International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 7, July-2018

Review on various schemes of Vector Controlled Induction Motor drive and Comparative Analysis

[1]Vaishali Sharma, [2]Dr. Rintu khanna
Electricaal deparment
Punjab Engineering College (Deemed To Be University)
Chandigarh, India
[1]vaishalisharma2512@gmail.com, [2]rintukhanna1@rediffmail.com

***Abstract*— Dynamic performance of induction motor drives with conventional control techniques is less than expected. With the vector control, the dynamic performances of induction motor drives are enhanced very well. The main objective of this paper is to provide the understanding of the three schemes of vector control of symmetrical 3-phase induction motor. Their block diagrams are presented and their equations are derived. In this paper, scalar and vector control are also discussed. Finally, it is seen that rotor-flux-oriented is easy to implement than the other schemes.**

***Keywords*—Induction motor (IM), scalar control, vector control, rotor-, airgap-, stator- flux oriented vector control.**

I. INTRODUCTION

The basic design of the DC motor is one reason of the simple controlling of DC motor which ensure the independent control of torque and flux in a DC drive. The field oriented control or vector control method is developed for the same. The basic idea of FOC is to transform the three phase stator currents (abc frame) into two equivalent orthogonal currents (d-q frame) which are decoupled from each other. And this two axis frame (two orthogonal currents) is known as Kron's Primitive machine modelling [1]. One component of the stator current produces magnetic field and other component produces the torque. The stator currents are controlled in both the phase and amplitude such that the magnetic field remains constant at its maximum permissible value and only the torque producing stator current component is changed to control the output torque.

II. BASIC PRINCIPLE OF VECTOR CONTROL

A. *Types of controlling*

For the induction machine, classification of the control techniques are made by Holtz (1998) from the point of view of the controlled signal:

1. Scalar control

a) Voltage/frequency (or v/f) control

In this control, two parameters are varied simultaneously i.e. voltage and frequency otherwise if one parameter is changed at a time then problem may occur, example if frequency decreases and voltage increases then coil may be burned. Torque can be accessed in all the operating points up to nominal speed, if this control method is used. This control is very simple to implement but cannot handle the controlling of speed in transients.

b) Stator current control and slip frequency control With the help of direct measurement of the machine parameters, these techniques can be implemented.

2. Vector control

Vector control provides the robust control in case of steady-state and transients as well. Vector control method is used to control the 3-phase symmetrical induction motor just like a separately excited DC motor.

B. Vector Control Theory

The main principle of vector control theory works with the rotating vectors in a complex coordinate system. The main purpose of this control method is to decouple the field components this method establishes two independent stator currents: torque producing component and flux producing component.

C. Two Axis frame Theory

D-Q model is a hypothetical model, it does not really exist. 3-phase symmetrical induction motor can be simulated by means of two axis model. But this hypothetical model have many applications. The transient behavior of 3-phase induction motors operated from single-phase supplies by d-q axis model [5].

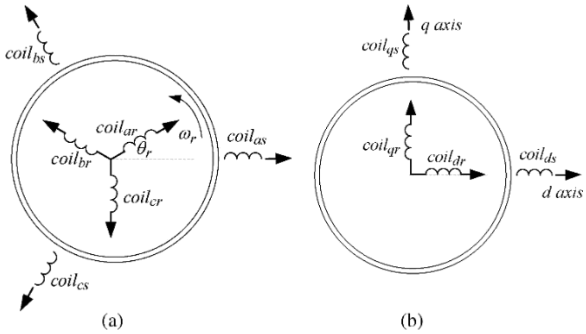

Fig. 1. (a) Stationary abc frame model and (b) transformed d-q frame of induction motor model.

$$\begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{os} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} \quad (1)$$

D. Reference frame Theory

The dynamic concept of the 3-phase induction machine based on the two real axis (d-q) reference frame, was first modelled mathematically and developed initially by Park (1929) for the synchronous machine. Using the symmetric configuration of the induction machine, Kovacs and Racz (1959) have detailed the space complex vector theory, and obtained a mathematical model for the steady-state analysis of the machine. For modelling the 3-phase symmetrical induction machine, both the above theories are used. The d-q frame is created to rotate synchronously with the stator or rotor voltage, current or flux vectors in the machine. The field coordinate systems can be obtained if the d-q frame rotates synchronously with the magnetic field (magnetic flux) within the machine. It is very needful for the purposes of controlling the motor to permit the reference frame to rotate synchronously with the rotor flux vector.

