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DC-DC CONVERTER FOR UNIVERSAL ELECTRIC VEHICLE CHARGING

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Abstract

For all-purpose Electric Vehicle (EV) charging applications, a single stage isolated bidirectional resonant network DC-DC converter is presented in this system. In order to enable the design of passive parts and gate drivers, the suggested converter operates with a set switching frequency and uses phase-shift control to achieve high efficiency throughout a notably wide output voltage range. For use in the dc grid, numerous high power dc-dc converter topologies have recently been put forth in the paper. Nonetheless, a number of dc-dc converter topologies have recently been suggested for use in dc grid applications. However, rather than doing a detailed analysis of each topology separately at this early stage, it is more advantageous to look into the various groups of converters based on the same design and operating principle. The issue with these, though, is that they aren't divided into multiple groups according to distinct criteria like conversion ratio, power density, or internal isolation. The proposed method looks into wide band gap semiconductors with gallium nitride switches to increase the power density by increasing the switching frequency. Combining a reconfigurable rectifier architecture with a multi-level inverter allows for easier usage of commercially available transistors by tolerating input voltage. When produced by utilizing a common three-phase universal ac input for power factor adjustment, and an output voltage range that accommodates a wide range of battery voltages from various car manufacturers.

Keywords- EV, Bidirectional Converter, Battery charger, Transformer, Arduino.

I. Introduction

EVs are becoming more and more appealing to owners of conventional internal combustion engine vehicles because they're one of the practical answers to the challenges of global warming and energy depletion. Because they can increase their driving range while the battery is charged, EVs powered by battery storage systems are gaining popularity. According to earlier research on the subject, which focused on EV technology, 50% of all cars would most likely be electrically driven by 2050. As a result, EVs will eventually contribute significantly to the burden on energy distribution networks. The adverse consequences of EVs on the electrical energy distribution network include issues with power quality, increased demand for electricity, security, and infrastructural implications. Consequently, an EV's battery charger must function well enough to have a unity power factor and zero distortion from harmonics in order to lessen these effects [1-4].

Numerous research have examined various techniques based on the kind and chemistry of batteries. For example, using a sinusoidal-ripple-current strategy when charging is a rapid charging technique. The charging method states that the battery's voltage and current, which are dependent on the batteries' charging time and state of charge, determine how much power may be used to charge them. Moreover, the battery charger is application-specific, meaning that there may be more than one nominal functioning point throughout the charging process. Power engineers therefore want to retain an adequate and consistent performance with acceptable dynamic reactions when they begin to develop a battery charger [5-9].

EV battery chargers can be classified as either on-board or off-board, and their power flow can be either unidirectional or bidirectional. The initial step in limiting hardware needs, reducing battery distributing, and streamlining connectivity issues is to charge unidirectionally. In bi-directional recharging, the battery energy is provided back into the grid by the system, which also accepts the charge from the grid and stabilises the power with enough power conversion. High power is usually the limit for on-board chargers because of factors including weight, budget, and available space. In order to get around these restrictions, some research addresses EV battery chargers as an integrated component of the electric motor. There are two types of on-board chargers: conductive and inductive. Although the inductive charger transfers power mechanically and is being expanded for the first and second levels, some charger systems in this field are stationary or model-based. The conduction method involves charging through a direct connection between the input and the connector. There are fewer off-board battery charging solutions because of limitations with regard to weight and space [10-16].

With less greenhouse gas emissions and pollution ahead, plug-in hybrid EV technology offers a substantial alternative for fuel and petrol consumption reduction. This is accomplished by reducing the engine's displacement and utilising regenerative braking to recover a significant portion of the vehicle's kinetic energy in its battery storage mechanism. As a result, the energy management system's significance inside the hybrid power train is growing. However, in order to make this system economically feasible, it must improve the overall dependability of the electric engine while simultaneously increasing efficiency and lowering the cost and weight of the electronics. An additional battery charger and an inverter are linked to a battery storage system that makes up the electric motor vehicle technology [17-21].

