RIDING INDEX:

- A typical Electrical Multiple Unit/Trailer (EMU/T) coach and the associated dynamics take into consideration of seven rigid bodies i.e. car body, two bogies, four wheels and axles and stiffness of primary and secondary suspensions.The dynamic performance of railroad vehicle as related to safety is evaluated in terms of specific performance indices, riding index (**W_z**-both ride comfort and ride quality).
- The quantitative measure of ride quality is one of such performance indices. Ride quality is interpreted as the capability of the railroad vehicle suspension to maintain the motion within the range of human comfort and or within the range necessary to ensure that there is no damage to the cargo it carries.
- Riding quality and comfort experienced by a passenger depend upon acceleration, the rate of change of acceleration &effect of mechanical vibration on the occupantand some other factors as like noise, moisture, temperature etc, and expressed by the following equations:

$$Ride\_Quality(W_q) = \left(a^3 B^3\right)^{\frac{1}{10}}$$

$$Ride\_Comfort(W_c) = \left(a^2 B^2\right)^{\frac{1}{6.67}}$$

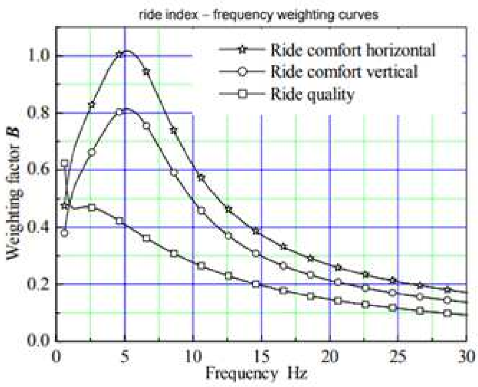
Where, **a** is the amplitude of acceleration in cm/s^2 and **B** the acceleration/frequency weighting factor.

- **The weighting factors** are defined in different direction,as shown in the diagram, by (i) the weighting function B for vehicle ride quality (ii) the weighting factor B for ride comfort in the horizontal direction (B_W)and (iii) the weighting factor B for ride comfort in the vertical direction (B_s).

The total ride index (W_z) can be obtained for a continuous spectrum by integration over the given range of frequencies:

$$Ride\_Index(W_z) = \left(\int_{f1}^{f2} a^3 B^3 df\right)^{\frac{1}{10}}$$

It is calculated from the dynamic response and defined by a number with no units.



Riding Evaluation Scales

Ride evaluation scales – ride quality and ride comfort

Ride index Wz	Ride quality
1	Very good
2	Good
3	Satisfactory
4	Acceptable for running
4.5	Not acceptable for running
5	Dangerous
Ride Index Wz	Ride comfort
1	Just noticeable
2	Clearly noticeable
2.5	More pronounced but not unpleasant
3	Strong, irregular, but still tolerable
3.25	Very irregular
3.5	Extremely irregular, unpleasant, annoying; prolonged exposure intolerable
4	Extremely unpleasant ; prolonged exposure harmful

❑ Requirements of electric traction

- High adhesion co-efficient so that tractive effort at start is high and rapid acceleration can be gained
- Speed control should be easy
- The wear caused on the brake shoes, wheel tyres and the track should be minimum
- Locomotive should be self contained and able to run on any route
- It should be possible to use regenerative braking
- The equipment should be capable of withstanding large temporary loads
- Pollution free
- No interference to the communication lines

❑ AC Traction Drive Vs DC Traction Drive

- **If the electric actuating mechanism is driven by DC motor, we call it DC drive system. If the actuating mechanism is driven by AC motor, we call it AC drive system,**
- **The AC Drive (alternating current), also known as Variable Frequency Drive**, works by converting the traction alternator output to DC (direct current) and reconverting it to a variable frequency AC which powers AC traction motors. The motors can have a speed range of zero to maximum rpm.
- The primary advantages of AC traction are adhesion levels up to 100% greater than DC and much higher reliability and reduced maintenance requirements of AC traction motors.

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❑ Traction motor selection/features

ELECTRICAL FEATURES

- ***High starting torque*** - *must be capable of developing high starting torque, specially when train is to be accelerated at a reasonably high rate as in case of urban or suburban services.*
- ***Desirable Speed-Torque and current-torque Characteristics*** *(as motor output proportion to (torque x speed)*
- ***Parallel running*** *- speed-torque and current-torque characteristics should be such that when the traction motors (2 or 4 or 6 motors) are operated in parallel and mechanically coupled, they share the load almost equally.*
- ***Overload capability***
- ***Simple speed control***
- ***Possibility of dynamic or regenerative braking***
- ***Better commutation***
- ***Capability of withstanding voltage fluctuations ,and temporary interruption of supply***

MECHANICAL FEATURES

- ***Light in weight.***
- ***Small space requirement.***
- ***Totally enclosed if mounted underneath the locomotive/motor coach to protect against ingress of dirt, dust, water and mud***
- ***Robust to withstand continuous vibration.***

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❑ Traction Motors/Drives

- No motor meets the aforesaid requirements. Some of the motors which finds application in traction are:

1. D.C series motors.
2. Single phase A.C series motors
3. Repulsion motors.
4. Three-phase Induction motors
5. Linear Induction motors

- Most suitable motors for DC systems are the DC series whereas for AC system the single phase AC series commutator motors and 3-phase induction motors are employed .

❑ Traction motor in India

Using single phase A.C. series commutator motor.

Using D.C. motor with tapped transformer and rectifier.

Using phase converter and induction motors.

Causes for favoring DC Series motors

Develops high torque at low speeds and low torque at high speed, exact requirement of the traction units

Torque is independent of the line voltage and thus unaffected by the variations in the line voltage.

D.C. series motors are less costly, however for some H.P more efficient and requires less maintenance than A.C. series motor.

Rail conductor system of track electrifications which is less costly with D.C. system than with A.C. system

Causes for favoring DC Series motors

The field flux varies as the armature current, as in the case of series motor, torque corresponding to the given armature current. Therefore, is independent of line voltage & thus unaffected by the variations in the line voltages.

Commutating properties of series motor are also very good as increases in the armature current as a result of heavy load torque results in the decrease of armature speed. This reduces the magnitude of e.m.f induced in the coils under going commutation which helps in achieving sparkless current collections

In case of dc series motor , upto the point of magnetic saturation, torque developed in proportional to the square of the current. Therefore, dc series motor requires comparatively less increased power input with the increase in load torque. Thus the series motor are capable of withstanding excessive loads.

Speed of dc series motor can be controlled by various methods.

