4. Control of Electrical Drives

1. Modes of operation

An electrical drive operates in three modes.

a) Steady State

b) Acceleration including starting

c) Deceleration including stopping.

- **As stated earlier, steady state operation takes place when the motor torque equals the load torque. i.e.**

$$T = T_l + J\frac{d\omega_m}{dt} \qquad \text{-----------------} \qquad 4.1$$

- The steady state operation for a given speed is realized by the adjustment of steady state motor speed torque curve such that the motor and load torques are equal at this speed.

- Change in speed is achieved by varying the steady state motor speed-torque curve so that motor torque equals the load torque at the new desired speed.

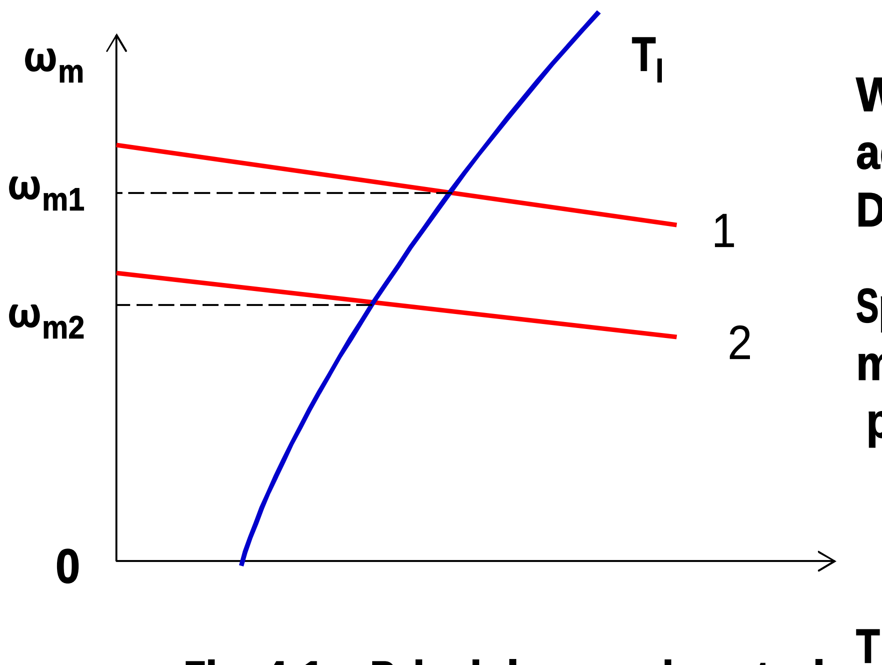


Fig. 4.1. Principle speed control

When the motor parameters are adjusted to provide speed torque curve 1, Drive runs at the desired speed ω_{m1}.

Speed is changed to ωm2 when the motor parameters are Adjusted to provide speed- torque curve 2.

- Acceleration and deceleration modes are transient operations.
- Drive operates in acceleration mode whenever an increase in its speed is required. For this motor speed-torque curve must be changed so that motor torque exceeds the load torque.
- Increase in motor torque is accompanied by an increase in motor current. Care must be taken to restrict the motor current within a value which is safe for both motor and power modulator.
- In applications involving acceleration periods of long duration, current must not be allowed to exceed the rated value.

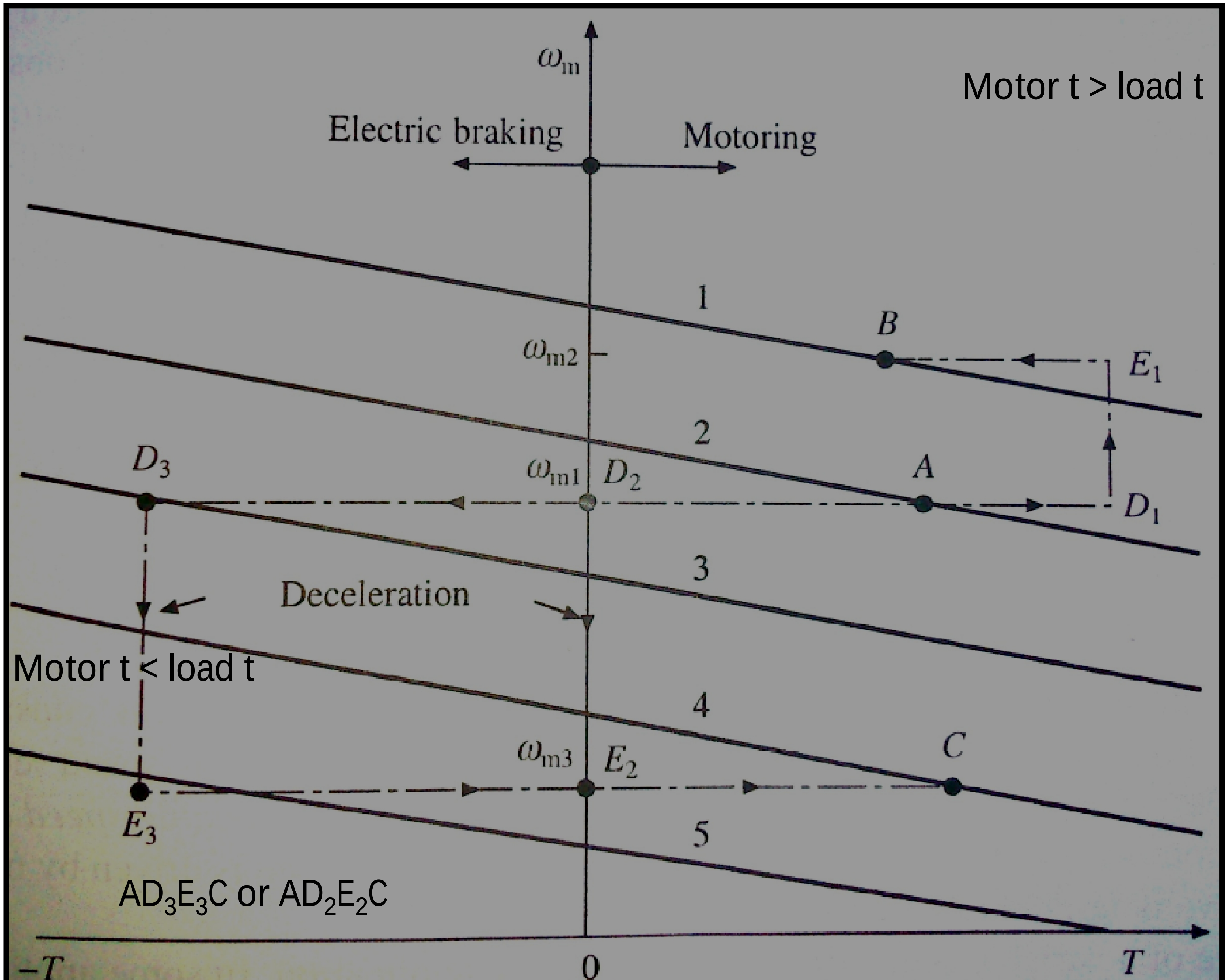
- Motor operation in deceleration mode is required when a decrease in its speed is required. Deceleration occurs when load torque exceeds the motor torque.

