Three Phase Traction Motor

Made Simple

11.2.2021

Historical background

- The electrical power got developed with DC
- The First railway used DC motors
- Three phase power was developed in 1890
- The AC became popular and soon AC motors came to railways

Historical background cont’d

- The first proper use of three phase traction motor was made in 1896
- The three phase motor was light, eliminated the commutator, needed less maintenance and regeneration was possible.
- We talk of advantages of three phase traction motors till this day.

Cont,d

- But the use of three phase needed two /three contact wires
- And also speed control was difficult
- This system was soon replaced with HV DC and thereafter single phase AC
- The solid state electronics got developed in 1970
- And the three phase traction motor again made its appearance.

D C Series Motor

- The field winding has fairly large section copper , it provides great resistance to shock and vibration;

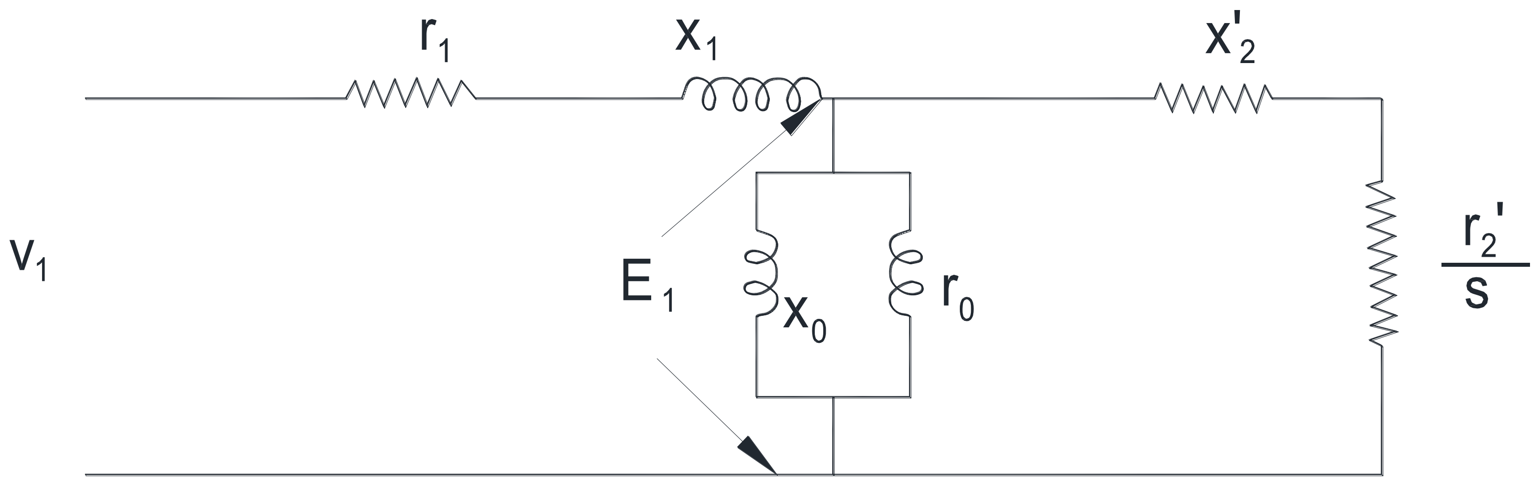
- Flux varies with the armature current,
- Variation in torque will always be greater than the variation in current

- The torque will be independent of variations in line voltage

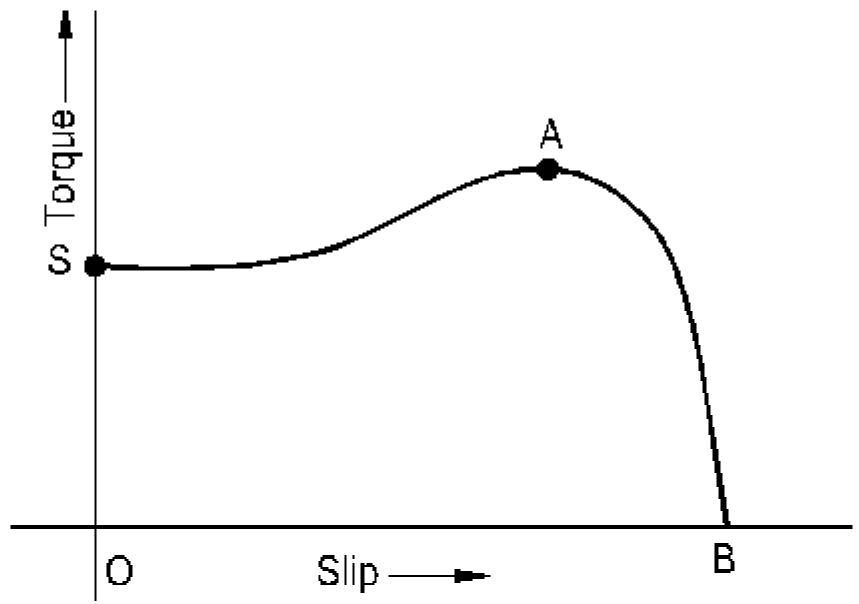
Cont’d

- The direct current motor is not subjected to the limitations of transformer.
- In series motor speed automatically decreases as the torque increases
- Parallel running possible
- DC series motor suits the railway application.
- The only major drawback being the presence of commutator and the brushes.

Induction Motor Equivalent Circuit Diagram



Torque Speed characteristics



Induction Motor

- The motor is a transformer with secondary shorted
- The speed of the motor is Ns = $\frac{120f}{P}$
- Torque is T =$sE2r2$ ÷ (r2)2 +(sx2)2
- The motor draws 6 to 7 times the rated current at start
- The starting torque is about half the maximum torque

