EL Capacitorless EV On-Board Charger Using Harmonic Modulation Technique

Submitted By

Shuchi Pathak (244102113)
Vikas Pal (244102114)

Under the Guidance of

Dr. Chandan Kumar

Department of Electronics and Electrical Engineering

Indian Institute of Technology Guwahati

North Guwahati, Assam - 781039, India

Contents

1 Contribution **2**

1.1 Shuchi Pathak 2

1.2 Vikas Pal 2

2 Abstract **3**

3 Introduction **3**

4 Proposed Converter Design **3**

5 Control Strategy of the Proposed battery charger **5**

6 Design Equations and Operating Principles **5**

7 MATLAB Simulation **6**

7.1 Simulation Results 7

7.1.1 Without using Harmonic Modulation Technique 7

7.1.2 Using Harmonic Modulation Technique 7

7.1.3 Primary Current of Resonant Converter 8

7.1.4 Secondary Current of Resonant Converter 8

8 Analysis and Efficiency Considerations **9**

9 Experimental Validation **9**

10 Advantages of the Proposed Charger **10**

11 Conclusion **10**

12 References **11**

1 Contribution

1.1 Shuchi Pathak

- Studied the working of the Battery charger model.
- Designed and developed the MATLAB/Simulink model for the battery charging system.
- Prepared the Presentation slides

1.2 Vikas Pal

- Studied the working of the Battery charger model.
- Prepared the Figures and Block Diagram using Microsoft Visio.
- Prepared the Technical Report using Latex.

2 Abstract

This report summarizes a novel design of an on-board charger (OBC) for electric vehicles (EVs) that eliminates the need for large electrolytic (EL) capacitors.

The charger combines a constant-frequency resonant converter and a discontinuous conduction mode (DCM) boost converter.

A harmonic modulation technique is employed to improve power factor (PF) and simplify control. Experimental results from a 3 kW prototype validate the proposed design, achieving high efficiency and nearly unity PF.

3 Introduction

Conventional OBCs typically use bulky EL capacitors to filter intermediate DC-link voltage ripples. These components are limited by short lifetimes and large size.

This paper introduces an EL capacitorless solution using a resonant converter and a DCM boost converter with harmonic modulation for improved PF and simplified control.

The proposed method allows implementation using a single digital controller without high computational demands.

4 Proposed Converter Design

The proposed charger consists of:

- A full -bridge Rectifier is used to convert the AC supply voltage to DC.
- A resonant converter operating at constant frequency, providing isolation and soft-switching.
- An interleaved DCM boost converter for charging control and harmonic regulation.