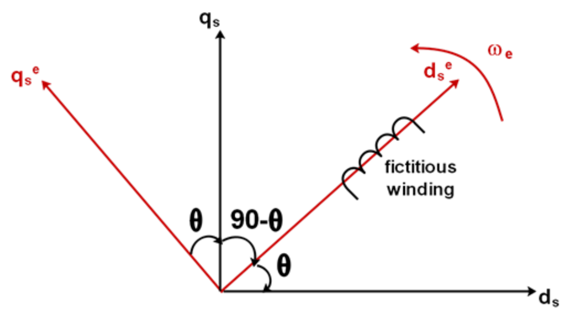

Fig. 2. d-q stationary (black) and synchronously rotating (red) reference frame attached to the rotor flux.

Reference frame is so chosen that reference frame is attached to the rotor flux vector in rotor flux oriented vector control. So that machine is analyzed from the synchronously

reference frame. $d^e - q^e$ axis ref. frame is rotating with synchronous speed (ω_e). We have fictitious windings on $d^e - q^e$ axis i.e. d_s^e winding and q_s^e winding. Similarly, we have d_r^e and q_r^e windings on rotor rotating at ω_e with rotor flux vector.

E. Types of Vector Control

Vector control technique can be used to vary the speed of an induction motor over a wide range.

Two types of vector controlling can be done are as follows:

a) Field orientation control (FOC)

- Indirect method

It is also called flux-feedforward control. This method uses the slip equation (relation) which is a necessary and sufficient condition for the production of field orientation and if the relation of slip is satisfied, then i_{ds}^e will be aligned with the field flux [2]. In this method, the modulus and space angle of the rotor flux linkage space phasor can be obtained by monitoring the stator currents and the rotor speed of the IM. Indirect field orientation is based on slip equation.

$$\omega_{sl} = \frac{1}{\tau_r}\frac{i_{qs}^e}{i_{ds}^e}$$

The space angle is generated by summing a rotor position signal and a slip position signal.

θ_e is evaluated indirectly.

$$\theta_e = \int (\omega_e)dt = \int (\omega_r + \omega_{sl})dt$$

$\omega_r \rightarrow$ It can be measured from sensor directly

$\omega_{sl} \rightarrow$ Measured from synchronously rotating 2 axis transformed stator currents.

- Direct method

It is also known as flux-feedback control. The modulus and space angle of the rotor flux linkage space are directly measured by hall- effect sensors or search coils. But difficulty in this method is to sense the rotor flux because to put sensor on the moving rotor is very difficult.

b) Direct torque and stator flux vector control

Direct torque control (DTC) is one of the good method which can be applied to control the torque (indirectly speed) of the 3-phase electric motors in VFD [3]. An estimation of the magnetic flux and electromagnetic torque based on the measured voltage and current of the induction motor can be calculated. Both analogue version (direct measurements) and digital version (estimation techniques) can be performed in these techniques.

III. SCHEMES OF VECTOR CONTROLLED IM

Vector control techniques becoming prominent and have potential for replacement of DC motor with the 3-phase induction motor drives, the aim of this paper is to gain attention towards the various vector control scheme strategies [4]. There are mainly three types of vector controlled induction motor and are discussed below:

(1) rotor-flux-oriented, (2) stator-flux-oriented, (3) airgap-flux-oriented control methods.

1) Rotor flux-oriented control method

The reference frame's choice is based on the dynamic study of the induction machine. As it is more convenient that the reference frame to be fixed to the rotor frame if the rotor circuits are unbalanced. For field oriented control systems, the most useful method is to refer the machine variables to a rotor reference frame. The principle of this control scheme is to mathematically achieve a rotor flux linkage vector ψ_r of a motor which entirely aligned to the d-axis of a rotating frame (the synchronous frame). Rotor flux is entirely along the d-axis.