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Causes for favoring DC Series motors

The dc series motor is simple & robust in construction.

The dc series motor, owing to its characteristics, is most suitable for urban & suburban services where high rate of acceleration is essential.

Description:

The traction motor is a four pole DC series motor in which field winding is connected in series with armature. It is a forced ventilated machine arranged for axle mounting on sleeve bearing.

Transverse movement is limited by the flanges of axle suspension bearing. An electric locomotive as well as diesel-electric locomotive in indian railway contain six dc traction motors at once.

Rating:

A traction motor has following ratings:

Voltage	-	285 volts
Current	-	980 ampere
Speed	-	360 rpm
Power	-	248 kw

Draw back

The main drawback of dc series motor are commutation Which restricts speed, current & voltage. Therefore is a risk of flash over & the brush gear requires considerable maintenance.

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Suitability of AC series Motors

This motor has surpassed the d.c series motor in terms of size, weight cost for the same rating.

For a given KW rating ac series motor is 1.5 to 2 times in size & weight of the corresponding dc series motor.

The construction cost of an ac series motor is much more than of a dc series motor.

The starting torque of a.c single phase motor is lower than that of dc series motor due to poor power factor at the start.

A.C single phase motor are not suitable for urban & suburban services, it requires high acceleration.
However, single phase motors are extensively used for main lines services.

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Suitability of AC series Motors for Traction

The speed of an ac series motor may be controlled efficiently by taps on a transformer. Which is not possible in case of a dc series motor.

However, single phase ac series motor have better performance on reduced supply frequency says 25 Hz. The higher frequency results in higher leakage reactances & hence a relatively poor power factor.

The maximum operating voltage for these motors is limited to 400 volts

Three Phase Induction Motors- Provides constant speed operation, developing low starting torque drawing high starting current and complicated control networks makes it unsuitable for electric traction work.
Automatic regeneration is the main advantage in electric traction with this motor.

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Suitability of 3-phase Induction Motors for Traction

It has simple & robust construction.
Trouble free operation.
Less maintenance.
High voltage operation consequently requiring reduced amount of current.

High starting current is drawn by Induction motor. However, when motor is started at low frequency, it draws less starting current. Hence, this disadvantage is overcome.

3 phase induction motor requires 3 phase supply. But transmission of 3-phase supply requires 3 wires or 2 wires (rail is used as 3rd wire). So it is costly.

But in Kando system, transmission is done by single phase system and phase converter drives 3- phase induction motor. Hence, this disadvantage of costly transmission is overcome by kando system. Hence, 3 phase Induction motors are suitable for urban/ sub-urban railway systems.

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Suitability of 3-phase Induction Motors for Traction

With the development of thyristorised inverter circuits, it has now been possible to invert the supply and obtain a variable frequency supply which could be used for the 3- phase Induction motor & a very smooth speed control can be obtained.

Automatic regeneration are the main advantages of 3-ph. Induction motor for traction.

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❑Basic equations for any DC series, shunt, compound and separately excited motors

The basic equations that can be applied to **all series, shunt, compound and separately excited dc motors, are:**

$$T = K_e \phi I_a$$
$$V = E + I_a R_a$$
$$E = K_e \phi n$$

Where,

E = back emf in volt; ϕ = flux per pole in weber; V = supply voltage in volt; I_a = Armature current in Amp; R = Armature resistance in ohm; n = speed of armature in rad/sec; T = torque developed in motor in N-mt.

The speed equation of DC motor :

$$n = \frac{V}{k_e \phi} - \frac{R_a T}{(K_e \phi)^2}$$

❑For DC series motors

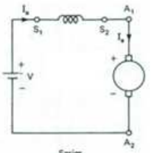
DC series motor

ϕ is proportional to armature current (I_a) and $\phi = K_f I_a$.

Thus,

$$T = K_e \phi I_a = K_e K_f I_a^2$$

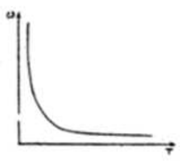
$$n = \frac{V}{\sqrt{K_e K_f}} \frac{1}{\sqrt{T}} - \frac{R_a}{K_e K_f}$$



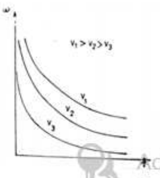
Series

- **Increase in torque (which is proportional to square of the armature current)** is accompanied by an increase in the armature current and therefore, an increase in flux.
- **As the flux increases with torque**, the speed must drop to maintain a balance between the induced voltage and the supply voltage. The characteristic is therefore, highly drooping.

Torque vs. current of series motor.

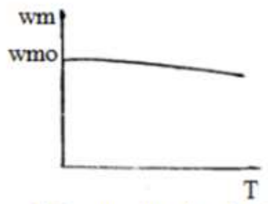


Speed vs. torque of series motor.

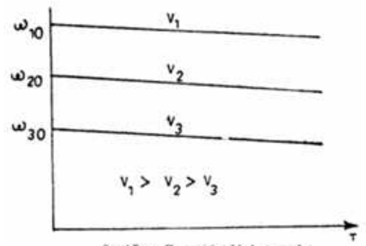


❑ DC shunt and separately excited motors

- **In the case of separately excited as well as shunt motors,** if the field voltage is maintained constant,and assuming the flux as constant, then **K_e ϕ =K (say)** constant This method is known as the constant torque method.



Speed-Torque ch. when load varies



Speed-Torque Characteristics of dc shunt motor for different armature voltages

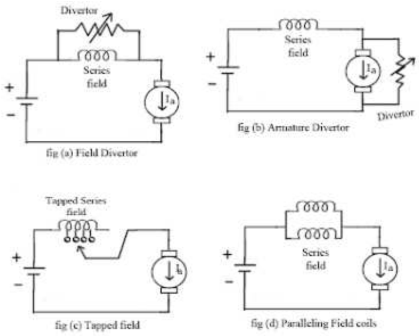
- The variable voltages can be obtained by phase controlled rectifier and DC-DC Chopper convertor.

❑ Traction motor control

- **Field flux control**
- **Armature resistance control (Rheostat control)**
- **Armature voltage control /Tap changer control**
- **Series parallel control**
- *Micro processor control*
- *Buck and boost method*
- *Metadyne control -*
- *Thyristor control – controlled rectification for variable DC voltage*
  - *Phase control*
  - *Chopper control*

1. Flux Control Method

- Field diverter: A variable resistance is connected parallel to the series field as shown in fig (a). This variable resistor is called as a diverter, as the desired amount of current can be diverted through this resistor and, hence, current through field coil can be decreased. Thus, flux can be decreased to the desired amount and speed can be increased.
- Armature diverter: Diverter is connected across the armature as shown in fig (b).



