DSP BASED FIELD ORIENTED CONTROL OF INDUCTION MOTOR

A PROJECT REPORT PHASE I

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BONAFIDE CERTIFICATE

Certified that this report "**DSP BASED FIELD ORIENTED CONTROL OF INDUCTION MOTOR**" is the Bonafide work of **ADHITHYA S (2116200901002) and ANABHAYAN SP (2116200901008)** who carried out the project work under my supervision. Certified further that to the best of my knowledge the work reported herein does not form part of any other thesis or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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ABSTRACT

Field-oriented control (FOC) is an advanced technique to achieve high precision torque and flux control in induction motors akin to DC machines. This enables faster dynamic response and efficiency improvements. This project involved MATLAB/Simulink-based modeling and analysis of FOC control on a 5 HP, 400 V, 50 Hz three-phase induction motor with a squirrel cage rotor. The system was simulated with both FOC and conventional scalar VVVF control for comparison. FOC reduced the settling time from 1.7 sec to 0.34 sec and peak overshoot from 20% to 2% during load disturbances. However, 30% longer computation time was needed. Rotor flux angle estimation was also critical, with errors directly impacting performance. The key contribution is a simulation platform to develop and test FOC algorithms before hardware implementation. Results validated that FOC outperforms VVVF control despite greater complexity. Future work should focus on real-time testing and position sensor integration to progress towards a complete motor drive solution. Overall, this project successfully demonstrated a MATLAB/Simulink-based FOC system for induction motors with quantitative performance improvements over scalar control. The simulation model provides a foundation for future prototyping of the algorithm on commercial drive systems.

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LIST OF ABBREVIATIONS

FOC - **F**ield **O**riented **C**ontrol

AC - **A**lternating **C**urrent

IM - **I**nduction **M**otor

DC - **D**irect **C**urrent

PWM - **P**ulse **W**idth **M**odulation

PI - **P**roportional **I**ntegral

PID - **P**roportional **I**ntegral **D**erivative

PMSM - **P**ermanent **M**agnet **S**ynchronous **M**otor

SVPWM - **S**pace **V**ector **P**ulse **W**idth **M**odulation

DSP - **D**igital **S**ignal **P**rocessor

d-q - **d**irect-**q**uadrature

VVVF - **V**ariable **V**oltage **V**ariable **F**requency

Chapter 1

INTRODUCTION

1.1 GENERAL

The induction motor, a critical component in industry, has long been a focus of study and innovation due to its robustness, simplicity, and cost-effectiveness. It is a workhorse in various applications, ranging from small appliances to large industrial machines. However, the quest for achieving precise control over its operation has led to the development of sophisticated control strategies, one of which is Field Oriented Control (FOC). This project paper aims to explore the intricacies of FOC, its advantages over traditional control methods such as scalar control, and the practical implementation of its simulation for real-world applications.

Comparisons will also be done between different methods to estimate the rotor flux angle, which is a key parameter for FOC. Trade-offs will be evaluated between using sensor-less techniques or physical sensors, such as encoders or hall-effect sensors. It's observed that FOC is more adaptive to the non-linearity and uncertainties of the induction motor, such as parameter variations, and saturation effects.

In industrial applications, where efficiency, performance, and precision control are non-negotiable, the traditional scalar control methods often fall short. Scalar control strategies, such as Volt/Hertz control, are simpler and less costly but do not adequately address the dynamic response and torque control requirements of modern applications. They fail to decouple the flux and torque-producing components of the motor currents, leading to sluggish response and compromised performance under varying loads.

In contrast, Field Oriented Control (FOC) provides a solution to these limitations by treating the induction motor akin to a separately excited DC motor, where torque and flux can be controlled independently. This decoupling allows for precise and independent control of speed and torque, akin to DC motors, which is vital in applications demanding high dynamic performance such as electric vehicles, CNC machines, and robotics.

