Objectives Practice Solutions

01. **Ans:** (b)

**Sol:** 
\[ B_{\text{max}} \propto \frac{V}{f} \]

Here \( V \) increases, \( f \) decreases to half 
\[ \Rightarrow B_{\text{max}} \text{ increased to double, which will drive the core in to deep saturation and also I}_{\text{n}} \text{ is very high to create double the rated flux.} \]

02. **Ans:** (d)

**Sol:**

\[ \frac{V}{f} \text{ ratio is not equal} \]

(i) \( W_{h} \propto \frac{V^{1.6}}{f^{0.6}} \); as frequency increases, the hysteresis loss will decreases.

(ii) \( W_{e} \propto V_{1}^{2} \) (Independent on frequency)

\[ \therefore \text{ Eddy current loss will be constant.} \]

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.

\[ (\therefore B \propto \frac{1}{A}) \]

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

05. **Ans:** (b)

**Sol:** 
\[ \cos \phi_{c} = \frac{R}{Z} \sqrt{5 \times R_{02}} \]

\[ \cos \phi_{c} = \frac{1}{\sqrt{5}} \]

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:** \( \frac{V}{f} \text{ Ratio is not constant} \)

\[ \therefore W_{h} \propto \frac{V_{1}^{1.6}}{f^{0.6}} \Rightarrow W_{h} \downarrow \text{ & } W_{e} = \text{ Const} \]

But “\( W_{h} \)” is due to core loss component of current \( I_{w} \).
\[ \Rightarrow \text{As } f \uparrow, \text{ } W_h \downarrow \Rightarrow I_\mu \downarrow. \]

Similarly \[ I_\mu \propto B_{\text{max}} \propto \frac{V}{f} \uparrow \]
\[ \Rightarrow f \uparrow \Rightarrow B_{\text{max}} \downarrow \Rightarrow I_\mu \downarrow \]

09. Ans: (b)
Sol: Deviation from first approximation is occurred by neglecting primary impedance drop, i.e \( I_0 Z_1 \).

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

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: \( W_i = 100 \text{ W at 40 Hz.} \)
\[ = 72 \text{ W at 30 Hz.} \]
At 40 Hz, \( W_i = Af + Bf^2. \)
\[ 100 = A \times 40 + B \times 40^2 \ldots \ldots (1) \]
At 30 Hz, \( 72 = A \times 30 + B \times 30^2 \ldots \ldots (2) \]
By solving above two equations,
\[ B = 1/100 \text{ and } A = 2.1 \]
Hysteresis loss, \( W_h = A \times f \)
\[ = 2.1 \times 50 \Rightarrow 105 \text{ W.} \]
Eddy current loss \( W_e = B \times f^2 \)
\[ = \frac{50 \times 50}{100} \]
\[ = 25 \text{ W.} \]

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 \( \Rightarrow W_i = 1050 \text{ W} \)
At 138 V, 30 Hz \( \Rightarrow W_i = 500 \text{ W} \)
\[ V_{11} = 230 \text{ V} \]
\[ \frac{V_{11}}{f_1} = \frac{230}{50} = 4.6 \]
\[ f_1 = 50 \text{ Hz} \]
\[ V_{12} = 138 \text{ V} \]
\[ \frac{V_{12}}{f_2} = \frac{138}{30} = 4.6 \]
\[ V_{12} = 138 \text{ V} \]
\[ f_2 = 30 \text{ Hz} \]
\[ \frac{V}{f} = \text{ constant} \]

at \[ \frac{V}{f} = \text{ constant} \]
\[ W_1 = Af^2 + Bf^2 \]

at 50 Hz \[ 1050 = A(50) + B(50)^2 \] ...... (i)
at 30 Hz \[ 500 = A(30) + B(30)^2 \] ...... (ii)

by solving equation (1) & (2), we get
\[ A = 10.1667 \]
\[ B = 0.2167 \]

Then at 230V, 50 Hz
\[ W_h = Af = 10.1667 \times 50 = 508.33 \text{ W} \]
\[ W_e = Bf^2 = 0.2167 \times (50)^2 = 541.75 \text{ W} \]

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: \[ P = V I_w \]
\[ \therefore \text{ Loss component } I_w = \frac{5 \times 10^3}{220} = 22.7 \text{ A} \]

18. Ans: (d)
Sol: Given that, no load loss components are equally divided,  
\[ W_h = W_e = 10 \text{ W} \]

Initially test is conducted on LV side

Now \[ \frac{V}{f} \text{ ratio is } \frac{100}{50} = 2 \]

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

Now \[ \frac{V}{f} \text{ ratio is constant, } W_h \propto f \text{ and } W_e \propto f^2. \]

\[ W_{h2} = W_h \times \left( \frac{f_2}{f_1} \right)^2 = 10 \times \left( \frac{40}{50} \right)^2 = 8 \text{ W} \]

\[ W_{e2} = W_e \times \left( \frac{f_2}{f_1} \right)^2 = 10 \times \left( \frac{40}{50} \right)^2 = 6.4 \text{ W} \]

Therefore,
\[ W_1 = W_{h2} + W_{e2} \]
\[ \Rightarrow 8 + 6.4 = 14.4 \text{ W} \]

In SC test,
\[ I(\text{HV side}) = 5 \text{ A} \]
\[ I(\text{LV side}) = 10 \text{ A} \]

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

\[ I_{sc} = \frac{V_{sc}}{Z_{01}} \]
\[ \cos \phi_{sc} = \frac{R_{01}}{Z_{01}} \]

23. Ans: (e)
Sol: The Condition for maximum efficiency
\[ W_{total} = (150 + 150) W \]
\[ = 300 W \]

24. Ans: (b)
Sol: kVA at $\eta_{max} = F.L kVA \times \sqrt{\frac{\text{Iron loss}}{F.L \text{Lcuploss}}}$

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, \[ K = \frac{\pi^2}{6}\rho; \]
\[ B_{max} = \text{Maximum flux density.} \]
\[ f = \text{frequency of eddy current (supply frequency).} \]
\[ t = \text{Thickness of lamination} \]
Observations:
\[ w_e \propto I^2 \]

The eddy current loss can be effectively reduced by reducing thickness of lamination.
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
\[ \therefore \text{Copper loss at half full load} = \left(\frac{1}{2}\right)^2 \times 220 \text{W} = 55 \text{W} \]
\[ \therefore \text{Total losses at half full load} = 150 + 55 = 205 \text{W} \]
Efficiency at half full load
\[ \eta = \frac{1}{2} \times 10^3 \times 1 \times 100 \]
\[ \frac{1}{2} \times 10^3 \times 205 \]
\[ = 96.06\% \]

27. Ans: (c)
Sol: \( \% \eta = \frac{(x)(VI) \cos \phi}{x(VI) \cos \phi + W_c + W_{cu}} \times 100 \)
\[ x = 1 \text{ (full load)} \]
\[ VI = 200 \text{ kVA}; \cos \phi = 0.9 \text{ lag}; W_c = 1.8 \text{ kW} \]
\[ W_{cu} = \left(\frac{1.1}{100}\right) \times 200 \times 10^3 = 2200 \text{ watts} \]
\[ \% \eta = \frac{(1)(200 \times 10^3)(0.9)}{(200 \times 10^3 + 0.9) + (1.8 \times 10^3) + 2200} \times 100 \]
\[ = 97.82\% \]

28. Ans: (a)
Sol: \% Reg = (%R) cos \phi_2 \pm (%X) sin \phi_2
For lagging power for
\[ \% \text{V.R} = (2)(0.8) + (4)(0.6) \]
\[ = 4\% \]
For leading power factor
\[ \% \text{V.R} = (2)(0.8) - (4)(0.6) \]
\[ = -0.8\% \]

29. Ans: (a)
Sol: Given %R = 1%, %X = 5% and \cos \phi = 0.8
\[ \% \text{Reg} = (%R) \cos \phi + (%X) \sin \phi \] (\therefore \text{lag pf})
\[ = (1)(0.8) + (5)(0.6) \]
\[ = 3.8\% \]

30. Ans: (a)
Sol: \( V.R = (%R) \cos \phi_2 - (%X) \sin \phi_2 \) [at leading p.f.]
At leading power factor, Resistive drop and reactive drop are opposing (cancelled out) each other
\[ \therefore \text{Total drop} = \text{zero} \Rightarrow \text{V.R is zero.} \]

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
\[ \eta = 96.2\% \]
\[ \eta = \frac{12000 \times 1}{12000 \times 1 + \text{losses}} = 0.962 \]
\[ \Rightarrow 12000 + \text{losses} = 12474 \]
Losses = 474 W
When connected across 360 V,
The rating becomes = \[ \frac{12}{1 - k} \times \frac{12}{1 - \frac{2}{3}} = 36 \text{kVA} \]
\[ \therefore \text{Efficiency} = \frac{36000 \times 0.85}{36000 \times 0.85 + \text{losses}} \]
\[ = \frac{30,600}{30,600 + 474} = 98.5\% \]

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 \( V_{l1} = 230 \text{V} \)
Rated frequency, \( f_1 = 50 \text{Hz} \)
Applied frequency, \( f_2 = 25 \text{Hz} \)
Let,
Applied voltage to LV winding = \( V_{r2} \)
We know that in a transformer
\[ I_m \propto \phi \propto \frac{V}{f} \]
Given that magnetizing current (\( I_m \)) is constant
\[ \therefore I_{m1} = I_{m2} \]
\[ \frac{V_{l1}}{f_1} = \frac{V_{r2}}{f_2} \]
\[ \frac{230}{50} = \frac{V_{r2}}{25} \]
\[ \therefore V_{r2} = 115 \text{V} \]
\[ \therefore \text{Voltage applied to low voltage winding so that magnetizing current is same is 115V.} \]

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, \( V_1 = 230 \text{V} \)
Frequency of applied voltage, \( f = 50 \text{Hz} \)
Let,
\[ V_2 = \text{Voltage induced in the secondary winding} \]
\[ B_m = \text{Maximum value of flux density in the core} \]
We know that in a transformer, expression for voltage transformation is given by,
\[ \frac{V_1}{V_2} = \frac{N_1}{N_2} \]
\[ \frac{230}{400} = \frac{100}{2} \]
\[ V_2 = 920 \]
In a transformer, expression for induced emf is given by
\[ E = 4.44 B_m A f N \] volts
\[ V_1 = 4.44 B_m A f N \]
\[ 230 = 4.44 \times B_m \times 250 \times 10^{-4} \times 50 \times 100 \]
\[ B_m = 0.4144 \text{ Wb/m}^2 \]
Induced EMF in the secondary winding = 920V
Maximum value of flux density in the core = 0.4144 Wb/m²

03.
Sol: Given,
Applied voltage, \( V_0 = 2300 \text{V} \)
No load current drawn, \( I_0 = 0.3 \text{A} \)
Power consumed \( P_0 = 200 \text{W} \)
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 \( r_1 = 3.5 \Omega \)
\[ \therefore \text{Primary Copper losses } P_{cu} = I_0^2 r_1 \]
\[ = (0.3)^2 \times 3.5 \]
\[ P_{cu} = 0.315 \text{W} \]
Core losses, \( P_c = P_0 - P_{cu} \)
\[ = 200 - 0.315 \]
\[ = 199.685 \text{W} \]
Core losses = 199.685W

04.
Sol: Given,
Power rating of the transformer,
\( (VA) = 150\times10^3 \text{VA} \)
Full load copper losses, \( P_{cu} = 1600 \text{W} \)
Iron losses, \( P_c = 1400 \text{W} \)
Power factor \( Pf = 1 \)
Let,
\( x = \text{fraction of full loading} \)
(i) Loading = 25% of full load
\[ \therefore x = 0.25 \]
Efficiency of transformer
\[ \eta = \frac{x(\text{VA} P_f)}{x(\text{VA}) + P_c + x^2 P_{cu}} \] ------ (1)
\[ \eta = \frac{(0.25)(150\times10^3)(1)}{37500 + 1400 + 100} \]
\[ \eta = 96.15\% \]
(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, \( \eta_{\text{max}} = 98\% \)
Loading at which maximum efficiency, 
\[ x_m = \frac{3}{4} = 0.75 \]
\[ x_m = 0.75 \]
Power factor, \( pf = 1 \)
Iron losses, \( P_c = 314 \text{W} \)

Let,
VA = power rating of the transformer
\( P_{cu} = \) copper losses at full load
At maximum efficiency
\[ P_c = x_m^2 P_{cu} \]
\[ 314 = (0.75)^2 P_{cu} \]
\[ P_{cu} = 558.2\text{W} \]

Given that \( \eta_{\text{max}} = 98\% \)
\[ \eta = \frac{x(VA)pf}{x(VA)pf + P_c + x_m^2 P_{cu}} \] (1)
\[ \eta_{\text{max}} = \frac{x_m(VA)pf}{x_m(VA)pf + P_c + x_m^2 P_{cu}} \]
\[ 0.98 = \frac{(0.75)(VA)(1)}{(0.75)(VA)(1) + 314 + 314} \]

VA = 41029.3VA

(i) Loading =50% of full load
\[ \Rightarrow x = 0.5 \]
From (1)
\[ \eta = \frac{(0.5)(41029.3)(1)}{(0.5)(41029.3)(1) + 314 + (0.5)^2(558.2)} \]
\[ \eta = 97.8\% \]

