Aryabhatta Knowledge University (AKU)

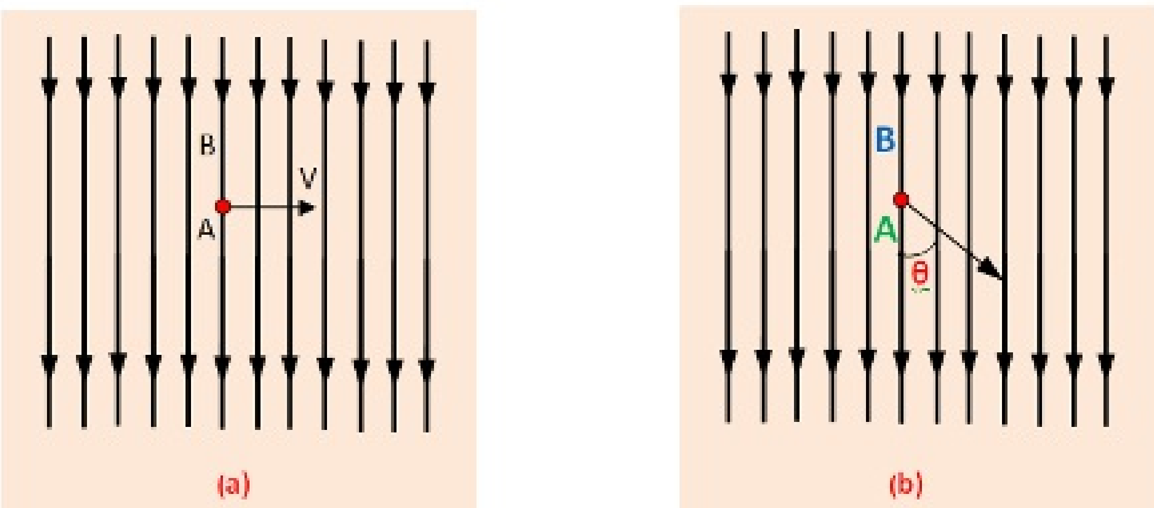
Electrical Engineering

Electrical Machines-1

Solved Exam Paper 2019

Question. Derive expression for dynamically induced e.m.f

A conductor A is located within a uniform magnetic field whose flux density is a uniform magnetic field. And the flux density is B wb ^{3}. In this fig. the movement of the conductor is shown by an arrow line. When the conductor A cuts across at right angles to the flux.



Let, 'l'= Length of the conductor lying within the field.

And it moves a distance dx in time dt,

So, the area swept by the conductor is =ldx.

Hence, flux cut by the conductor = l.dx X B,

Change in Flux = B.l.dx weber,

Time= dt second

According to Faraday's laws. The e.m.f induced in the conductor . And this induced e.m.f is known as dynamically induced e.m.f.

The rate of change of flux linkages $= \frac{Bldx}{dt} = Bl\frac{dx}{dt} = Blv$ volt [Where, $\frac{dx}{dt}$ is velocity]

If the conductor (A) moves at an angle θ with the direction of flux which is shown in (b).

Then the induced e.m.f is , $e = Blv\sin\theta$ volts $= \vec{lv} \times \vec{B}$
(i.e as cross product vector $\vec{V}$ and $\vec{B}$).

An example, the generator works on the production of dynamically induced e.m.f in the conductors.

Question. Differentiate between the following with one application of each with connection diagram and mathematical relationships:

i) Three 1-phase transformers connected to form a 3-phase transformer bank of same ratings

ii) One 3-phase transformer

It is found that generation, transmission, and distribution of electrical power are more economical in three phase system than a single phase system. For a three-phase system, three single-phase transformers are required. Three phase transformation can be done in two ways, by using a single three-phase transformer or by using a bank of three single phase transformers. There are advantages and disadvantages to each option.

A single 3 phase transformer costs around 15 % less than a bank of three single phase transformers. Again former occupies less space than later. For a very big transformer, it is impossible to transport a large three-phase transformer to the site and is instead easier to transport three single-phase transformers, which are erected separately to form a three-phase unit.

Another advantage of using a bank of three single phase transformers is that, if one unit of the bank becomes out of order, then the bank can be run as an open delta transformer.

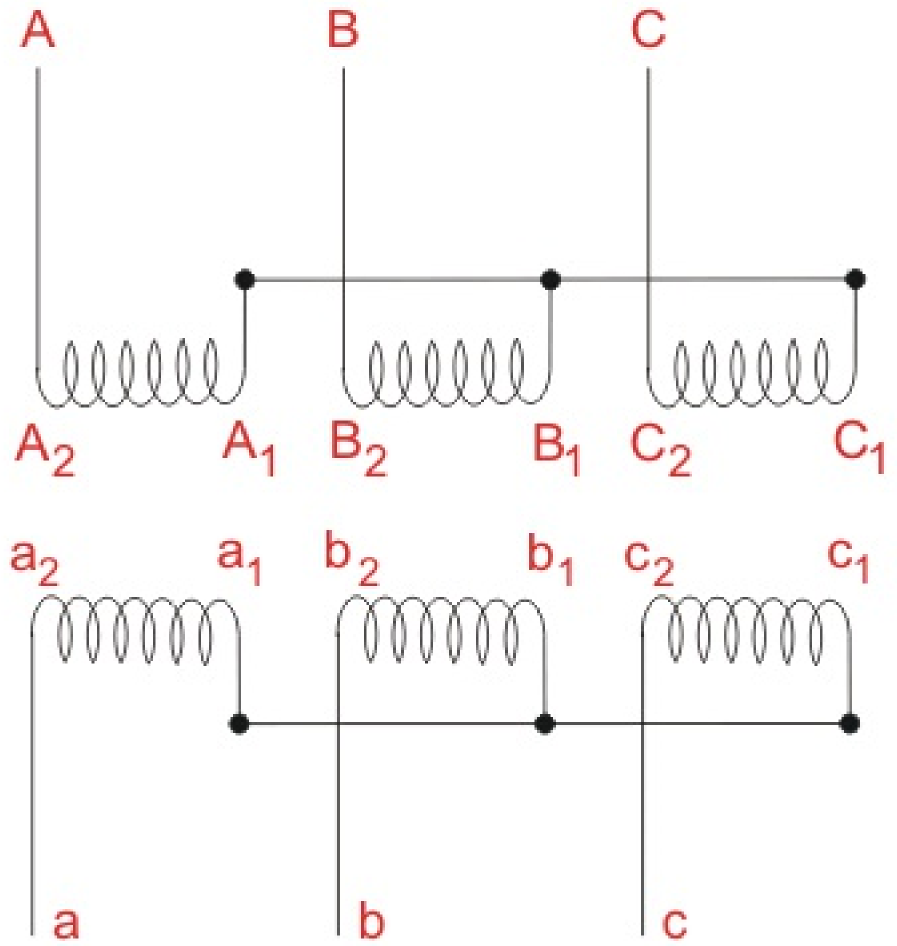
Connection of Three Phase Transformer

A verity of connection of three phase transformer are possible on each side of both a single 3 phase transformer or a bank of three single phase transformers.

Marking or Labeling the Different Terminals of Transformer

Terminals of each phase of HV side should be labeled as capital letters, A, B, C and those of LV side should be labeled as small letters a, b, c. Terminal polarities are indicated by suffixes 1 and 2. Suffix 1's indicate similar polarity ends and so do 2's.

