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Speed Control of Two Phase Induction Motor

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Abstract: **-- A motor is controlled according to the requirements of the load. This requires an adjustment of proper torque and speed. The current paper discusses a relationship between speed and the flux which is required for the control of 2-phase induction motor.**

Index Terms **– ASFC, 2-phase induction motor, V/F, control.**

I. INTRODUCTION

A 2-phase induction motor has low power applications in industry as well as it can be used in compressors, pumps, tread –mill etc. Hence control of 2-phase induction becomes a necessary subject of study .Whatever conventional methods of control are available for three phase motors can be extended to a 2-phase motor [1]. An induction motor with single phase can also be used for low power application but when it comes to variable speed application, the control of single phase induction motor is difficult. So 2-phase induction motor makes a good choice. A 2-phase motor needs a 2-phase supply for its operation. The conventional supplies available are three phase supply and a single phase supply, but a 2-phase supply is obtained with the help of 2-phase inverter .There are several configurations of 2-phase inverter .The popular inverter configurations are[4]:

1. 2-leg inverter
2. 3-leg inverter
3. 4-leg inverter

Each circuit gives a 2-phase outputs which are 90 degree apart. It helps in producing a rotating magnetic field which is a necessary condition for the operation of motor.

II MATHEMATICAL MODEL 2-PHASE INDUCTION MOTOR

A 2-phase induction motor has two windings which have same no. of turns. Hence can be called a symmetrical induction motor. The windings are present on the stator of 2-phase motor. The rotor is of squirrel cage type. Fig. 1 shows a schematic diagram of 2-phase induction motor.

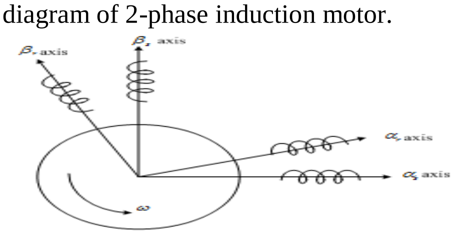

Fig. 1 2-Phase Induction Motor

In 2-phase induction motor, dynamic model can be written with the help of following equivalent circuits [3].

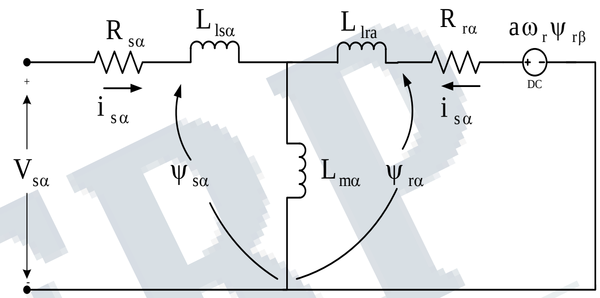

Fig. 2 Auxiliary winding in α-axis

Fig. 2 and fig. 3 shows equivalent circuit of 2-phase induction motor in α and β reference frame. Stator equation in stationary reference frame are given below

$$v_{s\alpha} = R_{s\alpha} i_{s\alpha} + \frac{d}{dt}\psi_{s\alpha} \qquad (1)$$

$$v_{s\beta} = R_{s\beta} i_{s\beta} + \frac{d}{dt}\psi_{s\beta} \qquad (2)$$

Rotor equations in stationary reference frame are given below

$$v_{r\alpha} = 0 = R_{r\alpha} i_{r\alpha} + \frac{d}{dt}\psi_{r\alpha} + a\omega_r \psi_{r\beta} \qquad (3)$$

$$v_{r\beta} = 0 = R_{r\beta} i_{r\beta} + \frac{d}{dt}\psi_{r\beta} - \frac{1}{a}\omega_r \psi_{r\alpha} \qquad (4)$$