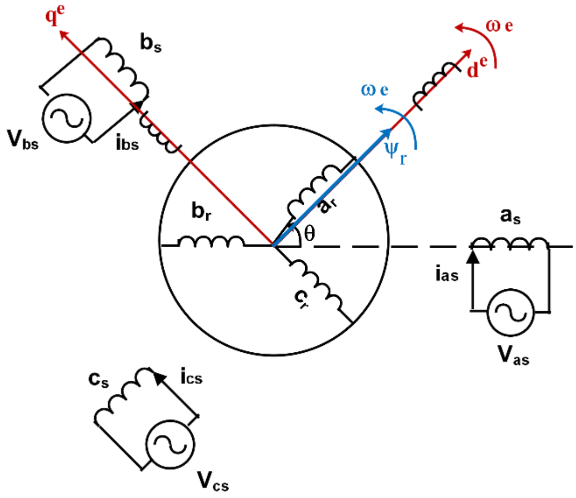

Fig. 3. Diagram of rotor-flux-oriented vector control

$$\psi_{dr}^{e} = \psi_{r} \quad (2)$$

This is total rotor flux and it is constant.

$$\psi_{qr}^{e} = 0 \quad (3)$$

No component of the airgap flux in the q-axis.

The rotor voltages equations are derived and formulated in the reference frame fixed to rotor flux linkage space phasor.

Equations for d-axis rotor

$$v_{dr}^{e} = 0 = r_r' i_{dr}^{e} + \text{þ}\psi_{dr}^{e} - \omega_{sl}\psi_{qr}^{e} \quad (4)$$

$$\psi_{dr}^{e} = L_r' i_{dr}^{e} + L_m i_{ds}^{e} \quad (5)$$

Using equations (2), (3), (4) & (5). Flux comes out to be

$$\psi_{r} = \psi_{dr}^{e} = L_m i_{ds}^{e} \quad (6)$$

Equations for q-axis rotor

$$v_{qr}^{e} = 0 = r_r' i_{qr}^{e} + \text{þ}\psi_{qr}^{e} + \omega_{sl}\psi_{dr}^{e} \quad (7)$$

$$\psi_{qr}^{e} = 0 = L_r' i_{qr}^{e} + L_m i_{qs}^{e} \quad (8)$$

Using equations (2), (3), (7) & (8). Slip speed comes out to be

$$\omega_{sl} = \frac{1}{\tau_r}\frac{i_{qs}^{e}}{i_{ds}^{e}} \quad (9)$$

By controlling the two currents, the slip of machine can be controlled.

Torque equation in rotor-flux-oriented vector controlled of induction motor is given by

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r'}\left[\psi_{dr}^{e}\, i_{qs}^{e}\right] \quad (10)$$

Torque produced by the motor is proportional to the product of the flux-producing stator current component and the torque-producing stator current component.

Its rugged construction and cost are main advantages of the AC system derive but controlling of motor always remains the main concern. There is coupling between flux and torque in the 3-phase induction motor, for decoupling torque and flux, standard two-axis machine concepts and rotor-flux- orientated vector control is used [5].

It is usually employed because of its simple implementation than the other schemes, as electromagnetic torque and magnetic flux can be controlled independently by two orthogonal stator current components.

2) Airgap flux-oriented control method

Air-gap flux orientation system has a magnetizing flux linkage vector ψ_m of a motor aligned to the d-axis of a rotating frame (the synchronous frame). Airgap flux vector is rotating in space with synchronous speed. The angle of airgap flux vector with phase a is θ_e^m and it is different from the angle of rotor flux vector with phase a.

$$\psi_{dm}^m = \psi_m \qquad (10)$$

The airgap flux in the d-axis in the reference frame oriented along the airgap flux vector. This is the total airgap flux.

$$\psi_{qm}^m = 0 \qquad (11)$$

No component of the airgap flux in the q-axis.

$$\psi_{dr}^m = \psi_{dm}^m + L_r' i_{dr}^m \qquad (12)$$

$$\psi_{qr}^m = \psi_{qm}^m + L_r' i_{qr}^m \qquad (13)$$

Equations for d-axis rotor

$$v_{dr}^m = 0 = r_r' i_{dr}^m + \text{þ}\psi_{dr}^m - \omega_{sl}\psi_{qr}^m \qquad (14)$$

