Abstract of Ph.D. Thesis
"EV Chargers for Two, Three, Four Wheelers and E-Buses with Power Factor Correction"
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For long enough, whole automobile industry has utilized internal combustion engines (ICE) to drive the public and private transport system. Consequently, toxic emissions owing due to exhaustive petroleum and gasoline fuel consumption, have raised serious health concerns and resulted in environmental pollution. According to world health organization (WHO) report, nation wise, India stands fourth in contributing to total percentage of global CO_2 emissions with a figure of 7%. Moreover, amongst the list of top ten most polluted cities of world, nine cities are situated in India. This is largely accounted by the population density, energy requirement, localisation of various industries and emissions from transport. India is dedicated to curtail its greenhouse gas (GHG) emissions by 35% from 2005-2030. Electric vehicles (EV) are going to dominate the automobile market in near future, which requires that everyone should have easy access to the facility to charge their vehicles. Anticipating an exponential growth in electric vehicles/hybrid electric vehicles (EV/HEV) in near future, the requirement of domestic and bulk charging stations with varying power ratings, is evident. Fluctuating fuel prices, frequent and costly vehicular maintenance and health concerns, have paved way for use of cleaner energy source in form of batteries to propel the automotive drive system. However, capacitive nature of batteries, results in drawing non-sinusoidal and harmonic rich current from utility grid resulting in humongous burden on the distribution transformer and malfunctioning of other connected equipment nearby.

However, international standards for power quality (PQ), such as IEEE-519 and IEC-61000-3-2 impose stern restrictions on any such solutions, which leads to poor PQ. Thus, a power factor correction stage to comply with this standard becomes absolutely mandatory and requires to be the part of any EV charging solution. Contrary to the growth of type EV's globally, the Indian EV sector observes great opportunity in EV charger solutions for small two wheelers (2-W) and three wheelers (3-W) since almost 80% of total vehicle population is accounted to them. Moreover, the power requirements and system architecture vary widely with different types of vehicles owing to different capacity of EV battery and charging voltages and current. Thus, in light of varying battery ampere hour (Ah) and kilo watt hour (kWh) capacity, the EV battery charger solution is not unique. Moreover, since the single phase AC utility supply switches are rated to a maximum current rating of 16A, the charging solution for EV batteries in four wheelers (4-W) and public transport require a battery charger power from three phase AC mains supply.

This work presents battery charging solutions for various types of transport starting from (2-W), (3-W), (4-W) and e-buses. The work is segmented in two parts. The first part aims to maintain good PQ indices at input AC mains by shaping sinusoidal current and regulating the DC link voltage. Thus, this power factor correction (PFC) solution adheres to the international standard of power quality such as IEC-61000-3-2. The second part is a DC-DC converter with transformer isolation, which imbibes the constant current (CC) and constant voltage (CV) algorithm for charging the EV battery. The practical converters for EV chargers are categorised according to the type of EV, such as 2-W, 3-W, 4-W and e-buses.

For small 2-W and 3-W, the input current shaping can be achieved by operating the PFC inductor in discontinuous inductor conduction mode (DICM) or continuous inductor conduction mode (CICM). The DICM control uses single voltage loop and provides a simple control structure. However, EV's with larger battery capacity requires larger charging current and shorter charging duration, therefore the control of front end PFC is CICM to limit the current stress in the switching devices and reduced electromagnetic interferences. This work investigates both DICM and CICM control for achieving power factor correction at input mains. Moreover, since the modern day EV chargers are intended to facilitate charging of EV batteries with different nominal voltages, the buck-boost PFC converters with PFC feature are proposed and investigated for wide range output voltages. A unique variable DC link algorithm is proposed, which not only provides wide output voltage, but in addition it reduces the switching loss in back end DC-DC inductor-inductor-capacitor (LLC) resonant converter.

Moving forward, EV chargers for 3-W and 4-W using boost converters and their variations along with LLC resonant converter are proposed. Comprehensive analysis with clear research objective of higher efficiency and small package is carried out in this work. Detailed design and experimental validation of various boost PFC based topologies like bridgeless, semi-bridgeless, interleaved and totem pole boost are presented in this work. Furthermore, three phase EV chargers for 4-W are investigated and design is extended for wide output voltage, typically 200V-1000V to cover entire range of e-buses. Lastly, bi-directional capability of proposed fully controlled EV charger is presented to demonstrate EV chargers ability to perform vehicle to home (V2H) and vehicle to grid (V2G) applications. The presented work aims to provide best in class efficiency, hence back end DC-DC converters with zero voltage switching (ZVS) features such as half bridge-LLC (HB-LLC) converter, full bridge-LLC (FB-LLC) converter and three level phase shifted half bridge converter (3L-PSHBC) along with synchronous rectifiers (SR) are designed, developed, analysed and presented in detail.