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A novel design of an isolated onboard charger for electric vehicles

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Abstract: The effectiveness of electric vehicles as a form of transportation has been studied in light of the expanding environmental concerns and ever-tighter emission regulations. Electric car battery charger topologies are crucial for boosting the use of electric automobiles (EVs). The study's onboard plug-in battery charger for electric cars supports SEPIC, resonant inverter, or LLC topology and is suitable for nearby electric e-bikes with a 48V battery pack. In order to obtain the least amount of grid current ripple, an adaptive DC link voltage technique is also recommended for achieving the appropriate DC link voltage under all voltage conditions. The charger also employs a voltage synchronisation strategy to ensure a seamless mode transition between the grid-connected and freestanding modes. MATLAB/Simulink is used to simulate and validate the on-board charger.

Index Terms— Electric Vehicle, Lithium-ion Battery, Battery charger, SEPIC converter, LLC resonant converter

1. Introduction

The battery is acknowledged as the primary power source in EVs and PHEVs, and there are numerous EV and PHEV projects now in development. Thus, it is essential to check battery chargers. The OBC must be lightweight and small because it is used in automobiles. There are two primary charger kinds that are taken into account. The first is a potent fast charger with a 30-minute 30-percent battery recharge time. As an alternative, there is an on-board battery charger (OBC). Right now, there are only isolated types of battery chargers available the development of an on-board non-isolated battery charger is the aim of this project. After that, reduce the price and space. High effectivenessand performance will also be the result of this. Circuitry must be included in every power supply design forthe process of charging portable gadget batteries. The complexity (and cost) of the charging system is mostly determined by the battery type and recharge time. Because it can only be charged from a fixed voltage, current-limited source, a Li-Ion battery is unique (this is usually referred to as constant voltage charging). A constant voltage (C-V) charger injects current into the battery in order to raise the battery's voltage above a particular threshold (usually referred to as the set-point voltage or set voltage).

For the cell to properly charge, the voltage must be at least at a specific level.Electric vehicle adoption could have a tremendous impact on society by advancing personal mobility technology, transitioning economies away from oil, and minimising the environmental impact of transportation [1].

PHEVs, or plug-in electric vehicles, provide the most optimistic strategy for coping with the electrification of a sizable percentage of the transportation industry [3].Internal combustion engines (ICE) are responsible for a significant portion of the poisons released into the environment each day, and these concerns have sparked a significant increase in interest in electrically powered vehicles [2]. The adoption of electric vehicles (EVs) is greatly aided by charging topologies for their batteries (EVBs).Because charging time is so important, A highly effective For hybrid and electric cars, an on-board AC/DC charger with a high power density that satisfies the constrained space and weight parameters is necessary [4]. On-board chargers are frequently used by plug-in hybrid electric vehicles (PHEVs) because they are more adaptable for domestic charging and provide fewer safety risks from battery heating [5].

According to the structure, there are two different several kinds of on-board battery chargers Battery-mounted DC-DC converters side and single-stage interfaces with the battery pack on the network side [6]. The initial step is to always only use one method of charging the battery, which reduces the amount of hardware required and often halts battery degradation [7].Several deployed battery charging systems for PEVs use two step AC/DC converters [8,9]. The charger typically consists of two stages: a second phase DC/DC converter for voltage regulation and galvanic confinement, and a first stage for rectifying the AC input voltage. Although a charger that makes use of power factor converters has efficiency levels of 90%, the performance is not great for medium or low loads. Front end converter topologies are frequently used because they have a low Total Harmonic Distortion (THD) and need for less complicated design [9–10]. The adoption of boost type converters also has the drawback of increasing circulating losses due to the Operating at a frequency different than resonance, LLC converter. Topologies of the Boost type are not a wise choice because it is possible that the various DC connection voltages will be lower than the grid's input voltage. In order to provide A front end conversion that can boost and buck voltage input is appropriate a wide range of

DC interface voltage. Hence, the LLC converter would contribute to increasing handling capability over the battery pack voltage range.

In this study's charger topology, an LLC converter is used for the back end and a SEPIC converter for the front. LLC converters are popular because of their advantages, which include short circuit safety, galvanic isolation, and a smooth switching mechanism using an adaptive capacitor method.The equivalent circuit of the suggested topology, its design, and the MATLAB/Simulink findings are covered in the parts that follow.

