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Design and Fabrication of an Inductive Motor with Spike Suppression Mechanism for Power-On Stability

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ABSTRACT: This study focused on the design and development of an inductive motor equipped with a spike suppression mechanism to address the challenges of power surges during startup, enhance energy efficiency, and improve operational reliability. Inductive motors, widely used in industrial and residential applications, often face issues with electrical spikes that compromise their efficiency and lifespan. The developed motor controller system integrates an inverter circuit and spike suppression mechanism, resulting in significant improvements in minimizing peak current, reducing energy consumption, and preventing mechanical failures.

The research followed a systematic process, starting with material selection and procurement, followed by conceptual design, fabrication, and testing. The final system was tested under two configurations: direct circuit and inverter circuit. Results demonstrated that the inverter configuration significantly reduced the peak current from 8 amperes to 2 amperes and the running current from 1.5 amperes to 0.4 amperes, showcasing the system's economic and operational benefits. The design also includes a PCB layout for optimized power regulation using PWM and IGBT modules.

This study provides a practical solution to energy inefficiencies and operational instabilities in water-pumping systems and lays a strong foundation for future innovations in motor control technologies. Recommendations for improvement include integrating advanced algorithms, real-time monitoring, and user-friendly interfaces to expand the system's adaptability and performance.

KEYWORDS: Motor Controller, Insulated Gate Bipolar Transistor (IGBT), Inverter Circuit, 3 Phase AC Motor, Suppression Mechnanism.

I. INTRODUCTION

Inductive motors are essential components in both industrial and residential applications, offering reliability and efficiency for various tasks. In households, these motors are commonly used for water-pumping systems, such as transporting water to rooftop tanks or reservoirs. However, despite their extensive use, a persistent challenge remains: the occurrence of electrical spikes during power-on. These spikes not only pose a risk to the motor's components but can also lead to reduced efficiency, equipment failure, and increased operational instability. This issue is particularly concerning in regions where energy resources are limited and systems must operate under stringent conditions (Smith & Johnson, 2020).

The rising energy demands in both household and industrial sectors exacerbate the need for more efficient and reliable motor technologies. The widening gap between energy supply and demand has prompted engineers and researchers to focus on innovative designs that enhance energy utilization while minimizing inefficiencies (Doe & Brown, 2021). Since the mid-1970s, the introduction of energy-efficient motors (EEMs) has contributed to addressing these concerns, with significant advancements over standard efficiency motors (STMs). EEMs offer better performance and reliability through optimized design, advanced materials, and precise manufacturing techniques (Taylor et al., 2020). However, despite these advancements, challenges such as power-on spikes have not been adequately addressed in most existing designs (Green & White, 2019).

This research focuses on the design and fabrication of an inductive motor equipped with a spike suppression mechanism. The primary objective is to enhance power-on stability while maintaining energy efficiency and operational

Reliability. By integrating this mechanism, the design aims to protect the motor and its connected systems from electrical

Surges, thereby improving overall performance and extending the motor's lifespan. Such advancements not only benefit individual users but also contribute to broader energy conservation efforts and sustainable technology practices. This study is expected to bridge the gap between existing motor technologies and the pressing need for innovative solutions to address energy efficiency and stability in real-world applications.

Objectives of the Study

The primary objective of this study is to develop a more efficient household water pumping system by designing and fabricating an inductive motor equipped with a spike suppression mechanism. This system aims to address common issues such as high electrical consumption during startup and current spikes that may lead to mechanical failures and increased maintenance. By incorporating innovative technologies, the study seeks to enhance the reliability, efficiency, and sustainability of water pumping systems for household use.

Specifically, this study aims to:

1. Design and fabricate an inductive motor integrated with a spike suppression mechanism to improve energy efficiency during startup and minimize high current surges.
2. Assess the economic benefits of the system by evaluating its reduced energy consumption compared to standard motor designs.
3. Analyze the effectiveness of the spike suppression mechanism in preventing mechanical switching failures, thus reducing maintenance requirements.

II. METHODS

The researchers began by identifying the materials required for their prototype. Once identified, the materials were procured through online platforms and local stores, ensuring their availability. The study followed a systematic approach encompassing several key steps: planning, problem formulation and identification, and concept development through theoretical analysis. Figure 1 illustrates the comprehensive process undertaken in this study.

