A Comparative study on scalar and vector control of Induction motor drives

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***Abstract*— In this paper speed control of an Induction Motor using Indirect Field Oriented Control (IFOC) method has been developed and simulated. In this work the complete mathematical model of field oriented controlled Induction Motor is described and simulated in MATLAB/SIMULINK. For studies a 200 HP(150kw) squirrel cage type IM has been considered. The comparative study of IFOC and conventional V/f control of IM is done in this work. The IFOC induction motor drive involves decoupling of the stator current components which produces torque and flux. It is seen that it provides smooth speed control, can generate full torque at zero speed and capable of fast acceleration and deceleration compared to V/f control.**

Keywords—IFOC, ,V/f control,IM

I. INTRODUCTION

Induction motors were used in the past mainly in applications requiring constant speed. This is because the conventional methods of their speed control were either been expensive or highly inefficient. Variable speed applications have been dominated by dc drives. The speed control of DC motors can be carried out in a simple way, since the torque and flux are decoupled. But they have the disadvantages of higher cost, higher rotor inertia and maintenance problems associated with commutators and brushes. Because of the availability of thyristors, power transistors, IGBT and GTO, in recent years the speed control of induction motors is becoming inexpensive. So now a days it is increasingly replacing the DC motors in high performance electrical motor drives [1]. However the technique of vector control or field oriented control (FOC) based on the rotor field orientation applied to the induction motor provides the decoupling between the torque and flux in a similar way to the DC machine [2]. Apart from this Induction motor offers many attractive features such as ruggedness, low cost and high efficiency. Therefore with the integration of power electronics and low cost and high speed microcontrollers the induction motor drives have reached a competitive position compared to DC machines. The least expensive and most widely used induction motor is the squirrel cage induction motor.

In this paper a comparative study between the conventional scalar control and vector or field oriented control is done. For the scalar control, closed loop V/f control [3] and for vector control, indirect field oriented control [4] are selected.

II. OVER VIEW OF DIFFERENT CONTROLLING SCHEMES FOR SPEED CONTROL OF THREE PHASE INDUCTION MOTOR.

A. SCALAR CONTROL.

Scalar control as the name indicates, the magnitude of the control variable is only varied, and it disregards the coupling effect in the machine. For example, the voltage of the machine can be controlled to control the flux, and frequency can be controlled to control the torque. However the flux and torque are also functions of frequency and voltage respectively. A scalar controlled drive gives somewhat inferior performance, but they are easy to implement. Scalar controlled drives have been widely used in industry, but the inherent coupling effect (both torque and flux are function of voltage or current and frequency) gives sluggish response and system is easily prone to instability because of higher order (fifth order) system effect. To make it clearer, if torque is increased by incrementing the slip (the frequency), the flux tends to decrease. It has been noted that the flux variation is also sluggish. The decrease in flux is then compensated by the sluggish flux control loop feeding in additional voltage. The temporary dipping of flux reduces the sensitivity of torque with slip and lengthens the response time.

There are several methods available to control the speed of induction motor by scalar control such as stator voltage control, supply frequency control, slip power recovery and rotor resistance control. The most commonly used speed control method in scalar control is closed loop V/f control, in which both supply voltage and frequency are varied keeping V/f ratio constant. However, their importance has diminished nowadays because of the superior performance of vector or Field oriented control drives.

B. VECTOR CONTROL OR FIELD ORIENTED CONTROL (FOC):

F. Blaschke in 1972 has introduced the principle of field orientation to realize dc motor like characteristics in an induction motor derive [2]. For the same, he used decoupled control of torque and flux in the motor and gives its name transvector control. In DC machine the field flux is perpendicular to the armature flux. Being orthogonal to each other, these two fluxes produce no net interaction on one another. Adjusting the field current can therefore control the DC machine flux, and the torque can be controlled independent of flux by adjusting the armature current. An AC machine is not so simple because of the interactions between the stator and the rotor fluxes, whose orientations are not held at 90 degrees but vary with the operating conditions. We can obtain DC machine-like performance in holding a fixed and orthogonal orientation between the field and armature fluxes in an AC machine by orienting the stator current with respect to the rotor flux so as to get independently controlled flux and torque. Such a control scheme is called field oriented control or vector control. This method is applicable to both induction motors and synchronous motors.

The vector control approach needs more calculations than other standard control schemes, but has the following advantages [5][6].