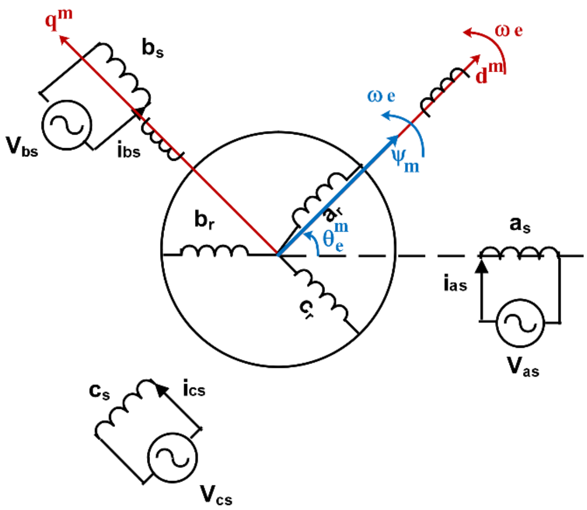

Fig. 4. Diagram of rotor-flux-oriented vector control

Using equations (10), (11), (12), (13) & (14). Stator current in airgap flux oriented comes out to be

$$i_{ds}^m = \frac{1}{(1+\tau_{lr}\text{þ})}\left[\frac{1+\tau_{lr}\text{þ}}{L_m}\psi_{dm}^m + \omega_{sl}\tau_{lr} i_{qs}^m\right] \qquad (15)$$

Equations for q-axis rotor

$$v_{qr}^m = 0 = r_r' i_{qr}^m + \text{þ}\psi_{qr}^m + \omega_{sl}\psi_{dr}^m \qquad (16)$$

Using equations (10), (11), (12), (13) & (16). Slip speed comes out to be

$$\omega_{sl} = \frac{(1+\tau_{lr}\text{þ})\, i_{qs}^m}{\tau_r\left[\frac{\psi_{dm}^m}{L_m} - \frac{\tau_{lr}}{\tau_r} i_{ds}^m\right]} \qquad (17)$$

Torque equation in airgap-flux-oriented vector controlled of induction motor is given by

$$T_e = \frac{3}{2}\frac{P}{2}\,\psi_{dm}^m\, i_{qs}^m \qquad (18)$$

Torque produced is proportional to the product of the magnetizing current space phasor and the torque producing stator current component. But there is coupling between these two phasors and so it requires somewhat more complicated control algorithms than that for the rotor flux orientation.

3) Stator flux-oriented control method

The principle of this control scheme is to mathematically achieve a stator flux linkage vector ψ_s of a motor entirely aligned to the d-axis of a rotating frame (the synchronous frame). Stator-flux vector is rotating in space with synchronous speed. The angle of stator-flux vector with phase a is θ_e^s and it is different from the angle of rotor flux vector with phase a. All are rotating synchronously in the space, the relative velocity between them in steady state is zero but sustained different angle with phase a-axis.

$$\psi_{ds}^s = \psi_s \quad (19)$$

$$\psi_{qs}^s = 0 \quad (20)$$

Equations for d-axis rotor

$$v_{dr}^s = 0 = r_r' i_{dr}^e + \text{þ}\psi_{dr}^s - \omega_{sl}\psi_{qr}^s \quad (21)$$

$$i_{ds}^s = \frac{1}{(1+\beta'\text{þ})}\left[\frac{1+\tau_r\text{þ}}{L_s}\psi_{ds}^s + \beta'\omega_{sl} i_{qs}^s\right] \quad (22)$$

Equations for q-axis rotor

$$v_{qr}^s = 0 = r_r' i_{qr}^s + \text{þ}\psi_{qr}^s + \omega_{sl}\psi_{dr}^s \quad (23)$$

$$\omega_{sl} = \frac{(1+\beta'\text{þ})\, i_{qs}^s}{\left[\frac{\tau_r}{L_s}\psi_{ds}^s - \beta'\, i_{ds}^s\right]} \quad (24)$$

