1. Electromagnetism basics & B-H curve

Magnetic Field

→ Region around magnetic material / moving electric charge within which force of magnetism acts

Magnetic Flux

→ Amount of magnetic field produced by magnetic source
SI : Weber (Wb)

Magnetic Flux Density

→ Amount of magnetic flux through a unit area placed $\perp^{ar}$ to direction of magnetic field
→ Denoted by B
→ $B = \frac{\phi}{A}$ → Magnetic Flux, → Area

SI – T or Wb/m^2

Magneto Motive Force (MMF)

→ The magnetic pressure which sets up magnetic flux in a magnetic circuit.

→ Denoted by F

$F = N\,I$ (I → Current, N → No. of turns of inductive coil)

SI – Ampere (At) (t → turns)

Magnetic Field Strength

→ Ratio of MMF needed to create certain Flux density (B) within a particular material per unit length of material
→ Denoted by H
SI – At/m (t – turns)

$H = \frac{NI}{l}$ (NI → MMF, l → length of magnetic circuit)

Relation b/w B & H

→ $B = \mu H$

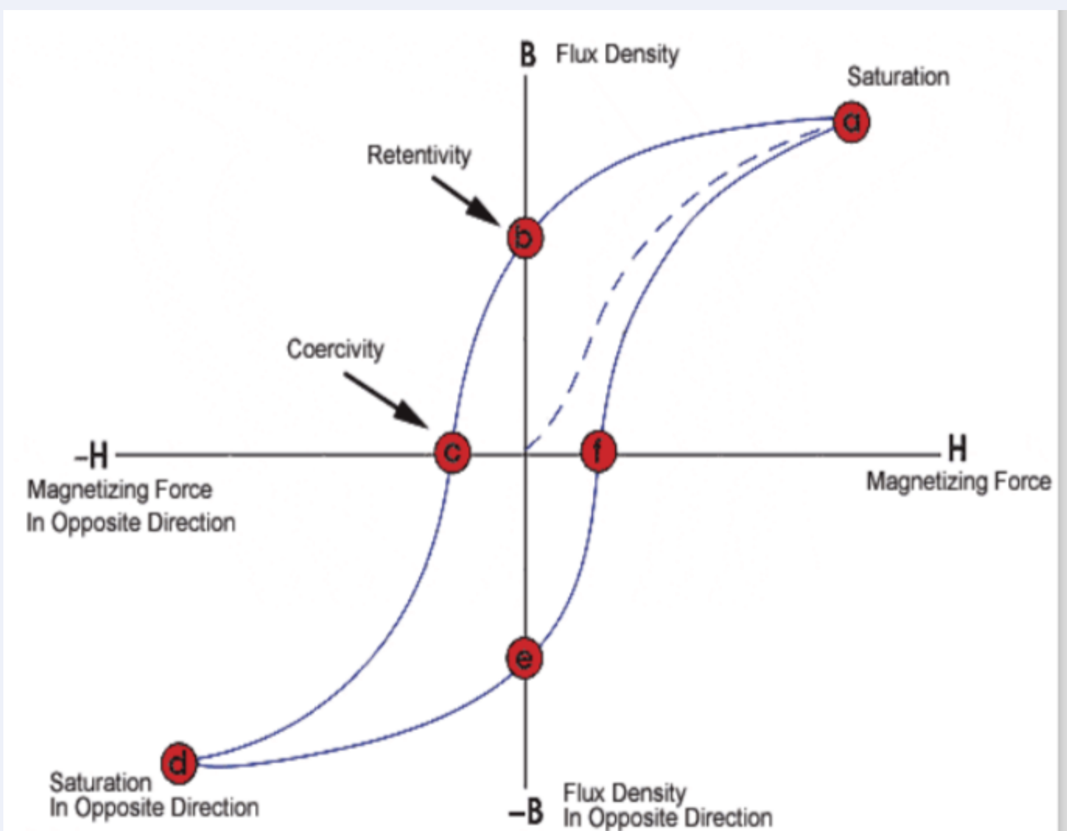
$\mu = \mu_0 \mu_r$

Magnetic Reluctance

→ Opposition offered by magnetic circuit to the production of magnetic flux
→ denoted by S
→ $S = \frac{l}{\mu_0 \mu_r A}$

SI – m^{-1}

Hysteresis Loop



Hysteresis Loop

Electric	Circuits	Magnetic	Circuits
V, EMF	(V)	MMF, F	(At)
I, Current	(A)	Flux, ϕ	(Wb)
R, Resistance	(Ω)	Reluctance, R	(At/Wb)
$R = \frac{l}{\sigma A}$		$R = \frac{l}{\mu_r \mu_0 A}$	
σ, Conductivity	(S/m)	Permeability, μ	(Tm/A)
G, Conductance	(S)	Permeance, G	(Wb/A)
J, Current Density	(A/m^2)	Flux Density, B	(Wb/m^2)
E, Electric Field Intensity	(V/m)	Magnetic Field Intensity, H	(At/m)
$I = V/R$		$\phi = F/R$	

Q1. A coil of 200 turns is wound uniformly over a wooden ring having a mean circumference of 60 cm & uniform cross-sectional area of 500 mm^2. If current through coil is 4A, calculate H, B, ϕ

A. $N = 200$

$2\pi r = 60 = 0.6\,m = l$

$A = 500 \times 10^{-6}\,m^2$

$H = \frac{NI}{l} = \frac{200 \times 4}{0.6} = 1333\,A/m$

$B = \mu_0 \mu_r H$

$= 4\pi \times 10^{-7} \times 1 \times 1333 = 1675\,\mu T$

$\phi = BA = 1675 \times 10^{-6} \times 500 \times 10^{-6} = 0.8375\,\mu Wb$

Q2. Calculate the MMF required to produce a flux of 0.015 Wb across an air gap of 2.5mm long having effective area of 200 cm^2

A. $\phi = 0.015$ $l = 2.5 \times 10^{-3}$ $A = 200 \times 10^{-4}$

$MMF = Hl$

$H = \frac{B}{\mu_0 \mu_r} = \frac{\phi}{A \mu_0 \mu_r} = 0.5968 \times 10^6\,At/m$

$MMF = 0.5968 \times 10^6 \times 2.5 \times 10^{-3} = 1492.077\,At$

Q3. A mild-steel ring having cross-sectional area = 500 mm^2 & mean circumference of 400 mm has coil of 200 turns uniformly. Calculate S, I if $\phi = 800\,\mu Wb$. Assume $\mu_r = 380$

A. $S = \frac{l}{\mu_0 \mu_r A} = \frac{400 \times 10^{-3}}{4\pi \times 10^{-7} \times 380 \times 500 \times 10^{-6}} = 1.67 \times 10^6\,m^{-1}$

$H = \frac{NI}{l} \Rightarrow I = \frac{Hl}{N} = \frac{Bl}{\mu_0 \mu_r N} = \frac{\phi l}{A \mu_0 \mu_r N}$

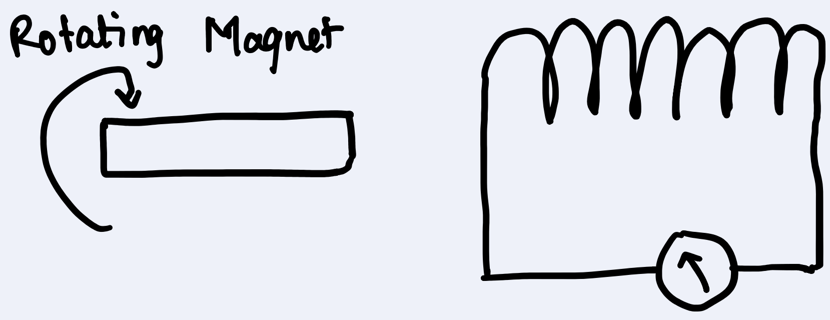
$I = \frac{800 \times 10^{-6} \times 400 \times 10^{-3}}{500 \times 10^{-6} \times 4\pi \times 10^{-7} \times 380 \times 200} = 6.7\,A$

2. Faraday's law

Faraday's Law

→ The EMF induced in a conductance due to a changing magnetic field is proportional to rate of change of flux

$$E = \frac{d\phi}{dt} = \frac{\text{change in } \phi}{\text{time}} = \frac{\text{final flux} - \text{initial flux}}{\text{time}}$$



→ To increase EMF :

i) Increase no. of turns
ii) Increase speed of rotation
iii) Increase speed of magnet