(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\(\times\)10^3VA

Iron losses, \( P_c = 350\text{W} \)
Full load copper losses, \( P_{cu} = 400\text{W} \)
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
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, \( \eta_{\text{max}} = 97.1\% \)

07.
Sol: Given,
Power rating of the transformer,
VA = 40\(\times\)10^3 VA
Maximum efficiency, \( \eta_{\text{max}} = 97\% \)
Maximum efficiency occurs at 80% of full load
\[ X_m = 0.8 \]
Power factor, \( pf = 1 \)
Let $P_{cu} = \text{full load copper loss}$
$P_c = \text{core loss}$

At maximum efficiency,
Core losses = Copper losses
$P_c = x_m^2 P_{cu} \quad \cdots (1)$

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

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

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

$P_c = 494.8W$

From (1),
$P_{cu} = \frac{P_c}{x_m} = 773.2W$

$P_{cu} = 773.2W$

<table>
<thead>
<tr>
<th>Time (hrs)</th>
<th>Load ($P_0$) kW</th>
<th>$P_{cu}$ (W)</th>
<th>$E_{cu}$ (kWh)</th>
</tr>
</thead>
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<td>9</td>
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<td>494.8</td>
<td>4.453</td>
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<td>8</td>
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</tr>
<tr>
<td>7</td>
<td>30</td>
<td>494.8</td>
<td>3.463</td>
</tr>
</tbody>
</table>

$E_{ct} = 11.87kWh$

$E_0 = P_0 \times t$ (kWh) \quad P_{cu,x} = x^2 P_{cu} (W) \quad E_{cu,x} = P_{cu,x} \times t$ (kWh)

$54 \quad (0.25)^2 \times 773 = 48.3 \quad 0.434$
$200 \quad 470.4 \quad 3.76$
$210 \quad 536.5 \quad 3.75$

$E_{ot} = 464 \text{ kWh}$ \quad $E_{cu,t} = 7.94 \text{ kWh}$
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) = \(50 \times 10^3\) VA

Loading at which maximum efficiency occurs = 90% of full load
\[ x_m = 0.9 \]

Maximum efficiency, \(\eta_{\text{max}} = 97.4\% \)

Let \(P_{\text{cu}}\) = full load copper losses
\(P_c\) = core losses

At maximum efficiency,
Core losses = copper losses and \(\text{pf} = 1\)
\[ P_c = x^2 P_{\text{cu}} \quad \text{(1)} \]

For a transformer
Efficiency,
\[ \eta = \frac{x \text{(VA)} \text{pf}}{x \text{(VA)} \text{pf} + P_c + x^2 P_{\text{cu}}} \quad \text{(2)} \]

\[ \eta_{\text{max}} = \frac{x_m \text{(VA)} \text{pf}}{x_m \text{(VA)} \text{pf} + P_c + x^2 P_{\text{cu}}} \]
\[ 0.974 = \frac{(0.9) \times (50 \times 10^3) \text{(1)}}{(0.9)(50 \times 10^3)(1)} + P_c + P_{\text{cu}} \]
\(P_c = 600.6\text{W} \)

From (1),
\[ 600.6 = (0.9)^2 P_{\text{cu}} \]
\(P_{\text{cu}} = 741.5\text{W} \)

(a) Given loading = full load
\(x = 1 \)

\[ \text{pf} = 0.8\ \text{lag} \]

from (2),
\[ \eta = \frac{\text{pf}}{\text{pf} + (0.8)(50 \times 10^3)(1) + (600.6)(1)} \]
\[ \eta = 96.75\% \]

(b) Loading = half load
\(x = 0.5\)
\(\text{pf} = 0.9\)
\[ \eta = \frac{\text{pf}}{\text{pf} + (0.9)(50 \times 10^3)(1/2)} \]
\[ \eta = 96.6\% \]

09. **Sol:** Given,

Initial frequency, \(f_1 = 50\text{Hz}\)
Core loss at 50Hz frequency, \(P_{c1} = 2000\text{W} \)

Final frequency, \(f_2 = 75\text{Hz} \)
Core loss at 75Hz, frequency, \(P_{c2} = 3200\text{W} \)

Also it is given that flux density, \(B\) is Constant

Hysteresis loss, \(P_h = k_n B^3 f\)
\[ P_h = C_1 f \quad \text{(1)} \]
\[ \text{Eddy current losses, } P_e = k_e B^2 f^2 \]
\[ P_e = C_2 f^2 \quad \text{(2)} \]

Core loss \(P_c = P_h + P_e \)
\[ P_c = C_1 f + C_2 f^2 \quad \text{(3)} \]
From (3),
\[ P_{c1} = C_1f_1 + C_2f_1^2 \]
\[ 2000 = 50C_1 + 50^2C_2 \]
\[ 40 = C_1 + 50C_2 \] -------(4)

From (3)
\[ P_{c2} = C_1f_2 + C_2f_2^2 \] -------(3)
\[ 3200 = C_1(75) + C_2(75)^2 \]
\[ 42.67 = C_1 + 75C_2 \] -------(5)

(4) – (5)
\[ 25C_2 = 2.67 \]
\[ C_2 = 0.1067 \text{ W/Hz}^2 \] -------(6)

Substituting (6) in (4) we get
\[ 40 = C_1 + 5.333 \]
\[ C_1 = 34.67 \text{ W/Hz} \] -------(7)

At 50Hz:
\[ P_{h1} = C_1f_1 \]
\[ P_{h1} = 1733.3 \text{ W} \]
\[ P_e = C_2f_1^2 \]
\[ P_{el} = 266.75 \text{ W} \]

At 75kHz:
\[ P_{h2} = C_1f_2 \]
\[ P_{h2} = 2600.25 \text{ W} \]
\[ P_{e2} = C_2f_2^2 \]
\[ P_{e2} = 600.18 \text{ W} \]

10. Ans: 2600 watt

Sol: Given \( V_1 = 1000 \text{ V}, f_1 = 50 \text{ Hz} \)
\[ V_2 = 2000 \text{ V}, f_2 = 100 \text{ Hz} \]
\[ W_{h1} = 700 \text{ W}, W_{e1} = 300 \text{ W} \]
\[ \frac{V}{f} = \text{constant} \]

Therefore, \( W_h \propto f \)

\[ W_{h2} \propto W_{h1} \left( \frac{f_2}{f_1} \right) = 700 \left( \frac{100}{50} \right) \]
\[ = 1400 \text{ watt} \]

\[ W_e \propto f^2 \]
\[ W_{e2} = W_{e1} \left( \frac{f_2}{f_1} \right)^2 = 300 \left( \frac{100}{50} \right)^2 \]
\[ = 1200 \text{ watt} \]

New core loss \( W_1 = W_{h2} + W_{e2} \]
\[ = 1400 + 1200 \]
\[ = 2600 \text{ watt} \]
\[
(\xi_x) = \frac{r_{el}}{Z_{1B}} = \frac{15.5}{312.5} = 4.96\%
\]
\[
\xi_r = 4.96\% \quad \text{(1)}
\]
Per unit reactance \( (\xi_x) = \frac{x_{el}}{Z_{1B}} = \frac{34.5}{312.5} \)
\[
\xi_x = 11.04\%
\]

(a) \( pf = 0.9 \text{lag} \)
\[
\cos \phi_2 = 0.9 \text{lag}
\]
Voltage regulation (R)
\[
= \xi_x \cos \phi_2 + \xi_x \sin \phi_2 \quad [\text{lag}]
\]
\[
\Rightarrow R = (4.96)(0.9) + (11.04)(0.436)
\]
\[
R = 9.27\% 
\]

(b) \( pf = 0.9 \text{lead} \)
\[
\cos \phi_2 = 0.9 \text{lead}
\]
Voltage regulation (R)
\[
= \xi_x \cos \phi_2 - \xi_x \sin \phi_2 \quad [\text{lead}]
\]
\[
\Rightarrow R = (4.96)(0.9) - (11.04)(0.436)
\]
\[
R = -0.35\% 
\]

12. **Sol:**

(a) Expression for voltage regulation is
\[
R = \xi_r \cos \phi_2 + \xi_x \sin \phi_2 \quad \text{(1)}
\]

For zero voltage regulation
\[
R = 0, \quad \Rightarrow \xi_r \cos \phi_2 + \xi_x \sin \phi_2 = 0
\]
\[
\Rightarrow \xi_r \cos \phi_2 = -\xi_x \sin \phi_2
\]
\[
\Rightarrow \tan \phi_2 = \frac{-\xi_x}{\xi_r}
\]
\[
\Rightarrow \phi_2 = \tan^{-1}\left(-\frac{\xi_x}{\xi_r}\right)
\]
\[
\Rightarrow \phi_2 = -\tan^{-1}\left(\frac{\xi_x}{\xi_r}\right)
\]

Power factor \( pf = \cos \phi_2 \)
\[
pf = \cos\left(\tan^{-1}\left(-\frac{\xi_x}{\xi_r}\right)\right)
\]

pf = \( \frac{\xi_x}{\sqrt{\xi_r^2 + \xi_x^2}} \), lead [\text{\therefore sign}]

Condition for zero voltage regulation is
\[
pf = \frac{\xi_x}{\sqrt{\xi_r^2 + \xi_x^2}}, \text{ lead}
\]
from (1)

for maximum regulation
\[
\frac{dR}{d\phi_2} = 0
\]
\[
\Rightarrow -\xi_r \sin \phi_2 + \xi_x \cos \phi_2 = 0
\]
\[
\xi_r \sin \phi_2 = \xi_x \cos \phi_2
\]
\[
\tan \phi_2 = \frac{\xi_x}{\xi_r}
\]
\[
\sin \phi_2 = \frac{\xi_x}{\sqrt{\xi_r^2 + \xi_x^2}} \quad \text{(2)}
\]
\[
\cos \phi_2 = \frac{\xi_r}{\sqrt{\xi_r^2 + \xi_x^2}}
\]

Substituting (2) in (1)
\[
\text{Max } R = \xi_r \frac{\cos \phi_2 + \xi_x \sin \phi_2}{\sqrt{\xi_r^2 + \xi_x^2}}
\]
\[
= \xi_r \left(\frac{\xi_r}{\sqrt{\xi_r^2 + \xi_x^2}}\right) + \xi_x \left(\frac{\xi_x}{\sqrt{\xi_r^2 + \xi_x^2}}\right)
\]
\[
= \frac{\xi_r^2 + \xi_x^2}{\sqrt{\xi_r^2 + \xi_x^2}}
\]
\[
= \xi_r \xi_x
\]
\[
= \text{Per unit impedance}
\]
Maximum voltage regulation = per unit impedance.

(b) Power rating of the transformer,
\[
(\text{VA})_B = 20 \times 10^3 \text{ VA}
\]
Primary rated voltage, \( V_{1B} = 2000\text{V} \)
Secondary rated voltage, \( V_{2B} = 200\text{V} \)
\[
r_1 = 3\Omega \quad x_1 = 5.3\Omega \\
x_2 = 0.05\Omega \quad x_2 = 0.1\Omega 
\]
\[ r_{eq} = r_1 + r_2 \left( \frac{N_1}{N_2} \right)^2 \]
\[ r_{eq} = 3 + 0.05 \left( \frac{2000}{200} \right)^2 = 3 + 0.05(100) \]
\[ r_{eq} = 8 \Omega \]
\[ x_{eq} = x_1 + x_2 \left( \frac{N_1}{N_2} \right)^2 \]
\[ x_{eq} = 5.3 + 0.1 \left( \frac{2000}{200} \right)^2 \]
\[ x_{eq} = 15.3 \Omega \]

Base impedance w.r.t. primary is
\[ Z_{1B} = \frac{V_{1B}^2}{(VA)_B} = \frac{(2000)(2000)}{20 \times 1000} \]
\[ Z_{1B} = 200 \Omega \]

Per unit resistance, \( \xi_r = \frac{r_{eq}}{Z_{1B}} \)
\[ \xi_r = \frac{8}{200} \]
\[ \xi_r = 4\% \]

Per unit reactance \( \xi_x = \frac{x_{eq}}{Z_{1B}} \)
\[ \xi_x = \frac{15.3}{200} \]
\[ \xi_x = 7.65\% \]

(i) pf = 0.8lag
Voltage regulation (R) = \( \xi_r \cos \phi_1 + \xi_x \sin \phi_2 \) [\( \phi_1 \) lagging]
\[ \Rightarrow R = 4(0.8) + 7.65(0.6) \]
\[ R = 7.79\% \]

(ii) pf = 1
Voltage regulation (R) = \( \xi_r \cos \phi_1 \pm \xi_x \sin \phi_2 \)
\[ R = 4(1) \pm 7.65(0) \]
\[ R = 7.79\% \]

(iii) pf = 0.707 leading
Voltage regulation (R) = \( \xi_r \cos \phi_1 - \xi_x \sin \phi_2 \)
\[ R = -2.58\% \]

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

\[ W_{cu\ \frac{1}{2} \text{ load}} = \left( \frac{1}{2} \right)^2 W_{cu \ \text{full load}} \]
\[ \therefore W_{cu \ \text{full load}} = 2^2 \times W_{cu \ \text{at half load}} = 2^2 \times 300 = 1200 W \]
Now copper losses at full load = 300 × 4 = 1200 W