2. ELECTRIC VEHICLE CHARGERS

The connection between the charging station and your automobile must have the appropriate plugs on both ends. That is logical, isn't it? Two different types of direct current (DC) connectors allow for fast charging up to 350 kW, while two different types of alternating current (AC) plugs provide charging up to 43 kW. Start with AC. There are two types of AC plugs:

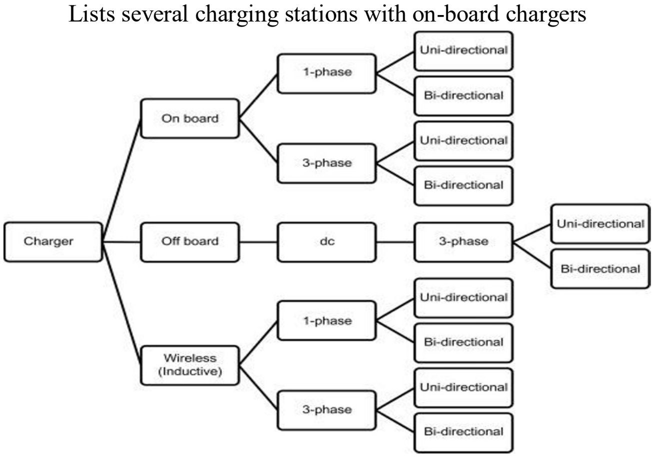
For EVs from North America and Asia, single-phase Type 1 plugs are the norm. Depending on the power output of the grid and your car's charging system, you can charge your car at a rate of up to 7.4 kW. Triple-phase plugs are Type 2 plugs since they have three additional current-carrying wires.Naturally, they might charge your car more quickly as a result. Depending on your car's charging capability and the grid, the maximum charging power that can be used at home is 22 kW, while the maximum charging power that can be used at public charging stations is 43 kW.

Any ac source's ac power can be converted into usable dc power using a device known as an on-board charger (OBC). It is normally found inside the car and performs power conversion as its main duty. An on-board charger therefore provides the advantage of recharging the electric car from a power outlet at our residences. Also, it saves the need to buy any additional equipment for power conversion.Estimates predict that between 2020 and 2027, the global On-Board Charger (OBC) market for electric vehicles will expand at a CAGR of 22.4%, reaching $10.82 billion. OBCs made by Electra EV typically offer a 25% higher DC-DC rating and a 30% faster charge time, enabling electric mobility applications to exceed end-user expectations.

The battery life and charging time are impacted by the battery charger's specifications.Let's take a closer look at an OBC. Controlling the flow of current from the grid to the traction battery is the main function of an on-board charger. Any source of power can be used to charge electric vehicles using an on-board charger (OBC).Electric vehicles are hence not constantly reliant on recharge stations.Another task of the OBC is to control the battery's charge by adjusting the voltage and current. The two fundamental types of charging are constant voltage and constant current. Constant current charging offers excellent efficiency and quick charging however the battery's lifespan may be reduced. The cause of this is excessive billing. During constant voltage charging, there is a chance that a sizable initial current will flow into the battery.

Table 1

Lists several charging stations with on-board chargers



The aforementioned problem can be fixed by starting the battery's charge with steady current. Once the voltage has reached certain amplitude, the battery is then charged via constant voltage charging. An on-board charger's main job is to control charging.

3. PROPOSED SYSTEM

The on-board plug-in electric car charger suggested in this work is built on the SEPIC and LLC resonant converters [11]. The SEPIC converter is one of the DC/DC converters that may change the output voltage to be greater, lower, or equal to the input voltage. SEPIC converter is taken into account because it is the best for front end converter. An illustration depicts the planned plug-in electric vehicle charger.

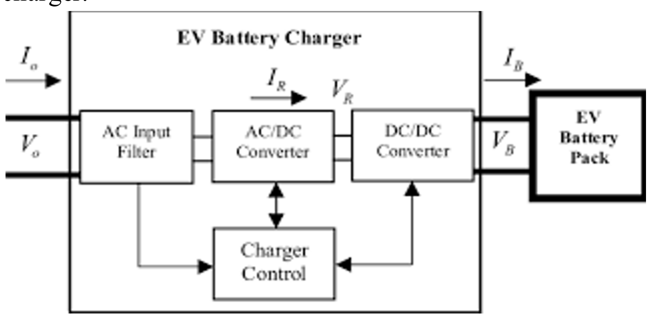


Fig.1. schematic for the charger for electric vehicles

The charger is supplied with 230V of electricity. The DC link voltage serves as the input for the rear end converter, also referred to as the LLC converter. The LLC converter functions as a voltage-controlled, galvanically separated second stage DC/DC converter. Given that it has a switching bridge, resonant tank, transformer rectifier circuit, and output capacitor, a complete bridge LLC converter is recommended. The 48V, 20Ah battery is charged using the suggested onboard charger. The proposed charger's corresponding circuit diagram is displayed.