The components of stator and rotor flux linkages equations can also be expressed as:

$$\psi_{s\alpha} = L_{s\alpha} i_{s\alpha} + L_{m\alpha} i_{r\alpha} \qquad (5)$$

$$\psi_{s\beta} = L_{s\beta} i_{s\beta} + L_{m\beta} i_{r\beta} \qquad (6)$$

$$\psi_{r\alpha} = L_{m\alpha} i_{s\alpha} + L_{r\alpha} + L_{r\alpha} i_{r\varepsilon} \qquad (7)$$

$$\psi_{r\beta} = L_{m\beta} i_{s\beta} + L_{r\beta} + i_{r\beta} \qquad (8)$$

Using equation (5)-(8), the stator and rotor currents equations can be obtained as:

$$i_{s\alpha} = \frac{L_{r\alpha}\psi_{s\alpha} - L_{m\alpha}\psi_{r\alpha}}{L_{s\alpha}L_{r\alpha} - L^2_{m\alpha}} \qquad (9)$$

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$$i_{s\beta} = \frac{L_{r\beta}\psi_{s\beta} - L_{m\beta}\psi_{r\beta}}{L_{s\beta}L_{r\beta} - L^2{}_{m\beta}} \qquad (10)$$

$$i_{r\alpha} = \frac{L_{s\alpha}\psi_{r\alpha} - L_{m\alpha}\psi_{s\alpha}}{L_{s\alpha}L_{r\alpha} - L^2{}_{m\alpha}} \qquad (11)$$

$$i_{r\beta} = \frac{L_{s\beta}\psi_{r\beta} - L_{m\beta}\psi_{s\beta}}{L_{s\beta}L_{r\beta} - L^2{}_{m\beta}} \qquad (12)$$

The equation of electromagnetic torque is given by the equation as:

$$T_e = P_p\left(L_{m\beta}i_{s\beta}i_{r\alpha} - L_{m\alpha}i_{s\alpha}i_{r\beta}\right) \qquad (13)$$

And the mechanical dynamic is modeled by the equation

$$J\frac{d}{dt}\omega_r = T_e - T_L \qquad (14)$$

where $v_{s\alpha}$, $v_{s\beta}$, $v_{r\alpha}$, $v_{s\beta}$ are the stator and rotor voltages, $i_{s\alpha}$, $i_{s\beta}$, $i_{r\alpha}$, $i_{s\beta}$ are the stator and rotor currents, $\psi_{s\alpha}$, $\psi_{s\beta}$, $\psi_{r\alpha}$, $\psi_{s\beta}$ are the stator and rotor flux linkages $R_{s\alpha}$, $R_{s\beta}$, $R_{r\alpha}$, $R_{s\beta}$ are the stator and rotor resistances, $L_{s\alpha}$, $L_{s\beta}$, $L_{r\alpha}$, $L_{s\beta}$ are the stator and rotor inductances, $L_{m\alpha}$, $L_{m\beta}$ are the magnetizing inductances, ω_r is the electrical rotor angular speed, T_e is the electromagnetic torque, T_L is the load torque, J is the rotor moment of inertia, $\frac{d}{dt}$ is the differential operator and a is the main per auxiliary winding turns ratio.In case of symmetrical 2-phase induction motor a=1

III V/F METHOD FOR SPEED CONTROL OF INDUCTION MOTOR

A v/f control is usually used for the control of induction motor because it is simple to implement and is economical.This method keeps the flux at the desired level so that machine will not experience the saturated condition and will develop sufficient torque for its operation. In this control it implies that when frequency is changed correspondingly the voltage should change for maintaining the flux constant This is a scalar control practiced during steady state condition. A steady state model is used for v/f control.