(i) Rated load at 0.86 power factor lagging
\[ P_{out} = 25 \times 10^3 \times 0.866 = 21650 \text{ W} \]
\[ P_{losses \ at \ rated \ load} = W_{cu \ \text{full load}} + W_{core \ losses} \]
\[ = 1200 + 250 = 1450 \text{ W} \]
\[ \% \eta = \frac{P_{out}}{P_{in} + P_{losses}} \times 100 \]
\[ = \frac{21650}{21650 + 1200 + 250} \times 100 = 93.72\% \]
\[ \% \text{efficiency} = 93.72\% \]

(ii) All day efficiency:
Since core losses remains same for 24 hours
\[ W_{core \ loss} = 250 \text{ W} \]
Copper losses values depends on load:
\[ \frac{1}{4} \ \text{full load for 4 hour at 0.8 pf} \]
\[ W_{cu} = \left( \frac{1}{4} \right)^2 \times 1200 \times 800 = 800 \text{ W} \]
\[ E_{out} = \frac{1}{4} \times 25 \times 10^3 \times 0.8 \times 4 = 20 \text{ kWh} \]
\[ \frac{1}{2} \ \text{full load for 10 hours at 0.8 pf} \]
\[ E_{out} = \left( \frac{1}{2} \right)^2 \times 1200 \times 25 \times 10^3 \times 0.8 \times 10 = 100 \text{ kWh} \]
\[\frac{3}{4} \text{ full load for 6 hours } W_{cu}\]

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

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

**Full load for 4 hours at 0.9 pf**

\[W_{cu} = 1200 \times 4 = 4800 \text{ W}\]

\[E_{out} = 25 \times 10^3 \times 0.9 \times 4 = 90 \text{ kWh}\]

\[\therefore \text{ Total output for 24 hours } E_{out} = 20 \text{ kWh} + 100 \text{ kWh} + 90 \text{ kWh} + 90 \text{ kWh} = 300 \text{ kWh}\]

Total copper losses for 24 hours \(W_{cu}\)

\[= 800 \text{ W} + 3000 \text{ W} + 4050 \text{ W} + 4800 \text{ W} = 12.650 \text{ kW}\]

**Total core losses for 24 hours** \(E_{loss}\)

\[= 250 \times 24 = 6 \text{ kWh}\]

\[\therefore \text{ All day efficiency } = \frac{E_{out}}{E_{out} + E_{loss}} = \frac{300}{300 + 12.650 + 6} = 94.147\%\]

\[\therefore \text{ All day efficiency, } \%\eta = 94.147\%\]

14. **Sol:** Voltage regulation for lagging pf is

\[R = \xi_{r} \cos \phi_{2} + \xi_{x} \sin \phi_{2} \quad -----(1)\]

\[\xi_{r} = \text{ perunit resit tan e} \quad \xi_{x} = \text{ perunit reac tan ce}\]

Given,

\[R_{1} = 4\% \quad \cos\phi_{21} = 0.8 \quad -----(2)\]

\[R_{2} = 4.4\% \quad \cos\phi_{22} = 0.6 \quad -----(3)\]

Substituting (2) in (1)

\[4 = \xi_{r} 0.8 + \xi_{x} 0.6\]

\[20 = 4\xi_{r} + 3\xi_{x} \quad -----(4)\]

Substituting (3) in (1)

\[4.4 = \xi_{r} (0.6) + \xi_{x} (0.8)\]

\[22 = 3\xi_{r} + 4\xi_{x} \quad -----(5)\]

Solving (4) and (5) we get

\[\xi_{r} = 2\%\]

\[\xi_{x} = 4\%\]

(i) from (1)

\[\text{For maximum regulation, } \frac{dR}{d\phi_{2}} = 0\]

\[-\xi_{r} \sin \phi_{2} + \xi_{x} \cos \phi_{2} = 0\]

\[\tan \phi_{2} = \frac{\xi_{x}}{\xi_{r}}\]

\[\tan \phi_{2} = \frac{4}{2} = 2\]

\[\tan \phi_{2} = 2\]

\[\phi_{2} = 63.43^\circ\]

\[\text{Pf} = \cos \phi_{2} - 0.447\]

\[\text{Pf for maximum regulation} = 0.447 \text{ lag}\]

(ii) \[\xi_{x} = \frac{P_{cu}}{VA} \Rightarrow 0.02 = \frac{P_{cu}}{VA}\]

\[\Rightarrow P_{cu} = 0.02VA\]

\[P_{cu} = \text{ full load copper loss}\]

\[VA = \text{ Power rating of the transformer}\]

\[\text{Efficiency, } \eta = \frac{x(VA)\text{pf}}{x(VA)\text{pf} + P_{c} + x^{2}P_{cu}}\]

\[P_{c} = \text{ core loss}\]

Given \(P_{c} = P_{cu}\)

\[P_{c} = 0.02VA\]

\[\text{Power factor, pf} = 1 \text{ and } x=1 \text{ [\because full load]}\]

\[\therefore \eta = \frac{(I)(VA)(I)}{(I)(VA)(I) + 0.02VA + 0.02VA}\]

\[= \frac{1}{1.04}\]

\[\eta = 96.1\%\]
15. Sol: Given,

Maximum possible voltage regulation, max
power factor at which regulation is maximum = 0.3

We know that,
Maximum regulation = Per unit impedance ($\xi_x$)

\[ \xi_x = 6\% \] ------(1)

Power factor at which regulation is maximum is

\[ Pf = \frac{\xi_x}{\sqrt{\xi_x^2 + \xi_r^2}} = 0.3 \]

\[ \frac{\xi_x}{\xi_r} = 0.3 \]

\[ \xi_x = 1.8\% \] ------(2)

Substituting (2) in (1) we get

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

\[ \sqrt{(1.8)^2 + \xi_r^2} = 6 \]

\[ \xi_r = 5.72\% \]

Given,

Pf = 0.8 lead

\[ \therefore \text{Voltage regulation} R \]

\[ = \xi_r \cos \phi_2 - \xi_x \sin \phi_2 \quad [\because \text{lead}] \]

\[ R = 1.8(0.8) - 5.72(0.6) \]

\[ R = -2\% \]

16. Sol: Given,

Maximum efficiency of the transformer,
\[ \eta_{\text{max}} = 97\% \]

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, $\xi_x = 10\%$

Let, $P_{\text{cu}}$ = full load copper loss

$P_c$ = core loss

We know that, at maximum efficiency

Core loss = copper loss

\[ P_c = x_r^2 P_{\text{cu}} \quad \text{------(1)} \]

\[ P_C = (0.75)^2 P_{\text{cu}} \]

Efficiency of a transformer,

\[ \eta_{\text{max}} = \frac{x_m (\text{VA})Pf}{x_m (\text{VA})Pf + P_c + x_m^2 P_{\text{cu}}} \]

\[ 0.97 = \frac{(0.75)(500 \times 10^3)(1)}{(0.75)(500 \times 10^3)(1) + P_c + P_{\text{cu}}} \]

\[ P_c = 5.799\text{kW} \]

\[ P_{\text{cu}} = 10.31\text{kW} \]

We know that,

\[ \xi_r = \frac{P_{\text{cu}}}{VA} = 10.31 = 2.06\% \]

\[ \xi_x = \sqrt{\xi_r^2 + \xi_x^2} = 10\% \]

\[ \xi_x = 9.78\% \]

Power factor (Pf) = 0.8pf lagging

\[ \cos \phi_2 = 0.8 \]

\[ \sin \phi_2 = 0.6 \]

\[ \text{Regulation, } R = \xi_r \cos \phi_2 + \xi_x \sin \phi_2 \quad \text{[} \because \text{lagging}] \]

\[ R = 2.06(0.8) + 9.78(0.6) \]

\[ R = 7.52\% \]
 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,
\[ E = V + I_a R_a \]
\[ E = 200 + (50)(0.5) = 225V \]
For motors,
\[ V = E_b + I_a R_a \]
\[ 200 = E_b + (50)(0.5) \]
\[ E_b = 175 V \]

03. **Ans: (d)**
**Sol:** For constant power output,
\[ E_b I_a = \text{constant} \]
\[ V_1 I_a = V_2 I_a (2) \]
\[ I_{a2} = 100 A \]

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:**
\[ I_{sh} = \frac{250}{50} = 5A \]
\[ I_a = I_L + I_{sh} = 195 + 5 = 200A \]
\[ E = V + I_a R_a \]
\[ = 250 + (200)(0.05) \]
\[ E = 260 V \]

06. **Ans: (b)**
**Sol:** \( E \propto \phi N \)
\[ E_1 = K \phi_1 N_1 = 136.8V \]
\[ E_2 = K(2\phi_1)(0.75N_1) = 1.5 E_1 \]
\[ \therefore E_2 = 1.5 \times 136.8 = 205.2V \]

07. **Ans: (d)**
**Sol:** Under maximum power developed conditions \( E_b = \frac{V}{2} \)
At no load, speed \( (N_0) = 1200 \) rpm
No load voltage \( V = E_b \)
\[ N_2 = \frac{E_b}{E_0} \frac{V}{N_2} = \frac{1200}{V} \]
\[ N_2 = 600 \text{ rpm (speed under maximum power developed condition)} \]

08. **Ans: (b)**
**Sol:** \( P = 4, N = 1500 \) rpm
\[ f = ? \]
\[ N = \frac{120f}{P} \]
\[ 1500 = \frac{120 \times f}{4} \]
\[ f = 50 \text{ Hz} \]
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  
\[ E_{g1} \propto (\phi_{sh} + \phi_{se}) N = 200V \]  
If \( \phi_{se} = 0 \)  
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: \( I_L = 100 \, \text{A}, \, I_{sh} = \frac{200}{100} = 2 \, \text{A} \)  
\[ I_a = I_{sh} + I_L = 2 + 100 = 102 \, \text{A} \]  
\[ E = V + I_aR_a = 200 + (102)(0.01) \]  
\[ E = 201.02 \, \text{V} \]

14. Ans: (a)  
Sol: Maximum efficiency will be obtained only when, Variable losses = Constant losses  
\[ \text{................. (1)} \]  
(i.e. copper loss)  
From data;  
Total losses = Input – Output  
\[ = 20 \, \text{kW} - 17 \, \text{kW} = 3000 \, \text{W} \]  
But Total losses =  
Copper losses+ Constant losses  
\[ \text{................. (2)} \]

15. Ans: (d)  
Sol: For series motor \( I_L = I_f = I_a \)  
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,  
\[ E_g = \left( \frac{\phi Z N}{60} \right) \left( \frac{P}{A} \right) \]  
\( \therefore E_g \propto (N \phi) \)  
Torque developed,  
\[ T = \left( \frac{Z \phi P}{2 \pi} \right) \left( \frac{I_a}{A} \right) \]  
\( \therefore T \propto (\phi I_a) \)
Electrical power developed, \( P = E_b \cdot I_a \)

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 \( I_a \) is constant
\( \therefore I_a \) is supplied from constant current source
From data \( \Rightarrow \) as \( I_f \) is supplied from constant voltage source,

\[
\phi = \text{constant (} \therefore \phi \propto I_t \)
\]

\[
I_f = \frac{V}{R_{sh}} = \text{constant}
\]

\( \therefore T \propto (\phi, I_a) = \text{constant irrespective of motor speed.} \)

24. Ans: (b)
Sol:

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

\( \therefore T \propto I_a^2 \Rightarrow \sqrt{T} \propto I_a \) \quad \ldots \ldots \quad (1)

(when saturation and armature reaction are neglected)

\[
\text{Speed, } N \propto \frac{1}{\phi} \propto \frac{1}{I_a} \quad \ldots \ldots \quad (2)
\]

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

\[
N \propto \frac{1}{\sqrt{T}} \Rightarrow \text{Rectangular Hyperbola}
\]

Flux ‘\( \phi \)’ is constant when saturation & armature reaction are considered \( \Rightarrow T \propto I_a \)

\( \therefore \) Speed, \( N \propto \frac{1}{\phi} = \text{constant for any value of } \phi \)
Torque i.e., \( N \propto T \) characteristics approaches to straight line.

