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New Compact Non-Isolated on Board Battery Charger for EVS

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Abstract-*This paper presents a non-isolated on board battery charger for electric vehicles. This replaces the battery charger with interleaved cascade buck boost converter by a cuk converter and an inverting amplifier which reduces the overall size of the system. Closed loop control provides precise control of load voltage. The proposed method uses less number of switches hence reduce the THD than the conventional method. The implementation using MATlab is also presented.*

Keywords: Cascade buck-boost converter, cuk converter, inverting amplifier, electric vehicles(EVs), non-isolation, on board battery charger, THD

1. Introduction

Nowadays there are various projects on EVs and PHEVs. In EVs and PHEVs battery is treated as the main power source. So study of battery charger is important. The OBC is implemented in vehicles so it has to be small and light. Two different types of charger are mainly considered. The first is a fast charger with large capacity, which can fully charge a battery in 30 min. The other is an on-board battery charger (OBC). Presently available all battery chargers are isolated types. This project aims in developing a On board battery charger which will be a non-isolated type. Then reduce the space & cost. This will also lead to high efficiency and performance. The circuitry to recharge the batteries in a portable product is an important part of any power supply design. The complexity (and cost) of the charging system is primarily dependent on the type of battery and the recharge time. A Li-Ion battery is unique, as it is charged from a fixed voltage source that is current limited (this is usually referred to as constant voltage charging). A constant voltage (C-V) charger sources current into the battery in an attempt to force the battery voltage up to a pre-set value (usually referred to as the set-point voltage or set voltage). Fig.1 shows the typical constant voltage charge profile.

The constant voltage charging cycle is divided into two separate segments: The current limit (sometimes called constant current) phase of charging is where the maximum charging current is flowing into the battery, because the battery voltage is below the set point. The charger senses this and sources maximum current to try to force the battery voltage up. During the current limit phase, the charger must limit the current to the maximum allowed by the manufacturer (shown as 1c here) to prevent damaging the batteries. About 65% of the total charge is delivered to the battery during the current limit phase of charging. Assuming a 1c charging current, it follows that this portion of the charge cycle will take a maximum time of about 40 minutes. The constant voltage portion of the charge cycle begins when the battery voltage sensed by the charger reaches 4.20V. At this point, the charger reduces the charging current as required to hold the sensed voltage constant at 4.2V, resulting in a current waveform that is shaped like an exponential decay. Once this voltage is reached, the charger will source only enough current to hold the voltage of the battery at this constant voltage (hence, the reason it is called constant voltage charging). The accuracy on the set point voltage is critical: if this voltage is too high, the number of charge cycles the battery can complete is reduced (shortened battery life). If the voltage is too low, the cell will not be fully charged.

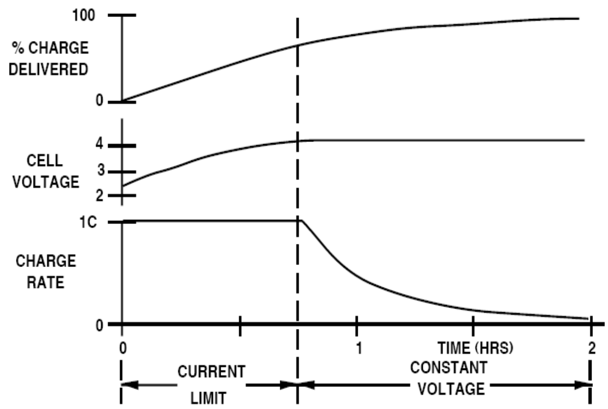

Figure 1: Constant voltage charge profile typical diagram

Fig. 2 shows a block diagram of the conventional OBC systems. This contains a two-stage structure, power factor correction (PFC) part, and dc–dc converter with high-frequency transformer part. With this structure cannot improve the maximum efficiency and a high-frequency transformer for wide-range output voltage and galvanic isolation has a negative influence on efficiency and power density. Hence, a high-efficiency non-isolated single-stage OBC is reasonable. This type of OBC features decreasing losses and volume, since the transformer that affects the efficiency and power density can be removed. Non-isolation type is very desirable for the OBC when considering efficiency, volume, and cost.

In the case of non-isolated single-stage OBC with interleaved cascade buck boost converter has some disadvantages that it contains large number of switches those in turn increase the THD of system. Complexity of the system is also increases. So go for this new compact non-isolated OBC is more reliable and economical.

