UNIT –V

SYNCHRONOUS MOTOR DRIVES

5.1 Introduction

Synchronous motor drives are close competitors to induction motor drives in many industrial applications.

They are generally more expensive than induction motor drives,but the advantages is that the efficiency is higher,which is tends to lower the life cycle cost.

The development of semiconductor variable frequency sources,such as inverters and cycloconverters has allowed their use in variable speed applications such as high power and high speed compressors,blowers ,induced and forced draft fans,main line traction,servo drives etc…

Synchronous motor variable speed Drives

5.2 Variable frequency control

Synchronous speed is directly proportinal to frequency,similar ti induction motors constant flux operation below base speed is achiecved by operating the synchronous motor with constant (V / f) ratio.

The synchronous motor either run at synchronous speed (or) it will not run at all.

Hence variable frequency control may employ any of the following two modes

1.True synchronous mode
2.Separate controlled mode
3.Self controlled mode

5.3 SEPARATE CONTROLLED MODE

This method can also be used for smooth starting and regenerative braking.An example for true synchronous mode is the open loop (V/f) speed control shown in fig

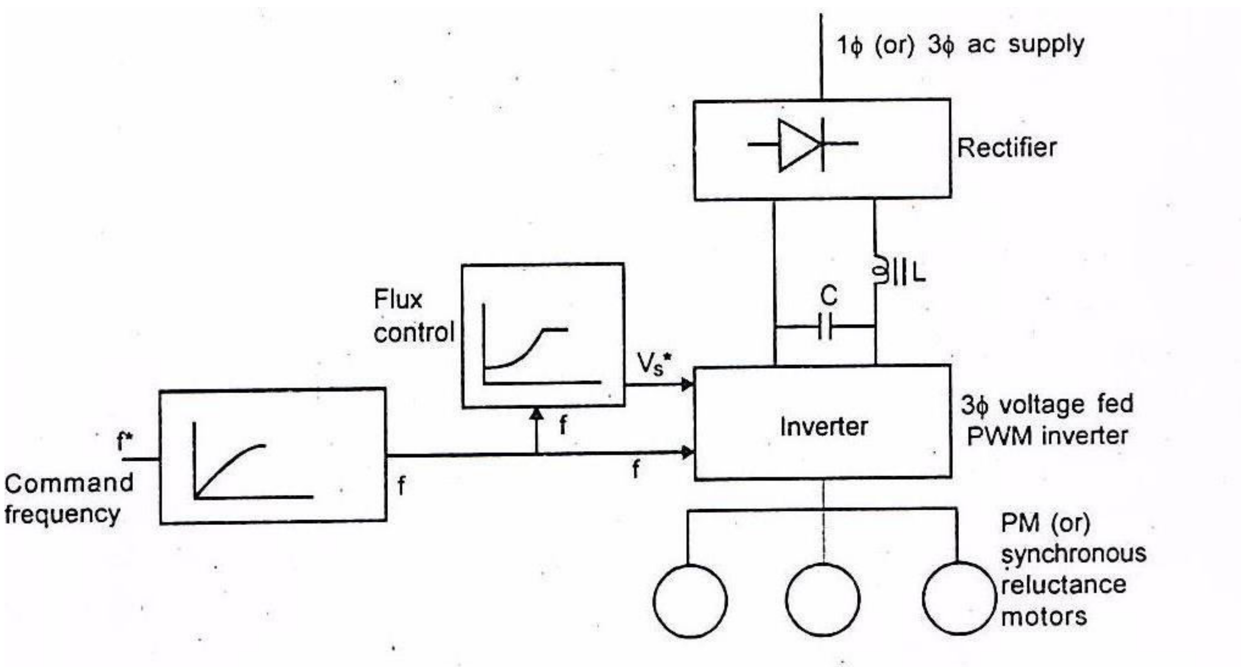

Fig (5.3) Separate Controlled Mode

Here all the machines are connected in parallel to the same inverter and they move in response to the command frequency f* at the input.The frequency command f* after passing through the delay circuit is applied to the voltage source inverters (or) a voltage fed PWM inverter.This is done so that the rotor source is able to track the change in frequency.

A flux control black is used which changes the stator voltage with frequency so as to maintain constant flux for speed below base speed and constant terminal voltage for speed above base speed.

The front end of the voltage fed PWM inverter is supplied from utility line through a diode rectifier and LC filter.the machine can be built with damper winding to prevent oscillations.

