

Vector Control of Three Phase Induction Motor

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Abstract - High dynamic performance, which is obtained from DC motors, became achievable from induction motors with the advances in power semiconductors, digital signal processors and development in control techniques. By using field oriented control, torque and flux of the induction motors can be controlled independently as in DC motors. The control performance of field oriented induction motor drive greatly depends on the stator flux estimation. Vector control, also called field-oriented control, is a variable-frequency drive control method in which the stator currents of a three-phase AC electric motor are identified as two orthogonal components that can be visualized with a vector. One component defines the magnetic flux of the motor, the other the torque. The control system of the drive calculates the corresponding current component references from the flux and torque reference given by the drives speed control. The simulation is done by using MATLAB/SIMULINK R2017a software. Hardware is implementing using dsPIC30f2010 micro controller.

Key Words: Field Oriented Control, Clarke transformation, Park transformation, PI controller, Hysteresis Current Controller, Driver Circuit, dsPIC30f2010.

1. INTRODUCTION

Variable speed drive systems are essential in many industrial applications. In the past, DC motors were used extensively in areas where variable speed operation was required, since their flux and torque could be controlled easily by the field and armature current.

DC motors have certain disadvantages, which are due to the existence of the commutator and the brushes. These problems can be overcome by the application of alternating current motors, which can have simple and rugged structure, high maintainability and economy. However, the speed or torque control of induction motors is more difficult than DC motors due to their nonlinear and complex structure. The torque of the DC motors can be controlled by two independent orthogonal variables, stator current and rotor flux, where such a decoupling does not exist in induction motors. Vector control makes it possible to control an AC motor in a manner similar to the control of a

separately excited DC motor, and achieve the same quality of dynamic performance. As for DC machines, torque control in AC machines is achieved by controlling the motor currents.

However, in contrast to a DC machine, in AC machine, both the phase angle and the modulus of the current has to be controlled, or in other words, the current vector has to be controlled. This is the reason for the terminology vector control.

2. FIELD ORIENTATION CONTROL

Vector control, also called field-oriented control (FOC), is a variable-frequency drive (VFD) control method in which the stator currents of a three-phase AC electric motor are identified as two orthogonal components that can be visualized with a vector. One component defines the magnetic flux of the motor, the other the torque. The control system of the drive calculates the corresponding current component references from the flux and torque reference given by the drives speed control.

2.1 PRINCIPAL OF FIELD ORIENTED CONTROL

The principle of FOC system of an induction motor is that the d-q coordinate reference frame is locked to the rotor flux vector, this results in decoupling of the variables so that flux and torque can be separately controlled by stator direct axis current i_{sd} and quadrature axis current i_{sq} respectively like in the separately excited DC machine.

If we take i_a, i_b, i_c as instantaneous currents in the stator phases, then the stator current vector is defined as follow

$$\vec{i}_s = i_a + i_b e^{j2\pi/3} + i_c e^{j4\pi/3}$$

(a, b, c) \rightarrow (α, β) (the Clarke transformation), which gives outputs of two coordinate time variant system.

$$i_{\alpha\beta o} = \begin{bmatrix} 1 & -1/2 & 1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$$

$(\alpha, \beta) \rightarrow (d, q)$ (the Park transformation), which gives outputs of two coordinate time invariant system.

$$i_{dq0} = \begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ \sin\theta & \sin(\theta - 2\pi/3) & \sin(\theta + 2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$$

2.2 Block Diagram of Field Oriented Control

The block shows the vector control mechanism. The motor is a three phase induction motor, here we used a quarter HP motor. The motor is fed by a three phase supply which is fed from the three phase inverter. The speed of the motor is feed back to the controller using a speed sensor which converts the speed to corresponding digital or analog value.

The current to the motor is sensed using current sensors. The output of current sensor is given to microcontroller, the three phase current component is transformed to two phase using Clark and Park transformations. By using Clark transformation abc component is converted into α and β and using park transformation it is converted into two phase d and q.