25. Ans: (c)
Sol: For differential compound motor,

\[
\phi_t = \phi_{sh} - \phi_{se}
\]

As load \( \uparrow \Rightarrow I_a \uparrow \Rightarrow \phi_{se} \uparrow \Rightarrow \phi_t \downarrow \)

But \( \uparrow \) No \( \phi \downarrow \Rightarrow \phi_t \downarrow \Rightarrow N \uparrow \)
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
\[ T \propto I_a^2 = \sqrt{T} \propto I_a \]
\[ N \propto \frac{1}{\phi} = \frac{1}{I_a} \propto \frac{1}{\sqrt{T}} \]
\[ N \propto \frac{1}{\sqrt{T}} \]
Rectangular hyperbola

28. Ans: (e)
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.
\[ \phi_1 = \phi_2 \text{ so } I_{a1} = I_{a2} \]

31. Ans: (b)
Sol: The speed control of dc shunt motor in both directions can be obtained by Ward Leonard method

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**Conventional Practice Solutions**

01.
Sol: Given,
- Terminal voltage, \( V_T = 230V \)
- Initial speed \( N_1 = 750 \text{ rpm} \)
- Armature current \( (I_{ca}) = 30A \)
- External resistance \( (R_{ext}) = 10\Omega \)
- Torque \( (T) \propto \text{ speed (N)} \)

Equivalent circuit of dc shunt machine

**Without external resistance:**

\[ V_t \]
\[ I_{a1} = 30A \]
\[ r_{a1} = 0 \]
\[ E_{b1} = 0 \]

From figure (1)
\[ E_{b1} = V_T - I_{a1} (r_a) \]
\[ E_{b1} = 230 - 30 (r_a) \]
\[ E_{b1} = 230 V \]

**With external resistance:**

\[ V_t \]
\[ I_{a2} \]
\[ r_f \]
\[ R_{ext} = 10\Omega \]
\[ r_{a1} = 0 \]
\[ E_{b2} \]

From figure (2)
\[ E_{b2} = V_T - I_{a2} (R_{ext} + r_a) \]
\[ E_{b2} = 230 - 30 (r_a) \]
\[ E_{b2} = 230 V \]

In shunt machine
\[ T \propto \phi I_a \]
\[ \therefore \frac{T_1}{T_2} = \frac{I_{a1}}{I_{a2}} \]  \[ \ldots (1) \]

But it is given that
\[ T \propto N \]
\[ \therefore \frac{T_1}{T_2} = \frac{N_1}{N_2} \]  \[ \ldots (2) \]
We know that in a shunt machine
\[ E_b \propto \phi N \]
\[ \therefore \frac{E_{b1}}{E_{b2}} = \frac{N_1}{N_2} \]............(3)
\[ \therefore \text{from (1), (2) and (3)} \]
\[ \frac{E_{b1}}{E_{b2}} = \frac{I_{a1}}{I_{a2}} \]............(4)
\[ 230 \times \frac{30}{230 - 10l_{a2}} = 30 \]
\[ 230l_{a2} = 9000 - 300l_{a2} \]
\[ I_{a2} = 13.02A \]............(5)
Substituting (5) in (3)
\[ \frac{230}{230 - 10l_{a2}} = \frac{750}{N_2} \]
\[ \therefore \text{N}_2 = 325.5 \text{ rpm} \]

02.
Sol: Given,
\[ V_t = 230 \text{ V} \]
\[ r_a = 0.2 \Omega \]
\[ r_f = 0.1 \Omega \]
\[ T = 70 \text{ Nm} \]
\[ N_1 = 1200 \text{ rpm} \]
\[ N_2 = 2000 \text{ rpm} \]
\[ I_{a2} = I_{a1}/2 \]
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 \[ P_{dev} = \frac{E_b}{I_a} = T \omega \]
\[ \therefore E_b I_a = T \omega \]

(230 – 0.3 I_a) I_a = (70) \times \frac{(1200)}{60} \times 2\pi
\[ 0.3I_a^2 - 230I_a + 8796.46 = 0 \]
\[ I_{a1} = 40.37 \text{ A} \]

(b) \[ I_{a2} = \frac{I_{a1}}{2} \]
\[ I_{a2} = 20.18 \text{ A} \]
\[ N_2 = 2000 \text{ rpm} \]
\[ E_b \propto \phi N \] [in dc motors]
\[ \frac{E_{b1}}{E_{b2}} = \frac{\phi_1 N_1}{\phi_2 N_2} \]
\[ V_t \times I_{a2} = \phi_1 \times 1200 \]
\[ 230 - 0.3I_a = \phi_1 \times 70 \times 2\pi \]
\[ 230 - 20.18 \times 0.3 = \phi_2 \times 2000 \]
\[ 217.89 - \frac{\phi_1}{2} \]
\[ 223.95 - \frac{2\phi_2}{2} \]
\[ \phi_2 = 0.6166 \phi_1 \]
\[ \therefore \% \text{ reduction in flux} = \frac{\phi_1 - \phi_2}{\phi_1} \times 100 \]
\[ = 38.3 \% \]
\[ \therefore \% \text{ reduction in flux} = 38.3 \% \]

03.
Sol: Given,
\[ V_t = 125 \text{ V} \]
\[ P_0 = 12.5 \text{ kW} \]
\[ r_f = 25 \Omega \]
\[ r_a = 0.1 \Omega \]
\[ V_b = 3.5 \text{ V} \]
Machine = dc shunt generator
Equivalent circuit of a dc shunt generator including brush voltage losses is as follows
\[ P_0 = V_t I_L \]
\[ 12.5 \times 10^3 = 125 \times I_L \]
\[ I_L = 100 \text{ A} \]
\[ I_f = \frac{V_t}{r_f} = \frac{125}{25} \]
\[ I_f = 5 \text{ A} \]
\[ I_a = I_L + I_f \]
\[ I_a = 105 \text{ A} \]
From the circuit,
\[ E_g = V_t + V_b + I_a r_a \]
\[ E_g = 125 + 3.5 + (105) (0.1) \]
\[ E_g = 139 \text{ V} \]

04. 

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

\[ \therefore \] % 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,
\[ r_a = 0.04 \Omega \]
\[ r_f = 110 \Omega \]
\[ V_f = 230 \text{ V} \]
\[ V_t = 230 \text{ V} \]
Core and mechanical loss (\( P_c \)) = 960\text{W}
Machine = separately excited generator
Field copper losses \( (P_{cu}) \) = \( \frac{V_f^2}{r_f} \)
\[ = \frac{(230)^2}{110} \]
\[ = 480.91\text{W} \]
(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 = \( P_{cu} + P_c \)
\[ = 480.91 + 960 \]
\[ = 1440.91 \text{ W} \]
At maximum efficiency,
Constant losses = variable losses
\[ 1440.91 = I_a^2 r_a \]
\[ \therefore I_a = 189.8 \text{ A} \]
(b) Power output at max efficiency is
\[ P_0 = V_t I_L \]
\[ P_0 = 230 \times 189.8 \text{ [} I_L = I_a \text{ for a separately excited generator}] \]
\[ \therefore P_0 = 43653.22 \text{ W} \]

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, \( \text{wb/m}^2 \) 
\( I = \) current in conductor, \( \text{A} \) 
\( L = \) length of conductor, \( \text{m} \) 
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 development 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, \( \phi = \) 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 
\[
T = \frac{E_bI_a}{\omega}
\]
Where, \( \omega = \frac{2\pi N}{60} \)
\( E_b = \frac{ZN\phi}{60} \left( \frac{P}{A} \right) \) 
\( T = 0.159 \frac{\phi Z P A}{A} \text{ N-m} \) 
\( = 0.162 \frac{\phi Z P A}{A} \text{ Kg – m} \) 
From the above relation we can write the Torque equation 
\[
T = K\phi I_a
\]
Where, \( K = \left( \frac{0.159 P Z}{A} \right) \) 

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 
\[
T_e = \frac{E_aI_a}{\omega_m}
\]
\[
T_e = \frac{E_aI_a}{2\pi N_s} = \frac{230 \times 40 \times 60}{2 \times \pi \times 1200} \]
\( T_e = 73.21 \text{ N-m} \) 
(iv) If the load is thrown off, the generated voltage is equal to the terminal voltage i.e. 240 volts. 
\[
E_a' = K'\phi N_0
\]
\[ \frac{E_a}{E_a^0} = \frac{N}{N_0} \]
\[ \frac{230}{240} = \frac{1200}{N_0} \]
\[ N_0 = 1252 \text{ rpm} \]

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, \[ \omega_m = \frac{V_t - I_a r_a}{K_a \phi} \]

(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 \( \omega_{m0} \).

Since \( I_a \) at no-load is negligibly small, the shunt motor no-load speed \( \omega_{m0} \) 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 \( \phi \) 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

\[ \omega_m = \frac{V_t - I_a r_a}{K_a \phi} \]

But \( T_e = K_a \phi I_a \) or \( I_a = \frac{T_e}{K_a \phi} \)

Substituting this value of \( I_a \) in
\[ \omega_m = \frac{1}{K_s \phi} \left[ \frac{V_i - T_e r_a}{K_s \phi} \right] \]
\[ = \frac{V_i}{K_s \phi} - r_a \frac{T_e}{K_s^2 \phi^2} \]
\[ = \omega_m - r_a \frac{T_e}{K_s^2 \phi^2} \]

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 \( \phi \), due to saturation and armature reaction. Since with increase of \( T_e \), \( \phi \) is reduced, \( T_e/\phi^2 \) 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 \((K_s\phi)^2\) 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 weakening the flux, \( N_1 = 960 \text{ rpm} \)
\[ I_{a1} = 50A \]
\[ \therefore \] Back EMF, \( E_{b1} = V - I_{a1} R_a = 200 \]
\[ - (50 \times 0.2) = 190V \quad \text{............ (1)} \]

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

\[ \Rightarrow T_2 = T_1 \]
\[ \Rightarrow \phi_2 I_{a2} = \phi_1 I_{a1} \]
\[ \Rightarrow (0.9\phi_1) I_{a2} = \phi_1 I_{a1} \]
\[ \therefore I_{a2} = \frac{I_{a1}}{0.9} = \frac{50}{0.9} = 55.5A \]

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, \( N \propto \frac{E_b}{\phi} \)

\[ \Rightarrow \frac{N_2}{N_1} = \frac{E_{b2} \phi_1}{E_{b1} \phi_2} \]
\[ \Rightarrow N_2 = 960 \times \frac{189.9}{190} \times \frac{\phi_1}{0.9\phi_1} \]
\[ = 1066.105 \text{ rpm} \]
\[ \therefore \] New motor speed, \( N_2 \approx 1066 \text{ rpm} \)

10.

Sol: Given data: \( V_i = 500V \),

output power = \( 25 \text{ HP} = 25 \times 746 \text{ W} \)
\[ R_f = 650\Omega, \quad R_a = 0.57\Omega, \quad I_L = 2.4A, \]

\[ V_b = 2V \quad (\text{brush drop}) \]
\[ I_f = \frac{500}{650} = 0.77A \]

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

Constant losses = \( V_b I_L - \frac{I_{a0}^2 R_a - V_b I_{a0}}{2} \)

(Where \( V_b \) = brush drop)
\[ = 500 \times 2.4 - (1.63)^2 \times 0.57 - 2 \times 1.63 \]
\[ = 1195.23 \text{ W} \]
Near at full load, $E_b I_a = 25 \times 746$
(power output)

Power input = power output + total losses.

$500(I_a + 0.77)$

$= 25 \times 746 + V_b I_a + \text{constant losses}$

$+ I_a^2 (0.57)$

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

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

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

$I_a = 831.96A, 41.04A$

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

Input = $V_t(I_a + I_0) = 500(41.04 + 0.77)$

$= 20905 \text{ W}$

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

$= 89.21\%$

11. Sol: Given,

$I_{d1} = 50A$

$V_t = 250 \text{ V}$

$N_2 = 1.4 N_2$

$T_2 = 1.4 T_2$

$r_a = 0.2 \Omega$

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

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

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

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

$E_{b1} = \phi_1 N_1$

$E_{b2} = \phi_2 N_2$

12. Sol: Given,

$V_t = 220 \text{ V}$

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

$I_{d1} = 15 \text{ A}$

$N_1 = 1000 \text{ rpm}$

$R_{ext} = 4.5 \Omega$

$I_{d2} = 10 \text{ A}$

Machine = dc series motor

Equivalent circuit of the motor without external resistance is as follows
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:

With external resistance:

\[ V_t = E_{b2} + I_{a2} (r_a + r_f + R_{ext}) \]
\[ 220 = E_{b2} + 15 (1 + 4.5) \]
\[ E_{b2} = 165 \ V \]

We know that,
\[ E_b \propto \phi N_1 \]
\[ \therefore \frac{E_{b1}}{E_{b2}} = \frac{\phi_1 N_1}{\phi_2 N_2} = \frac{I_{a1} N_1}{I_{a2} N_2} \]
\[ [\therefore \phi \propto I_a \text{ in series machine}] \]
\[ 205 = (15) \times 1000 \]
\[ 165 = 10 \times N_2 \]
\[ N_2 = 1207.3 \ rpm \]

14. Sol: Given,
\( P_0 = 5 \ kW \)
\( V_t = 250 - 0.5 I_L \)
Machine = dc shunt generator
In a dc shunt generator,
\[ P_0 = V_t I_L \]
\[ 5000 = (250 - 0.5 I_L) I_L \]
\[ 0.5 I_L^2 - 250 I_L + 5000 = 0 \]
\[ I_L = \frac{250 \pm \sqrt{(250)^2 - 4 \times 0.5 \times 5000}}{2 \times 0.5} \]
\[ I_L = 20.87 \ A \]
\[ V = 250 - 0.5 I_L = 250 - 0.5 (20.87) \]
\[ \Rightarrow V = 239.56 \ V \]
\[ R_L = \text{Load resistance} = \frac{V}{I_L} \]
\[ R_L = 11.48 \ \Omega \]
15. 
**Sol:** Given,  
\[ V_{t1} = 100V \]  
\[ P_{01} = 5kW \]  
\[ r_s + r_{sc} = 0.5\Omega \]  
\[ N_1 = 1000 \text{ rpm} \]  
\[ V_{t2} = ? \]  
\[ P_{02} = 8kW \]  
\[ N_2 = 1500 \text{rpm} \]  
Machine = dc series generator

**Equivalent circuit**

With initial conditions:

\[ E_{g1} = V_{t1} + I_{a1} (r_s + r_{sc}) \]  
\[ E_{g1} = 100 + I_{a1} (0.5) \]

With final conditions:

\[ E_{g2} = V_{t2} + I_{a2} (r_s + r_{sc}) \]  
\[ E_{g2} = V_{t2} + I_{a2} (0.5) \]

