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ELECTRONICS & TELECOMMUNICATION ENGINEERING

BASIC ELECTRICAL ENGINEERING

Volume - 1 : Study Material with Classroom Practice Questions

Chapter 1 Transformers
(Solutions for Text Book Practice Questions)

Objective Practice Solutions

01. Ans: (b)

Sol: $\uparrow B_{max} \propto \frac{V}{f\downarrow}$

Here $V \rightarrow$ constant, $f \rightarrow$ decreased to half

$\Rightarrow B_{max}$ increased to double, which will drive the core in to deep saturation and also I_μ is very high to create double the rated flux.

02. Ans: (d)

Sol: As $\frac{V}{f}$ ratio is not equal

(i) $W_h \propto \frac{V_1^{1.6}}{f^{0.6}}$; as frequency increases, the hysteresis loss will decreases.

(ii) $W_e \propto V_1^2$ (Independent on frequency)

$\therefore$ Eddy current loss will be constant.

03. Ans: (a)

Sol: Lenz's Law:

The direction of statically induced emf is such that the current due to this emf will flow through a closed circuit in such a direction that it will in turn produce some flux according to **Electro Magnetic Theory** and this flux must opposes the changes in main field flux which is the cause for production of emf as well as current.

04. Ans: (a)

Sol: Specific weight = $\frac{\text{weight of transformer}}{\text{kVA rating}}$

If flux density is high, then required cross sectional area of core will be less. $\left(\because B \propto \frac{1}{A}\right)$

Therefore transformer weight will be decreased, the transformer should have less specific weight.

05. Ans: (b)

Sol: $\cos\phi_{sc} = \frac{R}{Z} = \frac{R_{02}}{\sqrt{5} \times R_{02}}$

$\cos\phi_{sc} = \frac{1}{\sqrt{5}}$

06. Ans: (d)

Sol: In ideal transformer, resistance of windings and magnetic leakage flux are zero.

07. Ans: (d)

Sol: As leakage flux is more, coefficient of coupling of transformer will decrease and also the inductive reactance drop will be increased.

08. Ans: (a)

Sol: V = constant and $f > f_{rated}$

$\Rightarrow \frac{V}{f}$ Ratio is not constant

$\therefore W_h \propto \frac{V_1^{1.6}}{f^{0.6}\uparrow} \Rightarrow W_h \downarrow$ & W_e= Const

But "W_h" is due to core loss component of current I_w

$\Rightarrow$ As f $\uparrow$, $W_h \downarrow \Rightarrow I_w \downarrow$.

Similarly $\downarrow I_\mu \propto \downarrow B_{max} \propto \dfrac{V}{f\uparrow}$

$\Rightarrow f\uparrow \Rightarrow B_{max}\downarrow \Rightarrow I_\mu \downarrow$

09. Ans: (b)

Sol: Deviation from first approximation is occurred by neglecting primary impedance drop, i.e I_0Z_1.

10. Ans: (d)

Sol: If the leakage impedance parameters for both primary and secondary are required separately, then it is usual to take $X_1 = X_2 = \frac{1}{2}X_e$ refer to the same side and $X_m >> X_1(\text{or})X_2$

11. Ans: (c)

Sol: Copper loss $\propto I^2$ i.e depends on load current called variable losses.

Iron loss $(W_h + W_e) \propto V^2$ (applied voltage), called constant losses.

12. Ans: (a)

Sol: W_i = 100 W at 40 Hz.

= 72 W at 30 Hz.

At 40 Hz, $W_i = Af + Bf^2$.

$100 = A\times40 + B\times40^2$ ……. (1)

At 30 Hz, $72 = A\times30 + B\times30^2$ ……. (2)

By solving above two equations,

B = 1/100 and A = 2.1

Hysteresis loss, $W_h = A\times f$

$= 2.1\times50 \Rightarrow 105$ W.

Eddy current loss $W_e = B\times f^2$

$= \dfrac{50\times50}{100}$

= 25 W.

13. Ans: (c)

Sol:
- For a given kVA rating of transformer, more the design frequency, lesser the cross sectional area of the core and lesser will be the size and weight of transformer.
- For a given kVA rating and designed frequency of transformer, superior the magnetic material used for transformer core, higher will be the flux density and lesser will be the size and weight of the transformer.
- Copper loss is directly proportional to square of the current and resistance.

14. Ans: (a)

Sol: **Distribution transformer:** Cu-losses take place based on load cycle of Consumer and Iron losses takes place throughout 24 hrs. Iron losses are kept minimum while designing

Power transformer: Cu-losses and Iron losses takes place steadily throughout 24 hrs. Copper losses are kept minimum while designing.

Both assertion and reason are correct, reason is correct explanation to assertion.

15. Ans: (a)

Sol: At 230 V, 50 Hz $\Rightarrow W_I$ = 1050 W

At 138 V, 30 Hz $\Rightarrow W_I$ = 500 W

V_{11} = 230 V $\qquad \dfrac{V_{11}}{f_1} = \dfrac{230}{50} = 4.6$

f_1 = 50 Hz $\qquad \dfrac{V_{12}}{f_2} = \dfrac{138}{30} = 4.6$

$V_{12} = 138$ V

$f_2 = 30$ Hz $\qquad \dfrac{V_1}{f} =$ constant

at $\dfrac{v_1}{f} =$ constant

$W_I = Af + Bf^2$

at 50 Hz $\Rightarrow 1050 = A(50) + B(50)^2$ .... (i)

at 30 Hz $\Rightarrow 500 = A(30) + B(30)^2$ .... (ii)

by solving equation (1) & (2), we get

$A = 10.1667$

$B = 0.2167$

Then at 230V, 50 Hz

$W_h = Af = 10.1667 \times 50 = 508.33$ W

$W_e = Bf^2 = 0.2167 \times (50)^2 = 541.75$ W

16. Ans: (b)

Sol: Open circuit test is convenient to conduct on LV side by opening H.V winding due to the following reasons:

1. If the test is conducted on LV side, LV source sufficient to conduct the test to maintain rated flux.
2. If the test is conducted on LV side, low range meters are sufficient to conduct the test.
3. As magnitude of no-load current is more on LV side, this high no-load current can be accurately measured on LV side when compared to HV side.

Short circuit Test: As rated current is less on HV side, it is convenient to conduct this test on HV side by short circuiting LV terminals. By doing so low range of meters can be used for conducting this test.

17. Ans: (b)

Sol: $P = V I_w$

$\because$ Loss component $I_w = \dfrac{5\times10^3}{220} = 22.7$ A

18. Ans: (d)

Sol: Given that, no load loss components are equivally divided,

$W_h = W_e = 10W$

Initially test is conducted on LV side

Now $\dfrac{v}{f}$ ratio is $\dfrac{100}{50} = 2$

In HV side, applied voltage is 160V; this voltage on LV side is equal to 80V.

Now $\dfrac{V}{f}$ ratio is constant, $W_h \propto f$ and $W_e \propto f^2$.

$$W_{h2} = W_{h1} \times \frac{f_2}{f_1}$$

$$= 10 \times \frac{40}{50} = 8 \text{ W}$$

$$W_{e2} = W_{e1} \times \left(\frac{f_2}{f_1}\right)^2$$

$$= 10 \times \left(\frac{40}{50}\right)^2 = 6.4\text{W}$$

Therefore,

$W_1 = W_{h2} + W_{e2}$

$\Rightarrow 8 + 6.4 = 14.4$W

In SC test,

I(HV side) = 5A

I(LV side) =10A

As the SC tests were conducted at rated current on both sides, the copper losses are same.

19. Ans: (a)

Sol: 1. O.C. Test ----------- Iron loss

2. S.C. Test ------------ Copper loss

3. Sumpner's test-- Copper loss and iron loss

4. Load Test ---------- Total losses

20. Ans: (a)

Sol: It is equivalent circuit of the Transformer under S.C condition when referred to primary side.

21. Ans: (b)

Sol: **Open circuit test** is convenient to conduct on LV side by opening H.V winding due to the following reasons:

1. If the test is conducted on LV side, LV source sufficient to conduct the test to maintain rated flux.
2. If the test is conducted on LV side, low range meters are sufficient to conduct the test.
3. As magnitude of no-load current is more on LV side, this high no-load current can be accurately measured on LV side when compared to HV side.

Short circuit Test: As rated current is less on HV side, it is convenient to conduct this test on HV side by short circuiting LV terminals. By doing so low range of meters can be used for conducting this test.

22. Ans: (d)

Sol: By keeping V_{sc} is constant, if supply frequency is increased.

X_{01} increases; Z_{01} increases

$$\downarrow I_{sc} = \frac{V_{sc} = \text{const}}{Z_{01}\uparrow}$$

$$\downarrow \cos\phi_{sc} = \frac{R_{01} = \text{const}}{Z_{01}\uparrow}$$

23. Ans: (c)

Sol: The Condition for maximum efficiency $= 2W_i$

$\therefore$ At maximum efficiency

$W_{total} = (150 + 150)$ W

$= 300$ W

24. Ans: (b)

Sol: kVA at $\eta_{max} = \text{F.L kVA} \times \sqrt{\dfrac{\text{Iron loss}}{\text{F.L culoss}}}$

$$= \text{F.L kVA} \times \sqrt{\frac{P_C}{P_{SC}}}$$

25. Ans: (d)

Sol: **Methods to reduce Eddy current loss:**

The eddy current loss can be reduced by reducing conductivity of core. The conductivity of core can be reduced without affecting its magnetic properties by using following methods.

(i) By adding silica content up to an extent of 4 to 5 % to steel.

(ii) By using laminated core instead of solid core

Eddy current loss $w_e = KB_m^2 f^2 t^2$

Where, $K = \dfrac{\pi^2}{6\rho}$;

B_{max} = Maximum flux density.

f = frequency of eddy current (supply frequency).

t = Thickness of lamination

Observations:

$w_e \propto t^2$

The eddy current loss can be effectively reduced by reducing thickness of laminations.

Higher the design frequency of transformer, thinner will be the thickness of lamination required.

26. Ans: (c)

Sol: Core losses = 150 W (Constant)

Copper loss at full load = 220 W

$\therefore$ Copper loss at halt full load

$$= \left(\frac{1}{2}\right)^2 220\text{W} = 55 \text{ W}$$

$\therefore$ Total losses at half full load

$= 150 + 55$

$= 205$ W

Efficiency at half full load

$$= \frac{\frac{1}{2}\times 10^3 \times 1}{\frac{1}{2}\times 10\times 10^3 + 205}\times 100$$

$= 96.06\%$

27. Ans: (c)

Sol: $$\%\eta = \frac{(x)(VI)\cos\phi}{x(VI)\cos\phi + W_C + W_{cu}}\times 100$$

$x = 1$ ($\because$ full load)

$VI = 200$ kVA; $\cos\phi = 0.9$ lag; $W_c = 1.8$ kW

$$W_{cu} = \left(\frac{1.1}{100}\right)\times 200\times 10^3 = 2200 \text{ watts}$$

$$\%\eta = \frac{(1)(200\times 10^3)(0.9)}{(200\times 10^3\times 0.9)+(1.8\times 10^3)+2200}\times 100$$

$= 97.82\%$

28. Ans: (a)

Sol: % Reg = (%R) cos ϕ_2 ± (%X) sin ϕ_2

For lagging power for

% V.R = (2) (0.8) + (4) (0.6)

= 4%

For leading power factor

% V.R = (2)(0.8) – (4) (0.6)

= – 0.8%

29. Ans: (a)

Sol: Given %R = 1%, %X = 5% and $\cos\phi = 0.8$

% Reg = (%R)$\cos\phi$ + (%X)$\sin\phi$ ($\because$ lag pf)

= (1)(0.8) + (5)(0.6)

= 3.8%

30. Ans: (a)

Sol: V.R = (%R) cos ϕ_2 – (%X) sin ϕ_2 [at leading p.f]

At leading power factor, Resistive drop and reactive drop are opposing (cancelled out) each other

$\therefore$ Total drop = zero $\Rightarrow$ V.R is zero.

31. Ans: (c)

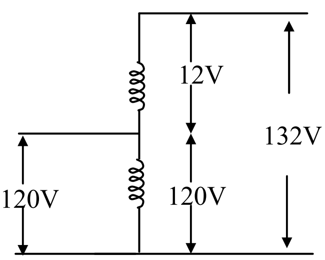
Sol: 3, 4, 5 condition's are necessary conditions 1 & 2 are desirable conditions for parallel operations.

32. Ans: (d)

Sol: If impedance decreases, current will increase and therefore sharing of load will increase.

33. Ans: (d)

Sol:



For series additive polarity of winding, voltage =132 V.

For series subtractive polarity of winding, voltage = 108 V.

34. Ans: (c)

Sol: 240/120 V, 12 kVA

$\eta = 96.2\%$

$$\eta = \frac{12000\times 1}{12000\times 1 + \text{losses}} = 0.962$$

$\Rightarrow$ 12000 + losses = 12474

Losses = 474 W

When connected across 360V,

$$\text{The rating becomes} = \frac{12}{1-k} = \frac{12}{1-\frac{2}{3}} = 36\,\text{kVA}$$

$$\therefore \text{ Efficiency} = \frac{36000\times 0.85}{36000\times 0.85 + \text{losses}}$$

$$= \frac{30{,}600}{30{,}600 + 474} = 98.5\%$$

35. Ans: (c)

Sol: In auto transformer, power is not only transferred by induction process but also by conduction process.

Conventional Practice Solutions

01.

Sol: Given,

Rated low voltage $V_{\ell 1} = 230$V

Rated frequency, $f_1 = 50$Hz

Applied frequency, $f_2 = 25$Hz

Let,

Applied voltage to LV winding = $V_{\ell 2}$

We know that in a transformer

$$I_m \propto \phi \propto \frac{V}{f}$$

Given that magnetizing current (I_m) is constant

$\therefore I_{m1} = I_{m2}$

$$\frac{V_{\ell 1}}{f_1} = \frac{V_{\ell 2}}{f_2}$$

$$\frac{230}{50} = \frac{V_{\ell 2}}{25}$$

$V_{\ell 2} = 115$V

$\therefore$ Voltage applied to low voltage winding so that magnetizing current is same is 115V.

02.

Sol: Given, number of turns in the primary winding, $N_1 = 100$

Number of turns in the secondary winding, $N_2 = 400$

Cross sectional area of the core, $A = 250\text{ cm}^2$

Voltage applied to primary winding, $V_1 = 230$V

Frequency of applied voltage, f = 50Hz

Let,

V_2 = Voltage induced in the secondary winding

B_m = Maximum value of flux density in the core

We know that in a transformer, expression for voltage transformation is given by,

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

$$\frac{230}{V_2} = \frac{100}{400}$$

$V_2 = 920$

In a transformer, expression for induced emf is given by

$E = 4.44 B_m AfN$ volts

$V_1 = 4.44\ B_m\ AfN_1$

$230 = 4.44\times B_m \times 250\times 10^{-4} \times 50 \times 100$

$B_m = 0.4144\ Wb/m^2$

Induced EMF in the secondary winding $= 920V$

Maximum value of flux density in the core $= 0.4144\ Wb/m^2$

03.

Sol: Given,

Applied voltage, $V_0 = 2300V$

No load current drawn, $I_0 = 0.3A$

Power consumed $P_0 = 200W$

Let,

No load power factor $= \cos\phi_0$

We know that,

$P_0 = V_0 I_0 \cos\phi_0$

$200 = 2300 \times 0.3 \times \cos\phi_0$

$\cos\phi_0 = 0.289$

No load power factor = 0.289

Primary resistance $r_1 = 3.5\Omega$

$\therefore$ Primary Copper losses $P_{cu} = I_0^2\ r_1$

$= (0.3)^2 \times 3.5$

$P_{cu} = 0.315W$

Core losses, $P_c = P_o - P_{cu}$

$= 200 - 0.315$

$= 199.685W$

Core losses = 199.685W

04.

Sol: Given,

Power rating of the transformer,

$(VA) = 150\times10^3$ VA

Full load copper losses, $P_{cu} = 1600W$

Iron losses, $P_c = 1400W$

Power factor Pf = 1

Let,

x = fraction of full loading

(i) Loading = 25% of full load

$\therefore$ x= 0.25

Efficiency of transformer

$$\eta = \frac{x(VA)pf}{x(VA)pf + P_c + x^2 P_{cu}} \quad \text{------- (1)}$$

$$\eta = \frac{(0.25)(150\times10^3)(1)}{(0.25)(150\times10^3)(1) + 1400 + (0.25)^2 \times 1600}$$

$$\eta = \frac{37500}{37500 + 1400 + 100}$$

$\eta = 96.15\%$

(ii) Loading = 33% of full Load

x = 0.33

From (1)

$$\eta = \frac{(0.33)(150\times10^3)(1)}{(0.33)(150\times10^3)(1) + 1400 + (0.33)^2 \times 1600}$$

$\eta = 96.9\%$

(iii) Loading = 100% of full Load $\Rightarrow$ x = 1

From (1)

$$\eta = \frac{(1)(150\times10^3)(1)}{(1)(150\times10^3)(1) + 1400 + (1)^2 \times 1600}$$

$\eta = 98.04\%$

05.

Sol: Given,

Maximum efficiency, $\eta_{max} = 98\%$

Loading at which maximum efficiency,

$x_m = \frac{3}{4} = 0.75$

$x_m = 0.75$

Power factor, pf = 1

Iron losses, $P_c = 314W$

Let,

VA = power rating of the transformer

P_{cu} = copper losses at full load

At maximum efficiency

$P_c = x_m^2 \ P_{cu}$

$314 = (0.75)^2 \ P_{cu}$

$P_{cu} = 558.2W$

Given that $\eta_{max} = 98\%$

$$\eta = \frac{x(VA)pf}{x(VA)pf + P_c + x^2 P_{cu}} \text{ ------(1)}$$

$$\eta_{max} = \frac{x_m(VA)pf}{x_m(VA)pf + P_c + x_m^2 \ P_{cu}}$$

$$0.98 = \frac{(0.75)(VA)(1)}{(0.75)(VA)(1) + 314 + 314}$$

VA = 41029.3VA

(i) Loading =50% of full load

$\Rightarrow x = 0.5$

From (1)

$$\eta = \frac{(0.5)(41029.3)(1)}{(0.5)(41029.3)(1) + 314 + (0.5)^2 \times (558.2)}$$

$\eta = 97.8\%$

(ii) Loading = 100% of full load

$\Rightarrow x = 1$

From (1)

$$\eta = \frac{(1)\ (41029.3)(1)}{(1)(41029.3)(1) + 314 + (1)^2 (558.2)}$$

$\eta = 97.92\%$

06.

Sol: Given, Power rating of the transformer (VA) $= 25\times10^3$VA

Iron losses, $P_c = 350W$

Full load copper losses, $P_{cu} = 400W$

Power factor pf =1

At maximum efficiency

Core losses = copper losses

$P_c = x^2 P_{cu}$

$350 = x^2(400)$

X = 0.9354

Maximum efficiency occurs at 93.54% at of full load

We know that, in a transformer

$$\text{Efficiency } \eta = \frac{x(VA)pf}{x(VA)pf + P_c + x^2 P_{cu}}$$

$$\eta = \frac{(0.9354)(25\times10^3)(1)}{(0.9354)(25\times10^3)(1) + 350 + 350}$$

$\eta = 97.1\%$

Maximum efficiency, $\eta_{max} = 97.1\%$

07.

Sol: Given,

Power rating of the transformer,

$VA = 40\times10^3$ VA

Maximum efficiency, $\eta_{max} = 97\%$

Maximum efficiency occurs at 80% of full load

$X_m = 0.8$

Power factor, pf = 1

Let P_{cu} = full load copper loss

P_c = core loss

At maximum efficiency,
Core losses = Copper losses

$P_c = x_m^2 P_{cu}$ ------- (1)

For a transformer,

Efficiency $\eta = \dfrac{x(VA)pf}{x(VA)pf + P_c + x^2 P_{cu}}$ ----- (2)

$$\eta_{max} = \frac{x_m(VA)pf}{x_m(VA)pf + P_C + x_m^2 P_{cu}}$$

$$0.97 = \frac{(0.8)(VA)(1)}{(0.8)(VA)(1) + P_c + P_c} \quad \text{[from (1)]}$$

P_c = 494.8W

From (1),

$P_{cu} = \dfrac{P_c}{x_m^2} = 773.2W$

P_{cu} = 773.2W

Time t(hrs)	Load (P_0) kW	Pf	$x = \dfrac{P_0}{(VA)pf}$	P_c(W)	$E_c = P_c \times (k\omega_n)$
9	6	0.6	$x = \dfrac{6}{40 \times 0.6} = 0.25$	494.8	4.453
8	25	0.8	x = 0.781	494.8	3.958
7	30	0.9	x = 0.833	494.8	3.463
					E_{ct} = 11.87kWh

$E_0 = P_0 \times t$ (kWh)	$P_{cu,x} = x^2 P_{cu}$ (W)	$E_{cu,x} = P_{cu,x} \times t$ (kWh)
54	$(0.25)^2\ 773 = 48.3$	0.434
200	470.4	3.76
210	536.5	3.75

E_{ot} = 464 kWh

E_{cu},t = 7.94 kWh

All day efficiency of a transformer is

$$\eta_{\text{all day}} = \frac{\text{total energy output}}{\text{total energy output} + \text{total energy losses}}$$

$$= \frac{464}{464 + 11.87 + 7.94}$$

$$\eta_{\text{all day}} = 95.9\%$$

08.