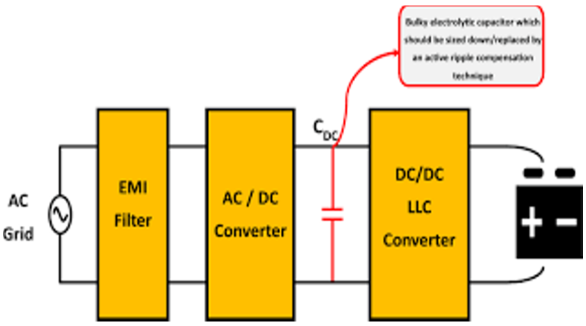


Fig.2. On-board Charger Block Diagram

4. CONTROL SYSTEM

4.1 Design of SEPIC Converter Fed LLC Converter

A Buck/Boost DC-DC converter that uses a single-ended primary inductor produces a DC output that differs from, equals, or is larger than the DC input. Two inductors make up the device; one is located one is connected to the ground, while the other is at the input. The two inductors are connected by a coupling capacitor.

The fundamental advantage of a SEPIC converter is that the output voltage's polarity matches that of the input voltage. The term "no-polarity inversion" refers to this phenomena. The capacitor c C1, the output capacitor C2, the two inductors L1 and L2, the diode D, and the load resistance make up the SEPIC converter circuit. Input and output circuits of SEPIC converter circuits share a common ground.To convert the input DC voltage to the desired output voltage level, the inductors L1, L2, and C1 exchange energy. The amount of energy delivered is often managed by a power transistor switch (S1), such as a MOSFET.

The SEPIC converter can be built to employ coupling inductors rather than discrete ones, which will increase efficiency and take up less room on the board (L1 & L2). When two windings (L1 & L2) are coupled in a single core, an inductor is said to be coupling.

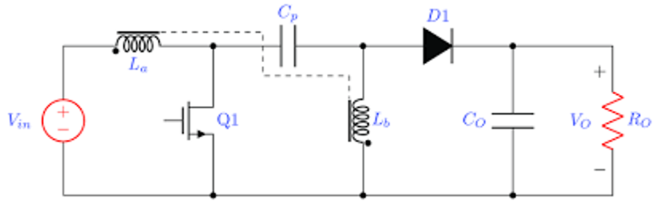


Fig. 3 converter for a single-ended primary inductor

It is an on-board, 1 KW AC mains-powered charger. The intended charger will operate on grid electricity with an input voltage of 230V, single phase, and 50Hz. With the aid of a diode bridge rectifier, the AC voltage is fixed. It is not necessary for the rectified output voltage in this rectifier application to be higher than grid voltage because the voltage gain of a SEPIC converter might be larger than or less than unity. These benefits for rectifier applications include getting access to a wide range of DC link voltage.

4.2. Proposed charger design o f SEPIC converter

In Fig. 2, the capacitor output could be without voltage ripple, and the matching duty ratio is shown in (1),

$$D = \frac{V_{out}}{V_m|sin\omega t|+V_{out}} \qquad (1)$$

"Vm" stands for the grid voltage, and "Vout" stands for the output voltage.

The ripple current is determined to be equal to 25% of the maximum input current when choosing inductors "L I and "L2" [8]. Calculations were made of the ripple current flowing in both "L I" and "L2.""are shown in (2);

$$\Delta I = I_{in} * 25\% \qquad (2)$$

The computed inductor values are displayed in (3);

$$L_1 = L_2 = \frac{v_{in} D_{min}}{\Delta I} \qquad (3)$$

With a switching frequency of 500 kHz, the values for both inductors are determined to be 150 pH. Based on formula (4) is used to calculate the RMS current through the capacitor and determine the coupling capacitor's value;

$$I_{c1}RMS = I_o\sqrt{\frac{(V_{out}+V_D)}{V_{in,min}}} \qquad (4)$$

Calculations for the SEPIC's capacitor value are shown in (5);

$$C_1 = \frac{I_o D_{max}}{\Delta V_{c1} F_{sw}} \qquad (5)$$

Where "AVc l""I0" stands for the output current, "Ci" represents the ripple voltage across the capacitor, and "Fsw" denotes the switching frequency of 500 kHz. The figure for capacitance is computed on the assumption that there will be a very tiny ripple voltage, or 5%. (5). When the switch Si is turned ON in a SEPIC converter, the inductor begins to charge and the output capacitor provides the output current. The capacitor experiences greater ripple as a result, thus it must be constructed to handle more ripple current. The formula described in determines the output capacitor (6),

$$C_2 \geq \frac{I_O D_{max}}{0.5 V_{ripple} F_{sw}} \geq 100\mu F \quad (6)$$

4.3 Proposed charger design o f LLC Converter

As seen in Fig. 2, the isolated LLC converter receives DC link voltage from the SEPIC converter in order to charge the Li-ion battery.
The calculation for the resonant peak current is presented in (7);

$$I_{RP} = \frac{2\pi P}{2 V_b} \quad (7)$$

It is possible to choose a switching frequency of 100 kHz to find the resonance capacitor.

