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SVM BASED SPEED CONTROL FOR THREE PHASE INDUCTION MOTOR USING F28069M DIGITAL SIGNAL CONTROLLER

PROF. SUBHASH RATHOD'[1], PROF. MARUTHI ARIGELA[2], ARMAN SAHERIAR[3], MOHD AMAAN RAFIQUI[4], ANAS BIN ESA[5], MOHD ASJAD KHAN[6]

[1]ASSOCIATIVE PROFESSOR, HEAD OF DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING, VIJAY RURAL ENGINEERING COLLEGE, NIZAMABAD, TELANGANA, INDIA

[2]ASSOCIATIVE PROFESSOR, DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING, VIJAY RURAL ENGINEERING COLLEGE, NIZAMABAD, TELANGANA, INDIA

[3,4,5,6]STUDENT, DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING, VIJAY RURAL ENGINEERING COLLEGE, NIZAMABAD, TELANGANA, INDIA

Abstract— Being highly robust and reliable, these motors find abundant applications in industrial systems involved in manufacturing, HVAC, and automation. The project has thus sought to provide a highly pragmatic and efficient solution for variable-speed control of a three-phase induction motor. Space Vector Modulation (SVM) has been preferred in the working of this system, a relatively advanced PWM technique, having its merits such as improved voltage utilization, reduced switching losses, and lower harmonic distortion when compared to the traditional Sinusoidal PWM (SPWM). The whole implementation is based on the Texas Instruments TMS320F28069M Digital Signal Controller, which belongs to the C2000 microcontroller family, created specifically for practical solutions in motor control applications. A PI controller in the closed-loop feedback system dynamically adjusts motor parameters so that speed control of the motor is made possible accurately even if the load parameter varies. Initially, MATLAB/Simulink simulations for the control system were performed, and the results indicated improvements in speed tracking, reduced steady-state error, and fast dynamic response. These results were experimentally validated with a hardware prototype, where motor speed was maintained within ±1% of the set point, exhibited very low overshoot, and 30% reduction in THD. Further studies investigated the effect of different modulation indices and PI tuning to an optimal trade-off between efficiency and responsiveness. This work proves that...

Index Terms— Space Vector Modulation (SVM), Induction Motor Control, Digital Signal Controller (DSC), TMS320F28069M, Speed Control, Field-Oriented Control (FOC), Pulse Width Modulation (PWM), Closed-Loop Control, Proportional-Integral (PI) Controller, MATLAB/Simulink Simulation, Embedded Motor Drive Systems, Total Harmonic Distortion (THD), Real-Time Control, C2000 Microcontroller, Sensor-Based Feedback.

1. Introduction

From the standpoint of industrial uses, an induction motor plays the role of a workhorse because of its ruggedness, superior efficiency, and lower cost. Among all types of electric motors, the three-phase squirrel cage induction motor remains the most popular and easiest to use for variable-speed drive applications such as fans, pumps, conveyors, and electric vehicles.

The key problem in using an induction motor is the precise and dynamic control of motor speed and torque, under varying load conditions. Traditional control, such as scalar, is simply not accepted for dynamic applications due to low transient response and low accuracy. This led to the invention of an advanced vector control method, namely Field-Oriented Control (FOC), with which torque and flux are decoupled and controlled almost like a DC motor in dynamic terms.

For FOC to be fully exploited with its advantage, efficient modulation needs to be employed to produce inverter switching signals. SVM has been touted as a significant step forward compared to the classical sinusoidal PWM: it has a better utilization of the DC bus voltage, produces the lowest harmonic distortions, and offers smooth control. SVM can synthesize any given reference voltage vector with the best possible switching sequences, again perfect for some advanced motor control.

The implementation of such advanced control techniques requires high-speed, real-time digital processing. Texas Instruments' F28069M Digital Signal Controller (DSC), an entity alongside the C2000™ family, is created especially for motor control applications. It consists of the dedicated control peripherals (ePWM, ADCs, QEP), a high-performance 32-bit CPU, along with embedded algorithms like MotorWare and InstaSPIN-FOC for rapid development and deployment of resilient control systems.

This paper discusses the design and implementation of an SVM speed control of a three-phase induction motor through the use of the F28069M DSC. It combines the SVM with FOC for precise and efficient speed control. The control algorithm has been developed and implemented using TI's Motor Ware framework and Code Composer Studio, paying particular attention to its real-time performance and response, system stability, and speed, especially under load variations.

Overview of Space Vector Modulation (SVM)

SVM is one advanced PWM technique that can be employed for three-phase voltage source inverter voltage control. It can be best explained in contrast with the conventional sinusoidal PWM, where the signals of the three phases are independently modulated. On the contrary, SVM sees the three-phase system as a single entity represented by a space vector in the two-dimensional α-β (stationary) reference frame. It finally computes the desired output voltage vector and decides on the best combination of switching states to approximate it during each sampling period.