Sol: Given power rating of the transformer (VA) $= 50\times10^3$ VA

Loading at which maximum efficiency occurs = 90% of full load

$x_m = 0.9$

Maximum efficiency, $\eta_{max} = 97.4\%$

Let P_{cu} = full load copper losses

P_c = core losses

At maximum efficiency,

Core losses = copper losses and pf = 1

$P_c = x^2 P_{cu}$ ------- (1)

For a transformer

Efficiency,

$$\eta = \frac{x(VA)pf}{x(VA)pf + P_c + x^2 P_{cu}} \quad \text{----- (2)}$$

$$\eta_{max} = \frac{x_m(VA)pf}{x_m(VA)pf + P_c + x_m^2 P_{cu}}$$

$$0.974 = \frac{(0.9)\times(50\times10^3)(1)}{(0.9)(50\times10^3)(1) + P_c + P_c}$$

$P_c = 600.6$W

From (1),

$600.6 = (0.9)^2 P_{cu}$

$P_{cu} = 741.5$W

(a) Given loading = full load

$x = 1$

pf = 0.8 lag

from (2),

$$\eta = \frac{(0.8)(50\times10^3)(1)}{(0.8)(50\times10^3)(1) + (600.6) + (1)^2(741.5)}$$

$$\eta = 96.75\%$$

(b) loading = half load

$x = 0.5$

pf = 0.9

$$\eta = \frac{(0.9)(50\times10^3)(1/2)}{(0.9)(50\times10^3)(0.5) + (600.6) + (1/2)^2(741.5)}$$

$$\eta = 96.6\%$$

09.

Sol: Given,

Initial frequency, $f_1 = 50$Hz

Core loss at 50Hz frequency, $P_{c_1} = 2000$W

Final frequency, $f_2 = 75$Hz

Core loss at 75Hz, frequency, $P_{c_2} = 3200$W

Also it is given that flux density, B is Constant

Hysteresis loss, $P_h = k_n B^x f$

$P_h = C_1 f$ -----(1)

[$\because$ B = constant and $C_1 = k_n B^x$]

Eddy current losses, $P_e = k_e B^2 f^2$

$P_e = C_2 f^2$ -------(2) [$\because$ B = constant and $C_2 = k_e B^2$

Core loss $P_c = P_h + P_e$

$P_c = C_1 f + C_2 f^2$ ------(3)

From (3),

$P_{c1} = C_1 f_1 + C_2 f_1^2$

$2000 = 50C_1 + 50^2 C_2$

$40 = C_1 + 50C_2$ -----(4)

From (3)

$P_{c2} = C_1 f_2 + C_2 f_2^2$ ------(3)

$3200 = C_1(75) + C_2(75)^2$

$42.67 = C_1 + 75C_2$ -------(5)

(4) – (5)

$25C_2 = 2.67$

$C_2 = 0.1067\ W/Hz^2$ -------(6)

Substituting (6) in (4) we get

$40 = C_1 + 5.333$

$C_1 = 34.67\ W/Hz$ ------(7)

At 50Hz:

$P_{h_1} = C_1 f_1$

$P_{h_1} = 1733.3W$

$P_{e_1} = C_2 f_1^2$

$P_{e1} = 266.75W$

At 75kHz:

$P_{h_2} = C_1 f_2$

$P_{h_2} = 2600.25W$

$P_{e_2} = C_2 f_2^2$

$P_{e_2} = 600.18\ W$

10. Ans: 2600 watt

Sol: Given $V_1 = 1000V$, $f_1 = 50Hz$

$V_2 = 2000V$, $f_2 = 100Hz$

$W_{h1} = 700W$, $W_{e1} = 300\ W$

$$\frac{V}{f} = \text{constant}$$

Therefore, $W_h \propto f$

$$W_{h2} \propto W_{h1}\left(\frac{f_2}{f_1}\right) = 700\left(\frac{100}{50}\right)$$

$= 1400$ watt

$W_e \propto f^2$

$$W_{e2} = W_{e1}\left(\frac{f_2}{f_1}\right)^2 = 300\left(\frac{100}{50}\right)^2$$

$= 1200$ watt

New core loss $W_i = W_{h2} + W_{e2}$

$= 1400 + 1200$

$= 2600$ watt

11.

Sol: Given,

Power rating of the transformer,

$(VA)_B = 20\times10^3$

Primary voltage rating, $V_{1B} = 2500V$

Secondary voltage rating, $V_{2B} = 500V$

$r_1 = 8\Omega$ $\quad x_1 = 17\Omega$

$r_2 = 0.3\Omega$ $\quad x_2 = 0.7\Omega$

$$r_{e1} = r_1 + r_2\left(\frac{N_1}{N_2}\right)^2$$

$$= 8 + 0.3\left(\frac{2500}{500}\right)^2$$

$= 8 + 7.5$

$r_{e1} = 15.5\ \Omega$

$$x_{e1} = x_1 + x_2\left(\frac{N_1}{N_2}\right)^2 = 17 + 0.7\left(\frac{2500}{500}\right)^2$$

$= 17 + 17.5$

$x_{e1} = 34.5\Omega$

Base impedance w.r.t primary side,

$$Z_{1B} = \frac{V_{1B}^2}{(VA)_B}$$

$$Z_{1B} = \frac{(2500)^2}{20\times10^3}$$

$Z_{1B} = 312.5\Omega$

Per unit resistance

$(\xi_r) = \dfrac{r_{e1}}{Z_{1B}} = \dfrac{15.5}{312.5} = 4.96\%$

$\xi_r = 4.96\%$ ------(1)

Per unit reactance $(\xi_x) = \dfrac{x_{e1}}{Z_{1B}} = \dfrac{34.5}{312.5}$

$\xi_x = 11.04\%$

(a) pf = 0.9lag

$\cos\phi_2 = 0.9$lag

Voltage regulation (R)

$= \xi_r\cos\phi_2 + \xi_x\sin\phi_2$ [lag]

$\Rightarrow R = (4.96)(0.9) + (11.04)(0.436)$

$R = 9.27\%$

(b) pf = 0.9lead

$\cos\phi_2 = 0.9$lead

Voltage regulation (R)

$= \xi_r\cos\phi_2 - \xi_x\sin\phi_2$ [lead]

$\Rightarrow R = (4.96)(0.9) - (11.04)(0.436)$

$R = -0.35\%$

12.

Sol:

(a) Expression for voltage regulation is

$R = \xi_r\cos\phi_2 + \xi_x\sin\phi_2$ ------ (1)

For zero voltage regulation

$R = 0, \Rightarrow \xi_r\cos\phi_2 + \xi_x\sin\phi_2 = 0$

$\Rightarrow \xi_r\cos\phi_2 = -\xi_x\sin\phi_2$

$\Rightarrow \tan\phi_2 = \dfrac{-\xi_r}{\xi_x}$

$\Rightarrow \phi_2 = \tan^{-1}\left(-\dfrac{\xi_r}{\xi_x}\right)$

$\Rightarrow \phi_2 = -\tan^{-1}\left(\dfrac{\xi_r}{\xi_x}\right)$

Power factor pf = $\cos\phi_2$

$pf = \cos\left(\tan^{-1}\left(\dfrac{-\xi_r}{\xi_x}\right)\right)$

$pf = \dfrac{\xi_x}{\sqrt{\xi_r^2 + \xi_x^2}}$, lead [$\because$ –sign]

Condition for zero voltage regulation is

$pf = \dfrac{\xi_x}{\sqrt{\xi_r^2 + \xi_r^2}}$, lead

from (1)

for maximum regulation

$\dfrac{dR}{d\phi_2} = 0$

$\Rightarrow -\xi_r\sin\phi_2 + \xi_x\cos\phi_2 = 0$

$\xi_r\sin\phi_2 = \xi_x\cos\phi_2$

$\tan\phi_2 = \dfrac{\xi_x}{\xi_r}$

$$\left.\begin{aligned}\sin\phi_2 &= \frac{\xi_x}{\sqrt{\xi_x^2 + \xi_r^2}}\\ \cos\phi_2 &= \frac{\xi_r}{\sqrt{\xi_r^2 + \xi_x^2}}\end{aligned}\right\} \text{--------(2)}$$

Substituting (2) in (1)

Max R = $\xi_r\cos\phi_2 + \xi_x\sin\phi_2$

$= \xi_r\left(\dfrac{\xi_r}{\sqrt{\xi_r^2 + \xi_x^2}}\right) + \xi_x\left(\dfrac{\xi_x}{\sqrt{\xi_r^2 + \xi_x^2}}\right)$

$= \sqrt{\xi_r^2 + \xi_x^2}$

$= \xi_z$

= Per unit impedance

Maximum voltage regulation = per unit impedance.

(b) Power rating of the transformer,

$(VA)_B = 20\times10^3$ VA

Primary rated voltage, $V_{1B} = 2000V$

Secondary rated voltage, $V_{2B} = 200V$

$r_1 = 3\Omega$ $\quad$ $x_1 = 5.3\Omega$

$r_2 = 0.05\Omega$ $\quad$ $x_2 = 0.1\Omega$

$$r_{eq} = r_1 + r_2\left(\frac{N_1}{N_2}\right)^2$$

$$r_{eq} = 3 + 0.05\left(\frac{2000}{200}\right)^2 = 3 + 0.05(100)$$

$r_{eq} = 8\Omega$

$$x_{eq} = x_1 + x_2\left(\frac{N_1}{N_2}\right)^2$$

$$x_{eq} = 5.3 + 0.1\left(\frac{2000}{200}\right)^2$$

$x_{eq} = 15.3\Omega$

Base is impedance w.r.t primary is

$$Z_{1B} = \frac{V_{1B}^2}{(VA)_B} = \frac{(2000)(2000)}{20\times1000}$$

$Z_{1B} = 200\Omega$

Per unit resistance, $\xi_r = \frac{r_{e1}}{Z_{1B}}$

$$\xi_r = \frac{8}{200}$$

$\xi_r = 4\%$

Per unit reactance $\xi_x = \frac{x_{e1}}{Z_{1B}}$

$$\xi_x = \frac{15.3}{200}$$

$\xi_x = 7.65\%$

(i) pf = 0.8lag

Voltage regulation (R) = $\xi_r \cos\phi_2 + \xi_x \sin\phi_2$ [$\because$ lagging]

$\Rightarrow$R = 4(0.8) + 7.65(0.6)

R = 7.79%

(ii) pf = 1

Voltage regulation (R) = $\xi_r \cos\phi_2 \pm \xi_x \sin\phi_2$

R = 4(1) $\pm$ 7.65(0)

R = 4%

(iii) pf = 0.707 leading

Voltage regulation (R) = $\xi_r \cos\phi_2 - \xi_x \sin\phi_2$

R = –2.58%

13.

Sol: 1-ϕ, 25 kVA, 2300/230 V, 50Hz distribution transformer,

Given, core losses at full voltage = 250 W

Copper losses at half load = 300 W

$$W_{cu\ ½\ load} = \left(\frac{1}{2}\right)^2 W_{cu\ fullload}$$

$\therefore$ $W_{cu\ full\ load} = (2)^2\ W_{cu}$ at half load

$= 2^2 \times 300 = 1200$ W

Now copper losses at full load = 300 × 4

= 1200 W

(i) Rated load at 0.86 power factor lagging

$P_{out} = 25 \times 10^3 \times 0.866 = 21650$ W

P_{losses} at rated load

$= W_{cu\ full\ load} + W_{core\ losses}$

$= 1200 + 250 = 1450$ W

$$= \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + P_{losses}}$$

$$\%\ \eta = \frac{21650}{21650+1200+250}\times100 = 93.72\%$$

% efficiency = 93.72 %

(ii) All day efficiency:

Since core losses remains same for 24 hours $W_{core\ loss} = 250$ W

Copper losses values depends on load:

$\frac{1}{4}$ full load for 4 hour at 0.8 pf

$$W_{cu} = \left(\frac{1}{4}\right)^2 \times 1200\times = 800\,\text{W}$$

$$E_{out} = \frac{1}{4}\times25\times10^3\times0.8\times4 = 20\,\text{kWh}$$

$\frac{1}{2}$ full load for 10 hours at 0.8 pf

$$E_{out} = \left(\frac{1}{2}\right)^2 \times1200\times25\times10^3\times0.8\times10$$

= 100 kWh

$\frac{3}{4}$ **full load for 6 hours w_{cu}**

$$W_{cu} = \left(\frac{3}{4}\right)^2 \times 1200 \times 6 = 4050 \text{ W}$$

$$E_{out} = \frac{3}{4} \times 25 \times 10^3 \times 0.8 \times 6 = 90 \text{ kWh}$$

Full load for 4 hours at 0.9 pf

$W_{cu} = 1200 \times 4 = 4800$ W

$E_{out} = 25 \times 10^3 \times 0.9 \times 4 = 90$ kWh

$\therefore$ Total output for 24 hours E_{out}

= 20kWh+100kWh + 90 kWh + 90 kWh

= 300 kWh

Total copper losses for 24 hours W_{cu}

= 800 W + 3000 W + 4050 W + 4800 W

= 12.650 kW

Total core losses for 24 hours E_{loss}

= 250 × 24 = 6 kWh

$$\therefore \text{ All day efficiency} = \frac{E_{out}}{E_{out} + E_{losses}}$$

$$= \frac{300}{300 + 12.650 + 6}$$

= 94.147%

$\therefore$ All day efficiency, %η = 94.147%

14.

Sol: Voltage regulation for lagging pf is

$R = \xi_r \cos\phi_2 + \xi_x \sin\phi_2$ -----(1)

ξ_r = perunit resistane

ξ_x = perunit reactance

Given,

$R_1 = 4\%$; $\cos\phi_{21} = 0.8$ ----(2)

$R_2 = 4.4\%$; $\cos\phi_{22} = 0.6$ -----(3)

Substituting (2) in (1)

$4 = \xi_r 0.8 + \xi_x 0.6$

$20 = 4\xi_r + 3\xi_x$ -------(4)

Substituting (3) in (1)

$4.4 = \xi_r(0.6) + \xi_x(0.8)$

$22 = 3\xi_r + 4\xi_x$ -------(5)

Solving (4) and (5) we get

$$\left.\begin{array}{l}\xi_r = 2\% \\ \xi_x = 4\%\end{array}\right\} \text{------(6)}$$

(i) from (1)

For maximum regulation,

$$\frac{dR}{d\phi_2} = 0$$

$$-\xi_r \sin\phi_2 + \xi_x \cos\phi_2 = 0$$

$$\tan\phi_2 = \frac{\xi_x}{\xi_r}$$

$$\tan\phi_2 = \frac{4}{2} = 2$$

$$\tan\phi_2 = 2$$

$\phi_2 = 63.43^0$

Pf = $\cos\phi_2$ = 0.447

Pf for maximum regulation = 0.447 lag

(ii) $\xi_x = \frac{P_{cu}}{VA} \Rightarrow 0.02 = \frac{P_{cu}}{VA}$

$\Rightarrow P_{cu} = 0.02VA$

P_{cu} = full load copper loss

VA = Power rating of the transformer

$$\text{Efficiency, } \eta = \frac{x(VA)pf}{x(VA)pf + P_c + x^2 P_{cu}}$$

P_c = core loss

Given $P_c = P_{cu}$

$P_c = 0.02VA$

Power factor, pf = 1 and x=1 [$\because$ full load]

$$\therefore \eta = \frac{(1)(VA)(1)}{(1)(VA)(1) + 0.02VA + 0.02VA}$$

$$= \frac{1}{1.04}$$

$$\eta = 96.1\%$$

15.

Sol: Given,

Maximum possible voltage regulation, max R= 6%

power factor at which regulation is maximum = 0.3

We know that,

Maximum regulation

= Per unit impedance (ξ_z)

$\xi_z = 6\%$ ------(1)

Power factor at which regulation is maximum is

$$pf = \frac{\xi_r}{\sqrt{\xi_r^2 + \xi_x^2}} = 0.3$$

$$\frac{\xi_r}{\xi_z} = 0.3$$

$\xi_r = 1.8\%$ ------(2)

Substituting (2) in (1) we get

$$\sqrt{\xi_r^2 + \xi_x^2} = 6\%$$

$$\sqrt{(1.8)^2 + \xi_x^2} = 6$$

$$\xi_x = 5.72\%$$

Given,

Pf = 0.8 lead

$\therefore$ Voltage regulation R

$= \xi_r \cos\phi_2 - \xi_x \sin\phi_2$ [$\because$ lead]

R = 1.8 (0.8) – 5.72(0.6)

R = –2%

16.

Sol: Given,

Maximum efficiency of the transformer, η_{max} = 97%

Loading at which efficiency is maximum,

$$x = \frac{3}{4} = 0.75$$

Power rating of the transformer, VA = 500×10^3 VA

Power factor, pf = 1

Independence drop, ξ_z = 10%

Let, P_{cu} = full load copper loss

P_c = core loss

We know that, at maximum efficiency

Core loss = copper loss

$P_c = x_m^2 P_{cu}$ ------ (1)

$P_C = (0.75)^2 P_{cu}$

Efficiency of a transformer,

$$\eta_{max} = \frac{x_m(VA)pf}{x_m(VA)pf + P_c + x_m^2 P_{cu}}$$

$$0.97 = \frac{(0.75)(500\times10^3)(1)}{(0.75)(500\times10^3)(1) + P_c + P_c}$$

P_c = 5.799kW

P_{cu} = 10.31kW

We know that,

$$\xi_r = \frac{P_{cu}}{VA} = \frac{10.31}{500} = 2.06\%$$

$\xi_r = 2.06\%$

$$\xi_z = \sqrt{\xi_r^2 + \xi_x^2} = 10\%$$

$\xi_x = 9.78\%$

Power factor (pf) = 0.8pf lagging

$\cos\phi_2 = 0.8$

$\sin\phi_2 = 0.6$

Regulation, R = $\xi_r \cos\phi_2 + \xi_x \sin\phi_2$

[$\because$ lagging]

R = 2.06(0.8) + 9.78(0.6)

R = 7.52%

Chapter 2 DC Machines

Objective Practice Solutions

01. Ans: (c)

Sol: Current in armature conductor of dc machine is AC and commutator is used for converting AC to DC and vice-versa

02. Ans: (c)

Sol: For generator,

$E = V + I_aR_a$

$E = 200 + (50)(0.5) = 225V$

For motors,

$V = E_b+I_aR_a$

$200 = E_b+ (50)(0.5)$

$E_b = 175$ V

03. Ans: (d)

Sol: For constant power output,

E_bI_a = constant

VI_a = constant (neglecting armature losses)

$V_1I_{a1} = V_2I_{a2}$

$V_2 = \frac{V_1}{2}$

$\therefore\ I_{a2} = I_{a1}(2)$

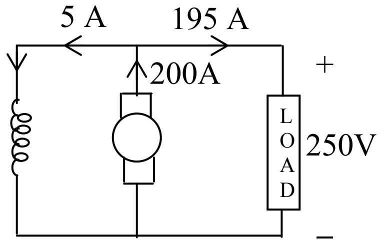
$I_{a2} = 100$ A

04. Ans: (d)

Sol: By short circuiting of series field winding the net flux developed by the generator decreases, then the emf generated also decreases.

05. Ans: (c)

Sol:



$I_{sh} = \frac{250}{50} = 5A$

$I_a = I_L + I_{sh} = 195 + 5 = 200A$

$E = V+I_aR_a$

$= 250+ (200)(0.05)$

$E = 260$ V

06. Ans: (b)

Sol: $E \propto \phi N$

$E_1 = K\phi_1N_1 = 136.8V$

$E_2 = K(2\phi_1)(0.75N_1) = 1.5\ E_1$

$\therefore\ E_2 = 1.5\times136.8 = 205.2V$

07. Ans: (d)

Sol: Under maximum power developed conditions $E_b = \frac{V}{2}$

At no load, speed (N_o) = 1200 rpm

No load voltage $V = E_b$

$\frac{N_2}{N_0} = \frac{E_{b2}}{E_{b0}}$

$\frac{N_2}{1200} = \frac{V/2}{V}$

N_2 = 600 rpm (speed under maximum power developed condition)

08. Ans: (b)

Sol: P = 4, N = 1500 rpm

f = ?

$N = \frac{120f}{P}$

$1500 = \frac{120\times f}{4}$

f = 50 Hz

09. Ans: (c)

Sol: The armature MMF waveform of a dc machine is triangular

10. Ans: (b)

Sol: Compensating winding are connected in series with armature.

11. Ans: (d)

Sol: I = 20A, V = 200V

$E_{g1} \propto (\phi_{sn} + \phi_{se})$ N = 200V

If ϕ_{se}= 0

Then $E_{g2} \propto \phi_{sh}$, N < 200V

E_{g2} decreases; it will become less than 200V

12. Ans: (a)

Sol: Emf generated due to clockwise rotation is

$E_g \propto \phi N = 200V$

By reversing the direction of rotation, the emf generated also get reversed

$E_g \propto \phi(-N) = -200V$

So, net voltage becomes zero.

