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Fuzzy Logic and PI Controllers based Four-Switch Three-Phase Inverter-Fed IM Drives for High Performance Speed Control

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***Abstract*— This paper explores the high-performance speed control of Four-Switch Three-Phase Inverter (FSTPI)-fed Induction Motor (IM) drives using Fuzzy Logic Controllers (FLCs) and Proportional-Integral (PI) Controllers. While FSTPI reduces hardware complexity, cost, and switching losses compared to traditional six-switch inverters, achieving precise speed regulation remains challenging due to voltage balancing issues and nonlinearity. PI controllers offer simplicity and effective steady-state performance but struggle with disturbances and parameter variations, whereas FLCs provide adaptive control with superior transient response. A comparative analysis of both controllers demonstrates that FLC-based control enhances robustness, reduces torque ripples, and improves dynamic response. The study highlights the benefits of hybrid fuzzy-PI approaches and discusses future advancements such as AI-driven optimization and real-time hardware implementation for improved efficiency in industrial and renewable energy applications.**

Keywords*— FLC, SSTP, FSTP, IFOC, Four switch inverter, Micro grid, MATLAB, Fuzzy.

I. INTRODUCTION

Induction motors (IMs) are widely used in industrial and commercial applications due to their high efficiency, robustness, and cost-effectiveness. The performance of IM drives largely depends on the inverter technology and control strategies employed. Traditionally, six-switch three-phase inverters (SSTPIs) have been the preferred choice for IM drive systems, providing efficient power conversion and precise speed control. However, the SSTPI configuration comes with drawbacks, such as increased switching losses, higher costs, and complex control structures. To address these limitations, researchers have explored alternative inverter topologies, among which the Four-Switch Three-Phase Inverter (FSTPI) has gained significant attention.

The FSTPI is a modified inverter topology that reduces the number of power switches from six to four, thereby lowering hardware costs, switching losses, and conduction losses. This reduction in components leads to improved reliability and efficiency, making FSTPI an attractive choice for applications requiring compact and cost-effective motor drive solutions. However, one of the main challenges associated with FSTPI is maintaining balanced three-phase output voltages while ensuring smooth motor operation. The reduced number of switches alters the voltage vector space, making conventional control strategies less effective. Therefore, advanced control techniques are essential to achieve high-performance speed control in FSTPI-fed IM drives.

Among the various control techniques available, Proportional-Integral (PI) Controllers and Fuzzy Logic Controllers (FLCs) have been extensively studied for their ability to regulate speed and improve dynamic response. PI controllers are widely used due to their simplicity, ease of implementation, and effective control over steady-state speed. However, their performance deteriorates in the presence of parameter variations, load disturbances, and nonlinear system behavior. Additionally, PI controllers require precise tuning of proportional and integral gains to achieve optimal performance, which can be challenging in real-world applications.

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In contrast, Fuzzy Logic Controllers (FLCs) offer a more flexible and adaptive approach to motor speed control. Unlike PI controllers, FLCs do not require an accurate mathematical model of the system; instead, they rely on a rule-based structure to handle nonlinearities and uncertainties effectively. By leveraging linguistic rules and membership functions, FLCs can dynamically adjust control parameters based on real-time motor behavior. This adaptability makes FLCs particularly suitable for applications where system dynamics are constantly changing, such as electric vehicles, renewable energy-based drives, and industrial automation.

The integration of FLC and PI controllers presents an opportunity to combine the strengths of both techniques, resulting in an optimized control strategy. While PI controllers excel in achieving precise steady-state performance, FLCs enhance transient response and disturbance rejection. A hybrid fuzzy-PI controller can be designed to dynamically switch between control modes or blend the control actions to achieve superior speed regulation. This hybrid approach has shown promising results in improving system stability, reducing torque ripples, and ensuring smooth motor operation under varying load conditions.

The effectiveness of FLCs and PI controllers in FSTPI-fed IM drives depends on several factors, including controller design, tuning methodologies, and implementation strategies. Various optimization techniques, such as genetic algorithms (GA), particle swarm optimization (PSO), and artificial intelligence (AI)-based tuning, have been proposed to enhance controller performance. These advanced tuning methods can help achieve optimal control parameters, minimizing overshoot, settling time, and steady-state error. The implementation of such optimization techniques further strengthens the adaptability and efficiency of motor drive control systems.