- full motor torque capability at low speed
- better dynamic behaviour
- higher efficiency for each operating point in a wide speed range
- decoupled control of torque and flux
- short term overload capability
- four quadrant operation

PRINCIPLES OF VECTOR CONTROL

The basic principles of vector control implementation can be explained with the help of fig. 1 where the machine model is represented in a synchronously rotating reference frame. The inverter is omitted from the figure, assuming that its current gain is unity. It generate currents i_a, i_b, and i_c as dictated by the corresponding command currents i_a*, i_b*, and i_c* from the controller. The machine terminal phase currents i_a, i_b, and i_c are converted to i_{ds}^s and i_{qs}^s components by $3\Phi/2\Phi$ transformation. These are then converted to synchronously rotating reference frame by the unit vector components $cos\ \theta_e$ and $sin\ \theta_e$ before applying to the d_e-q_e machine model. The controller makes two stages of inverse transformation so that the control currents $i_{ds}*$ and $i_{qs}*$ correspond to the machine currents i_{ds} and i_{qs} respectively. Also the unit vector ensures the correct alignment of current i_{ds} with the flux vector $\hat{\psi}$ r and i_{qs} perpendicular to it.

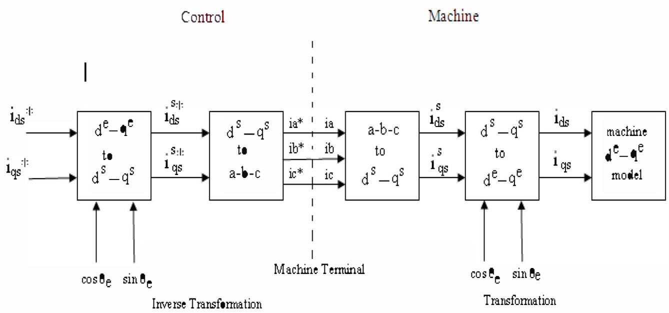

Fig 1. Vector control implementation principle with d_e-q_e machine model

The following two methods have been used in field oriented control.

1) Direct field oriented control (DFOC)
2) Indirect field oriented control (IFOC)

In Direct Field Oriented Control strategy rotor flux vector is either measured by using a flux sensor mounted in the air-gap or mathematically by using the voltage equations starting from the electrical machine parameters. In Indirect Field Oriented Control strategy rotor flux vector is estimated using the field oriented control equations (current model) requiring a rotor speed measurement. IFOC is more popular than DFOC due to its implementation simplicity and has become the industrial standard.

III. INDIRECT FIELD ORIENTED CONTROL(IFOC)

Fig.2 shows the block diagram of an Indirect Field Oriented Control Method. It consists of a slip frequency calculation, Inverter, Voltage and Current sensing Elements, integrator (I) for speed error signal and speed sensor element.

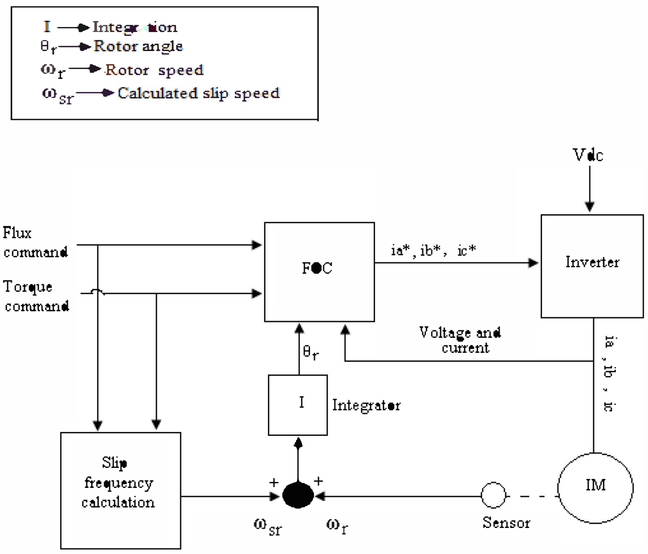

Fig.2 Indirect Field Oriented Control method of induction Motor.

In the indirect field oriented control method, the rotor flux angle and thus the unit vectors $cos\ \theta_e$ and $sin\ \theta_e$ are indirectly obtained by summation of the rotor speed and slip frequency. The IFOC method is essentially same as the direct field oriented control except that the rotor angle is generated in an indirect manner using the measured speed ω_r and the slip speed ω_{sr}. To implement the IFOC strategy, it is necessary to take the following dynamic equations into consideration with respect to the phasor diagram of Indirect Field oriented Control method of induction motor, which is shown in Fig.3.