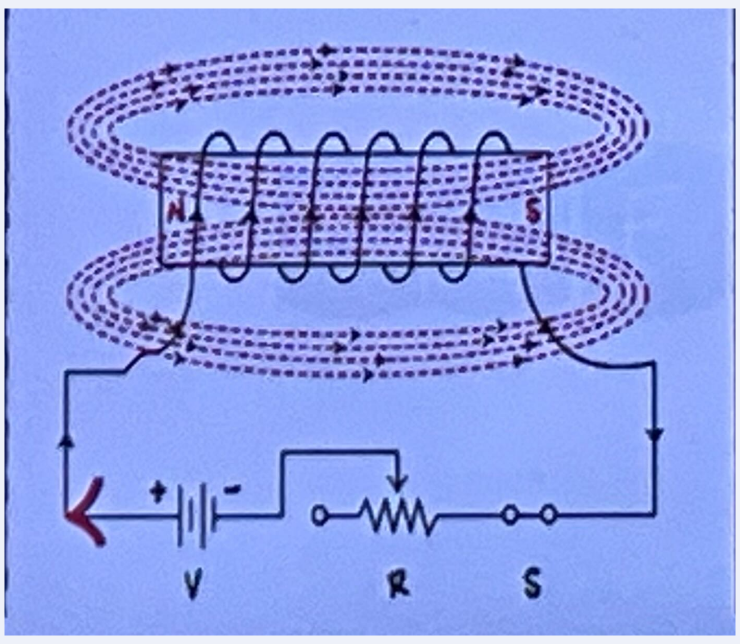
→ Induced EMF

- Statically Induced EMF
  - Self Induced EMF
  - Mutually Induced EMF
- Dynamically Induced EMF

Self Induced EMF

→ EMF induced in coil due to change of its own flux linked with it

→ EMF induces w/o physical motion of the coil or flux

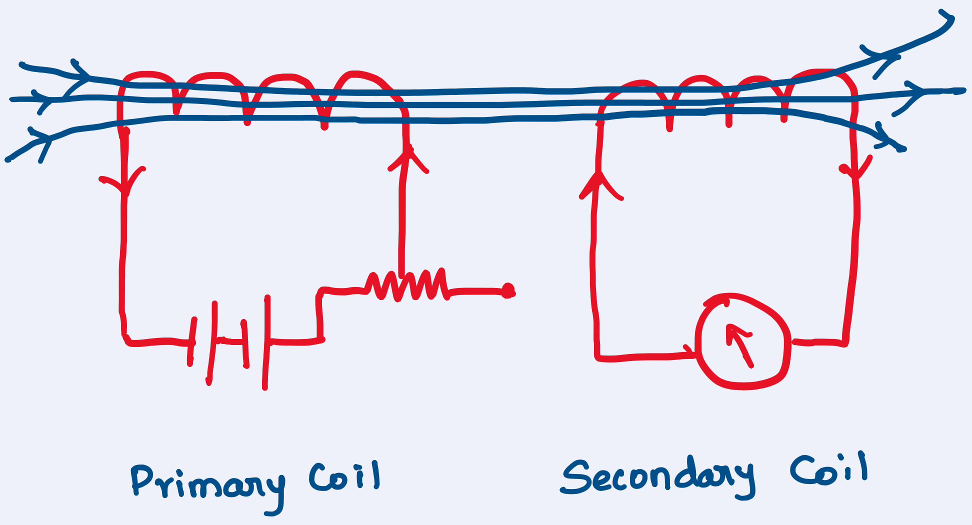


Mutual Induction

→ Phenomenon in which changing current in one coil induces EMF in another coil

$$\mathcal{E}_s = \left(-N_s \frac{\Delta\phi_s}{\Delta t}\right)$$

$$B = \frac{\Delta\phi}{\Delta A} \Rightarrow \Delta\phi = B\,\Delta A$$

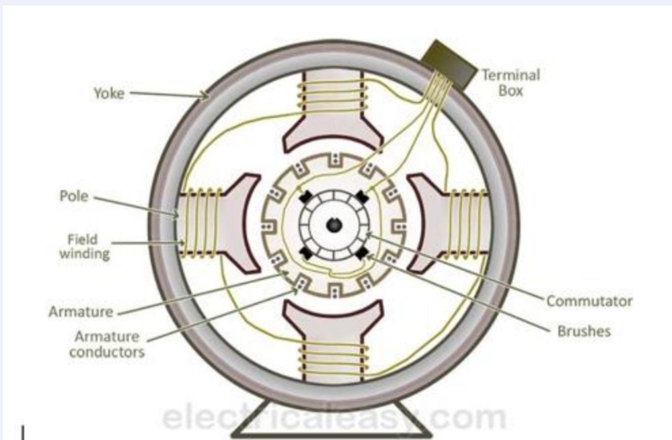


Electric Machines

- Static (DC)
  - DC Generator
  - DC Motor
- Rotational (AC)
  - Transformer
  - 3ϕ Induction motor

DC Machines

→ Principle of Operation :



DC Machine

→ DC Motor converts electrical energy into mechanical energy. Construction is similar to DC Generator

→ Whenever a current carrying conductor is placed in a magnetic field, it experiences force

$$\underset{\text{Force}}{F} = \underset{\text{Flux Density (wb/m}^2)}{B} \cdot \underset{\text{Current (A)}}{I} \cdot \underset{\text{Length of conductor (m)}}{L} = BIL\sin\theta$$

Lap Winding

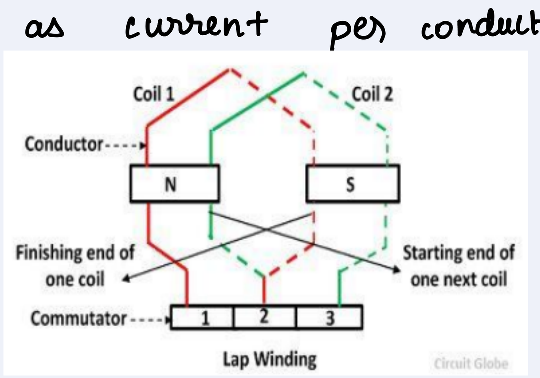
→ Used for high current, low voltage devices

→ Used to increase no. of $||^{el}$ paths enabling armature current to increase

→ Used to improve commutation as current per conductor decreases

$A = P \Rightarrow$ No. of poles

A: No. of Parallel paths



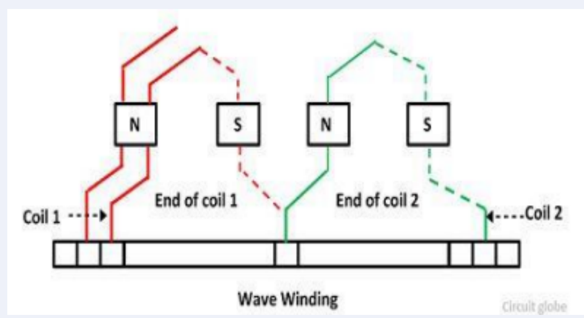
Wave Winding

→ Used for low current, high voltage devices

→ No. of parallel paths (A) is fixed to 2

→ No. of brushes = No. of parallel paths

→ No. of poles can be anything



EMF equation of DC Generator

→ P : No. of poles in stator

→ ϕ : Flux per pole (Wb)

→ A : No. of parallel paths — lap $\Rightarrow A = P$; wave $\Rightarrow A = 2$

→ N : Speed of armature (rpm)

→ E_g : EMF induced in any parallel path

→ Z : Total no. of conductors

The flux cut by a conductor in 1 rev $= P\phi$

Time taken to complete 1 revolution $= \frac{60}{N}$ secs

EMF induced in 1 conductor per sec, $E_g = \frac{P\phi}{60/N} = \frac{P\phi N}{60}$ Volts

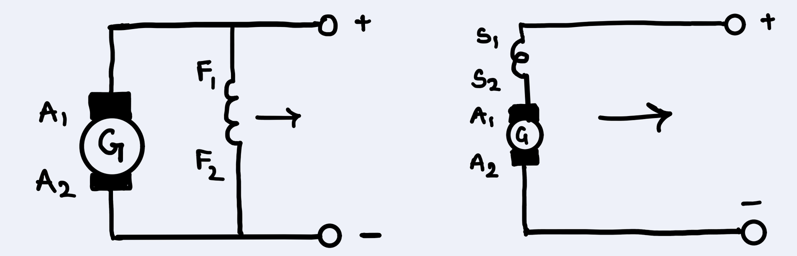
EMF induced for all conductors per parallel path, $E_g = \frac{P\phi N}{60} \times \frac{Z}{A}$ Volts

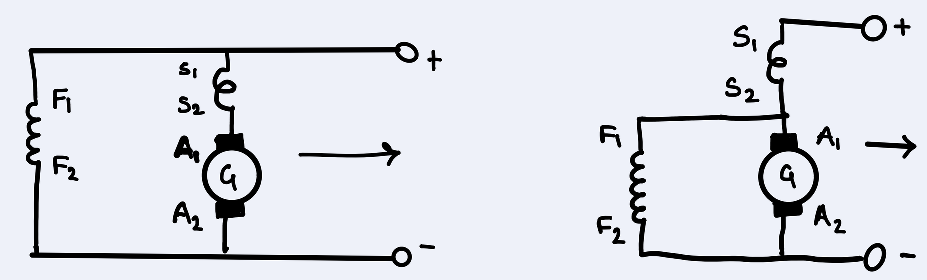
For lap winding, $A = P \Rightarrow E_g = \frac{P\phi N Z}{60P}$ Volts