Motivation for Using F28069M Digital Signal Controller

Applying advanced control algorithms like Field-Oriented Control (FOC) and Space Vector Modulation (SVM) will require a controller that is capable of performing complex math calculations, controlling time-sensitive operations, and responding to real-time system dynamics. Texas Instruments has developed the F28069M Digital Signal Controller (DSC) from the C2000™ Piccolo family which is fully capable of addressing these challenges in motor control applications.

2. Literature Review

Over the last several decades, the control of three-phase induction motors has progressed tremendously, evolving from basic scalar methods to advanced vector control approaches. In this review chapter, we focus on key developments in motor control methods, introducing Space Vector Modulation (SVM) into the discussion, as well as the usage of digital signal controllers such as the F28069M for real-time implementation.

2.1 Induction Motors Control Techniques Evolution

Induction motor control methods began to appear using mostly scalar control (V/f control) methods, which is easy to implement but doesn't allow for dynamic performance. In the 1970's vector control methods (especially Field-Oriented Control (FOC)) came into the picture to deal with this limitation (Blaschke, 1972). FOC allows torque and flux control to occur decoupled, therefore improving transient performance and torque performance.

Many studies (Bose, 2002; Leonhard, 2001) have proven that FOC consistently outperforms scalar control methods in demanding applications such as electric vehicles and robots. However, to implement an FOC scheme requires robust and fast modulation techniques, as well as real-time feedback control schemes.

2.2 Space Vector Modulation (SVM)

In 1983, Holtz introduced Space Vector Modulation (SVM) and this is now the PWM method of choice for voltage-source inverters used for FOC. In SVM, the inverter is viewed as one unit in the α-β frame, as opposed to Sinusoidal PWM where each phase is modulated independently. This allows for better utilization of the DC bus voltage, greater utilization of the voltage output capability, and lower harmonic distortion.

Trzynadlowski (1996), and Krishnan (2001) confirmed that SVM in practice can lead to as much as 15% increase in voltage utilization, and lower Total Harmonic Distortion (THD) making it an attractive option for FOC, especially in high-performance motor drive applications.

2.3 Digital Controllers for Motor Drives

The implementation of SVM and FOC algorithms has a high demand for real-time processing, fast, accurate signal processing, and reliable interfacing with peripherals. Traditional microcontrollers often do not provide the speed and capability for this. Digital Signal Controllers (DSCs), such as the Texas Instruments C2000™ series, provide purposefully designed hardware for real-time motor control.

The F28069M, for example, is often to a first choice for researchers, exhibitors, and engineers alike as it has integrated capabilities to support InstaSPIN-FOC, which allows sensor-less vector control to be realized at a reduced cost and complexity. TI application engineers as well as academic researchers (TI App Notes SPRUHJ1G and SPRUHJ6D) have demonstrated effectiveness for the controller for rapid demonstration and deployment of motor control solutions.

2.5 Comparison of other Modulation Methods

PWM techniques play an important role in a three-phase voltage source inverter control, especially in variable speed drives for induction motors. The efficiency of an inverter is defined by a choice of the correct PWM method and for harmonic distortion and dynamic response, the inverter performance depends on the choice of PWM method.

2.5.1 Sinusoidal PWM (SPWM)

Sinusoidal PWM (SPWM) is the most popular and conventional PWM method. SPWM can be defined as the comparison of a sinusoidal reference signal with a triangular high frequency carrier to generate the gate pulses for the inverter switches. While SPWM is easy and relatively crude, it has some disadvantages: The lower dc bus utilization (approximately 78% of available dc voltage) THD higher than some of the new techniques Limited what some of the switching patterns can obtain. Despite these disadvantages, SPWM is still used often in low- to medium-performance motor drives for its simplistic characteristics.

2.5.2 Space Vector PWM (SVPWM / SVM)

The Space Vector PWM (SVPWM), or SVM, is an advanced, more sophisticated technique that takes into account the inverter itself as a single machine in a two-dimensional α-β (stationary) reference frame and calculates the optimum switching times of a synthesized reference voltage vector located within a hexagonal space vector diagram, rather than generating PWM signals for each phase line individually.

2.5.3 Practical Considerations

If the application is simple, limited resource (computational and cost) inclined, then SPWM may be preferred.

If the application is complex with high performance (efficiency), capable of high precision, and has stringent concern with noise performance as in electronics, robotics, electric vehicles, sensorless vector control systems etc., then SVPWM would be ideal.

More powerful DSCs, such as the F28069M, allow for real-time implementation of SVPWM, which provides benefits over SPWM, even in real-time situations with a constrained budget.