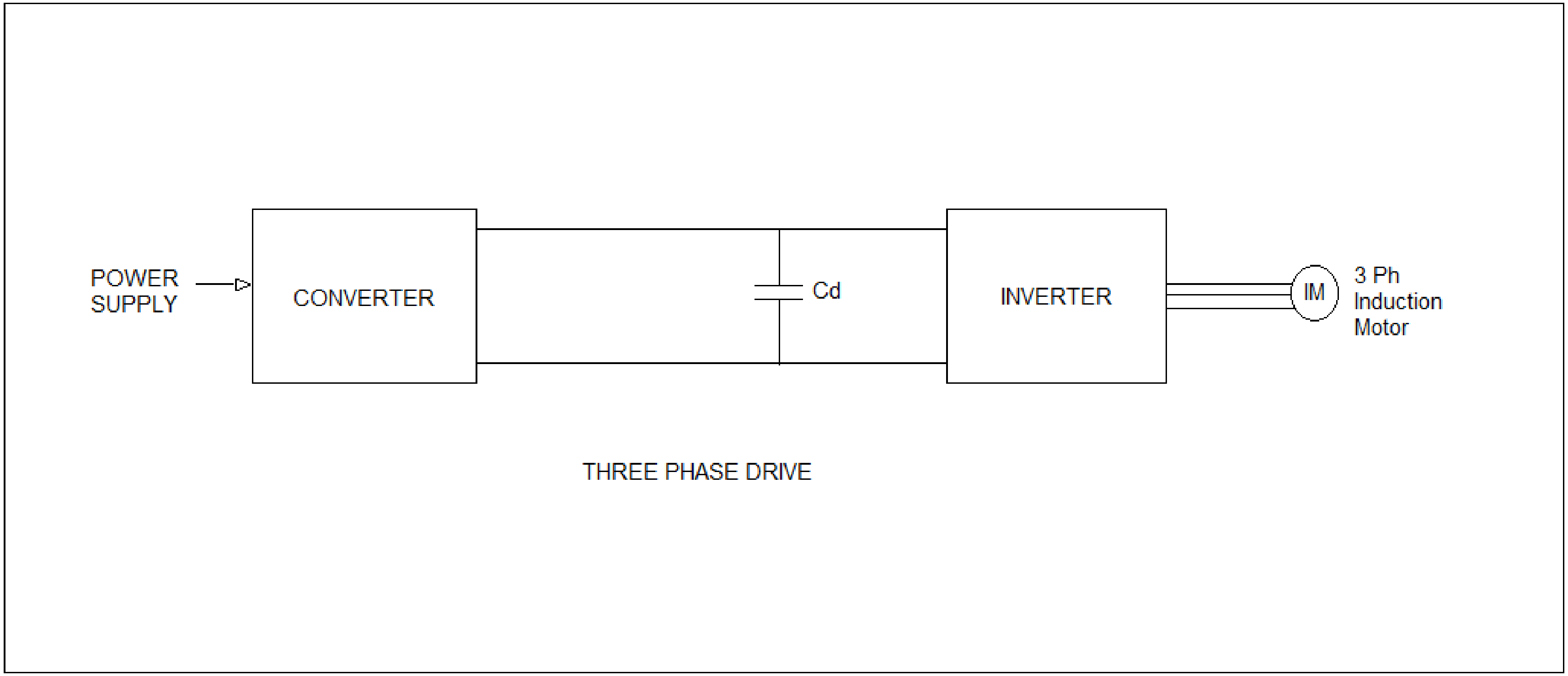
Cont’d

- Parallel operation of two motors is not possible unless current difference can be tolerated.
- Wheel diameters are needed to be almost equal

Comparison of Torques

Type	Torque	Starting current	Speed load characteristic	Range of speed Control
D.C. shunt	2T	2I	Constant	4:1
D.C. series	3T	2I	Inverse	3:1
Squirrel cage induction motor	T	6I	normal	normal
v/f Motor	T	I	v/f	v/f
Slip ring induction motor	2.5 T	2I	Normal	Comparable to dc shunt motor
Single phase A.C. series motor	3T	2I	Inverse	Several fixed speeds
Repulsion	3T	2I	Inverse	4:1

Basics of V/F drive



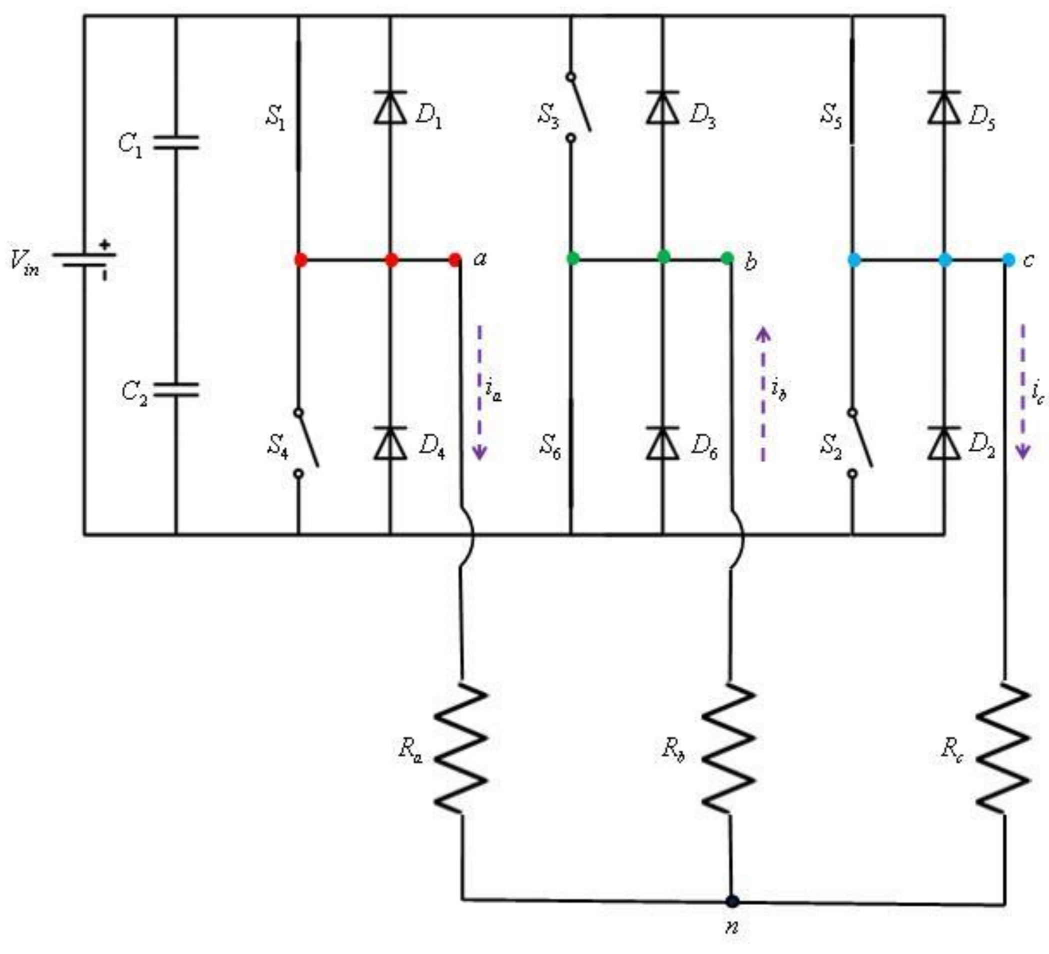
Components of 3 ph drive

- .Transformer/Generator
- Line converter
- DC link
- Capacitor
- Inverter

D C Link

- The DC links for electric loco Diesel loco and EMU are same with minor variation.
- The DC link of EMU and electric loco get power from transformer and Diesel loco gets it from generator
- The capacitor of Diesel loco is of higher size
- During dynamic braking the magnetising current is provided by the capacitor in diesel loco