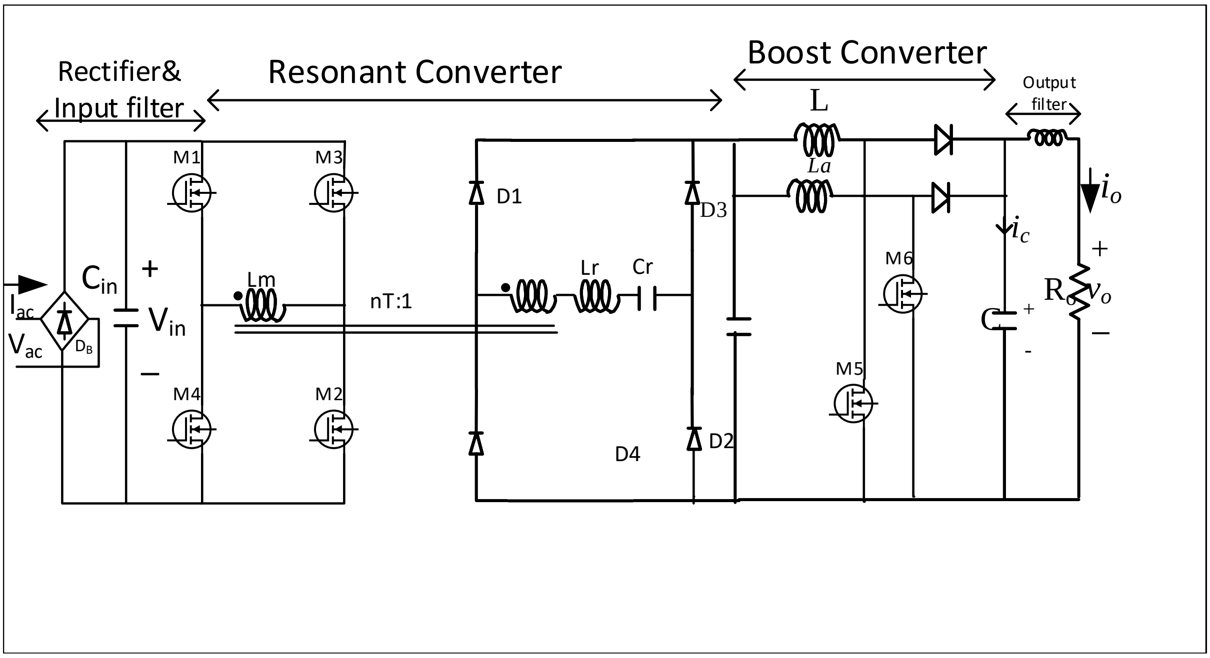

Figure 1: Block diagram of proposed charger system .

The boost converter performs line current harmonic control, as well as charging control. To reduce the magnetic component size and simplify the control algorithm, the boost converter adopts interleaved DCMoperation

The boost converter modulates its duty cycle to ensure high PF using a Harmonic Modulation Factor (HMF):

$$D[n] = D_0 \cdot HMF = \sqrt{\frac{2L_b^2 P_{o1}}{T_{sb} V_{L,pk}^2}} \cdot \sqrt{1 - \frac{v_L[n]}{V_{batt}}} \tag{1}$$

5 Control Strategy of the Proposed battery charger

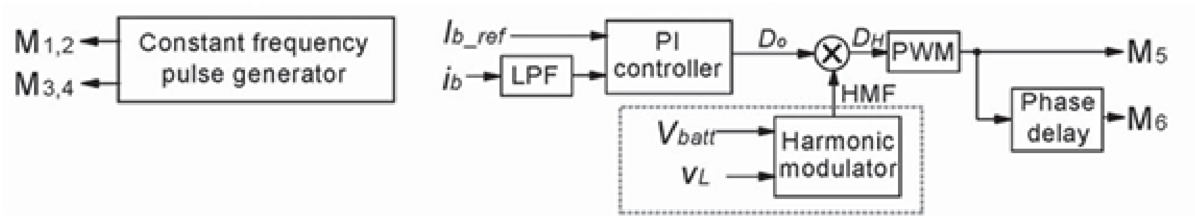

Figure 2: Control Algorithm

- Gate pulses are given to the primary side switches of the resonant converter through a pulse generator block such that alternate switches are operated together.
- PI Controller block is used to control the batter charging current.It takes the reference current and the actual current as it inputs and according to the values of P and I it controls the output.
- PWM block is generating gate pulses for the secondary side interleaved boost converter considering the harmonic modulation technique.
- Phase delay block is giving some delay to the gate pulse given to the second switch used in interleaved boost converter.

6 Design Equations and Operating Principles

Key design relationships: $\mathrm{i}_{L,pk}[n] = \frac{v_L[n]D[n]T_{sb}}{L_b}$
$|i_{ac}[n]| = \frac{2}{n_T} \cdot \frac{v_L[n]V_{batt}D[n]^2T_{sb}}{2L_b(V_{batt}-v_L[n])}$

To maintain Zero Voltage Switching (ZVS):

$$L_m \leq \frac{T_{dead}}{16f_{sr}\left(c_{ds}[V_{in}^{]} + c_j[V_{in}^{/}n_T]/n_T^2\right)} \tag{2}$$

7 MATLAB Simulation

- We have done the simulation based on the control algorithm explained in the given IEEE paper considering the parameters given in the paper.

