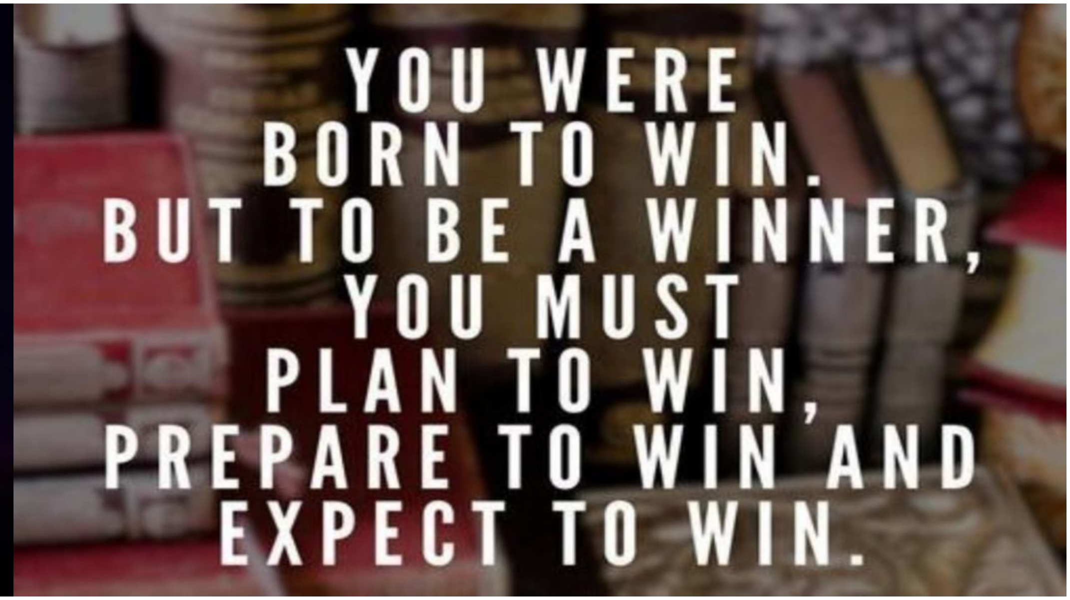



Lecture 1: Introduction to Electrical Machines and Per Unit System



COURSE DURATION

Chapter No.	Number of Hours
Basics and Transformers	60 hrs
DC Machines	40 hrs
Synchronous Machines	44 hrs
Induction Machines & Special m/c	36 hrs
	180 hrs

Syllabus

- IN Basics of EMT and Electrical Materials
- IN Transformer
- IN Electromechanical Energy Conversion (optional)
- DC Machine
- Synchronous Machine
- IN Induction Machine

ELECTRICAL MACHINE - SYLLABUS FOR GATE AND ESE

TRANSFORMER

- CONSTRUCTION OF TRANSFORMER
- EQUIVALENT CIRCUIT
- LOSSES AND EFFICIENCY
- THREE PHASE TRANSFORMER
- PARALLEL OPERATION
- INDUCED EMF
- TESTING OF A TRANSFORMER
- VOLTAGE REGULATION
- AUTO TRANSFORMER
- HARMONICS IN TRANSFORMER

DC MACHINE

- CONSTRUCTION OF DC MACHINES
- EQUIVALENT CIRCUIT
- SPEED CONTROL OF DC MOTOR
- ELECTROMECHANICAL ENERGY CONVERSION
- EMF AND TORQUE EQUATION
- LOSSES AND EFFICIENCY
- CHARACTERISTICS OF DC MACHINES

SYNCHRONOUS MACHINE

- INDUCED EMF
- EQUIVALENT CIRCUIT
- POWER ANGLE EQUATION
- LOSSES AND EFFICIENCY
- DROOP CHARACTERISTICS
- SYNCHRONOUS MOTOR
- CONSTRUCTION AND PHYSICAL PHENOMENON
- VOLTAGE REGULATION METHODS
- SYNCHRONOUS IMPEDANCE
- PARALLEL OPERATION
- VOLTAGE REGULATION
- SALIENT POLE MACHINES
- CASCADING OF MACHINES

