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RESEARCH ARTICLE **OPEN ACCESS**

ON BOARD CHARGERS IN EV APPLICATIONS USING BUCK-BOOST CONVERTERS

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ABSTRACT

This article suggested a two stage battery charger with interleaved bridgeless buck-boost based power factor correction (PFC) AC-DC converter at the stage one. The converter front end enhances power factor by the input current shaping with the dc line voltage. The back end provides the battery charged via a half bridge LLC Converter. This on-board charger(OBC) achieves a power factor of almost unity throughout the wide variety of input voltages.additionally,input current and for AC-DC conversion, voltage sensors are not necessary because of the conduction mode of discontinuous inductor current(DICM),further lowering the total coast and improving the converters dependability. Most low voltage(LV) systems are practically compatibility with OBC approach charges for batteries .the design formulas and comprehensive steady-state additionally, an examination of the suggested charger is provided. Lastly the validity is shown by simulation and hardware for this OBC, of a 1KW laboratory prototype yields an peak efficiency and input current THD as low.

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INTRODUCTION

Now days total world use of vehicle to grid (V2G) Topology main reason behind the Ev's technology decarbonizes transportation, lower pollution, lessens dependency on imported fuels, and encourages the adoption of novel urban mobility strategies. it makes it possible for electricity to move from an EVB to the grid .A single-phase power factor correction (PFC) ac-dc converter serves as a front end stage of an on board grid-to-vehicle (G2V) charger in a standard plunge-in electric vehicles (PEV) followed by the second stage, an isolated dc-dc converter. the most often utilized PFC A single –phase diode serves as the converter in onboard charger a boost converter after a bridge rectifier. It transforms the single phase ac voltage of 85Vac to 245Vac to controlled dc voltage. India's Evs industry is a lot of potential in EV charging systems. An electric vehicles battery can be charged by external it's called "off-board charger". If connected internal it's called "On- Board" charger. As seen on-board chargers are used for low-power ac charging while off-board chargers are used for high power AC and DC charging. The most common components of on-board battery charges (OBC) are an AC-DC converter and DC-DC converter with galvanic isolation. as essential component of OBC systems is the front-end AC-DC conversion. The THD, power factor, and device count of traditional front-end converters are minimal the battery will become heavier due to these drawbacks. meeting specifications including improved output voltage control, power factor correction (PFC) and a decrease in input current harmonics are crucial for an OBC.PFC based AC-DC Converters, an essential part of an EV charges, make it easier to obtain an efficient OBC with the ability to operate in either continuous inductor current conduction mode (CICM), DICM, or boundary inductor current conduction mode (BICM), these converters offers the same versatility as other power converters. In PFC converter-based on board charging, boost PFC converter topologies are generally favored a boost converter powers up after a diode full bridge rectifies(DBR) converter AC to DC.unfortunately,this design has problems with heat dissipation because to the high output capacitor current ripple and connecting DBR losses. many bridgeless topologies have higher common-mode noise, unwanted current, sensing circuit complexity, and voltage stresses than their counterparts generated from boost,buck-boost,cuk and SEPIC,Luo and Zeta. Totem pole dual-boost and bridgeless dual boost both lower CM noise, but doing so requires more conducting devices for every half cycle. high conduction losses in the majority of single-stage, isolated and non isolated topologies necessitate large heat sinks further resulting in thermal breakdown. As a result, they are inappropriate for application requiring high current and low voltage. however, heating concerns are not covered in the literature for single stage OBC applications with high voltage and low current.PFC converters in two stage topologies can operate in either pre-regulator mode at the front end or post-regulator mode at the rear end.PFC is completed at the front

end, and a pre-regulator type regulates the voltage and current at the back end. Three front-end sensors are required for PFC to function in CICM .In Contrast; two sensors are used by back-end converters to regulate the charging voltage and current. These converters are more expensive and challenging to regulate since the input phase needs to be adjusted to fit the grid.