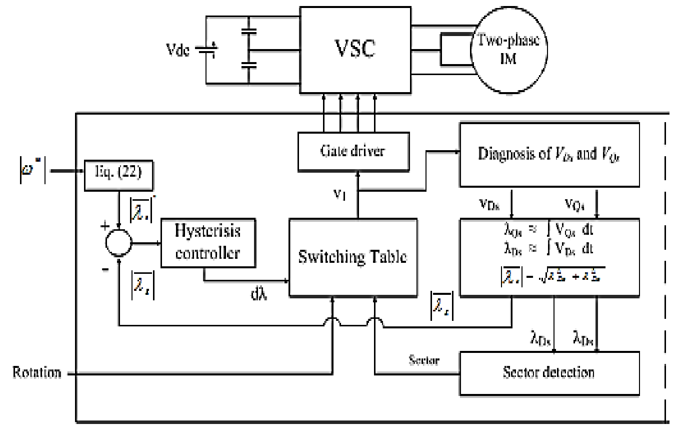

Fig. 4. Block diagram of ASFC method for 2-phase induction motor

IV. EQUATIONS FOR ASFC METHOD

The aforsaid method uses a 2-leg inverter. The space vectors and the flux sectors associated with 2 leg inverter is as shown in fig. 5[5]

The components of stator flux vector and its modulus are derived as follows;

$$\lambda_{Qs} = \int(V_{QS} - r_s i_{QS})dt \qquad (15)$$

$$\lambda_{DS} = \int(V_{DS} - r_s i_{DS})dt \qquad (16)$$

$$|\lambda| = \sqrt{\lambda_{Qs}{}^2 + \Lambda ds^2} \qquad (17)$$

Where r_s is the stator resistance , V_{QS}, V_{DS}, λ_{Qs}, λ_{DS} Iqs and Ids are components of stator voltage ,stator flux components and stator current components respectively.If the staor resistance is neglected the equation simplify to

$$\lambda_{QS} = \int V_{QS}\, dt \qquad (18)$$

$$\lambda_{DS} = \int V_{DS}\, dt \qquad (19)$$

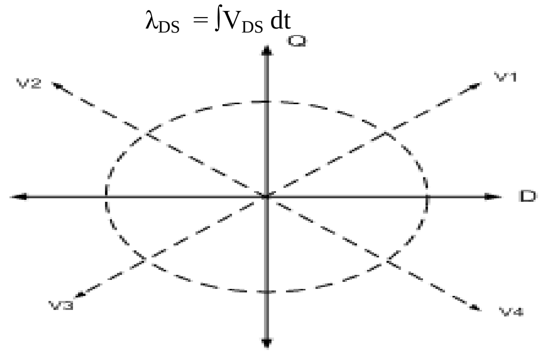

Fig.5 Flux sector of 2- leg inverter

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V APPROXIMATE STATOR FLUX CONTROL METHOD (ASFC METHOD)

In case of induction motor at starting also we want a flux in particular range. This method does the job of maintaining the flux at the designed level[2] during starting. Fig. 4 shows the setup used for achieving it. The method helps in controlling the flux and there is no need for controlling the torque hence no current transducer is used, thus making the method cost effective. In ASFC method, equations of simplified voltages are used to estimate the stator flux. This flux is required to calculate stator flux modulus. The calculated flux is compared with reference flux .The reference flux is obtained through the algorithm. The output of the hysteresis controller keep in check the rotating field velocity of induction motor. The relationship between the average velocity and stator flux modulus is derived as follows.

Perpendicular component	(Perpendicular component)/Vdc
$v_{1p}(\theta)$	$\frac{\sqrt{2}}{2}cos(\theta+\frac{\pi}{4})$
$v_{2p}(\theta)$	$\frac{\sqrt{2}}{2}cos(\theta-\frac{\pi}{4})$
$v_{3p}(\theta)$	$\frac{\sqrt{2}}{2}cos(\theta-\frac{3\pi}{4})$
$v_{4p}(\theta)$	$\frac{\sqrt{2}}{2}cos(\theta-\frac{5\pi}{4})$

VI. RELATION BETWEEN AVERAGE SPEED OF THE ROTATING FIELD AND FLUX.

A two leg voltage source converter gives 4 identical voltage sectors but we need to do analysis of only 1 voltage sector [2]. The stator flux sector is assumed to be in sector 1 (fig.5). The switching table determines which voltage vector to select i.e. v1 or v2 subject to the product of hysteresis controller. Table I shows how to select vector depending on the product of the hysteresis controller [1].

