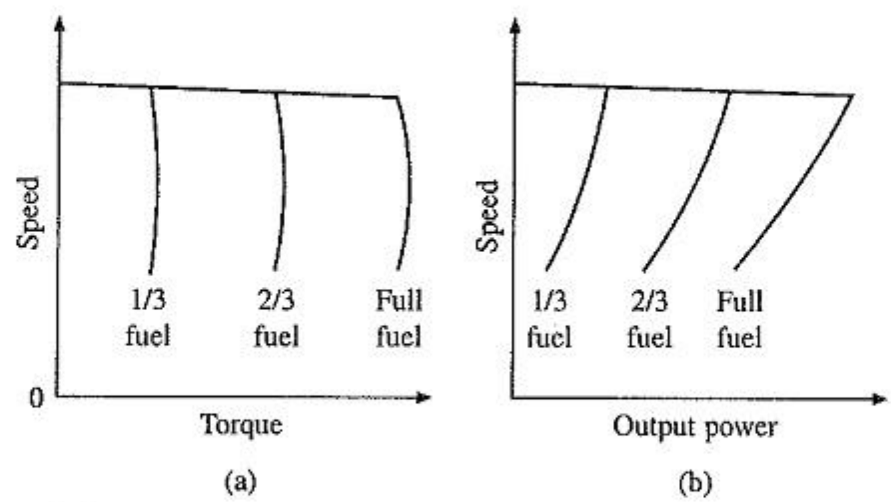
Syllabus:--Electric Traction – II: Salient features of traction drives Series – parallel control of dc traction drives (bridge transition) and energy saving Power Electronic control of dc and ac traction drives Diesel electric traction.

Diesel Electric Traction System:

Because of high initial cost, electric traction is justified only where there is sufficient volume of traffic. Diesel Electric Traction System is preferable where the traffic is limited. Boundary between these two alternatives depends on several factors such as initial cost, running cost, amount of traffic, maintenance etc. Diesel Electric Traction System is employed both for locomotives and motor coaches. As in electric traction, the locomotives are used in main line traction. Motor coaches are employed in branch lines with low traffic densities and are not used in suburban trains. Diesel electric locomotives are also used for transporting material in steel plants.

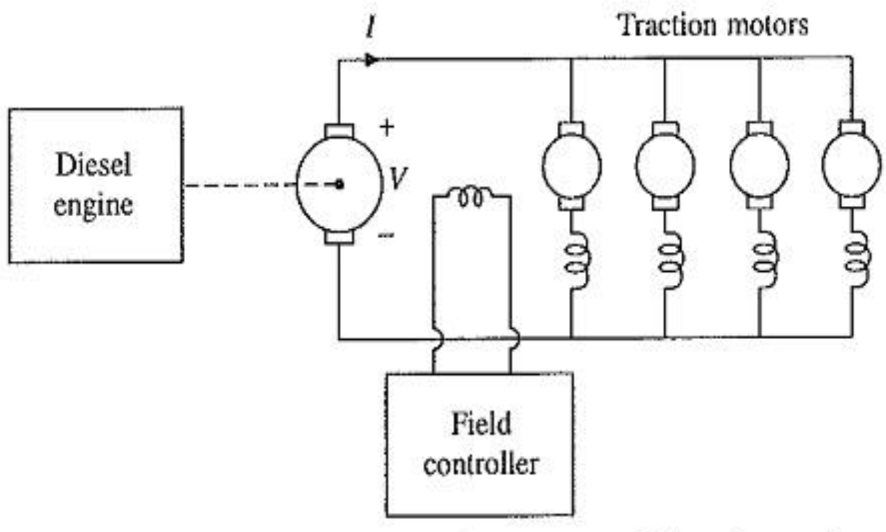


A diesel engine cannot function at low speeds and hence cannot be directly coupled to the driving wheels. It is employed at about its most favorable value of constant speed and power is transmitted to the driving wheels using either electric or hydraulic transmission. Both transmissions function like a gear system whose tooth ratio can be changed sleeplessly over a large range. The speed-torque and speed-power characteristics of a diesel engine for different levels of fuel injection are somewhat as shown in Fig. 10.26. These characteristic may vary with the type of engine, method of fuel injection, speed of working and degree of supercharging; but the nature remains as shown in Fig. 10.26. The torque is roughly independent of speed over an appreciable range, but tends to decrease somewhat at higher speeds. The value of speed corresponding to maximum power is fairly critical. Engine is, therefore, driven at the optimum speed and electric transmission (or torque converter) is used to transmit power to the driving wheels in a manner most suited to the traction load.