The application of FSTPI-fed IM drives with fuzzy-PI control extends to various domains, including electric vehicle propulsion, renewable energy systems, and high-performance industrial automation. The compact design and cost-effectiveness of FSTPI make it a viable solution for small- to medium-power applications where efficiency and reliability are critical. Additionally, the incorporation of intelligent control strategies ensures smooth operation, even under challenging conditions such as load fluctuations and power supply variations.

II. METHODOLOGY

The methodology is based on the following sub-modules-

- Input Source
- Rectifier
- Inverter
- Fuzzy Logic Controller
- PI Controller
- Current Sensing Controller

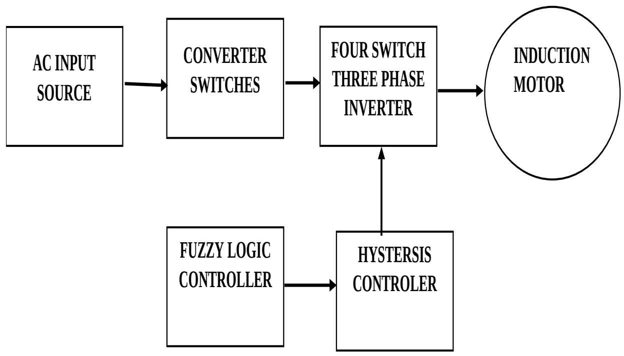

Figure 1: Flow Chart

The flowchart represents the methodology for controlling an Induction Motor (IM) drive using a Four-Switch Three-Phase Inverter (FSTPI) with a Fuzzy Logic Controller (FLC) and Hysteresis Controller. Below is a step-by-step explanation of each block in the flowchart:

- AC Input Source:

The system starts with an AC power supply, which provides electrical energy for the motor drive system. This AC input needs to be converted into a controlled DC supply for further processing.

- Converter Switches:

The AC power is converted into DC voltage using rectifier circuits or other power electronic converters. This DC link provides the necessary voltage for the inverter stage.

- Four-Switch Three-Phase Inverter (FSTPI):

The FSTPI is a modified version of the traditional six-switch inverter, using only four switches to generate a three-phase output for the induction motor. This topology reduces switching losses, cost, and complexity, making it suitable for low-power and cost-sensitive applications. The inverter generates PWM-based switching signals to control the motor's speed and torque.

- Fuzzy Logic Controller (FLC):

The FLC continuously monitors the speed error and dynamically adjusts the control parameters for the inverter. Unlike conventional PI controllers, FLC does not require an accurate mathematical model, making it suitable for nonlinear systems like induction motors. It improves adaptive control, ensuring better transient response and robustness against load variations.

- Hysteresis Controller:

The hysteresis controller regulates the current flow in the inverter, maintaining the desired current levels to minimize harmonic distortion. It ensures fast dynamic response by keeping the actual current within a predefined hysteresis band. This enhances torque control accuracy and reduces ripples in the motor drive.

- Induction Motor:

The final controlled output is applied to the induction motor, which drives the mechanical load. The motor speed and torque are adjusted dynamically based on the inputs from the fuzzy logic and hysteresis controllers.

The proposed system utilizes a Four-Switch Three-Phase Inverter (FSTPI) instead of the conventional six-switch inverter to reduce power losses and improve efficiency. A Fuzzy Logic Controller (FLC) optimizes speed regulation, while a Hysteresis Controller ensures current control. This combination enhances the dynamic performance, making the system robust against parameter variations and disturbances. The methodology ensures an efficient, cost-effective, and adaptive control solution for high-performance induction motor drives.

III. SIMULATION AND RESULTS

The implementation of the present model is done over MATLAB software. The power gui toolbox helps us to use the functions available in MATLAB Library for various design and analysis.