5.4 SELF CONTROLLED MODE

In self controlled mode, the supply frequency is changed so that the synchronous speed is same as that of the rotor speed.Hence, rotor cannot pull-out of slip and hunting eliminations are eliminated. For such a mode of operation the motor does not require a damper winding.

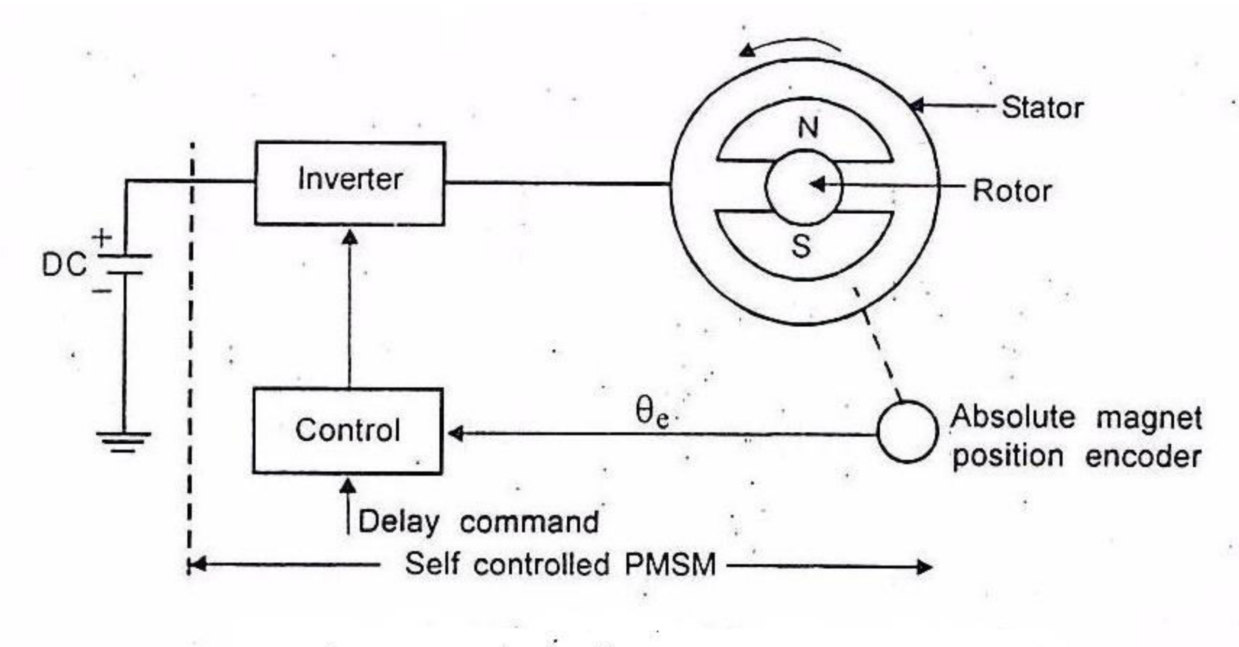

Fig (5.4)Self Controlled Mode

Fig shows a synchronous permanent magnet machine with self control.The stator winding of the machine is fed by an inverter that generates a variable frequency voltage sinusoidal supply.

Here the frequency and phase of the output wave are controlled by an absolute position sensor mounted on machine shaft, giving it self-control characteristics. Here the pulse train from position sensor may be delayed by the external command as shown in fig.

In this kind of control the machine behavior is decided by the torque angle and voltage/ current. Such a machine can be looked upon as a dc motor having its commutator replaced by a converter connected to stator. The self controlled motor run has properties of a dc motor both under steady state and dynamic conditions and therefore, is called commutator less motor (CLM).These machines have better stability behavior.

Alternatively, the firing pulses for the inverters can also be obtained from the phase position of stator voltages in which case the rotor position sensor can be dispensed with.

When synchronous motor is over excited they can supply the reactive power required for commutation thyristors. In such a case the synchronous machine can supply with inverter works similar to the line commutated inverter where the firing signals are synchronized with line voltages.

Here, the firing signals are synchronized with the machine voltages then these voltages can be used both for control as well as for commutation.Hence,the frequency of the inverter will be same as that of the machine voltages. This type of inverters are called load commutated inverter (LCI).Hence the commutation has simple configurations due to the absence of diodes, capacitors and auxiliary thyristors.

