General Engineering

for Post Graduate Diploma Course in Industrial Instrumentation & Process Automation (DIIPA)

(AC/DC MOTORS & DRIVES)

by

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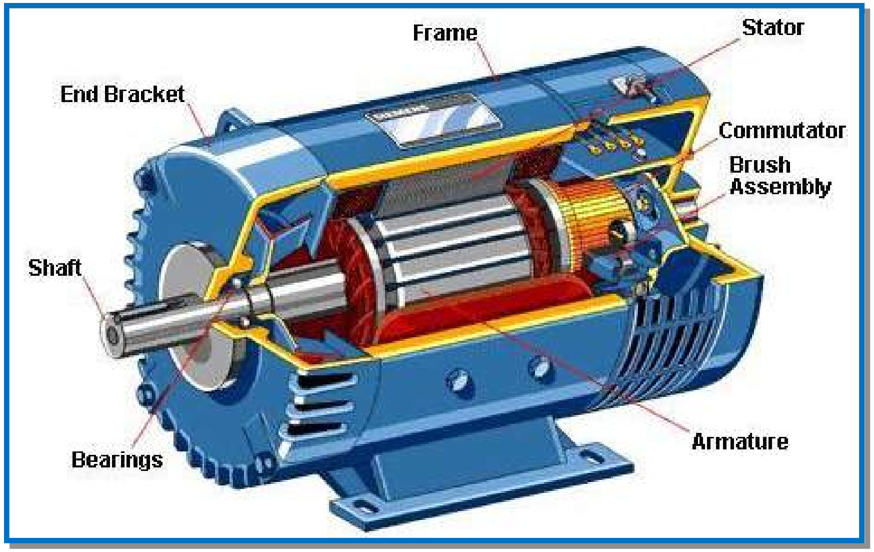
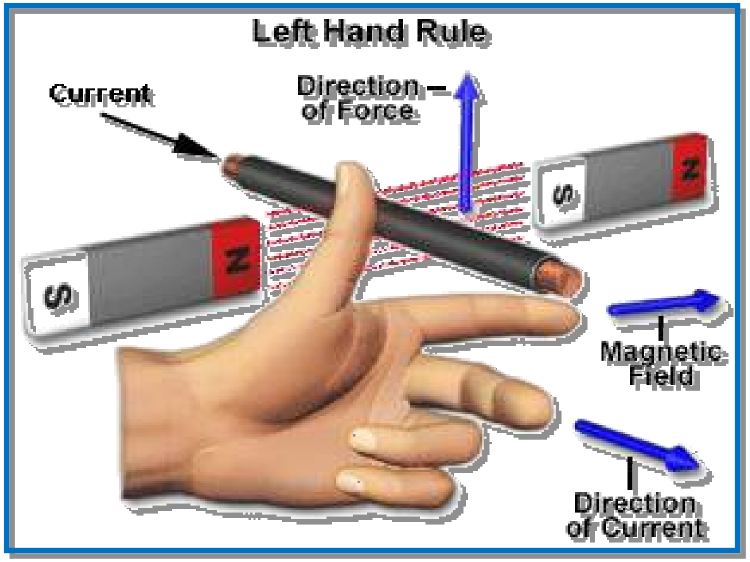
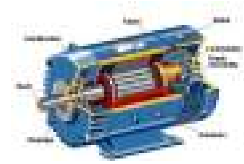
DC Motor
&
Drives

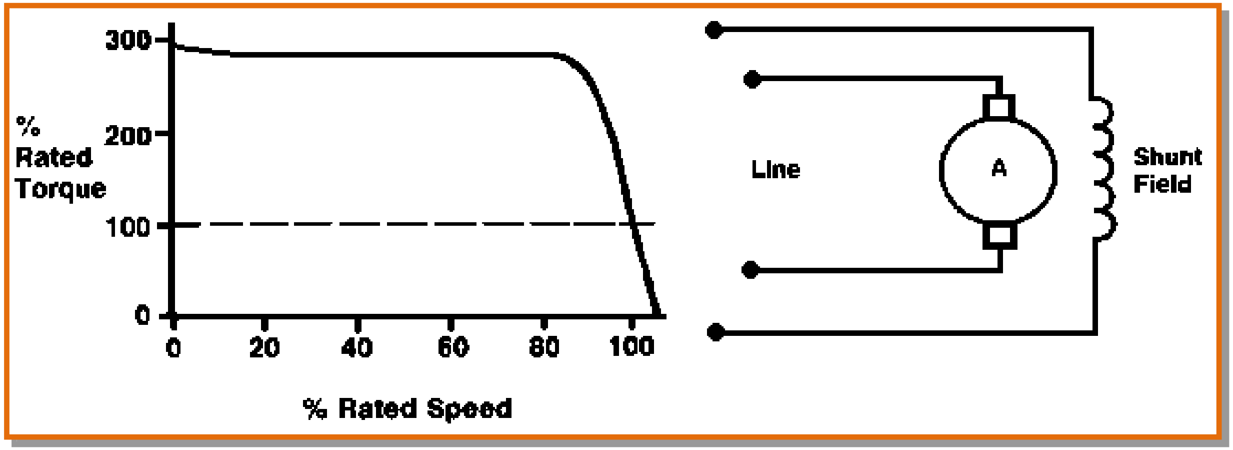




Advantages	Disadvantages
Ease of control	High maintenance
Deliver high starting torque	Large and expensive (compared to induction motor)
Near-linear performance	Not suitable for high-speed operation due to commutator and brushes
	Not suitable in explosive or very clean environment

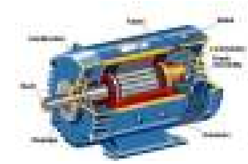
DC Shunt Motor

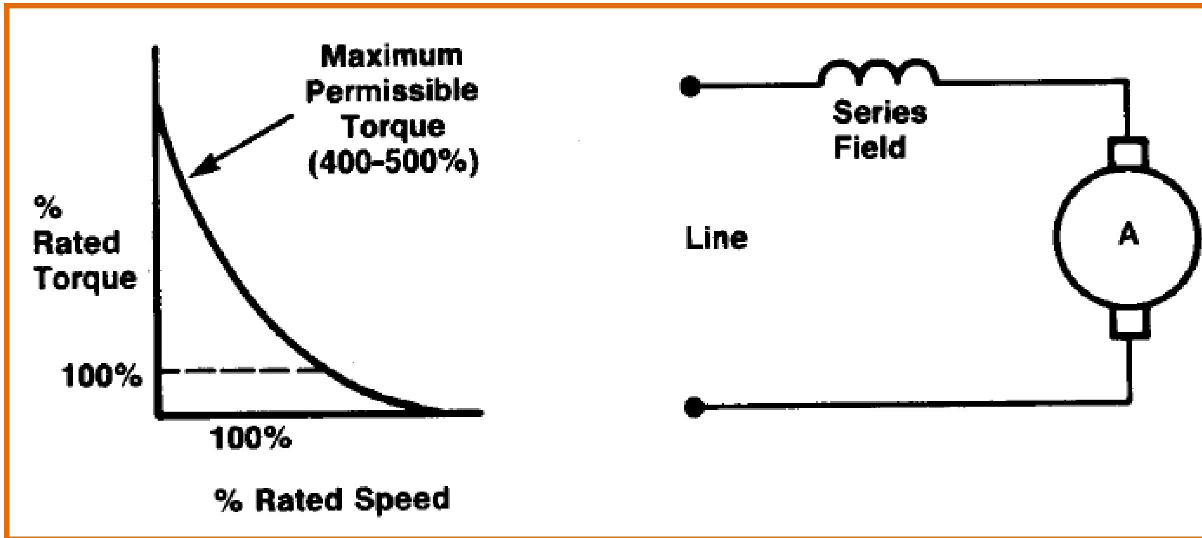




Characteristics	Applications
➢Speed is fairly constant ➢medium starting torque	Blowers and fans
	Centrifugal and reciprocating pumps
	Lathe machines
	Machine tools
	Milling machines

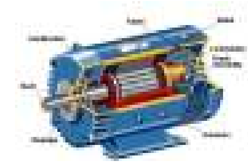
DC Series Motor

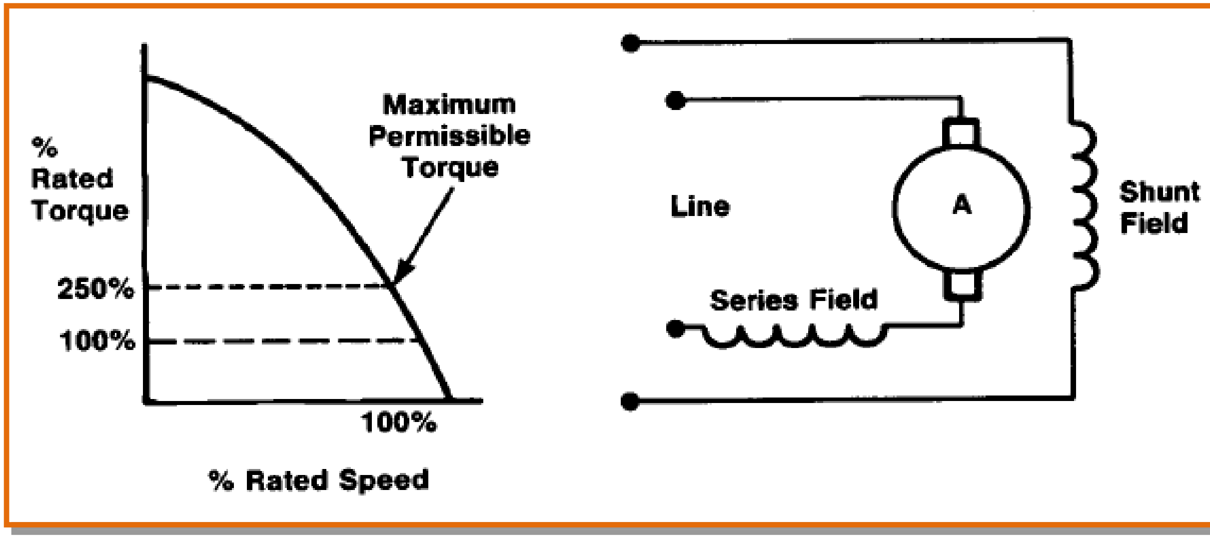




Characteristics	Applications
➢ High starting torque ➢ No load condition is dangerous ➢ Variable speed	Cranes
	Hoist, Elevators
	Trolleys
	Conveyors
	Electric locomotives

DC Compound Motor





Characteristics	Applications
➢High starting torque ➢No load condition is allowed	Rolling mills
	Punches
	Shears
	Heavy Planers
	Elevators

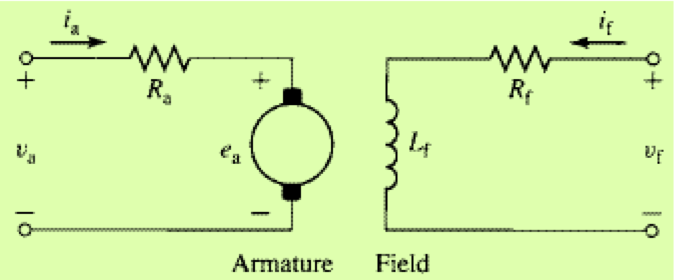
Speed and Torque Equations

$$V_t = E_a + I_a R_a$$

$$E_a = K_a \Phi \, \omega_m$$

$$\omega_m = \frac{V_t - I_a R_a}{K_a \Phi}$$

$$T = K_a \Phi \, I_a$$



$$\omega_m = \frac{V_t}{K_a \Phi} - \frac{R_a}{(K_a \Phi)^2} T$$

Vt is applied voltage

Ea is back emf

Ia is armature current

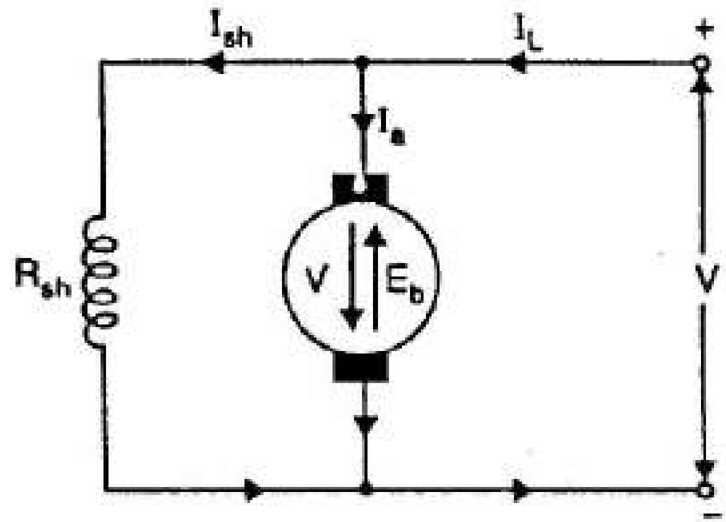
Ra is armature resistance

T is torque developed

Wn is motor speed

Back or Counter E.M.F.

