SCAD GROUP OF INSTITUTIONS

COURSE SYLLABUS

EE6401 - ELECTRICAL MACHINES – I LTPC 3 1 0 4

UNIT-I MAGNETIC CIRCUITS AND MAGNETIC MATERIALS 9

Magnetic circuits –Laws governing magnetic circuits - Flux linkage, Inductance and energy – Statically and Dynamically induced EMF - Torque – Properties of magnetic materials, Hysterisis and Eddy Current losses - AC excitation, introduction to permanent magnets-Transformer as a magnetically coupled circuit.

UNIT-II TRANSFORMERS 9

Construction – principle of operation – equivalent circuit parameters – phasor diagrams, losses – testing – efficiency and voltage regulation-all day efficiency-Sumpner‘s test, per unit representation – inrush current - three phase transformers-connections – Scott Connection – Phasing of transformer– parallel operation of three phase transformers-auto transformer – tap changing transformers- tertiary winding.

UNIT-III ELECTROMECHANICAL ENERGY CONVERSION AND CONCEPTS IN ROTATING MACHINES 9

Energy in magnetic system – Field energy and coenergy-force and torque equations – singly and multiply excited magnetic field systems-mmf of distributed windings – Winding Inductances-, magnetic fields in rotating machines – rotating mmf waves – magnetic saturation and leakage fluxes.

UNIT-IV DC GENERATORS 9

Construction and components of DC Machine – Principle of operation - Lap and wave windings-EMF equations– circuit model – armature reaction –methods of excitation-commutation and interpoles -compensating winding –characteristics of DC generators.

UNIT- V DC MOTORS 9

Principle and operations - types of DC Motors – Speed Torque Characteristics of DC Motors-starting and speed control of DC motors –Plugging, dynamic and regenerative braking- testing and efficiency – Retardation test- Swinburne‘s test and Hopkinson‘s test - Permanent magnet dc motors(PMDC)-DC Motor applications.

TEXT BOOKS:

1. Nagrath I. J and Kothari D. P. ‗Electric Machines‘, Fourth Edition, Tata McGraw Hill Publishing Company Ltd, 2010.

2. M.N.Bandyopadhyay, Electrical Machines Theory and Practice, PHI Learning PVT LTD., New Delhi, 2009.

3. Fitzgerald. A.E., Charles Kingsely Jr, Stephen D.Umans, ‗Electric Machinery', Sixth edition, Tata McGraw Hill Books Company, 2003.

REFERENCES:

1. P. C. Sen., ‗Principles of Electrical Machines and Power Electronics', John Wiley & Sons, 1997.

2. Syed A. Nasar, Electric Machines and Power Systems: Volume I, Mcgraw-Hill College; International Edition, January 1995.

3. Deshpande M. V., ―Electrical Machines‖ PHI Learning Pvt. Ltd., New Delhi, 2011.

4. P.S. Bimbhra, ‗Electrical Machinery', Khanna Publishers, 2003.

5. S.Sarma & K.Pathak ―Electric Machines‖, Cengage Learning India (P) Ltd., Delhi, 2011.

Web resources

http://www.textbooksonline.tn.nic.in/books/11/stdxi-voc-ema-em-1.pdf

http://nptel.ac.in/courses/IIT-MADRAS/Electrical_Machines_I/

http://www.ee.bgu.ac.il/~engconv/natan/chapman.pdf

Aim of the subject:

To expose the students to the basic principles of Electro mechanical Energy Conversion in Electrical apparatus and the operation of Transformers and DC machines.

Objectives:

- To discuss the fundamentals of magnetic circuits and materials.
- To make the students understand the basic construction and operation of DC Generators.
- To familiarize the students with DC Motors.
- To expose the students to the concept of Electro mechanical energy conversion.
- To make the students understand the basic construction and operation of Transformers.

Course Outcomes:

- To understand the magnetic material concept and analysis the magnetic materials
- To analysis the construction and operation of transformers.
- To examine the electrical machines using electromechanical energy conversion.

- To analysis the function of DC machines and its characteristics along with its speed control.

Books recommended:

1. B.L.Theraja"Electrical Technology"
2. Bakshi, "Electrical Machines-I"

Need and Importance for Study of the Subject:

Need for Study of the Subject:

- Makes it possible to design the simple motors– Mini projects.
- Allows students to upgrade their knowledge in electric field.
- Helps students/engineers in touch with the latest technologies.(Electric Machines)

Importance for Study of the Subject:

At the end of the course, the student should be able to:

- Design the simple homemade motors.
- Design and analyse performance of Transformers.
- Identify the optimal placing of special Machines.
- Understand the concept of Electromechanical energy conversion.

3. Industry Connectivity and Latest Developments

Industry Connectivity:

- The following companies (Industries) are connectivity to Electrical Machines: ABB Ltd,Allied
- Motion Technologies, AMETEK Inc, ARC Systems and Asmo, etc.

Latest Developments:

- Advanced electronic controlled machines.
- Design and control of the Brushless Doubly Fed twin Induction generator
- Development of single phase PM BLDC motor..
- Transformer in practice, Lopez-Fernandez.

Course Lesson Plan

Sl. No.	Topics	No of Hours	Cumulative Hours	Book
UNIT I MAGNETIC CIRCUITS AND MAGNETIC MATERIALS				
1	Magnetic circuits	1	1	T3
2	Laws governing magnetic circuits	1	2	T3
3	Flux linkage, Inductance and energy	1	3	T3
4	Statically and Dynamically induced EMF , Torque	1	4	T1
5	Properties of magnetic materials	1	5	T3
6	Hysteresis and Eddy Current losses	1	6	T1
7	AC excitation,	1	7	T3
8	Introduction to permanent magnets	1	8	T3
9	Transformer as a magnetically coupled circuit	1	9	T1
10	Tutorial problems	1	10	MSM
11	Tutorial problems	1	11	MSM
12	Tutorial problems	1	12	MSM
UNIT II TRANSFORMERS				
13	Construction , principle of operation ,equivalent circuit parameters	1	13	R3
14	Phasor diagrams, losses ,testing	1	14	T1
15	Efficiency and voltage regulation	1	15	T1
16	All day efficiency, Sumpner's test ,per unit representation	1	16	T1
17	inrush current ,three phase transformers-connections, Scott Connection	1	17	T1
18	Phasing of transformer	1	18	T1
19	Parallel operation of three phase transformers	1	19	T1
20	Auto transformer, tap changing transformers	1	20	T1
21	Tertiary winding.	1	21	T1

Sl. No.	Topics	No of Hours	Cumulative Hours	Book
22	Tutorial problems	1	22	MSM
23	Tutorial problems	1	23	MSM
24	Tutorial problems	1	24	MSM
UNIT III ELECTROMECHANICAL ENERGY CONVERSION AND CONCEPTS IN ROTATING MACHINES				
25	Energy in magnetic system	1	25	T1
26	Field energy and coenergy, force and torque equations	1	26	R1
27	Singly excited magnetic field systems	1	27	T3
28	Multiply excited magnetic field systems	1	28	T3
29	mmf of distributed windings	1	29	T1
30	Winding Inductances	1	30	T1
31	Magnetic fields in rotating machines	1	31	T1
32	Rotating mmf waves	1	32	T1
33	Magnetic saturation and leakage fluxes	1	33	T3
34	Tutorial problems	1	34	MSM
35	Tutorial problems	1	35	MSM
36	Tutorial problems	1	36	MSM
UNIT IV DC GENERATORS				
37	Construction , principle of operation ,equivalent circuit parameters	1	37	R3
38	Phasor diagrams, losses ,testing	1	38	T1
39	Efficiency and voltage regulation	1	39	T1
40	All day efficiency, Sumpner's test ,per unit representation	1	40	T1
41	inrush current ,three phase transformers-connections, Scott Connection	1	41	T1
42	Phasing of transformer	1	42	T1
43	Parallel operation of three phase transformers	1	43	T1
44	Auto transformer, tap changing transformers	1	44	T1

Sl. No.	Topics	No of Hours	Cumulative Hours	Book
45	Tertiary winding.	1	45	T1
46	Tutorial problems	1	46	MSM
47	Tutorial problems	1	47	MSM
48	Tutorial problems	1	48	MSM
UNIT V DC MOTORS				
	Construction and components of DC Machine	1	49	R3
50	Principle of operation, Lap and wave windings	1	50	R3
51	EMF equations	1	51	T1
52	Circuit model	1	52	T1
53	Armature reaction	1	53	T1
54	Methods of excitation	1	54	T1
55	Commutation and interpoles	1	55	T3
56	Compensating winding	1	56	T3
57	Characteristics of DC generators	1	57	T1
58	Tutorial problems	1	58	MSM
59	Tutorial problems	1	59	MSM
60	Tutorial problems	1	60	MSM

Total Hours: 60

INDEX

UNIT-I

INTRODUCTION

PART-A

1. Mention the types of electrical machines. [MAY/JUNE 2013]

There are three basic rotating machines types, namely

a. The dc machines

b. the poly phase synchronous machine (ac)

c. Poly and single phase induction machine (ac)and a stationary machine, namely Transformer

2. Mention the magnetic materials with example [APRIL/MAY 2015]

Dia Magnetic Materials

The materials whose permeability is below unity are called Dia magnetic materials. They are repelled by magnet.

Ex. Lead, gold, copper, glass, mercury

Para Magnetic Materials

The materials with permeability above unity are called Para magnetic materials. The force of attraction by a magnet towards these materials is low.

Ex.: Copper Sulphate, Oxygen, Platinum, Aluminum.

Ferro Magnetic Materials

The materials with permeability thousands of times more than that of paramagnetic materials are called Ferro magnetic materials. They are very much attracted by the magnet.

Ex. Iron, Cobalt, Nickel.

Permanent Magnet

Permanent magnet means, the magnetic materials which will retain the magnetic property at a] l times permanently. This type of magnets is manufactured by aluminum, nickel, iron, cobalt steel (ALNICO).

3.What is magnetostriction and coercivity? [APRIL/MAY 2015]

When ferromagnetic materials are subjected to magnetizing mmf, these may undergo small changes in dimension; this phenomenon is known as magnetostriction

It is the measure of mmf which, when applied to the magnetic circuit would reduce its flux density to zero, i.e., it demagnetizes the magnetic circuit.

4.Why the core of an electrical machines are laminated? [NOV/DEC 2015]

When the core is laminated, it gets divided into thin laminations. The path of the eddy currents is broken due to the insulating sheets present between the laminations. This eddy current through the core and reduces the eddy current losses.

5. Distinguish between leakage flux and fringing flux. .[MAY/JUNE 2014, MAY/JUNE 2013]

The small amount of flux always leak to the airgap that flux is called as leakage flux.The Flux spread out the edge of the airgap that flux is called as fringing flux

6. What are quasi static fields? [NOV/DEC 2015,MAY/JUNE 2014]

All the electromechanical energy conversion devices are slow moving devices because of inertia associated with the moving parts. Therefore, the fields in the device are also slow in nature.

7.What is core loss and eddy current loss? What is its significance in electric machines? [NOV/DEC 2015]

When a magnetic material undergoes cyclic magnetization, two kinds of power losses occur on it. Hysteresis and eddy current losses are called as core loss. It is important in determining heating, temperature rise, rating & efficiency of transformers, machines & other A.C run magnetic devices.

When a magnetic core carries a time varying flux, voltages are induced in all possible path enclosing flux. Resulting is the production of circulating flux in core. These circulating current do no useful work are known as eddy current and have power loss known as eddy current loss.

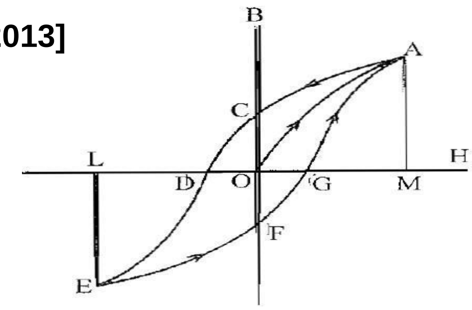
8. How will you find the direction of force produced using Fleming's left hand rule? [NOV/DEC 2015]

The thumb, forefinger & middle finger of left hand is held so that these fingers are mutually perpendicular to each other, then forefinger gives the direction of magnetic field, middle finger gives the direction of the current and thumb gives the direction of the force experienced by the conductor.

9.How hysteresis and eddy current losses are minimized? [APRIL/MAY 2015]

Hysteresis loss can be minimized by selecting materials for core such as silicon steel & steel alloys with low hysteresis co-efficient and electrical resistivity. Eddy current losses are minimized by laminating the core.

10.Draw the typical normal magnetization curve of ferromagnetic material.[MAY/JUNE 2013]



11.Define stacking factor.[NOV/DEC 2015]

The stacking factor is defined as the ratio of the net cross section area of magnetic core to gross cross section area of magnetic core. Due to laminations net cross section area will be always less than gross cross section area.

12. State faradays law of electromagnetic induction.[NOV/DEC 2008]

Whenever the current carrying conductor placed in a magnetic field the flux cut by the conductor it produces torque and dynamically induced emf. The magnitude of induced emf is proportional to rate of change flux linkage

$$e = Nd\Phi/dt$$

PART-B

1.Explain in detail about statically and dynamically induced emf. [NOV/DEC 2015]

Nature of induced emf

Whenever the number of magnetic lines of force linking with a current carrying conductor an emf get induced in that coil (or) conductor.

Magnitude of the induced emf is directly proportional to the rate of change of flux linkages

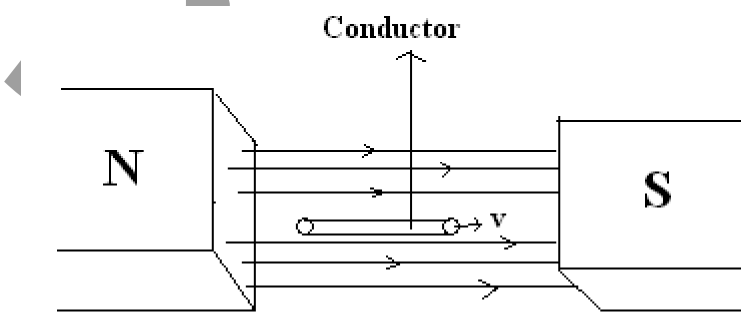
$$E=N\, d\Phi/dt$$

As per lenz's law the induced emf set upa current in such a direction so as to oppose the very cause producing it.

$$E=-N\, d\Phi/dt$$

DYNAMICALLY INDUCED EMF

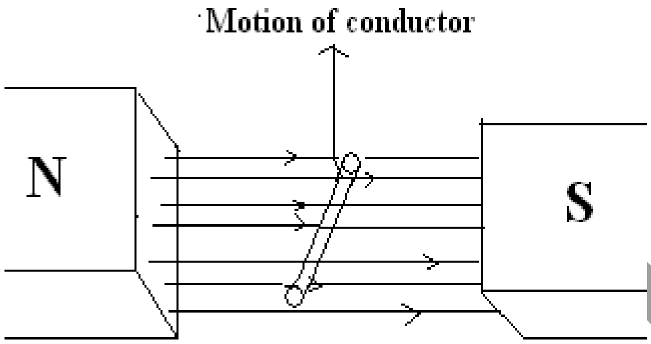
"An induced emf which is due to physical movement of magnet (or) coil is called dynamically induced emf"



Magnitude of dynamically induced emf

- ➢ If plane of the motion of the conductor is parallel to the plane of the magnetic field, then there is no cutting of flux lines and there cannot be any induced emf in the conductor.

- When plane of the flux is parallel to the plane of the motion of conductors then there is no cutting of flux, hence no induced emf.
- Motion of conductor is perpendicular to the flux. Hence whole length of conductor is cutting the flux line hence there is maximum possible induced emf in the conductor.



Such condition plane of flux and plane of motion are perpendicular to each other.
'When plane of the flux is perpendicular to the plane of the motion of the conductors then the cutting of flux is maximum and hence induced emf is also maximum.'

- Consider a conductor moving with velocity V m/s such that its palne of motion or direction of velocity is perpendicular to the direction of flux lines.

B=Flux density in wb/m^2

L=Active length of conductor in meters

V=Velocity in m/sec

- This conductor is moved through distance dx in a small time interval and,then

Area swept by conductor=$l*dx*m^2$

- Flux cut by conductor=Flux density*Area swept

$$d\Phi = B*l*dx \text{ wb}$$

- The magnitude of induced emf is propotional to the rate of change of flux
- E=Flux cut/time= $d\Phi/dt$ [N=1 as single conductor]

$$=Bl\, dx/dt$$

- dx/dt=rate of change of displacement=V

e=BLV volts is perpendicular to the direction of flux responsible for induced emf.

- The magnitude of induced emf

$$E= BLV\sin\Theta \text{ volts}$$

- If conductor is moving with a velocity V but at a certain angle Θ measured with respect to direction of the field then component of velocity VsinΘ

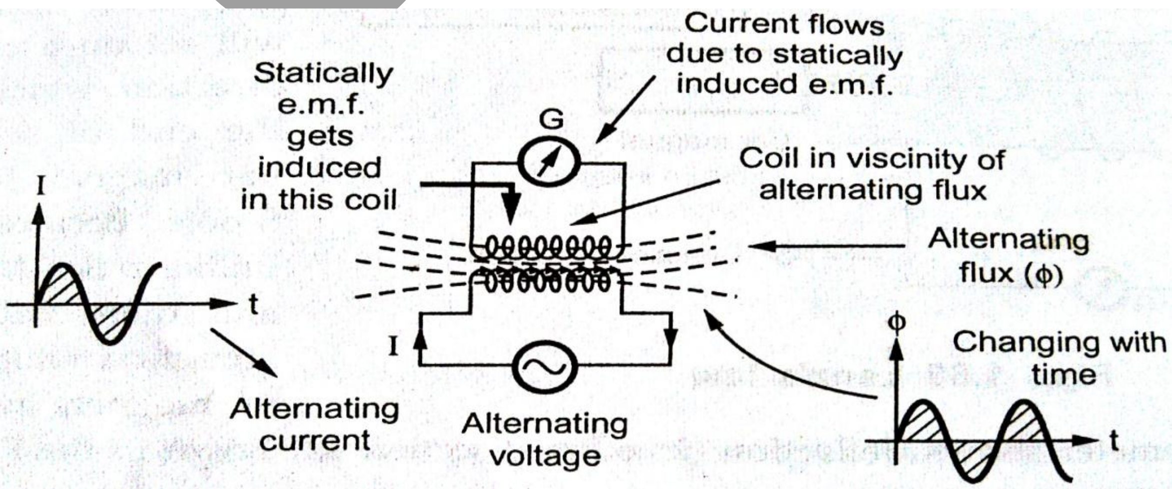
STATICALLY INDUCED EMF

"The change in flux lines with respect to coil can be achieved without physically moving the coil or magnet is called statically induced emf"

- An induced emf there must be change in flux associated with a coil. The change in flux can be achieved without any physical movement by increasing and decreasing the current producing the flux with respect to time.
- An electromagnet which is producing the necessary flux for producing emf. The current flow through the coil of an alternating one. It means it changes its magnitude periodically with time.
- There is no physical movement of magnet or conductor, it is the alternating supply which is responsible for an induced emf. The alternating flux linking with the coil itself, the emf gets induced in that coil itself.
- The statically induced emf is classified as
    1. Self-induced emf
    2. Mutually induced emf

SELF INDUCED EMF

- Consider a coil having 'N' turns and carrying current 'I'. When switch is closed the magnitude of current can be varied with the help of variable resistance. The flux produced by the coil links with the coil itself.
- The current '' is changed with the help of variable resistance, then flux produced will also change.
- According to faraday's law due to rate o change of flux linkages there will be induced emf in the coil
- So there is no physical moving coil the flux is induced emf the coil itself. This emf is called as self-induced emf.



SELF INDUCTANCE

- The direction of this induced emf will be oppose the cause producing it. When current is increased, self-induced emf reduces the current tries to keep it to original value.

Let

N- No. of turns

I-Current flowing in coil

Φ – Flux produced by the coil.

By Faradays law,

$$e = -N\frac{d\Phi}{dt} \text{------------(1)}$$

Consider the flux, Φ

$$\Phi = \frac{\Phi}{I} * I$$

Rate of change of flux,

$$d\Phi = \frac{\Phi}{I} * \frac{dI}{dt} - - - - -(2)$$

Subs (2) in (1) We get

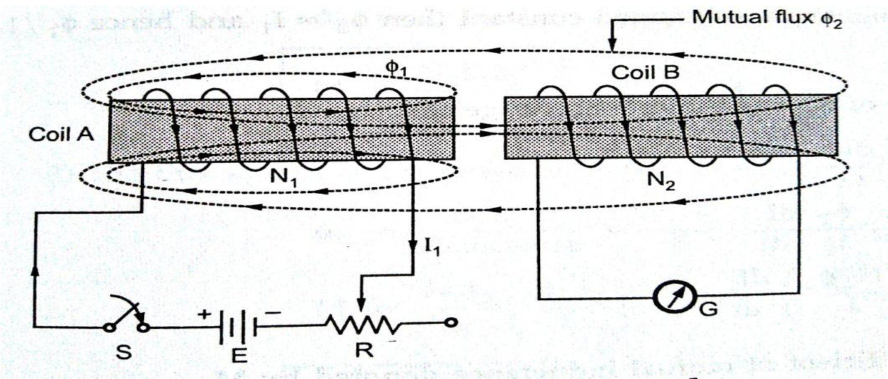
$$e = -N\frac{\Phi}{I} * \frac{dI}{dt}$$

$$e = -\left(\frac{N\Phi}{I}\right) * \frac{dI}{dt}$$

$e = -L\frac{dI}{dt}$ Where $\mathbf{L}(self\ Inductance) = \frac{N\Phi}{I}$

MUTUALLY INDUCED EMF AND MUTUAL INDUCTANCE

"The flux produced by one coil is getting linked with another coil and due to change in flux produced by first coil, there is induced emf I the second coil , then such emf is called mutually induced emf"



- The coil 'A' has N_1 turns and coil 'B' has N_2 turns .The coil A has switch 'S' with variable resistance.
- Current I_1 produces a total flux Φ_{11} in coil 1. The flux of coil 1 that links coil 1. The resulting self-inductance L_1 of coil 1 is

$e = -N_2 * \frac{d\Phi_2}{dt}$ ------(1)

Consider the flux, Φ

$$\Phi_2 = \frac{\Phi_2}{I_1} * I_1$$

Rate of change of flux,

$$d\Phi_2 = \frac{\Phi_2}{I_1} * \frac{dI_1}{dt} --- (2)$$

Subs (2) in (1) We get

$$e = -N_2 * \frac{\Phi_2}{I_1} * \frac{dI_1}{dt}$$

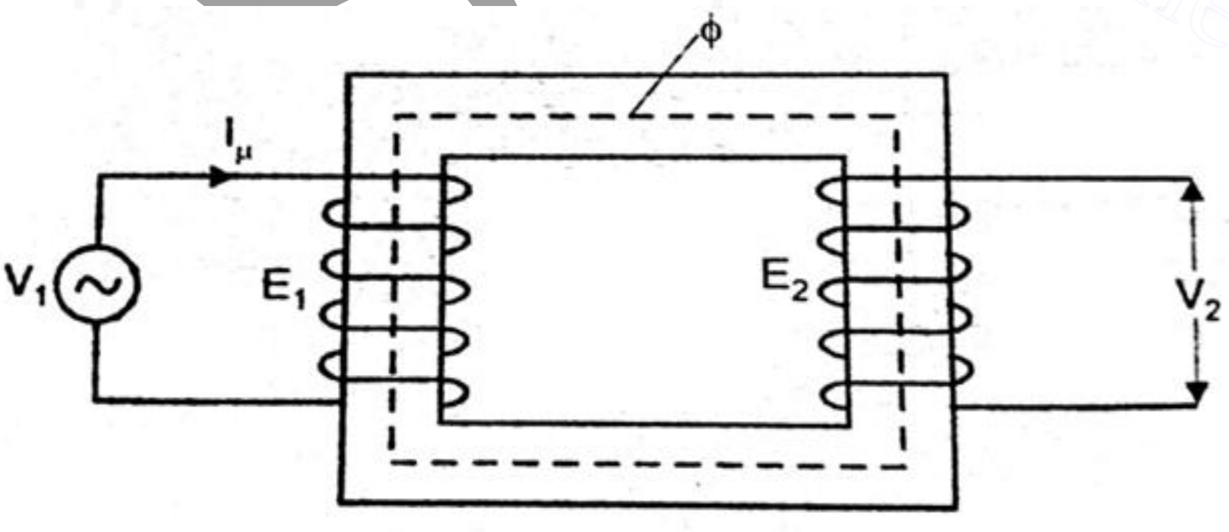
$$e = -\left(\frac{N_2\Phi_2}{I_1}\right) * \frac{dI_1}{dt}$$

$$e = -M * \frac{dI_1}{dt}$$

Where $M = \frac{N_2\Phi_2}{I_1}$

2.Explain in detail about magnetic circuit. .[MAY/JUNE 2014, MAY/JUNE 2013]

- Magnetic circuit is defined as the closed path followed by the flux lines. Electric circuit provides a path for electric current whereas magnetic circuit provides a path for magnetic flux.



- In a magnetic circuit, the magnetic lines of force leaves the north poles passes through the entire circuit and return the starting point.
- A magnetic circuit usually consist of materials having high permeability such as iron, soft steel etc.,
- These materials offer very small opposition to the flow of magnetic flux. consider a coil of N turns would on an iron core

F=I N(AT)

I=Current through the coil

N=Number of turn in the coil

Ampere's law

The total current piercing the surface enclosed by this path is easily

$$\int_{s}^{0} J.ds = NI = \int_{l}^{0} H.dl$$

J=Current density

- The magnetic field intensity H causes a flux density B to be set up at every point along the flux th.Which is given by

B= $\mu H=\mu 0\mu rH$ *(Flux path in core)*

B= $\mu H=\mu 0H$*(Flux path in air)*

$\mu 0 = relative\ permiability\ of\ \ the\ material$

The flux over a given area

Φ=$\int_{s} B.ds$

The flux set up in air path is known as leakage flux

F=NI=HcLc

Hc=Average magnitude of magnetic field intensity in the core

Lc=mean core length(m)

F=MMF in AT Φc=Flux in core,Bc=Flux density in core

Ac=Cross section area in core

- Now imagine that the exciting current I vary with time would indicate the Hc will vary in unison with it. Such fields are known as quasi-static field.

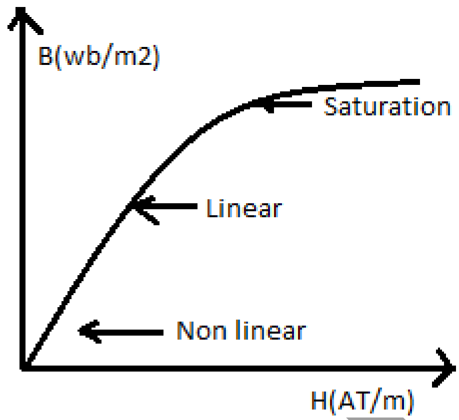
Bc=$\mu c\ Hc$

Φ=$\int_{s} B.ds$=BcAc

=μc Hc Ac=NI/(lc/ μc Ac)

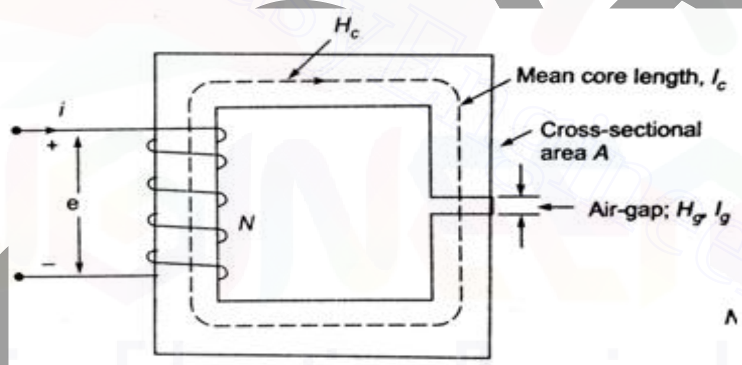
B-H RELATIONSHIP(MAGNETIZATION CHARACTERISTICS)

- The permeability $\mu 0$ is constant so that B-H relationship is linear.B-H relationship is strictly nonlinear in two parts respects-saturation and hysteresis.