Star-Star Transformer



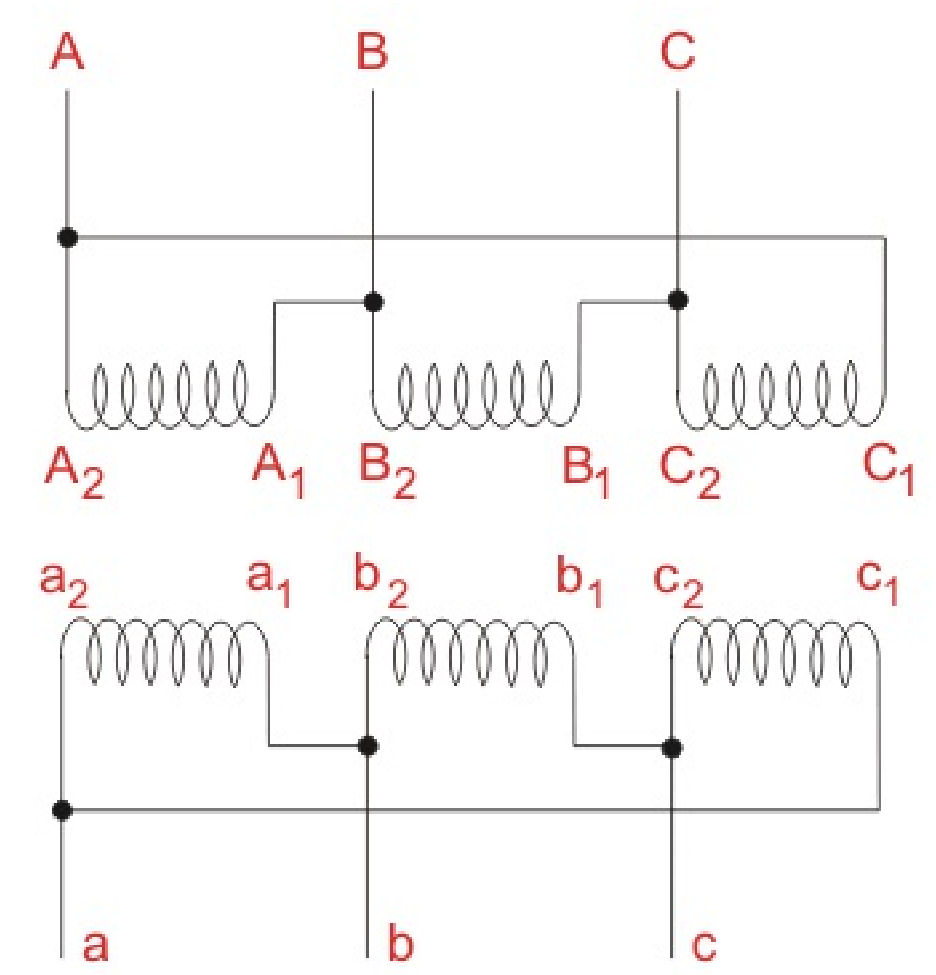
Star-Star Three Phase Transformer

Star-star transformer is formed in a 3 phase transformer by connecting one terminal of each phase of individual side, together. The common terminal is indicated by suffix 1 in the figure below. If terminal with suffix 1 in both primary and secondary are used as common terminal, voltages of primary and secondary are in same phase. That is why this connection is called zero degree connection or 0o – connection.

If the terminals with suffix 1 is connected together in HV side as common point and the terminals with suffix 2 in LV side are connected together as common point, the voltages in primary and secondary will be in opposite phase. Hence, star-star transformer connection is called 180o-connection, of three phase transformer

Delta-Delta Transformer

In delta-delta transformer, 1 suffixed terminals of each phase primary winding will be connected with 2 suffixed terminal of next phase primary winding.



Delta-Delta Three Phase Transformer

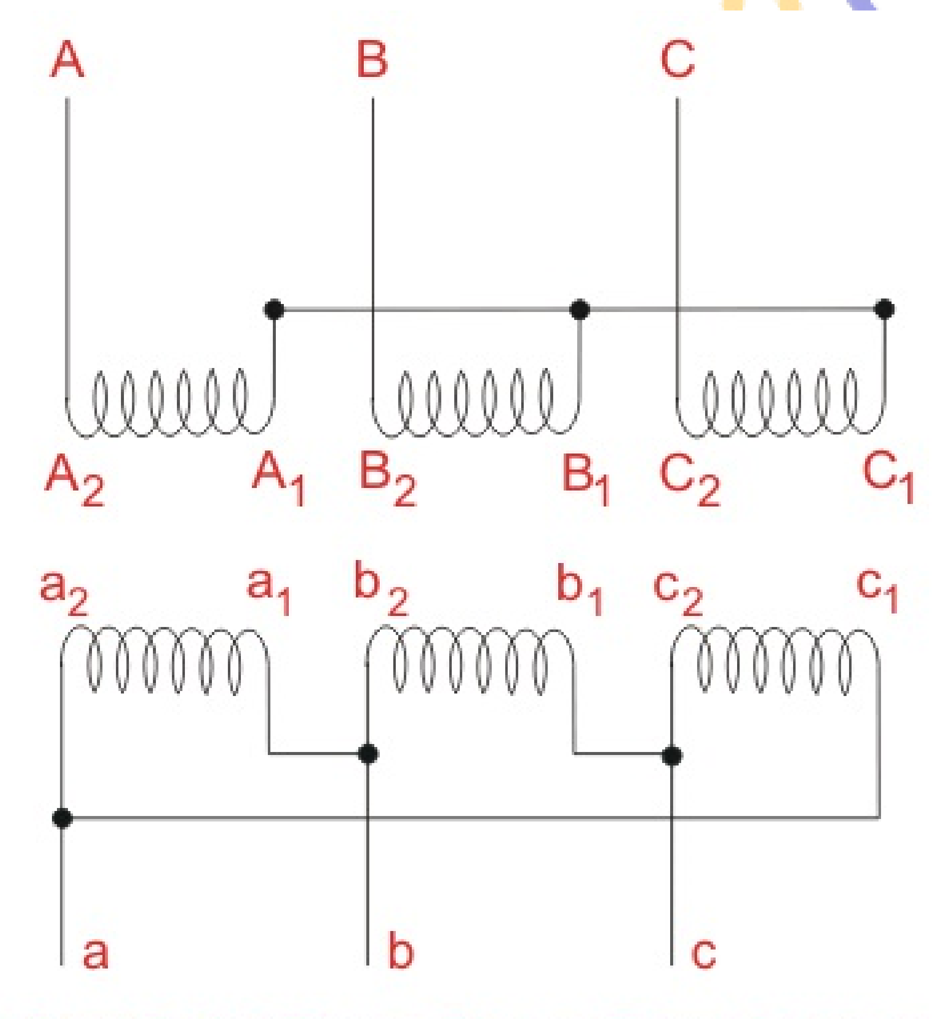
If primary is HV side, then A1 will be connected to B2, B1 will be connected to C2 and C1 will be connected to A2. Similarly in LV side 1 suffixed terminals of each phase winding will be connected with 2 suffixed terminals of next phase winding. That means, a1 will be connected to b2, b1 will be connected to c2 and c1 will be connected to a2.

If transformer leads are taken out from primary and secondary 2 suffixed terminals of the winding, then there will be no phase difference between similar line voltages in primary and secondary. This delta delta transformer connection is zero degree connection or

0o-connection. But in LV side of transformer, if, a2 is connected to b1, b2 is connected to c1 and c2 is connected to a1. The secondary leads of transformer are taken out from 2 suffixed terminals of LV windings, and then similar line voltages in primary and secondary will be in phase opposition. This connection is called 180o-connection, of three phase transformer.

Star-Delta Transformer

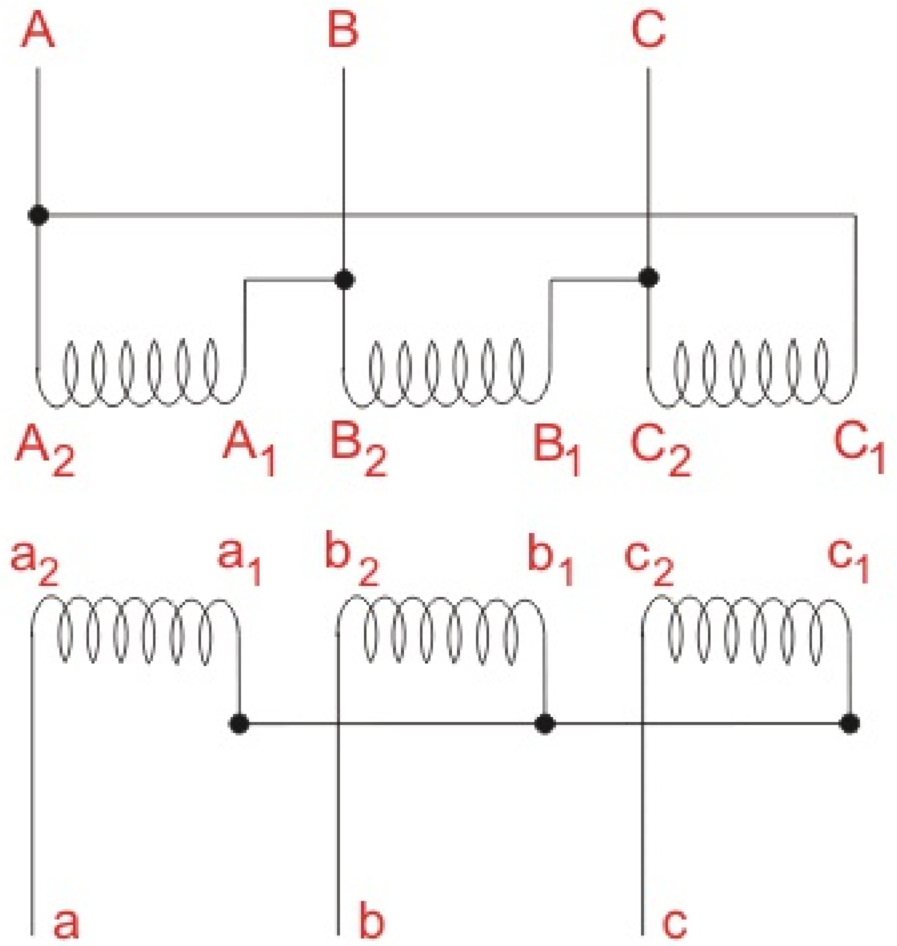
Here in star-delta transformer, star connection in HV side is formed by connecting all the 1 suffixed terminals together as common point and transformer primary leads are taken out from 2 suffixed terminals of primary windings.



