

# Extending battery life and reducing charging costs in electric vehicles through converter selection for on-board chargers

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## ABSTRACT

The electric vehicle (EV) sector is among the quickly expanding industries today. Global commitment to reducing pollution levels promotes interest in EVs. Fuel combustion engines emit around 10% of the globe's greenhouse gas emissions, which exacerbate the greenhouse effect. The emissions from electric vehicles are 17–27% less than those from internal combustion engines. The short battery life, high cost of charging, and lack of charging stations are some disadvantages of electric vehicles. The goal of this study is to suggest the ideal converter for the on-board charger (OBC), one that can extend battery life by lowering charging current at extremes of state of charge (SOC) and lower charging costs by increasing power factor (PF). The current control range than the isolated converter using transformers. Lastly, an analysis of the MATLAB/Simulink output findings is conducted to verify the effectiveness of the suggested OBC design with a non-isolated converter.

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## 1. INTRODUCTION

In comparison to cars with fuel-injected engines, electric vehicles (EVs) are less common while being a popular way to save fuel use. For the widespread use of electric vehicles in the future, numerous obstacles must be removed, such as those shown in Figure 1. In addition to the battery pack, the battery charger's performance design needs to be improved. Regular on-board chargers (OBCs) for EV, as illustrated in Figure 2, recharge the batteries using isolated converters with integrated transformers and a voltage converting isolation transformer for dependability. Traditionally, isolated chargers have two stages of operation: a rectifier in this initial stage serves for correcting the power factor and an isolated converter with coupled inductors in the second stage that is used to convert voltage from DC to DC [1], [2]. To ensure that the input (i/p) AC voltage has a sinusoidal shape and minimal total harmonic distortion, the PF rectifier controls both the i/p AC current and the output (o/p) DC voltage [3]. Bulky coupled inductors are used to filter i/p AC current ripples in isolated converters. The PF correction rectifier supplies a constant DC o/p voltage; hence, the transformer is needed to operate the DC-to-DC stage on an isolated voltage [4], [5].

The expansion of infrastructure for electric vehicles promotes the creation of new technologies, like drivetrain charging techniques [6], [7]. Developments in power electronics enable an EV to get charged faster. The quick charging feature allows the user to save time when charging an EV fleet. The growth of charging facilities accelerates the growth of off-board chargers and OBC [8], [9]. Figure 3 shows an elementary model of a non-isolated converter without a transformer.