INDUCTION MACHINE

- CONSTRUCTION & ROTATING MAGNETIC FIELD
- TORQUE SLIP CHARACTERISTICS
- TESTS ON AN INDUCTION MOTOR
- SPEED CONTROL
- SINGE PHASE INDUCTION MOTOR
- EQUIVALENT CIRCUIT
- POWER AND EFFICIENCY
- STARTING OF INDUCTION MOTOR
- STABILITY OF INDUCTION MOTOR

WEIGHTAGE OF ELECTRICAL MACHINE BY IIT ROORKEE

Chapter	Marks (2009)	Marks (2017 Shift 1)	Marks (2017 Shift 2)
1. Transformers	13	3	2
2. Electromechanical Energy Conversion	0	0	0
3. DC Machines	2	4	4
4. Synchronous Machines	3	3	3
5. Induction Machines	3	3	3
6. Special Machines	0	0	0
Total	**21**	**13**	**12**

WEIGHTAGE OF ELECTRICAL MACHINE IN GATE 2018 (IIT GUWAHATI)

Chapter	Marks
1. Transformers	3M
2. DC Machines	3M
3. Synchronous Machines	1M
4. Induction Machines	4M
Total	**11M**

WEIGHTAGE OF ELECTRICAL MACHINE IN GATE 2019 (IIT MADRAS)

Chapter	Marks
1. Transformers	2M
2. DC Machines	3M
3. Synchronous Machines	3M
4. Induction Machines	5M
Total	**13M**

WEIGHTAGE OF ELECTRICAL MACHINE IN GATE 2020 (IIT DELHI)

Chapter	Marks
1. Transformers	2M
2. DC Machines	3M
3. Synchronous Machines	5M
4. Induction Machines	1M
Total	**11M**

WEIGHTAGE OF ELECTRICAL MACHINE IN GATE 2021 (IIT BOMBAY)

Chapter	Marks
1. Transformers	2M
2. DC Machines	2M
3. Synchronous Machines	1M
4. Induction Machines	3M
Total	**8M**

WEIGHTAGE OF ELECTRICAL MACHINE IN GATE 2022 (IIT KHARAGPUR)

Chapter	Marks
1. Transformers	0M
2. DC Machines	2M
3. Synchronous Machines	2M
4. Induction Machines	6M
Total	**10M**

WEIGHTAGE OF ELECTRICAL MACHINE IN GATE 2023 (IIT KANPUR)

Chapter	Marks
1. Transformers	2M
2. DC Machines	1M
3. Synchronous Machines	3M
4. Induction Machines	4M
Total	**10M**

WEIGHTAGE OF ELECTRICAL MACHINE IN GATE 2024 (IISC BANGALORE)

Chapter	Marks
1. Transformers	1M
2. DC Machines	2M
3. Synchronous Machines	4M
4. Induction Machines	3M
Total	**10M**

WEIGHTAGE OF ELECTRICAL MACHINE IN ESE

ESE PRELIMS WEIGHTAGE — **30 TO 32 MARKS**

Which subject to be studied parallel to machine ?

- Network Analysis
  - ↳ foundation

Basic Requirement for Machine

- Laws of electromagnetism ← Lec-03 (M/C)
- Basics of network analysis
- AC analysis : complex calculations

→ Thought process ← Interviews

→ numericals : understand language ← approach

→ GATE : numericals

other exams : theory

Strategy

DO's

1. practice large no. of numericals
2. attend daily class on same day
3. revise PDF & make short notes
4. solve assignment on same day
5. attempt topic test regularly
6. ask relevant doubts

DONT's

1. make complete handwritten notes
2. procastinate
3. run after multiple sources
4. run ahead of me

Per Unit System

- This system involves dividing an electrical quantity by another quantity of same unit in order to reduce the magnitude & simplify calculations.

$$\text{pu value} = \frac{\text{actual value}}{\text{Base or reference value}}$$

** SN

Advantages of Per Unit System

(1) Calculation is easier
(2) Number of equation reduce (power system)
(3) Number of phases do not matter

Per Unit System

Single Phase System

4: electrical quantities → V, I, S, Z

- Out of 4 quantities, base values of 2 quantities are assumed and rest 2 are determined.
- Usually, we consider rated value as base value.