Star-Delta Three Phase Transformer

The delta connection in LV side is formed by connecting 1 suffixed terminals of each phase LV winding with 2 suffixed terminal of next phase LV winding. More clearly, a1 is connected to b2, b1 is connected to c2 and c1 is connected to a2. The secondary (here it considered as LV) leads are taken out from 2 suffixed ends of the secondary windings of transformer. The transformer connection diagram is shown in the figure beside. It is seen from the figure that the sum of the voltages in delta side is zero. This is a must as otherwise closed delta would mean a short circuit. It is also observed from the phasor diagram that, phase to neutral voltage (equivalent star basis) on the delta side lags by − 30o to the phase to neutral voltage on the star side; this is also the phase relationship between the respective line to line voltages. This star delta transformer connection is therefore known as − 30o-connection. Star-delta + 30o-connection is also possible by connecting secondary terminals in following sequence. a2 is connected to b1, b2 is connected to c1 and c2 is connected to a1. The secondary leads of transformer are taken out from 2 suffixed terminals of LV windings,

Delta-Star Transformer



Delta-Star Three Phase Transformer

Delta-star transformer connection of three phase transformer is similar to star – delta connection. If any one interchanges HV side and LV side of star-delta transformer in diagram, it simply becomes delta – star connected 3 phase transformer. That means all small letters of star-delta connection should be replaced by capital letters and all small letters by capital in delta-star transformer connection.

Delta-Zigzag Transformer

The winding of each phase on the star connected side is divided into two equal halves in delta zig zag transformer. Each leg of the core of transformer is wound by half winding from two different secondary phases in addition to its primary winding.

Star-Zigzag Transformer

The winding of each phase on the secondary star in a star-zigzag transformer is divided into two equal halves. Each leg of the core of transformer is wound by half winding from two different secondary phases in addition to its primary winding.

In star connection with earthed neutral, phase voltage i.e. phase to neutral voltage, is 1/√3 times of line voltage i.e. line to line voltage. But in the case of delta connection phase voltage is equal to line voltage. Star connected high voltage side electrical power transformer is about 10% cheaper than that of delta connected high voltage side transformer.

Let, the voltage ratio of transformer between HV and LV is K, voltage across HV winding is VH and voltage across LV winding is VL and voltage across transformer leads in HV side say Vp and in LV say Vs.

In

Star-Star Transformer

$$V_H = \frac{V_p}{\sqrt{3}} \; and \; V_L = \frac{V_s}{\sqrt{3}}$$

$$\Rightarrow \frac{V_p}{V_s} = \frac{V_H}{V_L}$$

$$\Rightarrow V_H = K.V_L$$

Voltage difference between HV & LV winding,

$$V_H - V_L = V_P - V_s = (K-1)V_s$$

In Star-Delta Transformer

$$V_H = \frac{V_p}{\sqrt{3}} \; and \; V_L = V_s$$

Voltage difference between HV & LV winding,

$$V_H - V_L = \frac{V_P}{\sqrt{3}} - V_s = \left(\frac{K}{\sqrt{3}} - 1\right) V_s$$

In Delta-Star Transformer

$$V_H = V_p \; and \; V_L = \frac{V_s}{\sqrt{3}}$$

Voltage difference between HV & LV winding,

$$V_H - V_L = V_P - \frac{V_s}{\sqrt{3}} = \left(K - \frac{1}{\sqrt{3}}\right) V_s$$

For 132/33KV Transformer K = 4

Case 1

Voltage difference between HV & LV winding,

$$(4-1)V_s = 3.V_s$$

Case 2

Voltage difference between HV & LV winding,

$$\left(\frac{4}{\sqrt{3}} - 1\right) V_s = 1.3V_s$$

Case 3

Voltage difference between HV & LV winding,

$$\left(4 - \frac{1}{\sqrt{3}}\right) V_s = 3.42V_s$$

In case 2 voltage difference between HV and LV winding is minimum therefore potential stresses between them is minimum, implies insulation cost in between these windings is also less. Hence for step down purpose star–delta transformer connection is most economical, design for transformer. Similarly it can be proved that for step up purpose delta-star three phase transformer connection is most economical.

Question. State and prove the condition for maximum efficiency of transformer

The efficiency of transformer is simply given as:

$$\boxed{\eta = \frac{output\ power}{output\ power + losses} \times 100\%}$$

- The output power is the product of the fraction of the rated loading (volt-ampere), and power factor of the load
- The losses are the sum of copper losses in the windings + the iron loss + dielectric loss + stray load loss.
- The iron losses include the hysteresis and eddy current losses in the transformer. These losses depend on the flux density inside the core. Mathematically,

  Hysteresis Loss :

  $P_h = k_h f B_{max}^n$

  Eddy Current Loss :

  $P_e = k_e f^2 B_{max}^n t^2$

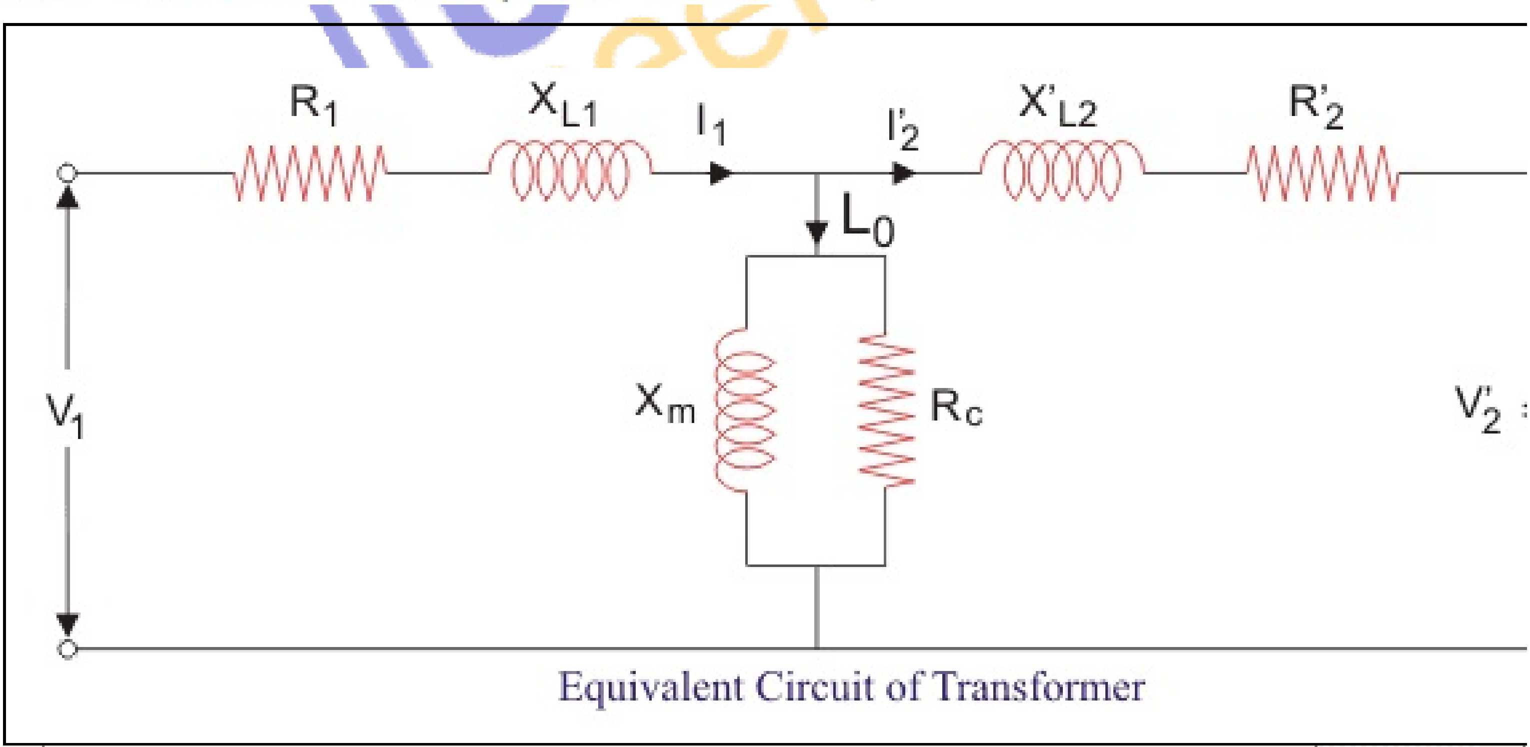
  Where kh and ke are constants, Bmax is the peak magnetic field density, f is the source frequency, and t is the thickness of the core. The power 'n' in the hysteresis loss is known as Steinmetz constant whose value can be nearly 2.

$$Total\ iron\ or\ core\ losses(P_i) = Hysteresis\ loss + eddy\ current\ lo$$

- The dielectric losses take place inside the transformer oil. For low voltage transformers, it can be neglected.
- The leakage flux links to the metal frame, tank,etc. to produce eddy currents and are present all around the transformer hence called stray loss, and it depends on the load current and so named as 'stray load loss.' It can be represented by resistance in series to the leakage reactance.