Hysteresis on linearity is the doubled value of B-H relationship exhibited in cyclic variation of H.

CORE WITH AN AIRGAP



- Transformers are wound on closed core. Rotating machines have a moving element and must therefore have air gaps in the cores out of necessity. Assume that air gap is narrow and the flux coming out of the core passes straight down the air gap such that the flux density in the air gap is the same as in the core.
- The flux in the gaps finges out so that the airgap flux density is somewhat less than that of the core.
- The MMF NI is now consumed in the core plus the gap.

$NI=H_cl_c+H_gl_g$

$NI=B_cl_c/\mu_c+B_gl_g/\mu_o$

$B_g=B_c$

$\Phi=B_cA=B_gA$

$NI=\phi(l_c/\mu_cA)+(l_g/\mu_oA)$

MAGNETIC CIRCUIT CALCULATION

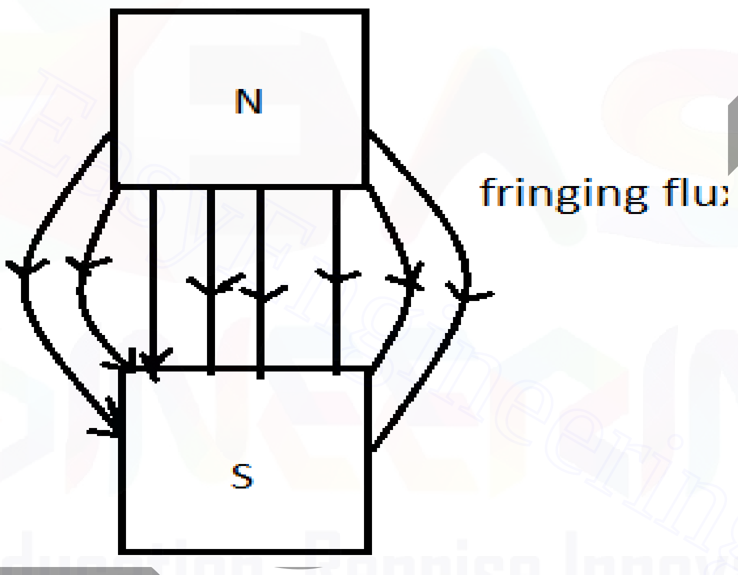
- It required to determine the excitation needed to establish a desired flux or flux density at a given point in a given point in a magnetic circuit.
- The flux is unknown and required to be determined for a given geometry of the magnetic circuit and specified mmf.

LEAKAGE FLUX

- A small amount of flux is always leak through the surrounding air. This stray flux is called as leakage flux. Leakage must be made for AC machines and transformers since their performance is affected.

FRINGING FLUX

- The flux spread out the edge of the airgap is called as fringing flux.
- The effect of fringing flux increases the cross section area of the airgap.



Stacking factor

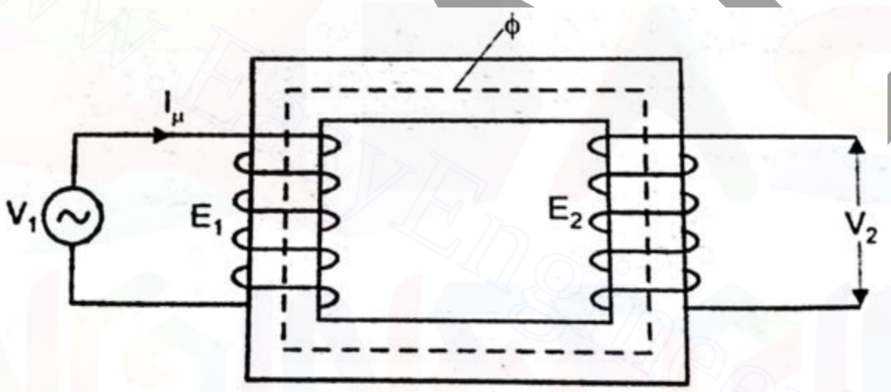
- Magnetic cores are made up lightly insulated lamination to reduce power loss due to eddy current.
- The net cross section area of the core occupied by the magnetic material is less than it gross section their ratio is known as stacking factor.

3.Explain AC operation of magnetic circuits and derive the energy stored in magnetic field. .[MAY/JUNE 2014]

- For establishing a magnetic field, energy must be spent, though to energy is required to maintain it. Take the example of the exciting coils of an electromagnet.
- The energy supplied to it is spent in two ways,
- (i) Part of it goes to meet I^2R loss and is lost once for all.
- (ii) part of it goes to create flux and is stored in the magnetic field as potential

energy, and is to the potential energy of a raised weight, when a mass M is raised through a height of H.

- When current through an inductive coil is gradually changed from Zero to a maximum, value then every change of it is opposed by the self-induced emf. Produced due to this change. Energy is needed to overcome this opposition.
- This energy is stored in the magnetic field and is, later on, recovered when the field collapse.
- In many applications and machines such as transformer and a.c machines, the magnetic circuits are excited by a.c supply. In such an operation, Inductance plays vital role even in steady state operation though in d.c it acts as a short circuit. In such a case the flux is determined by the a.c voltage applied and the frequency, thus the exciting current has to adjust itself according to the flux so that every time B-H relationship is satisfied.



- Consider a coil having N turns wound on iron core. The coil carries an alternating current 'i' varying sinusoidal. The flux Φ produced by the exciting current 'I' is also sinusoidal varying with time.Let

  N- No. of turns

  I-Current flowing in coil

  Φ – Flux produced by the coil.

By Faradays law,

$$e = N\frac{d\Phi}{dt}$$

For AC Circuit, $\Phi\Phi = \Phi_m \sin \omega t$

$$e = N\frac{d(\Phi_m \sin \omega t)}{dt}$$

$$e = \boldsymbol{N\Phi_m} \cos \omega t \,.\, \boldsymbol{\omega}$$

From the above equation consider the magnitude alone,

$$e_m = N\Phi_m \omega$$

RMS value is given by,

$$e_{RMS} = \frac{e_m}{\sqrt{2}}$$

$$e_{RMS} = \frac{N\Phi_m \omega}{\sqrt{2}}$$

Where $\omega = 2\pi f$

$$e_{RMS} = \frac{N\Phi_m (2\pi f)}{\sqrt{2}}$$

$$e_{RMS} = 4.44 N\Phi_m f$$

Energy stored in AC circuit;

Energy is the product of power and time.

$$\text{Energy} = \text{power} * \text{time}$$

$$\text{Power} = e * i$$

$$\text{Power} = e * i = N\frac{d\Phi}{dt} * i$$

$$\text{Power} = i * \frac{d\lambda}{dt}$$

For AC Circuit, $\text{Energy} = W_f$

$$W_f = \text{power} * \text{time}$$

$$W_f = \int_{t1}^{t2} i * \frac{d\lambda}{dt} * dt$$

$$W_f = \int_{t1}^{t2} i * d\lambda$$

Change the limit,

$$W_f = \int_{\lambda 1}^{\lambda 2} i * d\lambda$$

$$W_f = \int_{\lambda 1}^{\lambda 2} \frac{Hl}{N} * d\lambda$$

$$W_f = \int_{\lambda 1}^{\lambda 2} \frac{Hl}{N} * \mathbf{N}d\Phi$$

$$W_f = \int_{\lambda 1}^{\lambda 2} Hl * d\Phi$$

$$W_f = \int_{\lambda 1}^{\lambda 2} Hl * d(\mathbf{Ba})$$

$$W_f = \int_{B1}^{B2} Hl * \boldsymbol{a} * d\mathbf{B}$$

The above equation is the energy stored in AC circuit.

Energy per unit volume:

$$W_f = \int_{B1}^{B2} Hl\boldsymbol{a} * d\mathbf{B}$$

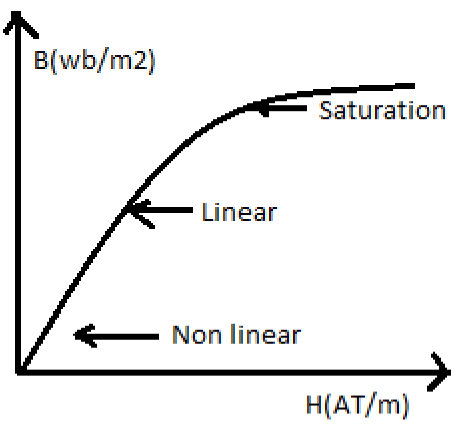
$$W_f = \int_{B1}^{B2} Hl\boldsymbol{a} * d\mathbf{B}$$

$$W_f = \int_{B1}^{B2} H * d\mathbf{B}$$

The above equation is the energy stored per unit volume in AC circuit.

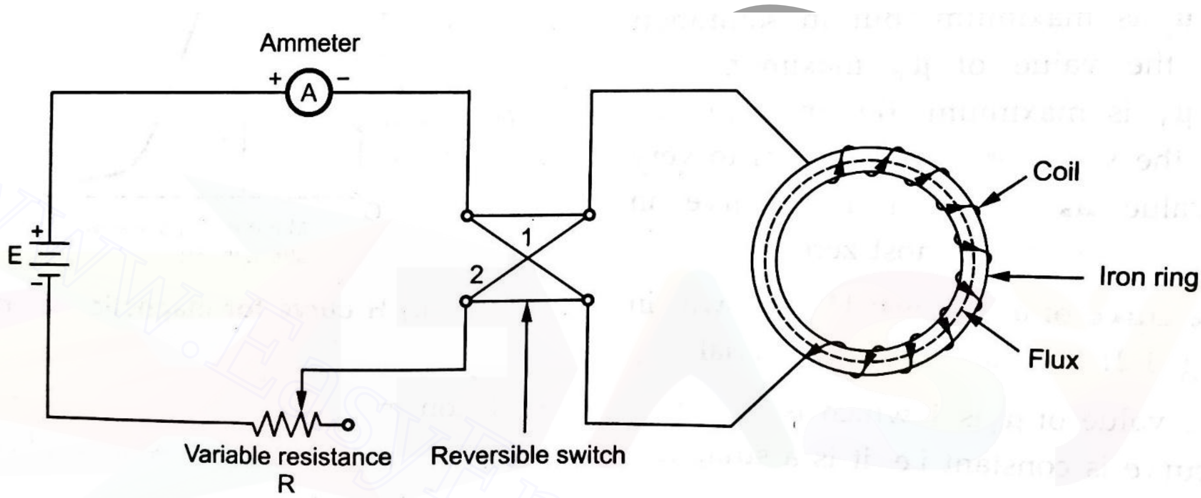
4.Explain the Hysteresis loop that occurs in magnetic circuits in B-H relationship (magnetization characteristics)

- The permeability $\mu 0$ is constant so that B-H relationship is linear-H relationship is strictly nonlinear in two parts respects-saturation and hysteresis.



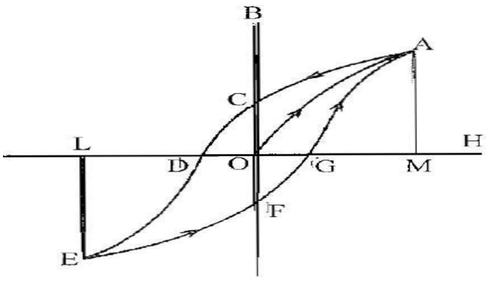
Hysteresis on linearity is the doubled value of B-H relationship exhibited in cyclic variation of H.

- Let us take a un magnetized bar of iron AB and magnetize in by placing it within the magnetizing field of a solenoid (H). The Field can be increased or decreased by increasing or decreasing current through it. Let `H' be increased in step from zero up to a certain maximum value and the corresponding of induction flux density (B) is noted.
- If we plot the relation between H and B, a curve like OA, as shown in Figure, is



obtained. The material becomes magnetically saturated at H = OM and has, at that time, a maximum flux density, established through it. If H is now decreased gradually (by decreasing solenoid current) flux density B will not decrease along AO (as might be expected) but will decrease less rapidly along AC.

- When it is Zero B is not zero, but has a definite value = OC. It means that on removing the magnetizing force H, the iron bar is not completely demagnetized This value of B (=OC) is called the residual flux density.
- To demagnetize the iron bar we have to apply the magnetizing force H in the reverse direction. When H is reversed by reversing current through the solenoid, then B is reduced to Zero at point D where H - OD.
- This value of H required to wipe off residual magnetism is known as coercive force and is a measure of the coercivity of materials i.e. its `tenacity' with which it holds on to its magnetism.



- This value of H required to wipe off residual magnetism is known as coercive force and is a measure of the coercively of materials i.e. its `tenacity' with which it holds on to its magnetism.
- After the magnetization has been reduced to zero value of H is further increased in the negative i.e. reverse direction, the iron bar again reaches a state of magnetic saturation represented by point E. By taking H back from its value corresponding to negative saturation (=OL) to its value for positive saturation (=OM), a similar curve EFGA is obtained. If we again start from G, the same curve GACDEFG is obtained once again.
- It is seen that B always lags behind H the two never attain zero value simultaneously. This lagging of B, behind H is given the name Hysteresis' which literally means `to lag behind.' The closed Loop ACDEFGA, which is obtained when iron bar is taken through one complete cycle of reversal of magnetization, is known as Hysteresis loop.

5.Explain the core losses that occurs in magnetic circuits in detail. **.[MAY/JUNE 2015,NO/DEC 2015,NOV/DEC 2012]**

Iron or Core losses

- These losses occur in the armature of a d.c. machine and are due to the rotation of armature in the magnetic field of the poles.

  They are of two types i) Hysteresis loss ii) Eddy current loss.

Hysteresis loss

- Hysteresis loss occurs in the armature of the d.c. machine since any given part of the armature is subjected to magnetic field reversals as it passes under successive poles. shows an armature rotating in two-pole machine. Consider a small piece ab of the armature.
- When the piece ab is under N-pole, the magnetic lines pass from a to b. Half are volition later, the same piece of iron is under S-pole and magnetic lines pass from b to a In order to reverse continuously the molecular magnets in the armature core, some amount of power has to be spent which is called hysteresis loss. It is

given by Steinmetz formula. This formula is

Hysteresis loss, $P_h = B^{16}_{max} fV$ watts

where

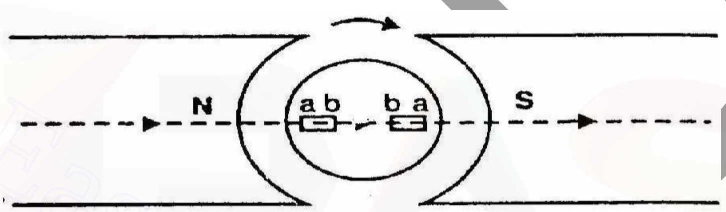
B_{max} = Maximum flux density in armature

f = Frequency of magnetic reversals

V = Volume of armature in m^3

h = Steinmetz hysteresis co-efficient

- In order to reduce this loss in a d.c. machine, armature core is made of such materials which have a low value of Steinmetz hysteresis co-efficient e.g., silicon steel Eddy current loss
- In addition to the voltages induced in the armature conductors, there are also



voltages induced in the armature core. These voltages produce circulating currents in the armature core.

- These are called eddy currents and power loss due to their flow is called eddy current loss. The eddy current loss appears as heat which raises the temperature of the machine and lowers its efficiency.
- If a continuous solid iron core is used, the resistance to eddy current path will be small due to large cross-sectional area of the core. Consequently, the magnitude of eddy current and hence eddy current loss will be large. The magnitude of eddy current can be reduced by making core resistance as high as practical.
- The core resistance can be greatly increased by constructing the core of thin, round iron sheets called laminations. The laminations are insulated from each other with a coating of varnish.
- Thus laminating a core increases the core resistance which decreases the eddy current loss.

Eddy current loss, $P_e = K_e B^2_{max} f^2 t^2 V$ watts

where,

K_e = Constant

B_{max} = Maximum flux density in Wb/m^2

f = Frequency of magnetic reversals in Hz

t = Thickness of lamination in m

V = Volume of core in m^3

PART C

1. **The total core loss of a specimen of silicon steel is found to be 1500W at 50 Hz, keeping the flux density to be constant, the loss become 3000W. When the frequency is raised to 75 Hz. Calculate the separately hysteresis loss and eddy current losses at each frequency. [Non/Dec 15]**

Solution

Hysteresis loss = $(B_M)^{1.6}Vk_Hf$

$W_h=Af$

$Ke(B_M)^2 t^2Vf^2$

$W_e= Bf^2$

Now core loss, $P=W_e+W_h$

$P=Af+Bf^2$

$P/f= A+Bf$ -------------------(A)

At 50 Hz, Core loss is 1500W

1500/50=A+50B

30= A+50B --------(1)

At 75 Hz, Core loss is 3000W

3000/60=A+75B

40= A+75B ---------------(2)

Solving (1) and (2) we get,

25B=10

B=0.4

Therefore

A=10

At 50 Hz

Hysteresis loss = Af = 10*50=500W

Eddy current loss= $Bf^2=0.4*(50)^2=1000W$

At 75 Hz

Hysteresis loss = Af = 10*75=750W

Eddy current loss= $Bf^2=0.4*(75)^2=2250W$

2. **A steel ring has a mean diameter of 20cm and cross sectional area 0f 25 cm^2 and a radial air gap of 0.8 mm. when excited by a current of 1A through a**

coil of 1000 turns wound on the ring core, it produces a air gap flux of 1 mWb Neglect the leakage flux. Calculate Relative permeability of steel and total reluctance of magnetic circuit.

Solution

A= 25 cm^2

L_g=0.8mm

I=1A

N=1000 turns

Φ=1mWb

Mean diameter=20 cm

Length of air gap=πd – length of air gap.

=π($20*10^{-2}$) – ($0.8*10^{-3}$)

L_i=0.6272m

$$\varphi = \frac{NI}{S_t}$$

$$S_t = \frac{NI}{\varphi} = \frac{1000 * 1}{1 * 10^{-3}}$$

$$S_t = 1000000 AT/Wb$$

$$S_t = S_i + S_g$$

$$S_g = \frac{L_g}{\mu_0 A} = \frac{0.8 * 10^{-3}}{\mu_0 * 25 * 10^{-2}}$$

$$S_g = 254777\ AT/Wb$$

$$S_i = S_T + S_g = 1000000 - 254777$$

$$S_i = 745222 AT/Wb$$

$$S_i = \frac{L_i}{\mu_0\, \mu_r A}$$

$$\mu_r = \frac{L_i}{\mu_0 S_i A} = \frac{0.6272}{4\pi * 10^{-7} * 25 * 10^{-2} * 745222}$$

$$\mu_r = \mathbf{268}$$

Relative Permeability Of Steel=268

Total Reluctance Of Magnetic Circuit=$1000000 AT/Wb$

3. **A iron bar of 30 cm long and 2 cm in diameter is bent into a circular shape. It is then wound into with a wire of 600 turns. Calculate the current require**

to produce a flux of 0.5mWb. If with no air gap and with a air gap of 1mm and μ_r=4000.

Solution:

$L_i = 30 * 10^{-2} m$

$d = 2 * 10^{-2} m$

N =600 turns

(i) With No air gap

$$A = \frac{\pi d^2}{4} = \frac{\pi(2 * 10^{-2})^2}{4} = \pi * 10^{-4} m^2$$

$$S_i = \frac{L_i}{\mu_0 \mu_r A} = \frac{30 * 10^{-2}}{4\pi * 10^{-7} * 4000 * \pi * 10^{-4}}$$

$$S_i = 1.9 * 10^5 \ AT/Wb$$

$$\varphi = \frac{NI}{S_i}$$

$$0.5 * 10^{-3} = \frac{600 * I}{1.9 * 10^5}$$

$$\boldsymbol{I = 0.158A}$$

(ii) With air gap

$$S_g = \frac{L_g}{\mu_0 \mu_r A} = \frac{1 * 10^{-3}}{4\pi * 10^{-7} * 1 * \pi * 10^{-4}}$$

$$S_g = 25.33 * 10^5 AT/Wb$$

$$S_t = S_i + S_g = 1.9 * 10^5 + 25.33 * 10^5$$

$$S_t = 27.1 * 10^5 AT/Wb$$

$$\varphi = \frac{NI}{S_t}$$

$$0.5 * 10^{-3} = \frac{600 * I}{27.1 * 10^5}$$

$$\boldsymbol{I = 2.258A}$$

UNIT – II

TRANSFORMERS

PART-A

1.Does transformer draw any current when secondary is open? Why?

yes, it(primary) will draw the current from the main supply in order to magnetize the core and to supply for iron and copper losses on no load. There will not be any current in the secondary since secondary is open.

2. Why transformers are rated in kVA?[NOV/DEC 2015,MAY/JUNE 2009]

Copper loss of a transformer depends on current & iron loss on voltage. Hence total losses depend on Volt-Ampere and not on PF. That is why the rating of transformers are in kVA and not in kW.

3.Give the emf equation of a transformer .

Emf induced in coil

$$e_{RMS} = 4.44 N \Phi_m f$$

f-frequency of AC input

Φ_m-maximum value of flux in the core

N-Number of turns.

4.Define voltage regulation.

Regulation is defined as change in magnitude of secondary terminal voltage, when full load i.e rated load of specified power factor supplied at rated voltage is reduced to no load, with primary voltage maintained constant.

$$\%Regulation = \frac{E_2 + V_2}{V_2}$$

5. Mention the applications of single phase auto transformer. [APRIL/MAY 2015]

Variable voltage regulators, variable voltage rectifiers and laboratories.

6. What are the typical uses of auto transformer? [NOV/DEC 2012]

(i)To give small boost to a distribution cable to correct for the voltage drop.

(ii)As induction motor starters.

(iii)As furnace transformers

(iv)As interconnecting transformers

(v)In control equipment for single phase and 3 phase elective locomotives

7. Why are breathers used in transformers?

Breathers are used to entrap the atmospheric moisture and thereby not allowing it to pass on to the transformer oil. Also to permit the oil inside the tank to expand and contract as its temperature increases and decreases. Normally silica gel is filled in the breather having pink colour. This colour will be changed to white due to continuous use, which is an indication of bad silica gel, it is normally heated and reused.

8. Why is the efficiency of a three phase induction motor is less than that of a three phase transformer?

Three phase induction motor is considered as rotating transformer. But due to rotating feature there are friction and wind age losses associated with it. While three phase transformer is a static device and there are no rotational losses present it. Hence the efficiency of a three phase induction motor is less than that of a three phase transformer.

9.Comparision of Core and Shell type transformers. [MAY/JUNE 2014]

Core type	Shell Type
The winding encircles the core	The core encircles most part of the windings
It has single a single magnetic circuit	It has double magnetic circuit.
The cylindrical type of coils are used	Generally, multilayer disc type or sandwich coils are used.
The construction preferred for low voltage transformers.	The construction preferred for high voltage transformers.
In a single phase type, the core has two limbs	In a single phase type, the core has three limbs

10. Distinguish power transformers & distribution transformers? [MAY/JUNE 2012]

Power transformers have very high rating in the order of MVA. They are used in generating and receiving stations. Sophisticated controls are required. Voltage ranges will be very high. Distribution transformers are used in receiving side. Voltage levels will be medium. Power ranging will be small in order of kVA. Complicated controls are not needed.

11.State all day efficiency of a transformer? [NOV/DEC 2012, MAY/JUNE 2009]

It is computed on the basis of energy consumed during a certain period, usually a day of 24 hrs. all day efficiency=output in kWh/input in kWh tor 24 hrs.

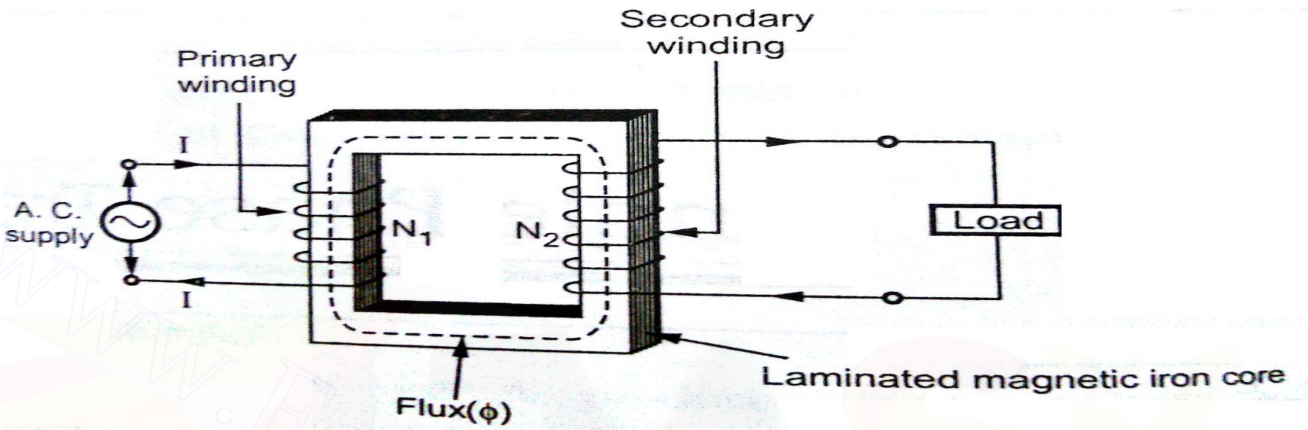
12. What happen when a DC supply is applied to a transformer? [NOV/DEC 2015]

Due to saturation of magnetic core a large current flows through the windings, without induced any emf. This large current burns the windings of the transformer.

PART-B

1.Describe the Construction and working principle of a transformer. [MAY/JUNE 2014, MAY/JUNE 2013,MAY/JUNE 2011]

A transformer can be defined as a static device which helps in the transformation of electric power in one circuit to electric power of the same frequency in another circuit. The voltage can be raised or lowered in a circuit, but with a proportional increase or decrease in the current ratings.



The main principle of operation of a transformer is mutual inductance between two circuits which is linked by a common magnetic flux. A basic transformer consists of two coils that are_electrically separate and inductive, but are magnetically linked through a path of reluctance. The working principle of the transformer can be understood from the figure

The simple construction of a transformer must need two coils having mutual inductance and a laminated steel core.

The two coils are insulated from each other and from the steel core. The device will also need some suitable container for the assembled core and windings, a medium with which the core and its windings from its container can be insulated.

In order to insulate and to bring out the terminals of the winding from the tank, apt bushings that are made from either porcelain or capacitor type must be used.

In all transformers that are used commercially, the core is made out of transformer sheet steel laminations assembled to provide a continuous magnetic path with minimum of air-gap included. The steel should have high permeability and low hysteresis loss.

For this to happen, the steel should be made of high silicon content and must also be heat treated. By effectively laminating the core, the eddy-current losses can be reduced.

The lamination can be done with the help of a light coat of core plate varnish or lay an oxide layer on the surface.

For a frequency of 50 Hertz, the thickness of the lamination varies from 0.35mm to 0.5mm for a frequency of 25 Hertz.

Core Type Transformers

The low voltage windings are placed nearer to the core as it is the easiest to insulate. The effective core area of the transformer can be reduced with the use of laminations and insulation.

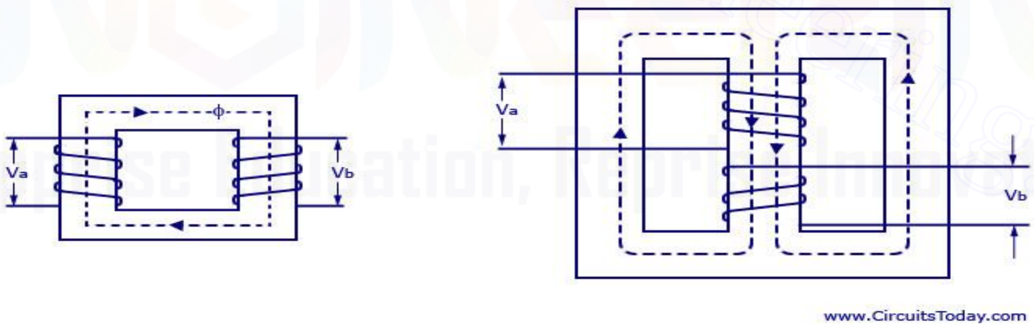
Shell-Type Transformers

In shell-type transformers the core surrounds a considerable portion of the windings. The comparison is shown in the figure below.

