ELECTRICAL TECHNOLOGY (15A02306)

LECTURE NOTES

B.TECH

(II-YEAR & I-SEM)

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II B.Tech I-Sem (E.C.E) **T Tu C**

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(15A02306) ELECTRICAL TECHNOLOGY

Objective:

Electrical Technology contains Single phase transformers, Induction motors, DC generators and motors which are widely used in industry are covered and their performance aspects will be studied.

UNIT- I DC GENERATORS

D.C. Generators – Principle of Operation – Constructional Features – E. M.F Equation– Numerical Problems – Methods of Excitation – Separately Excited and Self Excited Generators – Build-Up of E.M.F - Critical Field Resistance and Critical Speed - Load Characteristics of Shunt, Series and Compound Generators- Applications

UNIT – II D.C. MOTORS

D.C Motors – Principle of Operation – Back E.M.F. –Torque Equation – Characteristics and Application of Shunt, Series and Compound Motors-Speed Control of D.C. Motors: Armature Voltage and Field Flux Control Methods. Three Point Starter-Losses – Constant & Variable Losses – Calculation of Efficiency - Swinburne's Test.

UNIT-III SINGLE PHASE TRANSFORMERS

Single Phase Transformers - Constructional Details- Emf Equation - Operation on No Load and on Load - Phasor Diagrams-Equivalent Circuit - Losses and Efficiency-Regulation-OC and SC Tests – Sumpner's Test - Predetermination of Efficiency and Regulation.

UNIT-IV 3-PHASE INDUCTION MOTORS

Polyphase Induction Motors-Construction Details of Cage and Wound Rotor Machines- - Principle of Operation – Slip- Rotor Emf and Rotor Frequency - Torque Equation- Torque Slip Characteristics.

UNIT – V SYNCHRONOUS MACHINES

Principle And Constructional Features of Salient Pole and Round Rotor Machines – E.M.F Equation- Voltage Regulation by Synchronous Impedance Method- Theory of Operation of Synchronous Motor.

TEXT BOOKS:

1. Electric Machines –by I.J.Nagrath & D.P.Kothari,Tata Mc Graw Hill, 7th Edition.2005

2. Basic Electrical Engineering –By T.K.Nagasarkar and M.S. Sukhija Oxford University Press.

REFERENCE BOOKS:

1. Electrical and Electronic Technology, Hughes, Pearson Education.

2. Electrical Machines, P. S. Bimbhra, Khanna Publishers, 2011.

3. Basic Electrical Engineering, 2nd Edition, V.N. Mittle and Aravind Mittal, Mc Graw hill Education, 2006.

Unit 1

Principle of operation of dc generator, Emf equation of dc generators, different types of dc generator,Internal external characteristics of dc generators, Construction of dc machine

1.Derive the emf equation of DC generator ? (7 M)

Emf equation for dc generator

The derivation of EMF equation for DC generator has two parts:

1. Induced EMF of one conductor 2.Induced EMF of the generator

Derivation for Induced EMF of One Armature Conductor

For one revolution of the conductor,

Let,

Φ = Flux produced by each pole in weber (Wb) and

P = number of poles in the DC generator.

therefore, Total flux produced by all the poles = ø*p

And,

Time taken to complete one revolution = 60/N

Where,

N = speed of the armature conductor in rpm.

Now,according to Faraday's law of induction, the induced emf of the armature conductor is denoted by "e" which is equal to rate of cutting the flux.

Therefore,

$$e = -\frac{d\phi}{} \quad \text{and} \quad = \frac{total\ flux}{take}$$

Induced emf of one conductor is

$$e = \frac{\phi P}{\frac{60}{N}} = \phi P \frac{N}{60}$$

Derivation for Induced EMF for DC Generator

Let us suppose there are Z total numbers of conductor in a generator, and arranged in such a manner that all parallel paths are always in series. Here,

Z = total numbers of conductor

A = number of parallel paths

Then,

Z/A = number of conductors connected in series

We know that induced emf in each path is same across the line Therefore,

Induced emf of DC generator

E = emf of one conductor × number of conductor connected in series.

Induced emf of DC generator is

$$e = \phi P \frac{N}{60} X \frac{Z}{A} volts$$

Simple wave wound generator

Numbers of parallel paths are only 2 = A

Therefore,

Induced emf for wave type of winding generator is

$$\frac{\phi PN}{60} X \frac{Z}{2} = \frac{\phi ZPN}{120} volts$$

Simple lap-wound generator

Here, number of parallel paths is equal to number of conductors in one path i.e. P = A Therefore,

Induced emf for lap-wound generator is

$$E_g = \frac{\phi ZN}{60} X \frac{P}{A} volt$$

Q2. ***Explain About Construction of dc machine.***

Yoke of DC Generator

Yoke 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 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.

Armature Core of DC Generator

The purpose of armature core is to hold the armature winding and provide low reluctance path for the flux through the armature from N pole to S pole. Although a DC generator provides direct current but induced current in the armature is alternating in nature. That is why, cylindrical or drum shaped armature core is build up of circular laminated sheet. In every circular lamination, slots are either die - cut or punched on the outer periphery and the key way is located on the inner periphery as shown. Air ducts are also punched of cut on each lamination for circulation of air through the core for providing better cooling.

Armature Winding of DC Generator

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.

Commutator of DC Generator

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 commutator segment is connected with corresponding armature conductor through segment riser or lug.

Brushes of DC Generator

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. As shown in figure, the brush face is placed on the commutator segment with attached to the brush holder.

Bearing of DC Generator

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.

Q3.What are the Different Methods Of Excitationof dc generators ?

An electric generator or electric motor consists of a rotor spinning in a magnetic field. The magnetic field may be produced by permanent magnets or by field coils. In the case of a machine with field coils, a current must flow in the coils to generate the field, otherwise no power is transferred to or from the rotor. The process of generating a magnetic field by means of an electric current is called ***excitation***.

For a machine using field coils, which is most large generators, the field current must be supplied, otherwise the generator will be useless. Thus it is important to have a reliable supply. Although the output of a generator can be used once it starts up, it is also critical to be able to start the

generators reliably. In any case, it is important to be able to control the field since this will maintain the system voltage.

TYPES OF EXCITATION

(1)seperately excited generator (2)self excited generator.

SELF GENERATOR IS CLASSIFIED INTO 3 TYPES.

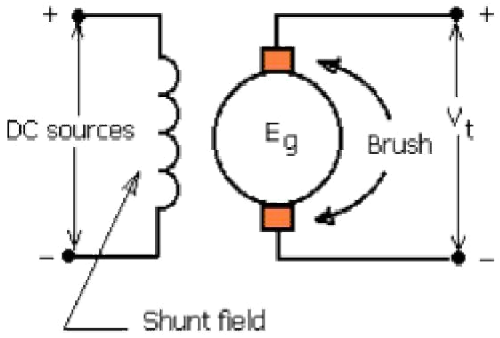
1.shunt generator. 2.series generator.
3.compound generator.

compoud generator is again classified into 2 types.

1.short shunt generator. 2.long shunt generator.

Separately excited generators.

These kind of generators has provided field exciter terminals which are external DC voltage source is supplies to produce separately magnetic field winding (shunt field) for magnetize of the generator as illustrated in figure as below.



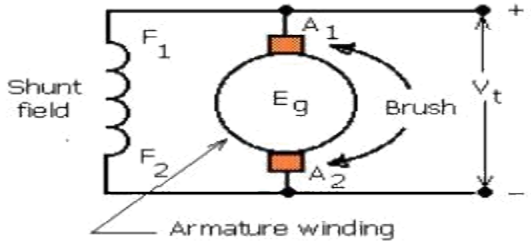
Separately excited generators.

Self excited field generators.

This type of generator has produced a magnetic field by itself without DC sources from an external. The electromotive force that produced by generator at armature winding is supply to a field winding (shunt field) instead of DC source from outside of the generator. Therefore, field winding is necessary connected to the armature winding. They may be further classified as

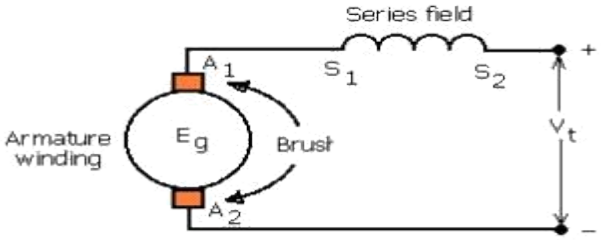
a) Shunt generator.

This generator, shunt field winding and armature winding are connected in parallel through commutator and carbon brush as illustrated in the figure below.



b) Series generator

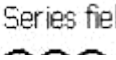
The field winding and armature winding is connected in series. There is different from shunt motor due to field winding is directly connected to the electric applications (load). Therefore, field winding conductor must be sized enough to carry the load current consumption and the basic circuit as illustrated below.

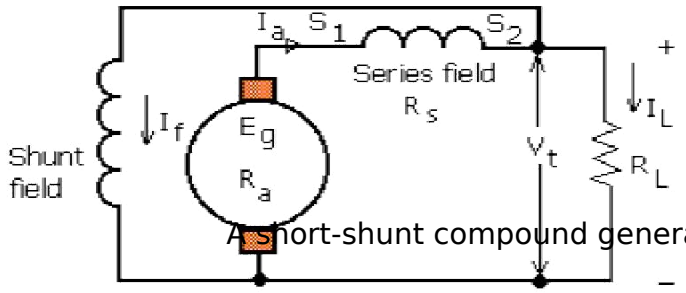


c) Compound generator

The compound generator has provided with magnetic field in combine with excitation of shunt and series field winding, the shunt field has many turns of fine wire and caries of a small current, while the series field winding provided with a few turns of heavy wire since it is in series with an

armature winding and caries the load current. There are two kinds of compound generator as illustrated in figure 5 and 6.





A short-shunt compound generator

A long-shunt compound generator

Q4.Explain O.C.C. Characteristic of separately excited generator

The generated electromotive force (EMF) is proportional to both of a magnetic density of flux per pole and the speed of the armature rotated as expression by the relation as following.

$$Eg = \kappa \varphi n$$

Where

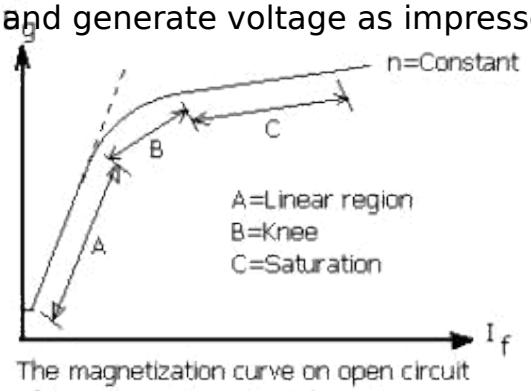
K = Constant for a specific machine

φ = The density of flux per pole

n = Speed of the armature rotation

Eg = Generator voltage

By holding the armature speed (n) at a constant value it can show that generator voltage (Eg) is directly proportional to the magnetic flux density. Which, flux density is proportionately to the amount of field current (If). The relation of field current and generate voltage as impressed by figure .



The magnetization curve on open circuit of the separately excited dc machine.

From the figure when the field current (If) is become zero a small generate voltage is produce due to a residual magnetism.

As the field current increases cause to increase generated voltage linearly up to the knee of the magnetization curve. Beyond this point by increasing the field current still further causes saturation of the magnetic structure.

Generator voltage (Eg) is also directly to the armature speed. The formula and a magnetization curve can be both impressed about this relation.

$$E_g' = E_g \times \frac{n'}{n}$$

Where

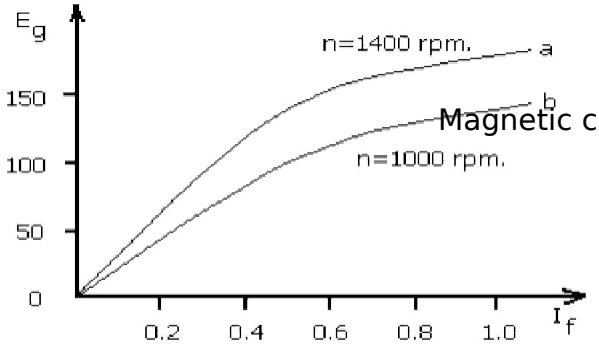
Eg = Generator voltage or the value of EMF at speed n Eg' = Generator voltage or the value of EMF at speed n’ n = Speed of the generator armature (n’ ≠ n)

Q5.Example 1:

The open circuit terminal voltage versus the field current for a separately excited DC generator with provided the following test data at revolving speed 1400 rpm as show by the table1 below.

Voltage (V)	6	30	58	114	153	179
Ampere (A)	0	0.1	0.2	0.4	0.6	0.8

Table 1 No-load characteristic for 1400 rpm and 1000 rpm



Magnetic curve for example 1

Solution

Curve (a) in figure 8 shows the characteristic at revolving speed 1400 rpm obtained by the data as show in table 1. To obtain the characteristic at 1000 rpm, is made of the relation as Eg = Kφn

For instance, at a field current of 0.4 Amp the terminal voltage is 114 volts, when the speed is reached to 1400 rpm and kept its field current constant at this value, the open circuit voltage at 1000 rpm becomes.

$$E_g = 114 \times \frac{1000}{1400} = 81.40 \text{ Volts}$$

6.Define Voltage Regulation ?