The equivalent circuit of the transformer referred to primary side is shown below. Here Rc accounts for core losses. Using Short circuit(SC) test, we can find the equivalent resistance accounting for copper losses as

$$R_e = R_1 + R'_2 \quad where, R'_2 = a^2 R_2$$



Equivalent Circuit of Transformer

Let us define x% be the percentage of full or rated load 'S' (VA) and let Pcufl(watts) be the full load copper loss and cosθ be the power factor of the load. Also, we defined Pi (watts) as core loss. As copper and iron losses are major losses in the transformer hence only these two types of losses are taken into account while calculating efficiency.

Then the efficiency of transformer can be written as :

$$\eta = \frac{xS\cos\theta}{xS\cos\theta + x^2 P_{cufl} + P_i}$$

Where, x^2P_{cufl} = copper loss(P_{cu}) at any loading x% of full load.

The maximum efficiency (ηmax) occurs when the variable losses equal to the constant losses. Since the copper loss is load dependent, hence it is a variable loss quantity. And the core loss is taken to be the constant quantity. So the condition for maximum efficiency is :

$$x^2 P_{cufl} = P_i$$

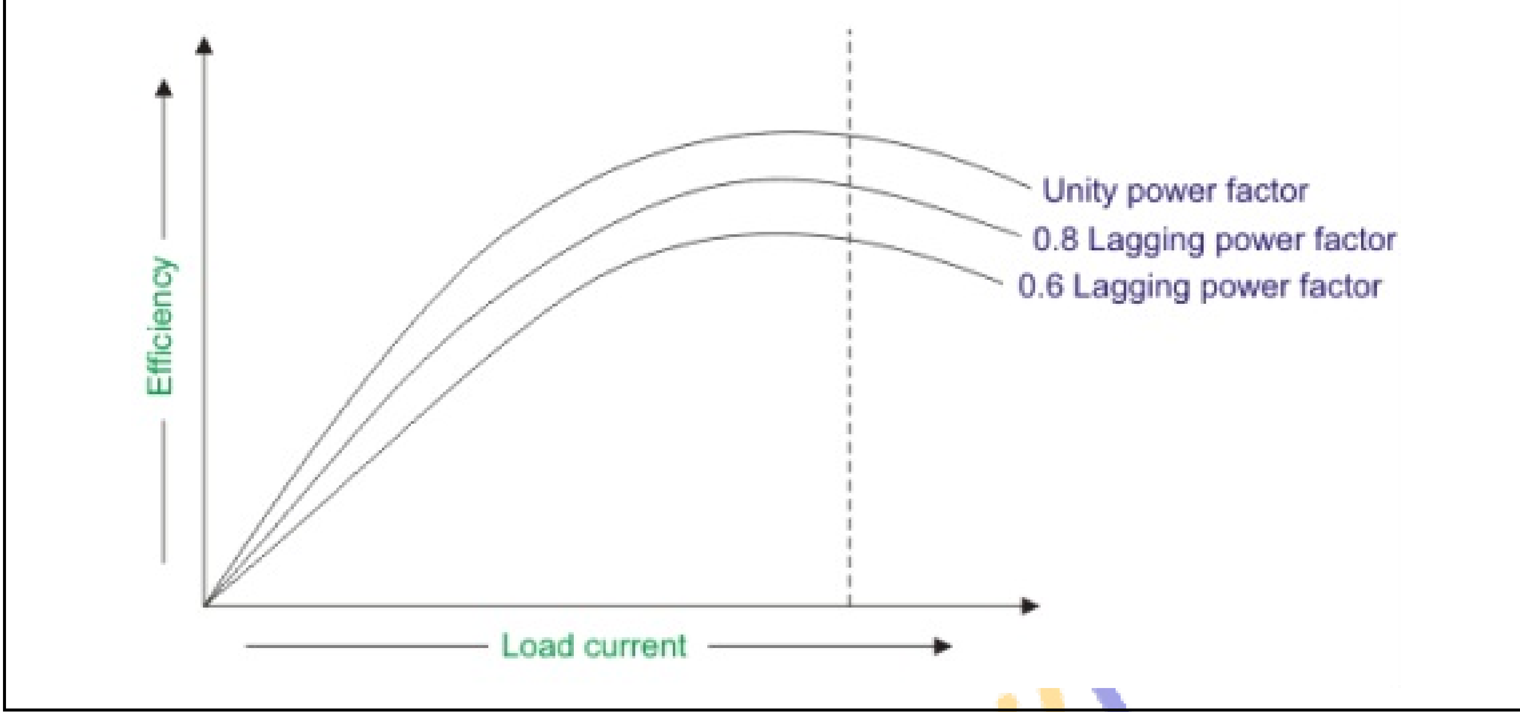
$$\Rightarrow x = \sqrt{\frac{P_i}{P_{cufl}}}$$

Now we can write maximum efficiency as :

$$\eta_{max} = \frac{xS\cos\theta}{xS\cos\theta + 2P_i}$$

This shows that we can obtain maximum efficiency at full load by proper selection of constant and variable losses. However, it is difficult to obtain maximum efficiency as copper losses are much higher than the fixed core losses.

The variation of efficiency with loading can be represented by figure below :



We can see from the figure that the maximum efficiency occurs at unity power factor. And the maximum efficiency occurs at the same loading irrespective of power factor of the load.

Question. What are the different losses in a D.C. machine? Which of them are variable losses? Derive the condition for maximum efficiency of D.C. machine

Copper Losses or Electrical Losses in DC Machine or Winding Loss

The copper losses are the winding losses taking place during the current flowing through the winding. These losses occur due to the resistance in the winding. In a DC machine, there are only two windings, armature and field winding.

Thus copper losses categories in three parts; armature loss, the field winding loss, and brush contact resistance loss. The copper losses are proportional to the square of the current flowing through the winding.

Armature Copper Loss in DC Machine

Armature copper loss = Ia2Ra

Where, Ia is armature current and Ra is armature resistance.

These losses are about 30% of the total full load losses.

Field Winding Copper Loss in DC Machine

Field winding copper loss = If2Rf

Where, If is field current and Rf is field resistance.

These losses are about 25% theoretically, but practically it is constant.

Brush Contact Resistance Loss in DC Machine

Brush contact loss attributes to resistance between the surface of brush and commutator. It is not a loss which could be calculated separately as it is a part of variable losses. Generally, it contributes to both the types of copper losses. So, they are factors in the calculation of the above losses.