$$C_r = \frac{I_{RP}}{2\pi F_s} \quad (8)$$

In order to obtain voltage gain, the conductance ratio of "Lm" and "Lr" is assumed to be 0.3, therefore the resonant inductor and the magnetising inductor can be calculated from (9) and (10) respectively (10),

$$L = \frac{1}{(2\pi f_s)^2 C_r} \quad (9)$$

$$L_m = 0.3 L_r \quad (10)$$

The proposed two-stage charger architecture makes use of the necessary inductor. For a 48V, 20Ah e-bike vehicle, a charging topology is made using the designed parameters. The infrastructure for charging is the first requirement for positioning in the optimal places.

4.4. Regulation of Adaptive DC Bus Voltage

To properly regulate the power import/export to the grid, the DC bus voltage must be greater than the peak PCC voltage. The adaptive DC bus voltage control selects a precise value for the DC bus to guarantee proper current control.To achieve this, the DC bus voltage is modified to correspond to variations in the PCC voltage.
Hence, the Vdc* is calculated as

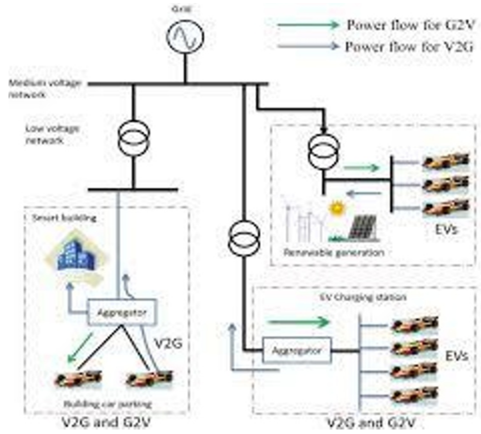


Fig. 4 Control for independent EV charging and discharging

Here, the value of the constant γ is selected as 1.1. The DC bus voltage is kept 10% more than the peak amplitude of the PCC voltage, considering the drop in the switches, coupling inductor and internal resistance of the coupling inductor.
Here, the value of the constant γ is selected as 1.1. The DC bus voltage is kept 10% more than the peak amplitude of the PCC voltage, considering the drop in the switches, coupling inductor and internal resistance of the coupling inductor.

$$V_{dc}^* = \gamma^* \sqrt{2V_s} \quad (11)$$

In this instance, the constant is set to 1.1. With the drop in the switches, coupling inductor, and internal connection inductor resistance taken into consideration, the DC bus voltage is kept 10% higher than the PCC voltage's peak amplitude.

5. SIMULATION RESULTS

MATLAB-Simulink is used to model the onboard plug-in charging system for electric vehicles with SEPIC and resonant inverter and an adaptive DC link voltage. The SEPIC converter's output voltage and current responds to a 48V battery. Fig. 6 displays the input voltage.

Table-II
Simulation parameters

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Simulation Parameters

	Parameter	Description	Value
1	Vin_ac	Input AC Voltage (AC mains)	230 V
2	Vin_dc	Input DC Voltage after rectification	400 V
3	Vstep_down	Step-down DC Voltage	250 V
4	Vinv_ac	Inverter AC Voltage	230 V
5	Vdc_link	DC Link Voltage	400 V
6	Vbatt	Battery Voltage	300 V
7	soc_initial	Initial State of Charge (SoC)	50%
8	soc_final	Final State of Charge (SoC)	90%
9	charge_time	Charging Time	3000 s
10	t_step	Time Step	1 s

In table II, the required inputs and predetermined component values are listed for the simulation of a resistive load.

