
KTUNOTES

Module VI

Speed control of synchronous motor drives

Synchronous motor

- A synchronous motor is constructionally same an alternator
- It runs at synchronous speed or it remains stand still
- Speed can be varied by varying supply frequency because synchronous speed, $N_s = (120f/p)$
- Due to unavailability of economical variable frequency sources, this method of speed control was not used in past & they were mainly used for constant speed applications
- The development of semiconductor variable frequency sources such as inverter & cycloconverter allowed the use of synchronous motor in variable speed applications
- It is not self starting. It has to be run upto near synchronous speed by some means & it can be synchronised to supply
- Starting methods : a) using an auxiliary motor
  b) using damper windings

Types of synchronous motors

- Commonly used synchronous motors are
  1. Wound field synchronous motor (Cylindrical & salient pole)
  2. Permanent magnet synchronous motor
  3. Synchronous reluctance motor
  4. Hysteresis motor
- All these motors have a stator with 3 phase winding which is connected to an AC source
- Fractional horse power synchronous reluctance & hysteresis motors employ a 1 phase stator

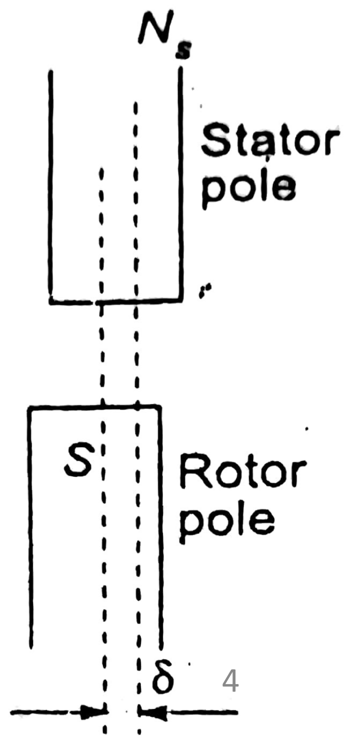
Operation of a wound field synchronous motor

- Rotor is provided with a DC field winding & damper windings
- Stator contain 3 phase winding & is connected to AC supply
- Stator produce the same number of poles as DC field produces
- When a 3 phase supply is given to stator, a rotating magnetic field revolving at synchronous speed is produced
- The DC excitation in rotor produces a field
- This field interacts with rotating magnetic field to produce a torque which is pulsating in nature & not unidirectional

- As a result synchronous motor is not self starting
- Normally the motor is made self starting by providing damper windings on rotor
- Due to the presence of damper windings, motor will start as an induction motor
- When speed of motor reaches near synchronous speed, DC excitation is given to rotor
- Now the rotor poles gets locked with rotating magnetic field poles in stator & continue to rotate at synchronous speed

Load angle/power angle/torque angle (δ)

- The rotor poles are locked with stator poles & both run at synchronous speed in same direction
- As load on motor increases, the rotor tends to fall back in phase by some angle
- This angle is known as load angle (δ)
- The value of δ depends upon the load



Pull out torque

The power produced by synchronous motor, $P_m = \frac{3VE}{X_s} Sin\delta$

Where, V = stator supply voltage

E = Field excitation voltage

Torque, $T = \frac{P_m}{\omega_s} = \frac{3VE}{\omega_s X_s} Sin\delta$

For a given value of supply voltage, frequency & field excitation, the torque will be maximum when δ = 90

i.e, $T_{\max} = \frac{3VE}{\omega_s X_s}$

- The maximum torque is known as *pull out torque*
- Any increase in torque beyond this value will cause the motor to slow down & the synchronism is lost
- This phenomenon is called *pulling out of step*