For a given constant load torque, if armature current is reduced then the flux must increase, as $T_a \propto \emptyset I_a$
This will result in an increase in current taken from the supply and hence flux Ø will increase and subsequently **speed of the motor** will decrease.

- Tapped field control: As shown in fig (c) field coil is tapped dividing number of turns. Thus we can select different value of Ø by selecting different number of turns.
- Paralleling field coils: In this method, several speeds can be obtained by regrouping coils as shown in fig (d).

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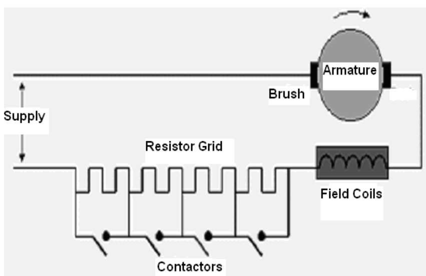
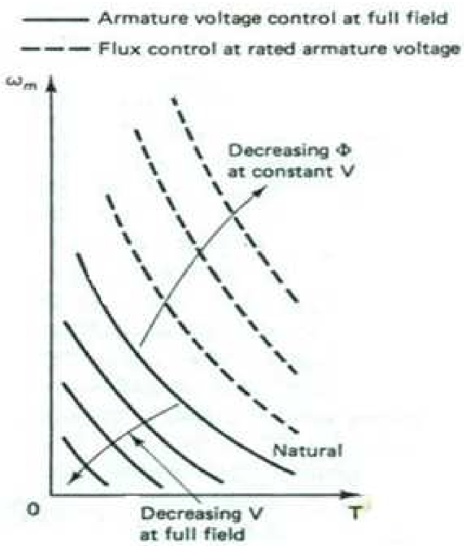
2. Rheostatic Control

By varying the armature circuit resistance, the current and flux both are affected.

The voltage drop in the variable resistance reduces the applied voltage to the armature, and as a result, the speed of the motor is reduced.

The **speed–current characteristic** of a series motor is shown in the figure





Speed-torque curves of series motors.

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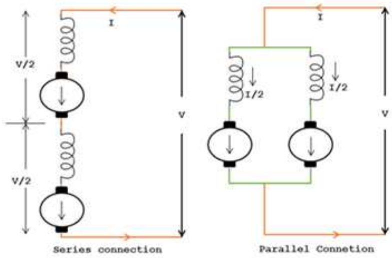
3. Series-Parallel Control of Dc series motors

This system is widely used in electric traction, where two or more mechanically coupled series motors are employed.

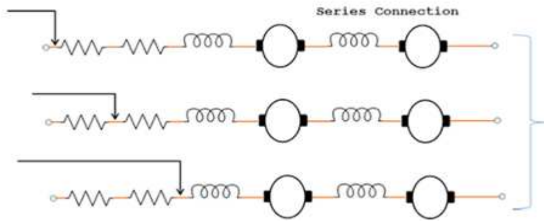
When in series, the motors have the same current passing through them, although voltage across each motor is divided.

When in parallel, the voltage across each motor is same although the current gets divided. ***This series parallel method is generally employed with the resistance control.***



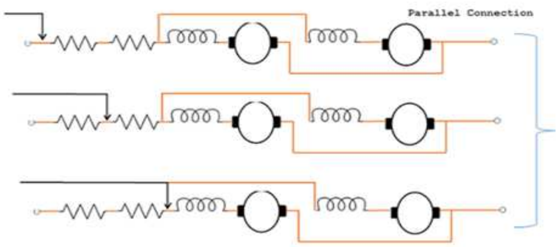
For low speeds, the motors are connected in series,

- At cessation, through a starting resistance the motors (say 2 –motors) are connected in series, and the starting resistance is gradually cut out step by step in rise with the speed.
- When the total resistance is cutout step by step the voltage supplied to each one of the motor is **about one-half of the line voltage and the speed is also increased about one-half times.**

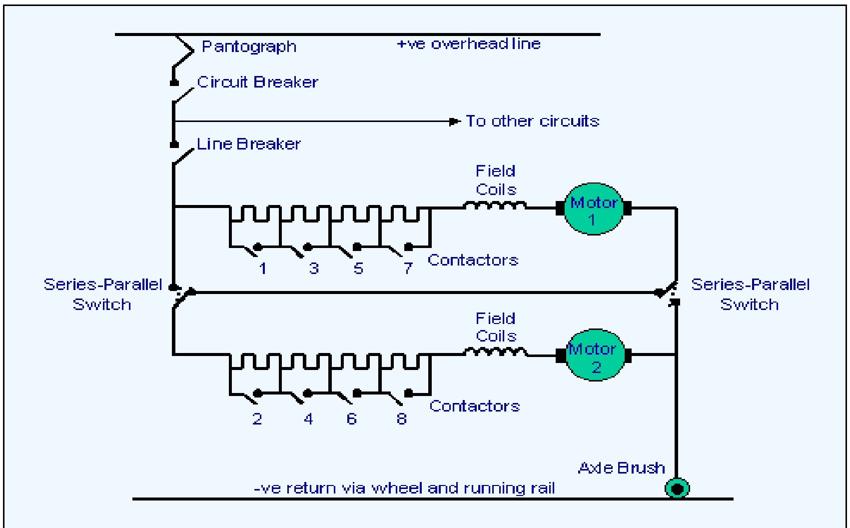


Series-Parallel Control of Dc series motors

- **For higher speeds, the motors are connected in parallel.**
  - Motors are to be connected in parallel and the resistance to be connected in series at the same time.
  - The starting resistance is again gradually reduced till full speed of the motor is achieved. **Each and every armature of the motor receives the full normal voltage and hence the speed is also high** . At that moment field control is attained.



Series-Parallel Control of DC series motors



Schematic of Simple DC Traction Motor Power Control Circuit

AC MOTOR DRIVE SYSTEM

- Since 1990's, with the rapid development of high power semiconductor devices and micro electronics technology, and the application of modern control theory and technology, people have made breakthroughs in AC motor drive system for adjusting speed.

- Nowadays, As a excellent drive and control technology, AC motor drive system has been widely used in the industry and railway traction system applications

AC series Motor

- *In a normal DC motor if direction of both field and armature current is reversed, the direction of torque remains unchanged. So when normal d.c. series motor is connected to an a.c. supply, both field and armature current get reversed and unidirectional torque gets produced in the motor hence motor can work on a.c. supply.* But performance of such motor is unsatisfactory for

i) *Tremendous eddy current losses in the yoke and field cores, which causes overheating.*

ii) Armature and field winding offer high reactance to a.c. due to which operating power factor is very low.

iii) The sparking at brushes is a major problem because of high voltage and current induced in the short circuited armature coils during the commutation period.

