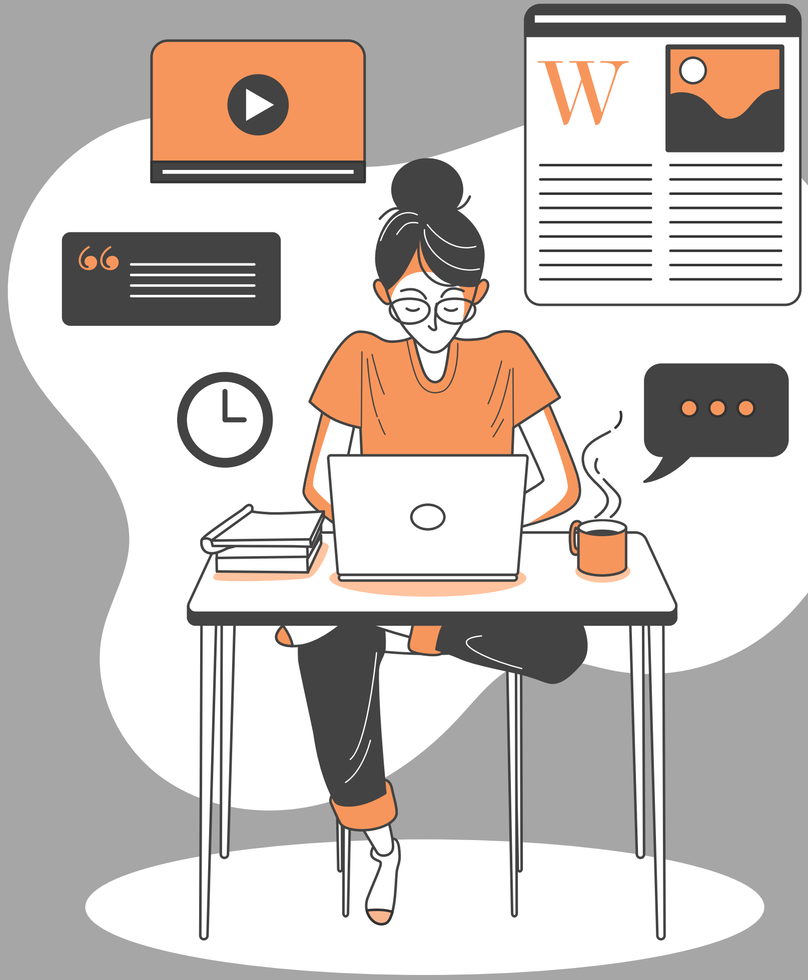
Engineering Excellence for Empowerment

Nadar Saraswathi College of Engineering & Technology

NSCET E-LEARNING PRESENTATION

LISTEN …   LEARN…   LEAD…



DEPARTMENT OF ELECTRICAL AND ELECTRONICS

IVth YEAR / VIIIth SEMESTER

EE6801 – ELECTRICAL ENERGY GENERATION, UTILIZATION AND CONSERVATION

M.ARIVALAGAN M.Tech., (Ph.D), M.I.S.T.E.,
Assistant Professor & HOD/EEE,
Nadar Saraswathi College of Engineering & Technology,
Vadapudupatti, Annanji (po), Theni – 625531.

UNIT – 1
ELECTRIC DRIVES AND TRACTION

FUNDAMENTALS OF ELECTRIC DRIVES

- ❖ System employed for motion control are called driver and drives employing Electric Motors Are Electrical Drives.

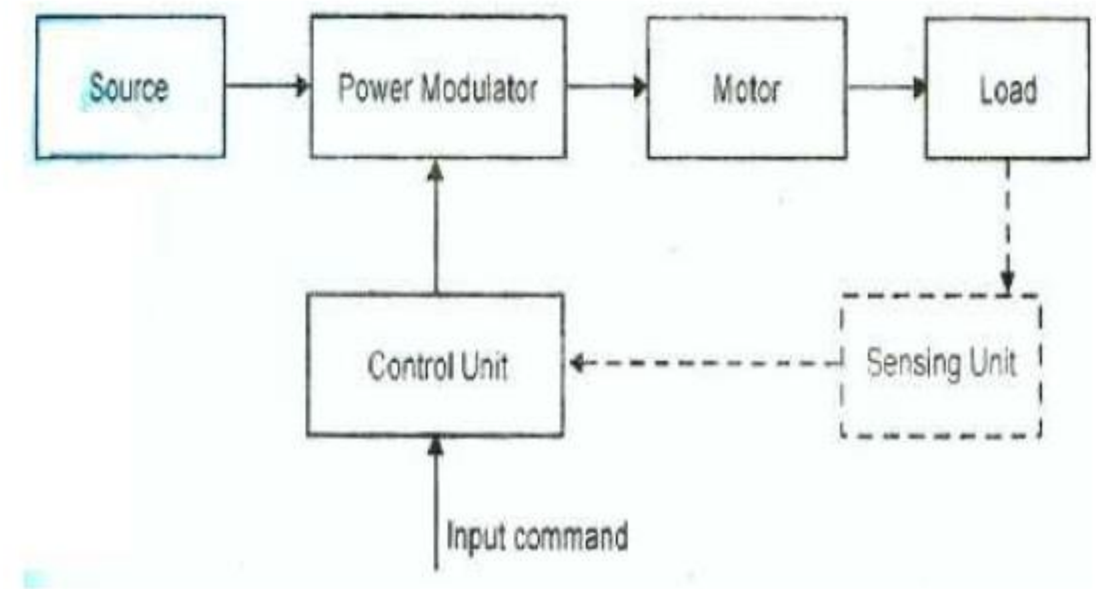
- ❖ Electric drives are characterized by the nature of speed torque characteristics such as constant torque drives or constant hp drives. These are sometimes characterized by the type of motor used.

- ❖ Electrical drives which employs solid state derives thyristors for their control operations are termed as solid state drives.

- ❖ Solid state drives are used in steel rolling mill, Paper mills, Printing machines, cranes and lifts, fan drives, Aircraft power supplies, etc.

COMPONENTS OF ELECTRICAL DRIVES

The block diagram of an electrical drives is shown below.



LOAD:

- Usually load requirements can be specified in terms of speed and torque demands.
- Fans, Pumps, Robots, Washing machines, Machine tools, Trains and drills.
- Load is usually machinery designed to accomplish a given task.

MOTOR:

- A motor having speed-torque characteristics and capabilities compatible to the load requirements is
- chosen most commonly used motor are

Dc motor: Shunt motor, Series motor, Compound motor and permanent magnet motors.

