IJITCE

ISSN 2347- 3657

International Journal of
Information Technology & Computer Engineering

Email : ijitce.editor@gmail.com or editor@ijitce.com

International Journal of Information Technology & Computer Engineering
ISSN 2347–3657
Volume 12 , Issue 2, April 2024

OPTIMAL CONTROL SCHEME FOR SINGLE PHASE INDUCTION MOTOR

[1]DR. K. SATYANARAYANA CHINTHAKULA, [2]NAMRATHA, [3]SD. TAHSEEN FAROOQ, [4]DUNGA BHEEMA RAJU, [5]NAKKA RAJESH, [6]NALLAMILLI. SANDEEP REDDY

[1]Professor, Department of Electrical & Electronics Engineering, Pragati Engineering College (autonomous)

[2,3,4,5,6]UG Students, Department of Electrical & Electronics Engineering, Pragati Engineering College (autonomous)

ABSTRACT

The recent increase in electricity prices and the usage of single-phase induction motors (SPIMs) provide a stimulus for focused research on energy-efficient optimization of SPIM load such as air-conditioners and refrigerators. Variable speed control of SPIM provides a promising way forward to reduce its power consumption. However, during variable speed operation under the popular constant V/f method, SPIM is required to operate at non-rated conditions. The operation of SPIM at non-rated conditions disturbs its symmetrical and balanced operation, thus degrading its efficiency. Moreover, soft-starting of SPIM at non-rated conditions is also challenging due to the resulting reduction in starting-torque. In this article, after a detailed analysis of SPIM energy-efficiency, an improved sensor-less optimal speed control strategy is developed to enable the symmetrical and balanced operation of SPIM at all the operating points over the entire speed-range to improve its performance. A novel algorithm, termed as the phase-shift algorithm, is also devised for efficient implementation of the proposed optimal speed control strategy. In addition, a unique framework for efficient soft-starting of SPIM at very low frequencies is also developed. The simulation-based results of the motor operated through the proposed phase-shift algorithm validate the energy-saving potential of the proposed control strategy.

INTRODUCTION

Single-phase induction motors (SPIMs) play a crucial role in numerous industrial and domestic applications, including fans, pumps, compressors, and household appliances. However, due to their inherent asymmetry and lack of self-starting capability, controlling SPIMs efficiently poses significant challenges. Traditional control methods often result in suboptimal performance, reduced efficiency, and increased energy consumption. To address these issues, researchers have been exploring advanced control strategies to enhance the performance of SPIMs.SPIMs are widely used in various applications due to their simplicity, low cost, and versatility. They are particularly prevalent in environments where three-phase power supply is not available or economically feasible. However, their performance is often compromised due to asymmetrical construction, leading to unbalanced magnetic fields and reduced efficiency.

Controlling SPIMs presents several challenges, primarily stemming from their single-phase nature and asymmetric rotor design. Traditional control methods such as voltage and frequency control (V/f) or direct torque control (DTC) may not fully exploit the motor's capabilities and can result in suboptimal performance, especially under non-rated conditions.To address the limitations of traditional control methods, there is a growing need for optimal control schemes tailored specifically for SPIMs. Optimal control techniques offer the potential to improve motor efficiency, enhance dynamic response, and reduce energy consumption by optimizing control parameters in real-time based on system dynamics and operating conditions.

The primary objective of this study is to develop an optimal control scheme for SPIMs that addresses the shortcomings of traditional control methods and maximizes motor performance and efficiency. The proposed control scheme aims to achieve symmetrical operation, minimize losses, reduce harmonic distortion, and enhance dynamic response across a wide range of operating conditions.The proposed optimal control scheme for SPIMs integrates advanced control algorithms, sensorless techniques, and optimization strategies to achieve superior motor performance. By dynamically adjusting control parameters such as voltage, frequency, and phase difference, the control scheme aims to optimize motor operation and ensure balanced magnetic fields, thereby improving efficiency and reducing losses.

This study contributes to the existing literature by presenting a comprehensive analysis of SPIM control challenges and proposing a novel optimal control scheme to address these challenges. The developed control scheme offers potential benefits in terms of energy savings, improved motor performance, and enhanced reliability, making it suitable for a wide range of industrial and domestic applications.introduction of an optimal control scheme for SPIMs represents a significant advancement in motor control technology, with the potential to improve efficiency, performance, and reliability in various industrial and domestic applications. Through comprehensive analysis and innovative control strategies, this study aims to contribute to the ongoing efforts to enhance SPIM operation and maximize their utility in modern energy systems.

