Transformerless Approaches in Light Electric Vehicle Charger Topologies

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ABSTRACT

People are paying more attention to charging solutions these days. Significant customer repercussions will occur if electricity quality is not maintained. The On-board Light Electric Vehicle (LEV) chargers uses single-stage power converters with improved power factor and high step-down voltage gain. In the case of LEV chargers, their application is limited by the usage of rectifiers and transformers on the front side. LEV chargers should be economical, lightweight, have minimal losses, and minimized distortion. Transformerless converter topologies utilize switched inductor networks in the single-step chargers with power factor correction control topology. The proportions and price of the magnetic elements in the transformers are decreased by the switched inductor networks, which are made up of inductors and diodes. In this article, various transformerless approaches in the charging topologies are discussed and their performance is analysed in MATLAB Simulink. Total harmonic distortions (THD) of source current and power factor are also evaluated to assure power quality attributes with and without rectifiers. THD improved to 2.38% in the transformerless topology.

Keywords: Switched Inductor Single Ended Primary Inductance Converter (SISEPIC), On-board chargers (OBC), SEPIC

1 Introduction

In the past fifteen years, there has been a massive rise in the usage of fossil fuels, which pollutes the environment and raises costs. A wonderful alternative to traditional fuel powered vehicles are electric mobility [1]. However, the proper control tactics to limit the harmonics supplied to the grid and to achieve a unity power factor (UPF) function are essential for the integration of these electrified automobiles into the transportation sector. The usual architecture of an EV charger is compensated by an AC-DC converter at the front face, a boost, buck, or buck-boost Power Factor Correction (PFC) converter, followed by a converter [2]– [3]. The performance of the separated converter influences how well this charger charges.

LEVs typically weigh about 100 kilograms. Most LEVs are currently and will continue to be e-bikes [4]. LEV batteries may be recharged directly from the power system using an off-board charger or a specialized onboard charger, relying on their power requirements [5]- [7]. The effectiveness of rechargeable batteries becomes more critical as the number of LEVs is predicted to increase. The total harmonic distortion and power factors [8]– [12] are used to measure the on-board charger's power-conversion effectiveness and energy quality. All of the installed pieces in the car must meet strict requirements for size, weight, and lifespan. The two-stage design of traditional onboard chargers [13]-[14] typically consists of a DC-DC power conversion stage and an active power factor correction (PFC) stage.

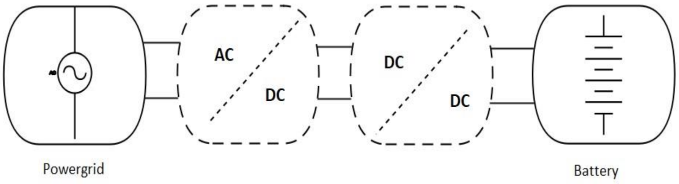

Figure 1: *Structure of Two-stage charger topology*

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Two stage charger topologies shown in fig.1. In general, two-stage setups offer ripple-free charging, but they are expensive, have a large number of devices, and are difficult to operate. Due to their inherent advantages of having fewer devices, being highly efficient, and having a simple layout, single-stage charging solutions are therefore becoming more popular. Single-stage charger topology depicted in Fig.2. PFC, efficiency, Improved voltage gain characteristics, longevity, and cost are the single-stage converter's top performance requirements. The converter's PF, which is composed of the displacement and distortion factors, is increased by the PFC feature in this case. The converter should have a smidgen THD and a high PF if it includes a PFC feature. To comply with EV regulations for OBC, such as the IEC610003-2 standard [15], which rigorously mandates that the supply current must be fulfilled with the grid code.

