INTRODUCTION

The system that causes the propulsion of a vehicle in which that driving force or tractive force is obtained from various devices such as electric motors, steam engine drives, diesel engine dives, etc. is known as traction system.

Traction system may be broadly classified into two types. They are electric-traction systems, which use electrical energy, and non-electric traction system, which does not use electrical energy for the propulsion of vehicle.

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.

Advantages and Disadvantages of Electric Traction

Electric traction system has many advantages compared to non-electric traction systems. The following are the advantages of electric traction:

- Electric traction system is more clean and easy to handle.
o No need of storage of coal and water that in turn reduces the maintenance cost as well as the saving of high-grade coal.
o 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.
o The maintenance and running costs are comparatively low.
o The speed control of the electric motor is easy.
o Regenerative braking is possible so that the energy can be fed back to the supply system during the braking period.
o 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.
o Electrically operated vehicles can withstand for overloads, as the system is capable of drawing more energy from the system.

In addition to the above advantages, the electric traction system suffers from the following drawbacks:

- 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.

REVIEW OF EXISTING ELECTRIC TRACTION SYSTEM IN INDIA

In olden days, first traction system was introduced by Britain in 1890 (600-V DC track). Electrification system was employed for the first traction vehicle. This traction system was introduced in India in the year 1925 and the first traction system employed in India was from Bombay VT to Igatpuri and Pune, with 1,500-V DC supply. This DC supply can be obtained for traction from substations equipped with rotary converters. Development in the rectifiers leads to the replacement of rotary converters by mercury arc rectifiers. But nowadays further development in the technology of semiconductors, these mercury arc valves are replaced by solid-state semiconductors devices due to fast traction system was introduced on 3,000-V DC. Further development in research on traction system by French international railways was suggested that, based on relative merits and
demerits, it is advantageous to prefer to AC rather than DC both financially and operationally.

Thus, Indian railways was introduced on 52-kV, 50-Hz single-phase AC system in 1957; this system of track electrification leads to the reduction of the cost of overhead, locomotive equipment, etc. Various systems employed for track electrification are shown in Table.

**Table** Track electrification systems

<table>
<thead>
<tr>
<th>S. no</th>
<th>System</th>
<th>Voltage</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DC system</td>
<td>600 V, 1,500 V, or 3,000 V</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>Single-phase AC system</td>
<td>15–25 kV is stepped down to 300–400 V</td>
<td>$\frac{162}{3}$ Hz and 25 Hz</td>
</tr>
<tr>
<td>3</td>
<td>Three-phase AC system</td>
<td>15–25 kV is stepped down to 3,300–3,600 V</td>
<td>$\frac{162}{3}$ Hz and 50 Hz</td>
</tr>
</tbody>
</table>

**SYSTEM OF TRACTION**

Traction system is normally classified into two types based on the type of energy given as input to drive the system and they are:

1. **Non-electric traction system**
   Traction system develops the necessary propelling torque, which do not involve the use of electrical energy at any stage to drive the traction vehicle known as electric traction system.
   
   *Ex:* Direct steam engine drive and direct internal combustion engine drive.

2. **Electric traction system**
   Traction system develops the necessary propelling torque, which involves the use of electrical energy at any stage to drive the traction vehicle, known as electric traction system.

   Based upon the type of sources used to feed electric supply for traction system, electric traction may be classified into two groups:

   1. Self-contained locomotives.
   2. Electric vehicle fed from the distribution networks.
Self-contained locomotives

In this type, the locomotives or vehicles themselves having a capability of generating electrical energy for traction purpose. Examples for such type of locomotives are:

1. **Steam electric drive**
   In steam electric locomotives, the steam turbine is employed for driving a generator used to feed the electric motors. Such types of locomotives are not generally used for traction because of some mechanical difficulties and maintenance problems.

2. **Diesel electric trains**
   A few locomotives employing diesel engine coupled to DC generator used to feed the electric motors producing necessary propelling torque. Diesel engine is a variable high-speed type that feeds the self- or separately excited DC generator. The excitation for generator can be supplied from any auxiliary devices and battery.
   Generally, this type of traction system is suggested in the areas where coal and steam tractions are not available. The advantages and disadvantages of the diesel engine drive are given below:

   **Advantages**
   - As these are no overhead distribution system, initial cost is low.
   - Easy speed control is possible.
   - Power loss in speed control is very low
   - Time taken to bring the locomotive into service is less.
   - In this system, high acceleration and braking retardation can be obtained compared to steam locomotives.
   - The overall efficiency is high compared to steam locomotives.

   **Disadvantages**
   - The overloading capability of the diesel engine is less.
   - The running and maintenance costs are high.
   - The regenerative braking cannot be employed for the diesel engine drives.

**Petrol electric traction**

This system of traction is used in road vehicles such as heavy lorries and buses. These vehicles are capable of handling overloads. At the same time, this system
provides fine and smooth control so that they can run along roads without any jerking.

Battery drives

In this drive, the locomotive consists of batteries used to supply power to DC motors employed for driving the vehicle. This type of drives can be preferred for frequently operated services such as local delivery goods traction in industrial works and mines, etc. This is due to the unreliability of supply source to feed the electric motors.

Electric vehicles fed from distribution network

Vehicles in electrical traction system that receives power from over head distribution network fed or substations with suitable spacing. Based on the available supply, these groups of vehicles are further subdivided into:

1. System operating with DC supply. Ex: tramways, trolley buses, and railways.
2. System operating with AC supply. Ex: railways.

Systems operating with DC supply

In case if the available supply is DC, then the necessary propelling power can be obtained for the vehicles from DC system such as tram ways, trolley buses, and railways.

Tramways: Tramways are similar to the ordinary buses and cars but only the difference is they are able to run only along the track. Operating power supply for the tramways is 500-V DC tramways are fed from single overhead conductor acts as positive polarity that is fed at suitable points from either power station or substations and the track rail acts as return conductor.

