4.ELECTRIC TRACTION

Introduction

- The process of moving any vehicle is called traction . If the electric energy is use in this process is called electric traction.
- Classified broadly into groups namely:

✓ **Non-Electric traction system/Mechanical traction system:-**

Traction system which do not involve the use of electricity such as steam engine drive, IC engine drive etc.

✓ **Electric traction system :-**

The system which use electrical power for traction system i.e. for railways, trams, trolleys, etc. is called electrical traction.

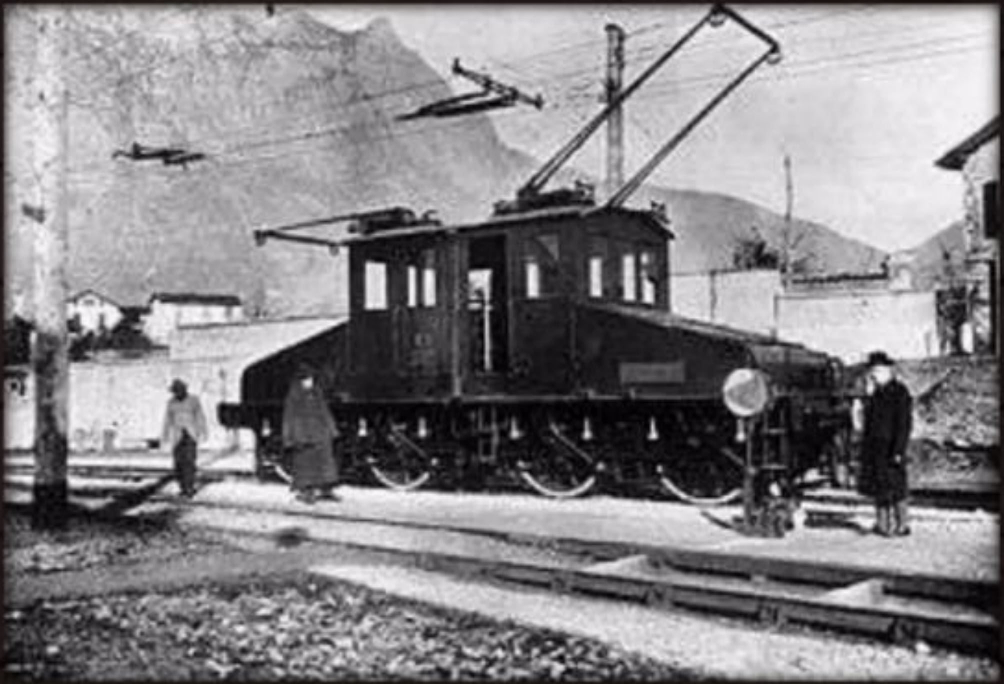
What is electric traction?

What's it all about?

- Electric traction is meant for locomotion in which the driving (tractive) force is obtained from electric motors (called as traction motors).
- It involves utilization of electric power for traction systems i.e., for railways, trams, trolleys etc.
- For traction purposes mostly 3-Phase Induction motors and d.c series motors are used and both have high starting torque, prevailing requirement for the high speed acceleration.

First AC Locomotive

- Italian Railways were the first in the world to introduce the electric traction.
- The world's first AC locomotive in Valtelina, northern Italy (1898–1902). Power supply: 3-phase 15 Hz AC, 3000 V (AC motor 70 km/h).
- It was designed by a Hungary company.
- The 106 km Valtellina line was opened on 4 September 1902.



Voltages Used For Electric Traction In India

- Typical Voltages used for electric Traction are 1.5kV DC and 25kV AC for mainline trains.
- Calcutta had an overhead 3kV DC system until the '60s.
- The Calcutta Metro uses 750V DC traction with a third-rail mechanism for delivering the electricity to the EMUs (Electric Multiple Units).
- The Calcutta trams use 550V DC with an overhead line (catenary) system with underground return conductors. The catenary is at a negative potential.
- The Delhi Metro uses 25kV AC overhead traction with a catenary system on the ground-level and elevated routes, and uses a rather unusual 'rigid catenary' or overhead power rail in the underground tunnel sections.
- Railway authorities purchases the power from the supply authorities and they give voltage supply of 132/110 KV at substation.

WHY ELECTRIC TRACTION SYSTEM?

- Cheapness : Low operation cost
- Cleanliness: Smoke and gas free
- Maintenance cost : 50% less than other steam engines
- Starting time and speed: Without loss of time.
- High starting torque : Uses of D.C & A.C series motor- very high starting torque.
- Braking : Regenerative breaking is used which feeds back energy.
- Saving in high grade coal : Saving of non-renewable energy source.

Requirements of ideal traction system

Normally, no single traction system fulfills the requirements of ideal traction system, why because each traction system has its merits and suffers from its own demerits, in the fields of applications.

The requirements of ideal traction systems are:

- ❖ Ideal traction system should have the capability of developing high tractive effort in order to have rapid acceleration.
- ❖ The speed control of the traction motors should be easy.
- ❖ Vehicles should be able to run on any route, without interruption.
- ❖ Equipment required for traction system should be minimum with high efficiency.

- It must be free from smoke, ash, durt, etc.
- Regenerative braking should be possible and braking should be in such a way to cause minimum wear on the break shoe.
- Locomotive should be self-contained and it must be capable of withstanding overloads.
- Interference to the communication lines should be eliminated while the locomotive running along the track.

REQUIREMENTS OF AN IDEAL TRACTION SYSTEM

- The starting tractive effort should be high so as to have rapid acceleration.
- The wear on the track should be minimum.
- The equipments should be capable of withstanding large temporary loads.
- Speed control should be easy.
- Pollution free.
- Low initial and maintenance cost.
- The locomotive should be self contain and able to run on any route.

Advantages Of Electric Traction

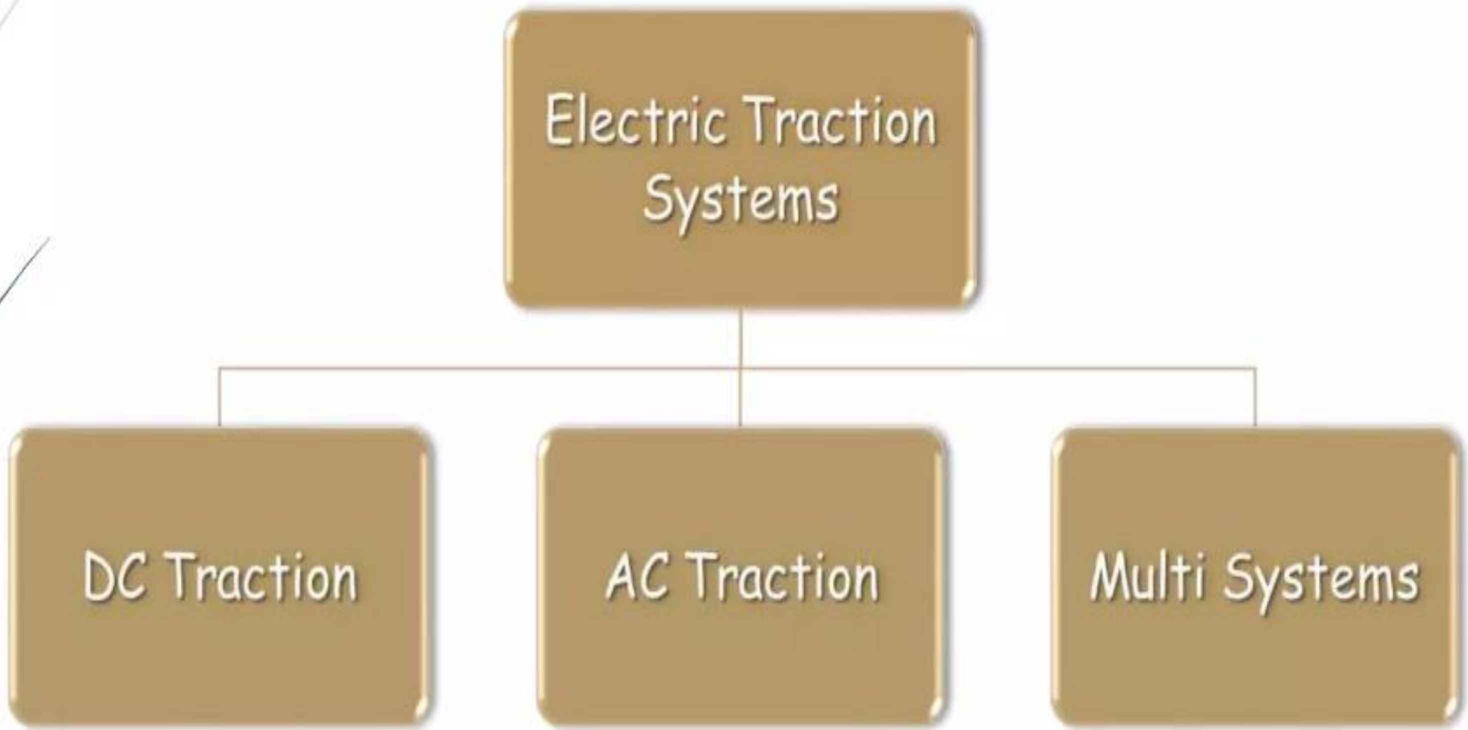
- Electric traction system is more clean and easy to handle.
- No need of storage of coal and water that in turn reduces the maintenance cost as well as the saving of high-grade coal.
- Electric energy drawn from the supply distribution system is sufficient to maintain the common necessities of locomotives such as fans and lights; therefore, there is no need of providing additional generators.
- The maintenance and running costs are comparatively low.

- The speed control of the electric motor is easy.
- Regenerative braking is possible so that the energy can be fed back to the supply system during the braking period.
- In electric traction system, in addition to the mechanical braking, electrical braking can also be used that reduces the wear on the brake shoes, wheels, etc.
- Electrically operated vehicles can withstand for overloads, as the system is capable of drawing more energy from the system.

Disadvantages of Electric Traction

- Electric traction system involves high erection cost of power system.
- Interference causes to the communication lines due to the overhead distribution networks.
- The failure of power supply brings whole traction system to stand still.
- In an electric traction system, the electrically operated vehicles have to move only on the electrified routes.
- Additional equipment should be needed for the provision of regenerative braking, it will increase the overall cost of installation.

TYPES OF ELECTRIC TRACTION SYSTEMS



SUPPLY SYSTEMS FOR ELECTRIC TRACTION:

- D.C system
- A.C system
  - Single phase
  - Three phase
- Composite system
  - Single phase AC to DC
  - Single phase to three phase

Supply Systems of Electric Traction

- The way of giving the power supply to locomotive unit is generally referred as traction electrification system.
- Presently, there are four types of track electrification systems are available based on the availability of supply. These are
- DC traction system
- Single phase AC traction system
- Three phase AC traction system
- Composite traction system

Systems of track electrification

- **DC System**
- **Single Phase AC System**
- **Three Phase AC System**
- **Composite System**
  - Single Phase - Three Phase System or Kando System
  - Single Phase - DC System

DC system

- In this system, D.C. series motors used for getting the necessary motive power, D.C. compound motors are also used for tramways and trolley buses where regenerative braking can be utilized.

- The operating voltage is from 600 V to 750 V for tramway and suburban railways and from 1500 V to 3000 V for mainline service.

Table 7.2 DC System

S. No.	Operating Voltage in Volts	Spacing between Sub-Station in km	Application
1.	600	3 to 5	Tramways, Trolley Bus
2.	1500 to 3000	30 to 40	Main Line Services

- The distribution system consists of one contact wire in case of tramways and two contact wires in case of trolley buses.
- The spacing of sub-stations depends upon the operating voltage and the traffic density of the route.