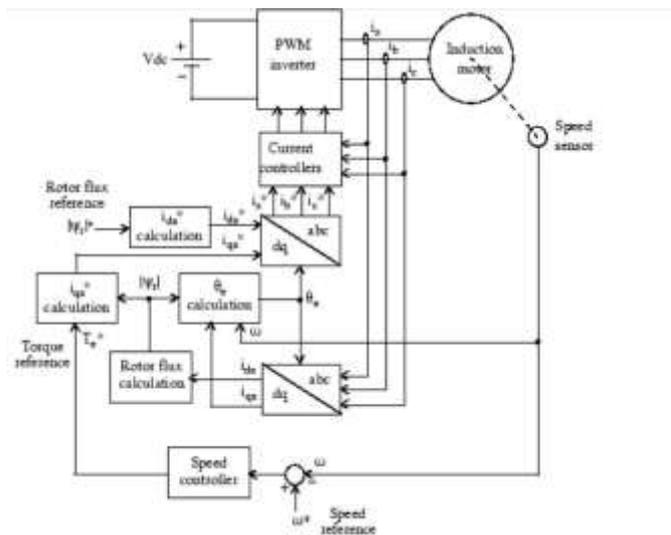


Figure 2.1: Block Diagram of Field Oriented Control

iqs calculation:

The stator quadrature-axis current reference i_{qs}^* is calculated from torque reference T_e^* as

$$i_{qs}^* = \frac{2}{3} \frac{L_r}{L_m} \frac{T_e^*}{[\Psi_r]}$$

Where L_r is the rotor inductance, L_m is the mutual inductance, and $[\Psi_r]$ is the estimated rotor flux linkage given by

$$[\Psi_r] = \frac{L_m \cdot i_{ds}}{1 + \tau_r s}$$

Where $\tau_r = L_r / R_r$ is the rotor time constant.

ids* calculation:

The stator direct-axis current reference i_{ds}^* is obtained from rotor flux reference input $[\Psi_r]^*$.

$$i_{ds}^* = \frac{[\Psi_r]^*}{L_m}$$

θe calculation:

The rotor flux position θ_e required for coordinates transformation is generated from the rotor speed ω_m and slip frequency ω_{sl} .

$$\theta_e = \int (\omega_m + \omega_{sl})$$

The slip frequency is calculated from the stator reference current i_{qs}^* and the motor parameters.

$$\omega_{sl} = \frac{L_m \cdot R_r \cdot i_{qs}^*}{[\Psi_r] \cdot L_r}$$

The i_{qs}^* and i_{ds}^* current references are converted into phase current references i_a^* , i_b^* , i_c^* for the current regulators. These obtained values are compared with the reference values. The output of the current sensor is given to the current controller. On comparing the obtained current value with reference value the various gates are triggered. The main task of the control systems in current regulated inverters is to force the current vector in the three phase load according to a reference trajectory. The hysteresis band current control is used very often because of its simplicity of implementation. The current control with a fixed hysteresis band has the disadvantage that the PWM frequency varies within a band because peak-to-peak current ripple is required to be controlled at all points of the fundamental frequency wave.

The method of adaptive hysteresis-band current control PWM technique where the band can be programmed as a function of load to optimize the PWM performance. The basic implementation of hysteresis current control is based on deriving the switching signals from the comparison of the current error with a fixed tolerance band. This control is based on the comparison of the actual phase current with the tolerance band around the reference current associated with that phase.

2.3 Design of PI controller

The torque command is generated from the speed error signal, processed through a PI controller. The commanded torque and flux producing components are processed through different blocks. The reference currents are compared with the actual current in the current controller

and the controller takes the necessary action to produce PWM pulses to trigger the inverter switches. The structure of the speed control loop is shown in Figure 2.

