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Space-vectors in machines

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Introduction

Various machines are in use for industrial applications and household applications. They have been tried for better control because it is the need of the hour. A performance of the machine basically depends on the rotating field produced in the air gap. Whatever control strategy we use the ultimate outcome is synchronously rotating field. This chapter gives an idea about the space vector, space vector modulation and the rotating field in machine.

I Control of Motor

Control strategies related to the motor:

There is a frequent need of controlling motor according to requirement of the load. This is only possible if we select a proper motor for the load. This is achieved by studying the characteristics of the motor and the characteristics of the load. With the knowledge of these characteristics a proper stable point of operation is reached during a steady state condition.

Control of motor during a transient condition is achieved in modern drives, where instant to instant load requirement is satisfied by the motor. Various techniques are tested and adopted for control of motor during transient condition. Such techniques have evolved in such a way that they have replaced all D. C. drives by A. C. drives.

II Types of Controls

The control strategies are classified under two heads 1) Scalar control 2) Vector control

Scalar Control ; It deals with changing the magnitude of the variable. v/f control is a scalar control where v/f ratio is kept constant such that the motor does not enter the saturation part of flux characteristic.

Vector Control ;It deals with change of magnitude as well as direction of the variable. Vector control is said to be a high performance drive with complicated algorithm. Most of the industries use the vector control.

III Concept of Space Vector

Space vector is the representation of a sinusoidal quantity in terms of magnitude and angle. Such quantities are available with machines. Consider a three phase machine stator with three phase windings Fig. 1 shows three symmetrical windings.

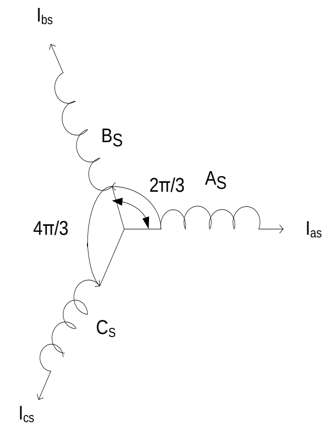

Fig. 1: Three Phase Windings of a three phase machine with orientation

If one of windings a carries a D. C. current I_A the flux distribution due to this current is sinusoidal in nature. This is possible due to design of the winding. The flux distribution has its peak magnitude along the axis of the coil. Thus we have current vector of the value $I_A\angle\alpha$ where α is the angle between space vector and the reference direction. If the reference direction is the axis of the winding α =0.
When all the three windings carry current each current can be represented by a space vector and we can have a resultant space vector. Consider a case when the phase currents have the values I_a = 1. 0A, I_b=-0. 5A and I_c =-0. 5A. These currents are represented by space vectors in fig. 2. the resultant vector is 1. 5 $\angle$0.

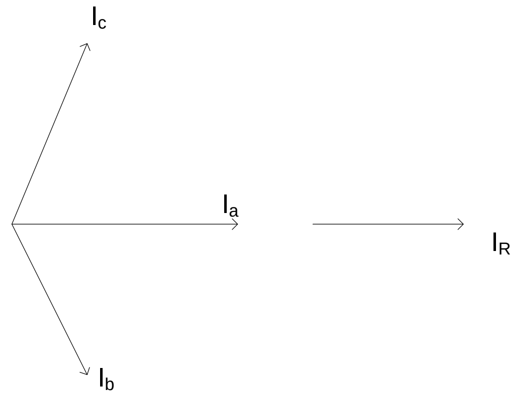

Fig. 2: The current vectors and a resultant current vector

Thus mathematically we can write

$$\mathbf{Ia} + \mathbf{I_b} + \mathbf{Ic} = \mathbf{Ir} \quad (1)$$

The equation reveals that the resultant has the information of three phasors. The variation of currents in the three phases will lead to variation in resultant. This is the foundation concept for the space vector control of three phase machine.

IV Space vector concept applied to mmf

Let the three mmf 's of a three phase machine be $F_{av,}$ F_{bv} and F_{cv},, then

$$\mathbf{F_{av}} = k i_a \angle 0^o \quad (2)$$

$$\mathbf{F_{bv}} = k i_b \angle \frac{2\pi}{3}^{\,o} \quad (3)$$

$$\mathbf{F_{cv}} = k i_c \angle -\frac{2\pi}{3}^{\,o} \quad (4)$$

The motivation of using space-vector notation is the convenient way in which they can be added. Thus

$$= k i_a \angle 0^{o+} k i_b \angle \frac{2\pi}{3}^{\,o} + k i_c \angle -\frac{2\pi}{3}^{o}$$

$$= k[i_a - 0.\ 5 i_b - 0.\ 5 ic]\mathbf{a_x} + k[\ \frac{\sqrt{3}}{2}(i_b - i_c)\ ]\mathbf{a_y} \quad (5)$$

Hence

$$|\ Fr| = k\{[\ i_a - 0.\ 5 i_b - 0.\ 5 i_c]^2 + 0.\ 75[i_b - i_c]^{\ 2}\ \}^{1/2} \quad (6)$$

And

$$\angle\ F_r = \tan^{-}\frac{\sqrt{3}(ib - \mathrm{Ic})}{2ia - 2ib - 2ic} \quad (7)$$

V The process of space-vector modulation

Eqn. (6) shows that the resultant space-vector is resolved into two components in the x and y directions. The magnitude of each component is dependent on the values of the currents i_a, i_b, and i_c. This means that by adjusting these values suitably, it is possible to control the magnitude and angle of the resultant space-vector.