13. Ans: (d)

Sol: $I_L = 100\,A$, $I_{sh} = \frac{200}{100} = 2A$

$I_a = I_{sh} + I_L = 2 + 100 = 102\,A$

$E = V + I_aR_a = 200 + (102)(0.01)$

E = 201.02 V

14. Ans: (a)

Sol: Maximum efficiency will be obtained only when, Variable losses = Constant losses ……………… (1)

(i.e. copper loss)

From data;

Total losses = Input – Output

= 20 kW – 17 kW = 3000 W

But Total losses =

Copper losses+ Constant losses ……….. (2)

$I_{sh} = \frac{V}{R_{sh}} = \frac{200}{50} = 4A$;

Input, $V.I_L$ = 20 kW = 20000W

200. I_L = 20000 $\Rightarrow$ I_L=100A

For shunt motor, $I_a = I_L - I_{sh}$

= 100 – 4 = 96A

In eq^n (2), Copper losses = $I_a^2R_a$

$= (96)^2 \times 0.04 = 368.64$

$\therefore$ Constant losses = total loss – copper loss

= 3000 – 368.68

= 2631.36W

$\therefore$ From eq^n (1), Total armature copper loss at max. Efficiency $\cong$ 2632 W

15. Ans: (d)

Sol: For series motor $\Rightarrow I_L = I_f = I_a$

but $\phi \propto I_f \propto I_a$

Developed torque in series motor,

$T \propto \phi.I_a \propto I_a^2$

$\therefore$ % increased torque, $\frac{T_2 - T_1}{T_1}$

$= \frac{I_{a2}^2 - I_{a1}^2}{I_{a1}^2} = \frac{144 - 100}{100} \times 100$

= 44%

16. Ans: (a)

Sol: In DC machine

Generate emf, $E_g = \left(\frac{\phi ZN}{60}\right)\left(\frac{P}{A}\right)$

$\Rightarrow E_g \propto (N\phi)$

Torque developed, $T = \left(\frac{Z\phi P}{2\pi}\right)\left(\frac{I_a}{A}\right)$

$\Rightarrow T \propto (\phi.I_a)$

Electrical power developed, $P = E_b.I_a$

Speed of the machine,

$$N = 60.\left(\frac{E_b}{\phi}\right)\left(\frac{A}{ZP}\right) \Rightarrow N \propto \left(\frac{E_b}{\phi}\right)$$

17. Ans: (c)

Sol: Due to reduction of armature reaction drop change in No load to Full load voltage is reduces so as the regulation also reduces

18. Ans: (d)

Sol: When shunt field winding is interchanged by series field winding. The operating flux of the motor will be very low that motor could not start.

19. Ans: (b)

Sol: If prime mover is failed then machine takes supply from lines, generator operates as motor. As changes in current direction in series field winding then cummulative compound generator becomes differentially compounded motor.

20. Ans: (c)

Sol: $T \propto I_a^2$

For series motor

21. Ans: (a)

Sol: Condition for maximum efficiency in any machine is Cu loss = iron loss

22. Ans: (c)

Sol: When terminal voltage is halved, voltage across field winding also get halved and hence flux also halved

23. Ans: (b)

Sol: From data $\Rightarrow I_a$ is constant

($\because I_a$ is supplied from constant current source)

From data $\Rightarrow$ as I_f is supplied from constant voltage source,

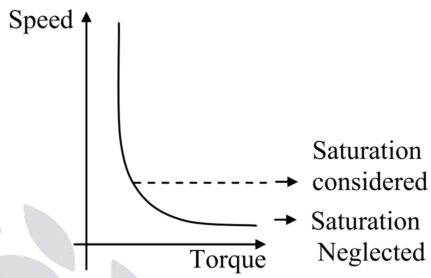
ϕ = constant ($\because \phi \propto I_f$)

$I_f = \frac{V}{R_{sh}}$ = constant

$\therefore T \propto (\phi.\ I_a)$ = constant irrespective of motor speed.

24. Ans: (b)

Sol:



We know that torque, $T \propto \phi.I_a$ but flux, $\phi \alpha$ I_{sh} (for series motor, $I_{sh} = I_a$)

$\therefore T \propto I_a^2 \Rightarrow \sqrt{T} \propto I_a$ ………. (1)

(when saturation and armature reaction are neglected)

Speed, $N \propto \frac{1}{\phi} \propto \frac{1}{I_a}$ ……….. (2)

$\therefore$ From (1) and (2)

$N \propto \frac{1}{\sqrt{T}} \Rightarrow$ Rectangular Hyperbola

Flux 'ϕ' is constant when saturation & armature reaction are considered $\Rightarrow T \alpha I_a$

$\therefore$ Speed, $N \propto \frac{1}{\varphi}$ = constant for any value of Torque i.e, N Vs T characteristics approaches to straight line.

25. Ans: (c)

Sol: For differential compound motor,

$\phi_r = \phi_{sh} - \phi_{se}$

As load $\uparrow \Rightarrow I_a \uparrow \Rightarrow \phi_{se} \uparrow \Rightarrow \phi_r \downarrow$

But $\uparrow N \alpha \frac{1}{\phi \downarrow} \Rightarrow$ as $\phi_r \downarrow \Rightarrow N \uparrow$

26. Ans: (d)

Sol: In DC series motor, Torque is directly proportional to square of current ($T \propto I_a^2$). Therefore if AC supply accidentally connected to DC motor; this AC current (either positive and negative of supply) through field and armature winding will always be in same direction (positive), hence torque will be unidirectional but due to AC nature of supply, torque will be pulsating nature.

27. Ans: (d)

Sol: In series motor

$$T \propto I_a^2 = \sqrt{T} \propto I_a$$

$$N \propto \frac{1}{\phi} \propto \frac{1}{I_a} \propto \frac{1}{\sqrt{T}}$$

$$N \propto \frac{1}{\sqrt{T}}$$

Rectangular hyperbola

28. Ans: (c)

Sol: $T \propto \phi I_a$

29. Ans: (c)

Sol: Here in 4-point starter unlike 3-point starter a separate path is being taken for holding coil.

30. Ans: (c)

Sol: $T \propto \phi.I_a$

For constant torque load,

$\phi_1 I_{a1} = \phi_2 I_{a2}$

Flux is constant as shunt field current is constant.

$\phi_1 = \phi_2$ so $I_{a1} = I_{a2}$

31. Ans: (b)

Sol: The speed control of dc shunt motor in both directions can be obtained by Ward Leonard method

Conventional Practice Solutions

01.

Sol: Given,

Terminal voltage, $V_T = 230V$

Initial speed $N_1 = 750$ rpm

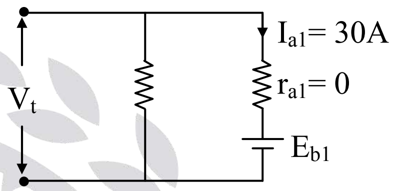
Armature current (I_{cu}) = 30A

External resistance (R_{ext}) = 10Ω

Torque (T) $\propto$ speed (N)

Equivalent circuit of dc shunt machine

Without external resistance:



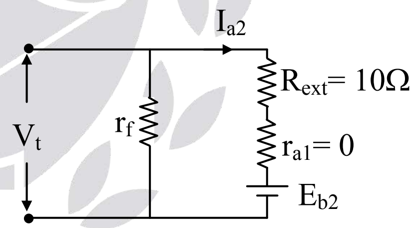
From figure (1)

$E_{b1} = V_t - I_{a1}(r_a)$

$E_{b1} = 230 - 30\,(r_a)$

$E_{b1} = 230$ V

With external resistance:



From figure (2)

$E_{b2} = V_t - I_{a2}(R_{ext} + r_a)$

$E_{b2} = 230 - 10I_{a2}$

In shunt machine

$T \propto \phi I_a$

$$\therefore \frac{T_1}{T_2} = \frac{I_{a1}}{I_{a2}} \quad \ldots\ldots\ldots\ldots(1)$$

But it is given that

$T \propto N$

$$\therefore \frac{T_1}{T_2} = \frac{N_1}{N_2} \quad \ldots\ldots\ldots\ldots(2)$$

We know that in a shunt machine

$E_b \propto \phi N$

$\therefore \dfrac{E_{b1}}{E_{b2}} = \dfrac{N_1}{N_2}$ …………(3)

$\therefore$ from (1), (2) and (3)

$\dfrac{E_{b1}}{E_{b2}} = \dfrac{I_{a1}}{I_{a2}}$ ………(4)

$$\frac{230}{230-10I_{a2}} = \frac{30}{I_{a2}}$$

$$230I_{a2} = 6900 - 300I_{a2}$$

$I_{a2} = 13.02\text{A}$ …………(5)

Substituting (5) in (3)

$$\frac{230}{230-10I_{a2}} = \frac{750}{N_2}$$

$\therefore$ N_2 = 325.5 rpm

02.

Sol: Given,

V_t = 230 V

r_a = 0.2 Ω

r_f = 0.1 Ω

T = 70 Nm

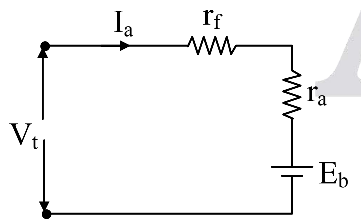
N_1 = 1200 rpm

N_2 = 2000 rpm

$I_{a2} = I_{a1}/2$

Machine = dc series motor

(a) Equivalent circuit of a dc series motor is as follows



From the above circuit,

$E_b = V_t - I_a(r_a + r_f)$

$E_b = 230 - I_a(0.1 + 0.2)$

$E_b = 230 - 0.3I_a$

Power developed $P_{dev} = E_b\, I_a = T\,\omega$

$\therefore E_b\, I_a = T\omega$

$$(230 - 0.3\, I_a)\, I_a = (70)\times\frac{(1200)}{60}\times 2\pi$$

$$0.3I_a^2 - 230I_a + 8796.46 = 0$$

I_{a1} = 40.37 A

(b) $I_{a2} = \dfrac{I_{a1}}{2}$

I_{a2} = 20.18 A

N_2 = 2000 rpm

$E_b \propto \phi N$ [in dc motors]

$$\frac{E_{b1}}{E_{b2}} = \frac{\phi_1 N_1}{\phi_2 N_2}$$

$$\frac{V_t - I_{a1}(r_a + r_f)}{V_t - I_{a2}(r_a + r_f)} = \frac{\phi_1 \times 1200}{\phi_2 \times 2000}$$

$$\frac{230 - 40.37\,(0.3)}{230 - 20.18(0.3)} = \frac{\phi_1(1.2)}{2\phi_2}$$

$$\frac{217.89}{223.95} = \frac{\phi_1(1.2)}{2\phi_2}$$

$\phi_2 = 0.6166\ \phi_1$

$\therefore$ % reduction in flux $= \dfrac{\phi_1 - \phi_2}{\phi_1}\times 100$

= 38.3 %

$\therefore$ % reduction in flux = 38.3 %

03.

Sol: Given,

V_t = 125 V

P_0 = 12.5 kW

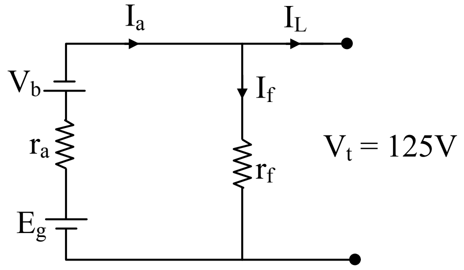
r_f = 25 Ω

r_a = 0.1 Ω

V_b = 3.5 V

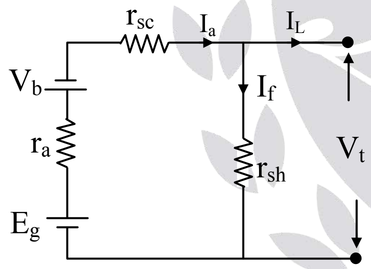
Machine = dc shunt generator

Equivalent circuit of a dc shunt generator including brush voltage losses is as follows



$\therefore P_0 = V_t I_L$
$12.5 \times 10^3 = 125 \times I_L$
$I_L = 100$ A
$$I_f = \frac{V_t}{r_f} = \frac{125}{25}$$
$I_f = 5$A
$I_a = I_L + I_f$
$I_a = 105$ A
From the circuit,
$E_g = V_t + V_b + I_a r_a$
$E_g = 125 + 3.5 + (105)(0.1)$
$E_g = 139$ V

04.
Sol: Given,
$V_t = 230$ V
$P_0 = 50$ kW
$(r_a + r_{se}) = 0.03\ \Omega$
$r_{sh} = 46\ \Omega$
$V_b = 2$V
Machine = long shunt compound generator
$\therefore$ Equivalent circuit is as follows



$P_0 = V_t I_L = 50 \times 10^3$
$\Rightarrow 230\ I_L = 50 \times 10^3$
$I_L = 217.4$ A
$$I_f = \frac{V_t}{r_{sh}} = \frac{230}{46} = 5A$$
$I_a = I_f + I_{sh} = 222.4$A
$\therefore I_a = 222.4$ A

From the circuit,
$E_g = V_t + V_b + I_a (r_a + r_{se})$
$E_g = 230 + 2 + (222.4)(0.03)$
$E_g = 238.672$

$$\%\text{ voltage regulation} = \frac{E_g - V_t}{V_t} \times 100$$
$$= \frac{238.672 - 230}{230}$$
$= 3.77\%$
$\therefore$ % voltage regulation = 3.77%

05.
Sol: Given,
$r_a = 0.04\ \Omega$
$r_f = 110\ \Omega$
$V_f = 230$ V
$V_t = 230$ V
Core and mechanical loss $(P_c) = 960$W
Machine = separately excited generator
$$\text{Field copper losses } (P_{cuf}) = \frac{V_f^2}{r_f} = \frac{(230)^2}{110}$$
$$(P_{cu,f}) = 480.91\text{W}$$

(a) In a dc separately excited generator,
Constant losses are field copper losses and mechanical losses
Variable losses are armature copper losses
$\therefore$ Constant losses $= P_{cuf} + P_c$
$= 480.91 + 960$
$= 1440.91$ W
At maximum efficiency,
Constant losses = variable losses
$1440.91 = I_a^2 r_a$
$\therefore I_a^2 (0.04) = 1440.91$
$I_a = 189.8$ A

(b) Power output at max efficiency is
$P_0 = V_t I_L$
$P_0 = 230 \times 189.8$ [$I_L = I_a$ for a separately excited generator]
$\therefore P_0 = 43653.22$ W
$$\text{Efficiency } \eta = \frac{\text{Power output}}{\text{Power output} + \text{Losses}}$$
$$= \frac{43653.22}{43653.22 + 1440.91 + 1440.91}$$
$\eta = 93.8$ %

06.

Sol: A DC motor converts electrical energy (dc power) into mechanical energy. We know that a current carrying conductor when placed in a magnetic field experience a mechanical force. This phenomenon is used in electric motors. (Lorentz force law)

The force is given by, F = BIL

Where B = magnetic flux density, wb/m^2

I = current in conductor, A

L = length of conductor, m

No. of conductors are arranged on the rotor.

The magnetic field is provided by the stator poles.

The supply to rotor winding (armature winding) is through commutator. Due to electromagnetic action between the rotor and stator flux, the force is developed which results in torque and rotation of the rotor.

Back EMF: The rotating conductors in a motor armature cut the flux from the poles causing developed of an emf. By Lenz's law, this end oppose the applied emf and is known as the back emf E_b. It is given by

$$E_b = \frac{ZN\phi}{60} \times \frac{P}{A} \text{ volts}$$

Where, ϕ = flux per pole

Z = Total no. of conductors

P = No. of poles

A = No. of parallel paths in armature

N = speed of rotation

Fundamental motor equation

$V = E_b + I_aR_a$

Where, R_a = armature resistance

V = terminal voltage

E_b = back emf

Mechanical power of a motor is given by

$P_m = VI_a - I_a^2R_a$

Torque: Torque on motor armature

$$T = \frac{E_bI_a}{\omega}$$

$$\text{Where, } \omega = \frac{2\pi N}{60}$$

$$E_b = \frac{ZN\phi}{60}\left(\frac{P}{A}\right)$$

$$T = 0.159.\frac{\phi ZPI_a}{A} \text{ N-m}$$

$$= 0.162\,\frac{\phi ZPI_a}{A}\text{Kg} - \text{m}$$

From the above relation we can write the Torque equation

$T = K\phi I_a$

$$\text{Where, } K = \left(\frac{0.159PZ}{A}\right)$$

07.

Sol:

(i) Here generating voltage 230 less than terminal voltage 240, so the machine work as motor

(ii) $V_t = E_a + I_ar_a$

$240 = 230 + I_ar_a$

$R_a = 0.25\Omega$

(iii) The electromagnetic Torque

$$T_e = \frac{E_aI_a}{\omega_m}$$

$$T_e = \frac{E_aI_a}{\frac{2\pi N_s}{60}} = \frac{230\times40\times60}{2\times\pi\times1200}$$

$T_e = 73.21$ N-m

(iv) If the load is thrown off, the generated voltage is equal to the terminal voltage i.e. 240 volts.

$E_a^1 = K_a^1\phi N_0$

$$\frac{E_a}{E_a^1} = \frac{N}{N_0}$$

$$\frac{230}{240} = \frac{1200}{N_0}$$

$N_0 = 1252$ rpm

08.

Sol: D.C. Shunt motor: For constant supply voltage, the field current is constant. At small values of armature current the demagnetizing effect of armature reaction is almost negligible and therefore the air gap flux is unaffected. For larger values of armature (or load) currents, the demagnetizing effect of armature reaction, decreases the air gap flux slightly.

The speed of a d.c. motor is given by

$$\omega_m = \frac{E_a}{K_a\phi}$$

$$E_a = V_t - I_a r_a$$

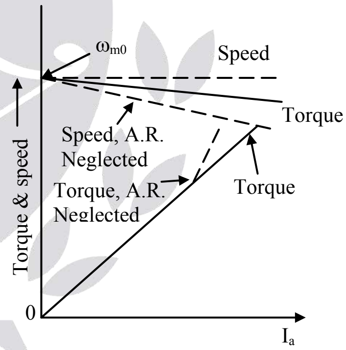
But, $\omega_m = \dfrac{V_t - I_a r_a}{K_a\phi}$

(i) **Speed-current characteristic**. For constant supply voltage V_t and constant field current I_f, the motor speed is affected by I_a r_a drop and demagnetizing effect of armature reaction. With the increase of I_a, the demagnetizing effect of armature reaction. Which reduces the field flux-therefore the motor speed tends to increase. But with the increase of I_a, voltage drop $I_a r_a$ increases and the numerator $(V_t - I_a r_a)$ decreases-therefore the motor speed tends to decrease. With the increase of I_a, the numerator decrement is more than the denominator decrement; in view of this, the speed of d.c. shunt motor with increase of I_a drops only slightly from its no-load speed ω_{m0}. Since I_a at no-load is negligibly small, the shunt motor no-load speed ω_{m0} is given by

$$\omega_{m0} = \frac{V_t}{K_a\phi}$$

In case the effect of armature reaction (AR) is neglected, then the denominator is constant. As a consequence, speed drops faster with I_a fig.(a). Illustrates speed-current characteristics of a shunt motor with and without AR. The curve marked speed is with AR included.

(ii) **Torque-current characteristic**: The expression $T_e = K_a\phi I_a$ reveals that if the flux ϕ is constant as in a shunt motor, the torque would increase linearly with armature current I_a. However, for larger I_a, the net flux decreases due to the demagnetizing effect of armature reaction. In view of this, the torque current characteristic deviates from the straight line, as illustrated in. In case the effect of AR is neglected, T_e versus I_a characteristic would be a straight line as shown.



(iii) **Speed-torque characteristic**: The speed-torque characteristic is also called the mechanical characteristic and under steady state conditions, it can be obtained as follows

From $\omega_m = \dfrac{V_t - I_a r_a}{K_a\phi}$

But $T_e = K_a\phi I_a$ or $I_a = \dfrac{T_e}{K_a\phi}$

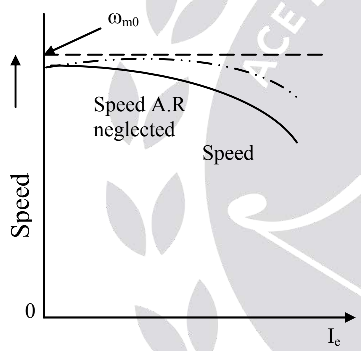
Substituting this value of I_a in

$$\omega_m = \frac{1}{K_a\phi}\left[V_t - \frac{T_e r_a}{K_a\phi}\right]$$

$$= \frac{V_t}{K_a\phi} - r_a\frac{T_e}{K_a^2\phi^2}$$

$$= \omega_m - r_a\frac{T_e}{K_a^2\phi^2}$$

It is seen from that with increase of T_e, the speed drops. Note that for larger T_e, larger I_a is required and this has the effect of reducing the air gap flux ϕ, due to saturation and armature reaction. Since with increase of T_e ϕ is reduced, T_e/ϕ^2 increases at a faster rate and the speed drops more rapidly with the increase of torque in a shunt motor as shown in figure.



If effect of AR is neglected, then $(K_a\phi)^2$ remains constant. As a result, the speed drop with T_e is slow as shown in figure.

09.