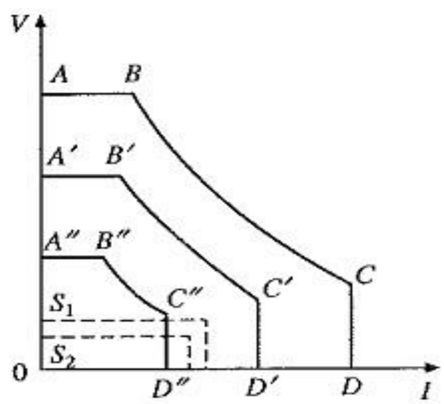
Several electric transmissions have been used, the most common ones are:

1. Diesel engine driven de generator feeding dc series motor.
2. Diesel engine driven three phase alternator supplying dc series traction motors through semiconductor diode rectifier.
3. Diesel engine driven alternator feeding squirrel-cage motors through diode rectifier followed by 3-phase voltage source inverter.

Diesel Engine Driven dc Generator Feeding dc Series Motors



Diesel engine has a very small overloading capacity. Even a 10% overload results in stalling the engine. It becomes necessary to modify the generator characteristics so that overloading of the diesel engine can be avoided. Desired V-I characteristic of the generator are shown in Fig. 10.28.



The ideal system of electric transmission for Diesel Electric Traction System locomotive is one in which full horse power of the engine can be utilised by conversion into tractive effort over the wide range of locomotive speeds, i.e. for a given fuel injection the generator output power must be held constant regardless of speed of the traction motors. When operating at full fuel injection, part BC of the characteristic ABCD ensures operation of the generator at constant power (V x I = constant). Part CD is obtained by imposing a limit on generator current for: (i) protecting the generator and motor and (ii) to limit the traction motor torque. Too high traction motor torque can produce two undesirable results: (1) with high adhesion between locomotive's driving wheels and rails, draw bar fracture might result, and (2) with low adhesion, slipping of driving wheels might result. Part AB is realised by imposing generator voltage limit so that: (a) generator and motor voltages do not exceed the rated value, and (b) motor speed will remain within a safe limit.

For lower diesel engine fuel injections, generator has the characteristics A'B'C'D' and A"B"C"D" etc. Parts B'C' and B"C"of these characteristics represent operation at a constant power. Current limits C'D' and C"D" and voltage limits A'B' and A"B"are incorporated for smooth acceleration and to deal with varying conditions of track related to slope, and condition and strength of rails.

The characteristics S_1 and S_2 are provided for shunting.

Diesel engine does not have **Starting Torque**. It is started by making generator to work as a motor. For this the generator may be fed from a battery.

Conventional DC and AC Traction Drives

The following advantages over dc drive employing resistance control:

- Higher efficiency as the starting, speed and torque control are done by varying armature voltage instead of armature resistance.
- Better adhesion, because with armature voltage control the motor speed-torque characteristics are less drooping compared to armature resistance control.
- In underground trains, one is forced to use low voltage due to limited space available between the train and tunnel. No such restriction is applicable to over ground traction. In case of dc traction, the maximum transmission voltage depends on the number of motors in series and their voltage rating because no simple means were available for stepping down the dc voltage. As the dc motor voltage rating because of commutator is restricted to 750 V dc and since two motors are permanently connected in series, the dc transmission voltage is chosen as 1500 V. In ac transmission as the voltage can be stepped down easily and efficiently by a transformer, it is possible to use 25 kV voltages for transmission. Because of the much higher transmission voltage, the cost of transmission and power loss in transmission are much lower in 25 kV ac traction than in 1500 V dc traction. Because of high cost, 1500 V dc traction is not used in new installation. Although because of the prohibitive cost of replacement it continues to be there wherever it was installed prior to the development of 25 kV ac traction.

The above dc traction schemes have several disadvantages.

- Low efficiency due to resistance control.

- Poor adhesion due to: (a) step change in torque and (b) more drooping speed-torque curves because of resistance control.
- Frequent maintenance due to large number of moving contacts.
- Unless very large sections are used in the starting and braking resistances, average accelerating and decelerating torques are substantially lower compared to the maximum torque the motors can produce. This slows down the average speed of a suburban train.