- In those applications where load torque is always present with substantial magnitude, enough deceleration can be achieved by simply reducing the motor torque to zero.

- In those applications where load torque may not always have substantial amount or where simply reducing the motor torque to zero does not provide enough deceleration, mechanical or electrical brakes may be employed to produce the required magnitude of deceleration.

- **During electric braking, motor current tends to exceed the safe limit. Appropriate changes are made to ensure that the current is restricted within safe limits.**

- **Usually, the electric braking is employed in applications requiring frequent, quick, accurate or rapid emergency stops.**
  eg. Suburban electric trains, etc



Speed transition paths (1 to 5 are motor speed torque curves)

- Let us consider the figure shown below to understand the acceleration and deceleration modes. The characteristics 1 – 5 are motor speed – torque curves for various parameters.
- The motor is operating at point A in steady state. Now transition from A to B is required. **This can be obtained by increasing the motor torque greater than load torque.** The motor will accelerate as the motor torque is greater than load torque. If the motor torque is held constant during acceleration the transient path consists of AD_1E_1B.
- During acceleration, care should be taken so that the current is in safe limit. The current value should not only be in safe value for motor, it also should be safe for power modulator and also dip in source voltage also to be considered which causes the disturbance in neighboring circuits.
- There are several methods available to limit the current. In some applications where smooth transition and smooth starting is required, the torque is increased steplessly. Such start is called soft start.

- When transition from operating point A to C required, the transition path is along either AD_3E_3C or AD_2E_2C. the deceleration is possible, **when motor torque is less than load torque**. This can be obtained by simply making motor torque is zero. In this case the transition path is AD_2E_2C.
- If fast transition is required, the motor torque can be made negative. In this case the transition path is AD_3E_3C. Sometimes mechanical braking can be applied to decelerate the drive but there many drawbacks with mechanical braking.

2. SPEED CONTROL AND DRIVE CLASSIFICATIONS

Constant speed or single speed drives: - ***are drives where the driving motor runs at a nearly fixed speed.***

Variable speed drives: - are drives needing step less change in speed and multispeed drives.

Multi-motor drive: - is when a number of motors are fed from a common converter, or when a load is driven by more than one motor.

- **Speed range a variable speed drive depends on the application. In some applications, it can be from rated speed to 10% of rated speed. In some other applications, speed control above rated speed is also desired and the ratio of maximum to minimum speed can be as high as 200. there are also applications where the range is as low as from rated speed to 80% of rated speed.**

- A variable speed drive is called **constant torque drive** if the drive's maximum torque capability does not change with change in speed setting. The corresponding mode (or region) of operation is called **constant torque mode.**
- The **constant power drive** and **constant power mode** (or region) are defined in the same way.
- Ideally, it is desired that for a given speed setting, the motor speed should remain constant as load torque is changed from no load to full load.
- In practice, *speed drops with an increase in the load torque*. Quality of speed control system is measured in terms of speed regulation

$$speed\ regulation = \frac{No\ load\ speed - Full\ load\ speed}{Full\ load\ speed} \times 100\%$$

4. Closed Loop control Drives

- **Feedback loops in electrical drive may be provided to satisfy one or more of the following requirements:**

  i) Protection

  ii) Enhancement of speed response

  iii) To improve steady-state accuracy

- **various closed loop configurations which usually find application in electrical drive are the following. The converter and associated control circuit is represented by a single box marked converter.**

4.1. Current limit control: - This scheme is employed to limit the converter and motor current below a safe limit during transient operations. It has a current feedback loop with a threshold logic circuit. ***As long as the current is within a set maximum value, feedback does not affect operation of the drive*****.**