→ Each system generally has 2 rating specified S_{rated}, V_{rated}.

** SN

$S_{base} = S_{rated}$
$V_{base} = V_{rated}$
$S = VI, I = S/V$

S = apparent power = $V_{rms} I_{rms}$
in ac we only consider rms values

$$I_{base} = \frac{S_{base}}{V_{base}}$$ ← rated value of current

$$Z_{base} = \frac{V_{base}}{I_{base}} = \frac{V_{base}^2}{S_{base}}$$

All base values are scalars and not phasors.

* While converting to pu, only mag. of the quantity changes but angle remains same.

Per Unit System

Three Phase System

** SN

- In 3-ϕ system, we have to assume separate base values for phase and line quantities.

$S_{base} = S_{rated}$: rated 3-ϕ apparent power

$V_{base} = V_{rated}$: rated L-L rms voltage (V_L)

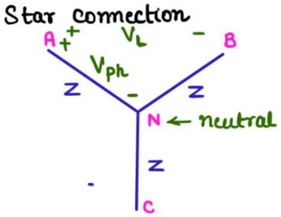
- $S = \sqrt{3} V_L I_L$

$$I_L(base) = \frac{S_{base}}{\sqrt{3} V_{base}}$$

$S = 3V_{ph} I_{ph} = \sqrt{3} V_L I_L$

In 3ϕ by default given values are line values & not phase values unless specified.

Star connection

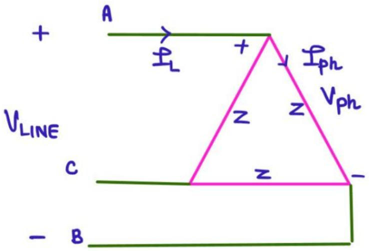


- $V_L = \sqrt{3} V_{ph}$

line voltage leads phase voltage by 30°

- $I_L = I_{ph}$

Delta connection



- $V_{LINE} = V_{ph}$
- $I_L = \sqrt{3} I_{ph}$
- line current lags phase current by 30°

** SN

Star	Delta
$V_{ph}(base) = V_L(base)/\sqrt{3} = \frac{V_{base}}{\sqrt{3}}$	$V_{ph}(base) = V_L(base) = V_{base}$
$I_{ph}(base) = I_L(base) = \frac{S_{base}}{\sqrt{3} V_{base}}$	$I_{ph}(base) = I_L(base)/\sqrt{3} = \frac{S_{base}}{3V_{base}}$
$Z_{base} = \frac{V_{ph}(base)}{I_{ph}(base)} = \frac{V_{base}^2}{S_{base}}$	$Z_{base} = \frac{3V_{base}^2}{S_{base}} = 3Z_Y$

Per Unit System

Three Phase System

Eg: star connection

$\bar{V}_{ph} = V\angle\theta \quad \bar{V}_L = \sqrt{3} V\angle\theta + 30^0$

$$\bar{V}_{ph}(pu) = \frac{V\angle\theta}{V_{ph}(base)} = \frac{V\angle\theta}{\frac{V_{base}}{\sqrt{3}}} = \frac{\sqrt{3}V}{V_{base}}\angle\theta$$

$$\bar{V}_L(pu) = \frac{\sqrt{3}V\angle\theta + 30}{V_L(base)} = \frac{\sqrt{3}V}{V_{base}}\angle\theta + 30^0$$

$\therefore$ by defining separate base values for phase and line quantities, we get same mag. of phase and line quantity in pu only angle is diff.

Per Unit System

Three Phase System

$$S = 3V_{ph}I_{ph} = \sqrt{3}V_L I_L$$

$$S_{base} = \sqrt{3}V_{base}\ I_{base}$$

$$S_{pu} = S/S_{base} = \frac{\sqrt{3}V_L I_L}{\sqrt{3}V_{base}I_{base}}$$

$$= \left(\frac{V_L}{V_{base}}\right)\left(\frac{I_L}{I_{base}}\right)$$

$$= V_{pu}\, I_{pu}$$

$S_{pu} = V_{pu} I_{pu}$

no factor of 3 or $\sqrt{3}$ which makes calculation easier & more accurate.