Three Phase Inverter



Inverter

- The out put of this motor appears more
- In case of DC EMU,

DC motor was of 183 KW

The AC motor is 220 KW

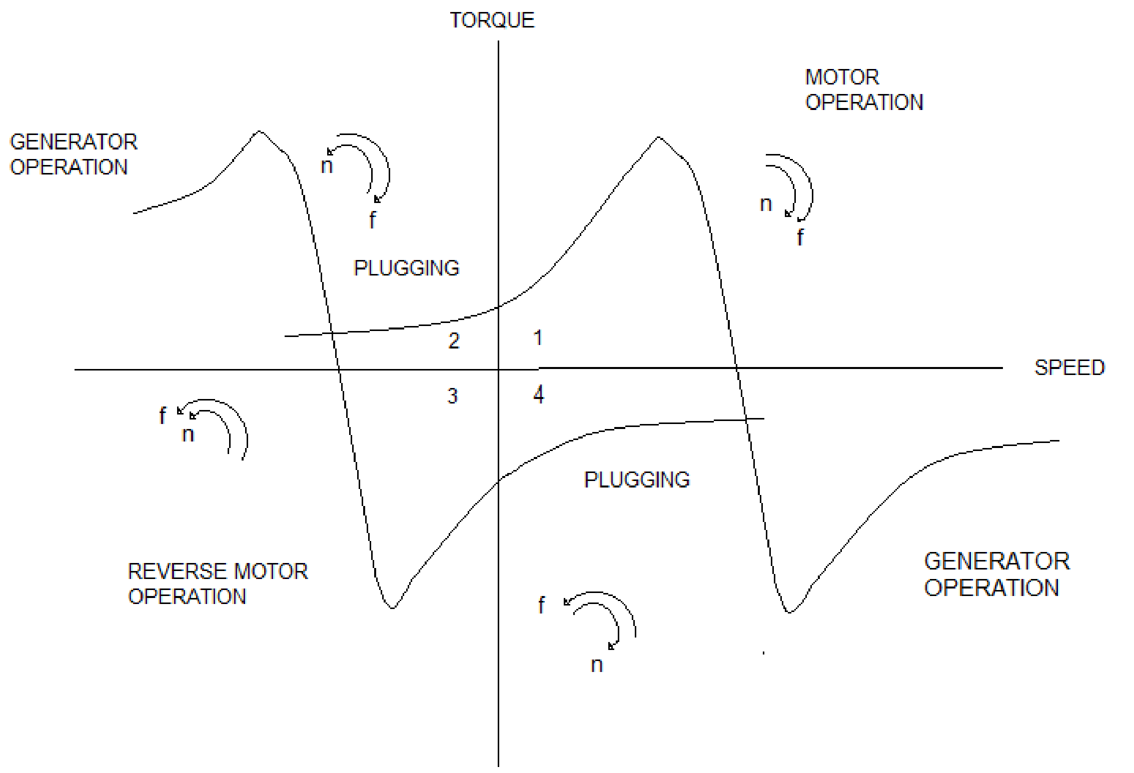
The WAG 9 motor is 850KW

The WAG7 motor is 670 KW one hour

But the hauling capacity of WAG7 is more

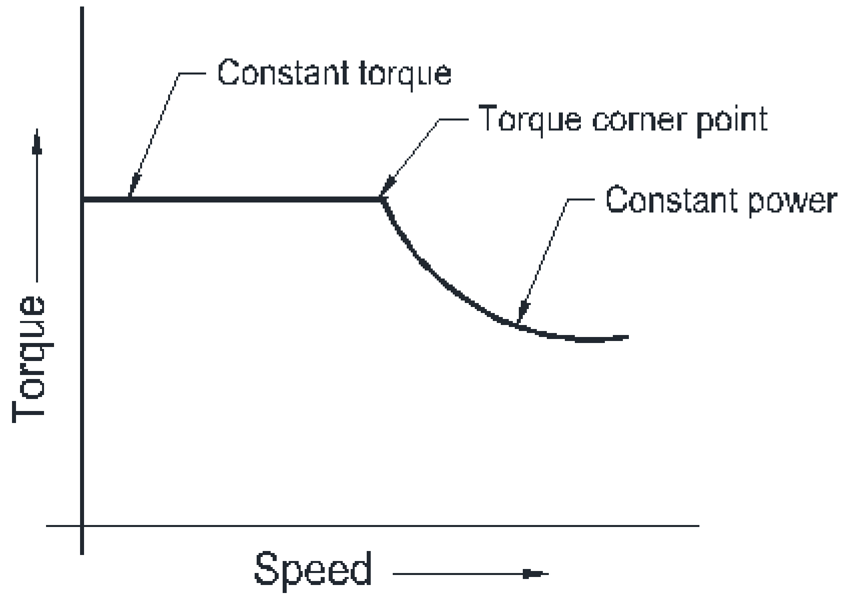
This is because the output is 1.5 VA and not 1.732VI. The motor has to be further de rated due to heat generated by harmonic current