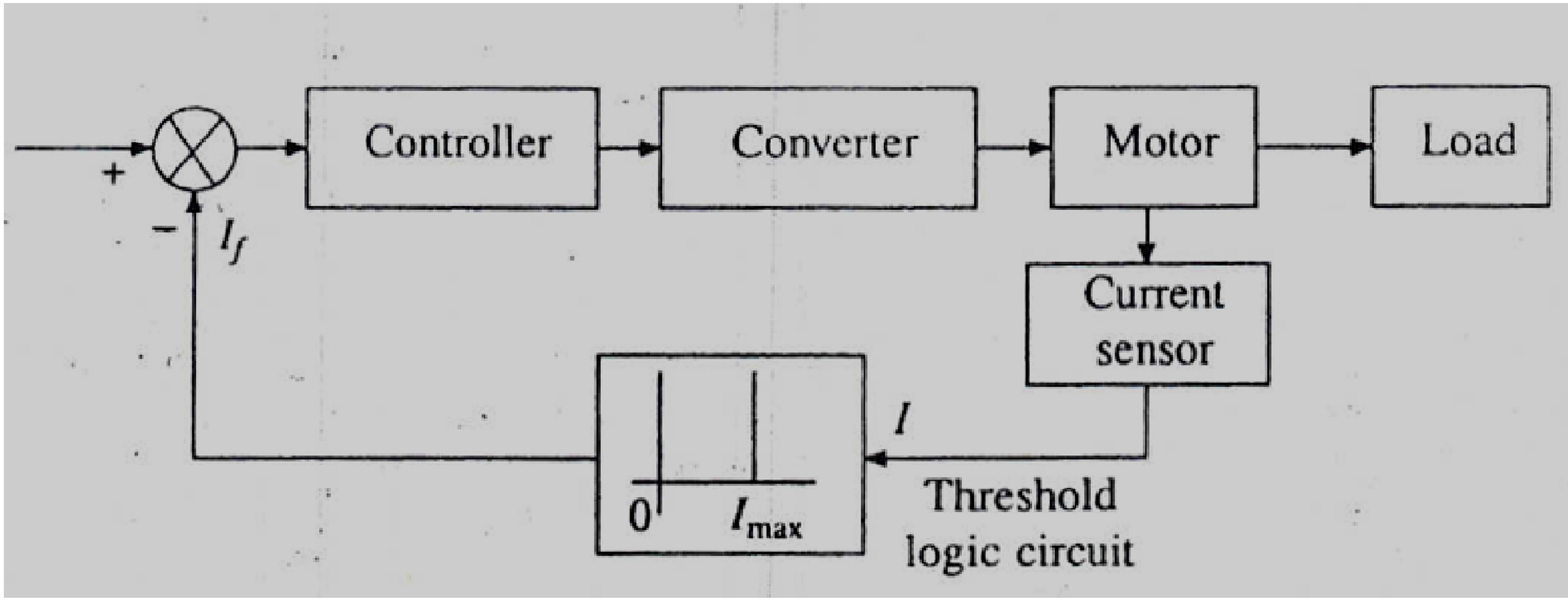


Fig. 4.2. Current limit control

- ***As long as the current is within a set maximum value, feedback does not affect operation of the drive.***
- **If current exceeds the set maximum value, feedback loop becomes active and current is forced below the set maximum value, which causes the feedback loop to become inactive again.**

- **If current exceeds the set maximum value, feedback loop becomes active and current is forced below the set maximum value, which causes the feedback loop to become inactive again.**

- **The current fluctuates around a set maximum limit during the transient operation until the drive condition is such that the current does not have a tendency to cross the maximum value.**

Eg. As is known, during starting of a motor, current will fluctuate around the set maximum value. When close to steady state operation point, current will not have tendency to cross the maximum value, consequently, feedback loop has no effect on the drive operation.

4.2. Closed loop Torque control: - **The closed loop torque control scheme finds application in battery operated vehicles, rail cars and electric trains.**

- **Driver presses the accelerator to set torque reference T*. Through closed loop control of torque, the actual motor torque T follows torque reference T*.**
- **Speed feedback loop is present through the driver. By putting appropriate pressure on the accelerator, driver adjusts the speed depending on traffic, road condition, car condition and speed limit.**

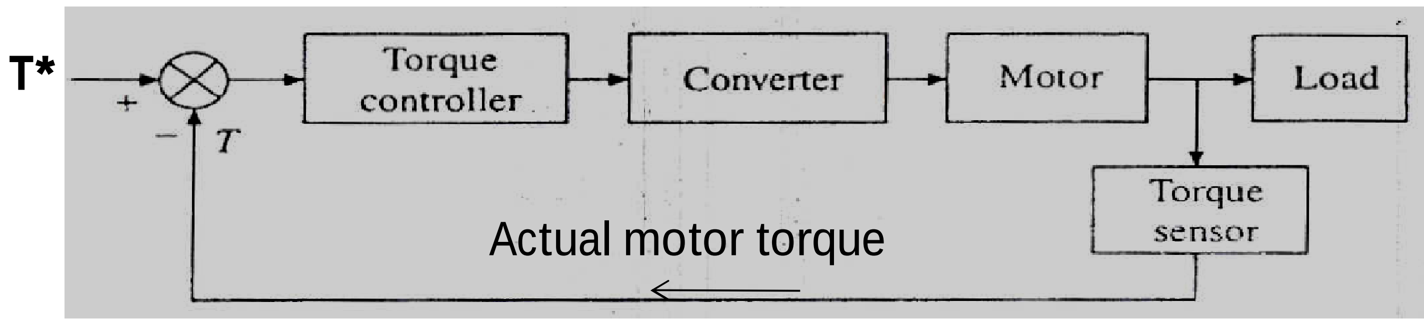


Fig. 4.3. closed loop torque control

4.3. Closed loop speed control: - **Closed loop speed control scheme is widely used electrical drives. It employs an inner current control loop within an outer speed loop. Inner current control loop is provided to limit the converter and motor current or motor torque below a safe limit.**