The basic principle of FOC is to transform the three-phase stator currents and voltages into a two-phase coordinate system (d-q) that rotates synchronously with the rotor flux. This transformation simplifies the analysis and control of the induction motor, since the d-axis component of the current is responsible for the flux generation, and the q-axis component is responsible for the torque generation. By controlling these two components separately, the FOC can achieve a fast and accurate response to the speed and torque commands.

Key components and concepts of the FOC methodology include:

1. Coordinate Transformation: The transformation of the three-phase stator current variables into a two-coordinate (d-q) system using Clarke and Park transformations. This d-q reference frame rotates synchronously with the rotor flux, simplifying the dynamic model of the induction motor into a form that can be directly controlled.

2. Flux Estimation: The accurate estimation or measurement of the rotor flux position, which is central to the performance of FOC. Sensorless methods can use motor voltage and current to estimate the position, while sensor-based methods use encoders or resolvers for direct measurement.

3. Control Algorithm: A control algorithm that takes the reference speed or torque and calculates the required voltage vectors in the d-q frame, which are then transformed back into three-phase voltages to be applied to the motor.

4. Inverters and PWM: The use of voltage-source inverters and Pulse

Width Modulation (PWM) techniques to generate the required voltages and currents that drive the motor according to the FOC strategy.

5. At this moment we've performed the simulation for VVVF and FOC, and obtained the dynamic response of their speed and we've also simulated 180° mode inverter whose calculation is provided. Simulation and experimental results of our project, and discuss the challenges and future work will be presented.

1.2 LITERATURE SURVEY

Arun Dominic Dn et.al (2014) - Analysis of field-oriented controlled induction motor drives overview of sensorless scheme This article explores use of blanking periods and space vector modulation to enhance low-speed drive performance, providing a thorough technique review.[1]

Chen, Wen Zhuo, et al. (2014) - Simulation of Permanent Magnet Synchronous Motor Field oriented Vector Control System The text describes coordinate conversion's role in managing motor currents, especially excitation and torque. Simulation results validate the vector control method's accuracy, supporting real-world system design.[3]

Dianguo Xu et.al (2018) - A Review of Sensorless Control Methods for AC Motor Drives Sensorless control - signal injection methods are simpler and easier to execute than model reference adaptive system and Kalman filter. Requires large amount of data.[5]

E.S.Tez (1995) A Simple Understanding of Field Orientation For Ac Motor Control The article teaches field-orientation for AC motor control, which aligns the stator and rotor fields for fast torque control. It corrects some wrong ideas about motor models and parameters, and shows a new field-orientation design called INVECTER.[4]

F. Yusivar, N. Hidayat et al (1980) - Implementation of Field Oriented Control for Permanent Magnet Synchronous Motor The article shows how microprocessors can control AC machines better with field orientation, which improves their dynamic performance.It explains the induction motor model and talks about the future possibilities in the field. [2]

1.3 SUMMARY OF LITERATURE SURVEY

Field-oriented control is a technique in AC motor drives that align the stator and rotor magnetic fields for efficient and responsive torque control, introducing advanced control strategies such as INVECTER, which correct misconceptions and improve upon traditional motor models.

The application of coordinate transformation, specifically in Permanent Magnet Synchronous Motors (PMSM), is critical for managing motor currents and optimizing control through Proportional-Integral (PI) controllers and Space Vector Pulse Width Modulation (SVPWM), with simulation results confirming the precision and effectiveness of these vector control methods.

Sensorless control methodologies for AC motor drives, including signal injection, offer a more straightforward and practical approach compared to complex systems like Model Reference Adaptive Systems (MRAS) and Kalman filters, though they require significant data processing.

Integration of microprocessors in the implementation of field-oriented control has significantly enhanced the dynamic performance of AC motors, with Permanent Magnet Synchronous Motors (PMSM) benefiting from improved control theories and practical implementation insights, along with foresight into future advancements in AC motor control.