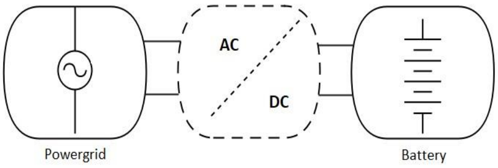


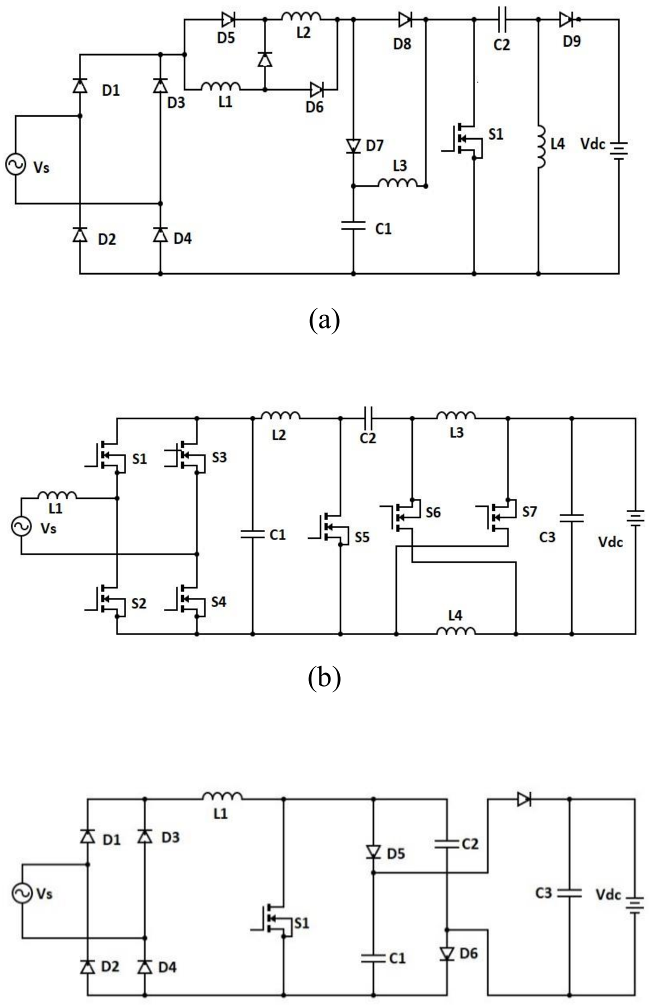
Figure 2: *Structure of Single stage charger topology*

Various converters are used in LEV chargers. Buck, Boost, Buck-boost, Cuk, Sepic and etc [16]- [24]. also, its interleaved topologies are used in single-phase chargers. Existing chargers have utilized a transformer-based one-step charging option for EVs and LEVs to achieve revamped voltage gain [25]- [29]. Transformers are used in these solutions. However, transformers greatly increase the voltage stress across switching devices due to their leakage inductance and negatively impact their efficiency, volume, and price. Further limiting the switching frequency of the power electronics circuits is the fact that at higher frequencies, the value of the transformer's leakage and magnetizing inductances becomes comparable. the use of many switched networks, interleaved and cascaded architectures, coupled inductors, quadratic converters, and others. Recently, researchers have begun to pay more attention to transformerless solutions [30]. It has been suggested to use a single stage transformerless charger.

2 Transformerless Charger Topologies

Existing transformerless topologies are depicted in Fig. [3]. Switched inductors (SI)or switched capacitors are used to optimize the overall voltage proportion. Furthermore, this network will replace the line frequency transformers. It will improve the voltage gain of the power electronic converters.Fig.3(a) shows a modified SEPIC converter [31], where the input side inductor is replaced by a switched inductor .it formed by three diodes and two inductors. Switched inductor in Fig.3(b) is formed by two switches and two inductor networks together [32]. A voltage source converter (VSC) is used at the charger's front end to rectify the supply and produce a DC voltage actively. In the second stage, a cascaded inductor cell is used. Fig.3(c) shows a modified switched capacitor network-based converter [33]. Which can use only in the boost application. This converter doesn't suitable for LEV chargers. It requires additional circuits for LEV charging purpose.

Diode Bridge Rectifiers (DBR) were required in the front end of each of these converters. It will enhance the size, quantity, and price. It has an impact on electricity quality. Also, the charger needs to be modest for LEV charging. Thus, it is preferable to use single-stage chargers. The topologies mentioned above also have complicated control logic.



