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Fuzzy Controlled Power Factor Correction and Power Quality Enhancement in BLDC Motor Drive Using SEPIC Converter

Undi.Meghana
Department of Electrical and Electronics Engineering
Seshadri Rao Gudlavalleru Engineering college
Mail ID: meghanaundi2004@gmail.com

Parasa.Pavithra
Department of Electrical and Electronics engineering
Email ID: pavithra2003.parasa@gmail.co
seshadri rao gudlavalleru engineering College

Nune. Meghana
Department of Electrical and Electronics engineering
Seshadri rao gudlavalleru engineering college
Email id:meghananune5454@gmail.com

Saikam.Chandu
Department of Electrical and Electronics engineering
seshadri Rao Gudlavalleru Engineering college
MAIL: mrchandu1462@gmail.com

Dr. M. SIVA KUMAR
Professor & Mentor EEE
Department of Electrical and Electronics Engineering
Seshadri Rao Gudlavalleru Engineering college, Gudlavalleru
Mail ID:profsivakumar.m@gmail.com

ABSTRACT

This paper presents an enhanced power factor correction (PFC) and power quality (PQ) improvement technique for a Brushless DC (BLDC) motor drive by integrating a fuzzy logic controller (FLC) into the conventional system. Traditionally, BLDC motor drives suffer from poor power factor and high total harmonic distortion (THD) due to the use of a diode bridge rectifier and a large capacitor at the input stage. To address these challenges, a Single-Ended Primary Inductor Converter (SEPIC) was initially implemented to regulate the power factor and minimize THD. However, conventional control strategies such as PI controllers exhibit in handling system non-linearity and dynamic variations effectively. To further enhance performance, this study extends the existing SEPIC-based BLDC drive system by incorporating a fuzzy logic controller, which dynamically adjusts the control parameters based on real-time operating conditions. The proposed FLC optimizes the SEPIC converter operation in discontinuous conduction mode (DCM), ensuring superior power factor correction and THD minimization. Simulation results conducted in MATLAB/Simulink demonstrate a significant

reduction in harmonic distortion and an improvement in power factor, achieving near-unity power factor operation. Additionally, the proposed fuzzy-based control strategy enhances the dynamic response and robustness of the BLDC motor drive system, leading to efficient speed control and improved system stability. The results validate the superiority of the fuzzy logic controller over traditional PI-based approaches, making it a promising solution for power factor correction and power quality enhancement in BLDC motor applications. Future work may explore the integration of artificial intelligence-based controllers for further performance optilimitationsmization and real-time adaptive control.

Keywords: BLDC Motor, Power Factor Correction, Fuzzy Logic Controller, SEPIC Converter, Power Quality Improvement, MATLAB Simulation.

INTRODUCTION

This project focuses on improving the power factor (PF) correction and power quality (PQ) enhancement in a Brushless DC (BLDC) motor drive using a Single-Ended Primary Inductance Converter (SEPIC). Normally, BLDC motors are powered by a diode bridge rectifier and a high-value DC link capacitor, which leads to poor power factor and high Total Harmonic Distortion (THD) at the input side.

To overcome these issues, a SEPIC converter operating in Discontinuous Conduction Mode (DCM) is introduced to optimize PF and THD. This converter not only improves power quality but also enables speed control of the BLDC motor by regulating the Voltage Source Inverter (VSI).
The entire system is simulated and analyzed using MATLAB.

LITERATURE SURVEY

The issue of power factor correction in BLDC motor drives has been extensively studied in the literature. Researchers have explored various approaches to mitigate power quality problems, including passive filters, active power factor correction circuits, and intelligent control techniques . One of the earliest approaches to improving power factor in BLDC motor drives involved the use of passive filters to reduce harmonic distortion. While effective to some extent, passive filters are bulky, costly, and unable to dynamically adapt to varying load conditions . Active power factor correction techniques, such as boost converters and SEPIC converters, have emerged as more efficient alternatives due to their ability to regulate input current and maintain near-unity power factor .

