Abstract of Ph.D. Thesis

"Design and Development of Portable and Off-Board Chargers for Wide Categories of Electric Vehicles"

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ABSTRACT

The increment of transportation needs along with a rise in pollution and depletion of fossil fuels divert world researcher's & original equipment manufacturers (OEMs) interest towards other energy sources, especially sustainable developments. In this manner, electrified way of transportation is most popular and old concept before internal combustion engine era. The wide-spread or equivalent deployment of electric or battery powered automobiles (both personal and commercial vehicles) require different Ampere-hour capacity of battery packs with a wide range of battery voltage segments. A variety of battery chemistries are adopted to serve multiple transportation requirements like improved energy density, fast/ultra-fast charging, longer charging/discharging cycles, higher thermal stability, and different cell voltage requirements. These prominent diverse technology development of battery packs for wide segment of electric automobiles simultaneously raise diverse charging requirements. In respect to these charging needs, a set of charging protocols & standards are proposed in the literature. These are especially defined based on type of charging (AC or DC), battery terminal voltage and power processing. All three ways of charging (portable, on-board and off-board charger) technologies are quite challenging due to wide battery voltage adaptation requirements, portability of reduced volumetric form-factor of complete design, higher efficiency, and higher durability requirements for grid connection along with bidirectional power transfer with vehicle to grid, vehicle to grid, and vehicle to home/vehicle/auxiliary loads.

In this manner, a commonly adopted power electronics design is inspired by multiple (2 or 3) isolated DC/DC stages and a common active power factor correction stage to facilitate wide battery voltage adaptability, which is not a good solution for portable design due to higher form-factor design. Moreover, there is no further modifications are introduced in conventional isolated DC/DC stages to facilitate higher conversion efficiency over wide variation range in battery terminal voltage and power. Since, conventionally similar half and full bridge isolated DC/DC converters are proposed either for constant voltage or constant power applications (like LED drivers, energy routers, telecom/server power supplies, and other auxiliary power supply). In this manner, this research work is aimed to address all these aforementioned inadequacies and challenges by considering universal design concept for portable EV charger development.

It is started by incorporating the beauty of magnetizing inductance into conventional hardware architecture of dual active bridge (DAB) DC/DC converter. Based on this, conventional dual phase shift modulation is modified with an optimization law. It facilitate complete zero voltage switching (ZVS) of both full bridges over wide range of voltage conversion ratio and power transfer. On the active front end converter side, a modified pre-filtering stage is presented for consistent operationof charger over any grid anomalies as per IEEE 1547-2019. For low cost & high voltage charging needs, a three level DAB based DC/DC power conversion concept is presented and it is validated by scaled hardware prototype development. The concept facilitate utilization of low cost, lower break over voltage silicon MOSFETs instead of higher voltage breaking capacity silicon-carbide MOSFETs. It is achieved by identifying safe operating region of converter with half voltage stress across each MOSFETs of corresponding DC link voltage. An optimization law also applied to restrict converter operation within minimal current/voltage stress region over wide deviation in voltage conversion ratio for different EV segments.

A multi-parametric coordinated hybrid control techniques are proposed for the operation of LLC resonating converters. Based on the maximum possible degree of freedoms in either half or full bridge resonating network with active consideration of battery voltage profile variation, control maintains its operation within ZVS region. By considering different EV portfolios like light electric vehicles, PVs and CVs, different portable charger designs are proposed. All these are proposed by taking individual or multiple segment EV owners into consideration. Some of the designs possess portable DC fast charging of a wide segment of PVs and CVs using a single charger, which reduces customer's dependency to invest in different EV chargers. On other hand, it simultaneously helps OEMs to

eliminate dependency on incorporation of on-board charger into vehicle, which reduce total vehicle cost.
All these proposed design modifications in either control, hardware or both architectures are modelled, simulated (MATLAB/Simulink) and tested on experimental prototype. All validations are implemented over multiple possible grid and battery side scenarios. Moreover, a discrete time domain approach also presented to implement proposed control architectures into TI's C2000 microcontroller versions e.g. THDSDOCK28335 and TMS320F28379D boards. The presented work is aimed to increase electrified transportation trend by reducing cost, and impressive compact/reliable/durable mobile designs of different EV charger segments to meet the needs of all types of customers.