Sol: V = 200V, $R_{sh} = 0.2\Omega$

Before weaking the flux, $N_1 = 960$ rpm,

$I_{a1} = 50A$

$\therefore$ Back EMF, $E_{b1} = V - I_{a1}R_a = 200 - (50 \times 0.2) = 190V$ ………….. (1)

Find speed (N_2), when flux reduced by 10%, i.e. $\phi_2 = 0.9\phi_1$

We know, for shunt motor, Torque, $T \propto (\phi . I_a)$

As the total torque assumed constant

$\Rightarrow T_2 = T_1$

$\Rightarrow \phi_2 I_{a2} = \phi_1 . Ia_1$

$\Rightarrow (0.9\phi_1)\, I_{a2} = \phi_1\, I_{a1}$

$\therefore I_{a2} = \dfrac{I_{a1}}{0.9} = \dfrac{50}{0.9} = 55.5A$

Back EMF, after weaken flux,

$E_{b2} = V - I_{a2}.R_a$

$= 200 - (55.5 \times 0.2) = 189.9V$

$\therefore$ But, speed of motor, $N \propto \dfrac{E_b}{\phi}$

$$\Rightarrow \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

$$\Rightarrow N_2 = 960 \times \frac{189.9}{190} \times \frac{\phi_1}{0.9\phi_1}$$

$= 1066.105$ rpm

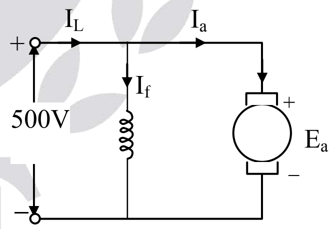
$\therefore$ New motor speed, $N_2 \approx 1066$ rpm

10.

Sol: Given data: $V_t = 500V$,

output power = 25HP = 25 × 746 W

$R_f = 650\Omega$, $R_a = 0.57\Omega$, $I_L = 2.4A$,



$V_b = 2V$ (brush drop)

$I_f = \dfrac{500}{650} = 0.77A$

At no load, $I_{a0} = I_L - I_f = 2.4 - 0.77 = 1.63A$

Constant losses $= V_t I_L - I_{a0}^2 r_a - V_b I_{a0}$

(Where V_b = brush drop)

$= 500 \times 2.4 - (1.63)^2 \times 0.57 - 2 \times 1.63$

$= 1195.23W.$

Near at full load, $E_b I_a = 25 \times 746$

(power output)

Power input = power output + total losses.

$500(I_a + 0.77)$

$= 25 \times 746 + V_b I_a$ + constant losses $+ I_a^2(0.57)$

$385 + 498I_a = 19845.23 + I_a^2(0.57)$

(or) $I_a^2 - 873I_a + 34140.75 = 0$

$$I_a = \frac{873 \pm \sqrt{(873)^2 - 4 \times 34140.75}}{2}$$

$I_a = 831.96A, 41.04A$

Where $I_a = 831.96A$ is a abnormal current.

Input $= V_t(I_a + I_f) = 500(41.04 + 0.77)$

$= 20905$ W

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} \times 100 = \frac{25 \times 746}{20905} \times 100$$

$= 89.21\%$

11.

Sol: Given,

$I_{a1} = 50A$

$V_t = 250$ V

$N_2 = 1.4\ N_2$

$T_2 = 1.4\ T_2$

$r_a = 0.2\ \Omega$

$$\frac{T_1}{T_2} = \frac{\phi_1 I_1}{\phi_2 I_2}$$

$$\frac{1}{1.4} = \frac{\phi_1}{\phi_2}\frac{50}{I_2}$$

$$\frac{\phi_1}{\phi_2} = I_2 \times \frac{1}{1.4} \times \frac{1}{50}$$

$$\frac{\phi_1}{\phi_2} = \frac{I_2}{70}$$

$$\frac{E_{b1}}{E_{b2}} = \frac{\phi_1 N_1}{\phi_2 N_2}$$

$$\frac{V_t - I_1 r_a}{V_t - I_2 r_a} = \frac{\phi_1}{\phi_2}\frac{N_1}{N_2}$$

$$\frac{250 - 0.2(50)}{250 - 0.2(I_2)} = \frac{I_2}{70} \times \frac{1}{1.4}$$

$$\frac{240}{250 - 0.2I_2} = \frac{I_2}{98}$$

$$23520 = 250I_2 - 0.2I_2^2$$

$$0.2I_2^2 - 250I_2 + 23520 = 0$$

$I_2 = 102.5$ A

$$\frac{\phi_1}{\phi_2} = \frac{I_2}{70}$$

$$\frac{\phi_1}{\phi_2} = \frac{102.5}{70}$$

$\phi_2 = 0.683\ \phi_1$

$$\therefore \text{ \% change in flux} = \frac{\phi_2 - \phi_1}{\phi_1} \times 100$$

% change in flux = –31.7 %

12.

Sol: Given,

$V_t = 220$ V

$r_a + r_{se} = 1\Omega$

$I_{a1} = 15$ A

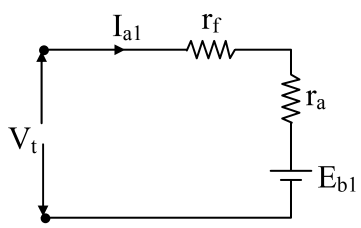
$N_1 = 1000$ rpm

$R_{ext} = 4.5\ \Omega$

$I_{a2} = 10$ A

Machine = dc series motor

Equivalent circuit of the motor without external resistance is as follows

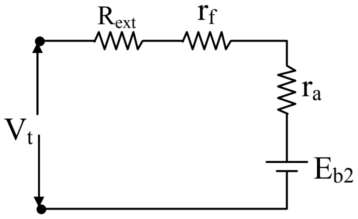


$V_t = E_{b1} + I_{a1}(r_a + r_f)$

$220 = E_{b1} + 15\,(1)$

$E_{b1} = 205$ V

With external resistance:



$V_t = E_{b2} + I_{a2}(r_a + r_f + R_{ext})$

$220 = E_{b2} + 10\,(1 + 4.5)$

$E_{b2} = 165$ V

We know that,

$E_b \propto \phi N_1$

$$\therefore \frac{E_{b1}}{E_{b2}} = \frac{\phi_1 N_1}{\phi_2 N_2} = \frac{I_{a1}\,N_1}{I_{a2}\,N_2}$$

[$\because$ $\phi \propto I_a$ in series machine]

$$\frac{205}{165} = \frac{(15)\times 1000}{10\times N_2}$$

$N_2 = 1207.3$ rpm

13.

Sol: Given,

$r_a = 0.7\ \Omega$

$r_f = 0.3\ \Omega$

$I_{a1} = 15$ A

$I_{a2} = 15$ A

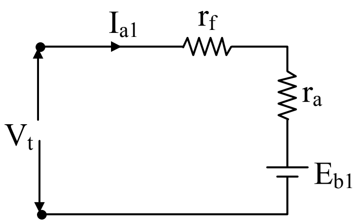
$V_t = 200$ V

$N_1 = 800$ rpm

$R_{ext} = 5\Omega$

Equivalent circuit of a dc series motor

Without external resistance:



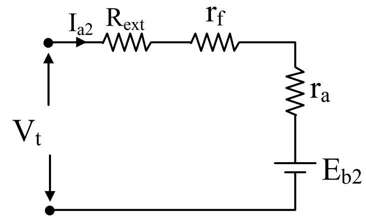
From figure (1)

$V_t = E_{b1} + I_{a1}(r_a + r_f)$

$200 = E_{b1} + 15\,(1)$

$E_{b1} = 185$ V

With external resistance:



From figure (2)

$V_t = E_{b2} + I_{a2}[(r_a + r_f) + R_{ext})$

$200 = E_{b2} + 15\,(0.3 + 0.7 + 5)$

$E_{b2} = 110$ V

$E_b \propto \phi N$ in a dc machine

$E_b \propto I_a N$ in a dc series machine [$\because$ $\phi \propto I_a$]

$$\therefore \frac{E_{b1}}{E_{b2}} = \frac{I_{a1}\,N_1}{I_{a2}\,N_2}$$

$$\frac{185}{110} = \frac{15\times 800}{15\times N_2}$$

$N_2 = 475.7$ rpm

14.

Sol: Given,

$P_0 = 5$ kW

$V_t = 250 - 0.5\,I_L$

Machine = dc shunt generator

In a dc shunt generator,

$P_0 = V_t\,I_L$

$5000 = (250 - 0.5\,I_L)\,I_L$

$$0.5 I_L^2 - 250 I_L + 5000 = 0$$

$$I_L = \frac{250 \pm \sqrt{(250)^2 - 4\times 0.5\times 5000}}{2\,(0.5)}$$

$I_L = 20.87$ A

$V = 250 - 0.5\,I_L = 250 - 0.5\,(20.87)$

$\Rightarrow V = 239.56$ V

R_L = Load resistance = $\dfrac{V}{I_L}$

$R_L = 11.48\ \Omega$

15.

Sol: Given,

$V_{t1} = 100V$

$P_{01} = 5kW$

$r_a + r_{se} = 0.5\Omega$

$N_1 = 1000$ rpm

$V_{t2} = ?$

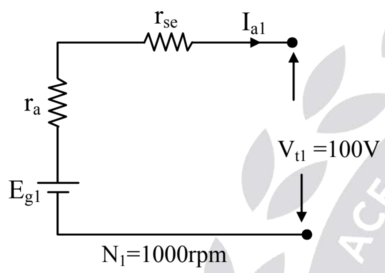
$P_{0_2} = 8kW$

$N_2 = 1500$rpm

Machine = dc series generator

Equivalent circuit

With initial conditions:

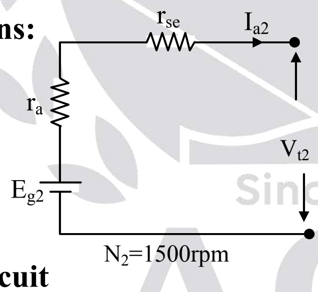


From the above circuit

$E_{g1} = V_{t1} + I_{a1}(r_a + r_{se})$

$E_{g1} = 100 + I_{a1}(0.5)$

With final conditions:



From the above circuit

$E_{g2} = V_{t2} + I_{a2}(r_a + r_{se})$

$E_{g2} = V_{t2} + I_{a2}(0.5)$

But $P_{01} = V_{t1} I_{a1}$

$5000 = 100\ I_{a1}$

$I_{a1} = 50A$

$E_{g1} = 100 + 50(0.5)$

$E_{g1} = 125V$

We know in a dc machine

$E_g \propto \phi N$

$E_g \propto I_a N$ [In series machine $\phi \propto I_a$]

$$\frac{E_{g1}}{E_{g2}} = \frac{I_{a1}N_1}{I_{a1}N_2}$$

$$\frac{125}{V_{t2} + 0.5I_{a2}} = \frac{50 \times 1000}{I_{a2} \times 1500}$$

$V_{t2} = 3.25\ I_{a2}$ -------(1)

But it is given that

$P_{02} = V_{t2}\ I_{a2}$

$8000 = (3.25\ I_{a2})I_{a2}$

$I_{a2} = 49.61A$

Substituting (2) in (1)

$V_{t2} = 161.24V$

16.

Sol: Given

Machine 1

No load terminal voltage (V_{01}) = 270V

Terminal voltage at 30A current (V_{L1})
= 220V

Terminal voltage (V_1) = $270 - \frac{50}{30} \times I_1$

$V_1 = 270 - \frac{5\ I_1}{3}$ -------(1)

Machine 2

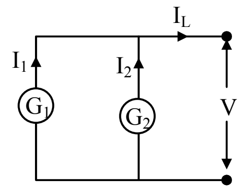
No load terminal voltage $(V_{02}) = 280V$

Terminal voltage at 30A current $(V_{L2}) = 220V$

$\therefore$ Terminal voltage (V_2) = $280 - \frac{60}{30} I_2$

$V_2 = 280 - 2I_2$

(i) When both machines are operating in parallel.



$I_L = I_1 + I_2$

Given load current I_L = 50A

$I_1 + I_2 = I_L$ = 50A

$\therefore I_1 + I_2$ = 50A ------- (1)

Make over $V_1 = V_2 = V$

$$270-\frac{5}{3}I_1=280-2I_2$$

$$2I_2-5\frac{I_1}{3}=10$$

$6I_2 - 5I_1 = 30$ ----(2)

From (1) and (2)
$I_1 = 24.54$ A
$I_2 = 25.45$A
$V_1 = V_2 = V = 280 - 2I_2$
$V_1 = V_2 = V = 229.1$V

(ii) Given load resistance $R_L = 10\Omega$
$V = I_LR_L = 10I_L = 10(I_1 + I_2)$
$\therefore V_1 = V_2 = V = 10(I_1 + I_2)$
$280 - 2I_2 = 10I_1 + 10I_2$
$10I_1 + 12I_2 = 280$
$5I_1 + 6I_2 = 140$ -----(3)

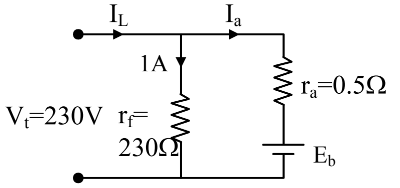
From (2) and (3)
$I_1 = 11$A
$I_2 = 14.167$A
$V_1 = V_2 = V = 280 - 2I_2$
$V = 251.67$A

17.
Sol: Given,
$V_t = 230$V
$r_a = 0.5\Omega$
$r_f = 230\Omega$
$N_0 = 1000$ rpm
$I_{L0} = 3$A
$I_{Lf} = 23$A

$$\phi_2=\phi_1-\frac{2\phi_1}{100}=0.98\phi_1 \quad [\therefore 2\% \text{ drop}]$$

Machine = dc shunt motor

Equivalent circuit:



$I_{Lo} = 3$A

$$I_f=\frac{V_t}{r_f}=\frac{230}{230}=1A$$

$I_f = 1$A
$I_{a0} = I_{L0} - I_f$
$I_{a0} = 2$A

$E_{b0} = V_t - I_{a0}\, r_a$
$E_{b0} = 230 - 2\times0.5$
$E_{b0} = 229$V

No load losses (rotational) $P_{rot} = E_{b0}\, I_{a0}$
$P_{rot} = 458$W

At full load:
$I_L = 23$A
$I_f = 1$A
$I_a = 22$A
$E_b = V_t - I_ar_a$
$= 230 - 22(0.5)$
$E_b = 219$V

Power developed $(P_{dev}) = E_bI_a$
$= (219)(22)$
$P_{dev} = 4818$ W
Load power $(P_O) = P_{dev} - P_{rot}$
$= 4818 - 458$
$P_o = 4360$W

$$\frac{E_{b0}}{E_b}=\frac{\phi_1N_1}{\phi_2N_2}$$

$$\frac{229}{219}=\frac{\phi_1\times(1000)}{(0.98)\phi_1\times N_2}$$

$N_2 = 975.85$rpm
$N_2 \approx 976$ rpm
$P_0 = T_0\omega$

$$T_0=\frac{4360}{\frac{976}{60}\times2\pi}=42.60\text{Nm}$$

Torque output $T_0 = 42.60$ Nm

18.

Sol: At the time of starting, the motor speed is zero.

Therefore counter emf $E_a\left(=K_a\phi\omega_m\right)$ is also zero.

Consequently for the armature circuit, the voltage equation is $V_t = 0+I_a\ r_a$ for shunt motor and $V_t = 0+I_a\ (r_a + r_s)$ for both series & compound motors with rated applied voltage the starting armature current is

$$I_a = \frac{V_t}{r_a}\left(\text{shunt motor}\right)$$

$$I_a = \frac{V_t}{\left(r_a + r_s\right)}\left(\text{series and compound}\right)$$

r_a & r_s Are much smaller, the motor draws large starting armature current from the supply mains.

Four-Point starter: Function of starter is to limit the starting current.

The '4' point starter is used when wide range of speed by shunt field control is required. Under normal running conditions with starter handle in the ON Position, the holding coil HC is in series with the starting resistance and an additional resistance R as shown in figure.

The function of resistance R is to prevent short circuit of the supply mains, in case the overload release OR operates, when HC gets short circuited by OR, the current through R is limited by its over resistance and starting resistance. When the motor is at rest starter handle H is kept in the OFF position. The starting resistance is connected between contact studs 1, 2, 3…6. For starting the motor, the handle is rotated to come in contact with stud1. As soon as handle H touches stud1, the shunt field and holding coil HC get connected in series across the supply, where as the armature gets connected in series with the entire starting resistance. Since the current begin to flow in both the field and armature windings. The motor starts rotating. After the armature has picked up sufficient speed, the handle H is moved to stud2, these by cutting out the resistance between stud1 and stud2. Movement of the handle is continued slowly fill the soft iron keeper touches the holding magnet.

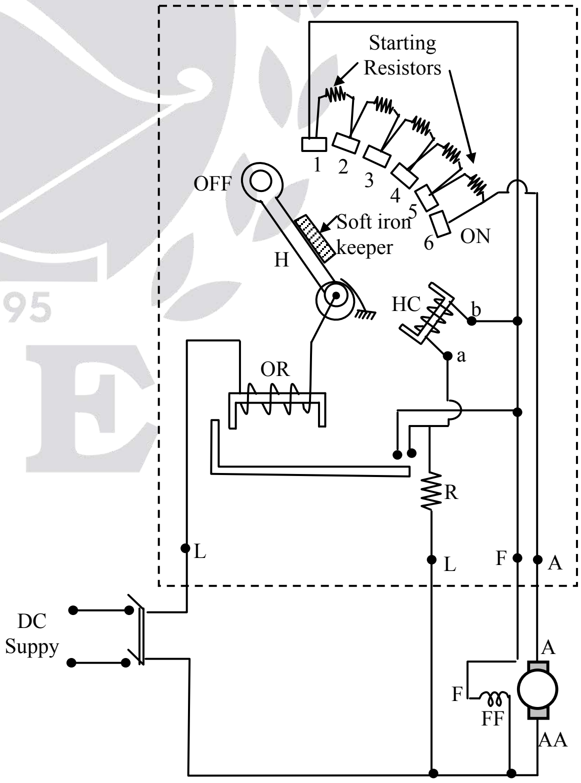


Fig. 4-point starter for dc shunt motor

19.

Sol: There are three kinds of electrical braking

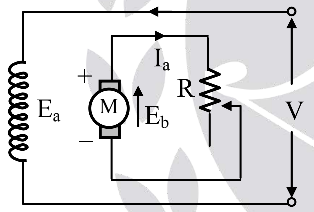
(a) Rheostatic or dynamic braking

(b) Plugging and

(c) Regenerative braking

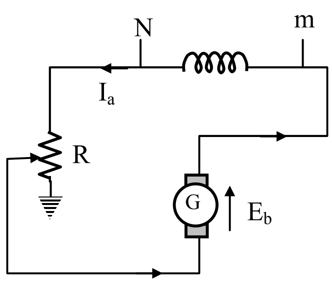
a) Rheostatic or Dynamic Braking (Shunt motor)

Figure shows the Rheostatic braking in which armature of the shunt motor is disconnected from the supply and it is connected across a variable resistance R. The field winding is kept undisturbed and his braking is controlled by varying the series resistance R. This method uses the generator action in a motor to bring it to lest.



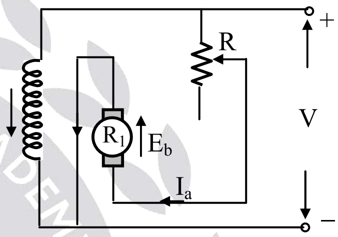
Series Motor:

In this method the motor is disconnected form supply, the field connection is reversed and the motor is connected through a variable resistor R.



b) Plugging or Reverse (shunt motor)

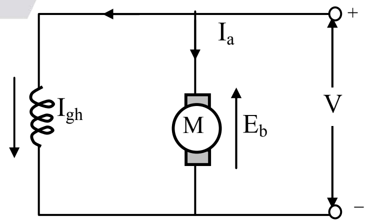
In this method, the armature terminals are reversed to rotate the motor in reverse direction and the applied voltage V and the back emf E_b start acting in the same direction. To limit the armature current, a resistance is inserted in series with the armature during reversing the armature. The kinetic energy of the system is dissipated in the armature and braking resistances.



c) Regenerative Braking

In regenerative braking, $E_b > V$. Figure shows regenerative braking scheme.

The I_a direction and armature torque T_B are reversed. Most of the braking energy is returned to the supply. Regenerative braking is used for down grade motion of an electric train. The kinetic energy of the system is dissipated in armature and braking resistor.



Chapter 3 Synchronous Machines

Objective Practice Solutions

01. Ans: (c)

Sol: The phase sequence of alternator can be reversed by changing the direction of rotor rotation (whether field may be rotating or armature rotating), but phase sequence is doesn't depends on polarities or direction of field current.

Whether the machine may be acting as generator or motor the phase sequence is related to rotor rotation only. Phase sequence is no way related with direction of field current (i.e., field polarities)

02. Ans: (c)

Sol: As the two alternators are mechanically coupled, both rotors should run with same speed. $\Rightarrow Ns_1 = Ns_2$

$$\Rightarrow \frac{120f_1}{p_1} = \frac{120f_2}{p_2}$$

$$\Rightarrow \frac{f_1}{f_2} = \frac{p_1}{p_2}$$

$$\Rightarrow \frac{p_1}{p_2} = \frac{50}{60} = \frac{5}{6} = \frac{10}{12}$$

$\Rightarrow p_1 : p_2 = 10 : 12$

Every individual magnet should contains two poles, such that number of poles of any magnet always even number.