Core Losses or Iron Losses in DC Machine or Magnetic Losses

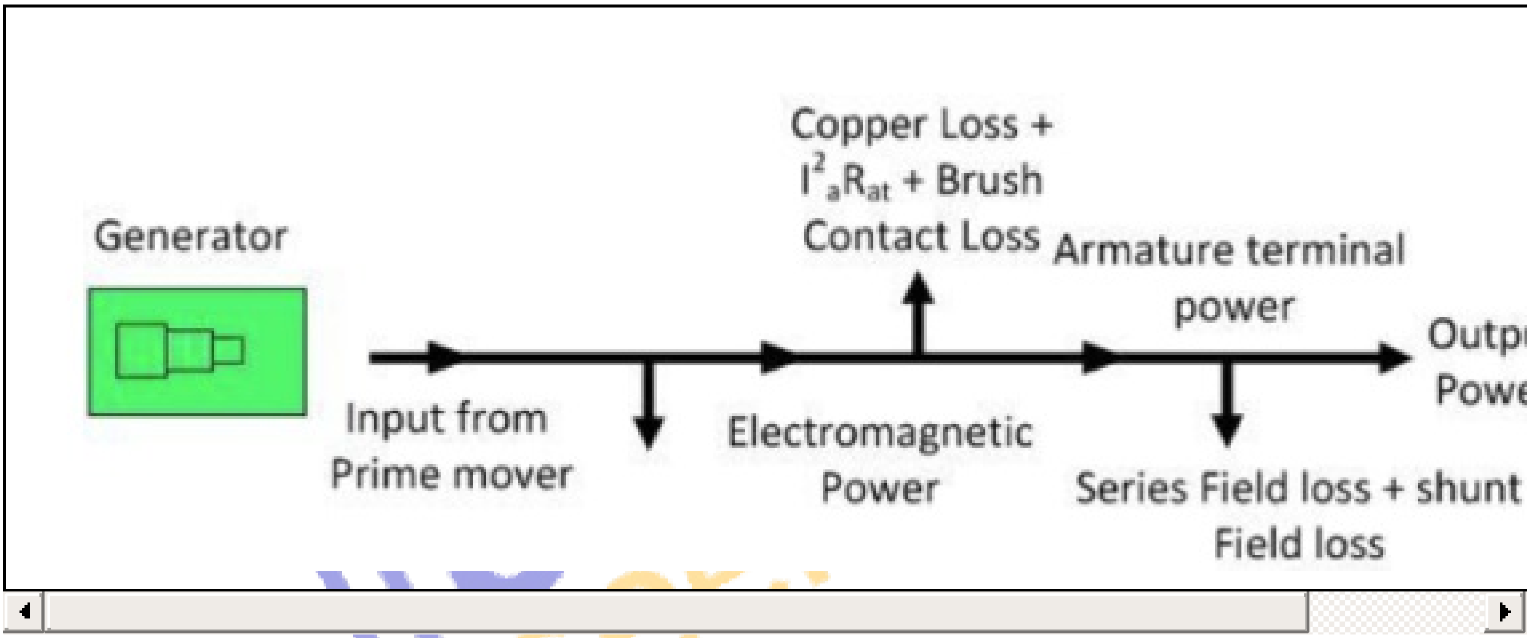
As iron core of the armature is rotating in magnetic field, some losses occurs in the core which is called core losses. Normally, machines are operated with constant speed, so these losses are almost constant. These losses are categorized in two form; Hysteresis loss and Eddy current loss.

Hysteresis Loss in DC Machine

Hysteresis losses occur in the armature winding due to reversal of magnetization of the core. When the core of the armature exposed to the magnetic field, it undergoes one complete rotation of magnetic reversal. The portion of the armature which is under S-pole, after completing half electrical revolution, the same piece will be under the

N-pole, and the magnetic lines are reversed in order to overturn the magnetism within the core. The constant process of magnetic reversal in the armature, consume some amount of energy which is called hysteresis loss. The percentage of loss depends upon the quality and volume of the iron.

The efficiency of the DC generator is explained below in the line diagram:



- I is the output current
- Ish is the current through the shunt field
- Ia is the armature current = I + Ish
- V is the terminal voltage.

Total copper loss in the armature circuit = $I_a^2 R_{at}$

Power loss in the shunt circuit = VIsh (this includes the loss in the shunt regulating resistance).

Mechanical losses = friction loss of bearings + friction loss at a commutator + windage loss.

Core losses = hysteresis loss + eddy current loss

Stray loss = mechanical loss + core loss

The sum of the shunt field copper loss and stray losses may be considered as a combined fixed (constant) loss that does not vary with the load current I.

Therefore, the constant losses (in shunt and compound generators) = stray loss + shunt field copper losses.

$$\text{Total Losses} = I_a^2 R_{at} + p_k + V_{BD} I_a$$

Generator efficiency is given by the equation shown below:

$$\eta_G = \frac{\text{Generator output}}{\text{Generator output} + \text{losses}}$$

$$\eta_G = \frac{VI}{VI + I_a^2 R_{at} + V_{BD} I_a + p_k}$$

$$I_a = I + I_{sh}$$

If Ish is small compared with Ir, then Ia = I

$$\eta_G = \frac{VI}{VI + I_a^2 R_{at} + V_{BD} I_a + p_k}$$

$$\eta_G = \frac{1}{1 + \frac{IR_{at}}{V} + \frac{V_{BD}}{V} + \frac{p_k}{VI}}$$

Therefore,

The efficiency ηG will be a maximum when the denominator Dr is a minimum.

$$D_r = 1 + \frac{IR_{at}}{V} + \frac{V_{BD}}{V} + \frac{p_k}{VI}$$

Where,

$$\frac{dD_r}{dI} = 0 \quad \text{and} \quad \frac{d^2 D_r}{dI^2} > 0$$

$$\frac{dD_r}{dI} = \frac{d}{dI}\left(1 + \frac{IR_{at}}{V} + \frac{V_{BD}}{V} + \frac{p_k}{VI}\right)$$

$$0 = 0 + \frac{R_{at}}{V} + \frac{p_k}{V}\left(-\frac{1}{I^2}\right) \quad \text{or}$$

Dr is minimum when

$$I^2R_{at} = p_k \; \dots\dots\dots(1)$$

Also,

$$\frac{d^2 D_r}{dI^2} = \frac{d}{dt}\left(\frac{R_{at}}{V} - \frac{p_k}{VI^2}\right) = \frac{2p_k}{VI^3} > 0$$

Since d2Dr/dI2 is positive, the expression given by the equation (1) is a condition for the maximum value of Dr and the condition for the maximum value of efficiency.

Equation (1) shows that the efficiency of a DC generator is maximum when those losses proportional to the square of the load current are equal to the constant losses of the DC generator.

This relation applies equally well to all rotating machines, regardless of the type of machine.

This relationship is sometimes incorrectly stated as maximum efficiency occurs when the variable losses are equal to the constant losses.

Load Corresponding to Maximum Efficiency

Let,

- Ifl be the full load current,
- IM is the current at maximum efficiency

$$I_M^2 R_{at} = p_k$$

$$I_M^2 = \frac{p_k}{R_{at}}$$

$$I_M^2 = \frac{I_{fl}^2 \, p_k}{I_{fl}^2 \, R_{at}}$$

$$I_M = I_{fl} \sqrt{\frac{p_k}{I_{fl}^2 \, R_{at}}}$$

For maximum efficiency, therefore, the current at maximum efficiency is given by the equation shown below:

$$\text{Current at Maximum Efficiency} = \text{Full load current X} \sqrt{\frac{\text{Constant los}}{\text{Full load coppe}}}$$

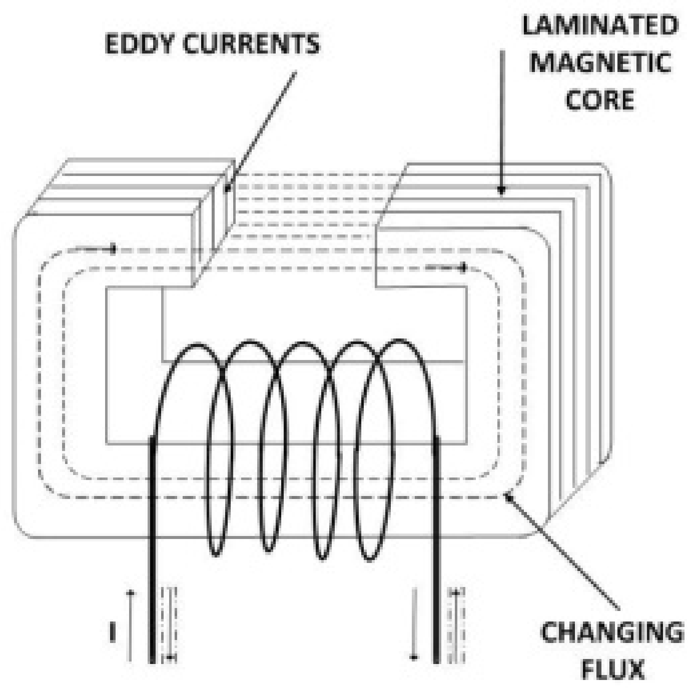
Question. What is eddy current loss? Discuss its undesirable effects. Suggest some remedies to minimize it along with some applications of eddy current

When an alternating magnetic field is applied to a magnetic material, an emf is induced in the material itself according to Faraday's Law of Electromagnetic induction. Since the magnetic material is a conducting material, these EMFs circulate current within the body of the material.

These circulating currents are called Eddy Currents. They will occur when the conductor experiences a changing magnetic field.