Ac motors: Induction motor and synchronous motors

Special m/c: Brushless Dc motor, Stepper motors and switching reluctance motors are also used.

POWER MODULATOR:

- Power modulator performs one or more of the following four functions:
- =>Modulates flow of power from the source to the motor in such a manner that motor is imparted by the speed torque characteristics required by the load.
- =>During transient operations such as starting braking and speed reversal it restricts source and motor current within permissible values excessive current drawn from the source may overload it or may course a voltage clip.
- =>Converts electrical energy of the source in the form suitable to the motor.
- =>Selects the mode of operation of the motor in motoring or braking.

CONTROL UNIT:

- Control unit has built in control for power modulation it usually operates at much lower voltage and power.
- In addition to operate the power modulator as desired it may also generate commands for the protection of power modulation and motor.
- Input command signal adjusts the operating point of the drive and forms an input to the control unit.
- Sensing of certain drive parameter such as motor current and speed may be required either for protection or for closed loop operation.

ADVANTAGES OF ELECTRICAL DRIVES:

- They hove flexible control characteristics the steady start and dynamic characteristics of electrical of electrical drives can be shaped to satisfy load requirements.
- Control gear required for speed control starting and braking is usually simple and easy to operate.
- They are available in wide range of torque of torque speed and power.
- Electric motor have high efficiency low or no load losses and considerable short time
- overloading capability compared to other prime movers they have longer life lower noise lower maintenance requirements andcleaner operation.
- They are adaptable to almost any operating conditions such as explosive and radioactive environments submerged in liquids, critical mountings, and so on.

ADVANTAGES OF ELECTRICAL DRIVES:

- Do not pollute the environment.
- In operate in all the 4 quadrants of speed torque plane with considerable scaring of energy during
- braking.
- Unlike other prime movers there is no need to refuel or warm up the motor
- They can be started instantly and can immediately be fully loaded.
- They are powered by electrical energy which has a number of advantages over other forms of energy.

CHOICE OF AN ELECTRIC MOTOR

There are certain factor that governs or influences, the selection choice electrical drives. They are:

Availability of Electrical Supply

- ❖ The electric drive is a drive system with electrical motor as a prime mover.
- ❖ The selection of electrical drive is based on the availability of electrical supply.
- ❖ There are three-types electrical supplies, namely AC
- ❖ supply, DC supply, and Rectified DC supply. If AC supply is available.
- ❖ Then AC drive is selected motor. An AC drive consists of AC motor as a drive motor .
- ❖ If DC supply is available, then DC drive is selected DC drive consist of DC motor as a drive motor.
- ❖ Hence nature of electrical supply available governs selection of electric drive.

Nature of Operation characteristics of Electric drive motors

The electric drive motor has different types of operating characteristics such as

1) Starting characteristics

2) Running characteristics

3) Speed control characteristics

4) Braking characteristics

- ❖ For example the running characteristic of electric drive motor shows how the motor behaves where it is loaded .
- ❖ In some cases if the load is increased , the speed of the motor is drastically reduced .so such motors are not selected for constant speed applications.

Economic Consideration

The electrical motor is selected based on two economic considerations, namely

1. Initial cost:

- The initial cost is nothing out capital cost. This is the cost occurred during purchase and erection.

2. Running cost:

- This is the cost running the electric drive. Ex: Maintenance cost , Fuel cost etc..

Type of the Drive system

- Type of the Drive system available also governs the choice of electric motor.
- There are three types of drive system namely Group drive, Individual diver and Multi motor drive. Assume that at any particular location, different small loads are available.
- Since the loads are separate unit, it can be driven by single large motor (group drive) So here a DC motor or an AC motor is selected with huge HP rating.

Types of Load

- The type of load available , also governs the selection of electric drive . Generally the loads are classified based on the Torque characteristics .
- Torque is the twisting force required to drive (rotate) the load ,based on the Torque characteristics loads are classified as follows.

1. Load requiring constant Torque with speed
2. Load requiring increasing Torque with speed
3. Load requiring high starting Torque (high inertia load)

- Assume that load cannot with high inertia available .
- This high inertia loads cannot be accelerated or deaccelerated quickly.
- They require high starting Torque. Therefore motor with high starting torque such as DC series or 3 (There Phase) Slip ring induction motor is selected .Thus type of load influence the choice of electric motor.

Mechanical considerations

i) Type of enclosure

ii) Type of bearings

iii) Type of Transmission devices

EnvironmentalConsiderations

I. Noise pollution

II. Environmental Pollution

Load – With standing Capability of motors:

- ❖ The size and rating required for the drive motor influence the selection of the electric drive motor. The size of the motor describes load- withstanding capability .when the motor is loaded, the line current drawn by the motor increases.
- ❖ As a result losses increases and more heat is developed .If the heat is hot dissipated then insulation in the motor fails leading to complete breakdown of the motor.
- ❖ Here duty cycle of the load and the Torque requirement are important factors in deciding size and rating of the motor.

Different Types Of Loading Of Drives:

- While selecting a motor it is necessary to consider the variation of load torque with speed and time. This is related to the torque rating of the motor i.e. how much and what
- type of torque motor can produce safely.
- The variation of load torque with speed basically decides the type of motor to be selected. While the variation of load torque with time decides the rating of the motor to be selected. Such a factor which influences the selection of rating of motor based on the load variation with time is called load variation factor.
- One cycle of variation of load is called a duty cycle. The different types of load variations with and corresponding examples of load are given below:

Different Types Of Loading Of Drives: contd..

i) Continuous or constant loads:In this type load occurs for a long time under the same conditions.e.g., fan type loads, paper making machines etc.

ii) Continuous variable loads : The load is variable over a period of time but occurs repetitively for a longer duration. e.g., metal cutting lathes, conveyers etc.

iii) Pulsating loads: A torque which exhibits a combination of constant load torque superimposed by pulsations. e.g., reciprocating pumps, compressors, all loads having crank shaft.

iv) Impact loads: These are peak loads occur at regular intervals of time. e.g., rolling mills, presses, sharing machines, forging hammers. Motors for such loads are provided with heavy fly wheels.

v)Short time intermittent loads : The load appears periodically identical duty cycles, each consisting of a period of applications of load and one or rest. e.g., all forms of cranes, hoists, elevators.

vi) Short time loads : A constant load appears on the drive and the system rests for the remaining period of cycle. e.g. motor- generator sets for charging batteries, household equipment.