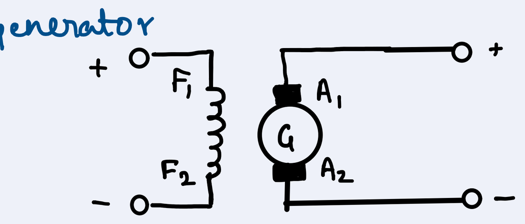
For Wave winding, $A = 2 \Rightarrow E_g = \frac{P\phi N Z}{120}$ Volts

Types of DC Generators

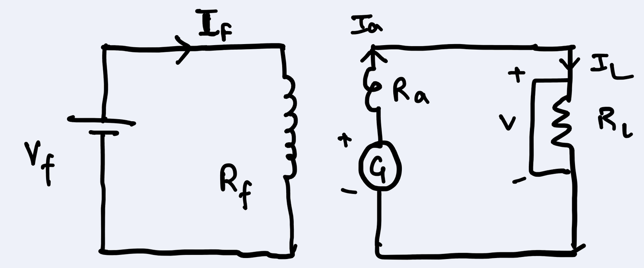
- Self - Excited DC Generators
  - Shunt
  - Series
  - Compound
    - Long Shunt Compound
    - Short Shunt Compound
- Seperately Excited DC Generator







Equivalent Circuit for seperately excited DC Generator



Stator Rotor

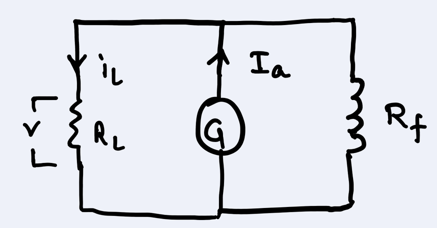
$E_g = V + I_a R_a$ (KVL)

$I_a E_g = V I_a + I_a^2 R_a$

$P_i = P_o + P_L$

and, $I_a E_g = I_a V + I_a^2 R_a + \underbrace{I_a V_{Brush}}_{\text{Loss}}$ — Potential drop due to brush contact

Equivalent Circuit of Parallel Generator Machine



$I_a = i_L + i_f$ (KCL)

$i_L = \frac{V}{R_L}$

$i_f = \frac{V}{R_f}$

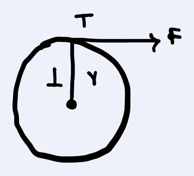
$I_a = \frac{P_L}{V} + \frac{V}{R_f}$

4. Torque equation

→ Turning moment about its axis

τ = Force × distance

= $F \times r$



$F = \frac{\tau}{r}$

$P_a = I_a E_g$ = Work done × time

$= F \times 2\pi r \times \frac{N}{60}$

$= \frac{\tau}{\cancel{r}} \times 2\pi \cancel{r} \times \frac{N}{60}$

$\Rightarrow \tau = \frac{I_a E_g \times 60}{2\pi N} = T_a$

$T_a = \frac{I_a \times P\phi N Z \times 60}{2\pi \times 60 \times AN}$

$T_a = \frac{I_a P\phi Z}{2\pi A}$

Q1. A 250V, 10kW separately excited generator has an induced emf of 255V at full load. If brush drop is 2V/brush, Calculate armature resistance of generator.

A. $E_g = 255V$ $V_{brush} = 2V/brush \Rightarrow 4V$ (2 Brushes)

$V = 250V$ $P_o = 10kW = I_a V$; $R_a = ?$

$P_o = I_a V$

$I_a = \frac{P_o}{V} = \frac{10000}{250} = 40A$

$E_g - I_a R_a - V - V_{brush} = 0$

$255 - 40(R_a) - 250 - 4 = 0$

$R_a = 25\,m\Omega$

Q2. The field current of DC Current machine is 2A & load current is 20A at 200V. Calculate

i) Generated EMF when working as generator

ii) Torque (in Nm) when running at 1500 rpm as motor

take armature resistance = 0.5 Ω

A. i) $I_f = 2A$ $I_L = 20A$

$I_a = I_f + I_L = 22A$

$E_g = I_a R_a + V$

$= 22 \times 0.5 + 200$

$= 211V$

ii) $T_a = \frac{I_a P\phi Z}{2\pi A} = \frac{I_a E_b \cdot 60}{2\pi N}$ $\left(I_s = I_a + I_f\right)$ $\left(I_a = I_s - I_f\right)$

E_g in motor $\Rightarrow E_g + I_a R_a = V \Rightarrow E_g = V - I_a R_a$

$= 200 - (18)(0.5) = 191V$

$T_a = \frac{18 \times 191 \times 60}{2 \times \pi \times 1500} = 21.898$ Nm

Q3. 8 pole operator has 500 armature conductors & has a useful flux per pole of 0.065 Wb. What will be emf generated if it's lap connected & runs at 1000 rpm? What must be speed at which it's to be driven to produce same emf if wave connected

A. $P = 8$; $z = 500$; $\phi = 0.065$ wb ; $P = A = 8$

$E_{g_1} = \frac{P\phi N}{60} \cdot \frac{Z}{A} = \frac{0.065 \times 1000 \times 500}{60 \times 8}$

$= 541.67$ W

Now for wind,

$N = \frac{541.67 \times 60 \times 2}{8 \times 0.065 \times 500} = 250$ rpm

Q4. A 6 pole lap around dc generator has 51 slots each has 18 conductors, The useful flux per pole is 35 mW. Find the generated emf in armature, if its driven at a speed of 750 rpm

A. $N = 750$; $P = 6$

$Z = 51 \times 18$

$\phi = 35 \times 10^{-3}$ Wb

$A = P$

$E_g = \frac{P\phi N Z}{60 A} = 401.625$ W

Q5. A Shunt generator 450A at 230V & resistance of shunt field & armature are 50 & 0.03 Ω. Calculate E_g

A. $I_L = 450A$

$V = 230V$ $I_a = I_L + \frac{V}{R_f}$

$R_f = 50\Omega$

$R_a = 0.03\Omega$ $= 450 + \frac{230}{50} = 454.6A$

$E_g = I_a R_a + V$

$= 454.6 \times 0.03 + 230$

$= 13.638 + 230$

$= \mathbf{243.638}$ V

Q6. An 8 pole DC generator has 650 armature conductors. The flux per pole is 20mWb. Find value of emf generated when armature is wave wound & rotating at speed 1200 rpm. What must be speed at which armature is to be driven to generate same emf, if armature is lap wound

A. $P = 8$; $z = 650$; $\phi = 20 \times 10^{-3}$

$N_1 = 1200$ rpm ⇒ wave

$E_g = \frac{P\phi N Z}{60 A} = \frac{8 \times 20 \times 10^{-3} \times 1200 \times 650}{60 \times 2} = 1040V$

$E_g = \frac{N\phi P Z}{60 A}$ ⇒ where $A = P$

$1040 = \frac{N \times 20 \times 10^{-3} \times 650}{60}$

$N = 4800$ rpm

Q7. A 4 pole generator with wave wound armature has 51 slots each having 24 conductors. The flux per pole is 10 mWb. At what speed must be armature rotate to give an induced emf of 0.24 kV. What will be voltage developed, if winding is lap connected & armature rotates at same speed?

A. $P = 4$; $Z = 51 \times 24 = 1224$ $\phi = 10^{-2}$ Wb

$E_{g_1} = 0.24 \times 10^3 V$ ⇒ Wave

$N_1 = \frac{E_g \times 60 \times A}{P\phi Z} = \frac{240 \times 60 \times 2}{4 \times 10^{-2} \times 1224} = 588$ rpm

$N = \frac{E_g \times 60 \times A}{P\phi Z}$

$E_g = \frac{588 \times 10^{-2} \times 1224}{60} = 120V$

Q8. A 4 pole 250V DC shunt meter has back emf of 240.8V & takes current of 20A. Calculate power developed. Take resistance of field windings as 250 Ω

A. $P = 4$ $E_g = 240.8V$ $R_f = 250\Omega$ $V = 250V$

$I_s = 20A$

$I_s = I_A + \frac{V}{R_f}$ ⇒ $I_a = 20 - \frac{250}{250} = 19A$

$P_i = I_a E_g = 19 \times 240.8$

$= 4575.2W$

Q9. Find useful flux per pole of 250V, 6 pole shunt motor having a 2 circuit connected winding with 220 conductors. At normal working temp, overall armature resistance including brushes is 0.2 Ω. Armature current is 13.3A at the no-load speed = 908 rpm

A. $V = 250V$ $P = 6$ ⇒ wave $Z = 220$

$I_a = 13.3A$ $R_a = 0.2\Omega$ $N = 908$

$V = I_a R_a + E_g$

$E_g = 250 - 13.3 \times 0.2$

$= 247.34V$

$E_g = \frac{P\phi N Z}{60 A} \Rightarrow \phi = \frac{E_g \times 60 \times 2}{6 \times 908 \times 220}$

$= 0.0247$ Wb

Q10. Determine total torque developed in a 250V, 4 poles DC shunt motor with lap winding, accomodated in 60 slots each containing 20 conductors. The armature current is 50A & flux free pole is 23 mWb

A. $V = 250V$, $P = 4$, lap, $Z = 60 \times 20 = 1200$

$I_a = 50A$ $\phi = 23 \times 10^{-3}$ Wb

$T_a = \frac{1}{2\pi} P\phi I_a \frac{Z}{A} = \frac{1}{2\pi} \times 4 \times 23 \times 10^{-3} \times 50 \times \frac{1200}{4}$

$= 219.63$ Nm

Q11. A 4 pole lap wound DC Generator has 40 slots. It runs at 1500 rpm. Flux per pole is 30mWb. Find conductors per slot to give a generated emf of 180V

A. $P = 4$ $N = 1500$

$A = P$ $\phi = 30 \times 10^{-3}$

$z = 40x$ $E_g = 180V$

$E_g = \frac{P\phi N Z}{60 A}$

$180 = \frac{4 \times 30 \times 10^{-3} \times 1500 \times 40x}{60 \times 4}$

$x = 6$

Q12. The armature of 4 pole DC generator has 47 slots, each containing 6 conductors. The armature winding is wave connected & flux per pole is 25mWb. At what speed must be driven to generate EMF 250V.

