Abstract of PhD Thesis on

Title: "Design and Development of Single Stage High Power Factor AC-DC Converters for Battery Charging Applications"

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The rapid growth of electric mobility, renewable energy systems, and energy storage, has significantly increased the demand for efficient, compact, reliable, and grid-friendly battery charging systems. Conventional grid-connected battery chargers predominantly employ two-stage architectures consisting of a front-end power factor correction (PFC) converter followed by an isolated or non-isolated DC–DC converter. Although such configurations provide good performance, they suffer from increased component count, higher cost, larger size, reduced power density, and cumulative efficiency penalties due to double power processing. This research addresses these limitations by proposing, analysing, and experimentally validating a family of single-stage PFC battery charger topologies that integrate PFC and DC–DC conversion into a single power-processing stage.

The core philosophy of this work is based on using discontinuous conduction mode (DCM) and discontinuous inductor current conduction mode (DICCM) operation to achieve inherent power factor correction. By appropriately shaping energy transfer mechanism in each switching cycle, the input current naturally follows grid voltage waveform, thereby achieving near-unity power factor and low input current harmonics distortion without requiring a dedicated current control loop and extensive sensing. This results in simplified control structures, reduced sensor count, and lower implementation cost.

The research begins with the development of a single-phase isolated low-power charger based on a DCM flyback topology, which demonstrates that galvanic isolation, inherent PFC, and reliable battery charging are achieved using a minimal number of components and a simple control. Subsequently, non-isolated bridgeless and interleaved buck–boost charger configurations are proposed to reduce conduction losses, suppress current ripple, and lower peak device stress while maintaining wide voltage conversion capability and high level of grid power quality.

To address applications requiring a wide input–output voltage range, a high-gain (quadratic) single-stage buck–boost PFC charger is developed, which achieves large voltage conversion ratios through structural voltage boosting rather than extreme duty cycle operation. This improves efficiency, reduces device stress, and enhances control robustness. Furthermore, an electrolytic-capacitor-less single-stage charger with active power decoupling is proposed using a bridgeless SEPIC-derived structure, which successfully eliminates twice-line-frequency ripple in battery current while significantly improving system lifetime and reliability.

The scope of the work is further extended to three-phase bidirectional charging system using a matrix-converter-based single-stage architecture. This configuration eliminates DC-link capacitor, supports grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operation, and provides reactive power support. A model predictive control (MPC) strategy is employed to achieve fast dynamic response and reduced sensor requirements.

Comprehensive steady-state analysis, design methodologies, and control strategies are developed for all proposed topologies. Effectiveness of proposed solutions is verified through extensive MATLAB/Simulink simulations and laboratory-scale experimental prototypes. Obtained results consistently demonstrate near-unity power factor, low grid current THD, stable charging performance, and fast dynamic response. Overall, this work establishes a unified, scalable, and experimentally validated framework for next-generation single-stage, high-performance, and grid-friendly battery charger systems suitable for modern energy storage and electric mobility applications.