Four Quadrant Operation

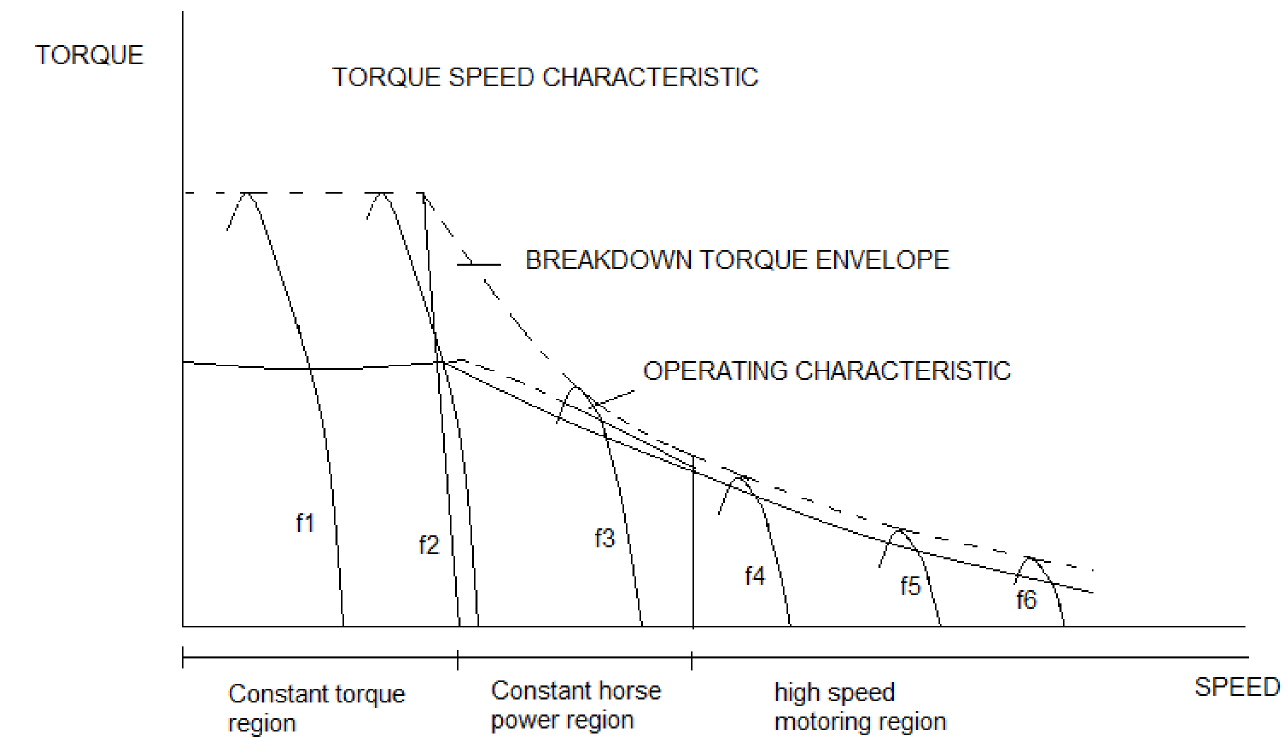


FOUR QUARDRANT OPERATION OF THREE PHASE MOTOR

Torque Speed characteristics

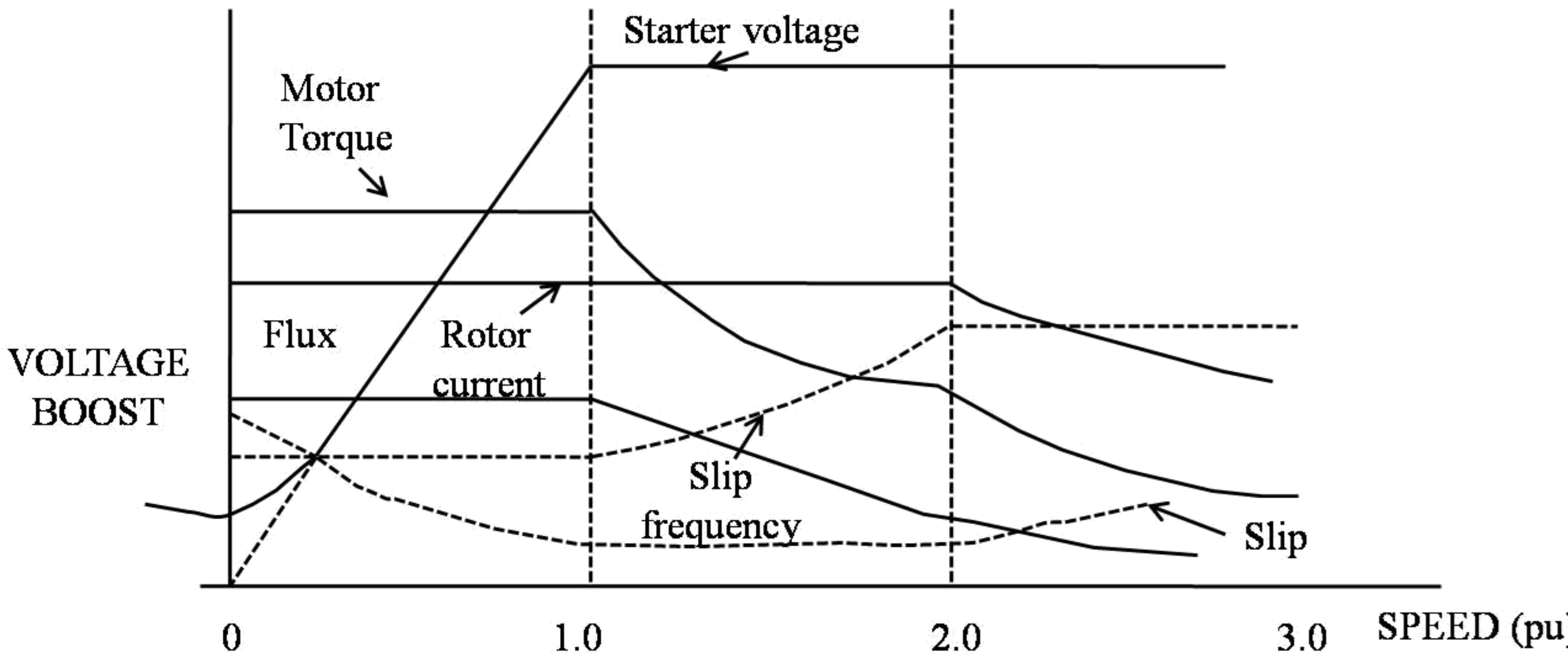


T-S Curves



T-S Cuvre for Traction Drive

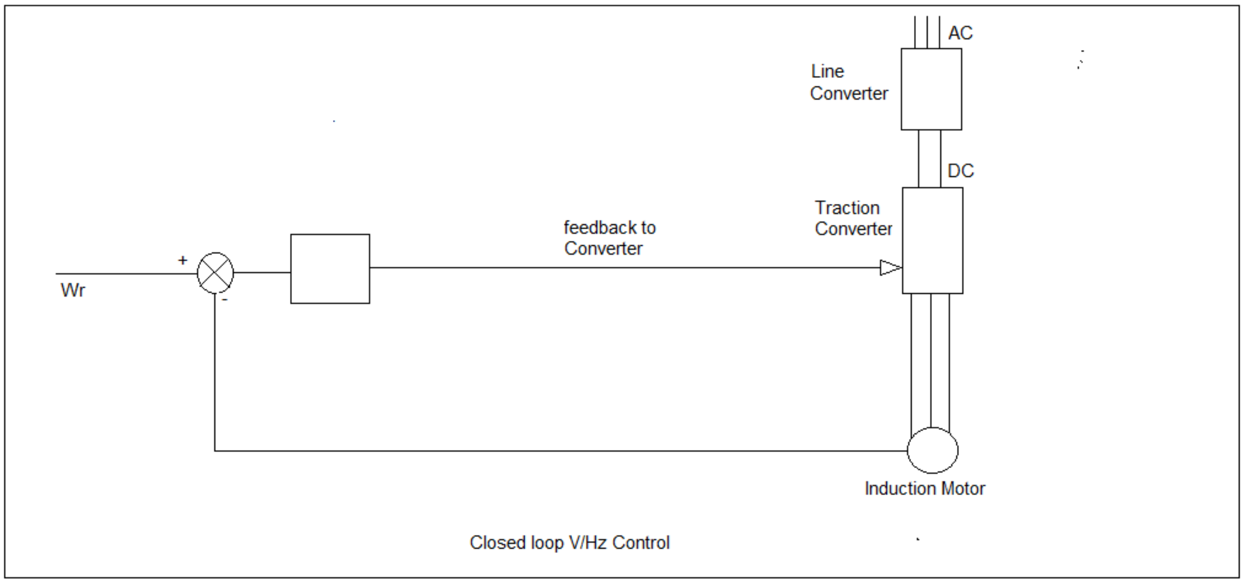
v v v f control



Induction motor voltage, current slip frequency and Torque as a function of speed for the torque speed operating characteristic

