UNIT II

Converters that are used to continuously translate electrical input to mechanical output or vice versa are called electric machines. The process of translation is known as electromechanical energy conversion. An electric machine is therefore a link between an electrical system and a mechanical system. In these machines the conversion is reversible. If the conversion is from mechanical to electrical energy, the machine is said to act as a generator. If the conversion is from electrical to mechanical energy, the machine is said to act as a motor. In these machines, conversion of energy from electrical to mechanical form or vice versa results from the following two electromagnetic phenomena:

- When a conductor moves in a magnetic field, voltage is induced in the conductor. (Generator action)
- When a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force. (Motoraction)

These two effects occur simultaneously whenever energy conversion takes place from electrical to mechanical or vice versa. In motoring action, the electrical system makes current flow through conductors that are placed in the magnetic field. A force is produced on each conductor. If the conductors are placed on a structure free to rotate, an electromagnetic torque will be produced, tending to make the rotating structure rotate at some speed. If the conductors rotate in a magnetic field, a voltage will also be induced in each conductor. In generating action, the process is reversed. In this case, the rotating structure, the rotor, is driven by a prime mover (such as a steam turbine or a diesel engine). A voltage will be induced in the conductors that are rotating with the rotor. If an electrical load is connected to the winding formed by these conductors, a current i will flow, delivering electrical power to the load. Moreover, the current flowing through the conductor will interact with the magnetic field to produce a reaction torque, which will tend to oppose the torque applied by the prime mover.

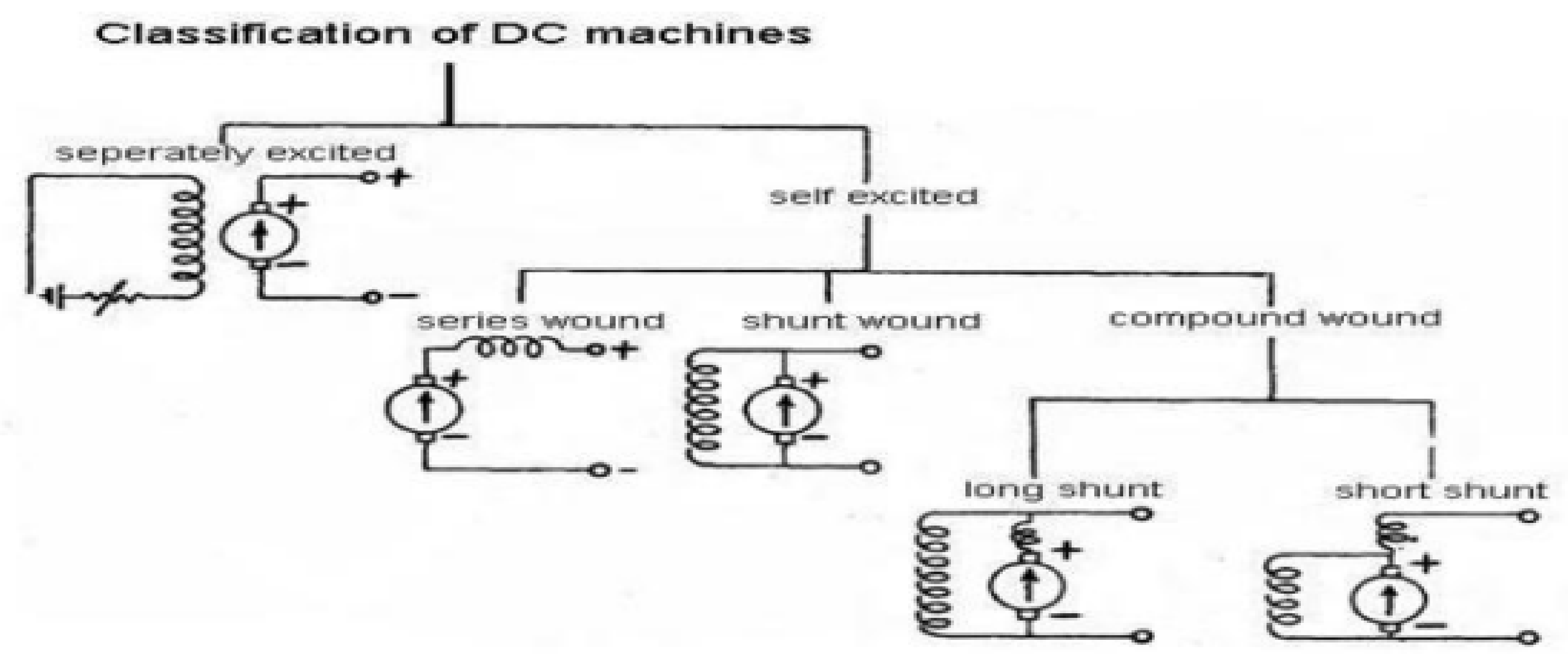


Figure 2.4 Classifications of DC Machines

Construction of DC machine:

A DC generator has the following parts 1. Yoke 2. Pole of generator 3. Field winding 4. Armature of DC generator 5. Brushes of generator and Commentator 6. Bearing

Yoke of DC Generator :Yoke or the outer frame of DC generator serves two purposes, 1. It holds the magnetic pole cores of the generator and acts as cover of the generator. 2. It carries the magnetic field flux. In small generator, yoke are made of cast iron. Cast iron is cheaper in cost but heavier than steel. But for large construction of DC generator, where weight of the machine is concerned, lighter cast steel or rolled

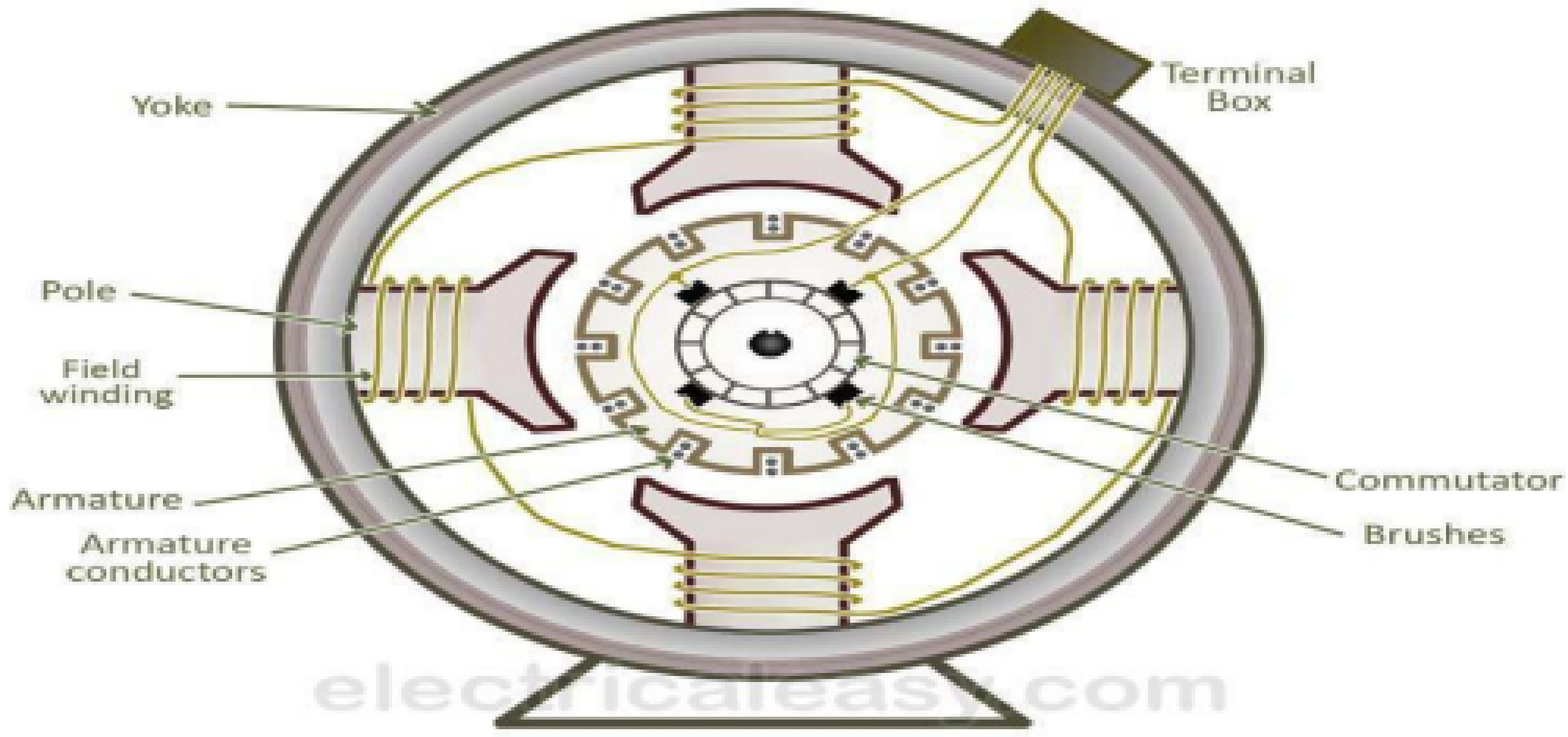


Figure 2.1 DC Machine construction

steel is preferable for constructing yoke of DC generator. Normally larger yokes are formed by rounding a rectangular steel slab and the edges are welded together at the bottom. Then feet, terminal box and hangers are welded to the outer periphery of the yoke frame.

Pole Cores: There are mainly two types of construction available. One: Solid pole core, where it is made of a solid single piece of cast iron or cast steel. Two: Laminated pole core, where it made of numbers of thin, limitations of annealed steel which are riveted together. The thickness of the lamination is in the range of 0.04" to 0.01". The pole core is fixed to the inner periphery of the yoke by means of bolts through the yoke and into the pole body. Since the poles project inwards they are called salient poles. The pole shoes are so typically shaped, that, they spread out the magnetic flux in the air gap and reduce the reluctance of the magnetic path. Due to their larger cross-section they hold the pole coil at its position. Pole Coils: The field coils or pole coils are wound around the pole core. These are a simple coil of insulated copper wire or strip, which placed on the pole which placed between yoke and pole shoes as shown.

Armature Winding: Armature winding are generally formed wound. These are first wound in the form of flat rectangular coils and are then pulled into their proper shape in a coil puller. Various conductors of the coils are insulated from each other. The conductors are placed in the armature slots, which are lined with tough insulating material. This slot insulation is folded over above the armature conductors placed in it and secured in place by special hard wooden or fiber wedges. Two types of armature windings are used − Lap winding and Wave winding.

