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Fuzzy Logic Control for DSP-Based Vector Control of a Five-Phase Induction Motor

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Abstract: *The proposed study introduces an indirect field-oriented controller to handle five-phase induction motor drives. The controller has its foundation on the fuzzy logic control technique. This paper uses the MATLAB/Simulink package to conduct its simulations. The experimental control system was created through a digital signal processing (DSP) circuit. The performance testing of the proposed system occurs in different operating settings. The proposed controller demonstrates reliability for operation in five-phase induction motor drives with high performance levels. The proposed methods receive verification from experimental trial results and simulation testing.*

Keywords: *Five-phase induction motor, five-phase inverter, fuzzy logic, and digital signal processor (DSP)*

I. Introduction

The simple structure along with robust endurance and acceptable efficiency qualifies induction motors (IM) to serve as essential industrial work equipment since many years. Multi-phase machines have become extensively utilized across transportation, textile and aerospace applications over the previous years. Three-phase drives represent the easiest solution for electrical drive applications. High-phase number drives surpass traditional three-phase drives in delivering several advantages like reduced rotor harmonic currents and amplified torque pulsation frequency and amplitude and reduced current per phase. This drive system also produces decreased dc-link current harmonics and achieves higher reliability.

The machine volume constant allows increasing torque per rms ampere through adding more phases to the system. Systems with multiple phases become necessary when dealing with power applications that need to protect switching components from excess strain. High power system implementation occurs through two approaches which combine multilevel inverters with three-phase machine supply and multileg inverters with multiphase machine supply. Research on multilevel inverters has surpassed other investigations in both quantity and quality.

The switching devices used in both methods operate through similar schemes because increased numbers of devices produce additional voltage levels for multilevel inverters and additional phases for multileg inverters as explained by [6]. The scientific analysis of multiphase machines consists of four distinct areas as described in [6] which include series/parallel connected multiphase machines, fault tolerant problems with multi-phase motor drives, harmonic injection to increase torque and improve stability and multi-phase pulse width modulation (PWM) techniques for multiphase machines.

II. DSP Based Vector

On its basis the n-phase space vector PWM (SVPWM) scheme uses timing control of available switching vectors as explained in Ref. [7]. The paper solely deals with the realization of sinusoidal phase voltage and nothing else. Various researchers examined the control and operational methods of a five-phase system powered by a two-level inverter. Researchers studied a two-level SVPWM with multiphase non-sinusoidal operation as a separate topic [9]. The converter needs to operate at a sufficient power level which matches the requirements of the machine and driving load. The power restrictions of semiconductor devices limit converter rating increases to particular thresholds.

After the adoption of inverter fed-motor drives the former limitation on motor phase numbers disappeared. The discovery that multi-phase motor drives received increased research attention and production led to the development of machines equipped with more than three phases [10]. The number of space voltage vectors in five-phase induction motor drives surpasses that of three-phase induction motor drives. A higher number of vectors enables the creation of an advanced switching vector table that selects voltage vectors according to real-time torque changes and stator flux values.

The main objective of this paper involves designing a speed control system for five-phase induction motors using a fuzzy logic controller (FLC). The process control parameters of the system function through a human behavior-based logical model known as a fuzzy rule-based system inside a Fuzzy Logic Controller (FLC). The main advantages of FLC over conventional controllers include its potential to handle all types of nonlinear functions alongside its autonomous design that works without needing precise mathematical system models.

The fundamental principle of the speed control algorithm is indirect vector control. Researchers have successfully implemented real-time operation of a customized FLC framework for 5-phase induction motor drive implementation. The proposed fuzzy speed controller undergoes testing for theoretical and experimental performance under different dynamic working environments [13]. Results include simulated findings which have been presented for analysis.