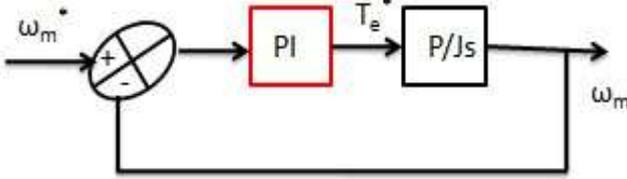


Figure 2.2: Structure of the speed control loop

The characteristic equation of the speed control loop is given by

$$1 + G_{PI}(s)H(s) = 0$$

$$G_{PI}(s) = k_p + k_i \frac{1}{s}, \quad H(s) = 0$$

For $J = 0.03 \text{ kg}\cdot\text{m}^2$ and $p = 2$, it becomes

$$1 + (k_p + k_i \frac{1}{s}) \frac{P}{Js}$$

After putting J and P value, equation becomes

$$s^2 + 66.67k_p s + 66.67k_i = 0$$

$$s^2 + 2\xi\omega_n s + 66.67\omega_n^2 = 0$$

This k_p and k_i are used in speed controller to generate torque as shown in figure 2.2. The role of the speed controller is to keep the motor speed equal to the speed reference input in steady state and to provide a good dynamic during transients. The controller can be a proportional-integral type

3. SIMULATION MODEL AND RESULTS OF VECTOR CONTROL OF INDUCTION MOTOR DRIVE

MATLAB is a high-performance language for technical computing. It supports linear and non-linear systems, modelled in continuous time, sampled time, or a hybrid of the two. Systems can also be multi rate, i.e. have different parts that are sampled or updated at different rates.

3.1 SIMULATION PARAMETERS

Table 1 describes the simulation parameters for the vector control of Induction Motor. Simulation is carried out using 1/4 HP induction motor and parameters are calculated by using No-load test and blocked rotor test. This is simulated in Matlab 2017a.

Simulation Parameter	
Parameter	Value
Stator Resistance	4.5Ω
Stator Inductance	0.8mH
Rotor Resistance	6.017Ω
Rotor Inductance	0.8mH
Mutual Inductance	34.7mH
Inertia	0.03 Kg.m ²
Friction Factor	0.1Nms
Pole pair	2

Table 1: Simulation Parameter

3.2 SIMULINK MODEL WITH RESULTS

3.2.1 Simulink Model Vector Control Induction Motor Drive

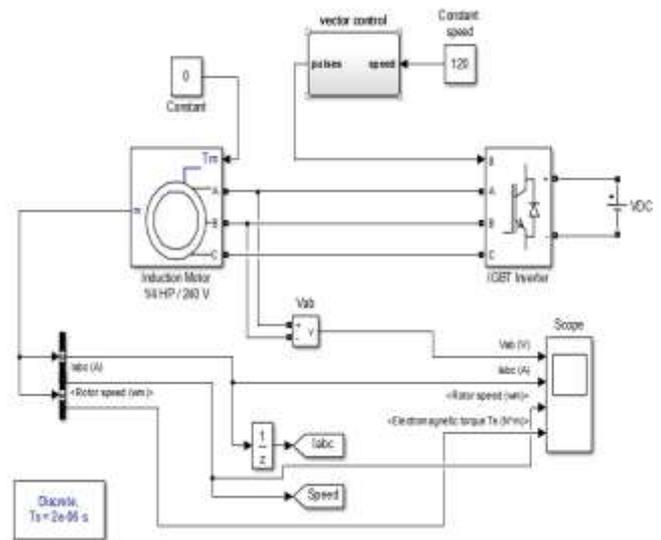


Figure 3.1: Simulink Model of Vector Control Induction Motor Drive

Figure 3.1 shows the Simulink model of vector control induction motor drive. There is a inverter, 1/4 HP induction motor and a close control process to generate PWM.

3.2.2 Simulink Model Vector Control Block

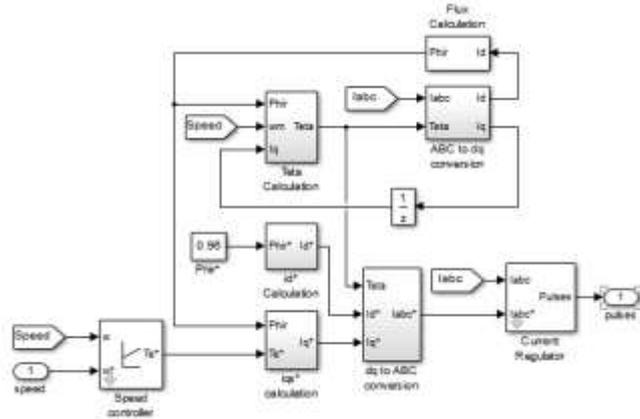


Figure 3.2: Simulink Model of Vector Control Block

Figure 4 shows the Simulink model of vector control block. There is Clarkes transformation block, Parks transformation block, theta calculation block, speed controller, flux calculation block and current controller. Controller circuit brings the speed of induction motor to constant value by using indirect vector control algorithm.