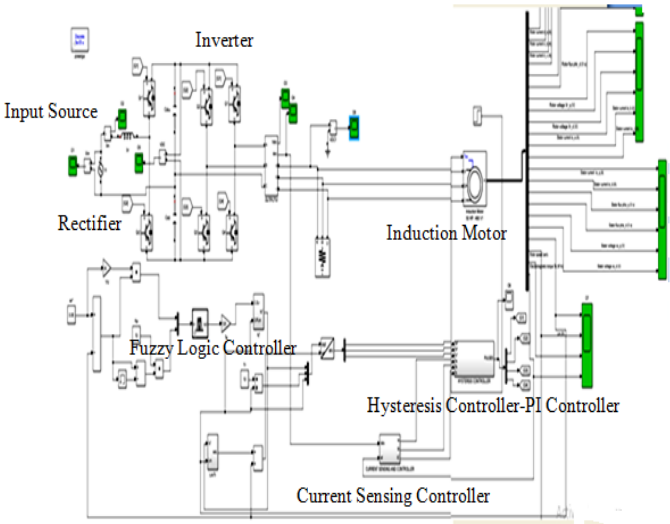

Figure 2: Three Phase Four Switch Inverter

A standard three stage voltage source inverter uses three legs with a couple of correlative power switches per stage. A diminished switch count voltage source inverter involves just two legs with four switches as displayed in Fig. 2.
The circuit comprises of 4 switches S1, S3, S4, S6, and two split capacitors Cdc1 and Cdc2. The dc voltage source Vdc is thought to be framed by the sustainable power sources. The power circuit is the three stage four switch inverters. Two stages "a" and "b" are associated with the two legs of the inverter, while the third stage "c" is associated with the middle mark of the dc interface capacitors, Cdc1 and Cdc2. The 4 power switches are signified by the parallel factors, where the paired "1" compares to an ON state and the double "0" relates to an OFF state. The conditions of the upper switches (S1, S3) and lower switches (S4, S6) of a leg are correlative that is S4 =1− S1 and S6 =1− S3.