Core Type and Shell Type Transformer Winding

The coils are form-wound but are multi-layer disc type usually wound in the form of pancakes. Paper is used to insulate the different layers of the multi-layer discs. The whole winding consists of discs stacked with insulation spaces between the coils. These insulation spaces form the horizontal cooling and insulating ducts. Such a transformer may have the shape of a simple rectangle or may also have a distributed form. Both designs are shown in the figure below:

Core Type and Shell Type Transformer Winding



Shell Type Transformers Distributed Form

A strong rigid mechanical bracing must be given to the cores and coils of the transformers. This will help in minimizing the movement of the device and also prevents the device from getting any insulation damage.

A transformer with good bracing will not produce any humming noise during its working and will also reduce vibration.

A special housing platform must be provided for transformers. Usually, the device is placed in tightly-fitted sheet-metal tanks filled with special insulating oil.

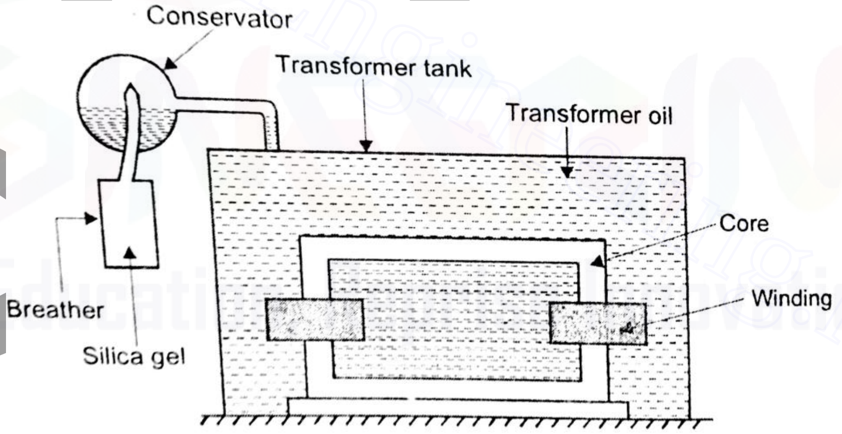
This oil is needed to circulate through the device and cool the coils. It is also responsible for providing the additional insulation for the device when it is left in the air.

The quality, durability and handling of these insulating materials decide the life of the transformer. All the transformer leads are brought out of their cases through suitable bushings. There are many designs of these, their size and construction depending on the voltage of the leads. Porcelain bushings may be used to insulate the leads, for transformers that are used in moderate voltages. Oil-filled or capacitive-type bushings are used for high voltage transformers.

The selection between the core and shell type is made by comparing the cost because similar characteristics can be obtained from both types. Most manufacturers prefer to use shell-type transformers for high-voltage applications or for multi-winding design.

When compared to a core type, the shell type has a longer mean length of coil turn. Other parameters that are compared for the selection of transformer type are voltage rating, kilo-volt ampere rating, weight, insulation stress, heat distribution and so on.

Transformer tank



The tank of liquid filled transformers often has radiators through which the liquid coolant circulates by natural convection or fins.

Some large transformers employ electric fans for forced-air cooling, pumps for forced-liquid cooling, or have heat exchangers for water-cooling.

An oil-immersed transformer may be equipped with a Buchholz relay, which, depending on severity of gas accumulation due to internal arcing, is used to either alarm or de-energize the transformer.

Oil-immersed transformer installations usually include fire protection measures such as walls, oil containment, and fire-suppression sprinkler systems.

Bushings

Larger transformers are provided with high-voltage insulated bushings made of polymers or porcelain. A large bushing can be a complex structure since it must provide careful control of the electric field gradient without letting the transformer leak oil.

Buchholz relay

Buchholz relay is a safety device which is generally used in large oil immersed transformers (rated more than 500 kVA). It is a type of oil and gas actuated protection relay. It is used for the protection of a transformer from the faults occurring inside the transformer, such as impulse breakdown of the insulating oil, insulation failure of turns etc. Working principle of buchholz's relay

The tank of liquid filled transformers often has radiators through which the liquid coolant circulates by natural convection or fins. Some large transformers employ electric fans for forced-air cooling, pumps for forced-liquid cooling, or have heat exchangers for water-cooling. An oil-immersed transformer may be equipped with a Buchholz relay, which, depending on severity of gas accumulation due to internal arcing, is used to either alarm or de-energize the transformer. Oil-immersed transformer installations usually include fire protection measures such as walls, oil containment, and fire-suppression sprinkler systems

Transformer Working

Transformer has primary and secondary windings. The core laminations are joined in the form of strips in between the strips you can see that there are some narrow gaps right through the cross-section of the core. These staggered joints are said to be 'imbricated'. Both the coils have high mutual inductance. A mutual electro-motive force is induced in the transformer from the alternating flux that is set up in the laminated core, due to the coil that is connected to a source of alternating voltage. Most of the alternating flux developed by this coil is linked with the other coil and thus produces the mutual induced electro-motive force. The so produced electro-motive force can be explained with the help of Faraday's laws of Electromagnetic Induction as

$$e=M*dI/dt$$

If the second coil circuit is closed, a current flows in it and thus electrical energy is transferred magnetically from the first to the second coil.

The alternating current supply is given to the first coil and hence it can be called as the primary winding. The energy is drawn out from the second coil and thus can be called as the secondary winding.

In short, a transformer carries the operations shown below:

- Transfer of electric power from one circuit to another.
- Transfer of electric power without any change in frequency.
- Transfer with the principle of electromagnetic induction.
- The two electrical circuits are linked by mutual induction.

This is a very useful device, indeed. With it, we can easily multiply or divide voltage and current in AC circuits.

Indeed, the transformer has made long-distance transmission of electric power a practical reality, as AC voltage can be “stepped up” and current “stepped down” for reduced wire resistance power losses along power lines connecting generating stations with loads.

At either end (both the generator and at the loads), voltage levels are reduced by transformers for safer operation and less expensive equipment.

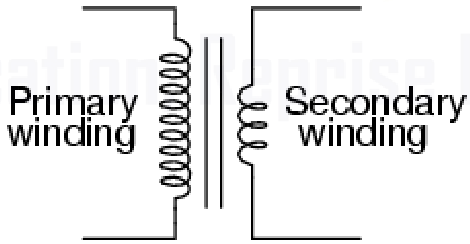
Conversely, a transformer designed to do just the opposite is called a step-down transformer.

Step up Transformer:

A transformer that increases voltage from primary to secondary (more secondary winding turns than primary winding turns) is called a step-up transformer.

Step down Transformer:

A transformer that decreases voltage from primary to secondary (less secondary



winding turns than primary winding turns) is called a step-down transformer.

2. Explain parallel operation of single phase transformer. and derive the emf equation of transformers. **[APRIL/MAY 2015,MAY/JUNE 2014,NOV/DEC 2012,MAY/JUNE 2011]**

PARALLEL OPERATION OF TRANSFORMERS

By parallel operation we mean two or more transformers are connected to the same supply bus bars on the primary side and to a common bus bar/load on the secondary side. Such requirement is frequently encountered in practice. The reasons that necessitate parallel operation are as follows:

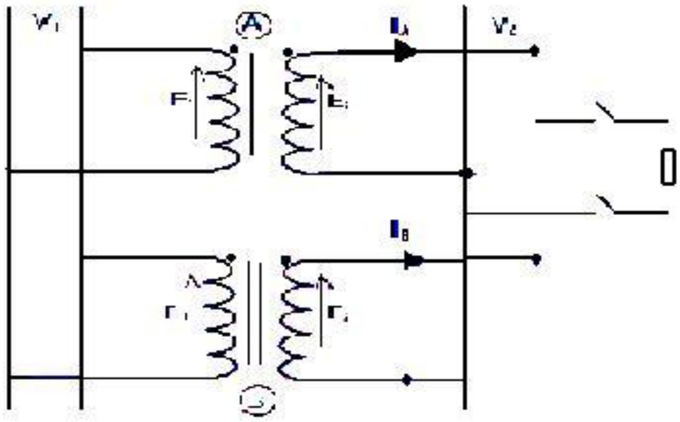
1. Non-availability of a single large transformer to meet the total load requirement.

2. The power demand might have increased over a time necessitating augmentation of the capacity. More transformers connected in parallel will then be pressed into service.
3. To ensure improved reliability. Even if one of the transformers gets into a fault or is taken out for maintenance/repair the load can have continued to be serviced.
4. To reduce the spare capacity. If many smaller size transformers are used one machine can be used as spare. If only one large machine is feeding the load, a spare of similar rating has to be available. The problem of spares becomes more acute with fewer machines in service at a location.
5. When transportation problems limit installation of large transformers at site, it may be easier to transport smaller ones to site and work them in parallel. Fig. 37 shows the physical arrangement of two single phase transformers working in parallel on the primary side. Transformer A and Transformer B are connected to input voltage bus bars. After ascertaining the polarities they are connected to output/load bus bars. Certain conditions have to be met before two or more transformers are connected in parallel and share a common load satisfactorily. They are,

1. The voltage ratio must be the same.
2. The per unit impedance of each machine on its own base must be the same.
3. The polarity must be the same, so that there is no circulating current between the transformers.
4. The phase sequence must be the same and no phase difference must exist between the voltages of the two transformers.

Where ,V_1=Load bus voltage V_2=Supply voltage

These conditions are examined first with reference to single phase transformers and then the three phase cases are discussed. Same voltage ratio generally the turns ratio and voltage ratio are taken to be the same. If the ratio is large there can be considerable error in the voltages even if the turns ratios are the same. When the primaries are connected to same bus bars, if the secondary's do not show the same voltage, paralleling them would result in a circulating current between the secondaries. Reflected circulating current will be there on the primary side also. Thus even without connecting a load considerable current can be drawn by the transformers and they produce copper losses. In two identical transformers with percentage impedance of 5 percent, a no-load voltage difference of one percent will result in a circulating current of 10 percent of full load current. This circulating current gets added to the load current when the load is connected resulting in unequal sharing of the load



. $P_A=V_2I_A$

$P_B=V_2I_B$

$P_A=P^*(Z_B/Z_A+Z_B)$

$P_B=P^*(Z_A/Z_A+Z_B)$

EMF EQUATION OF THE TRANSFORMER

In a transformer, source of alternating current is applied to the primary winding. Due to this, the current in the primary winding (called as magnetizing current) produces alternating flux in the core of transformer. This alternating flux gets linked with the secondary winding, and because of the phenomenon of mutual induction an emf gets induced in the secondary winding. Magnitude of this induced emf can be found by using the following

EMF equation of the transformer.

Let,

N_1 = Number of turns in primary winding

N_2 = Number of turns in secondary winding

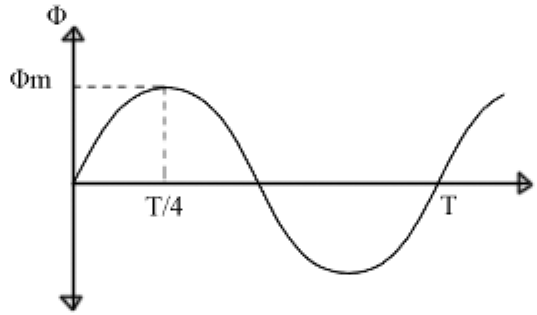
Φ_m = Maximum flux in the core (in Wb) = (B_m x A)

f = frequency of the AC supply (in Hz)

The flux rises sinusoidally to its maximum value Φ_m from 0.

It reaches to the maximum value in one quarter of the cycle i.e in T/4 sec

(where, T is time period of the sin wave of the supply = 1/f).



Therefore, average rate of change of flux = $\Phi_m / (T/4) = \Phi_m / (1/4f)$

Therefore, average rate of change of flux = $4f\ \Phi_m$ .... (Wb/s).

Now, Induced emf per turn = rate of change of flux per turn

Therefore, average emf per turn = $4f\ \Phi_m$ ....(Volts).

Now, we know,Form factor = RMS value / average value

Therefore, RMS value of emf per turn = Form factor X average emf per turn.

As, the flux Φ varies sinusoidally, form factor of a sine wave is 1.11

Therefore, RMS value of emf per turn = $1.11 \times 4f\ \Phi_m = 4.44f\ \Phi_m$

RMS value of induced emf in whole primary winding (E_1) = RMS value of emf per turn X Number of turns in primary winding

$E_1 = 4.44f\ N_1\ \Phi_m$ .... eq 1

Similarly, RMS induced emf in secondary winding (E_2) can be given as

$E_2 = 4.44f\ N_2\ \Phi_m$. .... eq 2

from the above equations 1 and 2,

$$E_1/N_1=E_2/N_2=K=4.44f\ \Phi_m$$

- This is called the **emf equation of transformer**, which shows, emf / number of turns is same for both primary and secondary winding.
- For an ideal transformer on no load, $E_1 = V_1$ and $E_2 = V_2$.
- where, V_1 = supply voltage of primary winding
  V_2 = terminal voltage of secondary winding

Voltage Transformation Ratio (K)

As derived above,

$$E_1/N_1=E_2/N_2$$

Where, K = constant

This constant K is known as **voltage transformation ratio**.

- If $N_2 > N_1$, i.e. $K > 1$, then the transformer is called step-up transformer.
- If $N_2 < N_1$, i.e. $K < 1$, then the transformer is called step-up transformer.

3. Explain the working and construction of auto transformer in detail.[NOV/DEC 2015,MAY/JUNE 2012,NOV/DEC 2009]

An **auto transformer** is an electrical transformer having only one winding.The part of the winding both primary and secondary

The winding has at least three terminals which is explained in the construction details

Some of the **advantages of auto-transformer** are that,

- They are smaller in size,
- Cheap in cost,
- Low leakage reactance,
- Increased kVA rating,
- Low exciting current etc.

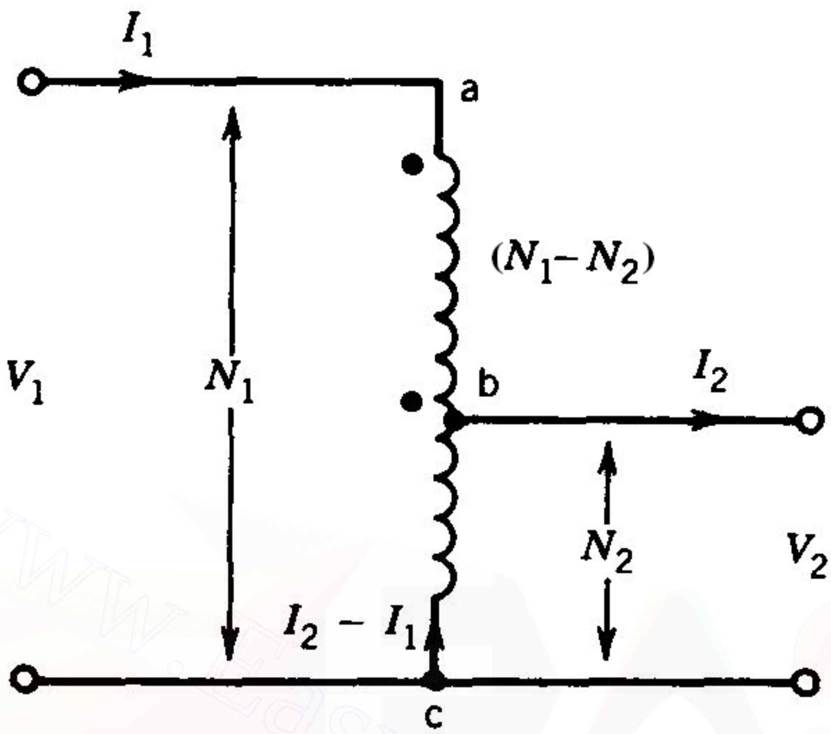
An example of **application of auto transformer** is, using an US electrical equipment rated for 115 V supply (they use 115 V as standard) with higher Indian voltages. Another example could be in starting method of three phase induction motors.

CONSTRUCTION OF AUTO TRANSFORMER

An auto transformer consists of a single copper wire, which is common in both primary as well as secondary circuit. The copper wire is wound a laminated silicon steel core, with at least three tappings taken out. Secondary and primary circuit share the same neutral point of the winding The construction is well explained in the diagram. Variable turns ratio at secondary can be obtained by the tappings of the winding (as shown in the figure), or by providing a smooth sliding brush over the winding. Primary terminals are fixed. Thus, in an auto transformer, you may say, primary and secondary windings are connected magnetically as well as electrically.

Working of auto transformer

As I have described just above, an auto transformer has only one winding which is shared by both primary and secondary circuit, where number of turns shared by



secondary are variable. EMF induced in the winding is proportional to the number of turns. Therefore, the secondary voltage can be varied by just varying secondary number of turns.

As winding is common in both circuits, most of the energy is transferred by means of electrical conduction and a small part is transferred through induction.

$$\frac{\text{Copper in auto transformer}}{\text{Copper in two winding transformer}} = \frac{(N_1-N_2)I_1+N_2(I_2-I_1)}{N_1I_1+N_2I_2}$$

$$=1-(2N_2I_1/N_1I_1+N_2I_2)$$

But $N_1I_1=N_2I_2$

The Ratio$=1-(2N_2I_1/2N_1I_1)=1-(N_2/N_1)=1-K$

This means that an auto transformer requires the use of lesser quantity of copper given by the ratio of turns. This ratio therefore denotes the savings in copper. As the space for the second winding need not be there, the window space can be less for an auto transformer, giving some saving in the lamination weight also. The larger the ratio of the voltages, smaller is the savings. As T2 approaches T1 the savings become significant. Thus auto transformers become ideal choice for close ratio transformations. The savings in material is obtained, however, at a price. The electrical isolation between primary and secondary

The considerable disadvantages of an auto transformer are,

- Any undesirable condition at primary will affect the equipment at secondary (as windings are not electrically isolated),
- due to low impedance of auto transformer, secondary short circuit currents are very high,
- harmonics generated in the connected equipment will be passed to the supply.

Advantages of Autotransformers:

- Its efficiency is more when compared with the conventional one.
- Its size is relatively very smaller.
- Voltage regulation of autotransformer is much better.
- Lower cost
- Low requirements of excitation current.
- Less copper is used in its design and construction
- In conventional transformer the voltage step up or step down value is fixed while in autotransformer, we can vary the output voltage as per out requirements and can smoothly increase or decrease its value as per our requirement.

4.Explain the Equivalent circuit of Transformer [NOV/DEC 2012,NOV/DEC 2009]

The assumption made are,

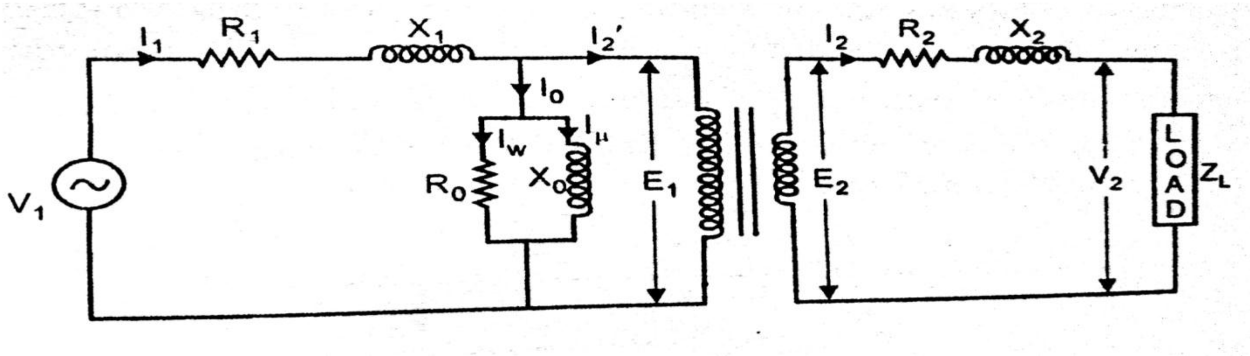
(a) Some leakage flux is present at both primary and secondary sides. This leakage gives rise to leakage reactance's at both sides, which are denoted as X_1 and X_2 respectively.

(b) Both the primary and secondary winding possesses resistance, denoted as R_1 and R_2 respectively. These resistances cause voltage drop as, I_1R_1 and I_2R_2 and also copper loss $I_1^2R_1$ and $I_2^2R_2$.

(c) Permeability of the core cannot be infinite hence some magnetizing current is needed. Mutual flux also causes core loss in iron parts of the transformer.

Equivalent circuit of transformer

Resistances and reactance's of transformer, which are described above, can be imagined separately from the windings (as shown in the figure below). Hence, the function of windings, thereafter, will only be the transforming the voltage.



The no load current I_0 is divided into, pure inductance X_0 (taking magnetizing components I_μ) and non induction resistance R_0 (taking working component I_w) which are connected into parallel across the primary. The value of E_1 can be obtained by subtracting I_1Z_1 from V_1. The value of R_0 and X_0 can be calculated as,

$R_0 = E_1 / I_w$ and $X_0 = E_1 / I_\mu$.

But, using this equivalent circuit does not simplify the calculations. To make calculations simpler, it is preferable to transfer current, voltage and impedance either to primary side or to the secondary side. In that case, we would have to work with only one winding which is more convenient.

From the voltage transformation ratio, it is clear that,

$E_1 / E_2 = N_1 / N_2 = K$

Now, lets refer the parameters of secondary side to primary.

Z_2 can be referred to primary as Z_2'

where, $Z_2' = (N_1/N_2)^2 Z_2 = K^2 Z_2$. ....where $K= N_1/N_2$.

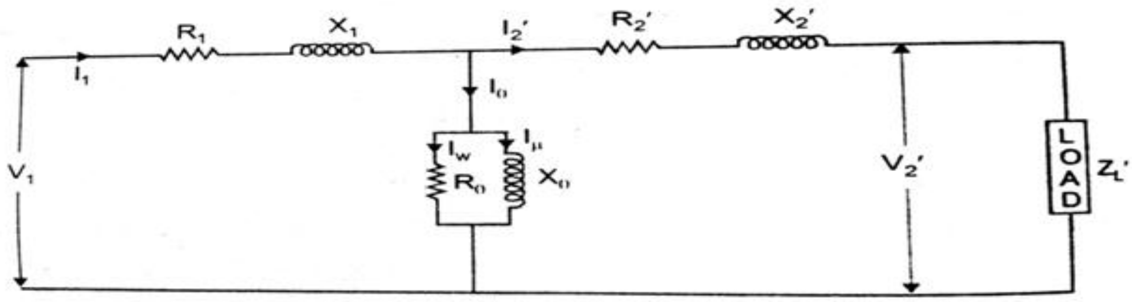
that is, $R_2'+jX_2' = K^2(R_2+jX_2)$

equating real and imaginary parts,

$R_2' = K^2R_2$ and $X_2' = K^2X_2$.

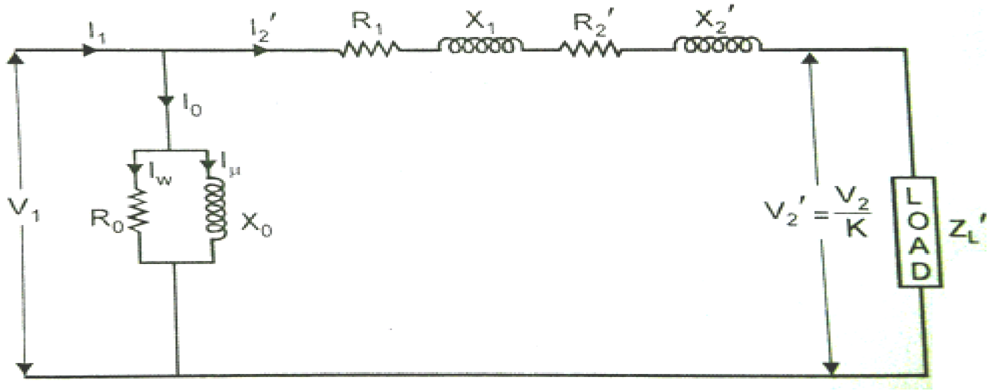
And $V_2' = KV_2$

The following figure shows the **equivalent circuit of transformer with**



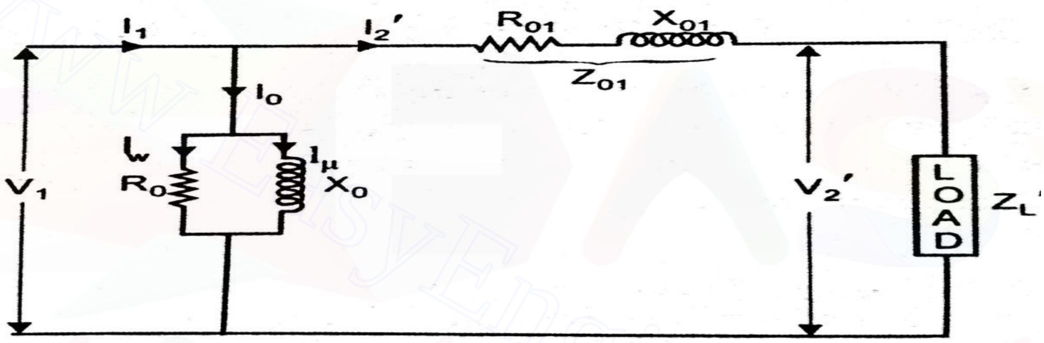
secondary parameters referred to the primary.

Now, as the values of winding resistance and leakage reactance are so small that, V_1 and E_1 can be assumed to be equal. Therefore, the exciting current drawn by the parallel combination of R_0 and X_0 would not affect significantly, if we move it to the input terminals as shown in the figure below.



Now, let $R_1 + R_2' = R'eq$ and $X_1 + X_2' = X'eq$

Then the **equivalent circuit of transformer** becomes as shown in the figure below



5.Explain in detail about Tap Changing of transformer.

Tap Changing

Regulating the voltage of a transformer is a requirement that often arises in a power application or power system. In an application it may be needed

1. To supply a desired voltage to the load.
2. To counter the voltage drops due to loads.
3. To counter the input supply voltage changes on load.

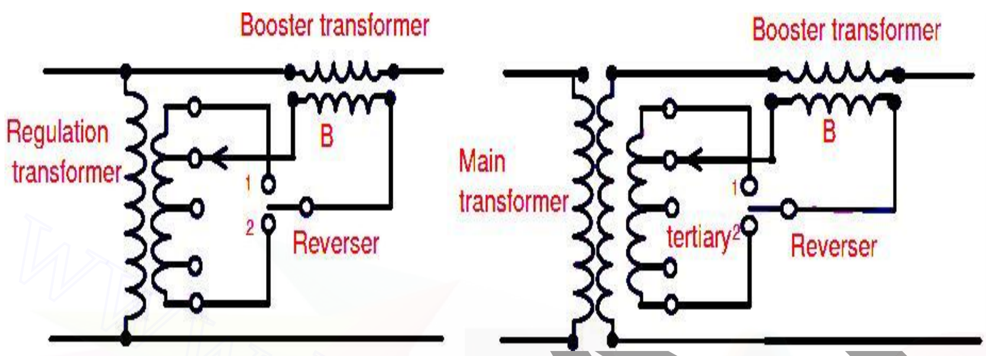
On a power system the transformers are additionally required to perform the task of regulation of active and reactive power flows.

The voltage control is performed by changing the turns ratio. This is done by provision of taps in the winding. The volts per turn available in large transformers is quite high and hence a change of even one turn on the LV side represents a large percentage change in the voltage. Also the LV currents are normally too large to take out the tapping from the windings. LV winding being the inner winding in a core type transformer adds to the difficulty of taking out of the taps.

Hence irrespective of the end use for which tapping is put to, taps are provided on the HV winding.

This may be called buck-boost arrangement. In addition to the magnitude, phase of the injected voltage may be varied in power systems. The tap changing arrangement and buck boost arrangement with phase shift are shown in Fig.

Tap changing can be effected when a) the transformers is on no- load and b) the load is still remains connected to the transformer



Taps	Switches closed
1	1,S
2	1,2
3	2,S
4	2,3
5	3,S
6	3,4
7	4,S
8	4,5

Provision of taps to control voltage is called tap changing. In the case of power systems, voltage levels are sometimes changed by injecting a suitable voltage in series with the line.