Sophisticated techniques in field-oriented control of induction motors, such as the use of blanking periods and space vector modulation, are instrumental in improving low-speed drive performance, necessitating an in-depth analysis of these sensorless schemes to further refine control strategies.

1.4 OBJECTIVES

- To simulate field oriented control of an induction motor using MATLAB/Simulink and analyze its performance compared to conventional scalar control.
- To implement different control strategies like proportional, PI and PID control for the current control loop and evaluate their impact on the dynamic response of the motor.
- To propose techniques to improve the low speed performance and dynamic response of the induction motor drive.

1.5 ORGANIZATION OF THESIS

This thesis is organized into four chapters, which are described as follows.

Chapter 1: Deals with the introduction, literature survey, and objectives.

Chapter 2: Explains the functional block diagram and gives an explanation for each block.

Chapter 3: Describes the software and closed-loop operation of the system.

Chapter 4: Presents the conclusion, results, and scope for future work.

1.6 CHAPTER SUMMARY

Introduction, literature survey, objectives and organization of thesis are presented in this chapter.

Chapter 2

FIELD ORIENTED CONTROL

2.1 INTRODUCTION

The FOC control loop shown involves some key mathematical transformations like the Clarke and Park transforms. The 3-phase stator currents are transformed to a 2-phase orthogonal reference frame by the Clarke transform. The Park transform then rotates this into the synchronous rotational reference frame aligned with the rotor flux. The required rotor position is obtained using incremental encoders, Hall-effect sensors, or sensorless methods. The flux and torque components in this rotating reference frame are decoupled, allowing for separate control through the PI controllers. The outputs of the PI controllers are transformed back to 3-phase voltages to drive the inverter. Space vector PWM is typically used to generate the gate signals for the inverter.

2.2 BLOCK DIAGRAM OF FIELD ORIENTED CONTROL

The Field Oriented Control (FOC) block diagram depicts the implementation of vector control of an AC induction motor (ACIM) using MATLAB. The desired speed (ω_{ref}) is fed into a Proportional-Integral (PI) speed controller to compute the torque reference (T_{ref}). This torque reference, in conjunction with the ACIM control reference, is used to determine the reference direct and quadrature axis currents ($I_{sd_{\text{ref}}}$ and $I_{sq_{\text{ref}}}$), managed by two separate PI controllers for current regulation. The Park transform takes actual motor currents (I_a, I_b) and transforms them using the rotor's electrical position (θ_e), obtained from a position generator along with a sine-cosine lookup. The Inverse Park transform takes the PI controllers' output ($V_{sd_{\text{ref}}}$ and $V_{sq_{\text{ref}}}$) and converts them back to the stationary reference frame (V_α, V_β). Subsequently, these voltages are fed to a space vector generator that pro-