G_1: p = 10, f = 50 Hz

$\Rightarrow N_s = 600$ rpm

(or)

G_2: p = 12, f = 60 Hz

$\Rightarrow N_s = 600$ rpm

03. Ans: (c)

Sol: As the ac supply given to the stator of synchronous motor, stator rotating magnetic poles are rotating at synchronous speed [say stator frequency = 50 Hz], means armature poles are interchanging their positions for every 10msec. But due to large inertia of rotor, it couldn't catch the quick reversal of stator poles. At standstill the rotor of a synchronous motor is subjected to alternate forces of repulsion and attraction, in other words there exist relative motion between stator field (poles) and rotor field (poles), means two field's are not stationary w.r.t each other.

$\therefore$ The average torque is zero, hence synchronous motor is not self starting.

04. Ans: (d)

Sol: These are the properties of cylindrical rotor synchronous machines.

05. Ans: (d)

Sol: For P – plate machine, $\frac{p}{2}$ cycles of e.m.f will be generated in one revolution thus for a p – pole machine

$$\theta_{elect} = \frac{p}{2}\theta_{mech}$$

06. Ans: (d)

Sol: Distribution winding eliminates "higher order harmonics" and short pitch winding processor eliminates "particular dominant harmonics" based on short pitch angle, hence resultant EMF wave closer to sine wave form.

07. Ans: (d)

Sol: Reason: When the rotor rotates at synchronous speed, there is no relative motion between armature flux and damper winding (since damper winding placed on rotor).Therefore EMF induced in the damper bars is zero means current through the damper bars equal to zero, hence damping torque production is zero.

08. Ans: (a)

Sol: Distribution: The distribution of the armature winding along the air-gap periphery tends to make the e.m.f. waveform sinusoidal.

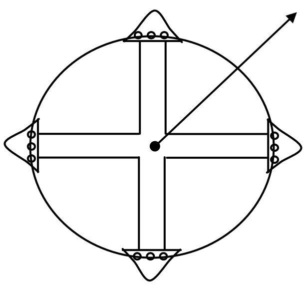
Chording: With coil-span less than pole pitch, the harmonics can be eliminated.

Skewing: By skewing the armature slots, only tooth harmonics or slot harmonics can be eliminated.

Fractional slot winding: With fractional slot winding slot harmonics can be eliminated.

09. Ans: (c)

Sol: Damper windings are provided on pole shoes with dampers in salient pole synchronous machine and these dampers on each pole are shorted by a "End ring".



Function of damper winding in Alternator:

(i) To suppress Negative sequence field

(ii) To eliminate Hunting

Function of Damper winding in synchronous motor:

(i) To eliminate hunting

(ii) For starting purpose

10. Ans: (b)

Sol: Distribution factor /belt factor/breadth factor/ spread factor (k_d):

$$k_d = \frac{\text{The e.m.f induced with Distributed winding}}{\text{The e.m.f induced with concentrated winding}}$$

$$k_d = \frac{\text{The vector sum of induced e.m.f}}{\text{The arithmatic sum of induced e.m.f}}$$

$$\boxed{k_d = \frac{\sin m\frac{\gamma}{2}}{m\sin\frac{\gamma}{2}}}$$

For n^{th} harmonic, $k_{dn} = \dfrac{\sin\frac{mn\gamma}{2}}{m\sin n\frac{\gamma}{2}}$

For concentrated winding, $k_d = 1$

$k_{d1} = k_{d2} = k_{d3}$ - - - - - = 1

For distributed winding, $k_d < 1$

Winding factor $K_w = K_p \times K_d$

11. Ans: (a)

Sol: The speed of n^{th} space harmonic is $= \frac{1}{n}F_1$

for 7^{th} space harmonic is $= \frac{1}{7}\times F_1$

$F_1 = \dfrac{120\times 50}{8} = 750 = \dfrac{1}{7}\times 750 = 107.14$

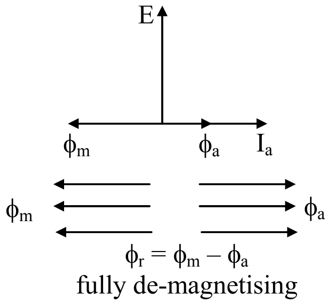
In forward direction

(6K ± 1) = '+' for forward

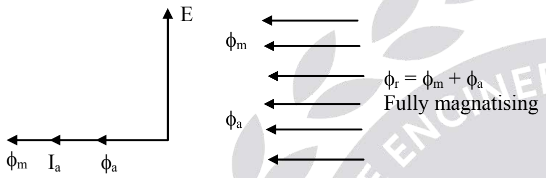
12. Ans: (b)

Sol: Alternator working under

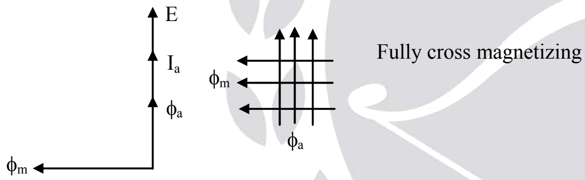
(i) ZPF lag pf



(ii) ZPF Lead pf



(iii) UPFpf

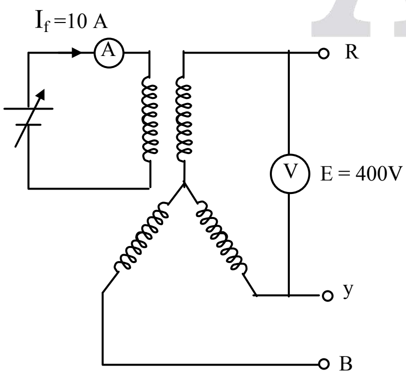


(iv) For intermediate lagging load, effect of armature reaction is partly cross-magnetizing and partly demagnetizing.

13. Ans: (a)

Sol: Open circuit characteristics (O.C.C)

$E\ V_s\ I_f\big|_{N = constart}$



Fiigure 3.33: Circuit diagram for O.C.C

- To get O.C.C, the alternator has to be driven at constant rated speed and the open circuit terminal voltage is noted as field current is gradually increased from zero.

We know that, $E = 4.44\, k_p k_d\, \phi\, f\, T$

$E \propto \phi \propto I_f$

$E \propto I_f$

$\therefore$ E vs $I_f \Rightarrow$ linear $\Rightarrow$ Before saturation

$\Rightarrow$ Non-linear $\Rightarrow$ After saturation

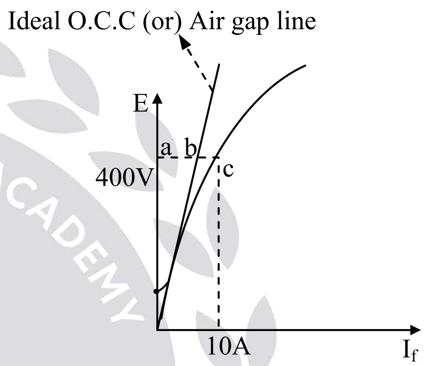


Figure 3.34: O.C.C of an alternator.

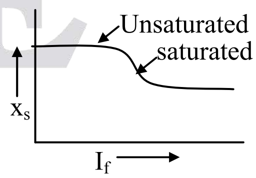
- When mmf (I_f) exceed a certain value the iron parts require a good amount of mmf and the saturation sets in.

ab = mmf (or I_f) for the air gap.

bc = mmf for the iron parts.

14. Ans: (b)

Sol:



$$Z_s \simeq X_s = \frac{E_{OC}}{I_{SC}}$$

I_f = constant

Up to knee point both OCC & SCC are linear.

$\therefore Z_s$ is constant for unsaturated position. But above knee OCC ic non linear & SCC is linear so Z_s decreases during saturated condition.

15. Ans: (a)

Sol: Y-axis indicates armature current (I_a) & X-axis indicates field current (I_f).

$\therefore$ V-curve Indicates the variation of 'I_a' w.r.t the changes in Excitation (I_f).

16. Ans: (d)

Sol: $$\text{S.C.R} = \frac{1}{X_s\,(\text{adjusted saturation})\,\text{P.U}}$$

17. Ans: (c)

Sol: $X_s = X_a + X_l$

Note: $X_s > X_a > X_l > R_a$

18. Ans: (a)

Sol: on d-axis

$$X_d = \frac{V_{max}}{I_{min}}$$

$$= \frac{108}{10} = 10.8\Omega$$

on q-axis

$$X_q = \frac{V_{min}}{I_{max}}$$

$$= \frac{96}{12} = 8\,\Omega$$

19. Ans: (a)

Sol: Power developed in synchronous machine

$$\Rightarrow P = \frac{EV}{X_s}.\sin\delta$$

$\Rightarrow P = P_{max}.\sin\delta$

$$\therefore P_{max} = \frac{EV}{X_s}$$

$\Rightarrow P_{max} \propto E, V$

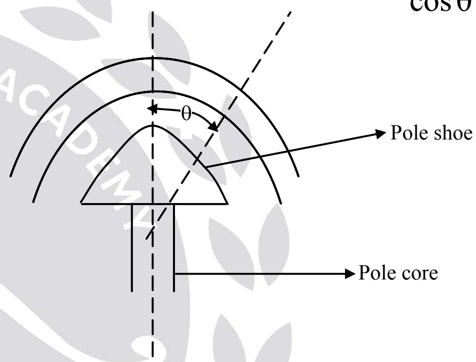
$\Rightarrow P_{max} \propto I_f$ and V $[\because E \propto I_f]$

20. Ans: (a)

Sol: The 'synchronous-impedance method' of finding the voltage regulation by a cylindrical rotor alternator is generally considered as a pessimistic method because saturation is not considered

21. Ans: (b)

Sol: Airgap length under pole shoe $\propto \dfrac{1}{\cos\theta}$



As $\theta\uparrow \Rightarrow \cos\theta\downarrow \Rightarrow$ airgaplength $\uparrow$

22. Ans: (d)

Sol: To run two alternators in parallel, the dark lamp test is preformed to ensure proper phase sequence matching

23. Ans: (c)

Sol: Reason: The prime mover speed of parallel connecting alternators can be anything which is depends on number of poles but frequency of an incoming alternator must be same to that of already existing alternator.

f = $\dfrac{P.N}{120}$; so, to get fixed frequency, if P $\uparrow$

$\Rightarrow$ N should be reduce.

Here P = number of poles of the machines and N = speed of rotor.

24. Ans: (d)

Sol: Salient pole synchronous machine:

$$P = \frac{EV}{X_d}\sin\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta$$

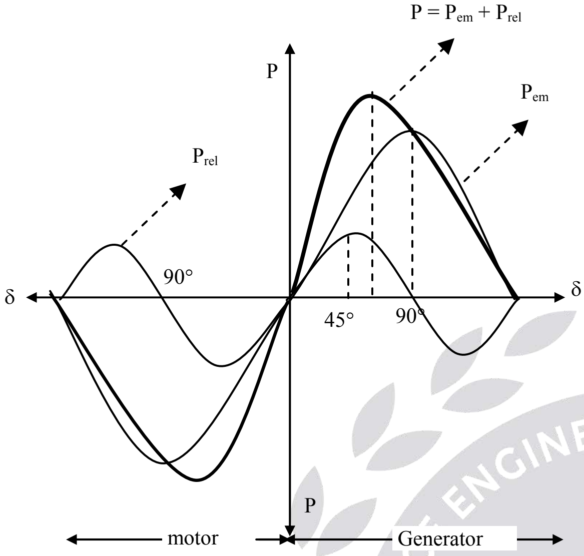
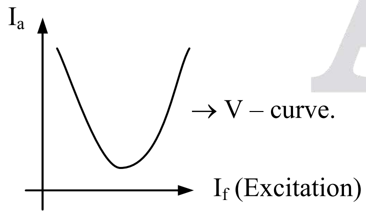


Figure : Power-Load angle Characteristic of a Salient pole synchronous machine

- P_{max} is obtained for load angle $\delta < 90^0$ (i.e in between 60^0 to 70^0)
- P vs δ curve is Non sinusoidal.
- Steady state stability is more for salient pole synchronous machine due to extra reluctance power.

25. Ans: (a)

Sol:



26. Ans: (c)

Sol: As the load on the synchronous motor is suddenly increased, the motor becomes hunt i.e, rotor speed fluctuates around synchronous speed and finally reaches to synchronous speed.

27. Ans: (c)

Sol: **1**. Open-circuit Characteristic------E_g Vs. I_f

2. V curve ------------I_a Vs. I_f

3. Internal Characteristic------------ E_a Vs. I_a

4. Inverted V-curve ------------- p.f. Vs. I_f

28. Ans: (d)

Sol:
1. The terminal voltage of incoming alternator must be same as that of the existing system otherwise circulating current flows between the two systems. The terminal voltage can be adjusted with the field excitation.
2. The frequency of incoming alternator must be same as that of the existing system otherwise circulating current flows between the two systems. At a particular instant there may be dead short circuit when the two voltages are in adding polarity.
   The frequency can be adjusted by varying the prime mover speed.
3. The phase sequence of incoming alternator must be same as that of the existing system otherwise large circulating currents exist, because the voltage across the two systems is equal to $\sqrt{3}$ times of their rated voltage.
4. The phase displacement between existing system and alternator should be same.
5. Synchronization is possible with different kVA rating alternators. Rating is not a problem to synchronization.

29. Ans: (c)

Sol: Power factor of alternator mainly depends on reactive power, which is depends on field excitation.

30. Ans: (c)

Sol: $P = \frac{EV}{X_s}\sin\delta$, when δ = 90

$$P_m = \frac{EV}{X_s}$$

31. Ans: (b)

Sol: When excitation of sailent pole synchronous motor is removed. It will take reactive power from bus bar and acts as a reluctance motor.

32. Ans: (b)

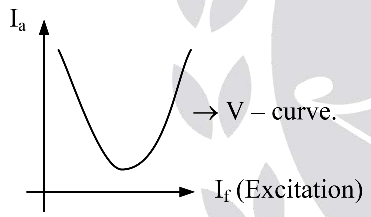
Sol: During starting, the field winding is short circuited with a low resistance to avoid damage of the field insulation and an induced voltage in the field winding will drive the current which will develop additional torque so that motor start with increased torque.

33. Ans: (a)

Sol: Synchronous motor maintains constant speed called synchronous speed irrespective of torque & it's load magnitude, so we can say torque will vary at constant speed.

34. Ans: (a)

Sol:



35. Ans: (d)

Sol: An over excited synchronous motor under no-load condition behaves as a capacitor which is used to improve the power factor. This is called synchronous condenser.

Conventional Practice Solutions

01.

Sol: Given,

For induction motor,

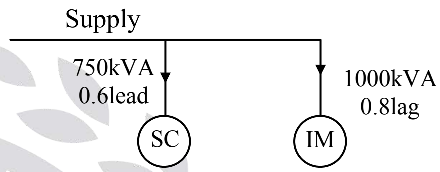
VA = 1000 kVA = Si

pf = 0.8 lag = $\cos\phi_i$

for synchronous condenser,

(VA) = 750 kVA = S_c

pf = 0.6 lead = $\cos\phi_c$



For Induction motor:

$P_i = S_i \cos\phi_i$

$= 1000 \times 0.8$

$P_i = 800\text{kW}$

$\theta_i = S_i \sin\phi_i$

$= 1000 \times 0.6$

$\theta_i = 600 \text{ kVAR}$

For synchronous condenser:

$P_c = S_c \cos\phi_c = 750 \times 0.6$

$P_c = 450\text{kW}$

$Q_c = S_c \sin\phi_c = 750 \times 0.8 = 600\text{kVAR}$

$Q_c = 600\text{kVAR}$

$\therefore\ S_i = P_i + j\theta_i$ [$\because$ lag]

$S_i = (800 + j600)$

But $S_c = P_c - jQ_c$ [$\because$ lead]

$S_c = (450 - j600)$

Apparent power from supply is

$S_s = S_i + S_c$

$= (800 + j600) + (450 - j600)$

$= (1250 + j0)$ kVA

$\Rightarrow$ Supply power factor $= \dfrac{P_s}{S_s} = \dfrac{1250}{1250} = 1$

$\therefore$ Supply power factor = 1

02.

Sol: Given,

(VA) = 1600 kVA

$V_L = 11\text{kV} \Rightarrow V_P = 6350.85\text{V}$

$X_s = 30\ \Omega$/phase

$r_a = 0$ [$\because$ negligible]

Base impedance $Z_B = \dfrac{V_L^2}{(VA)}$

$= \dfrac{\left(11\times10^3\right)^2}{1600\times10^3}$

$= 75.625\ \Omega$

$X_{s_{pu}} = \dfrac{X_s}{Z_B} = \dfrac{30}{75.625}$

$X_{s_{pu}} = 0.3967\text{pu}$

Zero regulation is possible only in leading pf case

$\overline{E}_f = \overline{V}_t + j\overline{I}_a X_s$ [for alternator neglecting r_a]

$\overline{E}_f = 1 + j0 + j1[\cos\phi + j\sin\phi](0.3967)$

$\overline{E}_f = 1 + j[0.3967\cos\phi] - (0.3967\sin\phi)$

$\overline{E}_f = [1 - 0.3967\sin\phi] + j(0.3967\cos\phi)$

$\left|\overline{E}_f\right|^2 = (1 - 0.3967\sin\phi)^2 - (0.3967\cos\phi)^2$

$1 = 1^2 + (0.3967)^2(\sin^2\phi + \cos^2\phi) - 2(0.3967)\sin\phi$

$(0.3967)^2(1) = 2(0.3967)\sin\phi$

$\sin\phi = 0.1983$

$\phi = 11.44^o$

$\therefore \cos\phi = 0.98$, lead

(ii) Insufficient data

03.

Sol: Given, $X_d = 1.4$

$X_q = 1$

$r_a = 0$

pf = 1

$\Rightarrow \cos\phi = 1$

$\Rightarrow \phi = 0$

$V = 1$

$\Rightarrow I = 1$ [rated kVA]

$\tan\psi = \dfrac{V\sin\phi + I_a X_q}{V\cos\phi + I_a r_a}$

$\tan\psi = \dfrac{1(0) + (1)(1)}{1(1) + 0}$

$\Psi = 45^o$

$\Psi = \delta + \phi$

$\Rightarrow \delta = 45 - 0$

$\delta = 45^o$

Power angle = 45^o

$$P = \frac{EV}{X_d}\sin\delta + \frac{V^2}{2}\left[\frac{1}{X_q} - \frac{1}{X_d}\right]\sin 2\delta$$

$$1 = \frac{E(1)}{1.4}\sin 45^o + \frac{(1)^2}{2}\left[\frac{1}{1} - \frac{1}{1.4}\right]\sin(2\times45^o)$$

$$1 = \frac{E}{\sqrt{2}\times1.4} + \frac{1}{2}\left[\frac{0.4}{1.4}\right](1)$$

E = 1.697

04.

Sol: Given,

$V_L = 11\text{kV} \Rightarrow V_p = \dfrac{11000}{\sqrt{3}} = 6350.35\text{V}$

$r_a = 0.3\ \Omega$/Phase

$X_s = 5\Omega$/phase

(VA) = 2000 kVA

Pf = 0.8lag

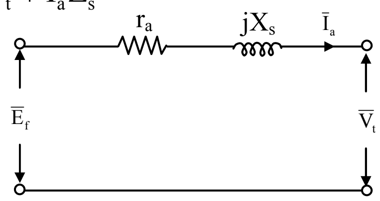
Rated current $(I_a) = \dfrac{(VA)}{\sqrt{3}V_L}$

$= \dfrac{2000\times10^3}{\sqrt{3}\times11\times10^3}$

= 104.97A

By taking terminal voltage as reference

$\overline{E}_f = \overline{V}_t + \overline{I}_a\overline{Z}_s$



$\therefore \overline{V}_t = V_p\angle 0^o$ [$\because$ reference]

$\bar{I}_a = I_a(0.8 - j0.6)$ [$\because$ pf = 0.8lag]

$\bar{z}_s = (r_a + jX_s) = (0.3 + j5)$

$\therefore \overline{E}_f = \overline{V}_t + \bar{I}_a\overline{Z}_s$

= 6350.85 + j0 + 104.97 (0.8 – j0.6) (0.3 + j5)

= 6350.85 + 104.97 (3.24 + j3.82)

= 6690.95 + j400.98

$|E_f| = 6702.95V$ …………(1)

In the second case,

Excitation is constant but, load pf is 0.8 leading. Hence terminal voltage will change

$\therefore\ \overline{E}_f = \overline{V}_t + \bar{I}_a\overline{Z}_s$

$\overline{E}_f = V_t\angle 0 + 104.97(0.8 + j0.6)(0.3 + j5)$

$\overline{E}_f = V_t + j0 + 104.97(-2.76 + j4.18)$

$\overline{E}_f = (V_t - 289.71) + j(438.77)$

$|\overline{E}_f| = \sqrt{(V_t - 289.71)^2 + (438.77)^2}$

$(6702.95)^2 = (V_t - 289.71)^2 + (438.77)^2$

$\Rightarrow V_t = 6978.3V$

$\therefore V_L = V_t\sqrt{3}$

$V_L = 6978.3 \times \sqrt{3}$

$V_L = 12086.7$ V

$\therefore$ Terminal voltage = 12.0867 kV

05.