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❑ AC series Motor

Some modifications are required, **when it is called a.c. series motor**:

i) *To reduce the eddy current losses, yoke and pole core construction is laminated.*

ii) The power factor can be improved by reducing the magnitudes of field and armature reactance.

iii) Field reactance can be decreased by reducing the number of turns. But this reduces the field flux ($N \propto 1/\Phi$), increases the speed and reduce the torque.

iv. To keep the torque same it is necessary to increase the armature turns proportionately. This increases the armature inductance.

To compensate for increased armature flux which produce severe armature reaction, it is necessary to use compensating winding in series with the armature('conductively compensated'- Fig(a)). The flux produced by this winding is opposite to that produced by armature and effectively neutralizes the armature reaction. For motors to be operated on a.c. and d.c. both, the compensation should be conductive.

If compensating winding is short circuited on its self as shown in the Fig. (b), the motor is said to be 'inductively compensated'. In this compensating winding acts as a secondary of transformer and armature as its primary. The ampere turns produced by compensating winding neutralise the armature ampere turns.

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❑ CONTROL OF 3-phase AC INDUCTION MOTOR

Starting

- DOL
  - Applies full supply voltage
  - Draws low p.f. starting current of 600%, causing dip in supply voltage
- Star Delta connection
  - Initially motor winding is arranged in STAR and when the motor attains a speed of 70-80% of rated speed, winding is re-arranged in DELTA.
  - Compared to DOL
    - Starting Current is reduced by $1/\sqrt{3}$ (i.e. 57%) and
    - Starting Torque & Power is reduced by 1/3 (i.e. 33%)

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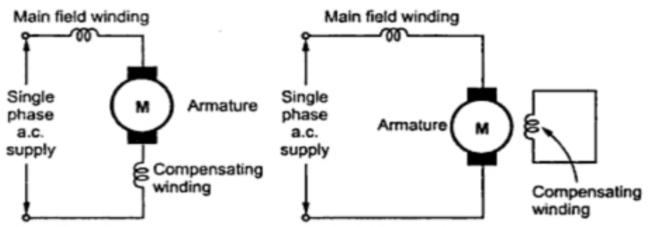
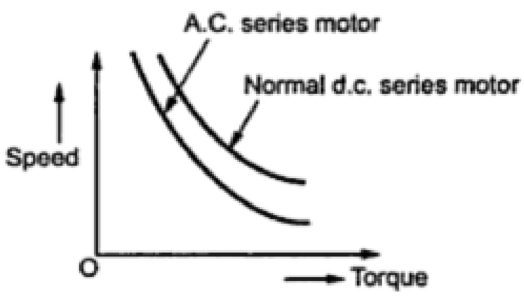


(a) Conductively compensated motor (b) Inductively compensated motor

- ➢ Speed-Torque Characteristics of ac series motor is similar to that of dc series motor
- ➢ The torque varies as square of the armature current and speed varies inversely as the armature current. The speed of such motor can be dangerously high on no load condition and hence it is always started with some load. Starting torque produced is high which is 3 to 4 times the full load torque.



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3-phase AC INDUCTION MOTOR

- Equivalent to Transformer where secondary is short circuited and free to rotate.
- The rotor can be either wound type or squirrel-cage type
- Three phase primary winding is mounted on Stator distributed spatially at 120 degree and fed with an AC supply.
- Resultant Field flux produced in the air gap, due to time and space varying each phase flux, is of constant magnitude but rotating at a synchronous speed of Ns
- (known as rotating magnetic field (RMF)
- Ns = 120(f/p), where, f - frequency and p - number of poles.
- This flux induces emf and current in the rotor.
- The current producer alternating flux around the rotor and causes it to rotate in the direction of stator flux and tries to catch N_s.
- In practice, rotor never succeeds in catching up RMF and always rotates at less speed than syn speed.

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3-phase AC INDUCTION MOTOR

- The difference between the syn. speed and actual speed (N_r) is called slip and given by ;
- % Slip = [$(N_s-N_r)/N_s$] *100
- The speed of IM is given by $N_r=N_s(1-s)$
- The induction of voltage and current in the rotor circuit will depend upon the relative motion between field and rotor.
- The electromagnetic torque (T) produced by three phase induction motor is given by,

$$T = \frac{3}{2\pi N_s} X \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}$$

- When the rotor is at standstill slip, s is one. So the equation of torque is,

$$T = \frac{3}{2\pi N_s} X \frac{E_2^2 R_2}{R_2^2 + X_2^2}$$

Where,
E_2 is the rotor emf, N_s is the synchronous speed, R_2 is the rotor resistance
X_2 is the rotor inductive reactance

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The torque produced by running three phase induction motor is given by

$$T \propto \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}$$

In low slip region $(sX)^2$ is very very small as compared to R_2. So, it can be neglected. So torque becomes

$$T \propto \frac{sE_2^2}{R_2}$$

Since rotor resistance, R_2 is constant so the equation of torque further reduces to

$$T \propto sE_2^2$$

We know that rotor induced emf $E_2 \propto V$. So, $T \propto sV^2$.

The equation above clears that if we decrease supply voltage torque will also decrease. But for supplying the same load, the torque must remain the same, and it is only possible if we increase the slip and if the slip increases the motor will run at a reduced speed. This method of speed control is rarely used because a small change in speed requires a large reduction in voltage,

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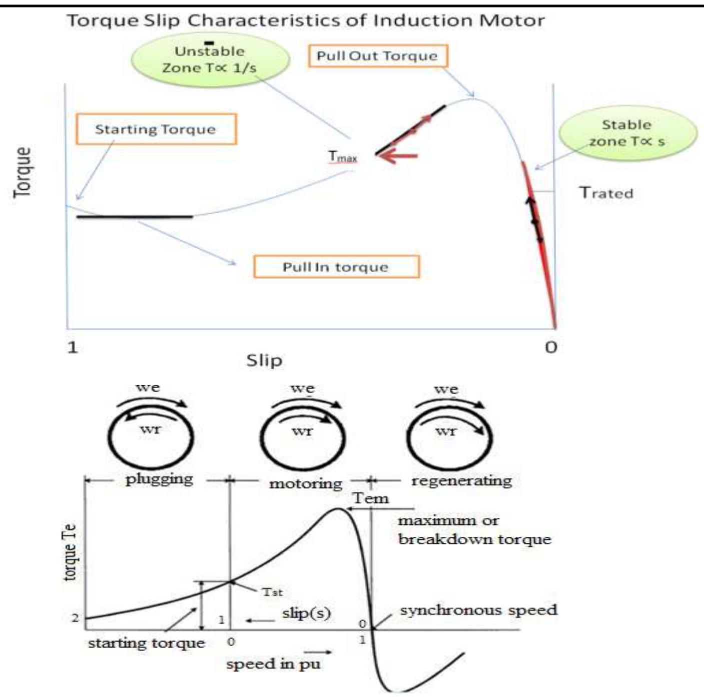