Coefficient of Adhesion in Traction

In Coefficient of Adhesion in Traction, the task of driving equipment consists of pushing the carriage on which it is mounted and pulling coaches and wagons behind it. Wheels coupled to the motors, either directly or through a reduction gear, are known as driving wheels. When motors run, driving wheels in their effort for rotation, exert a frictional force on the track tangentially backward at points of contact between the driving wheels and track. As a result, driving wheels experience a reaction in the forward direction, consequently wheels and the carriage move in forward direction.
If at the points of contact between driving wheel and the track, force applied is large, the wheels may slip, then the wheels turn but carriage remains stationary.

A very important factor in traction drives, Coefficient of Adhesion in Traction (μ_a), provides a quantitative measure of the tendency of wheels to slip and is defined as:

$$\mu_a = \frac{\text{Maximum tractive effort that can be applied without slipping of wheels}}{\text{Weight on the driving axles}} \qquad (10.1)$$

Weight on the driving axles is also the weight on driving wheels. It is also known as adhesive weight. Tractive effort is the total force at rims of driving wheels, and therefore, it is proportional to the motor torque. Value of the Coefficient of Adhesion in Traction depends on the condition of surfaces of driving wheels and track at the point of contact. The coefficient of adhesion is somewhat analogous to coefficient of friction; while latter depends on conditions at one point of contact, the former depends on conditions at several points of contact. Equation (10.1) suggests that for a given value of the Coefficient of Adhesion in Traction, there is a maximum value of torque that can be applied without the slipping of driving wheels; this in turn places restriction on the maximum value of acceleration.

When wheel of a train slips at start, it slides against the same point on the rail. Due to friction and heat produced, rail surface is damaged at the point of contact commonly called '**burning of track**'. It further increases the tendency to slip. As a result, the life of track and wheels reduce. In road vehicles, if wheel slip occurs when vehicle is already in motion, it not only reduces the life of tyres, but can lead to serious accidents as the driver looses complete control on the vehicle. That is why every care is taken in all electrical vehicles to avoid wheel slip.

The Coefficient of Adhesion in Traction depends on many factors such as

1. Type and condition of surfaces at the point of contact.
2. Vehicle speed.
3. Nature of motor speed-torque characteristic.
4. Motor connections.
5. Type of power modulator.

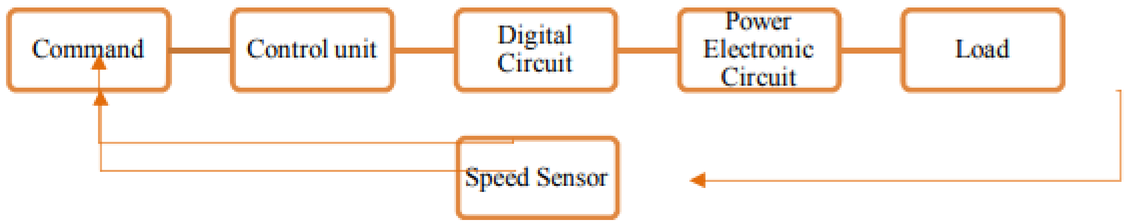
These are explained below.

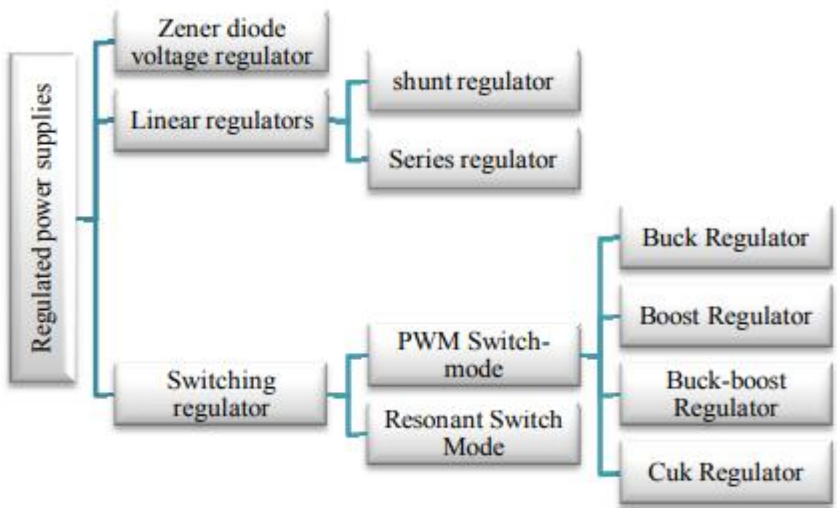
The coefficient of friction, and therefore, the coefficient of adhesion depends on the nature of material used for making the track and wheels and also on conditions of track and wheel surfaces, e.g. presence of oil, grease, water, snow and mud reduces the coefficient of adhesion. Electric buses possessing rubber tyres rolling on metalled road have much higher coefficient of adhesion than electric trains having steel wheels rolling on steel rails.