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  
\[ E_g \propto \phi N \]

\[ E_{g} \propto I_a N \]  
\[ E_{g1} = I_{a1} N_1 \]  
\[ E_{g2} = I_{a2} N_2 \]

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

\[ V_{t2} = 3.25 I_{a2} \]  
\[ \text{(i)} \]

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 \((V_{L1}) = 220V\)

\[ \text{Terminal voltage} \ (V_1) = 270 - \frac{50}{30} I_1 \]

\[ V_1 = 270 - \frac{5 I_1}{3} \]  
\[ \text{(i)} \]

**Machine 2**

No load terminal voltage \((V_{02}) = 280V\)  
Terminal voltage at 30A current \((V_{L2}) = 220V\)

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

\[ V_2 = 280 - 2 I_2 \]  
\[ \text{(i)} \]

When both machines are operating in parallel.

\[ I_L = I_1 + I_2 \]  
\[ \text{Given load current} \ I_L = 50A \]  
\[ I_1 + I_2 = I_L = 50A \]

\[ \therefore I_1 + I_2 = 50A \]  
\[ \text{(i)} \]

Make over  
\[ V_1 = V_2 = V \]
\[
270 - \frac{5}{3} I_1 = 280 - 2I_2 \\
2I_2 - \frac{5}{3} I_1 = 10 \\
6I_2 - 5I_1 = 30 \quad \text{----(2)}
\]

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 \( R_L = 10\Omega \)
\[
V = I_1 R_L = 10I_1 = 10(I_1 + I_2) \\
\therefore V_1 = V_2 = V = 10 (I_1 + I_2) \\
280 - 2I_2 = 10I_1 + 10I_2 \\
10I_1 + 12I_2 = 280 \\
5I_1 + 6I_2 = 140 \quad \text{-----(3)}
\]

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

17. Sol:

Given,
\[
V_t = 230V \\
r_a = 0.5\Omega \\
r_f = 230\Omega \\
N_0 = 1000\ rpm \\
I_{L0} = 3A \\
I_{Lf} = 23A \\
\phi_2 = \phi_1 - \frac{2\phi_1}{100} = 0.98\phi_1 \quad [\therefore 2\%\ drop]
\]

Machine = dc shunt motor

Equivalent circuit:

\[
\begin{align*}
I_f &= 1A \\
I_{a0} &= I_{L0} - I_f \\
I_{a0} &= 2A \\
E_{bo} &= V_t - I_{a0} r_a \\
E_{bo} &= 230 - 2\times0.5 \\
E_{bo} &= 229V \\
\text{No load losses (rotational) } P_{rot} &= E_{bo} I_{a0} \\
P_{rot} &= 458W
\end{align*}
\]

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

Power developed \( P_{dev} \) = \( E_b I_a \)
\[
P_{dev} = 4818\ W \\
\text{Load power } (P_o) = P_{dev} - P_{rot} \\
= 4818 - 458 \\
P_o = 4360W
\]

\[
E_{bo} = \frac{\phi_1 N_1}{\phi_2 N_2} \\
\frac{229}{219} = \frac{\phi_1 \times (1000)}{(0.98)\phi_1 \times N_2}
\]

\[
N_2 = 975.85rpm \\
N_2 \approx 976\ rpm
\]

\[
P_o = \frac{4360}{976 \times 2\pi} = 42.60Nm
\]

Torque output \( T_0 = 42.60\ Nm \)
18. **Sol:** At the time of starting, the motor speed is zero.

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

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

\[
I_a = \frac{V}{r_a} \text{ (shunt motor)}
\]

\[
I_a = \frac{V}{(r_a + r_s)} \text{ (series and compound)}
\]

\( r_a \) & \( r_s \) 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](image)
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 rest.

Series Motor:

In this method the motor is disconnected from 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.
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 depend 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 the same speed.  
\[ N_s_1 = N_s_2 \]  
\[ \frac{120f_1}{p_1} = \frac{120f_2}{p_2} \]  
\[ \Rightarrow f_1 = \frac{p_1}{p_2} f_2 \]  
\[ \Rightarrow \frac{p_1}{p_2} = \frac{50}{60} = \frac{5}{6} = \frac{10}{12} \]  
\[ \Rightarrow p_1 : p_2 = 10 : 12 \]  
Every individual magnet should contain two poles, such that number of poles of any magnet always even number.  
- \( G_1: p = 10, \ f = 50 \text{ Hz} \)  
  \[ \Rightarrow N_s = 600 \text{ rpm} \]  
- \( G_2: p = 12, \ f = 60 \text{ Hz} \)  
  \[ \Rightarrow N_s = 600 \text{ rpm} \]

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  
\[ \theta_{elec} = \frac{p}{2} \theta_{mech} \]

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 (kd):
\[
k_d = \frac{\text{The e.m.f induced with Distributed winding}}{\text{The e.m.f induced with Concentrated winding}}
\]
\[
k_d = \frac{\text{The vector sum of induced e.m.f}}{\text{The arithmetic sum of induced e.m.f}}
\]

\[
k_d = \frac{\sin\frac{m\gamma}{2}}{m\sin\frac{\gamma}{2}}
\]

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

For concentrated winding, \( k_d = 1 \)
\[
k_{d1} = k_{d2} = k_{d3} = \ldots = 1
\]
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 \( \frac{1}{n}F_i \)
for \( 7^{th} \) space harmonic is \( \frac{1}{7} \times F_i \)
\[
F_i = \frac{120 \times 50}{8} = 750 = \frac{1}{7} \times 750 = 107.14
\]
In forward direction
\( (6K \pm 1) = \text{‘+’ for forward} \)
12. **Ans: (b)**

**Sol:** Alternator working under

(i) ZPF lag pf

\[ E = 4.44 k_p k_d \phi f T \]
\[ E \propto \phi \propto I_f \]
\[ E \propto I_f \]

\[ \therefore E \text{ vs } I_f \Rightarrow \text{linear} \Rightarrow \text{Before saturation} \]
\[ \Rightarrow \text{Non-linear} \Rightarrow \text{After saturation} \]

(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)

\[ E = 400V \]
\[ I_f = 10A \]

\[ Z_s = X_s = \frac{E_{OC}}{I_{SC}} \]
\[ I_f = \text{constant} \]

Up to knee point both OCC & SCC are linear.

14. **Ans: (b)**

**Sol:**
\[ Z_s \] 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:  
\[
S.C.R = \frac{1}{X_s \text{ (adjusted saturation) P.U}}
\]

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  
\[
\Rightarrow P = \frac{EV}{X_s} \sin \delta
\]
  \[ \Rightarrow P = P_{max} \sin \delta \]

\[ \therefore \quad P_{max} = \frac{EV}{X_s} \]
\[ \Rightarrow P_{max} \propto E, V \]
\[ \Rightarrow P_{max} \propto I_f \text{ and } V \quad [ \therefore \quad E \propto I_f ]
\]

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 \( \propto \frac{1}{\cos \theta} \)

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.

\[ f = \frac{P.N}{120} \]; so, to get fixed frequency, if \( P \uparrow \)
\[ \Rightarrow N \text{ should be reduce.} \]
Here \( P = \) number of poles of the machines and \( N = \) speed of rotor.
24. Ans: (d)
Sol: Salient pole synchronous machine:
\[ P = \frac{EV}{X_d} \sin \delta + \frac{V^2}{2} \left( \frac{1}{X_d} - \frac{1}{X_s} \right) \sin 2\delta \]

25. Ans: (a)
Sol: 
\[ I_a \rightarrow V - \text{curve.} \]

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 \( \delta = 90 \)

\[ P_m = \frac{EV}{X_s} \]
31. Ans: (b)
Sol: When excitation of salient 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:

\[
\begin{align*}
I_a & \rightarrow V \text{ – curve.} \\
I_r (\text{Excitation}) &
\end{align*}
\]

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,
\[ VA = 1000 \, \text{kVA} = S_i \]
\[ \text{pf} = 0.8 \text{ lag} = \cos \phi_i \]
for synchronous condenser,
\[ (VA) = 750 \, \text{kVA} = S_c \]
\[ \text{pf} = 0.6 \text{ lead} = \cos \phi_c \]

\[ \begin{align*}
\text{Supply} & \\
750\text{kVA} & 0.6\text{lead} \rightarrow \text{SC} \\
1000\text{kVA} & 0.8\text{lag} \rightarrow \text{IM}
\end{align*} \]

**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:**
\[ P_c = S_c \cos \phi_c = 750 \times 0.6 \]
\[ P_c = 450\text{ kW} \]
\[ Q_c = S_c \sin \phi_c = 750 \times 0.8 = 600\text{ kVAR} \]
\[ Q_c = 600\text{ kVAR} \]

\[ \therefore S_i = P_i + j\theta_i \quad [\because \text{lag}] \]
\[ S_i = (800 + j600) \]

\[ \text{But } S_c = P_c - jQ_c \quad [\because \text{lead}] \]
\[ S_c = (450 - j600) \]

Apparent power from supply is
\[ S_s = S_i + S_c \]
\[ = (800 + j600) + (450 - j600) \]
\[ = (1250 + j0) \text{ kVA} \]

\[ \Rightarrow \text{Supply power factor } = \frac{P_s}{S_s} = \frac{1250}{1250} = 1 \]

\[ \therefore \text{Supply power factor } = 1 \]
02. Sol: Given,
(VA) = 1600 kVA
V_L = 11kV ⇒ V_p = 6350.85V
X_s = 30 Ω/phase
r_a = 0 \[∵ \text{negligible}\]

Base impedance \( Z_B = \frac{V_L^2}{(VA)} \)
= \( \frac{11 \times 10^3}{1600 \times 10^3} \)
= 75.625 Ω

X_{rs} = X_s = 30 Ω/phase
X_s = 0.3967pu

Zero regulation is possible only in leading pf case
\( \bar{E}_r = \bar{V}_r + j\bar{I}_sX_s \) [for alternator neglecting \( r_a \)]
\( \bar{E}_r = 1 + j0 + j[\cos \phi + j\sin \phi](0.3967) \)
\( \bar{E}_r = [1 - 0.3967 \sin \phi] + j(0.3967 \cos \phi) \)

1 = I^2 + (0.3967)^2 \( \sin^2 \phi + \cos^2 \phi \) - 2(0.3967)\sin \phi \( \phi = 11.44^\circ \)
\( \therefore \cos \phi = 0.98, \text{ lead} \)
(ii) Insufficient data

03. Sol: Given, \( X_d = 1.4 \)
\( X_q = 1 \)
\( r_a = 0 \)
\( \text{pf} = 1 \)
⇒ \( \cos \phi = 1 \)
⇒ \( \phi = 0 \)

04. Sol: Given,
\( V_L = 11kV ⇒ V_p = \frac{11000}{\sqrt{3}} = 6350.35V \)
\( r_a = 0.3 \Omega/\text{Phase} \)
\( X_s = 5\Omega/\text{phase} \)
(VA) = 2000 kVA
\( \text{Pf} = 0.8\text{lag} \)

Rated current \( (I_a) = \frac{(VA)}{\sqrt{3}V_L} \)
= \( \frac{2000 \times 10^3}{\sqrt{3} \times 11 \times 10^3} \)
= 104.97A

By taking terminal voltage as reference
\( \bar{E}_r = \bar{V}_r + j\bar{I}_sZ_s \)
\[ \therefore V_t = V_p < 0^\circ \quad [\therefore \text{reference}] \]

\[ \bar{I}_s = I_s (0.8 - j0.6) \quad [\therefore \text{pf} = 0.8\text{lag}] \]

\[ Z_s = (r_s + jX_s) = (0.3 + j5) \]

\[ \therefore \bar{E}_t = \bar{V}_t + \bar{I}_s \bar{Z}_s \]

\[ = 6350.85 + j0 + 104.97 (0.8 - j0.6) \]

\[ = 6350.85 + 104.97 (3.24 + j3.82) \]

\[ = 6690.95 + j400.98 \]

\[ |E_t| = 6702.95V \quad \ldots \ldots (1) \]

In the second case,

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

\[ \therefore \bar{E}_t = \bar{V}_t + \bar{I}_s \bar{Z}_s \]

\[ \bar{E}_t = V_t \angle 0^\circ + 104.97(0.8 + j0.6)(0.3 + j5) \]

\[ \bar{E}_t = V_t + j0 + 104.97(-2.76 + j4.18) \]

\[ \bar{E}_t = (V_t - 289.71) + j(438.77) \]

\[ |E_t| = \sqrt{(V_t - 289.71)^2 + (438.77)^2} \]

\[ (6702.95)^2 = (V_t - 289.71)^2 + (438.77)^2 \]

\[ \Rightarrow V_t = 6978.3V \]

\[ \therefore V_L = V_t \sqrt{3} \]

\[ V_L = 6978.3 \times \sqrt{3} \]

\[ V_L = 12086.7V \]

\[ \therefore \text{Terminal voltage} = 12.0867kV \]
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.
\[ \text{rpm} = 1000 - \frac{120 \times 50}{6} = 1000 \text{rpm} \]
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

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:

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.

