

VECTOR CONTROL OF INDUCTION MOTOR

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Abstract: This paper explains the basics of vector control of induction motor. It gives introduction to direct and indirect vector control methods. The effectiveness of direct vector control strategy is verified using MATLAB/Simulink model and results are presented to validate the effectiveness. Simulation results show the changes in the motor load torque, the dynamic changes of speed curve, which demonstrate that the real system can be well simulated with fast dynamic response speed, steady-state small of static error, and strong ability of anti-load disturbance.

Keywords: Vector Control, d-q Transformation.

I. INTRODUCTION

As compared to DC motors, AC motors have nonlinear characteristics such as high order, nonlinear, multivariable and strong coupling, which makes the high-performance speed governing difficult for AC motors. However, the advancement in power electronics technology and application of different control algorithms in motion control field such as vector control, adaptive control, and speed sensor-less control makes the performance of AC speed regulation system more and more superior.

In the field of AC induction motor control technology, vector control is a high-performance control method which is most widely used. The basic principle is based on the coordinate transformation theory, in which two orthogonal ac components in time phase are converted into two orthogonal dc components in space [1]. Based on analysis of asynchronous motor dynamic mathematical model and the principle of vector control, the motor control system is constructed through vector control method.

II. D-Q AXES OF THE INDUCTION MOTOR

A 3phase induction machine can be represented by an equivalent 2 phase machine direct (d) and quadrature (q) axes for stator and rotor. The figure shows the d-q representation of AC induction motor.

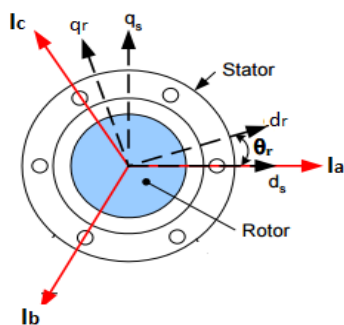


Fig. 1 d-q axis of Induction Motor. [10]

$$I_{ds} = I_a \quad (1)$$

$$I_{qs} = 1/\sqrt{3} (I_b - I_c) \quad (2)$$

Where I_a is placed in direction of ds.

For three phase balanced system, $I_a + I_b + I_c = 0$, hence,

$$I_{ds} = I_a \quad (3)$$

$$I_{qs} = 1/\sqrt{3} (I_b - I_c) \quad (4)$$

The equation shows the transformation of three phase stator current into two orthogonal vector ds and dq. This transformation is known as 'Clark Transformation'.

To convert these stationary stator frame components to rotating reference, 'park Transformation' is used.

The rotating reference frame is rotating at angular velocity ω and at an angle θ_r with respect to ds-qs axes i.e. θ_r represents the angular position of rotor flux. So, the park transformation equations are given as,

$$I_{dr} = I_{qr} (\sin\theta_r) + I_{ds} (\cos\theta_r) \quad (4)$$

$$I_{qr} = I_{qs} (\cos\theta_r) - I_{ds} (\sin\theta_r) \quad (5)$$

As per the vector control concept, I_{dr} is analogous to field current (the flux component) and the I_{qr} is analogous to armature current (the torque component).

$$\text{Hence, } T \propto (I_{dr}) * (I_{qr}) \quad (6)$$

III. VECTOR CONTROL OF INDUCTION MOTOR

The vector control implies that an AC motor is forced to behave as a dc motor using feedback control. Unlike the scalar control techniques, vector control not only involves the magnitude of control variables but also focuses on phasor alignment of the vector quantities of the motor. [4] As in the DC motor, torque control of induction motor is achieved by controlling the torque current component and flux current component independently. The algorithm for the vector control is based on two fundamental components. The first is the flux and torque producing currents. The three-phase current applied to the motor is converted to two quadrature currents. These two currents are direct (I_d) and quadrature (I_q) which produce flux and torque respectively in the motor. The I_q current is in phase with the stator flux and I_d is at right angles to I_q .