Sol: Given

$I_{SC} = 250A$

$V_{DC} = 1500V$

$\therefore Z_s = \dfrac{V_{OC}}{I_{SC}} = \dfrac{1500}{250}$

$Z_s = 6\Omega$

Given, $r_a = 2\Omega$

$X_s = \sqrt{Z_s^2 - r_a^2} = \sqrt{6^2 - 2^2} = 5.657\Omega$

$\therefore r_a = 2\Omega;\quad X_s = 5.657\Omega$

$I_a = 250A$

$V_L = 6.6kV \Rightarrow V_p = \dfrac{V_L}{\sqrt{3}} = 3810.5V$

pf = 0.8lag

$\overline{E}_f = \overline{V}_t + \bar{I}_a\overline{Z}_s$

$\overline{E}_f = 3810.5 + 250(0.8 - j0.6)(2 + j5.657)$

= 3810.5 + 250(5 + j3.326)

= 5060.5 + j831.5

$|\overline{E}_f| = 5128.3V$

$E_{f_{LL}} = E_f\sqrt{3}$

= 8882.57V

$\therefore$ Voltage across the terminals when load is switched off = 8882.57 V.

Chapter 4 Induction Machines

Objective Practice Solutions

01. Ans: (d)

Sol: In slip ring induction motor, if stator and rotor has different number of poles, the motor doesn't rotate.

02. Ans: (c)

Sol: Induction motor rotates at slightly less than the synchronous speed.

$$\therefore N_s = \frac{120\times 50}{6} = 1000\text{rpm}$$

N_r = less than 1000 rpm

03. Ans: (c)

Sol: In an induction motor, if the air gap is increased

1. Its power factor will reduce
2. Its magnetizing current increase

04. Ans: (b)

Sol: Skewing of a slot is shown in fig.1

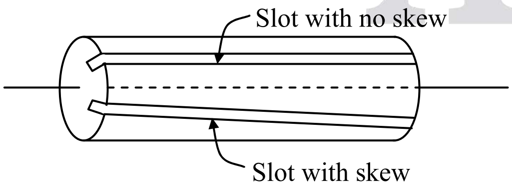


Fig. 1

Noise, vibrations, cogging, and crawling can be considerably reduced by skewing either the stator or the rotor. To eliminate the effects of any harmonic of the air-gap mmf, slots must be skewed by 2 pole-pitches corresponding to that harmonic. The usual practice is skew rotor slots by one stator slot-pitch.

A study of the torque–speed characteristics of an induction motor with skewing and without skewing shows that, with skewing,

1) Maximum or pull–out torque decreases.
2) Starting torque also decreases.

05. Ans: (a)

Sol: Open type slot:

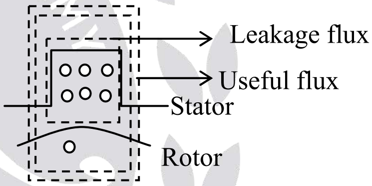


Figure: Open slots

Advantages:

(i) Windings can be placed into the slots very easily.
The winding which is formed before placed into the slots is called former winding.

(ii) Leakage reactance is less in open type slots. Therefore more amount of power will be transferred from stator to rotor and torque production is high.

06. Ans: (b)

Sol: Supply frequency, $f = \frac{1500\times 4}{120} = 50\text{Hz}$

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

$$\text{Slip, }\%S = \frac{N_s - N_r}{N_s}\times 100$$

$$\text{Slip, }\%S = \frac{1000-960}{1000}\times 100$$

$\%S = 4\%$

07. Ans: (a)

Sol: $$N_s = \frac{120\times 50}{4} = 1500\text{rpm}$$

$$\text{Slip}, S = \frac{N_s - N_r}{N_s} = \frac{1500-1440}{1500} = 0.04$$

The frequency of emf induced in rotor,
$F_r = SF_s$
$F_r = 0.04 \times 50$
$F_r = 2\text{Hz}$

08. Ans: (c)

Sol: If an induction motor by some means is rotated at synchronous speed the slip is equal to zero, therefore the emf induced in the rotor is zero and the torque developed by the rotor is zero.

09. Ans: (d)

Sol: The induction motor is rotates at slightly less than the synchronous speed, therefore synchronous speed is 300 rpm.

$$300 = \frac{120\times 50}{P}$$

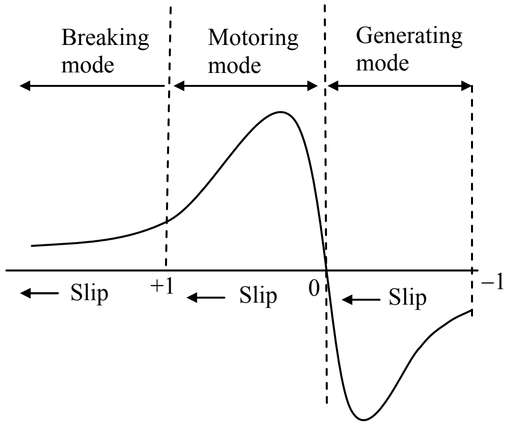
$\therefore$ P = 20

10. Ans: (c)

Sol: If any two leads of stator are interchanged in a 3-phase induction motor, the motor will run in a direction opposite to previous one.

11. Ans: (a)

Sol:



Torque-slip characteristics of a 3-phase Induction machine

12. Ans: (b)

Sol: The no load current shown by the induction motor is usually more than that of transformer.

13. Ans: (b)

Sol: $$\frac{T_{st}}{T_{FL}} = \frac{2s_m}{1+s_m^2}$$

Where $s_m = \frac{N_s - N_r}{N_s}$

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

$N_r = 1200$ rpm

$$\therefore\ s_m = \frac{1500-1200}{1500} = 0.2 = 20\%$$

$$\text{Now, } \frac{T_{st}}{T_{FL}} = \frac{2(0.2)}{1+(0.2)^2} = 0.384$$

14. Ans: (c)

Sol: $$\text{Efficiency } (\eta) = \frac{\text{output shaft power}}{\text{input power}}$$

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

$N_r = 975$ rpm (Given)

$\therefore\ s = \dfrac{N_s - N_r}{N_s} = \dfrac{1000-975}{1000} = 0.025$

Airgap power = Stator input − Stator losses

= 40 − 1 = 39 kW

Gross mechanical power output

= (1 − s) × Air gap power

= (1 − 0.025) × 39 = 38.025 kW

Shaft power output

= Gross mechanical power output − Mechanical losses

= 38.025 − 2 = 36.025 kW

$\therefore\ \% \eta = \dfrac{36.025}{40} \times 100$

= 90.0625%

15. Ans: (c)

Sol: Slip s = 5% = 0.05

Rotor output/gross mechanical power developed P_{ro} = 20 kW

Rotor copper loss $= \dfrac{s}{1-s} \times P_{r0}$

$= \dfrac{0.05}{1-0.05} \times 20k$

= 1052 W

16. Ans: (c)

Sol: In an induction motor, if the air gap is increased

1. Its power factor will reduce
2. Its magnetizing current increase

17. Ans: (b)

Sol: $T_e = \dfrac{180}{2\pi N_s} \times \dfrac{SE_2^2 R_2}{R_2^2 + (SX_2)^2}$

$T_e \propto V^2$

$T_2 = \dfrac{T_1}{4} = \dfrac{500}{4} = 125$ Nm

18. Ans: (*)

Sol: Slip at maximum torque,

$S_{Tm} = \dfrac{r_2}{X_2} = \dfrac{0.21}{0.7} = 0.3$

The speed at maximum torque,

$N_{Tm} = N_s(1 - S_{Tm})$

$N_{Tm} = 1500\ (1 - 0.3)$

$N_{Tm} = 1050$ rpm

19. Ans: (d)

Sol: As load on an induction motor goes on increasing, its power factor goes on increasing up to full load and then it falls again.

20. Ans: (b)

Sol: The rotor bars of squirrel cage induction motor are short circuited at both ends by end-rings of the same material, hence we unable to connect external resistance into rotor, so Rotor resistance control not applicable to cage induction motor.

21. Ans: (a)

Sol: Rotor current's in an induction motor is due to relative speed between stator RMF and physical rotor.

If $N_r = N_s$ i.e. if rotor rotating with 'N_S' speed in the same direction of stator RMF (N_s speed), then the relative speed between them is zero.

⇒ EMF induced in the rotor winding is zero.

⇒ Current's in rotor winding is zero.
Hence torque production is zero

⇒ At N = N_S ; rotor won't rotate, hence called "Asynchronous machine".

22. Ans: (d)

Sol: The main function of a starter in a 3-ϕ induction motor is to limit high starting current to reasonable values.

23. Ans: (a)

Sol: The speed control of induction motor by pole changing is suitable for cage motors only because the cage rotor automatically develops numbers of poles equal to the poles of stator winding.

24. Ans: (a)

Sol: The rotor will start rotating in such a direction that it will oppose the cause, i.e., the relative speed between the rotating field and stationary rotor conductors should decrease.

25. Ans: (c)

Sol: A large capacity three-phase induction motor is started using a star delta starter instead of starting direct on line. The starting current is reduced to one third its value.

26. Ans: (c)

Sol: If the motor is started by an auto transformer with x% tapping, the starting line current will be reduced by x^2 times.

27. Ans: (a)

Sol: The star delta starting current of an induction motor is 50 A. Its DOL starting current is 150 A.

28. Ans: (a)

Sol: $\frac{T_{st}}{T_{FL}} = X^2\left(\frac{I_{st}}{I_{FL}}\right)^2 \times S$

$\frac{1}{4} = X^2(4)^2 \times 0.03$

$\Rightarrow X = 72.2\%$

29. Ans: (c)

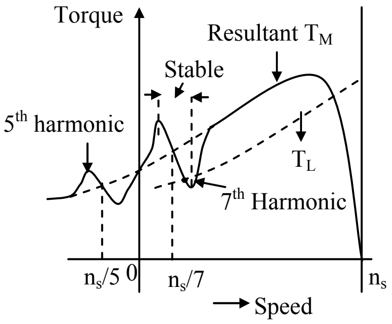
Sol: Magnitude of starting torque depends upon value of capacitor used at the time of starting. Practically permanent split capacitor start consist high value of capacitor and shaded pole type produces low starting torque.

30. Ans: (d)

Sol: In a single phase capacitor motor the direction of rotation will be in the opposite direction to the original when Capacitor is replaced by an inductor.

31. Ans: (d)

Sol: The tendency of squirrel cage induction motor to run at one seventh of the synchronous speed when connected to supply mains is called crawling. This is due to the space harmonics in the air gap flux wave. The dominant harmonics of the air gap flux wave are 5^{th} and 7^{th} harmonics. The 5^{th} harmonic flux rotates backwards with synchronous speed of $\frac{n_s}{5}$ and the seventh harmonic flux rotates forward at $\frac{n_s}{7}$. These harmonic fluxes produce their own harmonic torques of the same general torque-slip shape as that of the fundamental and will have stable operating regions around the rotor speeds of $-\frac{n_s}{5}$ and $\frac{n_s}{7}$ respectively. In the following figure, the superimposition of the fundamental, fifth and seventh harmonic torque- slip curves are shown.



In the motor operating mode of induction machine (i.e $0 < n < n_s$) there is a stable operating region around $\frac{n_s}{7}$th speed of the motor (see figure). If load torque curve intersects the motor torque curve in this stable region it results in stable operation of the induction motor around this low speed (i.e. $\frac{n_s}{7}$th speed). This phenomenon is known as crawling. This phenomenon is less prominent in slip ring induction machines as these possess higher starting torque than squirrel cage induction machines.

As the induction motor is working at low speeds, the slip will be high so rotor copper losses (s × Airgap power) will be more and efficiency will be poor. The crawling is also accompanied by much higher stator current and sometimes noise and vibration are also observed.

32. Ans: (b)

Sol: Functions of skewed rotor slots in induction motor

1. The skewed rotor slot increases the length of the copper bar thereby increases the resistance of the rotor bars and hence starting performance of the induction machine.
2. It makes the air gap flux distribution uniform thereby reduces harmonics torque produced by the machine.
3. As harmonic torque are reduced, the phenomenon due to harmonic torque can also be reduced.

Conventional Practice Solutions

01.

Sol: Given,

Number of poles, P = 4

Frequency $f_1 = 50Hz$

Speed of the motor, N = 1450 rpm.

Synchronous speed $N_s = \frac{120f_1}{p}$

$$N_s = \frac{120 \times 50}{4}$$

$$\Rightarrow N_s = 1500 \text{ rpm}$$

(a) Slip, $s = \frac{N_s - N}{N_s}$

$$s = \frac{1500 - 1450}{1500} = 0.0333$$

$$s = 3.33\%$$

(b) Frequency of rotor currents $f_2 = sf_1$

$$\Rightarrow f_2 = \frac{3.33}{100} \times 50$$

$$f_2 = 1.67Hz$$

(c) Angular velocity of stator field w.r.t stator

$= N_S$

$= 1500$ rpm

Angular velocity of stator field w.r.t rotor

$= sN_S$

$$= \frac{3.33}{100} \times 1500$$

$$= 50 \text{ rpm}$$

(d) Angular velocity of rotor field w.r.t rotor

$= sN_S$

$= 50$ rpm

Angular velocity of rotor field w.r.t stator

$= N_S$

$= 1500$rpm

02.

Sol: Given,

No load speed of induction motor,

$N_o = 1000$ rpm.

Full load speed, $N_{fl} = 950$ rpm

Frequency $f_1 = 50Hz$

In an induction motor ,No Load speed is very close by to synchronous speed

$N_s = 1000$ rpm

(a) We know synchronous speed, $N_S = \frac{120f_1}{p}$

$$\Rightarrow 1000 = \frac{120 \times 50}{p}$$

$$\Rightarrow p = 6$$

$\therefore$ Number of poles, p = 6

(b) Slip, $s = \frac{N_S - N}{N_S}$

$$\Rightarrow s_{f_1} = \frac{N_s - N_{f_1}}{N_s}$$

$$s_{f_1} = \frac{1000 - 950}{1000}$$

$$s_{f_1} = 5\%$$

(c) Frequency of rotor voltage $f_2 = s\, f_1$

$$\Rightarrow f_2 = 0.05 \times 50$$

$$f_2 = 50 \times 0.05$$

$$f_2 = 2.5Hz$$

(d) Speed of rotor field w.r.t rotor $= sN_S$

$= 0.05 \times 1000$

$= 50$ rpm

(e) Speed of rotor field w.r.t stator $= N_S$

$= 1000$rpm

03.

Sol: Given,

Power rating of the machine, $P_0 = 10kW$

Number of poles, p = 6

Frequency, $f_1 = 50Hz$

Full load slip, S = 0.04

At full load,

Power output = machine rating

$P_0 = 10kW$

Given,

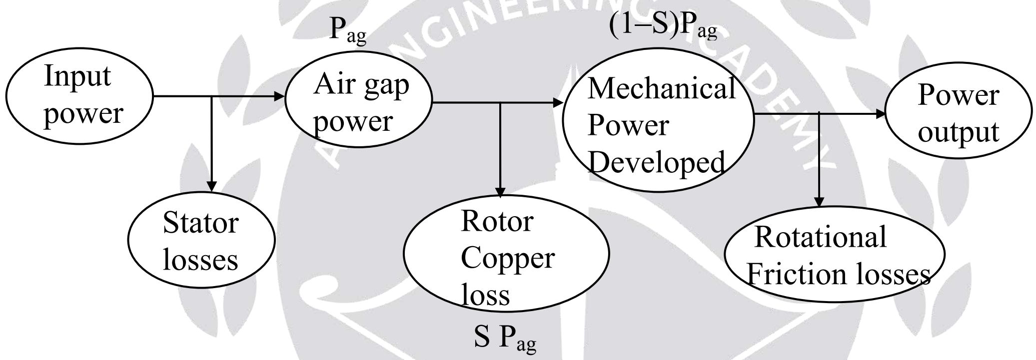
Friction and windage losses, $P_{f\&w}$ = 4% of output

$\therefore\ P_{f\&w} = 0.04 \times P_0$

$= 0.04 \times 10 \times 10^3$

$P_{f\&w} = 400W$

Power flow in an induction motor is as follows



(1) Mechanical power developed (p_{em}) = power output (P_0) + friction and windage losses ($P_{f\&w}$)

$\Rightarrow P_{em} = P_0 + P_{f\&w}$

$= 10000 + 400$

$P_{em} = 10400W$

$$\frac{\text{Rotor copper losses}}{\text{Mechanical power develped}\left(p_{em}\right)} = \frac{SP_{ag}}{(1-S)P_{ag}} = \frac{S}{1-S}$$

$$\frac{\text{Rotor copper losses}}{10400} = \frac{0.04}{1-0.04} = \frac{1}{24}$$

$$\text{Rotor copper losses} = \frac{10400}{24} = 433.3W$$

Rotor copper losses = 433.3 W

(2) Full load electromagnetic torque, $T_{em} = \dfrac{P_{em}}{\omega}$

$$T_{em} = \frac{10400}{\omega_s(1-s)} = \frac{10400}{\omega_s(1-0.04)}$$

Synchronous speed, $N_s = \frac{120f}{P} = \frac{120\times 50}{6} = 1000\,\text{rpm}$

$$N_s = 1000\,\text{rpm}$$

$$\omega_s = \frac{N_S}{60}\times 2\pi$$

$$\omega_s = 104.72\text{ rad/s}$$

$$\therefore T_{em} = \frac{10400}{104.72(1-0.04)}$$

$$T_{em} = 103.45\text{ Nm}$$

(3) Rotor efficiency, $\eta_r = 1 - S$

$$\eta_r = 1 - 0.04$$

$$\eta_r = 0.96$$

$$\eta_r = 96\%$$

04.

Sol: Given,

Power, rating of the motor, $P_0 = 30\text{kW}$

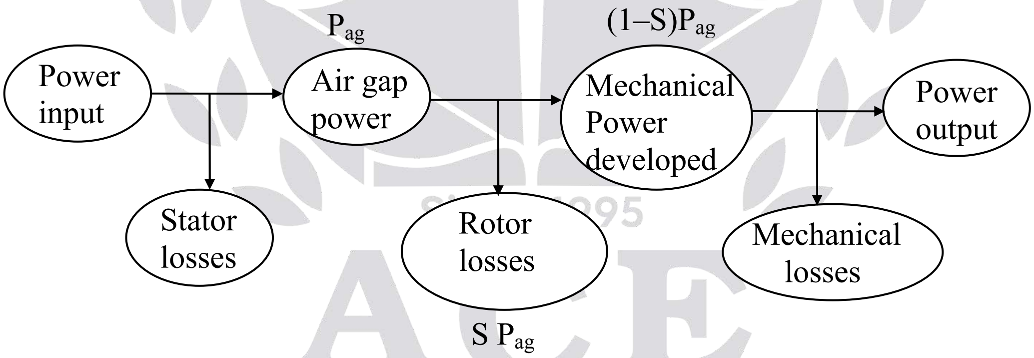
Full load slip, $S_{fl} = 0.03$

Stator losses, (P_{sL}) = 5% of input power

Mechanical losses (P_{rot}) = 1.5% of output

Rotor currents per phase (I_r) = 45 A

Power flow in induction motor is as follows,



Mechanical losses, (P_{rot}) = 1.5% of P_0

$$= \frac{1.5}{100}\times 30000$$

$$= 450\text{W}$$

Mechanical power developed (P_{em}) = power output (P_0) + Mechanical losses (P_{rot})

$$P_{em} = P_0 + P_{rot}$$

$$= 30000 + 450$$

$$P_{em} = 30450\text{ W}$$

$$\frac{\text{Rotor copper losses}}{\text{Mechanical power developed}} = \frac{SP_{ag}}{(1-S)P_{ag}} = \frac{S}{1-S}$$

$$\frac{\text{Rotor copper losses}}{30450} = \frac{0.03}{1-0.03} = \frac{3}{97}$$

$$\text{Rotor copper losses} = \frac{3}{97} \times 30450$$

Rotor copper losses = 941.75 W

Rotor copper losses = $3I_r^2 r_r = 941.75$

$r_r = 0.155\Omega$

05.

Sol: Given,

Poles, P = 6

Frequency, (f_1) = 50Hz

Speed of motor (N) = 935 rpm

Stator losses, (P_{Sl}) = 400W

Friction and windage losses ($P_{f\&w}$) = 1% of output

Rating of the motor (P_0) = 5hP = 3675 W [1hp=735 W]

P_0 = 3675 W

$P_{f\&w}$ = 1% of P_0

$$= \frac{1}{100} \times 3675\text{W}$$

$P_{f\&w}$= 36.75W

Mechanical power developed (P_{em})

= Power output (P_0)

+ friction and windage losses ($P_{f\&w}$)

$P_{em} = P_0 + P_{fw}$

= 3675 + 36.75

P_{em} = 3711.75 W

$$\text{Airgap power } (P_{ag}) = \frac{P_{em}}{1-S} = \frac{3711.75}{1-S}$$

$$\text{Synchronous speed, } (N_S) = \frac{120 f_1}{p} = \frac{120 \times 50}{6}$$

N_S = 1000 rpm

$$S = \frac{N_S - N}{N_S} = \frac{1000-935}{1000} = 0.065$$

S = 0.065

$$P_{ag} = \frac{3711.75}{1-0.065}$$

P_{ag} = 3969.8W

(a) Power input (P_{in})

= Air gap power (P_{ag}) + stator losses (P_{sl})

$P_{in} = P_{ag} + P_{SL}$

= 3969.8 + 400

P_{in}= 4369.8W

$\therefore$ Input power = 4369.8W

(b) Given,

Speed at maximum torque, N_{mT}= 800 rpm

$$\therefore S_{mT} = \frac{N_S - N_{mT}}{N_S}$$

$$S_{mT} = \frac{1000-800}{1000}$$

S_{mT} = 0.2

We know that

$$\frac{T_{fl}}{T_{max}} = \frac{2}{\frac{S_{fl}}{S_{mT}} + \frac{S_{mT}}{S_{fl}}}$$

$$\frac{T_{st}}{T_{max}} = \frac{2S_{mT}}{S_{mt}^2 + 1}$$

$$\therefore \frac{T_{f_1}}{T_{st}} = \frac{2S_{mT}S_{f1}}{S_{mt}^2 + S_{fl}^2} \times \frac{S_{mT}^2 + 1}{2S_{mT}}$$

$$\frac{T_{f1}}{T_{st}} = \frac{(S_{mT}^2 + 1)S_{f1}}{(S_{mT}^2 + S_{f1}^2)}.......(1)$$

$$T_{f1} = \frac{P_0}{\omega} = \frac{3675}{\frac{935}{60}\times 2\pi} = 37.5\text{Nm}$$

$\therefore$ T_{f1} = 37.5Nm………(2)

$\therefore$ From (1) and (2)

$$\frac{37.5}{T_{st}} = \frac{((0.2)^2+1)(0.065)}{(0.2)^2+(0.065)^2}$$

$\Rightarrow$ T_{st}= 24.5Nm

$\therefore$ Starting torque = 24.5Nm

06.