The phasor diagram suggests that for decoupling control, the stator flux component of current i_{ds} should be aligned on the *de* axis, and the torque component of current i_{qs} should be on the *qe* axis as shown in Fig 3[7].

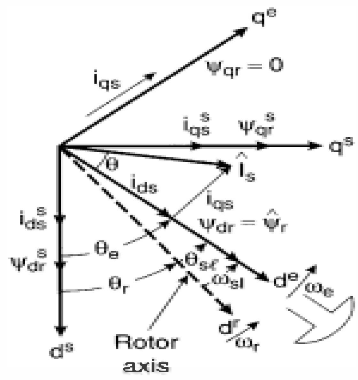

Fig.3 Phasor diagram of indirect field oriented control method of Induction motor.

For decoupling control, the rotor equations can be written as

$$\frac{d\psi dr}{dt} + R_r i_{dr} - (\omega_e - \omega_r)\psi_{qr} = 0 \quad (1)$$

$$\frac{d\psi qr}{dt} + R_r i_{qr} - (\omega_e - \omega_r)\psi_{dr} = 0 \quad (2)$$

The rotor flux linkage expressions are

$$\Psi_{dr} = L_r i_d r + L_m i_{ds} \quad (3)$$
$$\Psi_{qr} = L_r i_{qr} + L_m i_{qs} \quad (4)$$

From the above expressions we can write

$$i_{dr} = \frac{1}{Lr}\Psi_{dr} - \frac{Lm}{Lr} i_{ds} \quad (5)$$

$$i_{qr} = \frac{1}{Lr}\Psi_{qr} - \frac{Lm}{Lr} i_{qs} \quad (6)$$

By substituting (5) and (6) in (1) and (2) the inaccessible rotor currents can be eliminated.

$$\frac{d\psi dr}{dt} + R_r\frac{1}{Lr}\Psi_{dr} - \frac{Lm}{Lr} R_r i_{ds} - \omega_{sr}\psi_{qr} = 0 \quad (7)$$

$$\frac{d\psi qr}{dt} + R_r\frac{1}{Lr}\Psi_{qr} - \frac{Lm}{Lr} R_r i_{qs} - \omega_{sr}\psi_{dr} = 0 \quad (8)$$

Where $\omega_{sr} = (\omega_e - \omega_r)$

Also for decoupling control,

$$\Psi_{qr} = 0 \quad (9)$$

And

$$\frac{d\psi qr}{dt} = 0 \quad (10)$$

So that the rotor flux $\hat{\psi}$ r is directed on the *de* axis.

Substituting these equations in (7) and (8), we get

$$\frac{Lr}{Rr}\frac{d\hat{\psi} r}{dt} + \hat{\psi} r = L_m i_{ds} \quad (11)$$

$$\text{And } \omega_{sr} = \frac{Lm}{\hat{\psi} r}\frac{Rr}{Lr} i_{qs} \quad (12)$$

$$Te = \frac{3}{2}\left(\frac{P}{2}\right)\frac{Lm}{Lr}\hat{\psi} r\, i_{qs} \quad (13)$$

The signal ω_{sr} thus obtained is added with speed signal ω_r to generate frequency signal ω_e which is then integrated to obtain θ_e. The unit vectors *cos* θ_e and *sin* θ_e are generated from θ_e.

IV. CLOSED LOOP V/F CONTROL OF INDUCTION MOTOR

The constant Volts per Hertz principle is the most common scalar method for the speed control of induction motor drives. Since the magnitude of flux is proportional to the ratio between the magnitude and frequency of stator voltage, if this ratio is maintained constant, the stator flux will remain constant and so the motor torque will only depend on the slip frequency[8]. The block diagram for the closed loop speed control by constant V/f method is shown in figure below.

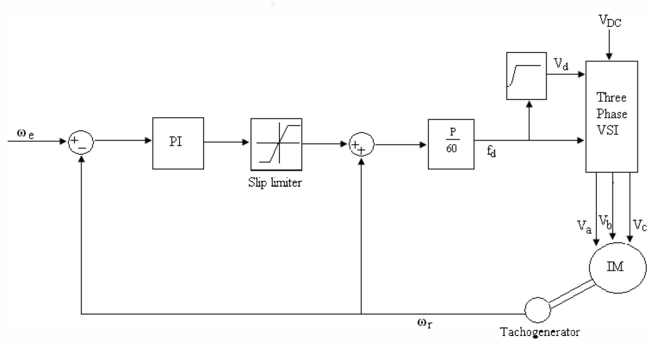

Fig.4 Block diagram for closed loop V/f control of Induction motor.