Voltage Regulation

When we add load on the generator, the terminal voltage will decrease due to

(a) The armature winding resistance is mainly of armature resistance. It is cause directly decrease in terminal voltage as following relation.

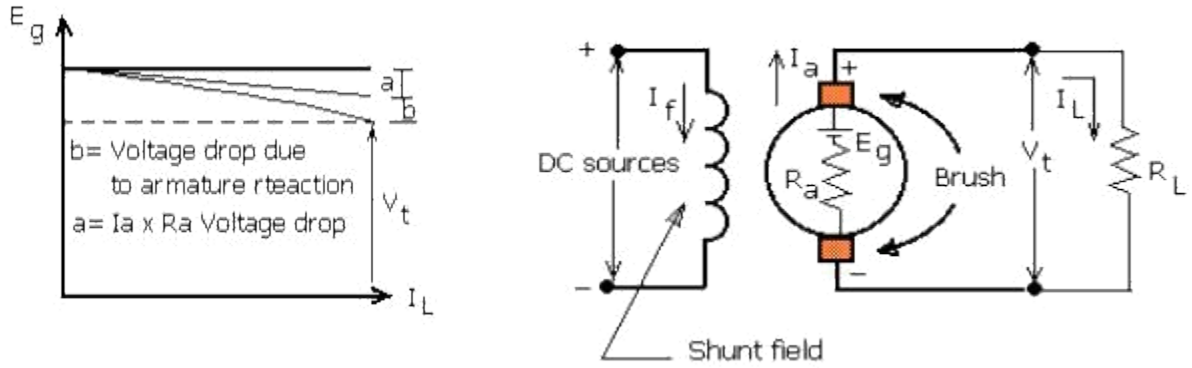
Vt = Eg - Ia Ra

Where,

Vt = Terminal or output voltage

Ia = Armature current or load current

Ra = Armature resistance



(a) Load characteristic of (b) Circuit diagram of a separately excited DC generator

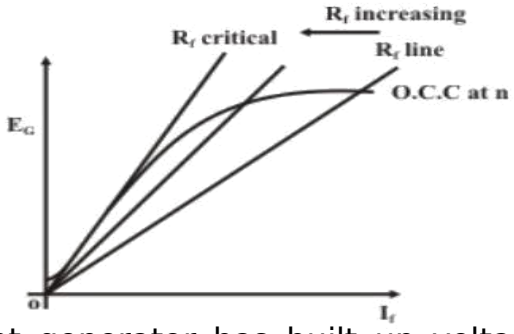
The decrease in magnetic flux due to armature reaction. The armature current establishes a magneto motive force (MMF), which it distorts to main flux, and makes result in weakened flux. We can put inter-pole between main field poles to reduce the armature reaction.

To have some measure by how much the terminal voltage change from no-load condition and on load condition, which is called “voltage regulation”.

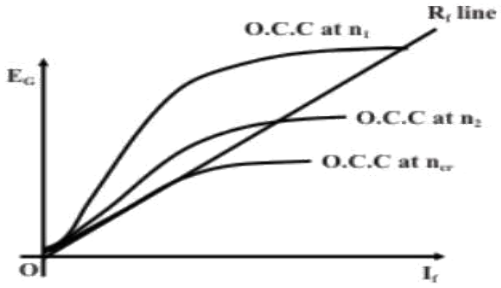
$$\text{Voltage regulation} = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100 = \%$$

7.Critical Field Resistance And Critical Speed **? 2m**

The **critical field resistance** is the maximum field circuit resistance for a given speed with which the shunt generator would excite. The shunt generator will build up voltage only if field circuit resistance is less than critical field resistance. It is a tangent to the open circuit characteristics of the generator at a given speed.



Suppose a shunt generator has built up voltage at a certain speed. Now if the speed of the prime mover is reduced without changing Rf, the developed voltage will be less as because the O.C.C at lower speed will come down (refer to figure). If speed is further reduced to a certain critical speed (ncr), the present field resistance line will become tangential to the O.C.C at ncr. For any speed below ncr, no voltage built up is possible in a shunt generator.

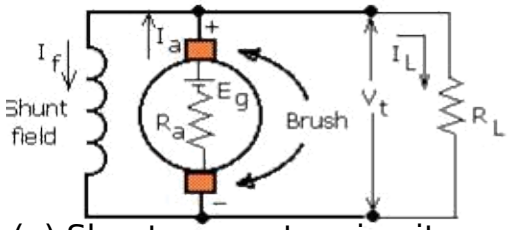


Critical Speed

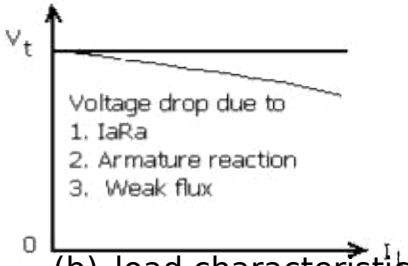
8.Clearly explain the Load characteristics of Dc Self excited

Self excited DC shunt generator

A shunt generator has its shunt field winding connected in parallel with the armature so that the machine provides it own excitation. For voltage to build up, there must be some residual magnetism in the field poles. There will be a small voltage (Er) generated.



(a) Shunt generator circuit



(b) load characteristic of shunt generator

If the connection of the field and armature winding are such that the weak main pole flux aids to the residual flux, the induced voltage will become larger. Thus more voltage applied to the main field pole and cause to the terminal voltage increase rapidly to a large value.

When we add load on the generator, the terminal voltage will decrease due to.

a) The armature winding resistance
b) The armature reaction
b) The weakened flux due to the connection of the generator to aids or oppose to the residual

Example: A shunt generator has field resistance of 60 ohms. When the generator delivers 60 kw the terminal voltage is 120 volts, while the generated EMF is 135 volts. Determine

a) The armature circuit resistance

b) The generated EMF when the output is 20 kw and the terminal voltage is 125 volts.

Solution

a) The circuit diagram when delivering 60 kw is as show in figure 11 the load current is

$$I_L = \frac{60{,}000 \text{ watts}}{120 \text{ volts}} = 500 \text{ Amperes.}$$

The field current supplied by the armature is

$$I_f = \frac{120 \text{ volts}}{60 \text{ ohms}} = 2 \text{ Amperes}$$

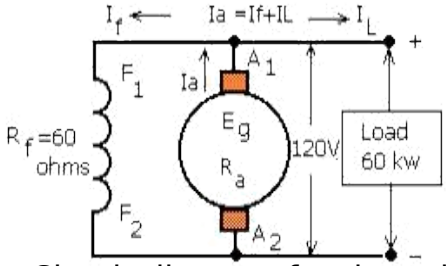
Therefore,

$$I_A = I_f + I_L = 500A + 2A$$
$$= 502 \text{ Amperes.}$$

Since,

$$V_t = E_g - I_a R_a$$

$$R_a = \frac{E_g - V_t}{I_a} = \frac{135 - 120}{52} = 0.28 \text{ Ohms.}$$



Circuit diagram for the solution of example 3

b) For a load of 20 kw when the terminal voltage is 135 volts, therefore the load current

$$I_L = \frac{20{,}000 \text{ watts}}{135 \text{ volts}} = 148.1 \text{ Amperes.}$$

And the field current is

$$I_f = \frac{135 \text{ volts}}{60 \text{ ohms}} = 2.25 \text{ Amperes}$$

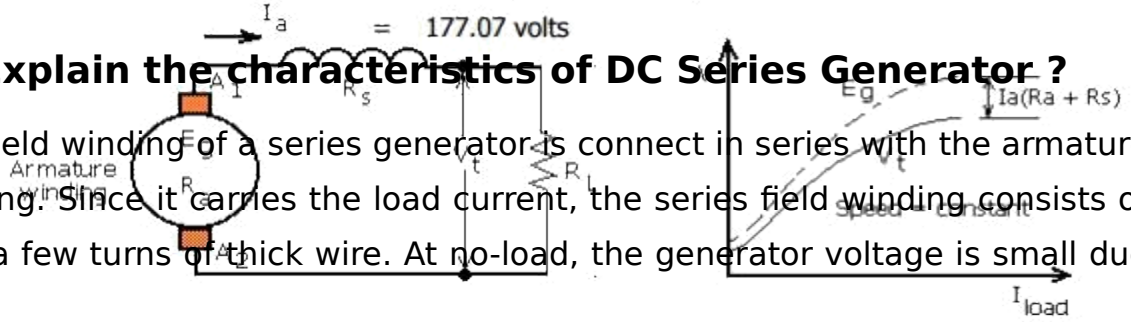
$$I_a = 148 + 2.25 = 150.25 \text{ Amperes}$$

$$E_g = V_t + I_a R_a$$

$$= 135 + (150.25 \times 0.28)$$

$$= 177.07 \text{ volts}$$

10.Explain the characteristics of DC Series Generator ?



The field winding of a series generator is connect in series with the armature winding. Since it carries the load current, the series field winding consists of only a few turns of thick wire. At no-load, the generator voltage is small due

to residual field flux only. When a load is added, the flux increase, and so does the generated voltage.

(a) Circuit diagram of series generator

(b) load characteristics

Figure shows the load characteristic of a series generator driven at a certain speed. The dash line indicated the generated EMF of the same machine with the armature opencircuited and the field separated excited. The different between the two curves is simply the voltage drop (IR) in the series field and armature winding.

$$V_t = Eg - Ia\ Ra + Rf$$

Where

Rf = The series field winding resistance

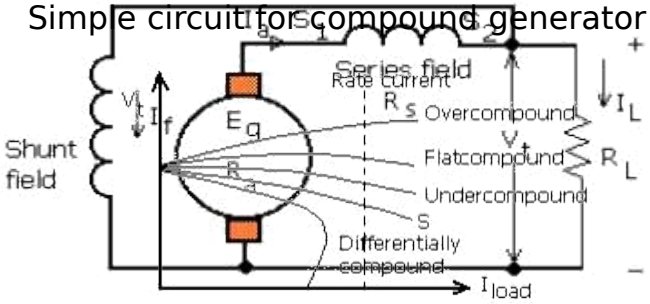
Ra = The armature winding resistance

The series generators are obviously not suited for applications requiring good voltage regulation. Therefore, they have been used very little and only in special applications for example, as voltage booster. The generator is placed in series with a supply line. When the current consumption is increase, the generated voltage of the series machine goes up because the magnetic field current is increases.

11.Explain the Characteristics of DC Compound generator ? 10M

The compound generator has both a shunt and a series winding. The series field winding usually wound on the top of a shunt field. The two winding are usually connected such that their ampere-turns act in the same direction. As such the generator is said to be cumulatively compound.

Simple circuit for compound generator



Terminal voltage characteristic of compound generator

(a) Curve s is represent the terminal voltage characteristic of shunt field winding alone. Under-compound, this condition the addition of series field winding too short it is cause the terminal voltage no rise to certain value and reduce while increasing in load current.

(b) Flat compound by increasing the number of a series field turns. It is cause to rise up in terminal voltage and when no-load and full load condition a terminal voltage is made nearly same value or equal.

(c) Over-compound, if the number of series field turns is more than necessary to compensated of the reduce voltage. In this case while a full load condition a terminal voltage is higher than a no-load voltage. Therefore over-compound generator may use where load is at some distance from generator. Voltage drop in the line has compensated by used of an over-compound generator.

(d) If a reversing the polarity of the series field occur this cause to the relation between series field and shunt field, the field will oppose to each other more and more as the load current increase. Therefore terminal voltage will drop, such generator is said to be a differentially compound.

The compound generator are used more extensively than the other type of dc generator because its design to have a wide variety of terminal voltage characteristics.

12. Define Machine Efficiency ? 2m

$$\text{Efficiency} = \frac{\text{Output power}}{\text{Input power}} \times 100\% \quad \text{or}$$

$$\text{Efficiency} = \frac{\text{Output power}}{\text{Input power} + \text{losses}}$$

The efficiency of any machine is the ratio of the ratio of the output power to the input power. The input power is provided by the prime mover to drive the generator. Because part of the energy delivered to the generator is

converted into heat, it represents wasted energy. These losses are generally minimized in the design stage; however, some of these losses are unavoidable.

13. Clearly Explain about Different Losses of a Dc Machine ?

The losses of generators may be classified as

1) Copper losses
   The copper losses are present because of the resistance of the windings. Currents flowing through these windings create ohmic losses. The windings that may be present in addition to the (I2 R) armature winding are the field windings, inter-pole and compensate windings.

2) Iron losses
   As the armature rotates in the magnetic field, the iron parts of the armature as well as the conductors cut the magnetic flux. Since iron is a good conductor of electricity, the EMF s induced in the iron parts courses to flow through these parts. These are the eddy currents. Another loss occurring in the iron is due to the Hysteresis loss is present in the armature core.