Coefficient of Adhesion in Traction is also affected by the speed of response of power modulator and drive. When a wheel slips, the wheel slip detection circuit gives command for the reduction of motor torque so that the slipping wheel can regain the grip. In a drive where the torque can be reduced faster, the tendency for wheel slip will be lower.

Power Electronics for Drive

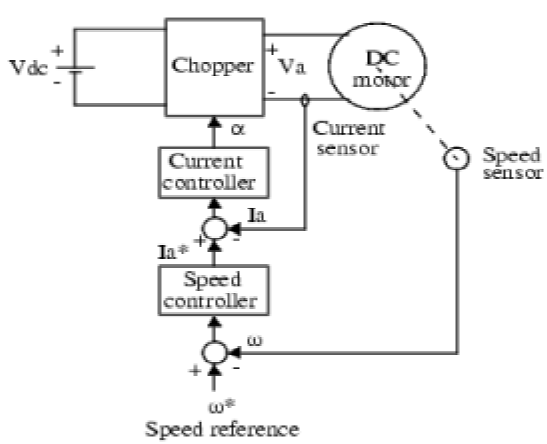
The advent of power electronics in the industries today has changed the scene completely. Direct current dc motors have been used in variable speed drives for a long time. The versatile control characteristics of dc motors have contributed to their extensive use in the industry, dc motor can provide high starting torque which is required for traction drives. Control over a large speed range, both below and above the rated speed can be easily achieved. The methods of speed-control are simpler and less expensive than those of alternating current motors. Fig. 1: Block diagram of Typical power electronics system, Thyristor dc drives frequently require sophisticated control systems. Both analogue and digital feedback controls are used. Phase-locked loop control techniques are employed in some dc drives to provide precise speed control and essentially zero speed regulation microcomputer control of complex drive systems can provide great operating flexibility when required. No wonder that today this technology is well understood and proven which resulted in its popularity the world over. Fig. 2: Classification of Regulated Power Supplies Power supply is the heart of any electronic system. Since electronic components are sensitive to voltage, the power supply must provide regulated voltage to the system for satisfactory performance. An ideal regulated power supply is an electronic circuit that provides a predetermined dc voltage as output, which is independent of: I) The current drawn by the load II) Any change in the input ac line voltage (RMS) III) Any change in temperature of components and ambient.





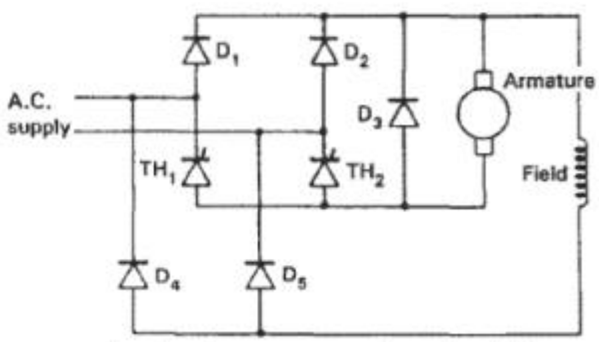
Methods for D.C. Motor Speed Control

The speed of a d.c. motor has to be controlled from an a.c. or d.c. source. The two basic method of dc motor speed control is shown in Fig. 3 is more common, where a controlled rectifier is used to supply the motor armature. The most common form of variable-speed d.c. drive is based on the control of armature voltage. Hence, the motor speed is dependent on the firing delay angle of the rectifier. The speed of the motor is determined its mean armature voltage, any oscillating torque produced by the harmonic voltage components being heavily damped by the motor inertia. If required, the field can be supplied via a controlled rectifier. Where the machine is required to generate, if rapid braking is required, then the converter must be capable of operation in the inverting mode.