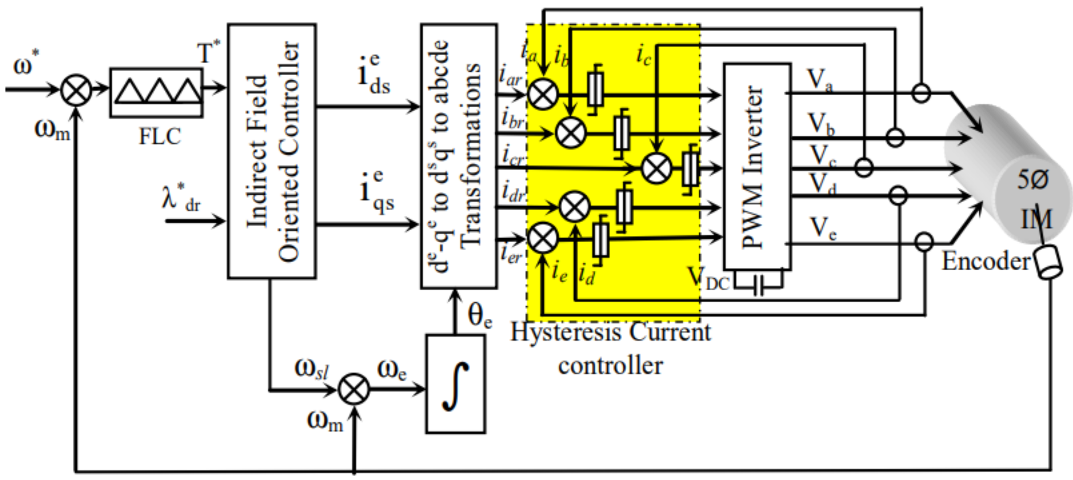

Fig 1: Proposed Speed Control System block diagram

III. Fuzzy Logic PI Controller

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Control systems established on traditional principles use a set of differential equations to demonstrate system parameters and input/output relationships. The implementation of fuzzy logic controllers does not require this exact mathematical model. A fuzzy logic controller includes three sequential blocks which are known as the input section and the processing portion and the output stage as depicted in Fig. 2. Input signals need transformation by the input block before they can perform pertinence functions [12]. The processing block invokes rules while making single results from each rule before combining them into an overall outcome. A control signal results from the combination of processed signals in the output block.