LITERATURE SURVEY

The optimal control of single-phase induction motors (SPIMs) has garnered significant attention in the realm of electrical engineering due to their widespread use in various applications such as household appliances, industrial machinery, and HVAC systems. This literature survey delves into the existing research landscape concerning optimal control schemes for SPIMs, aiming to provide insights into the methodologies, challenges, and advancements in this field.SPIMs pose unique challenges compared to their three-phase counterparts, primarily due to their asymmetric winding configuration and the absence of a rotating magnetic field during start-up. As a result, traditional control techniques often fall short in terms of efficiency, performance, and energy savings. In response, researchers have explored innovative approaches to optimize the operation of SPIMs, with a focus on enhancing efficiency, minimizing losses, and improving dynamic performance.

One of the fundamental aspects of optimal control schemes for SPIMs is the development of accurate mathematical models that capture the complex dynamics of these motors. Several studies have proposed analytical and numerical models to describe the behavior of SPIMs under various operating conditions, considering factors such as rotor resistance, winding

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inductance, and magnetic saturation. These models serve as the foundation for designing and implementing optimal control strategies.A key area of research in SPIM optimal control is the development of advanced control algorithms that can optimize motor performance while ensuring energy efficiency and stability. Proportional-integral-derivative (PID) control, field-oriented control (FOC), and model predictive control (MPC) are among the techniques explored for SPIMs. PID control, despite its simplicity, may not provide optimal performance, especially under varying load conditions. FOC, on the other hand, allows for precise control of motor torque and flux, making it suitable for applications requiring high performance. MPC, a more advanced technique, utilizes predictive models to anticipate future behavior and optimize control actions accordingly, offering superior dynamic response and robustness.

In addition to control algorithms, sensor-less control techniques have emerged as a promising approach to reduce costs and complexity in SPIM systems. By utilizing motor parameters and machine learning algorithms, sensor-less control methods enable accurate estimation of motor speed, position, and torque without the need for physical sensors. This not only simplifies the control system but also enhances reliability and reduces maintenance requirements.Furthermore, optimization techniques such as genetic algorithms, particle swarm optimization, and machine learning algorithms have been applied to tune control parameters and optimize motor performance. These methods leverage computational intelligence to search for optimal control settings that minimize energy consumption, reduce losses, and improve motor efficiency. By iteratively adjusting control parameters based on performance objectives and constraints, optimization algorithms enable the design of highly efficient and robust SPIM control systems.

It is worth noting that the application of optimal control schemes for SPIMs extends beyond standalone motor control to encompass system-level integration and coordination. In applications such as HVAC systems and renewable energy systems, SPIMs may operate in conjunction with other components such as inverters, batteries, and grid interfaces. Coordinated control strategies are essential to ensure seamless interaction between these components, optimize energy management, and maximize overall system performance.optimal control schemes play a crucial role in enhancing the efficiency, performance, and reliability of single-phase induction motors. Through the development of accurate mathematical models, advanced control algorithms, sensor-less techniques, and optimization methods, researchers have made significant strides in optimizing SPIM operation across various applications. Future research directions may include further refinement of control algorithms, integration with emerging technologies such as artificial intelligence and Internet of Things (IoT), and validation through experimental testing in real-world applications. By advancing the state-of-the-art in SPIM control, researchers can contribute to the development of more energy-efficient and sustainable electrical systems.

SIMULATION RESULTS

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The optimal control scheme for a single-phase induction motor (SPIM) is a crucial aspect in enhancing its performance and efficiency across various operating conditions. Through simulation, this control scheme can be effectively evaluated and validated. The simulation circuit for the optimal control scheme typically comprises several components interconnected to simulate the operation of the SPIM. Firstly, the power supply unit provides the necessary voltage and current to the motor. This power supply unit is usually modeled based on the specifications of the SPIM and the applied voltage frequency.Connected to the power supply is the control unit, which implements the optimal control algorithm for regulating the operation of the SPIM. The control unit receives feedback signals from sensors placed within the motor or simulated within the circuit to monitor parameters such as speed, current, and voltage. These feedback signals are essential for the control unit to adjust the control signals accordingly.