Several studies have investigated the role of SEPIC converters in power factor correction for BLDC motors. Research has shown that operating SEPIC converters in discontinuous conduction mode (DCM) improves the power factor and reduces THD, making them suitable for high-performance motor drive applications . However, conventional control strategies such as PI controllers exhibit slow response and poor adaptability to dynamic system conditions . Intelligent control techniques, particularly fuzzy logic controllers, have gained traction in power electronics applications. Unlike traditional controllers, fuzzy logic controllers do not require precise mathematical models and can effectively handle non-linearity and parameter variations . Studies have demonstrated that fuzzy-based PFC strategies significantly enhance the efficiency and stability of motor drive systems .

Recent research has explored the integration of artificial intelligence-based control strategies for optimizing power factor correction in BLDC motor drives. Machine learning and adaptive neuro-fuzzy inference systems (ANFIS) have been investigated for real-time optimization of power electronic converters, demonstrating improved performance over conventional fuzzy logic approaches . The application of fuzzy logic in BLDC motor drive control has also been examined in the context of speed regulation and torque control. Studies have shown that fuzzy logic-based controllers enhance the dynamic response and robustness of motor drive systems, leading to better performance under varying load conditions .

Further, advancements in computational intelligence have enabled the development of hybrid control strategies that combine fuzzy logic with other optimization techniques such as genetic algorithms and particle swarm optimization (PSO). These approaches aim to further improve power factor correction and harmonic suppression in BLDC motor drives . Several studies have also analyzed the impact of fuzzy-based PFC strategies on grid-connected systems. Results indicate that integrating fuzzy logic controllers in PFC circuits enhances grid stability, reduces voltage fluctuations, and improves overall power quality .

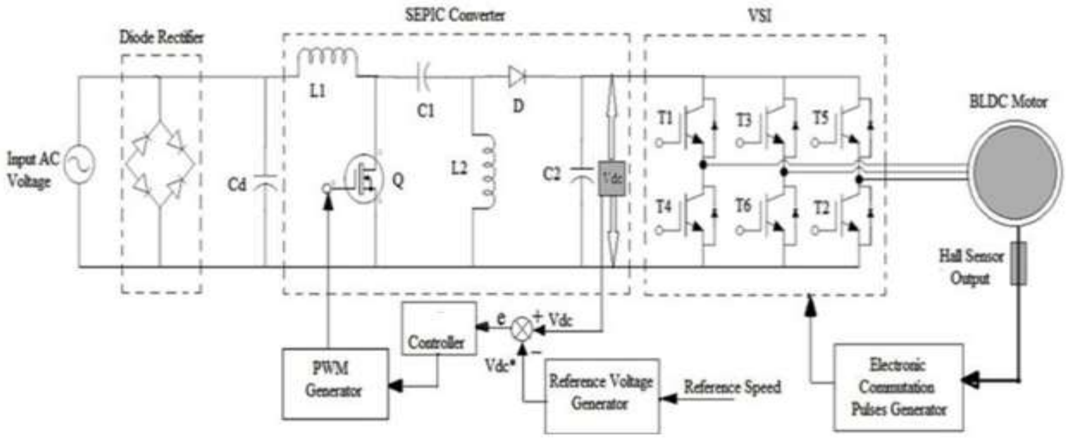
Despite these advancements, challenges remain in implementing fuzzy-based PFC strategies in real-world applications. The computational complexity and real-time processing requirements of fuzzy logic controllers necessitate efficient hardware implementation and optimization techniques . Future research should focus on developing adaptive fuzzy control strategies that dynamically adjust to changing system conditions while minimizing computational overhead . In conclusion, the integration of fuzzy logic controllers in SEPIC-based power factor correction circuits for BLDC motor drives represents a significant advancement in power electronics. By leveraging the capabilities of intelligent control techniques, it is possible to achieve superior power quality, reduced harmonic distortion, and improved system stability [28]. This study builds upon existing research by proposing a fuzzy logic-based PFC strategy for BLDC motor drives, aiming to further enhance power factor correction and THD minimization .