1.3 APPLICATION OF MOTOR FOR PARTICULAR SERVICE

Type	Advantages	Disadvantages	Typical application	Typical drive, output
Self-commutated motors				
Brushed DC	Simple speed control Low initial cost	Maintenance (brushes) Medium lifespan Costly commutator and brushes	Steel mills Paper making machines Treadmill exercisers Automotive Accessories	Rectifier, linear transistor(s) or DC chopper controller.

Brushless DC motor (BLDC) or (BLDM)	Long lifespan Low maintenance High efficiency	Higher initial cost Requires EC controller with closed-loop control	Rigid ("hard") disk drives CD/DVD players Electric vehicles RC Vehicles UAVs	Synchronous; singlephase or three-phase with PM rotor and trapezoidal stator winding; VFD typically VS PWM inverter type.
Switched reluctance motor (SRM)	Long lifespan Low maintenance High efficiency No permanent magnets Low cost Simple construction	Mechanical resonance possible High iron losses Not possible: * Open or vector control * Parallel operation Requires EC controller[	Appliances Electric Vehicles Textile mills Aircraft applications	PWM and various other drive types, which tend to be used in very specialized / OEM applications.

Universal Motor	High starting torque, compact, high speed.	Maintenance (brushes) Shorter lifespan Usually acoustically noisy Only small ratings are economical	Handheld power tools, blenders, vacuum cleaners, insulation blowers	Variable single phase AC, half-wave or fullwave phase-angle control with triac(s); closed-loop control optional.[

AC asynchronous motors				
AC polyphase squirrelcage Or woundrotor induction motor (SCIM) or (WRIM)	Self-starting Low cost Robust Reliable Ratings to 1+ MW Standardized types.	High starting current Lower efficiency due to need for magnetization.	Fixed-speed, traditionally, SCIM the world's workhorse especially in low performance applications of all types	Fixed-speed, low performance applications of all types. Variable-speed, traditionally, WRIM drives or fixed-speed V/Hz-controlled VSDs. Variable-speed, increasingly, vectorcontrolled VSDs displacing DC, WRIM and single-phase AC induction motor drives.

AC synchronous motors				
Wound rotor synchronous Motor (WRSM)	Synchronous speed Inherently more efficient induction motor, low power factor	More costly	Industrial motors	Fixed or variable speed, three-phase; VFD typically sixstep CS load commutated Inverter type or VS PWM inverter type.

Specialty motors

Pancake or axial rotor motors	Compact design Simple speed Control	Medium cost Medium lifespan	Office Equip Fans/Pumps, fast industrial and military servos	Drives can typically be brushed or brushless DC type.
Stepper Motor	Precision positioning High holding torque	Some can be costly Require a controller	Positioning in printers and floppy disc drives; industrial machine Tools	Not a VFD. Stepper position is determined by pulse counting.

Hysteresis Motor	Accurate speed control Low noise No vibration High starting Torque	Very low efficiency	Clocks, timers, sound producing or recording equipment, hard drive, capstan drive	Single-phase AC, twophase capacitor-start, capacitor run motor[
Synchronous reluctance motor (SyRM)	Equivalent to SCIM except more robust, more efficient, runs cooler, smaller footprint Competes with PM synchronous motor Without	Requires a controller Not widely available High cost	Appliances Electric vehicles Textile mills Aircraft applications	VFD can be standard DTC type or VS inverter PWM type.

1.4. TRACTION MOTORS

- The dc series motor possess a high starting torque and variable speed characteristics therefore it is very much used in traction application.
- It is more robust capable of withstanding very severe mechanical shock and take more overload.
- Ventilation for the motor should be carefully designed ,to avoid surface which attract dust,dirt,grit,from track or road.
- The field frame is of cast steel and usually of box type, with opening at each end bored and recessed to provide the armature bearing which are fastened securely by steel bolts screwed into it.
- Locomotive motors are axle mounted and wherever the HP exceeds 400 they are placed on the locomotive frame.
- The maximum speed and output of the motor decides the choice of mounting.

TRACTION MOTORS contd..

- 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 staring.
- 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.

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.
- DC series motor is having high-starting torque and having the capability of handling overloads that
- is essential for traction drives.
- These motors are having simple and robust construction.
- The speed control of the series motor is easy by series parallel control.
- 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.
- 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.

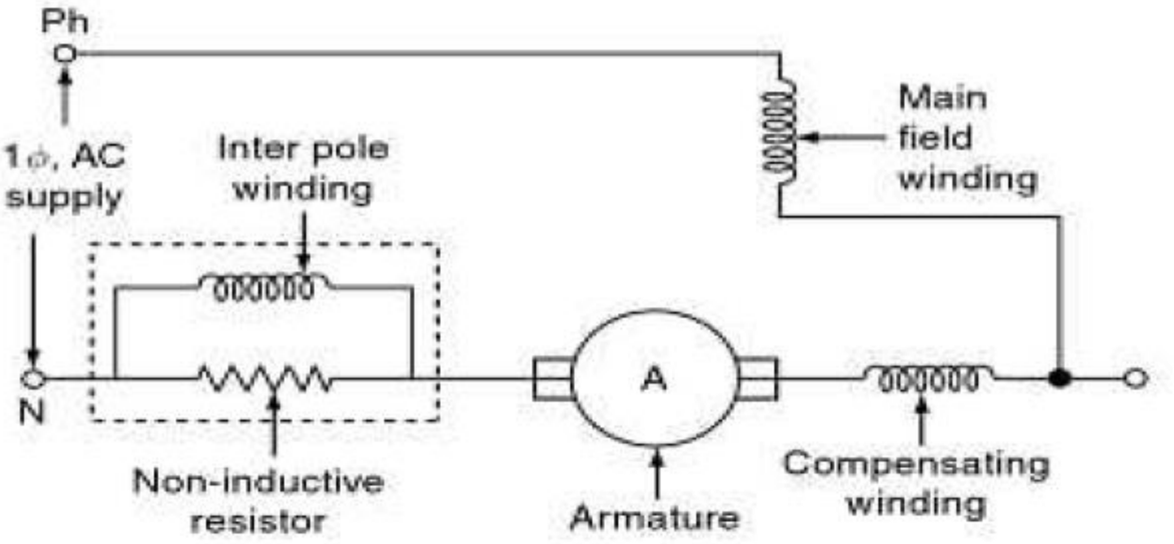
Shunt motor

- From the characteristics of DC shunt motor, it is not suitable for traction purpose, due to the
- following reasons:
- DC shunt motor is a constant speed motor but for traction purpose, the speed of the motor should
- vary with service conditions.
- 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 So that, for a given load torque, the
- shunt motor has to draw more power from the supply than series motor.
- 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.
- The flux developed by shunt motor is proportional to shunt field current and hence supply voltage.
- But the torque developed is proportional to φsh and Ia. Hence, the torque developed by the
- shunt motor is affected by small variations in supply voltage.