Variable frequency control of Synchronous motor

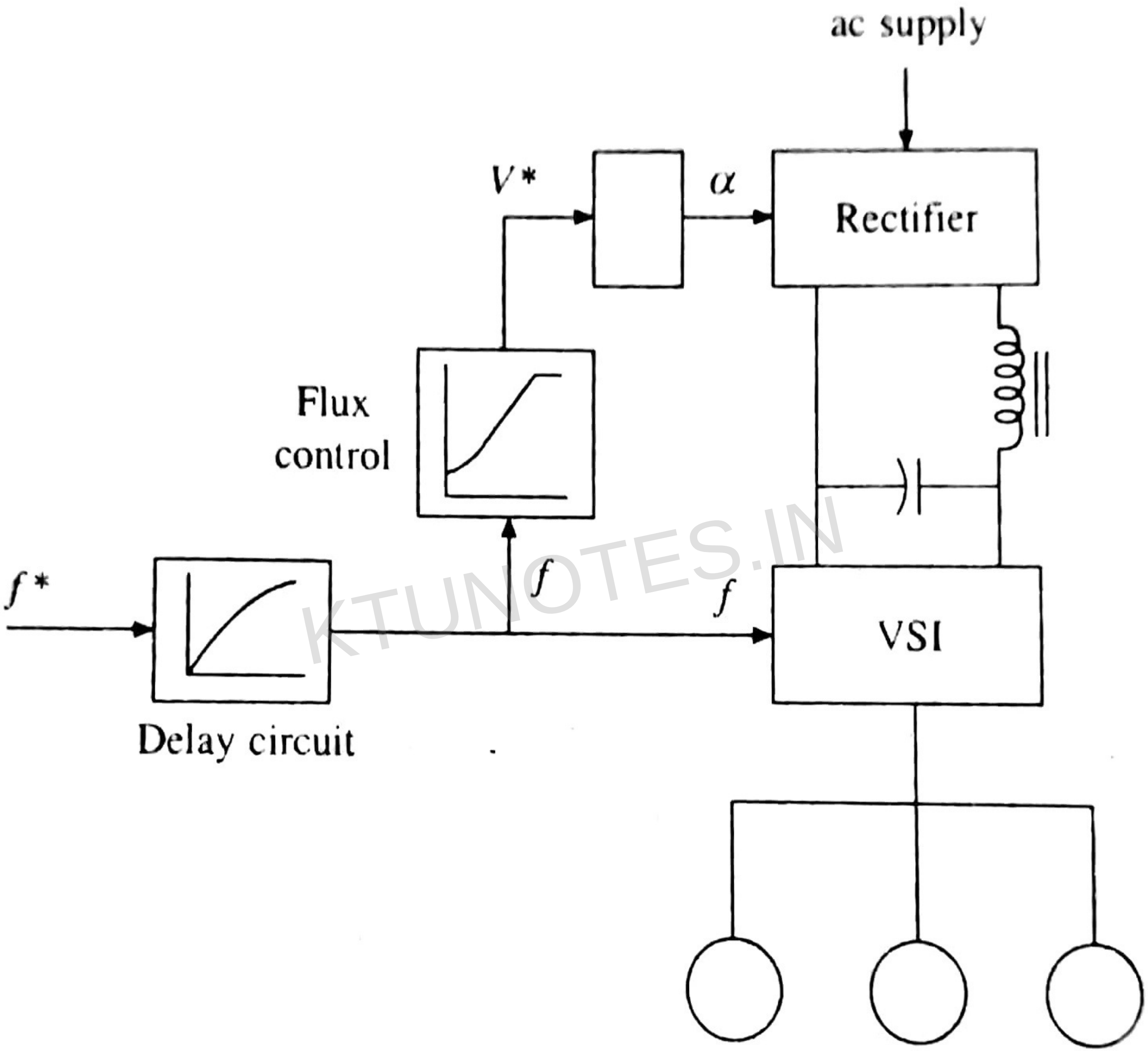
- Synchronous speed α frequency
- So by varying frequency, speed can be controlled
- Like in induction motor, upto base speed, the V/f ratio is kept constant & for speed above base speed, the terminal voltage is maintained at rated value & frequency is varied
- In variable frequency control, synchronous motor may operate in two modes