. These are called off load tap changing and on load tap changing. The Off load taps changing relatively costs less. The tap positions are changed when the transformer is taken out of the circuit and reconnected. The on-load tap changer on the other hand tries to change the taps without the interruption of the load current.

In view of this requirement it normally costs more. A few schemes of on-load tap changing are now discussed. Reactor method The diagram of connections is shown in Fig. 43. This method employs an auxiliary reactor to assist tap changing. The switches for the taps and that across the reactor(S) are connected as shown. The reactor has a center tapped winding on a magnetic core. The two ends of the reactor are connected to the two bus bars to which tapping switches of odd/even numbered taps are connected. When only one tap is connected to the reactor the shorting switch S is closed minimizing the drop in the reactor. The reactor can also be worked with both ends connected to two successive taps. In that case the switch 'S' must be kept open. The reactor limits the circulating current between the taps in such a situation. Thus a four step tapped winding can be used for getting seven step voltage on the secondary.

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1. Load need not be switched.
2. More steps than taps are obtained.
3. Switches need not interrupt load current as a alternate path is always provided.

The major objection to this scheme seems to be that the reactor is in the circuit always generating extra loss. Parallel winding, transformer method In order to maintain the continuity of supply the primary winding is split into two parallel circuits each circuit having the taps. as

Two circuit breakers A and B are used in the two circuits. Initially tap 1a and 1b are closed and the transformer is energized with full primary voltage. To change the tap the circuit breaker A is opened momentarily and tap is moved from 1a to 2a. Then circuit breaker A is closed. When the circuit A is opened whole of the primary current of the transformer flows through the circuit B. A small difference in the number of turns between the two circuit exists. This produces a circulating current between them. Next, circuit breaker B is opened momentarily, the tap is changed from 1b to 2b and the breaker is closed. In this position the two circuits are similar and there is no circulating current. The circulating current is controlled by careful selection of the leakage reactance.

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The circulating current is controlled by careful selection of the leakage reactance. Generally, parallel circuits are needed in primary and secondary to carry the large current in a big transformer. Provision of taps switches and circuit breakers are to be additionally provided to achieve tap changing in these machines. Series booster method in this case a separate transformer is used to buck/boost the voltage of the main transformer. The main transformer need not be having a tapped arrangement.

This can be obtained with the help of moving coil voltage regulators. Moving coil voltage regulator shows the physical arrangement of one such transformer. a, b are the two primary windings wound on a long core, wound in the opposite sense. Thus the flux produced by each winding takes a path through the air to link the winding. These fluxes link their secondary's a2 and b2. A short circuited moving coil s is wound on the same limb and is capable of being held at any desired position. This moving coil alters the inductances of the two primaries. The sharing of the total applied voltage thus becomes different and also the induced emf in the secondary's a2 and b2.

The total secondary voltage in the present case varies from 10 percent to 20 percent of the input in a continuous manner. By selecting proper ratios for the secondary's a2 and b2 one can get the desired voltage variation. Sliding contact regulators these have two winding or auto transformer like construction.

The winding from which the output is taken is bared and a sliding contact taps the voltage. The minimum step size of voltage change obtainable is the voltage across a single turn. The conductor is chosen on the basis of the maximum load current on the output side. In smaller ratings this is highly cost effective. Two winding arrangements are also possible. The two winding arrangement provides electrical isolation also.

PART C

1. **A 100 KVA, 3300/240 V, 50 Hz single phase transformer has 990 turns on primary. Calculate the number of turns on secondary and the approximate value of primary and secondary full load currents. [Apr/May 15]**

Solution:

$V_1 = 3300\ V$

$V_2 = 240\ V$

$N_1 = 990\ V$

$N_2 = ?$

$\frac{V_2}{V_1} = \frac{N_2}{N_1}$

$$N_2 = \frac{V_2}{V_1} * N_1$$

$$N_2 = \frac{240}{3300} * 990 = \mathbf{72\ turns}$$

$$I_1 = \frac{KVA}{V_1} = \frac{100 * 10^3}{3300} = 30.30\ A$$

$$\mathbf{I_1 = 30.30\ A}$$

$$I_2 = \frac{KVA}{V_2} = \frac{100 * 10^3}{240} = 416.6\ A$$

$$\mathbf{I_2 = 416.6\ A}$$

2. **A 500 KVA transformer has a core loss of 2200 W and a full load copper loss of 7500 w. If the power factor of load is 0.9 lagging. Calculate the full load efficiency and KVA at maximum efficiency. [Apr/May 15]**

Solution:

$$P_i = 2200\ W$$

$$P_{cu} = 7500\ W$$

$$p.f = 0.9$$

Efficiency at full load at 0.9 power factor

$$\eta = \frac{n\ KVA \cos\varphi}{n\ KVA \cos\varphi * P_i * n^2 P_{cu}} * 100$$

$$\eta = \frac{1 * 500 * 0.9}{(1 * 500 * 0.9) * 2.200 * 1^2 * 7.500} * 100$$

$$\eta = 97.88\%$$

KVA for maximum efficiency:

$$\text{KVA} = Full\ load\ KVA * \sqrt{\frac{P_i}{P_{cu}}}$$

$$\text{KVA} = 500 * \sqrt{\frac{2.2}{7.5}} = 270.8$$

$$\text{KVA for maximum efficiency} = 270.8\ KVA$$

3. **Calculate the efficiency for half and full load of 100 KVA for the power factor of unity and 0.8, the copper loss at full load is 1000 W and iron loss is 1000W[Nov/Dec 2015].**

Solution:

$$P_i = 1000\ W$$

$$P_{cu} = 1000\ W$$

$$KVA = 100$$

At half load and unity power factor.

$n = 0.5, cos\varphi = 1$

$$\eta = \frac{n\ KVA \cos\varphi}{n\ KVA \cos\varphi * P_i * n^2 P_{cu}} * 100$$

$$\eta = \frac{0.5 * 100 * 1}{(0.5 * 100 * 1) * 1 * 0.5^{2*} 1} * 100$$

$\eta = 97.56\%$

At full load and 0.8 power factor

$n = 1, cos\varphi = 0.8$

$$\eta = \frac{n\ KVA \cos\varphi}{n\ KVA \cos\varphi * P_i * n^2 P_{cu}} * 100$$

$$\eta = \frac{1 * 100 * 0.8}{(1 * 100 * 0.8) * 1 * 1^{2*} 1} * 100$$

$\eta = 97.56\%$

4. **The primary of the transformer is rated at 10A and 1000V. The open circuit readings are V_1=1000 V, V_2=500 V, I=0.42, P_{ac}=100W. The short circuit readings are I_1=10 A, V_1=125V and P_{ac}=400V. Find the equivalent circuit parameters for the output voltage of Z_L=19+12j ohms. [Apr/May 15]**

Solution:

$P_o = 100\ W$

$V_0 = 500\ v$

$I_0 = 0.42\ A$

$$P_o = V_0 I_0 cos\varphi_0$$

open circuit test

$$cos\varphi_0 = \frac{P_o}{V_0 I_0} = \frac{100}{500 * 0.42} = 0.47$$

$$I_m = I_0 sin\varphi_0 = 0.369\ A$$

$$I_c = I_0 cos\varphi_0 = 0.1992\ A$$

$$R_o = \frac{V_0}{I_c} = 2532.9\ ohms$$

$$X_o = \frac{V_0}{I_m} = 1355.01\ ohms$$

Short circuit test:

$$k = \frac{V_2}{V_1} = 0.5$$

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} = \frac{125}{10} = 12.5\ ohms$$

$$R_{sc} = \frac{W_{sc}}{I_{sc}^2} = \frac{400}{100} = 4\ ohms$$

$$Z_{1e} = \frac{Z_{sc}}{K} = \frac{12.5}{0.5^2} = 50\ ohms$$

$$R_{1e} = \frac{R_{sc}}{K} = \frac{4}{0.5^2} = 16\ ohms$$

$$X_{1e} = \sqrt{({Z_{1e}}^2 - R_{1e}^2)}$$

$X_{1e} = \sqrt{(50^2 - 16^2)}$ =47.37 Ohms

UNIT-3

ELECTRO ELECHANICAL ENERGY CONVERSION

PART-A

1.Describe multiply excited magnetic field system. [MAY/JUNE 2011]

The specially designed transducers have the special requirement of producing an electrical signal proportional to forces or velocities of producing force proportional to electrical signal. Such transducers require two or more excitation called as multiply excited magnetic field system.

2.Write down the advantages of short pitched coil.

The length required for the end connection of coils is less i.e., inactive length of winding is less. So less copper is required. Hence economical. Short pitching eliminated high frequency harmonics which distort the sinusoidal nature of emf. Hence waveform of an induced emf is more sinusoidal due to short pitching. As high frequency harmonics get eliminated, eddy current and hysteresis losses which depend on frequency also get minimized. This increases the efficiency.

3.Give example for single and multiple excited systems? [MAY/JUNE 2013,MAY/JUNE 2009]

Single excited system-reluctance motor, single phase transformer, relay coil

Multiply excited system-alternator, electro mechanical transducer.

4. Write the relation between electrical mechanical degrees. [APIL/MAY 2015]

$\theta_e = \theta_m$ **for two pole machine**

$\theta_e = P/2 * \theta_m$ **for 4 pole a.c machines**

5. Write the application of single and doubly fed magnetic systems? [MAY/JUNE 2013]

Singly excited systems are employed for motion through a limited distance or rotationthrough a prescribed angle. Whereas multiply excited systems are used where continues energy conversion take place and in ease of transducer where one coil

when energized the care of setting up of flux and the other coil when energized produces a proportional signal either electrical or mechanical

6. What is the significance of co energy? [MAY/JUNE 2014,MAY/JUNE 2013]

When electrical energy is fed to coil not the whole energy is stored as magnetic energy. the co energy gives a measure of other energy conversion which takes place in coil then magnetic energy storage

1. Field energy 2. Coenergy

7.Short advantages of short pitched coil?

1.Hormonics are reduced in induced voltage 2.Saving of copper 3.End connections are shorter

8. What is the significance of winding factor? [NOV/DEC 2012]

Winding factor gives the net reduction in emf induced due to short pitched coil wound in distributed type

Winding factor kw=kpkd kp= pitch factor

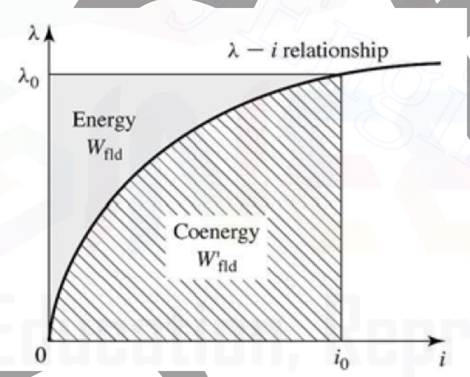
kd= distribution factor kp= cos(α/2)

kd= sin(mγ/2)/msin(γ/2)

9. What is mean by Pole pitch and Chording angle?[NOV/DEC 2008]

- Pole pitch: The distance between the centers of two adjacent poles is called pole pitch. One pole pitch is equal to 180 electrical degrees. It is also defined as the number of slots per pole.
- Chording angle: It is defined as that angle by which the coil pitch departs from 180 electrical degrees.

10. Draw the graphical relation between field energy and coenergy



11. What is meant by SPP? What is its significance ?[NOV/DEC 2015]

SPP = Slots/Pole /Phase The parameter is used to design the poles and inter-poles of a machine core.

12. Why do all practical energy conversion devices make use of the magnetic field as a coupling medium rather than electric field?[APRIL/MAY 2015,MAY/JUNE 2014]

When compared to electric field energy can be easily stored and retrieved form a magnetic system with reduced losses comparatively. Hence most all practical energy conversion devices make use of magnetic medium as coupling

13. Why fractional pitched winding is required than full pitched winding?[NOV/DEC 2015]

Fractional pitch winding require less copper compare to full pitch coil.

- It improves the commutation, and the mutual inductance of fractional pitch coil is smaller than full pitch coil.

PART-B

1. Explain in detail doubly excited magnetic system [APRIL/MAY 2015,NOV/DEC 2015, MAY/JUNE 2013,NOV/DEC 2012,NOV/DEC 2009]

For certain applications like that of electro mechanical transducers required specially two excitations

where one is used for establishing the required magnetic field and other for producing an electrical signal proportional to the force or velocity that is to be measured.

An alternator ay even requires multiple excitations such as one concerned with stator and other dealt with rotor. So it becomes essential to analysis a multiple excited system.

$$T_f=-\partial W_f(\lambda 1, \lambda 2,\theta)/ \partial\theta$$

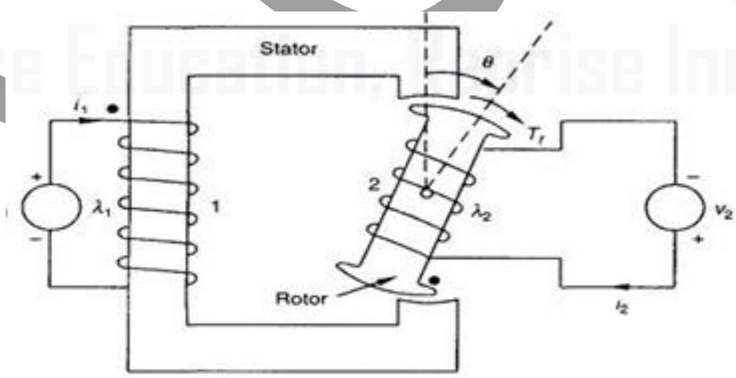
Where, the field energy is given by

$$W_f(\lambda_1, \lambda_2,\theta) =\int_0^{\lambda 1} i1\, d\lambda 1+\int_0^{\lambda 2} i2\, d\lambda 2 \quad \text{---------------} \quad 1$$

Analogous to Equation

$$i1=\partial W_f(\lambda 1, \lambda 2,\theta)/ \partial \lambda 1$$

$$i2=\partial W_f(\lambda 1, \lambda 2,\theta)/ \partial \lambda 2$$



$$\lambda_1=L_{11}i_1+L_{12}i_2 \quad \text{-----------------} \quad 2$$

$$\lambda_2=L_{21}i_1+L_{22}i_2 \;\; (L_{21}= L_{12}) \quad \text{-----------------} \quad 3$$

Solving for i1 and i2 in terms of λ_1, λ_2 and substituting in equation 1

Where the inductances are the functions of angle θ

$i_1= \beta_{11}\lambda_1+\beta_{12}\lambda_2$

$i_2 = \beta_{21}\lambda_1 + \beta_{22}\lambda_2$ ($\beta_{21} = \beta_{12}$)

$Wf(\lambda_1, \lambda_2, \theta) = \int_0^{\lambda 1} (\beta 11 \lambda 1 + \beta 12 \lambda 2)\, d\lambda 1 + \int_0^{\lambda 2} (\beta 21 \lambda 1 + \beta 22 \lambda 2)\, d\lambda 2$

$Wf(\lambda_1, \lambda_2, \theta) = \int_0^{\lambda 1} \beta 11 \lambda 1 d\lambda 1 + \int_0^{\lambda 1} \beta 12 \lambda 2\, d\lambda 1 + \int_0^{\lambda 2} \beta 21 \lambda 1\, d\lambda 2 + \int_0^{\lambda 2} \beta 22 \lambda 2\, d\lambda 2$

$Wf(\lambda_1, \lambda_2, \theta) = \beta 11 \int_0^{\lambda 1} \lambda 1 d\lambda 1 + \beta 12 \int_0^{\lambda 1 \lambda 2} d(\lambda 1 \lambda 2) + \beta 22 \int_0^{\lambda 2} \lambda 2\, d\lambda 2$

$Wf(\lambda 1, \lambda 2, \theta) = 1/2\, \beta_{11} \lambda 1^2 + \beta_{12} \lambda 1\, \lambda 2 + 1/2\, \beta_{22} \lambda 2^2$

$\beta_{11} = L_{22} / (L_{11}L_{22} - L_{12}^2)$

$\beta_{22} = L_{11} / (L_{11}L_{22} - L_{12}^2)$

$\beta_{12} = \beta_{21} = -L_{12} / (L_{11}L_{22} - L_{12}^2)$

The self and mutual inductance of the two exciting coils are functions of angle θ

If currents are used to describe the system state

$T_f = \partial Wf'(\lambda 1, \lambda 2, \theta) / \partial \theta$

Where the co-energy is given by

$Wf'(i_1, i_2, \theta) = \int_0^{i1} \lambda 1\, di1 + \int_0^{i2} \lambda 2\, di2$

$Wf'(i_1, i_2, \theta) = \int_0^{i1} (L11i1 + L12i2)\, di1 + \int_0^{i2} \lambda 2 = (L21i1 + L22i2)\, di2$

$Wf'(i1, i2, \theta) = 1/2\, L_{11}\, i_1^2 + L_{12}\, i_1\, i_2 + 1/2\, L_{22}\, i_2^2$

2.Explain in detail about singly excited magnetic system. [MAY/JUNE 2014, MAY/JUNE 2011,NOV/DEC 2009]

Consider the attracted armature relay excited by an electric source. The field produces a mechanical force F_f in the direction indicated which drives the mechanical system.

The mechanical workdone by the field when the armature moves a distance dx in positive direction is

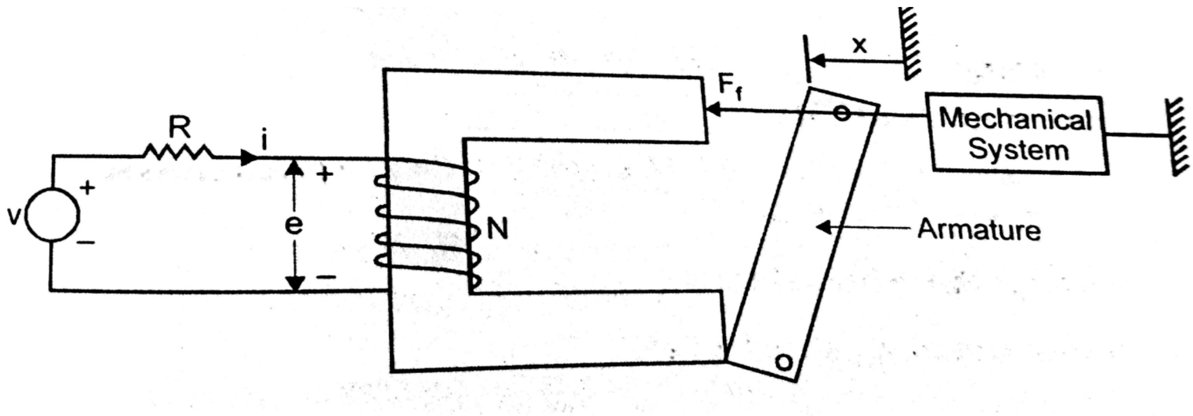
$$dW_m = F_f\, dx$$

This energy is drawn from the field by virtue of change dx in field configuration. As per the principle of energy conservation

Mechanical energy output=electrical energy input – increase in field energy

$$F_f\, dx = id\lambda = dW_f$$

F_f dx is the gross mechanical output, a part of which will be lost in mechanical friction.



$W_f = i\lambda - W_{f'}(i,x)$

Then $dW_f = d(i\lambda) - dW_{f'}(i,x)$

$dW_f = id\lambda + \lambda di - [(\partial W_{f'}/\partial i)\, di + (\partial W_{f'}/\partial x)\, dx]$

$dW_f = id\lambda - [id\lambda + \lambda di - ((\partial W_{f'}/\partial i)\, di + (\partial W_{f'}/\partial x)\, dx)]$

$F_f\, dx = (\partial W_{f'}/\partial i)\, di + (\partial W_{f'}/\partial x)\, dx)$

Because the incremental changes di and dx are independent and di is not present in the left hand side of equation, its coefficient on the ight-hand side must be zero.

$\partial W_{f'}/\partial i - \lambda = 0$

$\lambda = \partial W_{f'}/\partial i$

$F_f = W_{f'}(i,x)/\partial x$

This expression for mechanical force developed applies when I is an independent variable. It is current excited system.

If(λ, x) are taken as an independent variables,

$W_f = W_f(\lambda, x)$

$d\, W_f = (\partial W_f/\partial \lambda).d\, \lambda + (\partial W_f/\partial x).d\, x$

Substituting the equation

$F_f\, dx = id\lambda - (\partial W_f/\partial \lambda).d\, \lambda + (\partial W_f/\partial x).d\, x$

$F_f\, dx = -(\partial W_f/\partial x).d\, x + (i - \partial W_f/\partial \lambda)d\, \lambda$

Since d λ, the independent differential, is not present on the left hand side of this equation

$i - \partial W_f/\partial \lambda = 0$

$i = \partial W_f(\lambda, x)/\partial \lambda$

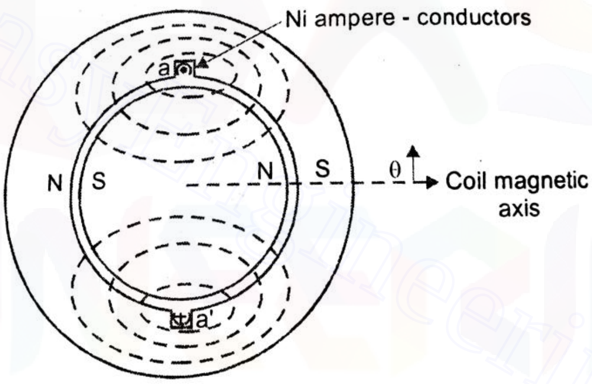
$F_f = -\partial W_f(\lambda, x)/\partial x$

3. With neat diagrams, explain the mmf space wave of one phase of a three phase distributed winding in a 2-pole machine and derive the expression for the fundamental mmf wave of the distributed winding in it.[NOV/DEC 2012,NOV/DEC 2009]

- An efficient design and satisfactory magnitude of emf to be induced or generated from an ac machine
- It is preferred to have distributed windings in the armature with number of slots distributed over the periphery accommodating open coils of distributed type as an AC machines found to have satisfactory.

MMF in a single coil winding

- A three phase ac machine is considered to possess a cylindrical rotor with a small uniform air gap between the stator and rotor.
- Let the coils be full-pitched coils with each coil having n number of turns. It considers the stator to be wound for two poles and to carry single turn full pitched coil.

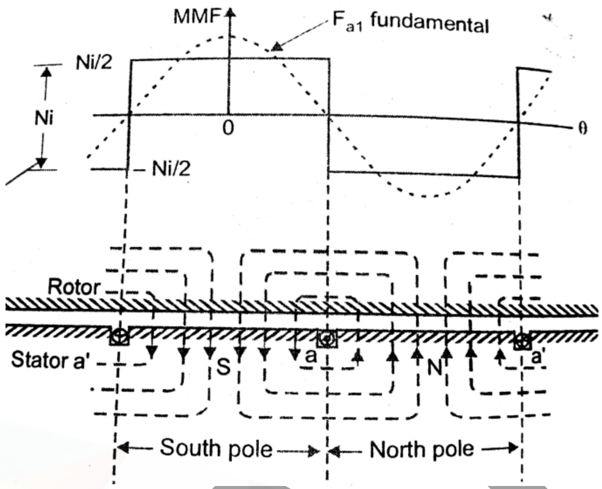


- As the current as an alternating quantity, it sets up a magnetic field with lines of flux in the direction. These lines found to flow from one end to another.
- It is conventional that always magnetic lines of flux flow from north pole to south pole. Hence the part of the stator from which the flux lines proceed is assume that to be north and the other end towards which the lux lines flow is assumed to be south.
- For the machine maintained at synchronous speed, the rotor iron surfaces should have opposite poles induced so as to get attracted and rotate synchronism.
- So south pole is induced in rotor close to the north pole of stator and a north pole is induced close to the south pole. The reluctance of the air gap is negligible then no mmf is lost I magnetization.
- Hence one half of this mmf (Ni/2) is used to set up flux linkages from stator (N pole) to rotor (S pole) through air gap and other half mmf

- (Ni/2) is to established flux linkages from rotor (N pole) to stator(S pole).
- Total change in mmf for the flux to link stator end to end in any slot is given by,

MMF=Ni/2-(-Ni/2)

MMF=Ni



- The fundamental becomes, mmf fa=4/π *Ni/2 cosθ

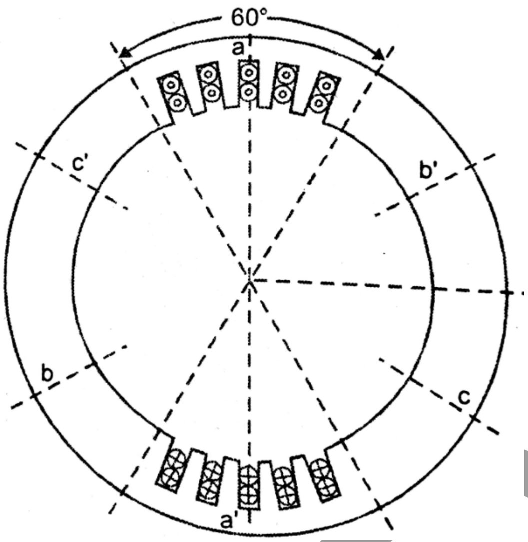
AT=Fp cosθ

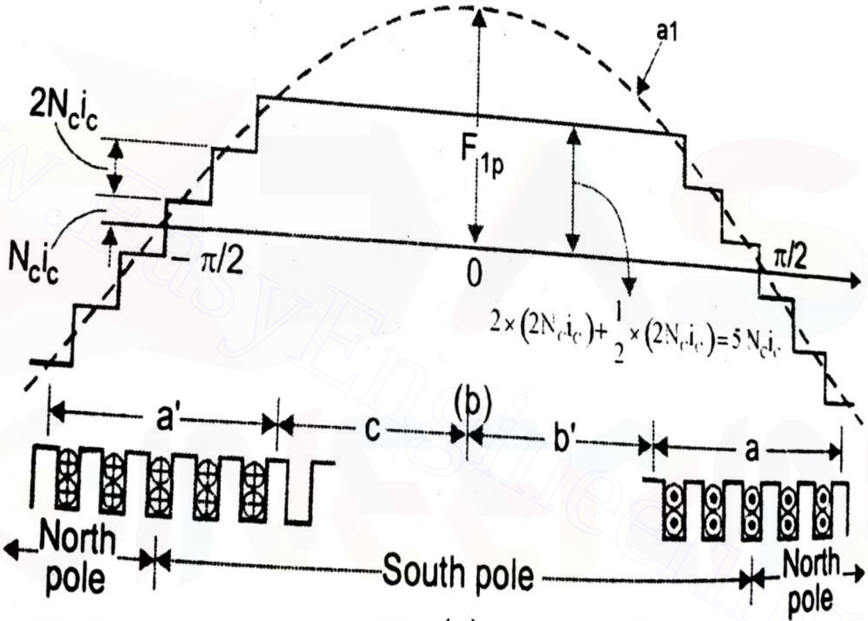
Fp=4/π *(Ni/2)

MMF in a multiple coil distributed winding

- It considers a wound rotor and a two layer winding in the stator with q slots/pole/phase. The mf developed in a single coil in each slot is super imposed to get the resultant mmf distribution.
- The mf wave becomes a stepped wave that can be approximated to a sine wave.
- The machine is designed for two pole arrangement, then half the ampere conductors of the middle slot of a phase group contributes to establish north pole.
- As a result, the net mmf is calculated as the vector sum of mmf at individual slot pairs separated by a pole pitch.
- The fundamental mmf wave are out of phase by

γ = πP/S rads





N_{ph}=Number of turns per phase

I_c=current in a coil

A=Number of parallel paths

At/parallel path=Nph*ic

AT/phase=Nph.ic.A

AT/ph=Nph.ia

I_a=ic*A

AT/phase/pole=Nph*ia/P

For distributed winding

AT/Ph/Pole=Nph*ia*Kb/P

Peak value of fundamental Fp=4/π *(Ni/P)*ia*Kb

MMF wave instantaneous value Fa=Fp cosθ

$F_a=4/\pi *(N_i/P)*i_a*K_b* \cos\theta$

This equation is satisfactory if the coils are full-pitched.