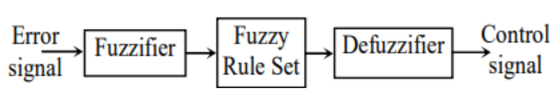


Fig 2: Fuzzy controller

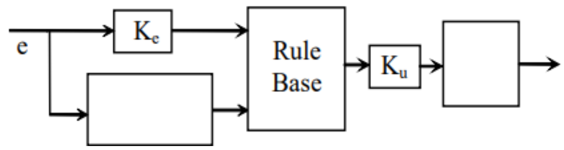


Fig 3: Fuzzy logic PI controller

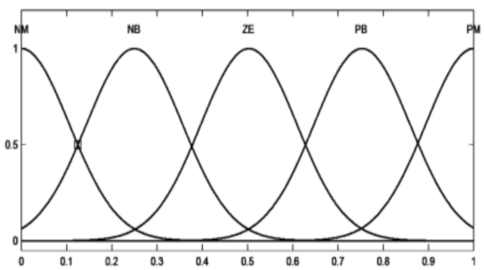


Fig 4: Error Memberships

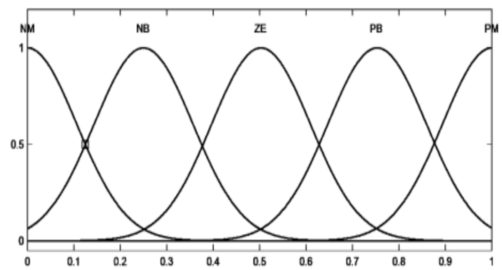


Fig 5: Rate of Change of Error

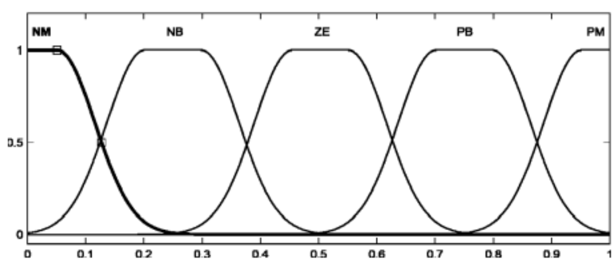


Fig 6: Output membership

IV. Results and Discussion

A vector control system for induction motors was built up to validate the proposed technological approach. The experimental system block schematic shows DSP board DSP 1104 with a 32-bit floating point DSP TI TMS32OC3I as its core in Fig. 7. A fixed point 16-bit TMS320P14 DSP operates as a slave processor component of the board [12]. The Hall-effect current transducers sense all five phase currents starting from ia through to ie. The signal conditioning circuit accepts this information and transfers it to the DSP. The 2048 PPR incremental encoder provides the rotor speed data to the encoder interface module installed on the DSP board.

The Simulink software enables control algorithm execution and distributes program code to the board through the host machine." The outputs from the board transmit ten logical signals through driver isolation circuits to the five-phase inverter. The chosen time interval for mental implementation runs to one hundred seconds. Figure 1 shows the control system which was designed for simulation use only. Multiple operating conditions are evaluated through experimental and simulation data that were created using the general-purpose simulation tool MATLAB/Simulink which demonstrates how effective the proposed approach can be [13]. Start-up and steady-state performance constitute the initial category and dynamic performance represents the second category.

Starting and Steady State Performance

The steady-state along with startup data can be found in Figures 8 and 9. Figure 8a and b presents data related to motor speed records. The signals from simulation appear in Figure 8b whereas Figure 8a presents real-time speed data collection. Both signals maintain direct correspondence starting from the startup phase up to the point of steady state. The real-time measurement of motor phase current appears as Figure 9a. The Figure 9b displays the signal matching data obtained from simulation. Both pictures show the controller switching transients through sine wave profiles of current signals.

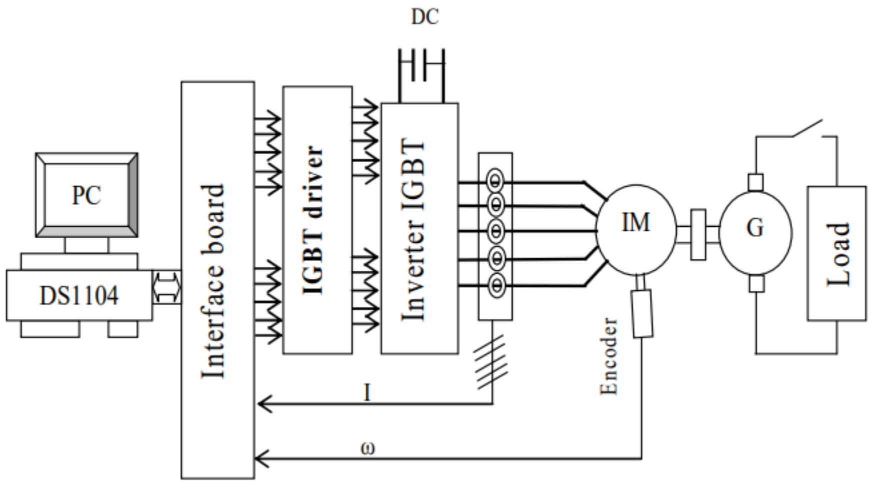


Fig 7: DSP-based control of induction motor experimental set-up

Dynamic Performance

The dynamic performance examination of the proposed system relied on multiple simulation tests and measurement procedures. Dynamic reactions of the proposed algorithm are investigated with respect to speed step alterations. The motor receives step changes in speed command under no load conditions to determine performance and track control system dynamic reactions that result from input variations during the period starting at t=1 second. The speed command for the motor changes from 120 rad/sec to 150 rad/sec during 2.5 seconds and returns to 120 rad/sec. The step changes in motor speed signals appear in Figure 10a and b.