  a) True synchronous mode /open loop mode

  b) Self controlled mode

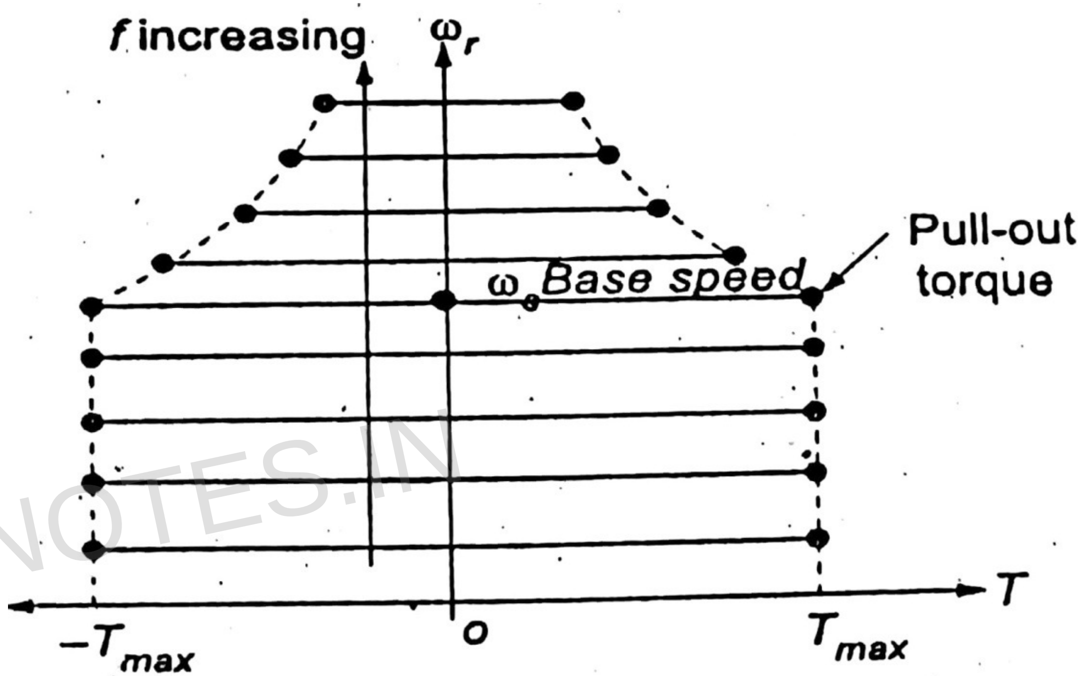
a) <u>True synchronous mode</u>

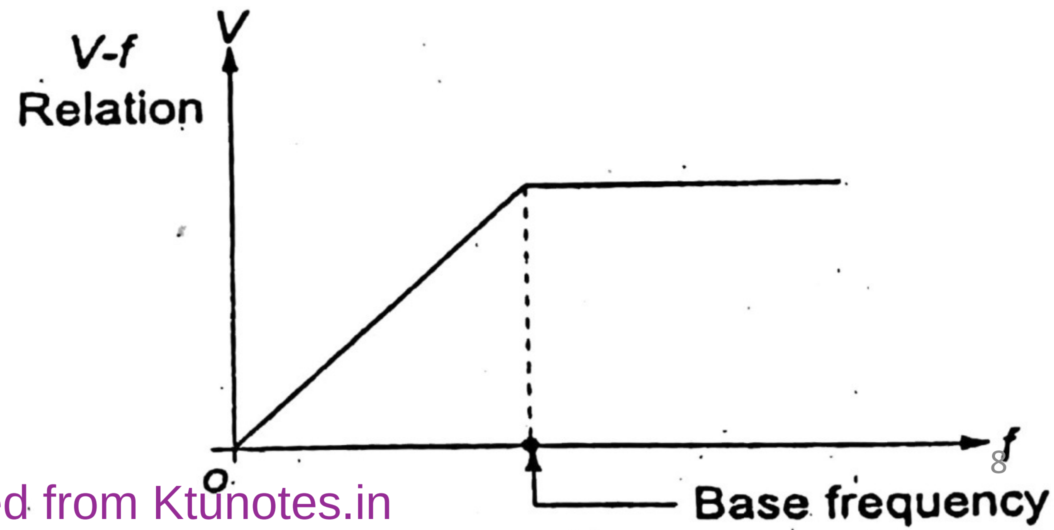
- Here the stator supply frequency is controlled from an independent oscillator
- Frequency from initial value to desired value is varied gradually so that the difference between synchronous speed & actual speed is always small