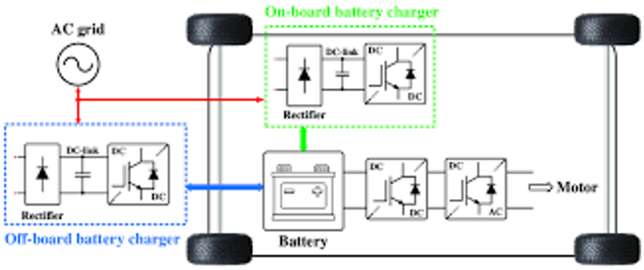

Fig.5 simulation model

Here, As shown in Figures 7 and 8, the SEPIC converter lowers the rectified voltage to 33.4V after the switching bridge of the LLC converter provides a square waveform that excites the LLC converter's resonant tank.The inductor depicted in figure 9 is subjected to a resonant sinusoidal current with an amplitude of 0.5 A. Fig. 10 displays the voltage across the dc link capacitor.

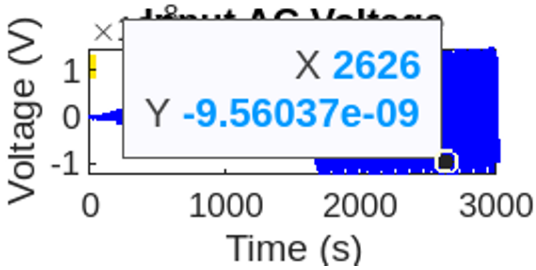

Fig. 6 input source

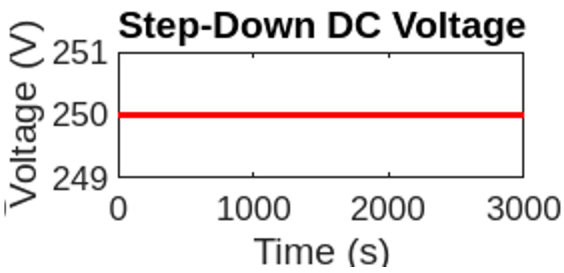

Fig. 7 step down voltage

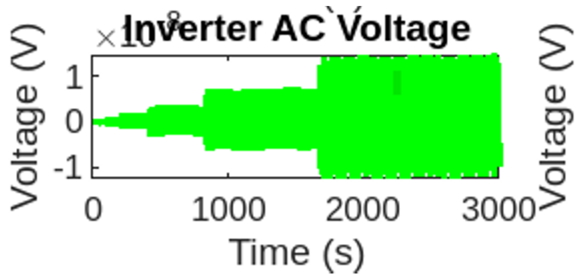

Fig. 8 Inverter voltage

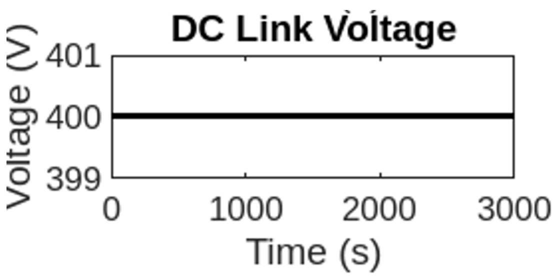

Fig. 9 dc voltage

The battery, which is charged as needed, is connected to the LLC converter. Figures 11 and 12, respectively, show the various battery attributes of voltage and SOC with time.

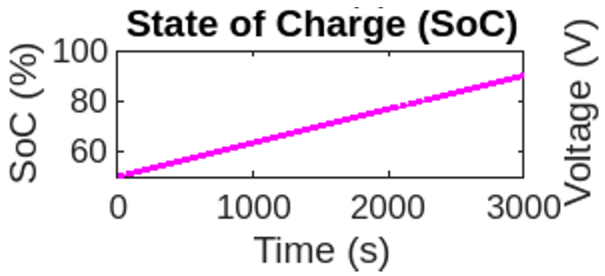

Fig. 10 Soc

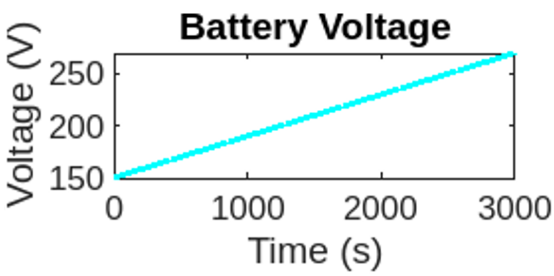

Fig. 11 battery voltage

6. CONCLUSION

This study described a SEPIC and LLC converter-based topology for an electric vehicle charger with a built-in plug.This can be effectively applied in applications for onboard charging of electric vehicles with grid connectivity. A 48V, 20Ah lithium ion battery for an e-bike is charged as part of the simulation. The efficiency of the LLC converter can be increased in future work by employing a variable DC link control method that maintains the switching frequency of the LLC converter close to the primary resonant frequency corresponding to the most maximum efficiency point.

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