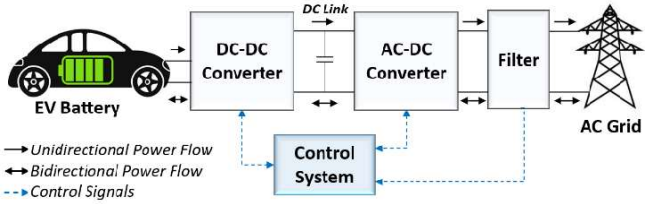


Fig. 1. Block diagram of conventional EV charging system

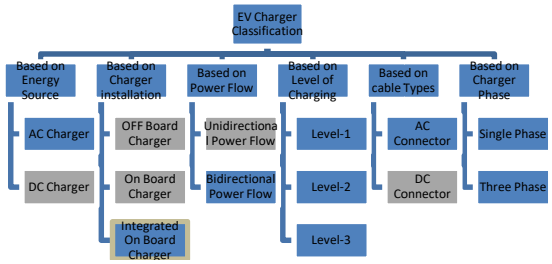


Fig. 2. Classifications EV charges

With input sinusoidal current shaping and power factor correction (PFC),the inner current control loop is used for CICM control at the front end on the other hand, the output voltage is controlled by the outside voltage control loop its becomes more difficult due to phase-locked loop(PLL) and the need for current controller with greater bandwidth on the inner side DICM,which has inherent feature like built-in PFC,fewer sensors, easy control, zero current switching(ZCS)turn-on of the power switches, and inherent zero diode reverse recovery losses, was made possible by the complexity and difficulty of establishing natural PFC for AC-DC in CICM. A bridgeless buck-boost converter for on board chargers is presented in where an LC filter is deployed to reduce switching harmonics in the ac line because the main switch is operating in DICM.this work only involved front-end PFC converters, whereas in the converter in used at the front-end of PFC and at the back-end a half-bridge LLC resonant converter achieve zero voltage switching (ZVS) turn-ON only. In DICM mode, UPF operation at AC mains is possible without input sensors, and the voltage-double configuration can reduce voltage stress on semiconductor switches. A bridgeless Cuk front end and an isolated fly back dc-dc converter at the back end are used by the two-stage EV chargers the fly back converter only works with power ratings, but it is inexpensive and simple to use because of its small component count. The fly back allows the front and back-end converters to be controlled independently because it does not use the cuk converters buck boost operation to reduce switching losses. In a front-eng PFC converter is used after a phase-shifted dc-dc converter for EV charges to obtain a wide range of output voltage. The high frequency transformer produces the high output voltage, whereas duty cycle management produces the low output voltage. In this configuration the PFC converter molds the ac current and regulates the dc link voltage, while the phase-shifted converter provides a broad output range.

The primary benefits and contribution of this OBC above traditional low-voltage EV battery chargers are as follows:

i) Unlike boost-based PFC converter, the reference dc link voltage limits for buck-boost derived PFC converters is independent of the ac voltage peak amplitude. the buck-boost topology used in this work yields a front-end converter with less harmonic content than the boost because an inductor working in DICM is linked to either the input or the output

ii) Due to the intrinsic power factor adjustment feature of DICM operation, a single sensor for the output DC link is adequate for PFC converter operation.

iii) In traditional chargers, the DBR at the front-end causes significant losses by conducting two diodes for fault AC half cycle by moving the diode rectifier from the supply side to the load side, this OBC creates a load side voltage doubler.the diodes will automatically reverse bias when the switch Sa/Sb is turned on, lowering the amount of conduction losses.

iv) Interleaved operation of the converter at the front end can reduce stress and make the charges suitable for higher KW operation. More significantly, the practicality is ensured by the converters capacity to dynamically work across a variety of AC and load variations.

v) Efficiency is increased as a result of the ZCS turn-on of the power switches at the front end PFC due to DICM operation and the soft switching of the back-end converter. To further increases efficiency, each interleaved leg has a switch and diode that operate during each switching cycle. In contrast, the majority of OBCs, such as boost-derived PFCs, necessitate the operation of two switches and two diodes every switching cycle.