(a)

(b)

(c)

Figure 3: *Existing transformerless topologies (a), (b) Switched inductor &(c) Switched capacitor topology*

3 Perfomance Analysis of Switched Inductor Converter

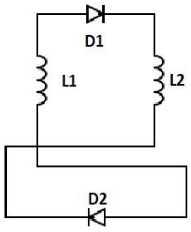


Figure 4: *Switched Inductor (SI) cell*

Two diodes and two inductors make up a SI link together shown in Fig.4. It has fewer components as compared to other switching inductor networks. The charger's size and price will also be reduced. This link takes the place of the output side inductor. There, parallel discharging and series charging takes place.

3.1 Switched Inductor SEPIC Using DBR

In the traditional SEPIC converter, Switched Inductor (SI) arrangement is used to increase the converter's static DC voltage gain, particularly at high line voltage, as shown in Fig.5 [34]. This single-stage charger offers low harmonic supply distortion and Unity Power Factor (UPF) performance. using a resistive load to simulate the attributes of the grid's charging cycle, the voltage follower approach is used. The output inductor's DCM action decreases the magnetic size needed for the inductors and the sensing devices during each switching cycle. Since the charger runs on the DCM for the output inductors, during a switching cycle, the entire function of the converter is split up into three distinct modes. Furthermore, it is believed that each switching cycle's battery current (I_0) and voltage (V_0) remain constant. The soft switching of switches and diodes is greatly aided by the charger's DCM function, which lessens inefficiencies and boosts the apparatus's efficiency. A minimum sensor is used to implement the battery charging performance in persistent current and voltage modes, which lowers the cost of the charger.