For combustion and regeneration brake functions, a converter is linked between the power source and an inverter. Three power stages make up the whole electrical training section of a traditional on-board EV battery charging: PFC stage, a DC to DC converter that raises the grid the voltage to the battery's voltage, and an isolation between the grid and the battery charging the network. Thus, in order to execute all of the plug-in EV operation options, three distinct power electronics converters are required [22-25].

This paper describes the functioning of a bidirectional EV battery charger that uses direct current control. The proposed method looks into wide band gap semiconductors with gallium nitride switches to increase the power density by increasing the switching frequency.

II. Proposed System

In order to enable the design of passive parts and gate drivers, the suggested converter operates with a set switching frequency and uses phase-shift control to achieve high efficiency throughout a notably wide output voltage range.

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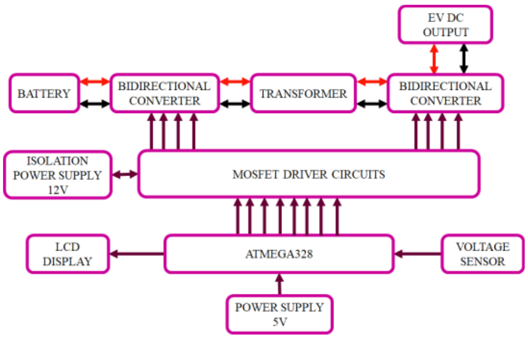

This paper describes the functioning of a bidirectional EV battery charger that uses direct current control. The structure of the bidirectional converters in the Arduino UNO-powered EV charger is seen in Figure 1. Because of this output voltage-independent constant current feature and the innovative effective phase-shift modulation that is suggested in this research. For battery charging modes that involve constant current, constant power, and constant voltage, all transistors can be soft switched with the lowest currents that circulate. As a result, the converter can function efficiently at high switching frequencies. The rapid charging, fast discharging, slow charging, and slow draining functions of the suggested bidirectional battery charger are all possible. The outcomes demonstrate that in all four working modes, the suggested control technique operates well and achieves high efficiency. Furthermore, the simulated findings demonstrate that there is a direct proportionality between the charging or discharging current and the pace at which the battery's state of charge changes.

A. Bidirectional Converter

Power can go in either way between two dc sources thanks to bidirectional dc–dc converters. Their versatility in switching the direction of current flow and, consequently, power, without affecting the voltage has led to their growing use in various applications such as computer power systems, telecom generators, chargers for batteries circuits, and dc uninterruptible generators. There have been reports in the literature on the possible application of resonant, soft switching, and hard switch PWM in bidirectional converters. However, in resonant mode executions, these topologies frequently result in higher component ratings; in soft switched circuits, they cause high output current ripple as well as loss of smooth switching at light loads; in integrated structures, they result in lack of galvanic isolation. A bidirectional dc–dc converter architecture is presented in this work for use as a battery charger and discharger. The proposed converter combines the popular push-pull current-fed and half-bridge topologies. The proposed converter uses only one transformer, in contrast to existing designs that require two to provide the required bidirectional power flow for battery charging and discharging. It makes use of MOSFETs' bidirectional power transmission feature.