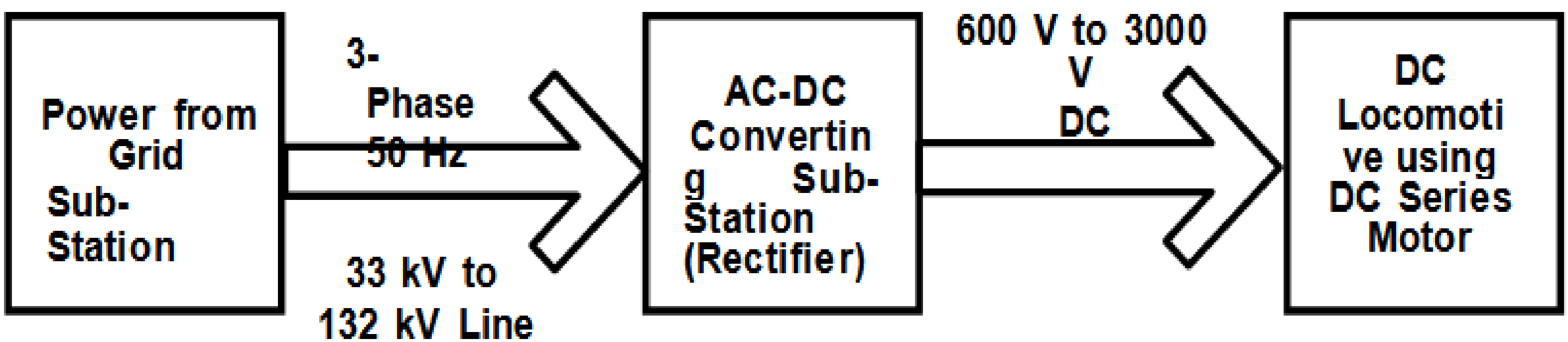


Figure 7.1 DC System

(a) Advantages

- DC series motor has better speed torque characteristics and smooth speed control.
- It offers high starting torque.
- It has low maintenance cost.
- Smaller weight per kW output.
- Batter speed control.
- Efficient braking system.

(b) Disadvantages

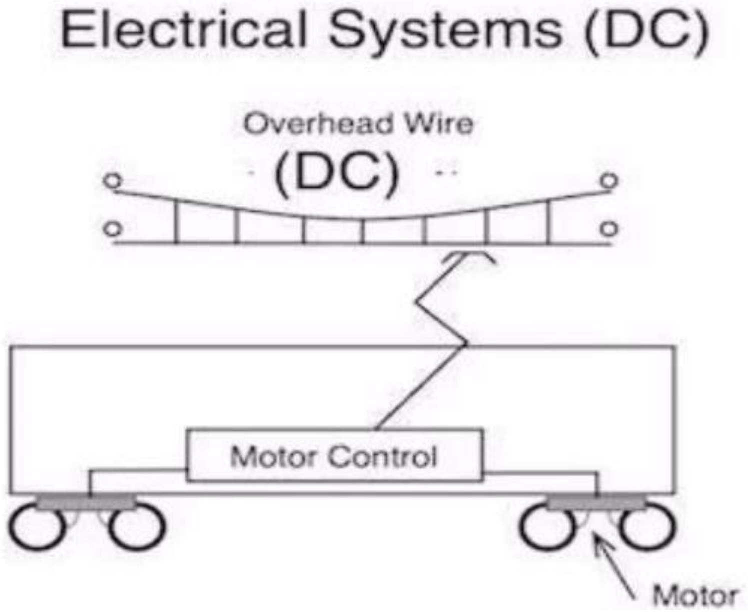
- This system has high cost of sub-station due to converting equipments.
- More number of sub-stations is required as they are spaced at shorter distance.
- Additional equipments like negative boosters are also required to maintain return voltage within specified limit.

DC Traction

- DC traction units use direct current drawn from conductor rail or an overhead line.
- The most popular line voltages for overhead wire supply systems – 15kV DC and 30kV DC.
- 600V - 750V DC volt range is used for third rail systems (additional rail is provided for supplying electricity to train and is called conductor rail).

Disadvantages :-

- Expensive substations are required at frequent intervals.
- The overhead wire or third rail must be relatively large and heavy.
- Voltage goes on decreasing with increase in length.



DC Traction

- DC traction units use direct current drawn from either a conductor rail or an overhead line.
- The most popular line voltages for overhead wire supply systems – 1500V DC and 3000V DC.
- 600V DC–750V DC volt range used for third rail systems (a means of providing electric power to a railway train, through a semi-continuous rigid conductor placed alongside or between the rails of a railway track and that additional rail is called conductor rail)
- Disadvantages- expensive substations are required at frequent intervals and the overhead wire or third rail must be relatively large and heavy.
- The low-voltage, series-wound, direct-current motor is well suited to railroad traction, being simple to construct and easy to control.

AC Traction

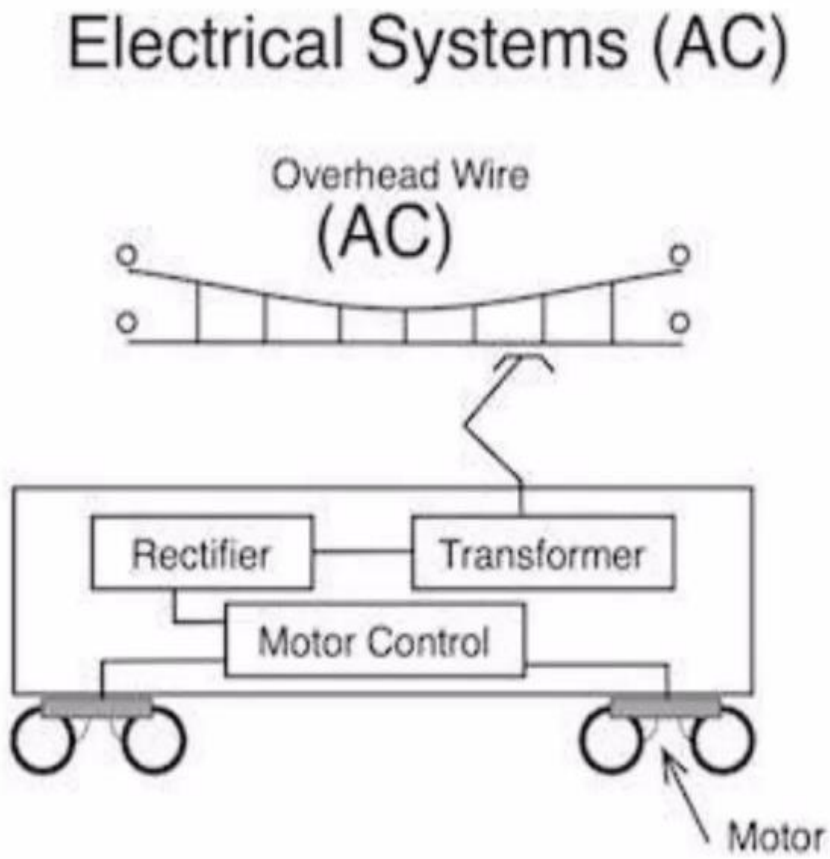
- AC Traction units draw alternating current from an overhead line.
- Typical Voltages Used are:-

  25 kV AC, 50 Hz

  25 kV AC, 60 Hz

Advantages :-

- Fewer substations are required.
- Lighter overhead current supply wire can be used.
- Reduced weight of support structure.
- Reduced capital cost of electrification.



AC Traction

- AC Traction units draw alternating current from an overhead line.
- Typical Voltages Used are:-
  - 15 kV AC, 16⅔ Hz (16.7 Hz)
  - 25 kV AC, 50 Hz
  - 25 kV AC, 60 Hz
- Fewer substations are required and the lighter overhead current supply wire can be used
- Reduced weight of support structure
- Reduced capital cost of electrification

WAG-9
Rated Power-5000 HP
Traction System- 25KV AC
Speed- 140 Km/hr
Traction Motor- DC Motor

Single phase AC System

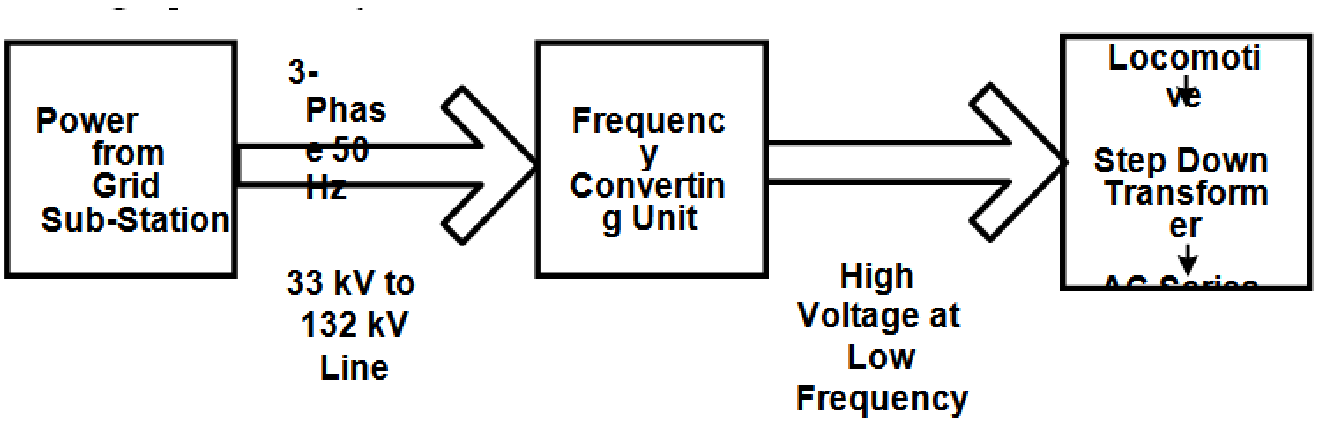


Figure 7.2 Single Phase AC System

(a)In single phase AC system ac series motors are used for getting necessary motive power

(b).The voltage employed for distribution network is 15 to 25 kV at 25 Hz, which is stepped down on locomotive to a low voltage suitable for supplying to single ac series motor.

- The spacing of substation is 50 to 80 km.
- The change of supply frequency become necessary because of
  - Batter performance.
  - Improves its commutation properties, power factor and efficiency.
  - Reduces the line reactance and hence the voltage drop.
- AC single phase system is invariably adopted for main line service.

The three phase AC system

- In this system 3-phase induction motor operating at 300 to 3600 V and low frequency are employed for getting the required motive power.
- The 3-phase induction motor
  - Simple
  - Robust in construction
  - High operating efficiency
  - Automatic regenerative braking without required any additional equipment.