Commutator: The commutator plays a vital role in DC generator. It collects current from armature and sends it to the load as direct current. It actually takes alternating current from armature and converts it to direct current and then send it to external load. It is cylindrical structured and is build up of wedge-shaped segments of high conductivity, hard drawn or drop forged copper. Each segment is insulated from the shaft by means of insulated commutator segment shown below. Each commentator segment is connected with corresponding armature conductor through segment riser or lug. Brushes The brushes are made of carbon. These are rectangular block shaped. The only function of these carbon brushes of DC generator is to collect current from commutator segments. The brushes are housed in the rectangular box shaped brush holder or brush box. As shown in figure, the brush face is placed on the commutator segment which is attached to the brush holder.

Bearing: For small machine, ball bearing is used and for heavy duty DC generator, roller bearing is used. The bearing must always be lubricated properly for smooth operation and long life of generator.

Armature winding Basically armature winding of a DC machine is wound by one of the two methods, lap winding or wave winding. The difference between these two is merely due to the end connections and commutator connections of the conductor. To know how armature winding is done, it is essential to know the following terminologies −

1. Pole pitch: It is defined as number of armature slots per pole. For example, if there are 36 conductors and 4 poles, then the pole pitch is 36/4=9.

2. Coil span or coil pitch (Ys): It is the distance between the two sides of a coil measured in terms of armature slots.

3. Front pitch (Yf): It is the distance, in terms of armature conductors, between the second conductor of one coil and the first conductor of the next coil. OR it is the distance between two coil sides that are connected to the same commutator segment.

4. Back pitch (Yb): The distance by which a coil advances on the back of the armature is called as back pitch of the coil. It is measured in terms of armature conductors.

5. Resultant pitch (Yr): The distance, in terms of armature conductor, between the beginning of one coil and the beginning of the next coil is called as resultant pitch of the coil

Principle of DC generator:

There are two types of generators, one is ac generator and other is DC generator. Whatever may be the types of generators, it always converts mechanical power to electrical power. An AC generator produces alternating power. A DC generator produces direct power. Both of these generators produce electrical power, based on same fundamental principle of Faraday's law of electromagnetic induction.

According to this law, when a conductor moves in a magnetic field it cuts magnetic lines of force, due to which an emf is induced in the conductor. The magnitude of this induced emf depends upon the rate of change of flux (magnetic line force) linkage with the conductor. This emf will cause a current to flow if the conductor circuit is closed. Hence the most basic tow essential parts of a generator are 1. a magnetic field 2. conductors which move inside that magnetic field.

EMF Equation of a DC Generator

Consider a DC generator with the following parameters,

P = number of field poles

Ø = flux produced per pole in Wb (weber)

Z = total no. of armature conductors

A = no. of parallel paths in armature N = rotational speed of armature in revolutions per min. (rpm)

Now,

Average emf generated per conductor is given by $d\Phi/dt$ (Volts) ... eq. 1

Flux cut by one conductor in one revolution = $d\Phi = P\Phi$ ⋯(Weber),

Number of revolutions per second (speed in RPS) = $N/60$

Therefore, time for one revolution = $dt = 60/N$ (Seconds)

From eq. 1, emf generated per conductor = $d\Phi/dt = P\Phi N/60$ (Volts) ⋯.(eq. 2)

Above equation-2 gives the emf generated in one conductor of the generator. The conductors are connected in series per parallel path, and the emf across the generator terminals is equal to the generated emf across any parallel path.

Therefore, $E_g = P\Phi NZ / 60A$ For simplex lap winding, number of parallel paths is equal to the number of poles (i.e. A=P), Therefore, for simplex lap wound dc generator,

$E_g = P\Phi NZ / 60P$ For simplex wave winding, number of parallel paths is equal to 2 (i.e P=2), Therefore, for simplex wave wound dc generator, $E_g = P\Phi NZ / 120$

Open Circuit Characteristic (O.C.C.) (E0/If)

Open circuit characteristic is also known as magnetic characteristic or no-load saturation characteristic. This characteristic shows the relation between generated emf at no load (E0) and the field current (If) at a given fixed speed. The O.C.C. curve is just the magnetization curve and it is practically similar for all type of generators. The data for O.C.C. curve is obtained by operating the generator at no load and keeping a constant speed. Field current is gradually increased and the corresponding terminal voltage is recorded. The connection arrangement to obtain O.C.C. curve is as shown in the figure below. For shunt or series excited generators, the field winding is disconnected from the machine and connected across an external supply.

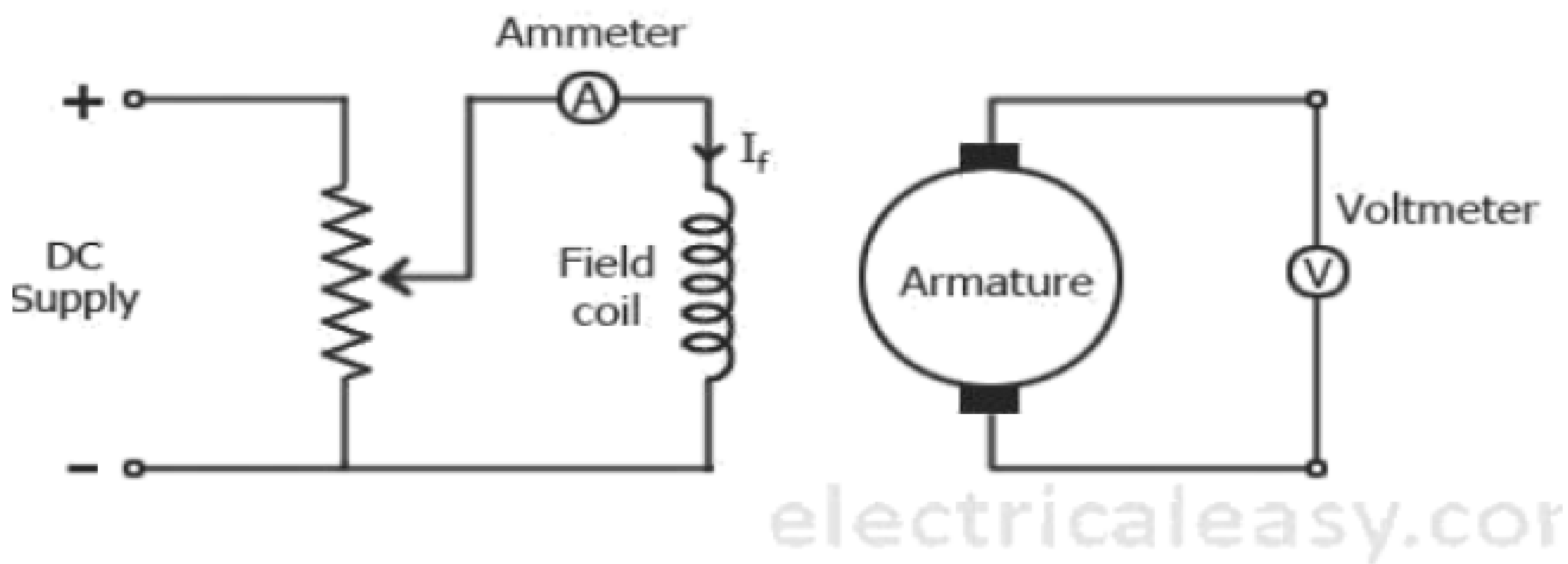
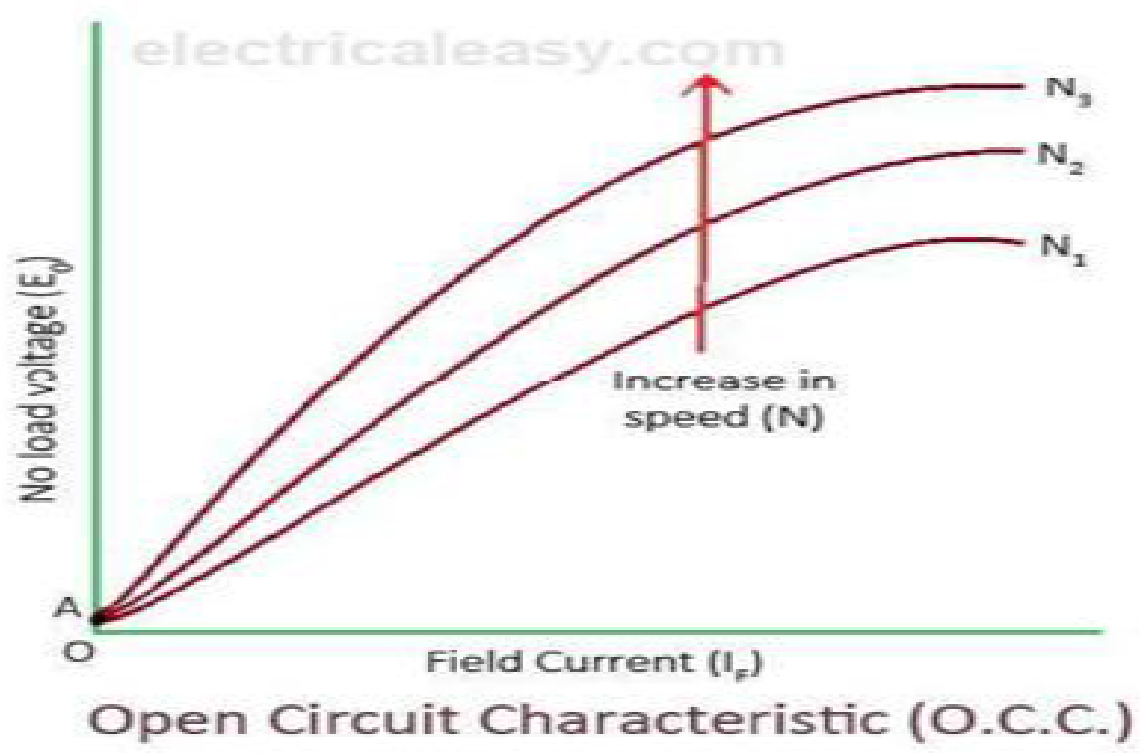


Figure 2. 6 OCC characteristics of DC generator

Now, from the emf equation of dc generator, we know that Eg = kϕ. Hence, the generated emf should be directly proportional to field flux (and hence, also directly proportional to the field current). However, even when the field current is zero, some amount of emf is generated (represented by OA in the figure below). This initially induced emf is due to the fact that there exists some residual magnetism in the field poles. Due to the residual magnetism, a small initial emf is induced in the armature. This initially induced emf aids the existing residual flux, and hence, increasing the overall field flux. This consequently increases the induced emf. Thus, O.C.C. follows a straight line. However, as the flux density increases, the poles get saturated and the ϕ becomes practically constant. Thus, even we increase the If further, ϕ remains constant and hence, Eg also remains constant. Hence, the O.C.C. curve looks like the B-H characteristic.