$F_p=4/\pi *(N_{ph}/P)*i_a*K_b*K_p$

$F_a= F_p \cos\theta$

$F_a=4/\pi *(N_{ph}/P)*i_a*K_b*K_p* \cos\theta$

$F_a=4/\pi *(N_{ph}/P)*i_a*K_b* \cos\theta/2* \cos\theta$

$K_w=K_p*K_b$

$F_a=4/\pi *(N_{ph}/P)*i_a*K_w* \cos\theta$

- From the basic properties chorded distributed windings help a lot I minimizing the effect of harmonics.

Hence the current can be approximated as pure sin wave.

$I_a=I_m \cos\omega t$

$F_a=4/\pi *(N_{ph}/P)*I_m*K_w* \cos\omega t \cos\theta$

$F_a=4/\pi *(N_{ph}/P)*\sqrt{2}*I_{rms}*K_w* \cos\omega t \cos\theta$

$=4\sqrt{2}/\pi *(N_{ph}/P)*I_{rms}*K_w* \cos\omega t \cos\theta$

$F_a=F_m \cos\omega t \cos\theta$

$F_m=4\sqrt{2}/\pi *(N_{ph}/P)*I_{rms}*K_w$

4. Derive the expression of energy through in magnetic field.[MAY/JUNE 2014]

- When a balanced three phase supply with 120 degree electrical phase angle separation is given to a balanced three phase winding with phases distributed in space so that relative space difference is 2π/3, causes a resultant mmf to rotate in the airgap between stator and rotor at a synchronous speed Ns=120f/p(rpm)
- But to justify this concept analytically, it is very important from both design and analysis.
- It considers that the three phase balanced supply allows the following balanced currents to flow through the windings as

$I_a=I_m \cos\omega t$

$I_b=I_m \cos(\omega t-120)$

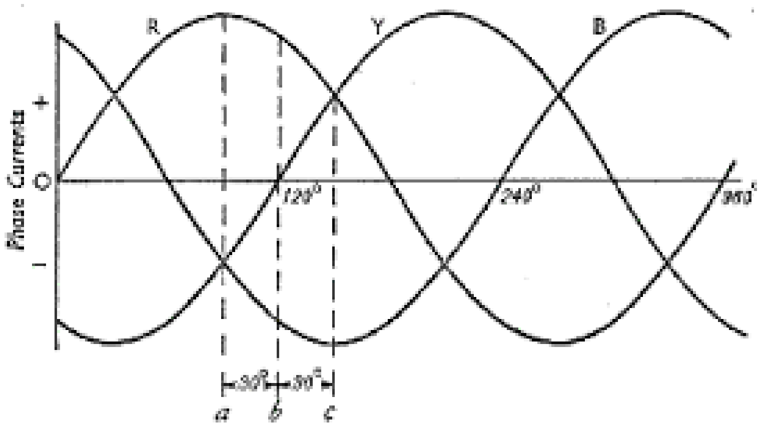
$I_c=I_m \cos(\omega t-240)$

- The principle of mutual inductance, these currents develop a magnetic field which is also separated by 120 degree with respect to the magnetic axes.

$F_a= F_m \cos\omega t\cos\theta$

$F_b= F_m \cos(\omega t-120) \cos(\theta-120)$

$F_c=F_m \cos(\omega t-240) \cos(\theta-240)$



The resulting mmf is given by

$F=Fa+Fb+Fc$

$F(\theta,t)= F_m \cos\omega t\cos\theta+ F_m \cos(\omega t-120) \cos(\theta-120)+ F_m \cos(\omega t-240) \cos(\theta-240)$

- By trigonometric relations

  $F(\theta,t)=3/2F_m \cos(\theta -\omega t)+1/2F_m\{(\cos(\theta +\omega t)+ \cos(\theta +\omega t-240)+ \cos(\theta +\omega t-480)$

  $\cos(\theta +\omega t-480)+ \cos(\theta +\omega t-480+360)+\cos(\theta +\omega t-120)$

  $F_m=3/2F_m \cos(\theta -\omega t)+1/2F_m\{(\cos(\theta +\omega t)+ \cos(\theta +\omega t-240)+ \cos(\theta +\omega t-120)$

- Algebraic sum of three vectors with a progressive phase difference of 120 degree equals to zero.

  $F(\theta,t)=3/2Fm \cos(\theta -\omega t)$

  Here the peak value of the mmf developed

  $F_p=3/2F_m$

  Sustituting the expression of Fm from equation

  $F_p=3/2\{4\sqrt{2}/\pi *(Nph/P)* Irms\}$

  $F_p=3*2\sqrt{2}/\pi *(Nph/P)*Irms$

  $F(\theta,t)= 3*2\sqrt{2}/\pi *(Nph/P)*Irms* \cos(\theta -\omega t)$

  At $\omega t=0$, the equation

  $F(\theta,0)= 3*2\sqrt{2}/\pi *(Nph/P)*Irms* \cos\theta$

- The net three phase mmf wave positive developed,attains a maximum current along the axis of phase 'a' when $\theta=0$.
- When the three phase balanced winding is given a three phase balanced supply and also proves that this mmf rotates in the airgap at the synchronous speed.

$$N_s=120f/P$$

5.Derive the Torque equation of round rotor machine or AC Machines.

Consider a two pole machine i.e stator and rotor has two poles

F_1=MMF produced by stator

F_2=MMF produced by rotor.

F_R=Resultant MMF

By cosine Rule,

$F_R^2= F_{12}=F_{22}+2F_1F_2\cos\alpha$-----------(1)

Assumptions:

The rotor is assumed to be smooth cylindrical, so that the air gap is unifom.

The MMF produced by stator and rotor is assumed to be sinusoidal.

The radial length of air gap(g) is very small when compared to the radius of stator.

MMF in air gap, $F_r= H_r * g$

$H_r = F_r/g$.

The reluctance of air gap is negligible.

The sinusoidal MMF space wave produces sinusoidal flux density wave is in phase

with it.

Let,

α-Angle between F_1 and F_2

D-Diameter of the air gap.

l- Axial length of air gap.

g-Radial length of air gap.

$$Torque = \frac{\partial W_f'}{\partial \alpha} - - - -(2)$$

Average Co-energy produced = $\frac{1}{2}\,\mu_0[Average\ value\ of\ H^2]$

$$= \frac{1}{2}\,\mu_0\left[\frac{1}{2}\,H^2{}_r\right]$$

$$= \frac{1}{4}\,\mu_0 H_r^2$$

Total Co-energy produced= Average Co-energy produced * Volume

$$W_f' = \frac{1}{4}\,\mu_0 H_r^2 * \pi D l g$$

$$W_f' = \frac{1}{4}\,\mu_0 \left(\frac{F_r}{g}\right)^2 * \pi D l g$$

$$W_f' = \frac{1}{4}\frac{\mu_0}{g}.\pi Dl[F_1^2 + F_2^2 + 2F_1F_2\cos\alpha]$$

$$Torque = \frac{\partial W_f'}{\partial\alpha}$$

$$=\frac{\partial}{\partial\alpha}(\frac{1}{4}\frac{\mu_0}{g}.\pi Dl[F_1^2 + F_2^2 + 2F_1F_2\cos\alpha])$$

$$Torque = -\frac{1}{2}\frac{\mu_0.\pi Dl}{g}F_1F_2\sin\alpha$$

For ‘P’ Pole machine,

$$Torque = \frac{P}{2}\left[-\frac{1}{2}\frac{\mu_0.\pi Dl}{g}F_1F_2\sin\alpha\right]$$

Part C

1. Two coupled coils have self and mutual inductances $L_{11} = 3 + \frac{1}{3X}$;$L_{22} = 1 + \frac{1}{3X}$; $L_{21} = L_{12} = \frac{1}{3X}$. Over a certain range of displacement x. The first coil is excited by a constant current of 10A and second coil by a constant current of -5A. Find the mechanical work done if the x changes from 0.5 to 1 and the energy supplied by each electrical sources.

Solution:

$$W_f^1 = \frac{1}{2}L_{11}i_1^2 + L_{12}i_1i_2 + \frac{1}{2}L_{22}i_2^2$$

$$W_f^1 = \frac{1}{2}\left[3 + \frac{1}{3X}\right](10)^2 + \left[\frac{1}{3X}\right]10.5 + \frac{1}{2}\left[1 + \frac{1}{3X}\right](-5)^2$$

$$= 162.5 + \frac{4.166}{X}$$

(i) $F_f = -\frac{4.166}{X}$

$$\Delta W_m = \int_{0.5}^{1} F_f.dx$$

$$\Delta W_m = \int_{0.5}^{1} -\frac{4.166}{X}.dx = -4.166\,J$$

(ii) $\Delta W_{e1} = \int_{0.5}^{1} i_1.d\lambda$

$$\lambda_1 = L_{11}i_1 + L_{12}i_2$$

$$=\left[3 + \frac{1}{3X}\right](10) + \left[\frac{1}{3X}\right](-5) = 30 + \frac{1.66}{X}$$

$$\lambda_1\ at\ x_1 = 30 + \frac{1.66}{0.5} = 33.33$$

$$\lambda_1 \, at \, x_2 = 30 + \frac{1.66}{1} = 31.66$$

$$\Delta W_{e1} = i_1 . \int_{\lambda_1 \, at \, x_2}^{\lambda_1 \, at \, x_1} d\lambda_1$$

$$\Delta W_{e1} = 10[31.66 - 33.33] = -16.66 \, J$$

(iii) $\Delta W_{e2} = \int_{0.5}^{1} i_2 . d\lambda$

$$\lambda_2 = L_{21} i_1 + L_{22} i_2$$

$$= \left[\frac{1}{3X}\right](10) + \left[1 + \frac{1}{3X}\right](-5) = -5 + \frac{1.66}{X}$$

$$\lambda_2 \, at \, x_1 = -5 + \frac{1.66}{0.5} = -1.667$$

$$\lambda_2 \, at \, x_2 = -5 + \frac{1.66}{1} = -3.333$$

$$\Delta W_{e2} = i_2 . \int_{\lambda_2 \, at \, x_2}^{\lambda_2 \, at \, x_1} d\lambda_2$$

$$\Delta W_{e2} = -5[3.333 + 1.667] = 8.333 J$$

(iv) Net electrical input

$= \Delta W_{e1} + \Delta W_{e2} =$ -16.667+8.333 = -8.333J

2. Two windings one mounted on the stator and the other mounted on a rotor have self-inductance of L_{11}=4.5 H, L_{22}=2.5 H, and L_{12}=2.8 cos θ H, Where θ is the angle between the axis of winding. The resistances of the winding may be neglected. Winding 2 is short circuited and the current in winding as a function of time i_1= 10 sin ωt A. Derive an expression for the numerical value of the instantaneous torque on the rotor in N-m in terms of angle θ

Solution:

L_{11}=4.5 H,

L_{22}=2.5 H

L_{12}=2.8 cos θ H

i_1= 10 sin ωt A

$$T_f = \frac{\partial W_f'(i_1, i_2, \theta)}{\partial \theta}$$

$$T_f = \frac{\partial}{\partial \theta}\left[\frac{\boldsymbol{L_{11} . i_1}^2}{\boldsymbol{2}} + \frac{\boldsymbol{L_{22} . i_2}^2}{\boldsymbol{2}} + \boldsymbol{L_{12} . i_1 . i_2}\right]$$

$$T_f = 0 - 2.8 sin\theta \, i_1 i_2 + 0$$

$T_f = 2.8 sin\theta \ i_1 i_2 - - - - - (1)$

$V_m \cos \omega t = 4.5 \frac{di_1}{dt} + [2.8 \cos \theta] \frac{di_2}{dt}$

$\frac{di_2}{dt} = -\frac{2.8}{2.5} \cos \theta \frac{di_1}{dt}$

$i_2 = -1.12 \cos \theta i_1$

Given $i_1 = 10 \sin \omega t$ and $i_2 = -1.12 \cos \theta * 10 \sin\omega t$

Using Equation 1,

$T_f = 0 - 2.8 sin\theta \ i_1 i_2$

$T_f = 2.8 sin\theta \ [10 \sin \omega t][-1.12 \cos \theta * 10 \sin\omega t]$

$T_f = 313.6 sin\theta . \cos\theta . sin^2 \omega t$

This is the instantaneous torque on rotor in Nm in terms of angle θ.

3. **Derive the torque developed in doubly excited magnetic system.**

Let

$i_1 - Current\ due\ to\ source\ 1$

$i_2 - Current\ due\ to\ source\ 2$

$\lambda_1 - Flux\ linlage\ due\ to\ i_1$

$\lambda_2 - Flux\ linlage\ due\ to\ i_2$

$$W_f = \int_0^{\lambda_1} i_1 . d\lambda_1 + \int_0^{\lambda_2} i_2 . d\lambda_2 - - - - - - - - - - (1)$$

From circuit,

$\lambda_1 = L_{11} . i_1 + L_{12} . i_2 - - - - - - - (2)$

$\lambda_2 = L_{22} . i_2 + L_{21} . i_1 - - - - - - - (3)$

From Equation (2),

$L_{11} . i_1 = \lambda_1 - L_{12} . i_2$

$$i_1 = \frac{\lambda_1 - L_{12} . i_2}{L_{11}} \qquad - - - - - - - (4)$$

Subs (4) in (3),We get

$$\lambda_2 = L_{22} . i_2 + L_{21} . \left[\frac{\lambda_1 - L_{12} . i_2}{L_{11}}\right]$$

$$\lambda_2 = L_{22} . i_2 + \left[\frac{L_{21} \lambda_1 - L_{12}{}^2 . i_2}{L_{11}}\right]$$

$$\lambda_2 = L_{22}.i_2 + \left[\frac{L_{21}\lambda_1 - L_{12}{}^2.i_2}{L_{11}}\right]$$

$$\lambda_2 = \frac{L_{11}.L_{22}.i_2 + L_{21}.\lambda_1 - L_{12}{}^2.i_2}{L_{11}}$$

$$\lambda_2 L_{11} = \boldsymbol{L_{11}L_{22}.i_2} + L_{21}\lambda_1 - \boldsymbol{L_{12}{}^2.i_2}$$

$$\boldsymbol{L_{12}{}^2.i_2 - L_{11}L_{22}.i_2} = L_{21}.\lambda_1 - \lambda_2.L_{11}$$

$$\boldsymbol{i_2[\,L_{12}{}^2 - L_{11}L_{22}]} = L_{21}.\lambda_1 - \lambda_2.L_{11}$$

$$\boldsymbol{i_2} = \frac{L_{21}.\lambda_1 - \lambda_2.L_{11}}{\boldsymbol{L_{12}{}^2 - L_{11}L_{22}}}$$

$$\boldsymbol{i_2} = \frac{L_{21}}{\boldsymbol{L_{12}{}^2 - L_{11}L_{22}}}.\lambda_1 + \frac{L_{11}}{\boldsymbol{L_{12}{}^2 - L_{11}L_{22}}}.\lambda_2$$

$$\boldsymbol{i_2} = \boldsymbol{\beta_{12}}.\lambda_1 + \boldsymbol{\beta_{22}}.\lambda_2 \quad -------(5)$$

Similarly,

$$\boldsymbol{i_1} = \boldsymbol{\beta_{11}}.\lambda_1 + \boldsymbol{\beta_{12}}.\lambda_2 \quad -------(6)$$

Subs (5) &(6) in (1)

$$W_f = \int_0^{\lambda_1} (\boldsymbol{\beta_{11}}.\lambda_1 + \boldsymbol{\beta_{12}}.\lambda_2).d\lambda_1 + \int_0^{\lambda_2} (\boldsymbol{\beta_{12}}.\lambda_1 + \boldsymbol{\beta_{22}}.\lambda_2).d\lambda_2$$

$$\boldsymbol{W_f = \frac{\beta_{11}.\lambda_1{}^2}{2} + \frac{\beta_{22}.\lambda_2{}^2}{2} + \beta_{12}.\lambda_1.\lambda_2}$$

$$\dot{W}_f = \int_0^{i_1} \lambda_1.di_1 + \int_0^{i_2} \lambda_2.di_2 -------(7)$$

Subs (2) & (3) in (7),

$$\dot{W}_f = \int_0^{i_1} (L_{11}.i_1 + L_{12}.i_2).di_1 + \int_0^{i_2} (L_{22}.i_2 + L_{21}.i_1).di_2$$

$$\boldsymbol{\dot{W}_f = \frac{L_{11}.i_1{}^2}{2} + \frac{L_{22}.i_2{}^2}{2} + L_{12}.i_1.i_2}$$

Therefore torque is given by,

$$T_f = \frac{\partial}{\partial\theta}\left[\frac{\boldsymbol{L_{11}.i_1{}^2}}{\boldsymbol{2}} + \frac{\boldsymbol{L_{22}.i_2{}^2}}{\boldsymbol{2}} + \boldsymbol{L_{12}.i_1.i_2}\right]$$

UNIT IV
DC GENERATORS
PART-A

1.Write down the emf equation for d.c.generator?[MAY/JUNE 2015,MAY/JUNE 2009]

$$e = \frac{PN\Phi Z}{60A}$$

P-No of poles: Z-Total noof conductor

Φ-flux per pole, N-speed in rpm.

2. Why the armature core in d.c machines is constructed with laminated steel sheets instead of solid steel sheets? .[MAY/JUNE 2013].

Lamination highly reduces the eddy current loss and steel sheets provide low reluctance path to magnetic field.

3. Why commutator is employed in d.c.machines? [MAY/JUNE 2011,MAY/JUNE 2009]

Conduct electricity between rotating armature and fixed brushes, convert alternating emf into unidirectional emf (mechanical rectifier).

4. Why pole shoe has been given a specific shape? [MAY/JUNE 2013].

It is necessary that maximum area of the armature comes acrossthe flux produced by the field winging. Pole shoe enlarges the area of armature core to come across flux, which is necessary to produce larger induced emf.

5. **How does D.C. motor differ from D.C. generator in construction? [MAY/JUNE 2013].**

Generators are normally placed in closed room and accessed by skilled operators only. Therefore, on ventilation point of view they may be constructed with large opening in the frame. Motors have to be installed right in the place of use which may have dust, dampness, inflammable gases, chemical.etc.to protect the motors against these elements, the motor frames are made either partially closed or totally closed or flame proof.

6. What are the advantages and disadvantages of Hopkinson's test?[MAY/JUNE 2014]

Advantages:

1.Power required for the test is small as compared to full load powers of the two machines.

2.The machines can be tested under full load conditions for long duration, the performance of the machines regarding commutation and temperature rise can be studied.

Disadvantage:

Two identical machines are required

7.What is the purpose of yoke in d.c machine? [MAY/JUNE 2013].

1.It acts as a protecting cover for the whole machine and provides mechanical support for the poles.

2.It carries magnetic flux produced by the poles

8. Why is Swinburne's test preferred to determine the efficiency of a dc machine? [MAY/JUNE 2012,NOV/DEC 2009]

This method involves purely electrical measurements which are capable of being carried out with a high degree of accuracy.

This method requires only a small fraction of the rated output the motor.

9.Under what circumstances does a dc shunt generator fails to generate?

Absence of residual flux, initial flux setup by field may be opposite in direction to residual flux, shunt field circuit resistance may be higher than its critical field resistance, load circuit resistance may be less than its critical load resistance

10. Define critical field resistance of dc shunt generator?

Critical field resistance is defined as the resistance of the field circuit which will cause the shunt generator just to build up its emf at a specified field.

11. Specify the role of inter-poles in DC machines. [APRIL/MAY 2015]

In modern DC machines inter-poles are provided to improve the commutation.

12. What is meant by residual emf in dc generator? [APRIL/MAY 2015]

It is induced emf in the self-excited dc generator due to the residual magnetism.

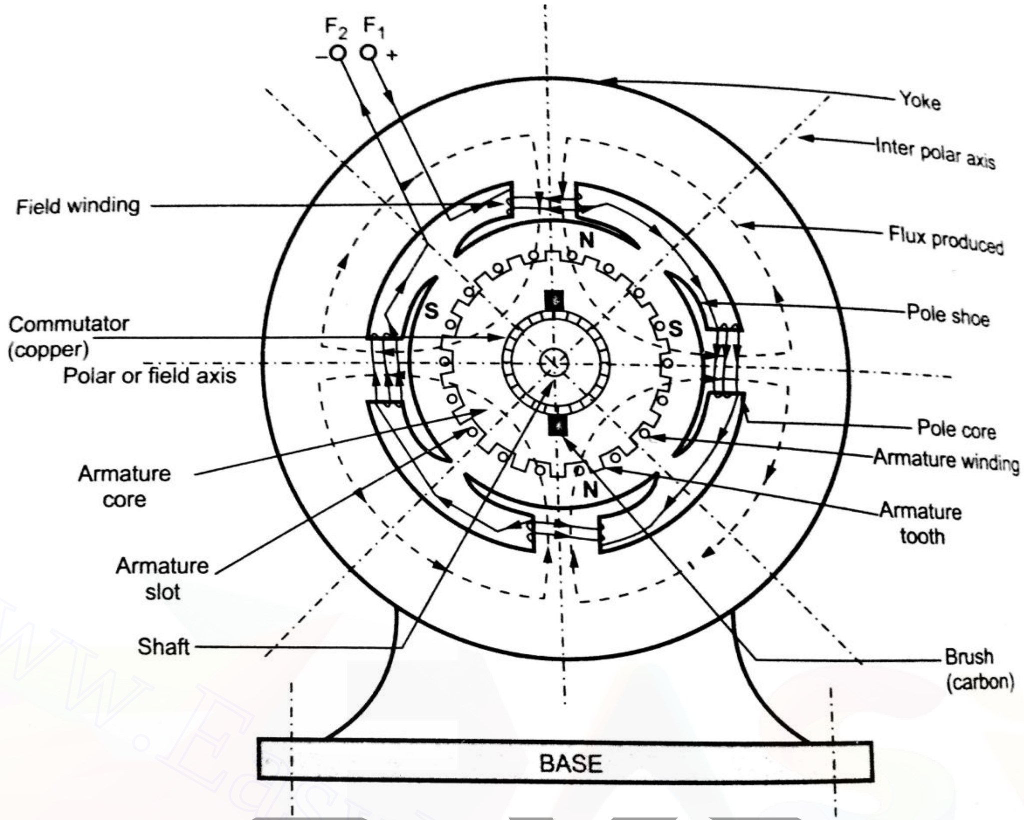
PART-B

1.Describe the construction and principle of operation of DC generator. [MAY/JUNE 2013].

Construction:

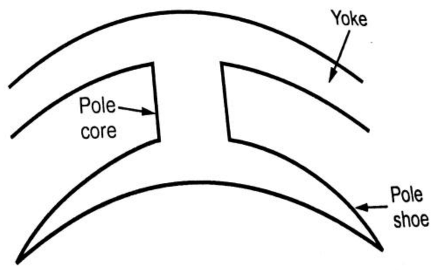
DC Generators or Dynamos are still in general use for many industrial applications, and small ones for speed measurement - tachogenerators - in some domestic gear as well as industrial. There are many types, with slightly different variations in operation depending on their usage.The basics are a Field, Armature, Commutator and Brushgear (plus casing & bearings).

The combination of field system and casing could be called a stator.



The field system provides a magnetic field to fixed pole pieces that the armature rotates within. with some units, the field uses permanent magnets. With others, the field is wound and powered, as an electromagnet. This allows the output voltage or power to be varied while the machine is run at fixed RPM.

The armature has a number of magnetic pole pieces made of a magnetically soft iron (that does not retain any magnetic field) arranged around a shaft that supports it and fits through the bearings in the casing. The pole piece area is often made from a stack of thin iron laminations with insulated surfaces, to avoid the circulating currents that could occur in a single large piece of metal. The poles are fitted with coils in a symmetrical pattern, and as the armature turns through the magnetic field from the field windings, voltage is induced in to the armature coils. The coils are connected to the commutator, which has a set of 'finger' contacts embedded in insulation & is attached to the armature shaft at on end of the windings.



The brushes are fitted in holders attached to (but insulated from) the casing, These are pressed against the commutator spring pressure, and pick up power from the armature windings at the optimum position in their rotation. (If an armature coil was directly connected to a load, the output would be AC - it would be working as an alternator. The commutator constantly connects the output, via the brushes, to the correct points in the armature windings to give a DC output.)

Above figure shows the constructional details of a simple 4-pole DC generator. A DC generator consists two basic parts, stator and rotor. Basic constructional parts of a DC generator are described below.

1. Yoke: The outer frame of a generator or motor is called as yoke. Yoke is made up of cast iron or steel. Yoke provides mechanical strength for whole assembly of the generator (or motor). It also carries the magnetic flux produced by the poles.
2. Poles: Poles are joined to the yoke with the help of screws or welding. Poles are to support field windings. Field winding is wound on poles and connected in series or parallel with armature winding or sometimes separately.

Pole shoe: Pole shoe is an extended part of the pole which serves two purposes, (i)to prevent field coils from slipping and (ii)to spread out the flux in air gap uniformly

1. Armature core: Armature core is the rotor of a generator. Armature core is cylindrical in shape on which slots are provided to carry armature windings.
2. Commutator and brushes: As emf is generated in the armature conductor's terminals must be taken out to make use of generated emf. But if we can't directly solder wires to commutator conductors as they rotate. Thus commutator is connected to the armature conductors and mounted on the same shaft as that of armature core. Conducting brushes rest on commutator and they slide over when rotor (hence commutator) rotates. Thus brushes are physically in contact with armature conductors hence wires can be connected to brushes.

The rotor in a dc machine is called an armature. The armature has cylindrical steel core that is composed of a stack of slotted laminations. Slots in laminations are aligned axially along rotor or shaft. Armature windings are placed in slots.

The stator in a dc machine is the field part of the machine. Field poles are located on stator and project inward. Each pole has a narrow iron core around which the exciting winding or field coil is placed. Field coil may consist of two or more separate windings.

A pole shoe distributes pole flux over rotor surface across a narrow air gap. Leads from the armature coils are connected to the commutator. Commutator consists of radial copper segments separated by an insulating material, usually mica. Current is conducted to the armature by carbon brushes that are held against the surface of the commutator by springs. Brushes wear with time, must be inspected regularly, and occasionally replaced.

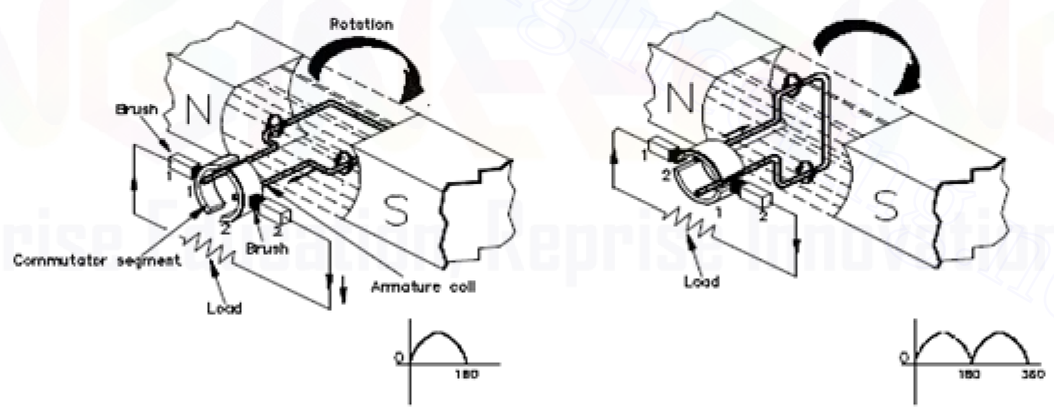
Copper commutator segments wear also and sometimes have to be resurfaced, or “turned down.” If not, the harder mica protrudes above the copper, and the brushes bounce, resulting in arcs that damage the commutator surface.

Recall from Module 3, DC Circuits, that there are three conditions necessary to induce a voltage into a conductor.

1. A magnetic field
2. A conductor
3. Relative motion between the two A DC generator provides these three conditions to produce a DC voltage output.

Theory of Operation

A basic DC generator has four basic parts: (1) a magnetic field; (2) a single conductor, or loop; (3) a commutator; and (4) brushes (Figure 3). The magnetic field may be supplied by either a permanent magnet or an electromagnet. For now, we will use a



permanent magnet to describe a basic DC generator.

