

Design, Simulation and Implementation of Space Vector Control for 3-Phase Induction Machine

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ABSTRACT:

This paper presents speed control of induction motor using park's formulation technique using MATLAB. AC induction motors, which contain a cage, are very popular in variable speed drives. In many industries, we need to speed control of AC induction motor allows vector control of the AC induction motor running in a closed loop with the speed/position sensor coupled to the shaft PWM modules are the hybrid controller's key features enabling motor control. The AC induction motor is a rotating electric machine designed to operate from a 3-phase source of alternating voltage. For variable speed drives, the source is normally an inverter that use power switches to produce approximately sinusoidal voltages and currents of controllable magnitude and frequency. In, the case of induction machines, the control is usually performed in the reference frame (d-q) attached to the rotor flux space vector. In this speed control, the complete system is simulated and explored the performance of speed control. The simulation results are presented based on MATLAB programming.

INTRODUCTION:

Induction machines [1] are the most widely used machines in fixed-speed applications due to reasons of cost, size, weight, reliability, ruggedness, simplicity, efficiency and ease of manufacture. For variable speed, high-performance drives, the dc machine is better than the induction machine, since an induction machine requires more complex methods of control [3]. The complexity arises because of the variable frequency power supply; ac signals processing and complex dynamics of the ac machine. Also it requires more

expensive, higher-rated inverters. The disadvantages of the induction machine are being eroded by the increasing Power of microprocessors and digital signal processors (DSP'S) with reducing cost and size, together with improvements in inverter technology. Hence it would be advantages to use induction machines as a basis for electrical to mechanical power conversion [5].

In many applications, the dynamic behavior of induction machine has an important effect up on the overall performance of the drive system. The realization of this requires a suitable mathematical model of the induction machine representation, which can be conveniently altered to simulate the Symmetrical induction machine in any reference frame. AC induction motors, which contain a cage, are very popular in variable speed drives. In many industries, we need to speed control of AC induction motor [7]. This drive application allows vector control of the AC induction motor running in closed-loop with the speed/position sensor coupled to the shaft.

SPACE VECTOR CONTROL:

The fast torque response obtained using vector control is achieved by estimating, measuring, calculating the magnitude and position of the motor flux in the machine.

If this flux is known, the stator current phasor can be aligned to maintain the field at he desired level and to produce torque as desired. A reference frame conversion

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is used to transform the three-phase stator currents into two orthogonal components, one to control the flux magnitude and the other current to control the developed torque. The main difficulty lies in the measurements or estimation of the flux position. The rotor flux position is required to calculate the stator current vector position in the stationary reference frame that is linked to the stator of the machine i.e. it is required to determine the orientation of the rotating field flux vector. Hence these controls are also called “field oriented control” [9].

There are two field orientation strategies to detect the rotor flux position. Direct vector control method uses sensors to directly track the flux position. Hall sensors are seldom used because of the high temperature inside the induction machine. Typical flux in a stationary reference frame and not the rotor flux, which is used in the decoupling network. So, flux linkage equations are necessary to derive the rotor flux from the flux sensor measurements. The required calculations introduce estimated machine parameters into the disturbance feed forward path causing detuning errors. The second category is called indirect vector control. Here, the flux position is derived using a calculated or estimated value of the angle between the flux and the rotor position measurement gives the rotor fluxes position [6].

The Principles of Vector Control:

The fundamental quantity that needs to be controlled in an induction motor is torque. Torque control of the inverter-fed induction motor is usually accomplished by means of vector control principles to ensure stability. With vector control, the torque and the flux of the induction motor are independently controlled in a manner similar to a separately excited dc motor. During operation of a vector controller, the magnitude and the phase of the supply current must be controlled in real time, in response to changes in both the speed and the torque demands. To reduce this problem to its simplest form, conventional two-axis theory is extensively used. By the selection of the correct reference frame, the three-phase ac rotational problem found in an induction motor can be reduced to a two-axis, stationary, dc

solution. Within the vector controller, the required motor currents are computed with reference to the rotor’s frame of reference, while the three-phase motor currents are referenced to the stator’s frame of reference. To achieve this, a set of transformations must be developed.