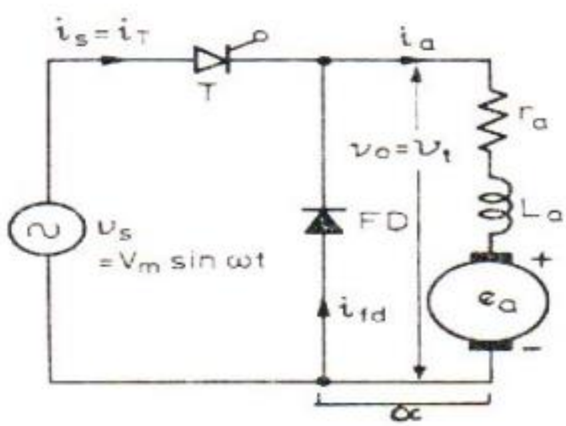
Single-Phase separately excited drives

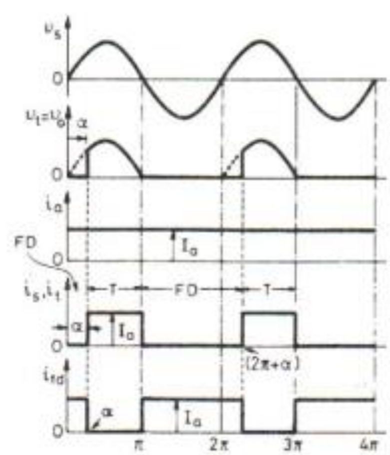
In phase-controlled dc drives, an ac to dc phase-controlled converter is used to control the dc drive motor. Controlled rectifier for dc drives are widely used in applications requiring a wide range of speed control and frequent starting, braking and reversing. Some prominent applications are in rolling mills, paper mills, printing presses, mine winders, machine tools, etc.



The converter used for a particular application depends on such factors as supply available, rating of the drive, amount of voltage ripple to be tolerated, reversible or non-reversible drive, need for regeneration etc. The basic circuit arrangement for a single-phase separately excited dc motor drive is shown in Fig. 4. The armature voltage is controlled by a semi converter or full converter and the field circuit is fed from the ac supply through a diode bridge. The motor current cannot reverse due to the Thyristors in the converters.

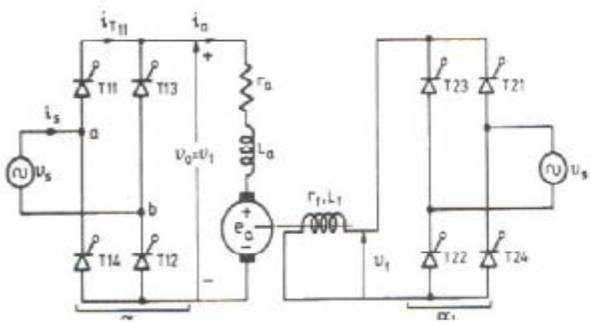
Single phase Half-wave Converter Drives Fig. 5 and Fig. 6, Half-wave converter for controlling a separately excited dc motor. It requires a single Thyristor and a freewheeling diode. In this circuit the motor current is always discontinuous, resulting in poor motor performance. This type of converter is employed only for motors below 400W.