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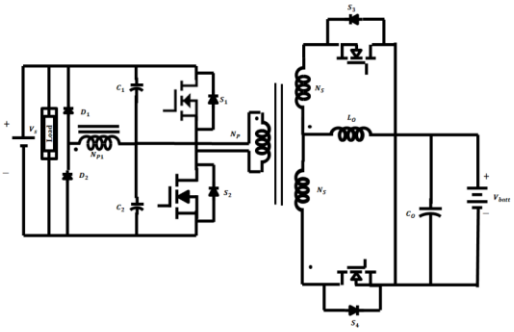
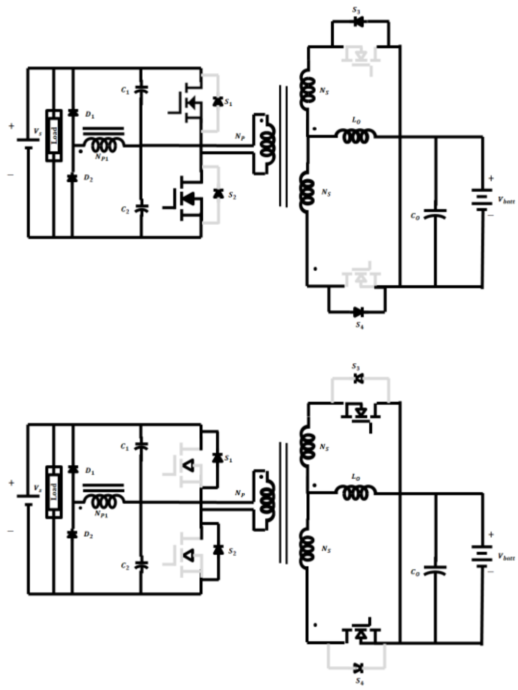


Fig. 2. Bidirectional DC-DC converter's topology

Fig. 2 depicts the basic power circuit architecture. Galvanic isolation between the battery and the dc mains is given by the transformer. The dc mains are linked to the converter's half-bridge primary side. A current-fed push-pull is formed by the secondary side, which is connected to the battery. There are two ways to operate the converter. When in the charging mode, the downstream load converters are powered by the energy from the DC mains, which also charges the battery within a certain input voltage range. Only the gated switches and their body diodes, which provide battery side rectification, function in this mode.

Charging Mode: In this mode, as shown in Fig. 3, the iL_0 is provided by the dc mains, V_s , which power the load converters. In doing so, the bidirectional converter's battery is charged to its nominal voltage. S_3 and S_4 are not switched at all, however S_1 and S_2 switches on the main side are gated at duty ratios lower than 0.5. In this mode, the bidirectional converter operates similarly to a buck converter. The various stages of function over a single switching time period T_S, are depicted in the idealised waveforms of Figure 4 are represented by the intervals T_0 to T_4 . During the switching cycle, the converter operates repeatedly.

Interval $t_0 - t_1$: At t_0, S_1 is ON and S_2 is OFF. There is a voltage Vs/2 across the main coil. On the secondary side, switch S_4, DS_4 forward-biased body diode offers rectification. The I_{batt} battery charging current is also transported by it.



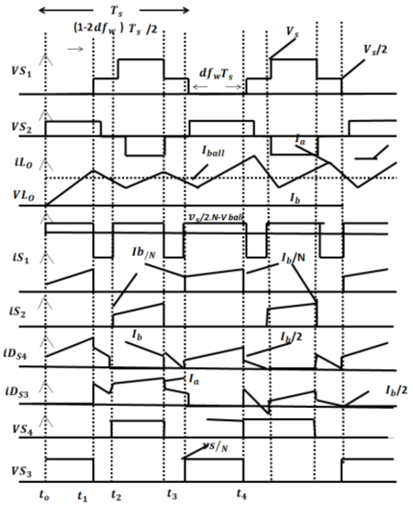


Fig. 6. Waveforms in the charging/forwarding mode

Interval $t_1 - t_2$: While switch S_2 remains off, switch S_1 is turned off at time t_1. Since there is no voltage across the main winding and, by extension, the secondary windings, there is no power transfer to the second winding throughout this idle interval. To charge the battery, the energy stored in L_0 causes the current iL_0 to freewheel via the body diodes DS_3 and DS_4. During this time, only half of the supply voltage Vs is visible across switches S_1 and S_2.

Interval $t_2 - t_3$: At t_2 , switch S_2 is switched ON while switch S_1 remains in the OFF position. The operation is the same as it was during the $t_0 - t_1$ interval, except at this point, secondary side rectification is provided by the body diode of switch S_3 , DS_3 . With an increase in the vL_0 , the iL_0 , climbs linearly once more. The whole battery charging current flows through the switch body diode DS_3.