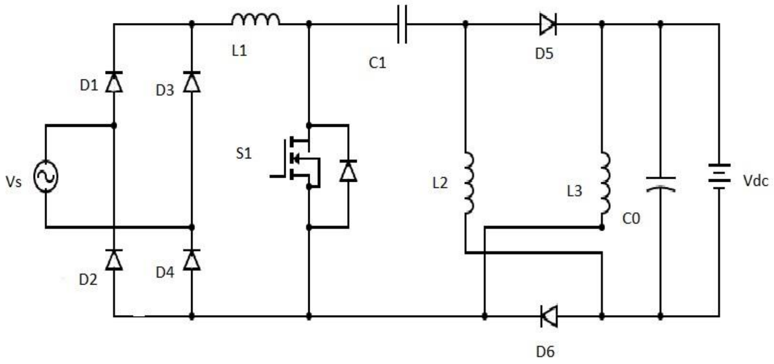


Figure 5: *SISEPIC using DBR*

3.2 Bridge-less, Transformer-less Switched Inductor SEPIC Converter

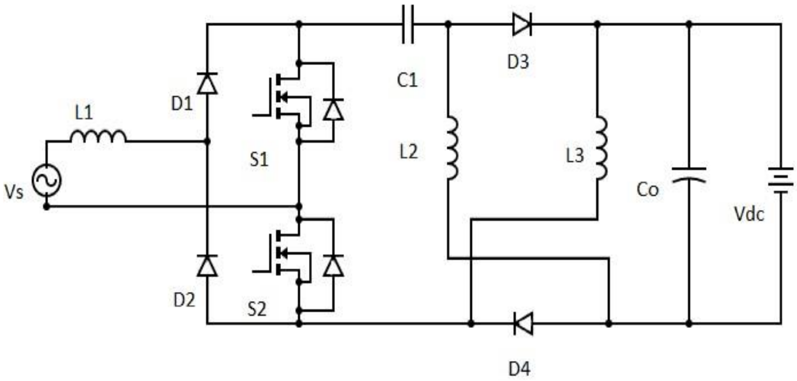


Figure 6: *SISEPIC Converter*

The SI cell arrangement results in an enhanced voltage gain when compared to a traditional SEPIC APFC apparatus [20]. Due to its bridgeless and transformerless construction, the proposed charger topology has minimal elements altogether., as shown in Fig.6. Lower losses, costs, and a smaller LEV charger are made possible by the fewer components. In order to decrease the size of the circuitry and to guarantee zero current switching of semiconductor parts, which in turn lowers losses, this charger is operated in DCM mode. Line-frequency and high-frequency diodes, switches, median and dc link capacitors, input and output inductors, and other components make up the charger (L_1, L_2, and L_3). By charging and discharging L_2 and L_3 in series and parallel, the D_3, D_4, L_2, and L_3 form a SI system, which increases the dc voltage gain of the traditional SEPIC. In addition, L_i and C_1 work in CCM operation while L_2 and L_3 were designed in DCM to make magnetic materials smaller.

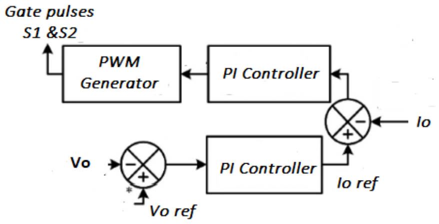


Figure 7: *Twin loop control*

The voltage follower with a twin loop construction is utilized to control the battery charging process described in Fig.7. This control topology will improve the THD and power factor and also ensure the batter charging levels.

4 Perfomance Analysis of Sisepic

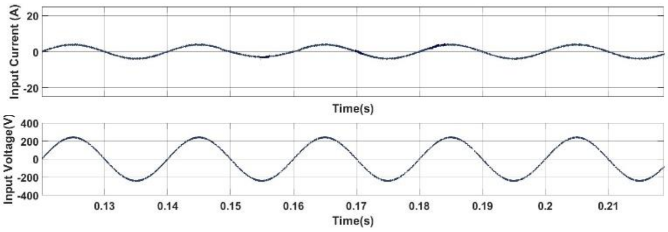
The design and selection of the system elements are depicted in Table 1. The entire system is developed in MATLAB Simulink. Each component is determined to work efficiently within the designated operating range, which validates the device's design. To guarantee the stable operation of the demonstrated BL SI link-based charger, a reliable and straightforward control method is used. It is interesting that the proposed control accomplishes two tasks at once; in addition to maintaining the proper charging profile on the battery side, it also makes sure that the supply side has a good power factor. Furthermore, using less no. of sensing devices and straightforward gate drive circuitry lowers the cost and complexity of the control outline.

Table 1: *Design specification of SISEPIC*

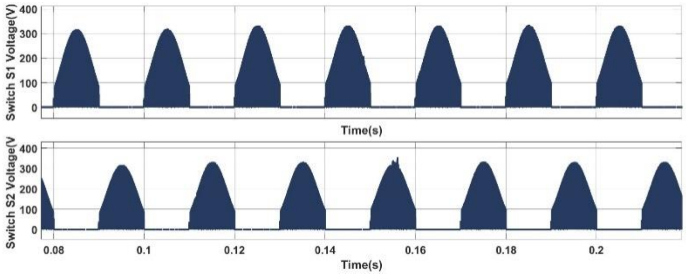
Description	Parameter	Value
Input Voltage	Vs	240 V
Power rating	Pr	450 W
Battery rating	V_b	48V,24Ah
Input Inductance	L_1	4.5 mH
Output Inductances	$L2$, $L3$	25 μH
Duty Ratio	D	0.36
Intermediate Capacitance	C_1	1.35 μ_F
DC Link Capacitance	Co	8.84 mF
Switching Frequency	fs	20 kHz

Simulation results are provided in the following Fig 8. Current ripples and high-frequency modules are reduced. Input voltage step down into 48V without using a transformer on the supply side. This same SI network converter is simulated in a two-stage manner using a diode bridge rectifier. It's input side waveform given in fig.9.