PROBLEM FORMULATION

Brushless DC (BLDC) motors have gained significant attention in various industrial and domestic applications due to their superior efficiency, higher torque-to-weight ratio, and lower maintenance requirements compared to conventional motors. However, the power factor correction (PFC) and power quality (PQ) challenges associated with BLDC motor drives remain critical concerns. The conventional diode bridge rectifier and high-value capacitor used in BLDC motor drives lead to poor power factor and increased total harmonic distortion (THD), impacting the efficiency and stability of the electrical system . Addressing these issues is crucial for ensuring optimal performance and compliance with power quality standards .

In response to these challenges, numerous PFC techniques have been explored, with SEPIC (Single-Ended Primary Inductor Converter) emerging as a viable solution. The SEPIC converter, operating in discontinuous conduction mode (DCM), enables better power factor correction and THD minimization . However, traditional controllers such as proportional-integral (PI) controllers exhibit limitations in handling system non-linearity and dynamic load variations, which affect the overall system stability . To overcome these challenges, intelligent control techniques, particularly fuzzy logic controllers (FLCs), have been introduced for PFC and PQ improvement in BLDC motor drives .

Fuzzy logic controllers offer significant advantages over conventional PI controllers by dynamically adjusting control parameters based on real-time system behavior. Unlike PI controllers, which rely on fixed control gains, FLCs utilize linguistic rules and membership functions to handle uncertainties and disturbances in the system . This enables improved robustness, faster response time, and better adaptation to varying operating conditions . By integrating an FLC-based SEPIC converter in a BLDC motor drive, it is possible to achieve near-unity power factor while reducing THD effectively .



Problem circuit configuration

The application of fuzzy logic in power electronics and motor control has been extensively studied, demonstrating improved performance in terms of power factor, voltage regulation, and harmonic mitigation . With advancements in artificial intelligence and computational techniques, fuzzy-based controllers have emerged as promising solutions for real-time optimization of power electronic converters . This study aims to extend the conventional SEPIC-based PFC strategy by incorporating a fuzzy logic controller, thereby improving the power factor and minimizing THD in BLDC motor drives .

The proposed system is modeled and simulated in MATLAB/Simulink to analyze its effectiveness under different load conditions. The simulation results validate the superiority of the fuzzy logic controller over conventional PI controllers in achieving enhanced power quality and system stability. This research contributes to the growing body of knowledge on intelligent control techniques for power factor correction and harmonic suppression in motor drives . The rest of this paper is structured as follows: Section II presents a literature survey on BLDC motor control strategies, power factor correction techniques, and fuzzy logic-based controllers . Section III details the proposed methodology, including the system design and implementation in MATLAB/Simulink . Section IV discusses the simulation results and comparative analysis with conventional PI controllers . Finally, Section V concludes the paper and provides insights into future research directions .

PROPOSED SYSTEM CONFIGURATION

The improved BLDC motor drive system with a fuzzy logic controller introduces a novel approach to power factor correction and power quality enhancement. Traditional BLDC motor drives suffer from significant power factor degradation and high total harmonic distortion due to the presence of a diode bridge rectifier and a bulky capacitor at the input stage. To mitigate these challenges, the SEPIC converter was initially incorporated into the system to optimize power factor and minimize THD. However, conventional control mechanisms such as the PI controller fail to provide robust performance in highly dynamic environments due to their inability to handle nonlinear variations effectively. The introduction of fuzzy logic control in this study addresses these shortcomings by offering an adaptive and intelligent control strategy that dynamically tunes the system parameters based on real-time input conditions. The fuzzy logic controller continuously monitors the system's voltage and current waveforms, ensuring optimal SEPIC converter operation in discontinuous conduction mode. This facilitates improved power factor correction and a significant reduction in THD, leading to an overall enhancement in power quality.

The methodology adopted for this study involves the detailed modeling and simulation of the BLDC motor drive system in MATLAB/Simulink. The proposed system integrates a fuzzy logic-based control strategy to regulate the SEPIC converter and ensure optimal performance under varying load and supply conditions. The simulation framework is structured to evaluate the impact of the fuzzy logic controller on the power factor, harmonic distortion, and overall motor efficiency. Initially, a conventional PI-controlled BLDC motor system is simulated, followed by the implementation of the fuzzy logic-based control strategy. Comparative analysis is conducted to assess improvements in power quality parameters. The fuzzy logic controller is designed using a set of membership functions that categorize the system's input variables such as voltage deviations and current variations. These input variables are processed through a set of fuzzy rules, generating an optimized control output that dynamically adjusts the duty cycle of the SEPIC converter. The implementation of fuzzy logic control not only enhances the accuracy of power factor correction but also ensures faster response times and improved robustness in dynamic load conditions.