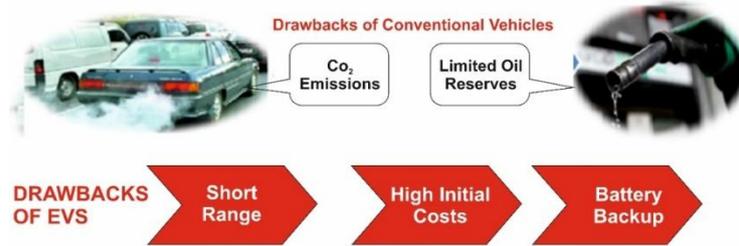


Figure 1. Conventional vehicles and electrical vehicles

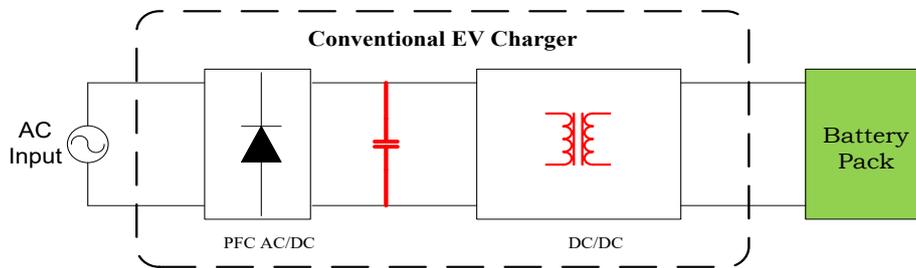


Figure 2. Charger with isolated DC/DC converter

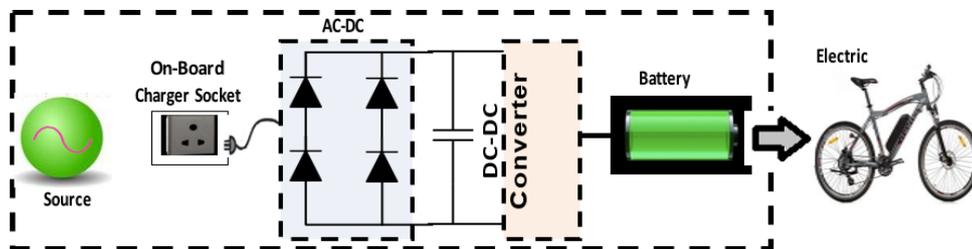


Figure 3. Charger with non-isolated DC/DC converter

The improvement of OBC schemes necessitates the investigation of various designs for high power density, simplicity, and cheap cost [10]-[13]. The OBC offers the consumer an alternative way to refuel the car at home. It lessens the electric vehicle's reliance on public charging stations. Furthermore, because public chargers are commercially priced, it reduces the cost of charging. Light electric vehicles, such as e-rickshaws, need a charging system with less than 1 kW electricity. Recent research has classified single-phase OBC into two stages: unidirectional OBC and bidirectional OBC [14]-[16]. To improve efficiency, a single-stage architecture for single-phase OBCs is proposed. It is made up of a DC-DC converter, a diode bridge rectifier, and a power factor circuit. The single-stage single-phase is used to shape the supply current in accordance with the supply voltage. It is used in accordance with the IEC 6100-3-2 standard [17], [18]. The current topology's diode bridge rectifier operates in unidirectional power flow. In a two-stage electrical vehicle charging system, the first stage is a diode bridge rectifier with a PF correction circuit, and the second stage is a DC-DC converter [19], [20]. The second-stage DC-DC converter is separated into two components: isolated and non-isolated.

The charger has a crucial influence on battery life and the efficiency of the vehicle. In EV applications, battery aging occurs through both draining and recharging. Irregular battery charging has an influence on battery endurance and lifespan, particularly at extremely low and extremely high levels of state of charge (SOC); it deteriorates the structure of cells and reduces the shelf life of an EV battery [21]-[23]. The declining performance about the battery may be detected as state of life (SOL). A traditional isolated converter with

a set turn ratio is unable to regulate the charging current at SOC values below 20% and above 80%. It is recommended to use a switching inductor buck converter in an on-board charger system to provide a high PF, a more effective non-isolated converter to address the issues [24], [25]. Figure 4 depicts the recommended non-isolated converter, which includes a switching inductor buck converter and a diode bridge rectifier [26], [27]. Switched inductors eliminate the need for big, cumbersome coupled inductors/transformers.

The analysis presented in this paper is i) a mathematical analysis demonstrating reduced losses of non-isolated converters by switched inductors in comparison to the traditional buck converter; ii) power factor correction topology applying with the proposed converter; iii) charging current control to improve battery life using the recommended non-isolated topology converter; and iv) simulation validation showing higher efficiency of the proposed non-isolated topology converter with switched inductor buck converter.

## 2. HYBRID BUCK TOPOLOGY IN SWITCHED INDUCTOR SYSTEM

The switch inductor hybrid buck topology is a variant of the conventional buck topology. It comprises 4 inductors, two diodes, and a single main switch (M). The  $L_2$  provides for correct current flow and separates the inductance into four portions ( $L_1$ ,  $L_2$ ,  $L_3$ , and  $L_4$ ). Though isolated inductors are utilized in this study to reduce size, work is in employed connected inductors. Six switches (S1–S6) are used in this study to switch four inductors, and they only operate in discontinuous conduction mode (DCM) for greater efficiency because zero current switching (ZCS) is allowed and reverse recovery loss is eliminated. DCM operation additionally allows for smaller inductance, which raises total power density.