The motor speed tracks its reference point within 0% steady state error because it produces smooth speed changes. Real-time acquired speed signals appear in Figure 10.a. The Figure 10.b illustrates the comparable signal obtained through simulation. The evidence shows that these speed signals maintain a robust connection between them. Figure 11a shows the phase current that corresponds to these speed step variations followed by Figure 11b. You can view the phase current in Figure 11a. The proposed controller demonstrates stable operation according to the obtained results as well as superior performance during dynamic responses.

The control system undergoes examinations of its load response through a speed instruction modification from 120 rad/sec to 150 rad/sec at t=0.75 seconds while operating at full load. A display of motor speed signals connected to these step changes appears in Figure 12a and b. The motor speed reaches its reference value without any noticeable steady state error during this step change process. A strong connection exists between the analyzed speed signals based on the measured data. The corresponding phase current appears in Figs. 13a and b during the speed step change.

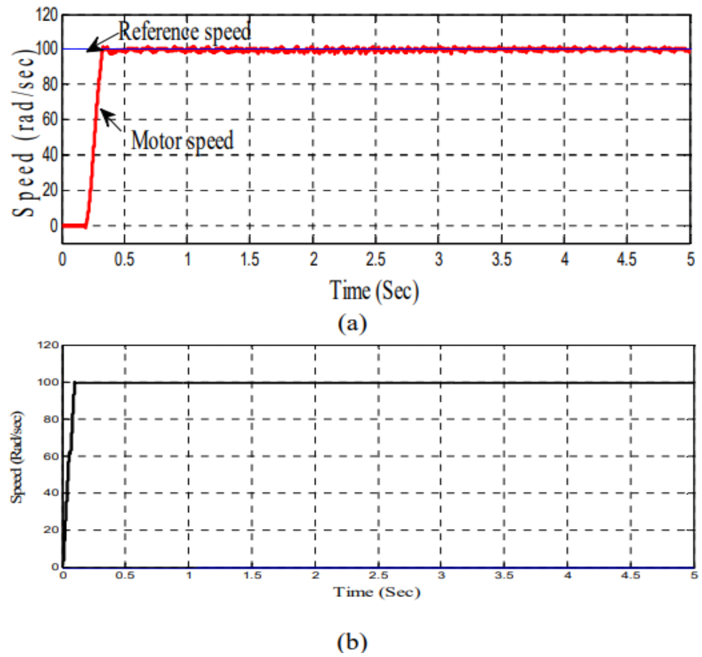


Fig 8: Start-up and steady-state, Motor Speed (a) Experimental (b) Simulation

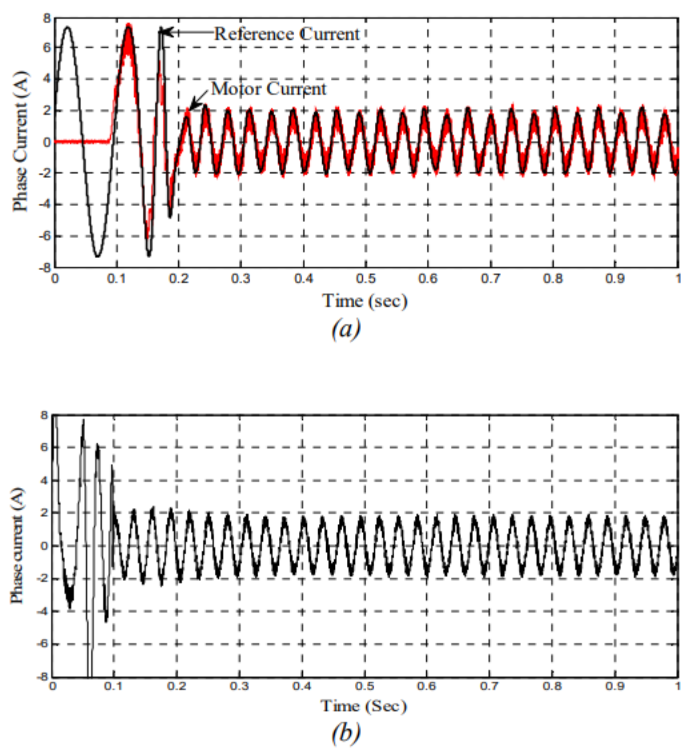
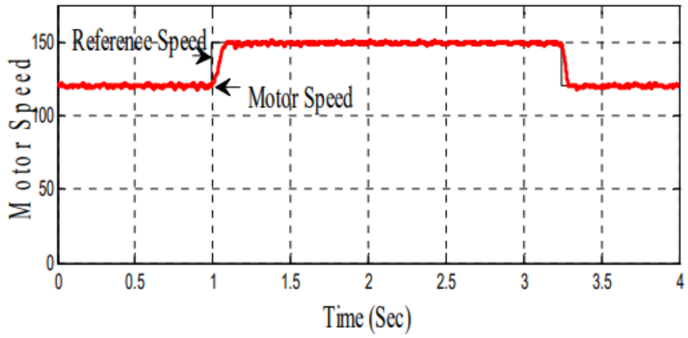
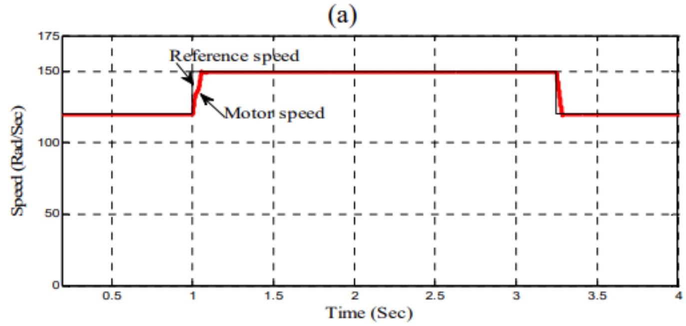


Fig 9: Start-up and steady-state, Motor Phase-a current (a) Experimental (b) Simulation

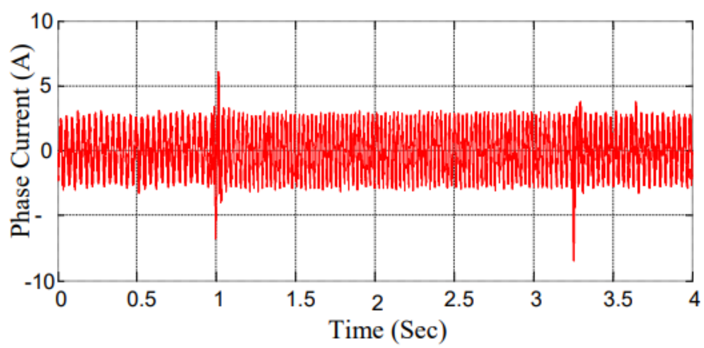


(a)

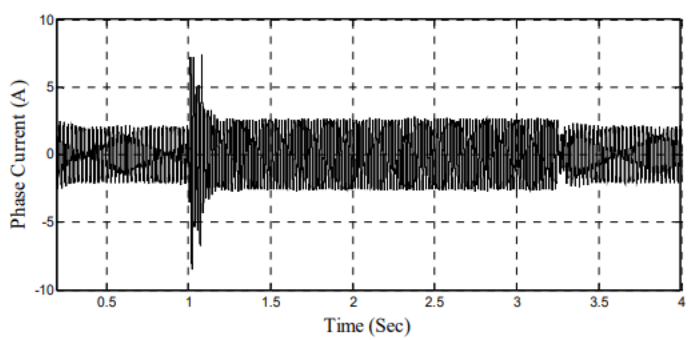


(b)

Fig 10: Speed step up and step-down changes, Motor Speed (a) Experimental (b) Simulation



(a)



(b)

Fig 11: Speed step up and step-down changes, Motor Phase-a current (a) Experimental (b) Simulation

