Systems of Track Electrification – There are four basic types of electrification systems as follows:

1. Direct Current (D.C.) System
2. Single Phase A.C. System
3. Three Phase A.C. System
4. Composite System

1.) **Direct Current System –** In this system the electric motors employed for getting the necessary motive power are usually d.c. series motors, although the compound motors are coming into favour for tramways and trolley buses where regenerative braking is desired. The electric traction in India started with dc system, 600 V to 750 V supply is used for urban services. For semi urban and main line services 1500 V to 3000 V is preferred. The contact system in d.c. may be of third rail type or overhead conductor type. The third rail type contact system is used for low voltages upto 750 V. The contact system is fed from substation which may be spaced 3 to 5 km for urban and suburban heavy traffic and 15 to 30 km for main line service. The substations receive power by high voltage 3 phase lines. These substations are usually unattended type using supervisory control system. This arrangement reduces the cost of transmission lines and copper losses in transmission lines.

The main advantage of d.c. traction is found in the series motor which have the most desirable characteristics of producing heavy starting torque, smaller weight per H.P., lower maintenance cost as compared with series a.c. motor. The main disadvantage of d.c. system is high cost of substation. Moreover substations have to be provided comparatively over shorter distances and negative boosters are needed with d.c. system to reduce corrosion in underground pipe work which is not there with a.c. system.

2.) **Single Phase A.C. System –** It has been observed that use of single phase series motor at low frequency supply improves its commutation properties; power factor and efficiency are also increased. The series motor is suitable for maximum operating voltage of 300 to 400 V. The voltage employed for distribution network is 15 kV to 25 kV at 16 2/3 Hz or 25 Hz, which is stepped down on the locomotive to a low voltage (300 to 400 V) suitable for supplying to single phase series motors by means of a stepdown transformer carried on the locomotive. The distribution network may be fed directly, at high voltage from a generating station when the extent of electrification is within a radius of about 30 km from the generating station. For longer distances, the economic voltage for the transformer substations are employed for feeding the distribution network. The spacing of the substations is 50 to 80 km because of low current requirement due to high voltage.

In case the supply at low frequency is obtained directly from a generating station exclusively meant for traction purposes, there is no problem as power corresponding to this frequency can always be generated. If however, electric supply is taken from industrial frequency network, which is usually the case, substations in addition to transformers have necessarily the frequency converters to convert 3 phase 50 Hz into single phase 16 2/3 or 25 Hz as required. The ac single phase system is invariably adopted for main line service where the cost of overhead structure is of more importance and rapid acceleration and retardation is not as important as for suburban railways.

3.) **Three Phase A.C. System –** This system of electrification existed in Italy. Two overhead conductors and rails from three phase supply for induction motor at 3.3 kV and frequency of 16 2/3 Hz. There was no need of transformer in the locomotive as induction motors could directly work on 3.3 kV. Besides high voltage supply which reduces the amount of current needed for operation, robustness and trouble free operation of induction motor was considered another advantage of this system. Apart from this, induction motor has property of automatic regenerative braking without additional equipment. Inspite of above advantages, this system could not find favour and has become obsolete due to the following reasons:

- Two overhead conductor feeding system becomes very much complicated at crossings and junctions.
- Constant speed characteristics of induction motor is not suited to traction work. However, locomotives having four speeds have been designed using cascade connections and pole changing method of speed control.
- Induction motors have speed torque characteristics similar to d.c. shunt motors. This is not suitable for parallel operation as with little difference in rotational speed caused due to unequal diameters of wheels, motors are loaded so differently. In other words load torque share by one motor will be materially different from that of the other.