The equipment used in tramways is similar to that used in railways but with small output not more than 40–50 kW. Usually, the tramways are provided with two driving axels to control the speed of the vehicles from either ends. The main drawback of tramways is they have to run along the guided routes only. Rehostatic and mechanical brakings can be applied to tramways. Mechanical brakes can be applied at low speeds for providing better saturation where electric braking is ineffective, during the normal service. The erection and maintenance costs of tramways are high since the cost of overhead distribution structure is costlier and sometimes, it may cause a source of danger to other road users.
**Trolley buses:** The main drawback of tramways is, running along the track is avoided in case of trolley buses. These are electrically operated vehicles, and are fed usually 600-V DC from two overhead conductors, by means of two collectors. Even though overhead distribution structure is costlier, the trolley buses are advantageous because, they eliminate the necessity of track in the roadways.

In case of trolley buses, rehostatic braking is employed, due to high adhesion between roads and rubber types. A DC compound motor is employed in trolley buses.

**SYSTEM OF TRACK ELECTRIFICATION**

Nowaday, based on the available supply, the track electrification system are categorized into.

1. DC system.
2. Single-phase AC system.
3. Three-phase AC system.
4. Composite system.

1 DC system

In this system of traction, the electric motors employed for getting necessary propelling torque should be selected in such a way that they should be able to operate on DC supply. Examples for such vehicles operating based on DC system are tramways and trolley buses. Usually, DC series motors are preferred for tramways and trolley buses even though DC compound motors are available where regenerative braking is desired. The operating voltages of vehicles for DC track electrification system are 600, 750, 1,500, and 3,000 V. Direct current at 600–750 V is universally employed for tramways in the urban areas and for many suburban and main line railways, 1,500–3,000 V is used. In some cases, DC supply for traction motor can be obtained from substations equipped with rotary converters to convert AC power to DC. These substations receive AC power from 3-phase high-voltage line or single-phase overhead distribution network. The operating voltage for traction purpose can be justified by the spacing between stations and the type of traction motors available. Theses substations are usually automatic and remote controlled and they are so costlier since they involve rotary converting equipment. The DC system is preferred for suburban services and road transport where stops are frequent and distance between the stops is small.
2 Single-phase AC system

In this system of track electrification, usually AC series motors are used for getting the necessary propelling power. The distribution network employed for such traction systems is normally 15–25 kV at reduced frequency of 163⅔ Hz or 25 Hz. The main reason of operating at reduced frequencies is AC series motors that are more efficient and show better performance at low frequency. These high voltages are stepped down to suitable low voltage of 300–400 V by means of step-down transformer. Low frequency can be obtained from normal supply frequency with the help of frequency converter. Low-frequency operation of overhead transmission line reduces the line reactance and hence the voltage drops directly and single-phase AC system is mainly preferred for main line services where the cost of overhead structure is not much importance moreover rapid acceleration and retardation is not required for suburban services.

3 Three-phase AC system

In this system of track electrification, 3-φ induction motors are employed for getting the necessary propelling power. The operating voltage of induction motors is normally 3,000–3,600-V AC at either normal supply frequency or 16⅔- Hz frequency.

   Usually 3-φ induction motors are preferable because they have simple and robust construction, high operating efficiency, provision of regenerative braking without placing any additional equipment, and better performance at both normal and seduced frequencies. In addition to the above advantages, the induction motors suffer from some drawbacks; they are low-starting torque, high-starting current, and the absence of speed control. The main disadvantage of such track electrification system is high cost of overhead distribution structure. This distribution system consists of two overhead wires and track rail for the third phase and receives power either directly from the generating station or through transformer substation.

   Three-phase AC system is mainly adopted for the services where the output power required is high and regeneration of electrical energy is possible.

4 Composite system

As the above track electrification system have their own merits and demerits, 1-φ AC system is preferable in the view of distribution cost and distribution voltage
can be stepped up to high voltage with the use of transformers, which reduces the transmission losses. Whereas in DC system, DC series motors have most desirable features and for 3-φ system, 3-φ induction motor has the advantage of automatic regenerative braking. So, it is necessary to combine the advantages of the DC/AC and 3-φ/1-φ systems. The above cause leads to the evolution of composite system.

Composite systems are of two types.

1. Single-phase to DC system.
2. Single-phase to three-phase system or kando system.

*Single-phase to DC system*

In this system, the advantages of both 1-φ and DC systems are combined to get high voltage for distribution in order to reduce the losses that can be achieved with 1-φ distribution networks, and DC series motor is employed for producing the necessary propelling torque. Finally, 1-φ AC distribution network results minimum cost with high transmission efficiency and DC series motor is ideally suited for traction purpose. Normal operating voltage employed of distribution is 25 kV at normal frequency of 50 Hz. This track electrification is employed in India.

*Single-phase to 3-φ system or kando system*

In this system, 1-φ AC system is preferred for distribution network. Since single-phase overhead distribution system is cheap and 3-φ induction motors are employed as traction motor because of their simple, robust construction, and the provision of automatic regenerative braking.

The voltage used for the distribution network is about 15–25 kV at 50 Hz. This 1-φ supply is converted to 3-φ supply through the help of the phase converters and high voltage is stepped down transformers to feed the 3-φ induction motors. Frequency converters are also employed to get high-starting torque and to achieve better speed control with the variable supply frequency.

**SPECIAL FEATURES OF TRACTION MOTORS**

The general features of the electric motors used for traction purpose are:

1. Mechanical features.
2. Electrical features.
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

A traction motor must have high-starting torque, which is required to start the motor on load during the starting conditions in urban and suburban services.

Speed control

The speed control of the traction motor must be simple and easy. This is necessary for the frequent starting and stopping of the motor in traction purpose.

Dynamic and regenerative braking

Traction motors should be able to provide easy simple rehostatic and regenerative braking subjected to higher voltages so that system must have the capability of withstanding voltage fluctuations.

Temperature

The traction motor should have the capability of withstanding high temperatures during transient conditions.

Overload capacity

The traction motor should have the capability of handling excessive overloads.
Parallel running

In traction work, more number of motors need to run in parallel to carry more load. Therefore, the traction motor should have such speed–torque and current–torque characteristics and those motors may share the total load almost equally.

Commutation

Traction motor should have the feature of better commutation, to avoid the sparking at the brushes and commutator segments.

TRACTION MOTORS

No single motor can have all the electrical operating features required for traction.