Scalar Control

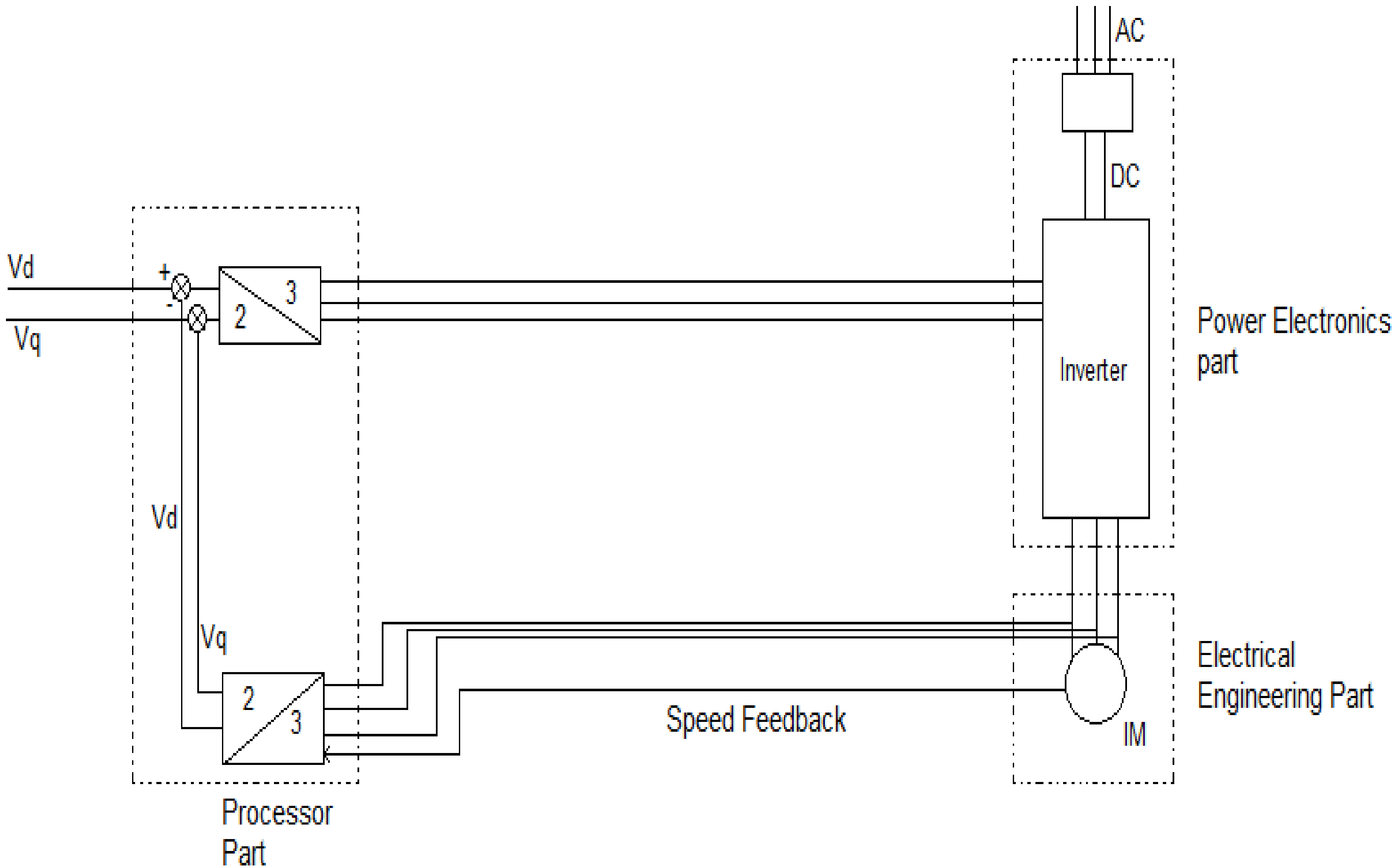
- The ac rms quantities can be considered as dc quantities as far as the magnitudes are considered. For the change of speed of induction motor, voltage can be changed disregard of the angle between voltage and current. The angle between the voltage and current is irrelevant here, only the magnitudes of the quantities are important for the speed control.