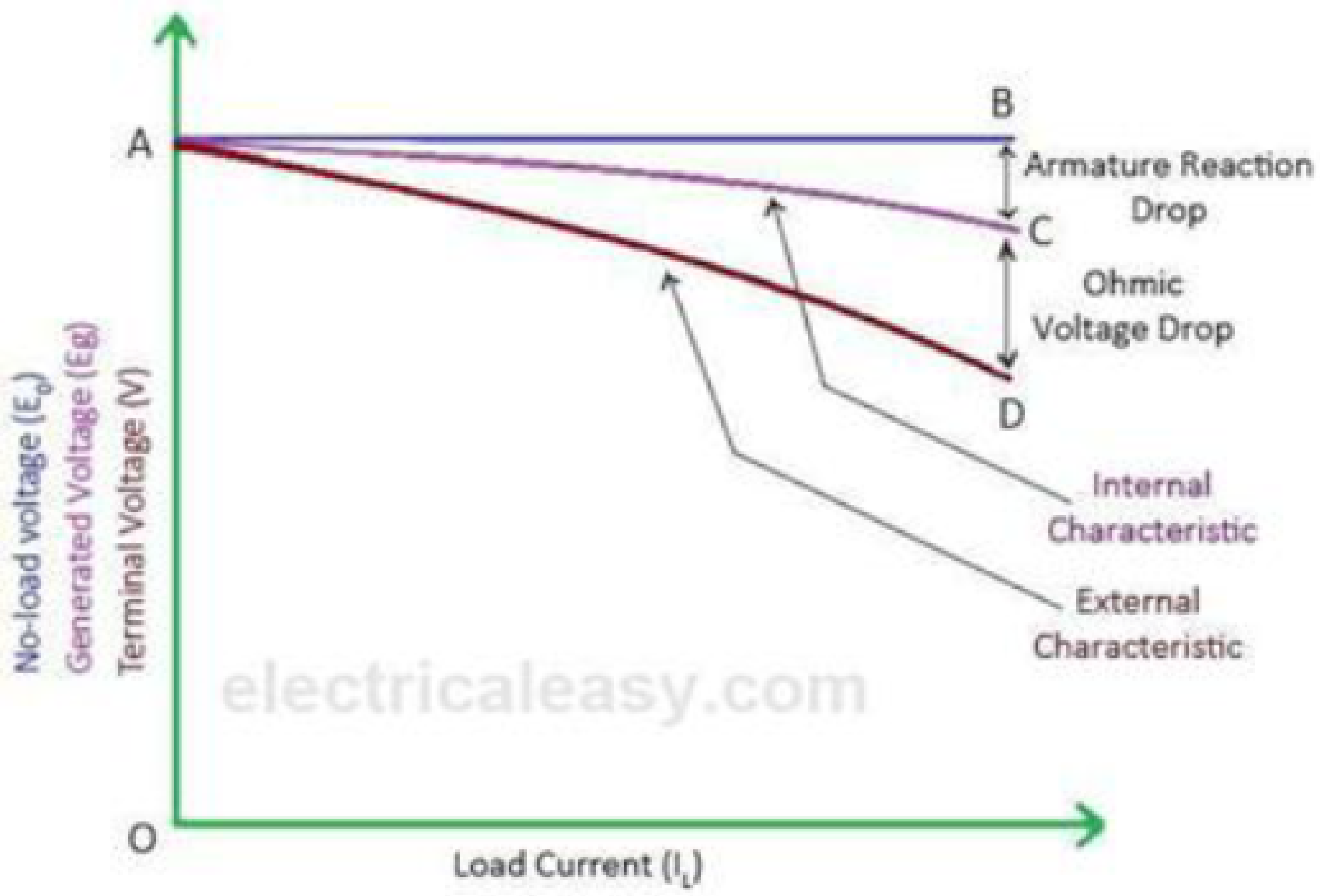
Internal Or Total Characteristic (E/Ia)

An internal characteristic curve shows the relation between the on-load generated emf (Eg) and the armature current (Ia). The on-load generated emf Eg is always less than E0 due to the armature reaction. Eg can be determined by subtracting the drop due to demagnetizing effect of armature reaction from no-load voltage E0. Therefore, internal characteristic curve lies below the O.C.C. curve.

External Characteristic (V/IL)

An external characteristic curve shows the relation between terminal voltage (V) and the load current (IL). Terminal voltage V is less than the generated emf Eg due to voltage drop in the armature circuit. Therefore, external characteristic curve lies below the internal characteristic curve. External characteristics are very important to determine the suitability of a generator for a given purpose. Therefore, this type of characteristic is sometimes also called as **performance characteristic** or **load characteristic**.

Characteristics of Separately Excited DC Generator



Characteristics of separately excited DC generator

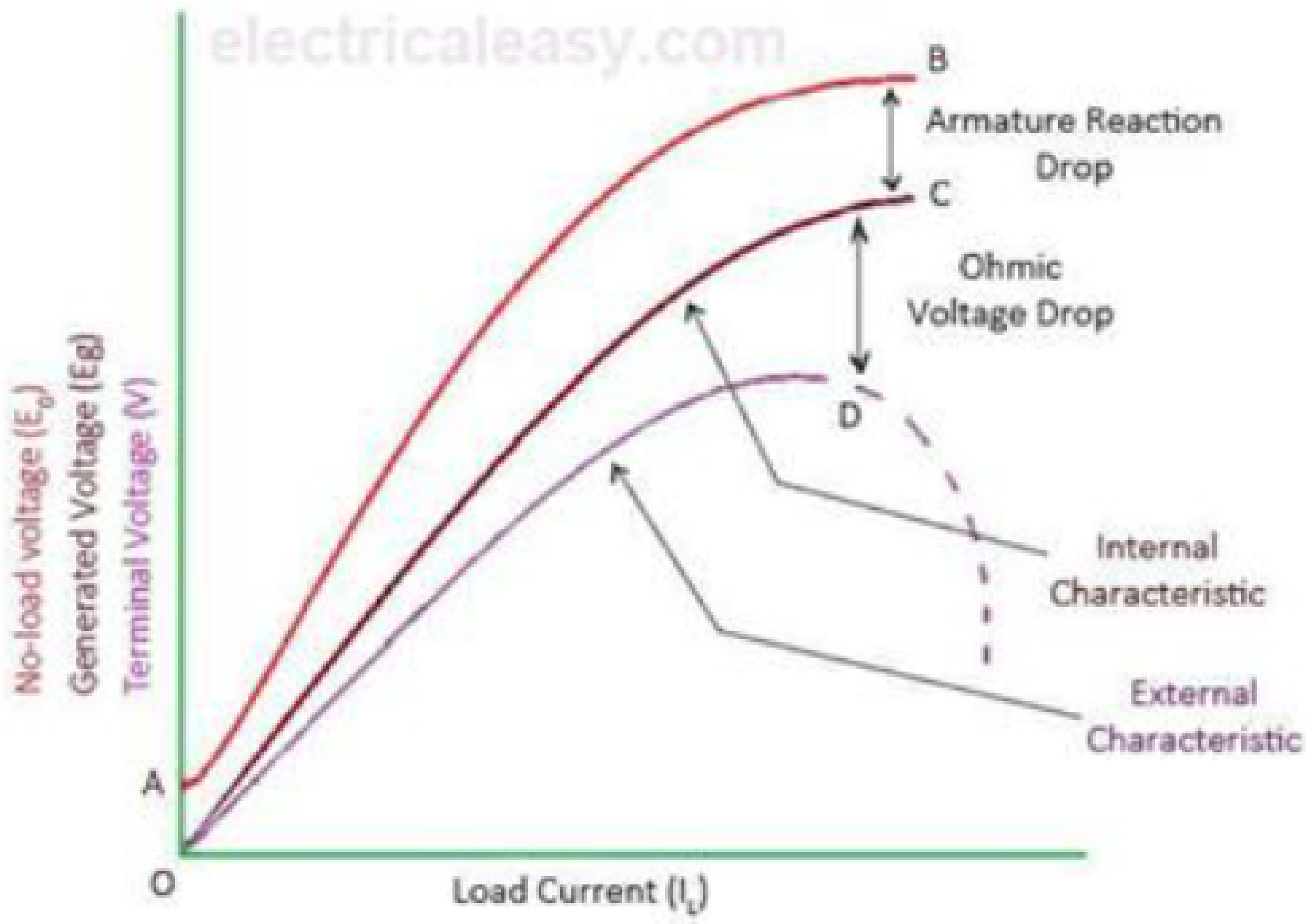
If there is no armature reaction and armature voltage drop, the voltage will remain constant for any load current. Thus, the straight line AB in above figure represents the no-load voltage vs. load current IL. Due to the demagnetizing effect of armature reaction, the on-load generated emf is less than the no-load voltage. The curve AC represents the on-load generated emf Eg vs. load current IL i.e. internal characteristic (as Ia = IL for a separately excited dc generator). Also, the terminal voltage is lesser due to ohmic drop occurring in the armature and brushes. The curve AD represents the terminal voltage vs. load current i.e. external characteristic.

Characteristics of DC Shunt Generator

To determine the internal and external load characteristics of a DC shunt generator the machine is allowed to build up its voltage before applying any external load. To build up voltage of a shunt generator, the generator is driven at the rated speed by a prime mover. Initial voltage is induced due to residual magnetism in the field poles. The generator builds up its voltage as explained by theO.C.C. curve. When the generator has built up the voltage, it is gradually loaded with resistive load and readings are taken at suitable intervals.

Characteristics of DC Series Generator:

The curve AB in above figure identical to open circuit characteristic (O.C.C.) curve. This is because in DC series generators field winding is connected in series with armature and load. Hence, here load current is similar to field current (i.e. IL=If). The curve OC and OD



Characteristics of DC series generator

represent internal and external characteristic respectively. In a DC series generator, terminal voltage increases with the load current. This is because, as the load current increases, field current also increases. However, beyond a certain limit, terminal voltage starts decreasing with increase in load. This is due to excessive demagnetizing effects of the armature reaction.