The fast torque response obtained using vector control is achieved by estimating, measuring, calculating the magnitude and position of the rotor flux in the machine. if this flux is known, the stator current phasor can be aligned to maintain the field at the desired level and to produce torque as desired. A reference frame conversion is used to transform the three-phase stator currents into two orthogonal components, one to control the flux magnitude and the other current to control the developed torque [8]. The main difficulty lies in the measurements or estimation of the flux position. The rotor flux position is required to calculate the stator current vector position in the stationary reference frame that is linked to the stator of the machine i.e. it is required to determine the orientation of the rotating field flux vector. Hence this control is also called “field oriented control”.

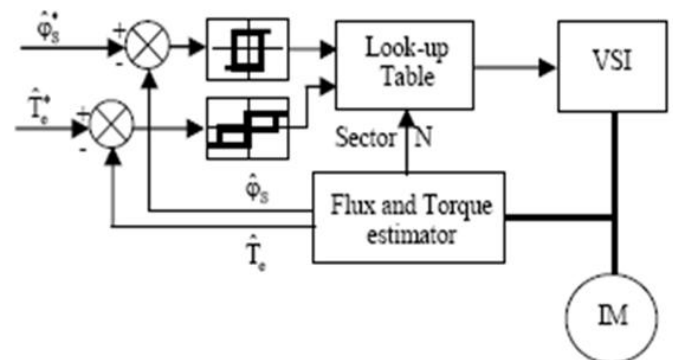


Fig: Basic Direct Control Scheme

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necessary to derive the rotor flux from the flux sensor measurements. The required calculations introduce estimated machine parameters into the disturbance feed forward path causing detuning errors [4].

Mathematical Model:

Assume that I_{sa} , I_{sb} , and I_{sc} are the instantaneous balanced 3-phase stator currents:

$$I_{sa} + I_{sb} + I_{sc} = 0 \quad 3.1$$

The stator current space vector can then be defined as follows:

$$I_s = k (I_{sa} + aI_{sb} + a^2I_{sc}) \quad 3.2$$

Where:

a and a^2 = The spatial operators, $a = e^{j2\pi/3}$, $a^2 = e^{j4\pi/3}$

k = The transformation constant and is chosen $k=2/3$

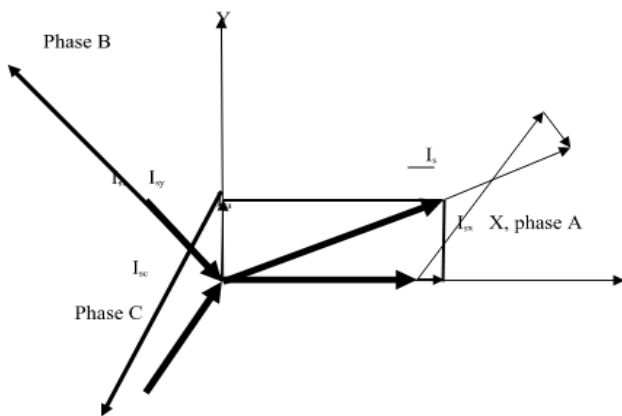


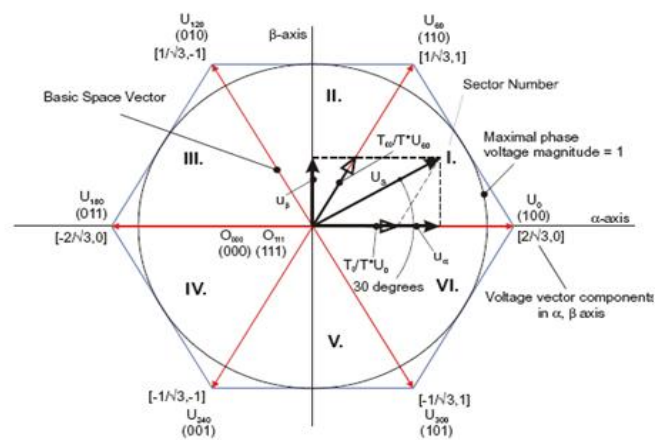
Fig: 3-phase to 2-phase conversion

Vector Control of Induction Machine:

The induction motors are widely used in fixed – speed as well as variable – speed applications. To obtain high – performance control of torque, speed, or position from an induction motor the method of vector control is used. Vector control can be used to provide at least the same performance from an inverter-driven induction motor as is obtainable from a separately excited dc motor [3].