Scalar control

Vector Control

- For railway torque is more important than the speed. The method of control where torque is more importance than the speed is called vector control or field orientation control.
- The field and the current is at right angles to each other in DC machines.
- Such flux control is achieved by use of the processor in vector control method of induction motor.



Vector control

Mathematics Of Vector control

- A current for the three phases can be denoted as,

- $I_1\cos(\theta)$, $I_2\cos(\theta-2\pi/3)$ and $I_3\cos(\theta+2\pi/3)$
- These are the magnitudes of the currents in three phases. To make them as vectors an angle is added to these magnitudes so that these vectors are properly spaced in the space. This is done by taking $I_1\cos(\theta)$ as reference and multiplying
- $I_2\cos(\theta-2\pi/3)$ by $\bar{a}$ which equals to
- $\cos 2\pi/3+j\sin 2\pi/3$
- The Euler's equality is $e^{j\theta} = \cos\theta + j\sin\theta$
- We multiply $I_3\cos(\theta+2\pi/3)$ by $\bar{a}^2$ which is complex conjugate of $\bar{a}$ which is $\cos 2\pi/3-j\sin 2\pi/3$

Cont'd

- Therefore total of these three phase currents become equal to,
- $I = I_1\cos(\theta) + I_2\cos(\theta-2\pi/3)*\bar{a} + I_3\cos(\theta+2\pi/3)*\bar{a}^2$ …….(b)
- Keeping $I_1\cos(\theta)$ aside, the sum of the balance terms can be found,

- $I_2\cos(\theta-2\pi/3)*\bar{a} + I_3\cos(\theta+2\pi/3)*\bar{a}^2$

- $= I_2\cos(\theta-2\pi/3)*(\cos 2\pi/3+j\sin 2\pi/3) + I_3\cos(\theta+2\pi/3)*(\cos 2\pi/3-j\sin 2\pi/3)$…..(A)
- Knowing,

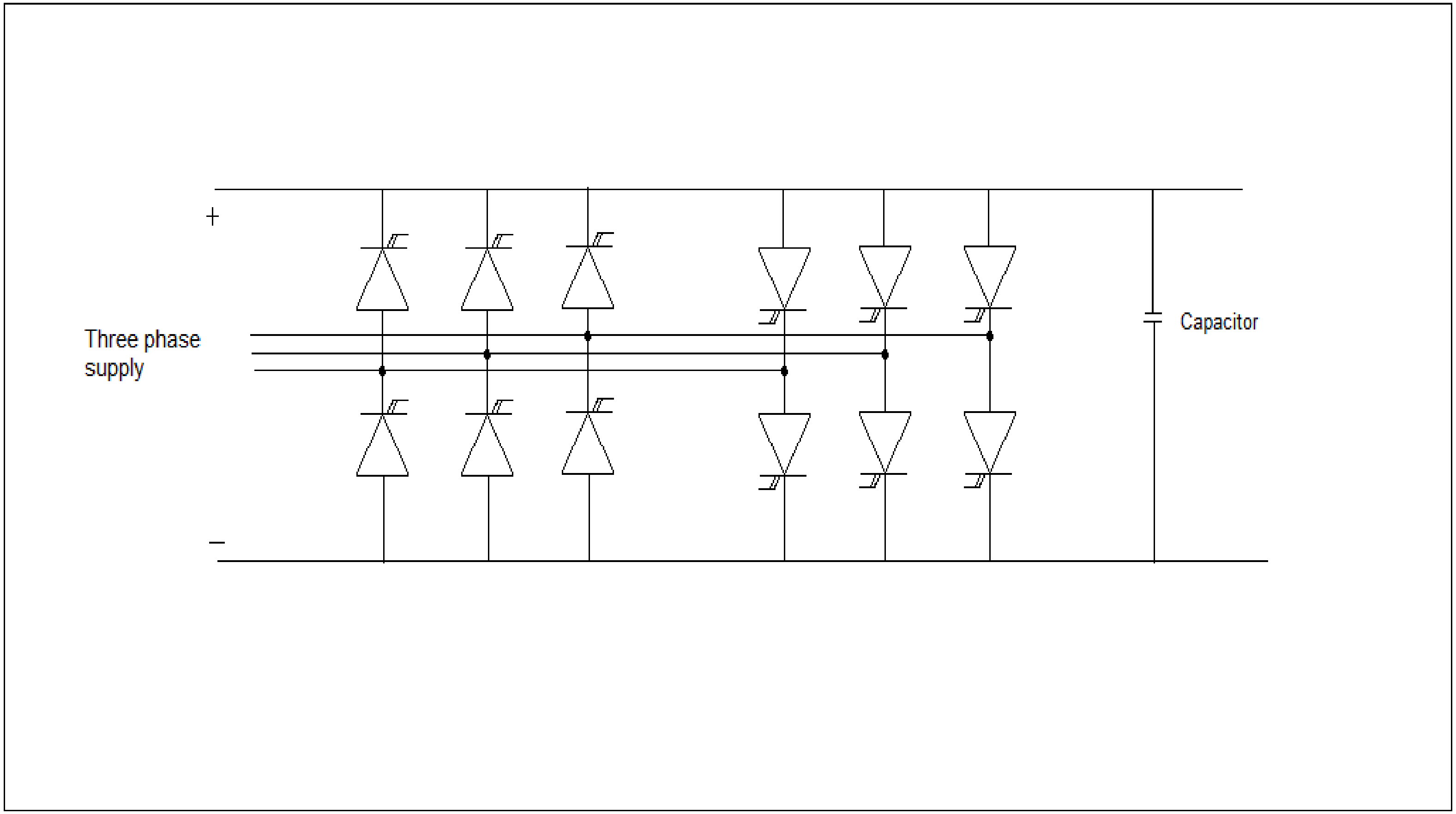
- $\cos(\theta-2\pi/3) = -1/2\cos\theta + \sqrt{3}/2\sin\theta$
- $\cos(\theta+2\pi/3) = -1/2\cos\theta - \sqrt{3}/2\sin\theta$