The closed loop speed controlled drive employs inner slip speed loop with a slip limiter and outer speed loop. The error in speed is processed through a PI controller and a slip regulator. The PI controller is used to get good steady state accuracy and to attenuate noise. The slip regulator sets the slip speed command ω_{sr} , whose maximum value is limited to limit the inverter current to a permissible value. The synchronous speed, obtained by adding the actual speed ω_r and slip speed ω_{sr} determines the frequency of the inverter output. The frequency command f_d also generates the voltage command through a Volts/Hz function generator.The voltage command V_d is then fed to the three phase voltage source inverter.

V. SIMULATION RESULTS

The simulation of both indirect field oriented and V/f controlled method is done using a 200HP(150Kw) squirrel cage induction motor. For simulation MATLAB 7.10(R2010a) /SIMULINK is used. Powergui tool in simpowersystems toolbox is used for simulation. The simulation results of IFOC and V/f control are given in Fig 5 and Fig 6.

SIMULATION RESULTS OF INDIRECT FIELD ORIENTED CONTROL OF INDUCTION MOTOR.

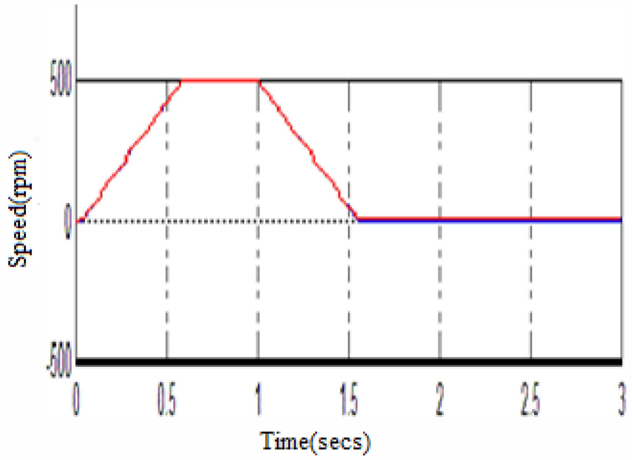

Fig.5a.The speed tracking of IFOC controlled Induction motor for a speed command signal of 500rpm.

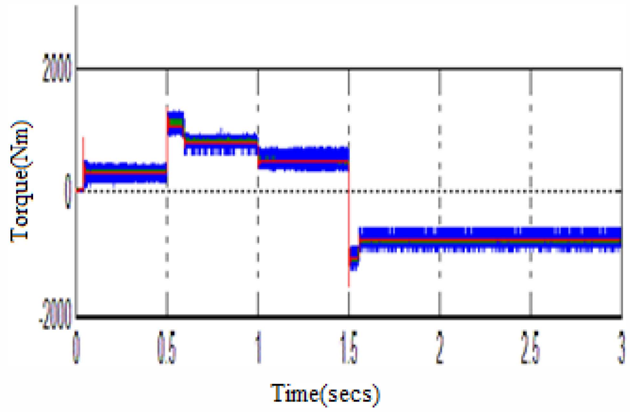

Fig.5b. The torque control of IFOC controlled Induction motor.

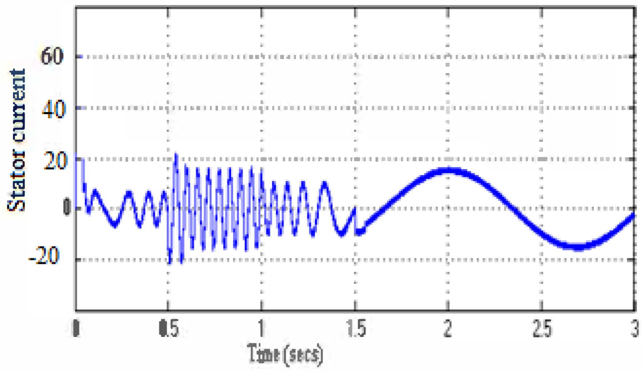

Fig 5c.Stator current with time for IFOC controlled induction motor.

Simulation result shows the superior performance of IFOC induction motor. Fig 5a shows that speed tracking is smooth and fast. The motor speed is exactly following the command signal. Also the acceleration and deceleration are fast. It shows that the transient response is better compared to other control methods.

The response of motor torque for successive change in the command torque in fig 5b shows the superiority of the controller. The solid line indicates the reference torque.The reference torque is positive till 1.5secs and then negative after 1.5 secs. Since the torque and flux are decoupled in IFOC, the torque control is fast with minimum error. The result also shows the full torque capability at low speed and the response to negative torque ensures the capability for multiquadrant operation.