   Other rotational losses consist of 3.1 bearing friction loss

   3.2 friction of the rushes riding on the commutator

   3.3 windage losses

Windage losses are those associated with overcoming air friction in setting up circulation currents of air inside the machine for cooling purposes. These losses are usually very small

14.Write a brief notes on Applications Of Dc Generators ? 10M

Applications of Separately Excited DC Generators

These types 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 are 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.

Applications of Series Wound DC Generators

These types of generators are restricted for the use of power supply because of their increasing terminal voltage 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. 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 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.

==========******* THE END ********==========

UNIT-II

DC MOTORS

1.Explain the Principle of operation of Dc motor ?

Consider a coil in a magnetic field of flux density B (figure). When the two ends of the coil are connected across a DC voltage source, current I flows through it. A force is exerted on the coil as a result of the interaction of magnetic field and electric current. The force on the two sides of the coil is such that the coil starts to move in the direction of force.

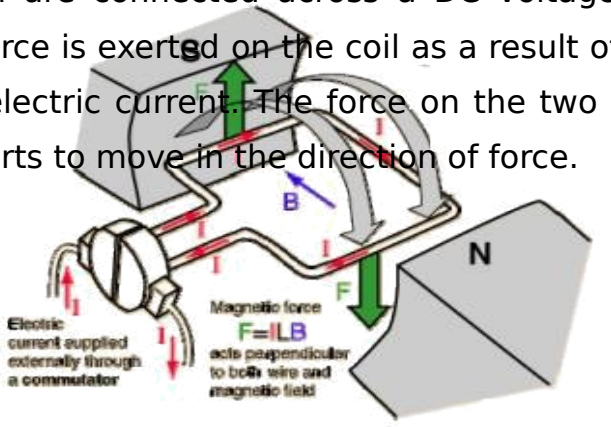


Fig.1. Torque production in a DC motor

In an actual DC motor, several such coils are wound on the rotor, all of which experience force, resulting in rotation. The greater the current in the wire, or the greater the magnetic field, the faster the wire moves because of the greater force created.

At the same time this torque is being produced, the conductors are moving in a magnetic field. At /dt) as shown inϕdifferent positions, the flux linked with it changes, which causes an emf to be induced (e = d figure 5. This voltage is in opposition to the voltage that causes current flow through the conductor and is referred to as a counter-voltage or back emf.

Fig.2. Induced voltage in the armature winding of DC motor

The value of current flowing through the armature is dependent upon the difference between the applied voltage and this counter-voltage. The current due to this counter-voltage tends to oppose the very cause for its production according to Lenz's law.It results in the rotor slowing down. Eventually, the rotor slows just enough so that the force created by the magnetic field (F = Bil) equals the load force applied on the shaft. Then the system moves at constant velocity.

2.Deduce the formula for Different Torques in DC motor ? 10M

Torque Developed

The turning or twisting moment of a force about an axis is called torque. It is measured by the product of the force and the radius at which this force acts.

Consider a pulley of radius meter acted upon by a circumferential force of newton which causes it to rotate at rpm.

Armature torque of a motor

Let T_a be the torque developed by the armature of a motor running at N rps. If T_a is in N-m, then

power developed $= T_a \times 2\pi N$ watt

We also know that electrical power converted into mechanical power in the armature $= E_b I_a$ watt.

Comparing above equations, we get $T_a \times 2\pi N = E_b I_a$

After simplification, if N in rps, $T_a = \dfrac{E_b I_a}{2\pi N}$

If N is in rpm, then $T_a = 9.55 \dfrac{E_b I_a}{N}$ N-m

Also, $T_a = 0.159 \phi Z I_a \times (P/A)$ N-m

Shaft torque

The whole of the armature torque, as calculated above, is not available for doing useful work, because of iron and friction losses in the motor. The torque which is available for doing useful work is known as shaft torque T_{sh}. The motor output is given by

Output $= T_{sh} \times 2\pi N$ watt provided T_{sh} is in N-m and N in rps.

Hence, $T_{sh} = \dfrac{Output_in_watts}{2\pi N}$, if N is in rps

And, if N is in rpm, then $T_{sh} = \dfrac{Output_in_watts}{2\pi N/60} = 9.55 \dfrac{Output}{N}$

What is back emf ? 2 m

Induced Counter-voltage (Back emf):

Due to the rotation of this coil in the magnetic field, the flux linked with it changes at different positions, which causes an emf to be induced (refer to figure 2).

The induced emf in a single coil, $e = d\phi_c/dt$

Since the flux linking the coil, $\phi c = \phi \text{Sin}\omega$

Induced voltage , e =
$\omega \phi \cos\omega t$ (1)

Note that equation (4) gives the emf induced in one coil. As there are several coils wound all around the rotor, each with a different emf depending on the amount of flux change through it, the total emf can be obtained by summing up the individual emfs.

The total emf induced in the motor by several such coils wound on the rotor can be obtained by integrating equation (4), and expressed as:

$$Eb = K \phi \omega_m \qquad (2)$$

where K is an armature constant, and is related to the geometry and magnetic properties of the motor, and ω_m is the speed of rotation.

The electrical power generated by the machine is given by:

$$Pdev = Eb\ Ia = K\phi\omega_m$$
I_a (3)

Draw the equivalent circuit of dc motor ? 2m

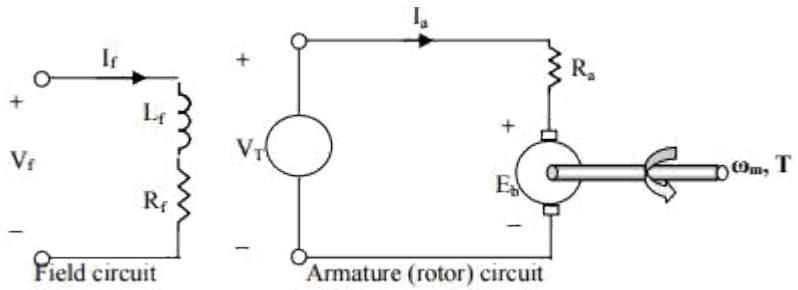


Fig.1. DC motor representation

Explain the importance of Counter EMF in DC motor ? 10m

When voltage is applied to dc motor, current will flow into the positive brush through the commutator into the armature winding. The motor armature winding is identical to the generator armature winding. Thus the conductors on the north field poles are carry current in one direction, while all conductors on the south field poles carry the current in opposite direction. When the armature carry current it will produce a magnetic field around the conductor of it own which interact with the main field. It is cause to the force developed on all conductors and tending to turn the armature.

The armature conductors continually cut through this resultant field. So that voltages are generated in the same conductors that experience force action. When operating the motor is simultaneously acting as generator. Naturally motor action is stronger than generator action.

Although the counter EMF is opposite with the supplied voltage, but it cannot exceed to applied voltage. The counter EMF is serves to limit the current in an armature winding. The armature current will be limited to the value just sufficient to take care of the developed power needed to drive the load.

In the case of no load is connected to the shaft. The counter EMF will almost equal to the applied voltage. The power develops by the armature in this case is just the power needed to overcome the rotational losses. It's mean that the armature current IA is controlled and limited by counter EMF therefore

$$Ia = \frac{VL - Ea}{Ra}$$

Where:

VL = Line voltage across the armature winding

Ra = Resistance of the armature winding

Ea = Induced EMF or generated voltage

Ia = Armature current

Since, EA is induced or generated voltage it is depend on the flux per pole and the speed of the armature rotate (n) in rpm.

Therefore

$$E_a = K \varphi n$$

Where:

K = the constant value depending on armature winding and number of pole of machine.

φ = Rotation of the armature

And,

$$K = \frac{Z \times P}{a}$$

Where:

Z = Total number of conductor in the armature winding

a = Number of parallel circuit in the armature winding between positive and negative brushes. For wave wound armature “a” = 2

Lap wound armature “a” = P

Distinguish armature and field speed control methods ? 10 M

Speed control of DC motor Many applications require the speed of a motor to be varied over a wide range. One of the most attractive features of DC motors in comparison with AC motors is the ease with which their speed can be varied.

We know that the back emf for a separately excited DC motor:

$$E_b = K \phi \omega_m = V_T - I_a R_a$$

Rearranging the terms,

$$\text{Speed } \omega_m = (V_T - I_a R_a)/K \phi$$

From the above equation, it is evident that the speed can be varied by using any of the following methods:

- Armature voltage control (By varying VT)
- . Field Control (By Varying ϕ)
- Armature resistance control (By varying Ra)

Armature voltage control

This method is usually applicable to separately excited DC motors. In this method of speed control, Ra and ϕ are kept constant.In normal operation, the drop across the armature resistance is small compared to Eb and therefore: $E_b \cong V_T$

Since, Eb = Kø ω_m

Angular speed can be expressed as:

$$\omega_m = V_T / K\phi \qquad (8)$$

From this equation, If flux is kept constant, the speed changes linearly with VT.

- As the terminal voltage is increased, the speed increases and vice versa. The relationship between speed and applied voltage is shown in figure 8. This method provides smooth variation of speed control.

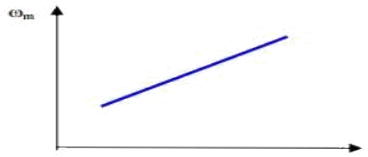


Fig.8.Variation of speed with applied voltage

Field Control , (ϕ)

In this method of speed control, Ra and VT remain fixed.

Therefore, from equation (7):

$$\omega_m \propto I/\phi$$

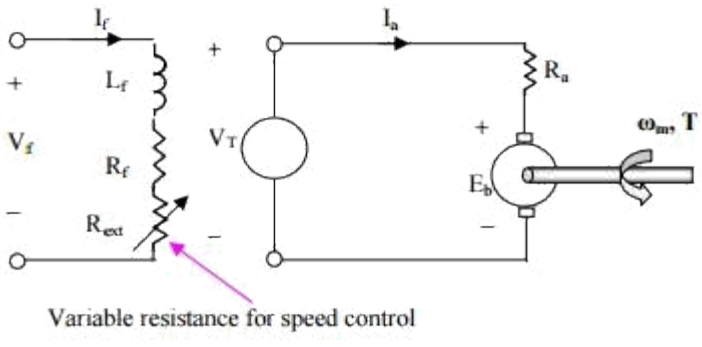
Assuming magnetic linearity, $\phi \propto$ If

$$\text{(OR)} \quad \omega_m \propto I/I_F \qquad (9)$$

i.e., Speed can be controlled by varying field current If.

- The field current can be changed by varying an adjustable rheostat in the field circuit (as shown in figure 9).

- By increasing the value of total field resistance, field current can be reduced, and therefore speed can be increased.



The relationship between the field winding current and angular speed is shown in figure 10

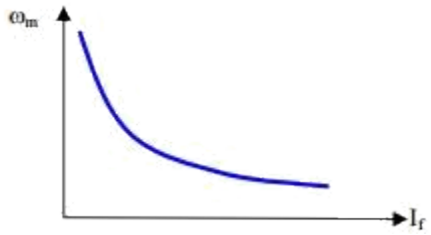


Fig.10: Variation of speed with field current

Armature Resistance Control

The voltage across the armature can be varied by inserting a variable resistance in series with the armature circuit.

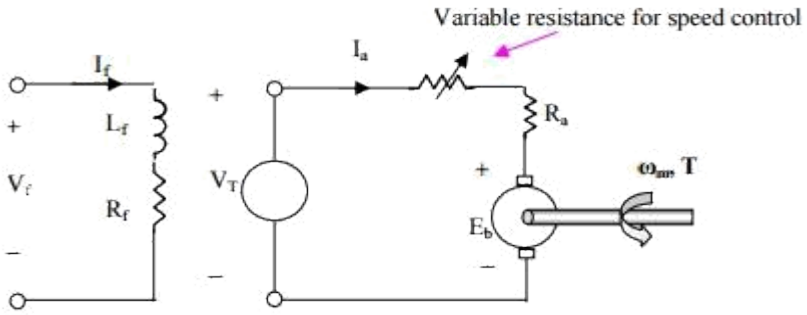


Fig.11. Armature resistance method for speed control

From speed-torque characteristics , we know that:

$$T_{dev} = \frac{K\phi}{R_a}(V_T - K\phi\omega_m)$$

For a load of constant torque V_T and ϕ are kept constant, as the armature resistance Ra is increased, speed decreases. As the actual resistance of the armature winding is fixed for a given motor, the overall resistance in the armature circuit can be increased by inserting an additional variable resistance in series with the armature. The variation if speed with respect to change in this external resistance is shown in figure 12. This method provides smooth control of speed.

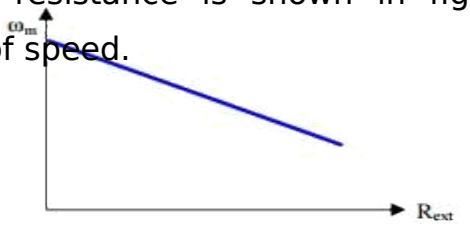


Fig:Variation of speed with external armature resistance

DC Shunt Motor speed control

All three methods described above can be used for controlling the speed of DC Shunt Motors.

Series Motor speed control

The speed is usually controlled by changing an external resistance in series with the armature.

