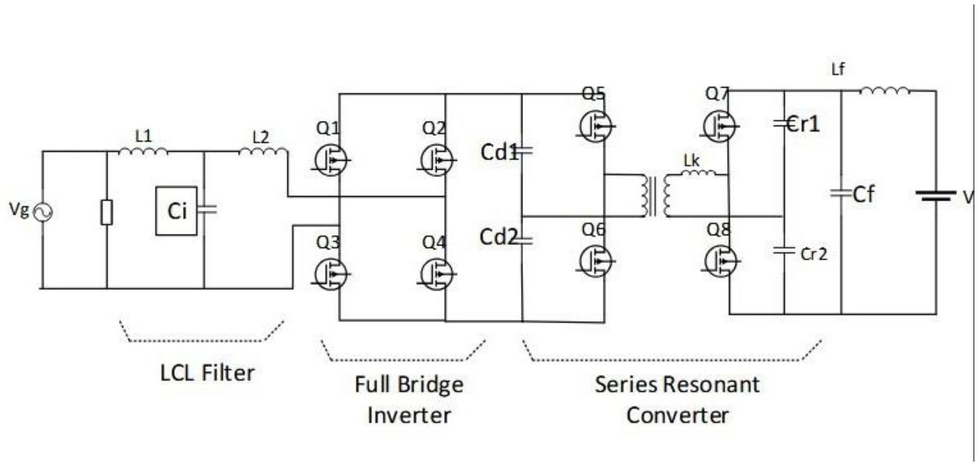

Figure 3: Circuit diagram of the proposed bidirectional EV charger..

The key components of a bidirectional EV charger include an AC/DC converter and a DC/DC converter, as illustrated in Figure 7. During the EV charging mode, the AC/DC converter rectifies AC power from the grid into DC power for battery charging. In the discharging mode, the converter operates in reverse, converting DC power from the EV battery into AC power to supply the grid.

The DC/DC converter regulates the bidirectional power flow using a direct current control technique.

The complete V2G bidirectional battery charger has been modeled and simulated using PSCAD/EMTDC software. The simulation model of the power converters used in the charger is shown in Figure

Control Strategy

In the proposed bidirectional charger, a bipolar Pulse Width Modulation (PWM) strategy is adopted for controlling the inverter switches in the AC-DC stage. This technique modulates the inverter output by comparing a reference sinusoidal signal with a high-frequency triangular carrier signal. When the reference is greater than the carrier, one diagonal switch pair (e.g., S_1 and S_4) is turned **ON**, resulting in an output voltage of $+V_{dc}$.

When the reference is less than the carrier, the opposite diagonal pair (e.g., S_2 and S_3) is turned **ON**, resulting in an output voltage of $-V_{dc}$.

In G2V or V2G, the grid voltage is normal, and the battery voltage reference V_b^* is set to the full-charge value. If the battery is not fully charged:

$$I_{L_g}^{d*} = \frac{2}{V_g^d} P_g^* \tag{3}$$

where P_g^* is desired charging/discharging power. A limiter and anti-windup mechanism are used in the PI controller.

Once fully charged, the PI controller regulates V_b. The I_{L_g} loop output becomes the reference for the V_c loop. The grid-side current i_{L_g} is indirectly controlled via v_c relative to v_g.

During grid failure, the mode switches to V2H. The V_c loop regulates AC voltage for home loads.

7 simulation circuit

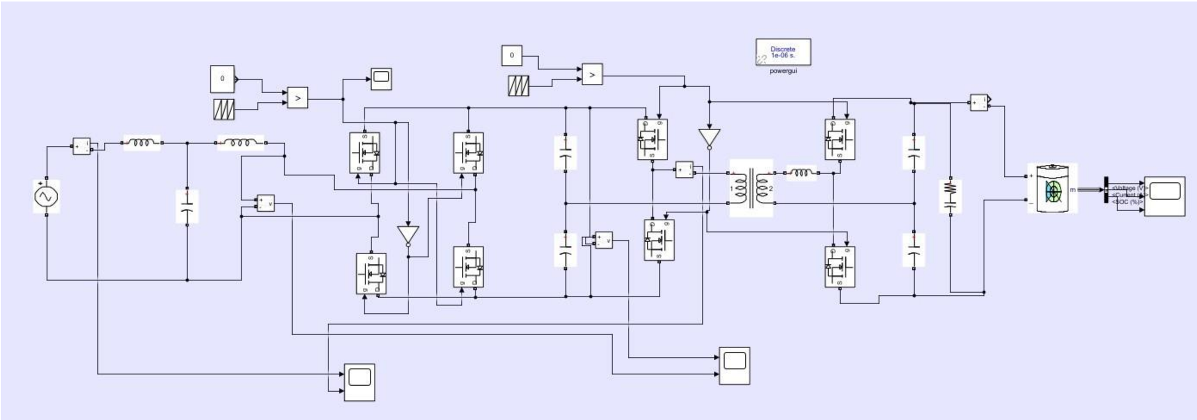

Figure 4: matlab simulation circuit of the proposed bidirectional EV charger in V2G mode.