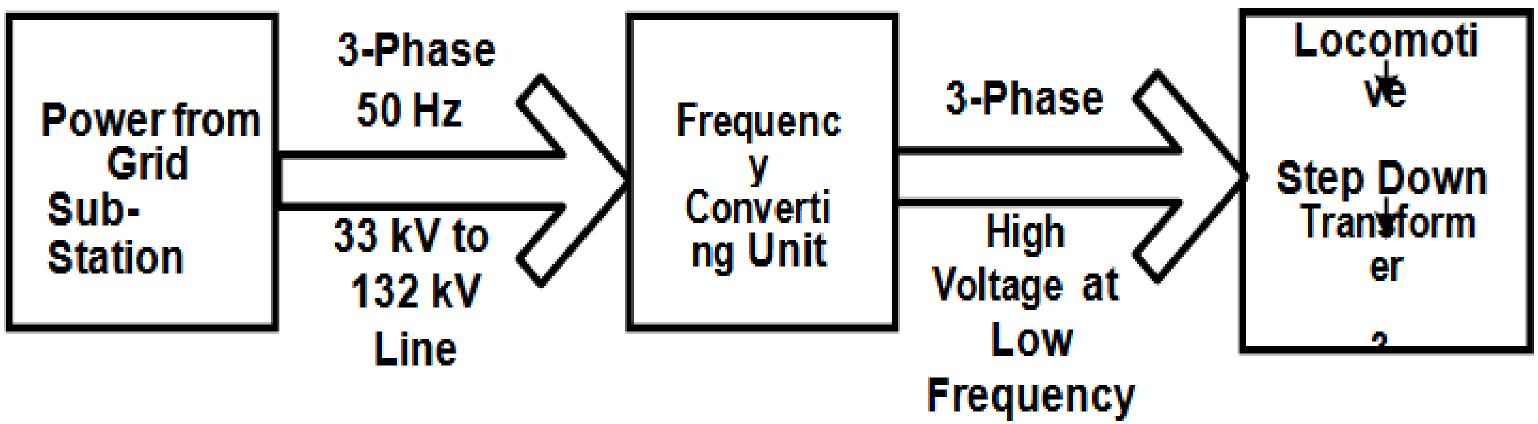


Figure 7.3 Three Phase AC System

- Drawbacks
  - Low starting torque
  - High starting current
  - Two overhead contact wires

Multi Systems

- Multi-system trains are used to provide continuous journeys along routes that are electrified using more than one system.
- One way to accomplish this is by changing locomotives at the switching stations.
- These stations have overhead wires that can be switched from one voltage to another.
- Another way is to use multi-system locomotives that can operate under several different voltages and current types.

In Europe, it is common to use four-system locomotives (1.5 kV DC, 3 kV DC, 15 kV 16⅔ Hz AC, 25 kV 50 Hz AC).

Multi Systems

- Because of the variety of railway electrification systems, which can vary even within a country, trains often have to pass from one system to another. One way to accomplish this is by changing locomotives at the switching stations.
- These stations have overhead wires that can be switched from one voltage to another and so the train arrives with one locomotive and then departs with another.
- Often, this is inconvenient and time-consuming Another way is to use *multi-system locomotives* that can operate under several different voltages and current types.

  In Europe, it is common to use four-system locomotives (1.5 kV DC, 3 kV DC, 15 kV 16⅔ Hz AC, 25 kV, 50 Hz AC)

The kando system (single phase to three phase system)

- In this system single phase high voltage (25 kV) at normal supply frequency is used to distribute power.
- The locomotive which carries a phase convertor which converts single phase AC to three-phase AC. The three-phase power is then fed to three-phase induction motors for getting necessary motive force.
- In this system only one contact wire of overhead system which is overcome the disadvantage of 3 phase AC system
- This system was adopted in Hungary in 1932.

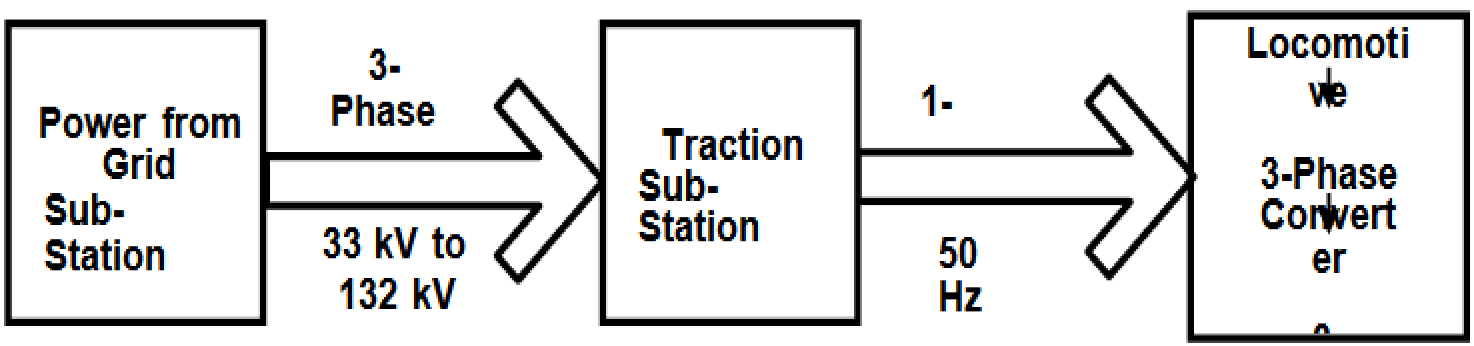


Figure 7.4 Kando System

Single phase to DC system

- This traction system is most popular and widely used system everywhere. It combines the single phase high voltage AC distribution at industrial frequency with DC series motor traction.

- In this, the overhead line carries single phase, 25KV, 50 Hz supply which is then stepped down to a desired range using step-down transformer located in the locomotive unit itself.

- This single phase supply is then converted into DC using rectifier (in the locomotive) and then applied to DC series motor.

- The advantages of this system include higher starting efficiency, less number of substations, simple substation design and lower cost of fixed installations.

Advantages of AC Traction Systems

- High power-to-weight ratio than forms of traction such as diesel or steam that generate power requiring on board prime mover.
  higher power-to-weight ratio, resulting in
  - Fewer locomotives
  - Faster acceleration
  - Higher practical limit of power
  - Higher limit of speed
  - Higher hauling capability
- No exhaust fumes or carbon emissions
- Less noise pollution (quieter operation)
- The maintenance cost of an electric locomotive is nearly 50% of that for a steam locomotive. Moreover, the maintenance time is also much less.
- An electric locomotive can be started at a moment’s notice whereas a steam locomotive requires two hours to heat up.
- The motors used in electric traction have a very high starting torque. Hence, it is possible to achieve higher acceleration of 1.5 to 2.5 km/h/s as against 0.6 to 0.8 km/h/s in steam traction.

Advantages of AC Traction Systems

- It is possible to use regenerative braking in electric traction system. It leads to the following advantages.
  - About 80% of the energy taken from the supply during ascent is returned to it during descent. And presently this returned energy is not sent back to public network but made available for other vehicles within the network
  - Goods traffic on gradient become safer and speedier.
- Since height of an electric locomotive is much less than that of a steam locomotive, its centre of gravity is comparatively low. This fact enables an electric locomotive to negotiate curves at higher speeds quite safely.
- electric trains may be powered from a number of different sources of energy (e.g. hydroelectricity, nuclear, natural gas, wind generation etc.) as opposed to diesel trains that are reliant on oil.
- electric trains do not have to carry around the weight of their fuel unlike diesel traction.
- A fully electrified railway has no need to switch between methods of traction thereby making operations more efficient. One country that approaches this ideal is Switzerland.

Disadvantages of AC Traction Systems

- Significant capital cost of electrification
- Increased maintenance cost of the lines
- Overhead wires further limit the clearance in tunnels
- Upgrading brings significant cost,

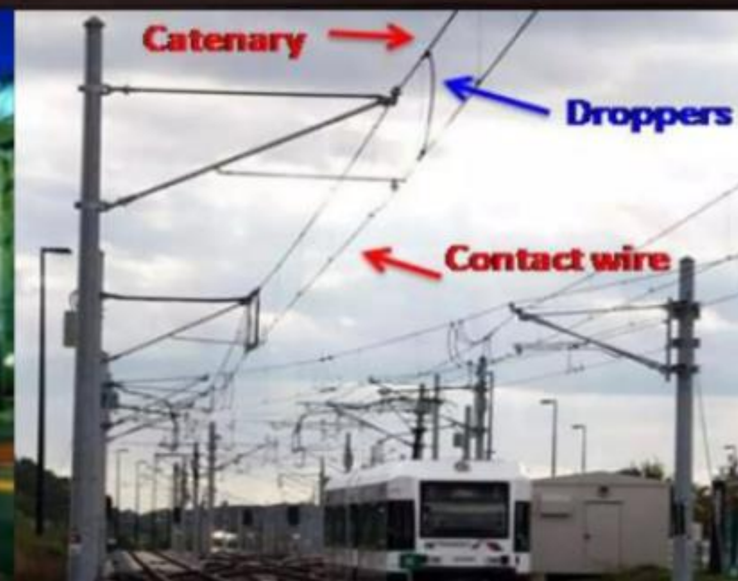
  especially where tunnels and bridges and other obstructions have to be altered for clearance
- Railway Traction needs immune power, with no cuts, warranting duplication of Transmission and Distribution systems, which obviously comes at a Premium Price.

System of Track Electrification

- Trolley wire or contact wire – suspended with minimum of sag so that contact between the trolley wire and current collector can be maintained at higher speeds.
- This wire is supported by another wire known as catenary.

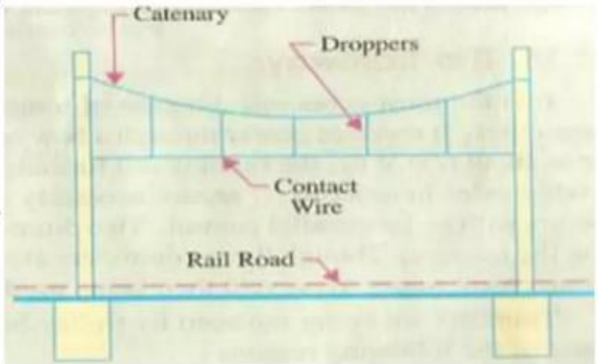
Two different types of Catenary construction can be used