This paper builds on the work done in which described a two-stage isolated battery charger with easy control and less complicated sensors for battery charging. Additionally, the issue of a floating DC ground with regard to the input is resolved by including an input filter in the prototype. Additionally, separate filtering is needed for differential mode (DM) and common mode (CM) noise reduction in a conventional AC/DC system. Here, the filter's size is decreased by using the CM filter's inductance with leakage that almost equals the DM inductor's magnitude. The structure of the article is as follows. The proposed two-stage OBC and its functioning are illustrated in Section II. Section III contains the controller design process and a detailed design study of every passive component. Section IV presents and analyzes the outcomes of the simulation and experiment. In Section V, the OBC that has been presented is compared to the state-of-the-art. In Section VI, the work's results are finally discussed.

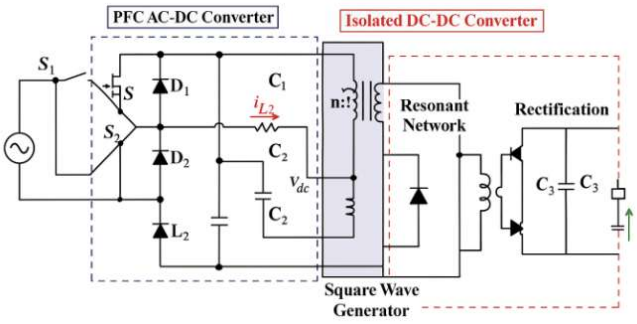


Fig. 3. Schematic diagram of proffered two stage On-board Battery Charger

From fig(3) a half bridge DC/DC converter for battery charging the front-end contains two bidirectional switches, two inductor, four diodes, and two capacitors for the ideal DC link voltage. A single gate can be used to control each bidirectional switches, Whereas a half bridge is utilized for square waves at the back-end high-frequency generation and rectification diodes at the secondary aspects despite carrying double the current, half bridge but only have half as many switches as full bridges. In a half-bridge arrangement, where the main winding requires just half as many spines to get the same magnetic flux and voltage gain swing similar to that of a full bridge arrangement consequently, a half bridge for this use a switching circuit is advised because tiny main currents due to the tendency of the inductor current zero every time the front-end converter switches with DICM, PFC attained automatically. by employing an interleaving technique, the issue of elevated peak currents brought on by DICM can get rid of more

input harmonics in DICM.the boost and buck boost derived PFC's input current given by

$$I_{in(t)}=\text{Boost} = \begin{cases} \frac{Vin,pk}{L}, & 0 < t < DT \\ \frac{Vin,pk-Vo}{L}, & DT < t < T \end{cases} \quad (1)$$

$$I_{in(t)}=\text{Buck-Boost} = \begin{cases} \frac{Vin,pk}{L}, & 0 < t < DT \\ 0, & DT < t < T \end{cases} \quad (2)$$

The DICM inductor is connected between the input and output in the boost configuration, but not in the buck-boost, according to (1) and (2).Thus the propagation of harmonics between there are switching harmonics and no input or output can be eliminated using a low size filter at the input.

Operation of Interleaved PFC AC-DC Converter: Current strains on all devices are reduced when the suggested architecture is operated in interleaved state. A 180^0 phase shift in the gate pulses is achieved by applying a half-cycle delay across one switching cycle is employed in two interleaved cells to drive the switches. When using the front-end interleaved, inductor design becomes crucial converter in order to always run in DICM waveforms of steady state throughout a single switching cycle.