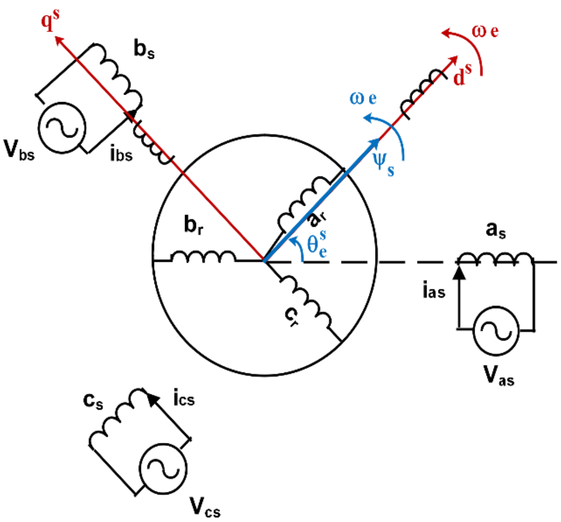

Fig. 5. Diagram of stator-flux-oriented vector control

The stator currents components can be independently controlled by controlling the terminal voltages but for this, decoupling circuit is put similar to airgap flux oriented vector control.

IV. DECOUPLING NETWORK

From equations (15), (17) & (18), it is analyzed that the controlling of electromagnetic torque and flux producing stator currents independently is only possible if equations (15) & (17) are decoupled. Coupling means if torque producing component of stator current is changed to change the electromagnetic torque then flux will also change [6].

To decouple torque and flux, a circuit called decoupling block is used. Fig. 6. Contains the decoupling block and the trans-vector rotation block which transform d-q stator current into three-phase (abc) stator currents.

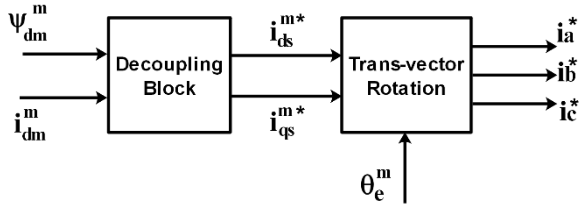

Fig. 6. Schematic diagram of decoupling network

V. RESULTS

TABLE I. COMPARISON BETWEEN 3 VECTOR CONTROL SCHEMES

Schemes	**Parameters**		
	Torque and Flux	***Decoupling block***	***Model Complexity***
Stator-flux-oriented	Coupled	Applied	More
Airgap-flux-oriented	Coupled	Applied	More
Rotor-flux-oriented	Decoupled	Not Applied	Less

VI. CONCLUSION

Various schemes of vector controlled induction motor i.e. rotor-, airgap-, stator-flux oriented vector control schemes were discussed in this paper. By analyzing the torque equations of all three schemes, it is concluded that the rotor-flux-oriented is used to decouple the electromagnetic torque and flux of induction motor whereas in airgap-flux and stator-flux oriented schemes, decoupling circuit is used to decouple the torque and flux which makes the implementation of vector control more complex. Implementation of rotor-flux-oriented vector control scheme is simpler than other schemes.

REFERENCES

[1] Kron, G. (1930) 'Generalized Theory of Electrical Machinery.pdf', *transactions A.I.E.E*, 49, pp. 666–685.

[2] Garcia, G. O. and Watanabe, E. H. (1994) 'Comparing the Indirect Field-Oriented Control with a Scalar Method', 41, pp. 201–207.

[3] Naik, B. S. (2014) 'Comparison of Direct and Indirect Vector Control of Induction Motor', 1, pp. 110–131.

[4] Hussain, S. and Bazaz, M. A. (2015) 'Review of vector control strategies for three phase induction motor drive', *2015 International Conference on Recent Developments in Control, Automation and Power Engineering (RDCAPE)*, pp. 96–101. doi: 10.1109/RDCAPE.2015.7281376.

[5] Kawamura, A. and Hoft, R. (1983) 'An Analysis of Induction Motor Field Oriented or Vector Control', *Power Electronics Specialists Conference, 1983 IEEE*, pp. 91–101. doi: 10.1109/PESC.1983.7069844.

[6] Mon-Nzongo, D. L. *et al.* (2017) 'Decoupling Network of Field-Oriented Control in Variable-Frequency Drives', *IEEE Transactions on Industrial Electronics*, 64(7), pp. 5746–5750. doi: 10.1109/TIE.2017.2674614.