When the armature of a d.c. motor rotates under the influence of the driving torque, the armature conductors move through the magnetic field and hence e.m.f. is induced in them as in a generator The induced e.m.f. acts in opposite direction to the applied voltage and in known as back or counter e.m.f. Eb.



back e.m.f. $E_b = P \varphi ZN/60A$

Significance of Back E.M.F.

The presence of back e.m.f. makes the d.c. motor a self-regulating machine i.e., it makes the motor to draw as much armature current as is just sufficient to develop the torque required by the load.

$$\text{Armature current, } I_a = \frac{V - E_b}{R_a}$$

(i) When the motor is running on no load, small torque is required to overcome the friction and windage losses. Therefore, the armature current Ia is small and the back e.m.f. is nearly equal to the applied voltage.

(ii) If the motor is suddenly loaded, the first effect is to cause the armature to slow down. Therefore, the speed at which the armature conductors move through the field is reduced and hence the back e.m.f. Eb falls. The decreased back e.m.f. allows a larger current to flow through the armature and larger current means increased driving torque. Thus, the driving torque increases as the motor slows down. The motor will stop slowing down when the armature current is just sufficient to produce the
increased torque required by the load.

(iii) If the load on the motor is decreased, the driving torque is momentarily in excess of the requirement so that armature is accelerated. As the armature speed increases, the back e.m.f. Eb also increases and causes the armature current Ia to decrease. The motor will stop accelerating when the armature current is just sufficient to produce the reduced torque required by the load.

It follows, therefore, that back e.m.f. in a d.c. motor regulates the flow of armature current i.e., it automatically changes the armature current to meet the load requirement.

Speed Control of D.C. Motors

The speed of a d.c. motor is given by:

$$N \propto \frac{E_b}{\phi}$$

or $$N = K\frac{(V - I_a R)}{\phi} \text{ r.p.m.}$$

where $R = R_a$ for shunt motor

$= R_a + R_{se}$. for series motor

There are three main methods of controlling the speed of a d.c. motor, namely:

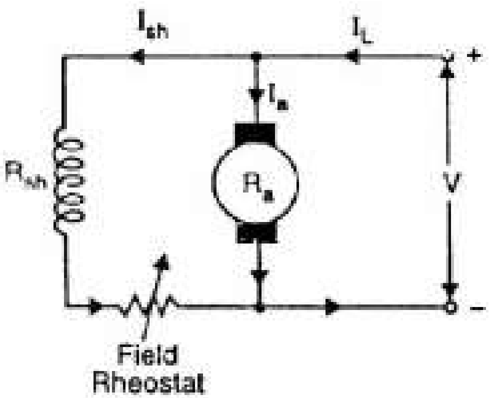
(i) By varying the flux per pole (φ). This is known as flux control method.

(ii) By varying the resistance in the armature circuit. This is known as armature control method.

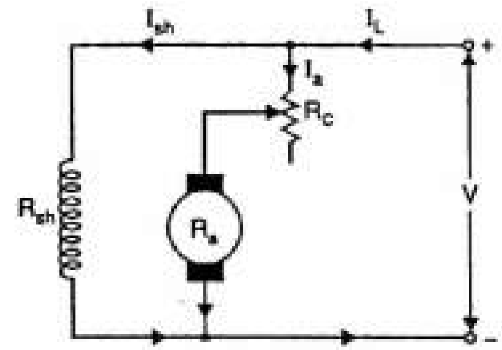
(iii) By varying the applied voltage V. This is known as voltage control method.

Speed Control of D.C. Shunt Motors

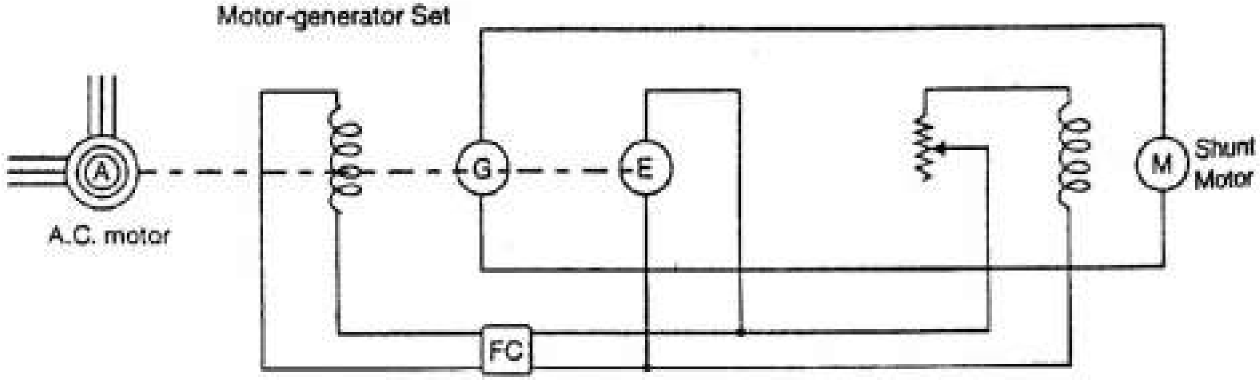
1. Flux control method



2. Armature control method



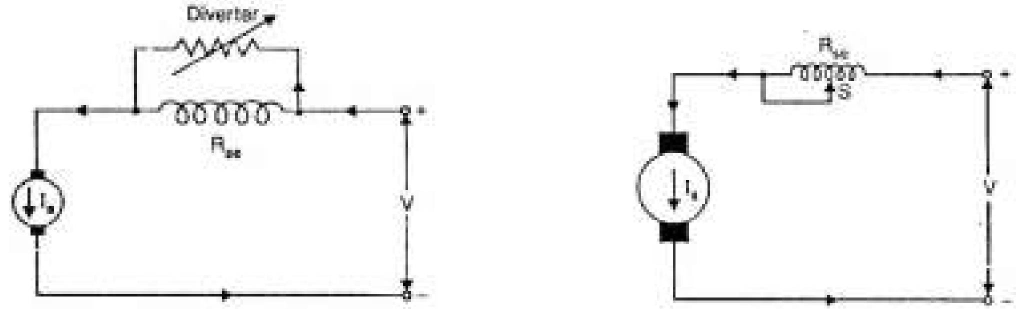
3. Voltage control method



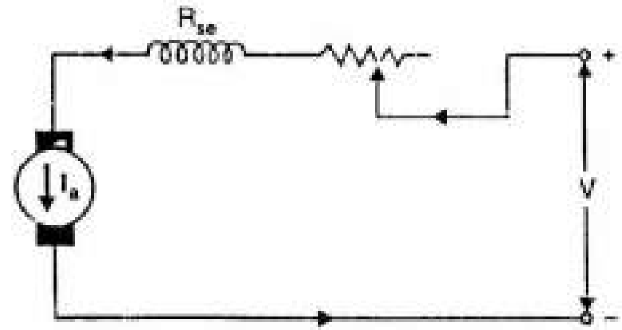
Ward-Leonard speed-control system.

