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Dynamic Performance Evaluation of a Five-Phases Induction Motor System controlled using Fuzzy Logic Director

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Abstract

The five-phase induction motor drive offers distinct benefits that enhance the motor's torque production capabilities. The proposed fuzzy logic controller is well suited for high-performance five-phase induction motor drives. This paper is discussed about a speed control strategy for a five-phase induction motor drive system using a Fuzzy Logic Controller (FLC). This controller adjusts system parameters through a rule-based fuzzy logic system, mimicking human reasoning for process control. The speed control algorithm employs indirect vector control.

Keywords: *Electric Current, Five Phase Induction Motor, Luzzy Logic Controller, Matlab, Simulink*

1.0 Introduction

1.1 Origin of Study

The field of multiphase variable-speed motor drives, particularly those involving multiphase induction motors, has seen significant advancements since the early 2000s. Research efforts globally have led to numerous noteworthy innovations in this area. This paper introduces a fuzzy logic controller designed for five-phase induction motor drives, utilizing an indirect rotor field-oriented control technique[1]. Induction motors are renowned for their simplicity, reliability, durability, and low maintenance requirements, which have led to their widespread application across various industries. Recently, there has been increasing interest in multiphase systems (those with more than three phases) due to their advantages over traditional three-phase systems. The earliest known reference to a multiphase motor drive dates back to 1969, when a five-phase induction motor drive fed by a voltage source inverter was introduced.

Five-phase motor drives offer several benefits compared to conventional three-phase induction motor drives, including reduced amplitude and increased frequency of torque pulsations, lower phase current

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without increasing phase voltage, minimized rotor harmonic currents, decreased DC link current harmonics, improved power density, enhanced torque output, and greater reliability[2]. These multiphase induction machines are typically used in high-power applications such as electric aircraft, ship propulsion systems, and electric or hybrid vehicles, where effective modulation techniques are crucial for optimal performance.

One limitation of multiphase motors is their need for a power electronic converter to interface with the commonly available three-phase supply. Historically, multiphase motors were not widely used due to the lack of suitable power supplies. However, advances in power electronics have significantly increased interest in multiphase machines. Modern high-power electronic devices used as switches in Voltage Source Inverters (VSI) have made it feasible to drive multiphase machines[3]. Despite their advantages, VSI's are still constrained by the power ratings of gate-turn-off type semiconductors, which limit their application to lower ranges of high power[4].

In recent decades, multi-level inverters have emerged.

In recent years, multi-level inverters have become a viable option for delivering high power outputs with voltage-restricted devices. High-power systems can be supplied using either multi-leg inverters for multiphase machines or multilevel inverters for three-phase machines. Advances in power semiconductor technology and power electronic converters have made induction motors a reliable choice for controlled-speed operations[5]. Extensive research has been conducted on control strategies for asymmetrical six-phase induction motor drives and methods for Pulse-Width Modulation (PWM) in Voltage Source Inverters (VSI), including comprehensive modeling and performance analysis for different multiphase induction motor systems.

Induction motor control techniques are broadly categorized into vector control and scalar control methods[6,7]. Vector control is very comprehensive because it controls not only the amplitude and frequency, but also the position of voltage, current and instantaneous current. This course discusses the benefits of multi-phase induction machines; their design; Key topics such as fundamental vector and linear control strategies and PWM control of multi-phase power source converters are covered. On the other hand, scalar control focuses only on controlling the amplitude and frequency of these roots. Recent research has examined scalar control of five-phase induction machines, along with field-oriented control strategies for these systems.