But then this natural commutation its not possible at low speeds upto 10% of base speed as the machine voltage are insufficient to provide satisfactory commutation. At that line some forced commutations circuit must be employed.

5.5 Self controlled synchronous motor Drive empolying load commuated Thyristor Inverter

In fig wound field synchronous motor is used for large power drives.Permanent magnet synchronous motor is used for medium power drives.This drive consists of two converters.i.e source side converter and load side converter.

The source side converter is a 3 phase 6 pulse line commutated fully controlled rectifier .When the firing angle range 0≤αs≤90°,it acts as a commutated fully contrlled rectifier.

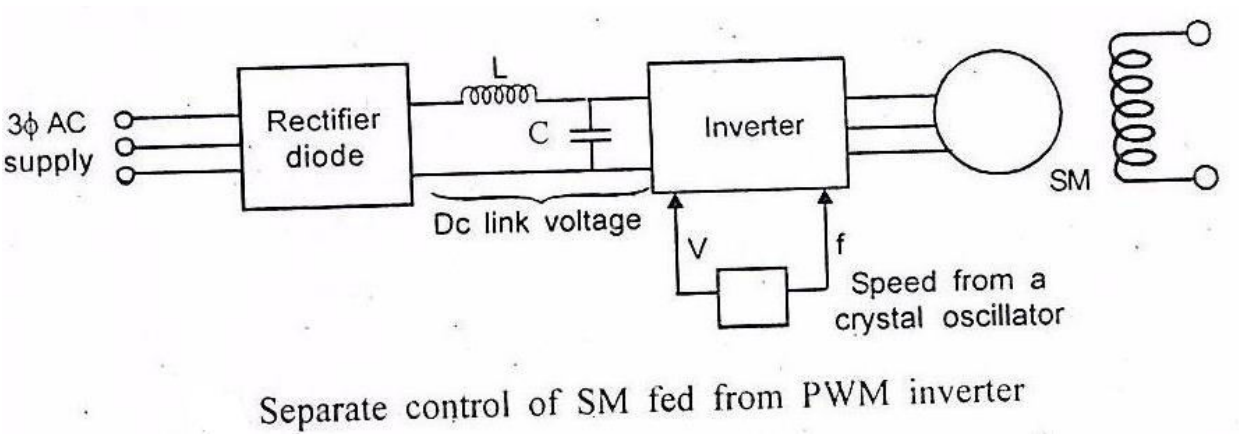

Fig (5.5) Separate control of SM fed from PWM inverter

During this mode ,output volatge Vds and output current Ids is positive.When the firing angle range is 90°≤αs≤180°,it acts as an line commutated inverter.During this mode,output voltage Vds is negative and output current Ids is positive.

When synchronous motor operates at a leading power factor ,thyristors of the load side 3φ converter can be commutated (turn off) by the motor induced voltages in the same way,as thyristors of a 3φ line commutated converter are commutated by supply voltage .Load commutation is defined as commutation of thyristors by induced voltages of load (here load is synchronous motor).