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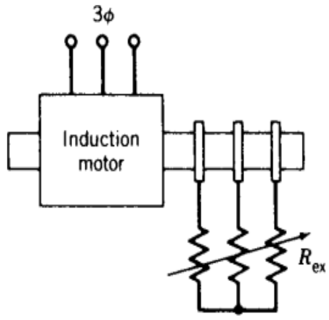
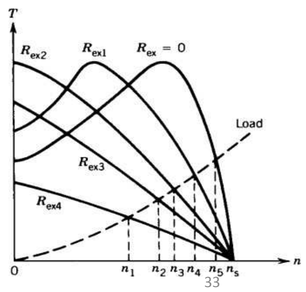
❑ Speed-Torque Control Techniques: OF 3-phase AC INDUCTION MOTOR

Control from stator side:

- **Rheostatic Control/supply voltage control**- Rheostat is added in the stator circuit & due to this voltage gets dropped
- **Pole-Changing Control** - Synchronous speed can be changed by changing the number of stator poles.

  Two separate windings in the stator are electrically isolated from each other and are wound for two different numbers of poles - Original sinusoidal mmf wave is modulated by another sinusoidal mmf wave having the different number of poles. Using a switching arrangement, at a time, supply is given to one winding only and hence speed control is possible.
- **Supply Frequency Control or V/f Control**
- **Cascade Control**
- **Combination of Cascading and Pole-Changing Control**





Control from Rotor Side

- ***Adding External Resistance on Rotor Side***
- ***Injecting Slip Frequency EMF into Rotor Side***
- ***Cascade Control Method***

❑ Braking in Traction in stopping Train

- **Both electrical and mechanical braking used.**
- **Mechanical braking provides holding torque.**
- **Electric Braking reduces wear on mechanical brakes, provides higher retardation, thus bringing a vehicle quickly to rest.**
- 3- Types of Electrical Braking used in Traction:
  - **Plugging or Reverse Voltage Braking**
  - **Rheostatic or Dynamic Braking**
  - **Regenerative Braking (the energy generated is supplied to the source)**
- Mechanical Braking
  - Compressed Air Brake
  - Vacuum Brake
  - Magnetic Track Brake

❑ Advantages & Disadvantages of Electric Braking in Traction

Advantages

(i) It is quite fast
(ii) It is quite cheap as far as maintenance part
(iii) Higher speed can be maintained
(iv) Heat produced during braking is not harmful
(v) It is free from fires and is smoother

Disadvantages

(i) It can stop the motor but it cannot hold it stationary.
(ii) It cannot be applied to all motors
(iii) Its initial cost is very high.

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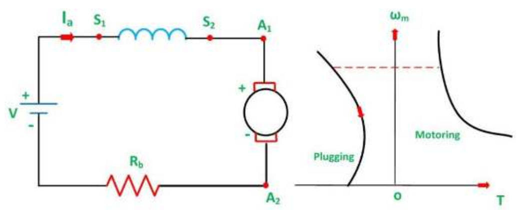
❑ Electric Braking : Plugging - Reverse current braking

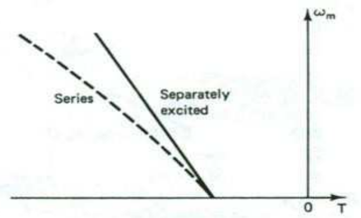
If the armature terminals (or supply polarity) of a separately excited (or shunt) motor when running are reversed, the supply voltage and the induced voltage will act in the same direction and the motor current will reverse, producing braking torque. This type of braking is called plugging.



The effective voltage across the armature will be almost twice the supply voltage. Thus, the armature current is reversed and a high braking torque is produced. An adjustable resistor R is placed in the circuit when changing the connections of armature to limit the current to safe value.

In the case of a series motor, either the armature terminals or field terminals should be reversed.

Plugging is an inefficient method of braking. Not only is power supplied by the load, but also the power taken from the source is wasted in resistances.



Speed-torque curves of dc motors under plugging.

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❑Dynamic / Rheostatic Braking

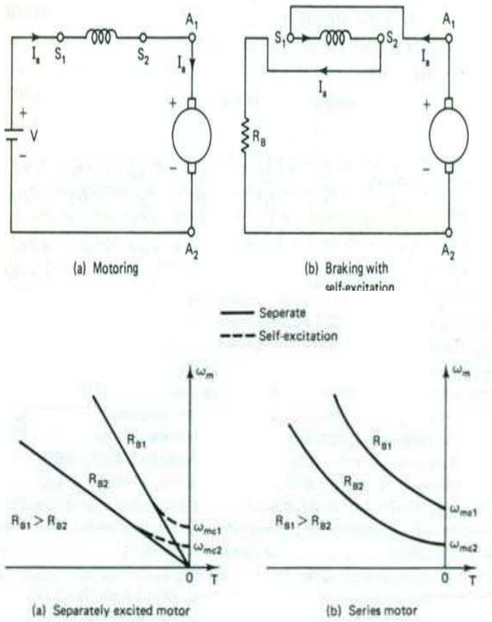
The motor which is at a running condition is disconnected from the source and connected across a resistance.

The rotor keeps rotating due to inertia and it works as a self-excited generator. The flow of the current and torque reverses.

During braking to maintain the steady torque sectional resistances are cut out one by one.

Series Motor:

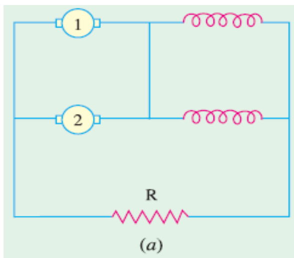
- ➢ For dynamic braking, the series motor is usually connected as a self-excited series generator. For the self- excitation, the current forced through the field winding by the induced emf aids the residual flux.
- ➢ This requirement is satisfied either by reversing the armature terminals or the field terminals.
- ➢ A suitable resistance is connected in series with the field to limit the current to a safe value.
- ➢ All the energy which is generated is dissipated in the form of heat in the resistance



Speed-torque curves of dc motors under dynamic braking.