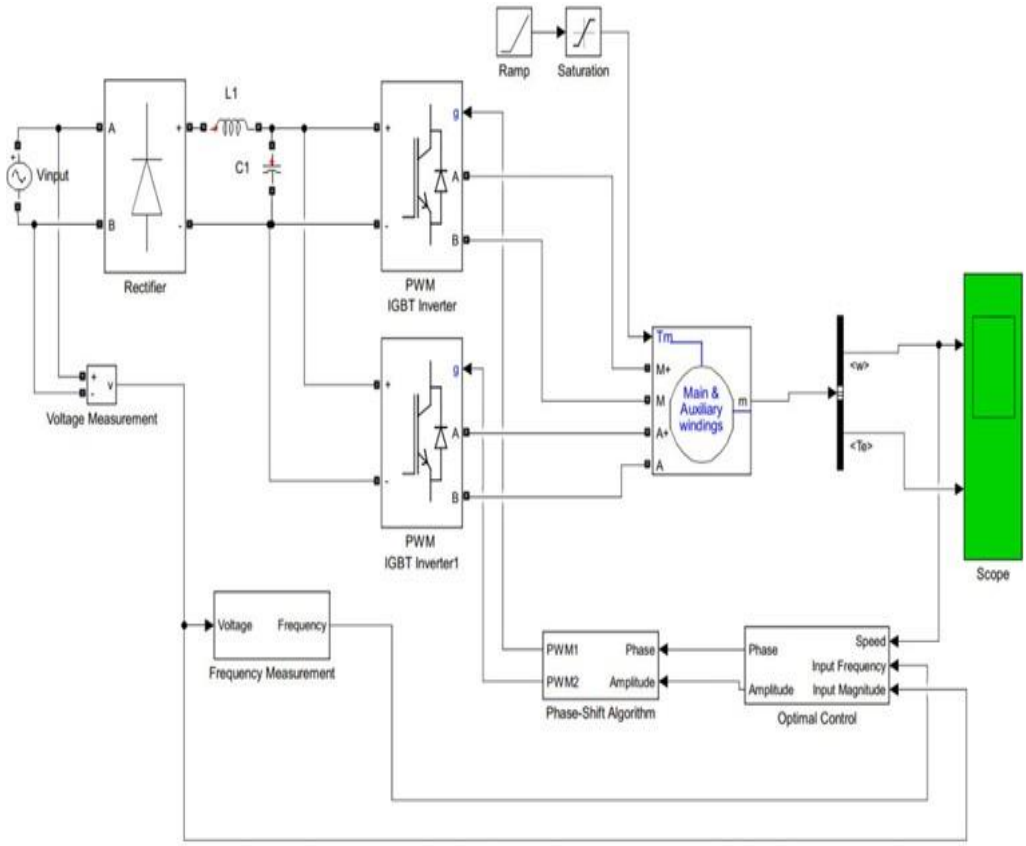

Fig 1. implementation of proposed strategy

One of the key components in the simulation circuit is the inverter or power electronic converter, responsible for converting the DC input from the power supply into AC output suitable for driving the SPIM. Depending on the specific control scheme and application requirements, the inverter may utilize different topologies such as voltage source inverters (VSIs) or current source inverters (CSIs).Additionally, the simulation circuit includes models of passive components such as resistors, capacitors, and inductors, which are essential for filtering and conditioning the electrical signals within the system. These components help

International Journal of Information Technology & Computer Engineering
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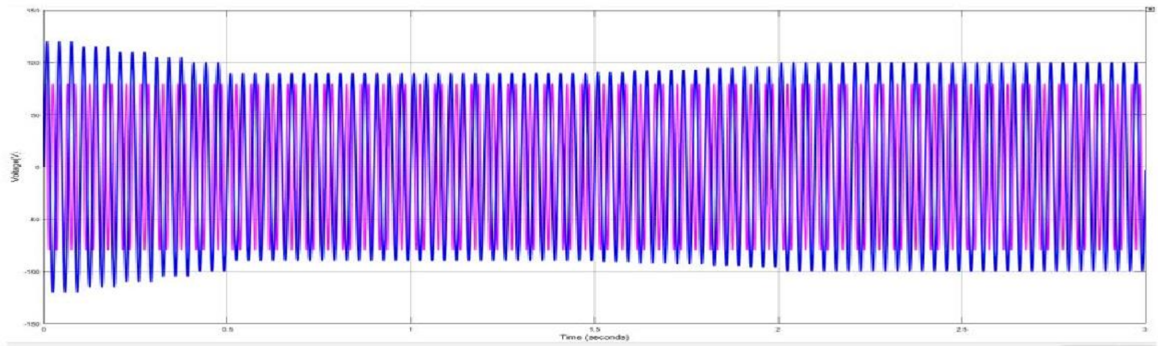
ensure smooth and reliable operation of the SPIM and the associated control electronics.