The basic function of vector control can be shown by following block diagram,

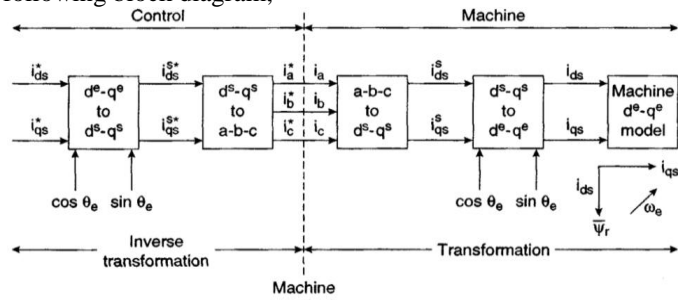


Fig 2. Vector Control Transformations [4]

IV. DIRECT VECTOR CONTROL METHOD

The required information regarding flux i.e. magnitude and position is obtained by direct flux measurement or estimation. Flux feedback control is used, and sensors measure the flux. The reference torque is provided by speed control loop designed as conventional PI controller. The reference electromagnetic torque and reference flux linkages due to current in stator coils are compared with calculated values. [10]

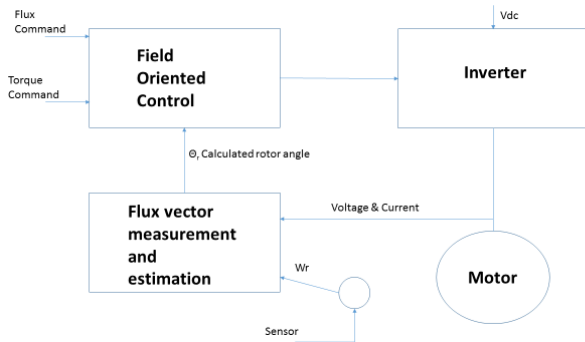


Fig 3. Direct vector control of induction motor [8]

Indirect Vector Control Method.

For this method, the unit vector signals (Sinθr & Cosθr) are generated in a feedforward manner. This method does not depend on the measurement of air-gap magnetic flux. Torque can be controlled by either changing *iqs e* or the slip speed ($\omega_e - \omega_r$). The rotor flux can also be controlled by varying *ids e*. Direct axis and quadrature axis of stationary rotor frame are aligned with rotor flux frame with the help of unit vectors. The unit vectors are used to transform the variables from stationary frame to synchronous frame. [10]

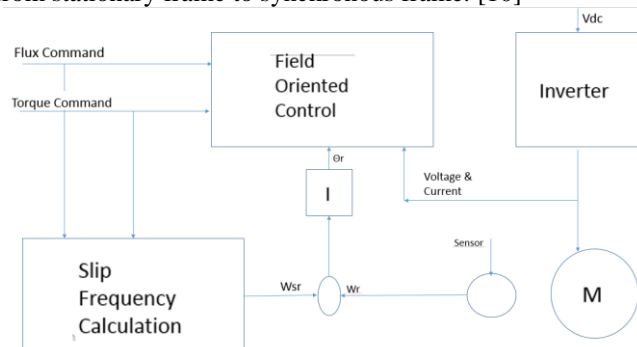


Fig 4. Indirect vector control of induction motor [8]

V. SIMULATIONS & SYSTEM CONFIGURATION

The system consists of 3-phase induction motor of 100 HP, 420V. The maximum speed is 1500rpm. The input to the system is given through DC voltage source of 460V. The stator currents do not directly govern the electromagnetic torque. Instead, it is the magnetizing branch currents that govern the electromagnetic torque. Therefore, the magnetizing branch currents should be controlled instead of the stator currents, which is the control variable if core is excluded from the modeling. The magnetizing branch currents mainly because these currents cannot be measured. Thus, it is necessary to estimate the reference stator currents from the reference magnetizing branch currents to maintain the proper rotor flux orientation in presence of core losses.

These can be calculated from the modified equations of the model. The modeling of these currents in MATLAB/Simulink is explained below.

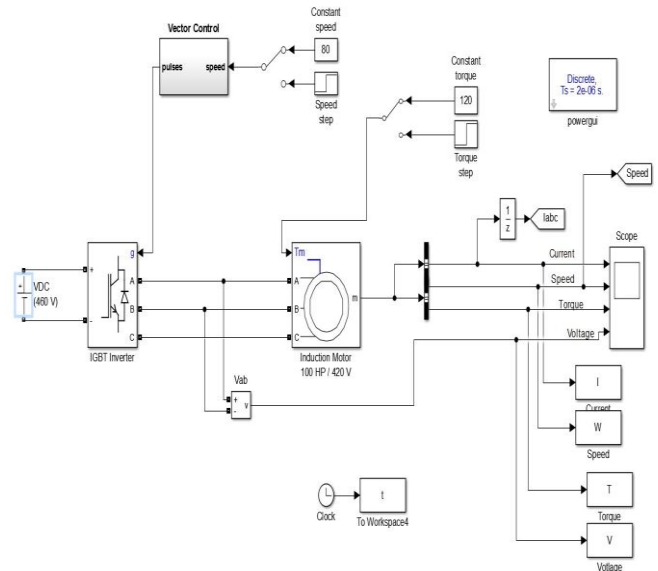


Fig 5. MATLAB/SIMULLINK Model of Vector Control of Three Phase Induction Motor

Subsystem Explanations;

Iq* Calculation:-



Fig 6. Iq* Calculation Subsystem.

