Study of Speed Control of ACIM Using Indirect Field Oriented Control

Shabbir Siddiqui, Hussain Khan I. Pathan, Mahfuz alam, Tahir Shaikh, Shraddha Hule

***Abstract*— This study has been undertaken to investigate the speed control ACIM using field oriented control. The principle of vector control of electric drives is based on the control of both the magnitude and the phase of each phase current and voltage. for this purpose, the study of available conventional and non-conventional approaches has been presented. This paper also presents a clear study which illustrates introduction of efficient vector control of ACIM.**

***Index Terms*— ACIM-ac induction motors, vector control**

I. INTRODUCTION

Induction motor or asynchronous motor is the most extensively used in the industrial, commercial, residential settings as these motors are simple and robust in construction having low cost and minimum maintenance, high dependability and sufficiently high proficiency due to these conveniences ACIM are most widely used in industrial applications. However, control of ACIM is more difficult than the control of DC machines, with the help of scalar methods speed can be control as it is simple to implement but it has the coupling effect thus it is responsible for slow response which leads to oscillations due to higher order effect. But in many operations and machinery in industries sensitive revolutions and torque adjustment have to be peripheral with high accuracy, so dc motor drives were generally used variable speed drives because of the simplicity of control due to decoupling between armature current and the field current.

The control and estimation of ac drives in general is considered more complex than these of dc drives and this complexity increases substantially if performance are demanded. Also to control the ACIM there are different types of conventional methods are available such as followings:

- Conventional approach-
1. Variable supply voltage control
2. Variable rotor resistance control
3. Constant volts/hertz control (scalar control)
- Non-conventional approach-
1. Direct torque control(DTC)
2. Vector control

First three speed control methods stated above have many drawbacks including saturation of core due to variation in flux. In the scalar control method, the steady state model of the motor is used and speed control is carried out with the fixed ratio of v/f. The scalar speed control method for ACIM is the most commonly known and used due to convenience of easy implementation. The fundamental property of this method is to keep ratio of the voltage which is supplied to the stator at speed between initial and final or rated value to the frequency (v/f) and therefore the air gap flux and induced torque is fixed. Speed control may be carried out keeping the voltage fixed and increasing the frequency at speed greater than rated speed thus weakening the air gap flux. The biggest downside of scalar method is that the rated torque is reduced as a result of the relative effect of the voltage which decreases with the stator resistance at low voltage of 3-5 HZ on the phase voltage.

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II. NON-CONVENTIONAL APPROACH

- Direct torque control(DTC)
- Vector control

The name direct torque control is derived by the fact that on the basis of errors between the reference and the estimated values of the torque and flux it is possible to directly control. DTC allows good torque control in steady state and transient operating conditioned as well to be obtained, it is well known that DTC having some downside that can be summarized in the following points:

1. Inconvenient to control torque and flux at very low speed
2. High current and torque ripple
3. Variable switching frequency behavior
4. High noise level at low speed
5. paucity of direct current control

these downsides can be overcome with the help of vector or field oriented control. With the help of this method ACIM can be control similar to the separately excited dc motor, the mmf produced by the armature current are spatially quadrature. Therefore, there is no magnetic coupling between field circuit and armature circuit thus the armature current can be changed independently and torque can be control swiftly keeping field flux constant.

In ac machines also the torque is produced by the interaction of flux and current but in induction motor (ACIM) the power is fed to the stator, only the current is responsible for production of torque and flux. This is obtained by controlling the magnitude frequency and phase of stator current by mathematical transformation and inverter control. So the control of the motor is obtained by controlling both magnitude and phase angle of the current. This kind of approach towards speed control method is called vector or field oriented control.

III. FIELD ORIENTED CONTROL

Vector or field oriented control in ACIM is executed by independently controlling torque component and field component of the stator current through a coordinated change in supply voltage amplitudes, phase and frequency with this method ACIM can give performance comparable to dc machines. In field orientation control current which is supplied to the motor is split into two components i.e. flux component and torque component, in which flux component is direct in phase with the rotor flux and torque component is directed in quadrature. It behaves like dc quantities in steady state. The torque component in space phasor can be written as [1]

$$T_e = KI_{ds}I_{qs} \text{ or } T_e = KI_{dr}I_{qr} \qquad (1)$$

n ACIM stator current phasor I_s produces the rotor flux and the torque component of stator current producing the flux is in phase with rotor flux of I_{ds} of the stator current is similar to field current of dc machine. The current I_{qs} is responsible for production of total flux and aligned to the direction of the flux vector. In an ACIM there are three distinct flux space phasors i.e. Air gap flux, stator flux and rotor flux. [1] The simple scheme is shown in fig.2

Vector control can be performed with respect to any of these flux phasor by attaching d axis of the reference, the respective flux space or direction. Rotating reference frame rotating with the total flux linkage space vector of the rotor as reference frame is the field frame. So this method is known as field oriented control method.