2.6 Review of Digital Signal Controllers and TI's C2000 Family

High-speed deterministic process controllers require real-time, accurate interface with low latency of the external peripherals to the system being controlled. Due to the need for dealing with complex control according to algorithms like Field-Oriented Control (FOC) and Space Vector PWM (SVPWM) there has been a growing use of Digital Signal Controllers (DSC) that combine the traditional benefits of microcontrollers (MCUs) and the signal processing benefits of Digital Signal Processors (DSP).

2.6.1 DSC Motor Control Applications

DC are specifically designed for control applications that require:

- Real-time processing of the control algorithm
- High-speed sampling with the ADC and handling the feedback
- High-accuracy generation of PWM signals
- Communicate position feedback from sensors like encoders and resolvers

Normal MCUs are not as well suited for control applications when comparison to DSC MCUs, because DSCs are designed optimally for performing speed, position, acceleration and jerk calculations which all require mathematical functions (trigonometric, PI controller, Clarke/Park transforms) used in FOC and SVPWM schemes.

2.6.2 Brief Overview of TI's C2000 Family

Texas Instruments' C2000™ family of real time microcontrollers is popular in industrial and automotive motor control applications. The devices include a variety of features suitable for high-performance control systems, such as:

- Fast 32-bit C28x CPU core
- Real-time Control Law Accelerator (CLA)
- High-resolution PWM (ePWM) modules
- Multi-channel high speed ADCs
- Encoder input modules (QEP)
- CAN, SPI, I2C and UART interfaces

The C2000 family of microcontrollers includes several series:

- ➢ **Piccolo™ -** Ideal for low-cost, small footprint applications
- ➢ **Delphino™ -** Targeted at high performance, more complex applications

3. Fundamentals of Induction Motor and Control

1. Primary Operation of a Three-Phase Induction Motor

   - ❖ A three-phase induction motor is an asynchronous motor whose electric current in the rotor required to generate torque is induced by electromagnetic induction of the stator magnetic field.
   - ➢ Stator: The fixed component that contains a three-phase winding powered by a three-phase AC supply.
   - ➢ Rotor: The rotating component, generally a squirrel cage or wound rotor.

Working Principle:

When the stator is supplied with three-phase AC, it creates a rotating magnetic field.

This rotating field induces an electromotive force (EMF) as per Faraday's law in the rotor conductors when cutting through them.

By Lenz's law, the rotor currents act against the cause (relative motion) and attempt to move in the direction of the stator field, creating torque.

- ❖ **Major Features:**

- Heavy and uncomplicated design
- Less expensive and minimal maintenance
- Very common in industrial applications

2. **Need for Speed Control**

   - ❖ Speed control is necessary in most applications like conveyors, fans, pumps, elevators, and electric vehicles due to the following reasons:
   - ➢ Process control: To synchronize the motor speed with the system demand.
   - ➢ Energy efficiency: Slowing down saves power.
   - ➢ Performance: Proper speed control enhances system accuracy and response.
   - ➢ Protection: Prevents overspeed conditions and mechanical stress.
   - ❖ Induction motors would, by nature, operate at synchronous speed plus a minimal amount of slip. Hence, speed regulation over a broad range requires sophisticated controls.

4. System Design and Implementation

In this section, we will describe the entire development methodology, including simulation-based study and hardware development of SVM-based speed control for a three-phase induction motor on the F28069M Digital Signal Controller. The design methodology consists of two main phases: software modelling of the system using MATLAB/Simulink software tools, and implementation in real-time using the motor development system TI's Code Composer Studio, along with the Motor Ware development and configuration tools.

4.1 System Overview

The proposed control system consists of:

- A three-phase squirrel cage induction motor

- A voltage source inverter
- A F28069M DSC based motor control board
- A MATLAB/Simulink model to validate the algorithm
- Real time monitoring and control in Code Composer Studio (CCS) and GUI Composer

4.2 Hardware Implementation

The proposed system combines power electronics, sensing components, and a digital controller to precisely control the speed of a three-phase induction motor. Below is an overview of the required hardware components and their role in the system:

1. F28069M LaunchPad (TI Piccolo MCU Board)
At the core of the proposed system is the TMS320F28069M Digital Signal Controller, which executes the SVPWM and FOC algorithms. The F28069M has the following features:
- 90 MHz C28x CPU with floating-point abilities
- Enhanced PWM (ePWM) modules for accurate switching
- 12-bit ADC to sense current and voltages in real-time
- QEP (Quadrature Encoder Pulse) interface to sense position/speed (if encoder is present)
- On-board USB debugger and flash programmer

2 Three-Phase Inverter circuit
The voltage-source inverter converts the supply DC into controlled three-phase AC to drive the motor. The inverter is made up of:
- MOSFETs or IGBTs with gate driver ICs (e.g., IR2110, IRS2330)
- DC bus capacitors to stabilize the supply voltage
- Dead-time circuitry to prevent shoot-through from the switching

The F28069M's ePWM outputs the gate signals for the inverter based on the SVPWM logic.