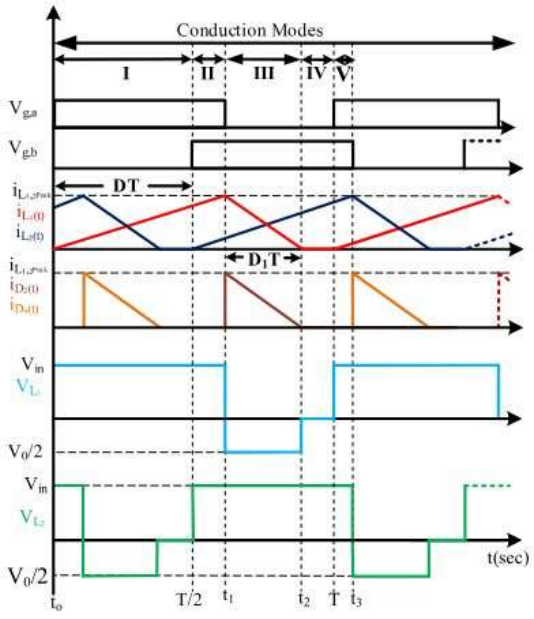


Fig. 4. Interleaved Waveform PFC AC-DC Converter

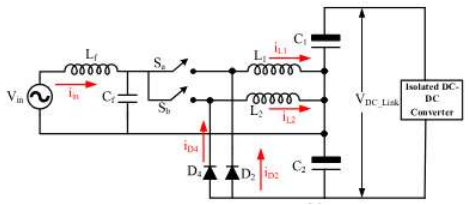


Fig. 5(a). Equivalent circuit during positive half cycle

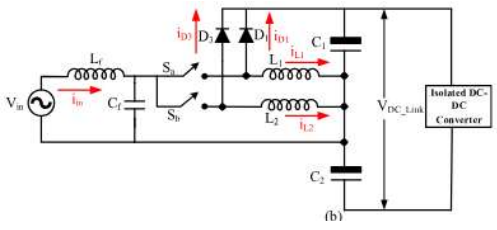


Fig. 5 (b). Equivalent circuit during negative half cycle

Both capacitor carry the same amount of voltage, the components are perfect, and the power switches causes a negligible voltage drop moving the diode rectifier from the front to the rear in a voltage doublers shape. The converter only functions in boost mode. So that the output diodes are activated when the switch S_a/S_b is in the are skewed in the other direction from the adjacent branch. The corresponding circuit for the suggested converter is displayed during positive and negative half cycles with respectively. Conduction losses are reduced when the switch Sa, Sb or only one diode of each interleaved cell in the currents path. There is very little voltage stress on any semiconductor.

Modes of Operation

Mode-I (t_0<t<T /2): The first cells switch Sa turns on in response to the gate pulse. the energy held in the inductor L_2 is released to the load via the diode D4,the current through the inductor L1 increases linearly, and the switch Sb in the second cell (interleaved) remains in non-conducting state.L1 is charging during this time.

The mathematically expression for the current through the inductor L1 is given by

$$I_{L1}(t) = \frac{Vin(t)}{I.1} * t \quad \ldots\ldots\ldots\ldots\ldots\ldots 3$$

Mode-II (T/2<t<t_1): Here, a positive gate signal that is 180 degrees phase displaced with respect to the gate pulse of Sa is applied to turn on switch Sb of the interleaved cell. Inductor L2 accumulates energy from the supply in conduction with L1, and iL2 increases linearly. Across the inductor L1 and L2,a positive voltage with magnitude equal to the input voltage is visible. During each half of the AC input cycle, each of the two diodes attached to the switch Sb interleaved cell will be active. The mode gate pulse for Sa is eliminated at the conclusion of this.

$$I_{L2}(t) = \frac{Vin(t)}{I.2} * t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

Mode-II (t_1<t<t_2): switch Sa is off in this instance. the inductor current iL1 freewheels across the diode D2 after dropping linearly. half of the total DC link voltage is carried by the capacitor split capacitor C2,Which is charged by demagnetizing energy from L1.when diode D2's current drops to zero.