In earlier days, DC motor is suited for traction because of the high-starting torque and having the capability of handling overloads. In addition to the above characteristics, the speed control of the DC motor is very complicated through semiconductor switches. So that, the motor must be designed for high base speed initially by reducing the number of turns in the field winding. But this will decrease the torque developed per ampere at the time of starting. And regenerative braking is also complicated in DC series motor; so that, the separately excited motors can be preferred over the series motor because their speed control is possible through semi-controlled converters. And also dynamic and regenerative braking in separately excited DC motor is simple and efficient.

DC compound motors are also preferred for traction applications since it is having advantageous features than series and separately excited motors.

But nowadays squirrel cage induction and synchronous motors are widely used for traction because of the availability of reliable variable frequency semiconductor inverters.

The squirrel cage induction motor has several advantages over the DC motors. They are:

1. Robust construction.
2. Highly reliable.
3. Low maintenance and low cost.
4. High efficiency.
Synchronous motor features lie in between the squirrel cage induction motor and the DC motor. The main advantages of the synchronous motor over the squirrel cage induction motor are:

1. The synchronous motors can be operated at leading power by varying the field excitation.
2. Load commutated thyristor inverter is used in synchronous motors as compared to forced commutation thyristor inverter in squirrel cage induction motors.

Even though such forced commutation reduces the weight and volume of induction motor, the synchronous motor is less expensive.

1. DC series motor

From the construction and operating characteristics of the DC series motor, it is widely suitable for traction purpose. Following features of series motor make it suitable for traction.

1. DC series motor is having high-starting torque and having the capability of handling overloads that is essential for traction drives.
2. These motors are having simple and robust construction.
3. The speed control of the series motor is easy by series parallel control.
4. Sparkless commutation is possible, because the increase in armature current increases the load torque and decreases the speed so that the emf induced in the coils undergoing commutation.
5. Series motor flux is proportional to armature current and torque. But armature current is independent of voltage fluctuations. Hence, the motor is unaffected by the variations in supply voltage.
6. We know that:

\[ N \propto \frac{1}{\phi} \frac{1}{I_a} \quad \text{and} \quad T \propto \phi I_a. \]

But for series motor \( \phi \propto I_a \)

\[ \therefore T \propto I_a^2. \]

\[ \therefore N \propto \frac{1}{I_a} \propto \frac{1}{\sqrt{T}}. \]

But the power output of the motor is proportional to the product of torque and speed.

\[ \therefore \text{Motor output} \propto T \cdot N \propto \sqrt{T}. \]
That is motor input drawn from the source is proportional to the square root of the torque. Hence, the series motor is having self-retaining property.

7. If more than one motor are to be run in parallel, their speed–torque and current–torque characteristics must not have wide variation, which may result in the unequal wear of driving wheels.

2 DC shunt motor

From the characteristics of DC shunt motor, it is not suitable for traction purpose, due to the following reasons:

1. DC shunt motor is a constant speed motor but for traction purpose, the speed of the motor should vary with service conditions.
2. In case of DC shunt motor, the power output is independent of speed and is proportional to torque. In case of DC series motor, the power output is proportional to \( \sqrt{T} \). So that, for a given load torque, the shunt motor has to draw more power from the supply than series motor.
3. For shunt motor, the torque developed is proportional to armature current \( (T \propto I_a) \). So for a given load torque motor has to draw more current from the supply.
4. The flux developed by shunt motor is proportional to shunt field current and hence
\[
\phi_{sh} \propto J_{sh} \propto \frac{V}{R_{sh}}.
\]
But the torque developed is proportional to \( \varphi_a \) and \( I_a \). Hence, the torque developed by the shunt motor is affected by small variations in supply voltage.
5. If two shunt motors are running in parallel, their speed–torque and speed–current characteristics must be flat and same. Otherwise, the currents drawn by the motor from the supply mains will be different and cause to unequal sharing of load.

**Example 9.1:** A DC series motor drives a load. The motor takes a current of 13 A and the speed is 620 rpm. The torque of the motor varies as the square of speed. The field winding is shunted by a diverter of the same resistance as that of the field winding, then determine the motor speed and current. Neglect all motor losses and assume that the magnetic circuit is unsaturated.

**Solution:**

Before connecting field diverter:

Speed, \( N_i = 620 \) rpm.
Series field current, \( I_{sel} = 13 \text{ A}. \)

The same current flows through the armature; so that,

\[ I_1 = I_{sel} = I_a = 13 \text{ A}. \]

After connecting field diverter, the field winding is shunted by the diverter of the same refinance; so that:

Series field current \( = I_{se2} = \frac{1}{2} I_2. \)

Since torque developed:

\[ T \propto \phi I_a \]
\[ \propto \phi I_1 \]
\[ \frac{T_2}{T_1} = \frac{T_2 I_2}{\phi I_1} = \frac{1/2 I_2^2}{2 I_1^2} \quad (i) \quad (\phi \propto I_{se} \text{ magnetic circuit is unsaturated}). \]

According to given data, the torque varies as the square of the speed.

\[ \frac{T_2}{T_1} = \frac{N_2^2}{N_1^2} \quad (ii) \]

From Equations (i) and (ii):

\[ \frac{I_2^2}{2 I_1^2} = \frac{N_2^2}{N_1^2} \]
\[
\frac{N_2}{N_1} = \frac{I_2}{\sqrt{2}I_1}.
\] 

(iii)

All the losses are neglected, and assume that the supply voltage is constant.

\[N \propto \frac{1}{\phi}\]

\[
\frac{N_2}{N_1} = \frac{\phi_1}{\phi_2}
= \frac{I_1}{\frac{1}{2}I_2}.
\] 

(iv)

From Equations (iii) and (iv):

\[
\frac{I_2}{\sqrt{2}I_1} = \frac{2I_1}{I_2}
I_2^2 = 2\sqrt{2} I_1^2
= 2 \times \sqrt{2} \times (13)^2
= 478.004.
\]

\[\therefore I_2 = 21.86 \text{ A}.\]

From Equation (iv):

\[
\frac{N_2}{N_1} = \frac{2I_1}{I_2}
N_2 = \frac{2I_1}{I_2} \times N_1
= 2 \times \frac{13}{21.86} \times 620
= 737.42 \text{ rpm}.
\]
Example: A series motor having a resistance of 0.8 Ω between its terminal drives. The torque of a fan is proportional to the square of the speed. At 220 V, its speed is 350 rpm and takes 12 A. The speed of the fan is to be raised to 400 rpm by supply voltage control. Estimate the supply voltage required.