In the switching inductor buck converter power factor correction design, the current moves across every operating stage. Regarding the analysis,  $L_1 = L_2 = L_3 = L_4 = L$  is the sum of the various inductor values. The four inductors will be in series when switch M is turned on, they will be charged to the input source voltage by turning on S3 and S6, with the o/p voltage provided to the battery being determined by the output across the filter capacitance. The average voltage across inductor  $V_L = (V_{in} - V_{out})/4$ . During switch M being OFF, the four inductors will be in parallel to the load by switching ON S1, S2, S4, and S5, the voltage across inductor  $V_L = (-V_{out})$ . To calculate the voltage gain of a switched inductor hybrid buck converter, the mean voltage along the inductor must remain zero for the whole time of operation, where the voltage gain is  $V_{out}/V_{in} = D/(4-3D)$ .

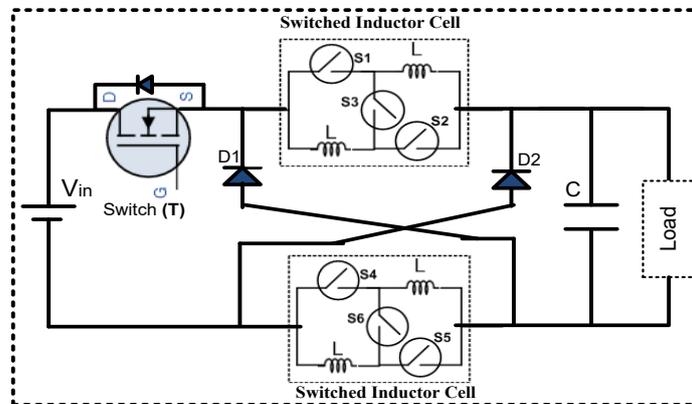


Figure 4. Switched inductor buck converter current flow when (a) M, S3, and S6 are on and (b) M is off and S1, S2, S4, S5 are ON

## 3. ANALYSIS OF POWER FACTOR CORRECTION AND CHARGE CURRENT CONTROL STRUCTURE

Figure 5 shows the complete non-isolated charging circuit with both power factor and current control units. Current control mode (CCM) is used in the suggested perfluorinated compound (PFC) switched inductor hybrid buck converter. CCM is simple to construct and enables a high power factor without requiring input source voltage sampling. The gradient of the inductor's current flow varies in proportion to the source voltage; hence, input voltage monitoring is not necessary. CCM monitors, observes, and limits the inductor current to enable and analyze each switching cycle. The direction in which the inductor's current flows all over each switching cycle.

Figure 6 depicts how the inductor current flow is monitored and contrasted to the baseline value less a slope adjustment ramp. If the measured current surpasses the ramp value, the switch turns off, arresting the current. To improve PF even more when operating in DCM2 mode, an additional scalar coefficient that normalizes to the slope compensation ramp value is employed. Switches are turned off by running them in DCM1 mode once the duty ratio reaches its maximum value, provided that the current does not exceed the compensation ramp's value.