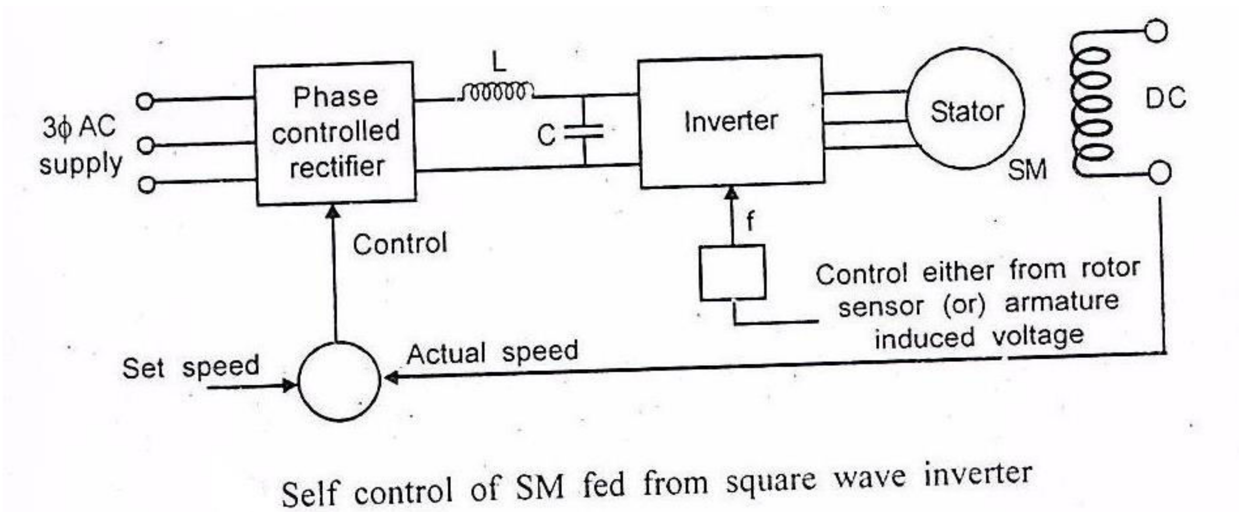

Fig (5.5.1) Self control of SM fed square wave inverter

Triggering angle is measured by comparison of induced voltage in the same way as by the comparison of supply voltages in a line commutated converter.Loas side converter operates as a rectifier when the firing angle range is 0≤αl≤90°.It gives positive Vdl and Id.When the firing angle range is 90°≤αl≤180°,it gives negative Vdl and positive Id.

For 0≤αs≤90°, 90°≤αl≤180° and with Vds >Vdl,the source side converter works as a line commutated rectifier and load side converter,causing power flow from ac source to the motor,thus giving motoring operation.

When firing angles are changed such that 90°≤αs≤180° and 0°≤αl≤90°,the load side converter operates as a rectifier and source side converter operates as an inverter.In this condition ,the power flow reverses and machine operates in regerative braking.The magnitude of torque value depends on (Vds – Vdl).Synchronous motor speed can be changed by control of line side converter firing angles.

When working as an inverter ,the firing angle has to be less than 180º to take care of commutation overlap and turn off of thyristors.The commutation lead angle for load side converter is

$$\beta l = 180^{\circ} - \alpha l$$

if commutation overlap is neglected ,the input ac current of the converter will lag behind input ac voltage by angle αl.Here synchronous motor input current has an opposite phase to converter input current,the motor current will lead its terminal voltage by a commutation lead angle βl.

Therefore the synchronous motor operates at a leading power factor. The commutation lead angle is low value, due ti this higher the motor power factor and lower the inverter rating.

5.6 CONSTANT MARGINAL ANGLE

The operation of the inverter at the minimum safe value of the margin angle gives the highest power factor and the maximum torque per ampere of the armature current,thus allowing the most efficient use of both the inverter and motor.