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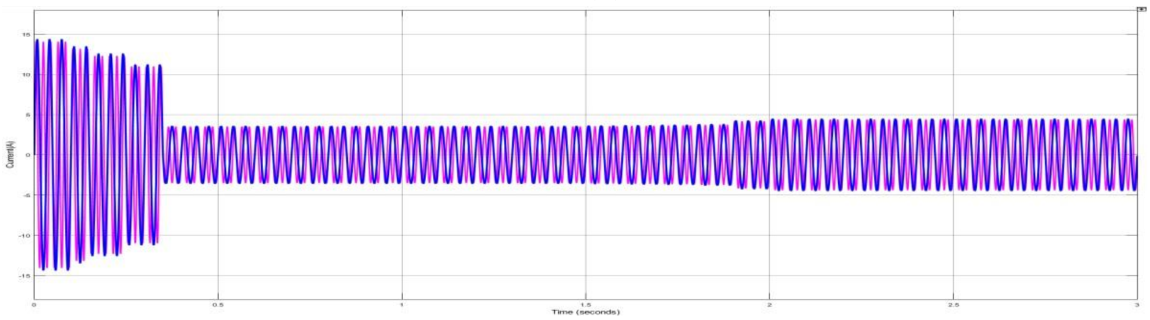

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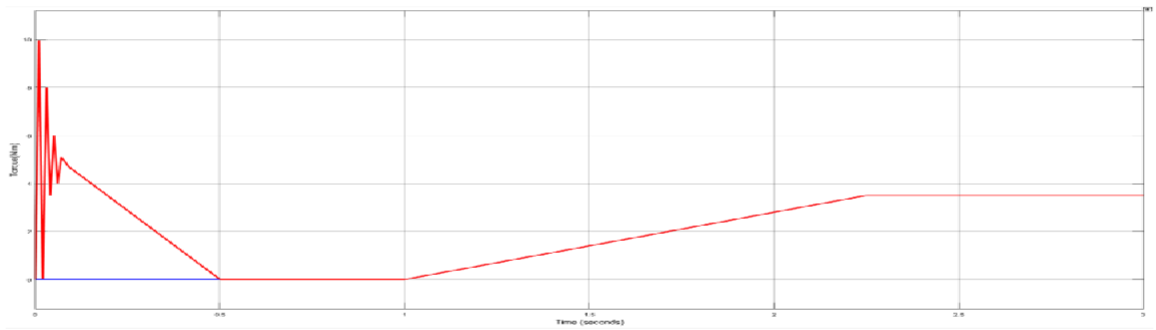

(c)

Fig 2. main and auxiliary voltages, current and torque at frequency =30Hz under the proposed optimal control strategy

Furthermore, the simulation circuit incorporates models of the SPIM itself, including its stator, rotor, and associated windings. These models are essential for accurately simulating the electrical and mechanical behavior of the motor under different operating conditions. Parameters such as motor constants, resistance, and inductance are carefully configured based on the specifications of the SPIM being studied.During simulation, various performance metrics such as speed response, torque characteristics, and energy efficiency are analyzed and evaluated. The control algorithm implemented in the control unit dynamically adjusts the control signals based on the feedback received from the motor sensors, optimizing the motor's performance in real-time.Simulation results provide valuable insights into the

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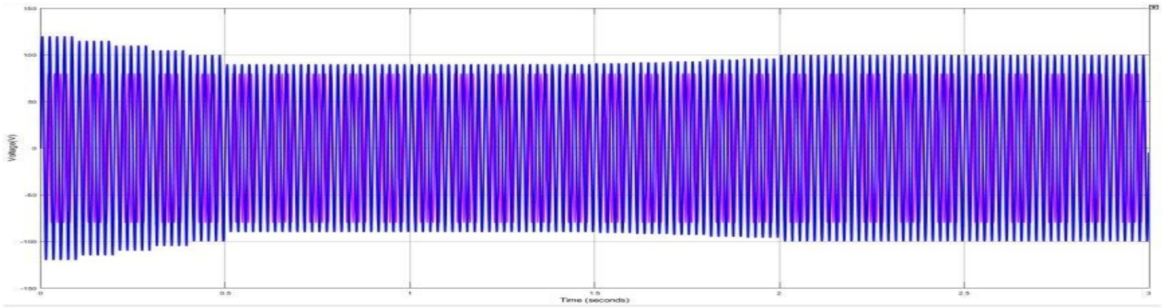
effectiveness of the optimal control scheme in regulating the operation of the SPIM. By comparing the simulated performance with theoretical expectations and experimental data, engineers can fine-tune the control algorithm and optimize the motor's performance further.