8 Results

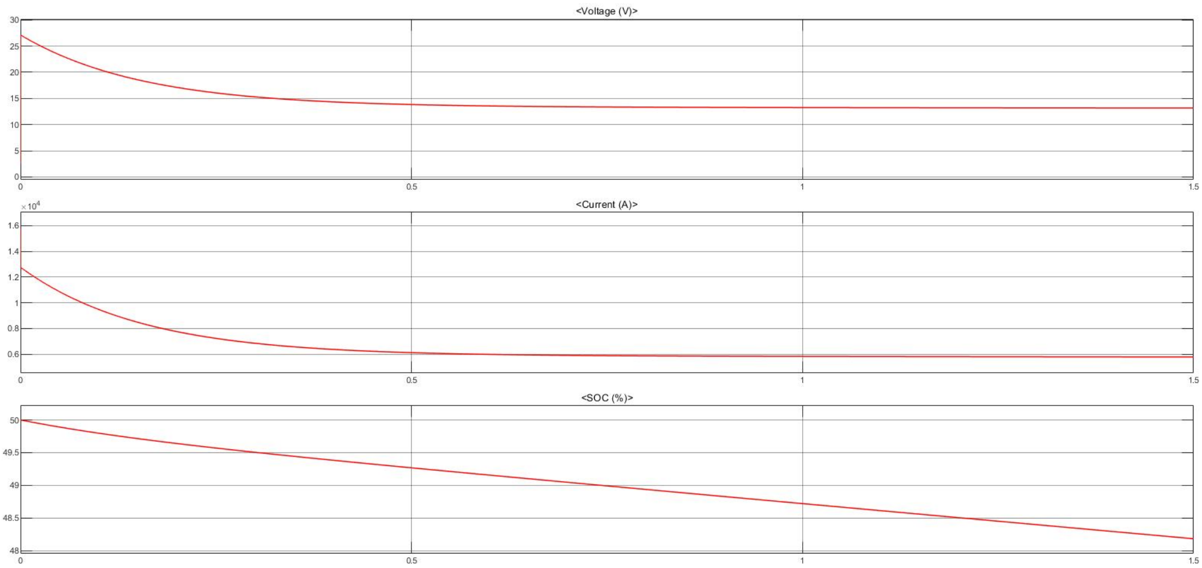

Figure 5: Simulation result of the proposed bidirectional EV charger in V2G mode (EV discharge).

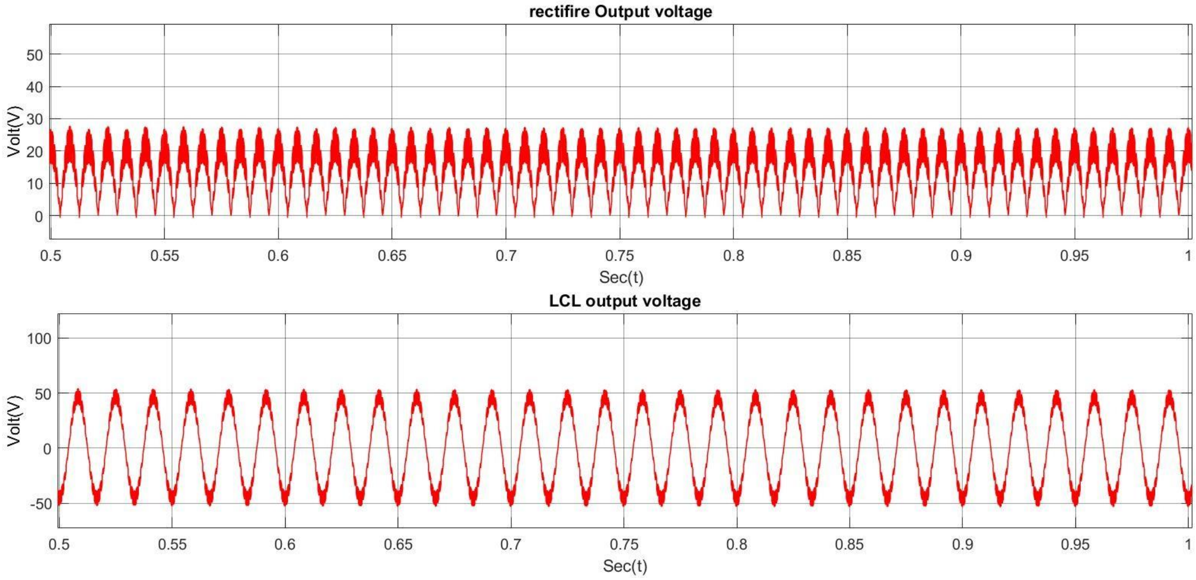

Figure 6: Simulation result of the proposed bidirectional EV charger in V2G mode.