**SN

$S_{pu} = V_{pu}\, I_{pu}$ ← apparent power

$P_{pu} = V_{pu}\, I_{pu} \cos\phi$ ← real power

$Q_{pu} = V_{pu}\, I_{pu} \sin\phi$ ← reactive power

- In pu angle of any quantity remains unchanged only mag. changes.

- real & imaginary parts of a quantity have same base value

$$S_{pu} = S/S_{base} = \frac{P+jQ}{S_{base}} = \frac{P}{S_{base}} + j\, Q/S_{base}$$

$$Z_{pu} = Z/Z_{base} = \frac{R+jX}{Z_{base}} = \frac{R}{Z_{base}} + j\frac{X}{Z_{base}}$$

Change Of Base

- In PS, there are multiple devices such as generation, transformer and transmission line and each has pu impedance defined on its own rating as base value.
- But we assume a common or universal base on which all pu Z must be based.
- Actual value is indep. of base but pu value depends on base.

**SN

Given Zpu(old) on base Sold & Vold compute Zpu(new) on base Snew & Vnew

$$Z(\Omega) = Z_{pu} \times Z_{base}$$

$$= Z_{pu}(old) \times \frac{V_{old}^2}{S_{old}}$$

$$Z_{pu}(new) = \frac{Z(\Omega)}{Z_{base}(new)} = \frac{Z(\Omega)}{V_{new}^2 / S_{new}}$$

**SN

$$\boxed{Z_{pu}(new) = Z_{pu}(old) \times \left(\frac{V_{old}}{V_{new}}\right)^2 \times \frac{S_{new}}{S_{old}}}$$

QUESTION-01

A three phase 50 MVA , 10KV generator has a reactance of 0.2 ohm per phase. Hence the per unit value of the resistance on a base of 100MVA, 25KV will be:

(a) 1.25
(b) 0.625
(c) 0.032
(d) 0.32

$Z(\Omega) = 0.2\,\Omega$

$Z_{base} = \frac{V_{base}^2}{S_{base}} = \frac{25^2}{100} = 6.25\,\Omega$

$Z_{pu} = \frac{Z(\Omega)}{Z_{base}} = \frac{0.2}{6.25} = 0.032\text{ pu}$

QUESTION-02

The per unit reactance of a 30 MVA, 13.2kV alternator is 0.4 p.u. The p.u value for a base voltage of 13.8 kV and 50MVAwill be

(a) 0.667p.u
(b) 0.638p.u
(c) 0.383p.u
(d) 0.610p.u

given pu value on a base of 30MVA, 13.2KV

asking pu value on a base of 50MVA, 13.8KV

$Z_{pu}(new) = Z_{pu}(old) \times \left(\frac{V_{old}}{V_{new}}\right)^2 \times \frac{S_{new}}{S_{old}}$

$= 0.4 \left(\frac{13.2}{13.8}\right)^2 \times \frac{50}{30}$

$= 0.61\text{ pu}$

QUESTION-03

connection not mentioned: assume Y

If a 250MVA, 11kV/400kV three-phase power transformer has leakage reactance of 0.05 per unit on the base of 250MVA and the primary voltage of 11kV, then the actual leakage reactance of the transformer referred to the secondary side of 400kV is

(a) 0.8Ω
(b) 0.0032 Ω
(c) 0.03125 Ω
(d) 32.0 Ω

In a transformer, pu Z on both sides of a transformer is same.

$X_{pu}(pri) = X_{pu}(sec) = 0.05\text{pu}$

$X(\Omega) = X_{pu} \times Z_{base}$

$= 0.05 \times \frac{V_{base}^2}{S_{base}} = 0.05 \times \frac{(400kV)^2}{250\,MVA}$

$= 32\,\Omega$

QUESTION-04

A three-phase transformer has rating of 20MVA, 220kV, (star)/ 33kV(delta) with leakage reactance 12%. The transformer reactance (in ohms) referred to each phase of the L.V. delta connected side is