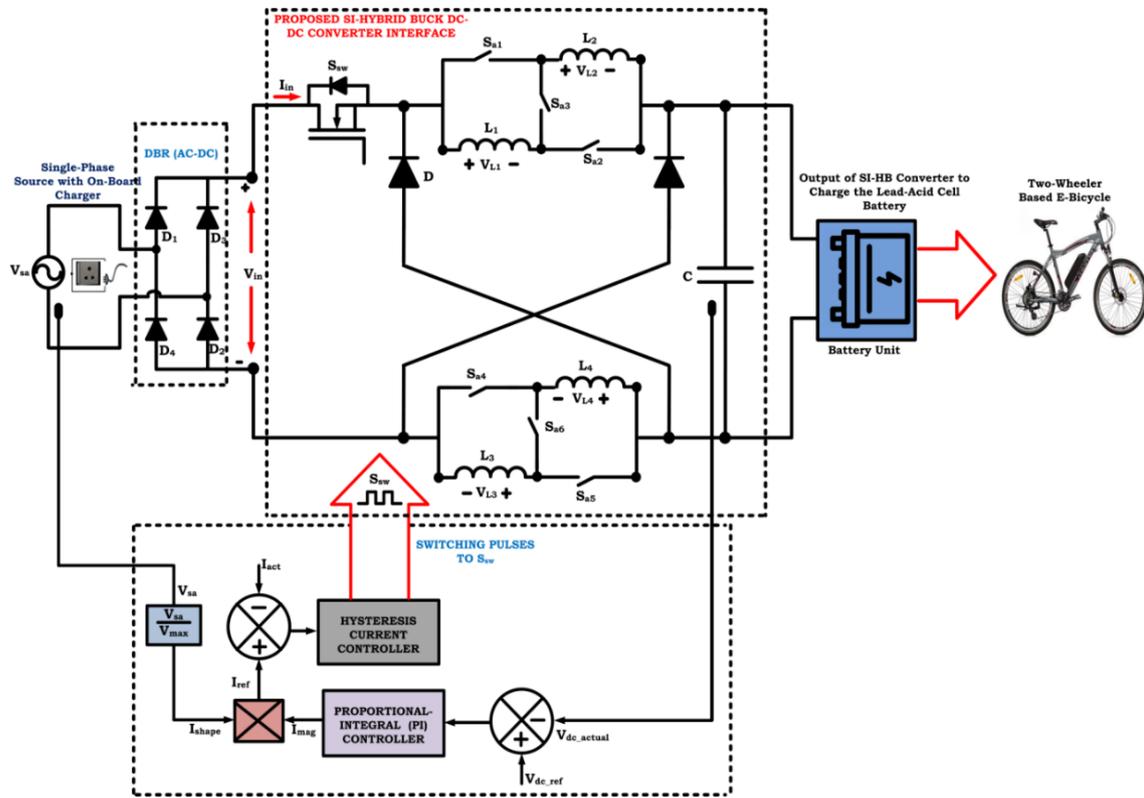


Figure 5. A switched inductor charging topology with power factor and current control unit

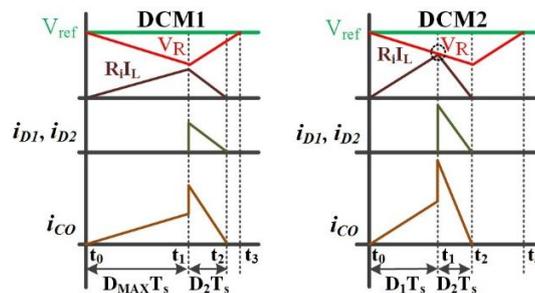


Figure 6. Switched inductor charger converter current control mode

It is set to 0.8 for the maximum duty ratio. MATLAB is used to analyze and evaluate different  $K_s$  values, ranging from 0.5 to 10. The optimal PF and total harmonic distortion (THD) performance is generally shown as  $K_s = 1$ . The stabilization of the capacity fade rates over usage time is the main factor contributing to their fall with cycle count. This behavior suggests that the passivation layer is continuing to grow and consolidate at the solid electrolyte contact, resulting in a more stable interface that slows down corrosion. Once more, though, oxidation is the main reason why the positive electrode is present during the storage stage. Internal resistance rises and power capability decreases as a result of longer charging times at higher SOC, which is the main factor influencing the oxidation properties. According to the Arrhenius equation, 50% less charging current should be used when charging the battery between 20% and 80% of SOC.

#### 4. SIMULATION RESULTS

Figure 7 shows the input source voltage, current, and distortion of the non-isolated converter and isolated converter. Figure 8 shows the total harmonic distortion of the non-isolated converter and the isolated converter of input current. Figure 9 shows the battery SOC and battery applied currents with the non-isolated converter.