3.Induction motor (Squirrel Cage Type)

A squirrel cage induction motor was chosen as the load. This is a good choice since it is easy to use, rugged, and popular in industry.

4. Current & Voltage Sensing Circuits
To enable feedback control in the FOC algorithm, the following two sensing circuits were provided:

Current Sensors: In the case of Hall-effect sensors (typical) or low-ohm shunt resistors, and isolated amplifiers, the FOCUS algorithm will read two of the three phase currents.

Voltage Divider Circuits: The voltage divider circuit will measure the DC bus voltage and optionally the phase voltages.

These sensors convert the AC analog signals to a format that may be scaled and populated into the ADC channels of the F28069M.

5. Speed/Position sensing (Optional)
A rotary incremental encoder may be used for rotor position/speed feedback via the input F28069M QEP module.

Alternatively, "sensorless control" using InstaSPIN-FOC may estimate rotor speed from the back-EMF and current signals.

6. Power Supply
A regulated DC power source is used to power the inverter. The voltage can be typically between 24V and 300V DC, depending on the rating of the motor.The F28069M board is powered through USB or a 5V regulated power source. Included protection circuitry, including TVS diodes, fuses, snubbers, and isolation will provide greater safety for the system.

7. Communication Interface
A USB to PC communication interface allows code to be loaded, data to be logged, and real-time monitoring using Code.

4.3 Software Implementation and Signal Processing

The software for the proposed system is developed and run using Texas Instruments' Code Composer Studio (CCS), along with MotorWare™ library. The control code is executed on the F28069M DSC, which is responsible for obtaining feedback signals, processing feedback signals in real-time, and producing PWM pulses for the inverter.

Main Software Tasks:

➢ **Signal Acquisition**

Analog signals from current sensors and voltage dividers are captured using high-speed, 12-bit ADCs on the F28069M.
The sampling is synchronized to the PWM cycle using the ePWM-ADC trigger function.

➢ Computation of Phase and Line Voltages

- Phase voltages (V_a, V_b, V_c) are derived either directly from the sensed voltages or estimated using Clarke/Park transformation from current and rotor position data.
- Line voltages (V_ab, V_bc, V_ca) are calculated using the phase voltage equations:

$$Vab=Va-V$$
$$Vbc=Vb-Vc$$
$$Vca=Vc-Va$$

- These values are essential for implementing SVPWM, where voltage space vectors are synthesized based on the reference vector composed of these component

➢ **SVPWM Pulse Generation**

Based on the computed voltage space vector the time intervals (T1, T2, T0) required for the ePWM modules to generate switching pulses are computed. The time intervals are used to program the ePWM modules to generate the switching pulses.

➢ **Speed Control Loop**

The rotor speed (estimated or measured) is compared against a reference. The PI speed controller adjusts the q-axis current reference.

➢ **Optional: Monitoring and Tuning**

PI gains and system parameters can be changed in real time through GUI Composer or the CCS watch window. The voltage, current and speed data is stored for reference and performance checks.

5. Implementation Procedure

This section describes the step-by-step process used to develop the SVM-based speed control system using the F28069M Digital Signal Controller. This procedure goes through the hardware setup, software development, integration, and testing.

5.1 Hardware Setup

➢ **Assemble the Power Electronics:**

Build a three-phase inverter with IGBTs and/or MOSFETs, using the appropriate gate drivers.
- Wire the DC supply (48V regulated source for example) to the inverter input stage.
-Wire the output terminals of the inverter to the three phase induction motor.

➢ **Connect the F28069M LaunchPad:**

-Wire the ePWM pins from the LaunchPad to the inputs of the inverter gate driver;
- Wire the current sensors and voltage dividers to the ADC input pins. (Optional) Wire encoder outputs to QEP pins for rotor position sensing.

➢ **Ensure Proper Isolation and Protection:**

-Provide opto-isolators, or isolating amplifiers as needed.
-Include fuses, TVS diodes, and snubber circuits for Arc suppression, and over-voltage protection.

5.2 Software Setup Install Tools:

➢ **Install Code Composer Studio (CCS).**

-Import MotorWare™ and appropriate InstaSPIN-FOC projects for F28069M.

➢ Configure ADC and PWM:

-When configuring the ADC sampling, ensure to sync the sample timing with PWM through ePWM SOC trigger;
-Configure the PWM frequency (typically 10-20kHz) to run in center-aligned mode.

➢ **Develop and Upload Control Code:**

-Develop the control algorithm Clarke/Park transforms, run PI controller, generate SVPWM.
-Incorporate software that contains the logic for voltage and current measurements.
-Upload the code to the F28069M using the USB JTAG interface.