\frac{300}{P} = \frac{120 \times 50}{4}

\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:

\begin{align*}
\text{Breaking mode} & \quad \text{Motoring mode} & \quad \text{Generating mode} \\
\text{Slip} & \quad +1 & \quad 0 & \quad -1
\end{align*}

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:

\begin{align*}
\frac{T_{st}}{T_{FL}} & = \frac{2s_m}{1 + s_m^2} \\
\text{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 \text{ rpm}
\end{align*}

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

\begin{align*}
N_s & = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000 \text{ rpm} \\
N_r & = 975 \text{ rpm (Given)}
\end{align*}
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
\[ \therefore \% \eta = \frac{36.025}{40} \times 100 = 90.0625\% \]

15. Ans: (c)
Sol: Slip \( s = 5\% = 0.05 \)
Rotor output/gross mechanical power developed \( P_{r0} = 20 \) kW
Rotor copper loss = \( \frac{s}{1-s} \times P_{r0} \)
\[ = \frac{0.05}{1-0.05} \times 20 \text{ k} = 1052 \text{ W} \]

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: \[ T_e = \frac{180}{2\pi N_s} \times \frac{SE^2 R_2}{R_2^2 + (SX_2)^2} \]
\[ T_e \propto V^2 \]
\[ T_e = \frac{T_1}{4} = \frac{500}{4} = 125 \text{ Nm} \]

18. Ans: (*)
Sol: Slip at maximum torque,
\[ S_{Tm} = \frac{r_2}{X_2} = \frac{0.21}{0.7} = 0.3 \]
The speed at maximum torque,
\[ N_{Tm} = N_s(1 - S_{Tm}) \]
\[ N_{Tm} = 1500 (1 - 0.3) \]
\[ N_{Tm} = 1050 \text{ rpm} \]

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 \( N_s = N_s \) 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.
\[ \Rightarrow \text{EMF induced in the rotor winding is zero.} \]
\[ \Rightarrow \text{Current’s in rotor winding is zero.} \]
\[ \text{Hence torque production is zero} \]
\[ \Rightarrow \text{At } N = N_s \text{ ; rotor won’t rotate, hence called “Asynchronous machine”}. \]
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: 
\[
\frac{T_{st}}{T_{FL}} = X^2 \left( \frac{I_{st}}{I_{FL}} \right)^2 \times S
\]
\[
\frac{1}{4} = X^2 (4)^2 \times 0.03
\]
\[
X = 72.2\%
\]

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 5th and 7th harmonics. The 5th 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 ($s \times \text{Airgap power}$) 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.
01.
Sol: Given,
Number of poles, \( P = 4 \)
Frequency \( f_1 = 50 \)Hz
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 \( f_2 = sf_1 \)
\[ \Rightarrow f_2 = \frac{3.33 \times 50}{100} \]
\[ f_2 = 1.67\text{Hz} \]

(c) Angular velocity of stator field w.r.t stator
= \( N_s \)
= 1500 rpm
Angular velocity of stator field w.r.t rotor
= \( sN_s \)
\[ = \frac{3.33 \times 1500}{100} \]
\[ = 50 \text{ rpm} \]

(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, \( N_{f1} = 950 \) rpm
Frequency \( f_1 = 50 \)Hz
In an induction motor ,No Load speed is very close by to synchronous speed \( N_s = 1000 \) rpm

(a) We know synchronous speed, \( N_s = \frac{120f_1}{p} \)
\[ \Rightarrow 1000 = \frac{120 \times 50}{p} \]
\[ \Rightarrow p = 6 \]
\[ \therefore \text{Number of poles, } p = 6 \]

(b) Slip, \( s = \frac{N_s - N}{N_s} \)
\[ \Rightarrow s = \frac{1000 - 950}{1000} \]
\[ s = 0.05 = 5\% \]

(c) Frequency of rotor voltage \( f_2 = sf_1 \)
\[ \Rightarrow f_2 = 0.05 \times 50 \]
\[ f_2 = 2.5\text{Hz} \]

(d) Speed of rotor field w.r.t rotor = \( sN_s \)
\[ = 0.05 \times 1000 \]
\[ = 50 \text{ rpm} \]

(e) Speed of rotor field w.r.t stator = \( N_s \)
\[ = 1000 \text{ rpm} \]
03.
Sol: Given,
Power rating of the machine, \( P_0 = 10 \text{kW} \)
Number of poles, \( p = 6 \)
Frequency, \( f_1 = 50 \text{Hz} \)
Full load slip, \( S = 0.04 \)

At full load,
Power output = machine rating
\( P_0 = 10 \text{kW} \)

Given,
Friction and windage losses, \( P_{f\&w} = 4\% \) of output
\[ \therefore P_{f\&w} = 0.04 \times P_0 = 0.04 \times 10 \times 10^3 = 400 \text{W} \]

Power flow in an induction motor is as follows

1. Mechanical power developed (\( p_{em} \)) = power output (\( P_0 \)) + friction and windage losses (\( P_{f\&w} \))
\[ \Rightarrow P_{em} = P_0 + P_{f\&w} = 10000 + 400 = 10400 \text{W} \]

Rotor copper losses
\[ \text{Mechanical power developed} (p_{em}) = \frac{S P_{ag}}{(1-S) P_{ag}} = \frac{S}{1-S} \]

Rotor copper losses
\[ \frac{0.04}{1-0.04} = \frac{1}{24} \]

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

Rotor copper losses = 433.3 W

2. Full load electromagnetic torque, \( T_{em} = \frac{P_{em}}{\omega} \)
\[ T_{em} = \frac{10400}{\omega_s (1-s)} = \frac{10400}{\omega_s (1-0.04)} \]
Synchronous speed, \( N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000 \text{ rpm} \)

\( N_s = 1000 \text{ rpm} \)

\[ \omega_s = \frac{N_s \times 2\pi}{60} \]

\[ \omega_s = 104.72 \text{ rad/s} \]

\[ T_{em} = \frac{10400}{104.72(1 - 0.04)} \]

\[ T_{em} = 103.45 \text{ Nm} \]

(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, \( P_r = 30kW \)

Full load slip, \( S_f1 = 0.03 \)

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

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

Rotor currents per phase, \( I_r = 45 \text{ A} \)

Power flow in induction motor is as follows,

\[
\begin{align*}
\text{Power input} & \rightarrow \ P_{ag} \\
\text{Air gap power} & \rightarrow \ (1-S)P_{ag} \\
\text{Stator losses} & \rightarrow \ S P_{ag} \\
\text{Rotor losses} & \rightarrow \ P_{rot} \\
\text{Mechanical losses} & \rightarrow \ \text{Mechanical power developed} \\
\text{Power output} & = P_{em} \\
\end{align*}
\]

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

\[ P_{rot} = \frac{1.5}{100} \times 30000 \]

\[ P_{rot} = 450 \text{ W} \]

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

\[ P_{em} = P_0 + P_{rot} \]

\[ P_{em} = 30000 + 450 \]

\[ P_{em} = 30450 \text{ W} \]
05.

Sol: Given,
Poles, \( P = 6 \)
Frequency, \((f_1) = 50\text{Hz}\)
Speed of motor \((N) = 935\text{rpm}\)
Stator losses, \((P_{Sl}) = 400\text{W}\)
Friction and windage losses \((P_{f&w}) = 1\% \) of output
Rating of the motor \((P_0) = 5\text{hp} = 3675\text{W}\)
\([1\text{hp}=735\text{W}]\)
\(P_0 = 3675\text{W}\)
\(P_{f&w} = 1\% \text{ of } P_0 = \frac{1}{100} \times 3675\text{W}\)
\(P_{f&w} = 36.75\text{W}\)

Mechanical power developed \(P_{em}\)
= Power output \((P_0)\)
+ friction and windage losses \((P_{f&w})\)
\(P_{em} = P_0 + P_{f&w} = 3675 + 36.75 = 3711.75\text{W}\)

Airgap power \(P_{ag}\)
\(= \frac{P_{em}}{1 - S} = \frac{3711.75}{1 - S} \)

Synchronous speed, \(N_S\)
\(= \frac{120f_1}{P} = \frac{120 \times 50}{6} = 1000\text{rpm}\)

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

Rotor copper losses
\(30450 = \frac{3}{1 - 0.03} = \frac{97}{97} \)

Rotor copper losses = \(\frac{3}{97} \times 30450 = 941.75\text{W} \)

Rotor copper losses = \(3I_r^2r = 941.75 \quad r_r = 0.155\Omega \)

\[
S = \frac{N_S - N}{N_S} = \frac{1000 - 935}{1000} = 0.065 \\
S = 0.065
\]

\[
P_{ag} = \frac{3711.75}{1 - 0.065} = 3969.8\text{W} \\
P_{ag} = 3969.8\text{W}
\]

(a) Power input \((P_{in})\)
\(= \text{Air gap power } (P_{ag}) + \text{stator losses } (P_{sl}) \)
\(P_{in} = P_{ag} + P_{sl} = 3969.8 + 400 = 4369.8\text{W} \)
\(. \) Input power = 4369.8W

(b) Given,

Speed at maximum torque, \(N_{mT} = 800\text{rpm}\)
\(\therefore S_{mT} = \frac{N_S - N_{mT}}{N_S} = \frac{1000 - 800}{1000} = 0.2 \)

We know that
\[
T_{fl} = \frac{2}{S_{fl}} \\
T_{max} = \frac{S_{fl}}{S_{mT}} + \frac{S_{mT}}{S_{fl}} \\
T_{st} = \frac{2S_{mT}}{S_{mT}^2 + 1} \\
T_{max} = \frac{2S_{mT}S_{fl}}{S_{mT}^2 + S_{fl}^2} \times \frac{S_{mT}^2 + 1}{2S_{mT}}
\]
\[
\frac{T_{f1}}{T_{st}} = \frac{\left( S_{mT} + 1 \right) S_{f1}}{\left( S_{mT}^2 + S_{f1}^2 \right)} \quad \text{(1)}
\]
\[
T_{f1} = \frac{P_0}{\omega} \cdot \frac{935}{60} = 37.5 \text{Nm}
\]
\[
\therefore \quad T_{f1} = 37.5 \text{Nm} \quad \text{.........(2)}
\]
\[
\therefore \quad \text{From (1) and (2)}
\]
\[
37.5 = \left( 0.2 \right)^2 + 1 \left( 0.065 \right)
\]
\[
T_{st} = \left( 0.2 \right)^2 + \left( 0.065 \right)^2
\]
\[
\Rightarrow \quad T_{st} = 24.5 \text{Nm}
\]
\[
\therefore \quad \text{Starting torque} = 24.5 \text{Nm}
\]

06.

Sol: Given,

Line voltage, \( V_L = 230 \text{V} \)
Line current, \( I_L = 60 \text{A} \)
Power factor, \( \cos \phi_1 = 0.866. \text{lagging} \)
Stator copper losses, \( P_{scu} = 850 \text{W} \)
Core losses, \( P_c = 450 \text{W} \)
Rotor losses, \( P_{cu} = 1050 \text{W} \)
Rotational losses \( P_{rot} = 500 \text{W} \)
Power input \( P_{in} = 20700 \text{W} \)
Total stator losses \( P_{sl} = P_{scu} + P_c = 850 + 450 = 1300 \text{W} \)

\( i) \) Air gap power \( P_{ag} = \) power input \( P_{in} \) – stator losses \( P_{sl} \)
\[
= 20700 – 1300 = 19400 \text{W}
\]
\[
P_{ag} = 19.4 \text{ kW}
\]

\( ii) \) Slip, \( S = \frac{\text{Rotor copper losses} \left( P_{cu} \right)}{\text{Air gap power} \left( P_{ag} \right)}
\]
\[
= \frac{1050}{19400}
\]
\[
S = 5.41\%
\]

\( iii) \) Mechanical power developed,
\[
(P_{em}) = (1–s)P_{ag}
\]
\[
\therefore \quad P_{em} = (1–0.0541) \cdot 19.4 = 18350 \text{ W}
\]

(iv) Output power \( (P_0) = P_{em} - P_{rot} = 18350 - 500 = 17850 \text{W} \)

(v) Efficiency \( (\eta) = \frac{\text{power output}}{\text{power input}} \)
\[
= \frac{17850}{20700} = 86.23\%
\]

07.