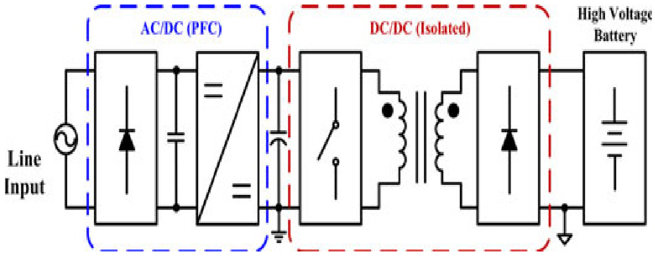

Figure 2: Conventional OBC- block diagram

2. Conventional Topology-Overview

There are many types of conventional dc–dc converters, which are applied to various industrial applications. However, some topologies are not suitable for the OBC due to the wide-range input condition. In order to charge a battery, the output voltage also varies widely. According to IEEE the selected topology should satisfy the following requirements for the OBC system:

1) The output voltage should be stably controlled for a wide input-voltage range;
2) The input current should comply with the standards of the unity PF;
3) High-frequency switching control should be applied to the OBC for small volume and light weight;
4) Simple or verified structure to ensure reliability is needed.

In order to achieve high efficiency, non-isolated topologies by eliminating a stage with the high-frequency transformer are more reasonable. In the point of view of the number of elements, isolated topologies need much more components than non-isolated topologies. In addition, the transformer and additional elements are directly connected with increasing the space and cost of the total system. Therefore, the non-isolated topologies which can perform step-down/step-up and compensate PF in single stage are considerable to attain high-efficiency and high-power density.

The conventional non-isolated topologies have some problems, which are reversal of the ground between the input and the output, and additional passive components, to attach on the OBC. In addition, these topologies have extra problems with the high-voltage stress of each component, because semiconductor switches (including diodes) should tolerate the summation of the input voltage and the output voltage during operation. In order to stand high-voltage stress, the semiconductor devices should have high ratings. This gives rise to large conducting losses, because the drift region of the internal junction structure becomes longer. In order to overcome these defects, cuk converter with inverting amplifier is mainly considered which is a series-connected cuk converter and inverting amplifier. Although it does not need any additional semiconductors switching devices, this topology has the same polarity of the input and the output and lower voltage stress than other non-isolated topologies.

Fig. 3 shows a non-isolated Cuk Converter. A non-isolated Ćuk converter comprises two inductors, two capacitors, a switch (usually a transistor), and a diode.

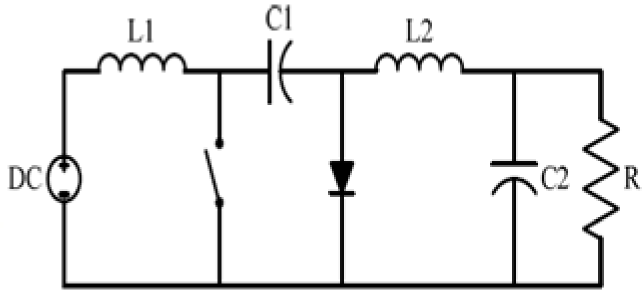

Figure 3: Non-isolated Cuk Converter

Output voltage magnitude can be either larger or smaller than that of the input. It is an inverting converter, so the output voltage is negative with respect to the input voltage. The inductor L_1 on the input acts as a filter for the dc supply to prevent large harmonic content. The energy transfer for the both converter depends on the capacitor C_1. The two inductors L_1 and L_2 are used to convert respectively the input voltage source (V_i) and the output voltage source (C_o) into current sources. In the proposed method this reversing polarity is corrected by using an inverting amplifier.

3. Proposed new compact non-isolated on board battery charger

As shown in Fig. 4, the proposed system consists of a series-connected single-phase rectifier, cuk converter with inverting amplifier for achieving high efficiency and reducing current ripple of the input and the output. Moreover the output voltage is controlled according to the demand of the battery using a closed loop control. In addition, the proposed circuit has the following advantages compared with the other non-isolated dc–dc converters such as buck converter, boost converter, buck-boost converter and sepic converter etc. The input and the output have the same polarity;

1) Voltage stress on semiconductor switching devices is less than that in other conventional topologies;
2) Reduced ripples in input and output current.
3) Reduced EMI problems.
4) Continuous input current.
5) Continuous output current.