Working Principle of A DC Motor

A motor is an electrical machine which converts electrical energy into mechanical energy. The **principle of working of a DC motor** is that "whenever a current carrying conductor is placed in a magnetic field, it experiences a mechanical force". The direction of this force is given by Fleming's left hand rule and it's magnitude is given by F = BIL. Where, B = magnetic flux density, I = current and L = length of the conductor within the magnetic field.

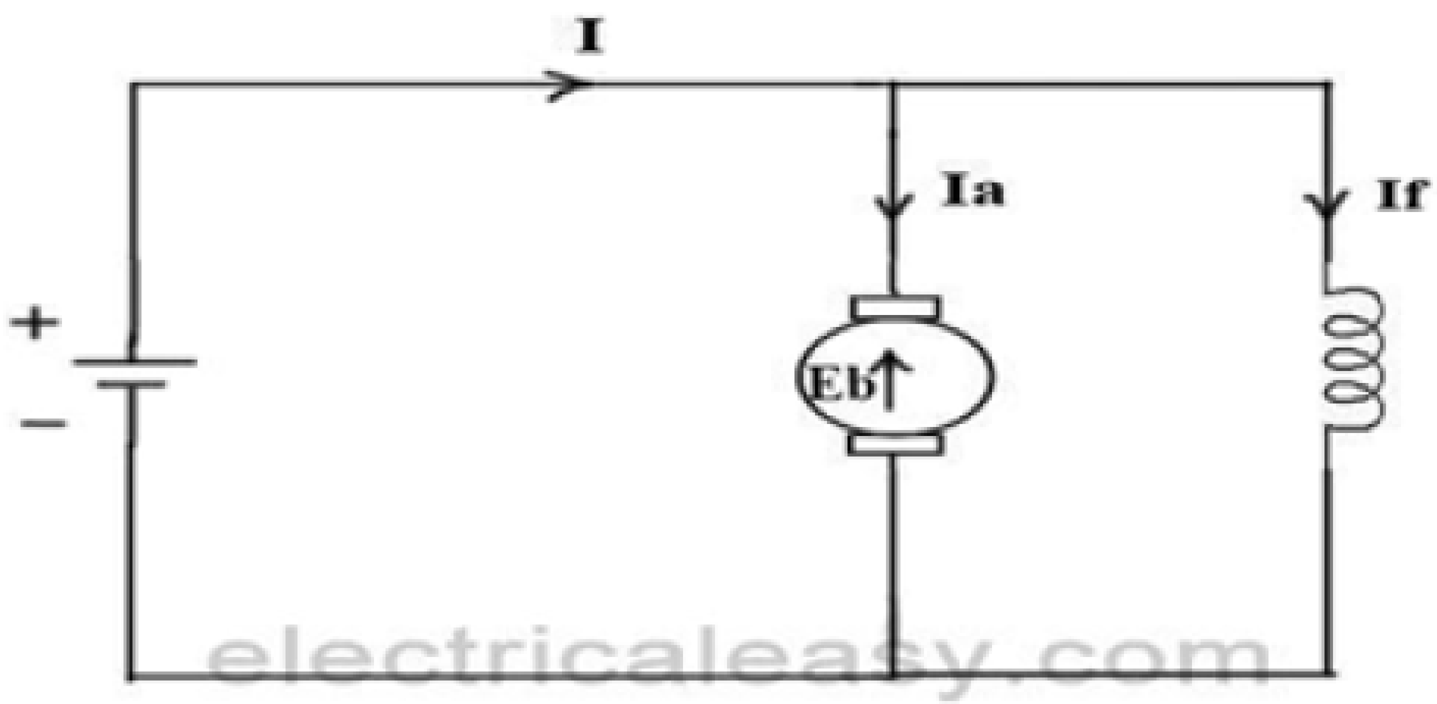
Fleming's left hand rule: If we stretch the first finger, second finger and thumb of our left hand to be perpendicular to each other AND direction of magnetic field is represented by the first finger,

When armature windings are connected to a DC supply, current sets up in the winding. Magnetic field may be provided by field winding (electromagnetism) or by using permanent magnets.

Back EMF

According to fundamental laws of nature, no energy conversion is possible until there is something to oppose the conversion. In case of generators this opposition is provided by magnetic drag, but in case of dc motors there is back emf.

When the armature of the motor is rotating, the conductors are also cutting the magnetic flux lines and hence according to the Faraday's law of electromagnetic induction, an emf induces in the armature conductors. The direction of this induced emf is such that it opposes the armature current (Ia) . The circuit diagram below illustrates the **direction of the back** emf and armature current. Magnitude of **Back emf** can be given by the emf equation of DC generator.



Significance of Back emf:

Magnitude of back emf is directly proportional to speed of the motor. Consider the load on a dc motor is suddenly reduced. In this case, required torque will be small as compared to the current torque. Speed of the motor will start increasing due to the excess torque. Hence, being proportional to the speed, magnitude of the back emf will also increase. With increasing back emf armature current will start decreasing. Torque being proportional to the armature current, it will also decrease until it becomes sufficient for the load. Thus, speed of the motor will regulate.
On the other hand, if a dc motor is suddenly loaded, the load will cause decrease in the speed. Due to decrease in speed, back emf will also decrease allowing more armature current. Increased armature current will increase the torque to satisfy the load requirement. Hence, presence of the back emf makes a dc motor 'self-regulating'.

Torque Equation of A DC Motor

When armature conductors of a DC motor carry current in the presence of stator field flux, a mechanical torque is developed between the armature and the stator. Torque is given by the product of the force and the radius at which this force acts.

- Torque $T = F \times r$ (N-m) …where, F = force and r = radius of the armature

- Work done by this force in once revolution = Force × distance = $F \times 2\pi r$
= circumference of the armature)

- Net power developed in the armature = word done / time

= (force × circumference × no. of revolutions) / time

= $(F \times 2\pi r \times N) / 60$ (Joules per second) .... eq. 2.1
But, $F \times r = T$ and $2\pi N/60$ = angular velocity ω in radians per second. Putting these in the above equation 2.1
Net power developed in the armature = $P = T \times \omega$ (Joules per second)

Armature Torque (Ta)

- The power developed in the armature can be given as, $Pa = Ta \times \omega = Ta \times 2\pi N/60$

The mechanical power developed in the armature is converted from the electrical power

- We know, $Eb = P\Phi NZ / 60A$
- Therefore, $Ta \times 2\pi N/60 = (P\Phi NZ / 60A) \times Ia$
- Rearranging the above equation,

$T_a = (PZ / 2\pi A) \times \Phi . I_a$ (N-m)

The term $(PZ / 2\pi A)$ is practically constant for a DC machine. Thus, armature torque is directly proportional to the product of the flux and the armature current i.e. Ta Φ.Ia

Characteristics of DC Motors

Generally, three characteristic curves are considered important for DC motors which are, (i) Torque vs. armature current, (ii) Speed vs. armature current and (iii) Speed vs. torque. These are explained below for each type of DC motor. These characteristics are determined by

Ta α ɸ.Ia and

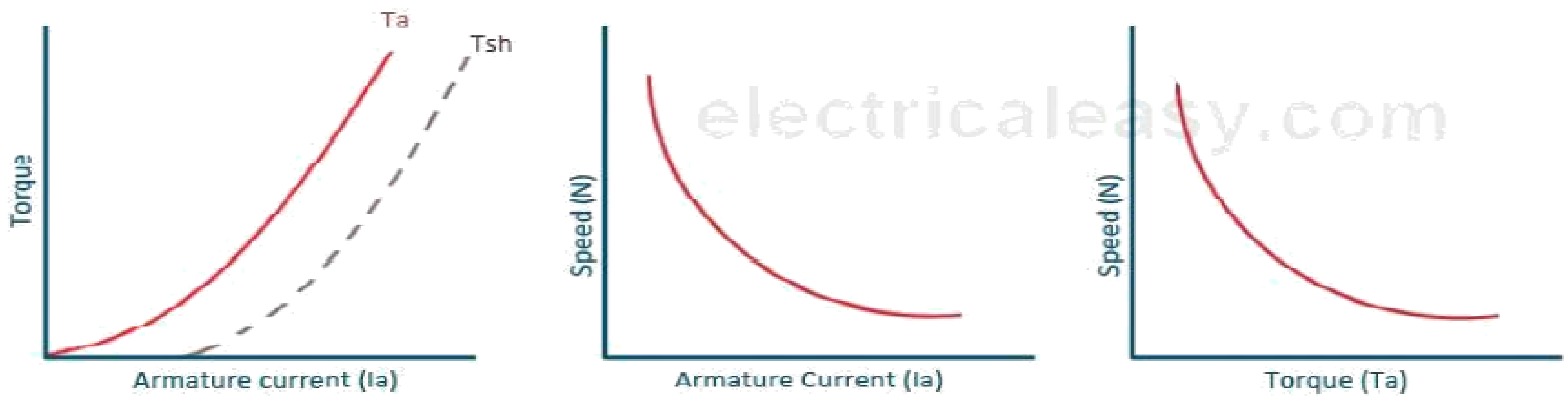
N α Eb/ɸ

Characteristics of DC Series Motors

Torque Vs. Armature Current (Ta-Ia)

This characteristic is also known as **electrical characteristic**. We know that torque is directly proportional to the product of armature current and field flux, Ta ɸ.Ia. In DC series motors, field winding is connected in series with the armature, i.e. Ia = If. Therefore, before magnetic saturation of the field, flux ɸ is directly proportional to Ia. Hence, before magnetic saturation Ta α Ia2. Therefore, the Ta-Ia curve is parabola for smaller values of Ia.

After magnetic saturation of the field poles, flux ɸ is independent of armature current Ia. Therefore, the torque varies proportionally to Ia only, T Ia.Therefore, after magnetic saturation, Ta-Ia curve becomes a straight line.



Characteristics of DC series motor

Speed Vs. Armature Current (N-Ia)

We know the relation, N Eb/ɸ

For small load current (and hence for small armature current) change in back emf Eb is small and it may be neglected. Hence, for small currents speed is inversely proportional to ɸ. As we know, flux is directly proportional to Ia, speed is inversely proportional to Ia. Therefore, when armature current is very small the speed becomes dangerously high. That is **why a series motor should never be started without some mechanical load**. But, at heavy loads, armature current Ia is large. And hence, speed is low which results in decreased back emf Eb. Due to decreased Eb, more armature current is allowed.