For dynamic braking - (a) Equalizer Connection and (b) Cross Connection

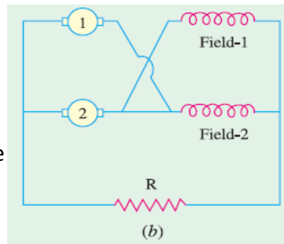
(a) Equalizer Connection



2 or more DC series motors employed in traction, are connected in parallel for braking, as series connection would produce too high voltage.
K.E. of the vehicle is utilized in driving the machines as generators, which is dissipated in braking resistance in the form of heat. **To ensure that the two machines share the load equally, an equalizer connection is used as shown in Fig-a.**

If it is not used, the machine whose acceleration builts-up first would send a current through the 2nd machine in opposite direction, causing it to excite with reverse voltage. So that the two machines would be short circuited on themselves. The current would be dangerously high. Equalizer prevents such conditions.

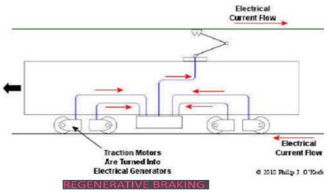
(b) Cross Connection



The field of machine-2 is connected in series with machine-1 Armature and the field of machine-1 is connected in series with machine -2 armature (Fig-b) . If the voltage of machine -1 is greater than that of 2, it will send greater current through field of machine-2, causing it to excite to higher voltage. At the same time machine -1 excitation is low, because of lower voltage of machine-2. Hence machine-2 will produce more voltage and machine-1 voltage will be reduced. *Thus , current in any of the motor will not go to a very high value, providing automatic compensation to operate the two machines satisfactorily.*

❑Regenerative Braking

- Regenerative braking is used especially where frequent braking and slowing of drives is required.
- It is most useful in holding a descending load of high potential energy at a constant speed.
- Regenerative braking is used to control the speed of motors driving loads such as in electric locomotives, elevators, cranes and hoists.
- ***Regenerative braking cannot be used for stopping the motor. It is used for controlling the speed down to about 16kmph, then rheostatic braking to about 6.5kmph and the mechanical braking is required to bring the locomotive to rest.***
- In order to achieve the regenerative braking, (i) the voltage generated by the machine should exceed the supply voltage and armature current should reverse and (ii) the voltage should be kept at this value, irrespective of machine speed.
- *The advantage is that the generated electrical energy is used instead of being wasted in rheostats as in the case of dynamic braking and plugging. Energy consumption for the run is considerably reduced by about 20-30%.*



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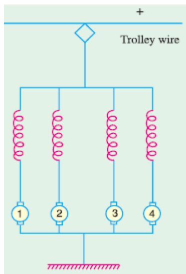
Regenerative Braking – Series Motor

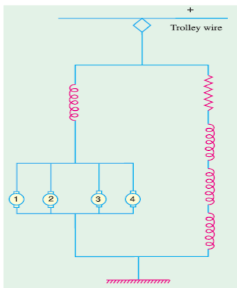
Series motor

- Fig. (a) shows the case of 4 series motors connected in parallel during normal running i.e. motoring.
- *Series motors cannot be used for regenerative braking in the same simple way, as the reversal of armature current will reverse the current through the field, and, therefore, the induced emf will also reverse.*
- However, a method of connection during regenerative barking, is to arrange the machines as shunt machines, with **<u>series fields of three machines connected across the supply in series with suitable resistance</u>** as shown in fig-b. The other field winding is still kept in series across the 4-parallel armatures. ***It acts like a compound generator.***

- ***<u>The New Delhi Metro</u>, after implementing regenerative capabilities, cut down its power/energy consumption substantially by about 30%.***



Motoring
(a)



Generating
(b)

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❑Regenerative Braking – 3-Phase Induction Motor

➢ Regenerative Braking

- An Induction motor works as a generator if mechanical speed is more than the synchronous speed.
- Regenerative braking occurs when the motors runs at a speed slightly above synchronous.
- But with a variable frequency source, regenerative braking of induction motor can occur for speeds lower than synchronous speed.
- When called upon to brake, the frequency applied to the stator is lowered below the mechanical speed and **what happens - torque and slip becomes negative with regeneration to start**. voltage is simultaneously reduced along with frequency.

➢Plugging

- Done by reversing the phase sequence of the motor i.e. by interchanging connections of any two phases of stator with respect to supply terminals.
- With that, the operation of motoring shifts to **plugging braking**.
- During plugging the **slip is (2 – s)**, where original slip of the running motor is **s**.

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❑Regenerative Braking – 3-Phase Induction Motor

Dynamic Braking or **rheostatic braking ----** ***Four types:***

- **AC Dynamic Braking-** The motor is made to run on a single phase supply by disconnecting any one of the three phase from the source, and it is either left open or it is connected with another phase.
- **DC Dynamic Braking -** The stator of a running induction motor is connected to a DC supply.
- **Self excited braking using capacitors** -Three capacitors are kept permanently connected across the source terminals of the motor to deliver enough reactive current to excite the motor and make it work as a generator.

  So, when the motor terminals are disconnected from the source it works as a self excited generator and the produced torque and field is in the opposite direction and the induction motor braking operation occurs.
- **Zero Sequence Braking -** All the three stator phases are connected in series and single phase AC or DC is connected across them. This type of connection is called zero-sequence connection, because current in all the stator windings are co-phasal.

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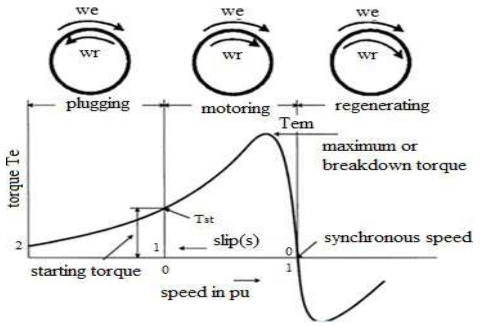
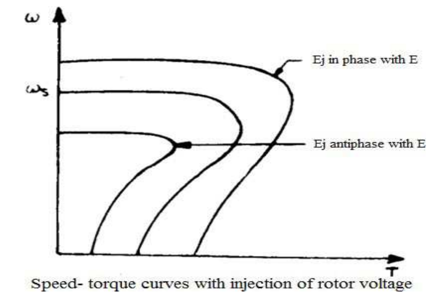




i) Motoring zone (0<s<1) ii) regenerating zone (s<0) iii) plugging zone (1<s<2)

- When slip increases, speed decreases but torque approaches maximum value. In the breakdown zone called quasi region, the stator drop is small and flux remains constant.