(a) 23.5
(b) 19.6
(c) 18.5
(d) 8.7

% value = pu value × 100% ** SN

12% = pu value × 100%

$X_{pu} = 0.12$ ← same on both sides of a T/F

$X(\Omega) = X_{pu} \times Z_{base}$

$= 0.12 \times 3\left(\frac{V_{base}^2}{S_{base}}\right)$

$= 0.12 \times 3\left(\frac{33^2}{20}\right) = 19.6\,\Omega$

QUESTION-05

Per unit impedance of transformer , measured from primary side and secondary side are

(a) Equal
(b) Depends on transformer ratio
(c) Depends on rating of transformer
(d) Depends on polarity of winding

QUESTION-06

The impedance value of a generator is 0.2 pu on a base value of 11 kV, 50MVA. The impedance value for a base value of 22 kV, 150MVA is

(a) 0.15pu
(b) 0.2pu
(c) 0.3pu
(d) 2.4pu

$$Z_{pu}(\text{new}) = Z_{pu}(\text{old}) \times \left(\frac{V_{old}}{V_{new}}\right)^2 \times \frac{S_{new}}{S_{old}}$$

$$= 0.2 \times \left(\frac{11}{22}\right)^2 \times \frac{150}{50}$$

$$= 0.15 \text{ pu}$$

QUESTION-07

A 75 MVA, 10kV synchronous generator has X_d=0.4 p.u. The X_d value (in p.u.) to a base of 100MVA 11 kV is

(a) 0.578
(b) 0.279
(c) 0.412
(d) 0.44

$$Z_{pu}(\text{new}) = Z_{pu}(\text{old}) \times \left(\frac{V_{old}}{V_{new}}\right)^2 \times \frac{S_{new}}{S_{old}}$$

$$= 0.4 \left(\frac{10}{11}\right)^2 \times \frac{100}{75} = 0.44 \text{ pu}$$

QUESTION-08

$V_{new} = 1.1\, V_{old}$

The per unit impedance of a synchronous machine is 0.242. If the base voltage is increased by 1.1 times, the per unit value will be

(a) 0.266
(b) 0.242
(c) 0.220
(d) 0.200

$$Z_{pu}(\text{new}) = Z_{pu}(\text{old}) \times \left(\frac{V_{old}}{V_{new}}\right)^2 \times \frac{S_{new}}{S_{old}}$$

$$= 0.242 \times \left(\frac{V_{old}}{1.1\, V_{old}}\right)^2 \times S/S$$

$$= 0.242/1.21 = 0.2 \text{ pu}$$

QUESTION-09

The impedance per phase of 3-phase transmission line on a base of 100 MVA, 100kV is 2pu. The value of this impedance on a base of 400 MVA and 400 kV would be

(a) 1.5pu
(b) 1.0pu
(c) 0.5pu
(d) 0.25pu

$$Z_{pu}(\text{new}) = Z_{pu}(\text{old}) \times \left(\frac{V_{old}}{V_{new}}\right)^2 \times \frac{S_{new}}{S_{old}}$$

$$= 2\left(\frac{100}{400}\right)^2 \times \frac{400}{100}$$

$$= 0.5 \text{ pu}$$

units

deca = 10^1
kilo = 10^3
mega = 10^6
giga = 10^9
tera = 10^{12}

deci = 10^{-1}
centi = 10^{-2}
milli = 10^{-3}
micro = 10^{-6}
nano = 10^{-9}
pico = 10^{-12}

Answer keys

1. C
2. D
3. D
4. B
5. A
6. A
7. D
8. D
9. C

Student's Assignment

Basic

Question-01

The impedance value of generator is 0.4 pu on a base value of 11kV, 100 MVA. The impedance value for a base value of 22kV, 150 MVA is:

(a) 0.15 pu
(b) 0.2 pu
(c) 0.3 pu
(d) 0.4 pu

Question-02

The per unit impedance of a generator in an interconnected power system, corresponding to its own voltage and kVA rating is 0.2Ω. Its per unit impedance corresponding to a new common base voltage and kVA rating, which are 80% of the generator base values selected for the whole system will be :

(a) 0.4Ω
(b) 0.1Ω
(c) 0.15Ω
(d) 0.25Ω

Question-03

A 22kV, 400 MVA generator has the reactance of 0.3 pu. The value of reactance on the new base 25 kV and 200 MVA will be:

(a) 0.116 pu
(b) 0.32 pu
(c) 0.58 pu
(d) 0.232 pu

Question-04

A 500 MVA, 18kV alternator has reactance of 0.25 p.u. Find the per unit reactance of the alternator for the base value of 100 MVA, 20 kV.