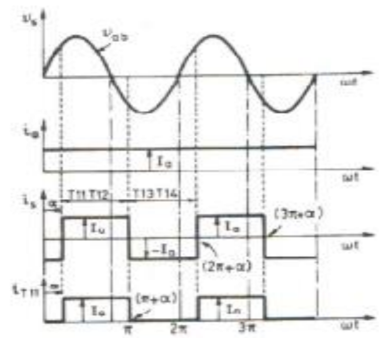




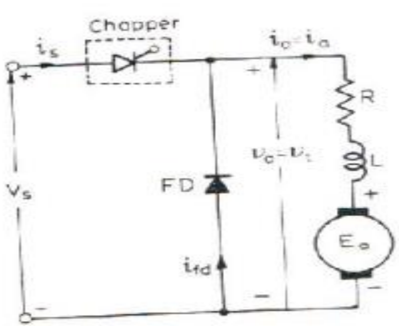
Single-phase full Converter Drive

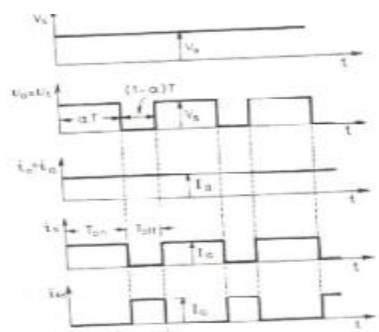
A full converter feeding a separately excited dc motor. In the full converter system Thyristor T11 and T13 are simultaneously triggered at α, and Thyristor T12 and T14 are triggered at (π + α). The voltage and current waveform under continuous current conduction are shown in Fig. 7(a) and figure7(b). The motor is always connected to the input supply through the Thyristor. Thyristors T21 and T23 conduct during the interval α < (π + α) and connect the motor to the supply. A full converter is a two quadrant converter in which the voltage polarity of the output can reverse, but the current remains unidirectional because of the unidirectional Thyristor. If the motor back emf is reversed, it will behave as a dc generator and will feed power back to the ac supply this is known as the inversion operation of the converter, the inversion mode of operation is used in the regenerative breaking of the motor.





DC chopper Drives A chopper circuit is used to refer to numerous types of electronic switching devices and circuits. Control of a dc motor speed by a chopper is required where the supply is dc or an ac voltage that has already been rectified to a dc voltage. A chopper may be thought of as an ac transformer since they behave in an identical manner. Chopper controlled dc drives have also applications in servos in battery operates vehicles such as forklift trucks, trolleys, and so on. A chopper is a static device that converts fixed dc input to a variable dc output voltage directly. Choppers are used for the control of dc motors because of a number of advantages, such as high efficiency, flexibility in control , light weight , small size, quick response, and regeneration down to very low speeds. The choppers offer a number of advantages over a controlled rectifiers for a dc motor control in open-loop configurations. A reduction or elimination of discontinuous conduction region improves speed regulation and transient response of a drive. The most important applications of choppers are in the speed control of dc motors used in industrial or traction drives.





Salient features of traction drives

The electric motors that generate power to rotate the wheels of the train are known as **traction motors**. The turning force produced by the traction motor is transmitted to the wheels of the train through the driving gear unit and axle. Traction motors should have high efficiency.

Desirable Characteristics of Traction Motors

The desirable characteristics and features of the electric motors used for traction purpose are described below.

1. Suitable Speed-Torque Characteristics. ...
2. High Overload Capacity. ...
3. Operate in Parallel. ...
4. Robust Construction. ...
5. Withstand Voltage Fluctuations. ...
6. Weight of Traction Motor. ...
7. Small Dimension. ...
8. Simple Speed Control.

Suitable Speed-Torque Characteristics

The traction motor should have suitable speed-torque characteristics. In a traction system, the torque required at start is very high, while during the constant speed, the torque requirement is not high because kinetic energy is developed and the tractive effort required is only for overcoming the track resistance and gravity component.

Therefore, the requirement is that the traction motor should develop very high starting torque which should fall off at high speeds.

High Overload Capacity

Traction motors should have high overload capacity. Traction motors are subjected to heavy loads that cause large rush of current. This high current may produce large armature reaction and bad commutation. The arcing produced on commutator surface may exceed over the whole periphery and flashover may occur, which is to be avoided at all costs.

Therefore, the traction motor should be capable of taking heavy loads without flashover.

Operate in Parallel

Traction motors should be capable of operating in parallel. In traction work, several motors operate at the same time. Therefore, the traction motors should be capable of operating in parallel.

However, there occurs a small difference in rotational speed of various motors because of uneven wear and tear of wheels. This should not produce wide variations in torques developed and current drawn by various motors.

Robust Construction

A traction motor must be robust in construction, so that it is capable to withstand continuous vibrations since these motors are subjected to severe conditions. Traction motors should be further provided with mechanical protection to prevent dirt, water, mud, etc.

Withstand Voltage Fluctuations

In traction work, on account of heavy current in rush at starting, considerable voltage fluctuation of supply line is a normal feature. Therefore, the traction motor should be capable of withstanding these voltage fluctuations without adverse effect on their performance.

Weight of Traction Motor

The weight of the traction motor should be minimum in order to increase the payload capacity of the vehicle. Also, the traction motor should have high power to weight ratio.

Small Dimension

Generally, the physical size of the motor depends on the type of insulation used. The traction motors are wound with class-H insulation. Also, the traction motor is located underneath a motor coach and the space underneath the motor coach is limited by the size of driving wheels and the track gauge. Therefore, the traction motor must be small in overall dimensions.

Simple Speed Control

Traction motors should have simple speed control. As the electric trains have to be started and stopped very often, the traction motor should be amenable to simple speed control methods.