Speed Control of D.C. Series Motors

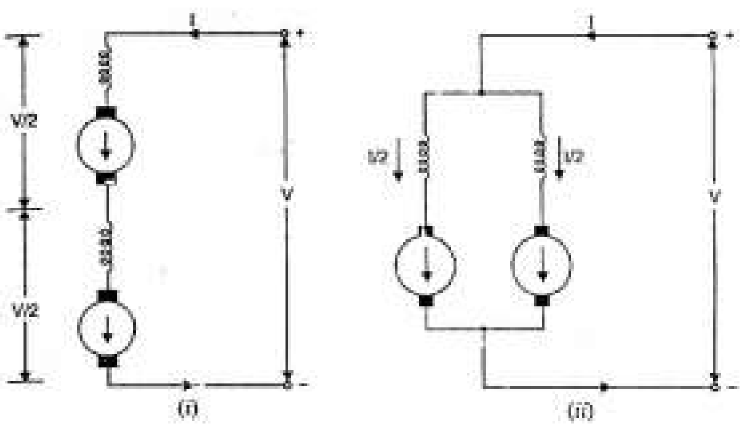
1. Flux control method



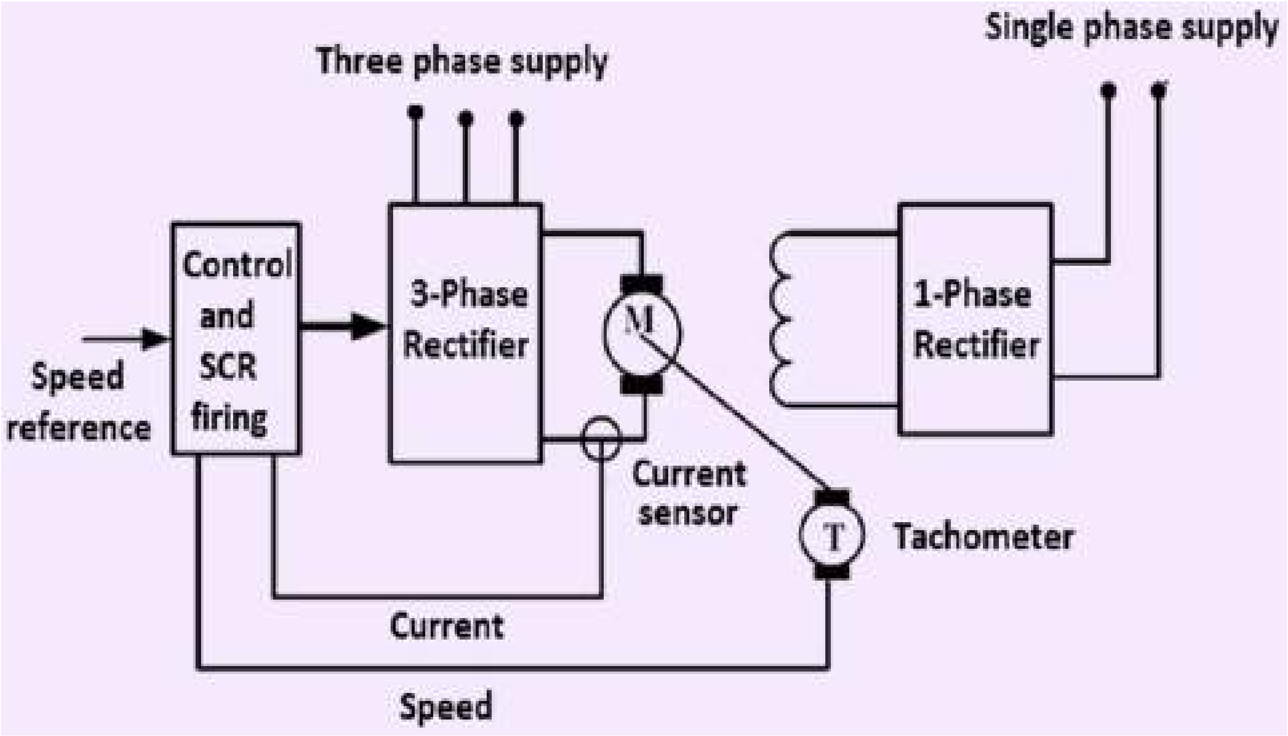
2. Armature-resistance control



3. Series-Parallel Control



Separately Excited DC Motor Drive



Armature Voltage

$$V_a = \frac{3V_{m,L-L}}{\pi}\cos\alpha_a$$

Armature Current

$$I_a = \frac{V_a - V_E}{R_a};\ V_E \text{ is the back emf}$$

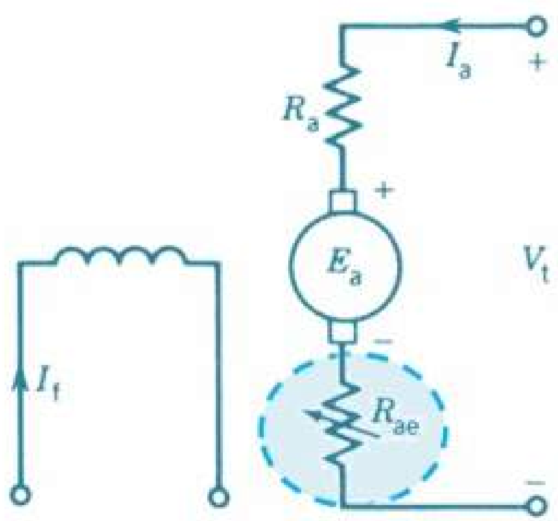
Field Voltage

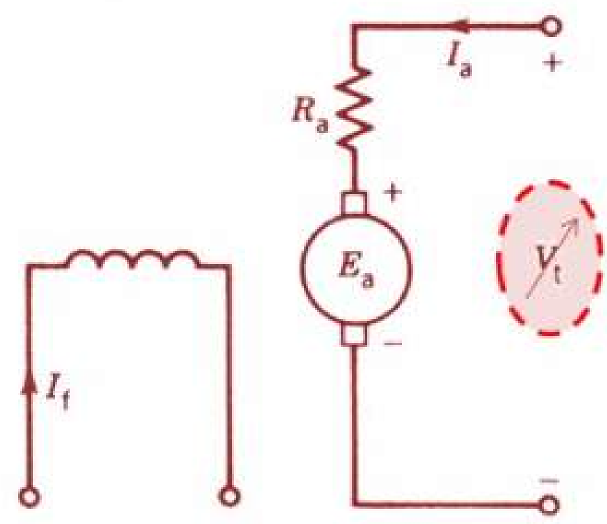
$$V_f = \frac{2V_m}{\pi}\cos\alpha_f$$

Starting of DC Motor

$$I_a = \frac{V_t - E_a}{R_a} \quad \text{at starting} \quad \omega = 0 \rightarrow E_a = 0$$

$$\therefore I_a \Big|_{Starting} = \frac{V_t}{R_a}$$





AC (Induction) Motor
&
Drives

Introduction

- The three-phase induction motors are the most widely used electric motors in industry.

- They run at essentially constant speed from no-load to full-load. However, the speed is frequency dependent and consequently these motors are not easily adapted to speed control.

- We usually prefer d.c. motors when large speed variations are required. Nevertheless, the 3-phase induction motors are simple, rugged, low-priced, easy to maintain and can be manufactured with characteristics to suit most industrial requirements.

Advantages

(i) It has simple and rugged construction.

(ii) It is relatively cheap.

(iii) It requires little maintenance.

(iv) It has high efficiency and reasonably good power factor.

(v) It has self starting torque.

Disadvantages

(i) It is essentially a constant speed motor and its speed cannot be changed easily.

(ii) Its starting torque is inferior to d.c. shunt motor.

Construction

A 3-phase induction motor has two main parts

(i) stator and (ii) rotor

The rotor is separated from the stator by a small air-gap which ranges from 0.4 mm to 4 mm, depending on the power of the motor.

Stator

It consists of a steel frame which encloses a hollow, cylindrical core made up of thin laminations of silicon steel to reduce hysteresis and eddy current losses.

A number of evenly spaced slots are provided on the inner periphery of the laminations.

The 3-phase stator winding is wound for a definite number of poles as per requirement of speed. Greater the number of poles, lesser is the speed of the motor and vice-versa.

Stator laminations

stator core with ribbed yoke

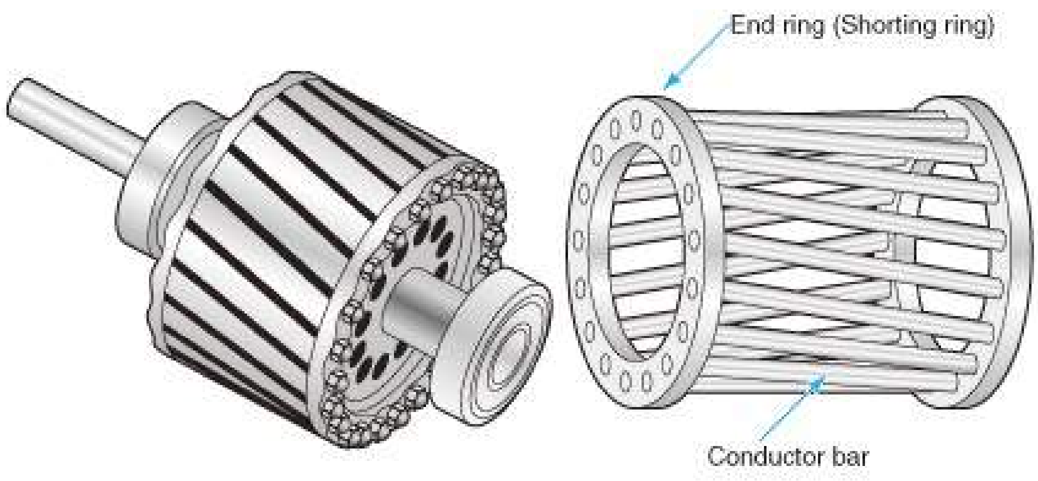
Rotor

The rotor, mounted on a shaft, is a hollow laminated core having slots on its outer periphery. The winding placed in these slots (called rotor winding) may be one of the following two types:

(i) Squirrel cage type *(ii) Wound type*

Squirrel cage rotor

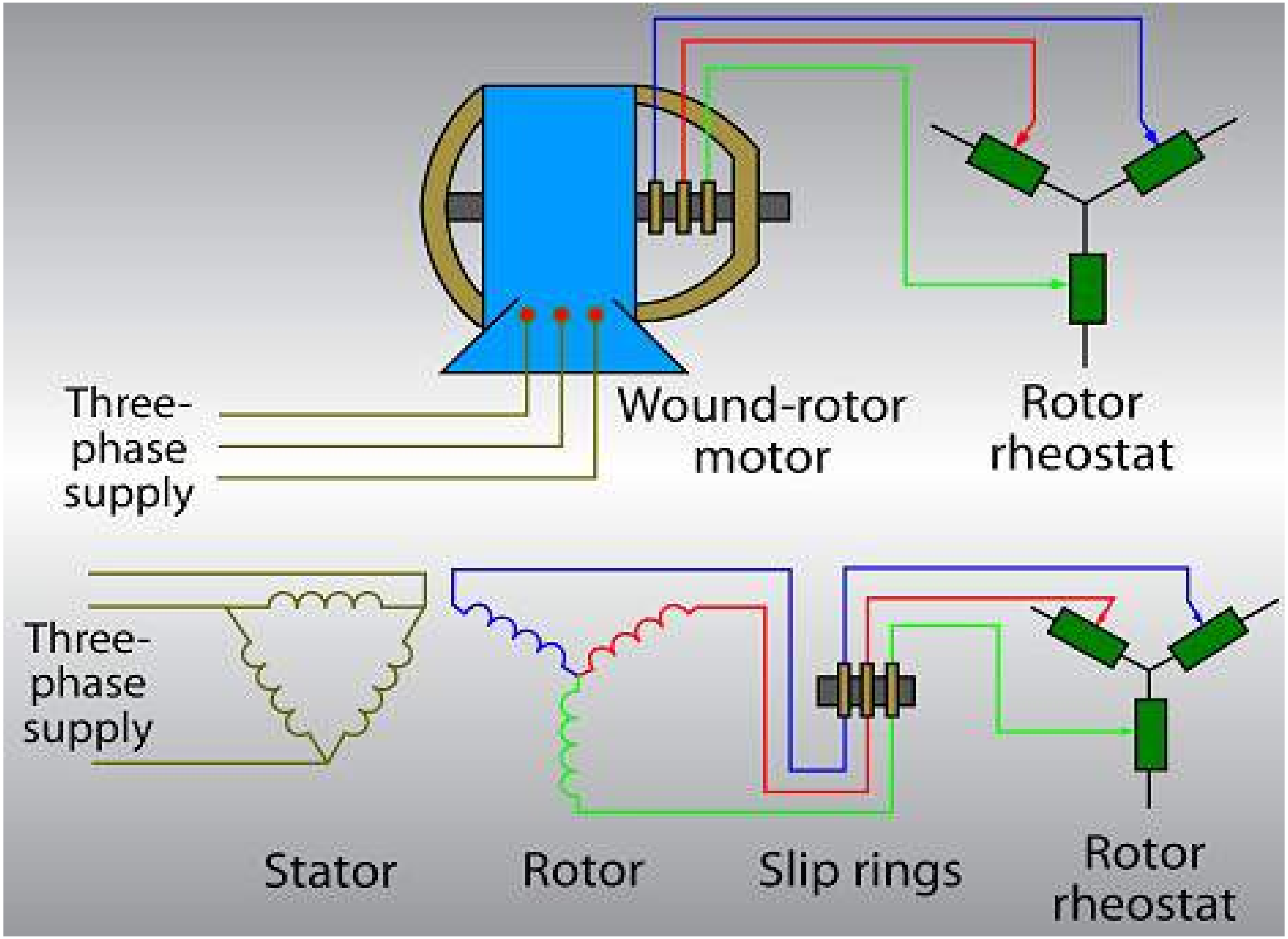
It consists of a laminated cylindrical core having parallel slots on its outer periphery. One copper or aluminum bar is placed in each slot. All these bars are joined at each end by metal rings called end rings. This forms a permanently short-circuited windingwhich is indestructible. The entire construction (bars and end rings) resembles a squirrel cage and hence the name. The rotor is not connected electrically to the supply but has current induced in it by transformer action from the stator.



(a) Rotor (b) Squirrel-cage conductor

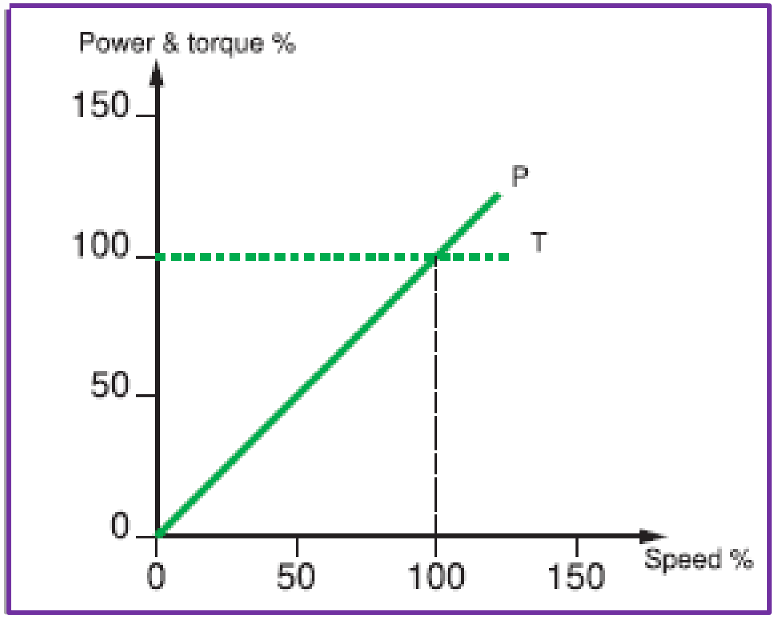
Wound rotor

It consists of a laminated cylindrical core and carries a 3- phase winding, similar to the one on the stator. The rotor winding is uniformly distributed in the slots and is usually star-connected. The open ends of the rotor winding are brought out and joined to three insulated slip rings mounted on the rotor shaft with one brush resting on each slip ring. The three brushes are connected to a 3-phase star-connected rheostat. At starting, the external resistances are included in the rotor circuit to give a large starting torque. These resistances are gradually reduced to zero as the motor runs up to speed.