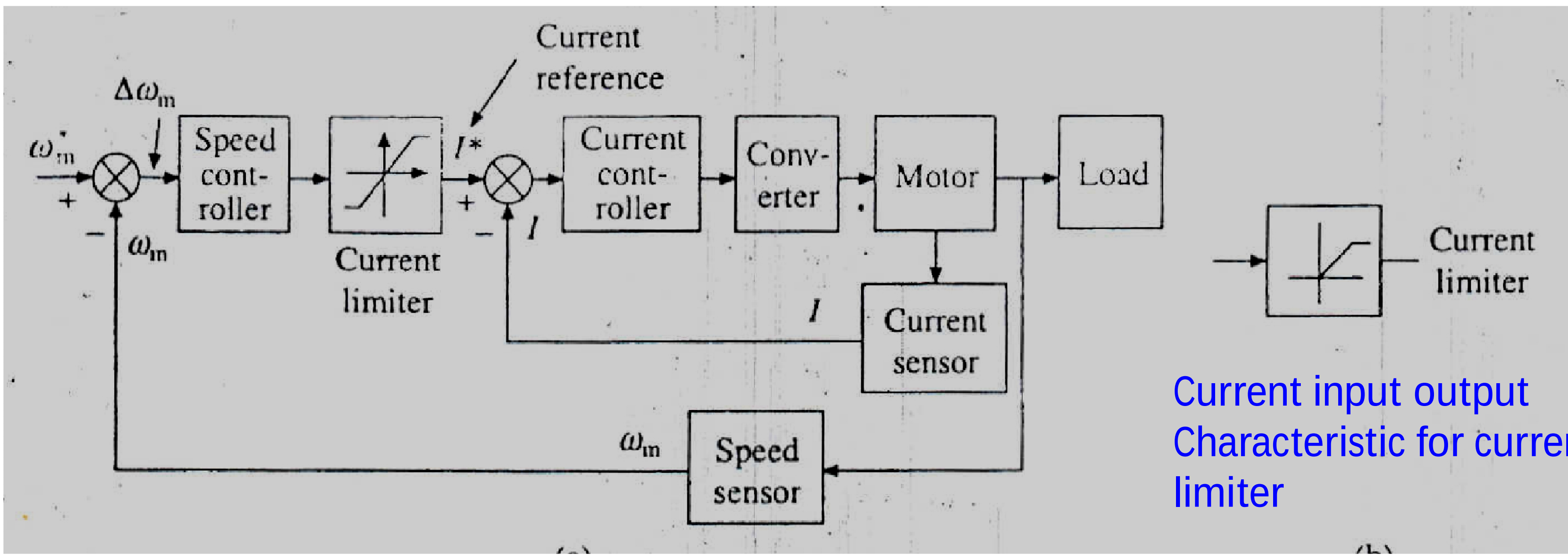


Fig. 4.4. Closed loop speed control

- **Inner current loop is also beneficial in reducing the effect of drive performance of any non linearity present in convertor-motor system.**

Fig 4.4. operates as follows;

- An increase in reference speed ω^*_m produces a positive error $\Delta\omega_m$.

-Speed error is processed through a speed controller and applied to a current limiter which saturates even for a small speed error. Consequently, limiter sets current reference for inner current control loop at a value corresponding to the maximum allowable current. Drive accelerates at the maximum allowable current. When close to the desired speed, limiter desaturates. Steady state is reached at the desired speed (with some steady-state error) and at current for which motor torque is equal to load torque.

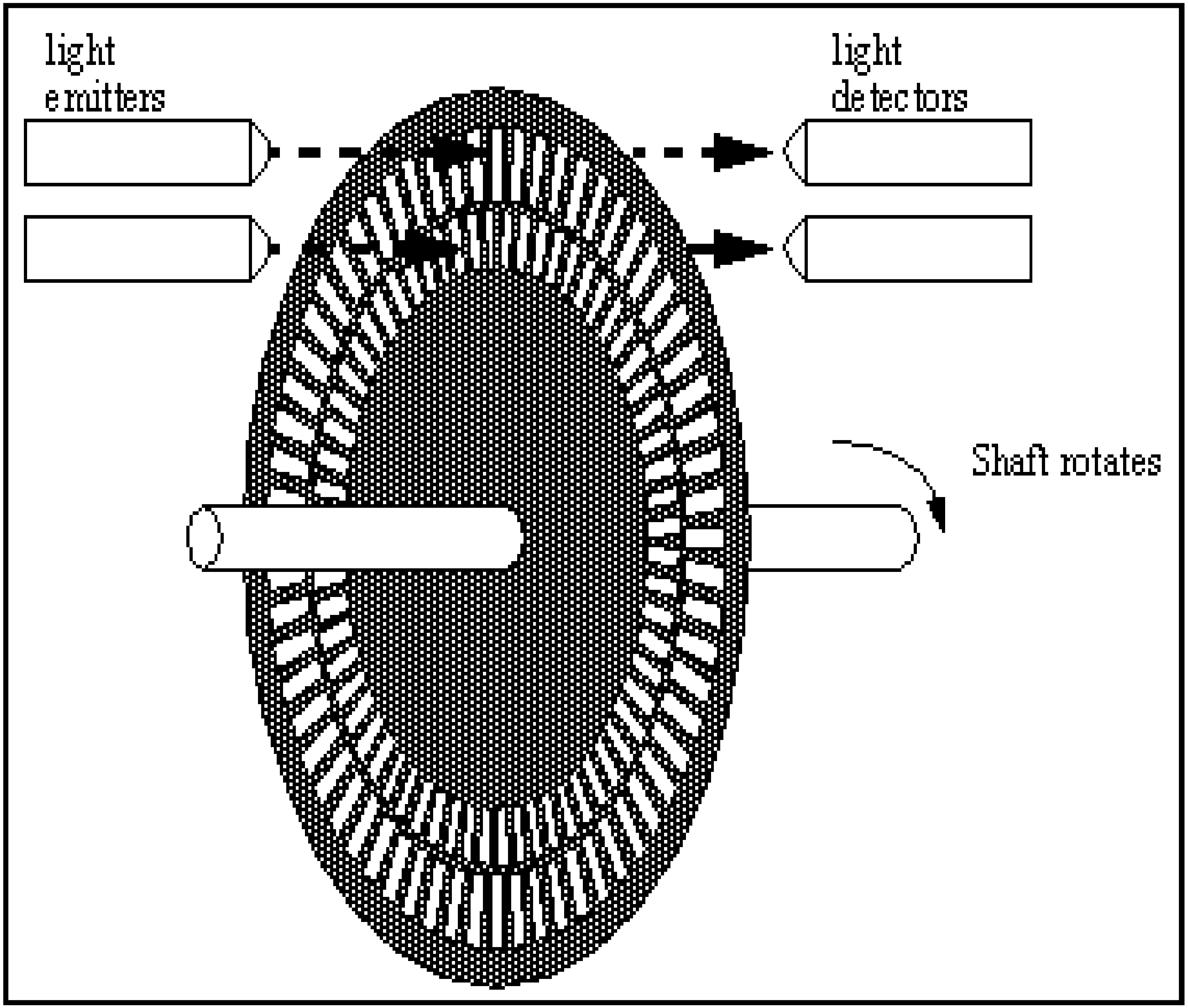
• **A decrease in reference speed ω^*_m produces a negative speed error. Current limiter saturates and sets current reference for inner current loop at a value corresponding to the maximum allowable current. Consequently, drive decelerates in braking mode at the maximum allowable current.**