AC series motor

- Practically, AC series motor is best suited for the traction purpose due to high-starting torque When
- DC series motor is fed from AC supply, it works but not satisfactorily due to some of the following
- reasons:
- 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.
- 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.
- Field winding inductance will result abnormal voltage drop and low power factor that leads to the
- poor performance of the motor.
- Induced emf and currents flowing through the armature coils undergoing commutation will
- cause sparking at the brushes and commutator segments.

AC Series motor



Three-phase induction motor

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

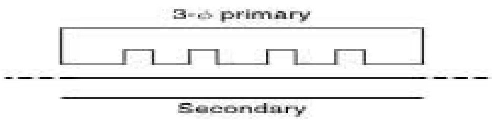
- Simple and robust construction.
- Trouble-free operation.
- The absence of commutator.
- Less maintenance.
- Simple and automatic regeneration.
- High efficiency.
- Three-phase induction motors also suffer from the following drawbacks.
- Low-starting torque.
- High-starting current and complicated speed control system.
- 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

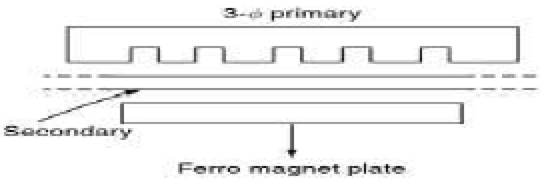
.

Linear induction motor

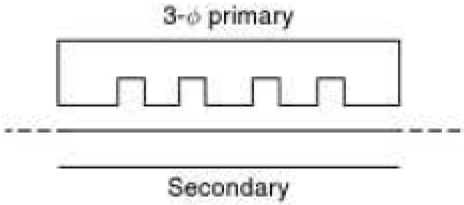
- It is a special type of induction motor that gives linear motion instead of rotational motion, as in the
- case of a conventional motor.
- In case of linear induction motor, both the movement of field and the movement of the
- conductors are linear.
- A linear induction motor consists of 3-φ distributed field winding placed in slots, and secondary is
- nothing but a conducting plate made up of either copper or aluminum
- 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. This drawback can be overcome by double primary system. 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.

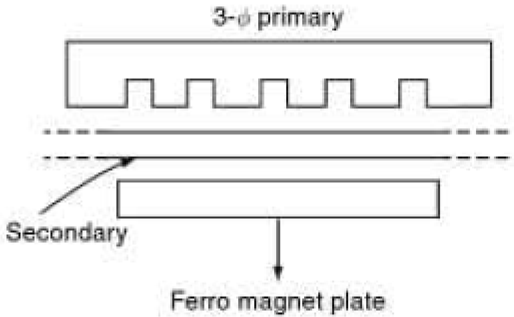
Linear Induction motor





Short single primary





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

CHARACTERISTIC FEATURES OF TRACTION MOTOR

Electrical features:

- ❖ High starting speed
- ❖ Simple speed control
- ❖ Series speed torque characteristics
- ❖ It should be suitable for dynamic or regenerative braking
- ❖ Even when the supply voltage fluctuate commutations should be good

Electrical features of Traction motor

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

Mechanical features

- Due to the high speed of the train the motor should be robust and should withstand continuous
- vibration
- Weight should be minimum and over all dimension should be small as they are to be placed beneath the locomotive or motor coach they should be protected from dirt and dampness
- No single motor fulfils the above needs the DC series and compound motors are found
- to be suitable for DC.
- AC series motor is found to be suitable for single and induction motors for three phase system.

SYSTEMS OF RAILWAY ELECTRIFICATION

- 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.

1-φ 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

3-φ 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.

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.

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

ELECTRIC BRAKING

- In this method of braking, the kinetic energy of the moving parts that is motor is converted into electrical energy which is consumed in a resistance as heat or alternatively it is returned to the supply source.
- Electric braking is superior to the friction braking as it is fast and cheap since there is no cost of maintenance of the brake shoes or lining.
- During braking operation a motor has to function as a generator.
- The motor can be held at stand still. In other words the electric braking cannot hold the motor at rest.
- Thus it becomes essential to provide mechanical brakes in addition to electric braking.

Various types of electrical braking are:
a) Plugging
b) Rheostatic braking
c) Regenerative braking

Plugging

- This is a simple method of electric braking and consists in reversing the connections of the armature of the motor so as to reverse its direction of rotation which will oppose the original direction of rotation of the motor and will bring it to zero speed when mechanical brakes can be applied.
- At the end of the braking period the supply to the motor is automatically cut off. This method of braking can be applied to the following motors.

1) DC motors

2) Induction motors

3) Synchronous motors

DC motors:

- To reverse a DC motors, it is necessary to reverse the connections of the armature while the connections of the field are kept the same. The direction of m.m.f remains the same even during braking periods.

Series motors:

- The arrangements of connection before and after the braking are shown in fig.

Shunt motors:

- The arrangements of connections before and after braking for shunt motor are shown in fig.
- Total voltage of V+ Eb is available across the armature terminals which causes a current Ito flow around the circuit.
- When Eb = V then the voltage across the armature is 2V and at the time of braking twice the normal voltage is applied to the resistance in series with the armature at this time in order to limit the current. While the motor is being braked, the current is still being drawn from the supply.

Electric braking to torque

T_B is proportional to ΦI ------------------------------ (1)

T_B = K ΦI ---------------------------- (2)

Where K is a constant

Current = V+ Eb / R ------------------------ (3)

Eb =K1NΦ --------------------- (4)

Where V is applied voltage

Eb is back emf of the motor.