Cont'd

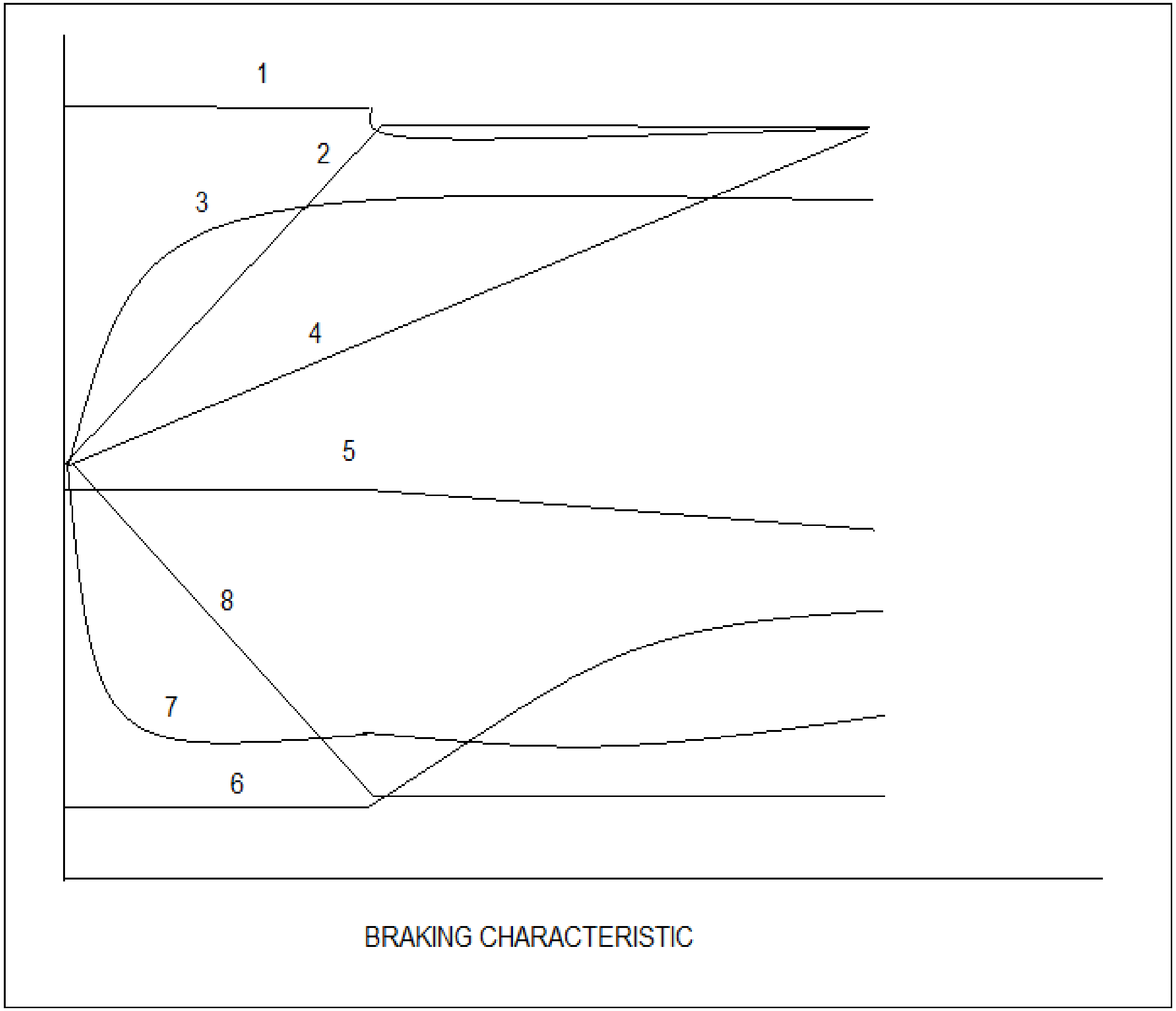
- $\cos 2\pi/3 + j\sin 2\pi/3 = -1/2 + j\sqrt{3}/2$
- $\cos 2\pi/3 - j\sin 2\pi/3 = -1/2 - j\sqrt{3}/2$

- Equation A will be simplified as $1/2\cos\theta + j3/2\sin\theta$, adding $\cos\theta$, kept aside above, the expression will become, $3/2\cos\theta + j3/2\sin\theta$
- The equation (b) above is thus reduced to two vectors which are at right angles to each other. The three vectors are thus transformed into two parts, what is called direct and quadrature axis. This is what is known as Clarke's transformation.
- Components of both voltage and the current are transformed into d-q axis.

Regeneration



The claim of 30 % is not logical



1stator current, 2 stator voltage, 3 efficiency, 4supply frequency , 5 rotor frequency , 6 Torque, 7power factor,8 stator power
'x' axis', represents the speed in rpm.

Advantages of this motor

- The absence of commutator,,
- The motor does not achieve a runaway speed.
- Due to the absence of the commutator, the three phase motor can be theoretically lighter
- The regeneration is easily possible in this motor.
- High speeds are possible with higher frequencies .

Problems of this Motor

- The problems can be divided into following major categories,
- Heat generation in rotor & stator.
- Unbalanced magnetic pull (UMP)
- Circulating current in the bearing, Pinion & Shaft,
- Opening of joints in the overhang portion of stator coils,
- Vibrations,
- Converter problems.

Heat Generation cont'd

Heat Generation

- More Harmonic loss than normal Induction Motor
- Big motors have more loss

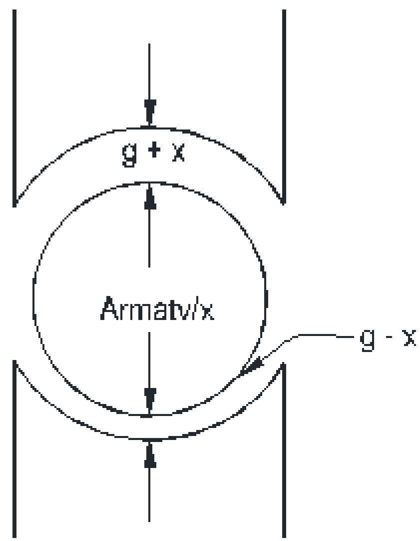
For example 30 HP motor with sinusoidal supply has no load loss as 687.5w and with non sinusoidal supply it is 765w or 77.5w more

- The heat gives rise to opening of rotor bar joints

Heat Generation con'd

- Tensile strength of copper drops with temperature rise
- Eddy current loss is more since it is Proportional to square of frequency and frequency is high in v/f drive
- Starting current in v/f drive is small but duration is more
- Unlike dc series motor, these motors work in regeneration mode adding to heat generated.