The digital simulation is performed using mat lab simulink software environment. The basic building block of the 3-phase A. C. Induction motor vector control is implemented using MATLAB / simulink software. The control process is based on a DC coupled voltage controlled strategy using both direct and

quadrature current components of the induction motor. Pulses are also produces using currents. The speed is varying with currents. So we use references currents, those are produces by using flux components and torque. These references currents are club with main currents and produce six none zero pulse currents. These pulses are fed to MOSFET. This MOSFET out puts are ac voltages (but not a sinusoidal. because filters are not use in this model) [2].



MATHEMATICAL CALCULATIONS:

- Set time = 0.6sec;
- Reference flux = 0.96wb
- Reference torque = 300;
- Reference speed = 80 rad/sec

Calculation of I_d^* :

$$I_d^* = \frac{\text{Flux}^*}{L_m} = \frac{0.96}{0.1664} = 57.7$$

Calculation of T_e^* :

Set proportional gain $K_p = 10$

Integral gain = 18

Reference speed $\omega^* = 80$ rad/sec

Actual speed = 1780 rpm = 29.67 rad/sec

$$\Rightarrow |T_e^*| = ((\omega^* - \omega) * K_p - (\omega^* - \omega) K_i * \frac{T}{2} * \frac{z+1}{z-1})$$

$$= (80 - 29.67) * 10 - (80 - 29.67) * \frac{18}{2} * 0.6 * 3$$

$$= 50.333 * 10 - 50.33 * 9 * 1.8$$

$$= 503.33 - 815.4$$

$$= 312 \text{ N-m}$$

$$\theta = \int_0^T (\omega_r + \omega_m) dt$$

$$\omega_r = 80$$

$$\omega_m = 29.67$$

$$\Rightarrow \theta = (80 + 2 * 29.67) * 0.6$$

$$= 139.34 * 0.6 = 83.604 \text{ rad}$$

$$= 9.63^{\circ}$$

$$\Rightarrow$$

$$I_d = \frac{2}{3} \left[\cos\theta * i_a + \left(\frac{\sqrt{3}}{2} \sin\theta - \frac{1}{2} \cos\theta \right) * i_b + \left(-\frac{\cos\theta}{2} - \frac{\sqrt{3}}{2} \sin\theta \right) * i_c \right]$$

$$\Rightarrow \cos\theta = 0.97,$$

$$\Rightarrow \sin\theta = 0.17$$

at T = 0.6 Sec. The Current IA settled at 200 Magnitude.

$$I_a = \frac{200}{\sqrt{3}} \quad I_b = \frac{164.54}{\sqrt{3}} \quad I_c = \frac{-164.54}{\sqrt{3}}$$

$$\Rightarrow I_d =$$

$$\frac{2}{3} \left(\frac{200}{\sqrt{3}} * 0.97 + \left(\frac{\sqrt{3}}{2} * 0.17 - 0.97 \right) * \frac{164.54}{\sqrt{3}} + \left(0.97 + \frac{\sqrt{3}}{2} * 0.17 \right) * \frac{16454}{\sqrt{3}} \right)$$

$$\Rightarrow 94.3 \text{ Amps}$$

$$\Rightarrow \text{Flux} = \frac{0.01664}{1 + 0.796} * 94.3$$

$$= 0.93 \omega b$$

$$\Rightarrow I_q^* = 0.3405 * \frac{312}{0.93}$$

$$= 114.23 \text{ Amps}$$

$$\Rightarrow I_a^1 = -i_q^* \sin\theta + i_d^* \cos\theta$$

$$I_a^1 = \left(-\frac{\cos\theta}{2} + \frac{\sqrt{3}}{2} \sin\theta \right) * i_d + \left(\frac{\sin\theta}{2} + \frac{\sqrt{3}}{2} \cos\theta \right) * I_q^*$$

$$I_a^1 = -114.23 * 0.17 + 57.7 * 0.97$$

$$= 36.55 \text{ Amps}$$

$$I_b^1 = (-0.97 + \sqrt{3} * 0.17) * \frac{57.7}{2} + (0.17 + \sqrt{3} * 0.97) * \frac{114.23}{2}$$

$$= 86.19 \text{ Amps}$$

$$\Rightarrow I_a^* = 36.56 \text{ Amps}$$

$$I_b^* = 86.19 \text{ Amps}$$

$$I_c^* = -I_a - I_b = -122.74 \text{ Amps}$$

RESULTS OBTAIN FROM SIMULATION:

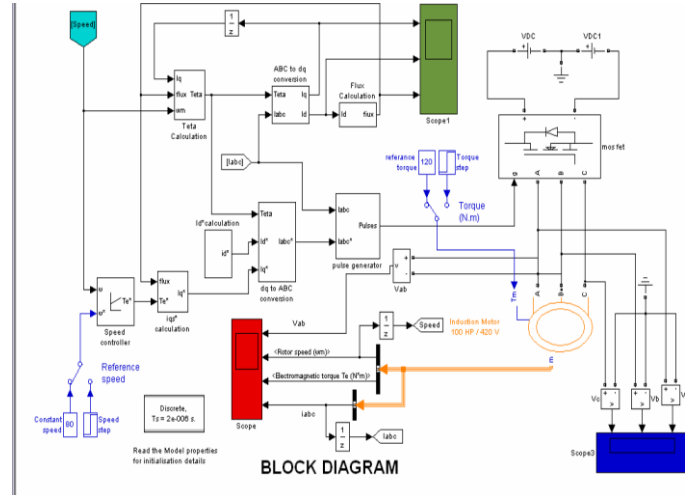
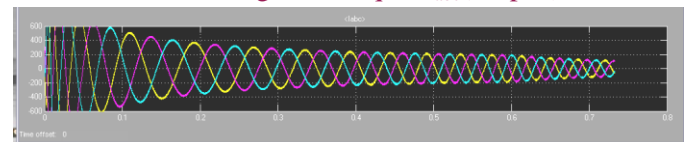


Fig: Output wave forms for V_{ab}, Rotor speed, Electromagnetic torque, I_{abc}(scope2)



Current wave forms:

Case 1:

Before the speed is not reach the speed reference W_{ref} the current wave form is not steady state. This is shown in bellow.

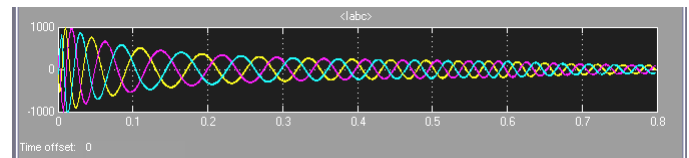


Fig: The Current waves before the speed reach W_{ref}
This case deals the current waves before the speed reach W_{ref} , so the current magnitude is vary.

Case 2:

After the speed is reach the W_{ref} , the current wave form is reach steady state. These wave forms are shown in below.

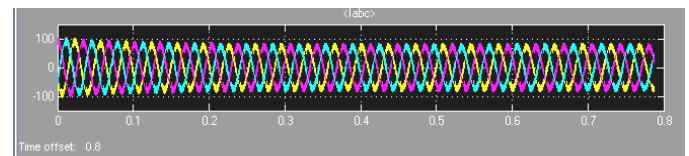


Fig: The Current waveform is reach steady state

Case 2 is under the steady state, so the speed is settle at the W_{ref} and currents are also reach steady state.

Voltage VAB Waveforms:

Case 1:

Before speed is reaching the W_{ref} , the voltage wave form is shown fig bellow.

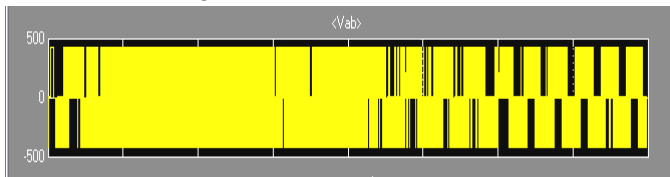


Fig: Voltage Waveform after speed is reach W_{ref} , the voltage is purely pulses, these wave forms are shown in below.

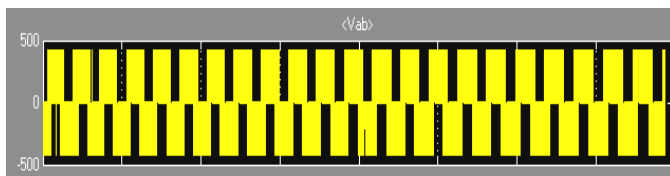


Fig: After the speed reach W_{ref} the V_{ab} is purely pulse voltage.