(a) 0.213 p.u.
(b) 0.1243 p.u.
(c) 0.4301 p.u.
(d) 0.0405 p.u.

Question-05

For a given base voltage and base volt-amperes, the per unit impedance value is x. for the doubled base values of both voltage and volt amperes, the per unit impedance will be

(a) 2x a
(b) 0.25 x
(c) 0.5 x
(d) No change

Question-06

A 3-phase 50 MVA 10kV generator has reactance of 0.2 ohm per phase. Hence the per unit value of the reactance on a base 100 MVA 25kV will be

(a) 1.25
(b) 0.625
(c) 0.032
(d) 0.32

Question-07

The per-unit impedance of a circuit element is 0.15. If the base kV and base MVA are halved then the new value of the per-unit impedance of the circuit element will be

(a) 0.075
(b) 0.05
(c) 0.30
(d) 0.60

Question-08

The direct axis reactance X_d of a synchronous generator is given as 0.4 pu based on the generator's name plate rating of 10kV, 75MVA, The base for calculation is 11kV, 100MVA. What is the pu value of X_d on the new base?

(a) 0.279
(b) 0.578
(c) 0.412
(d) 0.44

Question-09

The per unit value of a 4Ω resistor 100MVA base and 10kV base voltage is

(a) 2 pu
(b) 4 pu
(c) 0.4 pu
(d) 40 pu

Question-10

A 25MVA, 33kV transformer has a pu impedance of 0.9. The pu impedance at a new base 50MVA at 11kV would be

(a) 10.4
(b) 12.2
(c) 14.4
(d) 16.2

Moderate

Question-11

A three phase star-connected load is drawing power at a voltage of 0.9 pu and 0.8 power factor lagging. The three phase base power and base current are 100 MVA and 437.38 A respectively. The line-to-line load voltage in kV is ________.

Question-12

A transmission line has an impedance of 0.2 p.u. on 11 kV and 100 MVA base. __________ is new p.u. impedance on 22 kV and 200 MVA base.

Question-13

A 250 MVA, 11/400 kV 3-phase power transformer has a leakage reactance of 0.05 pu on the base of 250 MVA and 11kV. The reactance per phase of the transformer in ohms refer hv is

(a) 0.05 Ω (b) 0.8 Ω
(c) 160 Ω (d) 32 Ω

Question-14

The pu impedance value of an alternator corresponding to base values 13.2 kV and 30 MVA is 0.4 pu. The pu impedance is 0.0609 then the base voltage will be _____ kV.
Note: Consider new base MVA is 5 MVA.

(A) 14.56 (B) 13.81
(C) 13.26 (D) 14.25

Question-15

A three – phase transformer is rated 400MVA, 220/22kV Y/Δ. The short circuit reactance measured on the low voltage side of transformer is 0.121Ω. The per unit reactance of a transformer and the value to be used represent the transformer in a system whose base an high voltage side of transformer is 100 MVA and 230 kV is

Brain Teaser

Question-16

A generator (which may be represented by an EMF in series with an inductive reactance) is rated 500MVA, 22kV. Its Y-connected windings have a reactance of 1.1pu. Find the ohmic value of the reactance of the windings.

Question-17

A 3-phase transformer has rating of 20 MVA, 200 kV (star)–33 kV (delta) with leakage reactance of 12%. The transformer reactance (in ohms) referred to each phase of the L.V delta-connected side is

(a) 23.5
(b) 19.6
(c) 18.5
(d) 8.7

Question-18

The resistance and reactance of a 100 kVA 11000 | 400V, Δ-Y distribution transformer are 0.02 and 0.07 pu respectively. The phase impedance of the transformer referred to the primary is

(a) (0.02 + j0.07) Ω
(b) (0.55 + j1.925) Ω
(c) (15.125 + j52.94) Ω
(d) (72.6 + j254.1) Ω

Question-19

A 15 MVA, 33/11 kV, 3-phase transformer having an impedance of 16Ω on the high tension side is supplied from a generator rated 30 MVA, 11 kV. The pu impedances of the transformer calculated on its own base and on the generator base will be in the ratio

(a) 1 : 1
(b) 1 : 3
(c) 1 : 9
(d) 1 : 18

Question-20

The per unit impedance of a circuit element is 0.15. If the base kV and base MVA are halved, then what will be the new value of the per unit impedance of the circuit element?