Fig 5c shows the variation of stator current when the torque changes in steps.

SIMULATION RESULTS OF V/F CONTROL OF INDUCTION MOTOR.

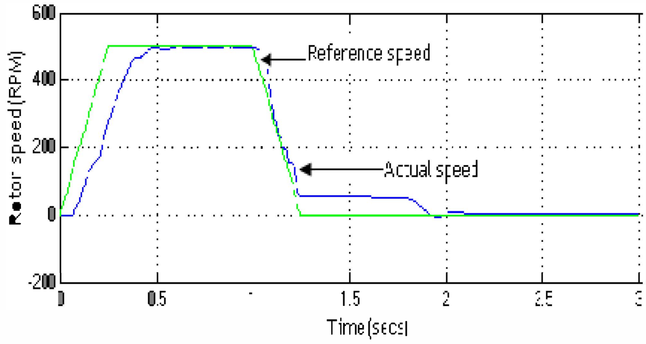

Fig.6a.The speed tracking of V/f controlled Induction motor for a speed command signal of 500rpm.

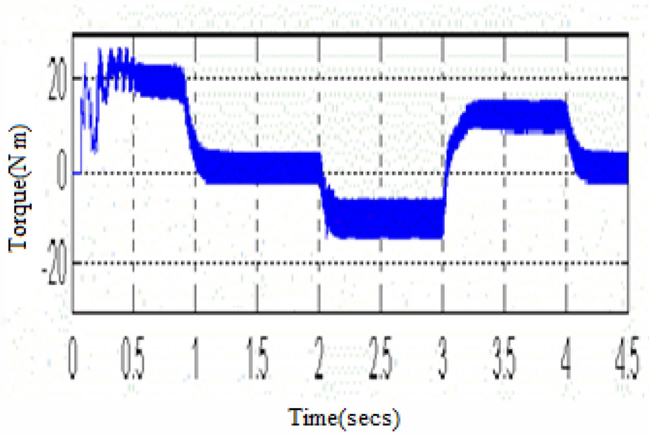

Fig.6b.The torque control of V/f controlled Induction motor.

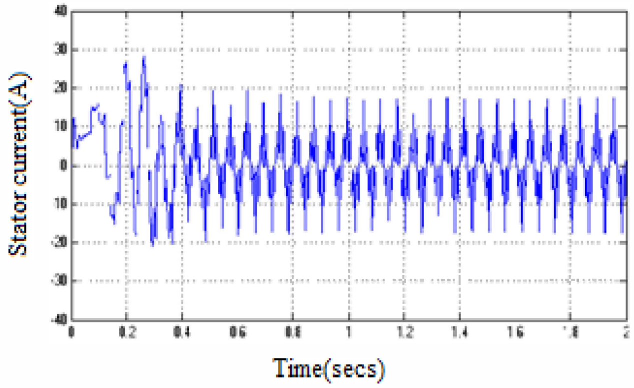

Fig.6c. Stator current with time for v/f controlled induction motor.

The simulation result (fig 6a) shows that speed tracking in V/f control is slow and not smooth as compared to IFOC control.But the acceleration and deceleration are fast.It shows that transient response is slow compared to IFOC. Also the torque response (fig 6b) is not as fast as in IFOC. This is because of the coupled nature of torque and flux.

VI. CONCLUSION

Both the control methods have advantages and disadvantages.

Scalar control is a cheap and well-implementable method. Because of these advantages and simplicity, many applications in the industry operate with this control technique. On the other hand it is not satisfactory for the control of drives with fast dynamic behaviour, since it gives slow response to transients. It is a low performance control, but it is a stable control technique.

The field oriented control method operates with fast responses. So it satisfies the requirements of dynamic drives where fast response is necessary. It is an excellent control method to handle transients. The only disadvantage is its complexity.

Both the IFOC and V/f control of Induction motor uses PI controller, which is an excellent controller for linear systems. It reduces the steady state error and provides a smooth tracking with the command signal. But if the system is influenced by uncertainties, which usually composed of unpredictable variations in the machine parameters, external load disturbances and unmodelled and nonlinear dynamics, it is very hard or impossible to design the robust control structure based on conventional PI controllers. To provide better control in the presence of such uncertainties PI controller can be replaced by other robust control techniques, such as optimal control, variable structure control, adaptive , fuzzy and neural control.

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