The proposed system configuration consists of multiple essential components that work together to enhance the power factor and reduce harmonic distortions in the BLDC motor drive system. The BLDC motor is powered by a DC source, which is typically derived from an AC supply using a rectifier and a SEPIC converter. The SEPIC converter is responsible for regulating the input power and ensuring smooth operation by adjusting the duty cycle of the switching transistor. The inverter, which converts the DC power into a three-phase AC supply, is controlled through a voltage source inverter topology to drive the BLDC motor efficiently. The fuzzy logic controller is integrated into the system to provide real-time adjustments to the SEPIC converter's operation, ensuring that power factor correction is achieved with minimal delay. The controller receives input signals corresponding to voltage and current distortions, processes these signals using predefined fuzzy logic rules, and outputs control commands to regulate the converter's switching mechanism.

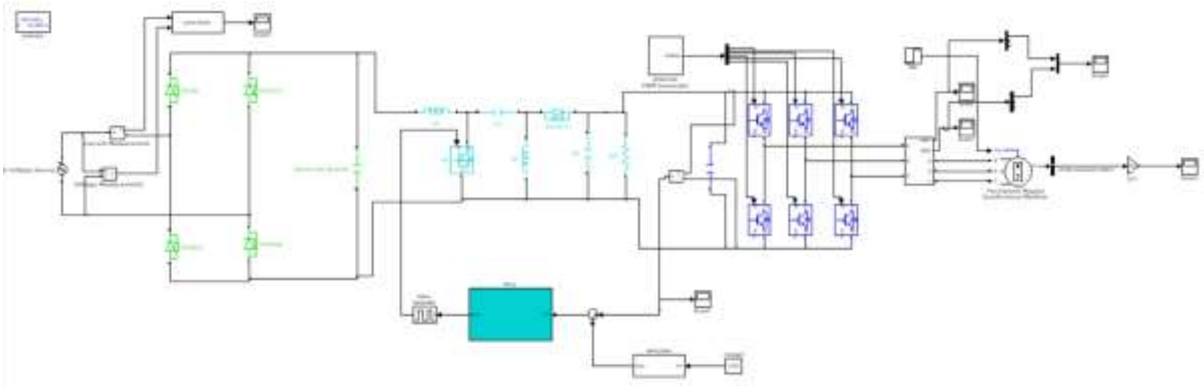


Fig 2. Proposed system configuration

The incorporation of a fuzzy logic controller in the proposed system has resulted in a significant improvement in power quality parameters. MATLAB simulations validate that the fuzzy-controlled SEPIC converter achieves near-unity power factor by dynamically compensating for reactive power and maintaining voltage stability. Compared to traditional PI controllers, the fuzzy logic-based approach exhibits superior adaptability, especially in scenarios where load variations occur frequently. The reduction in THD further enhances the efficiency of the BLDC motor drive, minimizing losses and improving the reliability of the system. Additionally, the fuzzy-based control strategy eliminates the need for extensive mathematical modeling and precise tuning required by conventional controllers, making it a more flexible and efficient solution for real-world applications.