The space vector method streamlines the modeling and control of converters and machines in standard three-phase motor drives. With advancements in modern power electronics, the number of phases is now considered a flexible design choice rather than a fixed requirement. This adaptability enables increased torque density in multiphase machines[8-14]. Moreover, using five or more phases allows for higher-order current harmonics to further enhance torque output. Challenges such as harmonic current and phase current distortion in multiphase machines have led to proposed solutions like Direct Torque Control (DTC) using Space Vector Modulation (SVM). DTC is a robust method, offering simpler implementation and better dynamic performance compared to Field-Oriented Control (FOC). SVM is also commonly used in five-phase voltage source inverters, although it involves a complex control structure and may produce undesirable low-order harmonics[15-27].

Different materials are used for manufacturing and production of machines using advance manufacturing process[28]. Kurhade *et al.* performed numerical simulations to study Phase Change Material (PCM) cooling for smartphones and their thermal performance[29-31]. Rahul Khot *et al.* explored how laser welding parameters affect the strength of TRIP steel[28-33]. Anant *et al.* used PCM to reduce chip temperatures effectively[31-33]. Shital *et al.* presented detailed reviews on heat transfer and its enhancement in tubular heat exchangers through jet impingement[34-36,]. Gadekar TD *et al.* carried out experimental research on gear EP lubricants blended with $Al_2O_3/SiO_2/ZrO_2$ composite additives to develop a predictive system[37-39]. Patil P *et al.* utilized a water-based Al_2O_3 nanofluid in material grinding due to its superior convective heat transfer and thermal conductivity characteristics[40]. Advanced techniques like solar system for recycling and biodiesel for performance evaluation is used[41-43].

1.2 Objective of the Study

To address these issues, a new control method for five-phase induction motors with concentrated windings and nearly rectangular waveform back EMF is proposed. This method uses a combination of Rotating Field-Oriented Control (RFOC) during steady-state conditions and DTC during dynamic conditions to improve performance. Among various control methods, space vector PWM is favoured for its ease of digital implementation and efficient use of the available DC bus voltage.

Recent literature provides extensive discussion on polyphaser device design, control methods, and PWM channels. It also explores the fault basic characteristics for polyphaser multirotor drives using the same inverter source, and how polyphaser devices can be used to generate power.

2.0 Modelling of Five Phase Induction Motor

Induction motors that work in three phases are capable of gently accelerating loads from a stop without generating torque that pulses at double the frequency of the line. This feature is not present in motors with fewer phases, like single-phase or two-phase motors, but it is present in motors with more than three phases, such five-phase or six-phase motors. An induction motor with five phases is first represented in its phase-variable form in order to construct a model for it. A transformation is then applied to simplify the model and remove time-varying inductance terms, resulting in the d-q-x-y-0 model. This model represents a five-phase induction motor with ten phase belts, each spaced 36^0apart around the stator's circumference, leading to a spatial displacement of 72^0 between phases ($\alpha = 2\pi/n$, where $n = 5$). The rotor winding is modelled as an equivalent five-phase winding, akin to the stator winding, based on a transformation ratio that aligns the rotor with the stator.

The induction motor in the sim power block kit is designed for three-phase systems and is not suitable for five-phase models. To solve this problem, we mathematically modify the variable phase model of the polyphaser machine so that the number of parameters remains constant, whether it is changing or changing. This transformation uses the clark transformation matrix to improve the representation of the model by replacing the old set of variables with the new set of variables.

3.0 Mathematical Modeling

This transformation separates the x–y component equations from all other components and removes the coupling between the stator and rotor. The rotor's x-y components are completely isolated from the d-q components as well as from one another. There are no x-y or zero-sequence components because the rotor winding is short-circuited. Consequently, because of the star configuration of the stator winding and the short-circuited rotor winding, the zero-sequence component equations for the stator and rotor are not subject to additional analysis. Zero-sequence components do not exist in star-connected multiphase systems with an odd number of phases and no neutral conductor, but they may appear in systems with an even number of phases. The equations for the x-y components can be ignored when vector control is used, which generates only d-q axis current components. This simplification makes the model of a five-phase induction machine in an arbitrary reference frame.