Interval $t_3 - t_4$: This interval's converter operation is similar to $t_1 - t_2$ interval. The energy stored in the inductor provides the battery charging current; no primary side switch is conducting. Both the DS_3 and DS_4 body diodes conduct equally and concurrently.

On the main side of the half bridge, Fig. 3 displays two catching diodes, D_1 and D_2, as well as a balancing winding N_{P1} . If the midway of C_1 and C_2 starts to wander N_{P1}, D_1 and D_2, and a tiny current flow through to make up for the drift.

Backup/Current-fed Mode: In case the DC mains fail, the converter functions in the manner depicted in Figure 4. The load receives electricity from the battery through discharge. The waveforms shown in Fig. 5 are used to depict the converter operating during this mode. The converter action, which is repeated during T_S , is described by the time intervals from $t_0 - t_4$.

Interval $t_0 - t_1$: At t_0 , S_3 is activated while S_4 is still in the ON state from the previous period. When the whole battery voltage appears across the transformer secondary, an effective SC occurs, causing the inductor N_S, to store energy. S_3 and S_4 split the inductor current L_0, evenly as it increases linearly. The load is provided by the bulk capacitors, C_1 and C_2, during this time.

Interval $t_1 - t_2$: At t_1, S_4 is switched OFF while S_3 is still ON. Now, the body diode DS_2 and the diode D_1 transmit the energy that was stored in the inductor L_1, during the preceding time to the load. This permits C_1 and C_2 to be charged equally and simultaneously through D_1 and DS_2, correspondingly.

Interval $t_2 - t_3$: The interval $t_0 - t_1$ and this interval are comparable. At time t_2, switch S_3 stays ON and switch S_4 turns ON as well. As a result, S_3 duty ratio is higher than 0.5. Since there is no voltage across N_P or N_{P1} , the load power is provided by the capacitors discharging.

Interval $t_3 - t_4$: The converter's action in this interval is similar to $t_1 - t_2$ interval. S_4 is switched off at t_3, yet it stays on. Using the primary diodes DS_1 and D_2, as well as the switch operating on the S_4, the L_0, flows to the main portion of the converter. Once more, equal charge of C_1 and C_2 is the outcome of DS_1 and D_2 conduction.

B. Modelling of EV Charger

The parts of an electric vehicle battery charger and the control methods used affect how the charger functions. The sensing circuits used in the first stage of control, as shown in At the moment, all commercial EVs use standard unidirectional chargers, with the diode bridge rectifier serving as the initial control step. The creation of controllers for single-phase chargers that include control gains chosen for fundamental frequency is particularly difficult due to voltage, current, and/or AC-DC converter fluctuations.

A three-phase PMW converter appropriate for Level 1, Level 2, and Level 3 charging is recommended depending on the VOC of converter concept. VOC control is used to operate the converter. Throughout the charging procedure at stations for charging, a full-bridge based PWM rectifier is used with a three-phase converter. The present research investigates the use of a bidirectional EV battery charger with a three-phase converter under these conditions. The input and output filters, PFC, and PWM rectifier in the suggested architecture can counterbalance the reactive and unstable active currents. The dimension of the capacitors and inductors on the input filter of the boost converter is crucial for the right reaction, which guarantees the charger's stability

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and the design's ideal operation.

C. Charging Infrastructure and Power Levels

The power, location, duration of charging, equipment, expense, and grid impact are all considered when discussing the power levels of EV chargers. The affordability and energy needs of on-board energy storage have increased, making the availability of charging infrastructure a crucial factor. The two most popular setups for the key EV charging components, which include cables, plugs, charge stands, power outlets, protection, and EV connections, are wall or pedestal mounted boxes and specialised cord sets. The specific designs vary from place to place and nation to nation based on utility requirements, voltage, frequency, and electrical grid connections.