Hysteresis Current Regulator

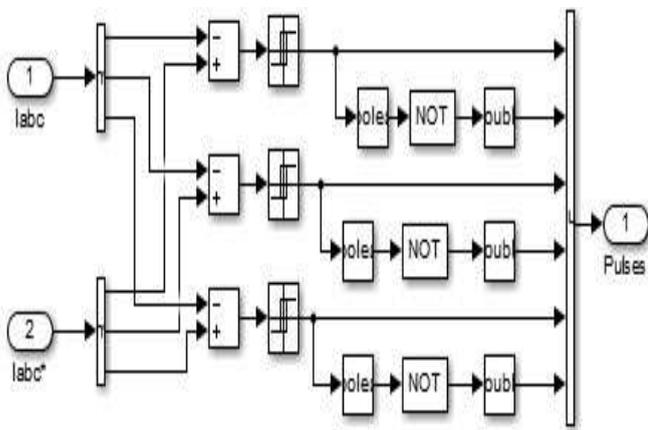


Figure 3.3: Hysteresis Current Regulator

The current regulator, which consists of three hysteresis controllers, is built with Simulink blocks. The motor actual currents are cater by the measurement output of the Asynchronous Machine block. The actual motor currents and reference current are compared in hysteresis type relay.

3.2.3 Simulation Results

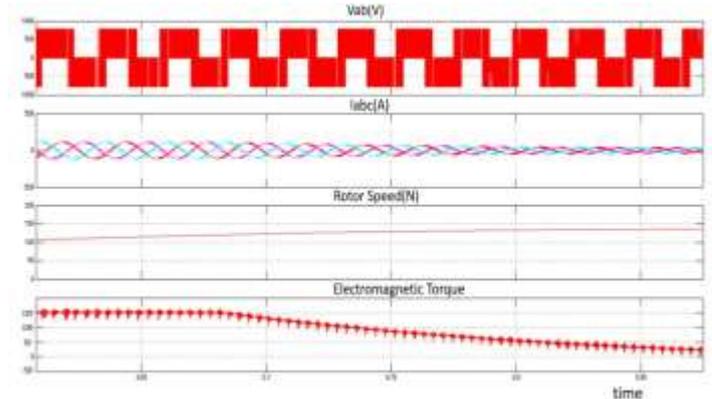


Figure 3.4: Using Current Controller Simulation Result
 (a) V_{DC} (b) I_{abc} (c) N (rpm) (d) T_e

Figure 6 shows output of Vector control Induction Motor which is using hysteresis controller technique to generate PWM, here we comparing reference current which is found by speed controller and current of induction motor.

3.2.4 Gate Pulses

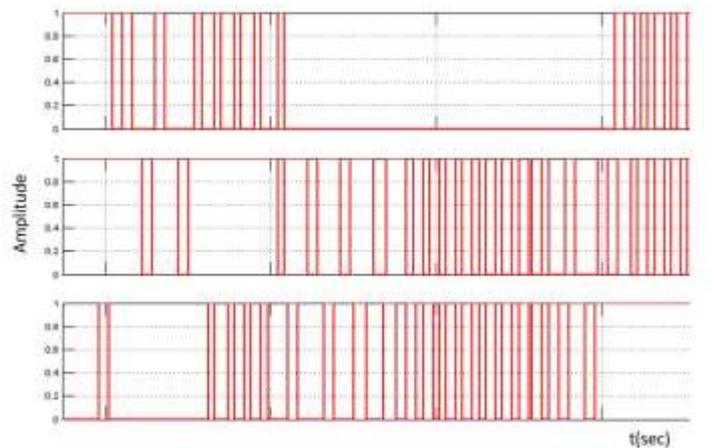


Figure 3.5: Simulation Pulses to Upper Inverter legs

This figures show the pulses to the upper Switches of Inverter obtained from simulation and pulse width changes according to the error in current. As we can see only two upper switches are ON simultaneously. So it's 180 mode of conduction of inverter.