Synchronous reluctance or
permanent magnet motors

- A drive operating in true synchronous mode is shown in previous slide
- Frequency command f* is applied to a VSI through a delay circuit so that rotor speed is able to track the changes in frequency
- A flux control block changes stator voltage with frequency to maintain a constant flux below base speed & constant terminal voltage above base speed





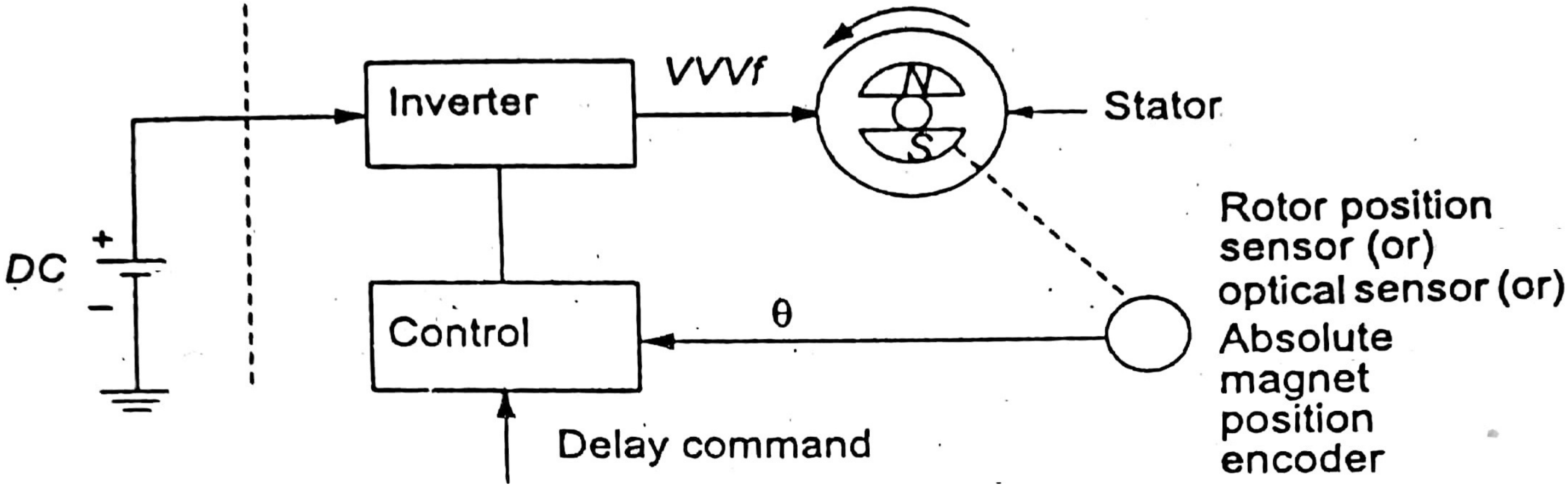
- Under steady operating conditions, a gradual increase in frequency causes the synchronous speed > actual speed & torque angle δ increases
- To follow this change in frequency, motor accelerates & settles at new speed after hunting oscillations which are damped by damper windings
- A gradual decrease in frequency causes the synchronous speed to become < actual speed & δ become negative
- To follow this change in frequency, the motor decelerates under regenerative braking
- Motor settles down at new speed after hunting oscillations
- The frequency must be changed gradually to allow the rotor to track the changes in revolving field, otherwise the motor may pull out of step
- This method is employed only in multiple synchronous motor drives requiring accurate speed tracking between motors
- E.g, fibre spinning mills, paper mills, textile mills

b) Self controlled mode

- A machine is said to be in self controlled mode if it gets its variable frequency from an inverter whose thyristors are fired in a sequence, using the information of rotor position or stator voltages

i) Rotor position sensor

- here a rotor position sensor is used, which measures the rotor position w.r.to stator & sends pulses to thyristor
- Hence the frequency of inverter output is decided by rotor speed
- Here the supply frequency is changed so that the synchronous speed is same as rotor speed & hence rotor cannot pull out of slip & hunting oscillations are eliminated
- A self controlled motor has properties of a DC machine both under steady state & dynamic conditions
- There fore it is called a commutator less motor