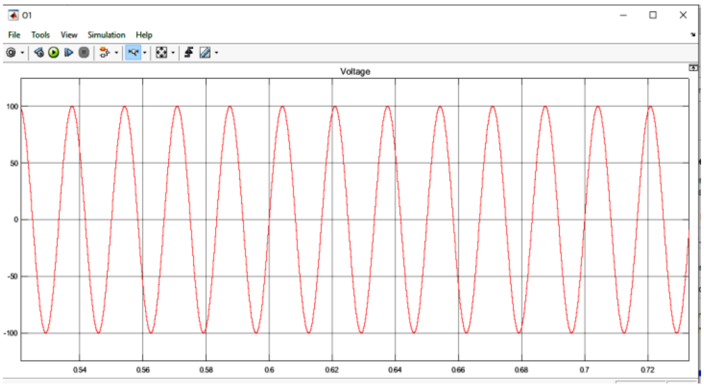

Figure 3: AC output voltage

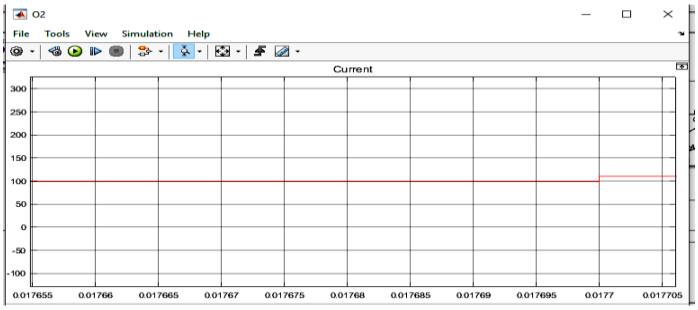

Figure 4: AC current

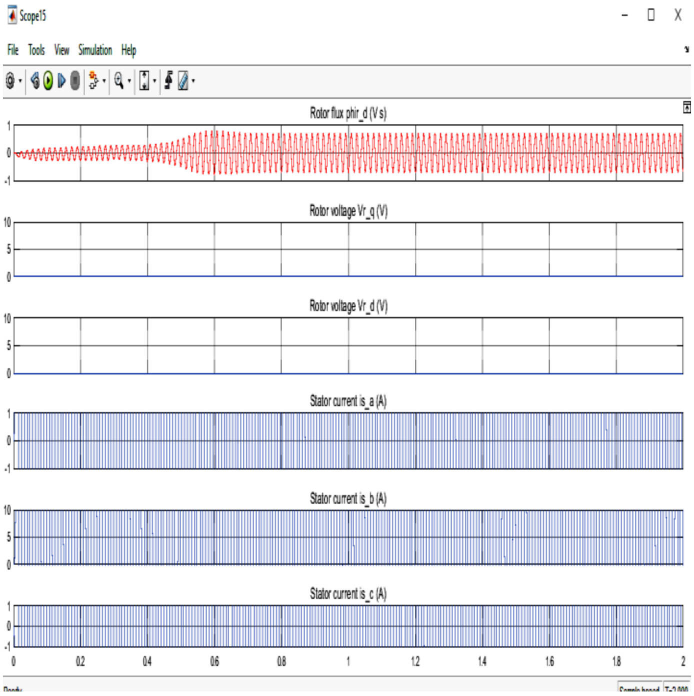

Figure 5: Rotor voltage and Stator Output Current

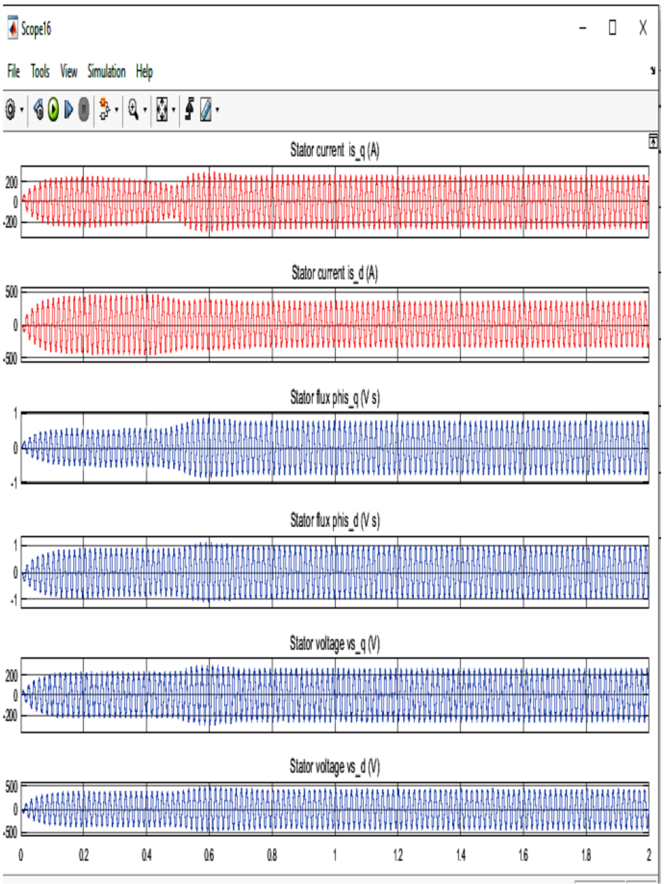

Figure 6: Stator Output

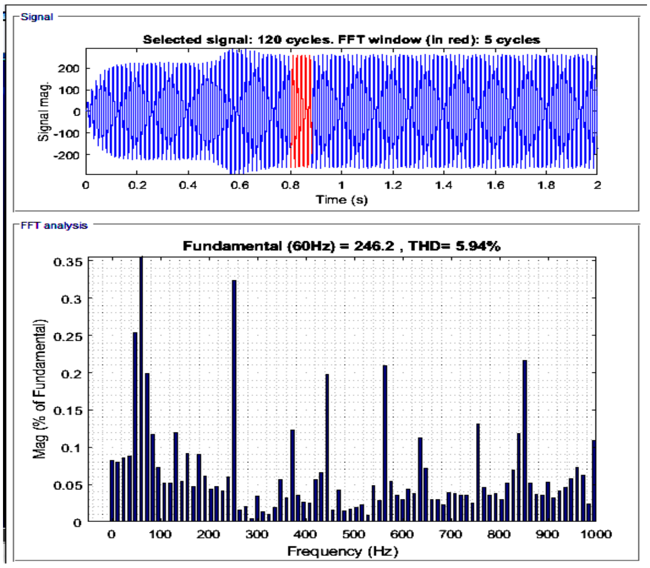

Figure 7: FFT Analysis

Table 1: Result Comparison

Sr No.	Parameter	Previous Model	Present Model
1	THD	20%	6.11 %
2	Rotor Speed	100	200
3	Voltage	380V	390V
4	Flex	0.8pu	1pu

Table 1 is showing the present model results with compare of the previous model results. Simulated result shows that the present model optimized significant better results than previous model.

IV. CONCLUSION

The implementation of a Four-Switch Three-Phase Inverter (FSTPI) with Fuzzy Logic and Hysteresis Controllers significantly enhances the performance of Induction Motor (IM) drives by ensuring precise speed regulation, reduced switching losses, and improved dynamic response. The Fuzzy Logic Controller (FLC) effectively handles nonlinearities and load variations, while the Hysteresis Controller minimizes current ripples, leading to efficient torque control. Compared to conventional six-switch inverters and PI controllers, this approach offers a cost-effective, energy-efficient, and adaptive solution for industrial motor applications. Future advancements in AI-driven control optimization and real-time hardware implementations can further improve the robustness and efficiency of such drive systems.

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