•**When close to the required speed, current limiter desaturates. The operation is transferred from braking to motoring. Drive then settles at a desired speed at current for which motor torque equals the load torque.**

• ***Current and speed controllers may consist of proportional and integral (PI), proportional and derivative(PD), or proportional, integral and derivative(PID) controller, depending on steady-state accuracy and transient response requirements*****.**

Speed Sensing:

- In closed loop control of drives, speed sensing is required. **A tachometer is used to measure the speed usually, which is an Ac or DC generator with higher order linearity between speed and generated voltage.** Typical generated voltages are 1 V per 100 RPM. To obtain linearity between speed and generated voltage, a DC tachometer is built with permanent magnets and sometimes with silver brushes to reduce the contact drop. **The generated voltage is filtered to have the smooth output voltage from the generator, it is required particularly for low speed applications.** Tachometers are available with an accuracy of . **Tachometers are coupled to the same shaft of the motor drive.** It should be connected such that natural frequency of the drive system or vibrations should not affect the accuracy. **When very high speed accuracies are required, shaft encoders are used with interfacing to the computer or micro controllers.**
- **Shaft encoder is made with either a transparent plastic or thin aluminum disc mechanically coupled to the shaft.**
- **In case of transparent plastic disc, it is painted with alternate transparent and non-transparent portions around its periphery.**
- **In case of aluminum disc, number of holes or slots uniformly made around its periphery. Now speed or position of the rotor is measured using an opto-coupler unit which consists of light source and light sensor.**
- **This unit is placed such that the encoder is made allowed to run between light and light sensor.**
- **When drive is rotating, the unit will generate a pulse whenever light falls on the light**


light
emitters
light
detectors
Shaft rotates

- In case of DC motor drives, speed can be sensed without tachometer when field current is held constant. Back EMF is given by

$$E = \frac{PZ}{2\pi A} \emptyset W_m$$

$$E = K_e \emptyset W_m.$$

- From the above equation, it clear **that back EMF is proportional to the speed if flux is constant**. The back EMF can be measured if armature current is measured from the equation In this case the accuracy affected by, difficulty in measuring the armature current, variation of flux due to fluctuations in the field voltage and armature resistance variation with temperature.

4.4. Speed sensing

- Sensing of speed is required for implementation of closed loop control schemes. Speed is usually sensed using tachometers coupled to the motor shaft.
- A tachometer may be ac or dc generator with a high order of linearity between its speed and output voltage. They are available to measure speed with an accuracy of ±0.1%.
- When very high speed accuracies are required, as in computer peripherals, digital tachometers are used.
- A digital tachometer employs a shaft encoder which gives a frequency proportional to the motor speed. Encoder consists of a transparent plastic or aluminium disc mechanically coupled to the motor shaft.

- Transparent plastic is alternatively painted black on its periphery to provide alternatively transparent and nontransparent parts.

- An opto-coupler unit consisting of a light source and a light sensor is so mounted that the disc will run in between light source and the sensor. Sensor senses the light source whenever a transparent part crosses opto-coupler and a voltage pulse is produced. Frequency of the pulse train is proportional to the speed of the shaft. Pulses are counted over a specific period to obtain a number proportional to speed.

4.5. Current sensing

- Current sensing is required for the implementation of current limit control, inner current control loop of closed-loop speed control, closed-loop torque control of a dc drive, for sensing fault conditions, etc.

- **Current in three phase ac circuits can be sensed using the following circuit.**

1. **The function of a current transformer is to step down a high magnitude alternating current to a low value.**