Now $iL_{(t)}$ is given by:

$$iL_t(t) = i_{L1,pk} - \frac{VDC}{2I.1} * D1T \quad \ldots\ldots\ldots\ldots\ldots\ldots 5$$

$$D1T = \frac{VDC}{2L1} * DT \quad \ldots\ldots\ldots\ldots\ldots\ldots 6$$

$$I_{L1\,pk} = \frac{Vin(t)}{I.1} * DT \quad \ldots\ldots\ldots\ldots\ldots\ldots 7$$

$$I_{D2,av} = \frac{iL1,pkD1T}{2T} \quad \ldots\ldots\ldots\ldots\ldots\ldots 8$$

Eq 6,7&8 gives

$$I_{D2,av} = \frac{V_{in}^2(t) * D^2T}{L*V_{DC}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 9$$

Average output current of the PFC converter for one cycle is given by

$$I_{DC,av} = \frac{1}{2\pi}\int_0^{\pi} i_{D2,av}\, d\theta = \frac{V_{in,pk}^2 * D^2T}{4L*V_{DC}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 10$$

Mode-IV (t2<t<T): when switch Sa is off,Sb continues to conduct, current via L2 increase linearly, and the load is powered by output capacitors C1 and C2.Time zero period during this mode is given by

$$T_2 = T - DT - D_1T \quad \ldots\ldots\ldots\ldots\ldots\ldots 11$$

DT and D_1T duty cycle periods with respect to S_a

Mode-V (T <t<t3): Switch Sa is switched ON for the subsequent cycle at the beginning of this mode, and switch Sb which was previously conducting, will be turned OFF at the conclusion of this mode L1 accumulated energy from the supply, and the inductor current (iL1) begins to increase linearly. positive voltage that is equal to the input voltage occurs across inductor L1 and L2.at the end of this phase, iL2 freewheels and drops through D3 during the negative half of the AC input and D4 during the positive half due to redundancy, the mathematical formulae for iD4 are not shown here but follow the same procedure as those for iD2 as previously defined.

$$I_{L2}(t) = i_{L2,pk} - \frac{V_{DC}}{2L_2} * D_1'T \quad \text{.....12}$$

Energy stored in inductors L_1,L_2 due to front end interleaving is given by

$$E=\frac{1}{2}L\left(\frac{i_{in,rms}}{2}\right)^2+\frac{1}{2}L\left(\frac{i_{in,rms}}{2}\right)^2 =\frac{1}{4}L*i_{in,rms}{}^2 \quad \text{.....13}$$

From above equation $L_1=L_2=L$. That the inductors stored energy will be reduced by half, the inductor volume will be less for the same power rating than the non-interleaved.in order to maintain DCM, the charging and conduction times for the inductor and diode should be shorter than the switching period because the duty cycle magnitudes for the switches Sa and Sb are equal, with the exception of the phase shift.

$$D < \left(\frac{G}{G+2*\sin(wt)}\right)^{DT+D_1T<T} \quad \text{.....14}$$

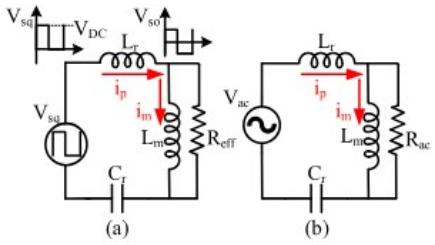
Whereas $G=\frac{V_{dc}}{V_{in}}$ for the converter to be in DICM, $wt=\frac{\pi}{2}$, now

$$D < \left(\frac{G}{G+2}\right) \quad \text{.....15}$$

The crucial voltage conversion factor is given by

$$G_{cr} < \frac{2D}{1-D} \quad \text{.....(16)}$$

Operation of Half-Bridge LLC DC-DC Converter: The half-bridge LLC topologys excellent efficiency,power density,low EMI,board input voltage range,soft-switching,and output voltage regulation capabilities have made it a popular option for the second stage of on-board EV charger. Furthermore, the converter is vulnerable to high noise levels due to the front end PFC's input drifting with respect to DC ground. Therefore, the second stage with the lowest EMI is selected for this PFC.



Simplified circuit of a LLC Half-bridge converter.