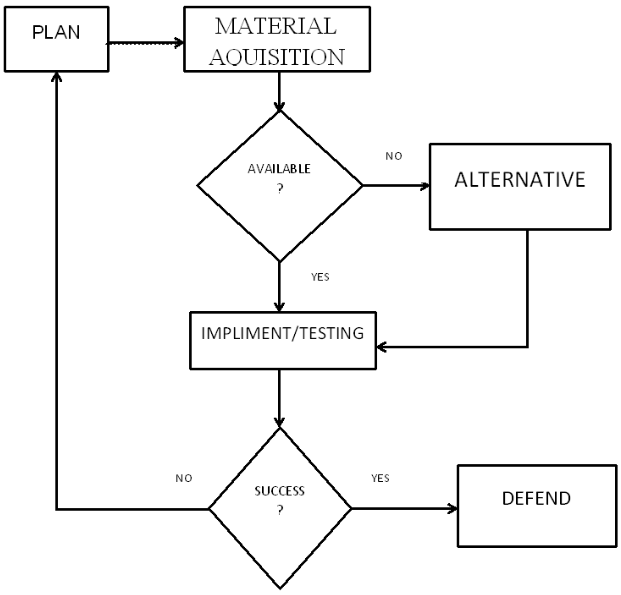

Fig 1. Block diagram of the conceptual framework

Variables and Design

In alignment with the study's objectives, the variables examined include the electric power (kW) consumed by the pump, efficiency (%), service life (years), value for money (in PHP), and the performance of the inverter system. These variables are critical in assessing the overall functionality, reliability, and cost-effectiveness of the proposed design.

The design primarily focuses on hardware components, with no software implementation involved. A 0.25 HP single-phase permanent split induction motor serves as the core of the system. This motor is connected to a soft-start inverter, which is integral to reducing power surges during operation and ensuring a stable performance.

The inverter system is a key component of the design and comprises several submodules. These include a power converter circuit, pulse-width modulation (PWM) modules, insulated-gate bipolar transistor (IGBT) modules, and IGBT drivers. Together, these elements work to regulate the motor's startup and operation, optimizing power usage and extending the service life of the motor. The integration of these components ensures the system's efficiency and aligns with the study's goal of minimizing energy consumption while enhancing reliability and cost-effectiveness. Figure 2 shows the block diagram.

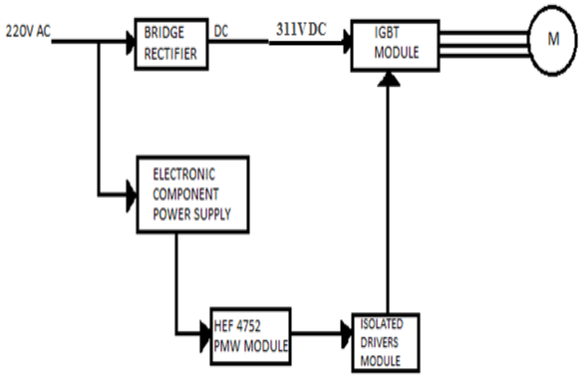

Fig 2. Block diagram of the prototype

Power Supply

The power supply for the system is managed by an inverter that plays a critical role in energy conversion and regulation. The process begins with the inverter converting the standard 220 volts AC power source into DC power using a bridge rectifier. This rectified DC output serves as the primary input for the insulated-gate bipolar transistor (IGBT), a key component in controlling the motor's operation.

The IGBT is managed by a combination of pulse-width modulation (PWM) and driver modules. These modules adjust the frequency and voltage of the DC power supplied to the IGBT, enabling precise control over the motor's performance. By varying the frequency through the PWM system, the inverter creates a synthesized AC power output from the DC supply, which is then utilized by the motor. This synthesized AC effectively mimics the characteristics of the original AC power source, allowing the motor to operate efficiently.

This design not only ensures stable power delivery to the motor but also helps in reducing energy spikes and enhancing the overall performance of the system. By leveraging this conversion process, the inverter contributes significantly to achieving the study's objectives of minimizing power surges, improving energy efficiency, and ensuring reliable operation. Figure 3 shows the power supply design.

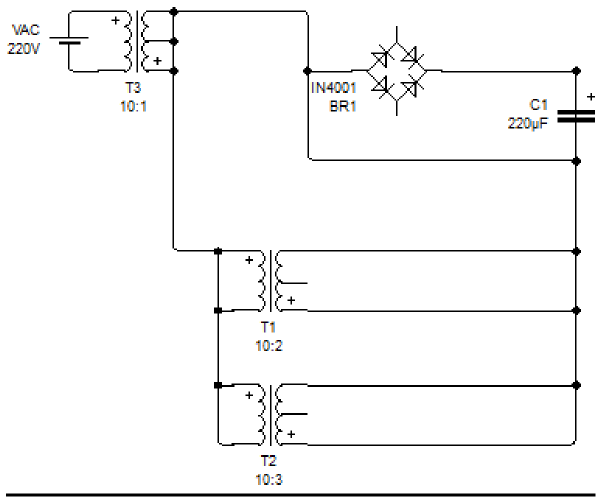

Fig 3. Power Supply Using 3 Transformers

PCB Design Layout

The Printed Circuit Board (PCB) design was created using ExpressPCB software, which was recommended by the researchers’ adviser due to its accessibility and user-friendly interface. The researchers opted to use single-sided PCBs for the design, as double-sided PCBs were deemed too complex and challenging to handle within the scope of this study.