As these currents are not responsible for doing any useful work, and it produces a loss (I2R loss) in the magnetic material known as an Eddy Current Loss. Similar to hysteresis loss, eddy current loss also increases the temperature of the magnetic material.

The hysteresis and the eddy current losses in a magnetic material are also known by the name iron losses or core losses or magnetic losses.



Eddy currents are undesirable since they heat up the core and dissipate electrical enegy in the form of heat.

(1)Eddy currents are minimized by using laminations of metal to make a metal core. The laminations are separated by an insulating material like lacquer.

(2) The plane of laminations must be arranged parallel to the magnetic field, so that they cut across the eddy current paths. This kind of arrangement reduces the strength of the edy currents.

(3) The dissipation of electrical enegy into heat depends on the square of the strength of electric current, heat loss can be reduced.

Since the resistance of an iron strip will be much larger than the resistance of the thick core, only very feeble eddy currents are produced in the iron strips and the transformer is saved from getting heated.

- In order to reduce the eddy current loss, the resistance of the core should be increased. In other words, low reluctance should be retained.
- In devices like transformers, the core is made up of laminations of iron. ie,the core is made up of thin sheets of steel, each lamination being insulated from others.
- As the laminations are thin, they will have relatively high resistance.
- Each lamination sheet will have an eddy current circulating within it.
- The sum of individual eddy current of the laminations are very less compared to that of using a single solid iron core.
- The eddy current loss is proportional to f^2. So at higher frequencies, the eddy current loss is very high.
- Under such conditions, the use of lamination sheets are not

enough.

- For this type of application, ferrite cores or iron dust cores are used. Using these materials, the eddy currents are limited to individual grains, so the eddy current loss is reduced considerably.

Question. Define voltage regulation of a transformer and derive conditions for i) zero regulation and ii) maximum regulation. Also draw the curve of variation of voltage regulation with power factor

Voltage Regulation of single-phase transformers is the percentage (or per unit value) change in its secondary terminal voltage compared to its original no-load voltage under varying secondary load conditions. In other words, regulation determines the variation in secondary terminal voltage which occurs inside the transformer as a result of variations in the transformers connected load thereby affecting its performance and efficiency if these losses are high and the secondary voltage becomes too low.

When there is no-load connected to the transformers secondary winding, that is its output terminals are open-circuited, there is no closed-loop condition, so there is no output load current (IL = 0) and the transformer acts as one single winding of high self-inductance. Note that the no-load secondary voltage is a result of the fixed primary voltage and the turn’s ratio of the transformer.

Loading the secondary winding with a simple load impedance causes a secondary current to flow, at any power factor, through the internal winding of the transformer. Thus voltage drops due to the windings internal resistance and its leakage reactance causes the output terminal voltage to change.

When the transformer is loaded with continuous supply voltage, the terminal voltage of the transformer varies. The variation of voltage depends on the load and its power factor.

Mathematically, the voltage regulation is represented as:

$$\text{Voltage Regulation} = \frac{E_2 - V_2}{E_2}$$

$$\%\ \text{Voltage Regulation} = \frac{E_2 - V_2}{E_2} \times 100$$

Where,

E2 – secondary terminal voltage at no load

V2 – secondary terminal voltage at full load

The voltage regulation by considering the primary terminal voltage of the transformer is expressed as,

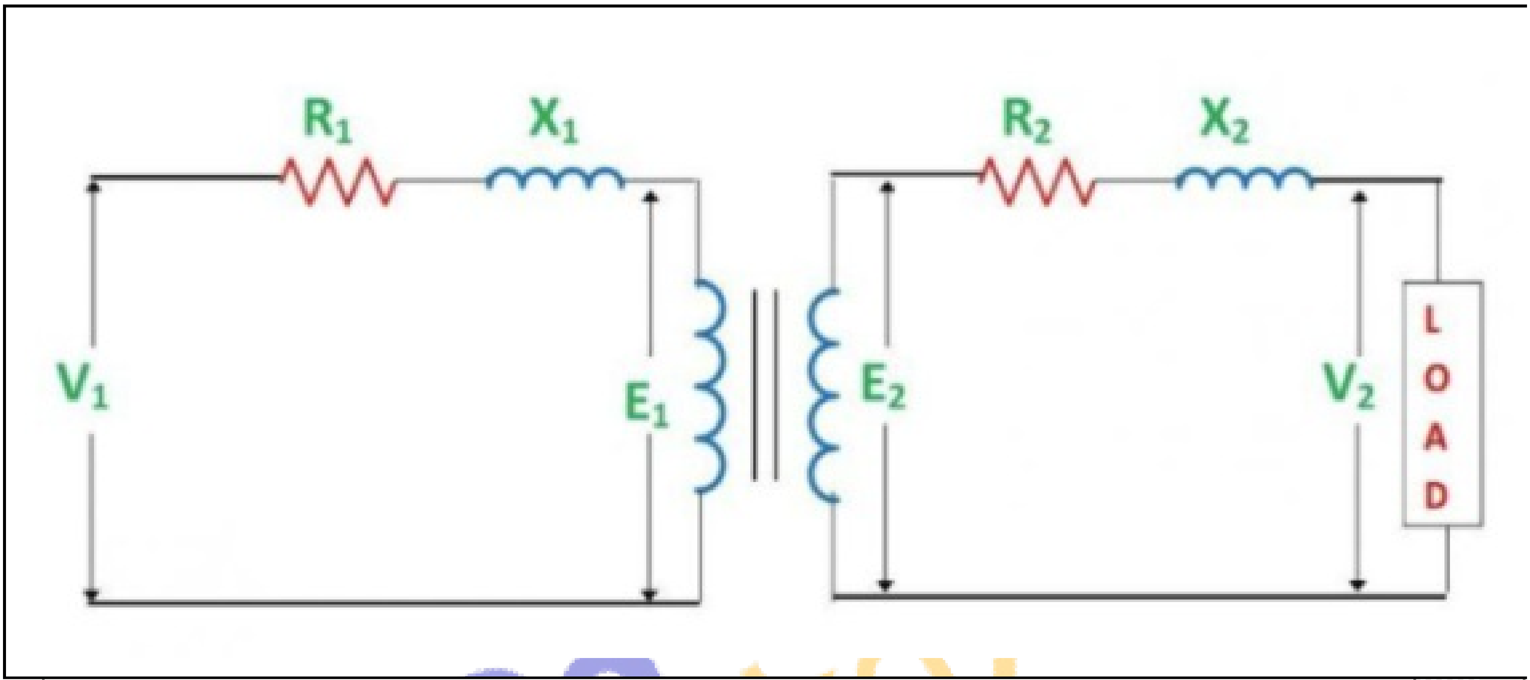
$$\%\ \text{Voltage Regulation} = \frac{V_1 - E_1}{V_1} \times 100$$

Let us understand the voltage regulation by taking an example explained below:

If the secondary terminals of the transformer are open-circuited or no load is connected to the secondary terminals, the no-load current flows through it.

If the no current flows through the secondary terminals of the transformer, the voltage drops across their resistive and reactive load become zero. The voltage drop across the primary side of the transformer is negligible.

If the transformer is fully loaded, i.e., the load is connected to their secondary terminal, the voltage drops appear across it. The value of the voltage regulation should always be less for the better performance of the transformer.



From the circuit diagram shown above, the following conclusions are made

- The primary voltage of the transformer is always greater than the induced emf on the primary side. **V1>E1**

- The secondary terminal voltage at no load is always greater than the voltage at full load condition. **E2>V2**

By considering the above circuit diagram, the following equations are drawn

$$V_1 = I_1R_1\text{Cos}\varphi_1 + I_1X_1\text{Sin}\varphi_1 + E_1$$

$$E_2 = I_2R_2\text{Cos}\varphi_2 + I_2X_2\text{Sin}\varphi_2 + V_2$$

Question. Discuss the application of:

i) d.c. generator

There are various types of DC generators available for several types of services. The **applications of these DC generators** based on their characteristic are discussed below:

Applications of Separately Excited DC Generators

This type of DC generators are generally more expensive than self-excited DC generators because of their requirement of separate excitation source. Because of that their applications are restricted. They are generally used where the use of self-excited generators are unsatisfactory.

1. Because of their ability of giving wide range of voltage output, they are generally used for testing purpose in the laboratories.
2. Separately excited generators operate in a stable condition with any variation in field excitation. Because of this property they are used as supply source of DC motors, whose speeds are to be controlled for various applications. Example- Ward Leonard Systems of speed control.

Applications of Shunt Wound DC Generators

The application of shunt generators is very much restricted for its dropping voltage characteristic. They are used to supply power to the apparatus situated very close to its position. These type of DC generators generally give constant terminal voltage for small distance operation with the help of field regulators from no load to full load.