UMP



UMP cont'd

- The gap "g" can never be ensured as uniform
- With eccentricity of "x", the resultant pull on one side will be,

$$\frac{B_{g^2}}{2\mu_0} \cdot A_p \left[\frac{g}{(g-x)} - \frac{g}{(g+x)}\right]$$

B_g is the flux density, A_p is area under the pole

- This is a very large force and can bend the shaft

Circulating current

- The stator induces voltage in the shaft
- This current can damage the bearings and gear teeth

Part	2004 – 05			2005 - 06			2006 - 07		
	No. of failures	Av. Population	FRPCPY	No. of failures	Av. Population	FRPCPY	No. of failures	Av. Population	FRPCPY
Pinion	18	324	5.6	33	336	9.8	64	354	18.1
Bearing	3	324	0.9	10	336	3.0	13	354	3.7

- A single insulated bearing cannot stop the flow completely
- The two insulating bearings will have voltage built up

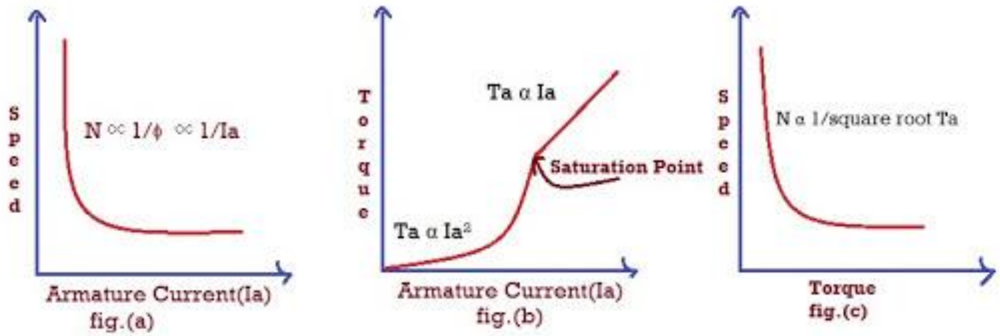
Other problems

- Opening of joints in the overhang portion of stator coils, is due to heat
- Vibrations is caused due to harmonics
- Converter is a part of motor for comparison with DC motor and has its own problems
- To get high starting torque, the gear ratio of this motor is high

THANKS

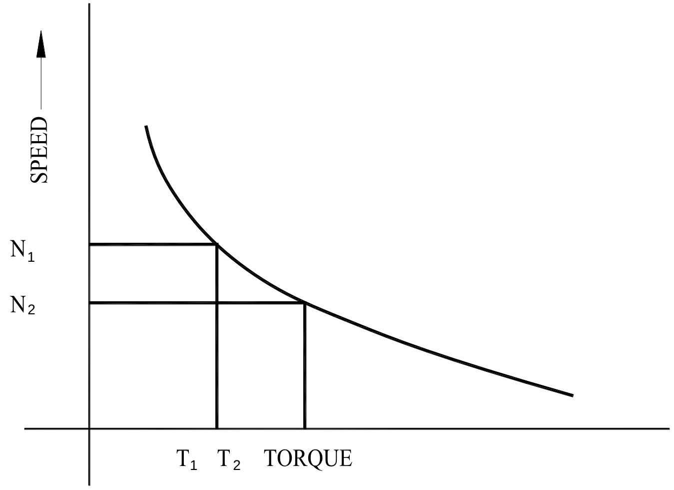
Three wire system

DC Series motor

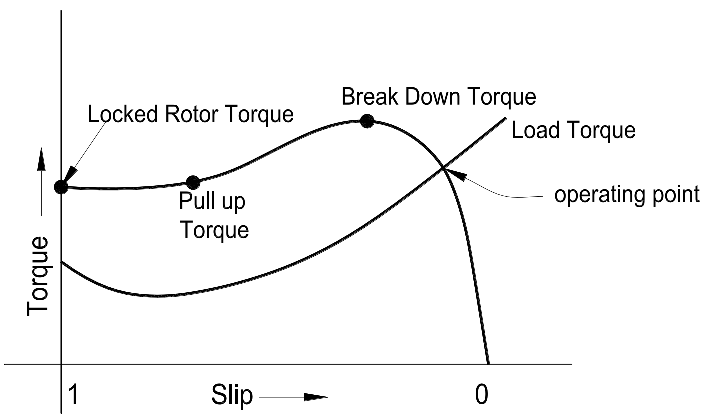


Characteristics of DC Series Motor

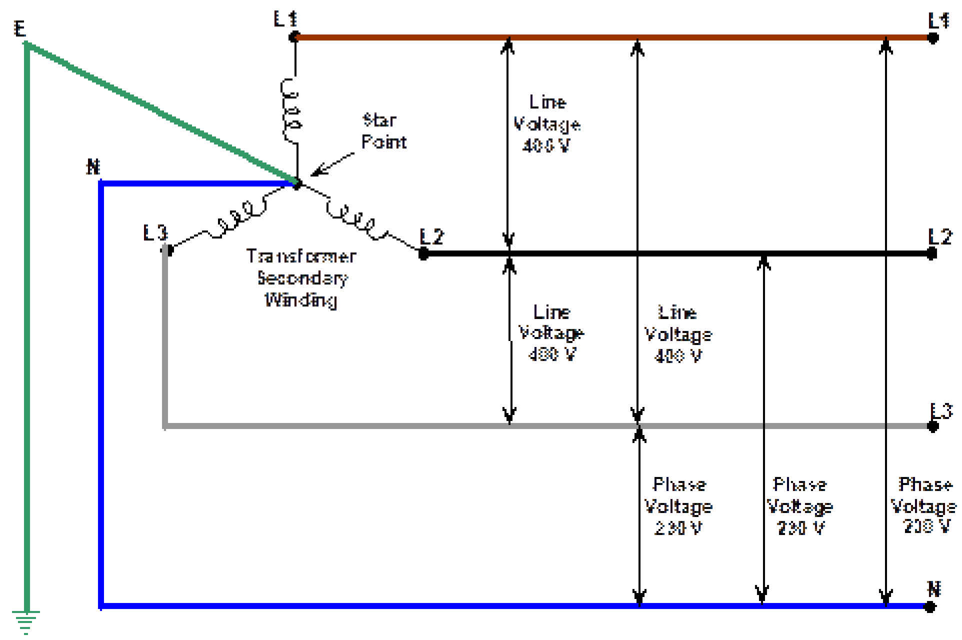
Difference in wheel diameter



I M characteristics



Typical Three Phase system



Variation in voltage