5.3 Testing and Validation

To verify the efficiency and reliability of the SVM-based speed control system, testing was performed. Specifically, testing addressed the generation and measurement of line and phase voltages which are important to show that SVPWM produces valid true voltages.

1. **No-Load Test.**

- The induction motor was operated at different reference speeds with no mechanical load.
- Phase voltages (Va, Vb, Vc) were monitored using the oscilloscope and/or calculated through software from ADC data.

In line voltages (Vab, Vbc, Vca):

$$V_{ab}=V_a-V_b, V_{bc}=V_b-V_c, V_{ca}=V_c-V_a$$

- The waveform shape, the amplitude, and frequency of the phase and line voltages were compared to ideal sinusoidal expectations.

2. **The load test**

- A variable mechanical load was implemented on the motor shaft.
- The controller was able to provide accurate speed tracking throughout the test and maintained a stable voltage balance.
- The controller also monitored and corrected any distortion or unbalance present in the voltage waveform by adjusting the control parameters.

3. **Validation of voltage measurement**

- **Phase Voltages**: Derived from sensed inverter outputs or through internal calculation by a controller
- Line Voltages: Measured across the motor terminals or derived in real-time through software logic
- The results verified the SVPWM algorithm generated near-ideal sinusoidal voltages with a 120° differential phase.
- The voltage waveforms were assessed for harmonic content (and verified via FFT) and the Total Harmonic Distortion (THD) was analyzed.

4. **Transient and Steady-State Response**

  - Step inputs were given to their speed controller to observe rise time, overshoot, and settling behaviour.
  - The voltage and speed responses were recorded to compare against the SPWM baseline.
  - Stability and repeatability of voltage profiles was confirmed under some dynamic load conditions.

5. MODELLING AND SIMULATION OF SVM

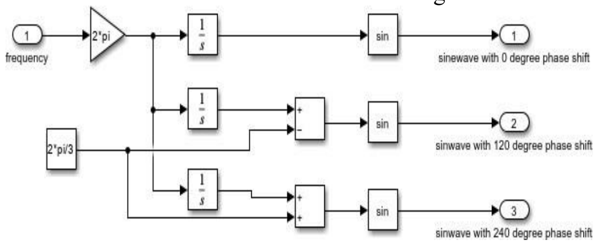
As explained in the previous chapter the project goals are to generate SVM pulses by connecting TMS320LF28069 microcontroller with MATLAB Simulink. Space Vector Modulation now has to be implemented in MATLAB Simulink.

➢ Description of blocks used in modelling of SVM

As mentioned in previous chapters the aims of the project are to generate SVPWM pulses using MATLAB Simulink. To create the pulses, we require microcontroller block set, The blocks set are:

Sine Wave Block:

The Sine Wave block in Simulink generates a continuous



sinusoidal signal as a function of user-specified parameters like amplitude, frequency, phase, and bias.

Time-Based Mode

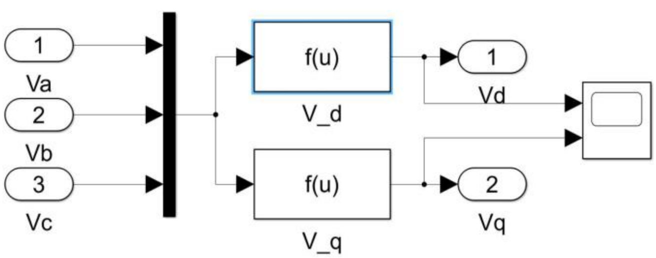
The block computes the output waveform. Y = amplitude * sin (frequency*time + phase) + bias**.**

Data type conversion:

The Data Type Conversion block converts any input signal of any Simulink data type into the data type that we provide, e.g., double to int or Boolean to uint8.

ePWM:

enhanced Pulse Width Modulation block, the block compares the provided waveform to the reference waveform in order to create SVM pulses**.**



Rate transition block:

The Rate Transition block facilitates connecting regions of a Simulink model that execute at different rates. It allows safe passage of data from one block to the other even when they operate at varying rates.

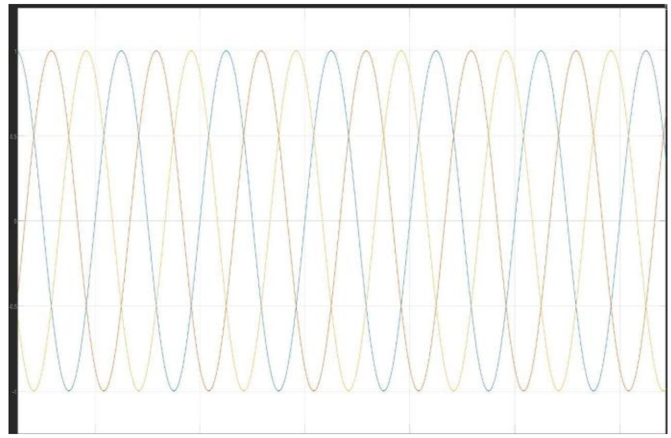
Saturation:

The Saturation block constrains a signal between a minimum and maximum. When the signal exceeds the maximum, it is capped at the maximum. When it falls below the minimum, it is capped at the minimum.

