Abstract

The electric vehicles (EVs) have become more popular in recent times and a reliable alternative to the conventional internal combustion (IC) engine vehicles as EVs do not require any fossil fuel as the source of energy, and thus does not have any tailpipe emissions. The evolution of all-electric vehicle from an IC engine vehicle had started by integrating a motor drive set to the existing IC engine set-up. The role of this motor drive is to supply additional torque during acceleration. This motor drive is powered by a battery pack, which is charged from the regenerative braking of the propulsion motor during deceleration phase. As there is no option to charge the battery pack externally by tapping from an external source, plugged-in hybrid electric vehicles came into existence. In plugged-in hybrid electric vehicle, the battery pack is larger as compared to the hybrid electric vehicle and this battery pack is charged from an external power source by plugging-in to the source. To completely eliminate the need of fossil fuel in driving a vehicle and completely eliminate the tailpipe emissions, the IC engine is completely removed from the vehicle and the battery pack is made even larger to support the entire driving cycle of the vehicle, called as all-electric vehicle or simply EVs.

Thus, the major parts of an EV can be listed as propulsion motor, battery pack and power processors. There are two major power processors in an EV, one to run the motor and the other to charge the battery pack. The battery pack of the EV is charged by using an EV charger, which is divided into two types, depending upon their placement. The on-board EV chargers are fitted within the vehicle, so that the vehicle can be charged from any wall socket, whereas the off-board chargers are the DC fast chargers and generally placed in the charging stations. The off-board chargers have higher power processing capabilities as compared to the on-board charges and hence their size and cost increase.

The on-board charger is a part of the vehicle as discussed earlier, and adds to the cost and weight of the EV. Therefore, it is necessary to optimize the number of components, while offering all the standard features like galvanic isolation, power factor correction (PFC) operation at the AC input side and constant current-constant voltage (CC-CV) charging at the battery side. Further, to power-up the propulsion motor, another power processor is required with the on-board system that converts DC power from the battery and supplies AC power to the propulsion motor. Thus, two different power processors are required on-board with the vehicle to cater two different modes of operations, charging and motoring. In order to reduce

the number of power processors and the components count, various power converter topologies are reported for EV charging, but either they contain more number of switches with complex control techniques or do not offer all the standard features as mentioned earlier. Further, many researchers have contributed to develop an integrated charger, but either they do not reutilize all the components of motoring mode while deriving the charger or they additionally require a rectifier unit during the charging mode.

In recent times, wireless power transfer (WPT) technology have attracted many researchers to find out different power electronic solutions for developing wireless EV chargers. The most important unit in the transmitting side power module of the wireless EV charger is the high frequency inverter. The MOSFETs used in high frequency inverter operates at high frequency as the inverter produces AC waves at high frequency. The already reported topologies use more number of switches and do not support both CC and CV modes of operations. So, reducing the number of switches while achieving soft switching properties saves the switching power losses and reduces the overall cost of the wireless EV charger. The transmitting side power processor along with the transmitting coil are placed beneath the ground level and the receiving side power processor along with the receiving side coil are fitted into the vehicle. Thus, the secondary side power converter also adds to the cost of the vehicle and it is always carried with the vehicle which reduces the performance parameters like range (miles/full charge) of the EV. Thus, in an EV with both wired and wireless charging facilities, three power processors are required for three modes of operations, which are propulsion, wired charging and wireless charging. Though many literatures have been reported to amalgamate these processors, but most of them fail to support all three modes of operation using only one on-board power processor.

In order to solve the above issues, this thesis proposes different power processors to optimize the number of components in a power processor and to reduce the number of power processors in an EV that supports both wired and wireless charging operations. The proposed power processors are briefed in the following paragraphs.