- Single Catenary
- Compound Catenary



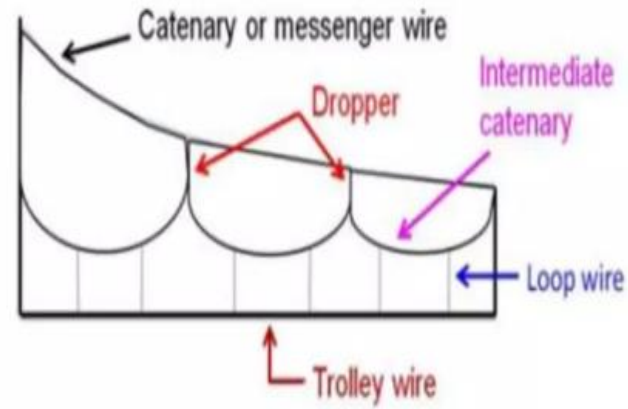
Type of Track Electrification

- Single Catenary Construction



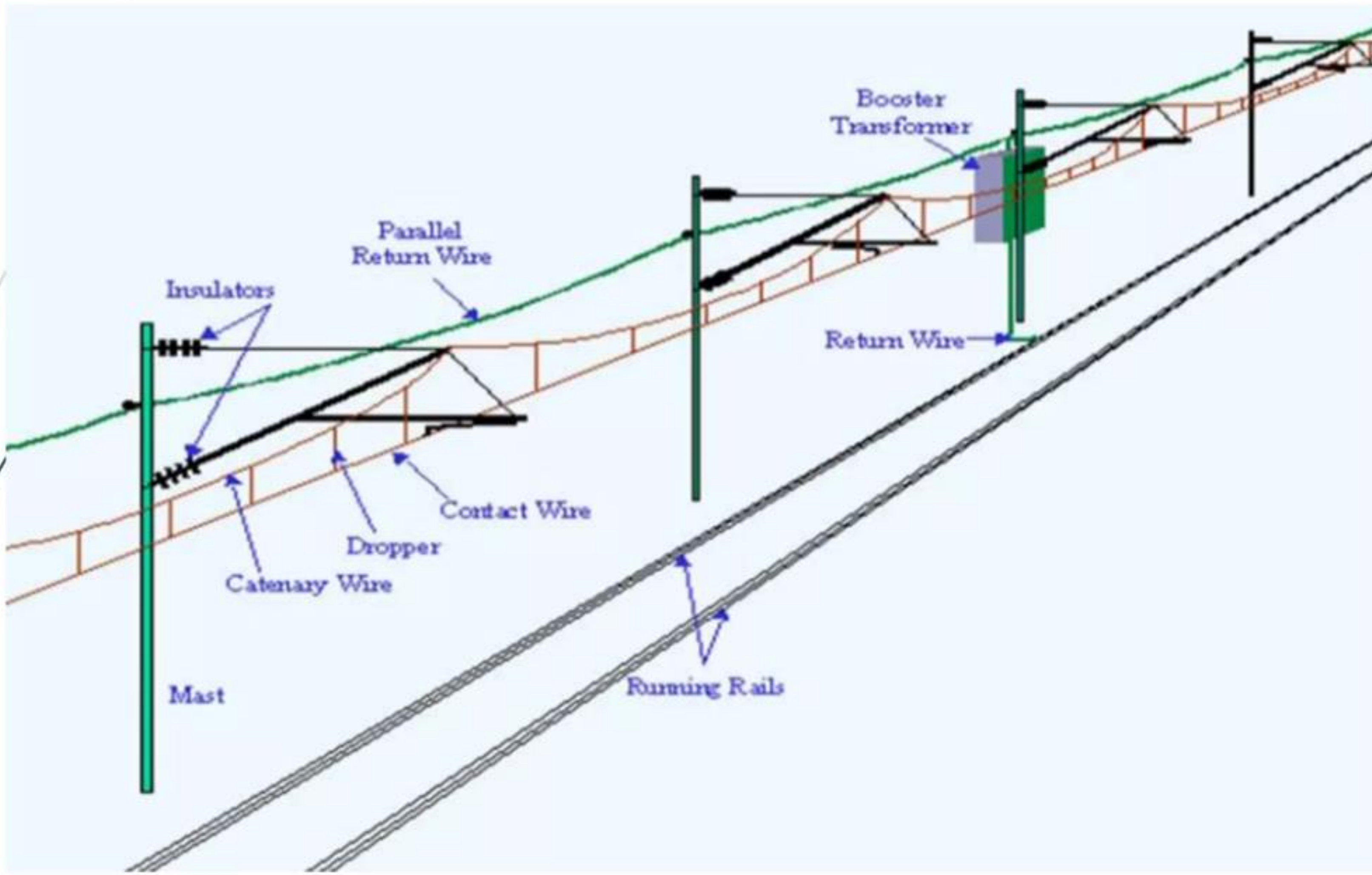
- Provided for speeds up to 120kmph.
- Span of catenary wire 45-90 m and sag of 1-2m.
- Relatively Cheaper
- Less Maintenance
- Suitable where traffic is denser more and operating speeds are low.

- Compound Catenary Construction



- Provided for speeds ranges 190-224kmph.
- Additional wire called intermediate wire is used to increase current carrying capacity i.e., to have increased traffic density.

Single Catenary Construction

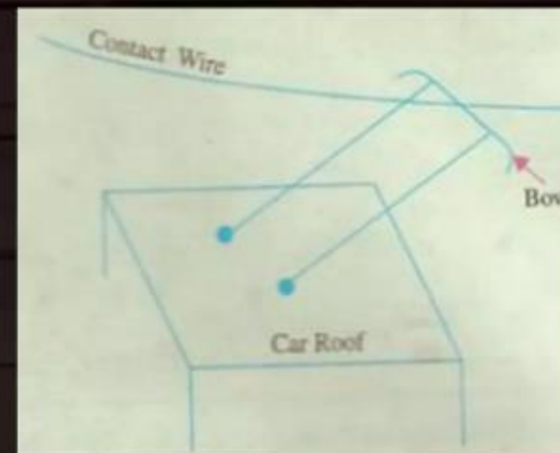


System of Track Electrification

- Current Collector- Current from the overhead wire is collected with the help of sliding contact collector mounted on the roof of the vehicle.
- Three types of Current collector-
  - Trolley Collector
  - Bow Collector
  - Pantograph Collector
- Trolley Collector- Used for Tramways and trolley buses, held in contact with Wire by spring.
- Suitable for low speeds upto 32kmph

System of Track Electrification

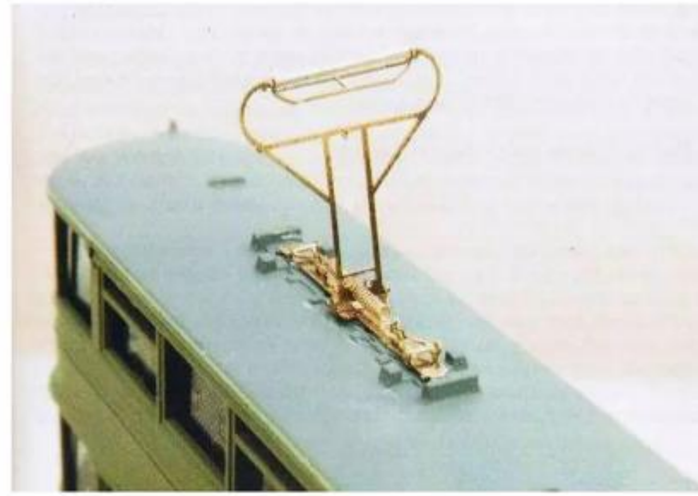
- **Bow Collector-** It uses a light metal strip or bow about 1 m long for current collection.
  Not suitable for railway work
  requiring speed of 120kmph and higher.
  Requires reversing arrangement of the bow



- **Pantograph Collector-** Main function is to maintain the link between overhead contact wire and power circuit of the locomotive at varying speeds in different climate and wind conditions
  This can be lowered or raised from cabin by air cylinders.

Types of current collector

- **Bow Collector-** A bow collector is one of the three main devices used on tramcars to transfer electric current from the wires above to the tram below. It has now been largely replaced by the pantograph.



- **Pantograph Collector-** Main function is to maintain the link between overhead contact wire and power circuit of the locomotive at varying speeds in different climate and wind conditions.

MAJOR COMPONENTS

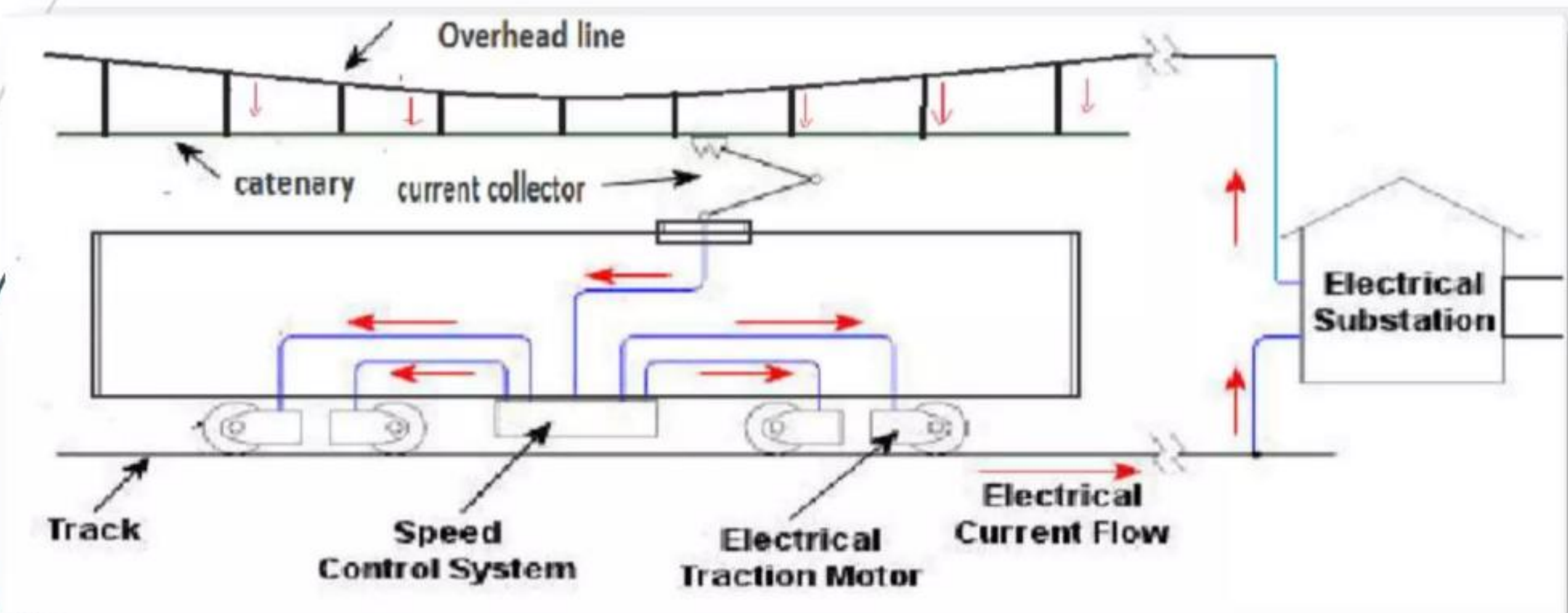
1-TRACTION SUBSTATION

2-OVERHEAD WIRING

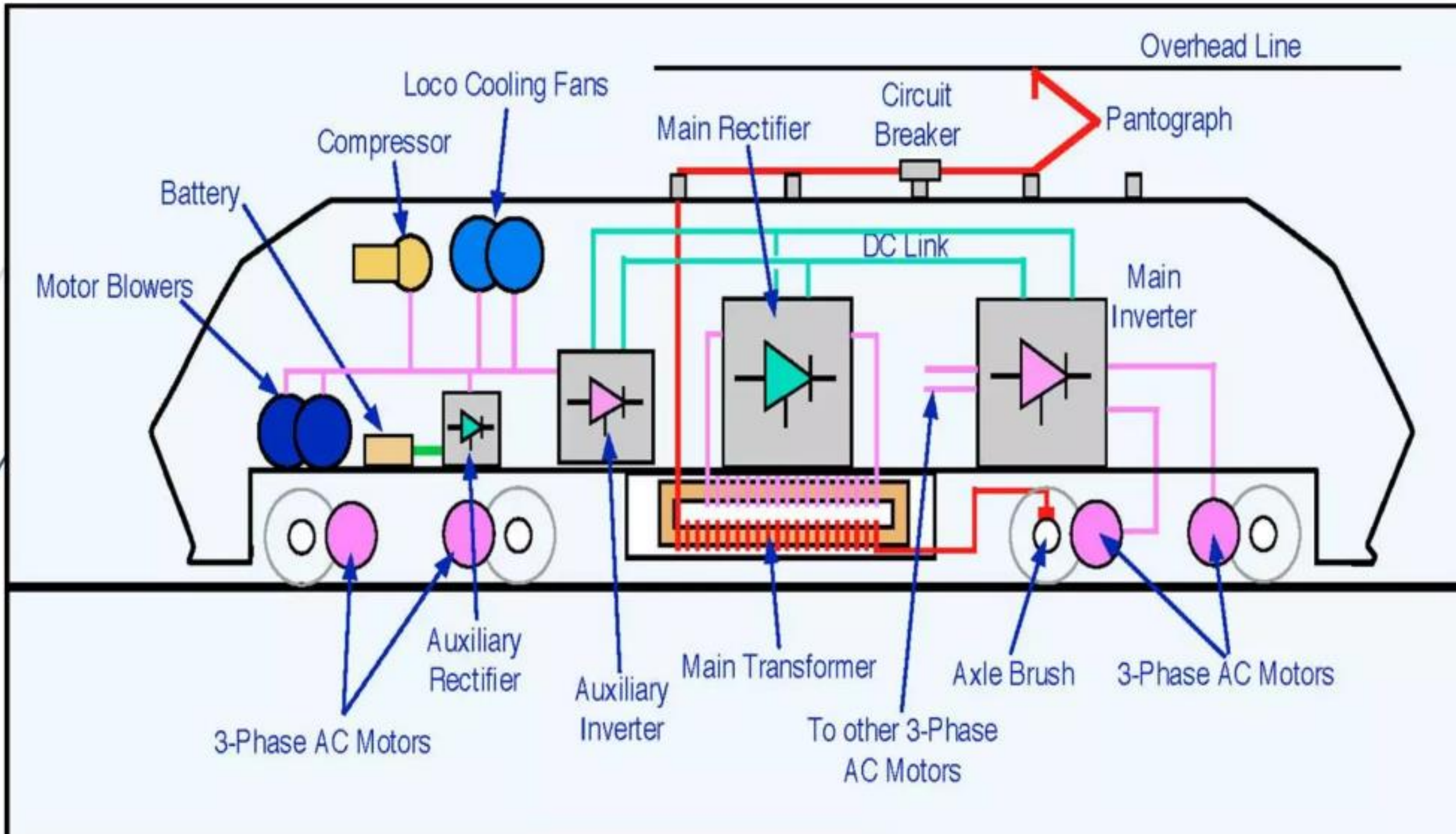
3-CURRENT COLLECTOR

4-TRACK

5-TRACTION SYSTEM (VEHICLE)