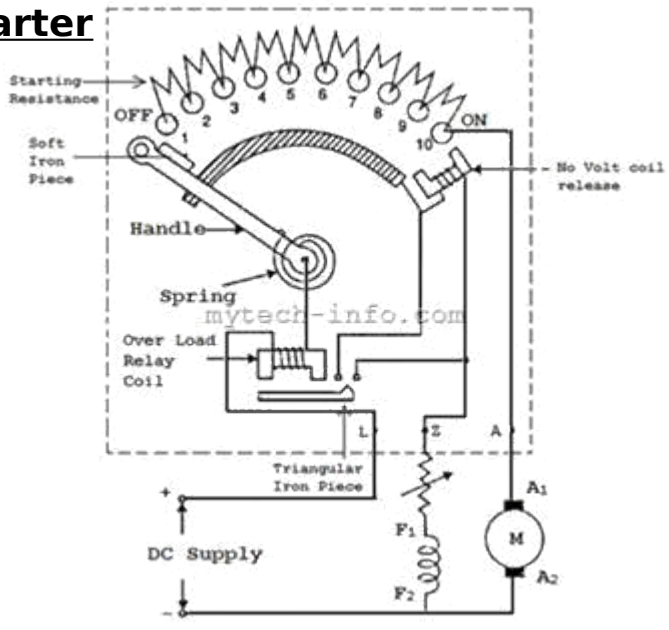
The other two methods described above are not applicable to DC series motor speed control.

Write applications of DC motors? 2 M

d.c. shunt motor	lathes,fans,pumps disc and band saw drive requiring moderate torques.
d.c. series motor	Electric traction, high speed tools
d.c. compound motor	Rolling mills and other loads requiring large momentary toques.

Explain the operation of 3-point starter ? 10M

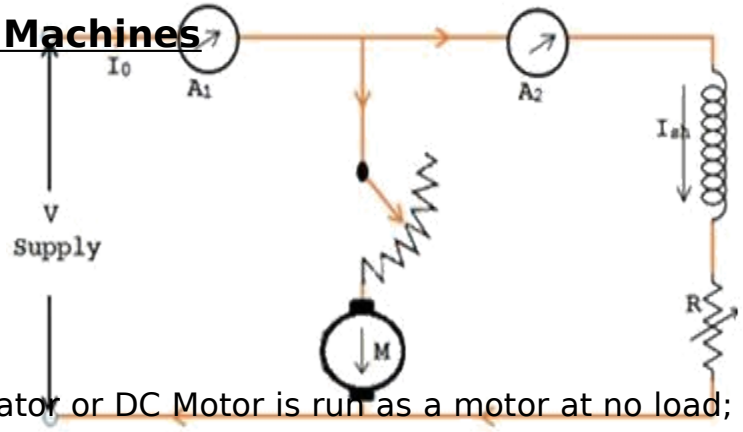
Three point starter



The figure above shows that typical representation diagram of a 3 point starter for DC shunt motors with its protective devices. It contains 3 terminals namely L, Z, & A; hence named 3 point starter. The starter is made up of of starting resistances divided into many section and which are connected in series within the armature. The each tapping point on the starting resistances is carried out to a no. of studs. The starter 3 terminals L,Z & A are connected to the positive terminal of line, shunt field and armature terminal of motor respectively. The remaining terminal of the shunt and armature are connected to the negative line terminal. The No volt coil release is connected in series with field winding. The handle one end is connected to the L terminal by means of over load release coil. Then another end of handle travels against the twisting spring & make touching base with every single stud in the course of starting operation, tripping out the starting resistance as it moves above every stud in clockwise.

Clearly explain about swimburns test how will u calculate efficiency of a dc machine .discuss merits and demerits ? 10 M

Swinburne's Test for DC Machines



In this technique, the DC Generator or DC Motor is run as a motor at no load; with that losses of the DC machines are determined. When the losses of DC machine well-known, then we can find the efficiency of a DC machine in advance at any desired load. In DC machines this test is applicable only throughout the flux is constant at all load (DC Shunt machine and DC Compound Machine). This test maintains of two steps;

Determination of Constant Losses:

On no load the DC machine run as a motor with the supply voltage is varied to the normal rated voltage. With the use of the field regulator R the motor speed is varied to run the rated speed which is shown in the figure.

Let

V = Supply Voltage

I_0 = No load current read by A_1

I_{sh} = Shunt Field current ready by A_2

No load armature current $I_{ao} = I_0 – I_{sh}$

No load Input power to motor = VI_0

No load Input power to motor = VI_{a0}

$$= V (I_0 – I_{sh})$$

As the output power is nil, the no loads input power to the armature provides Iron loss, armature copper loss, friction loss and windage loss.

Constant loss W_c = Input power to Motor – Armature copper loss

$$W_c = VI_0 – (I_0 – I_{sh}^2 R_a)$$

As the constant losses are identified, the efficiency of the DC machine at any loads can be determined. Suppose it is desired to determine the DC machine efficiency at no load current. Then, Armature current $I_a = I-I_{sh}$ (For Motoring)

$$I_a = I+I_{sh} \text{ (For Generating)}$$

To find the Efficiency when running as a motor:

Input power to motor = VI

Armature copper loss $=I_a^2R_a = (I-I_{sh}^2R_a)$

Constant Loss = W_c

Total Loss = $(I-I_{sh}2R_a)+W_c$

Motor Efficiency η = (Input power – Losses)/ Input

$\eta = \{VI – (I-I_{sh}^2R_a)\} / VI$

- **<u>Condition for maximum Efficiency in DC Machine</u>**

To find the Efficiency when running as a Generator:

Output Power of Generator = VI

Armature copper loss $= I_a^2 R_a = (I + I_{sh}^2 R_a)$

Constant Loss = W_c

Total Loss = $(I + I_{sh}^2 R_a) + W_c$

Motor Efficiency η= Output power/ (Output power + Losses)

$\eta = VI / \{VI + (I + I_{sh}^2 R_a) + W_c\}$

Merits:

- Since this test is no load test, power required is less. Hence the cost is economic.
- The efficiency of the machine can be found very easily, because the constant losses are well known.
- This test is appropriate.

Demerits:

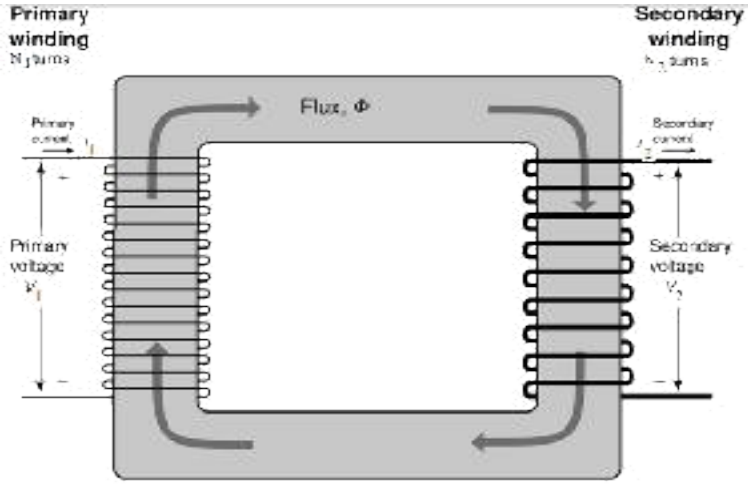
- When the DC machine is loaded, this test does not deliberate the stray load loss that occurs.
- Using this method we cannot check the DC machine performances at full load.

UNIT-III

SINGLE PHASE TRANSFORMERS

Constructional Details- Emf Equation -Operation on No Load and on Load - -Equivalent Circuit -Losses and Efficiency-Regulation-OC and SC Tests -Sumpner's Test -Predetermination of Efficiency and Regulation.

PRINCIPLE OF OPERATION OF A SINGLE PHASE TRANSFORMER



A single phase transformer works on the principle of mutual induction between two magnetically coupled coils. When the primary winding is connected to an alternating voltage of r.m.s value, V1 volts, an alternating current flows through the primary winding and setup an alternating flux ϕ, in the material of the core. This alternating flux ϕ, links not only the primary windings but also

the secondary windings. Therefore, an e.m.f e1 is induced in the primary winding and an e.m.f e2 is induced in the secondary winding, e1 and e2 are given:

$$e1 = -N1 \frac{d\varphi}{dt} \text{ --------- (a)}$$

$$e2 = -N2 \frac{d\varphi}{dt} \text{ ----------(b)}$$

If the induced e.m.f is e1 and e2 are represented by their rms values E1 and E2 respectively, then

$$E1 = -N1 \frac{d\varphi}{dt} \text{ --------- (1)}$$

$$E2 = -N2 \frac{d\varphi}{dt} \text{ ---------- (2)}$$

$$\text{Therefore, } \frac{E2}{E1} = \frac{N2}{N1} = k \text{ ---------- (3)}$$

K is known as the transformation ratio of the transformer. When a load is connected to the secondary winding, a current I2 flows through the load, V2 is the terminal voltage across the load. As the power transfered from the primary winding to the secondary winding is same, Power input to the primary winding = Power output from the secondary winding.

$E_{P1} = E_{P2}$

(Assuming that the power factor of the primary is equal to the secondary).

Or, $\frac{E2}{E1} = \frac{I1}{I2} = k$ ---- (4)

From eqn (3) and (4), we have

$$\frac{E2}{E1} = \frac{N2}{N1} = \frac{I1}{I2} = k \text{ ---------- (5)}$$

The directions of emf's E1 and E2 induced in the primary and secondary windings are such that, they always oppose the primary applied voltage V1.

Deduce EMF equation of a Transformer ? 10M

EMF Equation of a transformer:

Consider a transformer having,

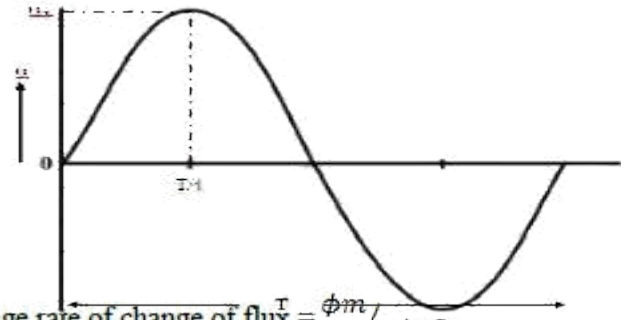
N1 =Primary turns

N2 = Secondary turns

Φm = Maximum flux in the core

Φm = Bm × A webers

f= frequency of ac input in hertz (Hz)



Therefore, average rate of change of flux $= \phi m / 1/4f$

$= 4f\varphi_m$

We know that, the rate of change of flux per turn means that the induced emf in volts.

Therefore, average emf induced per turn $= 4f\varphi_m$ volts.

Since the flux is varying [illegible] by multiplying the average value by the form factor.

Therefore, rms value of emf induced per turns $= 1.11 \times 4f \times \varphi_m$

$= 4.44f\varphi_m$ volts

The rms value of induced emfin the entire primary winding = (induced emf per turn) × number of primary turns

i.e, $E_1 = 4.44f\varphi_m \times N_1 = 4.44fB_m \times A \times N_1$

Similarly;

$E_2 = 4.44\ f\ \varphi_m \times N_2 = 4.44\ f\ B_m \times A \times N_2$

Clearly explain the operation of transformer at NO and ON load ? 10M

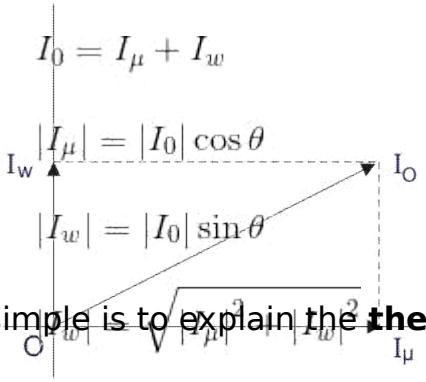
TRANSFORMER ON NO-LOAD

Theory of Transformer On No-load, and Having No Winding Resistance and No Leakage Reactance of Transformer

Let us consider one electrical transformer with only core losses, which means, it has only core losses but no copper loss and no leakage reactance of transformer. When an alternating source is applied in the primary, the source will supply the current for magnetizing the core of transformer.

But this current is not the actual magnetizing current, it is little bit greater than actual magnetizing current. Actually, total current supplied from the source has two components, one is magnetizing current which is merely utilized for magnetizing the core and other component of the source current is consumed for compensating the core losses in transformer. Because of this core loss component, the source current in **transformer on no-load** condition supplied from the source as source current is not exactly at 90° lags of supply voltage, but it lags behind an angle θ is less than 90°. If total current supplied from source is I_o, it will have one component in phase with supply voltage V_1 and this component of the current I_w is core loss component. This component is taken in phase with source voltage, because it is associated with active or working losses in transformer. Other component of the source current is denoted as I_μ. This component produces the alternating magnetic flux in the core, so it is watt-less; means it is reactive part of the transformer source current. Hence I_μ will be in quadrature with V_1 and in phase with alternating flux Φ.