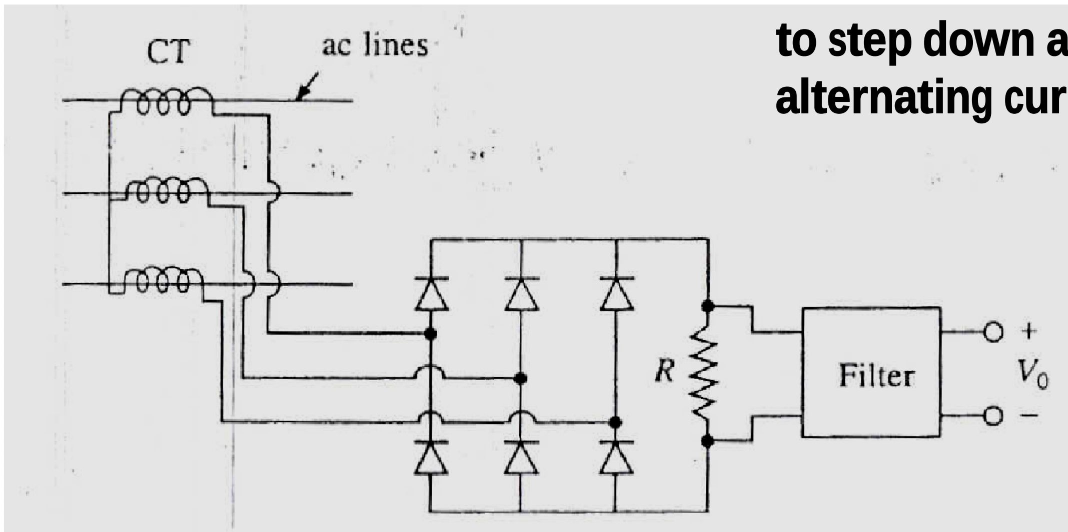
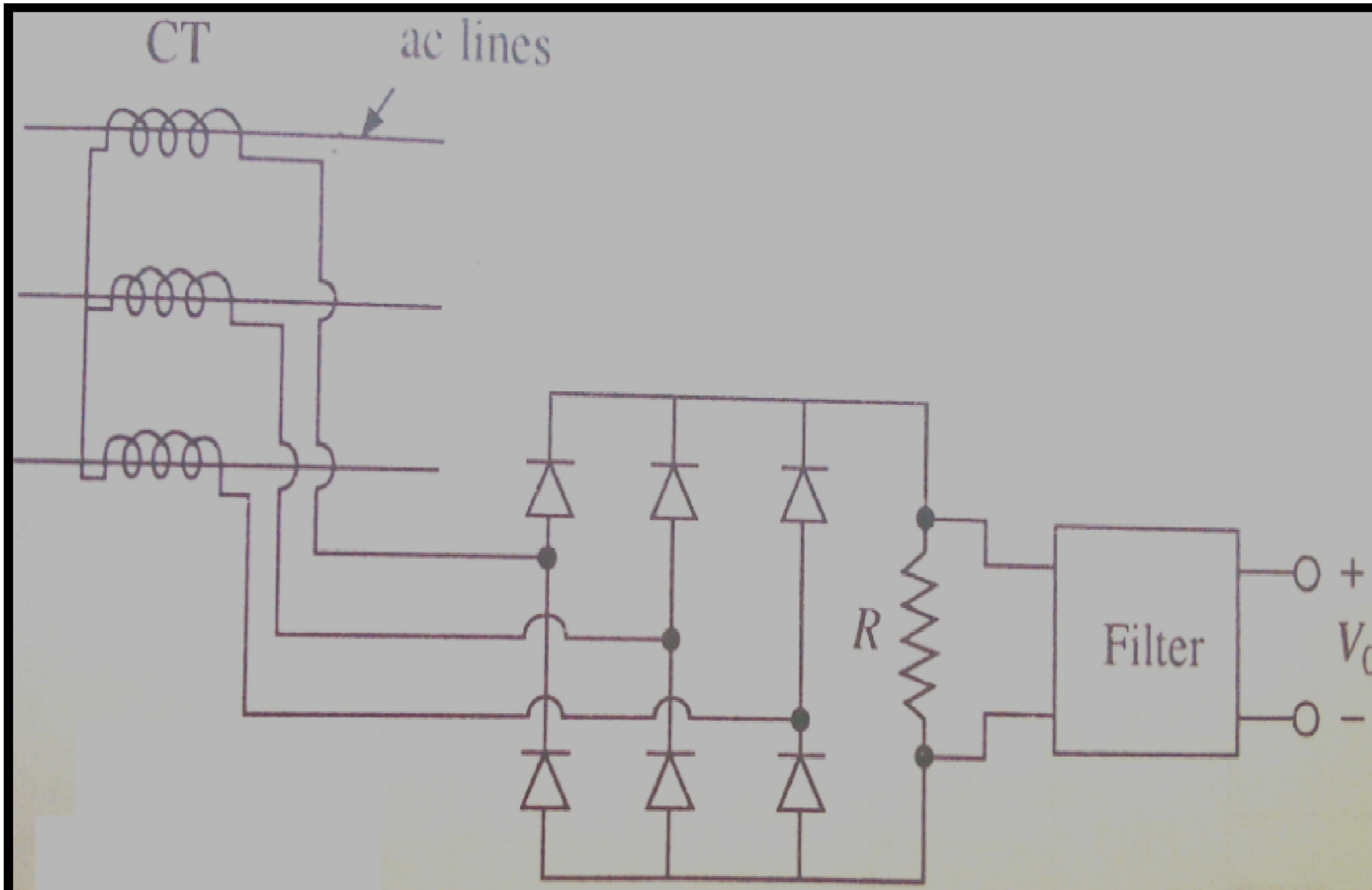
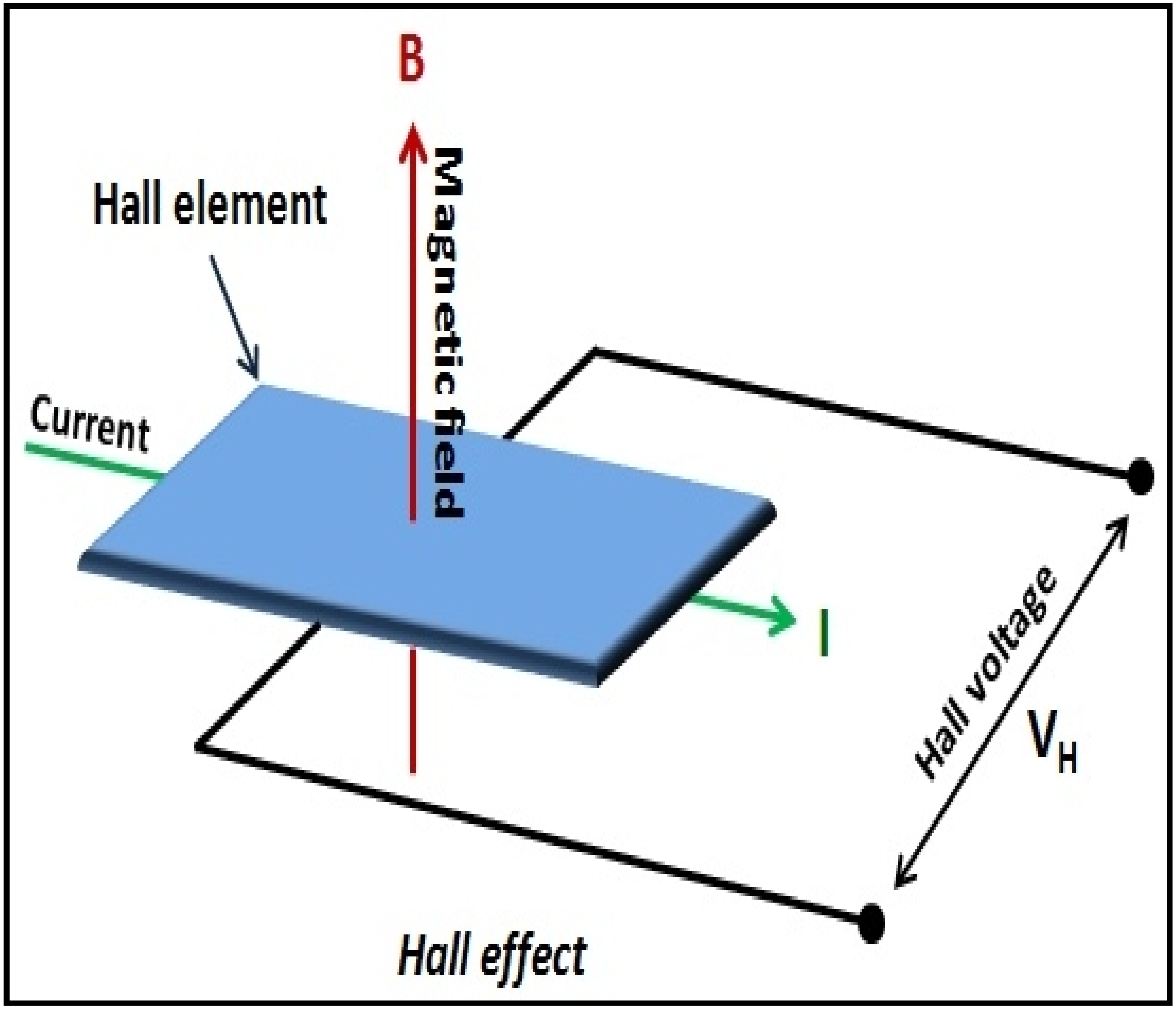