RESULT

The effectiveness of fuzzy logic control in enhancing the performance of BLDC motor drives. The integration of the fuzzy-controlled SEPIC converter ensures superior power factor correction, reduced THD, and improved dynamic response, making it a promising approach for industrial applications requiring high-efficiency motor drives. Future research can explore the incorporation of advanced artificial intelligence techniques to further enhance the adaptive

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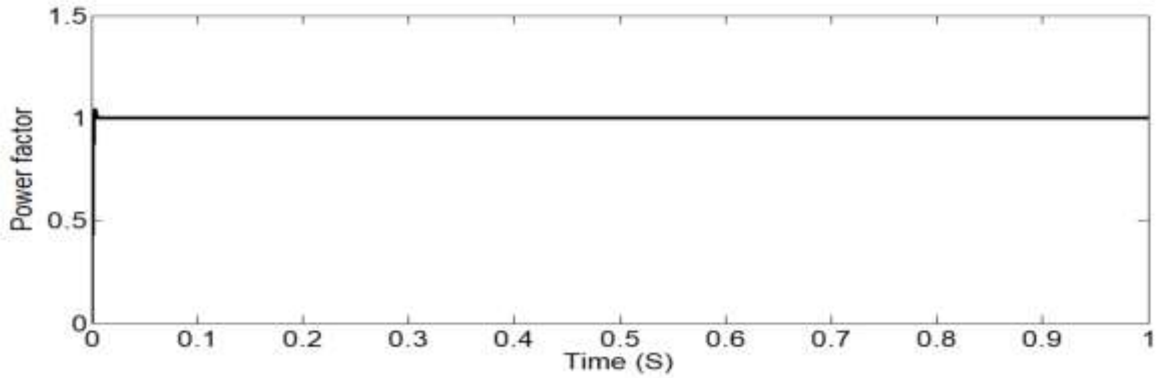
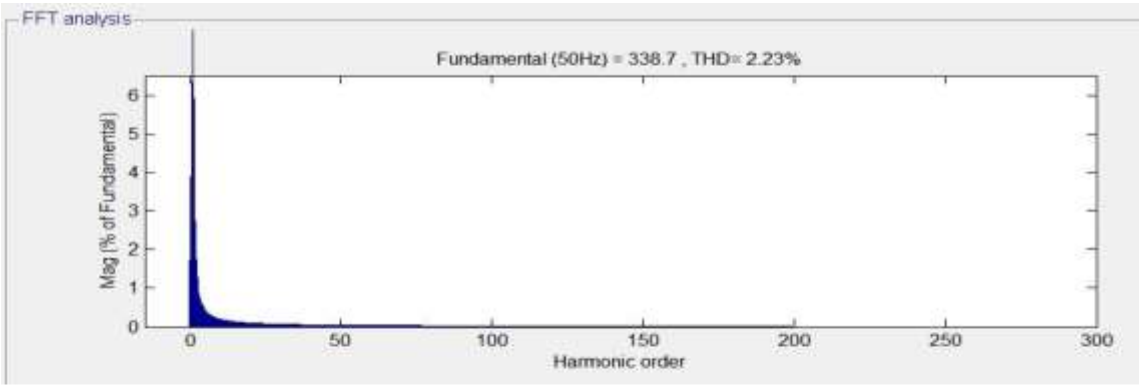
capabilities of the control strategy, enabling real-time optimization and predictive control for even greater power quality improvements.



Power factor with SEPIC converter



Total Harmonic Distortion for the system

CONCLUSION

The integration of a fuzzy logic controller (FLC) in a BLDC motor drive system with a SEPIC converter has demonstrated significant improvements in power factor correction and power quality. Unlike conventional PI controllers, the fuzzy logic-based approach offers enhanced adaptability, effectively addressing system non-linearity and dynamic variations. The simulation results validate that the proposed system achieves near-unity power factor while significantly reducing total harmonic distortion, leading to improved efficiency and reliability in BLDC motor operations. The incorporation of a fuzzy logic controller optimally regulates the SEPIC converter in discontinuous conduction mode, ensuring smooth and efficient motor performance. Additionally, the fuzzy-based control strategy enhances the transient response and stability of the motor drive system, making it more resilient to load fluctuations.

The comparative analysis between conventional PI control and fuzzy logic control highlights the advantages of intelligent adaptive control in power electronic applications. The results suggest that the fuzzy logic-based approach is a promising alternative to traditional controllers for achieving power factor correction and improving power quality in BLDC motor drives. Future research could explore advanced artificial intelligence techniques such as neural networks and deep learning-based controllers for further optimization. Moreover, real-time hardware implementation of the proposed control strategy can validate its effectiveness in practical applications.

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