Sol: Given,

Line voltage, V_L = 230V

Line current, I_L= 60A

Power factor, $\cos\phi_1$= 0.866. lagging

Stator copper losses, P_{scu}=850W

Core losses, P_C = 450 W

Rotor losses, P_{cur} = 1050W

Rotational losses P_{rot} = 500W

Power input (P_{in}) $= \sqrt{3}V_L I_L \cos\phi_1$

P_{in}= 20700 W

Total stator losses (P_{sL}) = P_{scu} + P_c

= 850 + 450

P_{sl} = 1300W

(i) Air gap power (P_{ag})

= power input (P_{in}) – stator losses (P_{sl})

= 20700 – 1300

= 19400W

P_{ag} = 19.4 kW

(ii) Slip, $S = \dfrac{\text{Rotor copper losses}(P_{cur})}{\text{Air gap power}(P_{ag})}$

$$= \frac{1050}{19400}$$

S = 5.41%

(iii) Mechanical power developed,

(P_{em}) = (1–s)P_{ag}

$\therefore$ P_{em} = (1–0.0541) P_{ag}

P_{em} = 18350 W

(iv) Output power (P_0) = P_{em} – P_{rot}= 18350 – 500

P_0 = 17850W

(v) Efficiency (η) $= \dfrac{\text{power output}}{\text{power input}}$

$$= \frac{17850}{20700}$$

η = 86.23%

07.

Sol: Given,

Poles, P = 4

Frequency, f = 50Hz

Starting torque (T_{st})

= 160% of full load torque (T_{f1})

$\therefore$ T_{st} = 1.6T_{f1}……….(1)

Maximum torque (T_{max}) = 200% of full load torque (T_{f1})

$\therefore$ T_{max} = 2T_{f1}……….(2)

(i) From (1) and (2)

$$\frac{T_{St}}{T_{max}} = \frac{1.6T_{f1}}{2T_{f1}}$$

$$\frac{T_{St}}{T_{max}} = \frac{4}{5}........(3)$$

But we know that

$$\frac{T_{st}}{T_{max}} = \frac{2S_{mT}}{S_{mT}{}^2+1}$$

[S_{mT} = slip at maximum torque]

$$\frac{4}{5} = \frac{2S_{mT}}{S_{mT}{}^2+1}$$

$$2S_{mT}^2 - 5S_{mT} + 2 = 0$$

S_{mT}=2, ½

$\therefore S_{mT}$ = 0.5 …….(4)

[$\therefore$ for a motor $\rightarrow$ 0 < s < 1]

Synchronous speed $N_S = \dfrac{120f}{p}$

$$N_S = \frac{120\times 50}{4}$$

N_S = 1500 rpm

Speed at maximum torque, N_{mT} = $N_s(1–S_{mT})$

N_{mT} = 1500(1 – 0.5)

N_{mT} = 750 rpm

(ii) In induction motor we know that,

$$\frac{T}{T_{max}} = \frac{2}{\frac{S_{mT}}{S} + \frac{S}{S_{mT}}}$$

$$\frac{T_{f1}}{T_{max}} = \frac{2}{\frac{S_{mT}}{S_{f1}} + \frac{S_{f1}}{S_{mT}}}$$

$$\frac{1}{2} = \frac{2}{\frac{0.5}{S_{f1}} + \frac{S_{f1}}{0.5}} \left[\text{from}(2)\text{and}(4)\right]$$

$$\frac{1}{2} = \frac{2S_{f1} \times 0.5}{S_{f1}^2 + 0.25}$$

$$S_{f1}^2 + 0.25 = 25f_1$$

$$4S_{f1}^2 - 8S_{f1} + 1 = 0$$

S_{f1} = 0.134, 1.866

$\therefore S_{f1}$= 0.134 [$\therefore$ for motor $\Rightarrow 0 < S < 1$]

$\therefore$ Speed at full load, $N_{f1} = N_S(1 - S_{f1})$

N_{f1} = 1500(1 – 0.134)

N_{f1} = 1299 rpm

08.

Sol: Given,

Poles, P = 4

Frequency, f = 60Hz

Full load speed, N_{f1} = 1710 rpm

$\therefore$ Synchronous speed, $N_S = \frac{120f}{p}$

$$N_S = \frac{120 \times 60}{4} = 1800\,\text{rpm}$$

N_S = 1800 rpm ……..(1)

Full load slip $S_{f1} = \frac{N_S - N_{f1}}{N_S}$

$$\therefore S_{f1} = \frac{1800 - 1710}{1800}\left[\text{from}(1)\right]$$

S_{f1}= 0.05 ………(2)

Given that

Starting current (I_{st}) = 6× full load current (I_{f1})

$$\therefore \frac{I_{St}}{I_{f1}} = 6......(3)$$

(a) In induction motors we know that

Torque (T) = $3I_2^2 \frac{R_2}{S}$

$$\therefore \frac{T_{St}}{T_{f1}} = \left(\frac{I_{St}}{I_{f1}}\right)^2 S_{f1}......(4)$$

$$\therefore \frac{T_{st}}{T_{f1}} = 6^2(0.05) \quad \text{[from (2) and (3)]}$$

$$\frac{T_{St}}{T_{f1}} = 1.8.......(5)$$

$\therefore$ Starling torque (T_{st})

= 180% of full load torque (T_{f1})

(b) We know that,

$$\frac{T_{St}}{T_{max}} = \frac{2S_{mT}}{S_{mT}^2 + 1}$$

$$\frac{T_{f1}}{T_{max}} = \frac{2S_{mT}\,S_{f1}}{S_{mT}^2 + S_{f1}^2}$$

$$\therefore \frac{T_{St}}{T_{f1}} = \frac{\left(S_{mT}^2 + S_{f1}^2\right)}{\left(S_{mT}^2 + 1\right)S_{f1}}$$

$$1.8 = \frac{\left(S_{mT}^2 + (0.05)^2\right)}{\left(S_{mT}^2 + 1\right)(0.05)}$$

$$S_{mT}^2 + 0.0025 = 0.09\left(S_{mT}^2 + 1\right)$$

$$S_{mT}^2(0.91) = 0.0875$$

$$S_{mT} = 0.31$$

Speed at maximum torque, $N_{mT} = N_S(1 - S_{mT})$

$\Rightarrow N_{mT}$ = 1800 (1 – 0.31)

N_{mT} = 1242 rpm

(c)
$$\frac{T_{max}}{T_{f1}} = \frac{S_{mT}^2 + S_{f1}^2}{2S_{mT}S_{f1}}$$

$$= \frac{(0.05)^2 + (0.31)^2}{2(0.05)(0.31)}$$

= 3.18

$\therefore$ Maximum toque

= 318% of full load torque

09.

Sol: Given

Slip at maximum torque, S_{mT} = 0.2

External resistance, R_{ext} = 0.5 Ω

Let,
R_2= Rotor resistance
X_2 = Rotor reactance

We know that

$$S_{mT} = \frac{R_2}{X_2}$$

$$0.2 = \frac{R_2}{X_2}$$

$X_2 = 5R_2$……..(1)

Equivalent rotor circuit resistance
$R^1 = R_2 + R_{ext}$
$\Rightarrow R^1 = R_2 + 0.5$
Given that, after adding external resistance
Starting torque = 75% of maximum torque
$T_{st} = 0.75\ T_{max}$

$$\therefore \frac{T_{St}}{T_{max}} = 0.75 = \frac{2S^1_{mT}}{\left(S^1_{mT}\right)^2 + 1}$$

$$\Rightarrow 3S^2_{mT} - 8S^1_{mT} + 3 = 0$$

$$S^1_{mT} = 0.451$$

$$\Rightarrow S^1_{mT} = \frac{R^1_2}{X_2}$$

$$\Rightarrow 0.451 = \frac{R_2 + 0.5}{X_2}$$

$$\Rightarrow 0.451 = \frac{R_2 + 0.5}{5R_2}$$

$$2.255R_2 = R_2 + 0.5 \Rightarrow R_2 = 0.4\Omega$$

$X_2 = 5R_2$
$\quad = 5\ (0.4)$
$X_2 = 2\Omega$
Rotor reactance (X_2) = 2Ω
Rotor resistance (R_2) = 0.4Ω

10.
Sol: Given,
Poles, P = 4
Frequency, f = 50Hz
Rotor resistance, $R_2 = 4.5\ \Omega$| phase
Stand still rotor reactance, $X_2 = 8.5\Omega$|phase
Starting Torque, T_{st} = 85Nm

Synchronous speed $N_s = \frac{120f}{P}$

$$N_s = \frac{120 \times 50}{4}$$

N_s = 1500 rpm

(1) Let, E_2 = stand still rotor voltage

$$\therefore T_{st} = \frac{3}{\omega_s}.\frac{E_2^2}{R_2^2 + X_2^2}.R_2$$

$$85 = \frac{3}{\frac{1500}{60} \times 2\pi}.\frac{E_2^2}{\left(4.5^2 + 8.5^2\right)}(4.5)$$

$$85 = \frac{3}{50\pi}\frac{E_2^2(4.5)}{\left(4.5^2 + 8.5^2\right)}$$

$\Rightarrow E_2$ = 302.46 V

(2) External resistance added is $R_{ext} = 2\Omega$
$\therefore$ Rotor circuit resistance $R^1_2 = R_2 + R_{ext}$

$$\therefore R^1_2 = 2 + 4.5 = 6.5\Omega$$

$$\therefore R^1_2 = 6.5\Omega$$

Starting torque, $T_{st} = \frac{3}{\omega_S}\frac{E_2^2\,R^1_2}{R^{12}_2 + x_2^2}$

$$\therefore T_{St} = \frac{3}{\frac{1500}{60} \times 2\pi}\frac{(302.46)^2(6.5)}{\left(6.5^2 + 8.5^2\right)}$$

T_{st} = 99.2Nm

11.
Sol: Given,
Rated frequency, f_1 = 50Hz
Applied frequency, f_2 = 40Hz
Rated voltage, = V_1
Applied voltage, $V_2 = 1.5V_1$

(1) We know that

Starting torque $T_{st}\ \alpha \frac{V^2}{f^3}$

$$\therefore \frac{T_{St1}}{T_{St2}} = \left(\frac{V_1}{V_2}\right)^2\left(\frac{f_2}{f_1}\right)^3$$

$$\frac{T_{St1}}{T_{St2}} = \left(\frac{V_1}{1.5V_1}\right)^2\left(\frac{40}{50}\right)^3$$

$$\frac{T_{St1}}{T_{St2}} = 0.227$$

Starting torque $T_{St}\ \alpha \frac{V}{f}$

$$\therefore \frac{I_{St1}}{I_{St2}} = \left(\frac{V_1}{V_2}\right)\left(\frac{f_2}{f_1}\right)$$

$$\frac{I_{St1}}{I_{St2}} = \left(\frac{V_1}{1.5V_1}\right)\left(\frac{40}{50}\right) = 0.533$$

Maximum torque $T_{max}\,\alpha \frac{V^2}{f^2}$

$$\therefore \frac{T_{max1}}{T_{max2}} = \left(\frac{V_1}{V_2}\right)^2\left(\frac{f_2}{f_1}\right)^2 = \left(\frac{V_1}{1.5V_1}\right)^2\left(\frac{40}{50}\right)^2$$

$$\frac{T_{max1}}{T_{max2}} = 0.284$$

(ii) Given that starting torque are equal

$$\therefore T_{St1} = T_{St2}$$

$$\frac{V_1^2}{f_1^3} = \frac{V_2^2}{f_2^3}$$

$$\left(\frac{V_1}{V_2}\right)^2 = \left(\frac{f_1}{f_2}\right)^3 = \left(\frac{50}{40}\right)^3$$

$$\Rightarrow \left(\frac{V_1}{V_2}\right) = 1.397$$

12.

Sol: Given,

Poles, P = 6

Frequency = 60Hz

Speed of motor, N_1=1140 rpm

Synchronous speed, $N_S = \frac{120f}{P}$

$$N_S = \frac{120\times(60)}{6}$$

N_S = 1200rpm

Slip, $S_1 = \frac{N_S - N_1}{N_S}$

$$S_1 = \frac{1200-1140}{1200}$$

S_1 = 5%

Let additional resistance to be added = R_x. Rotor resistance, R_2=0.2Ω| phase. It is given that motor is driving a constant torque load

$\therefore T_1 = T_2$

$$\Rightarrow \frac{3}{\omega_s}\frac{E_2^2}{\left(\frac{R_2}{S_1}\right)^2 + X_2^2}\left(\frac{R_2}{S_1}\right) = \frac{3}{\omega_S}\frac{E_2^2}{\left(\frac{R_2^1}{S_2}\right)^2 + X_2^2}\left(\frac{R_2^1}{S_2}\right)$$

$$\Rightarrow \frac{R_2}{S_1} = \frac{R_2^1}{S_2} ....(1)$$

Given that final speed, N_2 = 1000 rpm

$$\therefore S_2 = \frac{N_S - N_2}{N_S}$$

$$S_2 = \frac{1200-1000}{1200}$$

$$S_2 = \frac{1}{6}$$

From (1)

$$\frac{R_2}{S_1} = \frac{R_2^1}{S_2}$$

$$\frac{R_2}{S_1} = \frac{R_2 + R_x}{S_2}$$

$$\frac{0.2}{0.05} = \frac{.2 + R_x}{(1/6)}$$

$0.2 + R_x = 0.667$

$R_x = 0.467\Omega$

13.

Sol: Given,

Poles, P = 6

Frequency, f = 50Hz

Rotor resistance, R_2 = 0.2Ω

Initial speed, N_1= 960rpm

Final speed, N_2 = 800rpm

Synchronous speed, $N_S = \frac{120f}{p}$

$\Rightarrow N_S = \frac{120 \times 50}{6} = 1000\text{rpm}$

$N_S = 1000$rpm

Slip, $S_1 = \frac{N_S - N_1}{N_S}$

$= \frac{1000-960}{1000}$

$S_1 = 0.04$

Slip, $S_2 = \frac{N_S - N_2}{N_S} = \frac{1000-800}{1000}$

$S_2 = 0.2$

When load torque is constant,

$T_1 = T_2$

$\Rightarrow \frac{R_2}{S_1} = \frac{R_2^1}{S_2}$

$\Rightarrow \frac{0.2}{0.04} = \frac{R_2^1}{0.2}$

$\Rightarrow R_2^1 = 1\Omega$

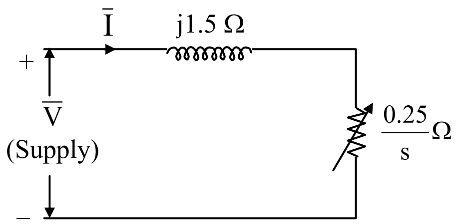
But $R_2^1 = R_2 + R_{ext} = 1$

$0.2 + R_{ext} = 1$

$R_{ext} = 0.8\Omega$

14.

Sol: 1. Using given data, equivalent circuit per phase of the motor is as shown in fig.1.



Data regarding R_c, X_n, r_1 and x_1 is not given, so these are ignored

fig.1

Shaft torque at (s = 0.019) = developed torque (if mechanical losses are neglected) =

$$T = \frac{3V^2(0.25)}{s\omega_s\left[(0.25/s)^2 + 1.5^2\right]} = 2400 \text{ N-m/r}$$

……….(1)

V and ω_s are not given. ω_s (synchronous speed in mechanical rad/sec) can be calculated as follows:

T = 2400 N-m/r. output = 373 kW.

T ω_r = torque × actual rotor speed = shaft power (since mechanical losses are neglected)

= 373 kW. ω_r

= $(373 \times 10^3/2400)$

= 155.42 r/s (mech)

Hence ω_s = 155.42/(1 – 0.019)

= 158.43 r/s (mech)

Which gives P = 3.97 poles, which can be corrected to 4 poles. With 4 poles, ω_s will be 157.08 r/s (mech).

Substituting in (1); V = 1294.2 Volts/ph.

Full load current

$= 1294.2\sqrt{\left[(0.25/0.019)^2 + 1.5^2\right]}$

= 97.7 A.

2. **Now external resistances of 2 Ω/ph are inserted into the rotor. The current is given to be unchanged.** It is assumed that the applied voltage/ph is also unchanged.

2.1 Finding the new slip:

The new equivalent circuit/ph is shown in fig.2.

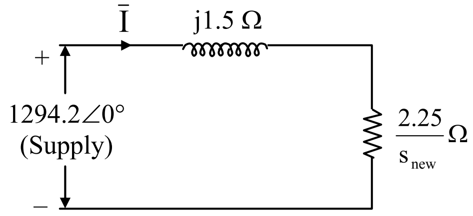


fig.2

$$I = \frac{1294.2}{\sqrt{\left[(2.25/s_{new})^2 + 1.5^2\right]}} = 97.7 \ldots\ldots(2)$$

From eq (2), the new slip $s_{new} = 0.171$.

Finding the new power output:

The stator current is given to be unchanged. If r_{21} and r_{22} are the rotor resistances and s_1 and s_2 are the slips before and after change, we have

$$\frac{V}{\sqrt{\left(\frac{r_{21}}{s_1}\right)^2 + x^2}} = \frac{V}{\sqrt{\left(\frac{r_{22}}{s_2}\right)^2 + x^2}}$$

From which $\frac{r_{21}}{s_1} = \frac{r_{22}}{s_2}$.

The torque before and after the change are, respectively,

$$\frac{3V^2(r_{21}/s_1)}{\omega_s\left[\left(\frac{r_{21}}{s_1}\right)^2 + x^2\right]} \text{and} \frac{3V^2(r_{22}/s_2)}{\omega_s\left[\left(\frac{r_{22}}{s_2}\right)^2 + x^2\right]}.$$

With $\frac{r_{21}}{s_1} = \frac{r_{22}}{s_2}$, these torques are the same.

The torque initially is given to be 2400 N-m/r. So after changing the rotor resistance also, the torque will be 2400 N-m/r.

New slip $s_2 = (r_{22}/r_{21})s_1$

$= 0.171$

New power output

$= 2400\,(1 - 0.171)(157.08)$

$= 312.53$ kW.

15.

Sol:

1. The problem specifies rotational losses as negligible. Hence the load torque is the same as the developed (or electromagnetic) torque.
2. The full load speed is 1440 rpm and full load shaft output is 20,000 W (from the given ratings). Hence rated load torque T_R is given by

   $\frac{T_R(1440 \times 2\pi)}{60} = 20{,}000$ from which

   $T_R = 132.6$ N-m/r.
3. There is another method of calculating the rated load torque, which should give the same value as above. This method is given below:

   The problem specifies the frequency as 50 Hz, but does not specify the number of poles. With a full load speed of

1440 rpm, the synchronous speed will be the nearest possible value greater than 1440 rpm. This is 1500 rpm, which will be obtained for 4 poles, at 50 Hz. Hence full load slip = 0.04.

Developed torque at this slip,

$T_d = (3V^2 r_2)/[s\omega_s \{(r_2/s)^2 + x_2^2\}]$

Substituting numerical values

T_d = 99.32 N-m/r = T_R

Thus does not agree with earlier result.

Let the slip at 120 Hz, 400 V operation be s.

At 120 Hz, x_2 becomes [(1.6×120)/50]

= 3.84 Ω.

Full load torque

$$T = \frac{3\times\left(400/\sqrt{3}\right)^2(0.4)}{s(120\pi)\left[\left(\frac{0.4}{s}\right)^2 + 3.84\right]}$$

Irrespective of whichever value of torque we use, slip comes out as a complex quantity which is not acceptable.