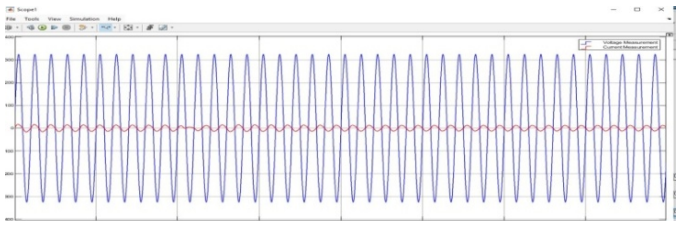
Circuit model approximating the first harmonic approximation (FHA): Above the three steps of a half-bridge LLC resonant converter. In this case, the operating frequency and the resonant frequency between Lr and Cr are the same. The primary side current, ip, is created by adding the magnetizing current, im, and the secondary side current, id, which is referred to as the primary. By switching S1 and S2 switches at 50% duty cycle, the voltage "Vsq" is produced as a square wave. A dead period will be inserted by the controller in between each transition. The resonant network filters out higher harmonic currents. Only sinusoidal current passes via the resonant network when a square wave voltage is applied. The current ip must trail the voltage applied to the resonant network, which is the essential component of the square wave voltage (Vsq) applied to the half-bridge, in order for the MOSFETs to turn on without any voltage across the drain and source. A ZVS operation occurs when current passes through the anti-parallel diode and the MOSFET activates while the voltage across the MOSFET remains zero. The resistive load on the secondary side of the transformer can be regarded as an effective resistor on the primary side [see Fig. 5(a)]. The parasitic effect and leakage flux on the secondary side of the transformer are not considered. Only the first harmonic is permitted to travel through the resonant network when using the first harmonic approximation (FHA) method. The LLC converter modeling is displayed in Fig. 5(b). The equivalent AC resistor's resistance can be computed as follows:

$$R_{AC}=\frac{8}{\pi^2}N^2R \quad \text{.....17}$$

RESULTS & DISCUSSION

The Matlab platform was used to simulate a 1KW model for the suggested OBC based on the specifications listed additionally, by creating front-end and back-end converter prototypes in accordance with Table II's criteria, an OBC is formed, allowing simulation performance to be practically verified. Real-time signals are produced for the PFC and DC-DC converter switches by the Digital Signal Processor (DSP) controller (TMS320F28379D). The steady state test results are then confirmed. The steady state simulation results for the front-end PFC converter running at 1KW with a 230v input voltage The input voltage waveform in steady-state operation is sinusoidal, and the input current waveform, which has a high power factor and a low distortion factor, follows the voltage waveform. Inductor currents iL1 and iL2 running in DICM under interleaved conditions .It can be shown that the PFC side DICM operation guarantees the switches Sa and Sb's ZCS turn-ON. Due to DICM operation, both switches Sa and Sb are activated when the currents flowing through the matching inductors L1 and L2, which are connected in series with the switches, are zero. When V in = 230 V at 1 kW, the voltage stress across the bidirectional switch Sa, Sb is displayed. The stress across a single switch of back-to-back coupled MOSFETs . Sa is regarded as a single switch for the sake of the analysis. Additionally, it is evident that most interleaved-based OBCs in the literature exhibit mild stress (Vin,pk+ VDC 2), which is relatively lower. In addition to the DC link voltage VDC, Fig. 8(d) displays single phase input voltage and current UPF operating with less input current harmonics. To confirm that the applied dynamic condition is effective, a sudden load change from 1 kW to 500 W is applied at t = 0.65 sec.

GRID Voltage and Current



DC Output Voltage

CONCLUSION

An effective option for battery charging applications is the suggested 2-stage on-board charger that is discussed in this article under both dynamic and steady-state circumstances, an enhanced power quality performance has been noted. The input side's peak current stress with low harmonic content is decreased by current division brought on by interleaving at the front end. Additionally, this charger's PFC converter does not require any input side sensors because it just employs one sensor to manage the output voltage. Additionally, 400 V DC-link is the ideal value since it minimizes losses at every stage. Additional losses are decreased by partial and complete soft switching at the front and back stages, respectively. The charger can also function for a wide variety of input voltages, from 110 V to 230 V, with a THD as low as 2.08% and individual input harmonic content that satisfies IEC61000-3-2 standards, according to the results of the practical performance verification.

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