R is the resistance of the motor, N is the speed, K1 is a constant

Substitute the value of Eb from equation (4) in (3)

Current I = (V + K1N Φ)/ R -------------------- (5) In view

of equations (2) and (5)

WhereK_2 =KV/ R -------------------- (7)

And K_3 = KK_1/R --------------------- (8) Apply

the results obtained to the series motor, where

Φ armature current (Ia) ------------------- (9)

Then electric braking in series motor,

= K_4 Ia + K_5 Ia^2 -------------------- (10)

In the case of shunt motor since flux is constant, so

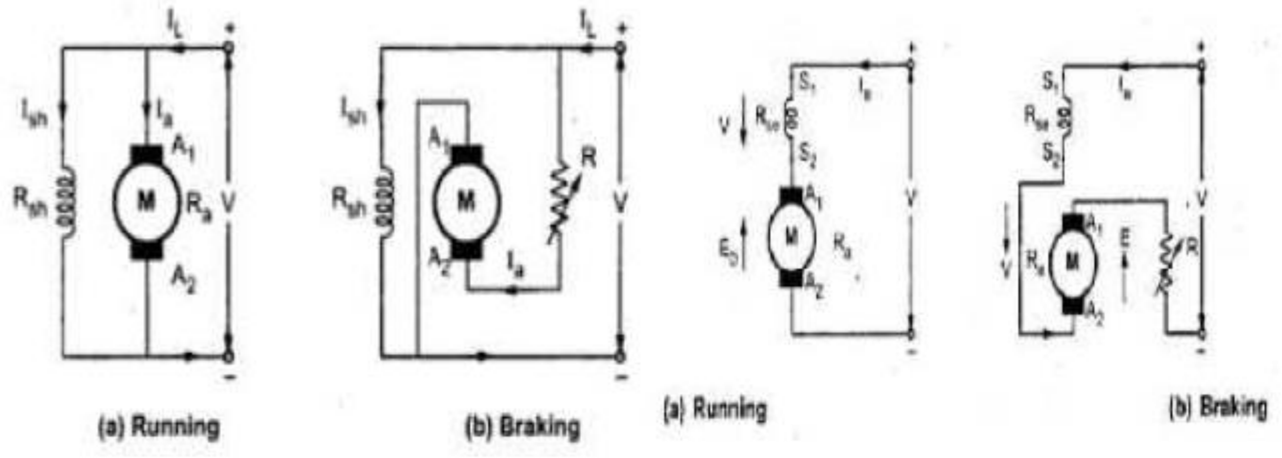
Electric braking torque TB =K_6 + K_7N ------------------- (11)

Wherever there is a load on the machine the load will also exert braking torque due to it and

then the total braking torque (T)

T = Electric braking torque + Load torque ------------- (12)

Plugging of DC Shunt and Series Motor



Induction motors

- In the case of induction motor its speed can be reversed by inter changing any of the two stator phases which reverses the direction of rotation of motor field.
- Actually at the time of braking when the induction motor is running at near synchronous speed.
- The point Q represents the torque at the instant of plugging one can notice that the torque increases gradually as one approaches the stand still speed.
- Different values of rotor resistance give rise to different shapes of speed torque curve in order to give any desired braking effect.
- The rotor current I2 can be calculated during
- the braking period from the following relation and is plotted as shown.

I2 = SE2 / sqrt [Re2+(SX2)2] ------------------- (13)

Where E2 is the e.m.f. induced in rotor at standstill

R2 is the rotor resistance

X2 is the standstill reactance of the rotor and

S2 is the percentage slip

Synchronous motors

- Plugging can be applied to the synchronous motors, with the only difference that the field on the rotor will be rotating in opposite direction to that of the rotating field on the stator with the synchronous speed and the relative velocity between the two will be twice the synchronous speed.
- This will meant that there is one synchronous motor torque but the same will be produced by the induction in the starting winding.
- Since most of the motors are equipped with starting winding, a synchronous motor provides satisfactory braking.

Rheostatic braking

In this method of braking, the motor is disconnected from the supply and run as generator driven by the remaining kinetic energy of the equipment that is the energy stored in motor and load which are to be braked.

The following drives can be braked by the rheostatic method:

i. DCmotor, ii. Induction motor, iii. Synchronous motor.

Shuntmotor

- In this type of motor, the armature is simply disconnected from the supply and is connected to as resistance in series with it, the field; winding remains connect to the supply as Fig.
- The braking can be adjusted suitably by varying the resistance in the armature circuit. In the case of failure of the supply, there is no braking torque because of absence of the field.

Series motor

- In this case of the connections are made as shown is fig during braking operation.
- The motor after disconnection from the supply in made to run as a DC series generator.
- Resistance inserted in the circuit must be less than the critical resistance otherwise the generator will not be self exciting.
- When the series motor is disconnected from the supply the direction of the armature current is reversed.
- Braking torque and speed

Electric braking torque is given by equation (3)

Braking current = Eb / R --------------------------------- (14)

Hence braking current of equation (14) and (4)

= K1ΦN/R ----------------------------------- (15)

Substitute the value of braking current is equation (1)

Electric braking torque = KK1Φ2N/R = K2Φ2N ------------------------ (16)

Where K2 = KK1/R ------------------------------- (17)

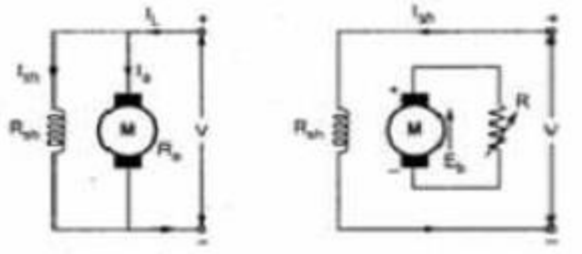
In the case of a series motor the flux dependent upon the armature current

=K3Ia2N ------------------------------ (18)

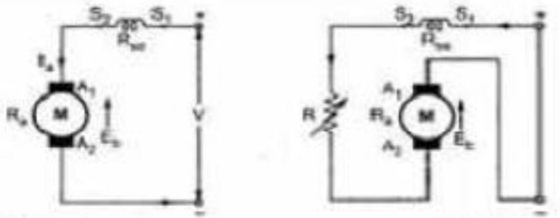
While in the case of shunt motor since flux is constant

Electric braking torque = K4N ------------------------------ (19)

Rheostatic Braking of DC Shunt and Series Motor



(a) Running (b) Braking



(a) Running (b) Braking

Induction motor

- In this case the stator is disconnected from the supply and is connected to DC supply which
- excites the windings thereby producing a DC field.
- The rotor is short-circuited across through resistance in each phase.
- When the short circuited rotor moves it outs the steady flux produced in the air gap due to DC current flowing in the stator produced in the air gap due to DC current flowing in the stator and an e.m.f is induced in the rotor conductors.
- The satisfactory application of this method is applicable only to the phase wound inductor motor
- where external resistance can be inserted in each phase.

Synchronous motors

- Rheostatic braking in the synchronous motors is similar to the rheostatic braking in induction motors. In this case the stator is shorted across resistance in star or delta and the machine
- works like an alternator supplying the current to the resistance, there by dissipating in kinetic energy in the form of losses in the resistances.