COMPONENTS OF AN A.C LOCOMOTIVE



Parts of Electric Locomotive:

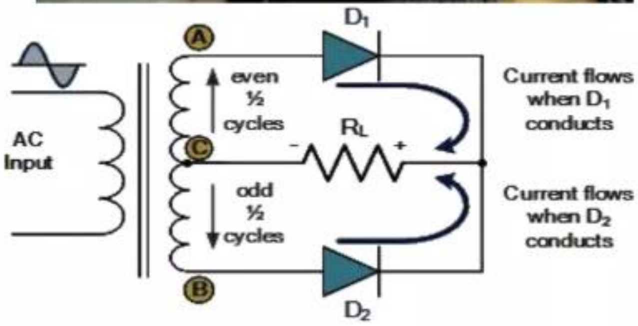
❖ TRANSFORMER

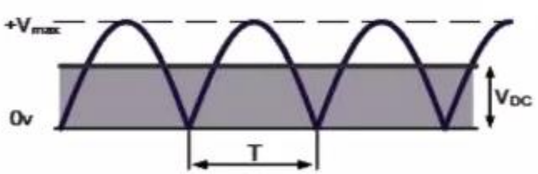
- The line voltage has to be stepped down before use on the train.
- Traction Transformers for trains and railway stock transform the overhead contact line voltage, which ranges mainly from 15 kV or 25 kV to voltages suitable for traction converters (0.7 kV and 1.5 kV)
- Normally transformers used are of rating 5600 kVA to 7200 kVA.

RECTIFIER

- A rectifier consist of thyristors and diodes which is used to convert AC to DC.
- Instead of conventional bridge rectifiers thyristors are used.
- A modern locomotive usually have at least two “Main Rectifier”.

$$V_{d.c.} = \frac{2V_{\max}}{\pi} = 0.637V_{\max} = 0.9V_{RMS}$$

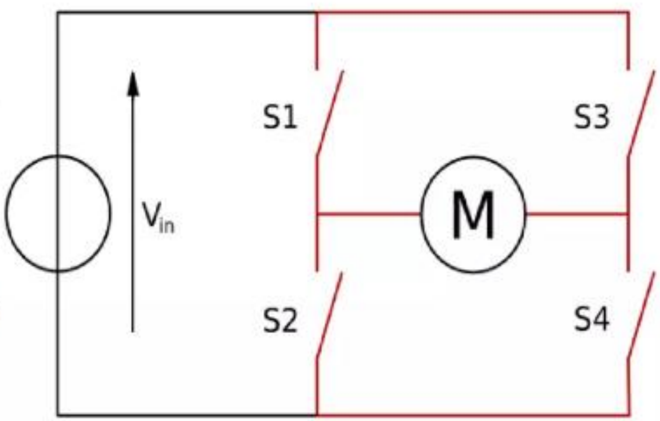


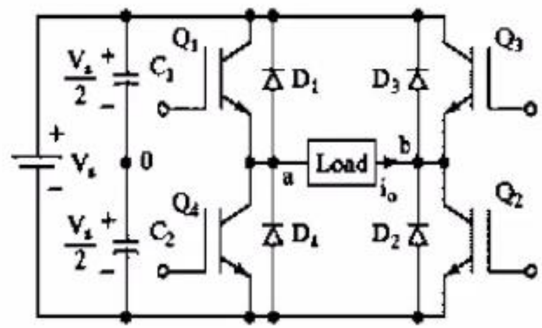


Output waveform

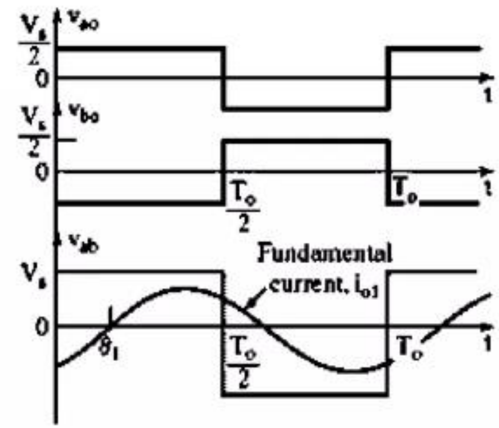
Inverter

- The inverters are used for converting DC power from a fixed voltage DC supply into an AC output voltage of variable frequency and fixed or variable output AC voltage.





(a) Circuit



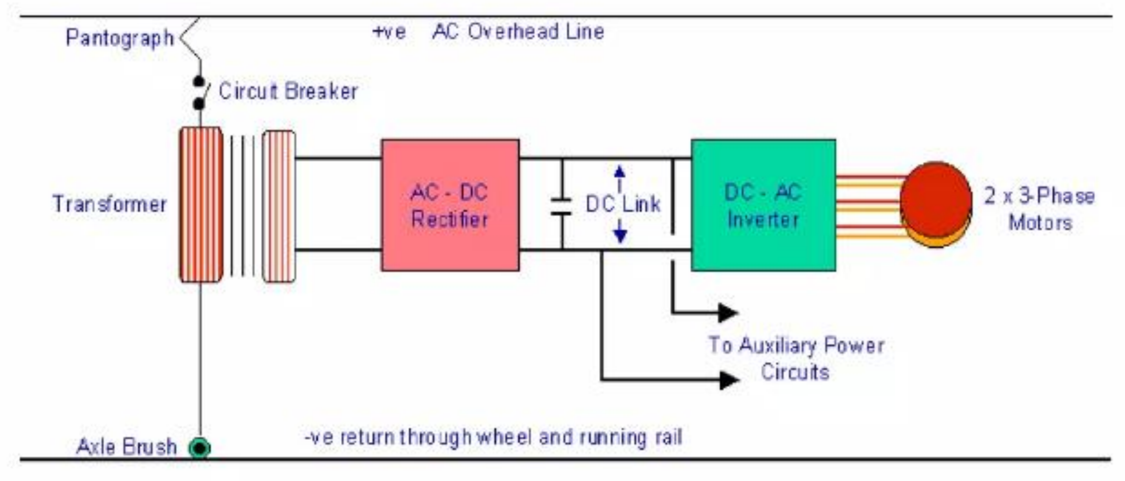
(b) Waveforms

$$V_{o(rms)} = \sqrt{\frac{2}{\pi}\int_0^{\pi} V_S^2\, d\theta} = V_S$$

$$V_{o1(rms)} = \frac{4V_S}{\sqrt{2}\pi} = 0.90V_S$$

DC Link

- Used on modern electronic power systems between the single phase rectifier and the 3-phase inverter.
- It is easier to convert the single phase AC from the overhead line to the 3-phase required for the motors by rectifying it to DC and then inverting the DC to 3-phase AC.



Schematic of single phase AC supply powering 3-phase AC motors

Train Lighting/Air Conditioning(TL/AC)

- Axel-driven generators are used to store batteries that power light , fans and electrical fittings.
- For powering air-conditioning equipment, an inverter was used to convert the DC output of a set of batteries to 415V AC.
- Older coaches use banks of 24V batteries while 110V in newer coaches.
- In Many air-conditioned coaches, a 'mid-on generator' (MOG) is used.

Train Lightning/Air Conditioning(TL/AC)

- Individual coaches are powered by axle-driven generators which charge storage batteries that power lights, fans and other electrical fittings.
- Older coaches use banks of 24V batteries while 110V in newer coaches.
- For powering air-conditioning equipment, an inverter was used to convert the DC output of a set of batteries to 415V AC. For some time now, however, groups of 110V alternators delivering 18-22kW each have been used to power air-conditioning equipment (the voltage is stepped up to 415V).
- In Many air-conditioned coaches, a 'mid-on generator' (MOG) is used; this is a 415V 3-phase alternator (either in one of the coaches or in a separate 'power-car'), the output from which is used both for the air-conditioning, and (stepped down to 110V) for the lights and fans.

A Glimpse on Indian Railways

- 4th largest network in the world, with 16 Zones, transporting over 10 billion passengers and over 1050 million tonnes of freight annually.
- IR employs about 1.6 million people, making itself the second largest commercial or utility employer in the world.
- With a view to reduce dependence on petroleum based energy IR has switched over electric traction. This also enables haulage of heavier loads at higher speeds, thus increasing throughput. It is a pollution free system and with the use of modern high horse power locos having regenerative braking, it becomes vastly energy efficient.
- India consumes 2% of World's oil, while Indian Railway uses only 1.7% of India 's Oil. This Fact shows that how diesel traction is not very much motivated in India.

	Country	Railway Length (Km)	Electrified Length (Km)
1	United States	226,427	<1,000
2	Russia	128,000	50,000
3	China	98,000	48,000
4	India	65,000	22,224
5	Canada	46,552	129
6	Australia	38,445	2,715
7	Germany	37,679	20,497
8	Argentina	35,897	136
9	South Africa	31,000	24,800
10	France	29,901	15,140

Source: International Union of Railways

Special features of TRACTION MOTORS

Mechanical Features:

- 1. A traction motor must be mechanically strong and robust and it should be capable of
- withstanding severe mechanical vibrations.
- 2. The traction motor should be completely enclosed type when placed beneath the locomotive
- to protect against dirt, dust, mud, etc.
- 3. In overall dimensions, the traction motor must have small diameter, to arrange easily beneath
- the motor coach.
- 4. A traction motor must have minimum weight so the weight of locomotive will decrease.
- Hence, the load carrying capability of the motor will increase.

