Anurag Sharma 2018EEZ8556

Thesis Title:
"Multi-Objective Design Optimization of Brushless DC and Synchronous Reluctance Motors for Light Electric Vehicle Applications"

Abstract

Electric Vehicles (EVs) are increasingly being adopted as a practical solution to mitigate air pollution. Within this transition, Light Electric Vehicles (LEVs), which include e-rickshaws and L5 category three-wheeled e-loaders, have become essential for last-mile connectivity in India. The traction motor is the primary determinant of vehicle performance because it directly influences the energy efficiency, reliability, and overall cost. Motivated by these considerations, this thesis addresses two independent research problems relevant to LEVs.

The thesis first deals with the design, development, and testing of a square-wave-driven Interior Permanent Magnet (IPM) Brushless DC (BLDC) motor. The motivation is to develop a cost-effective alternative to the commercially available Surface Permanent Magnet (SPM) BLDC motor for the e-rickshaw application. A key challenge associated with square-wave-driven IPM-BLDC motors is addressed, which is the degradation of average torque at high speeds due to high winding inductance. To solve this issue, trapezoidal notches are introduced on the quadrature axis of the rotor to reduce inductance and enhance high-speed torque capability. The proposed motor is also optimized using Non-dominated Sorting Genetic Algorithm II (NSGA-II) applied on the Support Vector Regression (SVR) surrogate model. The reliability and practicality of the proposed motor are evaluated through thermal, demagnetization, and rotor stress analyses. Additionally, commercial viability is assessed through the cost analysis of the motor. Finally, a 1 kW prototype of the motor is fabricated and validated in lab and field trials.

The second study focuses on traction motor design for L5 category three-wheeled e-loaders, which predominantly use rare-earth elements-based Permanent Magnet Synchronous Motors (PMSMs). Owing to their reliance on rare-earth magnets, these motors have an environmental impact and are subject to supply chain risks driven by geopolitical factors. As a rare-earth-free alternative, the Synchronous Reluctance Motor (SynRM) is investigated; however, its design is challenging due to the large number of rotor design parameters. A curved-barrier SynRM motor topology is developed and optimized to meet the performance targets. The main highlight of the study is the proposed online surrogate-assisted multi-objective optimization

framework with adaptive infill sampling. This approach significantly reduces computational time (i.e., the number of FEA runs) while achieving design solutions comparable to those of a conventional optimization approach. For a fair comparison, the study also includes optimization results using conventional approaches.

Overall, this thesis contributes: (i) two improved traction motor solutions aligned with the LEV requirements, and (ii) a computationally efficient online surrogate-assisted multi-objective optimization method that may be beneficial for high dimensional electric machine design problems.