If instantaneous current i_a, i_b, $i_c$in the stator phases then the stator phases then the stator current vector is defined as follow:

$$i_s = i_a + i_b e^{j2\pi/3} + i_c e^{j2\pi/3} \qquad (2)$$

these current space vector shows the three phase sinusoidal system. But this three phase sinusoidal system needs to be transformed into time invariant coordinate system. This transformation can be split into two steps with two time with two transformation method.

- $(abc) \rightarrow (\alpha\beta)$ (The Clark transformation) which gives a two coordinated time variant system.
- $(\alpha\beta) \rightarrow (dq)$ (Park transformation) which gives a two coordinated time invariant system.

In this process d-q component in stator reference frame. There are then transformed into field reference frame is at an angle of θf with respect to stator reference frame shown in fig.1 below. θf is field angle θsl is the slip angle and θr is the angle between stator current space vector and the reference field frame than

$$\theta f = \theta r + \theta s \qquad (3)$$

In terms of speed

$$\theta f = \int (\omega r + \omega sl)dt = \int \omega s\, dt \qquad (4)$$

These current which is transferred are compared with i_{ds}* and i_{qs}*. The obtained error signals are amplified and used to control flux and torque. Then these are transformed from field frame to stator frame using inverse transformation. By 2/3 transformation once d-q components are known these can be converted into abc components. These currents are compared with the actual motor current and used to control the switching of inverter current regulated three phase inverter used switching control is also used to regulates the values of these current. Due to decoupled of these current dynamic response can be achieved as that of DC motor. Current I_s can orient

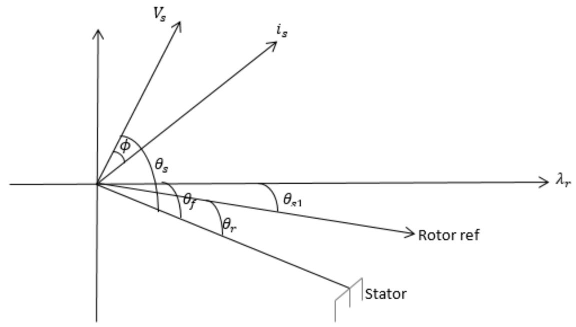

figure 1

with rotor flux axis or stator flux axis or with air gap flux axis for vector control but rotor flux orientation gives natural decoupling control whereas the air gap flux or stator flux orientation required compensation.

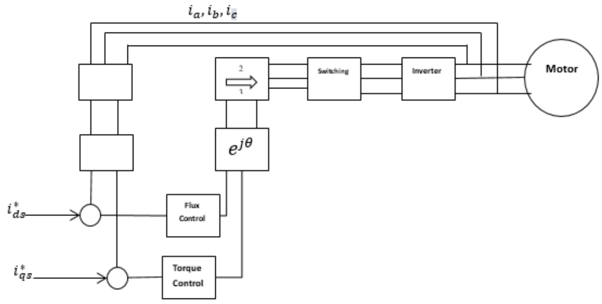

figure 2 Basic scheme of field oriented control

IV. DIRECT VECTOR CONTROL

In this method of field oriented control vector is obtained by the terminal voltage and current or flux linkage signal is achieved directly by flux evaluator or sensors requires specially assigned motor equipped with hall effect technology. In this it will be assured

that the position of rotor flux linkage vector d_r is known and it is at an angle of θf from stationary reference frame as illustrated in figure. The stator current Is, makes an angle θs with stator reference frame and an angle of θi with rotor flux linkage axis.

The component of current producing the rotor flux has to be in phase with dr. Thus I_f is resolved into d axis and q axis component in rotor flux linkage frame $Is \cos\theta = If$ is the field producing component and the component along q axis $It = Is \sin\theta t$ is the torque producing component since Is phasor rotates at synchronous speed and the rotor flux linkage space and slip speed. The relative speed between I_f and rotor field is zero. Thus current $I_t$and I_f are dc quantities and can be ideally used as control variables.[2]A block diagram of direct vector control is illustrated in fig.3.