Three-
phase
supply
Wound-rotor
motor
Rotor
rheostat
Three-
phase
supply
Stator
Rotor
Slip rings
Rotor
rheostat

Types of load

Constant Torque Loads

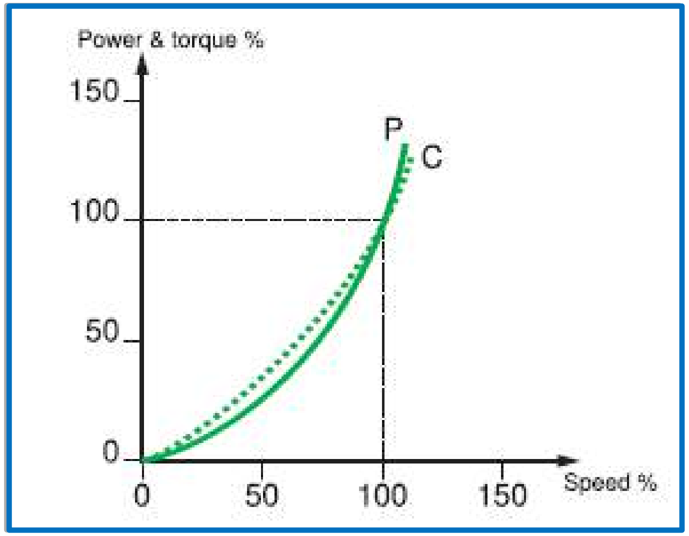


Belt conveyors

Planers

Rolling mills

Variable Torque Loads

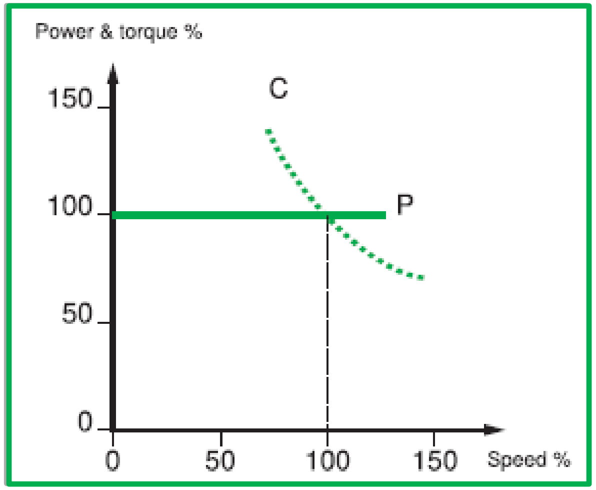


Pumps

Fans

Centrifuges

Constant Power Loads

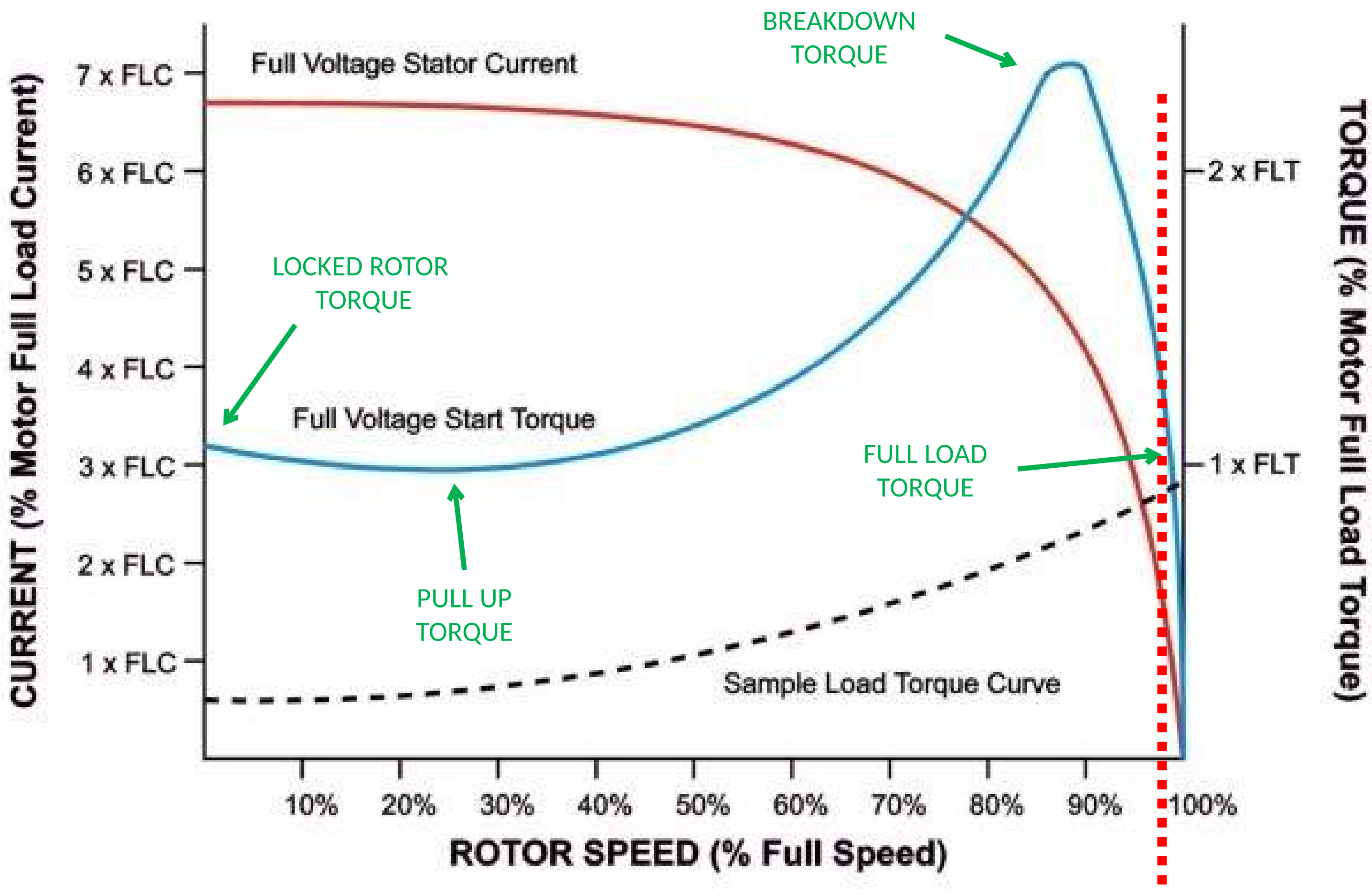


Winders

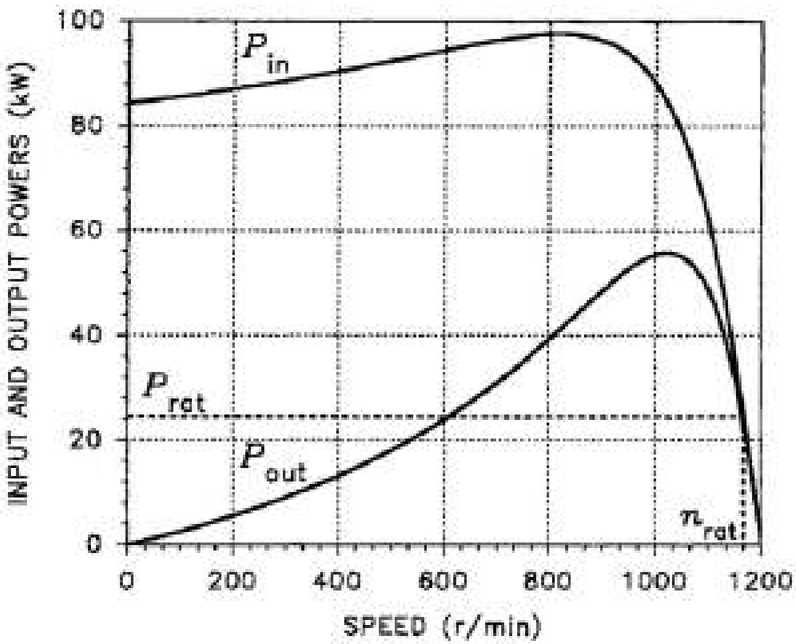
Rotary cutting machine

Facing lathe machine

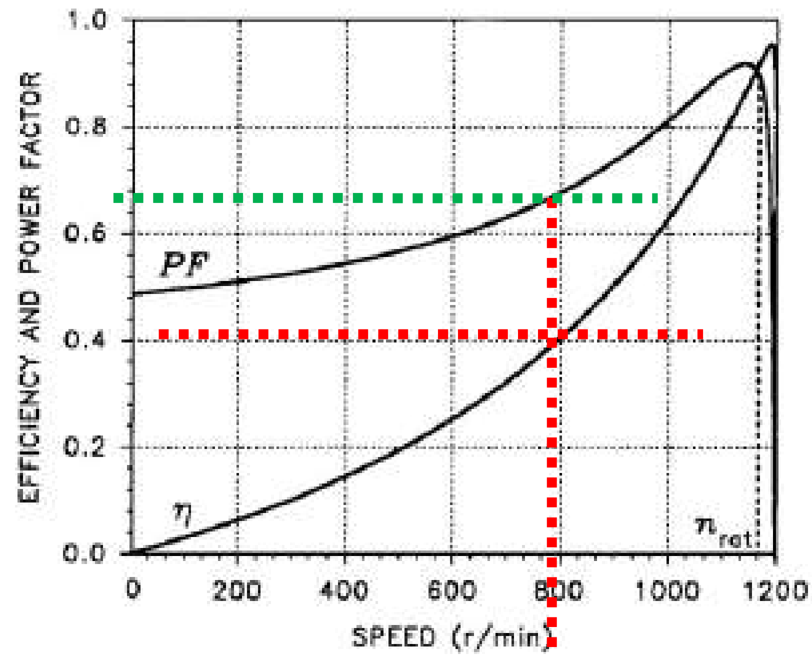
IM Characteristics (w.r.t. Speed)



…………(w.r.t. Speed)

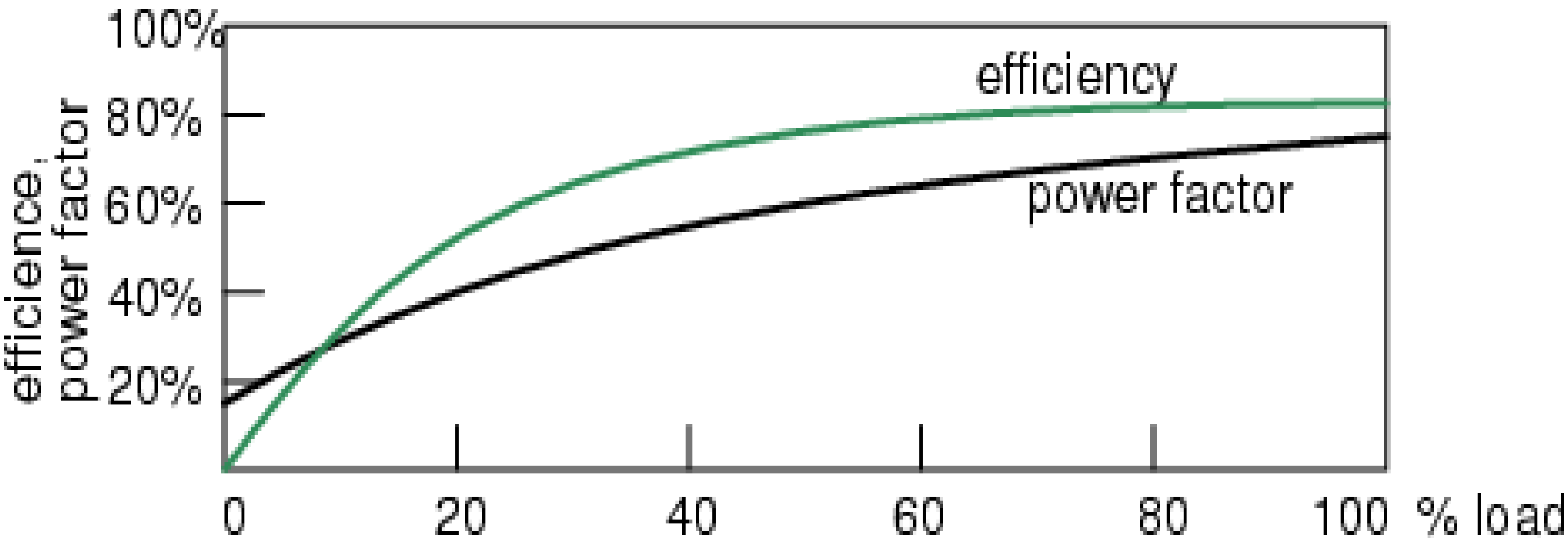


Power (i/p & o/p)
vs
Speed



Pf & efficiency
vs
Speed

IM Characteristics (w.r.t. Load)