TABLE I

	Sectors			
dλ	1	2	3	4
1	V_1	V_2	V_3	V_4
0	V_2	V_3	V_4	V_1

The component of voltage vector which is normal to the stator flux vector is responsible for the intencifing the stator flux angle and according to the length of voltage vector the linear speed changes. The normal part of the voltage vectors of the voltage source converter is shown in TableII. Average of the normal components of v1 & v2 gives linear speed. Fig. 6 shows normal and tangent component of selected vector v1.

TABLE II

Perpendicular component	(Perpendicular component)/Vdc
$v_{1_p}(\theta)$	$\frac{\sqrt{2}}{2}cos(\theta+\frac{\pi}{4})$
$v_{2_p}(\theta)$	$\frac{\sqrt{2}}{2}cos(\theta-\frac{\pi}{4})$
$v_{3_p}(\theta)$	$\frac{\sqrt{2}}{2}cos(\theta-\frac{3\pi}{4})$
$v_{4_p}(\theta)$	$\frac{\sqrt{2}}{2}cos(\theta-\frac{5\pi}{4})$

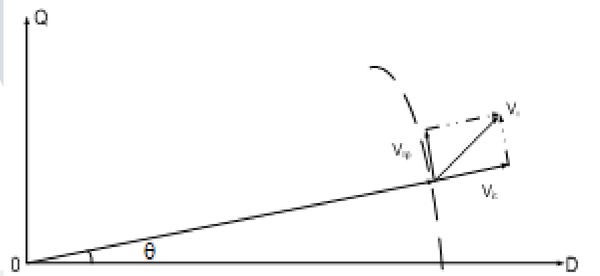

Fig. 6 Normal and Tangent part of selected voltage vector regarding stator flux vector

Hence the weighted average Vp is written as

$$Vp = P_{v1}(\theta)v1_p(\theta)+P_{v2}(\theta)v2_p(\Theta) \qquad (20)$$

Where,

$v1_p(\theta)$ is the perpendicular component of v1

$P_{v1}(\theta)$ is the probability of using v1

$v2_p$ is the perpendicular component of v2

$P_{v2}(\theta)$ is the probability of using v2

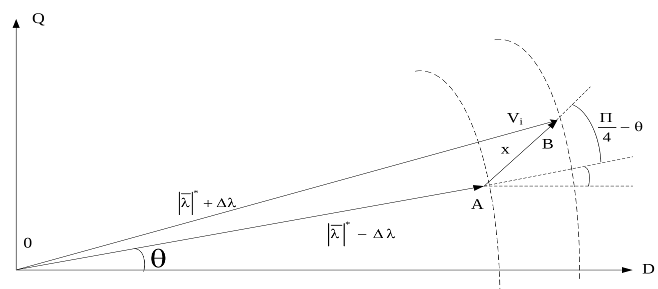

Fig. 7. Voltage vector v1 to intensify

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Initially it is assumed that flux has reached the minimum allowed value (│λ│*- Δλ), because the value should increase to │λ│*(Fig.7) voltage vector V_1 is chosen. From fig.7 the following equation is written as follows

$$(|\bar{\lambda}|^* + \Delta\lambda)^2 = x^2 + (|\bar{\lambda}|^* - \Delta\lambda)^2 - 2x(|\bar{\lambda}|^* - \Delta\lambda)\cos(\frac{3\pi}{4} + \theta) \quad (21)$$

Assuming $k = \frac{\Delta\lambda}{|\bar{\lambda}|^*}$ and $x' = \frac{x}{|\bar{\lambda}|^*}$

$$(1-k)^2 = \frac{x^2}{|\bar{\lambda}|^{*2}} + (1-k)^2 - 2\frac{x}{|\bar{\lambda}|^*}(1-k)\cos(\frac{3\pi}{4} + \theta)$$