- The simulation circuit consists of a rectifier circuit which is converting AC power supply to the DC.
- Then for dc-dc efficient conversion ,a series LC Resonant Converter is used followed by the boost converter.
- Boost converter is operated in Discontinuous conduction mode to cope up with the fast dynamics.
- Boost converter if operated in Continuous conduction mode requires high frequency and it is not easy to implement it with all the control algorithms of Power Factor Controller(PFC) and dc-dc converters.

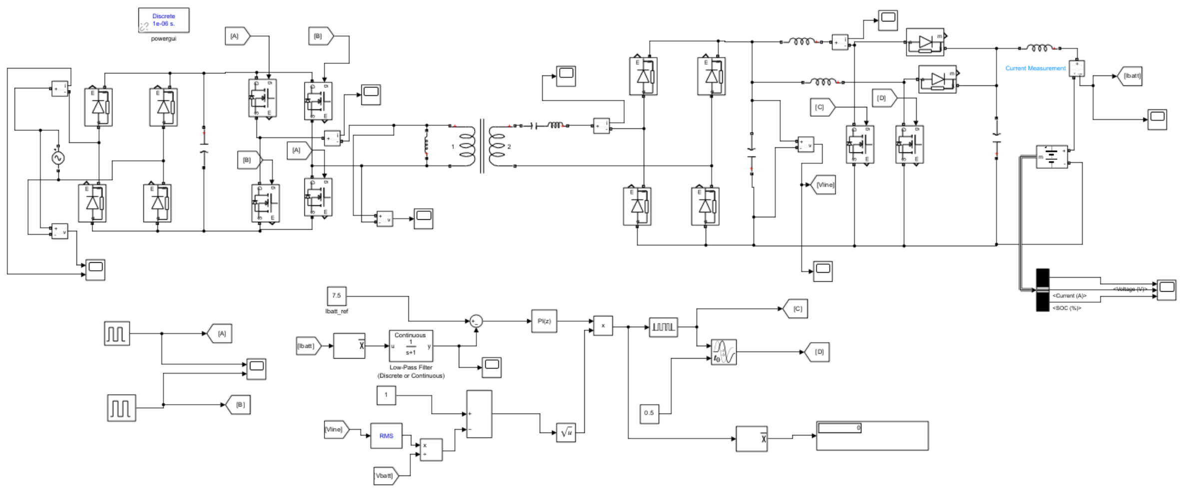