Steady state operation 80-100% of rated speed

Surge/Sags
- Stresses, premature failure

High inrush current during starting

Braking/Reversing
- Mechanical brake
  - Losses
  - Maintenance

i/p pf 0.2 to > 0.8
- no load to full load
- speed range

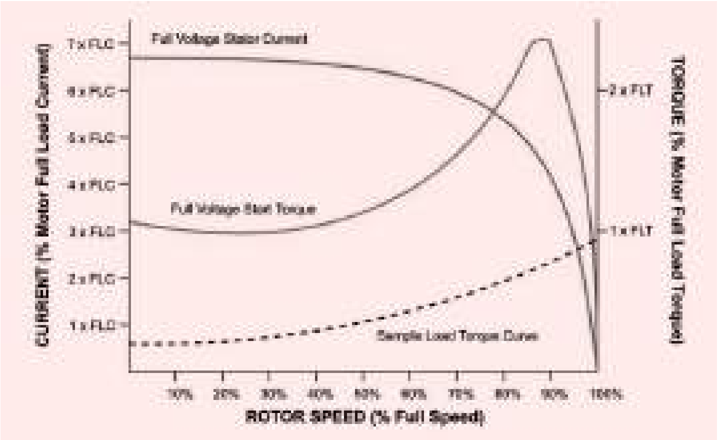
Torque pulsation at low speeds due to ↓pf (& harmonics)
- Motion jerky
- ↓ bearings' life

For variable torque operation e.g. fans, blowers, pumps,etc.
- ↓ speed by 20%
  = ↓ i/p power by 50%

Starters

Functions :

- **Start and stop the motor**
- **Limit high inrush current**
- **Permit automatic control when required**



- **Protect motor and other connected equipment from over voltage, no voltage, under voltage, single phasing, etc.**

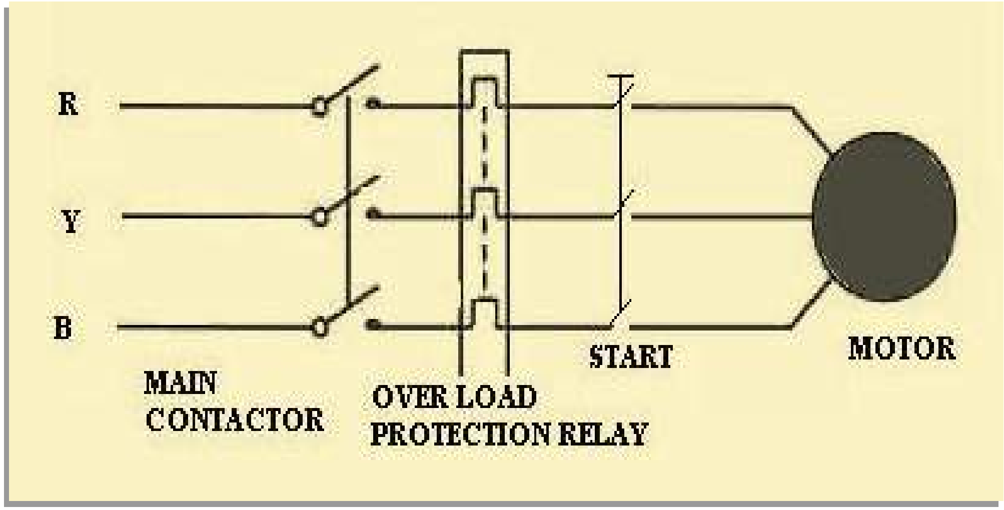
Types of starters : 3-ph Induction Motor

- **For squirrel cage IM :**
  - ❑ DOL Starter
  - ❑ Primary Resistance Starter
  - ❑ Auto Transformer Starter
  - ❑ Star-Delta Starter

- **For Slip-Ring IM :** ❑ Rotor Rheostat Starter

- **Other Starters :** ❑ Soft Starter

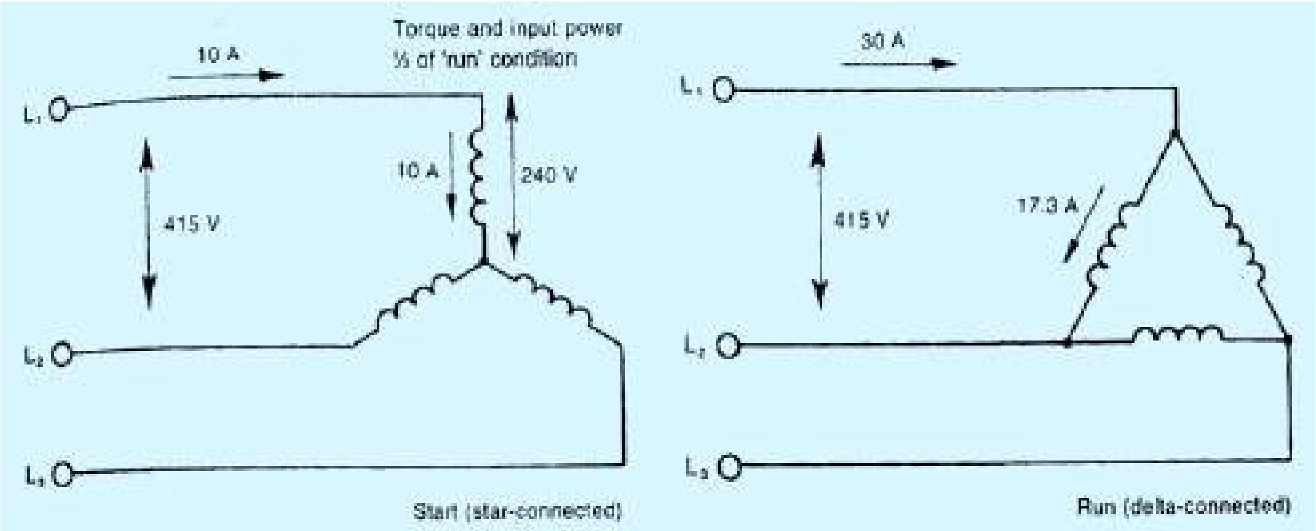
DOL starters



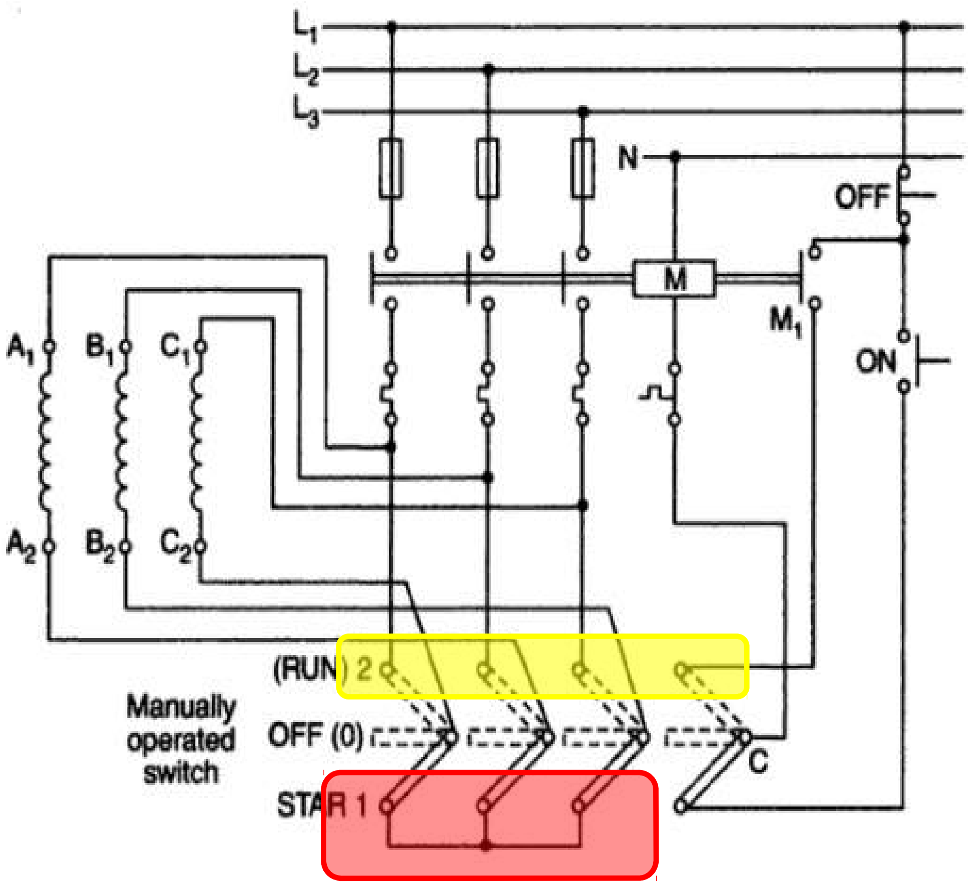
- used upto 5 HP
- equipped with the overload tripping mechanism
- simple circuitry and simple to use
- not feasible for high rating motors

Star-Delta Starter

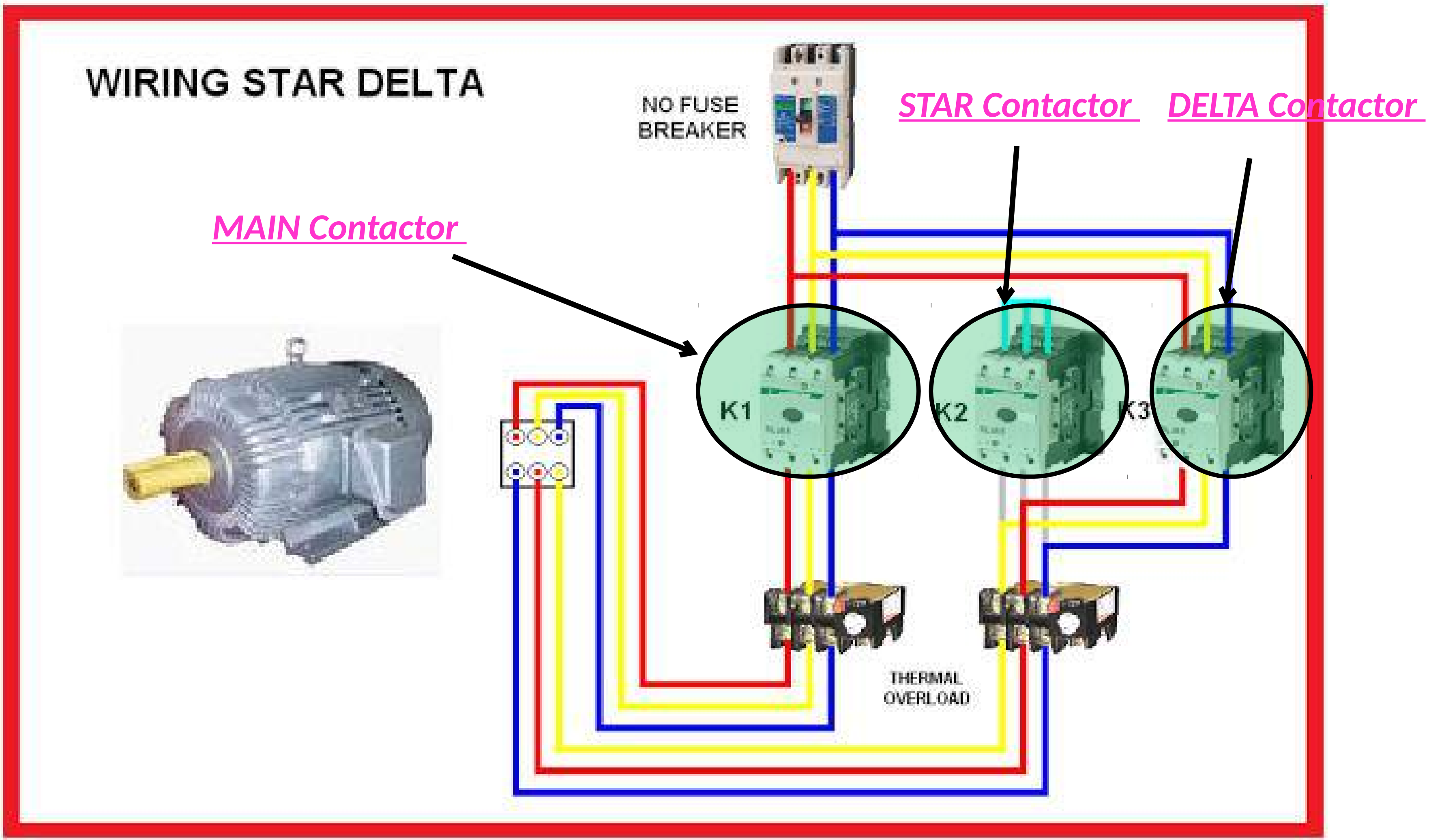
- It minimizes the large amount of starting inrush current that motors draw.
- It allows feeding the motor with 1/√3 or 58% of the full load current during starting condition resulting torque and input power as 1/3 of the run condition.