The efficiency of the converter will increase when the power loss in the circuit decreases and the voltage and current stress in the device decreases. FFT analysis is done to compare the THD between the converters. A comparison between Switched inductor-based SEPIC converter using a diode bridge rectifier and a bridgeless SISEPIC converter is depicted in Table II. When comparing the topology using DBR, Bridgeless topology has improved power quality. Most of the existing methods use DBR or Transformers. Line-frequency transformer dramatically bring down the power density and adequacy of the chargers. DBR increases the total device count as well as the conduction losses. Control techniques used in the available charging solutions are a little bit complex and it uses more sensing devices. When compared to the other topologies, Switched Inductor SEPIC Converter is a more reliable, compact, and cost-effective charging solution for LEV. By decreasing the overall number of parts in the conducting channel, the bridgeless architecture of the illustrated charger drastically decreased losses. Additionally, the DCM operation of this particular converter was taken into account to limit the dimension of the magnetic parts.



(a)



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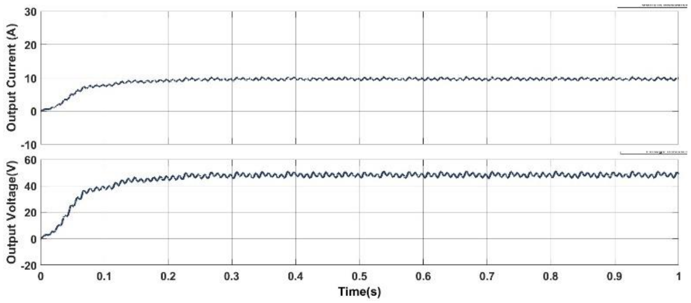
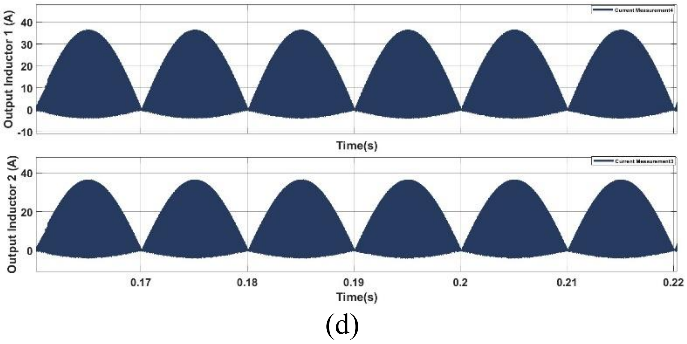


(c)



(d)

Figure 8: *Performance analysis of SISEPIC Converter; (a)* v_s, I_s, *(b)* V_{s1}, $V_{s2,}$ *(c)* V_o, I_o, *and (d)* I_{L2}, I_{L3}

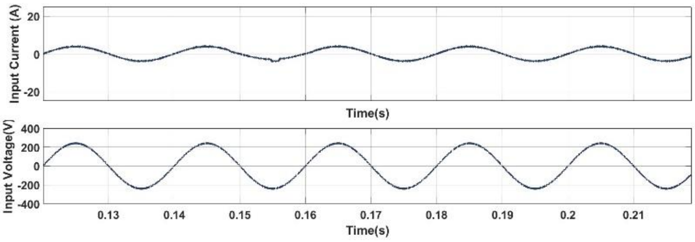


Figure 9: *Input current and voltage waveform of SISEPIC using DBR*

Table 2: *Comparison between SISEPIC with and Without DBR*

Converter	THD of the source current (%)
SISEPIC Using DBR	5.21
SISEPIC without DBR	2.38

5 Conclusion

The losses, size, device counts, and total cost of the chargers rise due to the use of transformers and diode bridge rectifiers. Transformers or Diode bridge rectifiers were employed in the front end of the majority of topologies. This will have an impact on the general performance of the charger and its size. In the case of LEV charges, the transformerless technique has many advantages. i.e., it lessens diode losses and the dimensions of the magnetic elements. When compared to the same SI topology using the DBR have more THD. Using the Tranformerless Bridgeless Switched Inductor SEPIC (SISEPIC) topology in LEV chargers is preferable. The charger's DC voltage gain was increased using an SI cell-based SEPIC converter, ensuring the input side had a high-power factor. While using fewer sensing devices, the control's overall complexity was also simplified.

6 Publisher's Note

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