A. $N = \frac{E_g \times 60 A}{P\phi Z}$

$= \frac{250 \times 60 \times 2}{4 \times 0.025 \times 282}$

$= 1063.82$ rpm

Q13. A 6-pole armature is wounded with 498 conductors. The flux & speed is such that avg. EMF generated in each conductor is 2V. The current in each conductor is 120A. Find Total current, EMF generated if i) wave ii) lap. Also find power generated in each case

A. $P = 6$, $Z = 498$, E_g/conductor = 2V

I_a/conductor = 120A

i) wave

$A = 2$

I_a in 1 path = 120A

Total $I_a = 120 \times 2 = 240A$

$E_g = \frac{P\phi N Z}{60 A} = 2 \times \frac{498}{2} = 498V$

$P_i = I_a E_g = 119.52$ kW

ii) lap

$A = P$

Current per path = 120A

Total Current = 120 × 6 = 720A

$E_g = \frac{P\phi Z N}{60 A} = 2 \times \frac{498}{6} = 166V$

$P_i = I_a \times E_g = 119.52$ kW

Q14. The armature of DC Machine has $R_a = 0.1\Omega$ & connected to 250V DC supply. Calculate generated EMF when running

i) As a generator giving 80A

ii) As a motor drawing 60A

A. $R_a = 0.1\Omega$

$V = 250V$

i) generator ⇒ $I_a = 80A$, $E_g = ?$

ii) motor ⇒ $I_a = 60A$, $E_b = ?$

i) $E_g = I_a R_a + V$

$= 80 \times 0.1 + 250 = 258V$

ii) $E_b = V - I_a R_a$

$= 250 - 60 \times 0.1 = 244V$

Q15. A 4 pole DC Motor is connected to 500V DC supply & takes an armature current of 80A. The resistance of armature circuit is 0.4 Ω. The armature is wave around with 522 conductors & useful flux per pole is 0.025 Wb. Calculate back emf of motor, speed & torque in armature

A. $E_b + I_a R_a = V$

$E_b = 500 - 80 \times 0.4$

$= 468V$

$E_b = \frac{P\phi N Z}{60 A}$

$N = \frac{E_b \times 60 \times A}{P\phi Z} = \frac{468 \times 60 \times 2}{4 \times 0.025 \times 522} = 1075.86$ rpm

$T_a = \frac{1}{2\pi} I_a \frac{P\phi Z}{A} = \frac{1}{2\pi} 80 \times 4 \times 0.025 \frac{522}{2} = 332.48$ Nm

Q16. DC motor draws 10A from 200V DC Supply. If its armature resistance = 0.5 Ω & runs at 1000 rpm, determine T_a

A. $I_a = 10A = I_s$ ⇒ Seperately Excited

$V = 200V$

$R_a = 0.5\Omega$ $N = 1000$ rpm

$T_a = \frac{I_a E_b 60}{2\pi N}$

$E_b + I_a R_a = V$

$E_b = 200 - 10 \times 0.5 = 195V$

$T_a = \frac{10 \times 195 \times 60}{2 \times \pi \times 1000} = 18.62$ Nm

Q17. A 4 pole generator having wave-wound armature winding has 51 slots, each slot containing 20 conductors. What will be voltage in machine when driven at 1500 rpm assuming flux per pole = 7 mWb

A. $E_g = \frac{P\phi N Z}{60 A} = \frac{4 \times 7 \times 10^{-3} \times 1500 \times 1020}{60 \times 2} = 357V$

Q18. 4 pole 220V DC Shunt generator supplies load of 3kW at 220. The resistance of armature winding is 0.1 and that of field winding is 110. Calculate Total armature current, Current flowing thru armature conductor, emf induced if armature is wave connected

A. $P = 4$, $V = 220V$, Shunt, Wave, $P_o = I_s V = 3000V$

$R_a = 0.1\Omega$, $R_f = 110\Omega$,

$I_f = \frac{V}{R_f} = \frac{220}{110} = 2A$

$I_s = I_a - 2 \Rightarrow I_a = \frac{3000}{220} + 2 = 15.63A$

$I_s = 13.63A$

$E_g = I_a R_a + V$

$= 15.63 \times 0.1 + 220 = 221.563V$

Wave, Current in each conductor

$\frac{I_a}{P} = \frac{15.63}{2} = 7.815A$

Q19. A 4 pole wave connected DC Shunt motor takes 22.5A from a 250V supply, $R_a = 0.5\Omega$ shunt resistor 125. no of armature conductors is 300 is the flux per pole is 0.02 Wb, calculate emf, N, T_a, Power

A. $I_s = I_a + \frac{V}{R_f}$

$I_a = 22.5 - \frac{250}{125} = 20.5A$

$E_b = V - I_a R_a$

$= 250 - 20.5 \times 0.5 = 239.75V$

$E_b = \frac{P\phi N Z}{60 A} \Rightarrow N = \frac{239.75 \times 60 \times 2}{4 \times 0.02 \times 300} = 1198.75$ rpm

$T_a = \frac{1}{2\pi} P\phi I_a \frac{Z}{A} = \frac{4 \times 0.02 \times 20.5 \times 300}{2\pi \times 2} = 39.15$ Nm

$P_o = I_a E_b = 20.5 \times 239.75 = 4.914$ kW

Q20. 500V, $P = 4$, $z = 492$, $I_L = 20A = I_s$

$R_a = 0.1\Omega$ $R_f = 250\Omega$ $\phi = 50$ mWb

$N = ?$ $T_a = ?$

A. $I_s = I_a + \frac{V}{R_f}$

$I_a = 20 - \frac{500}{250} = 18A$

$E_b = V - I_a R_a = 500 - 18 \times 0.1$

$= 498.2V$

$N = \frac{498.2 \times 60 \times 2}{4 \times 0.05 \times 492}$

$= 607.56$ rpm

$T_a = \frac{1}{2\pi} \frac{P\phi Z I_a}{A}$

$= 140.01$ Nm

5. Losses & Efficiency

- Losses in DC Machines
  - Copper Loss
    - Armature Copper Loss → $I_a^2 R_a$
    - Series Field Copper Loss → $I_a^2 R_a$
    - Parallel/Shunt Field Copper Loss → $I_f^2 R_f$
  - Iron Loss
    - Eddy Current Loss
    - Hysteresis Loss
  - Mechanical loss
    - Friction Loss
    - Windage Loss

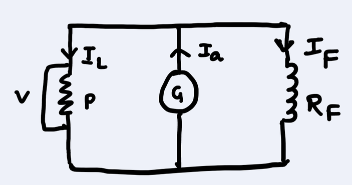
Variable Losses, $W_v = I_a^2 R_a$

Total Cu loss $= I_a^2 R_a + I_f^2 R_f$

Constant Losses

$=$ Iron Loss + Parallel Field Cu loss + Mech loss

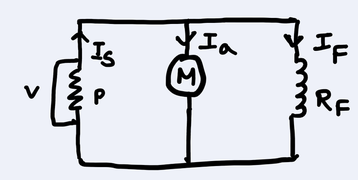
$=$ Iron Loss $+ I_f^2 R_f$ + Mech Loss



Generator

$I_a = I_L + I_F$

$= \frac{P}{V} + \frac{V}{R_F}$



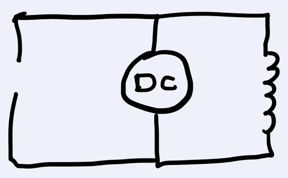
Motor

$I_a = I_S - I_F$

$= I_S - \left(\frac{V}{R_F}\right)$

No Load (or) Light Running

In no load DC Machine,



$P_i = P_o + \text{loss}$

$= P_o + W_c + W_v$, $P_o \to 0$

$P_i = W_c + W_v$

$P_{iNL} = W_c + W_{v_{NL}}$

$W_c = P_{iNL} - W_{v_{NL}} = V_s I_{S_{NL}} - I_{a_{NL}}^2 R_a$

Rating:

Generator → P_o, V_t, I_L

Motor → P_i, V_s, I_s

Efficiency

Generator → $\eta = \frac{P_o}{P_i} \times 100 = \frac{P_o}{P_o + W_c + W_v} \times 100$

Motor → $\eta = \frac{P_o}{P_i} \times 100 = \frac{P_i - (W_c + W_v)}{P_i} \times 100$

Q1. A 100 kW, 460V Shunt generator was run as a motor on no load at its rated voltage & speed. The total current taken was 9.8A including a shunt current of 2.7A. The resistance of the armature circuit at normal temperature was 0.11 Ω. Calculate efficiency at i) Full load 2) Half load

A. $P_i = 100\,kW$ $V_s = 460V$ $I_{S_{NL}} = 9.8A$ $I_F = 2.7A$

$R_a = 0.11\,\Omega$ $I_{aNL} = I_{S_{NL}} - I_F = 9.8 - 2.7 = 7.1\,A$

i) $\eta_{F.L} = \frac{P_i - (W_c + W_v)}{P_i} \times 100$

$W_c = I_{S_{NL}} V_s - I_{aNL}^2 R_a = 9.8 \times 460 - (7.1)^2 (0.11)$

$= 4.502\,kW$

$W_v = I_a^2 R_a$

$= (214.69)^2 \times 0.11$

$= 5070.16\,W = 5.07\,kW$

$I_a = I_s - I_F$

$= \frac{P}{V} - I_F$

$= \frac{100000}{460} - 2.7 = 214.69A$

$\eta = \frac{100 - (4.502 + 5.07)}{100}$

$= 90.428\%$

ii) $P = 50\,kW$

$W_c = 4.502\,kW$

$W_v = I_a^2 R_a$

$I_a = I_s - I_F = \frac{50000}{460} - 2.7 = 105.99A$

$W_v = (105.99)^2 (0.11) = 1.235\,kW$

$\eta = \frac{50 - 4.502 - 1.235}{50} = 88.52\%$

Q2. A 10kW, 250V DC shunt motor with armature resistance 0.8 Ω & field resistance of 275 Ω takes 3.91A when running light at rated Voltage & rated speed. Find

i) constant losses ii) η as generator, Output = 10 kW

iii) η as motor, Input = 10 kW

A. i) $W_c = I_{S_{NL}} V_s - I_{aNL}^2 R_a$

$= 3.91 \times 250 - 3^2 (0.8)$

$= 970.3\,W$

$I_{aNL} = I_{S_{NL}} - I_F$

$= 3.91 - \frac{V}{R_f} = 3.91 - \frac{250}{275}$

$= 3A$

ii) $W_v = I_a^2 R_a$

$= (40.91)^2 (0.8)$

$= 1338.84\,W$

$I_a = I_L + I_F$

$= \frac{P}{V} + \frac{V}{R_f} = \frac{10000}{250} + \frac{250}{275}$

$= 40.91\,A$

$\eta_{gen} = \frac{P_o}{P_o + W_c + W_v}$

$= \frac{10000}{10000 + 970.3 + 1338.84} \times 100 = 81.24\%$

iii) $W_v = I_a^2 R_a$

$= (39.01)^2 \times 0.8$

$= 1222.48\,W$

$I_a = I_s - I_F$

$= \frac{10000}{250} - \frac{250}{275}$

$= 39.1\,A$

$\eta_{motor} = \frac{P_i - W_c - W_v}{P_i}$

$= \frac{10000 - 970.3 - 1222.48}{10000} \times 100 = 78.07\%$

Q3. A DC Shunt machine connected to 200V DC mains has armature winding & field winding resistance of 0.5 Ω & 100 Ω respectively. Determine its efficiency:

i) When working as generator supplying output 20A

ii) When working as motor drawing 20A from mains

Given, from mechanical & iron losses to be 200 & 100 W

A. $V_s = 200V$; $R_f = 100\,\Omega$; Mech loss = 200W

$R_a = 0.5\,\Omega$; $I_{s\,gen} = 20A = I_{s\,motor}$; Iron loss = 100W

W_c = Mech loss + Iron loss $+ I_f^2 R_f$, $I_f^2 R_f = \frac{V_s^2}{R_f}$

$= 200 + 100 + \left(\frac{200 \times 200}{100}\right)$

$= 700\,W$

i) $W_v = I_a^2 R_a$

$= (22)^2 \times 0.5 = 242W$

$I_a = I_s + I_f$

$= 20 + \frac{200}{100} = 22A$

$\eta = \frac{P_o}{P_o + W_c + W_v} = \frac{4000}{4000 + 242 + 700}$

$= 80.93\%$

ii) Motor

$W_v = I_a^2 R_a$

$= 18^2 \times 0.5$

$= 162\,W$

$I_a = I_s - I_f$

$= 20 - \frac{200}{100} = 18A$

$\eta = \frac{P_i - W_c - W_v}{P_i}$

$= \frac{4000 - 700 - 160}{4000}$

$= 78.45\%$

Q4. A Shunt generator delivers 195A at a terminal voltage of 250V. The armature resistance & shunt field resistance are 0.02 Ω & 50 Ω. The iron & frictional losses = 950 W

i) Find emf ii) Copper losses iii) η_{motor}

A. $I_L = 195A$

$V_s = 250V$

$R_a = 0.02\,\Omega$

$R_f = 50\,\Omega$

$E_g = I_a R_a + V_s$

$= 200 \times 0.02 + 250$

$= 254\,V$

$I_a = I_L + I_f$

$= 195 + \frac{250}{50} = 200$

$W_{cu} = W_v + I_f^2 R_f$

$= I_a^2 R_a + \frac{V_s^2}{R_f}$

$= (200)^2 0.02 + \frac{250^2}{50}$

$= 800 + 1250 = 2050\,W$

$W_c =$ Iron + frictional

$= 950 + \frac{250^2}{50} = 2200\,W$

$I_a = I_s - I_f$

$= 195 - 5 = 190A$

$W_v = I_a^2 R_a$

$= 190^2 \times 0.02 = 722\,W$

$P_i = V_s I_L = 250 \times 195 = 48750$

$\eta_{motor} = \frac{P_i - W_c - W_v}{P_i} = \frac{48750 - 2200 - 722}{48750} = 94\%$

Q5. A 100 kW, 400V shunt generator was running as a motor on no load as its rated voltage & speed. The total current taken as 9.8A & shunt current of 2.7A. The resistance of armature circuit at normal temp was 0.11 Ω

Calc efficiency at i) full load ii) 25% load iii) 80% load

A. $P_i = 100\,kW$; $V_s = 400V$ ⇒ motor ; $I_{S_{NL}} = 9.8A$; $I_F = 2.7A$

$R_a = 0.11\,\Omega$; $I_{aNL} = 9.8 - 2.7 = 7.1A$

$W_c = V_s I_{S_{NL}} - I_{aNL}^2 R_a$

$= 400 \times 9.8 - (7.1)^2 \times 0.11$

$= 3914.46\,W$

i) $W_v = I_a^2 R_a$

$= (247.3)^2 \times 0.11$

$= 6727.30\,W$

$I_a = I_s - I_f = \frac{P}{V} - I_F$

$= \frac{100000}{400} - 2.7 = 247.3\,A$

$\eta = \frac{P_i - W_c - W_f}{P_i} = \frac{100000 - 3914.46 - 6727.3}{100000} = 89.35\%$

ii) $W_v = I_a^2 R_a$

$= (59.8)^2 \times 0.11$

$= 393.36\,W$

$I_a = \frac{P}{V} - I_F$

$= \frac{25000}{400} - 2.7 = 59.8A$

$\eta = \frac{25000 - 3914.46 - 393.36}{25000} = 82.76\%$

iii) $W_v = (197.3)^2 \times 0.11$

$= 4282\,W$

$I_a = \frac{80000}{400} - 2.7 = 197.3$

$\eta = \frac{80000 - 3914.46 - 4282}{80000} = 89.75\%$

Q6. A 4 pole 12kW 240V DC Generator has its armature conductor coils wave connected. If same machine is lap connected & all other thing remain constant, calculate voltage

A. $E_g = \frac{P \phi N Z}{60\,A}$

$P = 4$ ⇒ Wave ⇒ $A = 2$

$E_{g_W} = 240V$

⇒ $\frac{\phi N Z}{60} = \frac{E_g A}{P} = \frac{240 \times 2}{4} = 120$ (Constant)

In Lap,

$E_{g_L} = \frac{P \phi N Z}{60\,A}$; $P = 4$, $A = 4$, $\frac{\phi N Z}{60} = 120$