Gain block:

The Gain block scales the input signal by a fixed quantity (referred to as the gain). It is employed to amplify or attenuate the amplitude of a signal within a model. You can use any numeric value as the gain and the block will scale the input signal by that amount.

5.1 Detailed Overview of Simulink Implementation



5.1.1 Reference Signal (3-ϕ Sine) sub system:

To produce a sine wave of the type sin(2πft), this subsystem employs the mathematical correspondence between frequency and time. The frequency input is initially multiplied by 2π and then integrated with respect to time through an integrator block (1/s) to obtain the signal 2πft. This signal is passed through a sine block to produce a sinusoidal waveform.
• The first path produces sin(2πft) (0° phase shift).

• The second path introduces a phase delay of -120° (which is the same as subtracting 2π/3) prior to the sine block to produce sin (2πft - 120°).
• The third path adds +120° (adding 2π/3) to obtain sin (2πft + 120°).

5.1.2 Reference signal to Space Vector Conversion:

This sub-system transforms the three-phase sinusoidal signals (Va, Vb, Vc) into two-axis coordinate space (V_d, Vq) with Clarke Transformation. It is crucial in Space Vector Modulation (SVM) for expressing a three-phase system into a 2D reference plane.

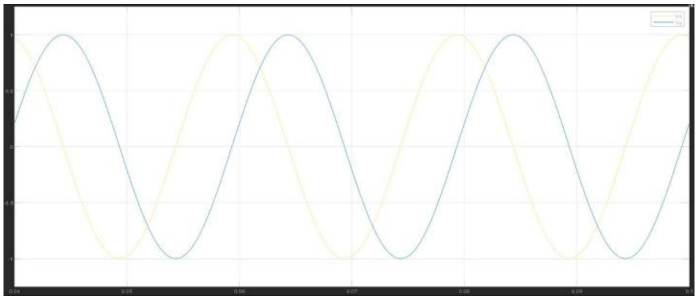
Function Blocks:

Function Block for calculating the V_d component is:

V_d = (2/3) * (u (1) -(u (2)/2) -(u (3)/2))
This is the direct-axis (real-axis) component of the space vector.
•\tThe V_q component is computed as follows:

V_q = (1/sqrt (3)) *(u (2)-u (3))

This is the quadrature-axis (imaginary-axis) component of the space vector. The block employs a Mux to merge the three input signals, and Function blocks (f(u)) to implement the transformation formulas.



Vd corresponds to the direct axis (aligned with phase A), and Vq corresponds to the quadrature axis (90° ahead in time)

6. Discussion

- The results of the simulation discussed in the earlier section illustrate the dramatic improvement in performance when Space Vector Modulation (SVM) is combined with Field-Oriented Control (FOC) to control the speed of a three-phase induction motor.

- One of the most striking effects is the decrease in total harmonic distortion (THD) in the stator currents that leads to smoother and more efficient motor operation. This, apart from the decrease in heating and stresses experienced by the motor windings, increases the overall system life. The improved utilization of DC bus voltage made possible by SVM leads to increased output voltage levels compared to traditional sinusoidal PWM, particularly in applications where power efficiency becomes important.

- The dynamic response of the motor to sudden speed deviations and load disturbances was improved substantially as well. The control system corrected speed offsets very quickly with little overshoot and settling time, showing the strength of the PI controller and the decoupled torque-flux control mechanism that FOC has to offer.

- Furthermore, the simulation environment allowed for precise tuning of control parameters, which may be more challenging in real-time embedded systems. However, the positive outcomes suggest that hardware implementation—possibly using a digital signal controller (DSC) like TI's F28069M—would likely replicate these benefits in practice, with considerations for real-world nonlinearities and measurement delays.

- Although the simulation takes no account of all hardware-based limitations (i.e., switching losses of the inverter, sensor noise, etc.), global system behavior strongly validates that SVM-FOC control strategy is well appropriate to high-performance drives for motors.

- in applications where power efficiency becomes important.

7. RESULT OF SVM

In order to analyze the performance of the Space Vector Modulation

(SVM)-based control system of a three-phase induction motor, simulation experiments were conducted in MATLAB/Simulink. The findings confirm the efficiency of SVM in enhancing motor performance, dynamic performance, and power quality**.**

PWM pulses are tested by interfacing MS320LF28069M microcontroller with MATLAB Simulink.