1. They are used for general lighting.
2. They are used to charge battery because they can be made to give

constant output voltage.

3. They are used for giving the excitation to the alternators.
4. They are also used for small power supply (such as a portable generator).

Applications of Series Wound DC Generators

These types of generators are restricted for the use of power supply because of their increasing terminal oltage characteristic with the increase in load current from no load to full load. We can clearly see this characteristic from the characteristic curve of series wound generator. They give constant current in the dropping portion of the characteristic curve. For this property they can be used as constant current source and employed for various applications.

1. They are used for supplying field excitation current in DC locomotives for regenerative breaking.
2. This types of generators are used as boosters to compensate the voltage drop in the feeder in various types of distribution systems such as railway service.
3. In series arc lightening this type of generators are mainly used.

Applications of Compound Wound DC Generators

Among various types of DC generators, the compound wound DC generators are most widely used because of its compensating property. Depending upon number of series field turns, the cumulatively compounded generators may be over compounded, flat compounded and under compounded. We can get desired terminal voltage by compensating the drop due to armature reaction and ohmic drop in the in the line. Such generators have various applications.

1. Cumulative compound wound generators are generally used for lighting, power supply purpose and for heavy power services because of their constant voltage property. They are mainly made

over compounded.

2. Cumulative compound wound generators are also used for driving a motor.
3. For small distance operation, such as power supply for hotels, offices, homes and lodges, the flat compounded generators are generally used.
4. The differential compound wound generators, because of their large demagnetization armature reaction, are used for arc welding where huge voltage drop and constant current is required.

At present time the **applications of DC generators** become very limited because of technical and economic reasons. Now a days the electric power is mainly generated in the form of alternating current with the help of various power electronics devices.

ii) d.c. shunt motor

The **applications of shunt DC motor** include the following.

- These motors are used wherever stable speed is required.
- This kind of DC motor can be used in Centrifugal Pumps, Lifts, Weaving Machine, Lathe Machines, Blowers, Fans, Conveyors, Spinning machines, etc.

Thus, this is all about an overview of **DC shunt motor**. From the above information finally, we can conclude that these motors are ideal where exact speed control is needed due to their self-regulating speed capacities. The applications of this motor mainly comprise machines instruments like grinders, latches & industrial tools like compressors as well as fans.

iii) d.c. series motor

- It is a variable speed motor i.e. very low speed at high torqe and vice versa. However at no load motor tends to occupy dangerous speed. The motor has a very high starting torque. So it is used for :

- The series DC motor is an industry workhorse for both high and low power, fixedandvariable speed electric drives.
- Applications range from cheap toys to automotive applications.
- They are inexpensive to manufacture and are used in variable speed household appliances such as sewing machines and power tools.

- Its high starting torque makes it particularly suitable for a wide range of traction applications.
- Industrial uses are hoists, cranes, trolly cars, conveyors, elevators, air compressors, vacuum cleaners, sewing machines etc.

Question. Why is parallel operation of transformers performed? Explain the complete laboratory procedure to perform the test

It is economical to installe numbers of smaller rated **transformers in parallel** than installing a bigger rated electrical power transformers. This has mainly the following advantages,

1. To maximize electrical power system efficiency:

Generally electrical power transformer gives the maximum efficiency at full load. If we run numbers of **transformers in parallel**, we can switch on only those transformers which will give the total demand by running nearer to its full load rating for that time. When load increases, we can switch none by one other transformer connected in parallel to fulfill the total demand. In this way we can run the system with maximum efficiency.

2. To maximize electrical power system availability:

If numbers of transformers run in parallel, we can shutdown any one of them for maintenance purpose. Other **parallel transformers** in system will serve the load without total interruption of power.

3. To maximize power system reliability:

If any one of the transformers run in parallel, is tripped due to fault of other **parallel transformers** is the system will share the load, hence power supply may not be interrupted if the shared loads do not make other transformers over loaded.

4. To maximize electrical power system flexibility:
   There is always a chance of increasing or decreasing future demand of power system. If it is predicted that power demand will be increased in future, there must be a provision of connecting transformers in system in parallel to fulfill the extra demand because, it is not economical from business point of view to install a bigger rated single transformer by forecasting the increased future demand as it is unnecessary investment of money. Again if future demand is decreased, transformers running in parallel can be removed from system to balance the capital investment and its return.

Conditions for Parallel Operation of Transformers

When two or more transformers run in parallel, they must satisfy the following conditions for satisfactory performance. These are the conditions for **parallel operation of transformers**.

1. Same voltage ratio of transformer.
2. Same percentage impedance.
3. Same polarity.
4. Same phase sequence.

Same Voltage Ratio

If two transformers of different voltage ratio are connected in parallel with same primary supply voltage, there will be a difference in secondary voltages. Now say the secondary of these transformers are connected to same bus, there will be a circulating current between secondaries and therefore between primaries also. As the internal impedance of transformer is small, a small voltage difference may cause sufficiently high circulating current causing unnecessary extra I2R loss.

Same Percentage Impedance

The current shared by two transformers running in parallel should be proportional to their MVA ratings. Again, current carried by these transformers are inversely proportional to their internal impedance. From these two statements it can be said that, impedance of transformers running in parallel are inversely proportional to their MVA ratings. In other words, percentage impedance or per unit values of impedance should be identical for all the transformers that run in parallel.

Same Polarity

Polarity of all transformers that run in parallel, should be the same otherwise huge circulating current that flows in the transformer but no load will be fed from these transformers. Polarity of transformer means the instantaneous direction of induced emf in secondary. If the instantaneous directions of induced secondary emf in two transformers are opposite to each other when same input power is fed to both of the transformers, the transformers are said to be in opposite polarity. If the instantaneous directions of induced secondary emf in two transformers are same when same input power is fed to the both of the transformers, the transformers are said to be in same polarity.

Same Phase Sequence

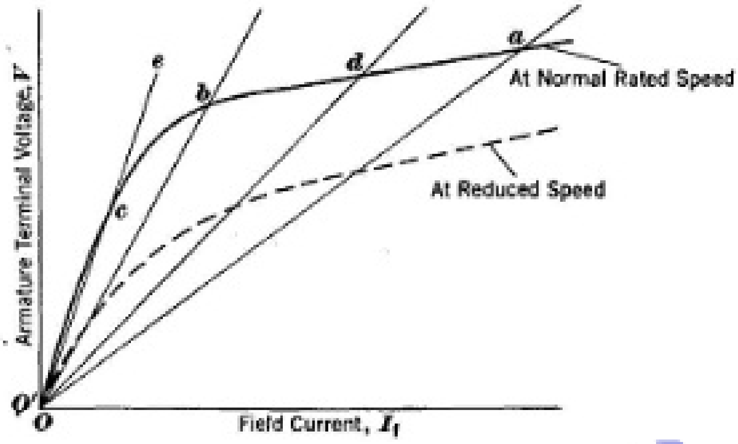
The phase sequence or the order in which the phases reach their maximum positive voltage, must be identical for two parallel transformers. Otherwise, during the cycle, each pair of phases will be short circuited.

The above said conditions must be strictly followed for **parallel operation of transformers** but totally identical percentage impedance of two different transformers is difficult to achieve practically, that is why the transformers run in parallel may not have exactly same percentage impedance but the values would be as nearer as possible.

Question. Describe the process of voltage build up in self-excited d.c. generators

When a generator is driven at constant speed without its shunt circuit being closed, a very small residual voltage (1 to 5 volts) appears at its terminals because of the residual magnetism remaining in the iron. When the field circuit is properly connected, the residual voltage forces a small exciting current through the field circuit and thereby increases the field strength.

Because of the increased field strength, the generated voltage increases. This reciprocal action continues until a point of stability is reached at which the flux produced by the current in the field is just sufficient to generate the voltage required to produce the field current. Most modern generators are so designed that, with no resistance in series with the field, the voltage will rise to about 125 per cent of rated value. This condition is represented by the point a in Fig. The straight line Oa is called a field resistance line because its slope V/I_f is equal to R_f, the resistance of the field circuit including the field rheostat. After the voltage has built up, it may be adjusted to any desired value between a and c by increasing the resistance of the field circuit by means of its rheostat. Generators are usually designed so that the rated voltage is generated at the point b or at somewhat higher field current. For every value of field-circuit resistance, the resistance line will have a particular slope, such as Od or Ob.