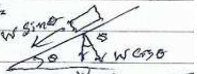
PROB: A 400 tonnes train travels down a gradient 1 in 70 for 120 secs, during which period its speed is reduced from 80 Kmph to 50 Kmph by regenerative braking. Tractive / Train resistance is 5 kg/tonne; Rotational inertia / rotating mass is 7.5 %; Overall efficiency is 75 %. Find the energy returned to the supply system.

1) Weight of the train $W = 400$ tonnes (Dead weight)
2) Rotational inertia $= 7.5\% = m$ (Rotational mass)
3) Effective weight $W_e = W + .075W = 1.075W = 430$ tonnes
4) Gradient $(G) = \frac{1}{70} \times 100\% = \frac{10}{7}\%$
5) Train Resistance / specific resistance $(r) = 5$ kg/tonne (dead weight) $= 5 \times 9$[illegible] N-m/
6) Overall efficiency $(\eta) = 75\%$
7) Period of Regeneration $= 120$ secs $(= t)$
8) During retardation, train speed reduced (V_1 to V_2): $V_1 = 80$ Kmph & $V_2 = 50$ Kmph
9) Energy regenerated and back to the supply ?

→ Tractive effort (F_g) to overcome the effect of gravity
$F_g = 98.1\,WG$ Newton $= 400 \times 98.1 \times 10/7$ (to be -ve) (supplying energy)

→ Tractive effort to overcome train resistance $(F_r) = W \cdot r \cdot 9.81$ Newton
$F_r = 400 \times 5 \times 9.81$ Newton (contributing to energy loss)

→ Net T.E during retardation $(F) = F_r - F_g$



$F = 400\left(5 \times 9.81 - 98.1 \times \frac{10}{7}\right) = 400(49.05 - 140.14)$ Newton
$= [-36,451]$ Newton (i.e energy may be gained)

→ Distance (S) travelled during retardation with de-celeration (β), $S = \frac{V_1^2 - V_2^2}{2\beta}$

So, $S = \frac{(V_1^2 - V_2^2)}{2\beta} \times \frac{1000}{3600} = \frac{(V_1 - V_2)(V_1 + V_2)}{2\beta} \times \frac{1000}{3600}$

$= \frac{(V_1 + V_2)}{2} \times \frac{1000}{3600} \times 120 \; (=t)$ seconds (as $t = 120$ sec)

$= \frac{80 + 50}{2} \times \frac{1000}{3600} \times 120 = 2167$ meters

→ Energy available during retardation (E_1) $= F \times S$

$E_1 = 36451 \times 2167 \times \left(\frac{1}{3600}\right) \times 1/1000$ kWh $= 21.94$ kWh

→ Accelerating train attaining speed of V_1 km/h is having K.E equal to $\frac{1}{2} m V_1^2 = \frac{1}{2} \frac{W_e}{g} \times V_1^2$ 5x

K-E stored $= \frac{1}{2} \times \frac{1000 W_e}{9.81 (=g)} \times \left(\frac{1000}{3600} V_1\right)^2$ kg-m

$= \frac{1}{2} \times 1000\, W_e \times \left(\frac{1000}{3600} V_1\right)^2$ N-m or watt-sec

$= \frac{1}{2} \times 1000\, W_e \times \left(\frac{1000}{3600} V_1\right)^2 \times \frac{1}{3600}$ watt-hr

$= 0.01072\, W_e V_1^2$ watt-hr

Similarly, K-E stored while the train is at speed V_2 km/h $= 0.01072\, W_e V_2^2$ watt hr.

→ Energy available for regeneration (E_2) =

$E_2 = 0.1072\, W_e (V_1^2 - V_2^2)$ Watt-hr.

$= 0.01072 \times 430 \times (80^2 - 50^2) \times \frac{1}{1000}$ kWh $= 17.97$ kWh

→ Total energy available for regeneration (avg) considering efficiency (η) of 75% is

$E = \eta (E_1 + E_2) = 0.75 (21.94 + 17.97)$ kWh

$\boxed{E = 29.93 \text{ kWh}}$

Traction Numerical :

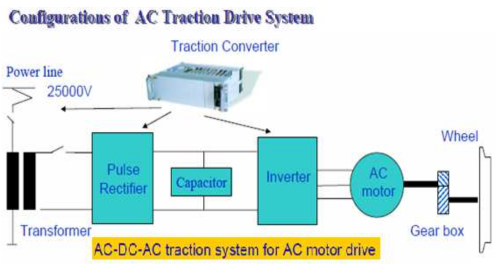
(i) Utilization of Electric Power and Electric Traction by J B Gupta

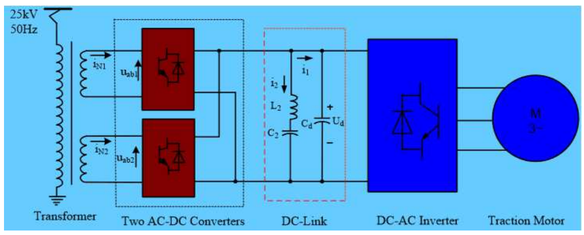
(ii) Utilization of Electric Power by N V Suryanarayana

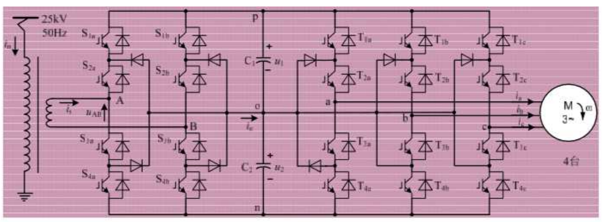
Recent trends in electric traction

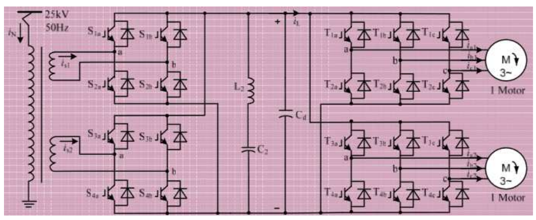
- Tap changer control
- Thyristor control
- Chopper control
- Micro processor control

Speed:
April, 4, 2007, TGV, 574km/h Paris
2011, 487.3km/h, , Beijing-shanghai, China;



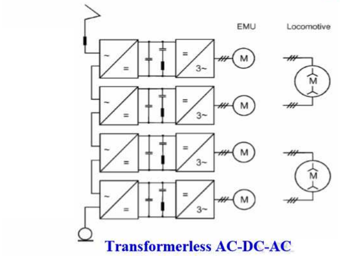






❑ Recent Trends in Technology Development

1. Transformerless Control Technique

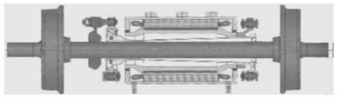


Transformerless AC-DC-AC Traction Drive system

2. Speed Sensorless Control Technology

Improving the reliability of traction drive system;
Reducing the size of traction motor (20%~30%)

3. PMSM Gearless Direct Drive Technology



SINGAPORE Mass Rapid Transit Corporation (SMRT) - six-car metro trains with **permanent-magnet synchronous traction motors** being fitted as part of the refurbisment of the existing drive equipment. Toshiba says the new traction motors will reduce power consumption by 30%, as well as cutting noise.