(a) 0.075
(b) 0.15
(c) 0.30
(d) 0.60

Answer Keys

1. C
2. D
3. A
4. D
5. C
6. C
7. C
8. C
9. B
10. D
11. 132 kV
12. 0.1 p.u.
13. D
14. B
15. 0.0762 p.u.
16. 1.07 p.u.
17. B
18. D
19. D
20. C

Lecture 2: Electrical Materials

ELECTRICAL MACHINE

Basics of Electrical Materials

- Conducting Materials
- Magnetic Materials
- Insulating Materials

Electrically Conducting Materials

(1) These materials can be divided into two categories:

High Conductivity Materials

(1) These materials are used for making windings in electrical machines as well as transmission and distribution of electrical energy.

eg: Cu, Al, Au, Ag etc. $\sigma_{Ag} > \sigma_{Au} > \sigma_{Cu} > \sigma_{Al}$ ** SN

High resistivity materials (alloys)

(1) These materials are used for making resistances and heating devices.

HIGHLY CONDUCTIVE MATERIALS

(1) The requirement to be satisfied by highly conducting materials are:
(2) Highest possible conductivity (Cu and Al)
(3) Least temperature coefficient of resistance $[R = R_0 [1+\alpha\Delta T]]$
(4) Adequate mechanical strength and absence of brittleness.
(5) Reusability and draw ability used in manufacturing wires of small section

α: temperature coefficient of resistance
α Must be low: resistance does not vary much with temperature.

COPPER

(1) It has electrical conductivity with adequate resistance to oxidation and corrosion.
(2) It is highly malleable and ductile metal.

(3) Most Electrical Machines employ winding of annealed highly conducting copper.

(4) Hard drawn copper wires are used in Electrical Machines because drawing increases mechanical strength



ALUMINIUM

- Aluminium is very abundant in the earth but it is not found in free state. It is obtained in pure form by processing its are called bauxite is a mixture of monohydrate and trihydrate aluminium oxide ($Al_2O_3.2H_2O$) and $Al_2O_3.3H_2O$).
- Bauxite is first purified and then dissolve in fused cryolite (double fluoride of aluminium and sodium).
- **Physical and mechanical properties:**
  (a) It has silvery colour and lustre.
  (b) It has melting point of 658^0C.
  (c) It is light weight metal having specific gravity of 2.7.

(d) It is a ductile metal, thereby it can be drawn into thin wires. It is extensible used in cables and conductors.

(e) Its ultimate strength is sufficient high (50 to 70 MPa).

(f) It is a good conductor of heat and electricity.

(g) It forms protective layer of aluminium oxide (Al_2O_3) when exposed to atmosphere. This protective layer makes it corrosion resistant.

(h) Pure aluminium is very soft and it can be made hard and tough when it is alloyed with elements like Ni, Mg, Si and Co.

(i) Aluminium hardened by cold working, can be amended by heating it to about 350^0C and then cooling in air.

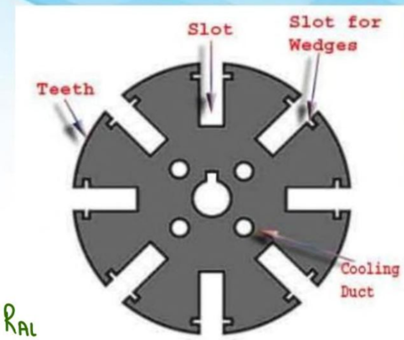
- If Cu wire is replaced by Al wire then Al wire must have higher CSA.

∴ Slots need to be redesigned & made wider.