Hence, total primary current in **transformer on no-load** condition can be represented as



Excitation Current of Transformer

Now you have seen how simple is to explain the **theory of transformer** in no-load

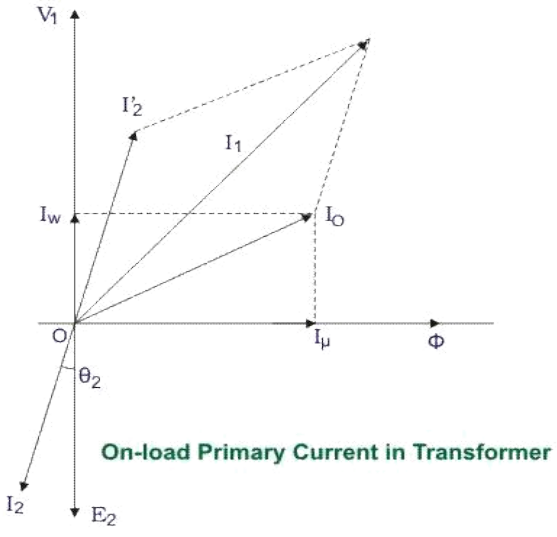
TRANSFORMER ON LOAD

Theory of Transformer On Load But Having No Winding Resistance and Leakage

Reactance

Now we will examine the behavior of above said **transformer on load**, that means load is

connected to the secondary terminals. Consider, transformer having core loss but no copper loss and leakage reactance. Whenever load is connected to the secondary winding, load current will start to flow through the load as well as secondary winding. This load current solely depends upon the characteristics of the load and also upon secondary voltage of the transformer. This current is called secondary current or load current, here it is denoted as I_2. As I_2 is flowing through the secondary, a self mmf in secondary winding will be produced. Here it is N_2I_2, where, N_2 is the number of turns of the secondary winding of transformer.



On-load Primary Current in Transformer

This mmf or magneto motive force in the secondary winding produces flux φ_2. This φ_2 will oppose the main magnetizing flux and momentarily weakens the main flux and tries to reduce primary self induced emf E_1. If E_1 falls down below the primary source voltage V_1, there will be an extra current flowing from source to primary winding. This extra primary current I_2' produces

extra flux φ' in the core which will neutralize the secondary counter flux φ_2. Hence the main magnetizing flux of core, Φ remains unchanged irrespective of load.

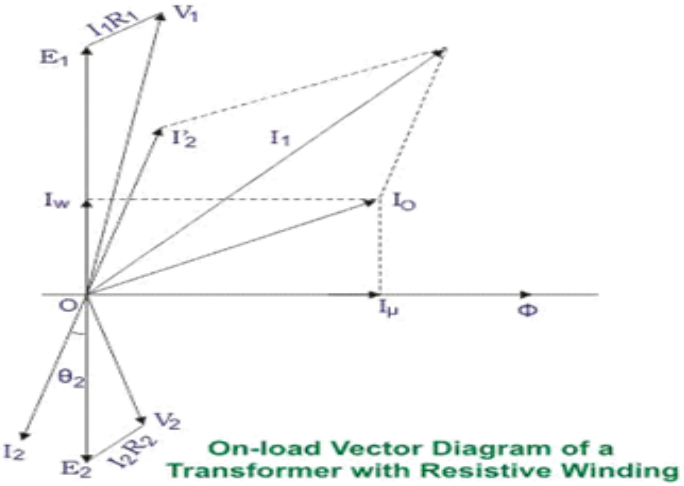
So total current, this transformer draws from source can be divided into two components, first one is utilized for magnetizing the core and compensating the core loss i.e. I_o. It is no-load component of the primary current. Second one is utilized for compensating the counter flux of the secondary winding. It is known as load component of the primary current. Hence total no load primary current I_1 of a electrical power transformer having no winding resistance and leakage reactance can be represented as follows

$$I_1 = I_0 + I_2'$$

Where θ_2 is the angle between Secondary Voltage and Secondary Current of transformer. Now we will proceed one further step toward more practical aspect of a transformer.

Transformer On Load, With Resistive Winding, But No Leakage Reactance

Now, consider the winding resistance of transformer but no leakage reactance. So far we have discussed about the transformer which has ideal windings, means winding with no resistance and leakage reactance, but now we will consider one transformer which has internal resistance in the winding but no leakage reactance. As the windings are resistive, there would be a voltage drop in the windings.



On-load Vector Diagram of a Transformer with Resistive Winding

We have proved earlier that, total primary current from the source on load is I_1. The voltage drop in the primary winding with resistance, R_1 is R_1I_1. Obviously, induced emf across primary winding E_1, is not exactly equal to source voltage V_1. E_1 is less than V_1 by voltage drop I_1R_1.

$$V_1 = E_1 + I_1R_1$$

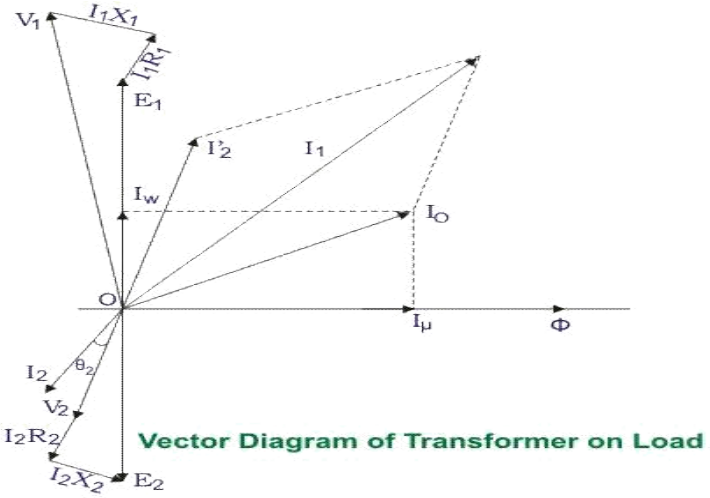
Again in the case of secondary, the voltage induced across the secondary winding, E_2 does not totally appear across the load since it also drops by an amount I_2R_2, where R_2 is the secondary winding resistance and I_2 is secondary current or load current.

$$V_1 = E_1 + I_1R_1$$

Similarly, voltage equation of the secondary side of the transformer will be

$$V_2 = E_2 - I_2R_2$$

Theory of Transformer On Load, With Resistance As Well As Leakage Reactance in Transformer Windings Now we will consider the condition, when there is leakage reactance of transformer as well as winding resistance of transformer.



Vector Diagram of Transformer on Load

Let leakage reactances of primary and secondary windings of the transformer are X_1 and X_2 respectively.

Hence total impedance of primary and secondary winding of transformer with resistance R_1 and R_2 respectively, can be represented as,

$$Z_1 = R_1 + jX_1 \ (impedance\ of\ primary\ winding)$$

$$Z_2 = R_2 + jX_2 \ (impedance\ of\ secondary\ winding)$$

We have already established the voltage equation of a **transformer on load**, with only resistances in the windings, where voltage drops in the windings occur only due to resistive voltage drop. But when we consider leakage reactances of transformer windings, voltage drop occurs in the winding not only because of resistance, it is because of impedance of transformer windings. Hence, actual voltage equation of a transformer can easily be determined by just replacing resistances R_1 & R_2 in the previously established voltage equations by Z_1 and Z_2.

Therefore, the voltage equations are,

$$V_1 = E_1 + I_1 Z_1 \ \& \ V_2 = E_2 - I_2 Z_2$$

$$V_1 = E_1 + I_1(R_1 + jX_1)$$

$$\Rightarrow V_1 = E_1 + I_1 R_1 + jI_1 X_1$$

$$V_2 = E_2 - I_2(R_2 + jX_2)$$

$$\Rightarrow V_2 = E_2 - I_2 R_2 - jI_2 X_2$$

Resistance drops are in the direction of current vector but, reactive drop will be perpendicular to the current vector as shown in the above **vector diagram of transformer**.

How u can estimated efficiency and voltage regulation of a transformer from O.C and S.C tests ? 10 M

O.C. and S.C. Tests on Single Phase Transformer

The efficiency and regulation of a transformer on any load condition and at any power factor condition can be predetermined by indirect loading

method. In this method, the actual load is not used on transformer. But the equivalent circuit parameters of a transformer are determined by conducting two tests on a transformer which are,

1.Open circuit test (O.C Test)

2.Short circuit test (S.C.Test)

The parameters calculated from these test results are effective in determining the regulation and efficiency of a transformer at any load and power factor condition, without actually loading the transformer. The advantage of this method is that without much power loss the tests can be performed and results can be obtained. Let us discuss in detail how to perform these tests and how to use the results to calculate equivalent circuit parameters.

Open Circuit Test (O.C. Test)

The experimental circuit to conduct O.C test is shown in the Fig. 1.

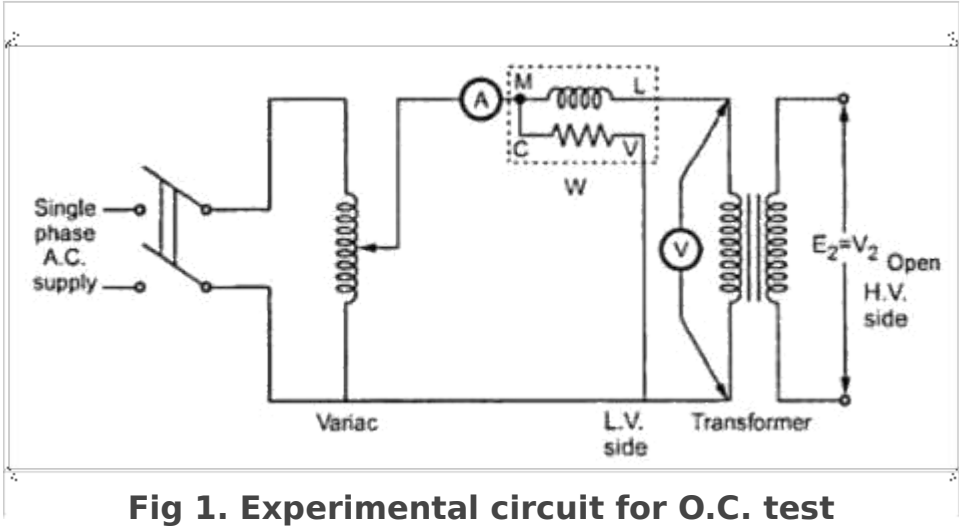


Fig 1. Experimental circuit for O.C. test

The transformer primary is connected to a.c. supply through ammeter, wattmeter and variac. The secondary of transformer is kept open. Usually low voltage side is used as primary and high voltage side as secondary to conduct O.C test.

The primary is excited by rated voltage, which is adjusted precisely with the help of a variac. The wattmeter measures input power. The ammeter measures input current. The voltemeter gives the value of rated primary voltage applied at rated frequency.

Sometimes a voltmeter may be connected across secondary to measure secondary voltage which is $V_2 = E_2$ when primary is supplied with rated voltage. As voltmeter resistance is very high, though voltmeter is connected, secondary is treated to be open circuit as voltmeter current is always negligibly small.

When the primary voltage is adjusted to its rated value with the help of variac, readings of ammeter and wattmeter are to be recorded.

Let,

V_o = Rated voltage

W_o = Input power

I_o = Input current = no load current

As transformer secondary is open, it is on no load. So current drawn by the primary is no load current I_o. The two components of this no load current are,

$$I_m = I_o \sin \Phi_o$$

$$I_c = I_o \cos \Phi_o$$

where $\cos \Phi_o$ = No load power factor

And hence power input can be written as,

$$W_o = V_o I_o \cos \Phi$$

The phasor diagram is shown in the Fig.

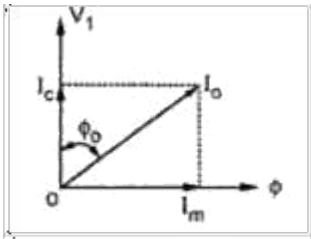


Fig.

As secondary is open, $I_2 = 0$. Thus its reflected current on primary is also zero. So we have primary current $I_1 = I_o$. The transformer no load current is always very small, hardly 2 to 4 % of its full load value. As $I_2 = 0$, secondary copper losses are zero. And $I_1 = I_o$ is very low hence copper losses on primary are also very very low. Thus the total copper losses in O.C. test are negligibly small. As against this the input voltage is rated at rated frequency hence flux density in the core is at its maximum value. Hence iron losses are at rated voltage. As output power is zero and copper losses are very low, the total input power is used to supply iron losses. This power is measured by the wattmeter i.e. W_o. Hence the wattmeter in O.C. test gives iron losses

which remain constant for all the loads.