Level 1 Charging

The quickest charging technique is allegedly level 1. Level 1 connects to the EV AC port of a 120 V/15 A single-phase connection, like the NEMA (5-15R), using a standard J1772 connector.32 for residential or commercial settings, no extra parts are required, and reduced off-peak variation rates could be offered at night.

Level 2 Charging

It is believed that the primary method of dividing up public and private services is level 2 billing. This kind of infrastructure for charging might also be included to prevent using a lot of power-hungry electrical parts. The current Level 2 device can charge at up to 80 A, 19.2 kW, and voltages between 208 and 240 V. Occasionally, certain equipment and connections are needed for installations at residential or public locations33. Nevertheless, even with on-board electrical systems, EVs like Tesla still need an outlet.

Level 3 Charging

Battery charging with Level 3 offers the potential to be completed in less than an hour and uses a commercial rapid charging technology. Similar to petrol stations, Level 3 chargers are able to be placed in highway stop areas and city fuel stations. For steady AC/DC conversion, Level 3 usually requires an off-board battery charger and operates at 480 V or more on a three-phase supply34. Usually, a direct DC connection is made between the charger and the EV. Seldom is it practical for residential areas.

III. Results and Discussions

To show the viability of the suggested system, an ATMEGA 328P controller is used in the construction of

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the EV charger model, which is done using a MATLAB simulation model.

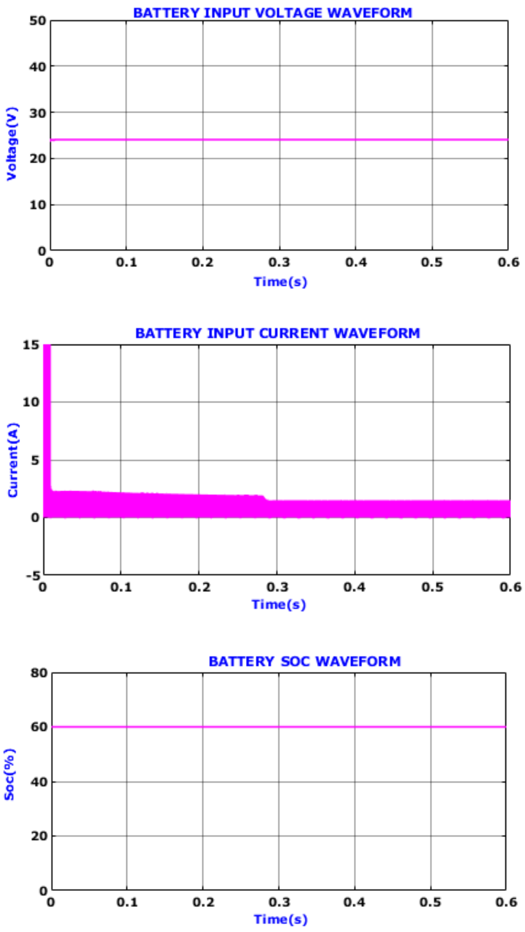
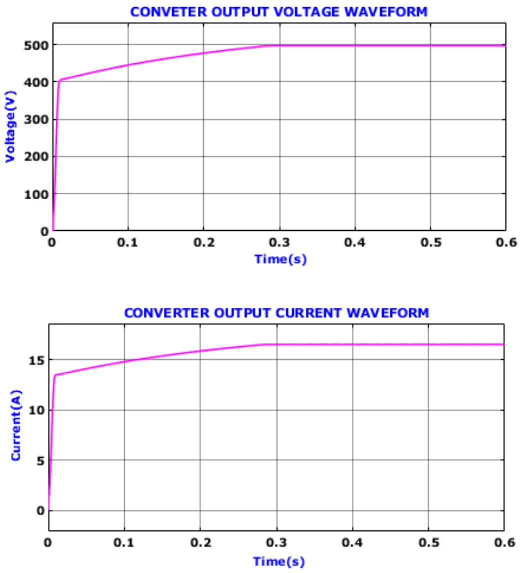


Fig. 7. Battery waveform (a) Voltage (b) Current (c) SOC

The batteries are initially charged to 60% SOC at a voltage of 25 V. Because of this, according on the battery's cell structure and level of charge, the capacity of the battery's voltage may be either greater or lesser than the designated voltage at the terminals. To verify the converter's efficiency, however, many SOC values are encountered. For different SOC levels, the system's control algorithm has met both the dynamic and steady state functioning conditions.