The mathematical model of a five-phase motor described is used for simulating the five-phase induction machine[6-7]. The machine's voltage equations in the common reference frame:

$$v_{xr}=R_r i_{xr}+P\Psi_{xr} \tag{1}$$

$$\Psi_{0r}=L_{lr} i_{0r} \tag{2}$$

$$\begin{gathered} T=\frac{SP}{2}M(i_{ar}*i_{gs}-i_{as}*i_{gr}) \\ T_e=PL_m[i_{dr}*i_{gs}-i_{ds}*i_{qr}] \end{gathered} \tag{3}$$

$$T_e-\ T_L-\frac{J\,d\omega}{P\,dt} \tag{14}$$

3.1 Method of Indirect Vector Controller

To design an indirect vector controller, it is necessary to determine the constants K_1 and K_2 shown in Figure 1, as well as the parameters for the speed PI controller.

In steady state operation under rated operating conditions (index *n* stands for ratedvalues).

$$T_{en}=P\frac{L_m}{L_r}\psi_r i_{qs}\psi_{rn}=L_m i_{dsn}\omega_{sln}=\frac{L_m i_{qsn}}{T_r\psi_{rn}} \tag{4}$$

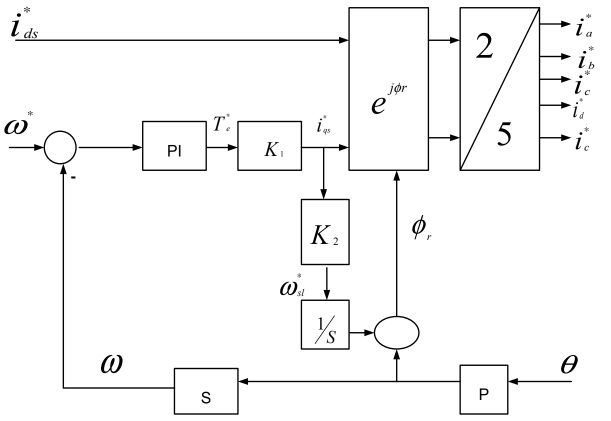

Figure 1. Indirect vector in the base speedregion[13].

$$\psi_r^* = \psi_{rn} T_L = T_{en}\omega_{sl} = \omega_{sln} \tag{5}$$

The RMS value of the stator current will be equal to the rated value. With the use of a power-invariant transformation, the magnitude of the stator current space vector will be greater than the RMS value. Therefore,

$$i_{sn} = \sqrt{5} I_{sn} = 4.6957A$$

$$i_{sn} = \sqrt{i_{dsn}^2 + i_{qsn}^2} \tag{6}$$

Considering RMS rotor flux is 0.5683

$\psi_{rn} = 1.2705\ Wb$ Just multiplying $\sqrt{5}$

$$T_{en} = 5 \times \frac{5}{3} = 8.33Nm \tag{7}$$

The rated torque is determined with Equation (4). By solving Equation (6) and the torque Equation of (4) one gets the rated stator d-q axis current components

$$i_{dsn} = 3.025\ A i_{qsn} = 3.5904 \tag{8}$$

The two constants defined in Equation (3) and required in the indirect vector control scheme of Figure 4.1 are finally

$$K_1 = \frac{1}{P}\frac{L_r}{L_m}\frac{1}{\psi_r^*} = \frac{1}{P}\frac{L_r}{L_m^2}\frac{1}{i_{ds}^*} = 0.431$$