The PCB layout process involved printing the designs onto stencils, which were then applied to the PCBs in a mirrored orientation to ensure the accurate placement of components. This method facilitated a precise and efficient transfer of the layout design onto the board.

Figure 4 illustrates the driver module prepared for the PCB layout, while Figure 5 presents the layout for the pulse-width modulation (PWM) module. These components are integral to the system's functionality, contributing to the regulation of power and ensuring the smooth operation of the motor. By using this approach, the researchers achieved a practical and effective design that aligns with the study's objectives of creating an efficient and reliable system.

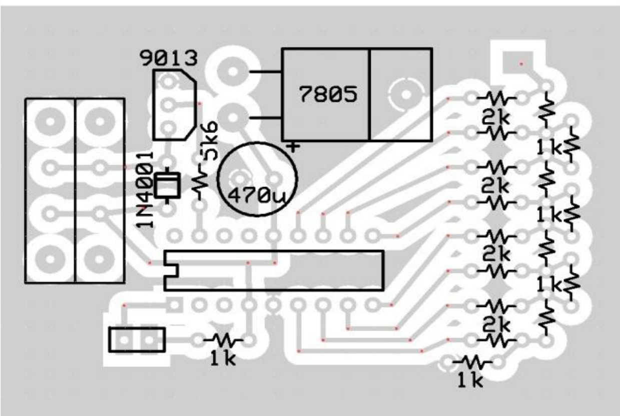

Fig 4. Showing the driver module to be printed on PCB

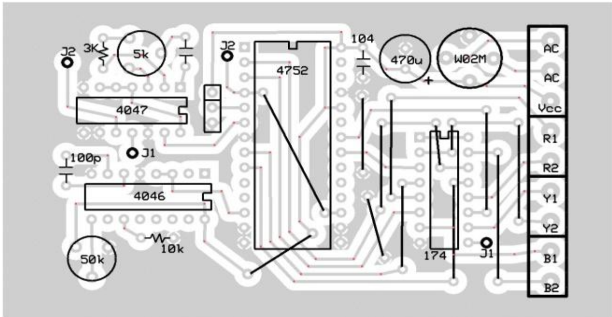

Fig 5. The Pulse Width Modulation (PWM)

Assembly and Fabrication

After the PCB has been processed, all necessary electronic parts and components are populated

Test Results

The designed motor controller was tested and demonstrated full functionality, providing users with two operational options to suit different needs. The first option is a direct circuit outlet, which operates without the system's spike suppression mechanism and inverter functionality. The second option utilizes the inverter circuit, which incorporates the spike suppression mechanism control system for enhanced efficiency and performance.

When the motor was tested using the direct circuit outlet, it exhibited a peak current of 8 amperes during startup and a running current of 1.5 amperes during operation. In comparison, the motor running through the inverter circuit showed a significantly reduced peak current of 2 amperes and a running current of 0.4 amperes. This demonstrates that the inverter circuit effectively minimizes energy consumption, particularly during startup, where current spikes typically occur.

The results indicate that the inverter circuit provides substantial energy savings and improved efficiency compared to the direct circuit option. These findings confirm the economic advantages of the system, especially in reducing power usage during startup phases. By integrating the inverter circuit, spike suppression mechanism as controller achieves its objective of enhancing energy efficiency while maintaining reliable performance, making it a practical and cost-effective solution for household and industrial applications.

III. RESULTS AND DISCUSSIONS

The final end-product successfully met the researchers' expectations, achieving the desired functionality and efficiency outlined in the study objectives. The design demonstrates a seamless operation, allowing the motor to run effectively while providing an innovative solution to traditional mechanical challenges. As illustrated in the figure, the motor can be electronically switched 'ON' by the operator, eliminating the need for manual mechanical interventions that often lead to inconvenience or potential wear and tear over time.

This electronic switching mechanism enhances the overall usability of the system, ensuring a smoother and more reliable user experience. By integrating advanced features such as the inverter circuit and spike suppression mechanism controls, the final product addresses common issues such as startup power surges and mechanical failures, further reinforcing its reliability and economic efficiency. The achievement of these design goals validates the effort invested in the conceptualization, fabrication, and testing phases of the project, paving the way for future applications and improvements in motor control technologies. Figure 6 shows the appearance of the system setup.