4.) <u>**Composite Systems**</u> – It has been seen that no system of electrification is good in all respects. Composite system combines the advantages of the dc/ac and 3 phase/single phase systems. The single phase ac system is preferable from the view point of the distribution and contact wire system. It can be converted into either three phase ac or dc at low voltage in the locomotive. At present there are two composite systems in use.

a. Single phase to three phase system or Kando system
b. Single phase to dc system

a) **Single Phase to Three Phase System or Kando System** – This system was developed in Hungary in 1932 and consists of 16 kV 50 Hz single phase overhead supply being converted to three phase supply at lower frequency by means of phase converter equipment carried on the locomotive. This three phase supply is fed to three phase induction motors. The advantage of this system is that complicated overhead trolley wire equipment ordinary three phase system is replaced by single wire system. Main drawbacks of induction motors for traction duty are: low starting torque, high starting current, absence of speed control. With the development of silicon controlled rectifier used as inverter it is possible to get variable low frequency supply say from 0.5 to 9 Hz. At this low frequency, induction motor develops high starting torque without drawing excessive current. Speed control is further easily obtained by varying the frequency of supply.

b) **Single Phase to D.C. System** – This system of traction employs 25 kV industrial frequency a.c. supply which has been adopted for all future electrification. In this system an overhead single phase 25 kV 50 Hz supply is employed which is stepped down by the transformer in the locomotive. This single phase supply is then converted to d.c. and used in driving d.c. series traction motors.

Advantages of 25 kV a.c. system over d.c. system – The following are the advantages of this system of track electrification over other systems particularly d.c. systems:

1. Light overhead catenary system – Due to high system voltage, line current for a given traction demand of power will be less. This reduces the cross section of conductor and at the same time supporting structures and foundations will be simple and light.
2. Saving in substations – Spacing between the substations depends very much upon the voltage regulation which a locomotive can tolerate. Under normal conditions it is

limited to 20% of normal voltage. Under abnormal conditions such as failure of substation equipment, it is limited to 40% so that at least essential auxiliaries such as brake exhausters and blowers are working. In d.c. system spacing of substations is very much influenced by the track resistance. In the case of a.c. system the rail impedance has little effect on the substation spacing because traction return current normally flows through the earth. Also due to the reduction in the line current, voltage drop in overhead equipment will be correspondingly be less in a.c. system than in d.c. system. This makes large spacing of 50 to 80 km between substations possible as against 12 to 30 km with d.c. 3000 V system and 5 to 12 km with 1500 V d.c system.

3. Starting efficiency of a.c. locomotive is higher than that of d.c. locomotive. In d.c. locomotive supply voltage at starting is reduced by resistors whereas in a.c. rectifier locomotive, reduced voltage starting is achieved by means of on load tap changer transformer installed on either the primary or the secondary of the transformer. The elimination of starting resistors makes the torque speed curve more steep which improves adhesion. This in turn reflects in the increased power weight ratios in the case of a.c. locomotive. For the same weight, electric locomotive is 2.3 times more powerful than diesel locomotive.

Disadvantages of 25 kV a.c. system – The following are the disadvantages of a.c. system

1. Interference with telecommunication circuits.
2. Single phase traction can produce both voltage and current imbalance. Current imbalance produces heating in the alternators supplying power to the network and the voltage imbalance causes heating in the induction motors connected to the systems.

Comparison Between Pure A.C. and D.C. Systems – The pure a.c. and pure d.c. systems can be compared as follows:

1. D.C. series motors develop more starting as well as running torque for same size than a.c. series motors. D.C. motors are therefore capable of giving high acceleration than a.c. series motor.
2. Number of speeds in case of d.c. series motors, except by chopper method are limited whereas by tap changing method many speeds are possible in case of a.c. series motors.
3. D.C. series motors are less costly, lighter for same h.p., more efficient and require less maintenance than a.c. series motors.
4. Regenerative braking is more efficient and has less complications in case of d.c. than with a.c. system
5. Number of substations needed for a given track kilometerage will be less with a.c. than with d.c. system.
6. More elaborate negative boosting is required in a.c. than in d.c. system. This is more so due to high impedance of track to a.c.
7. Overhead distribution system is lighter and less costly in a.c. than in d.c. system.
8. A.C. system has high interference with communication lines than d.c. system.
9. Rail conductor system of track electrification which is less costly, is possible with d.c. system than with a.c. system.