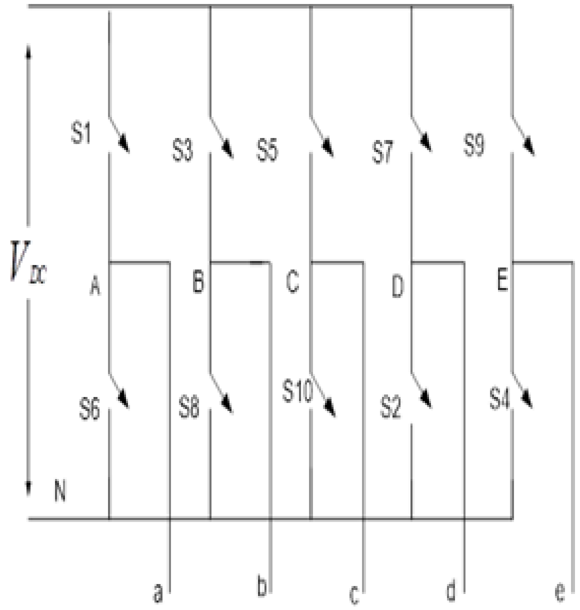

Figure 2. Five phase voltage source inverter power circuit[13].

$$K_2 = {\omega_{sl}^*}/{i_{qs}^*} = \frac{L_m}{T_r \psi_r^*} = \frac{1}{T_r i_{ds}^*} = 4.527$$

4.0 Simulation and Result

A five-phase induction motor's indirect rotor flux-oriented drive was modelled using a MATLAB or SIMULINK simulation program. The motor in the simulation is represented by a d-q model in the stationary reference frame. A PWM voltage source inverter powers the drive system, and the motor phase currents are subjected to hysteresis current control. A discrete anti-windup PI controller is used in the system's closed-loop speed control mechanism to control speed. When functioning in the limiting region, the anti-windup mechanism keeps the integral component of the controller from over saturating. Additionally, the torque can only be applied up to twice the rated value, or 16.67 Nm.

Once the rotor flux reaches a steady state, a speed command of 1200 rpm (or 1500 rpm) is issued at t = 0.3 s, with a ramp-up period from t = 0.3 to t = 0.35 s. The inverter's DC link voltage is set at 586.9 V (415√2). At t = 1 s, a step load torque equal to the rated torque of the motor (8.33 Nm) is applied, allowing the system to reach steady state.

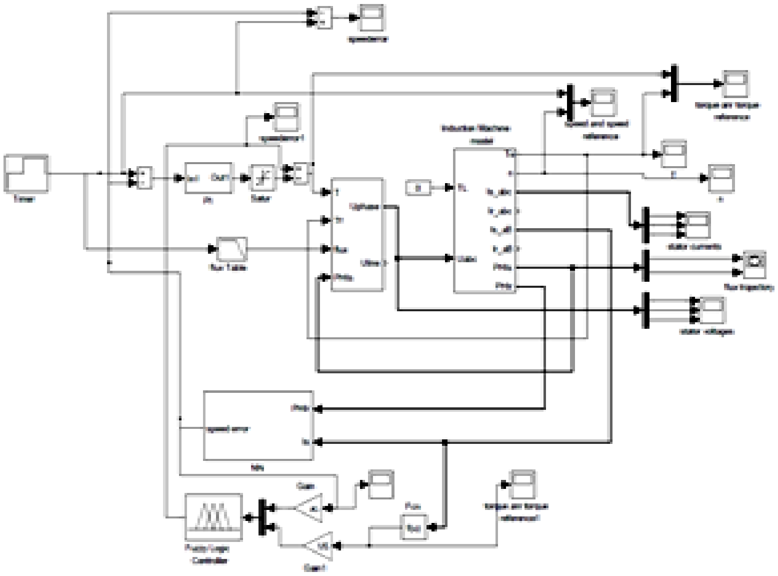

Figure 3. Simulation diagram of fuzzy logic based controller for five phase induction motor[14].