Solution:

\[ R_a + R_w = 0.8 \, \Omega, \quad V_1 = 220 \, \text{V}, \quad N_1 = 350 \, \text{rpm}, \quad I_1 = I_{a1} = 12 \, \text{A} \]

\[ N_2 = 400 \, \text{rpm}. \]

Use the torque equation, \( T \propto \phi I_a \propto I_a^2 \) as \( \phi \propto I_a \):

\[
\frac{T_1}{T_2} = \left( \frac{I_{a1}}{I_{a2}} \right)^2.
\]  

(i)

Also \( T \propto N^2 \) (given)

\[
\frac{T_1}{T_2} = \left( \frac{N_1}{N_2} \right)^2.
\]  

(ii)

Equating Equations (i) & (ii):

\[
\left( \frac{N_1}{N_2} \right)^2 = \left( \frac{I_{a1}}{I_{a2}} \right)^2.
\]

\[
\left( \frac{350}{400} \right)^2 = \left( \frac{12}{I_{a2}} \right)^2
\]

\[
\therefore I_{a2} = 13.7 \, \text{A}.
\]
Use the speed equation

\[ N \propto \frac{E_b}{\phi} \propto \frac{E_b}{I_a} \]

\[ \frac{N_1}{N_2} = \frac{E_{bl}}{E_{b2}} \times \frac{I_{a2}}{I_{a1}} \]  \hspace{1cm} (iii)

Now, \( E_{b1} = V_1 - I_{a1}(R_a + R_w) \)

\[ = 220 - 12(0.8) = 210.4 \text{ V}. \]

In second case, the voltage is to be changed from \( V_1 \) to \( V_2 \).

\[ \therefore E_{b2} = V_2 - I_{a2}(R_a + R_w) \]

\[ = V_2 - 13.7(0.8) = V_2 - 10.96. \]

\( E_{b1} \) and \( E_{b2} \) are substituted in Eq (iii):

\[ \frac{350}{400} = \frac{210.4}{V_2 - 10.96} \times \frac{13.7}{12} \]

\[ V_2 - 10.96 = 274.52 \]

\[ V_2 = 284.52 \text{ V}. \]

\[ \therefore \] This is the new supply voltage required to raise the speed from 350 rpm to 400 rpm.

**Example:** A 230-V DC shunt motor takes a current of 20 A on a certain load. The armature resistance is 0.8 Ω and the field circuit resistance is 250 Ω. Find the resistance to be inserted in series with the armature to have the speed is half if the load torque is constant.

**Solution:**

\[ I_{L1} = 20 \text{ A}. \]
\[ I_{sh} = \frac{V}{R_{sh}} = \frac{230}{250} = 0.92 \text{ A.} \]

\[ I_{a1} = I_{a1} - I_{sh} = 20 - 0.92 = 19.08. \]

\[ E_{b1} = V - I_{a1}R_s = 230 - 19.08(0.08) = 214.736 \text{ V.} \]

\[ T \propto \varphi I_a \propto I_a \quad (\because \varphi \text{ is constant}). \]

\[ \frac{T_1}{T_2} = \frac{I_{a1}}{I_{a2}} = 1 \quad \text{as torque is constant} \]

\[ \therefore I_{a1} = I_{a2} = 19.08 \text{ A.} \]

\[ R_s = \text{external resistance in armature} \]

\[ E_{b2} = V - I_{a2}(R_s + R_x) = 230 - (19.08)(0.8 + R_x). \]

Now, \[ N \propto \frac{E_b}{\varphi} \propto E_b \quad (\because \varphi \text{ is constant}) \]

\[ \therefore \frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \]

\[ \frac{1}{0.5} = \frac{214.736}{230 - 19.08(0.8 + R_x)} \]

\[ 230 - 19.08(0.8 + R_x) = 214.736 \times 0.5 = 107.368 \]

\[ 19.08(0.8 + R_x) = -107.368 + 230 = 122.632 \]

\[ 0.8 + R_x = 6.43 \]

\[ R_x = 6.43 - 0.8 \]

\[ R_x = 5.62 \Omega. \]

**AC series motor**

Practically, AC series motor is best suited for the traction purpose due to high-starting torque ([Fig. 9.1](#)). When DC series motor is fed from AC supply, it works but not satisfactorily due to some of the following reasons:

1. If DC series motor is fed from AC supply, both the field and the armature currents reverse for every half cycle. Hence, unidirectional torque is developed at double frequency.
2. Alternating flux developed by the field winding causes excessive eddy current loss, which will cause the heating of the motor. Hence, the operating efficiency of the motor will decrease.

3. Field winding inductance will result abnormal voltage drop and low power factor that leads to the poor performance of the motor.

4. Induced emf and currents flowing through the armature coils undergoing commutation will cause sparking at the brushes and commutator segments.

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**Fig.** AC series motor

Hence, some modifications are necessary for the satisfactory operation of the DC series motor on the AC supply and they are as follows:

1. In order to reduce the inductive reactance of the series field, the field winding of AC series motor must be designed for few turns.
2. The decrease in the number of turns of the field winding reduces the load torque, i.e., if field turns decrease, its mmf decrease and then flux, which will increase the speed, and hence the torque will decrease. But in order to maintain constant load torque, it is necessary to increase the armature turns proportionately.
3. If the armature turns increase, the inductive reactance of the armature would increase, which can be neutralized by providing the compensating winding.
4. Magnetic circuit of an AC series motor should be laminated to reduce eddy current losses.
5. Series motor should be operating at low voltage because high voltage low current supply would require large number of turns to produce given flux.
6. Motor should be operating at low frequency, because inductive reactance is proportional to the frequency. So, at low frequency, the inductive reactance of the field winding decreases.

The operating characteristics of the AC series motor are similar to the DC series motor. Weight of an AC series motor is one and a half to two times that of a DC series motor. And operating voltage is limited to 300 V. They can be built up to the size of several hundred kW for traction work.

At the time of starting operation, the power factor is low; so that, for a given current, the torque developed by the AC motor is less compared to the DC motor. Thus, the AC series motor is not suitable for suburban services with frequent stops and preferred for main line service where high acceleration is not required.

Three-phase induction motor

The three-phase induction motors are generally preferred for traction purpose due to the following advantages.