4. Four Quadrant PWM Rectifiers (2-Level/3-Level)

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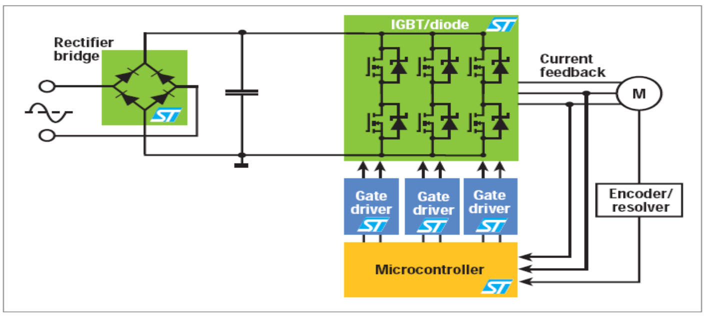
Micro processor control



High-frequency vector three-phase induction motor drive

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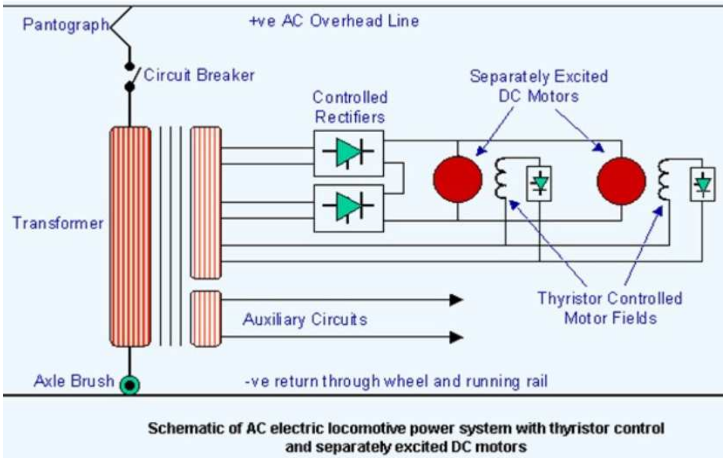
Thyristor control



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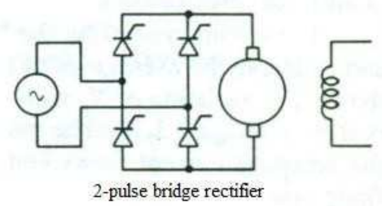
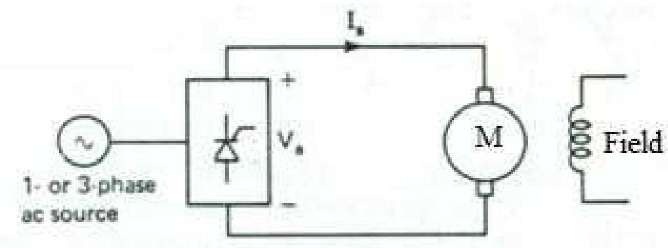
Phase controlled converter for speed control

- Controlled rectifier circuits, some are fed from a single-phase supply or from a 3- phase supply.
- Controlled rectifier circuits are classified as fully-controlled and half- controlled rectifiers.
- Single-phase controlled rectifiers are employed up to a rating of 10 kW and in some special cases up to 50 kW.
- Performance of a drive is improved when the rectifier pulse number is increased.
- Six-pulse operation is realized by employing the three-phase fully-controlled bridge rectifier. Twelve-pulse operation can also be obtained by connecting two six-pulse bridge controlled rectifiers.



Single-phase fully controlled rectifier (Two quadrant operation)



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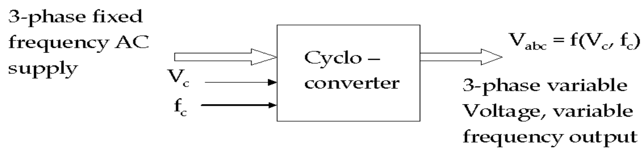
Cyclo- converter



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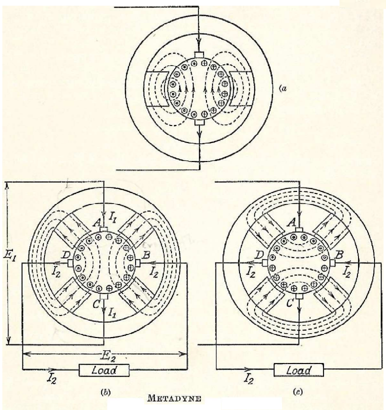
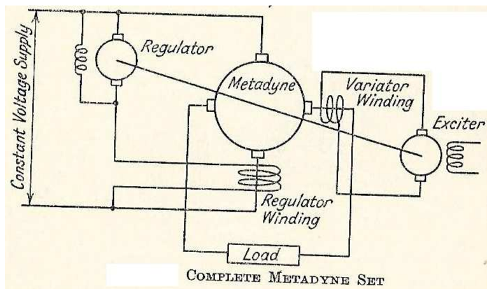
Metadyne

$$\left.\begin{aligned} E_1 &= KI_2 + k_v I_v \\ E_2 &= KI_1 + k_r I_r \end{aligned}\right\}$$





- In speed control of DC –motor, a great deal of energy gets wasted in the resistances connected in series with the motor, slowly cut out.
- To avoid such energy wastage, a rotating transformer for dc power with a transformation ratio that can be varied (continuously, if desired).It can draw power from a constant (DC) voltage source and deliver it at a constant current and varying voltage to an accelerating motor.It is the principle of Metadyne.
- The metadyne has a DC armature, but twice as many poles and brushes with the given armature as an ordinary dc machine.

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END