Torque wave forms:

Case 1:

Before speed is reaching the W_{ref} , the torque is reach maximum.

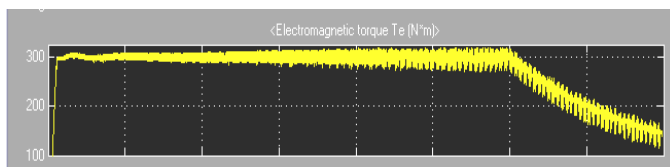


Fig: In this case the torque is decrease with speed reach W_{ref} .

Case 2:

After speed is reach W_{ref} , the torque is reach its reference value, these wave forms are shown in below.

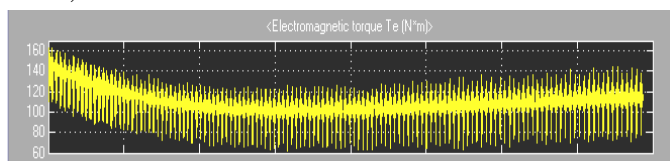


Fig: At speed reach W_{ref} the torque is settling at reference torque.

Flux wave forms:

Id and Iq wave forms:

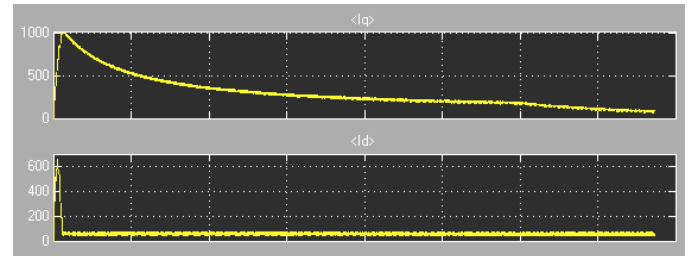


Fig: Currents are at the flux is before flux reference value

Flux at flux reference:

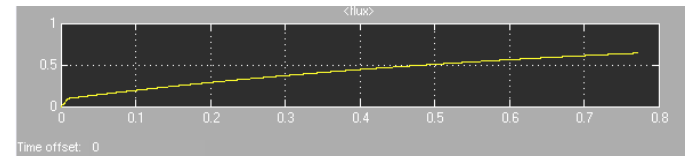


Fig: The flux reaches the flux reference value

The fast torque response obtained using vector control is achieved by estimating, measuring, calculating the magnitude and position of the motor flux in the machine. The stator currents are transformed from the stationary to synchronous reference frame. Direct vector control scheme for induction motor was simulated using Mat lab Simulink software package. The basic building block of the 3-phase A. C. Induction motor vector control is implemented using MATLAB / simulink software. It is possible to control the speed of the machine by comparing the actual motor speed W_r with a reference speed command W_{ref} . The error is used to calculate the command torque current component I_{qse} * using a continuous time PID controller which is given as the command input to the controlled. the above simulation has been tested for different cases.

CONCLUSION

Direct vector control scheme for induction motor was simulated using Mat lab Simulink software package. The rating of the machine simulated is 100HP, 420V, 4 Pole, 50Hz, three phase induction motor. Results obtained using the simulation done are presented. The speed, torque, rotor flux and current responses when the

reference speed is changed from 0 to 100 rad/sec at $t = 0$ seconds with no load on the motor. The speed, torque responses when the reference speed is changed from 0 rad/sec to 80 rad/sec at $t = 1$ second with no load in the motor, after the motor has attained steady state with speed reference at 100 rad/sec.

The speed and current responses when the reference speed is changed from 0 rad/sec to 80 rad/sec at $t = 0.6$ seconds after the motor has attained steady state with speed reference at 50 rad/sec and also with 50% of rated load applied at $t = 0.8$ seconds. The speed and current responses when the reference speed is changed from 0 to 100 rad/sec at $t = 0.6$ second with no load on the motor. Rotor flux and current responses when the reference speed is changed from 0 rad/sec (i.e. its rated speed) to 80 rad/sec at $t = 0.6$ seconds with no load on the motor, after the motor has attained steady state with speed reference at 80 rad/sec.

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