DC voltage output from the inverting amplifier is a analog signal because of its varying nature due to variations in input and load conditions. Hence a closed loop control is needed to get precise charging voltage for battery being used. PWM generator receives analog signal from the inverting amplifier and generate appropriate PWM signals for turn on the switch at the proper time period. According to the analog voltage value the PWM generator generate signals of different pulse width. Hence obtain the voltage control. Fig.5 shows the simulation circuit of proposed system in MATlab.

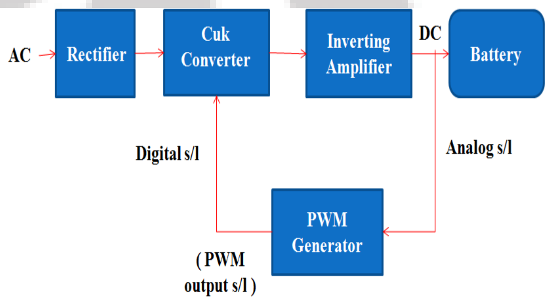

Figure 4: Block diagram of proposed system

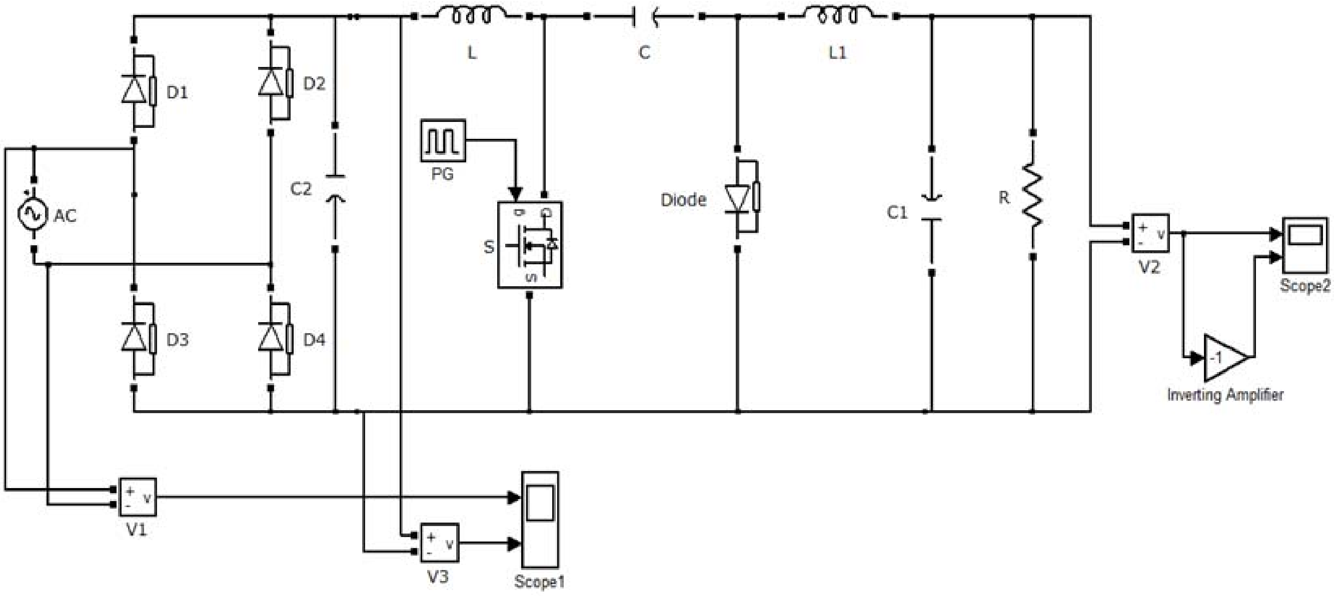

Figure 5: Simulation circuit in MATlab

4. Results and Discussions

The proposed method uses less number of switches hence reduced THD is obtained. Fig.6. shows the simulation output boost mode. Fig.7. shows the simulation output of buck mode. Fig.8 shows the physical structure of the system.