If the resistance is made so high that the slope of the resistance line, as Oe, is equal to or greater than that of the lower straight part of the magnetization curve, the voltage of the generator will collapse and will drop to the residual value O'. A generator may fail to build up for any of the following reasons:

1. Field-circuit resistance too high; including open circuit.

2. Speed too low.

3. Residual magnetism lost.

4. Direction of rotation incorrect.

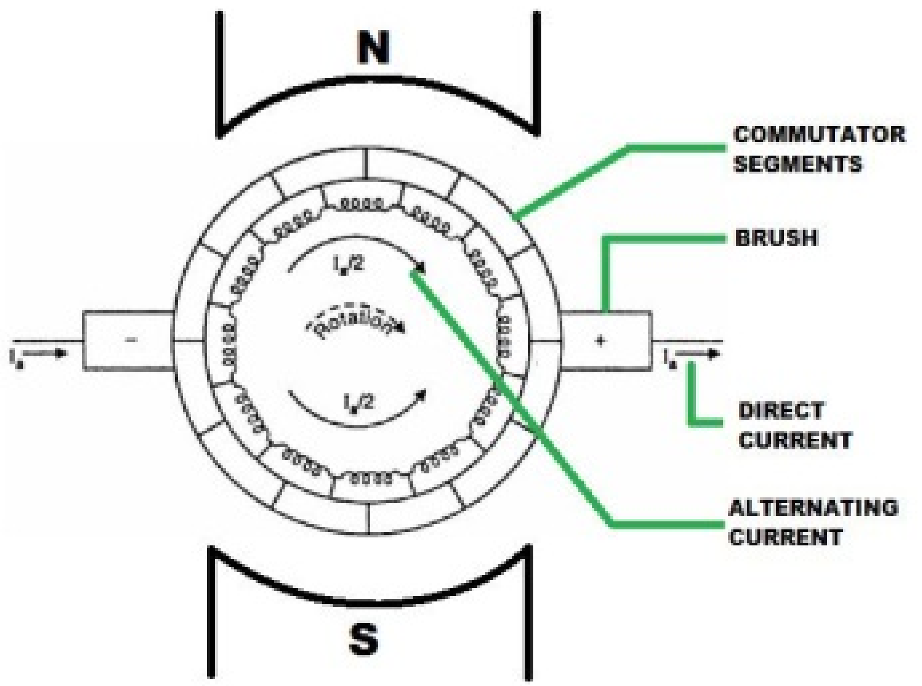
5. Generator terminals connected to external circuit of too low resistance.

6. Shunt-field terminals reversed.

A If the generator speed be reduced, the magnetization curve will be reduced in height proportionately, as shown by the dash curve of Fig. 10-15. Whereas at rated speed the generator would build up when the field resistance line is Ob, this line is too steep to permit build-up at the reduced speed. If the direction of rotation is incorrect, the residual voltage will force current through the field coils in a direction to demagnetize the field, and build-up cannot occur. If the generator is connected to a load circuit of too low resistance, the load-circuit current due to residual voltage may, by its magnetizing action in the armature, prevent build-up. Residual magnetism may be restored by connecting the field circuit to any suitable source of direct current.

Question. Explain with a neat labelled diagram the commutation process in a D.C. machine. Also suggest the remedies for it

For the explanation of commutation process, let us consider a DC machine having an armature wound with ring winding. Let us also consider that the width of the commutator bar is equal to the width of the brush and current flowing through the conductor is IC.



Let the commutator is moving from left to right. Then the brush will move from right to left.

At the first position, the brush is connected the commutator bar b (as shown in fig 1). Then the total current conducted by the commutator bar b into the brush is 2IC.

When the armature starts to move right, then the brush comes to contact of bar a. Then the armature current flows through two paths and through the bars a and b (as shown in fig 2). The total current (2IC) collected by the brush remain same.

As the contact area of the bar a with the brush increases and the contact area of the bar b decreases, the current flow through the bars increases and decreases simultaneously. When the contact area become same for both the commutator bar then same current flows through both the bars (as shown in fig 3).

When the brush contact area with the bar b decreases further, then the current flowing through the coil B changes its direction and starts to flow counter-clockwise (as shown in fig 4).

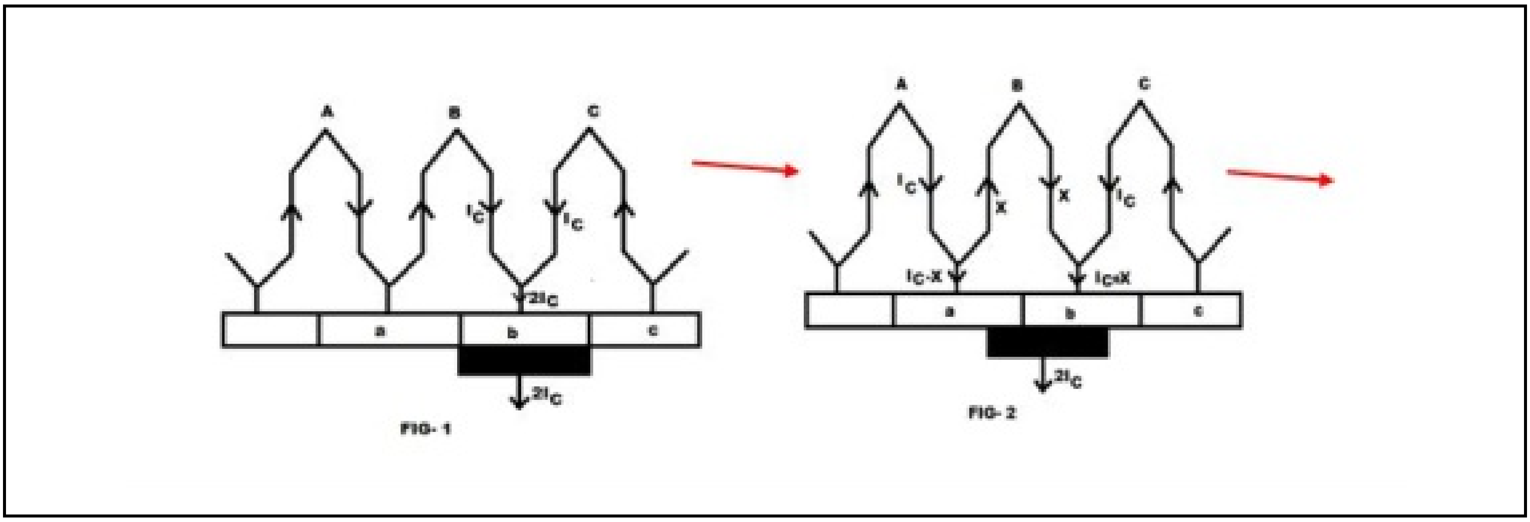
When the brush totally comes under the bar a (as shown in fig 5) and disconnected with the bar b then current IC flows through the coil B in the counter-clockwise direction and the short circuit is removed.

In this process the reversal of current or the process of commutation is done.

Methods of Improving Commutation

There are three methods of sparkles commutation:

1. Resistance Commutation
2. Voltage Commutation
3. Compensating Windings



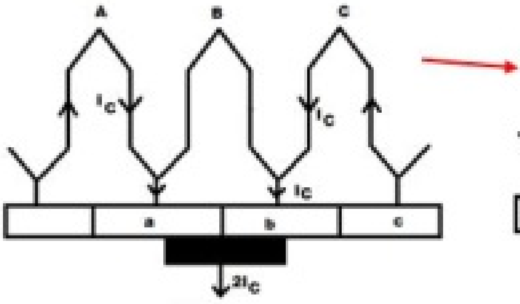


FIG- 3

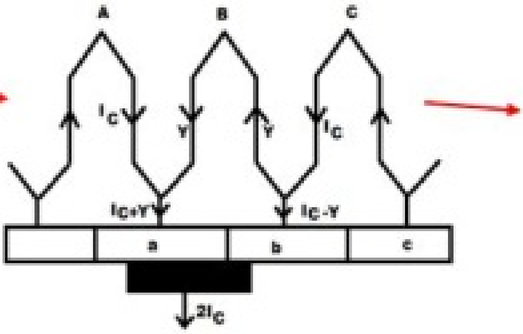


FIG-4

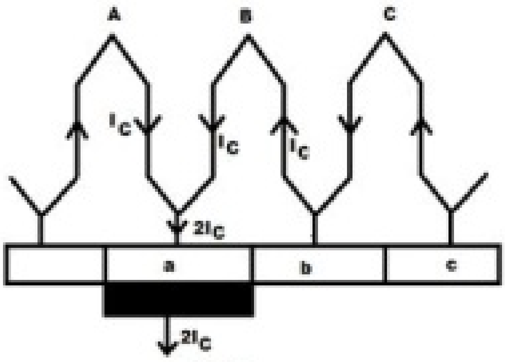


FIG- 5