Figure 3: SIMULATION CIRCUIT

7.1 Simulation Results

7.1.1 Without using Harmonic Modulation Technique

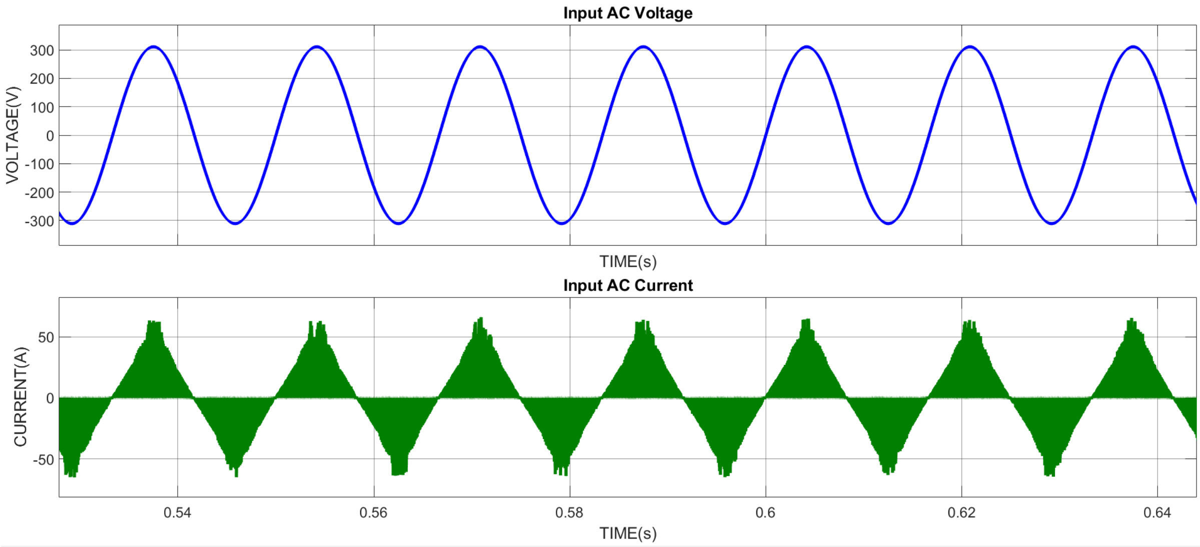

Figure 4: Without Harmonic Modulation

7.1.2 Using Harmonic Modulation Technique

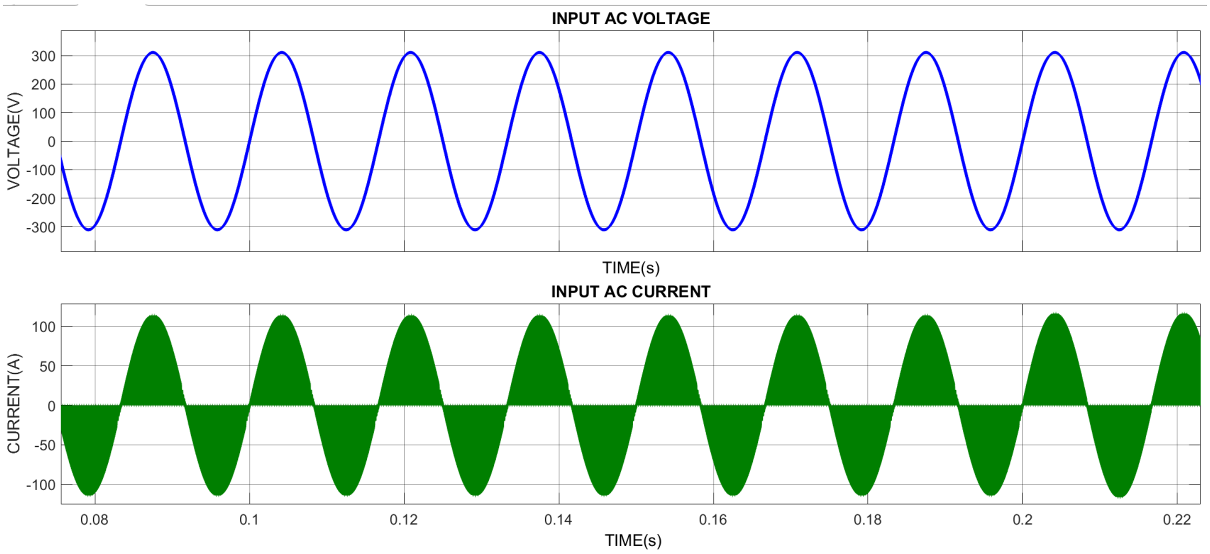

Figure 5: Using Harmonic Modulation Technique

7.1.3 Primary Current of Resonant Converter

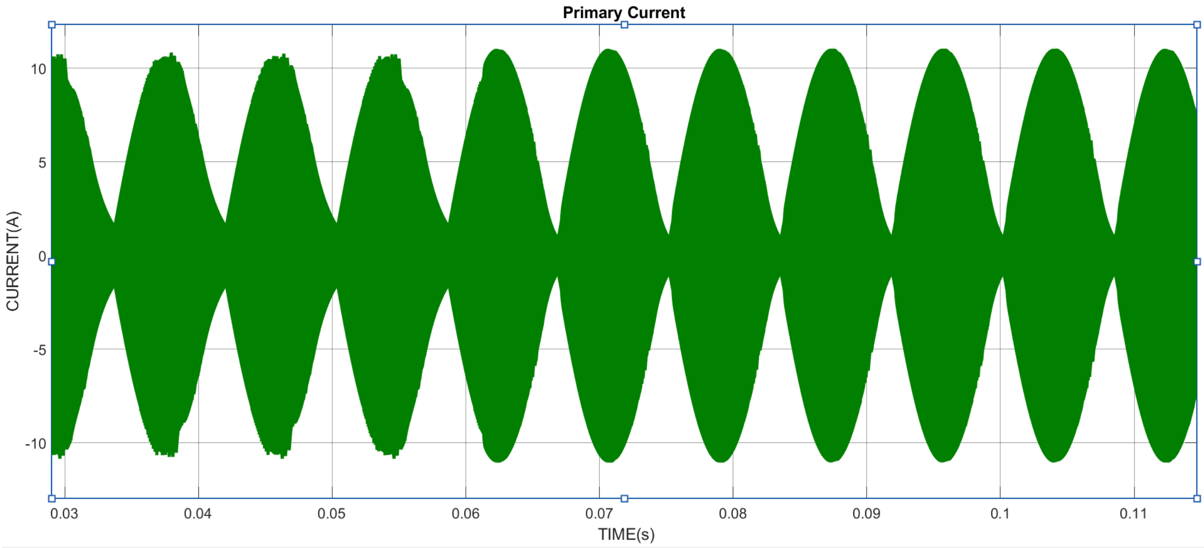

Figure 6: Primary current

7.1.4 Secondary Current of Resonant Converter

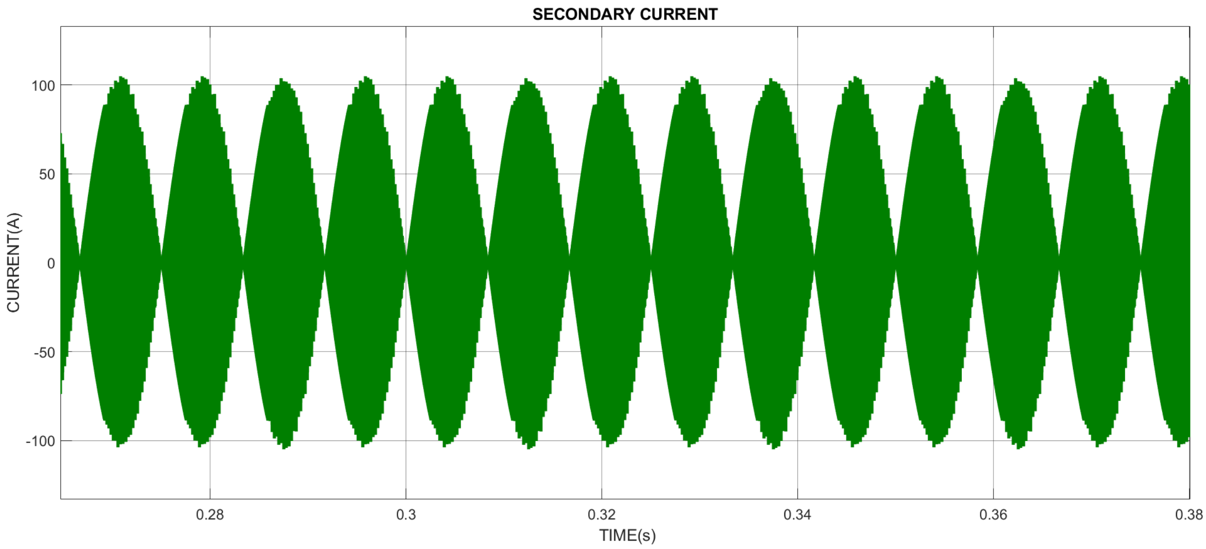

Figure 7: Secondary Current

8 Analysis and Efficiency Considerations

- The resonant converter gain is robust near its designed operating point when L_m is chosen to balance ZVS and gain sensitivity.
- Critical boost inductance $L_{b,max}$ ensures DCM across all load conditions:

$$L_{b,max} = \frac{(V_{batt} - V_{L,pk})T_{sb}V_{L,pk}^2}{4P_{o1}V_{batt}} \tag{3}$$

9 Experimental Validation

A 3 kW prototype was developed with the following specifications:

- Input: 220/110 V AC, 60 Hz; Output: 280–450 V DC, up to 8 A
- Transformer: EE6565 core; Control: TMS320F28335 DSP