Table.1: Inferences from simulation

AC Voltage (V)	Pulse generator, Pulse width (%)	DC Voltage (V)
2.5	20	1.35
2.5	25	1.75
2.5	30	2
2.5	35	2.5
2.5	40	3
2.5	45	3.4
2.5	50	3.8
2.5	55	4.1
2.5	60	4.5
2.5	65	4.9
2.5	70	>5

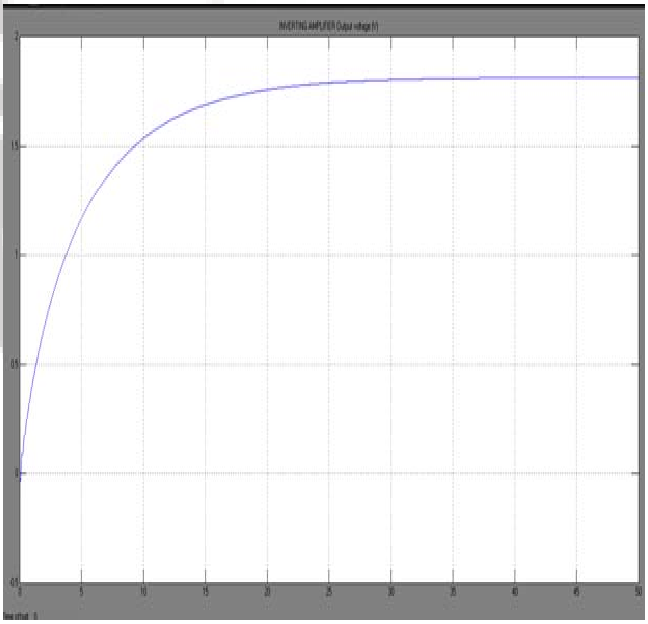

Figure 7: Simulation output-buck mode

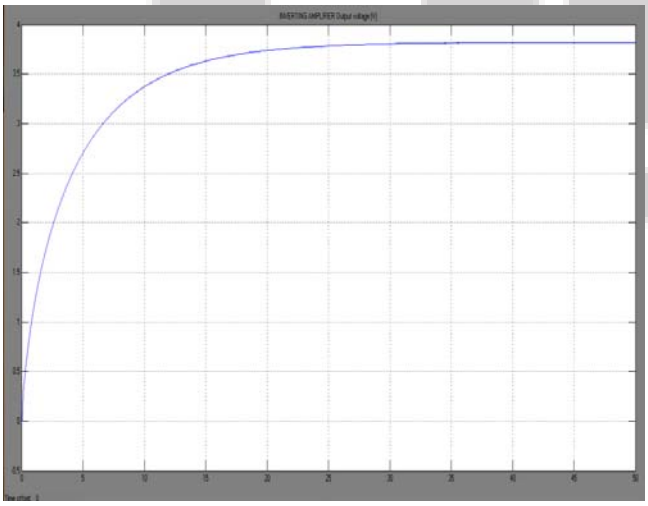

Figure 6: Simulation output-boost mode

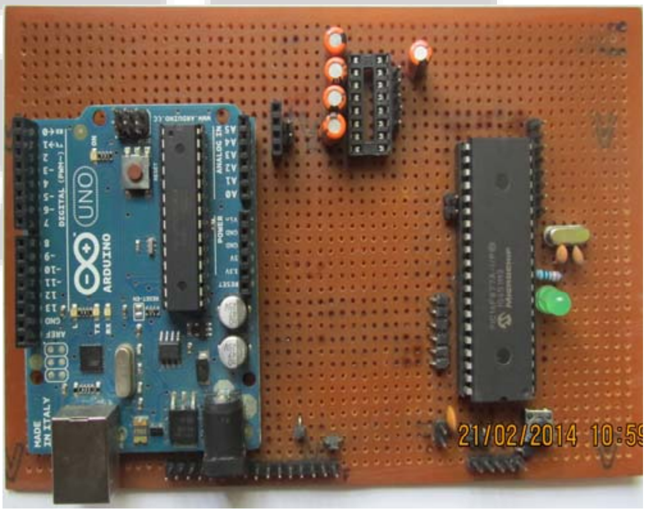

Figure 8: Physical structure of the system

5. Conclusion

The implementation of a non-isolated OBC for EVs has been presented, with a minimal total size and improved efficiency, as the main requirements for eco-friendly vehicles such as EVs and PHEVs. For achieving the targeted high-power density and high efficiency, a non-isolated cuk converter with inverting amplifier has been selected. According to the results of the analysis, a sequential control strategy is determined in the full spectrum of the input and output conditions. The proposed system was verified through experiment with the implemented hardware. The advantages of the proposed OBC can be summarized as follows:

1) The number of components is less than conventional OBCs;
2) High-power density and high efficiency are obtained by the single-stage structure without the high-frequency transformer;
3) High performance is also attained in the wide input and output voltage range for charging a battery.
4) Less volume;
5) Low losses;
6) Low cost compared to conventional type;
7) Reduced complexity.

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