(b)

Fig. 8. Converter output (a) Voltage (b) Current

The output voltage and current of the suggested converter are simulated and are displayed in Figure 8. The results indicate an output voltage of 500V and an output current of 20 amps.

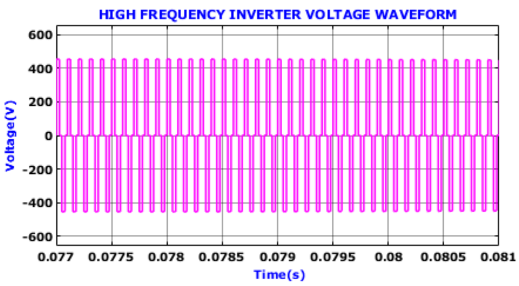


Fig. 9. High frequency inverter voltage

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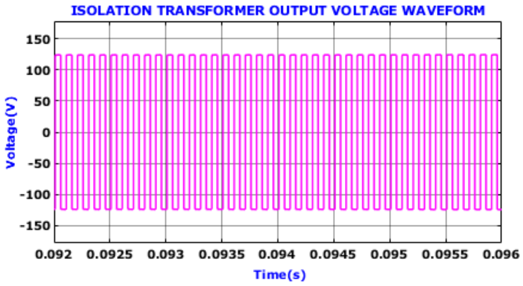
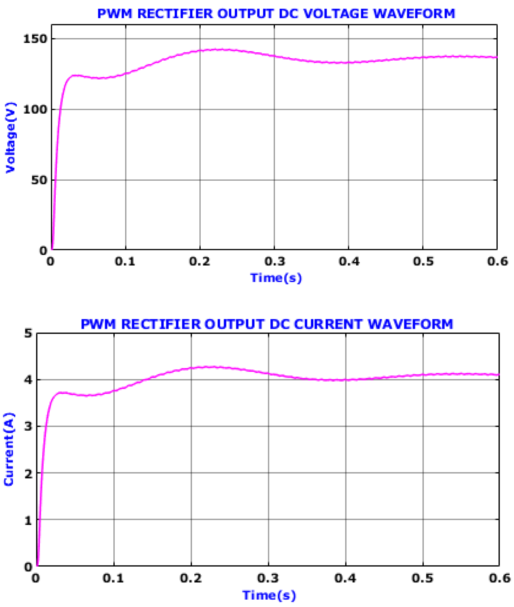


Fig. 10. Isolation transformer output voltage



(b)

Fig. 11. PWM rectifier output (a) voltage (b) current

The effectiveness of the suggested converter as it reacts to step changes in the DC voltage reference is displayed in Figures 10 and 11. It nearly reaches the unit power factor rectifier, which is currently meeting the battery charger's specifications. In the meanwhile, the battery of an electric car is steadily charged due to the constant voltage and current.

Figure 12. Output from IoT app

Figure 12 shows the output from the IoT app in which it displays battery voltage of 24V, battery current of 2 amps, Converter output voltage and current as 500V and 16 A respectively.

IV. Conclusion

Power converter interleaving has been demonstrated to be a viable way to increase transient response, efficiency, and reliability. An interleaved topology has been suggested by this system for the commonly used converter. Through interleaving, the suggested architecture can dramatically lower conduction loss, improving the converter's overall efficiency. Since two inductors share the total current in the boost stage, the converter's power density can also be enhanced. Because there are two phases that are interleaved, it can help improve converter dependability. The suggested converter is also shown to have improved light load functioning, which lessens or does away with the requirement for burst mode control. Thus, going forward, the suggested converter and control system may be deemed a formidable contender for applications involving universal electric vehicle chargers.

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