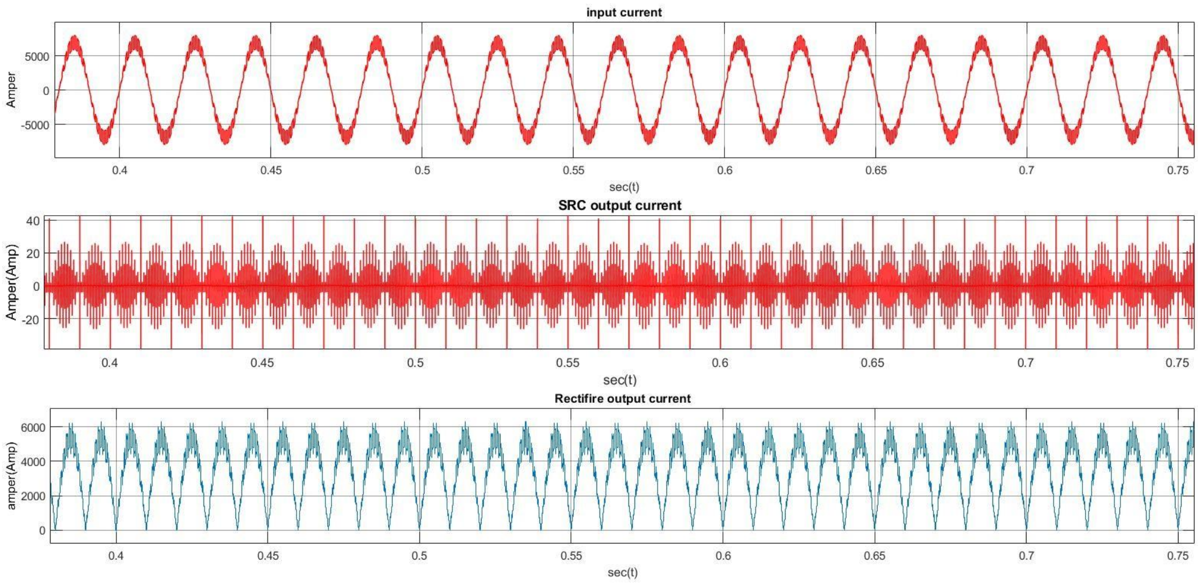

Figure 7: input,output current of converter.

9 Conclusion

This paper has presented a bidirectional electric vehicle (EV) battery charger incorporating a direct current control strategy to support vehicle-to-grid (V2G), grid-to-vehicle (G2V), and vehicle-to-home (V2H) operations. The proposed charger is capable of operating under various charging and discharging modes, including fast and slow rates, thereby enhancing flexibility and applicability in a variety of use cases. Simulation results validate that the proposed control strategy achieves high efficiency across all operating modes. Additionally, the results confirm a direct proportional relationship between the charging/discharging current and the rate of change in the battery's state of charge (SOC), ensuring predictable and controllable energy flow. The complete modeling of the EV battery and the bidirectional charger was implemented using MATLAB/Simulink. The functional benefits of V2G, G2V, and V2H were successfully demonstrated, showcasing the system's potential for future smart grid integration and home energy management applications.

References

[1] A. Emadi, S. S. Williamson, and A. Khaligh, "Power electronics intensive solutions for advanced electric, hybrid electric, and fuel cell vehicular power systems," *IEEE Transactions on Power Electronics*, vol. 21, no. 3, pp. 567–577, May 2006.

[2] A. Emadi, Y. Lee, and K. Rajashekara, "Power electronics and motor drives in electric, hybrid electric, and plug-in hybrid electric vehicles," *IEEE Transactions on Industrial Electronics*, vol. 55, no. 6, pp. 2237–2245, Jun. 2008.

[3] M. Yilmaz and P. T. Krein, "Review of the impact of vehicle-to-grid technologies on distribution systems and utility interfaces," *IEEE Transactions on Power Electronics*, vol. 28, no. 12, pp. 5673–5689, Dec. 2013.

[4] M. C. Kisacikoglu, M. Kesler, and L. M. Tolbert, "Single-phase on-board bidirectional PEV charger for V2G reactive power operation," *IEEE Transactions on Smart Grid*, vol. 6, no. 2, pp. 767–775, Mar. 2015.