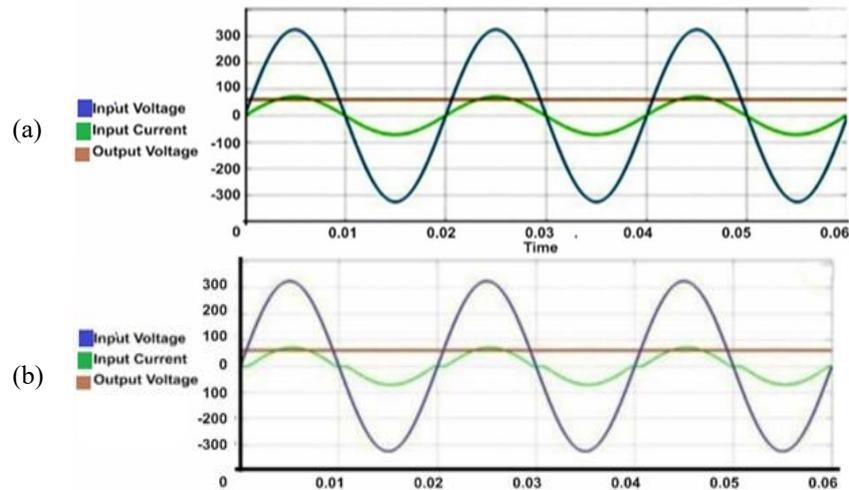


Figure 7. Comparison of input voltage, input current and output voltage, in an EV charger with non-isolated and isolated converters: (a) non-isolated converter with switched inductors input voltage, input current, and output voltage, and (b) isolated converter with input voltage, input current, and output voltage

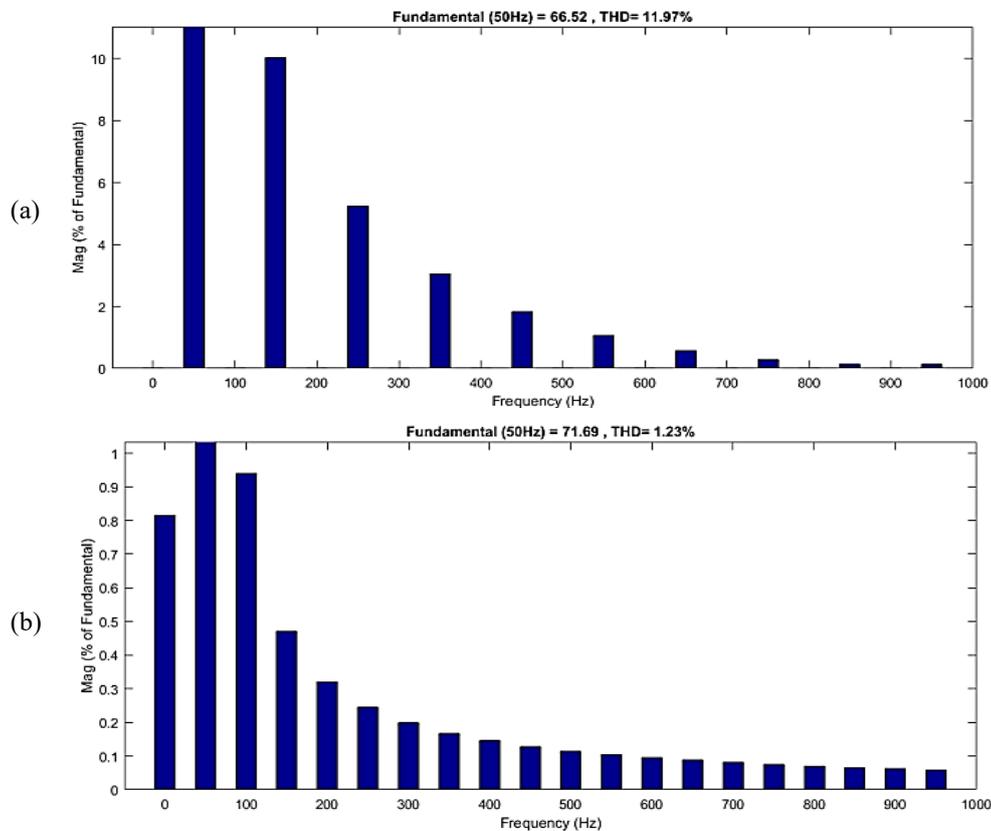


Figure 8. Comparison of THD levels of input current in an EV charger with non-isolated and isolated converters: (a) non-isolated converter THD of input current and (b) isolated converter THD of input current