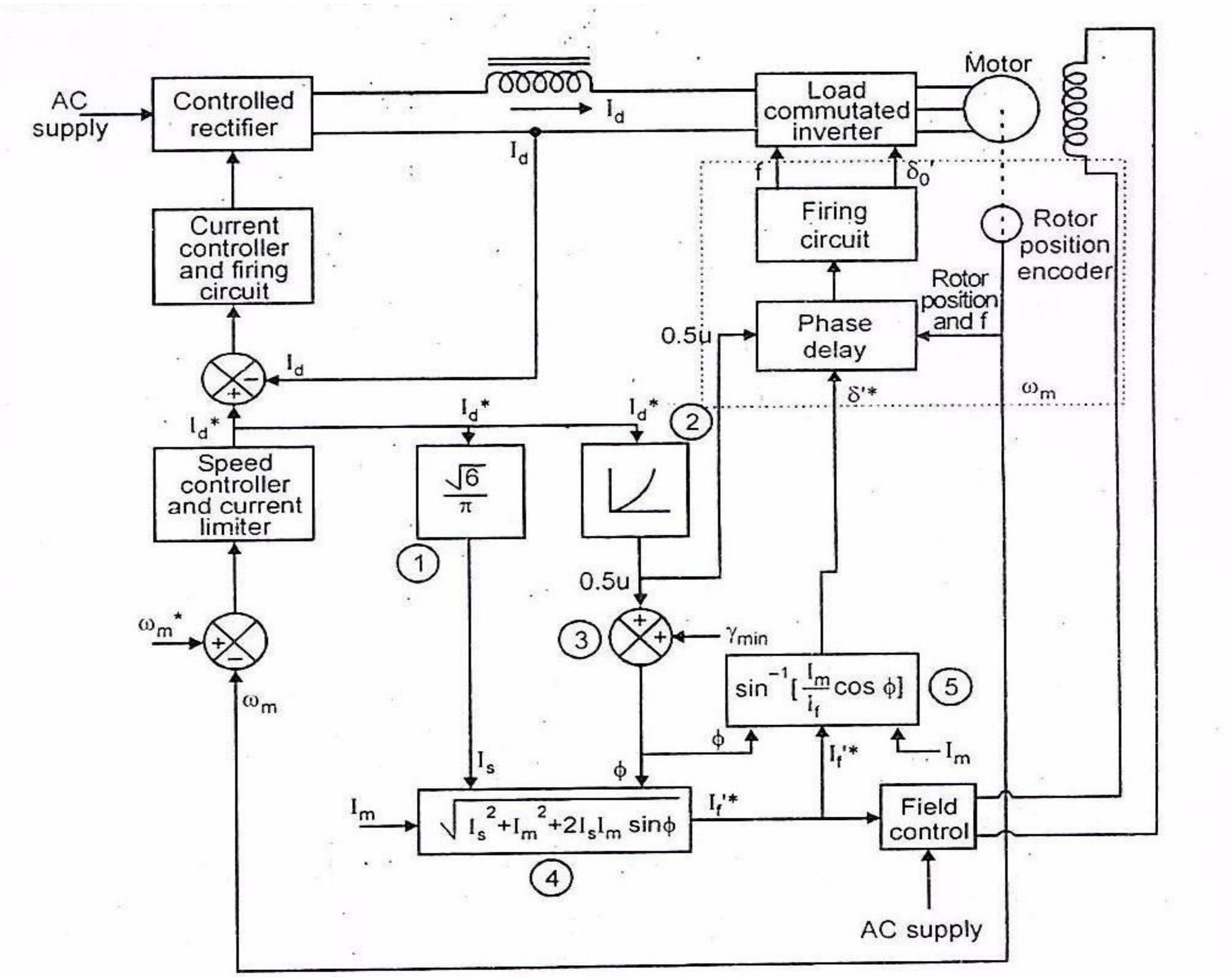

Fig (5.6) Constant Marginal Angle Control

Fig shows the constant margine angle control for a wound field motor drive employing a rotor position encoder.This drive has an outer speed loop and an inner current loop.The rotor position can be sensed by using rotor position encoder.It gives the actual value of speed ωm.This signal is fed to the comparator.This comparator compares ωm and ωm* (ref value).

The output of the comparator is fed to the speed controller and current limiter.It gives the reference current value Id*.Id is the DC link current.It is sensed by current sensor and fed to the comparator.The comparator compares Id and Id*.The output of the comparator is fed to the currrent controller.It generates the trigger pulses.

It is fed to the cotrolled rectifier circuit.In addition ,it has an arrangement to produce constant flux operation and constant margin angle control.

From the value of dc link current command Id*,Is and 0.5u are produced by blocks (1) and (2) respectivly .The signal φ is generated from γmin and 0.5u in adder (3).

In block (4) If' is calculated from the known values of Is,φ and Im.Note that the magnetizing current Im is held constant at its rated value Im to keep the flux constant.

If* sets reference for the closed loop control of the field current I_F.Blocks (5) calculates δ'* from known,values of φ and If*

The phase delay circuit suitably shifts the pulses produced by the encoder to produce the desired value of δ_0'.This signal is fed to the load commutated inverter.

The load commutated inverter drives are used in medium power,high-power and very high power drives,and high speed drives such as compressors,extructers ,induced and forced draft fans,blowers,conveyers,aircraft test facilities,steel rolling mills,large ship propulsion,main line traction,flywheel energy storage and so on.

This drive also used for the starting of large synchronous machines in gas turbine and pumpled storage plant.

High power drives employ rectifiers with higher pulse numbers,to reduce torque pulsations.The converter voltage ratings are also high so that efficient high voltage motors can be employed.