4. DESIGN OF HARDWARE

4.1 Block Diagram

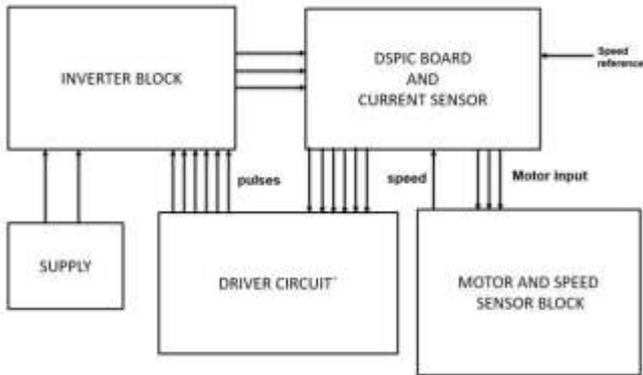


Figure 4.1: Block Diagram of FOC

The current sensor takes current I_{abc} from motor terminals and speed sensor senses the speed of motor. The input is given to the controller Dspic30f2010. It is in the Micro controller all calculations are made. Corresponding gate pulses are given to drive circuit. The drive circuit drives the inverter. Driver circuit act as a isolation circuit. From the inverter motor is connected.

4.2 Inverter Design

We have selected a quarter hp motor (200W,240V).
 Maximum motor current = wattage/3 * voltage
 $= 200/3 * 240 = 0.28A$

IGBT rating should be greater than motor rating .So we selected FGA25n120.

4.3 Program Algorithm

- Step 1: Start.
- Step 2: Initialize Rotor inductance(L_r), Mutual Inductance(L_m), Rotor Resistance(R_r) and Flux Reference.
- Step 3: Declare all the variables.
- Step 4: Declare current and speed input pins.
- Step 5: Declare PWM output pins.
- Step 6: Take feedback from current sensor and convert to 2D by clarks, parks transformations.
- Step 7: Find theta.
- Step 8: Take input from speed sensor and find torque component.
- Step 9: Calculate reference current and convert back to 3D.
- Step 10: Generate PWM signals using hysteresis controller.
- Step 11: Stop.