$W_o = P_i =$ $\cos \Phi_o = W_o / (V_o I_o)$ = no load power factor

Iron losse Calculations : We know that,

Once $\cos \Phi_o$ is known we can obtain,

$W_o = V_o I_o \cos \Phi$

$I_c = I_o \cos \Phi_o$

$$\text{and} \quad I_m = I_o \sin \Phi_o$$

Once I_c and I_m are known we can determine exciting circuit parameters as,

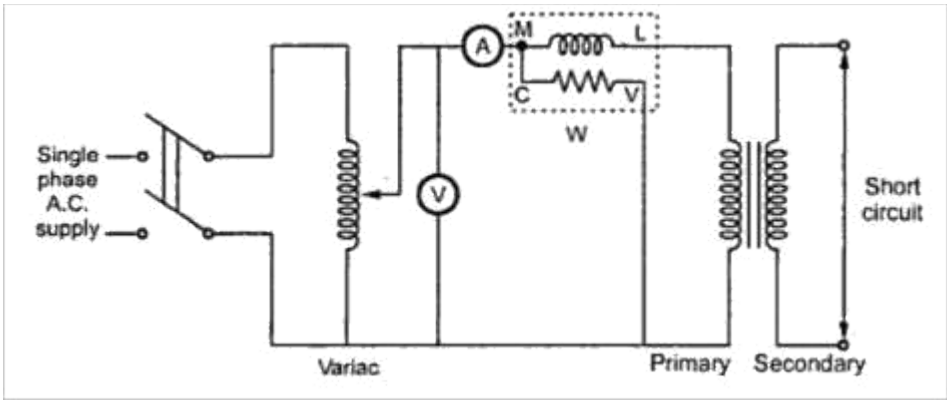
$$R_o = V_o / I_c \quad \Omega$$

$$\text{and} \quad X_o = V_o / I_m \quad \Omega$$

Key Point : The no load power factor cos Φ_o is very low hence wattmeter used must be low power factor type otherwise there might be error in the results. If the meters are connected on secondary and primary is kept open then from O.C. test we get R_o'and X_o' with which we can obtain R_o and X_o knowing the transformation ratio K.

Short Circuit Test (S.C. Test)

In this test, primary is connected to a.c. supply through variac, ammeter and voltmeter as shown in the Fig. 3.



Experimental circuit for O.C. test

The secondary is short circuited with the help of thick copper wire or solid link. As high voltage side is always low current side, it is convenient to connect high voltage side to supply and shorting the low voltage side.

As secondary is shorted, its resistance is very very small and on rated voltage it may draw very large current. Such large current can cause overheating and burning of the transformer. To limit this short circuit current, primary is supplied with low voltage which is just enough to cause rated current to flow through primary which can be observed on an ammeter. The low voltage can be adjusted with the help of variac. Hence this test is also called low voltage test or reduced voltage test. The wattmeter reading as well as voltmeter, ammeter readings are recorded.

Now the current flowing through the windings are rated current hence the total copper loss is full load copper loss. Now the voltage supplied is low which is a small fraction of the rated voltage. The iron losses are function of applied voltage. So the iron losses in reduced voltage test are very small. Hence the wattmeter reading is the power loss which is equal to full load copper losses as iron losses are very low.

$W_{sc} = (P_{cu})$ F.L. = Full load copper loss

$\therefore$

Calculations : From S.C. test readings we can write,

$$W_{sc} = V_{sc}\, I_{sc} \cos \Phi_{sc}$$

$\therefore$ $\cos \Phi sc = V_{sc}\, I_{sc} / W_{sc}$ = short circuit power factor

$$W_{sc} = I_{sc}^2\, R_{1e} = \text{copper loss}$$

$\therefore$ $R_{1e} = W_{sc} / I_{sc}^2$

while $Z_{1e} = V_{sc} / I_{sc} = \sqrt{(R_{1e}^2 + X_{1e}^2)}$

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

We know that, From O.C. test, $W_o = P_i$

From S.C. test, $W_{sc} = (P_{cu})$ F.L.

$$\therefore \quad \% \eta \text{ on full load} = \frac{V_2 (I_2)\, \text{F.L.} \cos \phi}{V_2 (I_2)\, \text{F.L.} \cos + W_o + W_{sc}} \times 100$$

Thus for any p.f. $\cos \Phi_2$ the efficiency can be predetermined. Similarly at any load which is fraction of full load then also efficiency can be predetermined as,

$$\% \eta \text{ at any load} = \frac{n \times (\text{VA rating}) \times \cos \phi}{n \times (\text{VA rating}) \times \cos \phi + W_o + n^2 W_{sc}} \times 100$$

where n = fraction of full load

$$\text{or} \qquad \% \eta = \frac{n V_2 I_2 \cos \phi}{n V_2 I_2 \cos \phi + W_o + n^2 W_{sc}} \times 100$$

where

$I_2 = n\, (I_2)$ F.L.

Calculation ofRegulation

From S.C. test we get the equivalent circuit parameters referred to primary or secondary.

The rated voltages V_1, V_2 and rated currents (I_1) F.L. and (I_2) F.L. are known for the given transformer. Hence the regulation can be determined as,

$$\% R = \frac{I_2 R_{2e} \cos\phi \pm I_2 X_{2e} \sin\phi}{V_2} \times 100$$

$$= \frac{I_1 R_{1e} \cos\phi \pm I_1 X_{1e} \sin\phi}{V_1} \times 100$$

where I_1, I_2 are rated currents for full load regulation.

For any other load the currents I_1, I_2 must be changed by fraction n.

∴ I_1, I_2 at any other load = n (I_1) F.L., n (I_2) F.L.

Question: A 5 KVA, 500/250 V, 50 Hz, single phase transformer gave the following readings,

O.C. Test : 500 V, 1 A, 50 W (L.V. side open)

S.C. Test : 25 V, 10 A, 60 W (L.V. side shorted)

Determine : i) The efficiency on full load, 0.8 lagging p.f.

ii) The voltage regulation on full load, 0.8 leading p.f.
iii) The efficiency on 60% of full load, 0.8 leading p.f.
iv) Draw the equivalent circuit referred to primary and insert all the values in it.

Solution : In both the tests, meters are on H.V. side which is primary of the transformer. Hence the parameters obtained from test results will be referred to primary.

From O.C. test, V_o = 500 V, I_o = 1 A, W_o = 50 W

∴ $\cos \Phi_o = W_o/V_o I_o = 50/(500x1) = 0.1$

$I_c = I_o \cos = 1 \times 0.1 =$ 0.1 A

$$\% \eta = \frac{(\text{VA rating}) \cos\phi_2}{(\text{VA rating}) \cos\phi_2 + P_i + (P_{cu})\text{ F. L.}} \times 100$$

∴ and $I_m = I_o \sin \Phi_o = 1 \times 0.9949 = 0.9949$ A

$$= \frac{5 \times 10^3 \times 0.8}{5 \times 10^3 \times 0.8 + 50 + 60} \times 100 = 97.32\ \%$$

$\therefore$ $R_o = V_o / I_c = 500/0.1 = 5000\ \Omega$

and $X_o = V_o/I_m = 500/0.9949 = 502.52\ \Omega$

and $W_o = P_i$ = iron losses = 50 W

From S.C. test, $V_{sc} = 25$ V, $I_{sc} = 10$ A, W

$\therefore$ $R_{1e} = W_{sc} / I_{sc}^2 = 60/(10)$

$Z_{1e} = V_{sc} / I_{sc} = 25/10 = 2.5\ \Omega$

$\therefore$ $X_{1e} = \sqrt{(2.5^2 - 0.6^2)} = 2.4269\ \Omega$

(I_1) F.L. = VA rating/V_1

$= (5 \times 10^3)/500 = 10$ A

and $I_{sc} = (I_1)$ F.L.

$\therefore$ $W_{sc} = (P_{cu})$ F.L. = 60 W

i) η on full load, cos = 0.8 lagging

ii) Regulation on full load, cos $\Phi_2 = 0.8$ leading

$$\% R = \frac{(I_1)\text{ F. L. } R_{1e}\cos\phi - (I_1)\text{ F. L. } X_{1e}\sin\phi}{V_1} \times 100$$

$$= \frac{10 \times 0.6 \times 0.8 - 10 \times 2.4269 \times 0.6}{500} \times 100$$

$$= -1.95\ \%$$

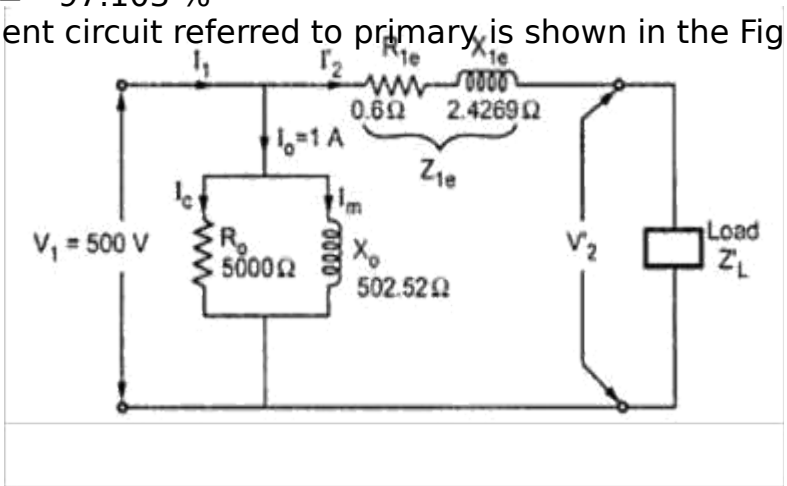
iii) For 60% of full load, n = 0.6 and cos $\Phi_2 = 0.8$ leading]

$\therefore$ P_{cu} = copper loss on new load = $n^2 \times (P_{cu})$ F.L.

$= (0.6)^2 \times 60 = 21.6$ W

$= 97.103\ \%$

iv) The equivalent circuit referred to primary is shown in the Fig. 4



UNIT-IV

3-PHASE INDUCTION MOTORS

Poly phase Induction Motors-Construction Details of Cage and Wound Rotor Machines-

Principle of Operation -Slip- Rotor Emf and Rotor Frequency -Torque Equation -Torque Slip Characteristics.

Question 1. Explain the principle of operation of 3-Θ induction motor ?

Principle of Operation The operation of a 3-phase induction motor is based upon the application of Faraday Law and the Lorentz force on a conductor. The behaviour can readily be understood by means of the following example.

Consider a series of conductors of length l, whose extremities are short-circuited by two bars A and B (Fig.3.3 a). A permanent magnet placed above this conducting ladder, moves rapidly to the right at a speed v, so that its magnetic field B sweeps across the conductors. The following sequence of events then takes place.

1. A voltage E = Blv is induced in each conductor while it is being cut by the flux (Faraday law).

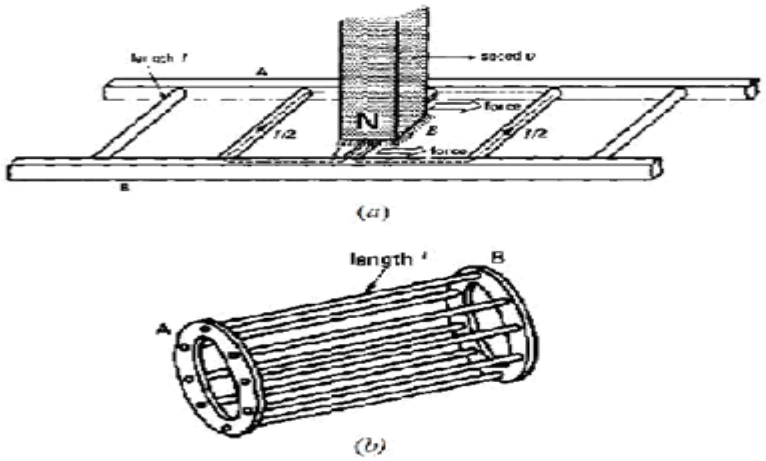
2. The induced voltage immediately produces a current I, which flows down the conductor underneath the pole face, through the end-bars, and back through the other conductors.

3. Because the current carrying conductor lies in the magnetic field of the permanent magnet, it experiences a mechanical force (Lorentz force).

4. The force always acts in a direction to drag the conductor along with the magnetic field. If the conducting ladder is free to move, it will accelerate toward the right. However, as it picks up speed, the conductors will be cut less rapidly by the moving magnet, with the result that the induced

voltage E and the current I will diminish. Consequently, the force acting on the conductors wilt also decreases. If the ladder were to move at the same speed as the magnetic field, the induced voltage E, the current I, and the force dragging the ladder along would all become zero.

In an induction motor the ladder is closed upon itself to form a squirrel-cage (Fig.3.3b) and the moving magnet is replaced by a rotating field. The field is produced by the 3-phase currents that flow in the stator windings.



Question 2 :Derive torque Equation of 3-phase induction motor ?

Snatch the characteristics of slip-torque ?

Slip:

In practice, the motor never succeeds in catching up with the stator fieldIf it really did so, then there would be no relative speed between the two, hence no rotor emf, no rotor current and so there will be no torque to maintain rotation. That is why the rotor runs at a speed which is always less than yhe speed of the stator field. The difference in speed depends upon the load on the motor.

The difference between the synchronous speed and the actual speed of the rotor is known as slip. It is expressed as a percentage of the synchronous speed.

$$\%slip\ s = \frac{N_s - N}{N_s} \times 100$$

Sometimes, $N_s - N$ is called the slip speed.

The rotor speed is $N = N_s(1-s)$

It may be noted here that revolving flux is rotating synchronously, relative to the stator (i.e. stationary space) but at slip speed relative to the motor.