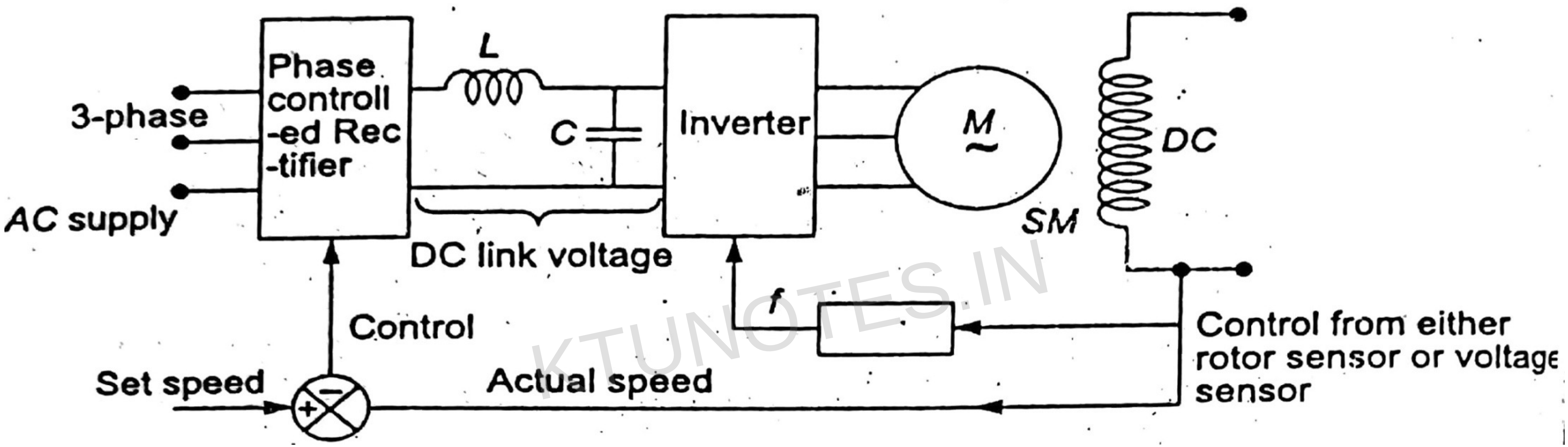
ii) *Stator voltage sensor*

- Here the firing pulses for inverter switches are derived from stator induced voltages (stator induced voltages depends on rotor position)
- The synchronous machine with the inverter can be considered to be similar to a line commutated converter where the firing pulses are synchronised with the line voltage
- Variable speed synchronous motor drives are generally operated in self controlled mode