Speed Vs. Torque (N-Ta)

This characteristic is also called as **mechanical characteristic**. From the above two **characteristics of DC series motor**, it can be found that when speed is high, torque is low and vice versa

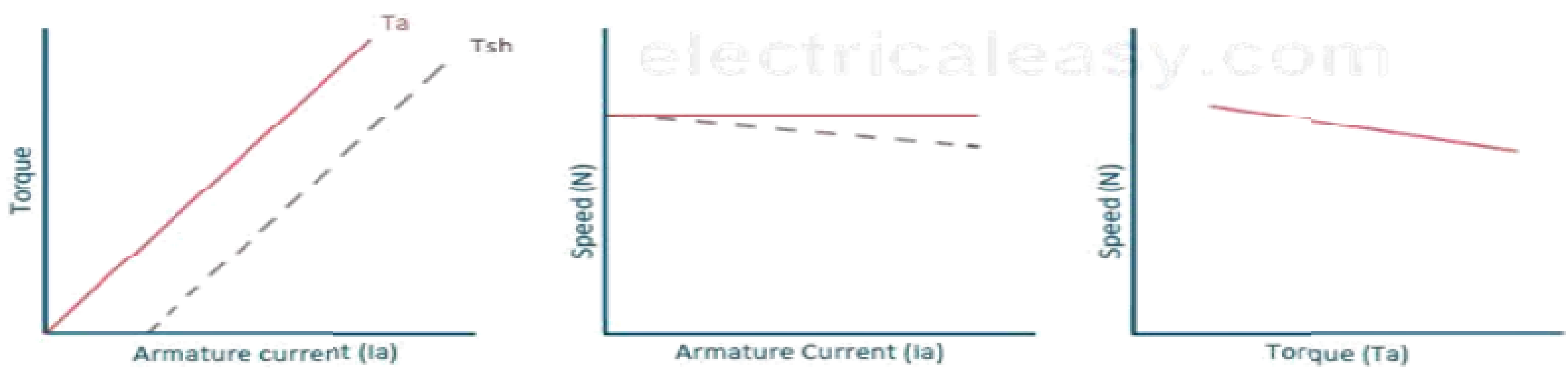
Characteristics of DC Shunt Motors

Torque Vs. Armature Current (Ta-Ia)

In case of DC shunt motors, we can assume the field flux ϕ to be constant. Though at heavy loads, ϕ decreases in a small amount due to increased armature reaction. As we are neglecting the change in the flux ϕ, we can say that torque is proportional to armature current. Hence, the Ta-Ia characteristic for a dc shunt motor will be a straight line through the origin. Since heavy starting load needs heavy starting current, **shunt motor should never be started on a heavy load.**

Speed Vs. Armature Current (N-Ia)

As flux ϕ is assumed to be constant, we can say N Eb. But, as back emf is also almost constant, the speed should remain constant. But practically, ϕ as well as Eb decreases with increase in load. Back emf Eb decreases slightly more than ϕ, therefore, the speed decreases slightly. Generally, the speed decreases only by 5 to 15% of full load speed. Therefore, **a shunt motor can be assumed as a constant speed motor**. In speed vs. armature current characteristic in the following figure, the straight horizontal line represents the ideal characteristic and the actual characteristic is shown by the dotted line.



Characteristics of DC shunt motor

Speed control of DC motor:

Speed control of dc motor is either done manually by operator or by means of automatic control device. Here speed can be controlled by changing :

- The terminal voltage of the armature.
- The external resistance in the armature circuit Ra
- The flux per pole

Therefore speed control of dc motor is classified into

- Armature control methods
- Field control methods

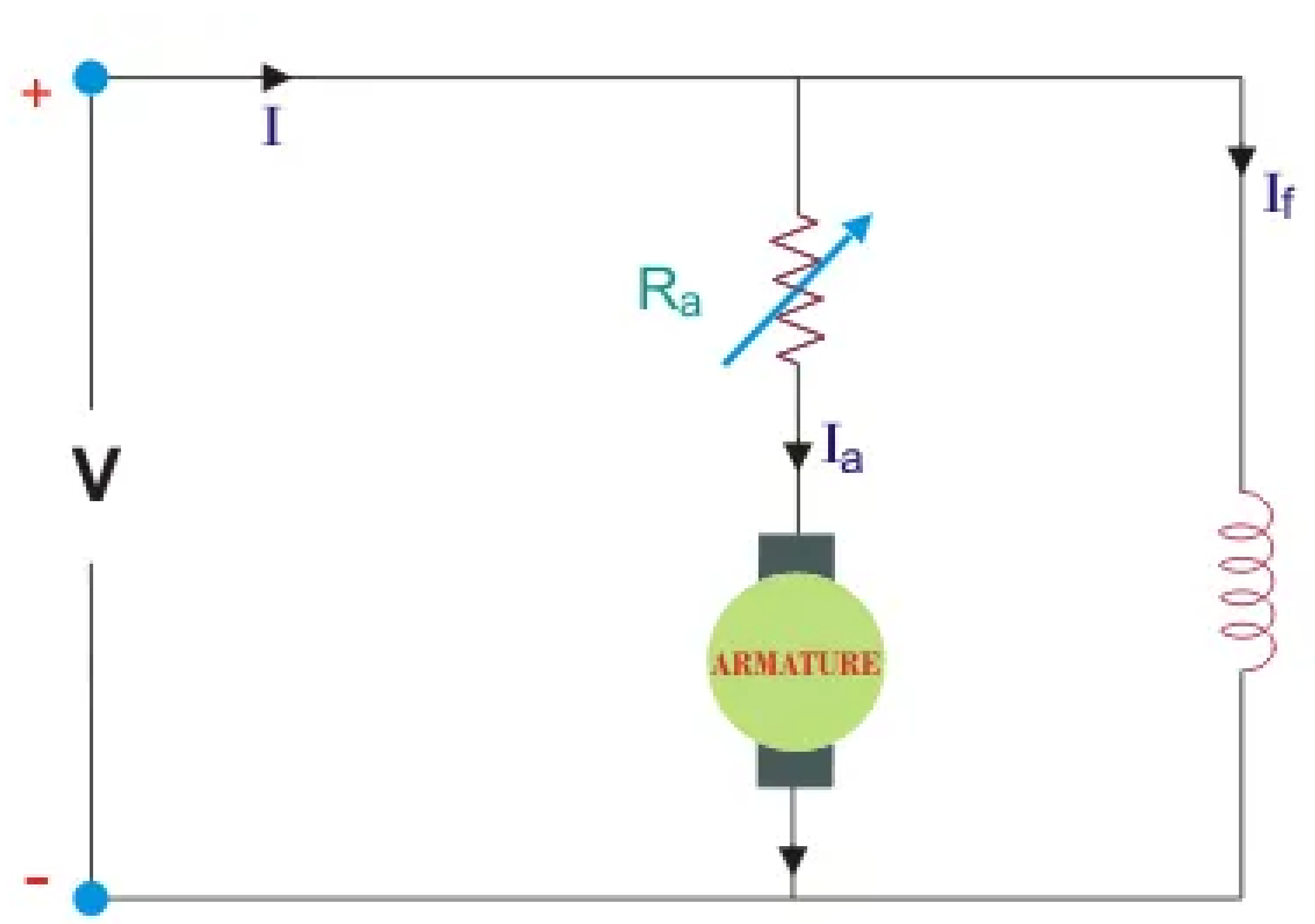
Speed control of dc series motor:

Speed adjustment of dc series motor by armature control method is classified into :

- Armarure resistance control method
- Shunted armature control method
- Armature terminal voltage control

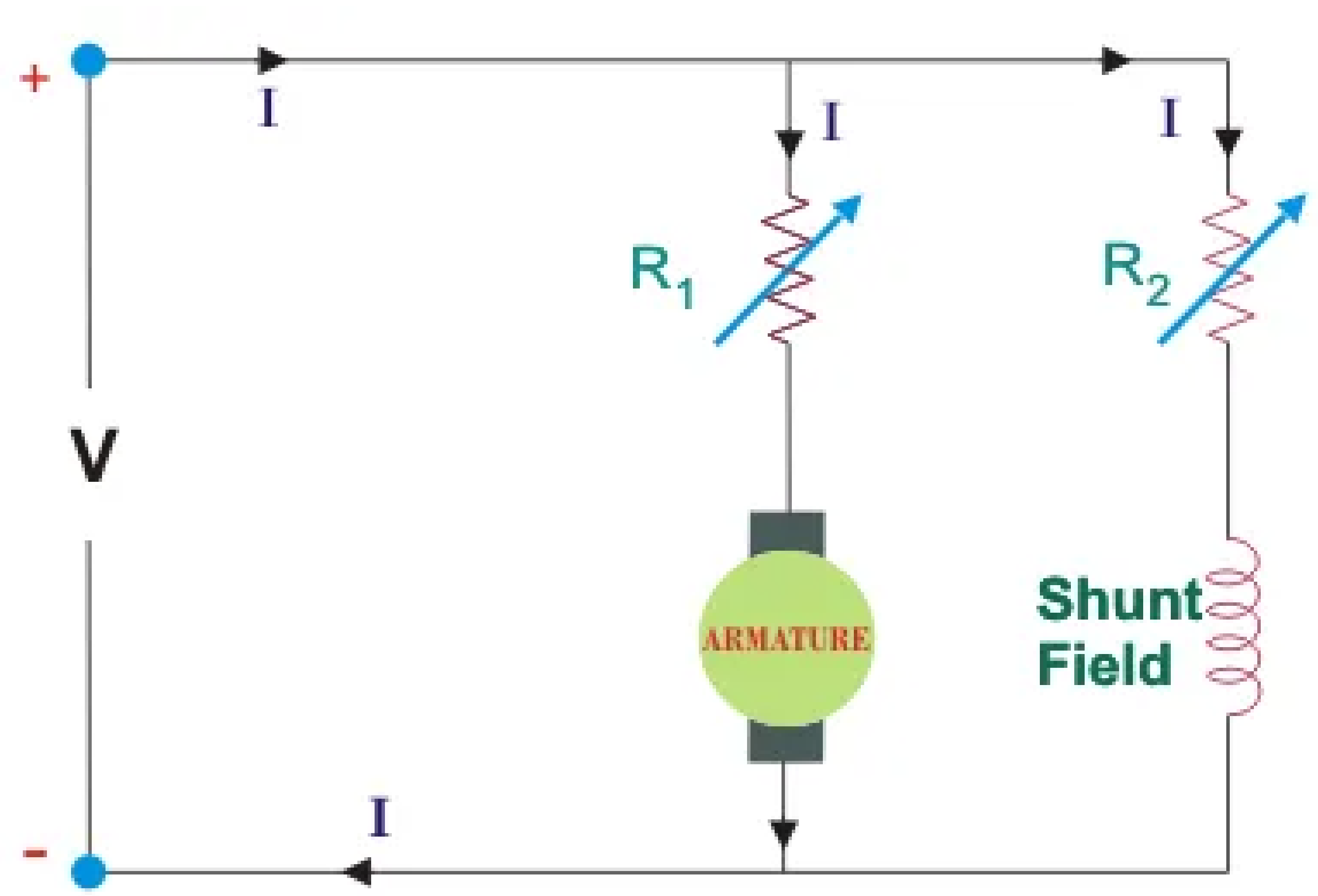
Armarure resistance control method

This is the most common method employed. Here the controlling resistance is connected directly in series with the supply of the motor as shown in the fig. The power loss in the control resistance of DC series motor can be neglected because this control method is utilized for a large portion of time for reducing the speed under light load condition. This method of speed control is most economical for constant torque. This method of speed control is employed for DC series motor driving cranes, hoists, trains etc.