A single conductor, shaped in the form of a loop, is positioned between the magnetic poles.As long as the loop is stationary, the magnetic field has no effect (no relative motion). If we rotate the loop, the loop cuts through the magnetic field, and an EMF (voltage) is induced into the loop. When we have relative motion between a magnetic field and a conductor in that magnetic field, and the direction of rotation is such that the conductor cuts the lines of flux, an EMF is induced into the conductor. The magnitude of the induced EMF depends on the field strength and the rate at which the flux lines are cut, as given in equation (5-1). The stronger the field or the more flux lines cut for a given period of time, the larger the induced EMF.

$E_g = K\Phi N$

where

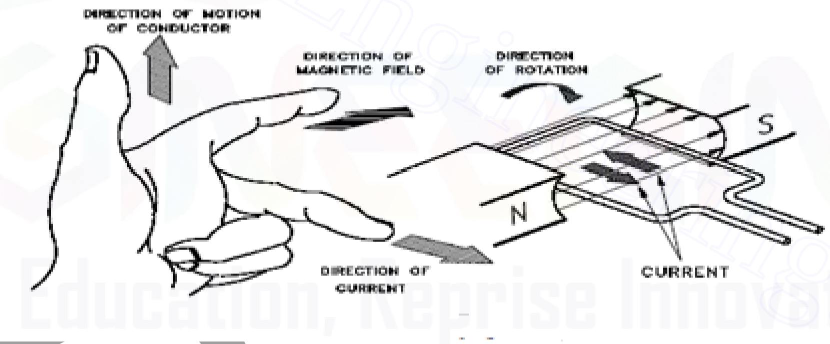
E_g = generated voltage

K = fixed constant

Φ = magnetic flux strength

N = speed in RPM

The direction of the induced current flow can be determined using the "left-hand rule" for generators. This rule states that if you point the index finger of your left hand in the direction of the magnetic field (from North to South) and point the thumb in the direction of motion of the conductor, the middle finger will point in the direction of current flow (Figure 4). In the generator shown in Figure 4, for example, the conductor closest to the N pole is traveling upward across the field; therefore, the current flow is to the right, lower corner. Applying the left-hand rule to both sides of the loop will show that current flows in a counter-clockwise direction in the loop.



The commutator converts the AC voltage generated in the rotating loop into a DC voltage. It also serves as a means of connecting the brushes to the rotating loop. The purpose of the brushes is to connect the generated voltage to an external circuit. In order to do this, each brush must make contact with one of the ends of the loop. Since the loop or armature rotates, a direct connection is impractical. Instead, the brushes are connected to the ends of the loop through the commutator.

In a simple one-loop generator, the commutator is made up of two semi cylindrical pieces of a smooth conducting material, usually copper, separated by an insulating material. Each half of the commutator segments is permanently attached to one end of the rotating loop, and the commutator rotates with the loop.

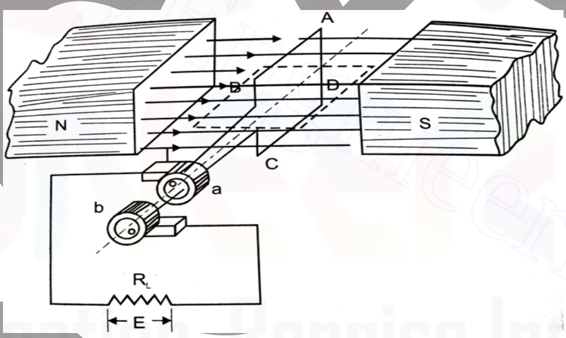
The brushes, usually made of carbon, rest against the commutator and slide along the commutator as it rotates. This is the means by which the brushes make contact with each end of the loop.

Each brush slides along one half of the commutator and then along the other half. The brushes are positioned on opposite sides of the commutator; they will pass from one commutator half to the other at the instant the loop reaches the point of rotation, at which point the voltage that was induced reverses the polarity.

Every time the ends of the loop reverse polarity, the brushes switch from one commutator segment to the next. This means that one brush is always positive with respect to another.

The voltage between the brushes fluctuates in amplitude (size or magnitude) between zero and some maximum value, but is always of the same polarity in this manner, commutation is accomplished in a DC generator.

A dc generator is an electrical machine which converts mechanical energy into direct current electricity. This energy conversion is based on the principle of production of dynamically induced emf.



According to Faraday's law of electromagnetic induction, when a conductor moves in a magnetic field (thereby cutting the magnetic flux lines), a dynamically induced emf is produced in the conductor. The magnitude of generated emf can be given by emf equation of DC generator. If a closed path is provided to the moving conductor, then generated emf causes a current to flow in the circuit.

Thus in DC generators, as we have studied earlier, when armature is rotated with the help of a prime mover and field windings are excited (there may be permanent field magnets also), emf is induced in armature conductors. This induced emf is taken out via commutator-brush arrangement.

2.Derive the EMF equation of a DC generator and explain about the significance of back emf [APRIL/MAY 2015,MAY/JUNE 2013]

EMF equation

Let

Ø = flux/pole in Wb (weber)

Z = total no. of armature conductors

P = No. of generator poles

A = No. of parallel paths in armature

N = rotational speed of armature in revolutions per min. (rpm)

E = emf induced in any parallel path in armature

By Faradays law,

$$e = \frac{d\Phi}{dt}$$

$$d\Phi = \mathrm{P}\Phi, dt = \frac{60}{N}$$

$$e = \frac{\mathrm{P}\Phi}{\frac{60}{N}} = \frac{PN\Phi}{60}$$

Consider that there is Z conductors placed in A parallel path, So the induced emf is given by

$$e = \frac{PN\Phi}{60} * \frac{Z}{A}$$

$$e = \frac{\boldsymbol{PN\Phi Z}}{\boldsymbol{60A}}$$

This is the induced emf in generator.

For lap winding, A=P

$$e = \frac{N\Phi Z}{60}$$

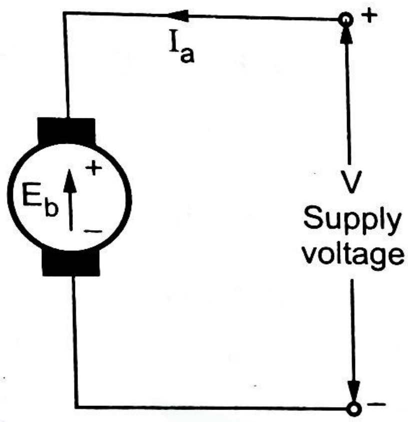
For lap winding, A=2

$$e = \frac{PN\Phi Z}{120}$$

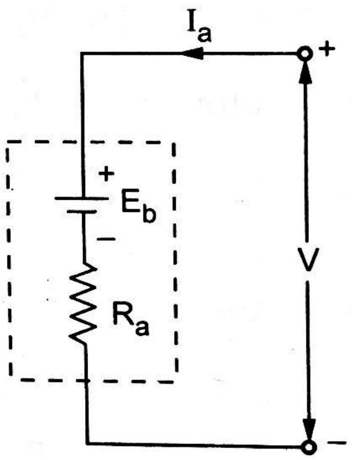
Significance of back emf

A DC motor is also a generator at the same time and the voltage it would produce under rotation when it's disconnected from the supply is the back emf, also called counter emf because it's in opposite polarity to the supply voltage and tends to cause outward current flow from machine to supply

A DC machine working as a motor will have its counter emf always less than the supply voltage. The difference would depend on amount of mechanical load tied to the motor. As a result, current would flow into the machine. When it's working as a generator the counter emf is more than supply voltage (0) and as a result current flows out of the machine. Similarly, during regenerative braking the counter emf is more than supply voltage and as a result current flows out of the machine.



(a) Back e.m.f. in a d.c. motor



(b) Equivalent circuit

It is seen in the generating action, that when a conductor cuts the lines of flux, e.m.f. gets induced in the conductor. In a d.c. motor after a motoring action armature starts rotating and armature conductors cut the main flux. So there is a generating action existing in a motor.

After a motoring action, there exists a generating action. There is an induced emf in the rotating armature conductors according to Faraday's law of electromagnetic induction. This induced emf in the armature always acts in the opposite direction of the supply voltage. This is according to the Lenz's law which states that the direction of the induced emf is always so as to oppose the cause producing it.

In a DC motor, electrical input, i.e. the supply voltage is the cause and hence this induced e.m.f. opposes the supply voltage. This emf tries to set up a current through the armature which is in the opposite direction to that, which supply voltage is forcing through the conductor.

So as this e.m.f. always opposes the supply voltage, it is called back emf and denoted as E_b. Though it is denoted as E_b., basically it gets generated by the generating action which we have seen earlier in case of generators. So its magnitude can be determined by the e.m.f. equation which is derived earlier. So

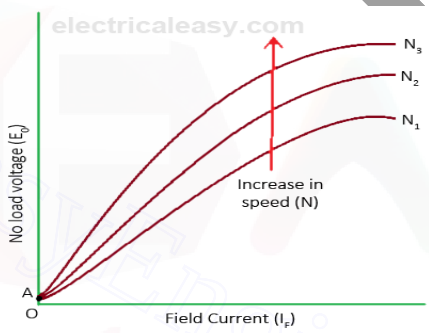
$$e = \frac{PN\Phi Z}{60A}$$

3. Explain characteristics of DC generator. [NOV/DEC 2015,APRIL/MAY 2015,MAY/JUNE 2011]

Three characteristics of DC generators are taken into considerations: (i) Open Circuit Characteristic (O.C.C.), (ii) Internal or Total Characteristic and (iii) External Characteristic. These characteristics of DC generators are explained below.

1. OPEN CIRCUIT CHARACTERISTIC (O.C.C.) (E_0/I_F)

Open circuit characteristic is also known as **magnetic characteristic** or **no-load saturation characteristic**. This characteristic shows the relation between generated emf at no load (E_0) and the field current (I_f) at the given fixed speed. The O.C.C. curve is just the magnetization curve and it is practically similar for all type of generators. The data for O.C.C. curve is obtained by operating the generator at no load and keeping speed constant. Field current is varied and the corresponding terminal voltage is recorded.



Open Circuit Characteristic (O.C.C.)

The above figure shows a typical no-load saturation curve or open circuit characteristics for all types of DC generators.

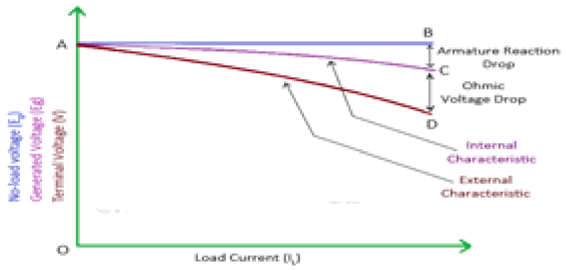
2. Internal or Total Characteristic (E/I_a)

The internal characteristic curve shows the relation between the on-load generated emf (Eg) and the armature current (I_a). The on-load generated emf Eg is always less than E_0 due to armature reaction. Eg can be determined by subtracting the drop due to demagnetizing effect of armature reaction from no-load voltage E_0. Therefore, internal characteristic curve lies below O.C.C. curve.

3. External Characteristic (V/I_L)

The external characteristic curve shows the relation between the terminal voltage (V) and load current (I_L). The terminal voltage V is less than generated emf Eg due to voltage drop in the armature circuit.

Therefore, the external characteristic curve lies below the internal characteristic curve. External characteristics are very important to determine the suitability of a generator for a given purpose.



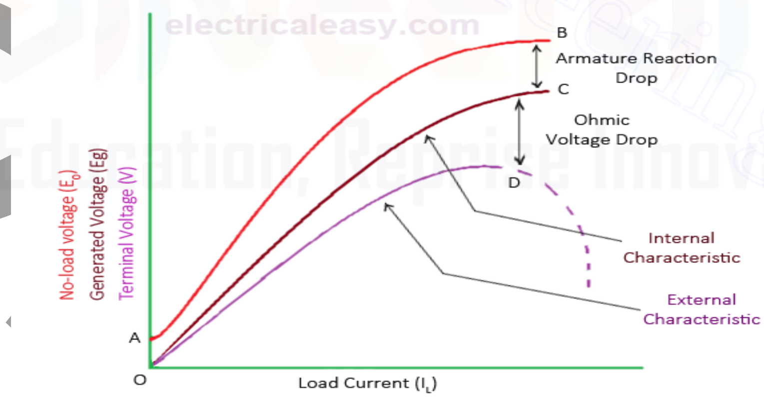
Characteristics of separately excited DC generator

Internal and external characteristic curves are shown below for each type of generator.

If there is no armature reaction and armature voltage drop, voltage will remain constant for any load current.

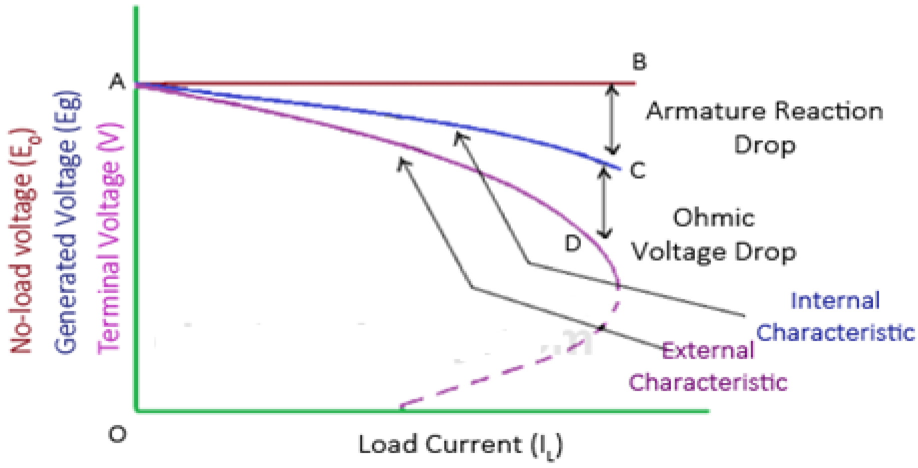
Thus the straight line AB in above figure represents the no-load voltage vs. load current I_L. Due to demagnetizing effect of armature reaction the on-load generated emf is less than the no-load voltage. The curve AC represents the on-load generated emf E_G vs. load current I_L i.e. internal characteristic. The curve AD represents the terminal voltage vs. load current i.e. external characteristic.

Characteristics of DC Series Generator



Characteristics of DC series generator

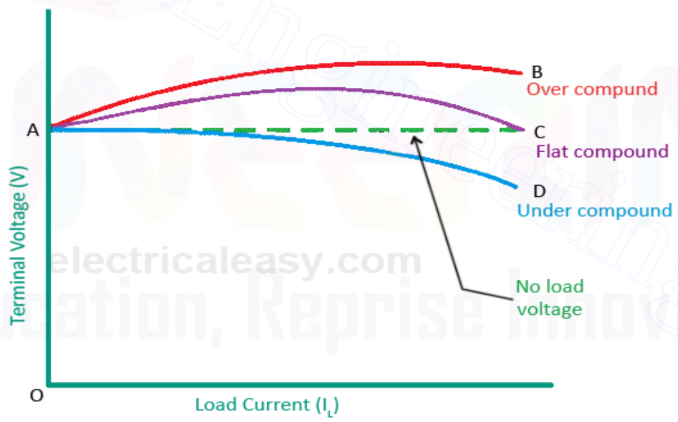
The curve AB in above figure identical to open circuit characteristic (O.C.C.) curve. This is because, in DC series generators field winding is connected in series with armature and load. Hence, here load current is similar to field current. The curve OC and OD represents internal and external characteristic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



Characteristics of DC shunt generator

When load resistance is decreased in DC shunt generator, the load current increases. But, load resistance can be decreased upto a certain limit, beyond this limit any further decrease in load resistance results in decreasing load current and terminal voltage. Consequently, the external characteristic curve turns back as shown by dotted line in above figure.

Characteristics of DC Compound Generator



External characteristic of DC compound generator

The above figure shows the external characteristic of DC compound generators. If series winding is adjusted so that, increase in load current causes increase in terminal voltage then the generator is called to be over compounded.

The external characteristic for over compounded generator is shown by the curve AB in above figure.

If series winding is adjusted so that, terminal voltage remains constant even the load current is increased, then the generator is called to be flat compounded.

The external characteristic for a flat compounded generator is shown by the curve AC. If the series winding has lesser number of turns than that would be required to be flat compounded, then the generator is called to be under compounded. The external characteristics for an under compounded generator is shown by the curve AD.

4. Explain in about detail about the effect of armature reaction of D.C machines. [NOV/DEC 2015, NOV/DEC 2009]

ARMATURE REACTION

"The effect of armature flux on main flux is called as armature reactio*n"*In a unloaded d.c machine armature current is vanishingly small and the flux per pole is decided by the field current alone.

The uniform distribution of the lines of force gets upset when armature too carries current due to loading. In one half of the pole, flux lines are concentrated and in the other half they are rarefied.

Qualitatively one can argue that during loading condition flux per pole will remain same as in no load operation because the increase of flux in one half will be balanced by the decrease in the flux in the other half.

Since it is the flux per pole which decides the emf generated and the torque produced by the machine, seemingly there will be no effect felt so far as the performance of the machine is concerned due to armature reaction. This in fact is almost true when the machine is lightly or moderately loaded.

The effect of magnetic field set up by armature current on the distribution of flux under main poles of a generator. The armature magnetic field has two effects:

(i) It demagnetizes or weakens the main flux and

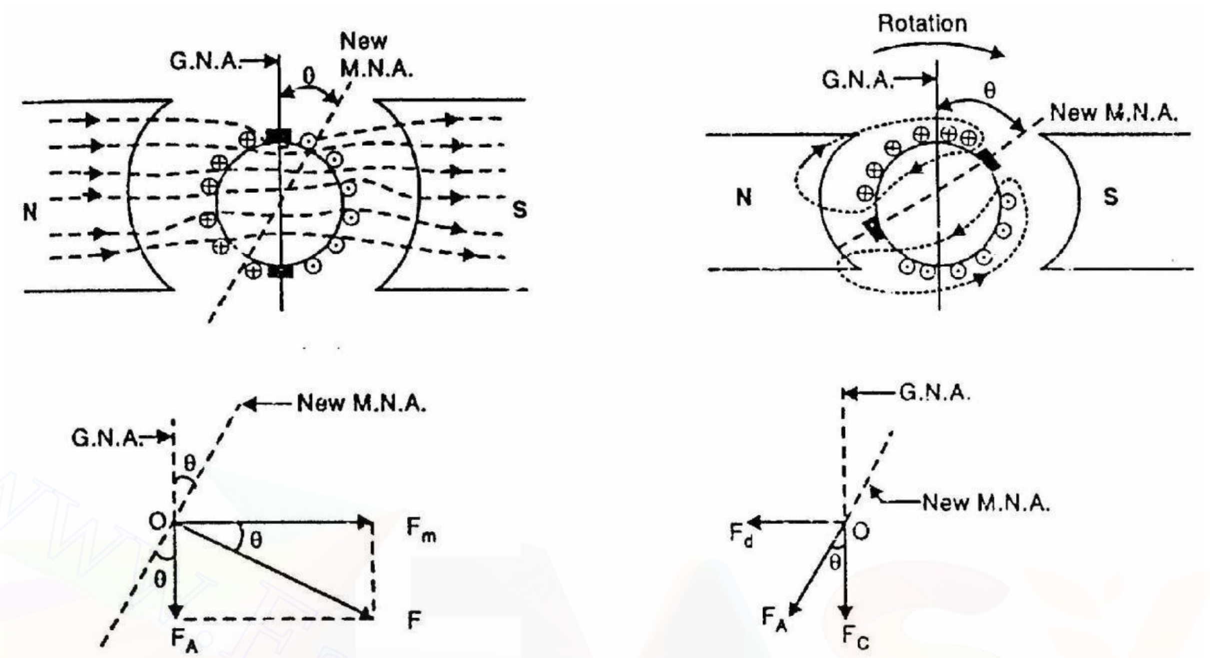
(ii) It cross-magnetizes or distorts it.

The flux distribution of a bipolar generator when there is no current in the armature conductors. The brushes are touching the armature conductors directly, although in practice, they touch commutator segments,

It is seen that:

(a) the flux is distributed symmetrically with respect to the polar axis, which is the line joining the centers of NS poles.

(b) The magnetic neutral axis (M.N.A.) coincides with the geometrical neutral axis (G.N.A.). Magnetic neutral axis may be defined as the axis along which no emf is



produced in the armature conductors because they move parallel to the lines of flux. Or M.N.A. is the axis which is perpendicular to the flux passing through the armature.

Brushes are always placed along M.N.A. Hence, M.N.A. is also called ‘axis of commutation’ because reversal of current in armature conductors takes place across this axis. Vector OFm which represents, both magnitude and direction, the mmf of producing the main flux.

The field (or flux) set up by the armature conductors alone when carrying current, the field coils being unexcited. The current direction is downwards in conductors under N-pole and upwards in those under S-pole.

However, at rated armature current the increase of flux in one half of the pole is rather less than the decrease in the other half due to presence of saturation. In other words there will be a net decrease in flux per pole during sufficient loading of the machine.

This will have a direct bearing on the emf as well as torque developed affecting the performance of the machine.

The armature mmf (depending on the strength of the armature current) is shown separately both in magnitude and direction by the vector OFA. Under actual load conditions, the two mmf exist simultaneously in the generator.

It is seen that the flux through the armature is no longer uniform and symmetrical about the pole axis, rather it has been distorted. The flux is seen to be crowded at the trailing pole tips but weakened or thinned out at the leading pole tips (the pole tip which is first met during rotation by armature conductors is known as the leading pole tip and the other as trailing pole tip).

The resultant mmf OF (The new position of M.N.A.) which is found by vectorially combining OFm and OFA. And the new position of M.N.A which is always perpendicular to the resultant mmf vector OF, is also shown in the figure. With the shift of M.N.A., say through an angle θ brushes are also shifted so as to lie along the new position of M.N.A. Due to this brush shift, the armature conductors and hence armature current is redistributed.

All conductors to the left of new position of M.N.A.but between the two brushes, carry current downwards and those to the right carry current upwards. The armature mmf is found to lie in the direction of the new position of M.N.A. (or brush axis). The armature mmf is now represented by the vector OFA.

OFA can now be resolved into two rectangular components, OFD parallel to polar axis and OFC perpendicular to this axis. We find that:

(i) Component OFC is at right angles to the vector OFm representing the main mmf It produces distortion in the main field and is hence called the cross-magnetizing or distorting component of the armature reaction.

(ii) The component OFd is in direct opposition of OFm which represents the main mmf It exerts a demagnetizing influence on the main pole flux. Hence, it is called the demagnetizing or weakening component of the armature reaction.

Apart from this, due to distortion in the flux distribution, there will be some amount of flux present along the q-axis (brush axis) of the machine. This causes commutation difficult. In the following sections we try to explain armature reaction in somewhat detail considering motor and generator mode separately.

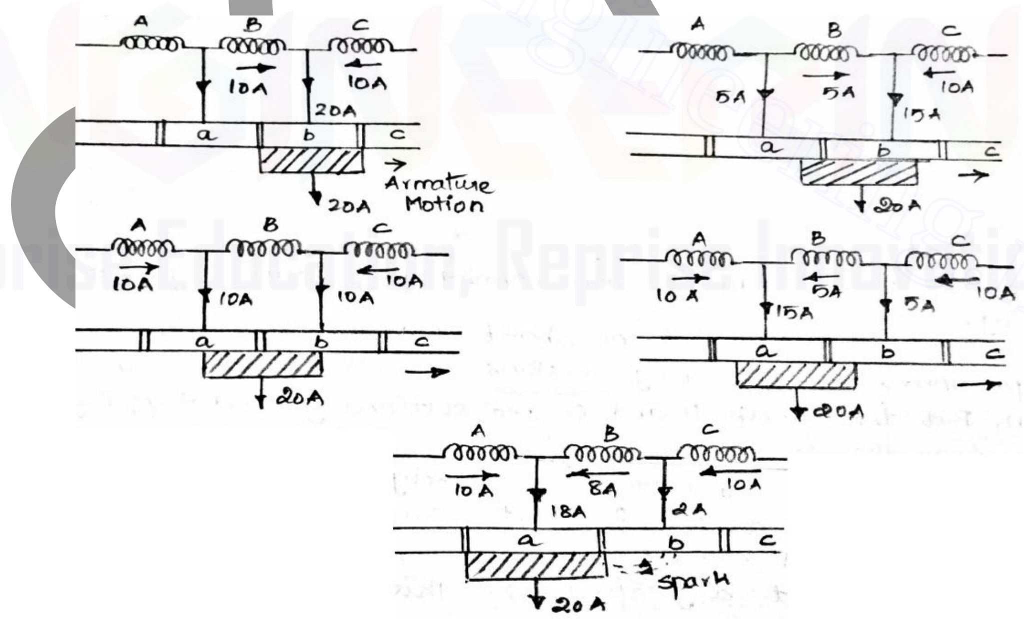
5.Explain in about detail about commutation of D.C machines. [NOV/DEC 2015,NOV/DEC 2012,MAY/JUNE 2009]

COMMUTATION

- The emf induced in the conductors are always sinusoidal and commutator converts this sinusoidal emf into Unidirectional emf.

"The reversal of current is likely to take place in short interval when a coil is short circuited by a brush. So that transfer of current from one diction to other is carried out without any sparking. This process is called commutation"

- Thus a process by which current in the shot circuited coil is reversed while it crosses the MNA. The time during which the coil remains shot circuited is known as commutation period. This period is generally the order of 0.0005 to 0.002sec.
- The commutation is said to be ideal when current changes from +I to zero and zero to –I the commutation period.
- The sparking is produced between the commutation and brush if current is not reversed by that time. This will lead to damage of commutator as well as brush. Hence for satisfactory operation of DC machine proper commutation is required.
- Consider coil B is about to be short circuited. The brush is about to come in conduct with commutator segment 'a' suppose that coil is carrying current of 10 A so that total brush current 20A as every coil meeting at the brush supplies half the brush current independent of lap or wave wound armature.
- The coil B is entering short circuit period. The current in the coil B has reduced from 10A to 5A as the other 5A flows via segment 'a'. The total current remaining same at 20A. But area of contact of the bush is more with segment 'b' than segment 'a'.



- The coil b is in the middle of its short circuit period the current I coil B is reduced to zero.
- The current 10A pass to the brush directly from coils A and C.
- The total current again 20A and the contact area of brush with the segments 'a' and 'b' are equal.

- The coil b is now under group of coils to the right of brush.
- The contact area of the brush with segment ‘b’ decreasing whereas with segment ‘a’ is increasing.
- Coil b is now carrying 5A in other direction. Thus current of 15A is passed segment ‘a’ to the brush while the other 5A is supplied by coil C and pass from segment ‘b’ to the brush. Again the total current is 20A.
- Ideal commutation is assumed then current through coil B will reverse at the end of commutation.
- The current flowing through coil B is only 8A instead of 10A. So difference I coil current is 2A jumps directly through segment ‘b’ to the brush through air and produce spark.

Under commutation

- The current varies uniformly represented y straight line BC the commutation is said to be linear commutation.
- But it observes self-induced emf in the coil will try to maintain the current in the same direction. The commutation is said to be under commutation.

Over commutation

- If reversal of current in the coil is faster than ideal or linear commutation than also sparking may be occur. This commutation is known as over commutation

PART C.