Fig. 4.5. current sensing in three phase AC lines.

- **As can be seen from the figure, the current transformer output is rectified, applied across the resistor R and filtered. Voltage drop V_0 is proportional to the current in AC lines. Major limitation of this type is it can not sense phase currents.**



Sensing of current in three-phase ac lines


B
Magnetic field
Hall element
Current
I
Hall voltage
V_H
Hall effect

- The two common methods of measuring the DC current are:
- i) **This involves the use of a current sensor employing Hall-effect.**
- It works on the principle that when a hall element is subjected with a flux in one direction and current in other direction, a voltage will be induced in the third direction.
- The output voltage is proportional to the strength of magnetic field and magnitude of current.
- It involves the use of a non-inductive resistance shunt in conjunction with isolation amplifier which has an arrangement for amplification and isolation between power and control circuit.

Microprocessor based control of electric drives

- The speed of a 3-phase induction motor can be controlled by stator voltage control, rotor voltage control and stator voltage and frequency control.
- The stator voltage control and rotor voltage control methods give only a limited range of speed control.
- However, the stator voltage and frequency control methods give only a limited range of speed control. The stator is fed by a variable frequency supply. Since the synchronous speed is directly proportional to frequency, the speed can be controlled as per requirement.
- As the frequency is changed, it is necessary to vary the stator voltage also to keep the V/F ratio constant. This ensures that the motor is operated at constant flux.
- This ensures that the motor is operated at constant flux.

- For Block diagram
- The 3-phase ac supply is converted to DC by phase controlled rectifier. If necessary this dc voltage is filtered to remove the harmonics. The inverter converts the dc voltage into variable frequency ac voltage which is fed to the induction motor.
- A tachogenerator senses the speed and produces a voltage proportional to speed.
- A/D converter changes this voltage to digital form and feeds it to MPU.
- A reference speed signal is also fed to MPU.
- The error signal is converted to analog form by D/A converter and fed to logic circuit.

- The logic circuit sends a proper signal to the firing circuit of the inverter. Thus, the output voltage and frequency of the inverter are adjusted as per the speed requirements.
- A current transformer measure the line current.
- A/D converter changes this current to digital form and feeds it to MPU for current monitoring and control.