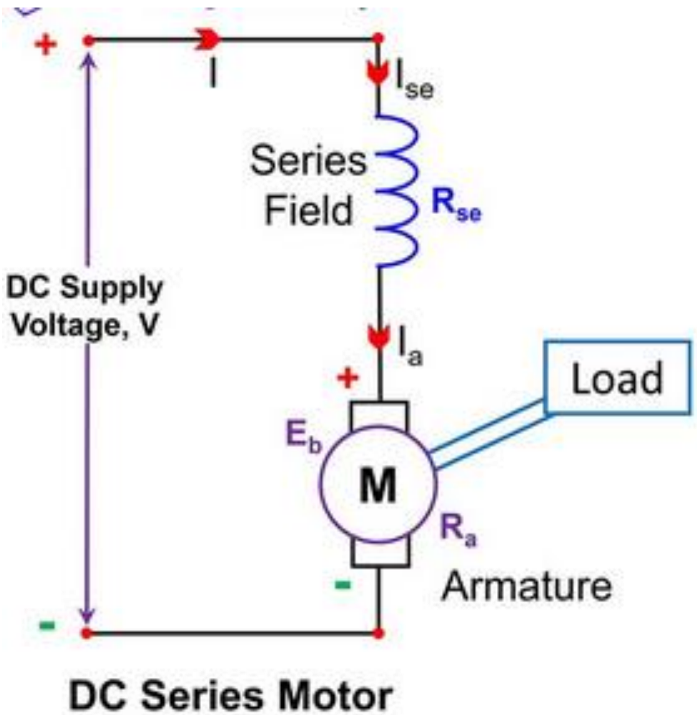
Electrical features

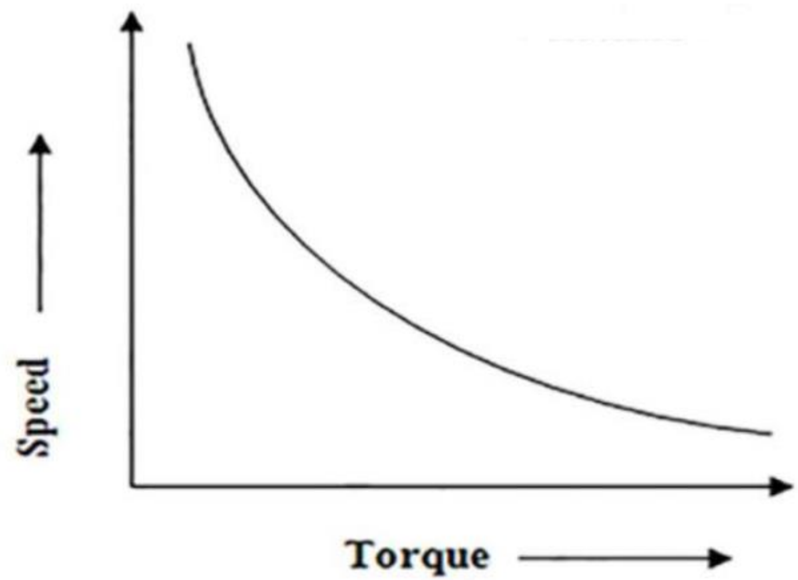
- High-starting torque
- Speed control
- Dynamic and regenerative braking
- Temperature
- Overload capacity
- Parallel running
- Commutation

Traction Motors

- D.C 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.
- Single phase A.C Series Motors- Starting torque is lower than dc series motor due to poor power factor at starting
  This motor has surpassed the d.c series motor in terms of size, weight cost for the same rating.
  Maximum operating voltage 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.

D.C. Series Motor





$$T \propto I_a^2$$

$$N \propto \frac{1}{I_a}$$

Hence, WE can write,

$$N \propto \frac{1}{\sqrt{T}}$$

D.C. Series Motor

The aspects pertaining to the suitability of a dc series motor for traction duty are given below:

- It generates high torque at low speeds and low torque at high speeds which is required to accelerate the vehicle.
- Speed-torque and speed-current characteristics of a dc series motor are steep. So, the difference in speed of motors due to different wear of driving wheels is less.
- As field flux is directly proportional to armature current, torque for a given current will not be affected by voltage fluctuations.
- Series speed torque curve gives stable operation because as the speed increases, torque decreases.
- If armature current increases (due to heavy load torque), then speed decreases. Therefore, the emf induced decreases and spark-less commutation can be obtained.
- Since torque is proportional to the square of armature current, less current is needed to increase the torque. Therefore, the series motor can withstand heavy load torque.

D.C. Series Motor

- For a given increase in torque, the horsepower (power = torque x speed, as torque increases, speed decreases) remains almost constant. This indicates the self-relieving property of the series motor.
- Series motor is amenable to various speed control methods.
- Without special arrangements, a series motor cannot be used for regenerative braking.
- Since the series field time constant is low, the back emf becomes zero in case of power failure. So, the initial rush of current on temporary interruption of supply is more in the series motor.

Applications of Series Motor :

- Due to low weight and high starting torque, series motors can develop high starting torque. Therefore, they are suitable for **urban and suburban services** where a high rate of acceleration is required which can be met by a series motor. In a 1500V dc system, the dc series motor may be operated either at 1500V or 750V by connecting them in series permanently.

Single Phase A.C. Series Motor

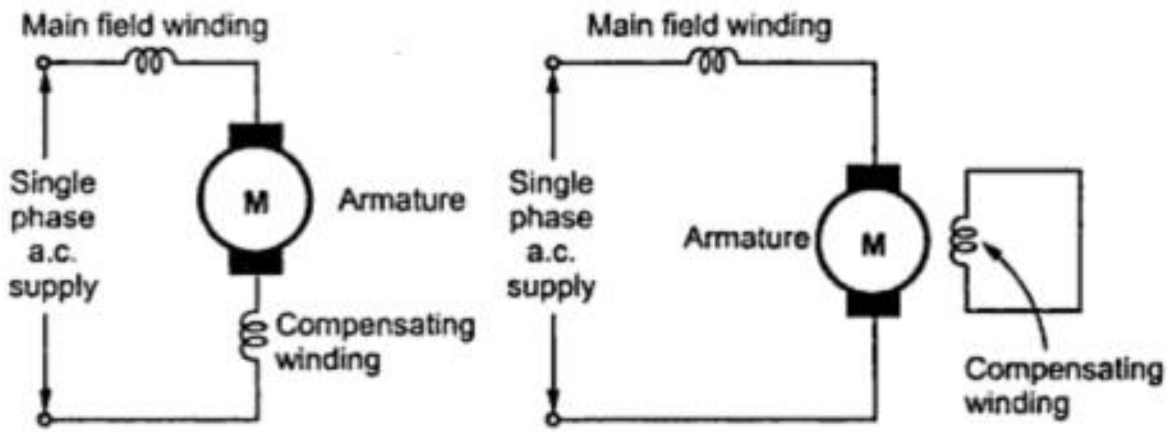
If an **ordinary dc series motor is fed from an ac supply**, it would operate as ac series motor but not very satisfactorily owing to the following reasons:

- Since the **field and armature currents both reverse every half cycle**, the **torque** would be exerted at a **double frequency in one direction**.
- The alternating flux set up by the field winding due to alternating current causes **excessive eddy current losses in fixed core and yokes**, thereby increasing the motor temperature and decreasing the operating efficiency.
- The inductance of field and armature winding **decreases the power factor** and causes some abnormal voltage drops which in turn affects the performance of the motor.
- There will be **heavy sparking at the brushes undergoing commutation**.
- In order to **reduce the reactance** of the series field, **ac series motors are built** with as **few turns as possible**.

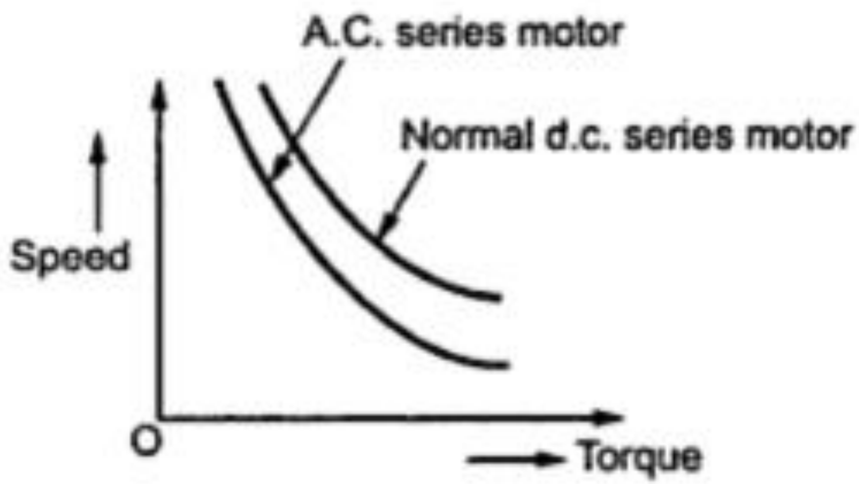
Single Phase A.C. Series Motor

- Reduction in the number of turns on the field winding results in the reduction of flux per pole leading to an increase in the speed for a given current and therefore there would be a reduction in the load torque available for a given current. Hence to develop the required load torque, the number of armature conductor have to be increased proportionately.
- The increase in armature conductors would increase inductive reactance of the armature which can be neutralized by **providing the compensating winding** (compensating winding neutralizes completely the armature MMF).
- The **air gap is made very small** because of a very weak field which is necessary to obtain **a high power factor**.
- The **yoke and field of the motor are laminated** in order to **reduce eddy current losses**.
- To reduce sparking, brush width is decreased.
- Series inductive reactance is directly proportional to the frequency, so ac series motor characteristics are **better at low frequencies**.

Single Phase A.C. Series Motor



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



Single Phase A.C. Series Motor

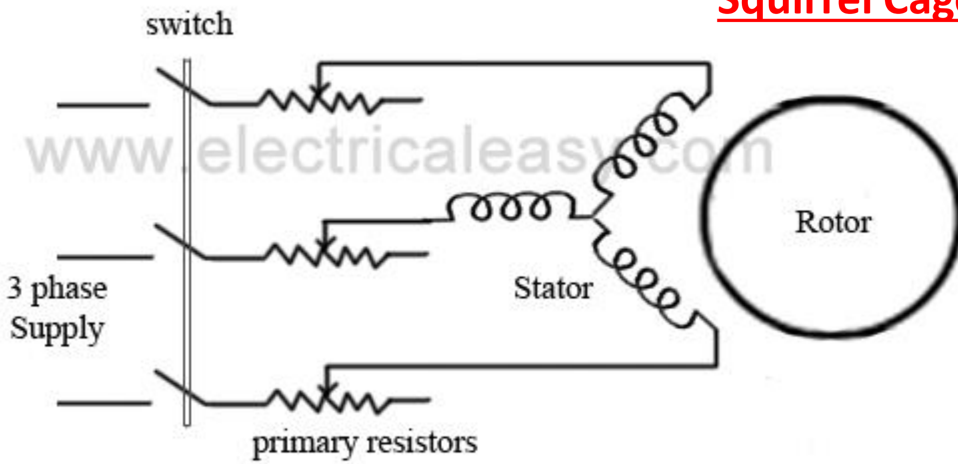
Applications of Single Phase AC Series Motor :

- The operating characteristics of an ac series motor are similar to a series motor. In which **speed is inversely proportional to the armature current** and the **torque produced will be equal to the square of the armature current**.
- In a **traction system, an AC series motor of several hundred KW** is usually employed.
- Due to poor power factor at starting, **AC series motor has low starting torque compared to DC motor**.
- So, they are **not suitable for urban and suburban services** where high starting torque is needed. So they can be employed for mainline traction service.