$E_{g_L} = \frac{4 \times 120}{4} = 120\,V$

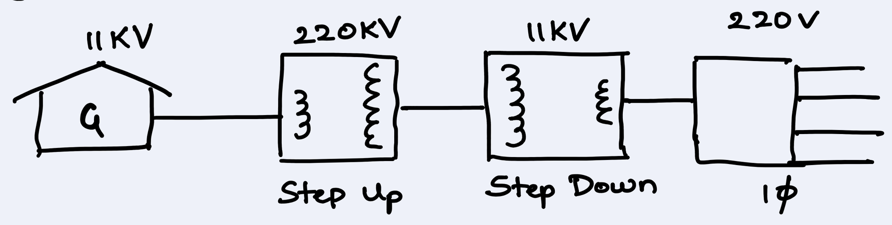
6. Transformers

→ Static Device

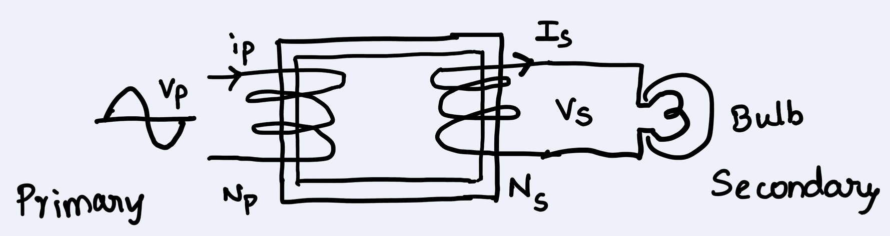
→ $\eta = 95 - 98\%$

→ Only AC Signal

→ frequency ⇒ constant



→ Core Type :



$E_1 = -N_1 \frac{d\phi}{dt}$ $\quad E_2 = -N_2 \frac{d\phi}{dt}$

$\frac{E_2}{E_1} = \frac{N_2}{N_1} = K$ (Turn ratio)

If $N_2 > N_1 \Rightarrow K > 1 \Rightarrow$ Step up

$N_1 > N_2 \Rightarrow K < 1 \Rightarrow$ Step down

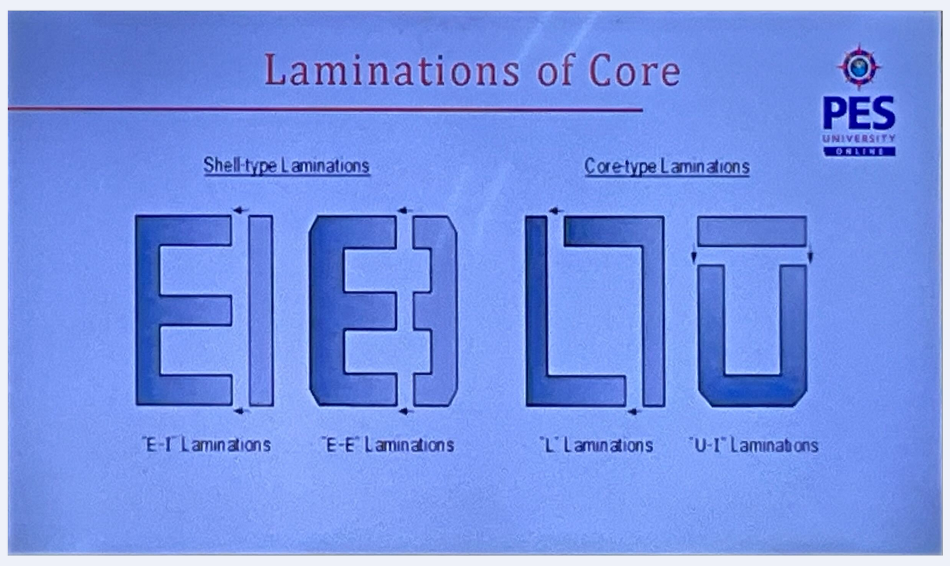
Ideal Transformers

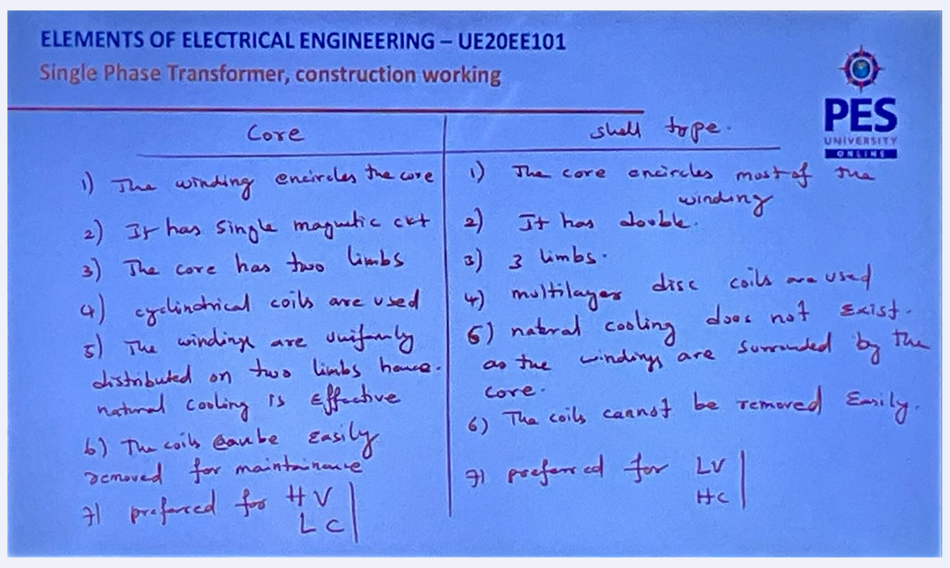
$V_1 I_1 = V_2 I_2$ (or) $E_1 I_1 = E_2 I_2$

$\Rightarrow \frac{I_2}{I_1} = \frac{E_1}{E_2} = \frac{N_1}{N_2}$

$I \propto \frac{1}{N}$ for both primary & secondary

Core v/s Shell Type





EMF eq. in transformer

$E_1 = -N_1 \frac{d\phi}{dt}$

$-N_1 \phi_m \cos\omega t \times \omega$

$-N_1 \omega \phi_m (\sin(90 - \omega t))$

$N_1 \omega \phi_m \sin(\omega t - 90)$

$2N_1 \pi f \phi_m \sin(\omega t - 90)$

$E_m = 2N_1 \pi f \phi_m$

$E_{rms} = \frac{2N_1 \pi f \phi_m}{\sqrt{2}} = 4.44 N_1 f \phi_m$

Q1. The primary winding of a transformer is connected to a 240V, 50Hz Supply. The secondary winding has 1500 turns. If the max value of core flux is 0.00207 Wb, Determine i) E_2 = ? 2) N_1 = ? 3) A = ? if B = 0.465 T

A. $E_2 = 4.44 \phi N_2 f$

$= 4.44 \times 0.00207 \times 1500 \times 50$

$E_2 = 689.31 V$

$\frac{E_2}{E_1} = \frac{N_2}{N_1} \Rightarrow N_1 = \frac{E_1 N_2}{E_1} = \frac{240 \times 1500}{689.31} = 522$

$B = \frac{\phi}{A} \Rightarrow A = \frac{\phi}{B} = \frac{0.00207}{0.465} = 4.45 \times 10^{-3} m^2$

Q2. A 50KVA transformer has $N_1 : N_2 = 300 : 20$. The primary winding is connected to 2200V, 50 Hz Calculate i) E_2 = ? ii) I_1 = ? I_2 = ? iii) ϕ_{max} = ?

A. $\frac{N_1}{N_2} = \frac{E_1}{E_2} \Rightarrow E_2 = \frac{2200}{15} = 146.67 V$

$P = E_1 I_1 \Rightarrow I_1 = \frac{50000}{2200} = 22.72A$

$P = E_2 I_2 \Rightarrow I_2 = \frac{50000}{146.67} = 340.9A$

$E_1 = 4.44 \phi_m N_1 f$

$\phi_m = \frac{E_1}{4.44 N_1 f} = \frac{2200}{4.44 \times 300 \times 50} = 33 mWb$

Q3. The required no load ratio in a single phase 50Hz core type transformer is 6000/150 V. Find the no. of turns per limb on the high & low voltage side if flux = 0.06Wb

A. $\frac{E_1}{E_2} = \frac{6000}{150}$ $\quad \phi_m = 0.06$

$E_1 = 4.44 \phi_m N_1 f$

$N_1 = \frac{6000}{4.44 \times 0.06 \times 50} = 450.45$

$N_2 = \frac{150}{4.44 \times 0.06 \times 50} = 11.26$

$\frac{E_1}{N_1} = 13.32$ $\quad \frac{E_2}{N_2} = 13.32$

Q4 A 10KVA, 2000/200 V, 50Hz, Single Phase transformer has 75 turns on its secondary. If net cross sectional area of core = 150 cm², Determine i) I_1, I_2 = ? ii) N_1 = ? iii) I_1, I_2 under ½ load iv) B = ? v) $\frac{E}{N}$ = ?