1. Simple and robust construction.
2. Trouble-free operation.
3. The absence of commutator.
4. Less maintenance.
5. Simple and automatic regeneration.
6. High efficiency.

Three-phase induction motor also suffer from the following drawbacks.

1. Low-starting torque.
2. High-starting current and complicated speed control system.
3. It is difficult to employ three-phase induction motor for a multiple-unit system used for propelling a heavy train.

Three-phase induction motor draws less current when the motor is started at low frequencies. When a three-phase induction motor is used, the cost of overhead distribution system increases and it consists of two overhead conductors and track rail for the third phase to feed power to locomotive, which is a complicated overhead structure and if any person comes in contact with the third rail, it may cause danger to him or her.
This drawback can be overcome by employing kando system. In this system, 1-φ supply from the overhead distribution structure is converted to 3-φ supply by using phase converters and is fed to 3-φ induction motor.

The speed controller of induction motor becomes smooth and easy with the use of thyristorized inverter circuits to get variable frequency supply that can be used to control the speed of three-phase induction motor.

Nowadays, by overcoming the drawbacks of three-phase induction motor, it can be used for traction purpose.

Linear induction motor

It is a special type of induction motor that gives linear motion instead of rotational motion, as in the case of a conventional motor.

In case of linear induction motor, both the movement of field and the movement of the conductors are linear.

A linear induction motor consists of 3-φ distributed field winding placed in slots, and secondary is nothing but a conducting plate made up of either copper or aluminum as shown in Fig.
The field system may be either single primary or double primary system. In single primary system, a ferro magnetic plate is placed on the other side of the copper plate; it is necessary to provide low reluctance path for the magnetic flux. When primary is excited by 3-φ AC supply, according to mutual induction, the induced currents are flowing through secondary and ferro magnetic plate. Now, the ferro magnetic plate energized and attracted toward the primary causes to unequal air gap between primary and secondary as shown in Fig. 9.2(a). This drawback can be overcome by double primary system as shown in Fig. 9.2(b). In this system, two primaries are placed on both the sides of secondary, which will be shorter in length compared to the other depending upon the use of the motor.

When the operating distance is large, the length of the primary is made shorter than the secondary because it is not economical to place very large 3-φ primary.
Generally, the short secondary form of system is preferred for limited operating distance, as shown in

When 3-φ primary winding is excited by giving 3-φ AC supply, magnetic field is developed rotating at linear synchronous speed, $V_s$.

The linear synchronous speed is given by:

$$V_s = 2\tau f \text{ m/s},$$

where $\tau$ is the pole pitch in m and $f$ is the supply frequency in hertz.

Note: here, the synchronous speed does not depend upon the number of poles but depends upon the pole pitch and the supply frequency.

1. Short single primary.
2. Short double primary.
3. Short secondary.

The flux developed by the field winding pulls the rotor same as to the direction of the magnetic field linearly, which will reduce relative speed between field and rotor plate. If the speed of the rotor plate is equal to the magnetic field, then the field would be stationary when viewed from the rotor plate. If rotor plate is rotating at a speed more than linear synchronous, the direction of a force would be reversed, which causes regenerative braking.

The slip of the linear induction motor is given by:

$$s = \frac{V_s - V}{V_s},$$

where ‘$V$’ is the actual speed of the rotor plate.

The speed–torque (tractive effort) characteristics is shown in Fig. 9.3.
Fig. 9.3 Torque–speed characteristics

Therefore, force or tractive effort is given by:

\[ F = \frac{P_2}{V_s}, \]

where ‘\( P_2 \)’ is the actual power supply to the rotor.

**Advantages**

1. Simple in construction.
2. Low initial cost.
3. Maintenance cost is low.
4. Maximum speed is not limited due to centrifugal forces.
5. Better power to weight ratio.

**Disadvantages**

1. High cost of providing collector system.
2. Poor efficiency and low power factor, due to high currents drawn by the motor because of large air gap.

**Applications**

Linear induction motor are generally used in:

- High-speed rail traction.
- Trolley cars and metallic belt conveyors.
Synchronous motor

The synchronous motor is one type of AC motor working based upon the principle of magnetic lacking. It is a constant speed motor running from no-load to full load. The construction of the synchronous motor is similar to the AC generator; armature winding is excited by giving three-phase AC supply and field winding is excited by giving DC supply. The synchronous motor can be operated at leading and lagging power factors by varying field excitation.

The synchronous motor can be widely used various applications because of constant speed from no-load to full load.

- High efficiency.
- Low-initial cost.
- Power factor improvement of three-phase AC industrial circuits.

BRAKING

If at any time, it is required to stop an electric motor, then the electric supply must be disconnected from its terminals to bring the motor to rest. In this method, even though supply is cut off, the motor continue to rotate for long time due to inertia. In some cases, there is delay in bringing the other equipment. So that, it is necessary to bring the motor to rest quickly. The process of bringing the motor to rest within the pre-determined time is known as braking.

A good braking system must have the following features:

- Braking should be fast and reliable.
- The equipment to stop the motor should be in such a way that the kinetic energy of the rotating parts of the motor should be dissipated as soon as the brakes are applied.

Braking applied to bring the motor to rest position is of two types and they are:

1. Electric braking.
2. Mechanical braking.
Electric braking

In this process of braking, the kinetic energy of the rotating parts of the motor is converted into electrical energy which in turn is dissipated as heat energy in a resistance or in sometimes, electrical energy is returned to the supply. Here, no energy is dissipated in brake shoes.

Mechanical braking

In this process of braking, the kinetic energy of the rotating parts is dissipated in the form of heat by the brake shoes of the brake lining that rubs on a wheel of vehicle or brake drum.

*The advantages of the electric braking over the mechanical braking*

- The electric braking is smooth, fast, and reliable.
- Higher speeds can be maintained; this is because the electric braking is quite fast. This leads to the higher capacity of the system.
- The electric braking is more economical; this is due to excessive wear on brake blocks or brake lining that results frequent and costly replacement in mechanical braking.
- Heat produced in the electric braking is less and not harmful but heat produced in the mechanical braking will cause the failure of brakes.
- In the electric braking, sometimes, it is possible to feed back electric energy during braking period to the supply system. This results in saving in the operating cost. This is not possible in case of mechanical braking.