5.7 POWER FACTOR CONTROL

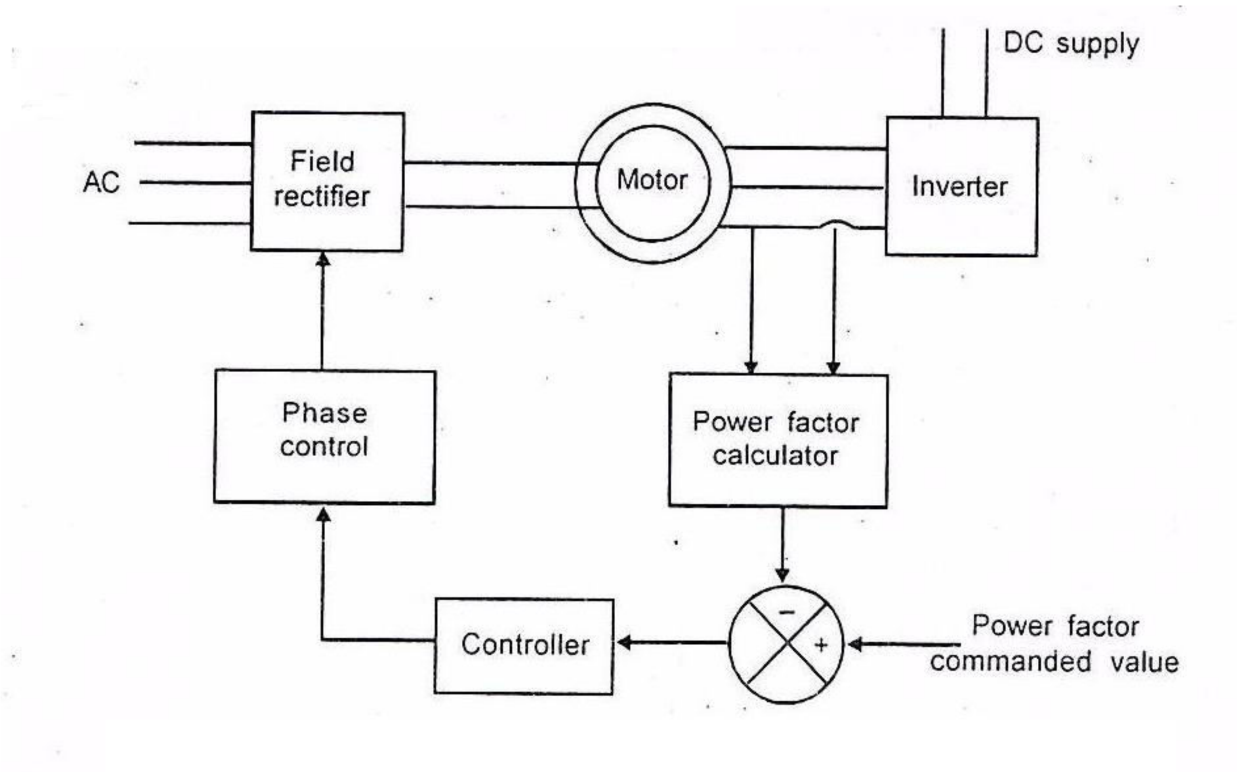

Fig (5.7) Power Factor Control

Fig shows the block diagram of automatic closed loop adjustment of power factor.The main aim of adjustment of power factor is the variation of the field current.This is possible in a wound field machine. If the motor is operated at a power factor of unity,the current drawn by it will have the lowest magnitude for a given power input and therfore the lowest internal copper losses.

From this diagram ,the motor voltage and current are sensed and fed to the power factor calculator.The power factor calculator computes the phase angle between the two and therefore the power factor.It is the actual power factor value.The computed power factor value is compared against the power factor commanded value by using error detector.The error is amplified by thye error amplifier,and its output varies the field current power factor confirm to the commanded value.

5.8 VECTOR CONTROL

The vector control decouples the two components of stator current,one providing the air gap flux and the other producing the torque.

It privides independent control of flux and troque,and the control characteristic is linearized.

Operating principles of vector control

Generally ,a vector controlled induction motor drive can operate as a separtly excited dc motor drive.fig shows separately excited dc motor diagram.