The deliberate process of adjusting the values of these currents to achieve the desired magnitude and angle of the resultant space vector is space vector modulation intended in the control of induction motor drives.

Though the resultant mmf space-vector discussed so far is made up of three constituent space-vectors having their individual directions $\frac{2\pi}{3}$ radians apart from each other. Eqn. (6) shows that two space vectors at 90^o apart from each other are the minimum necessary and sufficient ones for implementing space-vector modulation. This will correspond to the operation of a two-phase machine. On the other hand, the expression of space-vector as a magnitude at some angle θ indicates that if phase windings are available for every angle Φ possible, the space-vector modulation can be obtained just by switching currents continuously from one phase winding at an angle Φ to the next phase winding available at an angle Φ +d Φ. However having a large number of phases for the induction motor is neither practical nor desirable. Hence ' three as the 4

VI. A Look at the conventional three phase induction motor

It is well-known that in a conventional three-phase induction motor running from a constant voltage constant frequency bus bars, with a three phase winding has the phase currents written as-

: $i_a = I_m \cos \omega t$ (8)

: $i_b = I_m \cos(\omega t - \frac{2\pi}{3})$ (9)

: $i_c = I_m \cos(\omega t + \frac{2\pi}{3})$ (10)

Corresponding mmf space vector are as

$\mathbf{F_{av}} = kIm\cos\omega t \angle 0^o$

: $= kI_m \cos\omega t a_x$ (11)

$\mathbf{F_{bv}} = kI_m \cos(\omega t - \frac{2\pi}{3}) \angle \frac{2\pi}{3}$

$= kI_m \cos(\omega t - \frac{2\pi}{3}) \cos\frac{2\pi}{3} \mathbf{a_x} + kI_m \cos(\omega t - \frac{2\pi}{3}) \sin\frac{2\pi}{3} \mathbf{a_y}$

: $= -0.5kI_m \cos(\omega t - \frac{2\pi}{3}) \mathbf{a_x} \frac{+\sqrt{3}}{2} kI_m \cos(\omega t - \frac{2\pi}{3}) \mathbf{a_y}$ (12)

$\mathbf{F_{cv}} = kI_m \cos(\omega t + \frac{2\pi}{3}) \angle -\frac{2\pi}{3}$

$= kI_m \cos(\omega t - \frac{2\pi}{3}) \cos\frac{2\pi}{3} a_x - kI_m \cos(\omega t - \frac{2\pi}{3}) \sin\frac{2\pi}{3} a_y$

: $= 0.5Im\cos(\omega t + \frac{2\pi}{3}) \mathbf{a_x} - \sqrt{3}/2 kI_m \cos(\omega t + \frac{2\pi}{3}) \mathbf{a_y}$ (13)

Hence the x-component **F** rx of the resultant mmf **F** r is

$\mathbf{F}_{rx} = kI_m[\cos\omega t - 0.5\cos(\omega t - \frac{2\pi}{3}) - 0.5\cos(\omega t + \frac{2\pi}{3})]$

$= kI_m[\cos\omega t + \cos\omega t \cos\frac{2\pi}{3})$

: $= 1.5kI_m \cos\omega t$ (14)

And the y-component $\mathbf{F}_{ry}$ of F_r is

$\mathbf{F}_{ry} = \sqrt{3}/2 kI_m[\cos(\omega t - \frac{2\pi}{3}) - \cos(\omega t + \frac{2\pi}{3})]$

$= 1.5\ kI_m(2\sin\omega t \sin\frac{2\pi}{3})$

: $= 1.5\ kI_m \sin\omega t$ (15)

Hence $\mathbf{F}_r = \mathbf{F}_{rx} a_x + \mathbf{F}_{ry} a_y$

$= 1.5kIm[\cos\omega t\ \mathbf{a_x} + \sin\omega t\ \mathbf{a_y}]$

: $= 1.5kI_m \angle \omega t$ (16)

Equation (16) implies that the system of three phase currents modulate the angle of the resultant space-vector in a continuous analog fashion. The magnitude is decided by the voltage of the system. Thus the millions of three phase induction motors have been implementing space-vector modulation for about hundred years now, though the terms space-vector and space-vector modulation are coined only recently. (since1975)