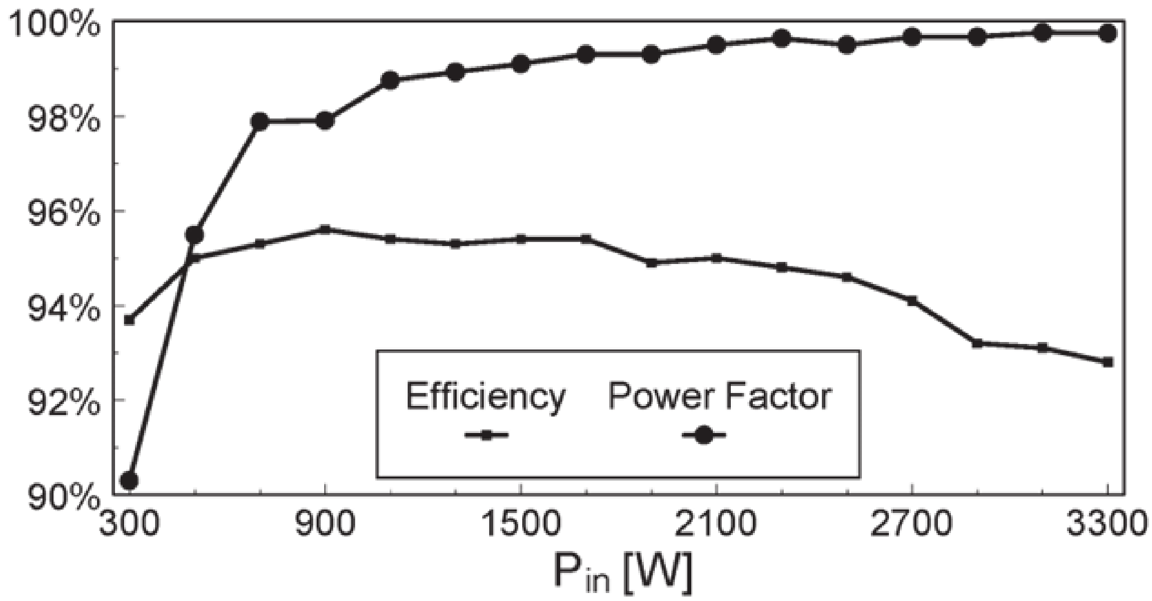

Figure 8: Efficiency plot

Key results:

- PF: 0.998 at rated condition
- Efficiency: 92.8%
- Smooth line current waveform and ZVS operation achieved

10 Advantages of the Proposed Charger

- **Elimination of EL capacitors:** Enhances charger lifetime and reduces bulk.
- **Simplified control algorithm:** Allows low-cost digital implementation.
- **High power factor:** Maintains unity PF using harmonic modulation.
- **Compact and efficient:** Interleaved DCM operation enables downsizing of magnetics and reduces ripple.
- **Zero Voltage Switching:** Reduces switching losses and improves reliability.

11 Conclusion

- The proposed capacitorless charger design achieves high PF and efficiency while reducing component size and extending lifetime.
- To improve the PF in DCM operation, optimal operational duty ratio has been analyzed, and harmonic modulation technique has been also proposed based on this analysis.
- Harmonic modulation and DCM operation simplify the control scheme, enabling compact and cost-effective digital implementation.
- This architecture shows strong potential for future EV charger designs.

12 References

1. M. Yilmaz and P. T. Krein, “Review of battery charger topologies, charg ing power levels, and infrastructure for plug-in electric and hybrid ve hicles,” IEEE Trans. Power. Electron., vol. 28, no. 5, pp. 2151–2169, May 2013.

2. J. F. Chen, R. Y. Chen, and T. J. Liang, “Study and implementation of a single-stage current-fed boost PFC converter with ZCS for high voltage applications,” IEEE Trans. Power. Electron., vol. 23, no. 1, pp. 379–386, Jan. 2008.

3.F. Musavi, W. Eberle, and W. G. Gunford, “A high-performance single phase bridgeless interleaved PFC converter for plug-in hybrid electric vehi cle battery chargers,” IEEE Trans. Ind. Appl., vol. 47, no. 4, pp. 1833–1843, Jul./Aug. 2011.