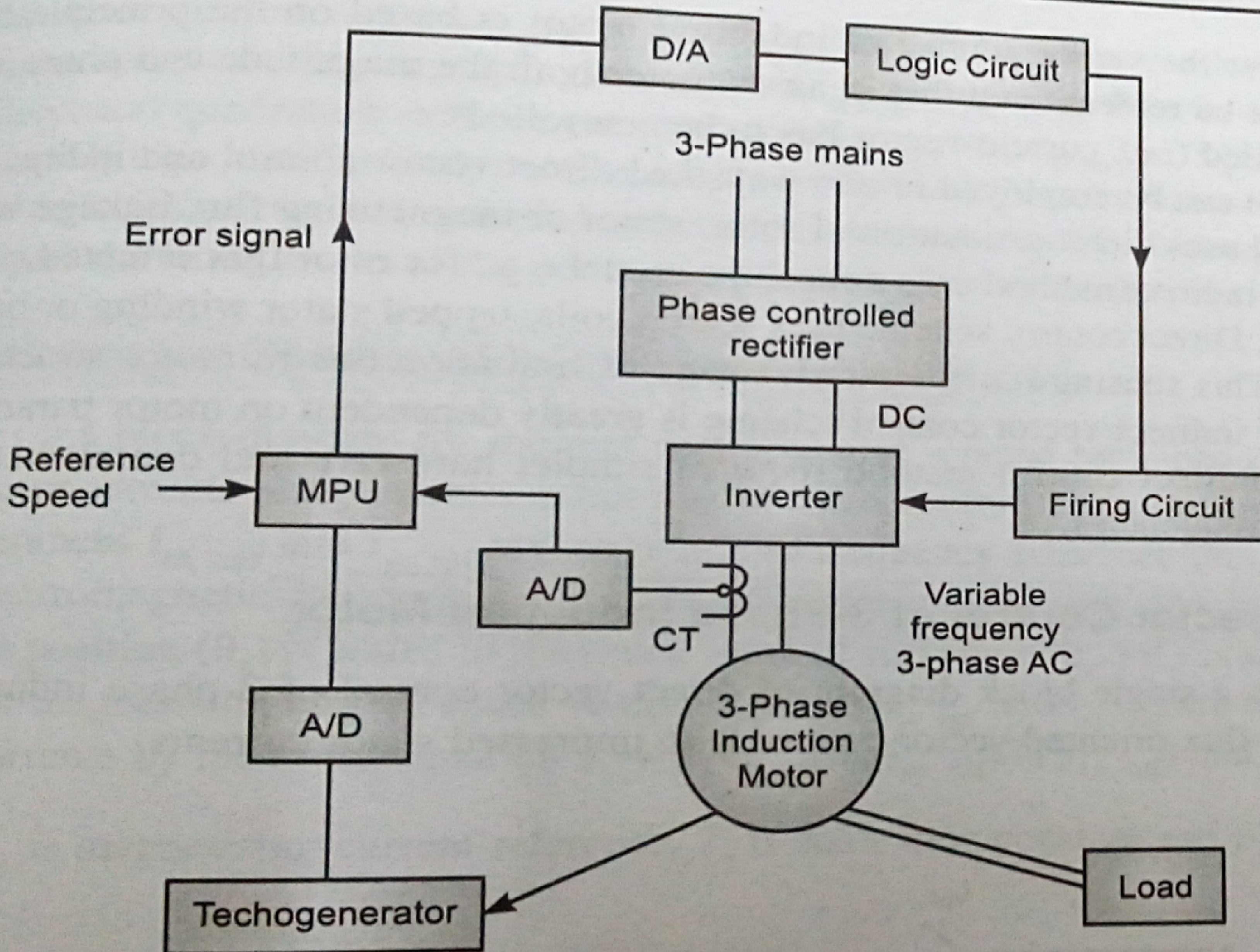


Fig. 6.30 Microprocessor based speed control of 3-phase induction motor.

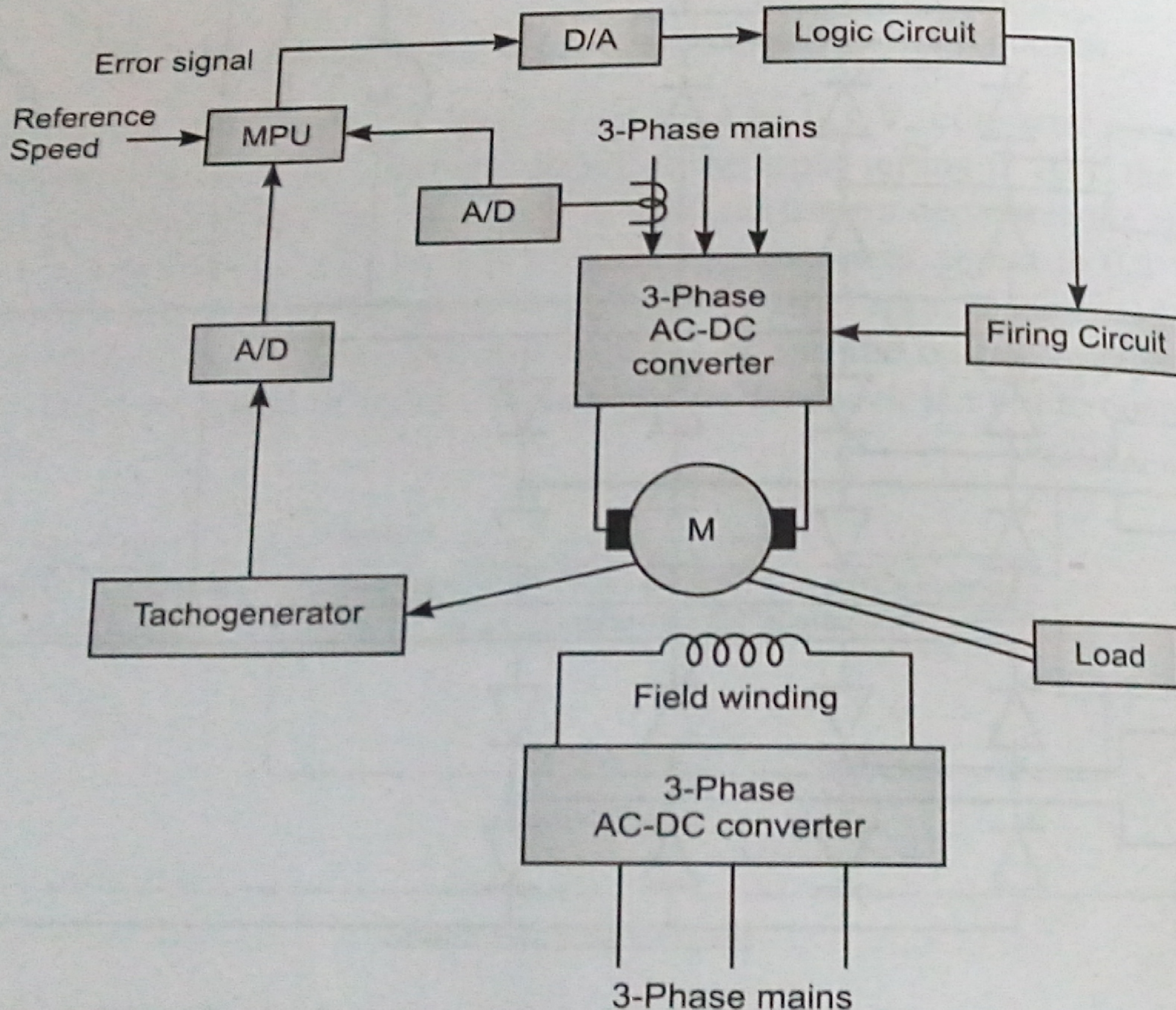


Fig. 5.32 Microprocessor based speed control of separately excited DC motor.

Microprocessor Based drive:

- **Advantages:**
- □ The complexity of the system is reduced
- □ The software supported control using micro-processors performs the function of controllers, feedback, decision making of the drive system
- □ The hardware implementation in thyristerised controller unit four-quadrant operation using dual converter, vector control can be realized with software programs on micro-processor with least possible hardware
- □ Digital control has an inherent improved noise immunity
- □ The control is free from drift and parameter variation due to temperature
- **Limitations:**
- □ Due to communication between the microprocessor and the analog circuitry done by A/D and D/A converter, there are sampling and quantizing error
- □ The response in micro-processor is slow in comparison with dedicated hardware
- □ The development of software may be costly and time consuming