The block is used to calculate the Iq*. The equation for Iq* is given as,

$$Iq^* = \left(\frac{2}{3}\right) * \left(\frac{2}{p}\right) * \left(\frac{Lr}{Lm}\right) * \left(\frac{Te}{Flux}\right) \quad (7)$$

Where,

Lr- leakage inductance of rotor, referred to stator. = 35.5mH

Lm- Magnetizing inductance. = 34.7mH,

P= Number of poles = 4

Id* Calculation

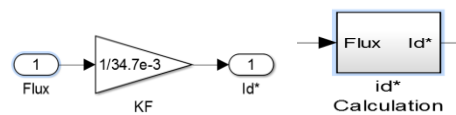


Fig 7. Id* Calculations Subsystem

This block calculates the Id*.

The equation for Id* is given as,

$$Id^* = \left(\frac{Flux}{Lm}\right) \quad (8)$$

d-q to ABC Conversion:

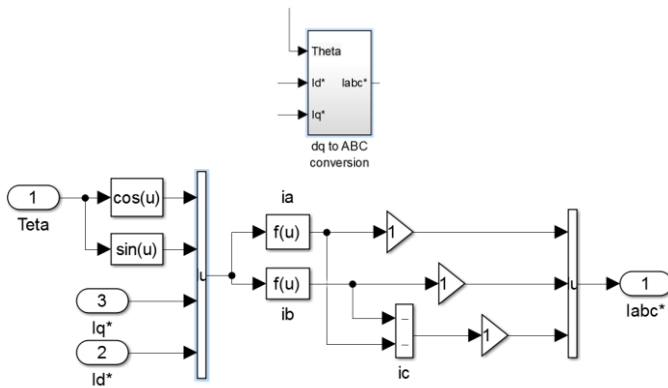


Fig 8. d-q to abc conversion subsystem

This block is used to transform the Iq* & Id* to Iabc* i.e. dq to abc conversion.

The equations used in function blocks are given as,

$$I_a = (I_d^*) * \cos(\theta) - (I_q^*) * \sin(\theta) \quad (9)$$

$$I_b = (I_d^*) * \cos(\theta - 2\pi/3) - (I_q^*) * \sin(\theta - 2\pi/3) \quad (10)$$

$$I_c = (I_d^*) * \cos(\theta + 2\pi/3) - (I_q^*) * \sin(\theta + 2\pi/3) \quad (11)$$

Pulse generator for Gate:

These Iabc* and Iabc are combined with the help of vector method and hysteresis is generated using relay combinations to generate a pulse for gate. The switching action takes place inside the subsystem and using the NOT gate pulses are generated.

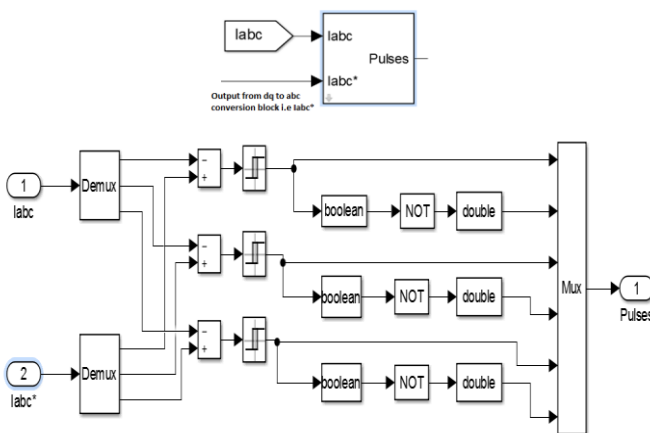


Fig 9. Gate pulse generating Subsystem

Output of relay is analog while Not gate requires the digital signal so Boolean block converts the analog signal into digital form. The digitally generated signal from NOT gate is converted to analog output using double block.