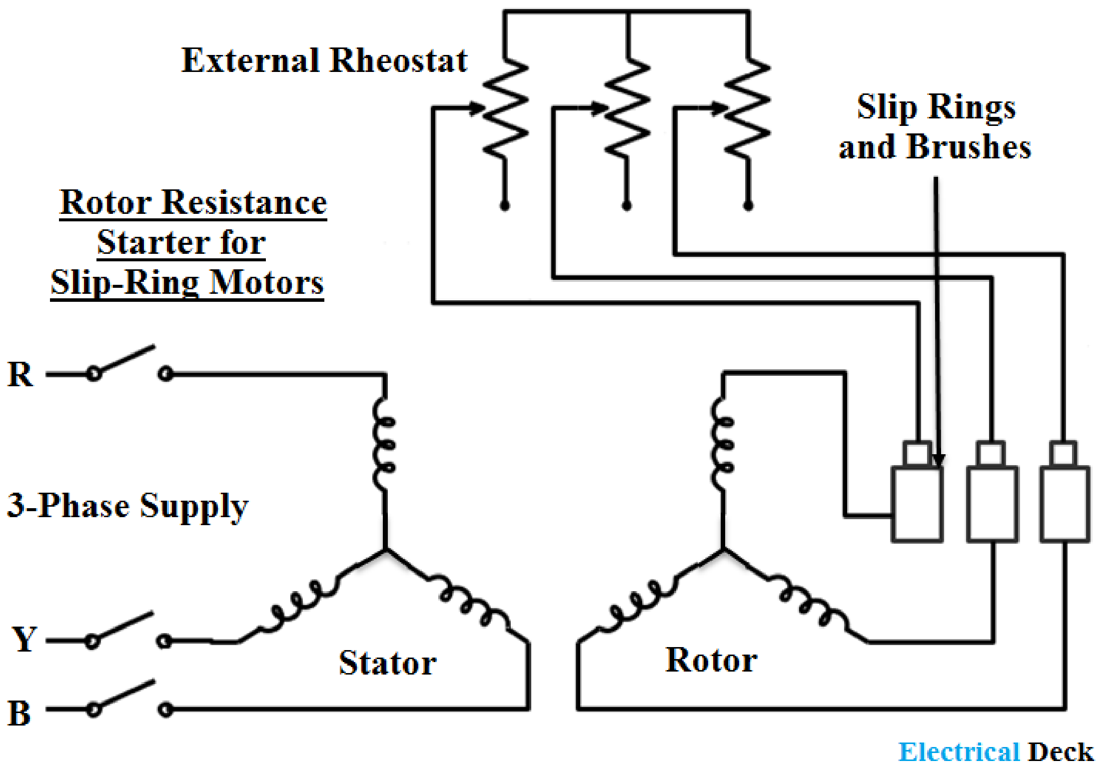
Three Phase A.C. Induction Motor

- Earlier three-phase induction motor was considered a constant speed machine. But with the advent of power electronics, many characteristics of a three-phase induction motor can be modified to suit the requirements of traction.
- The factors governing the suitability of a three-phase induction motor for traction applications are given below.
- It has many advantages as simple, robust construction, trouble-free operation, less maintenance, and high voltage operation requiring reduced current and easy braking.
- With the development of power electronic inverter circuits, the variable output frequency can be obtained. This can be used to control the speed of a three-phase induction motor.
- With variable-frequency input to the induction motor, good efficiency and power factor can also be obtained by lowering the synchronous speed of the motor.
- Starting current of the motor can be decreased by starting the motor at a low frequency using semiconductor converters.

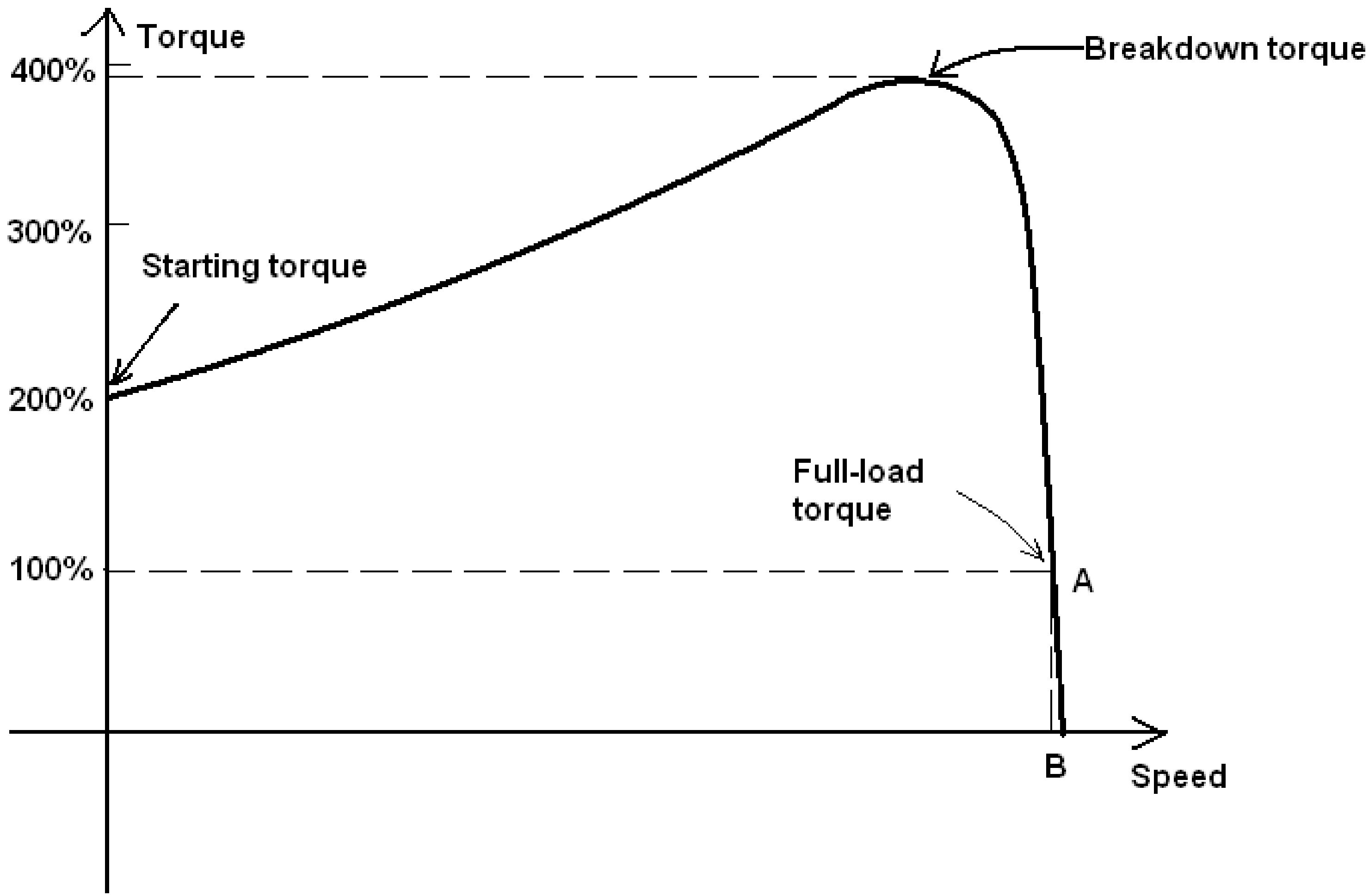
Squirrel Cage Induction Motor



Slip Ring Induction Motor



$$T = \frac{ksV^2R_2}{R_2^2 + (sX_2)^2}$$



Torque-Speed Characteristics of Three Phase Induction Motor

Three Phase A.C. Induction Motor

Applications of Three-Phase Induction Motor :

- The traction systems employing three-phase induction motors consist of two overhead conductors for two phases and a track rail for the third phase. This makes the overhead structure complicated and may also lead to electric shock if any person gets in contact with the third rail.
- This can be overcome by using the Kando system. In this system, a single-phase high voltage supply is given by a single overhead conductor. The locomotive has phase converters that will convert the single-phase to three-phase at the desired frequency and feed it to the three-phase induction motor.

Comparison between DC traction and AC traction Motors

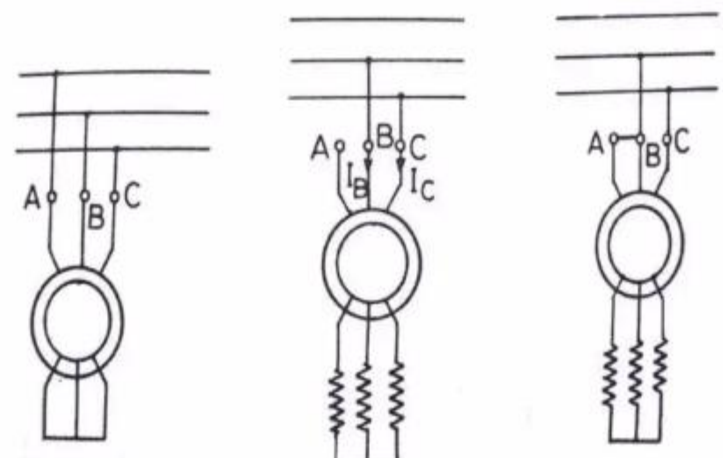
Factor	DC Traction	AC Traction
Motor	DC series motor.	AC series motor.
Performance	Good performance.	Not as good as that used for DC traction.
Starting torque	More.	Less.
Speed control	The speed control of DC series Motor is limited.	Wide range of speed control is Possible.
Interference	DC system causes less interference with Communication lines.	It will produce more interference with Communication lines.
Overhead distribution	Heavier and more costly Comparatively.	Lighter and less costly.
Substations	The number of substations required for a given track distance on DC traction is More.	The number of substations required in AC traction is less.
Weight of Copper	Weight of cu required per track km is more.	Weight of cu required per track km is less.
Application	Tramway, Trolley bus.	Main Line Service.

ELECTRICAL BRAKING

We can say that it is the process of reducing speed of any rotating machine. Classified into three categories-

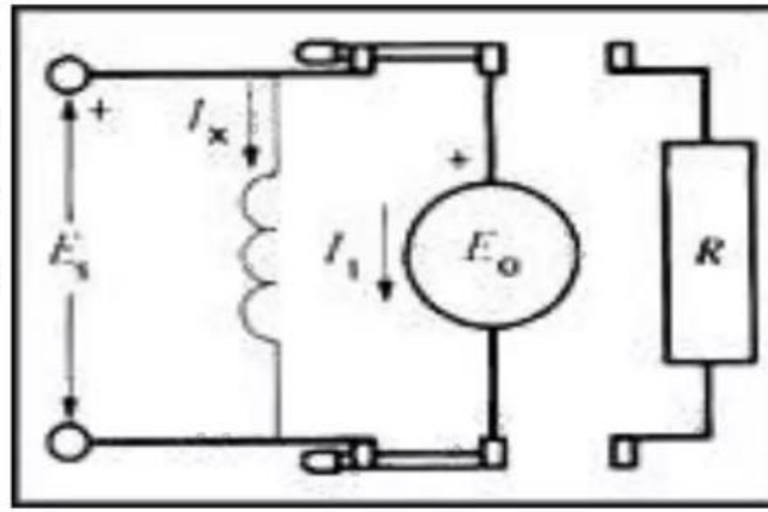
1.Plugging 2.Rheostatic braking 3.Regenerative braking

1)**Plugging-** Plugging is applied by changing phase sequence of synchronous or induction motors. The main disadvantage of this method is that here power is wasted.

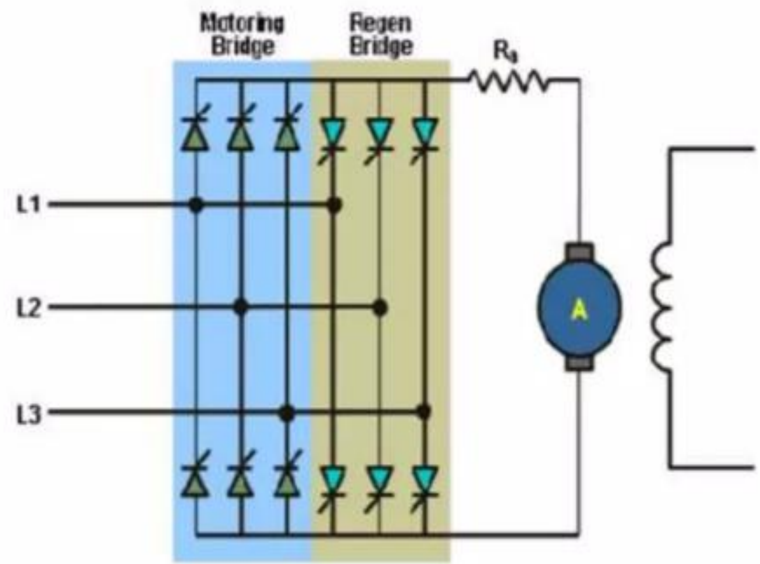


(a) Motoring (b) Two lead connection (c) Three lead connection

2)Rheostatic breaking-Connection are made changed from power configuration to brake configuration and resistor are inserted in motor circuit.



3) Regenerative braking- Motors become generators and feed resulting current back into supply system.