Disadvantages

In addition to the above advantages, the electric braking suffers from the following disadvantages.

- During the braking period, the traction motor acts generator and electric brakes can almost stop the motor but it cannot hold stationary. Hence, it is necessary to employ mechanical braking in addition to electric braking.
- Traction motor has to work as a generator during braking period. So that, motor has to select in such a way that it should have suitable braking characteristics.
- The initial cost of the electric braking equipment is costlier.
TYPES OF ELECTRIC BRAKING

Electric braking can be applied to the traction vehicle, by any one of the following methods, namely:

1. Plugging.
2. Rehostatic braking.
3. Regenerative braking.

Plugging

In this method of braking, the electric motor is reconnected to the supply in such a way that it has to develop a torque in opposite direction to the movement of the rotor. Now, the motor will decelerate until zero speed is zero and then accelerates in opposite direction. Immediately, it is necessary to disconnect the motor from the supply as soon as system comes to rest.

The main disadvantage of this method is that the kinetic energy of the rotating parts of the motor is wasted and an additional amount of energy from the supply is required to develop the torque in reverse direction, i.e., in this method, the motor should be connected to the supply during braking. This method can be applied to both DC and AC motors.

Plugging applied to DC motors

Pulling is nothing but reverse current braking. This method of braking can be applied to both DC shunt and DC series motors by reversing either the current through armature or the field winding in order to produce the torque in opposite direction, but not both. The connection diagrams for both DC shunt and DC series motors during normal and braking periods are given as follows.

The connection diagram for normal running conditions of both DC shunt and DC series motors are shown in Figs. 9.4 (a) and 9.5 (a). The back emf developed by the motor is equal in magnitude and same as to the direction of terminal or supply voltage. During the braking, the armatures of both shunt and series motors are reversed as shown in Fig. 9.4 (b) and Fig. 9.5 (b). Now, the back emf developed by the motor direction of terminal voltage. A high resistance ‘R’ is connected in series with the armature to limit high-starting current during the braking period.
Current flowing through the armature during normal run condition:

\[ I_1 = \frac{V - E_b}{R_a}, \]  

(9.1)
where $V$ is the supply voltage, $E_b$ is the back emf, and $R_a$ is the armature resistance.

Current flowing through the armature during braking period:

$$I_2 = \frac{V - (-E_b)}{R_a + R} = \frac{V + E_b}{R_a + R} = \frac{V + E_b}{R'} \quad \text{[\because R' = R_a + R]}$$

∴ Electric braking torque, $T_b \propto \phi I_2$.

$$T_B = K_1 \phi I_2 = K_1 \phi \left(\frac{V + E_b}{R'}\right) = \frac{K_1 \phi V}{R'} + \frac{K_1 \phi E_b}{R'}, \quad (9.2)$$

But we know that:

$$E_b \propto N\phi. \quad (9.3)$$

Substitute Equation (9.3) in Equation (9.2):
where \( \varphi \).

We know that, in case of series motor flux (\( \varphi \)) developed by the winding is depending the current flowing through it.

\[
\therefore T_B = \frac{K_1 \varphi V}{R'} + \frac{K_1 K_2 \varphi^2 N}{R'}
\]

\[
= \frac{K_1 \varphi V}{R'} + \frac{K_2 \varphi^2 N}{R'} \quad \quad [\therefore K_2 = K_1 K_2]
\]

\[
= K_4 \varphi = K_4 \varphi^2,
\]

(9.4)

where \( K_4 = \frac{K_1 V}{R'} \) and \( K_4 = \frac{K_2 N}{R'} \).

In case of shunt motor, the flux remains constant.

\[
\therefore T_B = K_6 I_a + K_7 I_a^2.
\]

(9.5)

During the normal operating condition, the rotating magnetic field developed by the stator and the rotation of rotor are in the same direction. But during the braking period, plugging is applied to an induction motor by reversing any two phases of the three phases of stator winding in order to change the direction of the rotating magnetic field as shown in Fig. 9.6. So that, the rotating magnetic filed and the rotor will be rotating in opposite direction. So that, the relative speed between emf and rotor is nearly twice the synchronous speed \( N_s - (-N_s) = 2N_s \).
Slip during the braking period:

\[ S = \frac{-N_s - N_s}{N_s} = \frac{-2N_s}{N_s} = -2 \]

But the voltage induced in the rotor \( (E_2) \) is proportional to the slip \( (S) \times \) stator voltage \( (V) \):

\[ \therefore E_2 \propto SV. \]

So, the rotor voltage during the braking period is twice the normal voltage. To avoid the damage of the rotor winding, it should be provided with additional insulation, to withstand the high induced voltage.

The rotation of the magnetic field in the reverse direction produce torque in reverse direction; thereby applying the brakes to the motor. The braking of induction motor can be analyzed by the torque–slip characteristics shown in Fig. 9.7.
Fig. 9.7 Torque–slip characteristics

Rotor current during the braking period,

\[ I_{2b} = \frac{SE_2}{\sqrt{R_2^2 + (S^2 X^2)^2}}. \]

The characteristic curve for the rotor current and the rotor voltage with the variation of the slip is shown in Fig. 9.8.

Plugging applied to synchronous motor

Normally, the stator winding of the synchronous motor is fed with 3-\( \varphi \) AC supply to produce the rotating magnetic field that induces stator poles. And, the field winding is excited by giving the DC supply thereby inducing the rotor poles. At
any instant, the stator poles gets locked with the rotor poles and the synchronous motor rotating at the synchronous speed. In this method of plugging applied to synchronous motor, simply it is not possible to produce the counter torque during the braking period by interchanging any two of three phases. This is due to the magnetic locking of stator and rotor poles (Fig. 9.9).

In order to develop the counter torque, the rotor of synchronous motor should be provided with damper winding. The EMF induced in the damper winding whenever there is any change, i.e., the reversal of the direction of the stator field. Now, according to Lenz's law, the emf induced in the damper winding opposes the change which producing it. This emf induced in the damper winding produces the circulating current to produce the torque in the reverse direction. This torque is known as braking torque. This braking torque helps to bring the motor to rest.

Rheostatic or dynamic braking

In this method of braking, the electric motor is disconnected from the supply during the braking period and is reconnected across same electrical resistance. But field winding is continuously excited from the supply in the same direction. Thus, during the starts working as generator during the braking period and all the kinetic energy of the rotating parts is converted into electric energy and is dissipated across the external resistance.