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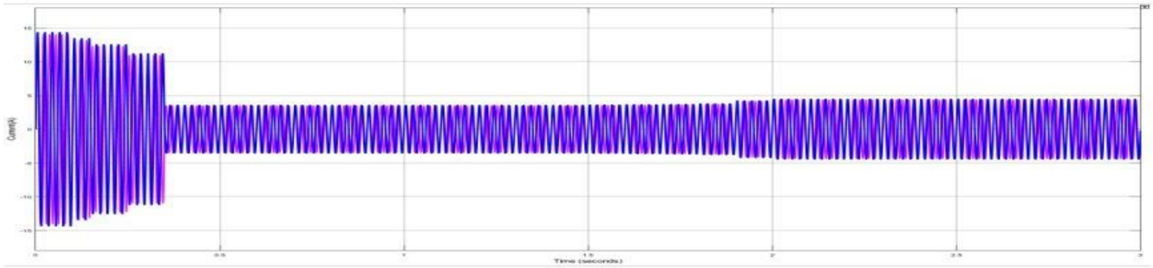

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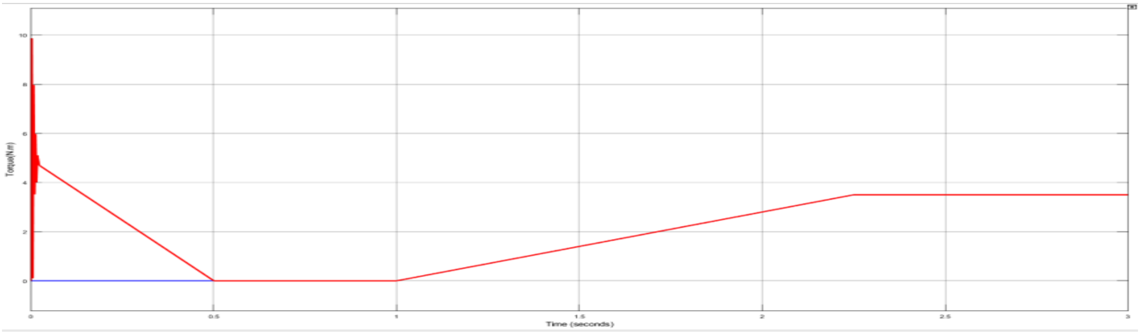

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Fig6.9 : main and auxiliary voltage, current and torque at frequency =60Hz under the proposed optimal control strategy

Overall, the simulation circuit for the optimal control scheme of a single-phase induction motor plays a crucial role in evaluating and refining the control algorithm's effectiveness. Through comprehensive simulation studies, engineers can gain a deeper understanding of the motor's behavior and develop more efficient and reliable control strategies for various industrial applications.

CONCLUSION

it is evident that traditional methods for speed control of SPIMs are inadequate due to the formation of elliptical magnetic fields during non-rated starting and operational conditions. Through an in-depth analysis of SPIM energy efficiency, a novel sensor-less control approach has been devised to enhance performance under non-rated conditions by ensuring symmetrical and balanced SPIM operation. This is achieved by dynamically and optimally controlling the auxiliary voltage and phase difference between winding voltages alongside constant V/f control, facilitated by the developed optimal control scheme.Simulation-based assessments of the optimal control strategy showcase superior energy efficiency compared to conventional SPIM energy optimization techniques. Additionally, the proposed control algorithm facilitates soft-starting of SPIMs with significant starting torque at low frequencies, leading to a notable reduction in inrush current. Simulation results validate a substantial decrease in inrush current, contributing to enhanced energy savings.In essence, the developed sensor-less optimal control strategy not only improves SPIM energy efficiency across varied operating conditions but also enables efficient soft-starting, ultimately leading to considerable energy savings and improved performance in SPIM applications.

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