- Assume 2 wires, one made of Cu and other of Al having same length and same resistance. $R_{Cu} = R_{Al}$

$$\frac{\rho_{Cu} \times l}{A_{Cu}} = \frac{\rho_{Al} \times l}{A_{Al}}$$

$$A_{Al}/A_{Cu} = \rho_{Al}/\rho_{Cu} > 1 \quad [\rho_{Al} > \rho_{Cu}]$$



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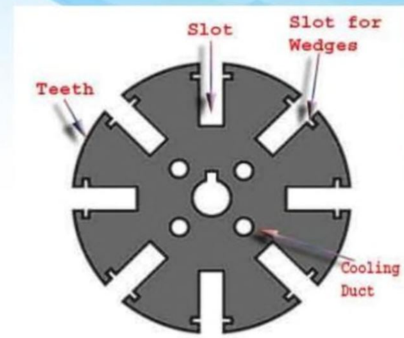
- For IM of rating < 100KW Al can be used to design bars of squirrel cage rotor.
- Al can be used to make foil type winding in small T/F.
- Al can be used to construct tank of a transformer to reduce Stray Load Losses.
- Al gets oxidized rapidly to form Al_2O_3 to prevent further oxidation.



Property	Copper	Al
Cost	1	0.49
Cross-section area	1	1.62
Diameter	1	1.27
Volume	1	2.04
Weight	1	0.49
Breaking strength	1	0.64

ELECTRICAL CARBON MATERIAL

**SN

(1) These materials are made from graphite or other forms of carbon.

(2) Conductivity of carbon is slightly less than metals & alloys & therefore used to make brushes in electrical machines.

(3) Brush carbon are graphited i.e. heat treated to increase size of crystal to raise conductivity & reduce hardness.

(4) They should have smooth surface to avoid wear & tear of commutator.

(5) Carbon has negative temperature co-efficient so as current increases, the temperature of brush increases due to losses and resistance reduces so the brush voltage drop remains constant.

MAGNETIC MATERIALS

Magnetic materials are those materials in which a state of magnetisation can be induced. On magnetisation, a material can create a magnetic field in the surrounding area. Magnetic properties of materials originate from the motion of their electrons and their magnetic moments (dipoles). Though, the electron orbits are associated with magnetic moments, but the orbital arrangements may be such that it may prevent a net permanent magnetic moment resulting from the atoms. The magnetic moments can interact in different ways and these moments may align in parallel or antiparallel way with equal or unequal magnitude.

- Magnetic effects exist outside the material when it has a net permanent magnetic moment. The magnetism is a form of energy. A magnetic material can perform work when it lifts iron fillings against the force of gravity.

There are five classes into which all the magnetic materials can be grouped according to their magnetic behaviour which include

(i) Diamagnetic substances (ii) Paramagnetic Substances
(iii) Ferromagnetic substances (iv) Ferrimagnetic substances
(v) Anti-ferromagnetic substances

1. DIA-MAGNETIC MATERIALS

- Diamagnetic substances show a very weak form of magnetism when placed in a magnetic field. They become weakly magnetised in a direction opposite to the magnetisation of the external field. Therefore, purely diamagnetic substances are repelled by a magnetic field.
- Weak form of magnetism that exist only external field is applied. SN **
- Induced magnetization is very small is in a direction opposite to external field.
  ↳ net dipole moment/volume

Susceptibility, $\chi_m < 0$

$$\chi_m = \frac{\text{magnetization}}{\text{external field}} = \frac{\vec{M}}{\vec{H}}$$ ← tendancy of a material to get magnetized.

$\vec{M}$: net dipole moment/volume, $\vec{M}$ & $\vec{H}$ are anti-parallel dir^n

← relative permeability

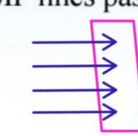
χ_m is a very small -ve value eg: -0.001 μ_r = 0.999 ** SN

$\mu_r = 1+\chi_m < 1$ (slightly less than 1)

$\vec{B}$ (magnetic flux density): no. of MF lines passing per unit area.

$\vec{B} = \mu_0\mu_r\vec{H}$

$\because \mu_r < 1;\ \vec{B} < \mu_0\vec{H}$



density is represented by closeness of field lines.

$\vec{B}$ inside diamagnetic material < air

Closeness of field lines $\propto \vec{B}$

$\vec{B}\downarrow$ inside dia. Mag. Material: field lines move away

μ_0 = permeability of air/free space