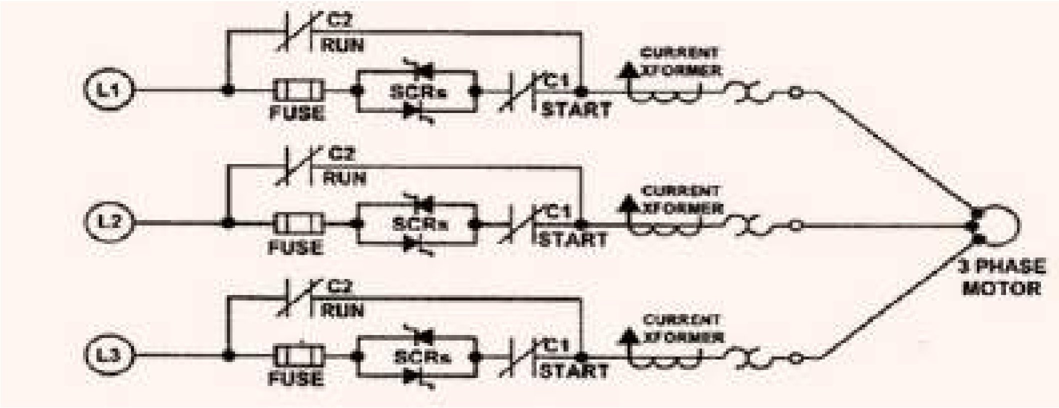
Manual (oil-filled) Y-Δ starters



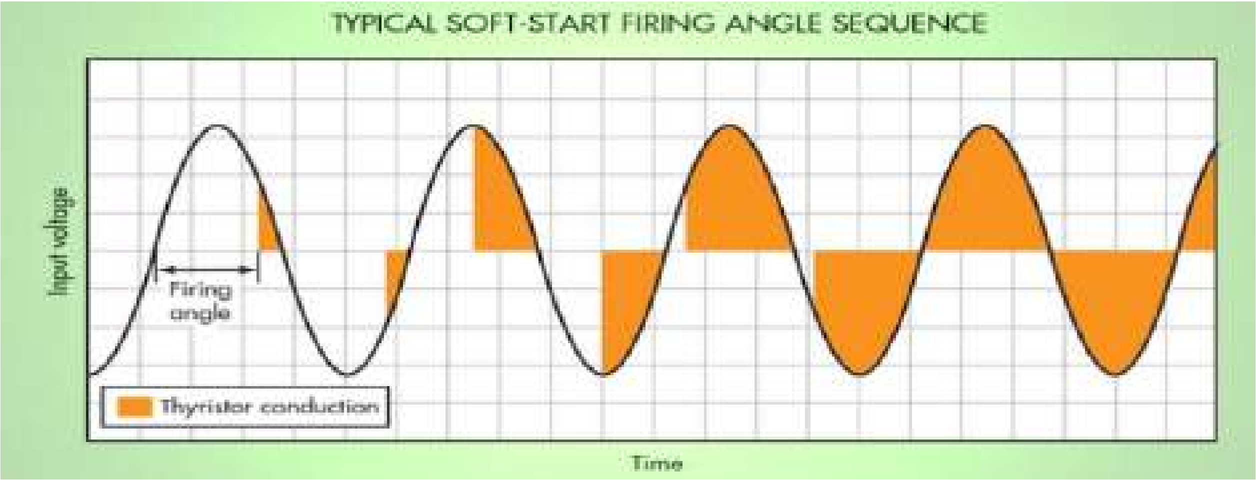
Automatic Y-Δ starters



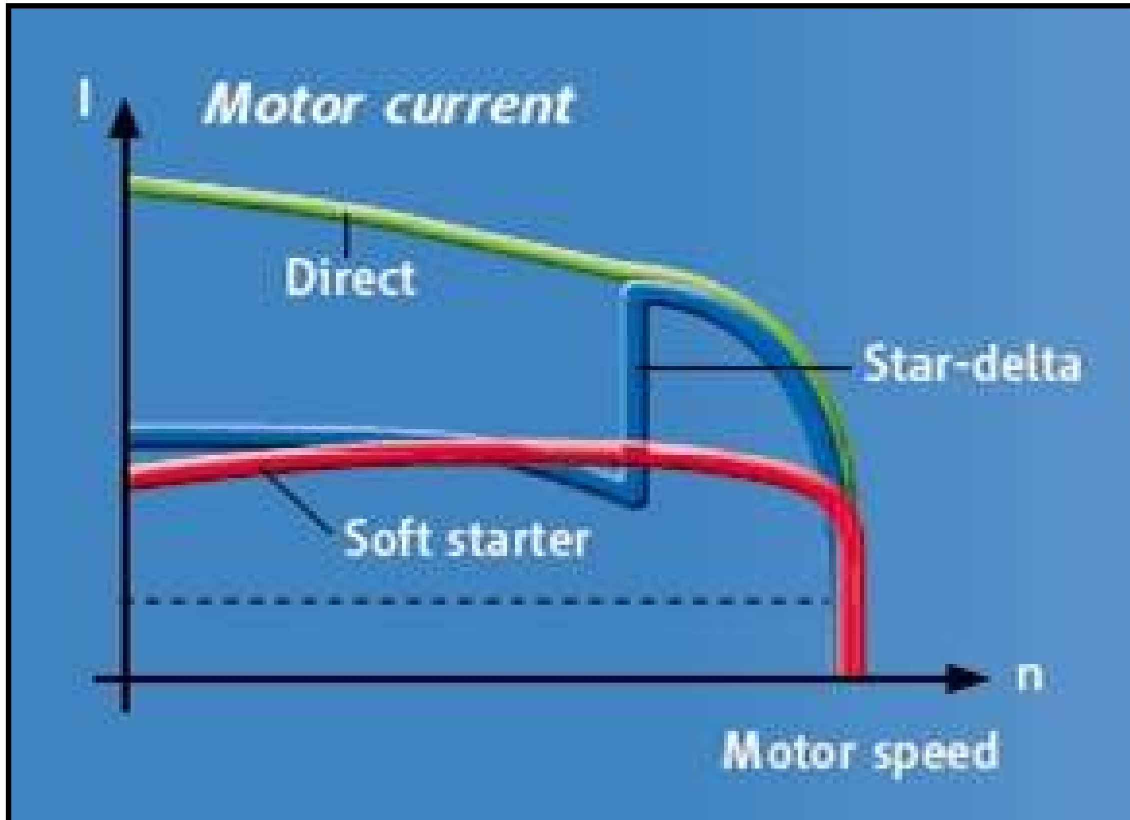
Soft Starters



- No current peak
- No torque peaks
- Negligible voltage dip



Current vs Speed…..IM Starters



Speed and Torque Equation

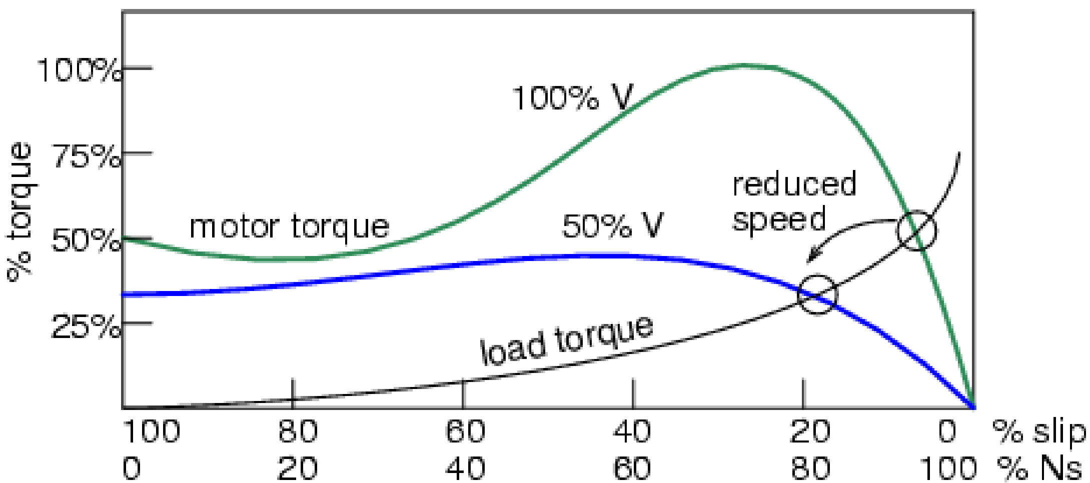
$$Torque,\ T = \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2} \times \frac{3}{2\pi n_s}$$

$$\textit{Speed of Rotor} = \frac{120 \times F\,(1 - S)}{P}$$

Speed can be controlled/changed by –

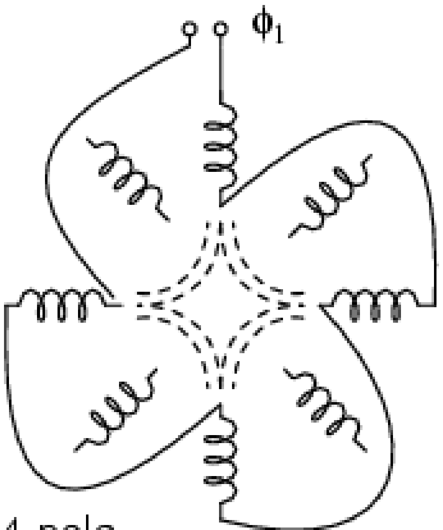
- **Controlling/changing Slip** **(Stator Voltage Control Method)**
- **Changing No. of poles**
- **Controlling/ changing supply frequency** **(frequency control method)**
- **Volt/Hertz control method**

Stator Voltage Control Method

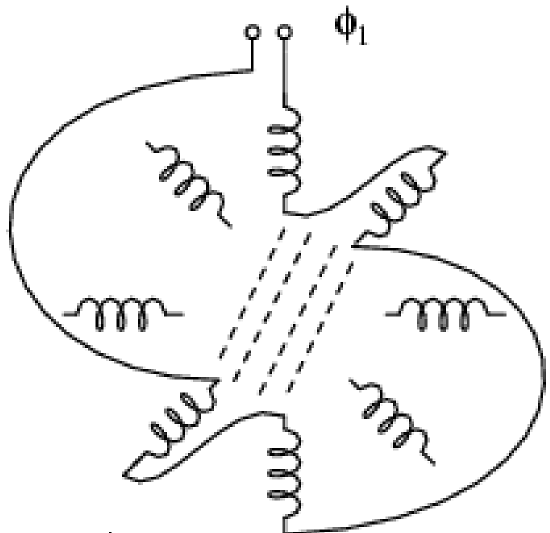


- Not suitable for constant torque applications.
- Poor Power factor
- Used mainly in low power applications such as fans, blowers, centrifugal pumps, etc.