Substituting x' and solving

$$x' + 2x'(1-k)\sin(\frac{\pi}{4} + \theta) - 4k = 0$$

By comparing it with quadratic equation $ax^2 + bx + c = 0$ and apply it in the formula $\frac{-b + \sqrt{b^2 - 4ac}}{2a}$

We obtain

$$x' = \sqrt{4k + (1+k)^2 \sin^2(\frac{\pi}{4} + \theta)} - (1+k)\sin(\frac{\pi}{4} + \theta) \quad (22)$$

By applying Maclaurin series in the above equation, we obtain

$$x' = \sqrt{k^2 + \frac{2k(2 - \sin^2(\frac{\pi}{4} + \theta)}{\sin^2(\frac{\pi}{4} + \theta)} + 1} \quad (23)$$

The equation (21) when compared to equation (22) the following equation is written

$$x' = \sqrt{k^2 + ak + 1} \quad (24)$$

The flux developing vector of normalise length is obtained as

$$x' = \frac{2k}{\sin(\frac{\pi}{4} + \theta)} \quad (25)$$

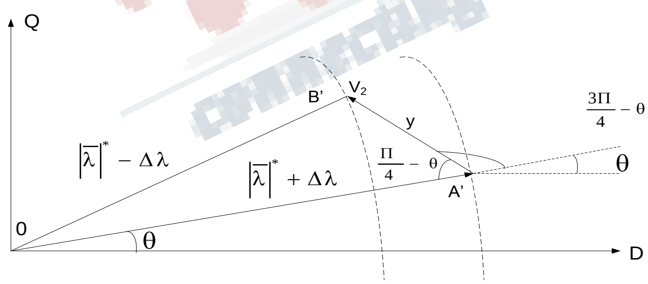

Fig. 8. Voltage vector v2 to weaken the stator flux vector.

When the flux reaches the maximum allowed value of $|\bar{\lambda}|^* + \Delta\lambda$ in the sector 1 v_2 is selected to reduce the stator flux modulus.(fig.8) Similar calculations in OA'B' triangle, gives the normalized length of flux-weakening vector as

$$y' = \frac{2k}{\cos(\frac{\pi}{4} + \theta)} \quad (26)$$

Therefore by using the values obtained from equation (25and (26) we can derive the probablities as

$$P_{v1}(\theta) = \frac{x'}{x' + y'} = \frac{\cos(\frac{\pi}{4} + \theta)}{\sin(\frac{\pi}{4} + \theta) + \cos(\frac{\pi}{4} + \theta)} \quad (27)$$

$$P_{v1}(\theta) = \frac{y'}{x' + y'} = \frac{\sin(\frac{\pi}{4} + \theta)}{\sin(\frac{\pi}{4} + \theta) + \cos(\frac{\pi}{4} + \theta)} \quad (28)$$

From (17), (18), (19), and (20) .Table I, the linear speed can be derived as

$$V_p = P_{v1}(\theta)v1_p(\theta) + P_{v2}(\theta)v2_p = \frac{V_{dc}}{2\cos\theta} \quad (29)$$

Therefore, by integrating the stator flux vector, we can obtain the rotational speed as[2]

$$\omega_{avg} = \frac{2}{\pi}\int_{-\frac{\pi}{4}}^{\frac{\pi}{4}} \frac{V_{dc}}{2\cos(\theta)|\bar{\lambda}|^*} d\theta \cong 0.56\frac{V_{dc}}{|\bar{\lambda}|^*} \quad (30)$$

From equation (30) the rotating field speed is controlled by adjusting the stator flux modulus. Thus speed of 2-phase induction motor can be controlled from the flux adjustment.

VII CONCLUSION

In this paper, a method named as ASFC is studied for controlling the speed of 2-phase induction motor, The ASFC method is most suitable and cost effective. It shows appropriate dynamic behaviour of the drive. The method is implemented be used for high speed application and it can perform well even in transient condition.

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