1.7.3 Regenerative braking

- In this type of braking the motor is not disconnected from the supply but remains connected to it and its feeds back the braking energy or its kinetic energy to the supply system.
- This method is better than the first and second methods of braking since no energy is wasted and rather it is supplied back to the system. This method is applicable to following motors:

(i) D.Cmotors (ii) Induction motors

D.C motors: Shunt motor

In a DC machine where energy will be taken from the supply or delivered to it depends upon the induced emf, if it in less than the line voltage the machine will operate as motor and if it is more than the line voltage, the machine will operate as generator.

Series motor

- In this case, complications arise due to fact that the reversal of the current in the armature would cause a reversal of polarity of the series field and hence back emf would be reversed.

Induction motor

- In the case of induction motors, the regenerative braking is inherent, since an induction motor
- act as a generator when running at speeds above synchronous speeds and it feeds power back to the supply system. No extra auxiliaries are needed for this purpose.
- This method is however very seldom used for braking but its application is very useful to lifts.

TRACTION MOTOR CONTROL

- The traction motor control is required for stating without drawing excessive current from the supply for providing smooth acceleration without sudden shock, to avoid damage to couplings and inconvenience to the passengers and for speed control depending upon the type of service.

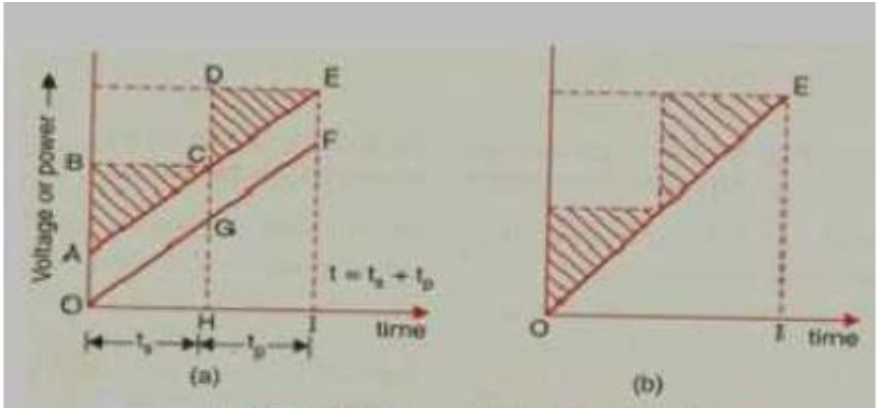
i)D.C.Series motor control

Armature resistance control

- The current drawn by d.c. motor is given by where V is the supply voltage, the back and R is the total armature circuit resistance.
- At start, therefore, an external resistance in series with the armature should be connected in order to limit the starting current as value of armature resistance is usually quite small.

- A suitable value of starting resistance is connected so that the starting current does not exceed a certain maximum value of
- As the motor accelerates, back is built up and current starts decreasing from its maximum value. When certain minimum value of current is reached, the resistances are cut off.
- As the motor accelerates, back is built up and current starts decreasing from its maximum value. When certain minimum value of current is reached, a suitable value of If voltage drop across the armature resistance is neglected, energy wasted in starting resistance is given by the shaded area of figure.

Armature resistance control



Energy Diagram. Series Parallel Operation

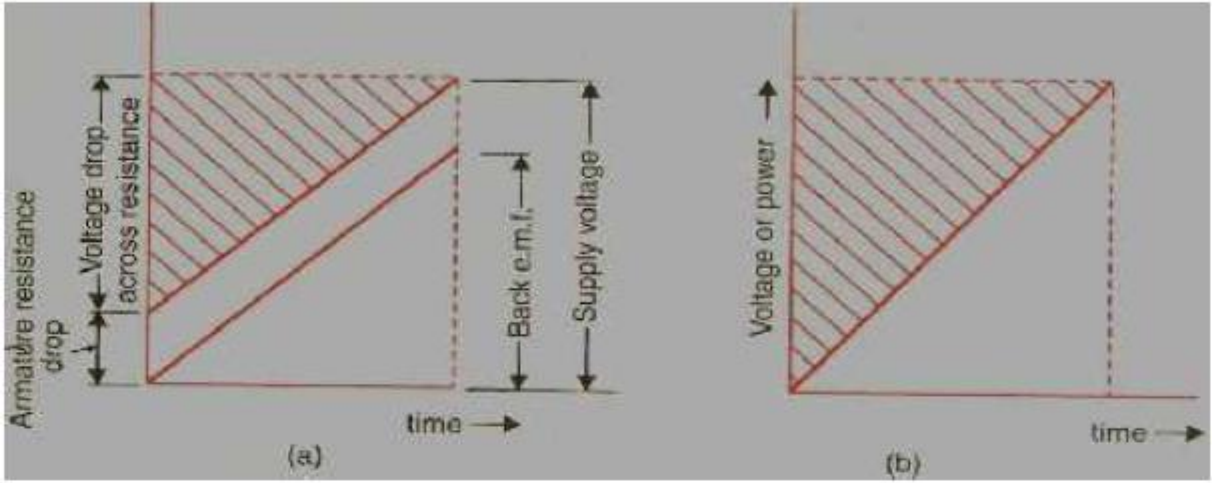
Series Parallel Control

- This method of control assumes that at least tow motors are being used which are connected in series at start for low speed and in parallel for full speed running. Hence, the name series – parallel control.
- With two motors, therefore, half the supply voltage is applied across each motor and they will run to approximately half the rated speed at which they are switched in parallel and full voltage is applied to each motor when they run finally at their rated speed.
- Normally, in order to limit the starting current to suitable values, external resistances are connected in series at starting and are cut out gradually with the motors in the series connection and are reintroduced when the motors are switched into parallel and again gradually they are cut out.

Series-parallel control contd..

- Between OH the two motors are connected in series and at H, half of the voltage is applied across each motor when the resistance is cut out completely.
- At this instant GH is the back developed across each motor and GC is the armature drop. Upto time the energy wasted per motor is given by the hatched area ABC.
- At point H and beyond i.e., the motors are switched in parallel with the suitable amount of resistance reintroduced and the acceleration continues till time when the total resistance is again cut off.
- The ordinate IF represents the back developed by each motor and FE the armature drop of each motor.
- The area CDE represents the energy loss per motor during the period again assuming armature drop to be negligible, the duration of starting for series and parallel operation will be identical.