Slip for maximum torque = (0.4/3.84)

= 0.1042

Chapter 5 Power Systems

Objective Practice Solutions

01. Ans: (d)

Sol: Water used = 60 × 10^6 cubic meter/year

$$\therefore Q = \frac{60\times10^6}{365\times24\times3600} = 1.9\,m^3/sec$$

Head = 40 m

$$P = \frac{735.5}{75}QH\eta\ kW$$

$$= \frac{735.5}{75}\times1.9\times40\times1$$

$$= 745.3\ kW$$

02. Ans: (c)

Sol: Overall efficiency of the power station is

$$\eta_{overall} = \eta_{thermal}\times\eta_{elect} = 0.30\times0.92 = 0.276$$

Units generated / hour = $(100\times10^3)\times1$

$= 10^5$ kWh

Heat produced / hour,

$$H = \frac{\text{Electrical output in heat units}}{\eta_{overall}}$$

$$\frac{10^5\times860}{0.276} = 311.6\times10^6\ kcal$$

($\therefore$ 1kWh = 860 kcal)

$$\therefore \text{Coal consumption/hour} = \frac{H}{\text{Calorific value}}$$

$$= \frac{311.6\times10^6}{6400}$$

$$= 48687\text{kg}$$

03. Ans: (c)

Sol: 1 Hp = 735. 5 W

(or)

= 0.735 kW

Developed power,

$$P = \frac{735.5}{75}\times Q\times W\times H\times\eta\ \text{Watts}$$

Here, Density of water W = 1000kg/m^3

Discharge of water (Q) = 1m^3/s,

efficiency (η) =100% and

Water head (H) = 1m

$$\therefore\ P = \frac{735.5}{75}\times1000\times1\times1 = 9.80kW$$

04. Ans: (d)

Sol: H = 102 m

Q = 30 m^3/sec

η = 80%

P = ηWQH × 1000

P = 0.8 × 30 × 102 × 9.81

P = 24,014.88

P = 24,014.88 × 1000

P = 24MW

05. Ans: (b)

Sol: H = 204m

Q = 8 m^3/sec

η = 0.8

$$P = \frac{0.736}{75}\times W\eta QH$$

$$P = \frac{0.8\times1000\times8\times204\times0.736}{75}$$

= 12812.288kW ≈ 12,800 kW

06. Ans: (a)

Sol: Weight of water

= volume of water is stored×density

= $(10\times10^5)\times993$ kg

$= (10\times10^5)\times993\times9.81$ N

$= 9741.33\times10^6$ N

Energy produced $= W\times H\times\eta_{overall}$
by volume of water

$= 9741.33\times10^6\times50\times1.00$ watt-sec

(losses are neglected, overall efficiency is 100%)

$$= \frac{9741.33\times10^6\times50}{3600}\text{ Whr}$$

$= 135.3$ MWhr

07. Ans: (d)

Sol: $N_s = 300$ rpm

$f = 50$ Hz

$$N_s = \frac{120f}{P} \Rightarrow P = \frac{120f}{N_s} = \frac{120\times50}{300} = 20$$

$P = 20$.

08. Ans: (c)

Sol: In the fully charged state, the negative plate consists of lead, and the positive plate lead dioxide, with the electrolyte of concentrated sulfuric acid. Overcharging with high charging voltages generates oxygen and hydrogen gas by electrolysis of water, which is lost to the cell. A lead acid battery cell is fully charged with a specific gravity of 1.265 at 80° F. For temperature adjustments, get a specific gravity reading and adjust to temperature by adding.

09. Ans: (b)

Sol: The state of discharge of a lead acid cell is determined by specific gravity of electrolyte

10. Ans: (a)

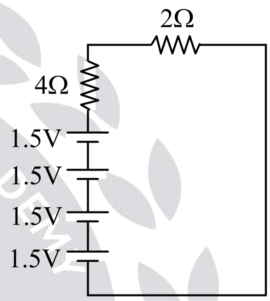
Sol: The storage battery, which is generally used in electric power station is lead acid cell.

11. Ans: (c)

Sol: In general terms, the capacity of a cell/battery is the amount of charge available expressed in ampere-hour(Ah).

12. Ans: (c)

Sol: Given data
Four identical batteries is 1.5 V
Internal resistance 1Ω
Series feed load of 2Ω



The current in the circuit $= \frac{6}{6} = 1\,A$

13. Ans: (c)

Sol: The capacity of the battery is usually expressed as a number of ampere-hour. One ampere-hour is the amount charge delivered when a current of one ampere is delivered for one hour. Ampere-hour efficiency always greater than watt-hour efficiency.

14. Ans: (c)

Sol: Storage cell in an auto mobile has lead for negative, PbO_4 for positive electrode and sulphuric acid for electrolyte

15. Ans: (c)

Sol: A commonly used primary cell is dry ice

16. Ans: (c)

Sol: In lead acid battery, the density of acid indicates charge of battery.

17. Ans: (a)

Sol: For the process of electrolysis, the supply required is dc supply.

18. Ans: (c)

Sol: As each cell of voltage V of n are connected in series the total voltage becomes = nV and the capacity of each cell is same. So capacity of battery is nothing but capacity of each cell.

19. Ans: (c)

Sol: Cells (or) batteries connected in series have the positive terminals of one cell (or) battery connected in the negative terminals of another cell (or) battery. This has the effect of increasing the overall voltage but the overall capacity remains the same.

20. Ans: (b)

Sol: Sulphation in a lead-acid battery occurs due to incomplete charging.

21. Ans: (b)

Sol: Electrolyte of lead acid battery cell is a solution of sulfuric acid and distilled water. The specific gravity of pure sulfuric acid is about 1.84.

22. Ans: (b)

Sol: Trickle charging means charging a fully charged battery under no-load at a rate equal to its self-discharge rate, thus enabling the battery to remain at it's fully charged level.

23. Ans: (c)

Sol: Given data

A battery is charged at 5A for 8 hours,

Discharged at 4A in 9 hours,

Output = $9 \times 4 = 36$

Input = $5 \times 8 = 40$

$$\% \eta = \frac{\text{output}}{\text{input}} = \frac{36}{40} = 90\%$$

Conventional Practice Solutions

01.

Sol: Given,

Mean head (H) = 50m

Catchment area (A) = 200 km^2

Annual rainfall (h) = 420cm

Loss due to evaporation (e_L) = 30%

Turbine efficiency (η_t) = 85%

Alternator efficiency (η_a) = 80%

Evaporation efficiency (η_e) = $1 - e_L$ = 70%

Let,

P = Density of water = 1000kg/m^3

E_t = Total energy that can be generated by the hydro power plant.

$E_t = (MgH)\times\eta_t\times\eta_a\times\eta_e$

$E_t = ((PV)gH)\times\eta_t\times\eta_a\times\eta_e$

$E_t = P(Ah)gH\times\eta_t\times\eta_a\times\eta_e$

$= 1000\times200\times10^6\times4.2\times9.8\times50\times0.85\times0.8\times0.7$

$= 1.959216\times10^{14}$J

E_t = 54422.67 MWh

Average power that can be generated

$$(P_0) = \frac{E_t}{t(hrs)}$$

$$(P_0) = \frac{E_t}{365\times24}$$

$$= \frac{54422.67}{8760}$$

P_0 = 6.21MW

02.

Sol: u_0 = Speed of free wind in unperturbed state

A = Area through which air column passing

ρ = Density of air

Then power available in wind

$$P_0 = \frac{1}{2}(\rho.A.u_0).u_0^2 = \frac{1}{2}(\rho A)u_0^3 \;\ldots\ldots\; (1)$$

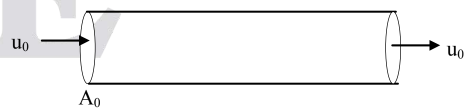
$$\frac{P_0}{A} = \frac{1}{2}\rho u_0^3 \;\ldots\ldots\ldots\ldots\; (2)$$

Energy content of the wind per unit area for a specified period is

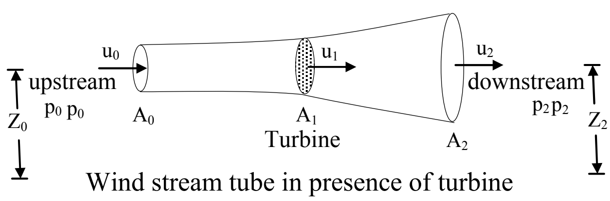
$$\frac{E_0}{A} = \int_0^\tau \frac{P_0}{A}.d\tau = \frac{1}{2}\rho\int_0^\tau u_0^3\, d\tau$$

Power Extraction from Wind:

- Wind turbine is used to harness useful mechanical power from wind.
- The rotor of the turbine collets energy from the whole area swept by the rotor.
- The maximum power extraction can be bound by the help of betz model.



Unperturbed Wind stream tube in absence of turbine



Wind stream tube in presence of turbine

Betz model for expanding air-stream tube

Wind stream tube in presence of turbine

Mass flow rate (incompressible fluid)

$$\dot{m} = \rho\, A_0u_0 = \rho A_1u_1 = \rho A_2\, u_2 \quad \text{..... (3)}$$

Force or thrust on Rotor

$$(F) = \dot{m}u_0 - \dot{m}u_2 \text{ ......(4)}$$

Power extracted by turbine

$$P_T = F.u_1 = \dot{m}\,(u_0 - u_2)\, u_1 \text{ .... (5)}$$

Power extraction can also be written like difference in kinetic energy at the upstream and downstream.

$$P_T = \tfrac{1}{2}\dot{m}\left(u_0^2 - u_2^2\right) \text{ .... (6)}$$

(5) = (6)

$$u_1 = \left(\frac{u_0 + u_2}{2}\right) \text{ .... (7)}$$

a = interference factor defined as

$$a = u_0 - u_1 / u_0 \qquad \text{........ (8)}$$

$u_1 = (1 - a)\, u_0$

$$\text{or } a = (u_0 - u_2) / 2u_0 \qquad \text{....... (9)}$$

Now by the help of equations 3, 5, 7, 8

$$P_T = 4a\,(1 - a)^2 \left(\frac{1}{2}\,\rho A_1\; u_0^3\right) \qquad \text{...... (10)}$$

Compare with equation (2)

$$P_T = C_P\, P_0 \qquad \text{.... (11)}$$

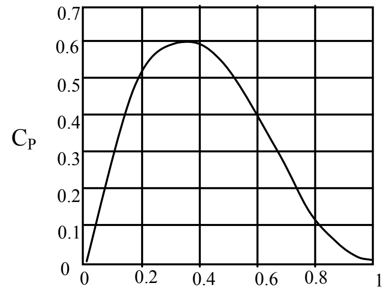
C_P = Fraction of available power in the wind or power coefficient.

$$C_P = 4a(1 - a)^2 \text{ ..... (12)}$$

Maximum value of C_ρ can be

$C_{P,max} = 0.593$

So According to Betz Model 59.3% is the maximum energy that can be extracted from wind.



Variation of Power coefficient (C_P) with interference factor (a)

Note: Likewise we can also calculate Axial thrust on turbine and torque developed by the turbine.

03.

Sol: Given, power output, P_0 = 500MW

Efficiency of power plant, η = 33%

Energy output per fission, e_f = 190Mev

Molecular weight of 4.235 (m) = 253g/mole

Enrichment (e) = 3%

1kg of fuel rods contain 30g of 4.235 (enrichment is 3%)

30g of U-235 contain $6.023 \times 10^{23} \times \dfrac{30}{235}$ atoms of 4.235

1 atoms of U-235 produces 190MeV of energy

$6.023 \times 10^{23} \times \dfrac{30}{235}$ atoms produces

$= 190\times10^{6}\times1.6\times10^{-19}$J

$\times\ 6.023\times10^{23}\times\dfrac{30}{235}$ of energy

$= 233.74\times10^{10}$ J of energy

But efficiency is 33%

$\therefore$ Electrical energy output/1kg of fuel rods is

$e_0 = 0.33\times2.33.74\times10^{10}$ J

$e_0 = 77.135\times10^{10}$ J/kg

(a) Total energy output of the plant is

$E_0 = P_0\times t$

$= 500\times10^{6}\times(8760)\times(3600)$

$= 1.5768\times10^{16}$ J

Total mass of fuel consumed in kg is

$$M = \frac{E_0}{e_0}$$

$$M = \frac{1.5768\times10^{16}}{77.135\times10^{10}}$$

M = 20442kg

(b) Energy output of 1kg of fuel burn up is

$= 233.74\times10^{10}$J

Energy output for 1 tonne (1000kg) of fuel burn up is

$E_{x0} = 233.74\times10^{13}$ J

$= 2.3374\times10^{7}$ MJ

$= \dfrac{233.74\times10^{7}}{3600\times24}$ MWdays

$E_{x0} = 27053.24$ MWd

04.

Sol: r = 12 m

$v_1 = 16\ ms^{-1}$ (initial velocity)

$v_2 = 8\ ms^{-1}$ (final velocity)

$P = 1.2\ kgm^{-3}$

$\Rightarrow$ velocity of the blades is

$$v = \frac{v_1+v_2}{2}$$

$$\Rightarrow v = \frac{16+8}{2}$$

$v = 12\ ms^{-1}$

$\Rightarrow$ Power generated by wind mill is

$P = \dfrac{1}{2}C_P PAV^3$ $[C_P = 1$ in ideal case$]$

$\Rightarrow P = \dfrac{1}{2}\times1\times1.2\times\pi(12)^2\times(12)^3$

P = 469.03 kW

05.

Sol: Given,

Gross, power output (P_0) = 1000MW

Internal power consumption (P_{aux}) = 9%

Total mass of coal wxd /day (M)

= 9800 tonnes per day

Heating value of coal (C_c) = 26MJ/kg

Total gross electrical output per day in terms of energy is $(E_{g0}) = P_c\times t$

$= 1000\text{Mw}\times24\times3600$

$= 864\times10^{11}$J

Total Heat energy input (E_i) = M C_c

$E_i = 9800\times10^3\times26\times10^6$

$E_i = 2548\times10^{11}$J

Gross efficiency (η_g) = $\dfrac{E_{g0}}{E_i}$

$= \dfrac{864\times10^{11}}{2548\times10^{11}}$

Gross efficiency = 33.9%

Net efficiency (η_n) = $\eta_g\times\eta_{aux}$

= 33.9×(1- 0.09)

Net efficiency, η_n = 30.8%

06.

Sol: Given,

Total volume of water (V)

= 1 million cubic meters

Density of water (P_w) = 993 kg/m^3

Mean head (H) = 50m

Losses = negligible

⇒ Efficiency = 100%

Energy produced by the water is

$E_0 = \eta mgH$

$E_0 = \eta$ (PV) gH

= (1.0) (993×10^6) ×9.8×50

= 4.8657×10^{11}J

= 4.8657×10^5 MJ

= 135.16MWh

Energy output = 135.16 MWh

07.

Sol: Given,

Annual load factor (Plf) = 0.75

Annual capacity factor (pcf) = 0.6

Plant use factor (puf) = 0.65

Maximum demand (P_m) = 60Mw

Let, C = plant capacity

(a) $\text{PLF} = \dfrac{\text{Average demand}}{\text{Maximum demand}}$

$0.75 = \dfrac{\text{Average demand}}{60\text{MW}}$

∴ Average demand = 45MW

Annual energy production (E_0)

= Average demand × 8760(hrs)

∴ E_0 = 45×8760 = 394200 MWh

$E_0 = 394.2\times10^6$ KWh

(b) $\text{PCF} = \dfrac{\text{Average load}}{\text{Plant capacity}}$

$0.6 = \dfrac{45\text{MW}}{C}$

C = 75Mw

Plant capacity = 75Mw

Reserve capacity

= Plant capacity – Peak load

∴ Reserve capacity = 75 – 60 = 15MW

(c) $\text{PUF} = \dfrac{\text{Energy genrated per year}}{\text{Plant capacity}\times\text{hours in operation}}$

$0.65 = \dfrac{\text{average load}\times 8760(\text{hours})}{C\times(\text{hours in operation})}$

Hours in operation = $\dfrac{45\times 8760}{75\times 0.65}$

Hours in operation = 8086.15 Hours

Total hours plant is not operated

= 8760 - Total hours of operation

$\therefore$ Total hours plant is not in service

= 674 hours

08.

Sol: Given,

Peak load (P_P) = 60MW

Maximum demand of load 1 is (P_1)

= 30MW

Maximum demand of load 2 is (P_2)

= 20 MW

Maximum demand of load 3 is (P_3)

= 10 MW

Maximum demand of load 4 is (P_4)

= 14 MW

Annual load factor (PLF) = 0.5

(a) $\text{PLF} = \dfrac{\text{Average load}}{\text{Peak load}}$

$0.5 = \dfrac{\text{Average load}}{60}$

Average load = 30MW

(b) Energy supplied (E_0)

= Average load × time (h)

$E_0 = 30\times10^6\times8760$

$E_0 = 2.628\times10^{11}\,\text{Wh}$

$= 2.628\times10^8$ KWh

$E_0 = 2.628\times10^5$ MWh

(d) Diversity factor (D_f) = $\dfrac{P_1+P_2+P_3+P_4}{P_\ell}$

$= \dfrac{30+20+10+14}{60}$

$D_f = 1.233$

(c) Demand factor = $\dfrac{1}{D_f} = \dfrac{1}{1.233}$

Demand factor = 0.81

09.

Sol: Given,

Charging rate (C_c) = 2C

Charging current (I_c) = 10A

Discharge rate (C_d) = 0.2C

Let,

t_c = charging time

t_d = discharging time

I_d = discharge current

Ah = Ampere hours stored in the battery.

(a) We know that

$C_c t_c = 1$

$2\times t_c = 1$

$t_c = 0.5$ hours

(b) Ah = $I_c t_c$

= 10×0.5

Ah = 5Ah

(c) $Ah = I_d t_d$

$5 = I_d t_d$

But, $C_d + t_d = 1$

$0.2 \times t_d = 1$

$t_d = 5$ hours -----(d)

$\therefore\ 5 = I_d \times t_d$

$$I_d = \frac{5}{5} = 1A$$

$I_d = 1A$

10.

Sol: Given, Source voltage (V_s) = 10V

Ampere hour of each battery (Ah) = 10Ah

Terminal voltage of battery (V_b) = 2V

Load resistance, (R_L) = 1.9Ω

Internal resistance during charging (r_c)

= 0.25Ω

Internal resistance during discharging (r_d)

= 0.4Ω

Let,

I_c = charging current of each battery

I_d = discharging current of each battery

I_L = load current

C_c = charge rate

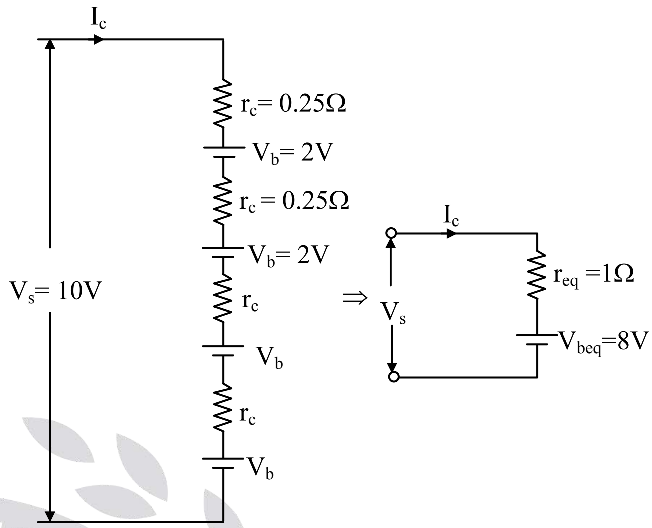
C_d = discharge rate

t_c = charging time

t_d = discharge time

During charging.

Circuit is as follows:



(a) From the above equivalent circuit,

$$I_c = \frac{V_s - V_{beq}}{r_{eq}}$$

$$= \frac{10-8}{1}$$

$I_c = 2A$

(b) $Ah = I_c t_c = I_d t_d$

$10 = 2 \times t_c$

$t_c = 5$hours

$C_c\ t_c = C_d t_d = 1$

$C_c \times 5 = 1$

$C_c = 0.2C$ rate

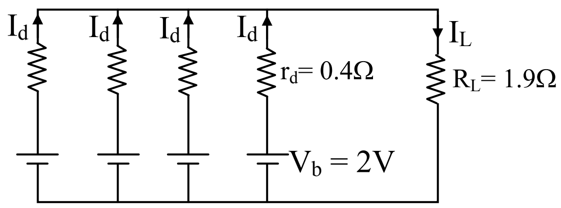
(c) Ah stored = 10Ah (given)

Wh stored = $V_b \times Ah$

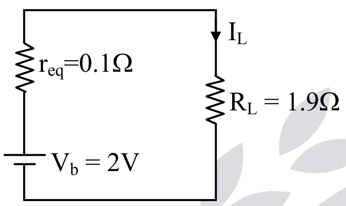
$= 2 \times 10$

Wh stored = 20Wh

(d) Circuit during discharge is as follows,



$$\Updownarrow$$



From the above circuit we can say that

$4I_d = I_L$

$4I_d = 1$

$I_d = 0.25A$

$$I_L = \frac{V_d}{r_{eq} + R_L}$$

$$I_L = \frac{2}{0.1 + 1.9}$$

$I_L = 1A$

(e) $Ah = I_d t_d$

$10 = (0.25)\, t_d$

$t_d = 40$ hours

$C_d t_d = 1$

$C_d \times 40 = 1$

$C_d = 0.025$ C rate

(f) load current $I_L = 1A$

Load voltage $V_L = I_L R_L$

$V_L = 1 \times 1.9$

$V_L = 1.9V$

(g) Energy supplied by supply during charging is

$E_s = V_s I_c t_c = 10 \times 2 \times 5 = 100Wh$

$\Rightarrow E_s = 100Wh$

Energy given to load during discharge is

$E_d = V_L I_L t_d = 1.9 \times 1 \times 40 = 76Wh$

Charge discharge efficiency (η)

$$= \frac{E_d}{E_s} = 76\%$$