ABSTRACT

Ceiling fans constitute a dominant share of household electrical energy consumption in tropical and subtropical regions, particularly in countries such as India, where their widespread and continuous usage magnifies even marginal inefficiencies. Conventional ceiling fans predominantly employ single-phase induction motors (SPIMs), which, despite their robustness and low manufacturing cost, exhibit limited efficiency improvement potential under evolving energy-efficiency regulations.

This thesis addresses these limitations through the systematic design, analysis, optimization, and experimental validation of energy-efficient permanent magnet–based motor topologies tailored specifically for low-power ceiling fan applications. The work begins with a critical review of conventional fan motor technologies, experimental performance assessment methods, and emerging permanent magnet brushless DC (PMBLDC) solutions. An integrated experimental framework is developed to enable laboratory-scale performance evaluation of ceiling fans, incorporating direct shaft-torque measurement using a calibrated reaction torque sensor and airflow estimation through grid-based velocity measurements combined with Kriging-based interpolation. This approach establishes a reliable correlation between electromagnetic torque production and aerodynamic air delivery without reliance on large-scale standard test chambers. A comprehensive analytical design methodology for an exterior-rotor PMBLDC motor suitable for ceiling fan operation is presented, incorporating manufacturability constraints through the use of trapezoidal permanent magnets selected from commercially available grades. The analytically designed motor is validated using two-dimensional finite element analysis and experimentally verified through a fabricated prototype, demonstrating close agreement between predicted and measured performance. To further improve performance-to-cost trade-offs, a hybrid Halbach array–consequent pole surface permanent magnet (HBA-CPSPM) topology is proposed and optimized using a combined design-of-experiments and multi-objective genetic algorithm framework.

The optimized design achieves reduced torque ripple and lower rare-earth magnet usage while maintaining the required torque output, as confirmed through experimental testing. In addition, a novel C-type magnet topology PMBLDC motor is introduced, utilizing axial permanent magnets to effectively harness end-winding leakage flux inherent in short-stack, large-diameter ceiling fan motors. Three-dimensional finite element analysis demonstrates enhanced flux linkage, increased torque capability, and reduced input power compared to conventional radial-flux PMBLDC configurations. To support rapid preliminary design and topology comparison, a computationally efficient composite empirical–finite element methodology is developed for Halbach and Halbach-consequent pole rotors. By introducing a flux concentration factor derived from reduced-order finite element simulations, the proposed method significantly improves air-gap flux density estimation accuracy while reducing computational effort. Overall, the research demonstrates that substantial reductions in ceiling fan power consumption can be achieved through coordinated electromagnetic design, reduced-order modeling, and targeted experimental validation. The proposed motor topologies and methodologies provide practical, manufacturable, and cost-effective pathways toward meeting current and future energy-efficiency standards for domestic ceiling fan applications.