Theta calculation:

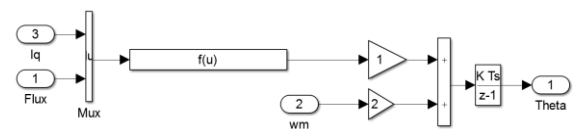
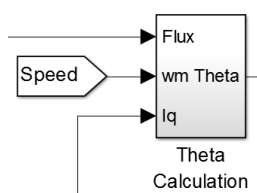


Fig. 10 Theta Calculation subsystem

The block gives the theta (θ), required for dq to abc and abc to dq transformation. By using the integration block for integration of rotor frequency we can calculate theta (θ).

$$\theta = \int (W_r + W_m) \quad (12)$$

Equation for rotor frequency (W_r) is given as,

$$W_r = \frac{(L_m * I_q)}{(T_r * Flux)} \text{ rad/s} \quad (13)$$

W_m = Rotor mechanical speed.

L_m = 34.7mh

L_r = 35.5mh

R_r = rotor resistance referred to stator, = 0.228 ohms

T_r = Time constant = $(\frac{L_m}{R_r})$ sec.

ABC to d-q Conversion

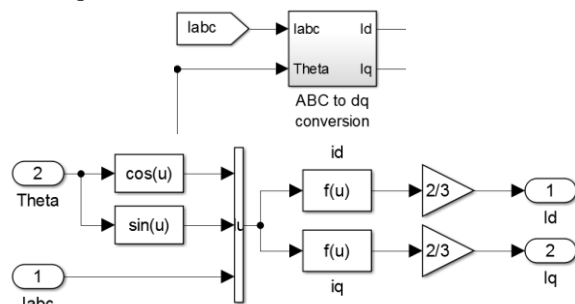


Fig 11. Abc-dq conversion subsystem

This block is used to transform the Iabc to Id and Iq i.e. ABC to dq transformation.

The equations used are,

$$I_d = (2/3) * [(I_a * \cos(\theta)) + (I_b * \cos(\theta - 2\pi/3)) + (I_c * \cos(\theta + 2\pi/3))] \quad (14)$$

$$I_q = (2/3) * [(I_a * \sin(\theta)) + (I_b * \sin(\theta - 2\pi/3)) + (I_c * \sin(\theta + 2\pi/3))] \quad (15)$$

These Id and Iq are used for flux calculation and theta Calculation respectively.

Flux Calculation

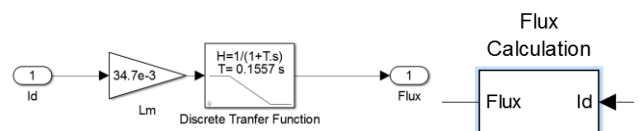
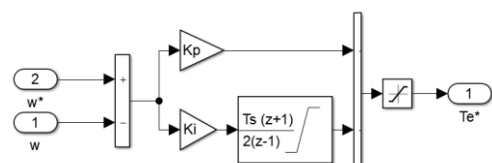


Fig 12. Flux calculation subsystem

The flux is calculated using the equation,

$$Flux = \frac{L_m * I_d}{1 + T_r * s} \quad (16)$$

The Discrete Transfer Function block applies the z-transform transfer function to each independent channel of the input Electromagnetic Torque (T_e) Calculation;



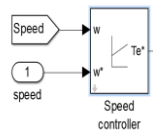


Fig 13. Torque Calculation subsystem

This block gives the electromagnetic torque. The reference speed and the measured speed are given to discrete time integrator through proportional constant (K_p) and integral constant (K_i).