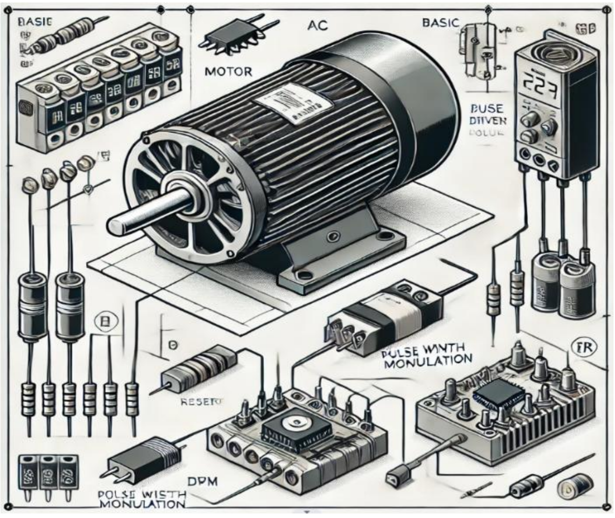

Fig 6. Actual Appearance of the System

The researcher conducted testing using test instruments to further investigate the results of the spike suppression mechanism.

Figure 7 illustrates the findings. The top graph, without a spike suppression mechanism, shows high-amplitude voltage spikes exceeding 200V, caused by the rapid collapse of the magnetic field in an inductive load during switching. These sharp transients pose significant risks to circuit components, generating noise and potential damage. In contrast, the bottom graph, with a suppression mechanism, demonstrates reduced spike amplitudes and smoother transitions. This partial suppression is achieved as the mechanism absorbs and dissipates some of the transient energy, thereby improving voltage stability. However, residual spikes persist, suggesting the need for further optimization.

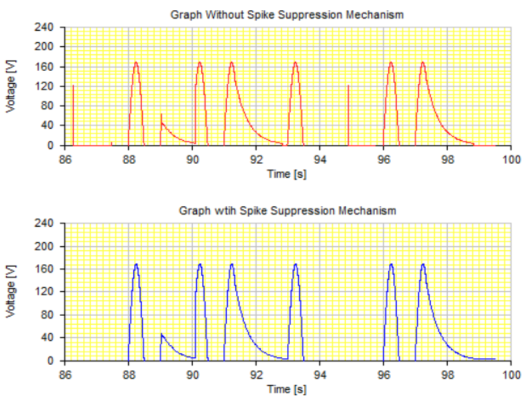

Fig 7. Actual Result Graph

CONCLUSION

Electric motors are integral to daily life, playing a vital role in both household and industrial activities. In households, electric motors are primarily used for water distribution to tank reservoirs, consuming more electrical energy than most appliances. This high energy demand can exacerbate issues of uneven energy distribution and disparities between supply and demand.

To address these challenges, the study successfully designed and developed an inductive motor with a spike suppression mechanism. The motor incorporates advanced components, including an inverter circuit and control systems, which effectively reduce peak current, minimize energy consumption, and prevent mechanical failures. These innovations enhance energy efficiency and operational reliability, particularly in household and industrial water-pumping applications.

The findings validate the design's ability to improve motor performance while maintaining ease of use and low maintenance requirements. By offering a practical and energy-efficient solution to common motor-related issues, the system addresses the growing need for sustainable technologies. Furthermore, the study provides a foundation for future research, supporting the development of advanced motor control systems to tackle emerging challenges and meet diverse user needs.

RECOMMENDATION

To further enhance the effectiveness and applicability of the study, the following recommendations are proposed. These suggestions aim to improve the design, functionality, and overall impact of the motor controller system. By addressing potential limitations and exploring additional features, future studies can refine and expand upon the existing framework, contributing to more innovative and sustainable motor technologies.

1. **Integration of Advanced Control Algorithms:** Incorporate advanced control algorithms, such as artificial neural networks or adaptive control systems, to further optimize the motor's performance and energy efficiency.
2. **Testing Under Diverse Load Conditions:** Conduct extensive testing of the motor controller system under various load conditions and environments to assess its reliability and adaptability in different scenarios.
3. **Improvement of User Interface:** Develop a user-friendly control interface, such as a touchscreen or mobile application, to enhance the accessibility and ease of operation for end-users.
4. **Incorporation of Real-Time Monitoring:** Include real-time monitoring features, such as sensors and data loggers, to track the motor's performance, energy consumption, and operational health for predictive maintenance.
5. **Evaluation of Long-Term Cost-Effectiveness:** Perform a detailed cost-benefit analysis to evaluate

the long-term economic benefits of the system compared to conventional motor controllers, providing valuable insights for potential adopters.

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