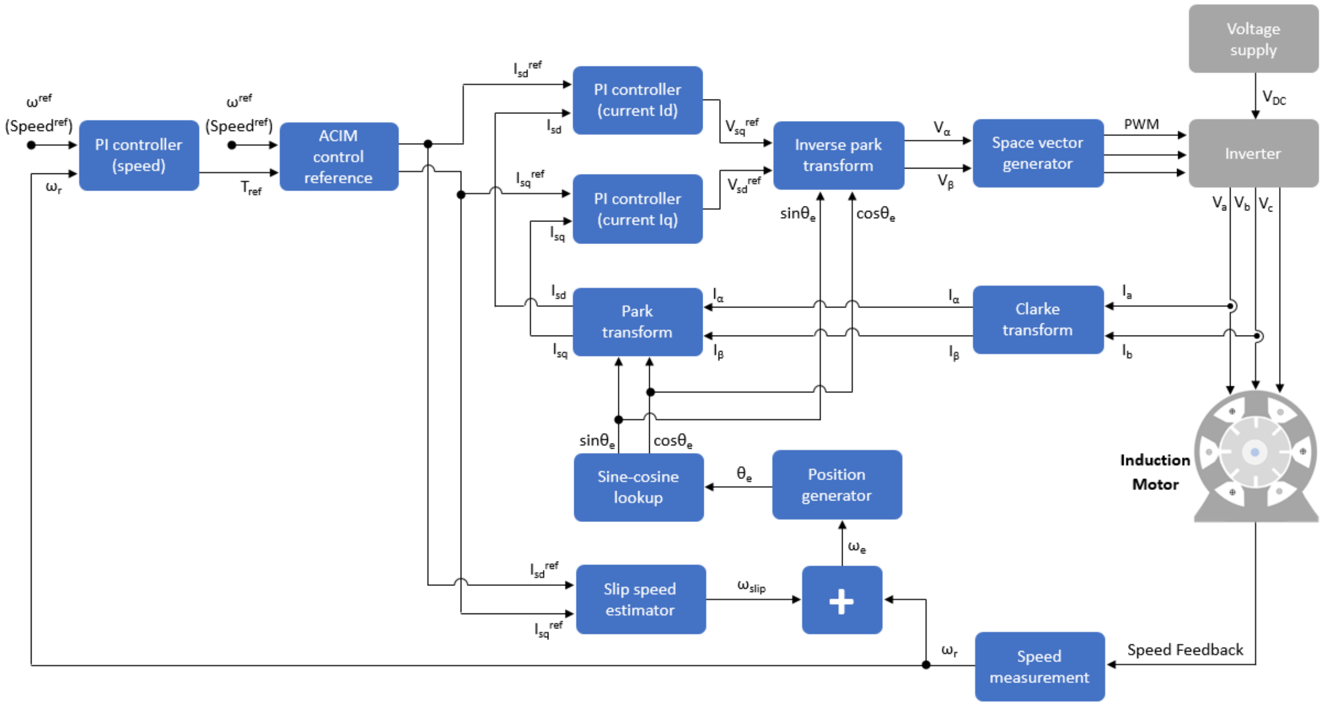

Figure 2.1: Block Diagram Of FOC For I.M.

duces pulse-width modulation (PWM) signals for the inverter, which then drives the induction motor. The motor's actual speed (ω_r) is measured and compared to the reference speed to ensure closed-loop control. Additionally, the slip speed estimator feeds into the position generator for accurate control, completing the FOC system loop. The block diagram shown in Fig. 2.1 depicts the main components of FOC for induction motor drive.

This block diagram represents a typical vector control (also known as field-oriented control) for an AC Induction Motor (ACIM). It's an advanced control strategy used in variable frequency drives (VFDs) to control the torque and speed of a three-phase AC induction motor. Let's discuss each block and their roles in the control scheme:

1. PI Controller (speed): This is a Proportional-Integral controller for the speed loop. It takes the speed reference (ω_{ref} or Speed$^{\text{ref}}$) and compares

it with the actual rotor speed (ω_r). The output of the PI controller is a reference torque (T_{ref}), which sets the desired motor torque corresponding to the target speed.

2. ACIM Control Reference: It translates the reference torque into current components that will achieve this torque. These current components are referenced in the d-q coordinate system, where I_{sd}^{ref} is the direct-axis current reference, and I_{sq}^{ref} is the quadrature-axis current reference.

3. PI Controllers (current I_d and I_q): There are two PI controllers here for the current loop—one for the direct-axis current (I_{sd}) and another for the quadrature-axis current (I_{sq}). These controllers ensure that actual motor currents match the current references derived from the speed controller.

4. Park Transform: This block transforms the three-phase stator currents (I_a, I_b, I_c) into a two-axis current vector (I_d, I_q) in the rotating reference frame (d-q frame), which simplifies control of the motor.