One of the main advantages of the rehostatic braking is electrical energy is not drawn by the motor during braking period compared to plugging. The rehostatic braking can be applied to various DC and AC motors.
Rehostatic braking applied to DC motors

The rheostatic braking can be applied to both DC shunt and DC series motors, by disconnecting the armature from the supply and reconnecting it across and external resistance. This is required to dissipate the kinetic energy of all rotating parts thereby bringing the motor to rest.

DC shunts motor

Figure 9.10 shows the connection diagram of the DC shunt motor during both normal and braking conditions. In case of DC shunt motor, both armature and field windings are connected across the DC supply, as shown in Fig. 9.10 (a.)

During the braking period, the armature is disconnected from the supply and field winding is continuously excited by the supply in the same direction, as shown in Fig. 9.10 (b). The kinetic energy of all rotating parts is dissipated in the resistor ‘R’ now the machine starts working as generator. Now, braking developed is proportional to the product of the field and the armature currents. But the shunt motor flux remains constant, so the braking torque is proportional to armature current at low-speeds braking torque is less and in order to maintain constant braking torque, the armature is gradually disconnected. Hence, the armature current remains same thereby maintaining the uniform braking torque.
In this braking, which is applied to DC series motor, the armature is disconnected from the supply and is reconnected across an external resistance ‘$R$’ shown in Fig. 9.11 (a) and (b). But, simply, it is not possible to develop the retarding torque by the DC series motor after connecting armature across the resistance as DC shunt motor.

Fig. Rheostatic braking of DC series motor

In case of DC series motor, both the field and armature windings are connected across the resistance after disconnecting the same from the supply; current directions of both the field and armatures are reversed. This results in the production of torque in same direction as before. So, in order to produce the braking torque only the direction of current in the armature has to be reversed. The connection diagram of DC series is shown in Fig. 9.11.

If more than one motor has to be used as in electric traction. All motors can be connected in equalizer connection as shown in Fig. 9.12. In this connection, one machine is excited by the armature current of another machine.
The current flowing through the armature during braking period:

\[ I_a = \frac{E_b}{R + R_a}, \quad (9.7) \]

where \( E_b \) is the back emf developed, \( R \) is the external resistance, and \( R_a \) is the armature resistance.

And we know that, back emf \( E_b \propto \phi \cdot N \)

\[ E_b = K_1 \phi N. \]

\[ \therefore \text{Braking current} \quad I_a = \frac{K_1 \phi N}{R + R_a}. \quad (9.8) \]

Braking torque, \( T_B \propto \phi \cdot I_a. \)

\[ \therefore T_B = K_2 \phi I_a. \quad (9.9) \]
Now, substitute Equation (9.8) in Equation (9.9):

\[
.\ .\ T_B = K_2\phi \left( \frac{K_1\phi N}{R + R_s} \right)
\]

\[
= \frac{K_1K_2\phi^2 N}{R + R_s} = K_3\phi^2 N \quad \Rightarrow \quad \cdot \cdot K_3 = \frac{K_1K_2}{R + R_s}.
\]

For shunt motor flux is practically constant:

\[
.\ .\ T_B = K_3 I_n^2 N. \quad \quad (9.10)
\]

**DC series motor**

In case of DC series motor, it is not easy to apply regenerative braking as of DC shunt motor. The main reasons of the difficulty of applying regenerative braking to DC series motor are:

1. During the braking period, the motor acts as generator by reversing the direction of current flowing through the armature, but at the same time, the current flowing through the field winding is also reversed; hence, there is no retarding torque. And, a short-circuit condition will set up both back emf and supply voltage will be added together. So that, during the braking period, it is necessary to reverse the terminals of field winding.

2. Some sort of compensating equipment must be incorporated to take care of large change in supply voltage.

On doing some modifications during the braking period, the regenerative braking can be applied to DC series motor. Any one of the following methods is used.

**Method-I (French method)**

If one or more series motors are running in parallel, during the braking period, the field windings, of all series motors, are connected across the supply in series with
suitable resistance. Thereby converting all series machines in shunt machines as shown in Fig. 9.15.

![Diagram of regenerative braking of DC series motor]

**Fig.** Regenerative braking of DC series motor

The main advantage of this method is, all armatures are connected in parallel and current supplied to one machine is sufficient to excite the field windings of all the machines, and the energy supplied by remaining all the machines is fed back to the supply system, during the braking period.

*Method-II*

In this method, the exciter is provided to excite the field windings of the series machine during the regenerative braking period. This is necessary to avoid the dissipation of energy or the loss of power in the external resistance.

Whenever the excitation of field winding is adjusted to increase the rotational emf more than the supply voltage, then the energy is supplied to the supply system. At that time, the field winding of the series machine is connected across an excited being driven by motor operated from an auxiliary supply. Now, during the braking period, the series machine acts as separately excited DC generator which supplies
energy to the main lines. A stabilizing resistance is used to control the braking torque (Figs. 9.16 and 9.17).

Fig. Regenerative braking
Method-III

In this method, the armature of exciter is connected in series. With the field winding of series machine, this combination is connected across the stabilizing resistance.

Here, the current flowing through stabilizing resistance is the sum of exciter current and regenerated current by the series machines.

During the braking period, the regenerated current increases the voltage drop across the stabilizing resistance, which will reduce the voltage across the armature circuit and cause the reduction of the exciter current of the series machine field winding. Hence, the traction motors operating as series generators.

Regenerative braking applied to 3-φ induction motor

Regenerative braking is applied to the induction motor by increasing its speed above the synchronous speed. Now, the induction motor acting as an induction generator that feeds power to the main line. The torque slip characteristics of the induction motors are shown in Fig. 9.18.

![Fig. Torque vs slip characteristics](image)

Regenerative braking

Motoring

Braking

With resistance

Without resistance

Torque

Slip
The main advantage of the induction motor is during the braking period; no need of placing external resistance in the rotor circuit. The speed during the braking remains almost constant and independent of the gradient and the weight of the train.

This regenerative braking applied to an induction motor can save 20% of the total energy leads the reduction of operating cost.