VSI fed Synchronous Motor Drives

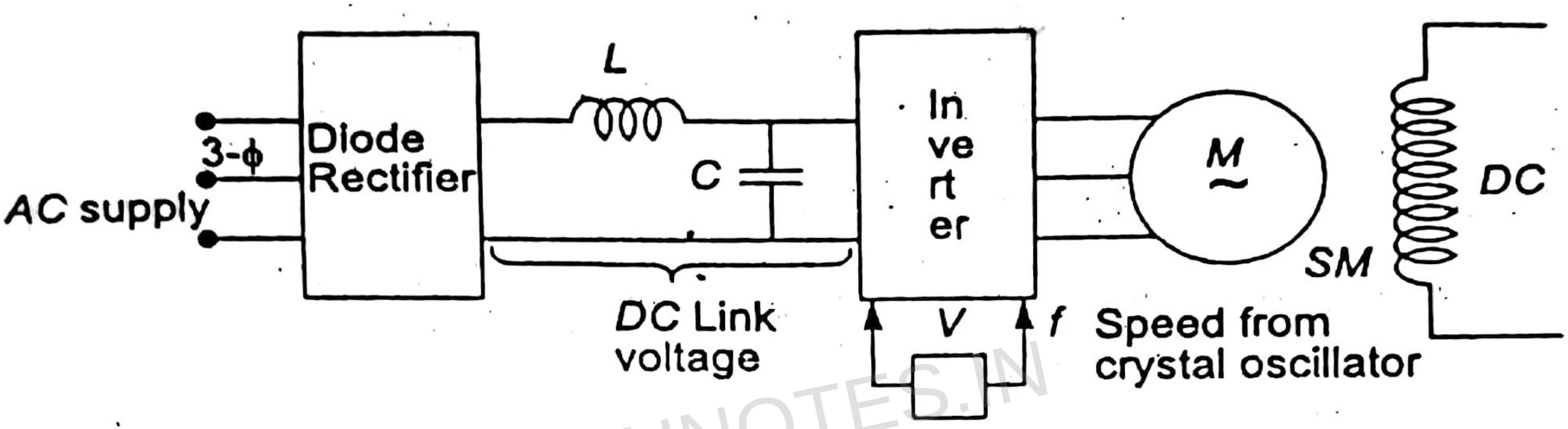
- VSI fed synchronous motor drives can be classified as

1. **Self control mode using a rotor position sensor or stator voltage sensor**



- Here the output frequency is controlled by the inverter & voltage is controlled by the controlled rectifier
- If the inverter is PWM inverter, both frequency & voltage can be controlled within the inverter
- Upto base frequency, V/f ratio is kept constant & above base speed f is varied by keeping V at rated value

2. **True synchronous mode where the speed of motor is determined by the external independent oscillator**



- Here the output frequency & voltage is controlled within the PWM inverter
- If the inverter is not PWM controlled, then the voltage is controlled by using a controlled rectifier & frequency is controlled by the inverter

Advantages & drawbacks of True synchronous mode operation

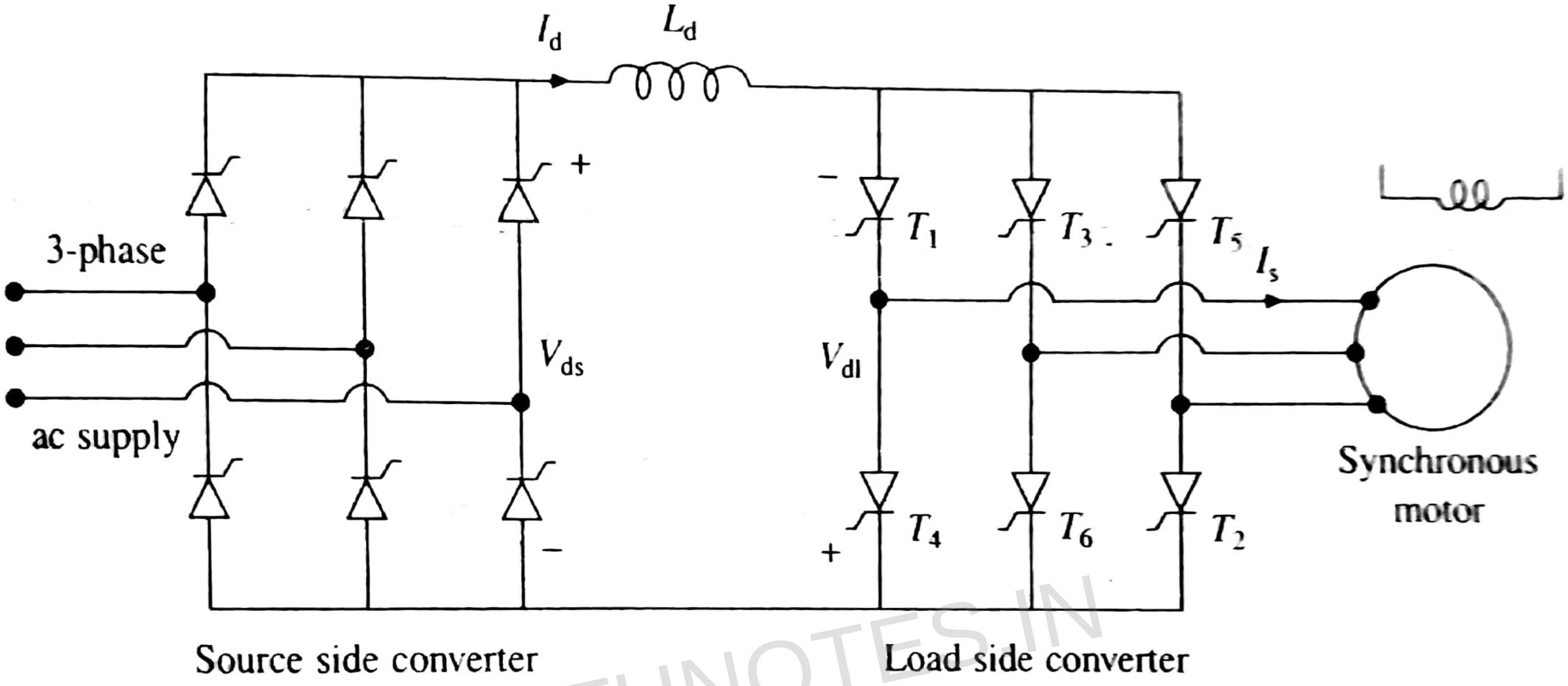
- Multi motor drive is possible
- Involve hunting & stability problems
- Can be implemented by using VSI & CSI
- Power factor can be controlled in a wound field synchronous motor by controlling the field excitation