A novel two-stage isolated on-board charger with all standard features having minimum switch count is proposed in this thesis. The first stage of the proposed charger taps AC power from the grid and converts it to DC with boost capability and feeds to the second stage. The second stage is an isolated DC-DC stage consisting of a series LLC resonant circuit. The first stage of the proposed charger is responsible for AC to DC conversion with PFC operation that consists of two switches and two diodes. The second stage is a DC-DC converter having a half bridge LLC resonant configuration along with an isolation transformer. The complete charger consists of only four switches and four diodes, which is minimum among the reported chargers. Conventionally, in case of a two-stage charger, two separate control loops are used with multiple PWM signals for multiple switches. This work proposes a novel control technique that manages both the PFC operation as well as CC-CV optimal battery charging with a single controlled PWM signal. The detailed operation of the proposed charger and its modeling are presented in this work. A 500 W scaled down laboratory prototype is built to validate the proof of the concept.

In order to amalgamate both the charging and propulsion power modules, a compact reconfigurable on-board power converter for EVs is proposed in this thesis. The proposed converter serves the purpose of a battery charger and a three-phase voltage source inverter (VSI) to drive the traction motor. The three-phase VSI is the backbone of this converter that can be either reconfigured to a propulsion unit or a battery charger by adding few more power electronic components. During charging mode, the topology is reconfigured to form a front-end boost PFC rectifier, which is cascaded by a DC-DC converter through a DC link. The same power stage is reconfigured to operate as a three-phase VSI to drive the traction motor during propulsion mode. Thus, it reduces the switch count by eliminating the requirement of a separate inverter stage. Simultaneously the weight, volume and cost of the overall system reduce. A unified control technique is implemented which is capable to achieve near-unity power factor operation of front-end boost rectifier as well as optimal battery charging without sensing the DC link voltage. This control scheme is implemented using a single control loop for both stages by eliminating the need of two separate control loops for each stage of the charger.

A novel wireless EV charger using resonant inverter is also proposed in this thesis that draws power from a single-phase AC supply and charges the EV battery pack with CC-CV optimal charging algorithm. As the proposed wireless EV charger draws power from a single-phase supply, this can be installed in public charging infrastructures as well as in home premises. The proposed charger is capable to maintain constant current and constant voltage at the battery terminal, and simultaneously maintains near unity power factor at the input side using PFC operation. Thus the proposed wireless EV charger satisfies all the criteria of a standard EV charger. The heart of the wireless power transfer (WPT) scheme is a high frequency inverter. In this work, an EF_2 inverter is used to generate high frequency AC in such a way that it can deliver power with variable loading conditions, while maintaining constant current (CC) or constant voltage (CV) according to the requirement of CC-CV charging profile. To supply power to the EF_2 inverter, an AC-DC front-end converter (stage-I) is integrated with the charger. The stage-I is operated as a constant voltage source to the EF_2 inverter for CC mode and constant current source for CV mode operation. The CC-CV at the battery end and PFC at the input end are achieved only by controlling the gate pulse of stage-I of the proposed wireless EV charger. The transmitting and the receiving coils of the WPT system are first simulated using Ansys Maxwell package and the complete charger is then simulated using PSIM simulation software. A 200 W scaled-down laboratory prototype of the proposed wireless EV charger is developed and tested with a resistive load to validate the idea. The wireless power transfer is achieved for a maximum distance of 12 cm between the transmitting and receiving coils. The charger is experimentally tested to charge a 12 V and a 24 V battery packs.

In case of EV with both wired and wireless EV charging features, the on-board system conventionally requires three different power processors for three different modes of operations, which are propulsion, wired charging and wireless charging. In order to optimize the cost, weight and volume of the EV, this thesis proposes a reconfigurable power processor for EV capable of serving the purpose of three different power modules required for propulsion, wired charging and wireless charging. In both the wired and wireless charging methods, the proposed technique draws power from the single-phase wall outlet and then charges the EV battery pack with CC-CV charging logic and performs PFC operation at the input AC side. A laboratory scale prototype is developed and the proposed concept is experimentally validated using a 24 V, 30 Ah battery set and a 24 V, 400 W BLDC motor.