**Regenerative braking applied to AC series motors**

It is not simple way to apply regenerative braking to an AC series motor. In this method, the armature of traction motor is connected to the top changing transformer through iron cored reactors $RE_1$ and $RE_2$ and commutating pole winding ‘C’.

An auxiliary transformer is provided to excite the field winding of the traction motor. Let us assume ‘$V$ ’ be the voltage of tap-changing transformer and $I_f$ is the field current of traction motor. Due to the presence of reactor, $I_f$ lags $V$ by an angle 90° of traction motor is phase with exciting current as shown in Fig. 9.19.

![Phasor diagram](image)

**Fig.** Phasor diagram

From the phasor diagram, the vector difference of $\vec{V}$ and $\vec{E}$ gives voltage across iron-cored reactor $RE_1$. Now, the armature current $I_a$ lags $\left[ I_a \cdot RE_1 \right]$ by 90°. And, the braking torque developed the series machine will be proportional to $I_a \cos \phi$. And, the power returned to the supply is also proportional $I_a \cos \phi$. So that, proper phase angle must be obtained for efficient braking effect arise in the regenerative braking applied to an AC series motor are:
During the regenerative braking, the braking torque is proportional to the operating power factor. In order to operate the series motor at high power factor field, winding must be excited separately from other auxiliary devices.

Proper phase-shifting device must be incorporated to ensure correct phase angle.

To overcome the difficulty stated above, a special arrangement is adopted that is known as Behn Eschenburg method of regenerative braking.

The circuit diagram for applying regenerative braking to an AC series motor is shown in Fig. 9.20.

Fig. 9.20 Regenerative braking of AC series motor

TRACTION MOTOR CONTROL

Normally, at the time of starting, the excessive current drawn by the electric motor from the main supply causes to the effects. So that, it is necessary to reduce the current drawn by the traction motor for its smooth control such as:

1. To achieve smooth acceleration without any jerking and sudden shocks.
2. To prevent damage to coupling.
3. To achieve various speed depending upon the type of services.

Control of DC motors

At the time of starting, excessive current is drawn by the traction motor when rated voltage is applied across its terminals. During the starting period, the current drawn by the motor is limited to its rated current. This can be achieved by placing a resistance in series with the armature winding. This is known as starting resistance; it will be cut off during the normal running period thereby applying rated voltage across its armature terminals. By the resistance of starting resistor, there is considerable loss of energy takes place in it.

∴ At the time of switching on, the back emf developed by the motor $E_b = 0$.

\[ \therefore \text{Supply voltage, } V = I_a R_a + V_s. \]  \hspace{1cm} (9.11)

where $V_s$ is the voltage drop across starting resistance and $I_a R_a$ is the voltage drop in armature.

During the running condition:

\[ V = I_a R_a + V_s + E_b. \]  \hspace{1cm} (9.12)

At the end of accelerating period, the total starting resistance will be cut off from the armature then:

\[ V = I_a R_a + E_b. \]  \hspace{1cm} (9.13)

1. Various drops during staring and running with armature resistance.
2. Various drops during starting and running with negligible armature resistance.

When armature resistance is neglected $R_a = 0$ and ‘$t$’ is the time in seconds for starting, then total energy supplied is, $V_aI_a t$ watts-sec and the energy wasted in the starting resistance at the time of starting can be calculated from Fig. 9.21(b) as:

\[
= \text{Area of } \Delta^{PRQ} \times I_a \\
= \frac{1}{2} VI_a \\
= \frac{1}{2} VI_a t \text{ W-sec}. \quad (9.14)
\]

---

**Fig**Traction control of DC motor

That is whatever the electrical energy supplied to the motor, half of the energy is wasted during the starting resistor.

∴ The efficiency of the traction motor at time of starting, $\eta_{\text{start}} = 50\%$. 
AUXILIARY EQUIPMENT

A traction system comprises of the following auxiliary equipment in addition to the main traction motors required to be arranged in the locomotive are discussed below.

Motor–generator set

Motor–generator set consists of a series motor and shunt generator. It is mainly used for lighting, control system, and the other power circuits of low voltages in the range 10–100 V. The voltage of generator is effectively controlled by automatic voltage regulator.

Battery

It is very important to use the battery as a source of energy for pantograph, to run auxiliary compressor, to operate air blast circuit breaker, etc. The capacity of battery used in the locomotive is depending on the vehicle. Normally, the battery may be charged by a separate rectifier.

Rectifier unit

If the track electrification system is AC motors and available traction motors are DC motors, then rectifiers are to be equipped with the traction motors to convert AC supply to DC to feed the DC traction motors.
Transformer or autotransformer

Depending on the track electrification system employed, the locomotive should be equipped with tap-changing transformers to step-down high voltages from the distribution network to the feed low-voltage traction motors.

Driving axles and gear arrangements

All the driving motors are connected to the driving axle through a gear arrangement, with ratios of 4:1 or 6:1.

TRANSMISSION OF DRIVE

Drive is a system used to create the movement of electric train. The electric locomotives are specially designed to have springs between the driving axles and the main body. This arrangement of springs reduces the damage not only to the track wings but also to the hammer blows.

The power developed by the armature of the traction motors must be transferred to the driving axels through pinion and gear drive. There are several methods by which power developed by the armature can be transferred to the driving wheel.

Gearless drive

Gearless drives are of two types.

Direct drive

It is a simple drive. The armatures of the electric motors are mounted directly on the driving axle with the field attached to the frame of locomotive. In this system, the poles of electric motors should be flat so that the armature can be able to move freely without affecting the operation. Here, the size of the armatures of the traction motor is limited by the diameter of the driving wheels. The arrangement of direct drive is shown in fig,
**Direct quill drive**

Quill is nothing but a hollow shaft. Driving axle is surrounded by the hollow shaft attached by springs. The armature of the motor is mounted on a quill. The speed and the size of the armature are limited by the diameter of the driving wheels.

**Geared drive**

In this drive, the armature of the traction motor is attached to the driving wheel through the gear wheel system. Now, the power developed by the armature is transferred to the driving wheel through the gear system. Here, gear drive is necessary to reduce the size of the motor for given output at high speeds (Fig. 9.33). The gear ratio of the system is usually 3–5:1.
**Fig.** Geared drive

*Brown–Boveri individual drive*

In this drive, a special link is provided between the gear wheel and driving wheel, which provides more flexibility of the system.