F

requency of rotor curre

When the rotor is stationary, the frequency of rotor current is same as the supply frequency. But when the rotor starts revolving, then the frequency depends upon the relative speed or on slip speed. Let at any slip-speed, the frequency of the rotor current be f''. Then,

$$N_s - N = \frac{120f'}{P}, \text{ also } N_s = \frac{120f}{P}$$

After solving, we get, $\frac{f'}{f} = \frac{N_s - N}{N_s} = s$

Then, rotor current have a frequency of

$$f' = sf$$

Where, I_2 = rotor current at standstill

TORQUE EQUATION

ϕ_2 = angle between rotor emf and rotor current

K = a constant

Denoting rotor emf at standstill by E_2 , we have that

$E_2 \alpha \phi$

Hence, $T \alpha E_2 I_2 \cos\phi_2$ or $T = E_2 I_2 \cos\phi_2$

Where, K_1 is another constant.

Starting torque

The torque developed by the motor at the instant of starting is called starting torque.

Let E_2 = rotor emf per phase at standstill

R_2 = rotor resistance per phase

X_2 = rotor reactance per phase at standstill

$Z_2 = \sqrt{(R_2^2 + X_2^2)}$ =rotor impedance per phase at standstill

Then, $I_2 = \frac{E_2}{Z_2} = \frac{E_2}{\sqrt{(R_2^2 + X_2^2)}}$

$\cos\phi_2 = \frac{R_2}{Z_2} = \frac{R_2}{\sqrt{(R_2^2 + X_2^2)}}$

Starting torque, $T_{st} = K_1 E_2 I_2 \cos\phi_2 = K_1 E_2 \frac{E_2}{\sqrt{(R_2^2 + X_2^2)}} \frac{R_2}{\sqrt{(R_2^2 + X_2^2)}}$

Or, $T_{st} = K_1 \frac{E_2^2 R_2}{(R_2^2 + X_2^2)}$

Now, $K_1 = \frac{3}{2\pi N_s}$

Hence, $T_{st} = \frac{3}{2\pi N_s} \frac{E_2^2 R_2}{(R_2^2 + X_2^2)}$

Where, N_s = synchronous speed in rps

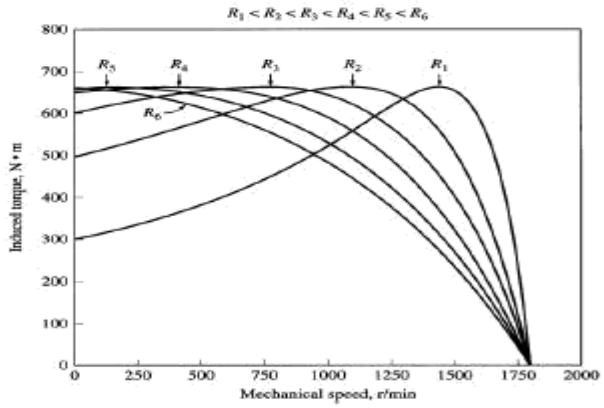


Fig. Effect of rotor resistance on torque-speed characteristic

TORQUE – SPEED CHARACTERISTICS

For small values of slip *s*, the torque is directly proportional to *s*.

For large values of slip *s*, the torque is inversely proportional to *s*.

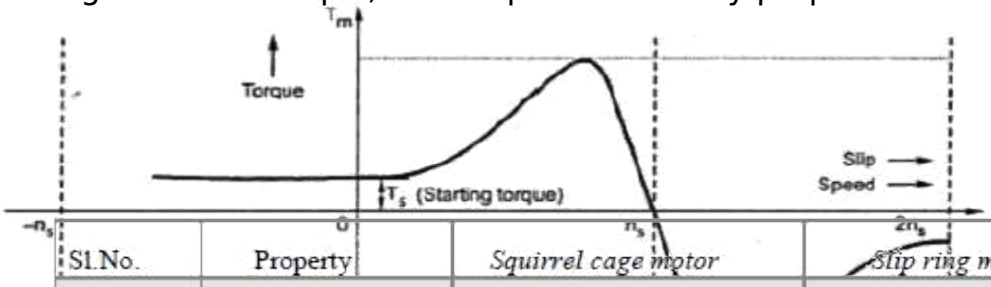


Fig. Complete torque-speed characteristic of a three phase induction machine

Question 3:Distinguish squirrel cage and slip ring induction motor

Sl.No.	Property	*Squirrel cage motor*	*Slip ring motor*
1.	**Rotor Construction**	*Bars are used in rotor. Squirrel cage motor is very simple, rugged and long lasting. No slip rings and brushes*	*Winding wire is to be used.* *Wound rotor required attention.* *Slip ring and brushes are needed also need frequent maintenance.*
2.	**Starting**	*Can be started by D.O.L., star-delta, auto transformer starters*	*Rotor resistance starter is required.*
3.	**Starting torque**	*Low*	*Very high*
4.	**Starting Current**	*High*	*Low*
5.	**Speed variation**	*Not easy, but could be varied in large steps by pole changing or through smaller incremental steps through thyristors or by frequency variation.*	*Easy to vary speed.* *Speed change is possible by inserting rotor resistance using thyristors or by using frequency variation injecting emf in the rotor circuit cascading.*
6.	**Maintenance**	*Almost ZERO maintenance*	*Requires frequent maintenance*
7.	**Cost**	*Low*	*High*

		varied in large steps by pole changing or through smaller incremental steps through thyristors or by frequency variation.	*Speed change is possible by inserting rotor resistance using thyristors or by using frequency variation injecting emf in the rotor circuit cascading.*
6.	**Maintenance**	*Almost ZERO maintenance*	*Requires frequent maintenance*
7.	**Cost**	*Low*	*High*

UNIT – V SYNCHRONOUS MACHINES

Principle And Constructional Features of Salient Pole and Round Rotor Machines-E.M.F Equation-Voltage Regulation by Synchronous Impedance Method- Theory of Operation of Synchronous Motor.

1.Explain the principle of operation of AC Synchronous motor ?

Theory of operation of synchronous motor

Electrical motor in general is an electro-mechanical device that converts energy from electrical domain to mechanical domain. Based on the type of input we have classified it into single phase and 3 phase motors. Among 3 phase induction motors and synchronous motors are more widely used. When a 3 phase electric conductors are placed in a certain geometrical positions (In certain angle from one another) there is an electrical field generate. Now the rotating magnetic field rotates at a certain speed, that speed is called synchronous speed. Now if an electromagnet is present in this rotating magnetic field, the electromagnet is magnetically locked with this rotating magnetic field and rotates with same speed of rotating field.

Synchronous motors is called so because the speed of the rotor of this motor is same as the rotating magnetic field. It is basically a fixed speed motor because it has only one speed, which is synchronous speed and therefore no intermediate speed is there or in other words it's in synchronism with the supply frequency. Synchronous speed is given by

$$N_s = \frac{120f}{p}$$

2.Write a short notes about Constructional Details of AC Machine? With principle of operation ?

There are mainly two types of rotor used in **construction of alternator**,

1. Salient pole type.
2. Cylindrical rotor type.

CONSTRUCTION OF SALIENT POLE ROTOR MACHINES

The construction of a synchronous motor(with salient pole rotor) is as shown in the figure at left. Just like any other motor, it consists of a stator and a rotor. The stator core is constructed with thin silicon lamination and insulated by a surface coating, to minimize the eddy current and hysteresis

losses. The stator has axial slots inside, in which three phase stator winding is placed.

The stator is wound with a three phase winding for a specific number of poles equal to the rotor poles.

The rotor in synchronous motors is mostly of salient pole type. DC supply is given to the rotor winding via slip-rings. The direct current excites the rotor winding and creates electromagnetic poles. In some cases permanent magnets can also be used. The figure above illustrates the construction of a synchronous motor very briefly.

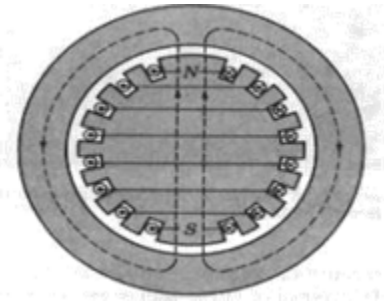
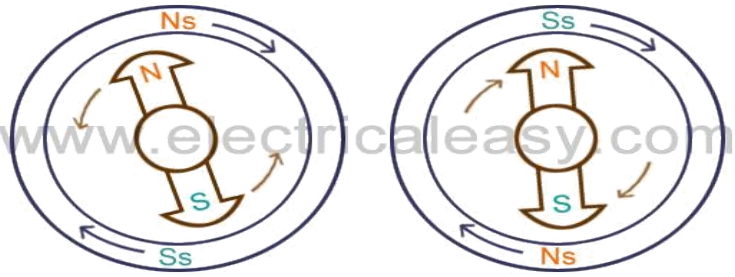


Fig. Salient pole synchronous machine

Working principle of salient pole synchronous machine

The stator is wound for the similar number of poles as that of rotor, and fed with three phase AC supply. The 3 phase AC supply produces rotating magnetic field in stator. The rotor winding is fed with DC supply which magnetizes the rotor. Consider a two pole **synchronous machine** as shown in figure below.



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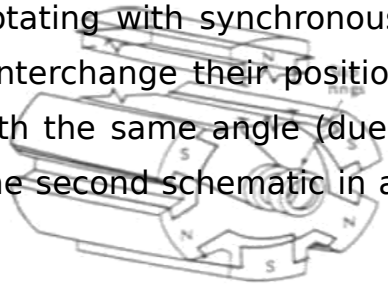
Now, the stator poles are revolving with synchronous speed (lets say clockwise). If the rotor position is such that, N pole of the rotor is near the N pole of the stator (as shown in first schematic of above figure), then the poles of the stator and rotor will repel each other, and the *torque produced will be anticlockwise*.

- The stator poles are rotating with synchronous speed, and they rotate around very fast and interchange their position. But at this very soon, rotor can not rotate with the same angle (due to inertia), and the next position will be likely the second schematic in above figure. In this case,



poles of the stator will attract the poles of rotor, and *the torque produced will be clockwise.*

Fig. Salient pole rotor

¬ Hence, the rotor will undergo to a rapidly reversing torque, and the motor will not start. But, if the rotor is rotated upto the synchronous speed of the stator by means of an external force (in the direction of revolving field of the stator), and the rotor field is excited near the synchronous speed, the poles of stator will keep attracting the opposite poles of the rotor (as the rotor is also, now, rotating with it and the position of the poles will be similar throughout the cycle). Now, the rotor will undergo unidirectional torque. The opposite poles of the stator and rotor will get locked with each other, and the rotor will rotate at the synchronous speed.

The salient features of pole field structure has the following special feature-

1. They have a large horizontal diameter compared to a shorter axial length.
2. The pole shoes covers only about $^{2}/_{3}$rd of pole pitch.
3. Poles are laminated to reduce eddy current loss.
4. The salient pole type motor is generally used for low speed operations of around 100 to 400 rpm, and they are used in power stations with hydraulic turbines or diesel engines.

Construction of round (or) cylindrical rotor synchronous machine

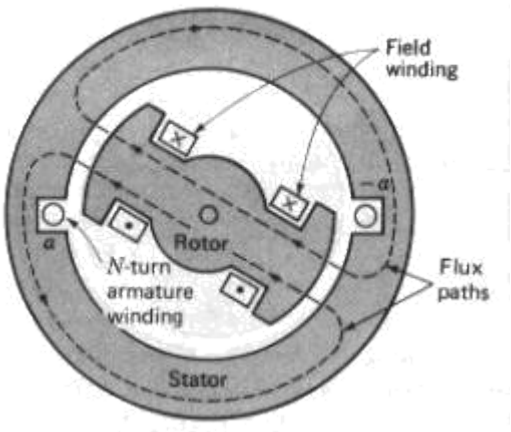


Fig. Round (or) cylindrical rotor

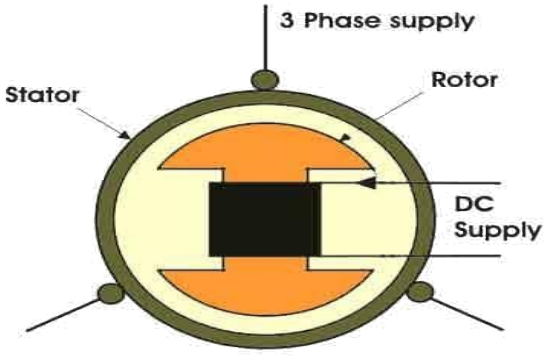
The cylindrical rotor is generally used for very high speed operation and are employed in steam turbine driven alternators like turbo generators. The cylindrical rotor type machine has uniform length in all directions, giving a cylindrical shape to the rotor thus providing uniform flux cutting in all directions. The rotor in this case consists of a smooth solid steel cylinder, having a number of slots along its outer periphery for hosing the field coils.

The cylindrical rotor alternators are generally designed for 2-pole type giving very high speed of $N_s = (120 \times f)/P = (120 \times 50) / 2 = 3000$ rpm. Or 4-pole type running at a speed of $N_s = (120 \times f) / P = (120 \times 50) / 4 = 1500$ rpm. Where f is the frequency of 50 Hz.

