

Abstract of Ph.D. Thesis
“Design, Development and Control of Brushless Direct Current Motor Drives for Ceiling Fan”
Mr. Amit Kumar (2017EEZ7531), Research Scholar

The development of permanent magnet brushless direct current motor (PMBLDCM) drives has focused on energy efficiency and cost reduction, owing to their superior features compared to traditional motors. PMBLDCMs offer high efficiency, high torque to weight ratio, compact size, high power density, silent operation, exceptional reliability, and minimal wear and tear, making them an ideal choice for various low to medium-power applications. These characteristics have led to their widespread use in various household appliances like ceiling fans, mixer juicers, table fans, exhaust fans, and air conditioning.

This thesis aims to develop high-frequency power factor correction (PFC) converters for cost-effective PMBLDCM drives specifically designed for low-power ceiling fan applications. The PMBLDCM relies on a three-phase voltage source inverter (VSI) for electronic commutation, which is facilitated by rotor position sensing using Hall-Effect sensors. Traditional PMBLDCM ceiling fan drive (CFD) operates on a single-phase AC supply through an uncontrolled diode bridge rectifier (DBR), passive PFC, continuous conduction mode (CCM) buck PFC, or CCM flyback PFC, combined with a high value electromagnetic interference filter and DC-link capacitor. This system draws a distorted and peaky current rich in harmonics, resulting in high total harmonic distortion (THD) and an elevated crest-factor in the supply current, leading to a poor power factor (PF) at the supply input. These high current harmonic distortions exceed the limits specified by IEC 61000-3-2 for Class D equipment. To address these issues, single-phase high-frequency AC-DC PFC converters are employed to enhance the power factor and minimize THD at the supply input.

The selection of an appropriate PFC converter for low-power PMBLDCM based CFD depends on various factors, such as the number of components in the converter, the voltage and power ratings of the motor, the need for galvanic isolation, and the overall CFD system cost and efficiency. Based on this, PFC converter configurations are categorized into five types: non-isolated high-frequency PFC converters, isolated high-frequency PFC converters, non-isolated high-frequency integrated PFC converters, isolated high-frequency integrated PFC converters, and high-frequency bridgeless non-isolated/isolated PFC converters. High-frequency bridgeless configurations are specifically designed to reduce conduction losses in the front-end high-frequency PFC converter by partially or fully eliminating the diode bridge rectifier. Additionally, the control strategy of the high-frequency PFC converter plays a crucial role in determining the overall CFD system's performance and cost. In this work, high-frequency PFC converters are designed to achieve high step-down gain with their desired operating duties and operate in discontinuous inductor current mode (DICM). The DC-link voltage of these high-frequency PFC converters is controlled using a voltage follower approach, eliminating the need for voltage and current sensors.

This work presents the analysis, design, DICM modeling, and control of buck-boost categorized high-frequency PFC converters to enhance power quality at the supply input of a PMBLDCM based CFD. A key focus is placed on simplifying control mechanisms, minimizing the number of sensors, reducing costs, and improving the overall efficiency of the CFD system. Additionally, some new configurations of single-phase high-frequency AC-DC PFC converters are proposed for powering the PMBLDCM drive used in ceiling fan applications. The speed of the PMBLDCM is controlled by adjusting the DC-link voltage of the VSI, which drives the PMBLDCM. This approach enables the VSI to operate with fundamental frequency switching, thereby reducing switching losses.

A novel sensorless control method for high-frequency AC-DC PFC converters is also developed to control the DC-link voltage. Additionally, a simple back-EMF-based sensorless control approach for the PMBLDCM is designed, allowing variable DC-link voltage control for speed change of the motor. The performance of these high-frequency PFC converters fed PMBLDCM based CFDs is validated through models created in the MATLAB/Simulink environment. Experimental verification is also conducted using a laboratory-developed hardware prototype of the sensorless high-frequency PFC converters feeding PMBLDCM based CFD. Performance evaluation encompasses steady-state performance at different operating speeds, dynamic performance during speed change, and robustness against supply voltage fluctuations at the AC supply input. Steady-state analysis includes the voltage and current key waveforms of high-frequency PFC converter components (MOSFET switch, inductor, high-frequency transformer, diode, and capacitor) to establish component selection criteria. Furthermore, the presented high-frequency PFC converters demonstrate compliance with power quality standards, maintaining supply current harmonic distortion within limits specified by IEC 61000-3-2 for Class D. These findings underscore the potential of the presented high-frequency PFC based PMBLDCM drives as energy-efficient, cost-effective, and high-performance solutions for ceiling fan applications.