Shunted Armature Control

The combination of a rheostat shunting the armature and a rheostat in series with the armature is involved in this method of speed control. The voltage applied to the armature is varies by varying series rheostat R_1. The exciting current can be varied by varying the armature shunting resistance R_2. This method of speed control is not economical due to considerable power losses in speed controlling resistances. Here speed control is obtained over wide range but below normal speed.



Armature Terminal Voltage Control

The speed control of DC series motor can be accomplished by supplying the power to the motor from a separate variable voltage supply. This method involves high cost so it rarely used.

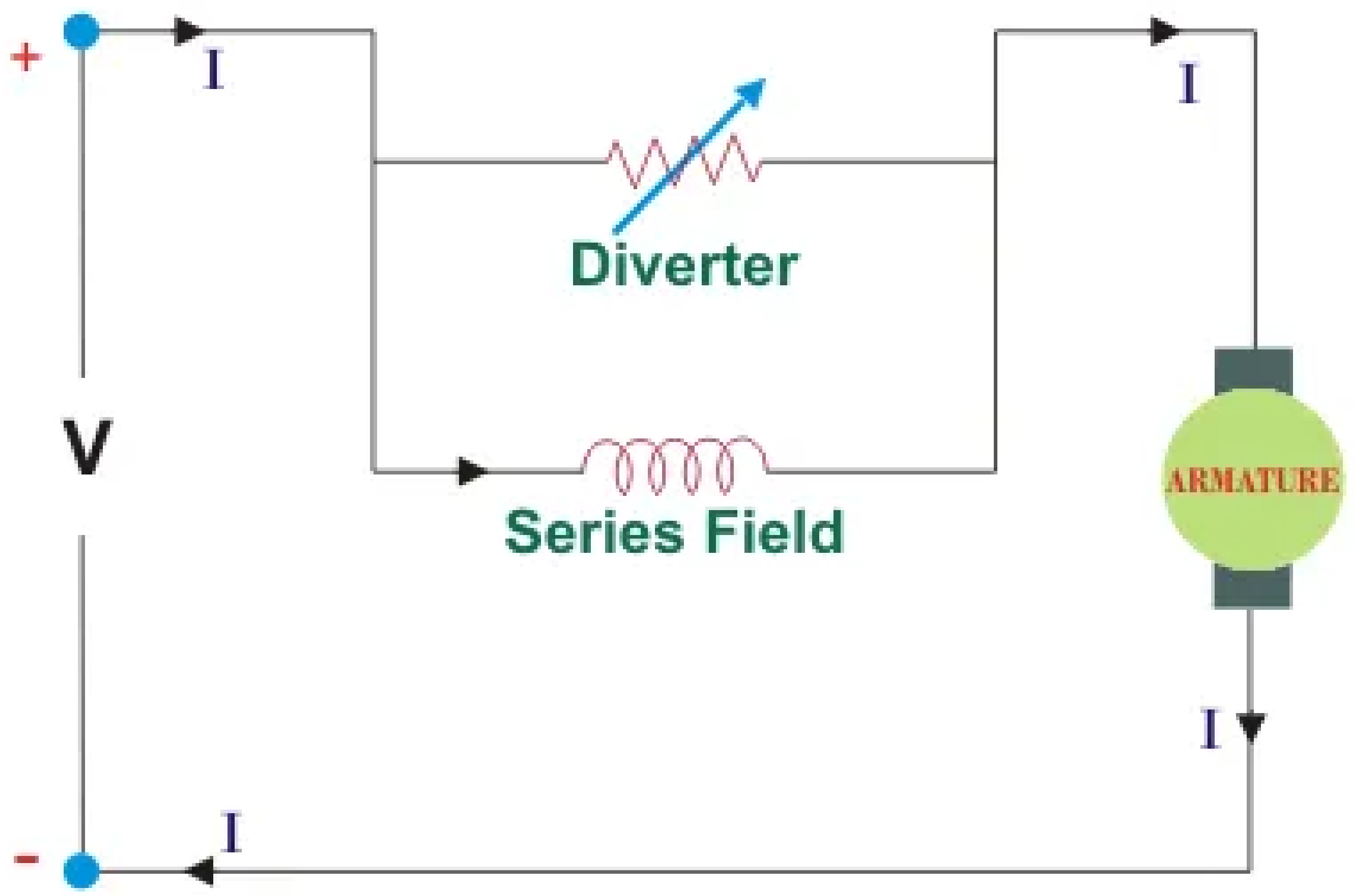
Field Controlled DC Series Motor

Speed adjustment of a DC series motor by **field control** may be done by:

1. Field Diverter Method
2. Tapped Field Control

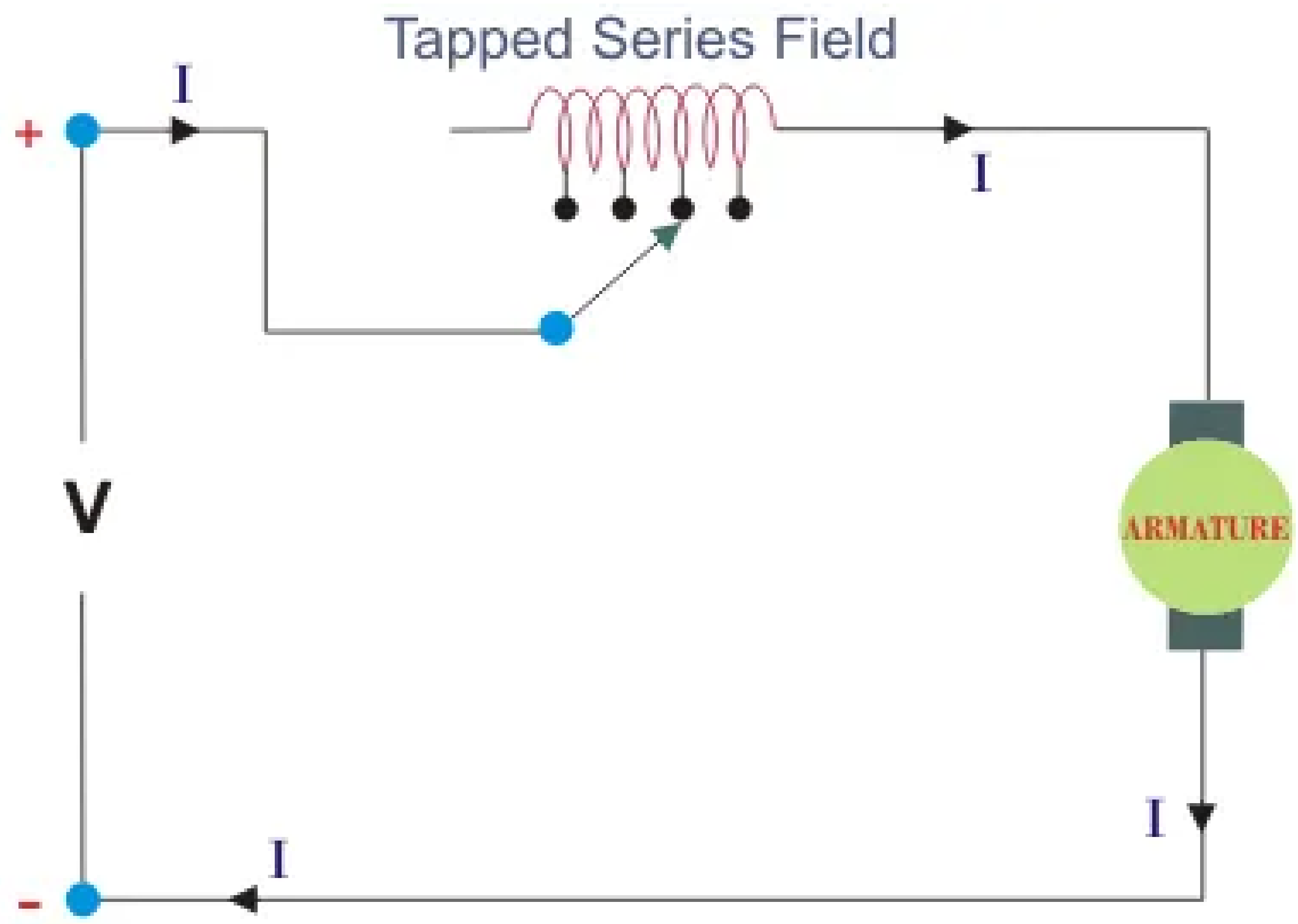
Field Diverter Method

This method uses a diverter. Here the field flux can be reduced by shunting a portion of motor current around the series field. Lesser the diverter resistance less is the field current, less flux therefore more speed. This method gives speed above normal and the method is used in electric drives in which speed should rise sharply as soon as load is decreased.



Tapped Field Control

This is another method of increasing the speed by reducing the flux and it is done by lowering number of turns of field winding through which current flows. In this method a number of tapping from field winding are brought outside. This method is employed in electric traction.