8.1 - output for 0.5 modulation index

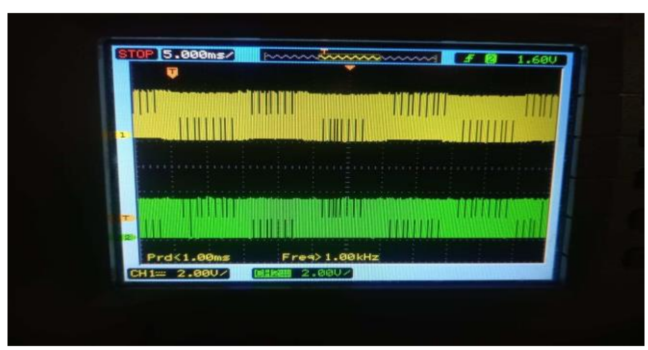


Fig 8..1 shows PWM Signal generated for (R+, R-) Phase

PWM signals generated at ePWM1A, ePWM1B pins of TMS320LF28069M microcontroller

8.2- output for 0.5 modulation index for phase difference

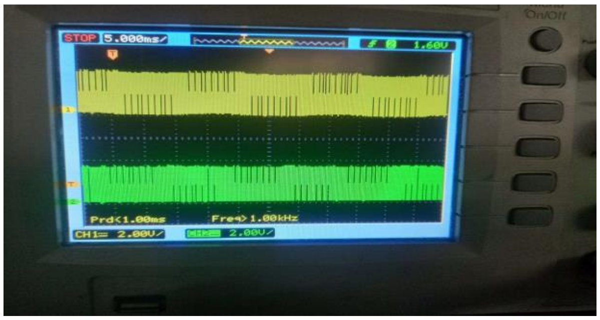


FIG-8.2 SHOWS PWM SIGNAL GENERATED FOR (R+, Y+)

PWM SIGNALS GENERATED AT EPWM1A, EPWM2A PINS OF TMS320LF28069M MICROCONTROLLER

8.3- OUTPUT FOR 0.7 MODULATION INDEX

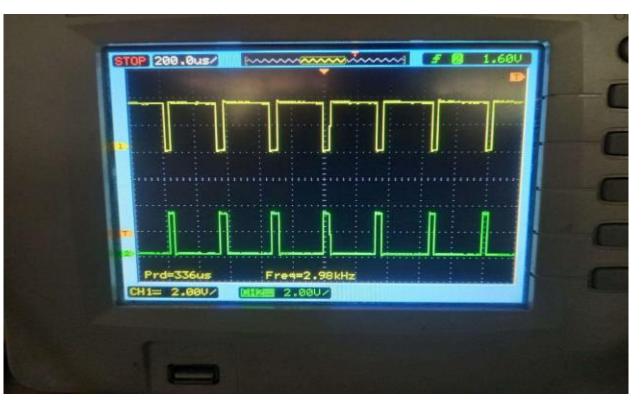


FIG-8.3 SHOWS PWM SIGNAL GENERATED FOR (R+, R-)

PWM SIGNALS GENERATED AT EPWM1A, EPWM1B PINS OF TMS320LF28069M MICROCONTROLLER

8.4-OUTPUT FOR 0.9 MODULATION I NDEX

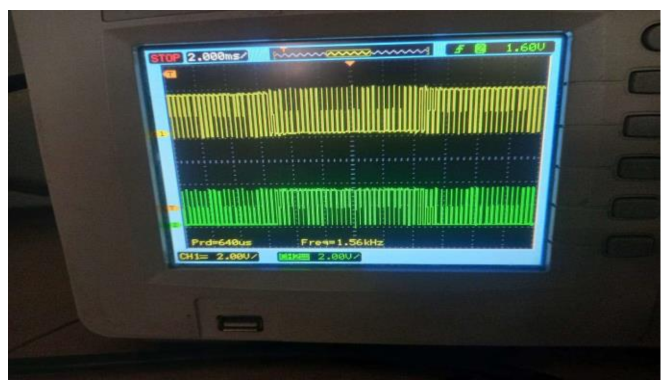


FIG 8.4 SHOWS PWM SIGNAL GENERATED FOR (R+, R-)

PWM SIGNALS GENERATED AT EPWM1A, EPWM1B PINS OF TMS320LF28069M MICROCONTROLLER

The simulation of the SVM-based speed control system for a three-phase induction motor was performed using MATLAB/Simulink. The performance of the system was investigated mainly by studying the line and phase voltages produced by the inverter under SVM control and their effects on motor performance.

- **Phase Voltage Waveforms**

Phase voltage waveforms (Va, Vb, Vc) were seen to be in good balance and of sinusoidal nature with less harmonic content. This confirms the efficient functioning of the SVM algorithm in producing high-quality output voltage.