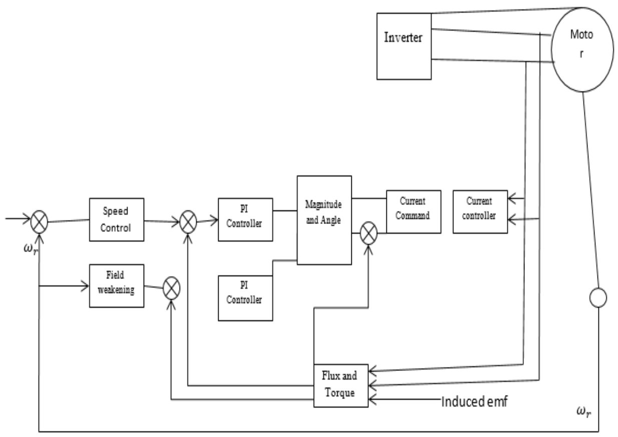

figure 3 Direct vector control scheme

However, use of sensors is very expensive because unique modification of the motor is required for placing the sensors which sense the flux. There may be inaccuracies by calculating rotor flux directly from directly sensed signal because at low speed due to stator resistance voltage drop in the stator voltage equation and inaccuracies due to variation on flux level and temperature. With this inaccuracy of motor, the rotor flux position, torque and flux components are not completely decoupled as result dynamic response becomes deficient. This method has so many downsides as it requires number of sensors and to fulfill this requirement special modification of motor is needed which further becomes a tedious task as well as devastating due to increase in cost. Thus this scheme is not favored.

V. INDIRECT VECTOR CONTROL

In indirect field oriented control method, the relative speed of the rotor flux linkage space vector is determined and integrated to obtain angle of movement of the field with respect to the rotor. This angle is added to the measured angle moved by rotor to obtain θr. Indirect vector has lot of dominance over direct FOC due to following reasons: [2][3][1]

1. The sensors are not required.
2. The dynamic performance of Indirect FOC is much better than direct vector control due to various precedence
3. Cost is reduced due to absence of sensor as that of direct FOC
4. Drift problems are eliminated
5. Torque response is improved
6. It is possible to control the torque at low frequencies and low speed
7. Accurate four quadrant operations possible
8. No need to do special modification in motor.
9. Requires less power hence overall performance is improved

So indirect vector control is very popular in industrial applications. With the help of phasor diagram it is possible to understand the principle of indirect FOC as shown: [1]

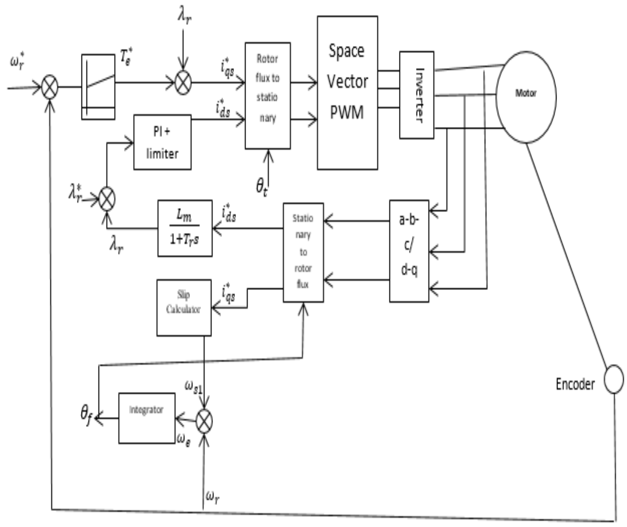

figure 4 Block diagram of indirect Vector control

The angle θf will be varying with time as the rotor flux linkage space vector dr rotates and is referred as field angle where rotor speed ωr and rotor field speed is ωsl. Stator current can be directly controlled as motor is supplied through current the rotor equation with subscript e to indicate synchronous reference frame [1]

$$\frac{d\lambda_{dr}^{e}}{dt} = R_r i_{dr}^{e} - \omega_{s1}\lambda_{qr}^{e} \quad (5)$$

$$\frac{d\lambda_{qr}}{dt} + R_r i_{qr} - \omega_{s1}\lambda_{dr} = 0$$ (here the subscript e is ignored) (6)