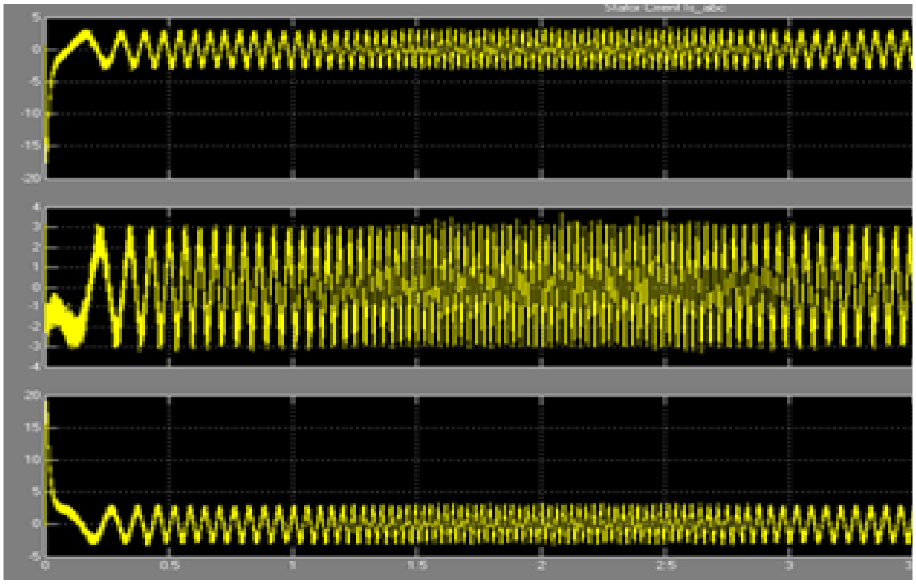

Figure 4. Profile of stator current using fuzzy logic.

Subsequently, a speed reversal is performed, ramping up between t = 1.2 and t = 1.25 s. throughout the simulation, the rotor flux and its reference values, motor speed and torque responses, and reference and actual currents during acceleration are monitored.

Figure 4 and Figure 5 illustrate the profile of stator current and torque control of induction motor for the various range of speed control using fuzzy logic. Figure 6 and Figure 7. The change in the Speed of motor is observed whenever there is change in load on the motor. Speed response with design the fuzzy logic controller to control a speed of induction motor for varying load keeping the motor speed to be constant.

The rotor flux settles at the reference value after the initial transient period and remains constant throughout the 2-s simulation, indicating the effectiveness of the

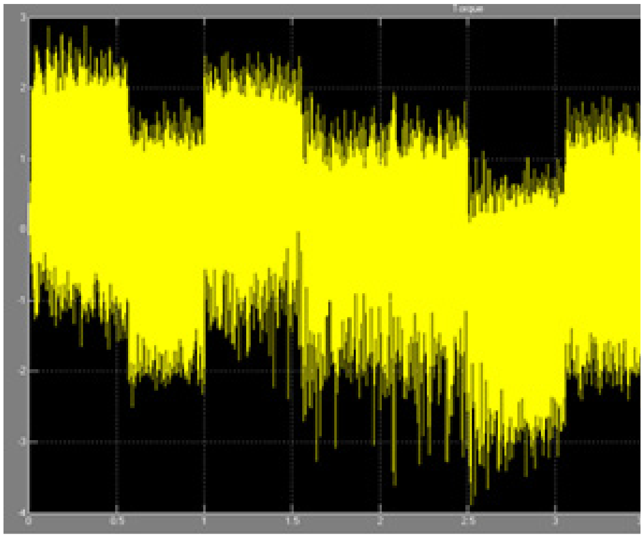

Figure 5. Profile of torque using fuzzy logic.