However, there are very severe restrictions to this space vector modulation. Both the magnitude and frequency 'ω of the supply voltage being constant, the space-vector magnitude and the rotational speed of the vector is constant. The three-phase induction motor fed from the utility mains is confined essentially to a constant speed operation However, it has been appreciated for a long time that a variable-voltage, variable frequency supply will free the induction motor from the shackles of a constant-speed operational environment

VII VOLTAGES AS SPACE VECTORS

The voltage vectors are obtained with the help of inverter. Fig. 3 shows the familiar three-leg inverter configuration. The upper and lower switches are complementary

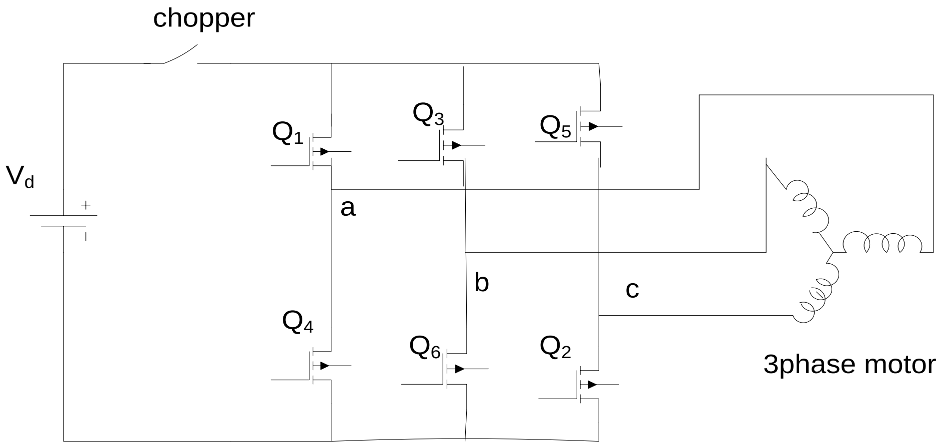

Fig. 3: Three leg inverter driving three phase motor

Hence there are eight possible switch combinations 000, 001, 010, 011, 100, 101, 110, and111(0 corresponds to open switch and 1 corresponds to closed position for the upper switches.)Table 1 gives a summary of Table 1 gives a summary of the switching states and the corresponding phase to neutral voltage of an isolated neutral three-phase machine.

State	A B C	**Va**	**V_b**	**V_c**	**V_R**
0	000	0	0	0	0
1	100	$\frac{2}{3}V_d$	$-\frac{1}{3}V_d$	$\frac{1}{3}V_d$	$\frac{2}{3}V_d\angle 0$
2	110	$\frac{1}{3}V_d$	$\frac{1}{3}V_d$	$-\frac{2}{3}V_d$	$\frac{2}{3}V_d\angle 60$
3	010	$-\frac{1}{3}V_d$	$\frac{2}{3}V_d$	$-\frac{1}{3}V_d$	$\frac{2}{3}V_d\angle +120$
4	011	$-\frac{2}{3}V_d$	$\frac{1}{3}V_d$	$\frac{1}{3}V_d$	$\frac{2}{3}V_d\angle 180$
5	001	$-\frac{1}{3}V_d$	$-\frac{1}{3}V_d$	$\frac{1}{3}V_d$	$\frac{2}{3}V_d$
6	101	$\frac{1}{3}V_d$	$-\frac{2}{3}V_d$	$\frac{1}{3}V_d$	0
7	111	0	0	0	0

The voltage vectors(V_R) obtained are used for controlling motor.

VIII. ROTATING MAGNETIC FIELD

The voltage vectors obtained in VII are used for various control techniques of motor. Whichever technique is used for controlling the motor the ultimate outcome is a rotating magnetic field. Fig. 4 shows a rotating magnetic field of a two phase induction motor.

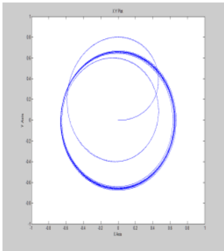

Fig. 4: Rotating field of two phase induction motor.

VIII. CONCLUSIONS

The space in which the space vectors are defined is the annular cylindrical air gap between the stator and rotor defined as space vectors and can be added like the ordinary vectors in a two dimensional space. cores of an electrical machine. The mmf and the flux density distribution are primarily periodic functions of angle θ along the periphery of the air gap. When these periodic distributions are sinusoidal in space they are The voltage applied to a phase can be looked upon as space vector oriented along its axis. Through the use of semiconductor switches the magnitudes of the three voltage space vectors can be suitably chosen to obtain any specific magnitude and angle for the resultant space vector. This is the mechanism involved in space vector modulation.

The three phase balanced voltages in a three phase induction motors are sinusoidaly varying functions of time with a successive phase difference of $\frac{2\pi}{3}$ radians. The three space vectors add up to give resultant space vector of constant amplitude rotating in θ space at a constant angular speed. this is an analogue space vector modulation.

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