1. **A 4 pole DC shunt generator with lap connected armature supplies 5KW at 230V. The armature and field copper losses are 360W and 200W respectively. Calculate the armature current and generated emf. [Apr/May 15]**

Solution:

Power= 5KW

V=230V

Field copper losses=200W

Armature copper losses=360W

$$I_L = \frac{P}{V} = \frac{5000}{230}$$

$$I_L = 21.7A$$

Field copper losses=200W

$$VI_{sh} = 200$$

$$I_{sh} = \frac{200}{V} = \frac{200}{230} = 0.86A$$

$I_{sh} = 0.86A$

Armature Current $I_a = I_L + I_{sh} = 21.7 + 0.86$

$I_a = 22.56\ A$

Armature copper losses=360W

$I_a^2 R_a = 360$

$$R_a = \frac{360}{I_a^2} = \frac{360}{22.56^2} = 0.707\ Ohms$$

$R_a = 0.707\ Ohms$

$E_G = v + I_a R_a$

$E_G = 230 + 22.56(0.707) = 245.9$

$E_G = 245.9V$

2. In a 400V, Dc compound generator the resistance of armature, series and shunt windings are 0.10,0.05 and 100 ohms respectively. The machines supply power to 20 resistive heaters, each rated 500W, 400 V. Calculate the induced emf and armature current, when the generator is connected in (1) Short shunt (2) Long shunt. Allow brush contact drop of 2V per brush. [Apr/May 15]

Solution:

Power= 500W(20 No)

=10,000W

V=400V

$R_a = 0.10\ ohms$

$R_{se} = 0.05\ ohms$

$R_{sh} = 100\ ohms$

$V_{brush} = 2\ V$

$$I_L = \frac{P}{V} = \frac{10000}{400}$$

$I_L = 25A$

(i) Long Shunt:

$$I_{sh} = \frac{V}{R_{sh}} = \frac{400}{100} = 4A$$

$$I_{sh} = 4\ A$$

$$I_a = I_L + I_{sh} = 25 + 4$$

$$I_a = 29\ A$$

$$E_G = v + I_a R_a + I_a R_{se} + V_{brush}$$

$$E_G = 400 + (29 * 0.05) + (29 * 0.1) + 4 = 408.3$$

$$E_G = 408.3V$$

(ii) Short Shunt:

$$I_L = 25A$$

$$I_{sh} = \frac{V + I_L R_{se}}{R_{sh}}$$

$$I_{sh} = 4.0125\ A$$

$$I_a = I_L + I_{sh} = 25 + 4.0125$$

$$I_a = 29.0125\ A$$

$$E_G = v + I_a R_a + I_a R_{se} + V_{brush}$$

$$E_G = 400 + (25 * 0.05) + (29.0125 * 0.1) + 4 = 408.151$$

$$E_G = 408.151V$$

3. **Two shunt generator are connected in parallel to supply a load of 5000 A. Each machines have a armature resistance of 0.03 ohms and field resistance of 60 ohms. EMF in one machine is 600 V and other machines is 640 V. What power does the machines supply? [Nov/Dec 15**]

Solution:

$$I_a = 5000\ A$$

$$R_a = 0.03\ ohms$$

$$R_{sh} = 60\ ohms$$

$$E_{G1} = 600\ V$$

$$E_{G2} = 640\ V$$

$$P_1 = ?\ P_2 = ?$$

Generator 1

$$I_{a1} = I_{L1} + I_{sh1}$$

$$E_{G1} = v + I_{a1} R_{a1}$$

$E_{G1} = v + (I_{L1} + I_{sh1})R_{a1}$

$1.0005V+0.03I_1=600$--------(1)

Generator 2

$E_{G2} = v + I_{a2}R_{a2}$

$E_{G2} = v + (I_{L2} + I_{sh2})R_{a2}$

$1.0005V+0.03I_2=640$--------(2)

Solving equations, we get

$I_2 = 5000 - I_1$

Solving we get

$I_2 = 3166.66$ A

$I_1 = 1833.33$ A

Substitute the valve of I_2 in equation 2

V=544.72 V

Power output of machine 1,

$=VI_1$

=544.7 * 1833.33

P_1=998.65 KW

Power output of machine 2,

$=VI_2$

=544.7 * 3166.66

P_2=1724.94 KW

UNIT-V

DC MOTOR

PART-A

1.What is back emf in d.c. motor?[MAY/JUNE 2012,MAY/JUNE 2009]

- As the motor armature rotates, the system of conductor come across alternate north and south pole magnetic fields causing an emf induced in the conductors.
- The direction of the emf induced in the conductor is in opposite to current. As this emf always opposes the flow of current in motor operation it is called as back emf.

2.Name the different methods of electrical braking of dc motors.

- Dynamic braking
- Regenerating braking
- Counter current braking or plugging

3. Why are carbon brushes preferred for dc machines?

- The high contact resistance carbon brushes help the current in the coil undergoing commutation to attain its full value in the reverse direction at the end of commutation.
- The carbon brushes also lubricate and give less wear and tear on commutator surface.

4. What is the function of no-voltage release coil in D.C. motor starter? [NOV/DEC 2015]

As long as the supply voltage is on healthy condition the current through the NVR coil produce enough magnetic force of attraction and retain the starter handle in ON position against spring force. When the supply voltage fails or becomes lower than a prescribed value then electromagnet may not have enough force to retain so handle will come back to OFF position due to spring force automatically.

5. Enumerate the factors on which speed of a d.c.motor depends?

$N= (V- I_aR_a)/\Phi$ so speed depends on air gap flux, resistance of armature, voltage applied to armature.

6. Why is the emf not zero when the field current is reduced to zero in dc generator?

Even after the field current is reduced to zero, the machine is left out with some flux as

residue so emf is available due to residual flux.

7. What are the conditions to be fulfilled by for a dc shunt generator to build back

emf?[MAY/JUNE 2012,MAY/JUNE 2009]

The generator should have residual flux, the field winding should be connected in such a manner that the flux setup by field in same direction as residual flux, the field resistance should be less than critical field resistance, load circuit resistance should be above critical resistance.

8. How will you change the direction of rotation of d.c.motor?

Either the field direction or direction of current through armature conductor is reversed.

9.Name any four applications of DC series motor.[MAY/JUNE 2013]

Electric traction, Mixies,Hoists, Drilling machines

10. What is the necessity of starter in dc motors?[NOV/DEC 2015]

When a dc motor is directly switched on, at the time of starting, the motor back emf is zero. Due to this, the armature current is very high. Due to the very high current, the motor gets damaged. To reduce the starting current of the motor a starter is used.

11. Why DC series motor is suited for traction applications? [APRIL/MAY 2015,NOV/DEC 2015]

It provides high starting torque. So DC series motor is suited for traction applications

PART-B

1.Explain in detail about the working of starter with the help of diagram. [NOV/DEC 2015,APRIL/MAY 2015,NOV/DEC 2012]

Three Point Starter

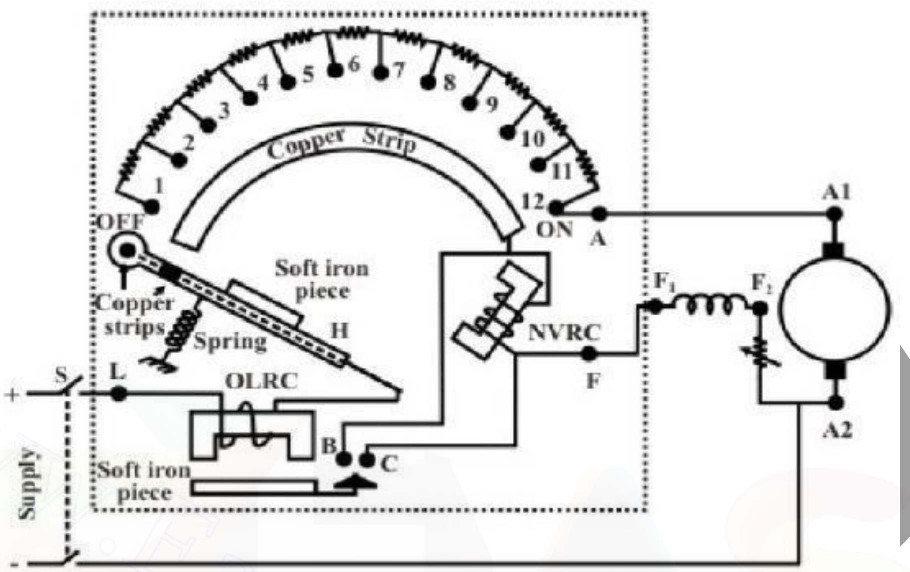
A “3-point starter” is extensively used to start a D.C shunt motor. It not only overcomes the difficulty of a plain resistance starter, but also provides additional protective features such as over load protection and no volt protection.

The diagram of a 3-point starter connected to a shunt motor is shown in figure. Although, the circuit looks a bit clumsy at a first glance, the basic working principle is same as that of plain resistance starter. The starter is shown enclosed within the dotted rectangular box having three terminals marked as A, L and F for external connections.

Terminal A is connected to one armature terminal Al of the motor. Terminal F is connected to one field terminal F1 of the motor and terminal L is connected to one supply terminal as shown. F2 terminal of field coil is connected to A2 through an external variable field resistance and the common point connected to supply (-ve).

The external armatures resistances consist of several resistances connected in series and are shown in the form of an arc. The junctions of the resistances are brought out as terminals and marked. Just beneath the resistances, a continuous copper strip also in the form of an arc is present.

There is a handle which can be moved in the clockwise direction against the



spring tension. The spring tension keeps the handle in the OFF position when no one attempts to move it. Now let us trace the circuit from terminal L (supply + ve).

The wire from L passes through a small electro magnet called OLRC, (the function of which we shall discuss a little later) and enters through the handle shown by dashed lines.

Near the end of the handle two copper strips are firmly connected with the wire.

The furthest strip is shown circular shaped and the other strip is shown to be rectangular. When the handle is moved to the right, the circular strip of the handle will make contacts with resistance terminals 1, 2 etc.

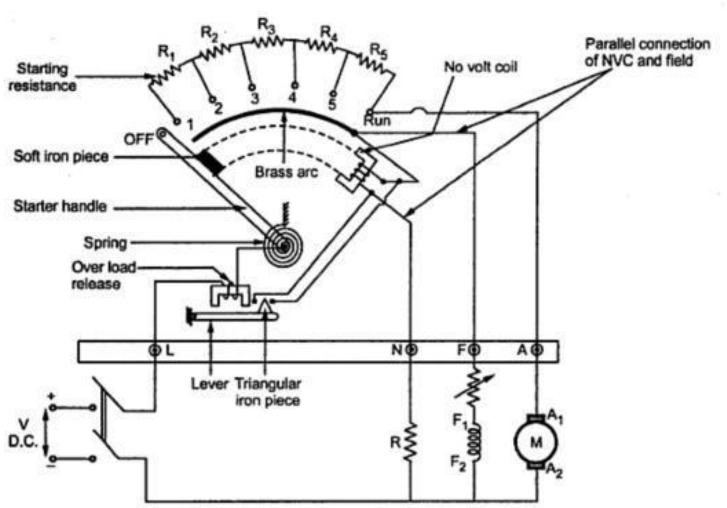
On the other hand, the rectangular strip will make contact with the continuous arc copper strip. The other end of this strip is brought as terminal F after going through an electromagnet coil (called NVRC). Terminal F is finally connected to motor field terminal Fl.

Working principle

In the operation of the starter, initially the handle is in the OFF position. Neither armature nor the field of the motor gets supply. Now the handle is moved to stud number 1. In this position armature and all the resistances in series gets connected to the supply. Field coil gets full supply as the rectangular strip makes contact with arc copper strip. As the machine picks up speed handle is moved further to stud number 2. In this position the external resistance in the armature circuit is less as the first resistance is left out. Field however, continues to get full voltage by virtue of the continuous arc strip. Continuing in this way, all resistances will be left out when stud number 12 (ON) is reached. In this position, the electromagnet (NVRC) will attract the soft iron piece attached to the handle. Even if the operator removes his hand from the handle, it will still remain in the ON position as spring restoring force will be balanced by the force of attraction between NVRC and the soft iron piece of the handle. The no volt release coil (NVRC) carries same current as that of the field coil. In case supply voltage goes off, field coil current will decrease to zero. Hence NVRC will be de-energized and will not be able to exert any force on the soft iron piece of the handle. Restoring force of the spring will bring the handle back in the OFF position.

The starter also provides over load protection for the motor. The other electromagnet, OLRC overload release coil along with a soft iron piece kept under it, is used to achieve this. The current flowing through OLRC is the line current IL drawn by the motor. As the motor is loaded, Ia hence IL increases. Therefore, IL is a measure of loading of the motor. Suppose we want that the motor should not be over loaded beyond rated current. Now gap between the electromagnet and the soft iron piece is so adjusted that for $I_L \leq$ Irated the iron piece will not be pulled up. However, if IL≤Irated force of attraction will be sufficient to pull up iron piece. This upward movement of the iron piece of OLRC is utilized to de-energize NVRC. To the iron a copper strip is attached. During over loading condition, this copper strip will also move up and put a short circuit between two terminals B and C. Carefully note that B and C are nothing but the two ends of the NVRC. In other words, when over load occurs a short circuit path is created across the NVRC. Hence NVRC will not carry any current now and gets de-energized. The moment it gets deenergised, spring action will bring the handle in the OFF position thereby disconnecting the motor from the supply. Three-point starter has one disadvantage. If we want to run the machine at higher speed (above rated speed) by field weakening (i.e., by reducing field current), the strength of NVRC magnet may become so weak that it will fail to hold the handle in the ON position and the spring action will bring it back in the OFF position. Thus we find that a false disconnection of the motor takes place even when there is neither over load nor any sudden disruption of supply.

Four-Point Starter



The four-point starter eliminates the drawback of the three-point starter. In addition to the same three points that were in use with the three-point starter, the other side of the line, L1, is the fourth point brought to the starter when the arm is moved from the "Off" position. The coil of the holding magnet is connected across the line. The holding magnet and starting resistors function identical as in the three - point starter.

The possibility of accidentally opening the field circuit is quite remote. The four - point starter provides the no-voltage protection to the motor. If the power fails, the motor is disconnected from the line.

2.Explain any two methods of testing of DC machines. [NOV/DEC2015, MAY/JUNE 2014]

Swinburne's Test

For a d.c shunt motor change of speed from no load to full load is quite small. Therefore, mechanical loss can be assumed to remain same from no load to full load.

Also if field current is held constant during loading, the core loss too can be assumed to remain same.

In this test, the motor is run at rated speed under no load condition at rated voltage. The current drawn from the supply I_{L0} and the field current I_f are recorded (figure 40.3). Now we note that:

Input power to the Motor, $P_m = VI_{Lo}$

Cu loss in the field circuit $P_{f1} = VI_f$

Power input to the armature $= VI_{Lo} - VI_f$

$= V(I_{Lo} - I_f)$

$= VI_{ao}$

Cu loss in the armature circuit $=I_{ao}^2 r_a$

Gross power developed y armature$=VI_{ao}-I_{ao}^2 r_{ao}$

$=(V-I_{a0}r_{ao})I_{ao}$

$=E_{bo}I_{ao}$

Net mechanical output power, $P_{net,mech} = E_b\, I_a - P_{rot}$

Efficiecy of the loaded motor $=(E_b I_a - P_{rot})/VI_L$

Since the motor is operating under no load condition, net mechanical output power is zero. Hence the gross power developed by the armature must supply the core loss and friction & windage losses of the motor. Therefore,

$$P_{core}+P_{friction}=(V-I_{ao}r_a)I_{ao}=E_{bo}I_{ao}$$

Since, both P_{core} and $P_{friction}$ for a shunt motor remains practically constant from no load to full load, the sum of these losses is called constant rotational loss i.e.,

$$\text{Constant rotational loss}, P_{rot}=P_{core}+P_{friction}$$

In the Swinburne's test, the constant rotational loss comprising of core and friction loss is estimated from the above equation.

After knowing the value of P_{rot} from the Swinburne's test, we can fairly estimate the efficiency of the motor at any loading condition. Let the motor be loaded such that new current drawn from the supply is I_L and the new armature current is I_a

Input power to the motor, $P_m=VI_L$

Cu loss in the field circuit $P1=VI_f$

Power input to the armature $=VI_L-VI_f$

$=V(I_L-I_f)$

$=Vi_a$

Cu loss in the armature circuit $=I_{a2}r_a$

Gross power developed y armature$=V_{ia}-I_{a2}r_a$

$=(V-I_A r_a)I_a$

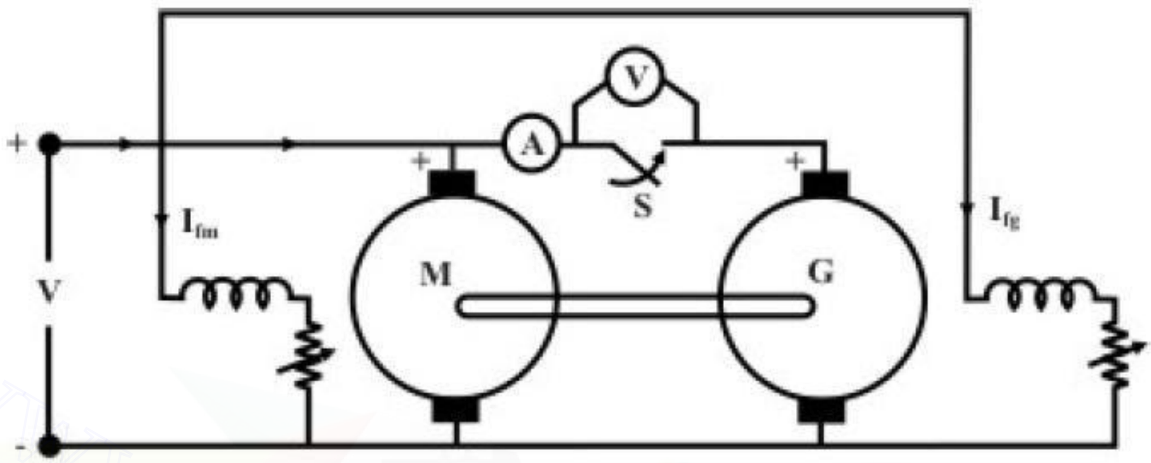
$=E_b I_a$

Net mechanical output power, $P_{net,mech} = E_b\, I_a - P_{rot}$

Efficiecy of the loaded motor $=(E_b I_a - P_{rot})/VI_L$

Hopkinson’s test

This as an elegant method of testing d.c machines. Here it will be shown that while power drawn from the supply only corresponds to no load losses of the machines, the armature physically carries any amount of current (which can be controlled with ease). Such a scenario can be created using two similar mechanically coupled shunt machines. Electrically these two machines are eventually connected in parallel and controlled in such a way that one machine acts as a generator and the other as motor. In other words, two similar machines are required to carry out this testing which is not a bad proposition for manufacturer as large numbers of similar machines are manufactured



Procedure

Connect the two similar (same rating) coupled machines as shown in figure With switch S opened, the first machine is run as a shunt motor at rated speed. It may be noted that the second machine is operating as a separately excited generator because its field winding is excited and it is driven by the first machine. Now the question is what will be the reading of the voltmeter connected across the opened switch S? The reading may be (i) either close to twice supply voltage or (ii) small voltage. In fact the voltmeter practically reads the difference of the induced voltages in the armature of the machines. The upper armature terminal of the generator may have either + ve or negative polarity. If it happens to be +ve, then voltmeter reading will be small otherwise it will be almost double the supply voltage

Since the goal is to connect the two machines in parallel, we must first ensure voltmeter reading is small. In case we find voltmeter reading is high, we should switch off the supply, reverse the armature connection of the generator and start afresh. Now voltmeter is found to read small although time is still not ripe enough to close S for paralleling the machines. Any attempt to close the switch may result into large circulating current as the armature resistances are small. Now by adjusting the field current I_{fg} of the generator the voltmeter reading may be adjusted to zero ($E_g \approx E_b$) and S is now closed. Both the machines are now connected in parallel

Loading the machines

After the machines are successfully connected in parallel, we go for loading the machines

i.e., increasing the armature currents. Just after paralleling the ammeter reading A will be close to zero as $E_g \approx E_b$. Now if I_{fg} is increased (by decreasing R_{fg}), then E_g becomes greater than E_b and both I_{ag} and I_{am} increase, Thus by increasing field current of generator (alternatively decreasing field current of motor) one can make $E_g > E_b$ so as to make the second machine act as generator and first machine as motor. In practice, it is also required to control the field current of the motor I_{fm} to maintain speed constant at rated value. The interesting point to be noted here is that I_{ag} and I_{am} do not reflect in the supply side line. Thus current drawn from supply remains small (corresponding to losses of both the machines). The loading is sustained by the output power of the generator running the motor and vice versa. The machines can be loaded to full load current without the need of any loading arrangement

Calculation of efficiency

Let field currents of the machines be are so adjusted that the second machine is acting as generator with armature current I_{ag} and the first machine is acting as motor with armature current I_{am} as shown in figure 40.7. Also let us assume the current drawn from the supply be I_1. Total power drawn from supply is VI_1 which goes to supply all the losses (namely Cu losses in armature & field and rotational losses) of both the machines

Power drawn from supply=VI_1

Field Cu loss for motor=VIf_m

Field Cu loss for generator =VI_{fg}

Armature Cu loss for motor =$I^2{}_a r_{am}$

Armature Cu loss for generator=$I^2{}_{ag} r_{ag}$

Rotational losses of both the machines=$VI_1-(VI_{fm}+VI_{fg}+I^2{}_{am}r_{am}+I^2{}_{ag}r_{ag})$

Speed of both the machines are same, it is reasonable to assume the rotational losses of both the machines are equal; which is strictly not correct as the field current of the generator will be a bit more than the field current of the motor, Thus, Once P_{rot} is estimated for each machine we can proceed to calculate the efficiency of the machines as follows,

Rotational loss of each machine, $P_{rot}= [VI_1-(VI_{fm}+VI_{fg}+I^2{}_{am}r_{am}+I^2{}_{ag}r_{ag})]/2$

Efficiency of the motor

As pointed out earlier, for efficiency calculation of motor, first calculate the input power and then subtract the losses to get the output mechanical power as shown below,

Total power input to the motor=power input to its field+ power input to the armature

$P_{inm}=VI_{fm}+VI_{am}$

Losses of the motor$=VI_{fm}+I^2_{am}r_{am}+P_{rot}$

Net mechanical output power $P_{outm}=P_{ing}-(VI_{fm}+I^2_{am}r_{am}+P_{rot})$

$$\eta m=P_{outm}/P_{inm}$$

EFFICIENCY OF GENERATOR

Losses of the generator$=VI_{fg}+I^2_{ag}r_{ag}+P_{rot}$

Net mechanical input power $P_{ing}=P_{outg}-(VI_{fg}+I^2_{ag}r_{ag}+P_{rot})$

$$\eta g=P_{outm}/P_{inm}$$

Advantages of Hopkinson's Test

1. This test requires very small power compared to full-load power of the motor-generator coupled system. That is why it is economical.

2. Temperature rise and commutation can be observed and maintained in the limit because this test is done under full load condition.

3. Change in iron loss due to flux distortion can be taken into account due to the advantage of its full load condition

Disadvantages of Hopkinson's Test

1. It is difficult to find two identical machines needed for Hopkinson's test.
2. Both machines cannot be loaded equally all the time.
3. It is not possible to get separate iron losses for the two machines though they are different because of their excitations.
4. It is difficult to operate the machines at rated speed because field currents vary widely.

3.Explain in detail about the Characteristics of DC motors.[APRIL/MAY 2015,MAY/JUNE 2012]

Generally, three characteristic curves are considered for DC motors which are, (i) Torque vs. armature current (Ta - Ia), (ii) Speed vs. armature current and (iii) Speed vs. torque. These are explained below for each type of DC motor. These characteristics are determined by keeping following two relations in mind. $T_a \propto \Phi.I_a$ and $N \propto E_b/\Phi$

Characteristics of DC series motors

Torque vs. armature current (Ta-Ia)

This characteristic is also known as electrical characteristic. We know that torque is directly proportional to armature current and flux, $T_a \propto \Phi.I_a$. In DC series motors, field winding is connected in series with armature. Thus, before magnetic saturation of the field, flux Φ is directly proportional to Ia. Therefore, before magnetic saturation Ta α Ia^2. At light loads, Ia as well as Φ is small and hence the torque increases as the square of the armature current.

Therefore, the Ta-Ia curve is parabola for smaller values of Ia. After magnetic saturation of the field winding, flux Φ is independent of armature current Ia.

Therefore, the torque varies proportional to Ia only, T α Ia. Therefore, after magnetic saturation, Ta-Ia curve becomes straight line.The shaft torque (Tsh) is less than armature torque (Ta) due to stray losses.

In DC series motors, (prior to magnetic saturation) torque increases as the square of armature current, these motors are used where high starting torque is required

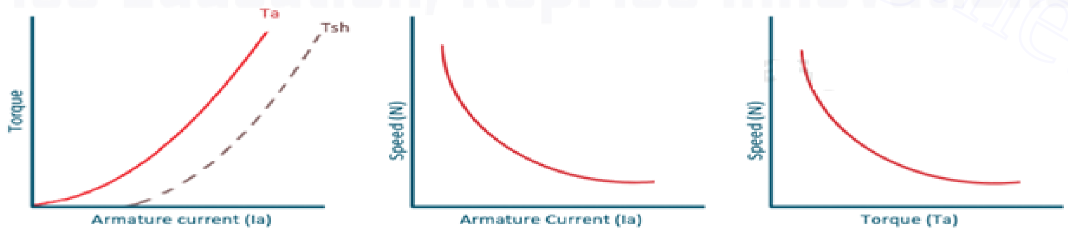
Speed vs. armature current (N-Ia)

We know the relation, N α Eb/Φ. For small load current (and hence for small armature current) change in back emf Eb is small and it may be neglected. Thus, for small currents speed is inversely proportional to Φ. As we know, flux is directly proportional to Ia, speed is also inversely proportional to Ia.

When armature current is very small the speed becomes dangerously high. That is why a series motor should never be started without some mechanical load.But, at heavy loads, armature current Ia is large. And hence speed is low which results in decreased back emf Eb. Due to decreased Eb, more armature current is allowed.

Speed vs. torque (N-Ta)

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



Characteristics of DC series motor

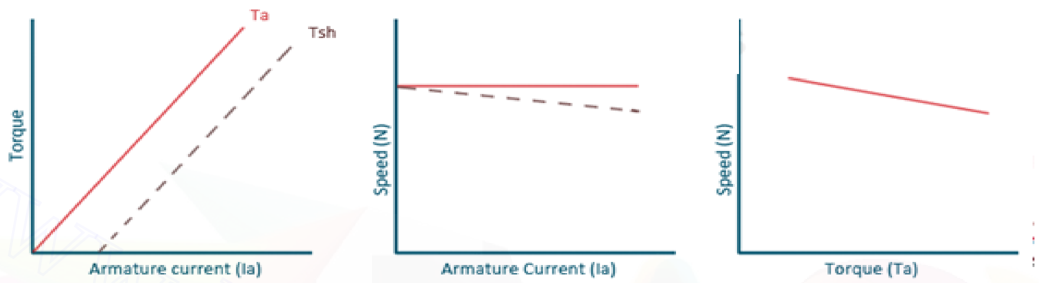
and vice versa. Characteristics of DC shunt motors

Torque vs. armature current (Ta-Ia)

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

Speed vs. armature current (N-Ia)

As flux Φ is assumed constant, we can say N α Eb. But, back emf is also almost constant, the speed remains constant. But practically, Φ as well as Eb decreases with increase in load. But, the Eb decreases slightly more than Φ, and hence the speed decreases slightly. Generally, the speed decreases by 5 to 15% of full load speed only. And hence, a shunt motor can be assumed as a constant speed motor.



Characteristics of DC shunt motor

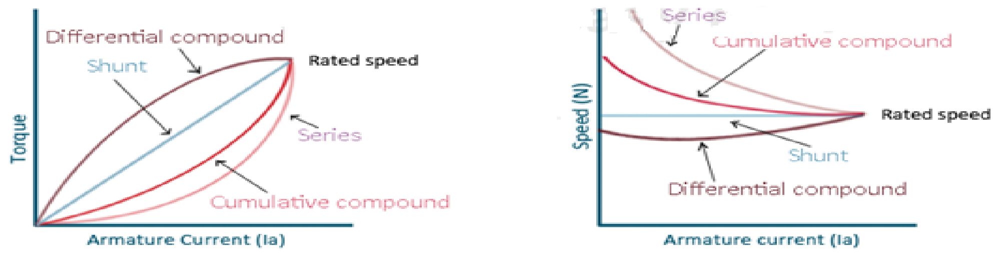
Characteristics of DC compound motor

DC compound motors have both series as well as shunt windings.In a compound motor series and shunt windings are connected such that series flux is in direction with shunt flux then the motor is said to be cumulatively compounded. And if series flux is opposite direction as that of the shunt flux, then the motor is said to be differentially compounded.