Changing number of Poles



4-pole



2-pole

N_s = 120 f/P
= 120 x 50/4
= 1500 rpm

N_s = 120 f/P
= 120 x 50/2
= 3000 rpm

Pumps, wherein two speeds can be used to control the output flow

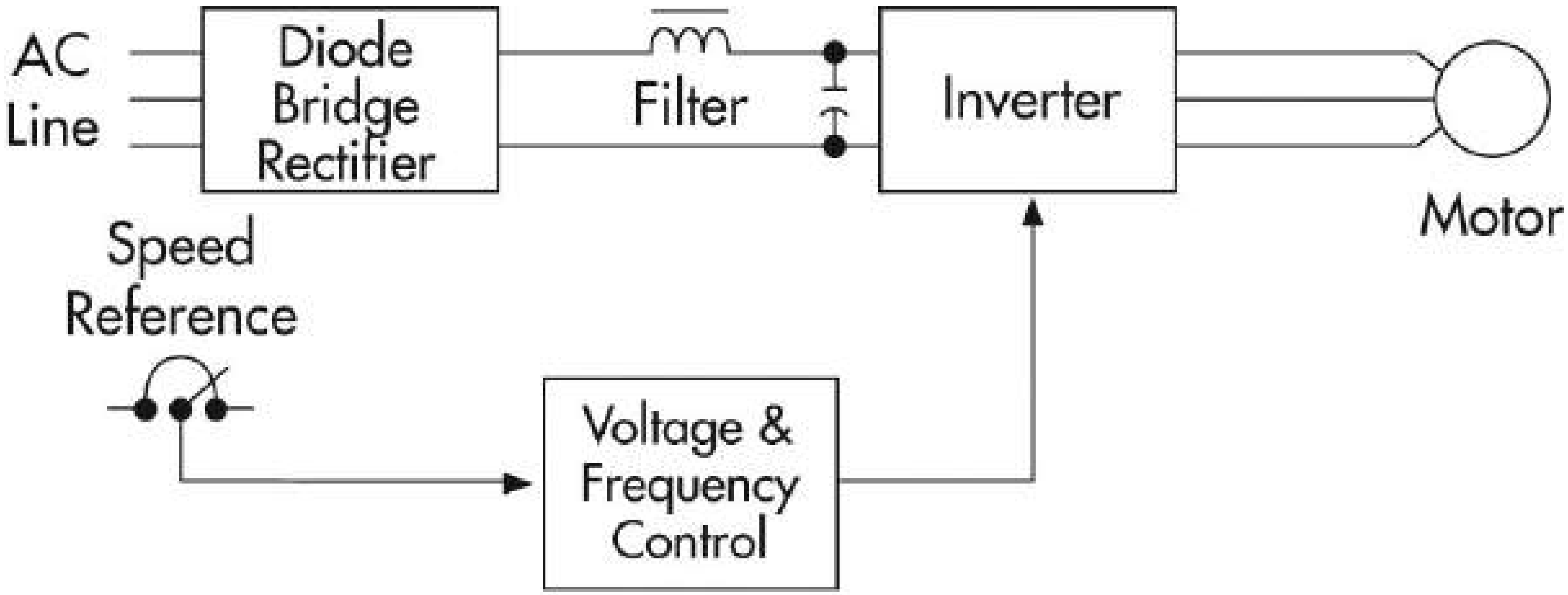
Fans, to get variable air flow output

Cranes, where two speeds can be used in hoisting applications.

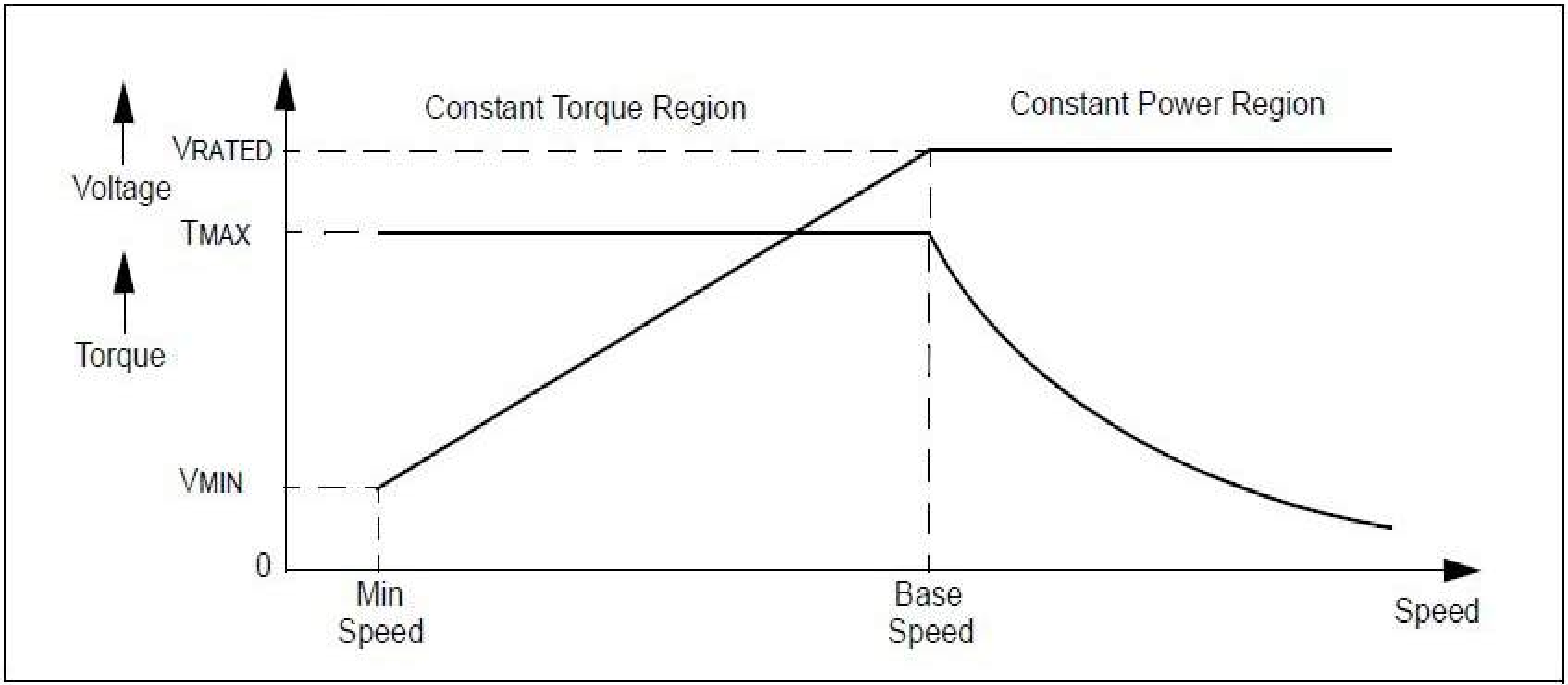
Frequency Control Method

- If frequency is decreased (keeping voltage constant), saturation of air-gap flux takes place
- Lower the frequency, lower the reactance. Motor current may be too high.
- If frequency is increased above rated value, both air-gap flux and current decreases. Torque decreases.
- Method rarely used.

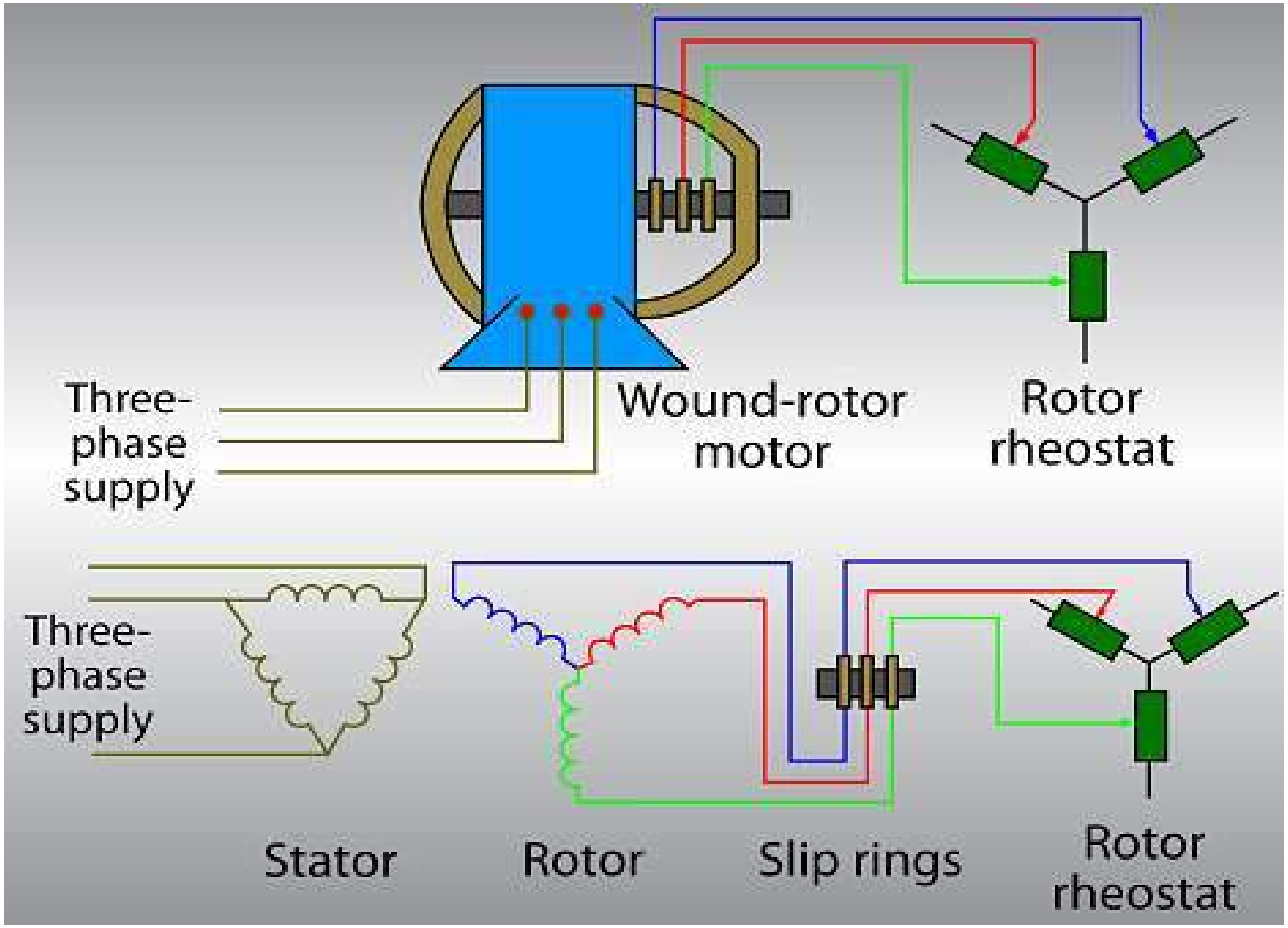
Variable Frequency Drive (Scalar)