Sol: Given,

Poles, \( P = 4 \)
Frequency, \( f = 50 \text{Hz} \)
Starting torque \( (T_{st}) \) = 160% of full load torque \( (T_{f1}) \)
\[
\therefore \quad T_{st} = 1.6T_{f1} \quad \text{.........(1)}
\]

Maximum torque \( (T_{max}) \) = 200% of full load torque \( (T_{f1}) \)
\[
\therefore \quad T_{max} = 2T_{f1} \quad \text{.........(2)}
\]

(i) From (1) and (2)
\[
\frac{T_{st}}{T_{f1}} = 1.6 \quad \frac{T_{max}}{T_{f1}} = 2
\]
\[
\Rightarrow \quad T_{st} = 1.6T_{f1} \quad \text{.........(3)}
\]

But we know that
\[
T_{st} = 2S_{mT}T_{f1} + 1
\]

\[
S_{mT} = \frac{2S_{mT}}{5} + 1
\]

\[
2S_{mT}^2 - 5S_{mT} + 2 = 0
\]

\[
S_{mT} = 2, \frac{1}{2}
\]
\[
\therefore \quad S_{mT} = 0.5 \quad \text{.........(4)}
\]

[\( S_{mT} \) = slip at maximum torque]

\[
\therefore \quad \text{for a motor} \quad 0 < s < 1
\]

Synchronous speed \( N_s = \frac{120f}{p} \)
\[
N_s = \frac{120 \times 50}{4}
\]
\[
N_s = 1500 \text{ rpm}
\]

Speed at maximum torque, \( N_{mT} = N_s(1–S_{mT}) \)
\[
N_{mT} = 1500(1 - 0.5) = 750 \text{ rpm} \]
(ii) In induction motor we know that,
\[
\frac{T}{T_{\text{max}}} = \frac{2}{S_{mT} + S}
\]
\[
\frac{T_{fl}}{T_{\text{max}}} = \frac{2}{S_{mT} + S_{fl}}
\]
\[
1 + \frac{2}{S_{fl}} = \frac{0.5}{0.5}
\]
\[
2\left(\frac{S_{fl} \times 0.5}{S_{fl} + 0.25}\right) = \frac{2S_{fl}^2 - 8S_{fl} + 1}{0}
\]
\[
S_{fl} = 0.134, 1.866
\]
\[
\therefore S_{fl} = 0.134 \quad \text{[for motor \(0 < S < 1\)]}
\]
\[
\therefore \text{Speed at full load, } N_{fl} = N_S (1 - S_{fl})
\]
\[
N_{fl} = 1500(1 - 0.134)
\]
\[
N_{fl} = 1299 \text{ rpm}
\]

08.
Sol: Given,
Poles, \(P = 4\)
Frequency, \(f = 60\text{Hz}\)
Full load speed, \(N_{fl} = 1710 \text{ rpm}\)
\[
\therefore \text{Synchronous speed, } N_S = \frac{120f}{P}
\]
\[
N_S = \frac{120 \times 60}{4} = 1800 \text{ rpm}
\]
\[
N_S = 1800 \text{ rpm} \ldots \ldots \ldots (1)
\]
Full load slip \(S_{fl} = \frac{N_S - N_{fl}}{N_S}\)
\[
S_{fl} = \frac{1800 - 1710}{1800} \left[\text{from (1)}\right]
\]
\[
S_{fl} = 0.05 \ldots \ldots \ldots (2)
\]

Given that
Starting current \((I_{st}) = 6\times\) full load current \((I_{fl})\)
\[
\therefore I_{st} = 6 \ldots \ldots (3)
\]
\[
I_{fl} = \frac{1}{S_{fl}} \left(\frac{I_{st}}{I_{fl}}\right)^2 \quad \text{[from (2) and (3)]}
\]
\[
T_{st} = 6^2(0.05) = 1.8 \ldots \ldots \ldots (5)
\]
\[
\therefore \text{Starling torque } (T_{st}) = 180\% \text{ of full load torque } (T_{fl})
\]

(a) In induction motors we know that
\[
\text{Torque } (T) = 3I_{st}^2 \frac{R_2}{S}
\]
\[
\therefore \frac{T_{st}}{T_{fl}} = \left(\frac{I_{st}}{I_{fl}}\right)^2 \quad \text{[from (2) and (3)]}
\]
\[
\frac{T_{st}}{T_{fl}} = 6^2(0.05) = 1.8 \ldots \ldots \ldots (5)
\]
\[
\therefore \text{Starling torque } (T_{st}) = 180\% \text{ of full load torque } (T_{fl})
\]

(b) We know that,
\[
\frac{T_{st}}{T_{fl}} = \frac{2S_{mT}}{S_{mT} + 1}
\]
\[
\therefore \frac{T_{st}}{T_{fl}} = \frac{2S_{mT}}{S_{mT} + 1}
\]
\[
\therefore \text{Speed at maximum torque, } N_{mT} = N_S (1 - S_{mT})
\]
\[
N_{mT} = 1800 (1 - 0.31)
\]
\[
N_{mT} = 1242 \text{ rpm}
\]
\[
S_{mT} = 0.31
\]
\[
\therefore \text{Maximum torque } = 318\% \text{ of full load torque}
\]

09.
Sol: Given
Slip at maximum torque, \(S_{mT} = 0.2\)
External resistance, \(R_{ext} = 0.5 \Omega\)
Let,
\[ R_2 = \text{Rotor resistance} \]
\[ X_2 = \text{Rotor reactance} \]

We know that
\[ S_{mT} = \frac{R_2}{X_2} \]
\[ 0.2 = \frac{R_2}{X_2} \]
\[ X_2 = 5R_2 \ldots \ldots (1) \]

Equivalent rotor circuit resistance
\[ R_1 = R_2 + R_{\text{ext}} \]
\[ \Rightarrow R_1 = R_2 + 0.5 \]

Given that, after adding external resistance
Starting torque = 75% of maximum torque
\[ T_{st} = 0.75 T_{\text{max}} \]
\[ \frac{T_{st}}{T_{\text{max}}} = 0.75 = \frac{2S_{mT}^2}{\left(S_{mT}^1\right)^2 + 1} \]
\[ \Rightarrow 3S_{mT}^2 - 8S_{mT}^1 + 3 = 0 \]
\[ S_{mT}^1 = 0.451 \]
\[ S_{mT}^1 = \frac{R_2^1}{X_2} \]
\[ \Rightarrow 0.451 = \frac{R_2 + 0.5}{X_2} \]
\[ \Rightarrow 0.451 = \frac{R_2 + 0.5}{5R_2} \]
\[ 2.25R_2 = R_2 + 0.5 \Rightarrow R_2 = 0.4 \Omega \]
\[ X_2 = 5R_2 \]
\[ = 5 \times (0.4) \]
\[ X_2 = 2 \Omega \]

Rotor reactance \( (X_2) \) = 2 \( \Omega \)
Rotor resistance \( (R_2) \) = 0.4 \( \Omega \)

10. 
**Sol:** Given,
- Poles, \( P = 4 \)
- Frequency, \( f = 50 \text{Hz} \)
- Rotor resistance, \( R_2 = 4.5 \Omega \) phase
- Stand still rotor reactance, \( X_2 = 8.5 \Omega \) phase
- Starting Torque, \( T_{st} = 85 \text{Nm} \)

Synchronous speed \( N_s = \frac{120f}{P} \)
\[ N_s = \frac{120 \times 50}{4} = 1500 \text{ rpm} \]

(1) Let, \( E_2 = \text{stand still rotor voltage} \)
\[ \therefore T_{st} = \frac{3}{\omega_s} \frac{E_2^2}{R_2^2 + X_2^2} \cdot R_2 \]
\[ 85 = \frac{3}{1500 \times 2\pi} \frac{E_2^2}{(4.5^2 + 8.5^2)} \]
\[ 85 = \frac{3}{50\pi} \frac{E_2^2}{(4.5^2 + 8.5^2)} \]
\[ \Rightarrow E_2 = 302.46 \text{ V} \]

(2) External resistance added is \( R_{\text{ext}} = 2 \Omega \)
\[ \therefore R_1 = R_2 + R_{\text{ext}} \]
\[ \Rightarrow R_1^2 = 2 + 4.5 = 6.5 \Omega \]
\[ \therefore R_2^1 = 6.5 \Omega \]

Starting torque, \( T_{st} = \frac{3}{\omega_s} \frac{E_2^2 R_2}{R_2^2 + X_2^2} \cdot R_2 \]
\[ \therefore T_{st} = \frac{3}{1500 \times 2\pi} \frac{302.46^2}{(6.5^2 + 8.5^2)} \]
\[ \Rightarrow T_{st} = 99.2 \text{Nm} \]

11. 
**Sol:** Given,
- Rated frequency, \( f_1 = 50 \text{Hz} \)
- Applied frequency, \( f_2 = 40 \text{Hz} \)
- Rated voltage, \( V_1 \)
- Applied voltage, \( V_2 = 1.5V_1 \)

(1) We know that
Start torque \( T_{st} \propto \frac{V_1^2}{f_1^3} \)
\[ \frac{T_{st1}}{T_{st2}} = \left( \frac{V_1}{V_2} \right)^2 \left( \frac{f_2}{f_1} \right)^3 \]
\[
\frac{T_{st1}}{T_{st2}} = \left(\frac{V_2}{1.5V_1}\right)^2 \left(\frac{40}{50}\right)^3
\]

\[\frac{T_{st1}}{T_{st2}} = 0.227\]

Starting torque \(T_{st} \propto \frac{V}{f}\)

\[
I_{st1} = I_{st2} = \left(\frac{V_1}{1.5V_1}\right) \left(\frac{40}{50}\right) = 0.533
\]

Maximum torque \(T_{max} \propto \frac{V^2}{f^2}\)

\[
\frac{T_{max1}}{T_{max2}} = \left(\frac{V_1}{V_2}\right)^2 \left(\frac{f_2}{f_1}\right)^2 = \left(\frac{V_1}{1.5V_1}\right)^2 \left(\frac{40}{50}\right)^2
\]

\[\frac{T_{max1}}{T_{max2}} = 0.284\]

(ii) Given that starting torque are equal

\[
\frac{T_{st1}}{T_{st2}} = \frac{V_1^2}{V_2 f_2^3} = \frac{V_2^2}{V_1 f_1^3}
\]

\[
\left(\frac{V_1}{V_2}\right)^2 = \left(\frac{f_1}{f_2}\right)^3 = \left(\frac{50}{40}\right)^3
\]

\[\Rightarrow \left(\frac{V_1}{V_2}\right) = 1.397\]

12.

Sol: Given,

- Poles, \(P = 6\)
- Frequency = 60Hz
- Speed of motor, \(N_1 = 1140\) rpm
- Synchronous speed, \(N_s = \frac{120f}{P}\)

\[
N_s = \frac{120 \times (60)}{6} = 1200\text{rpm}
\]

Slip, \(S = \frac{N_s - N_1}{N_s}\)

\[S_1 = \frac{1200 - 1140}{1200} = 5\%
\]

Let additional resistance to be added = \(R_x\).

Rotor resistance, \(R_2 = 0.2\Omega\) phase. It is given that motor is driving a constant torque load.

\[
T_1 = T_2
\]

\[
\Rightarrow \frac{E_2^2}{S_1} \left(\frac{R_2}{S_1}\right) = \frac{3}{\alpha} \frac{E_2^2}{S_2} \left(\frac{R_1^2}{S_2}\right) + X_2^2
\]

\[
\Rightarrow \frac{R_2}{S_1} = \frac{R_1^2}{S_2} \quad \text{......(1)}
\]

Given that final speed, \(N_2 = 1000\) rpm

\[
S_2 = \frac{N_s - N_2}{N_s}
\]

\[S_2 = \frac{1200 - 1000}{1200} = \frac{1}{6}
\]

From (1)

\[
R_2 = \frac{R_1^2}{S_2}
\]

\[
R_2 = \frac{R_x + R}{S_1}
\]

\[
\frac{R_x}{S_2} = \frac{1}{6}
\]

\[
R_x = 0.467\Omega
\]

13.

Sol: Given,

- Poles, \(P = 6\)
- Frequency, \(f = 50Hz\)
- Rotor resistance, \(R_2 = 0.2\Omega\)
- Initial speed, \(N_1 = 960\) rpm
- Final speed, \(N_2 = 800\) rpm
Synchronous speed, \( N_s = \frac{120f}{p} \)
\[ \Rightarrow N_s = \frac{120 \times 50}{6} = 1000 \text{rpm} \]
\( N_s = 1000 \text{rpm} \)

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, \( T_1 = T_2 \)
\[ \Rightarrow \frac{R_2}{S_1} = \frac{R_1}{S_2} \]
\[ \Rightarrow \frac{0.2}{0.04} = \frac{R_1}{0.2} \]
\[ \Rightarrow R_1 = 1 \text{Ω} \]
But \( R_2^1 = R_2 + R_{\text{ext}} = 1 \)
\[ 0.2 + R_{\text{ext}} = 1 \]
\[ R_{\text{ext}} = 0.8 \text{Ω} \]

Shaft torque at \( (s = 0.019) \) = developed torque (if mechanical losses are neglected) =
\[ T = \frac{3V^2(0.25)}{s_{01}\left[(0.25/s)^2 + 1.5^2\right]} = 2400 \text{ N-m/r} \]
\[ \text{......(1)} \]

V and \( \omega_s \) are not given. \( \omega_s \) (synchronous speed in mechanical rad/sec) can be calculated as follows:
\[ T = 2400 \text{ N-m/r. output} = 373 \text{ kW}. \]
\[ T \omega_r = \text{torque} \times \text{actual rotor speed} = \text{shaft power (since mechanical losses are neglected)} \]
\[ = 373 \text{ kW. } \omega_r \]
\[ = (373 \times 10^3/2400) \]
\[ = 155.42 \text{ r/s (mech)} \]
\[ \text{Hence } \omega_s = 155.42/(1 - 0.019) \]
\[ = 158.43 \text{ r/s (mech)} \]

Which gives \( P = 3.97 \) poles, which can be corrected to 4 poles. With 4 poles, \( \omega_s \) will be 157.08 r/s (mech).

Substituting in (1); \( V = 1294.2 \text{ Volts/ph.} \)

Full load current
\[ = 1294.2 \sqrt{(0.25/0.019)^2 + 1.5^2} \]
\[ = 97.7 \text{ A.} \]

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](image)

\[ I = \frac{1294.2}{\sqrt{\left(\frac{2.25}{s_{new}}\right)^2 + 1.5^2}} = 97.7 \quad \ldots \ldots \ldots (2) \]

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

\[ V \sqrt{\left(\frac{r_{21}}{s_1}\right)^2 + x^2} = V \sqrt{\left(\frac{r_{22}}{s_2}\right)^2 + x^2} \]

From which \( \frac{r_{21}}{s_1} = \frac{r_{22}}{s_2} \).