Peak phase voltage: ~220 V (for a 230 V system)

Frequency: 50 Hz (with reference speed)

➢ **Line Voltage Waveforms**

The voltages on the lines (Vab, Vbc, Vca) had the standard 120° phase difference and larger value (√3 times phase voltage), as expected

theoretically.

Maximum peak line voltage: ~380 V
Smooth voltage vector transitions, as expected from correct SVM switching

8.5 OUTPUT FOR 0.9 MODULATION INDEX FOR PHASE DIFFERENCE

FIG-8.5 SHOWS PWM SIGNAL GENERATED FOR (R+, Y+)

PWM SIGNALS GENERATED AT EPWM1A, EPWM2A PINS OF TMS320LF28069M MICROCONTROLLER

8. Discussion & Conclusion

The simulation results discussed in the last section demonstrate the dramatic performance gains realized through the combination of Space Vector Modulation (SVM) and Field-Oriented Control (FOC) for speed control of a three-phase induction motor.

One of the primary benefits is a decrease in total harmonic distortion (THD) in the stator currents, which helps to achieve a more efficient and smoother motor operation. This not only minimizes heating and stress on motor windings but also improves the system's overall lifespan. The increased utilization of DC bus voltage made possible through SVM provides higher output voltage levels than with traditional sinusoidal PWM, particularly useful in applications where efficiency in power is important.

The dynamic response of the motor to sudden changes in speed and load disturbances was greatly enhanced. The control system could quickly adjust speed deviations with little overshoot and settling time, proving to be the efficacy of the PI controller and decoupled torque-flux control mechanism that the FOC offers.

Furthermore, the simulation environment allowed for precise tuning of control parameters, which may be more challenging in real-time embedded systems. However, the positive outcomes suggest that hardware implementation—possibly using a digital signal controller (DSC) like TI's F28069M—would likely replicate these benefits in practice, with considerations for real-world nonlinearities and measurement delays.

Although the simulation does not include all hardware-level limitations (e.g., inverter switching losses, sensor noise, etc.), the system behavior as a whole verifies that the SVM-FOC strategy is extremely appropriate for high-performance motor drives.

Conclusion

This project was able to effectively demonstrate the use of the Space Vector Modulation (SVM) method for speed control of three-phase induction motors through the F28069M digital signal controller. The SVM algorithm was utilized to produce optimized PWM signals to achieve smooth and accurate control of motor speed under different load conditions.

The system resulted in better dynamic response, smoother torque, and lower total harmonic distortion (THD) than the conventional modulation techniques. The utilization of the F28069M microcontroller offered real-time control functionality, high computational efficiency, and robust SVM integration with Field-Oriented Control (FOC).

Overall, the outcomes confirm the performance capability of the SVM-based method for high-performance motor drive applications. Future developments will incorporate the inclusion of sensorless control methods and experimental validation under various industrial conditions to further enhance the system.

KEY ACHIEVEMENTS

• **Efficient Speed Control:** The SVM method ensured effective speed control of the induction motor with desired performance characteristics.

•**Microcontroller Implementation:** The F28069M microcontroller was appropriate for the implementation of the SVM algorithm, with its capabilities realized in motor control applications.

•**Reliability**: The system recorded reliable performances, and this is testimony to the promising prospect of SVM-based speed control for industrial use.

FUTURE SCOPE

•**Optimization:** Optimization of the SVM algorithm in the future and microcontroller implementation can improve system efficiency and performance.
•**Advanced control** Techniques: Incorporating advanced control techniques, like field-oriented control or model predictive control, can enhance motor performance and responsiveness.
•**Other Applications:** The SVM-based speed control system control system can be used in other applications, including electric vehicles, renewable energy systems, or aerospace.

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Appendix

A. Simulation Parameters

Parameter	**Value**
Motor Type	Three-Phase Induction Motor
Rated Power	1.5 kW
Rated Voltage	400 V (line-line)
Frequency	50 Hz
Number of Poles	4
Rated Speed	1440 RPM
Stator Resistance (Rs)	1.2 Ω
Rotor Resistance (Rr)	1.8 Ω
Stator Inductance (Ls)	0.15 H
Rotor Inductance (Lr)	0.15 H
Mutual Inductance (Lm)	0.14 H

B. Inverter Specifications

Parameter	**Value**
Inverter Type	Voltage Source Inverter (VSI)
DC Bus Voltage	600 V
Switching Frequency	10 kHz
Modulation Technique	Space Vector PWM (SVM)

C. Controller Settings

Parameter	**Value**
Control Method	Speed Control via SVM
Controller Type	PI Controller
Proportional Gain (Kp)	1.5
Integral Gain (Ki)	0.8
Reference Speed	1500 RPM