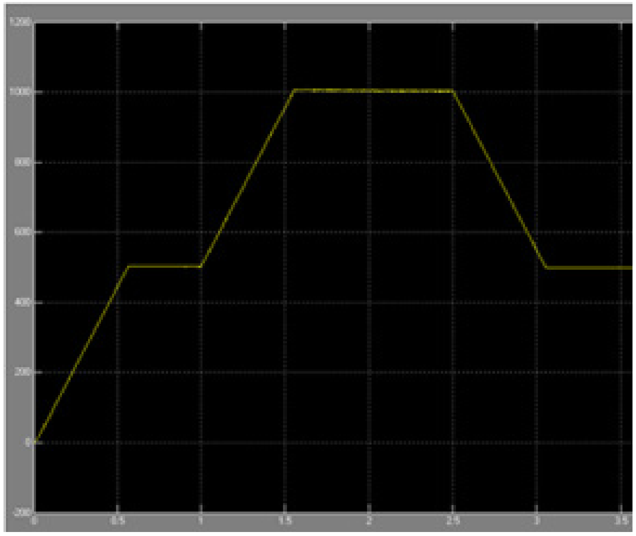

Figure 2. Profile of logic speed using fuzzy logic.

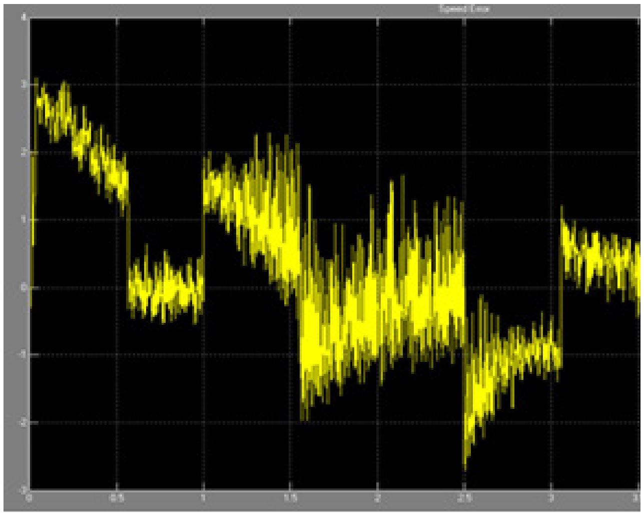

Figure 6. Profile of logic speed using fuzzy logic.

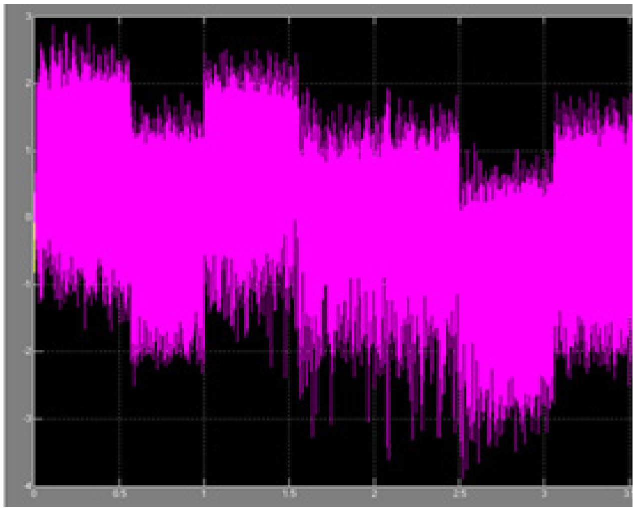

Figure 8. Torque and reference torque.

rotor flux and torque control. During acceleration, the torque and engine speed align with the commanded quantity, and the maximum torque is quickly replaced. The actual motor phase current closely aligns with the reference, resulting in a torque response that mirrors the torque reference. There is adequate voltage margin to accommodate the entire acceleration transient within the specified torque limits.

7.0 Conclusion

The flexible use of fuzzy logic theory in controlling five-phase induction motor drive systems has explored. Based on the dynamic model of the five-phase induction motor drive system using vector control techniques, a simple fuzzy logic controller design has been introduced. Through simulation, the efficacy of this fuzzy logic controller has been verified, showcasing its performance under various operating conditions. Simulation results indicated that the fuzzy logic controller offers superior dynamic performance compared to a conventional fixed PI controller. The fuzzy logic controller significantly enhances speed control of the five-phase induction motor across various operating scenarios.

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