Volt/hertz control characteristics

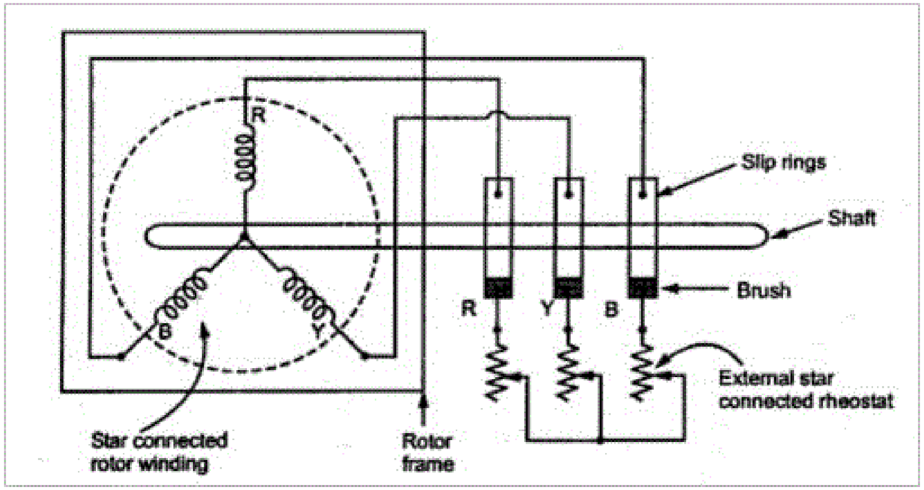


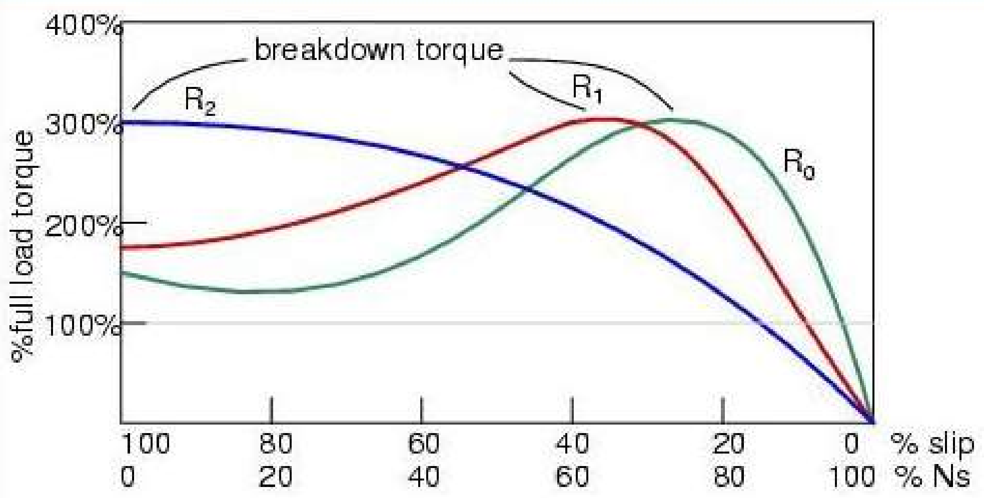
Slip Ring Induction Motor Drives



➢Speed variation by rotor resistance control.

➢around **10% to 15%** of the power is lost as heat, in the rotor resistance.





Station wise %age Power Consumption

- A typical sugar factory has around 400 electrical motors on its inventory, including stby, ranging from few KW to 2 MW of ratings.
- Around 60-80 of these motors are equipped with VFDs

Various Station	%age consumption of Elect. Power
Cane preparation & Juice extraction	50 - 60 %
Juice Clarification	10 – 15 %
Crystallization	15 – 20 %
Centrifugal	10 – 15 %
Miscellaneous	10 %
Total	100 %

Cane unloading

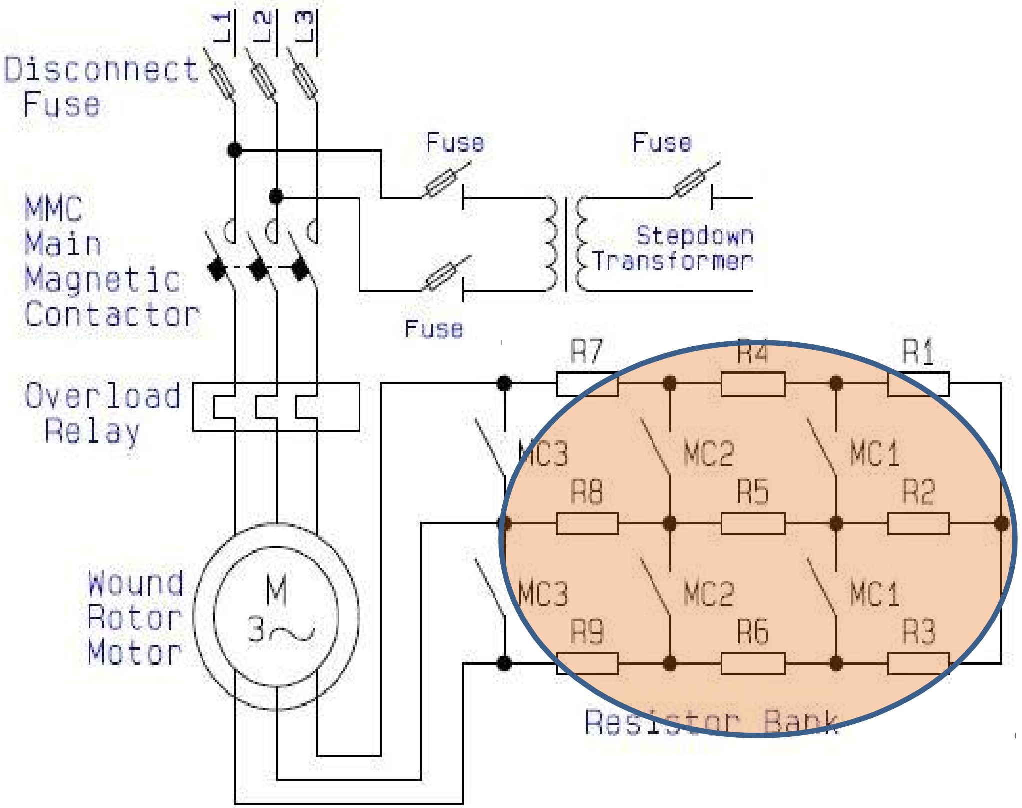
- Three motion........three motors
- Slip Ring Induction Motors
- External resistance cum contactor based Drives

Cane unloading

- Three motion........three motors
- Slip Ring Induction Motors
- External resistance cum contactor based Drives

Particular	Type of motor	H.P.
Hoisting Drum Drive	Squirrel cage/slip ring induction motor	25-35
Holding Drum Drive	Squirrel cage/slip ring induction motor	25-35
Long Travel Drive	Slip Ring induction motor	10
Cross Travel Drive	Slip Ring induction motor	7.5

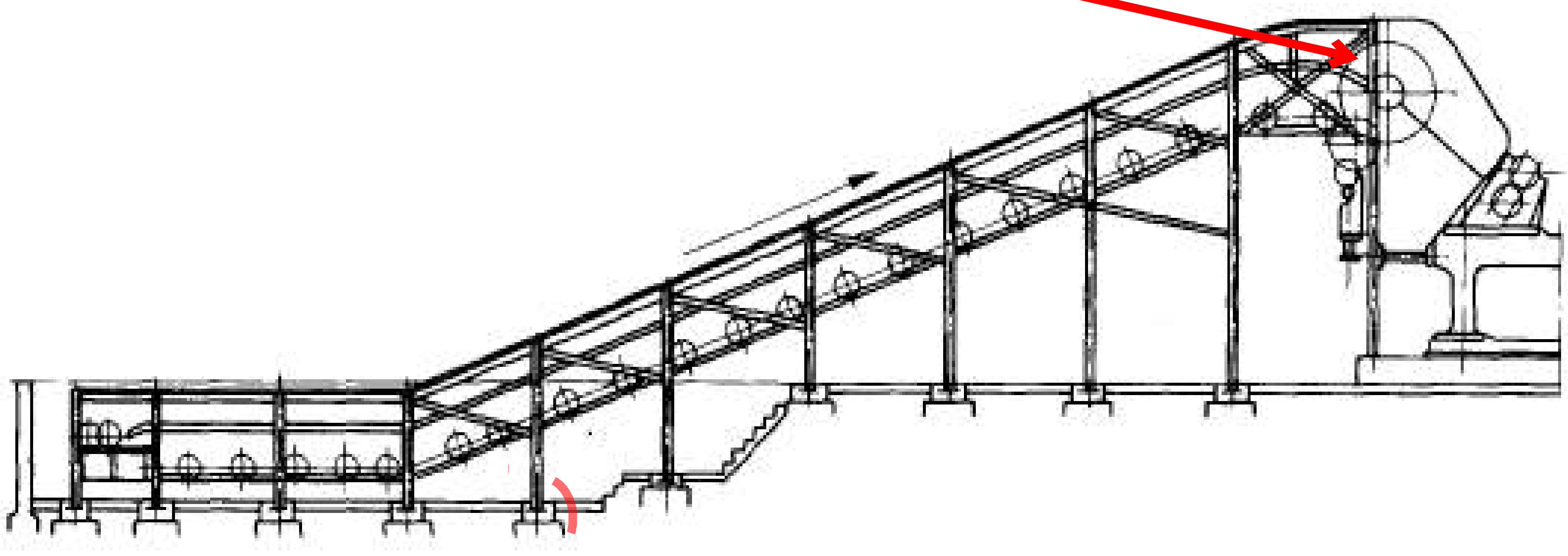
Drive for unloading



SRIM is invariably used

Cane Carrier

Dyno-Drive (Induction Motor)



Cane Preparation

- Slip Ring Induction Motors are invariably used
- Huge rotating special knives/hammers are used for preparation
- Variable load.........a challenge
- No dedicated modern drives has been designed.

Cane milling

- Consumes more than 25% of total power
- Induction Motors (Squirrel Cage)
- VFDs are used for speed control

Energy savings with VFDs on pumps

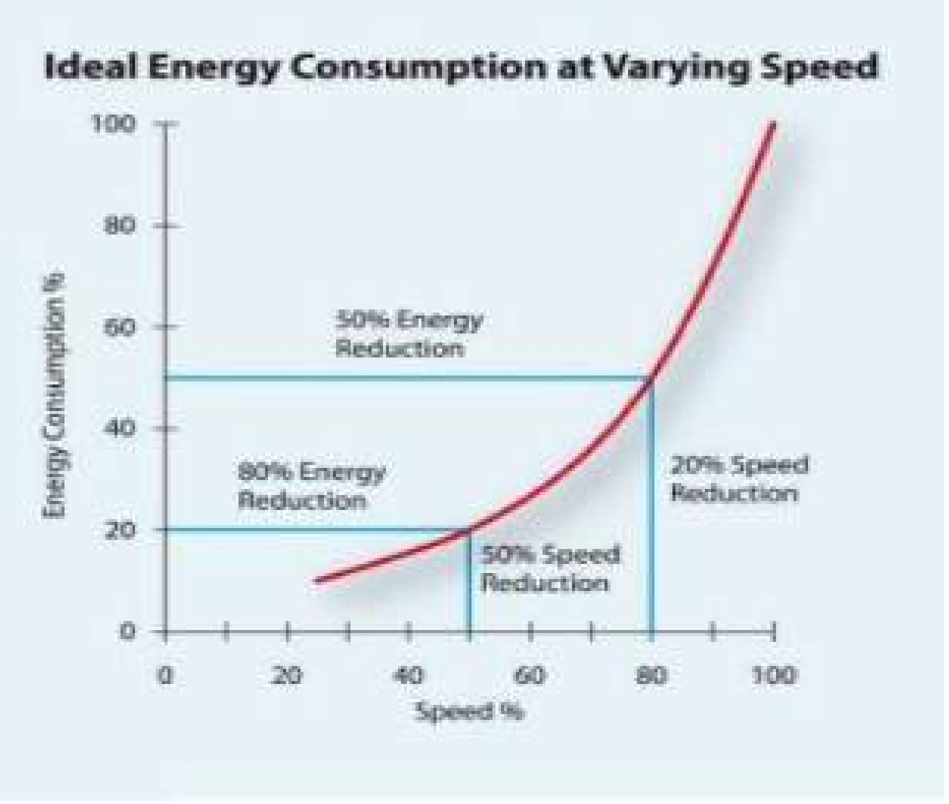
- Flow α Speed
- Power α $(Speed)^3$

- 20% reduction in speed

  = 50 % reduction in energy

- 50% reduction in speed

  = 80% reduction in energy



VFDs on Fans (ID/FD)