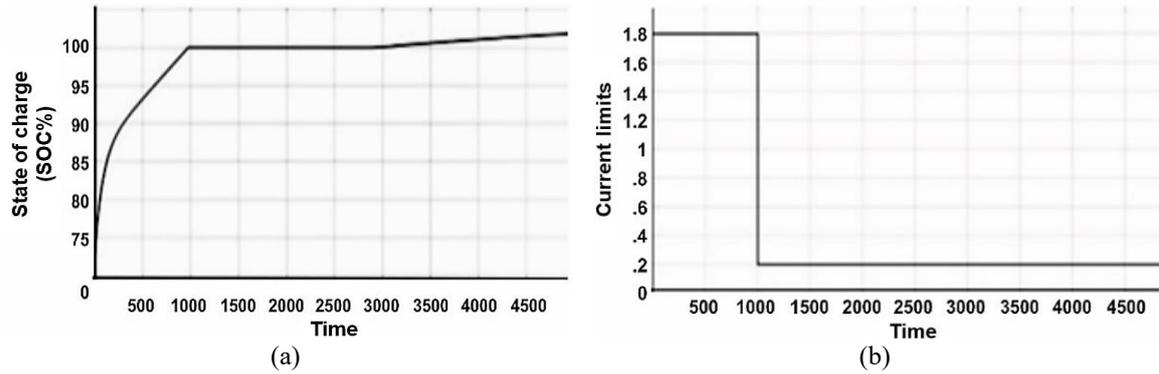


Figure 9. An EV battery performance when connected to non-isolated converter: (a) battery SOC with non-isolated converter and (b) battery applied currents with non-isolated converter

**5. CONCLUSION**

For use as an electric car charger, a non-isolated buck topology PFC converter with a switched inductor and controlled current mode was presented, examined, and validated using simulation results. A briefing was given on how to choose the Ks ramp value and implement the current regulated mode to a switched inductor buck PFC converter. These data validate the non-isolated switching inductor buck converter's usefulness and efficiency as an electric car charger. The suggested single-stage switched-inductor hybrid-buck converter improves utility-grid current while maintaining sinusoidal, balanced, and fundamental character. It adjusts for harmonic distortions, improves the utility-grid power factor, and achieves higher power-quality characteristics, making it ideal for two-wheeler EV applications. The THD spectrum of utility-grid current is determined to be less than 1%, which meets IEEE-519/1992 criteria. Furthermore, the PF is close to unity. Furthermore, the recommended single-stage switched-inductor hybrid-buck converter generates a high-step-down gain (over traditional topologies) output voltage at battery terminals without the use of any two-stage conversion stages, allowing for a simple onboard charger, affordable price, significant power density, minimal switch stress, superior efficiency, and dependable performance. This work can potentially be expanded to include non-EV chargers to have a better power factor and improve battery life and efficiency.

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Ganneyy Poorna Chandra Rao		✓				✓		✓	✓	✓	✓	✓		
Puvvula Venkata Rama Krishna	✓		✓	✓			✓			✓	✓		✓	✓
Swathi Karike		✓			✓				✓					
Sailaja Kethireddy					✓		✓			✓		✓		✓
Sareddy Venkata Rami Reddy	✓					✓				✓				
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Rekha Rangam	✓								✓					

C : Conceptualization  
 M : Methodology  
 So : Software  
 Va : Validation  
 Fo : Formal analysis

I : Investigation  
 R : Resources  
 D : Data Curation  
 O : Writing - Original Draft  
 E : Writing - Review & Editing

Vi : Visualization  
 Su : Supervision  
 P : Project administration  
 Fu : Funding acquisition

## CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

## DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [SK], upon reasonable request.

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