Advantages & drawbacks of Self controlled mode operation

- Eliminates hunting & stability problems
- Good dynamic response
- Can be implemented by using VSI & CSI
- Load commutation of inverter is possible & no need of forced commutation
- Power factor can be controlled in a wound field synchronous motor by controlling the field excitation

Self controlled synchronous motor drive employing a load commutated thyristor inverter

- A CSI fed synchronous motor drive may employ a load commutated thyristor inverter
- When a synchronous motor is fed from a CSI, it can be operated in self controlled mode or true synchronous mode
- When fed from CSI, synchronous motor is operated at leading power factor so that the inverter will work as a load commutated inverter
- A load commutated inverter fed synchronous motor under self controlled mode is shown in figure
- The source side converter is a 6 pulse line commutated thyristor converter
- For a firing angle range $0<\alpha_s<90$, it works as a line commutated fully controlled rectifier delivering positive V_d & I_d
- For a firing angle range $90<\alpha_s<180$, it works as a line commutated inverter delivering negative V_d & I_d



- When synchronous motor is operated at leading power factor, thyristors of load side converter can be commutated by motor induced voltages in the same way, as thyristors of a line commutated converter are commutated by line voltages
- Commutation of thyristors by induced voltages of load is known as load commutation
- The load side converter will work as an inverter for $90<\alpha_L<180$
- For $0<\alpha_L<90$, it work as a rectifier

Motoring operation – for $0<\alpha_S<90$ & $90<\alpha_L<180$, source side converter works as rectifier & load side converter as inverter causing power to flow from AC source to motor

Generating operation - for $90<\alpha_S<180$ & $0<\alpha_L<90$, load side converter work as rectifier & source side converter as inverter causing power to flow from motor to AC source

- The DC link inductor L_d reduces ripples in the DC link current
- Due to L_d, load side converter works as a CSI
- For operating in self controlled mode, rotating magnetic field speed should be same as rotor speed
- This condition is achieved by making the frequency of load side converter output voltage equal to frequency of voltage induced in the armature
- Normally hall sensors are used to obtain rotor position information
- The difference between CSI fed induction motor drive & synchronous motor drive is that induction motor drive uses forced commutation & synchronous motor drive uses load commutation