Where

$$\lambda_{dr} = L_r i_{dr} + L_m i_{ds} \quad (7)$$

$$\lambda_{qr} = L_r i_{qr} + L_m i_{qs} \quad (8)$$

From above equations the rotor current can be obtained in terms of stator currents as

$$i_{dr} = \frac{\lambda_{dr} - L_m i_{ds}}{L_r} \quad (9)$$

$$i_{qr} = \frac{\lambda_{qr} - L_m i_{qs}}{L_r} \quad (10)$$

Substituting these values of rotor currents in equations for flux linkages

$$\frac{d\lambda_{dr}}{dt} + \frac{R_r}{L_r}\lambda_{dr} - \frac{L_m}{L_r}R i_{ds} - \omega_{sl}\lambda_{qr} = 0 \quad (11)$$

$$\frac{d\lambda_{qr}}{dt} + \frac{R_r}{L_r}\lambda_{qr} - \frac{L_m}{L_r}R i_{qs} - \omega_{sl}\lambda_{dr} = 0 \quad (12)$$

The rotor flux linkage can be assumed to be assumed to be aligned with d^e axis, such that

$\lambda_{qr} = 0$ and $\frac{d\lambda_{dr}}{dt} = 0$ and total rotor flux $\lambda_r = \lambda_{dr}$.

Substituting these values in above equations,

The field producing component of the stator current can be obtained i.e.

$$i_f = i_{ds} = \frac{1}{L_m}\left(\lambda_r + \frac{L_r d\lambda_r}{R_r\, dt}\right) \quad (13)$$

And the torque producing component of stator current

$$i_T = i_{qs} = \omega_{sl}\frac{L_r\lambda_r}{L_m R_r} \quad (14)$$

And the torque is given by

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\lambda_r i_{qs} = K_T\lambda_r i_T \quad (15)$$

From the torque and flux producing components of stator current and rotor field angle θ_f, the reference d q axis currents are obtained as:

$$\begin{bmatrix} i_{qs}^* \\ i_{ds}^* \end{bmatrix} = \begin{bmatrix} \cos\theta_f & \sin\theta_f \\ -\sin\theta_f & \cos\theta_f \end{bmatrix}\begin{bmatrix} i_T^* \\ i_f^* \end{bmatrix} \quad (16)$$

From d-q component of stator current the line current can be obtained as

$$\begin{bmatrix} i_{as}^* \\ i_{bs}^* \\ i_{cs}^* \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ \frac{-1}{2} & -\frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & \sqrt{\frac{3}{2}} & 1 \end{bmatrix}\begin{bmatrix} i_{qs}^* \\ i_{ds}^* \\ 0 \end{bmatrix} \quad (17)$$

Selecting the q axis along the „a" axis of the stator current in the line currents can be written as

$$i_{as}^* = i_{qs}^* = |i_s^*|\sin\theta_s \quad (18)$$

$$i_{bs}^* = i_{qs}^* = |i_s^*|\sin(\theta_s - \tfrac{2\pi}{3}) \quad (19)$$

$$i_{cs}^* = i_{qs}^* = |i_s^*|\sin(\theta_s + \tfrac{2\pi}{3}) \quad (20)$$

These three phase stator current commands are generated as derived in equation and can be implemented as shown in flow chart in figure 5

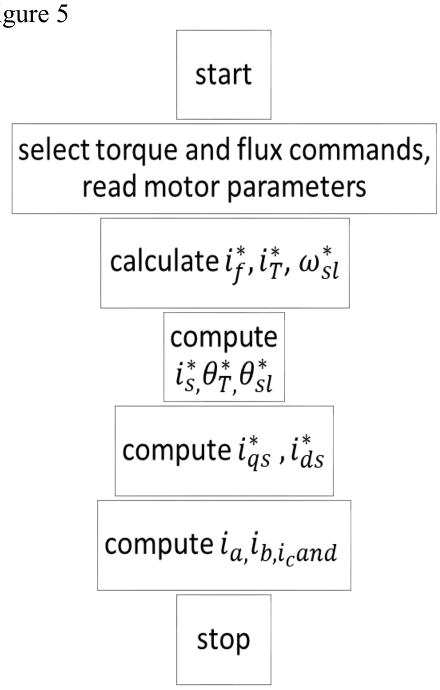

figure 5 flow chart for direct vector control

VI. CONCLUSION

This paper dealt with the study of speed control of ACIM-ac induction machine. following a description of common downsides of classic control structures it has been shown how the indirect field oriented control overcomes these downsides and what kind of benefits indirect field oriented controlled ac drive can bring. This paper has also presented a clear study which illustrates introduction of efficient vector control of ACIM. Also as far as scalar methods are concern it has been studied that although they are cheap but cannot achieve the performance of a direct current motor. Therefore, vector control applications are required for high-performance drives close to the performance of a direct current motors. The performance of indirect vector controlled induction motor in steady state and transient conditions are comparatively good.

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