The a cylindrical rotor synchronous generator does not have any projections coming out from the surface of the rotor, rather central polar area are provided with slots for housing the field windings as we can see from the diagram above. The field coils are so arranged around these poles that flux density is maximum on the polar central line and gradually falls away as we move out towards the periphery. The cylindrical rotor type machine gives better balance and quieter-operation along with lesser windage losses.

Construction of Synchronous Motor

Normally it's construction is almost similar to that of a 3 phase induction motor, except the fact that the rotor is given dc supply, the reason of which is explained later. Now, let us first go through the basic construction of this type of motor.



Synchronous Motor

From the above picture, it is clear that how this type of motors are designed. The stator is given is given three phase supply and the rotor is given dc supply.

3. evaluate the effiency of an AC machine By SIM method ?

Voltage regulation by synchronous impedance method

This method is also called E.M.F. method of determining the regulation. The method requires following data to calculate the regulation.

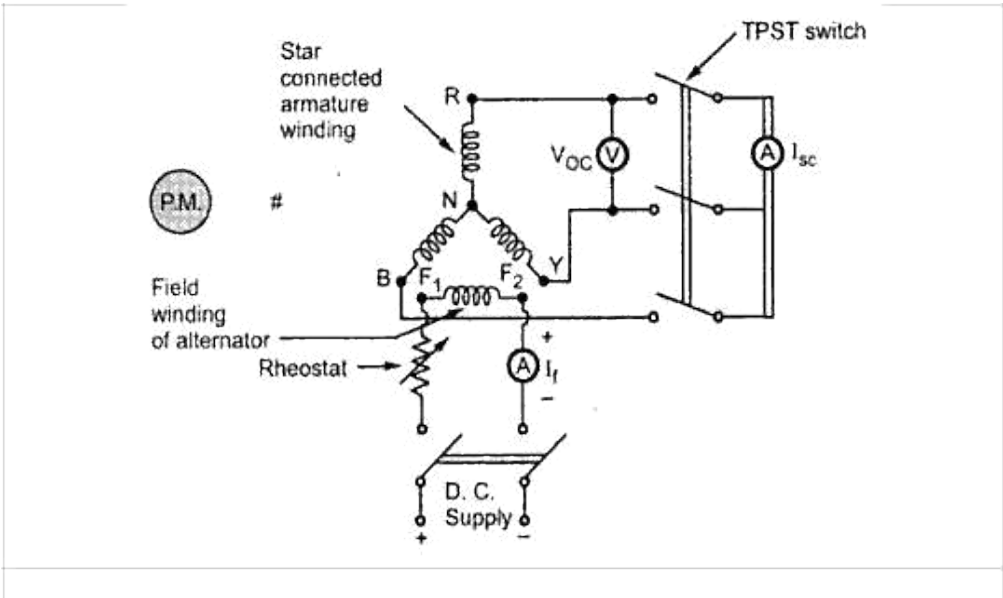
1.The armature resistance per phase (R_a).

2. Open circuit characteristics which is the graph of open circuit voltage against the field current. This is possible by conducting open circuit test on the alternator.

3. Short circuit characteristics which is the graph of short circuit current against field current. This is possible by conducting short circuit test on the alternator.

Let us see, the circuit diagram to perform open circuit as well as short circuit test on the alternator. The alternator is coupled to a prime mover capable of driving the alternator at its synchronous speed. The armature is connected to the terminals of a switch. The other terminals of the switch are short circuited through an ammeter. The voltmeter is connected across the lines to measure the open circuit voltage of the alternator.

The field winding is connected to a suitable d.c. supply with rheostat connected in series. The field excitation i.e. field current can be varied with the help of this rheostat. The circuit diagram is shown in the Fig.



Open Circuit Test

Procedure to conduct this test is as follows :

i) Start the prime mover and adjust the speed to the synchronous speed of the alternator.

ii) Keeping rheostat in the field circuit maximum, switch on the d.c. supply.

iii) The T.P.S.T switch in the armature circuit is kept open.

iv) With the help of rheostat, field current is varied from its minimum value to the rated value. Due to this, flux increasing the induced e.m.f. Hence voltmeter reading, which is measuring line value of open circuit voltage increases. For various values of field current, voltmeter readings are observed.

Note : This is called open circuit characteristics of the alternator, called O.C.C. This is shown in the Fig.

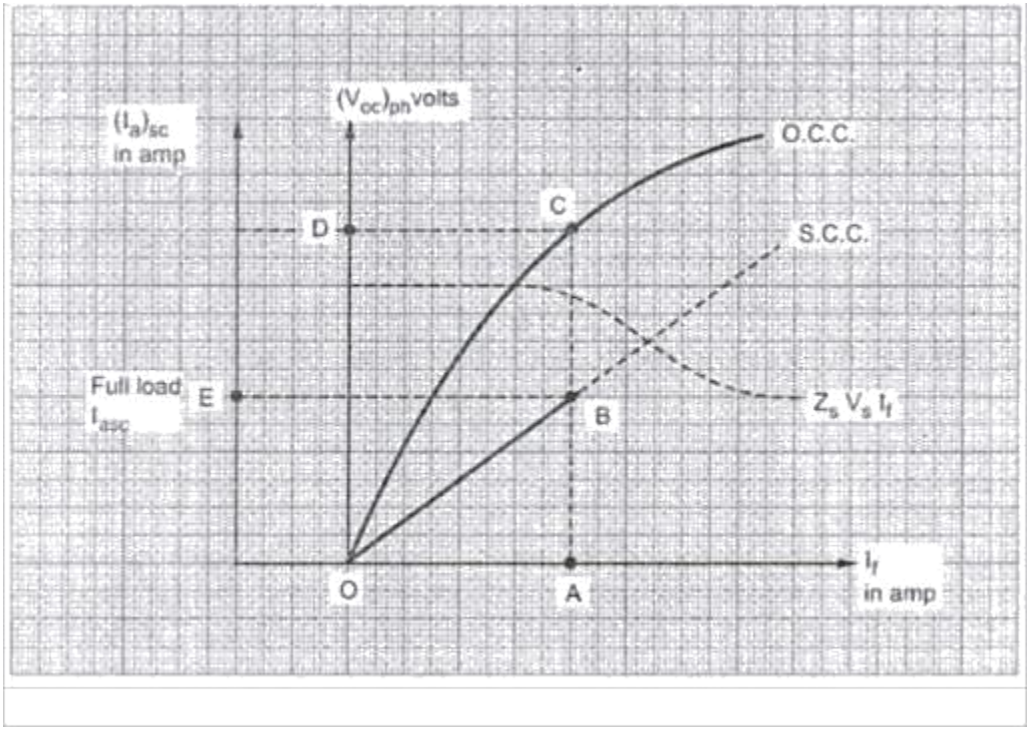


Fig. O.C.C. and S.C.C. of an alternator

Short Circuit Test

After completing the open circuit test observation, the field rheostat is brought to maximum position, reducing field current to a minimum value. The T.P.S.T switch is closed. As ammeter has negligible resistance, the armature gets short circuited. Then the field excitation is gradually increased till full load current is obtained through armature winding. This can be observed on the.

ammeter connected in the armature circuit. The graph of short circuit armature current against field current is plotted from the observation table of short circuit test. This graph is called short circuit characteristics, S.C.C. This is also shown in the Fig.

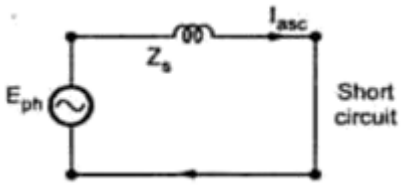
The S.C.C. is a straight line graph passing through the origin while O.C.C. resembles B-H curve of a magnetic material.

Note : As S.C.C. is straight line graph, only one reading corresponding to full load armature current along with the origin is sufficient to draw the straight line.

Determination of From O.C.C. and S.C.C.

The synchronous impedance of the alternator changes as load condition changes. O.C.C. and S.C.C. can be used to determine Z_s for any load and load p.f. conditions.

In short circuit test, external load impedance is zero. The short circuit armature current is circulated against the impedance of the armature winding which is Z_s. The voltage responsible for driving this short circuit current is internally induced e.m.f. This can be shown in the equivalent circuit drawn in the Fig. 5.3.



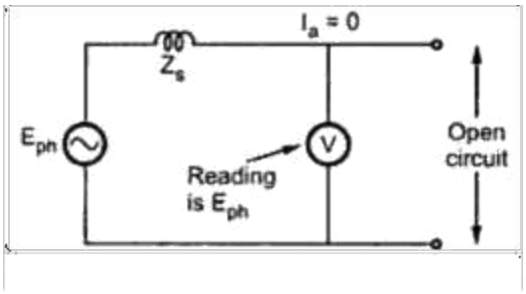
From the equivalent circuit we can write,

$$Z_s = E_{ph} / I_{asc}$$

Now value of I_{asc} is known, which can observed on the alternator. But internally induced e.m.f. can not be observed under short circuit condition. The voltmeter connected will read zero which is voltage across short circuit.

To determine Z_s it is necessary to determine value of E which is driving I_{asc} against Z_s.

So if the terminal of the alternator are opened without disturbing I_f which was present at the time of short circuited condition, internally induced e.m.f. will remain same as E_{ph}. But now current will be zero. Under this condition equivalent circuit will become as shown in the Fig.



It is clear now from the equivalent circuit that as $I_a = 0$ the voltmeter reading $(V_{oc})_{ph}$ will be equal to internally induced e.m.f. (E_{ph}).

$$\therefore \quad \boxed{E_{ph} = (V_{oc})_{ph} \text{ on open circuit}}$$

This is what we are interested in obtaining to calculate value of Z_s. So expression for Z_s can be modified as,

$$Z_s = \left.\frac{(V_{oc})_{ph}}{(I_{asc})_{ph}}\right|_{\text{for same } I_f}$$

So O.C.C. and S.C.C. can be effectively to calculate Z_s.

The value of Z_s is different for different values of I_f as the graph of O.C.C. is non linear in nature. So suppose Z_s at full load is required then,

Thus in general, $\boxed{Z_s = \left.\frac{\text{Phase e. m. f. on open circuit}}{\text{Phase current on short circuit}}\right|_{\text{For same excitation current}}}$

I_{asc} = full load current.

From S.C.C. determine I_f required to drive this full load short circuit I_a. This is equal to 'OA', as shown in the Fig.2.

Now for this value of I_f, $(V_{oc})_{ph}$ can be obtained from O.C.C. Extend kine from point A, till it meets O.C.C. at point C. The corresponding $(V_{oc})_{ph}$ value is available at point D.

$V_{oc})_{ph}$ = OD

While $(I_{asc})_{ph}$ = OE

$$\therefore \quad Z_s \text{ at full load} = \left.\frac{(V_{oc})_{ph}}{\text{Full load } (I_{asc})_{ph}}\right|_{\text{same } I_f \text{ (same excitation)}}$$

$$= \left.\frac{OD}{OE}\right|_{\text{same } I_f = OA}$$

at full load

General steps to determine Z_s at any load condition are :

i) Determine the value of $(I_{asc})_{ph}$ for corresponding load condition. This can be determined from known full load current of the alternator. For half load, it is half of the full load value and so on.

ii) S.C.C. gives relation between $(I_{asc})_{ph}$ and I_f. So for $(I_{asc})_{ph}$ required, determine the corresponding value of I_f from S.C.C.

iii) Now for this same value of I_f, extend the line on O.C.C. to get the value of $(V_{oc})_{ph}$. This is $(V_{oc})_{ph}$ for same I_f, required to drive the selected $(I_{asc})_{ph}$.

iv) The ratio of $(V_{oc})_{ph}$ and $(I_{asc})_{ph}$, for the same excitation gives the value of Z_s at any load conditions.

The graph of synchronous impedance against excitation current is also shown in the Fig. 2.

Regulation Calculations

From O.C.C. and S.C.C., Z_s can be determined for any load condition.

The armature resistance per phase (R_a) can be measured by different methods. One of the method is applying d.c. known voltage across the two terminals and measuring current. So value of R_a per phase is known.

Now $$Z_s = \sqrt{(R_a)^2 + (X_s)^2}$$

$$\therefore \quad \boxed{X_s = \sqrt{(Z_s)^2 - (R_a)^2}\ \Omega/\text{ph}}$$

So synchronous reactance per phase can be determined.

No load induced e.m.f. per phase, E_{ph} can be determined by the mathematical expression derived earlier.

$$\boxed{E_{ph} = \sqrt{(V_{ph}\cos\phi + I_a R_a)^2 + (V_{ph}\sin\phi \pm I_a X_s)^2}}$$

where V_{ph} = Phase value of rated voltage

I_a = Phase value of current depending on the load condition $\cos\Phi$ = p.f. of load

Positive sign for lagging power factor while negative sign for leading power factor, R_a and X_s values are known from the various tests performed.

The regulation then can be determined by using formula,

$$\% \text{ Regulation} = \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100$$

==========******** ALL THE BEST *****========