4.4 Hardware Setup

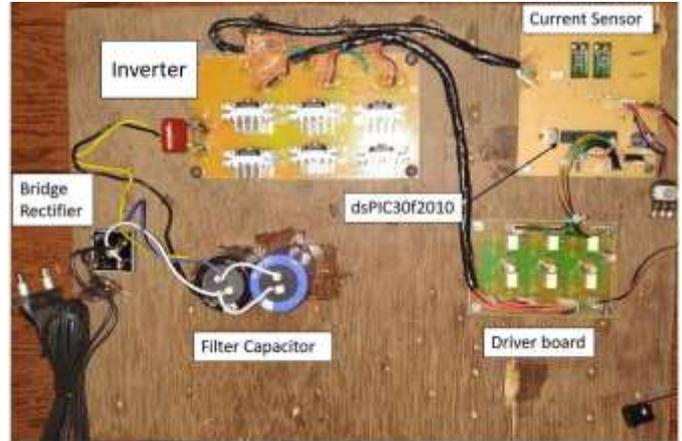


Figure 4.2: Prototype of FOC

4.5 Result

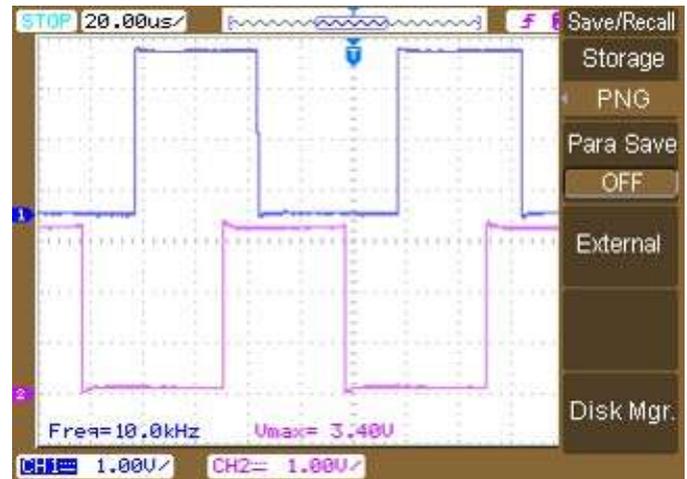


Figure 4.3: pulses to switch 1&3

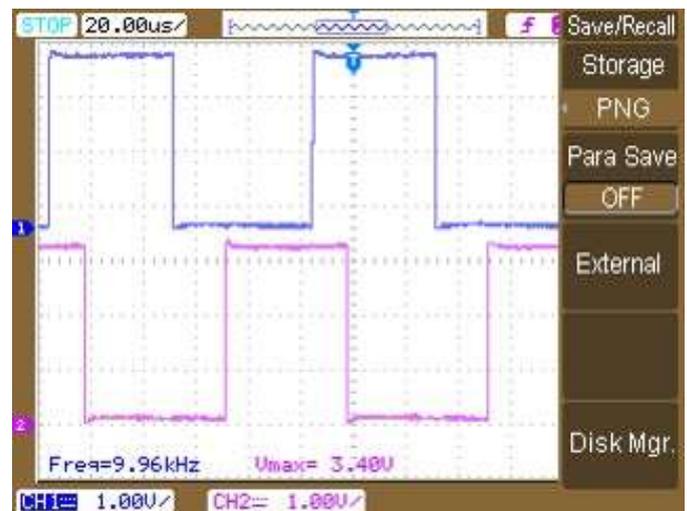


Figure 4.4: pulses to switch 1&5

Figure 4.3 shows the pulses given to switch 1 and 3. Figure 4.4 shows the pulses given to switch 1 and 5.

In this mode of conduction, every device is in conduction state for 180° where they are switched ON at 60° intervals.

The terminals A, B and C are the output terminals of the bridge that are connected to the three-phase delta or star connection of the load. The switch S1-S6 are switches in the inverter. The operation of a balanced star connected load is explained. For the period $0^\circ - 60^\circ$ the switches S1, S5 and S6 are in conduction mode. The terminals A and C of the load are connected to the source at its positive point. The terminal B is connected to the source at its negative point.

5. CONCLUSION

Vector control in three phase induction motor has been implemented and simulated the same using Matlab Simulink and desired torque, speed characteristics are obtained. Fast response of vector control make it better than other method of speed control of induction motor, by using this method we attain maximum response in minimum time. By using vector control using in induction motor we are getting transient response will be fast because torque control by i_{qs} does not affect flux. It allows for speed control in all four quadrants (without additional control elements) as negative torque is directly taken care of in vector control. The simulation is done by using MATLAB/SIMULINK R2017a software. Hardware was implement using dsPIC30f2010 micro controller.

REFERENCES

- [1] Yuan Lin and Vijay Vittal, "Modeling of Rectifier-Controlled Induction Motor Drive Load in Transient Stability Simulation Tools " IEEE Transactions on Power System, Jan. 2018.
- [2] Y. Liu, V. Vittal, J. Undrill, and J. H. Eto, "Transient model of air conditioner compressor single phase induction motor ", IEEE Trans. Power System, vol. 28, no. 4, pp. 4528 - 4536, Nov. 2013.
- [3] Y. Liu and V. Vittal, "Distribution side mitigation strategy for fault induced delayed voltage recovery," IEEE PES General Meeting, pp. 1-5, July 2014.
- [4] N. Mohan, T. Undeland, and W. Robbins, "Power Electronics: Converters, Applications, and Design", 3rd ed. New York: Wiley , 2003.
- [5] P. C. Sen, "Electric Motor Drives and Control: Past, Present and Future ", IEEE Trans. on Industrial Electronics, Vol. 37, No. 6, December 1990.