Characteristics of both these types are explained below.

(a)Cumulative compound motor

Cumulative compound motors are used where series characteristics are required but the load is likely to be removed completely. Series winding takes care of the heavy load, whereas the shunt winding prevents the motor from running at dangerously high speed when the load is suddenly removed. These motors are generally employed a flywheel, where sudden and temporary loads are applied like in rolling mills.



Characteristics of DC compound motor

(b)Differential compound motor:

In differential field motors, series flux opposes shunt flux, the total flux decreases with increase in load. Due to this, the speed remains almost constant or even it may increase slightly with increase in load. Differential compound motors are not commonly use, but they find limited applications in experimental and research work.

4.What are the different methods of Speed control in DC motor.[MAY/JUNE 2014,MAY/JUNE 2013]

Back emf of a DC motor E_b is the induced emf due to rotation of the armature in magnetic field. Thus value of the E_b can be given by the EMF equation of a DC generator.

$$E_b = {}^{P\O NZ}/_{60A}$$

(where, P= no. of poles, Ø=flux/pole, N=speed in rpm, Z=no. of armature conductors, A=parallel paths)

E_b can also be given as,

$$E_b = V - I_aR_a$$

thus from above equations

$$N = {}^{E_b\,60A}/_{P\O Z}$$

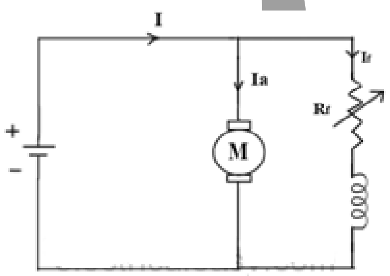
but, for a DC motor A, P and Z are constant

N α $K^{E_b}/_{\varnothing}$ (where, K=constant)

thus, it shows speed is directly proportional to back emf and inversely proportional to the flux per pole.

Speed control of Shunt motor

1. Flux control method



It is seen that speed of the motor is inversely proportional to flux. Thus by decreasing flux speed can be increased and vice versa. To control the flux, a rheostat is added in series with the field winding, as shown in the circuit diagram.

Adding more resistance in series with field winding will increase the speed, as it will decrease the flux. Field current is relatively small and hence I^2R loss is small, hence this method is quiet efficient. Though speed can be increased by reducing flux with this method, it puts a limit to maximum speed as weakening of flux beyond the limit will adversely affect the commutation

2. Armature control method

Speed of the motor is directly proportional to the back emf E_b and $E_b = V - I_aR_a$. That is when supply voltage V and armature resistance R_a are kept constant, speed is directly proportional to armature current I_a. Thus if we add resistance in series with armature, I_a decreases and hence speed decreases. Greater the resistance in series with armature, greater the decrease in speed.

3. Voltage Control Method

A) **Multiple voltage control:**

In this method the, shunt filed is connected to a fixed exciting voltage, and armature is supplied with different voltages. Voltage across armature is changed with the help of a suitable switchgear. The speed is approximately proportional to the voltage across the armature.

B) **Ward-Leonard System**:

This system is used where very sensitive speed control of motor is required (e.g electric excavators, elevators)M_2 is the motor whose speed control is required.M_1 may be any AC motor or DC motor with constant speed.G is the generator directly coupled to M_1. In this method the output from the generator G is fed to the armature of the motor M_2 whose speed is to be controlled. The output voltage of the generator G can be varied from zero to its maximum value, and hence the armature voltage of the motor M_2 is varied very smoothly. Hence very smooth speed control of motor can be obtained by this method.

Speed control of series motor

1. Flux control method

A) Field diverter:

A variable resistance is connected parallel to the series field. This variable resistor is called as diverter, as desired amount of current can be diverted through this resistor and hence current through field coil can be decreased. Hence flux can be decreased to desired amount and speed can be increased.

B) Armature diverter:

Diverter is connected across the armature For a given constant load torque, if armature current is reduced then flux must increase.

As, $T_a \alpha ØI_a$

This will result in increase in current taken from the supply and hence flux Ø will increase and subsequently speed of the motor will decrease.

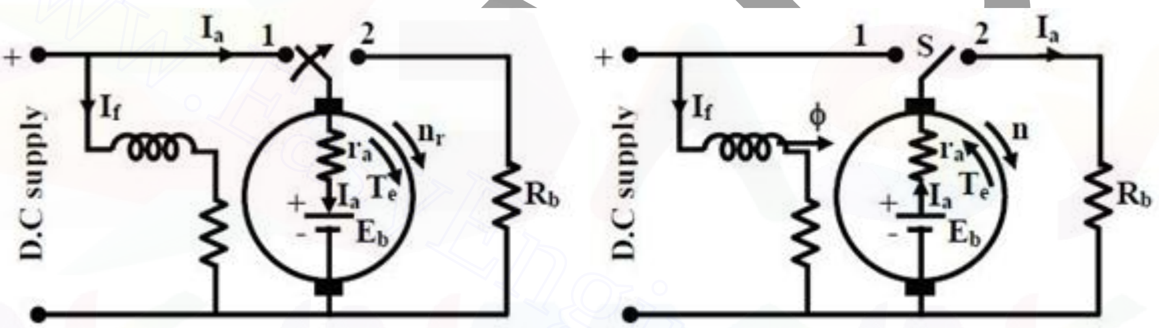
C) Tapped field control:

Field coil is tapped dividing number of turns. Thus we can select different value of Ø by selecting different number of turns.

5.Explain in detail about any two types of braking of DC Machines.

Rheostat braking

Consider a d.c shunt motor operating from a d.c supply with the switch S connected to position 1. S is a single pole double throw switch and can be connected either to position 1 or to position 2. One end of an external resistance R_b is connected to position 2 of the switch S as shown



Let with S in position 1, motor runs at n rpm, drawing an armature current I_a and the back emf is E_b = kφ n. Note the polarity of E_b which, as usual for motor mode in opposition with the supply voltage. Also note T_e and n have same clock wise direction.

Now if S is suddenly thrown to position 2 at t = 0, the armature gets disconnected from the supply and terminated by R_b with field coil remains energized from the supply. Since speed of the rotor cannot change instantaneously, the back emf value E_b is still maintained with same polarity prevailing at t = 0_-. Thus at t = 0_+, armature current will be $I_a = E_b/(r_a + R_b)$ and with reversed direction compared to direction prevailing during motor mode at t= 0.

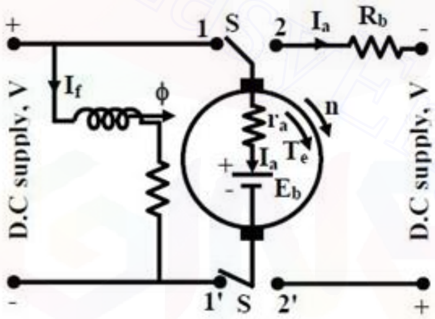
Obviously for t > 0, the machine is operating as generator dissipating power to R_b and now the electromagnetic torque T_e must act in the opposite direction to that of n since I_a has changed direction but φ has not (recall $T_e \propto φ\ I_a$). As time passes after switching, n decreases reducing K.E and as a consequence both E_b and I_a decrease. In other words, value of braking torque will be highest at t = 0_+, and it decreases progressively and becoming zero when the machine finally come to a stop.

Plugging or dynamic braking

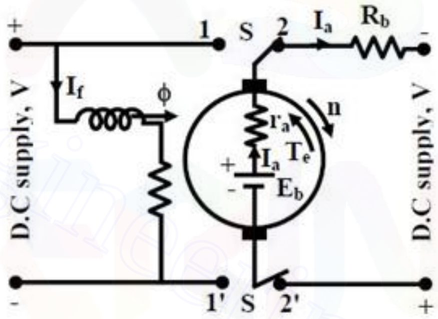
. Here S is a double pole double throw switch. For usual motoring mode, S is connected to positions 1 and 1'. Across terminals 2 and 2', a series combination of an external resistance R_b and supply voltage with polarity as indicated is connected. However, during motor mode this part of the circuit remains inactive.

To initiate braking, the switch is thrown to position 2 and 2' at t = 0, thereby disconnecting the armature from the left hand supply. Here at $t = 0_+$, the armature current will be $I_a = (E_b + V)/(r_a + R_b)$ as E_b and the right hand supply voltage have additive polarities by virtue of the connection. Here also I_a reverses direction producing T_e in opposite direction to n

I_a decreases as E_b decreases with time as speed decreases. However, I_a cannot become zero at any time due to presence of supply V. So unlike rheostat braking, substantial magnitude of braking torque prevails. Hence stopping of the motor is expected to be much faster than rheostat breaking. But what happens, if S continuous to be in position 1' and 2' even after zero speed has been attained.



Machine operates as motor



Machine operates as generator during braking (plugging).

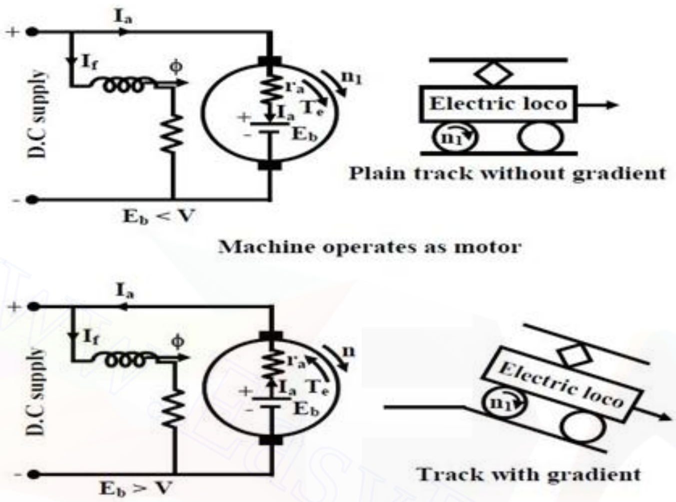
The answer is rather simple; the machine will start picking up speed in the reverse direction operating as a motor. So care should be taken to disconnect the right hand supply, the moment armature speed becomes zero.

Regenerative braking

A machine operating as motor may go into regenerative braking mode if its speed becomes sufficiently high so as to make back emf greater than the supply voltage i.e., $E_b > V$. Obviously under this condition the direction of I_a will reverse imposing torque which is opposite to the direction of rotation.

The normal motor operation is shown in figure 39.27 where armature motoring current I_a is drawn from the supply and as usual $E_b < V$. Since $E_b = k\varphi\, n_1$. The question is how speed on its own become large enough to make $E_b < V$ causing regenerative braking. Such a situation may occur in practice when the mechanical load itself becomes active.

Imagine the d.c motor is coupled to the wheel of locomotive which is moving along a plain track without any gradient Machine is running as a motor at a speed of n_1 rpm. However, when the track has a downward gradient, component of gravitational force along the track also appears which will try to accelerate the motor and may increase its speed to n_2 such that $E_b = k\varphi\, n_2 > V$.



Direction of I_a reverses, feeding power back to supply. Regenerative braking here will not stop the motor but will help to arrest rise of dangerously high speed.

PART C

1. **A 400 V DC shunt motor has no load speed of 1450 rpm, the line current being 9A. At full loaded condition, the line current is 75A. If the shunt field resistance is 200 ohms and armature resistance is 0.5 ohms. Calculate full load speed. [Apr/May 2015]**

Solution:

$V=400V$

$N_1=1450$ rpm

$I_{L1}=9A$

$I_{L2}=75A$

$R_{sh}=200$ ohms

$R_a=0.5$ A

$N_2=?$

$$I_{sh} = \frac{V}{R_{Sh}} = \frac{400}{200} = 2A$$

$I_{a1} = I_{L1} - I_{sh}$

$= 9 - 2 = 7A$

$E_{b1} = V - I_{a1}R_a$

$= 400 - (7*0.5)$

$= 396.5V$

$I_{a2} = I_{L2} - I_{sh} = 75 - 2$

$= 73$ A

$E_{b2} = V - I_{a2}R_a$

$= 400 - (73*0.5)$

$= 363.5V$

$$N_2 = \frac{E_{b2}}{E_{b1}} * N_1$$

$$= \frac{396.5}{363.5} * 1450$$

$$N_2 = 1329\ rpm$$

2. A 230 V Dc shunt motor on no load runs at a speed of 1200 rpm and draws a current of 4.5 A. The armature and shunt field resistance are 0.3 ohms and 230 ohms respectively. Calculate the back emf and speed, when loaded and drawing a current of 36A. [Apr/May 2015]

Solution:

$V = 230V$

$N_1 = 1200rpm$

$I_{L1} = 4.5A$

$R_a = 0.3A$

$R_{sh} = 230$ Ohms

$I_{L2} = 36$ A

$E_{B2} = ?$

$N_2 = ?$

$$I_{sh} = \frac{V}{R_{Sh}} = \frac{230}{230} = 1A$$

$$I_{a1} = I_{L1} + I_{sh} = 4.5 - 1 = 3.5A$$

$$E_{B1} = V - I_{a1}R_a$$

$= 230 - (3.5*0.3)$

$= 228.95V$

$$I_{a2} = I_{L2} + I_{sh} = 36 - 1 = 35A$$

$E_{B2} = V - I_{a2}R_a$

=230 – (35*0.3)

=219.5V

$N_2 = \frac{E_{b2}}{E_{b1}} * N_1$

$N_2 = \frac{219.5}{228.9} * 1200$

$N_2 = 1150\ rpm$

3. **The Hopkinson test on two similar shunt machines gave the following data's line voltage =110V, line current 48A, Armature current 230A, field current 3A and 3.5A for motor and generator respectively. Armature resistance is 0.035 ohms. Calculate efficiency for both machines**.

Solution:

I_1=48A

I_1+I_2=233A

I_4=3A

I_2=185A

Armature Cu loss of Motor= $(230)^2$*0.035=1851.5

Field Cu loss of motor= 110*3=330

Total loss of motor= 1851.5+330=2181.5

Armature Cu loss of Generator= $(188.5)^2$*0.035= 1243.6

Field Cu loss of Generator= 110*3.5= 385

Total loss of Generator=1243.6+385=1628.6

Stray Loss= VI_1+[Total loss of motor+ Total loss of Generator]

W_s=1469.9

W_s/2=1469.9/2=734.9

Efficiency of Motor:

$$\text{Efficiency} = \frac{output\ power}{input\ power}$$

$$\text{Efficiency} = \frac{input\ power - losses}{input\ power}$$

$$\text{Efficiency} = \frac{V(I_1 + I_2) - [\text{Total loss of motor} + \text{Ws}/2]}{V(I_1 + I_2)}$$

$$\text{Efficiency} = \frac{110(233) - [2181.5 + 734.9]}{110(233)}$$

$$\text{Efficiency} = 88.6\%$$

Efficiency of Generator:

$$\text{Efficiency} = \frac{output\ power}{input\ power}$$

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

$$\text{Efficiency} = \frac{(110 * 185)}{(110 * 185) + [1628.6 + 734.9]}$$

$$\text{Efficiency} = 89.5\%$$

Reg. No. :

Question Paper Code : 80373

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2016.

Fourth Semester

Electrical and Electronics Engineering

EE 6401 — ELECTRICAL MACHINES – I

(Regulations 2013)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. What is Hysteresis Losses? [P. No : 2]
2. Define Flux Linkage.
3. Define Voltage Regulation of a transformer. [P. No. 16]
4. Draw Scott connection of a transformer.
5. What is Magnetic saturation?
6. What is meant by distributed winding?
7. Write EMF equation of D.C generator. [P. No : 45]
8. What is the use of Interpole in D.C machine? [P. No. 45]
9. List various method of starting D.C motor.
10. What is meant by dynamic braking in D.C motor?

PART B — (5 × 16 = 80 marks)

11. (a) Obtain the expression for Dynamically induced EMF and force. (16)
[P. No : 2]

Or

(b) Explain the AC operation of Magnetic circuit. [P. No : 9] (16)

12. (a) The following data were obtained on a 20 kVA, 50 Hz, 2000/200 V distribution transformer:

	Voltage (V)	Current (A)	Power (W)
OC test with HV open-circuited	200	4	120
SC test with LV short-circuited	60	10	300

Draw the approximate equivalent circuit of the transformer referred to the HV and LV sides respectively. [P.No:30] (16)

Or

(b) With circuit explain Sumpner's test and how to obtain efficiency of a transformer. (16)

13. (a) Obtain the expression for field energy and mechanical force. (16)

[P.No:35]

Or

(b) Explain about the Magnetic field in rotating machines. [P.No:39] (16)

14. (a) Explain the construction and operation of D.C generator. [P.No:46] (16)

Or

(b) Describe the process of commutation in D.C machine. [P.No:55] (16)

15. (a) In a Hopkinson's test on a pair of 500-V. 100-kW shunt generators, the following data was obtained:

Auxiliary supply, 30 A at 500 V: Generator output current, 200 A Field currents, 3.5 A 1.8 A

Armature circuit resistances, 0.075 Ω each machine. Voltage drop at brushes, 2 V (each machine).

Calculate the efficiency of the machine acting as a generator. (16)

[P.No:73]

Or

(b) With a circuit, explain how to obtain efficiency of D.C Generator by conducting Swinburne's test. (16)

Reg. No. [ ]

Question Paper Code : 57316

B.E./B.Tech. DEGREE EXAMINATION, MAY/JUNE 2016

Fourth Semester

Electrical and Electronics Engineering

EE6401 – ELECTRICAL MACHINES – I

(Regulations 2013)

Time : Three Hours **Maximum : 100 Marks**

Answer ALL questions.

PART – A (10 × 2 = 20 Marks)

1. State Ampere's Law.
2. Define Leakage Flux. [P.No : 1]
3. Define all day efficiency of a transformer. [P.No : 16]
4. What is Inrush current in a transformer ?
5. Define Co-energy. [P.No : 33]
6. What is meant by winding inductance ?
7. Compare Lap and Wave windings. [P.No : 45]
8. Draw various characteristics of D.C. shunt generator. [P.No : 51]
9. Draw speed-torque characteristics of DC series motor. [P.No : 67]
10. What is meant by Plugging ?

PART – B (5 × 16 = 80 Marks)

11. (a) Summarize the properties of magnetic materials. **(16)**

OR

(b) Explain the Hysteresis and eddy current losses and obtain its expression. **(16)**
[P.No : 11]

12. (a) With a circuit explain how to obtain equivalent circuit by conducting O.C & S.C test in a single phase transformer. **(16)**

OR

(b) Explain the various three phase transformer connection and parallel operation of three phase transformer. [P.No : 25] **(16)**

13. (a) Obtain the expression for energy in a attracted armature relay magnetic system. **(16)**
[P.No : 35]

OR

(b) With an example explain the Multiple-excited magnetic field system. **(16)**
[P.No : 34]

14. (a) Explain the Armature Reaction in D.C machine. [P.No : 54] **(16)**

OR

(b) (i) Obtain EMF equation of D.C. generator. [P.No : 50] **(8)**

(ii) A 4-pole dc motor is lap-wound with 400 conductors. The pole-shoe is 20cm long and the average flux density over one-pole-pitch is 0.4T, the armature diameter being 30 cm. find the torque and gross-mechanical power developed when the motor is Drawing 25A and running at 1500 rpm. **(8)**

15. (a) The no-load test of a 44.76 kW, 220-V, D.C. shunt motor gave the following figures :

Input current = 13.25 A; Field current = 2.55 A; Resistance of the armature at 75°C = 0.032Ω and Brush drop = 2V. Estimate the full-load current and efficiency. [P. No : 73] **(16)**

OR

(b) Explain the method to obtain efficiency at full load by conducting Hopkinson's test. [P. No : 63] **(16)**

Reg. No. :

Question Paper Code : 27214

B.E./B.Tech. DEGREE EXAMINATION, NOVEMBER/DECEMBER 2015.

Fourth Semester

Electrical and Electronics Engineering

EE 6401 — ELECTRICAL MACHINES — I

(Regulations 2013)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. Define Stacking factor. [P. No: 2]
2. What are quasi static fields? [P. No: 1]
3. Why transformer rating is in KVA? [P. No : 16]
4. What happen when a DC supply is applied to a Transformer? [P. No : 16]
5. What are the requirements of Excitation system?
6. What do you meant by SPP? What is its significant? [P. No : 33]
7. Why fractional Pitched Winding is required than full pitched winding?
8. Define Winding factor?
9. State Fleming's Left hand rule?
10. Why DC Series motor is called as Variable speed motor?

PART B — (5 × 16 = 80 marks)

11. (a) Explain clearly the statically and dynamically induced EMF. (16)
[P. No: 2]

Or

(b) (i) Derive an expression for an energy density in a magnetic circuits. (6)

(ii) Explain in detail "Eddy current loss". (4)

(iii) The total core loss of a specimen of Silicon Steel is found to be 1500W at 50HZ keeping the flux density constant the loss become 3000W when the frequency is raised to 75HZ. Calculate separately the hysteresis and eddy current losses for each of these frequencies. [P. No: 13] (6)

12. (a) (i) Derive the expression for saving of copper in autotransformer. (6)

[P. No : 23]

(ii) Calculate the efficiency for half, full load of a 100 KVA transformer for the P.F of unity and 0.8 the copper loss at full load is 1000 W and iron loss is 1000 W. [P. No : 30] (10)

Or

(b) The primary of the transformer is rated at 10 A and 1000 V. The open circuit reading are V_1 = 1000V, V_2 = 500V, I = 0.42A, Pac = 100W. The short circuit readings are I_1 = 10A, V_1 = 125V and Pac = 400 W. Draw the equivalent circuit for the Transformer. Predict the output voltage for the load impedance ZL = 19 + j12 ohms and draw the phasor diagram. (16)

[P. No : 30]

13. (a) Two windings, one mounted in stator and other at rotor have self and mutual inductance of L_{11} = 4.5 and L_{22} = 2.5, $L_{12} = 2.8\cos\theta$ H, where θ is the angle between axes of winding. Winding 2 is short circuited and current in winding as a function of time is $i_1 = 10\sin\omega t$A

(i) Determine the expression for numerical value in Newton-meter for the instantaneous value of torque in terms of θ. (8)

(ii) Compute the time average torque in Newton-meter when θ = 45°. (4)

(iii) If the rotor is allowed to move, will it continuously rotate or it will come to rest? If later at which value of θ_0. [P. No : 42] (4)

Or

(b) (i) In an electromagnetic relay, functional relation between the current i in the excitation coil, the position of armature is x and the flux linkage ψ is given by $i = 2\psi^3 + 3\psi(1 - x + x^2)$, $x > 0.5$. Find force on the armature as a function of ψ. (8)

(ii) Show that the torque developed in a doubly excited magnetic system is equal to the rate of increase of field energy with respect to displacement at constant current. (8)

14. (a) (i) Explain the armature reaction and Commutation in detail for a Dc machine. [P. No : 54] (10)

(ii) Two Shunt generators are connected in parallel to supply a load of 5000 A each machine has a armature resistance of 0.03 Ω and field resistance of 60 Ω. EMF on one machine is 600V and in other machine is 640V. What power does each machine supply? (6)

[P. No : 57]

Or

(b) (i) Draw and explain the load characteristics of DC Compound generators in detail. [P No : 51] (8)

(ii) A long Shunt Compound generator has a shunt field winding of 1,000 turns per pole and series field winding of 4 turns per pole and a resistance of 0.05Ω. In order to obtain the speed voltage both at load and full load for operating as shunt generator. It is necessary to increase the field current by 0.2A. The full load armature current of the compound generator is 80A. Calculate the diverter resistance connected in parallel of series field to obtain flat compound operation? (8)

15. (a) Why starters are necessary? Explain in detail the construction and working operation of 4 point starter. [P No 61] (16)

Or

(b) (i) Explain in detail the construction and working operation of Retardation test on DC Motor. [P No. 46]. (10)

(ii) Derive in detail the condition for maximum efficiency of DC Machine. (6)

Reg. No. :

Question Paper Code : 77131

B.E./B.Tech. DEGREE EXAMINATION, APRIL/MAY 2015.

Fourth Semester

Electrical and Electronics Engineering

EE 6401 — ELECTRICAL MACHINES – I

(Regulation 2013)

Time : Three hours Maximum : 100 marks

Answer ALL questions.

PART A — (10 × 2 = 20 marks)

1. What is meant by statically induced EMF?

2. Mention the materials suitable for fabrication of Permanent Magnets.

3. Specify the applications of autotransformer?

4. Mention the role of tertiary winding in Transformer.

5. Why do all practical energy conversion devices make use of the magnetic field as a coupling medium rather than an electric field?

6. Write the equation, which relates rotor speed in electrical and mechanical radian/second.

7. Specify the role of Interpoles in DC Machine?

8. What is meant by residual emf in DC generator?

9. Specify the techniques used to control the speed of DC shunt motor for below and above the rated speed?

10. Why DC series motor is suited for traction applications?

PART B — (5 × 16 = 80 marks)

11. (a) Explain the methods of energy conversion via Electric Field, with examples of Electrical Machines. (16)

Or

(b) (i) Specify the causes for Hysteresis and Eddy current losses in Electrical Machines. Also suggest the methods in construction to minimize the above losses. [P.No : 11] (8)

(ii) State properties of magnetic material suitable for fabrication Permanent Magnet and Electromagnet. (8)

12. (a) (i) What is meant by Inrush Current in Transformer? Specify the nature of Inrush currents and its problem during Transformer Charging. (6)

(ii) A 500 KVA Transformer has a core loss of 2200 watts and a full-load copper loss of 7500 watts. If the power factor of the load is 0.90 lagging, calculate the full load efficiency and the KVA load at which maximum efficiency occurs. [P.No : 30] (10)

Or

(b) (i) Specify the conditions for parallel operation of Transformer. Also explain the effect of load sharing due to impedance variation between transformers during parallel operation. [P.No : 21] (6)

(ii) A 100 KVA, 3300 V/240 V, 50 Hz, Single phase transformer has 990 turns on the primary. Calculate the number of turns on secondary and the approximate value of primary & secondary full load currents. [P.No : 30] (10)

13. (a) With neat sketch explain the multiple excited magnetic field system in electromechanical energy conversion systems. Also obtain the expression for filed energy in the system. [P.No : 34] (16)

Or

(b) Derive the torque equation of a round rotor machine. Also clearly state the assumptions made. [P.No : 41] (16)

14. (a) (i) Draw and explain the load characteristics of Differentially and Cumulatively compound DC generator. [P.No: 51] (6)

(ii) A 4 pole DC shunt generator with lap connected armature supplies 5 kilowatt at 230 Volts. The armature and filed copper losses are 360 Watts and 200 Watts respectively. Calculate the armature current and generated EMF? [P.No: 57] (10)

Or

(b) (i) Derive the EMF equation of DC generator. [P.No: 50] (6)

(ii) In a 400 volts, DC compound generator, the resistance of the armature, series and shunt windings are 0.10 ohm, 0.05 ohm and 100 ohms respectively. The machines supplies power to 20 Nos. resistive heaters, each rated 500 watts, 400 Volts. Calculate the induced emf and armature currents when the generator is connected in (1) Short Shunt (2) Long Shunt. Allow brush contact drop of 2 volts per brush. [P.No: 57] (10)

15. (a) (i) Why starting current is high at the moment of starting a DC Motor? Explain the method of limiting the starting current in DC motors. [P.No: 61] (6)

A 400 Volts DC Shunt motor has a no load speed of 1450 RPM, the line current being 9 Amperes. At full loaded condition, the Line current is 75 Amperes. If the shunt field resistance is 200 Ohms and armature resistance is 0.5 Ohm. Calculate the full load speed. [P.No: 73] (10)

Or

(b) (i) Draw the speed Torque characteristics of DC Shunt and Series motor. Also from the characteristics specify the applications for each motor. [P.No: 67] (6)

(ii) A 230 Volts DC Shunt motor on no-load runs at a speed of 1200 RPM and draws a current of 4.5 Amperes. The armature and shunt field resistances are 0.3 ohm and 230 ohms respectively. Calculate the back EMF induced and speed, when loaded and drawing a current of 36 Amperes. [P.No: 73]. (10)