Mechanics of Train Movement

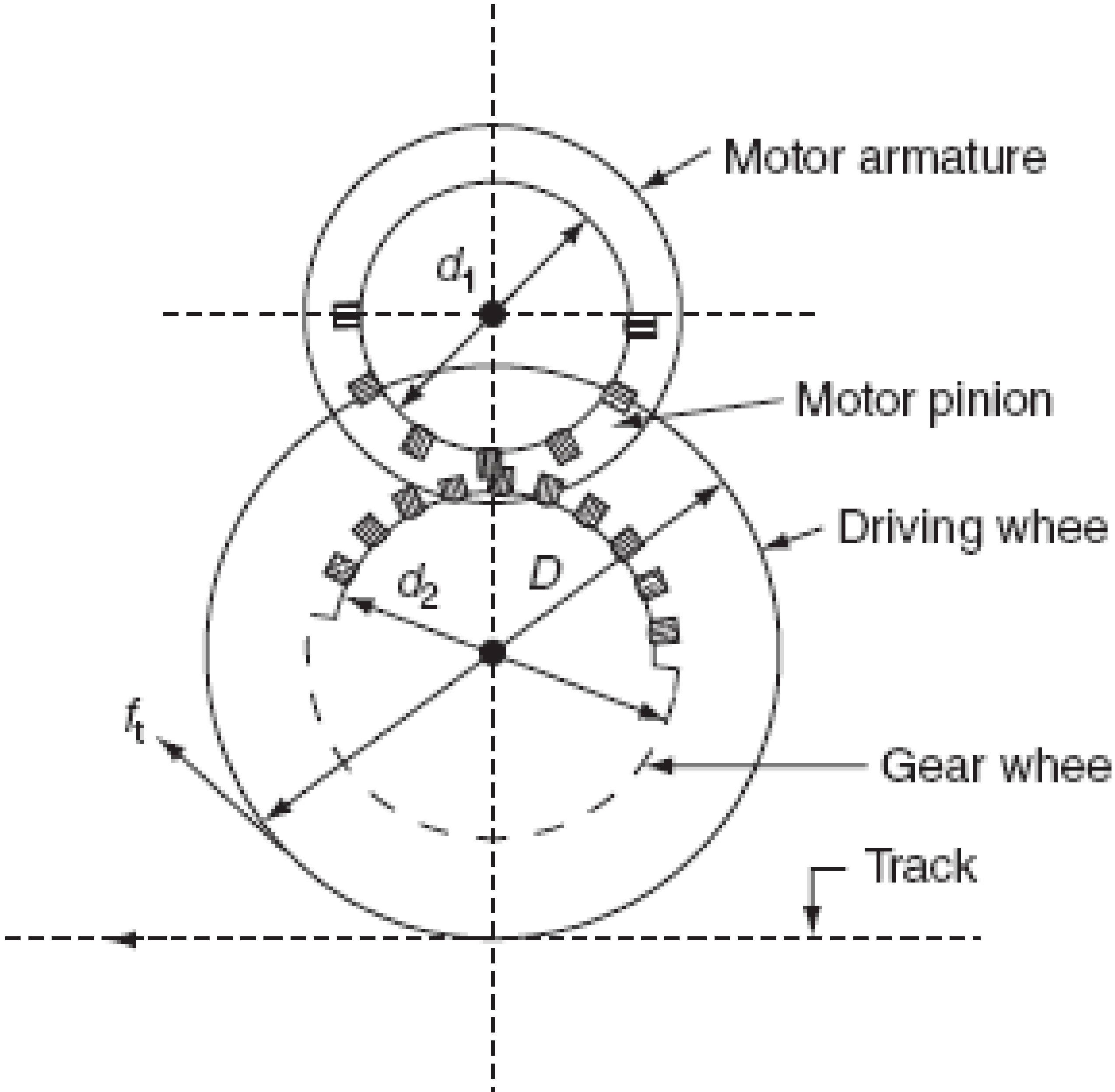
- It is the **effective force acting on the wheel of locomotive**, necessary **to propel the train** is known as '***tractive effort***'*. It is denoted with the symbol Ft.*
- *The tractive effort is a vector* quantity always acting tangential to the wheel of a locomotive. It is measured in newton.
- The net effective force or the **total tractive effort (*Ft*)** *on the wheel of a locomotive or a train to run* on the track is equals to the sum of tractive effort:

  1. Required for linear and angular acceleration (*Fa).*
  2. To overcome the effect of gravity (*Fg).*
  3. To overcome the frictional resistance to the motion of the train (*Fr).*

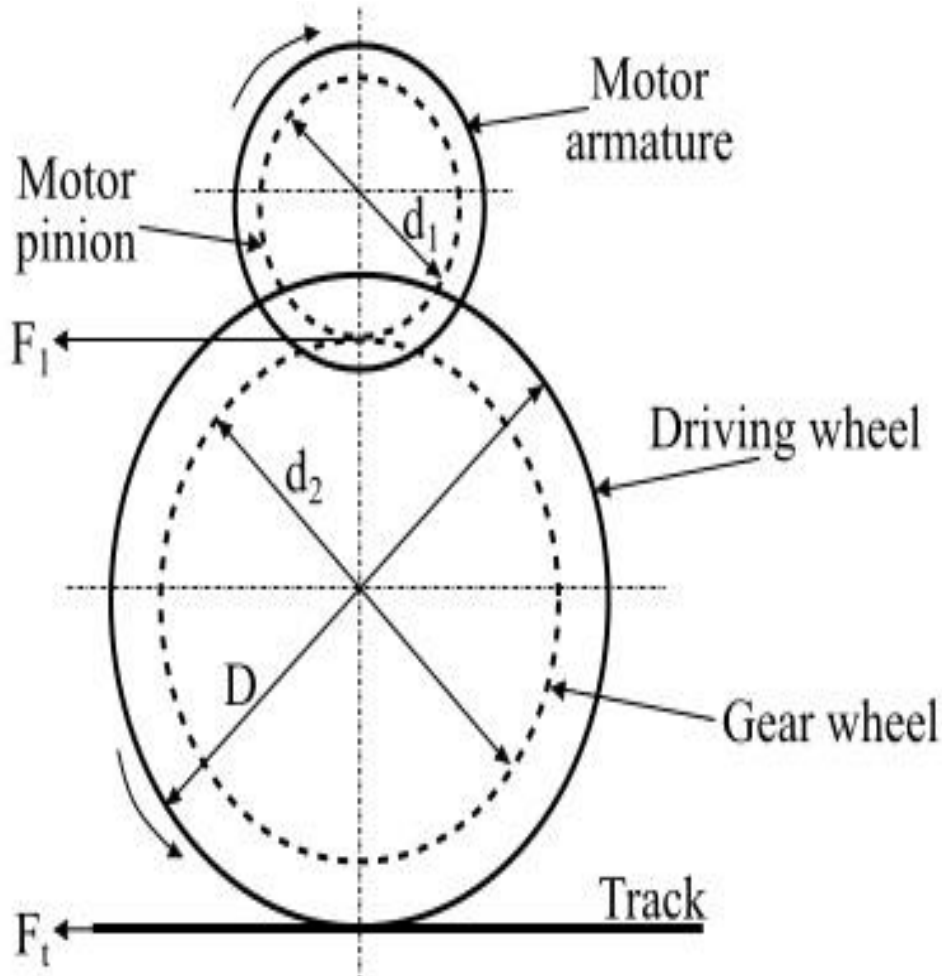
Mechanics of train movement

- The electric locomotive consists of pinion and gear wheel meshed with the traction motor and the wheel of the locomotive.
- Here, the gear wheel transfers the tractive effort at the edge of the pinion to the driving wheel.

Mechanics of Train Movement



Mechanics of Train Movement



Mechanics of Train Movement

- Here, the armature of the driving motor has a pinion of the diameter d_1 attached to it.
- The tractive effort at the edge of the pinion is transferred to the driving wheel by means of a gearwheel.

- T = Torque extertED by the motor in N_m
- F_1 = Tractive effort at the pinion
- F_t = Tractive effort at the wheel
- γ = Gear ratio
- d_1 = Diameter of pinion
- d_2 = Diameter of gear wheel
- D = Diameter of driving wheel
- η = Efficiency of power transmission from motor to driving axle

Mechanics of Train Movement

Hence, the torque exerted by the motor is given by,

$$T = F_1 \times \frac{d_1}{2}$$

$$\therefore \text{Tractive effort at pinion}, F_1 = \frac{2T}{d_1} \quad \cdots (1)$$

Now, the tractive effort transferred to the driving wheel is,

$$F_t = \eta F_1 \left(\frac{d_2}{D}\right) = \eta \cdot \frac{2T}{d_1}\left(\frac{d_2}{D}\right)$$

$$\Rightarrow F_t = \eta T \left(\frac{2}{D}\right)\left(\frac{d_2}{d_1}\right)$$

$$\because \text{Gear ratio}, \gamma = \frac{d_2}{d_1}$$

$$F_t = 2\eta\gamma\left(\frac{T}{D}\right) \quad \cdots (2)$$

Equation (2) gives the value of tractive effort at the driving wheel.

Mechanics of Train Movement

- The maximum frictional force between the driving wheel and the track is equal to $\boldsymbol{\mu W}$.
- Where, μ is the **coefficient of adhesion** between the driving wheel and the track and W is the weight of the train on the driving axles, known as **adhesive weight**.
- The **adhesive weight** is defined as the total weight to be carried on the driving wheels. The slipping will not take place unless

$$F_t > \mu W$$

- Therefore, for the motion of trains without slipping, the tractive effort should be less than or at the most equal to $\boldsymbol{\mu W}$.
- From the above discussion it is clear that the magnitude of the tractive effort that can be employed for propulsion of train depends upon the weight coming over the driving wheels and the coefficient of adhesion between the driving wheel and the track.

Coefficient of Adhesion

- The coefficient of adhesion is defined as the ratio of the maximum tractive effort that can be applied without slipping of wheels to the adhesive weight, i.e.,

$$\mu = \frac{\text{Maximum tractive effort that can be applied without slipping of wheels}}{\text{Adhesive weight}}$$

- Also, the **coefficient of adhesion decreases with the increase in speed**. The normal value of the coefficient of adhesion with the **clean and dry rails is 0.25** and with **wet or greasy rails it is as low as 0.08**.
- Since the higher value of tractive effort can be used in electric traction so that the electric train can be made to accelerate at a faster rate. This results in saving of time, especially, when the distance between the stops is small.

Problem: An electric train has eight motors geared to driving wheels, each wheel is 80 cm in diameter. Determine the torque developed by each motor to accelerate the train. The tractive effort required for accelerating the train to a speed of 50 kmph in 30 seconds is of 117590 N, the gear ratio is 4 to 1 and the gearing efficiency is 85%.

Given data,

- Diameter of wheel, D = 80 cm = 0.8 m
- Tractive effort, F_t = 117590 N
- Gear ratio, γ = 4
- Gearing efficiency, η = 85% = 0.85

Hence, the total torque developed by 8 motors is,

$$T = \frac{F_t \times D}{2\gamma\eta} = \frac{117590 \times 0.8}{2 \times 4 \times 0.85} = 13834.117 \text{ NM}$$

Therefore, the torque developed by each motor is,

$$T_{\text{each motor}} = \frac{13834.117}{8} = 1729.26 \text{ NM}$$

SPEED TIME CURVE FORTRAIN MOVEMENT

- Acceleration
  - Constant acceleration
  - Speed curve running
- Free run or constant speed period
- Coasting period
- Retardation or braking period

TYPICAL SPEED TIME CURVES FOR DIFFERENT SERVICES

- Urban or city services
- Sub urban services
- Main line services

TYPES OF SPEED IN TRACTION

- crest speed
- Average speed
- Schedule speed

FACTORS AFFECTING ENERGY CONSUMPTION

- Distance between the stops.
- Train resistance
- Acceleration and retardation.
- Gradient
- train equipment.

RECENT TRENDS IN ELECTRIC TRACTION

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