Speed Control of DC Shunt Motor

The classification of **speed control methods for a DC shunt motor** are similar to those of a DC series motor. These two methods are:

1. Armature Control Methods
2. Field Control Methods

Armature Controlled DC Shunt Motor

Armature controlled DC shunt motor can be performed in two ways:

Armature Resistance Control
Armature Voltage Control

Armature Resistance Control:

In armature resistance control a variable resistance is added to the armature circuit. Field is directly connected across the supply so flux is not changed due to variation of series resistance. This is applied for DC shunt motor. This method is used in printing press, cranes, hoists where speeds lower than rated is used for a short period only.

Advantages of Armature Controlled DC Shunt Motor

1. Very fine speed control over whole range in both directions
2. Uniform acceleration is obtained
3. Good speed regulation
4. It has regenerative braking capacity

Disadvantages of Armature Controlled DC Shunt Motor

1. Costly arrangement is needed, floor space required is more
2. Low efficiency at light loads
3. Drive produced more noise.

Field Controlled DC Shunt Motor:

In this method, speed variation is accomplished by means of a variable resistance inserted in series with the shunt field. An increase in controlling resistances reduces the field current with a reduction in flux and an increase in speed. This method of speed control is independent of load on the motor. Power wasted in controlling resistance is very less as field current is a small value. This method of speed control is also used in DC compound motor.

Disadvantages of Field Rheostat Controlled DC Shunt Motor

Creeping speeds cannot be obtained.
Top speeds only obtained at reduced torque.
The speed is maximum at minimum value of flux, which is governed by the demagnetizing effect of armature reaction on the field.

DC Motor Speed Control Theory

To derive the speed of a DC motor, we start with the equation for the DC motor's EMF (Electromagnetic Force). We know that the EMF equation of DC motor is equal to:

$$E = \frac{NP\phi Z}{60A}$$

Hence rearranging the equation:

N = 60A E / PZØ

With k = PZ/60A, then:

N = E / kØ

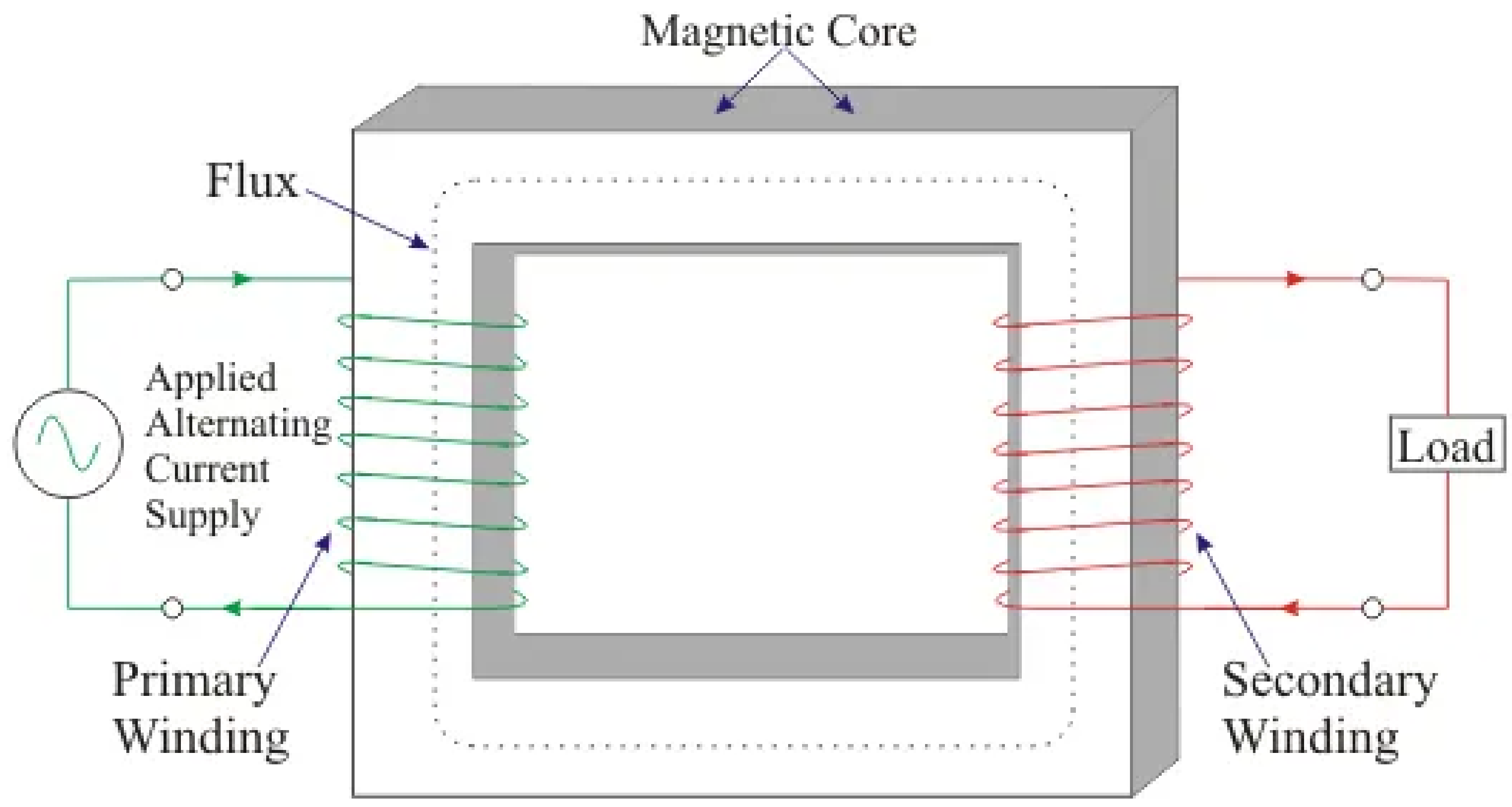
Hence with E = V − I_aR_a, we derive the speed of the DC motor (N):

$$N = \frac{V - I_a R_a}{k\phi}$$

Principle and operation of single phase transformer:

A single phase transformer is a type of transformer which operates on single-phase power. A transformer is a passive electrical device that transfers electrical energy from one circuit to another through the process of electromagnetic induction. It is most commonly used to increase ('step up') or decrease ('step down') voltage levels between circuits.

A single phase transformer consists of a magnetic iron core serving as a magnetic transformer part and transformer cooper winding serving as an electrical part.



Single Phase Transformer

$$E_{rms} = 4,44 \times f \times N \times \Phi_{max}$$

Depending on the electrical network where the transformer is installed, there are two transformer types, three-phase transformers and **single phase transformers**.

Thus the voltage is induced in the secondary winding with the same frequency as the voltage of the primary side. The induced voltage value is determined by Faraday' s Law.

Where,
f → frequency Hz
N → number of winding turns
Φ → flux density Wb

If the load is connected on the secondary transformer side the current will flow through secondary winding. Basically, the **single phase transformers** can operate as step up transformer or step down transformers.

The main parts of a transformer are windings, core, and isolation. The windings should have small resistance value and usually they are made of copper (rarely of aluminum). They are wound around the core and must be isolated from it.
Also, the turns of the winding have to be isolated from each other. The transformer core is made from very thin steel laminations which have high permeability. The laminations have to be thin (between 0.25 mm and 0.5 mm) because of decreasing power losses (known as eddy current losses).
They have to be isolated from each other, and usually, the insulating varnish is used for that purpose. The transformer insulation can be provided as dry or as a liquid-filled type. The dry-type insulation is provided by synthetic resins, air, gas or vacuum.

The oil has a long life cycle, good isolation characteristics, overload capability, and also provides transformer cooling. Oil insulation is always used for big transformers.

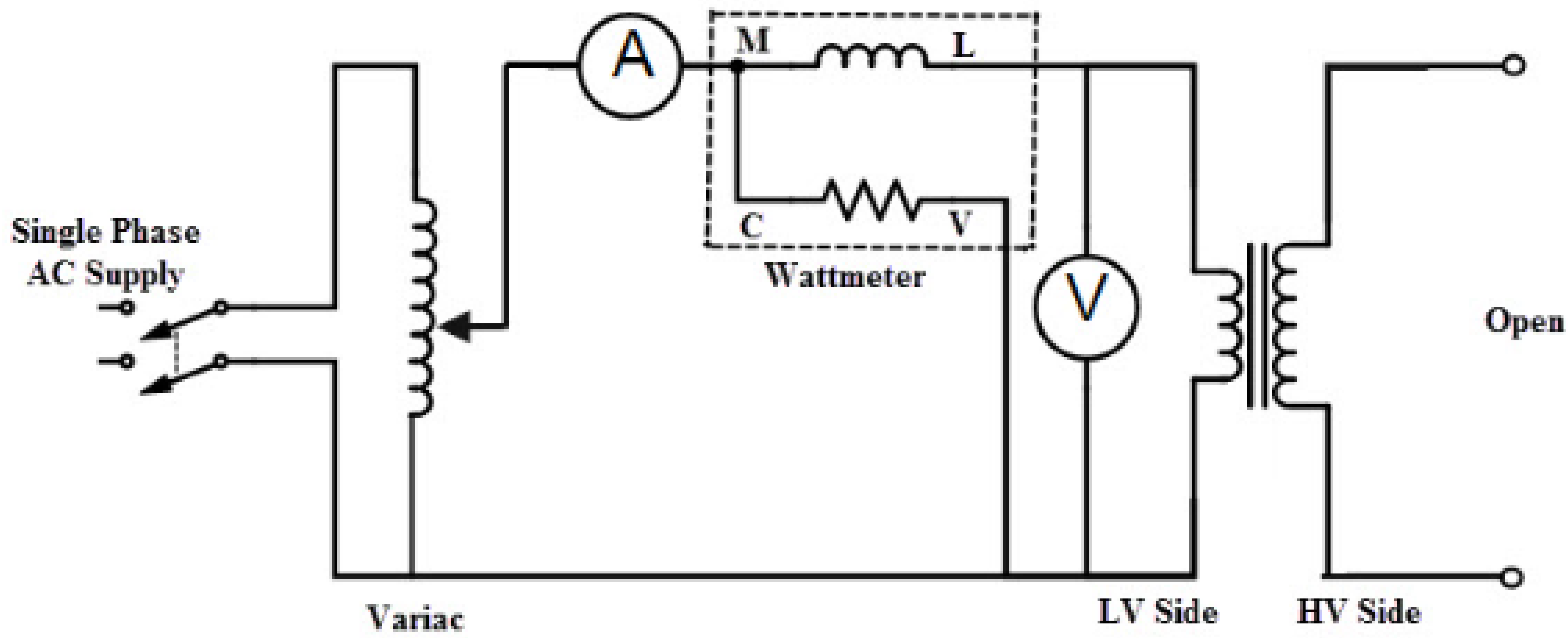
The **single phase transformer** contains two windings, one on primary and the other on the secondary side. They are mostly used in the single-phase electrical power system. The three-phase system application means using three single-phase units connected in the three-phase system. This is a more expensive solution, and it is used in the high voltage power system.