A. $P = E_1 I_1 = E_2 I_2$

$I_1 = 5A$ $\quad I_2 = 50A$

$\frac{E_1}{E_2} = \frac{N_1}{N_2} \Rightarrow N_1 = 750$

$E_1 = 4.44 \phi_m N_1 f$

$\phi_m = 0.012 Wb$

$B = \frac{\phi_m}{A} = \frac{0.012}{0.01} = 1.2T$

$P = E_1 I_1 = E_2 I_2$ (for ½ load)

$I_1 = 2.5A$ $\quad I_2 = 25A$

$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 2.67$

Q5 A 10 KVA, 200/400 V, 50Hz, Single phase transformer has maximum flux in core of 7.21 mWb, Determine i) I_1, I_2 = ? ii) N_1 = ? iii) A = ? if B_m = 1.4T

A. $P = E_1 I_1 \Rightarrow I_1 = 50A$

$P = E_2 I_2 \Rightarrow I_2 = 25A$

$E_1 = 4.44 \phi_m N_1 f$

$N_1 = \frac{200}{4.44 \times 7.21 \times 10^{-3} \times 50} = 125.$

$B_m = \frac{\phi_m}{A}$

$A = \frac{0.00721}{1.4} = 5.15 \times 10^{-3} m^2$

Q6. A 10KVA Single phase transformer moving on a 50Hz AC supply supplies power at a load voltage of 500V. If the max value of core flux is 10mWb & No. of primary turns is 400, Determine i) N_2 ii) E_1 iii) I_1, I_2 iv) A if B_m = 1.4T

A. $E_2 = 4.44 \phi_m N_2 f$

$N_2 = 225$

$\frac{E_2}{E_1} = \frac{N_2}{N_1} \Rightarrow E_1 = 888.02V$

$I_1 = \frac{P}{E_1} = 11.26A$

$I_2 = \frac{P}{E_2} = 20A$

$A = \frac{\phi_m}{B_m} = 7.14 \times 10^{-3} m^2$

Q7. An iron-cored transformer has 200 turns on primary & 100 turns on secondary. A suppy of 400V, 50Hz is given to primary & impedance of (4+3i) Ω is connected across secondary. Assume ideal behaviour. i) E_2 = ? I_2 = ? ii) I_1 = ? iii) P = ?

A. $\frac{E_2}{E_1} = \frac{N_2}{N_1} \Rightarrow E_2 = 200V$

$E_2 = I_2 Z_2$

$I_2 = 40\angle -36.86 A \Rightarrow 40A$

$\frac{I_2}{I_1} = \frac{E_1}{E_2} \Rightarrow I_1 = 20A$

$P = E_1 I_1 = E_2 I_2 = 8KVA$

Q8. The max flux density in the core of 1100/220V, 50Hz, 100 KVA transformer 3.5T. If emf per turn is 5.5V, Calc i) A ii) N_1, N_2 iii) I_1, I_2 = ? iv) I_1, I_2 at 25%

A. $E_1 = 1100V$ $\quad E_2 = 220V$ $\quad f = 50 Hz$ $\quad P = 100KVA$

$B_m = 3.5T$ $\quad E/N = 5.5V$

$\frac{E_1}{N_1} = 5.5 \Rightarrow N_1 = 200$ $\quad \frac{E_2}{N_2} = 5.5 \Rightarrow N_2 = 40$

$\phi_m = \frac{1100}{4.44 \times 200 \times 50} = 0.0247 Wb$

$A = \frac{\phi_m}{B_m} = \frac{0.0247}{3.5} = 7.05 \times 10^{-3} m^2$

$I_1 = \frac{P}{E_1} = 90.9A$ $\quad I_2 = \frac{P}{E_2} = 454.54A$

for 25% load, $I_1 = \frac{P}{E_1} = 22.72A$ $\quad I_2 = \frac{P}{E_2} = 113.63 A$

Q9 A single phase transformer has 400 primary & 100 secondary turns. Net cross sectional area = 60 cm². If primary winding to be connected to 50Hz supply at 500V. Calculate peak value of flux density in core & voltage induced in secondary winding

A. $\frac{E_2}{E_1} = \frac{N_2}{N_1} \Rightarrow E_2 = 125V$

$E_1 = 4.44 \phi_m N_1 f$

$\phi_m = 5.63 \times 10^{-3} Wb$

$B_m = \frac{5.63 \times 10^{-3}}{60 \times 10^{-4}} = 0.938T$

Q10. A 5KV 50Hz single phase transformer has primary & secondary turns 100 & 80 at certain flux density, the individual emf per turn in primary is 2.5V, Determine Voltage & Current in both winding

$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 2.5V$ $\quad E_1 = 300V$ $\quad E_2 = 200V$

$P = E_1 I_1 = E_2 I_2$

$I_1 = 16.67A$

$I_2 = 25A$

Q11. A 125KVA transformer has primary voltage of 2000 at 60Hz if no. of turns on primary & secondary windings are 182 & 40, Voltage, Flux, Full load primary & secondary currents ?

A. $P = 125KVA$ $\quad N_1 = 182$

$E_1 = 200V$ $\quad N_2 = 40$

$\frac{E_2}{E_1} = \frac{N_2}{N_1} \Rightarrow E_2 = 43.95V$

$P = E_1 I_1 = E_2 I_2$

$I_1 = 625A$

$I_2 = 2844.14A$

$E_1 = 4.44 \phi_m N_1 f \Rightarrow \phi_m = 4.125 \times 10^{-3} Wb$

Q12. Find No. of turns of primary & secondary of 415/240V 50Hz transformer if area of core is 50cm² & max value of flux density in core is 1.3 Wb/m²

A. $E_1 = 415V$ $\quad E_2 = 240V$ $\quad A = 50 \times 10^{-4} m^2$ $\quad B_m = 1.3T$ $\quad f = 50Hz$

$\phi_m = B_m \cdot A = 6.5 \times 10^{-3} Wb$

$E_1 = 4.44 \phi_m N_1 f \Rightarrow N_1 = 287.59$ turns

$E_2 = 4.44 \phi_m N_2 f \Rightarrow N = 166.32$ turns

Q13. A 3000/300V 50Hz single phase transformer has an emf per turn of 15V & max flux density 1.5T. Find no. of primary & secondary turns and area.

A $E_1 = 3000V$ $\quad E_2 = 300V$ $\quad B_m = 1.5T$

$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 15V \Rightarrow N_1 = 200$ $\quad N_2 = 20$

$E_1 = 4.44 \phi_m N_1 f$

$\phi_m = 0.0675 Wb \Rightarrow A = \frac{\phi_m}{B_m} = 0.045 m^2$

Q14. A 100 KVA 6000/400V 50Hz Single phase transformer has 100 turns in secondary. Calculate i_1, i_2, N_1 & ϕ

A. $P = 100KVA$

$E_1 = 6000V$

$E_2 = 400V$

$f = 50Hz$

$N_2 = 100$

$\frac{E_1}{N_1} = \frac{E_2}{N_2} \Rightarrow N_1 = 1500$

$P = E_1 I_1 = E_2 I_2$

$I_1 = 16.67A$ $\quad I_2 = 250 A$

$\phi_m = \frac{E_2}{4.44 N_2 f} = 0.018 Wb$

7. 3 Phase induction motor

Advantages -

i) Simple & rugged
ii) Low cost & reliable
iii) High efficiency
iv) Low maintainance cost
v) Self - starting motor
vi) Can be manufactured to suit industry requirements
vii) Most widely used motors

→ It has 2 Main Parts

i) Rotor (Rotating Part) (ii) Stator (stationary Part)

→ Squirrel Cage motor

- Rotor winding is compared of Cu bars embedded in rotor slots & shorted at both ends of rings
- Simple, low cost, robust, low maintainance

→ Phase Wound rotor / slip ring motor

- Rotor windings are wound by wires. The winding terminals can be connected to external circuits through slip rings & brushes
- More expensive

→ RMF = Rotating Magnetic Field

N_s = Synchronous speed / RMF speed

$N_s = \frac{120f}{P}$ $\left(\begin{array}{l} f = \text{freq} \\ P = \text{poles} \end{array}\right)$

→ Working

- RMF is setup in stator when 3ϕ supply is given
- Stationary motor conductors cuts revolving field due to EMI, & emf is induced in motor conductors
- As motor conductors are short circuited, current flows through them
- Hence, it becomes a current carrying conductor in magnetic field, which experiences the force & starts rotating

→ N ⇒ Speed of rotor

$N < N_s$

Diff b/w N & N_s is slip

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

$N \propto f$ (f = freq of RM)

$f_r = sf$ $\left(\begin{array}{l} f_r = \text{freq of rotor} \\ s = \text{slip} \end{array}\right)$

Q1. A 3ϕ induction motor has 6 poles & runs at 960 rpm on full load. It is supplied from an alternator having 4 poles & running at 1500 rpm. Calculate the full load slip & freq of rotor currents of induction motor

A.