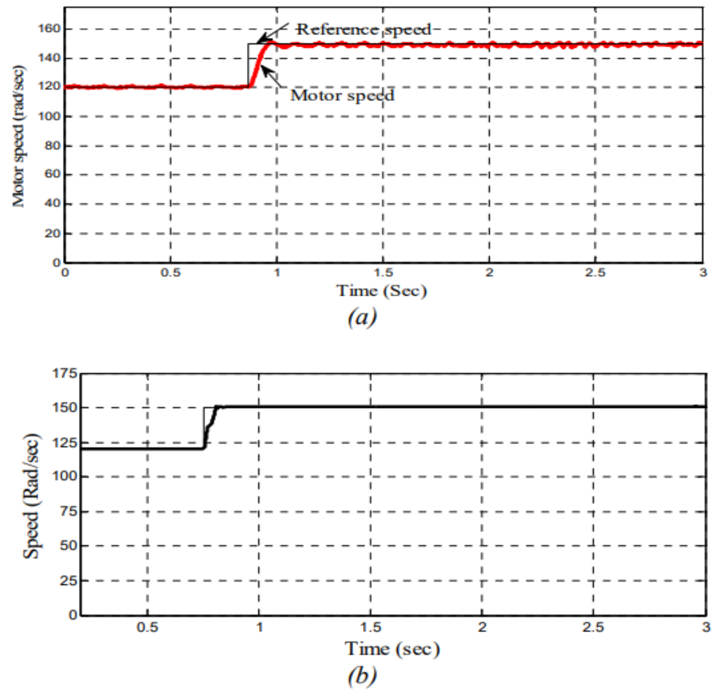


Fig 12: Speed step up change, Motor Speed: (a) Experimental (b) Simulation

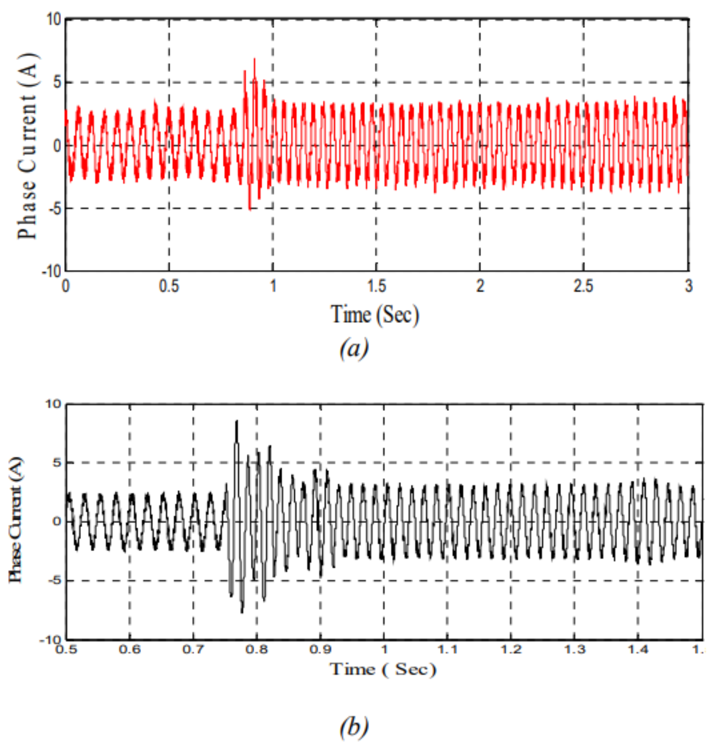


Fig 13: Fig.13 Speed step up change, Motor Phase-a current (a) Experimental (b) Simulation

V. Conclusion

The speed instruction goes from 120 rad/sec to 150 rad/sec during full load conditions starting at t=0.75 seconds to assess control system response. The speed indications for the motor can be observed during these step alterations according to Figures 12a and b. The steady state inaccuracy remains minimal while the motor controller brings its speed to match its reference value. The speed markers demonstrate a powerful relationship between them. The phase current measurements for the test speed change appear in Figures 13a and b.

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