Open Circuit and Short Circuit Test on Transformer

It is possible to predict the performance of a transformer at various levels of load by knowing all the equivalent circuit parameters. These circuit parameters are supplied in terms Open Circuit (OC) and Short Circuit (SC) test data of a transformer. Without actually loading the transformer, these two assessed tests give the test results, which are used to determine the equivalent circuit parameters.

Open Circuit or No Load Test on Transformer

The open circuit (OC) test is carried out by connecting LV side (as primary) of the transformer to the AC supply through variac, ammeter, voltmeter and wattmeter instruments. The secondary side or HV side terminals are left open and in some cases a voltmeter is connected across it to measure the secondary voltage.



When a single phase supply is given to the transformer, the rated value of the primary voltage is adjusted by varying the variac. At this rated voltage, the ammeter and wattmeter readings are to be taken. From this test, we get rated voltage V_O, input or no load current I_O and input power W_O.

In OC test, transformer is operated at rated voltage at rated frequency so the maximum loses will be the flux in the core

W_O = Iron losses

The no load shunt parameters are calculated from the OC test as

The no load power factor, $\cos \Phi_O = W_O/V_O I_O$

Once the power factor is obtained, the no load component currents are determined as:

Magnetizing component of no load current, $I_m = I_O \sin \Phi_O$

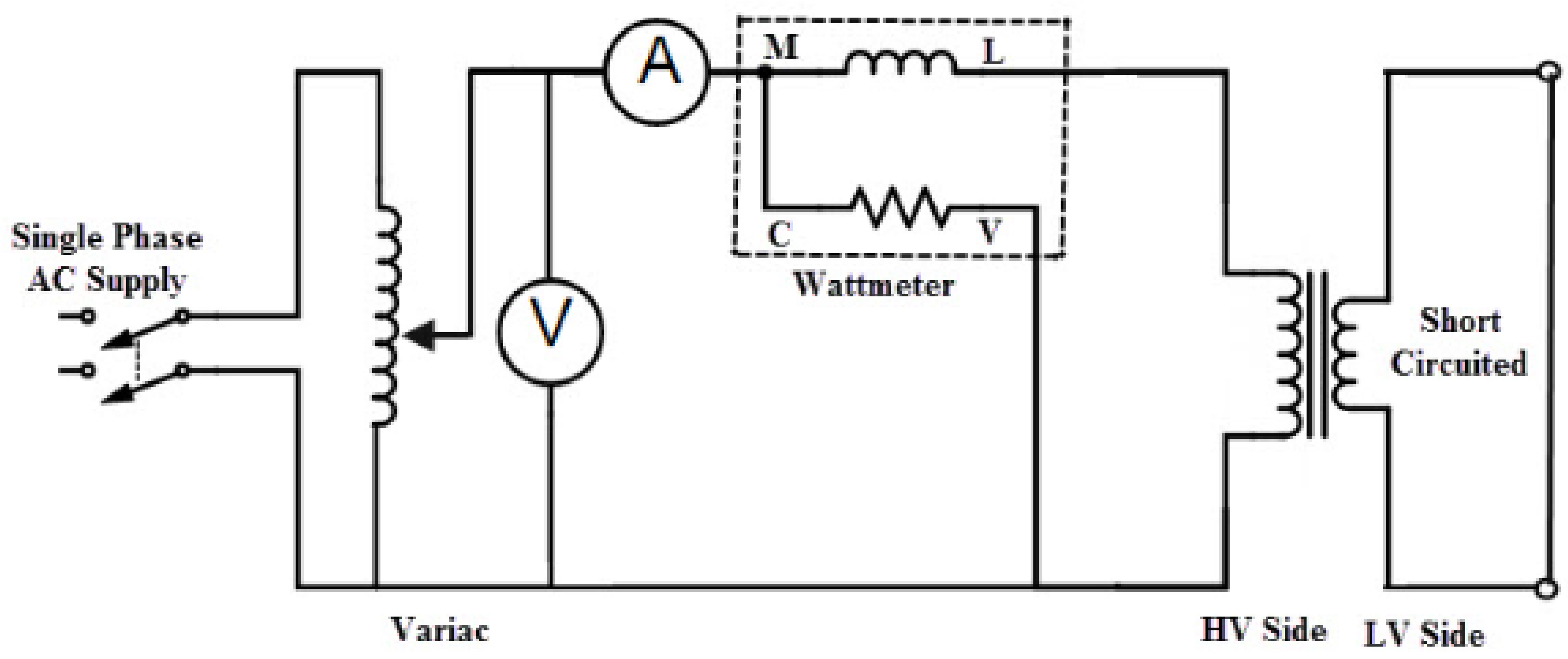
Core loss component of no load current, $I_m = I_O \cos \Phi_O$

Then, the magnetizing branch reactance, $X_O = V_O / I_m$

Resistance representing core loss, $R_O = V_O / I_O$

Short Circuit Test on Transformer

This test is performed to find series branch parameters of an equivalent circuit such as equivalent impedance (Z_{o1} or Z_{o2}), total winding resistance (R_{o1} or R_{o2}) and total leakage reactance (X_{o1} or X_{o2}). Also, it is possible to determine copper losses at any desired load and total voltage drop of the transformer referred to primary or secondary. In this test, usually LV winding is shorted by a thick wire. And the test is conducted on the other side, i.e. HV side (as primary).



In Short Circuit (SC) test, the primary or HV winding is connected to the AC supply source through voltmeter, ammeter, wattmeter and a variac as shown in figure. This test is also called as Reduced Voltage Test or Low Voltage Test. As the secondary winding is short circuited, at rated voltage, the transformer draws a very large current due to its very small winding resistance.

Such high current can cause overheating and also burning of the transformer. Thus, to limit the high current, the primary winding must be energized with a low voltage, which is just enough to produce the rated current in the primary of the transformer.

As the iron or core losses are function of voltage, these losses are very small. Therefore, the wattmeter reading shows the power loss or I_2 R loss equal to the full load copper losses of the whole transformer.

W_{sc} = Full load copper losses

Form the test results we determine the series branch parameters of an equivalent circuit as

Equivalent resistance referred to HV side, R01 = W_{sc}/ I_{sc}^2

Equivalent impedance referred to HV side, Z01 = V_{sc} / I_{sc}

Equivalent leakage reactance referred to HV side, X01 = $\sqrt{(Z^2 01 - R^2 01)}$

And also short circuit power factor, Cos $\Phi_{sc} = W_{sc}/V_{sc}I_{sc}$

Calculation of Efficiency from O.C. and S.C. Tests

As we have seen that, the practical transformer has two types of major losses namely copper and core losses. The temperature of the transformer rises due to these losses which are dissipated as heat. Due to these losses, input power drawn by the primary no longer equal to the output delivered at secondary. Therefore, the efficiency of the transformer is given as

Efficiency, η = Power output in KW/ Power input in KW

= Power output in KW/ (Power output in KW + Losses)

= Power output in KW/ (Power output in KW + Copper loss + Core loss)

An electrical motor is an electromechanical device that converts electrical energy into mechanical energy. In the case of three-phase AC (Alternating Current) operation, the most widely used motor is a **3 phase induction motor**, as this type of motor does not require an additional starting device. These types of motors are known as self-starting induction motors.

To get a good understanding of the working principle of a three-phase induction motor, it’s essential to understand the construction of a 3 phase induction motor. A 3 phase induction motor consists of two major parts:

- A stator
- A rotor

Stator of 3 Phase Induction Motor

The **stator** of three phase induction motor is made up of numbers of slots to construct a 3 phase winding circuit which we connect with 3 phase AC source. The three-phase winding is arranged in such a manner in the slots that they produce one rotating mag The **rotor** of three phase induction motor consists of a cylindrical laminated core with parallel slots that can carry conductors. The conductors are heavy copper or aluminum bars fitted in each slot and short-circuited by the end rings. The slots are not exactly made parallel to the axis of the shaft but are slotted a little skewed because this arrangement reduces magnetic humming noise and can avoid stalling of the motor.netic field when it is switched on the three-phase AC supply source.

Rotor of 3 Phase Induction Motor

The **rotor** of three phase induction motor consists of a cylindrical laminated core with parallel slots that can carry conductors. The conductors are heavy copper or aluminum bars fitted in each slot and short-circuited by the end rings. The slots are not exactly made parallel to the axis of the shaft but are slotted a little skewed because this arrangement reduces magnetic humming noise and can avoid stalling of the motor.

Working of Three Phase Induction Motor

Production of Rotating Magnetic Field

The stator of the motor consists of overlapping winding offset by an electrical angle of 120^{o}. When we connect the primary winding, or the stator to a 3 phase AC source, it establishes rotating magnetic field which rotates at the synchronous speed.

According to Faraday’s law an emf induced in any circuit is due to the rate of change of magnetic flux linkage through the circuit. As the rotor winding in an induction motor are either closed through an external resistance or directly shorted by end ring, and cut the stator rotating magnetic field, an emf is induced in the rotor copper bar and due to this emf a current flows through the rotor conductor.
Here the relative speed between the rotating flux and static rotor conductor is the cause of current generation; hence as per Lenz’s law, the rotor will rotate in the same direction to reduce the cause, i.e., the relative velocity.
Thus from the **working principle of three phase induction motor**, it may be observed that the rotor speed should not reach the synchronous speed produced by the stator. If the speeds become equal, there would be no such relative speed, so no emf induced in the rotor, and no current would be flowing, and therefore no torque would be generated. Consequently, the rotor cannot reach the synchronous speed. The difference between the stator (synchronous speed) and rotor speeds is called the slip. The rotation of the magnetic field in an induction motor has the advantage that no electrical connections need to be made to the rotor.

Thus the **three phase induction motor** is:

- Self-starting.
- Less armature reaction and brush sparking because of the absence of commutators and brushes that may cause sparks.
- Robust in construction.
- Economical.
- Easier to maintain.