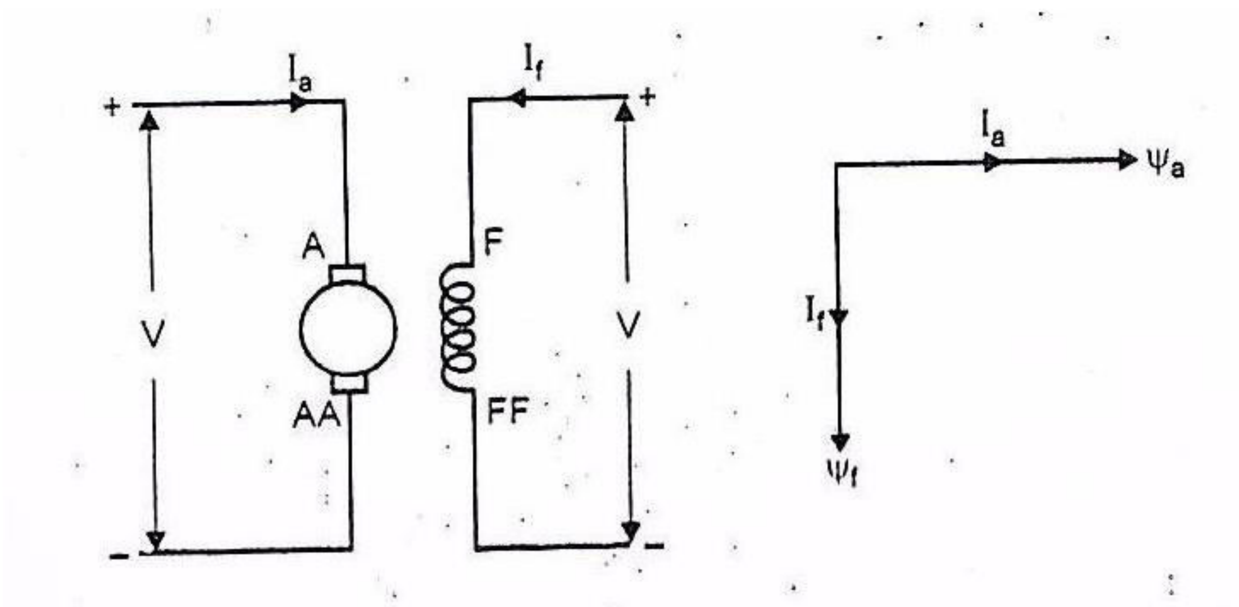

Fig (5.8) circuit diagram of vector control

In a DC machine ,the developed torque is given by

$Td = K_t I_a I_f$

Where

Kt – torque constant

Ia – Armature current(torque component)

If – Field current (Field component)

The construction of a DC machine is such that the field flux linkage Ψf produce by If is perpendicular to the armature flux linkage Ψa produced by Ia.

These space vectors ,which are stationary in space ,are orthogonal or decoupled in nature,Due to this ,a dc motor has fast transient response.But ,an induction motor cannot give such fast transient response due to its inherent coupling problem.

DC machine –like performance can also be extented to an induction motor if the machine is controlled in s synchronously rotating reference frame (d^e-q^e),where the sinusoidal variables appear as DC quantities in the steady state.

Fig shows simple block diagram of vector controlled induction motor .

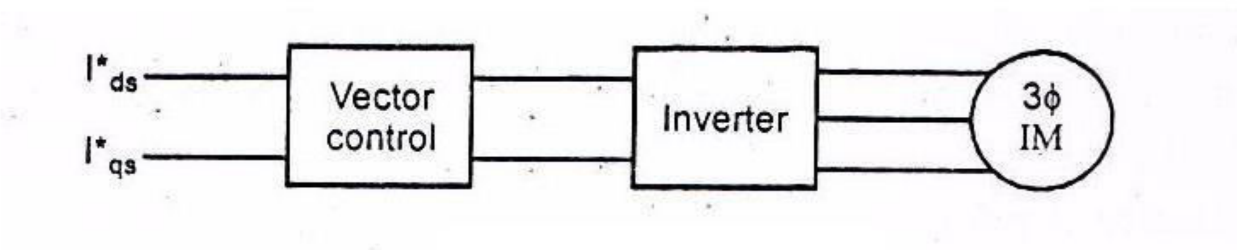

Fig (5.8.1) Block diagram of vector controlled induction motor

There are two current inputs are fed to the vector control.one is i*ds and other i*qs.

i*ds= direct –axis component of stator current

i*qs = quadrature –axis component of stator current

these currents are synchronously rotating reference frame.with vector control ,ids is analogous to the field current If and iqs is analogous to armature current Ia of dc motor .therefore the torque developed in an induction motor is given by

$$Td = Km\ \bar{\Psi}r If$$

$$= Kt\ ids\ iqs$$

$\bar{\Psi}r$ = absolute peak value of the sinusoidal space flux linkage vector $\bar{\Psi}r$

ids = field component

iqs = torque component