Self-Relieving Property

Traction motor should have self-relieving property. The speed-torque characteristics of the traction motor should be such that the speed may reduce with the increase in load, i.e.,

The motors having such speed-torque characteristics are self-protective against excessive overloading as the power output of the motor is proportional to product of torque and speed, i.e.,Hence, this gives a self-relieving property to a traction motor.

Withstand Temporary Interruption of Supply

There can be temporary interruption of supply when section insulators and cross-overs are crossed with the controller ON. Hence, the traction motor should withstand these fluctuations without heavy inrush of current.

Dynamic or Regenerative Braking

A traction motor should be amenable to easy and simple methods of dynamic or regenerative braking.

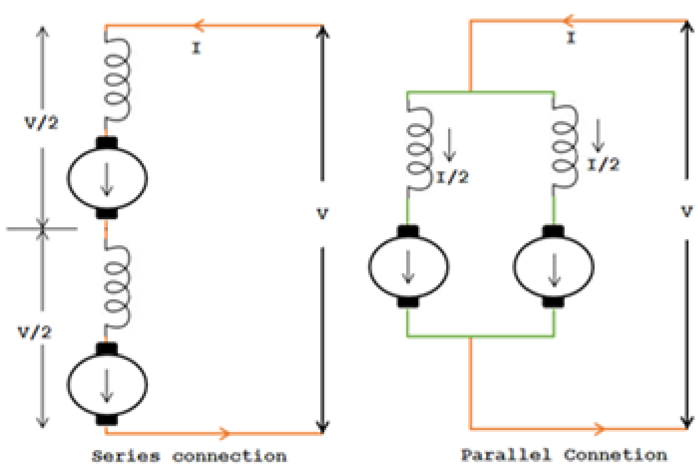
Series-Parallel Speed Control in DC traction drives

Series-parallel speed control of a DC series motor is used to regulate and adjust the engine's rotational speed by altering its field and armature circuit connections. This control method configures the field and armature winding in a series-parallel combination, allowing for precise speed regulation. By adjusting the field circuit, the magnetic field strength around the armature can be varied, directly affecting the motor speed. The series-parallel control scheme provides a wider range of speed control than other methods and enables fine-tuning of the motor's performance.

Applications of Series-Parallel Speed Control

The motor's torque-speed characteristics can be modified to match the desired speed requirements by changing the configuration from series to parallel or vice versa. This control technique finds applications in various industries where precise speed control of DC series motors is essential, such as electric vehicles, industrial machinery, and robotics. The series-parallel speed control of DC series motors offers flexibility, efficiency, and reliability, making it a preferred choice for applications that demand accurate and adjustable motor speeds.

Another way is called the series-parallel technique to control the DC series motor. This method is normally used in traction by connecting two or more series motors coupled mechanically at the same load.



Whenever the series motors are connected in sequence (series), as shown in the figure, every motor's armature receives one-half of the rated voltage. Thus, the speed will be less. If the series motors are connected in parallel, every armature of the engine gets the full normal voltage, and hence the speed is also high. Thus, we can achieve the two rates (low or high) by connecting the motor in series or parallel. Note that for the same load on the pair of engines, the system's speed would run nearly four times once the engines are in parallel as while they are in series.

Some of the key areas where this control method finds application are:

Electric Vehicles

Series-parallel speed control is crucial in electric vehicles, where precise control over motor speed is essential for optimal performance. This technique allows for efficient acceleration, deceleration, and speed regulation, improving energy efficiency and range.

Industrial Machinery

DC series motors are commonly used in various industrial machinery applications such as conveyors, pumps, and machine tools. The series-parallel speed control enables precise adjustment of motor speeds, allowing for better management of processes and improved productivity.

Robotics

Robotics applications often rely on DC series motors for their motion control systems. The series-parallel speed control technique enables precise and dynamic control of robot movements, ensuring accuracy, agility, and smooth operation.

Automation Systems

In automation systems requiring controlled motion, series-parallel speed control provides the necessary flexibility to regulate motor speeds according to specific tasks. This control method is utilized in automated assembly lines, packaging machinery, and material handling systems.

Medical Equipment

DC series motors with series-parallel speed control are employed in various medical equipment, such as surgical tools, robotic prosthetics, and imaging devices. The ability to finely adjust motor speeds ensures safe and accurate operation during medical procedures.