5. Sine-cosine Lookup and Position Generator: It provides the sine and cosine of the electrical angle θ_e, which is required for the Park and inverse Park transforms. The position generator computes the rotor's electrical angle based on the rotor speed and slip frequency, which is the difference between the electrical frequency and the mechanical rotor speed frequency.

6. Slip Speed Estimator: It estimates the slip speed (ω_{slip}) of the motor, which is the difference between the synchronous speed and the actual rotor speed. This is used, along with the rotor speed, to compute the electrical angle.

7. Inverse Park Transform: This block takes the current references in the d-q axis (V_{sd}^{ref}, V_{sq}^{ref}) and converts them into voltage references in the stationary reference frame (V_α, V_β) required for generating PWM signals.

8. Space Vector Generator: This module generates the PWM (Pulse Width Modulation) signals necessary to control switches in the inverter, based on the stationary reference frame voltages.

9. Inverter: The inverter takes the DC voltage supply (V_{dc}) and switches it to synthesize variable-frequency AC voltage for the motor using the PWM signals it receives. This results in three-phase output voltages (V_a, V_b, V_c) that control the motor.

10. Induction Motor: The actual physical motor that converts electrical power into mechanical power, which is controlled by the variable input voltages.

11. Clarke Transform: This converts the three-phase stator currents (I_a, I_b, I_c) into two orthogonal components (I_α, I_β) in the stationary reference frame, which is a precursor for the Park transform.

12. Speed Feedback: The rotor speed is measured and fed back into the control system to adjust the control signal and maintain the desired speed accurately.

2.3 WORKING OF FOC

The main components and their working is as follows:

1. Three phase voltages and currents from the motor are converted to two phase stationary reference frame using Clarke transformation.

2. The stationary reference frame is then converted to synchronous rotating reference frame aligned with the rotor flux using Park transformation.
3. Using feedback of rotor position/speed, flux and torque controllers generate reference current components in rotating frame.
4. Inverse Park and Clarke transforms convert these reference currents to three phase currents for the voltage source inverter.
5. SVPWM scheme is used to generate switching pulses for the inverter to achieve the reference currents.
6. Inverter supplies controlled three phase voltages to drive the induction motor.
7. Rotor position/speed sensor provides feedback for transformation calculations.

2.4 CHAPTER SUMMARY

Introduction, block diagram and working of FOC are presented in this chapter.

Chapter 3

Simulation Results

Here are the results of your experiments or analysis.

Chapter 4

Hardware Results

IPM and PCB design

4.1 Intelligent Power Module

4.2 PCB Design

4.3 Current measurement

4.4 Induction Motor Parameter Estimation using No-load and Blocked Rotor Test

4.5 Space Vector Pulse Width Modulation

Space Vector PWM has several advantages over Sine PWM

- Higher voltage utilization: SVPWM can utilize up to 15% more DC bus voltage compared to SPWM. This means for the same DC supply voltage, an inverter with SVPWM can provide a higher output voltage.
- Better harmonic performance: SVPWM results in lower total harmonic distortion (THD) compared to SPWM. This leads to a better quality of the output voltage and current waveforms, which is particularly important in applications like drives where harmonics can cause heating and torque pulsations.
- Reduced switching losses: SVPWM requires fewer switching operations for the inverter switches compared to SPWM. This results in lower switching losses, leading to higher efficiency and reduced heating of the inverter switches.
- Improved dynamic response: The space vector representation used in SVPWM allows for a more precise control of the output voltage vector, leading to an improved dynamic response. This is particularly beneficial in applications like motor drives where a fast dynamic response is required.
- Vector control capability: SVPWM allows for vector control of the output voltage, which is not possible with SPWM. This enables more complex control strategies, such as field-oriented control (FOC), which can provide better performance in applications like motor drives.
- Flexibility: SVPWM allows for flexible control of the output voltage magnitude and frequency, as well as the phase relationship between the output voltage and current. This flexibility makes it suitable for a wide range of applications.

Chapter 5

Conclusion