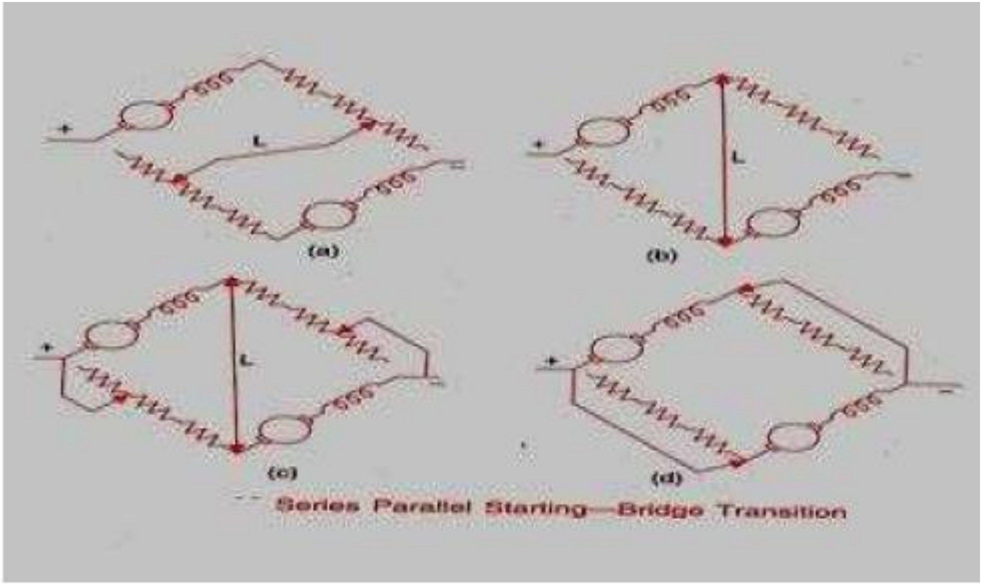
Series-Parallel Control



Shunt transition:

- Since during the torque developed by the motor is reduced suddenly, the vehicle experiences a sudden jerk and causes inconvenience to the passengers, this method is normally employed for light vehicles like trams etc.
- The advantage of the bridge transition method is that during transition, the motors are always connected to the supply and as the resistances are so adjusted that the value of current remains same, the torque does not change and hence uniform acceleration is obtained without causing inconvenience to the passengesrs.
- This method is used for railway traction.

Shunt Transition



Speed control by field weakening

- The armature voltage control is used whenever speeds lower than normal speeds are required, and field control is used when speeds more than normal are required.
- In case of traction motors, due to certain design difficulties, field control is usually limited to one or two tappings so that an increase of 15 to 30 in speed is made possible.
- Since the speed is inversely proportional to the flux, by weakening the filed, the speed is increased.
- For weakening the field either a diverter is provided or the field is tapped.
- A combination of both the filed and voltage control provides sufficient flexibility in the operation of traction motors.

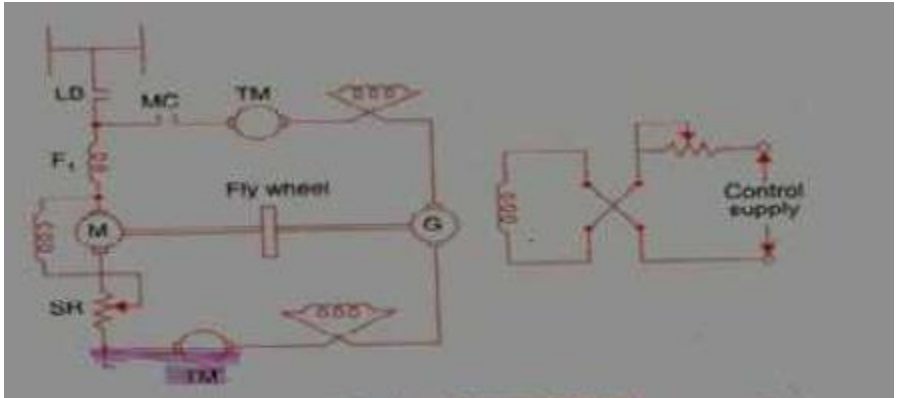
Buck and Boost method

- The armatures of both the traction motors and the motor generator set are connected in series and across the supply. When the generator voltage equals the supply voltage and is in opposition to it, the main contractor (MC) is closed.
- Under this condition, there is no voltage across the traction motors and hence their speed is zero.
- If now the generator voltage is reduced, voltage across traction motors starts increasing and their speed rises.
- When generator voltage is zero, full supply voltage appears across the motors i.e., each motor receives one half of the supply voltage.
- If the polarity of the generated equals supply voltage, each traction motor will receive voltage equal to supply voltage.
- Thus by adjusting the generator excitation the equivalent supply voltage can be reduced or boosted up. Following are the advantages of this method:

Buck and Boost Method contd..

- It is possible to obtain any operating speed of traction motors, whereas in case of resistance controllers only a few speeds are possible.
- In case of temporary interruption in the supply, the K.E. of the fly wheel can be utilized in generating energy from the MG set and fed to the traction motors.
- There is no energy loss in the starting resistance of the traction motors. However, loss does take place in the starting resistance of motor generator set.

