Chapter 6

Conclusion and Scope of Future Work

5.1 Introduction

Optimal design of power processors plays a vital role while designing the powertrain architecture of an electric vehicle (EV). The design optimization of power electronic modules includes the reduction of components, without affecting the reliability and safety features that leads to reduction in cost, weight and volume of the vehicle. The weight of the power processor greatly affects the performance parameters, like miles/full charge because the weight of the power modules adds to the total weight of the vehicle as these on-board modules are carried with the vehicle throughout its journey. The power processors already reported in the literature with lesser number of switches do not satisfy all the standard features such as galvanic isolation and power-factor correction operation. Further, separate power processors are used in an EV for different operations like motoring and charging. In case of EV with wireless charging feature, an additional power module is required to be on-board with the EV system that adds to cost, weight and volume to the system.

In order to address the above-discussed issues, a two-stage on-board EV charger with minimum switch count and having all the standard features of an EV charger is proposed in this thesis. To reduce the number of power processors, the power electronic converter required for propulsion and charging operations are amalgamated into a single reconfigurable power converter. Further, a single-phase based novel wireless EV charger with single switch resonant inverter is proposed in this thesis. To accommodate both wired and wireless charging features, a single reconfigurable power processor is proposed in this thesis that eliminates the need of three different power modules in an EV.

This chapter summarizes the conclusions of the work carried in this thesis. Also a brief note about the future scope of the work is included in this chapter.

5.2 Conclusion

A two-stage isolated EV charger with all standard features and a novel control technique called “single controlled PWM technique (SCPT)” is proposed in this thesis. The first stage of the proposed two-stage charger converts AC from the single-phase grid and maintains the DC-link at its output, which is the input to the second stage of the charger. The first stage is responsible for maintaining near unity power factor at the AC input side. The second stage of the charger provides galvanic isolation and is responsible to maintain constant current or constant voltage at the battery terminal according to the CC-CV optimal battery charging logic. Additionally, a novel control scheme called "single controlled PWM technique (SCPT)" is proposed in this thesis that manages CC-CV operation at the battery side and power factor correction operation at the input side. The SCPT reduces the mathematical complexities, as the DC-DC stage requires no controllers, unlike the conventional two-loop control strategy with multiple controlled PWM signals. Both PFC operation and optimal CC-CV charging are ensured using only a single controlled PWM signal. The detailed analysis of the proposed circuit is provided and its mathematical modelling is presented in this work. A comprehensive comparison of the proposed charger with the existing two stage chargers and their control techniques has been carried out in detail in this thesis. The switch count in the proposed EV charger is found to be minimum as compared to the existing chargers. A scaled-down laboratory prototype is developed to validate the proposed work and its experimental results are included in this work. A maximum efficiency of 97.6% is achieved with the proposed charger for a 24 V, 30 Ah battery set.

To replace two different power processors for propulsion and charging modes, a single reconfigurable on-board power converter (R-OPC) for EV is presented in this thesis. A three-phase, six-switch VSI is considered as the backbone for developing this R-OPC. The proposed converter is reconfigured to serve both charging and propulsion operations of the EV, thus reducing the cost of the EV and improving the overall power density of the on-board system. The mathematical analysis and the detailed operation of the proposed R-OPC in both the propulsion and charging modes are presented in this work. The motor phase windings are reutilized as circuit inductances during the charging mode to avoid any additional inductors, which further improves the power density of the topology. The mode transition in the proposed work is achieved with the help of contactors. The contactors are operated in zero current condition, which eliminates switching losses across the contactors during mode transition. The proposed approach achieves improvement in power density and reduction in switch count as compared to recent literatures presenting contemporary power converters for EVs. A unified control loop scheme capable of near unity power factor operation at the input stage and performing optimal CC-CV charging of the battery in one single control loop is also implemented. A 500 W prototype is developed to validate the performance of the proposed R-

OPC. The proposed R-OPC is also validated using CC-CV charging of a 24 V, 30 Ah lead acid battery.

A single-phase wireless battery charger for EV applications is proposed in this thesis. The control scheme of the charger ensures PFC operation at the input grid side along with CC-CV charging of the battery. The transmitting side power module of the proposed wireless EV charger has two-stages. The first stage consists of a AC-DC boost converter that supplies power to the second stage. The second stage is a high frequency inverter (HF inverter) that produces constant AC current and voltage at high frequency to support CC and CV modes of operations. During the CC mode, the AC-DC stage supplies DC power at constant voltage to the EF_2 inverter, which produces constant AC current at high frequency. At the receiving side, this constant HFAC current is rectified to charge the battery with constant DC current. Similarly, during CV mode the EF_2 inverter is fed by the AC-DC stage with constant current for producing constant HFAC voltage at the output of the inverter. The constant AC voltage at high frequency is then rectified by the rectifier unit to charge the battery with constant DC voltage. The WPT coils are first simulated using Ansys Maxwell and the value of leakage inductances and mutual inductance are used to simulate the complete charger in PSIM simulation platform. A scaled-down experimental prototype is developed in the laboratory to verify the proposed charger and tested to transfer 200 W power wirelessly over a distance of 12 cm. Finally, a 12 V, 30 Ah and a 24 V, 30 Ah batteries are charged wirelessly using the proposed charger.

To reduce the number of power processors and to optimize the cost, weight and volume of the EV with both wired and wireless charging features, an on-board reconfigurable power processor (RPP) is proposed in this thesis that serves as three different power converter topologies during three different modes, which are propulsion, wired charging and wireless charging. The proposed RPP restructures itself to three different converter topologies by changing the connections among the elements. The restructuring is achieved by using four point contactors, where the fixed contact of each contactors is connected to any one of the three available contactor positions to provide three modes of operations. The proposed circuit, its mathematical analysis and the control scheme during all three modes are explained in detail to give a clear picture of the proposed RPP. A test prototype of the proposed power processor is developed in the laboratory, and is satisfactorily tested in all three modes. The loss distribution and power loss analysis is also done for both the wired and wireless charging modes.

5.3 Scope of Future Work

- The developed two-stage EV charger can be scaled up to 6.6 kW for charging the real time EV battery pack in a short duration.
- The reconfigurable on-board power converter can be developed in order to drive a 30 kW motor during propulsion mode and to operate as a 6.6 kW charger during charring mode.
- The concept of reconfiguration can be applied to the power electronic converters used in renewable energy and micro-grid systems, where charging and discharging of energy storage system plays a major role.
- Different coil designs can be explored to increase the coil-to-coil efficiency between the transmitting and receiving side coils in proposed wireless EV charger.
- Multiple options can be explored to improve the distance between the transmitting and receiving coils to provide improved ground clearance to the vehicle.
- The switching frequency of HF inverter can be increased to MHz level so that the real potential of GaN devices can be explored.

To run the HF inverter at higher power levels, series and parallel combinations of GaN devices can be used.