VI. SIMULATION RESULTS

The simulation results observed are presented below,

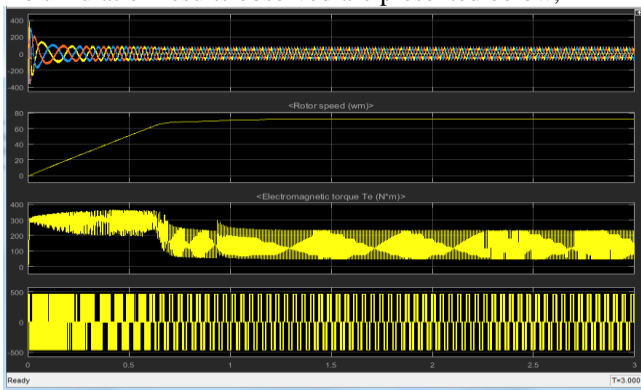


Fig 14 Simulation results

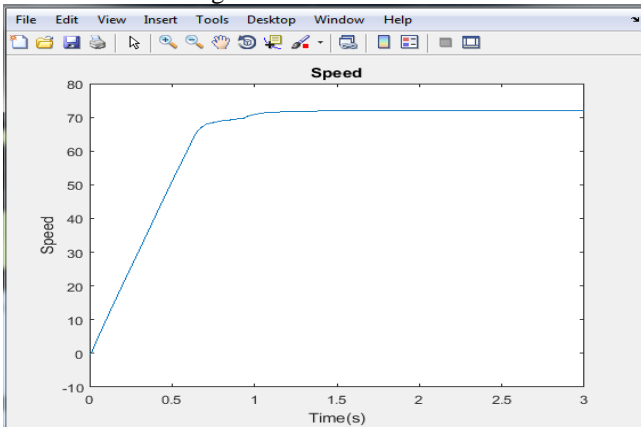


Fig 15 Speed v/s time

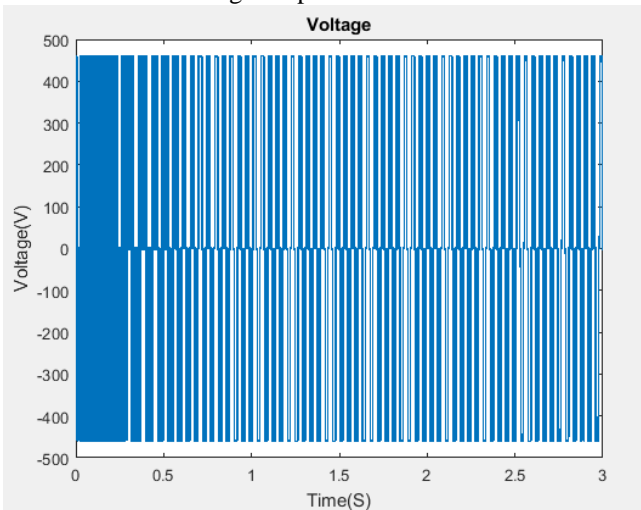


Fig 16 voltage v/s Time

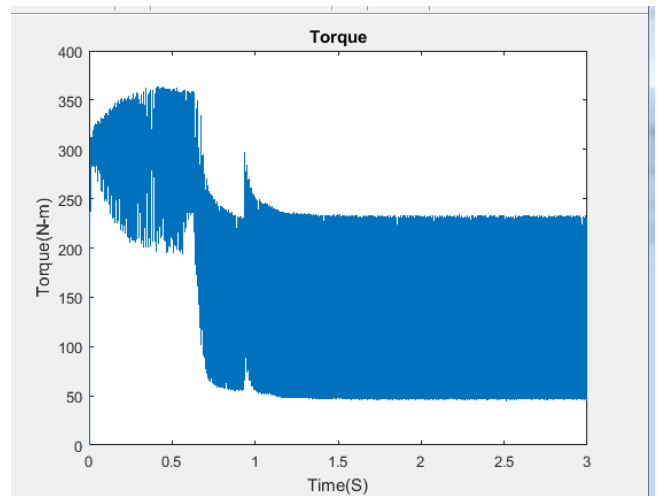


Fig 17 Torque v/s time

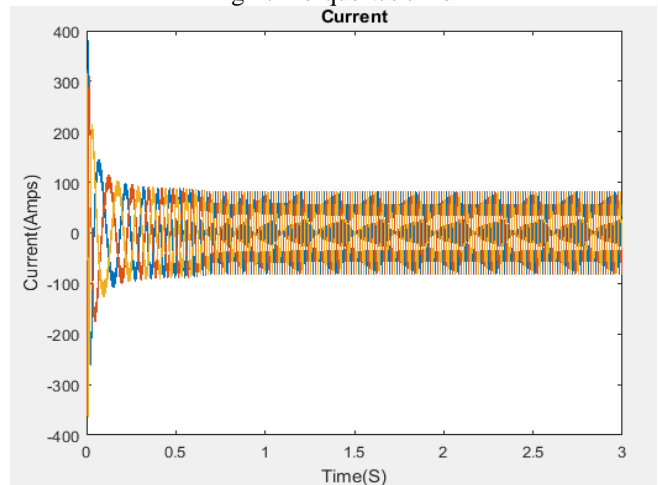


Fig 18 Current v/s time

VII. CONCLUSION

Based on the sufficient analysis of induction motor mathematical model and vector principle, simulation model in MATLAB/SIMULINK has been constructed. In conclusion, the vector control of induction motor is achieved by estimating, measuring, calculating the magnitude and position of motor flux in machine. Based on simulation results it can be concluded that dynamic response is fast, steady tracking has high precision and the torque has instantaneous response characteristics, all of which are consistent with the theoretical analysis of vector control. Torque generating component and magnetic field generating component can be controlled independently and the dynamic response observed is good. It is observed that in direct vector control, the stator magnetic flux slowly reaches the desired value and when motor is loaded it might deviate from the desired values. Like the dc machines, induction motor can also be controlled in four quadrants.

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