Buck-Boost Method

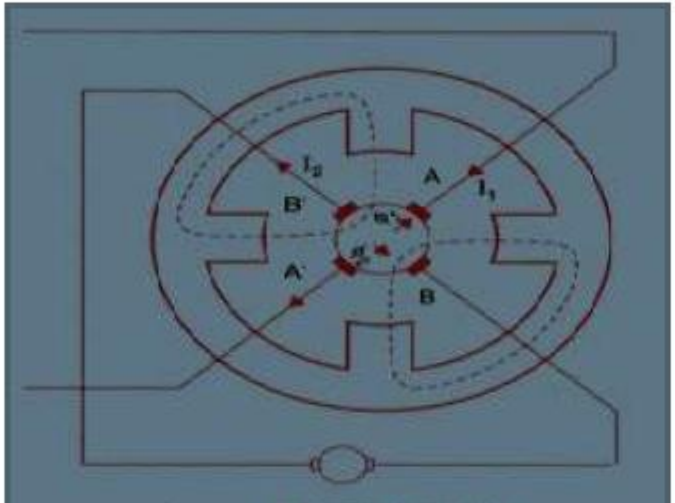


Buck and Boost Method

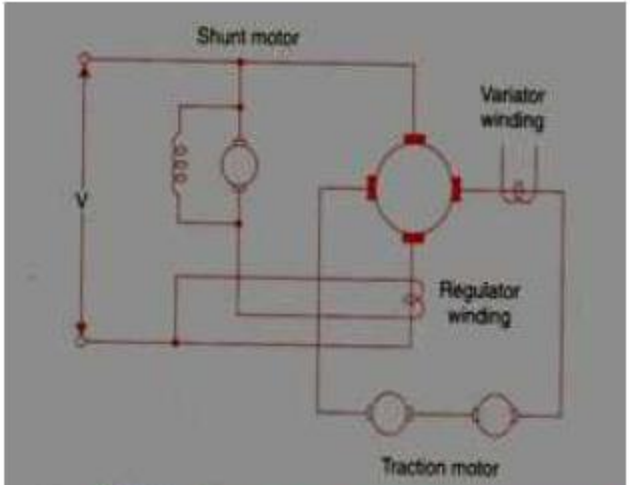
Metadyne Control

- Machines with more than two brush sets per pair of poles are called metadynes.
- It is a device which converts power at constant voltage and variable current into one with constant current variable voltage.
- The main advantage of Metadyne control is that the loss is much lower than in case of resistance starting method current throughout the starting periods can be maintained constant hence uniform tractive effort is developed which avoids jerky movement of train which otherwise exists in resistance striating methods where the current varies between a certain maximum and minimum value whenever the notch position is changed.

Metadyne Control



A Basic Metadyne



Metadyne Converter alongwith its Control components

Metadyne control contd..

- Suppose the output from the converter is more than its input, therefore, the speed of the converter goes down.
- With this the speed of the shunt motor also goes down and the back developed decreases.
- For the same supply voltage the armature current, therefore, increases and hence the current through the regulator winding increases which will have more demagnetizing effect along AA.
- In order to have same value of flux the current drawn by the converter, therefore, increases.
- Hence input to the converter increases and balance between output and input is restored and the metadyne again runs at a constant speed by shunt motor.

TRACK EQUIPMENT AND COLLECTION GEAR

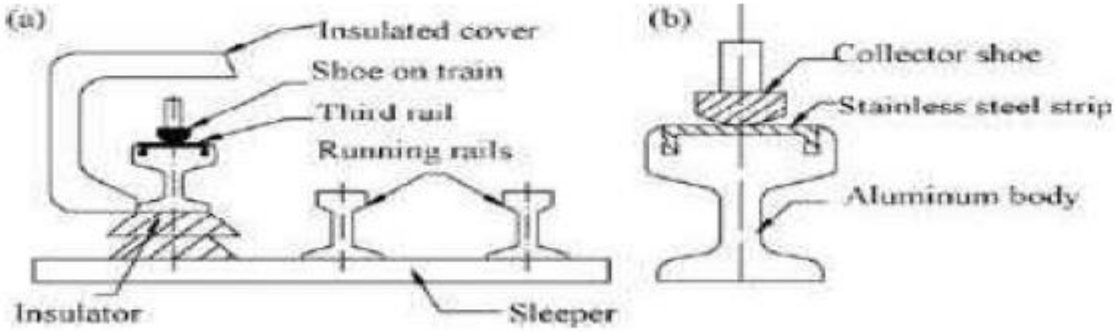
- There are mainly two systems for locomotives, tramways or trolley buses.

  a. Conductor rail system. b. Overhead system.

Conductor Rail System:

- It is employed at 600V for suburban services since it is cheaper, inspection and maintenance easier. The current is supplied to the electrically operated vehicle.
- The insulated return rail is elimination to electrolytic action due to currents on other public services buried in the cicinity of railway tunnels. A special steel alloy (iron 99.63%, carbon 0.05%, manganese 0.2%, phosphorus 0.05%, silicon 0.02% and sulphur 0.05%) is used.
- It has a resistance of about the conductor rail is not fixed rigidly to the insulators in order to take care of the contraction and expansion of rails.
- The current can be collected at about 300 to 500A. At least two shoes must be provided on each side to avoid discontinuity in the current flow and for voltage 1200V.

Conductor Rail System



Overhead System:

- This system is adopted when the trains are to be supplied at high voltage of 1500V or above.
- This system is used for ac railways and also used with dc tramways, trolley buses and locomotives operating at voltages 1500V and above with return conductor.

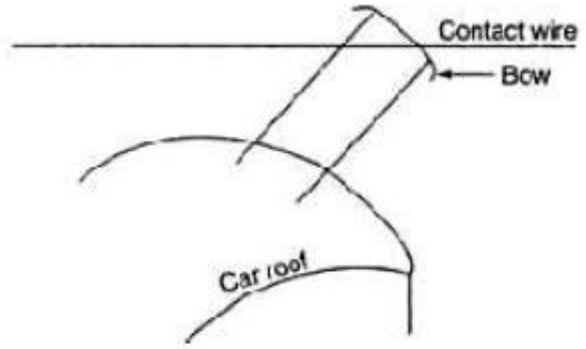
Three types of current collectors are commonly used.

a) Trolley Collector:

- It is employed with tramways and trolley buses.
- It consists of a grooved gun metal wheel or grooved slider shoe with carbon insert carried at the end of a long pole.
- The other end of this pole is hinged to a swiveling base fixed to the roof of the vehicle.
- The necessary upward pressure for the pole and current collector is achieved by springs.
- As two trolley wires are required for a trolley bus, a separate trolley collector is provided for each wire.

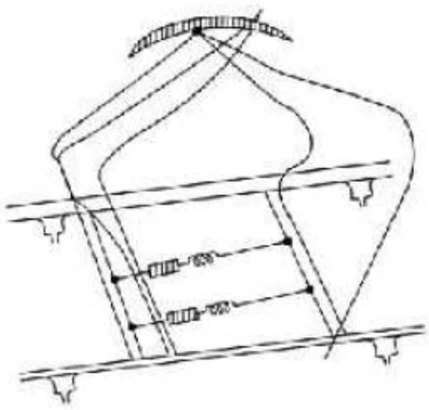
Bow Collector:

- The low collector consists of light metal strip or low 0.6 or 0.9 m wide pressing against the trolley wire and attached to a framework mounted on the roof of vehicle.
- Collection strip is made of soft material such as copper, aluminum or carbon that it should wear instead of trolley wire as i than trolley wire.



Pantograph Collector:

- The pantograph is employed in railways for collection of current where the operating speed is as high as 100 or 130 kmph and current to be collected are as large as 2000 or 3000A.
- Pantograph are mounted on the roof of the vehicles and usually carry a sliding shoe for contact with the overhead trolley wire. The contact shoes are usually about 1.2m long.



Pantograph Collector: (contd..)

- There may be a single shoe or two shoes on each pantograph.
- Materials used for pantograph is often steel with wearing plates of copper or bronze inserted.
- The pressure varies from 5 to 15kg.