Stator:
$P = 4$
$N_s = 1500$ rpm
$f = ?$
$N_s = \frac{120f}{P}$
$f = 50$ Hz

Motor:
$P = 6$
$N = 960$ rpm
$f = 50$ Hz
$N_s = \frac{120f}{P} = 1000$ rpm

$S = \frac{N_s - N}{N_s} \times 100 = 4\%$

$f_r = sf = 0.04 \times 50$
$= 2$ Hz

Q2. A 3ϕ induction motor with 4 poles is supplied from an alternator having 6 poles & running at 1000 rpm. Calculate i) N_s ii) N, if s = 0.04 iii) f_r if N = 600 rpm

A.

Motor:
$P = 4$
$f = 50$ Hz

Stator:
$P = 6$
$N_s = 1000 \text{ rpm} = \frac{120f}{P}$
$\Rightarrow f = 50$ Hz

i) $N_s = \frac{120f}{P} = 1500$ rpm

ii) $S = \frac{N_s - N}{N_s} \Rightarrow N = 1500 - (0.04)1500$
$= 1440$ rpm

iii) $S = \frac{N_s - N}{N_s} = \frac{1500 - 600}{1500} = 0.6$

$f_r = sf = 0.6 \times 50 = 30$ Hz

Q3. A 6 pole induction motor supplied from a 3ϕ 50Hz supply has a rotor freq of 2.3 Hz. Calculate S% & N

A. $f_r = sf$

$s = \frac{f_r}{f} = \frac{2.3}{50} = 0.046 \Rightarrow 4.6\%$

$N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000$ rpm

$S = \frac{N_s - N}{N_s} \Rightarrow N = N_s(1 - S)$
$= 1000(1 - 0.046)$
$= 954$ rpm

Q4. An 8 pole 50Hz 3ϕ induction motor runs at speed of 740 rpm under No load condition & has slip of 5% under full load cond^n, Determine i) N_s ii) S_{NL} iii) N_{FL} iv) f_{rFL} v) f_r when stand still

NL = No Load   FL = Full Load

A. $P = 8$, $N_{NL} = 740$ rpm, $S_{FL} = 5\%$
$f = 50$ Hz

i) $N_s = \frac{120f}{P} = \frac{120 \times 50}{8} = 750$ rpm

ii) $S_{NL} = \frac{N_s - N}{N_s} \times 100 = \frac{750 - 740}{750} \times 100 = 1.34\%$

iii) $S_{FL} = \frac{N_s - N_{FL}}{N_s} \Rightarrow N_{FL} = N_s(1 - S_{FL})$
$= 750(1 - 0.05)$
$= 712.5$ rpm

iv) $f_{rFL} = S_{FL} f = 0.05 \times 50 = 2.5$ Hz

v) $N = 0 \Rightarrow S = 1$
$\frac{N_s - N}{N_s} = \frac{N_s}{N_s} = 1$
$f_r = sf = 1 \times 50 = 50$ Hz

Q5. An 8pole alternator at 750 rpm supplies power to 3ϕ induction motor. If induction motor is running at 1440 rpm under full load cond^n,
i) f = ? ii) P_{motor} = ? iii) $S_{FL}\%$ iv) f_{rFL} = ? v) N_{NL} = ? if $S_{NL} = 1\%$

A. $P = 8$, $N_s = 750$ rpm, $N_{FL} = 1440$ rpm

i) $f = \frac{N_s P}{120} = 50$ Hz

ii) For $N_s > N_{FL}$, P = ?
if $P = 2$, $N_s = \frac{120 \times 50}{2} = 3000$ ✗
$P = 4$, $N_s = \frac{120 \times 50}{4} = 1500$ ✓ $= N_s$
$P = 6$, $N_s = \frac{120 \times 50}{6} = 1000$ ✗

iii) $S = \frac{N_s - N_{FL}}{N_s} = \frac{1500 - 1440}{1500} = 0.04 \Rightarrow 4\%$

iv) $f_r = S_{FL} f = 0.04 \times 50 = 2$ Hz

v) $N_{NL} = N_s(1 - S_{NL})$
$= 1500(1 - 0.01)$
$= 1485$ rpm

Q6. A 4 pole 3ϕ induction motor is supplied power from 415V, 50Hz 3ϕ supply. It has no load & full load slips of 1% & 4%. Find
i) N_s ii) N_{NL} & f_r iii) N_{FL} & f_r
iv) f_r when motor is just about to start

A. $P = 4$ $V = 415$V $f = 50$ Hz
$S_{NL} = 1\%$ $S_{FL} = 4\%$

i) $N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500$ rpm

ii) $N_{NL} = N_s(1 - S_{NL})$
$= 1500(1 - 0.01)$
$= 1485$ rpm
$f_r = S_{NL} f$
$= 0.01 \times 50 = 0.5$ Hz

iii) $N_{FL} = N_s(1 - S_{FL})$
$= 1500(1 - 0.04)$
$= 1440$ rpm
$f_r = S_{FL} \times f$
$= 0.04 \times 50$
$= 2$ Hz

iv) About to start $N = 0$
$S = 1$
$f_r = 1 \times f$
$= 50$ Hz

UNIT-4 EEE Formulas

→ $B = \frac{\phi}{A}$ (Magnetic Flux Density)

$\phi \rightarrow Wb$, $A \rightarrow m^2$, $B \rightarrow Wb/m^2$ (or) T

→ $F = NI$ (Magnetic Motive Force)

$I \rightarrow A$, $N \rightarrow t$, $F \rightarrow At$

→ $H = \frac{NI}{l} = \frac{F}{l}$ (Magnetic Field Strength)

$H \rightarrow At/m$

→ $B = \mu H$ (Relation b/w B & H)

$= \mu_0 \mu_r H$

→ $S = \frac{l}{\mu_r \mu_0 A}$ (Magnetic Reluctance)

$S \rightarrow m^{-1}$

→ $\mathcal{E}_s = -N_s \frac{\Delta \phi_s}{\Delta t}$

→ $F = BIL\sin\theta$ (Force)

$L \rightarrow m$, $I \rightarrow A$, $B \rightarrow Wb/m^2$

→ Lap winding ⇒ $A = P$

$A \rightarrow$ Parallel Paths, $P \rightarrow$ Poles

→ Wave winding ⇒ $A = 2$

P can be anything

→ $\tau = F \times r$ (Torque)

$= \frac{I_a P \phi Z}{2\pi A}$

→ Variable loses, $W_v = I_a^2 R_a$

Constant losses = Iron Loss + $I_f^2 R_f$ + Mech. Loss

Total Copper losses, $W_{cu} = I_a^2 R_a + I_f^2 R_f$

→ $I_a = I_L + I_F$ (Generator)

$= \frac{P}{V} + \frac{V}{R_F}$

$I_a = I_S - I_F$ (Motor)

$= I_S - \frac{V}{R_F}$

→ $P_{i_{NL}} = W_c + W_{v_{NL}}$ (No Load DC Machine)

$V_s I_{S_{NL}} = W_c + I_{a_{NL}}^2 R_a$

→ Generator (P_o, V_t, I_L) ⇒ $\eta = \frac{P_o}{P_o + W_c + W_v} \times 100$ (Efficiency)

Motor (P_i, V_s, I_s) ⇒ $\eta = \frac{P_i - W_c - W_v}{P_i} \times 100$

→ $\frac{I_2}{I_1} = \frac{E_1}{E_2} = \frac{N_1}{N_2}$ (Ideal Transformer)

$E_{rms} = 4.44 \, N \, \phi_{max} f$

→ $N_s = \frac{120 f}{P}$

$N_s \rightarrow$ Synchronous Speed, $f \rightarrow$ frequency, $P \rightarrow$ No. of poles

$\% S = \frac{N_s - N}{N_s} \times 100$ $(N < N_s)$

$S \rightarrow$ Slip, $N \rightarrow$ Rotor Speed

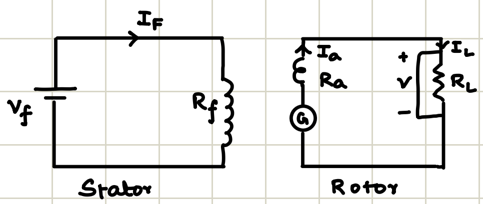
$f_r = S \cdot f$

$f_r \rightarrow$ frequency of R.M, $S \rightarrow$ slip, $f \rightarrow$ freq of rotor

→ $E_g = \frac{P \phi N Z}{60 A}$ (EMF equation)

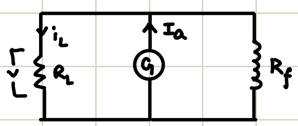
$E_g \rightarrow V$, $\phi \rightarrow$ Flux Per pole, $N \rightarrow$ Speed of armature (rpm), $Z \rightarrow$ Total no. of conductors, $A \rightarrow$ No. of parallel paths, $P \rightarrow$ No. of Poles

→



$I_a E_g = I_a V + I_a^2 R_a + I_a V_{Brush}$ (Equivalent Circuit for seperately excited DC Generator)

→



$I_a = i_L + i_f$

$= \frac{V}{R_L} + \frac{V}{R_f}$

$= \frac{P_L}{V} + \frac{V}{R_f}$

(Equivalent Circuit for Parallel Generator Machine)