The torque before and after the change are, respectively,

\[ 3V^2 \left(\frac{r_{21}}{s_1}\right) \text{ and } 3V^2 \left(\frac{r_{22}}{s_2}\right) \]

\[ \omega_s \left[ \left(\frac{r_{21}}{s_1}\right)^2 + x^2 \right] \text{ and } \omega_s \left[ \left(\frac{r_{22}}{s_2}\right)^2 + x^2 \right] \]

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.

\[ \text{New slip } s_2 = \left(\frac{r_{22}}{r_{21}}\right)s_1 = 0.171 \]

\[ \text{New power output} = 2400 \left(1 - 0.171\right)(157.08) = 312.53 \text{ kW.} \]

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

\[ T_R \left(1440 \times 2\pi\right) = 20,000 \text{ from which } \]

\[ T_R = 132.6 \text{ N-m/r.} \]

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,
\[ T_d = \frac{3V^2r_2}{\omega_s \left\{ \left(\frac{r_2}{s}\right)^2 + x_2^2 \right\} } \]

Substituting numerical values
\[ T_d = 99.32 \text{ N-m/r} = T_R \]

Thus does not agree with earlier result.

Let the slip at 120 Hz, 400 V operation be s. At 120 Hz, \( x_2 \) becomes \[ [(1.6 \times 120)/50] = 3.84 \Omega. \]

Full load torque
\[ T = \frac{3 \times \left( \frac{400}{\sqrt{3}} \right)^2 (0.4)}{s(120\pi) \left( \frac{0.4}{s} \right)^2 + 3.84} \]

Irrespective of whichever value of torque we use, slip comes out as a complex quantity which is not acceptable.

Slip for maximum torque = \( \frac{0.4}{3.84} \)
\[ = 0.1042 \]
### Objective Practice Solutions

01. **Ans:** (d)  
**Sol:** Water used = $60 \times 10^6$ cubic meter/year  
\[
\therefore Q = \frac{60 \times 10^6}{365 \times 24 \times 3600} = 1.9 \text{ m}^3/\text{sec}
\]
Head = 40 m  
\[
P = \frac{735.5}{75} Q H \eta \text{ kW}
\]
\[
= \frac{735.5}{75} \times 1.9 \times 40 \times 1
\]
\[
= 745.3 \text{ kW}
\]

02. **Ans:** (c)  
**Sol:** Overall efficiency of the power station is  
\[
\eta_{\text{overall}} = \eta_{\text{therm}} \times \eta_{\text{elect}} = 0.30 \times 0.92 = 0.276
\]
Units generated / hour = $(100 \times 10^3) \times 1$
\[
= 10^5 \text{ kWh}
\]
Heat produced / hour,  
\[
H = \frac{\text{Electrical output in heat units}}{\eta_{\text{overall}}}
\]
\[
10^5 \times 860 = 311.6 \times 10^4 \text{ kcal}
\]
\[
0.276
\]
\[
(\therefore 1 \text{ kWh} = 860 \text{ kcal})
\]
\[
\therefore \text{Coal consumption/hour} = \frac{H}{\text{Calorific value}}
\]
\[
= \frac{311.6 \times 10^6}{6400}
\]
\[
= 48687 \text{ kg}
\]

03. **Ans:** (c)  
**Sol:** 1 Hp = 735. 5 W  
\[
\therefore 0.735 \text{ kW}
\]
Developed power,  
\[
P = \frac{735.5}{75} \times Q \times W \times H \times \eta \text{ Watts}
\]
Here, Density of water $W = 1000 \text{ kg/m}^3$
Discharge of water $(Q) = 1 \text{ m}^3/\text{sec}$,  
\[
\eta = 100\%	ext{ and}
\]
\[
\text{Water head} (H) = 1 \text{m}
\]
\[
\therefore P = \frac{735.5}{75} \times 1000 \times 1 \times 1 = 9.80 \text{ kW}
\]

04. **Ans:** (d)  
**Sol:**  
\[
H = 102 \text{ m}
\]
\[
Q = 30 \text{ m}^3/\text{sec}
\]
\[
\eta = 80\%
\]
\[
\eta = WQH \times 1000
\]
\[
P = 0.8 \times 30 \times 102 \times 9.81
\]
\[
P = 24,014.88
\]
\[
P = 24,014.88 \times 1000
\]
\[
P = 24MW
\]

05. **Ans:** (b)  
**Sol:**  
\[
H = 204 \text{ m}
\]
\[
Q = 8 \text{ m}^3/\text{sec}
\]
\[
\eta = 0.8
\]
\[
P = \frac{0.736}{75} \times W \eta Q H
\]
\[
= \frac{0.8 \times 1000 \times 8 \times 204 \times 0.736}{75}
\]
\[
= 12812.288kW \approx 12,800 \text{ kW}
\]

06. **Ans:** (a)  
**Sol:**  
\[
\text{Weight of water}
\]
\[
= \text{volume of water is stored} \times \text{density}
\]
\[
= (10 \times 10^5) \times 993 \text{ kg}
\]
(10 \times 10^5) \times 993 \times 9.81 \text{ N} \\
= 9741.33 \times 10^6 \text{ N}

Energy produced = W \times H \times \eta_{overall} 
by volume of water 
= 9741.33 \times 10^6 \times 50 \times 1.00 \text{ watt-sec} 
(losses are neglected, overall efficiency is 100%) 
= \frac{9741.33 \times 10^6 \times 50}{3600} \text{ Whr} \\
= 135.3 \text{ MWhr}

07. Ans: (d)  
Sol: \( N_s = 300 \text{ rpm} \) 
\( f = 50 \text{ Hz} \) 
\( N_s = \frac{120f}{P} \Rightarrow P = \frac{120f}{N_s} = \frac{120 \times 50}{300} = 20 \text{ N} \) 
\( P = 20. \text{ N} \)

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 = \( \frac{6}{6} = 1 \text{ A} \)

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, PbO4 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 km²
- Annual rainfall (h) = 420cm
- Loss due to evaporation (e_L) = 30%
- Turbine efficiency (\( \eta_t \)) = 85%
- Alternator efficiency (\( \eta_a \)) = 80%
- Evaporation efficiency (\( \eta_e \)) = 1 – e_L = 70%

Let,
- \( P = \) Density of water = 1000kg/m³
- \( E_t = \) Total energy that can be generated by the hydro power plant.

\[
E_t = (MgH) \times \eta_t \times \eta_a \times \eta_e
\]

\[
E_t = P(Ah)gH \times \eta_t \times \eta_a \times \eta_e
\]

\[
E_t = 1000 \times 200 \times 10^6 \times 4.2 \times 9.8 \times 50 \times 0.85 \times 0.8 \times 0.7
\]

\[
= 1.959216 \times 10^{14} J
\]

\[
E_t = 54422.67 \text{ MWh}
\]

Average power that can be generated

\[
(P_0) = \frac{E_t}{t(\text{hrs})}
\]

\[
(P_0) = \frac{54422.67}{365 \times 24}
\]

\[
= 6.21 \text{ MW}
\]

**02.**

**Sol:** \( u_0 = \) Speed of free wind in unperturbed state
- \( A = \) Area through which air column passing
- \( \rho = \) Density of air

Then power available in wind

\[
P_0 = \frac{1}{2} (\rho A u_0^3) = \frac{1}{2} (\rho A) u_0^3 \quad \ldots \ldots (1)
\]

\[
P_0 = \frac{1}{2} \rho u_0^3 \quad \ldots \ldots \quad (2)
\]

Energy content of the wind per unit area for a specified period is

\[
E = \frac{1}{2} \int_0^T P \, d\tau = \frac{1}{2} \int_0^T \rho u_0^3 \, d\tau
\]

**Power Extraction from Wind:**

- Wind turbine is used to harness useful mechanical power from wind.
- The rotor of the turbine collects energy from the whole area swept by the rotor.
- The maximum power extraction can be limited by the help of betz model.

![Wind Stream Tube Diagram](attachment:wind_stream_tube.png)

Unperturbed Wind stream tube in absence of turbine

![Betz Model Diagram](attachment:betz_model.png)

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)
\[ \dot{m} = \rho A_0 u_0 = \rho A_1 u_1 = \rho A_2 u_2 \]

..... (3)

Force or thrust on Rotor
\[ (F) = \dot{m} (u_0 - u_2) \]

Power extracted by turbine
\[ P_T = F . u_1 = \dot{m} (u_0 - u_2) u_1 \]

Power extraction can also be written like difference in kinetic energy at the upstream and downstream.
\[ P_T = \frac{1}{2} \dot{m} (u_0^2 - u_2^2) \]

(5) = (6)
\[ u_1 = \left( \frac{u_0 + u_2}{2} \right) \]

a = interference factor defined as
\[ a = \frac{u_0 - u_1}{u_0} \]

\[ u_1 = (1 - a) u_0 \]

or \[ a = \frac{(u_0 - u_2)}{2u_0} \]

Now by the help of equations 3, 5, 7, 8
\[ P_T = 4a (1-a)^2 \left( \frac{1}{2} \rho A_1 u_0^3 \right) \]

Compare with equation (2)
\[ P_T = C_p P_0 \]

(11)

\[ C_p = \text{Fraction of available power in the wind} \]

\[ C_p = 4a(1-a)^2 \]

Maximum value of \( C_p \) can be
\[ C_{p,\text{max}} = 0.593 \]

So According to Betz Model 59.3% is the maximum energy that can be extracted from wind.

Note: Likewise we can also calculate Axial thrust on turbine and torque developed by the turbine.

03.
Sol: Given, power output, \( P_0 = 500\text{MW} \)

Efficiency of power plant, \( \eta = 33\% \)

Energy output per fission, \( \epsilon_f = 190\text{MeV} \)

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 \( 6.023 \times 10^{23} \times \frac{30}{235} \) atoms of 4.235

1 atoms of U-235 produces 190MeV of energy

\[ 6.023 \times 10^{23} \times \frac{30}{235} \] atoms produces
\[ = 190 \times 10^6 \times 1.6 \times 10^{-19} \text{J} \]
\[ \times 6.023 \times 10^{23} \times \frac{30}{235} \text{ of energy} \]
\[ = 233.74 \times 10^{10} \text{ J of energy} \]

But efficiency is 33%

\[ \therefore \text{Electrical energy output/1kg of fuel rods is} \]
\[ e_0 = 0.33 \times 2.33.74 \times 10^{10} \text{ J} \]
\[ e_0 = 77.135 \times 10^{10} \text{ J/kg} \]

(a) Total energy output of the plant is
\[ E_0 = P_0 \times t \]
\[ = 500 \times 10^6 \times (8760) \times (3600) \]
\[ = 1.5768 \times 10^{16} \text{ J} \]

Total mass of fuel consumed in kg is
\[ M = \frac{E_0}{e_0} \]
\[ = \frac{1.5768 \times 10^{16}}{77.135 \times 10^{10}} \]
\[ M = 20442 \text{ kg} \]

(b) Energy output of 1kg of fuel burn up is
\[ = 233.74 \times 10^{10} \text{ J} \]

Energy output for 1 tonne (1000kg) of fuel burn up is
\[ E_{x0} = 233.74 \times 10^{13} \text{ J} \]
\[ = 2.3374 \times 10^7 \text{ MJ} \]
\[ = \frac{233.74 \times 10^7}{3600 \times 24} \text{ MWdays} \]
\[ E_{x0} = 27053.24 \text{ MWd} \]

04.

Sol: \( r = 12 \text{ m} \)
\[ v_1 = 16 \text{ m/s} \] (initial velocity)
\[ v_2 = 8 \text{ m/s} \] (final velocity)
\[ P = 1.2 \text{ kgm}^{-3} \]

\[ \Rightarrow \text{velocity of the blades is} \]
\[ v = \frac{v_1 + v_2}{2} \]
\[ \Rightarrow v = \frac{16 + 8}{2} \]
\[ v = 12 \text{ m/s} \]

\[ \Rightarrow \text{Power generated by wind mill is} \]
\[ P = \frac{1}{2} C_p PAV^3 \quad [C_p = 1 \text{ in ideal case}] \]
\[ \Rightarrow P = \frac{1}{2} \times 1 \times 1.2 \times \pi(12)^2 \times (12)^3 \]
\[ P = 469.03 \text{ kW} \]

05.

Sol: Given,

Gross, power output \( (P_0) = 1000 \text{MW} \)

Internal power consumption \( (P_{\text{aux}}) = 9\% \)

Total mass of coal wxd /day \( (M) \)
\[ = 9800 \text{ tonnes per day} \]

Heating value of coal \( (C_c) = 26 \text{MJ/kg} \)

Total gross electrical output per day in terms of energy is \( (E_{g0}) = P_0 \times t \)
\[ = 1000 \text{Mw} \times 24 \times 3600 \]
\[ = 864 \times 10^{11} \text{J} \]
Total Heat energy input \( (E_i) = M C_c \)
\[ E_i = 9800 \times 10^3 \times 26 \times 10^6 \]
\[ E_i = 2548 \times 10^{11} \text{J} \]

Gross efficiency \( (\eta_g) = \frac{E_0}{E_i} \)
\[ = \frac{864 \times 10^{11}}{2548 \times 10^{11}} \]
Gross efficiency \( = 33.9\% \)

Net efficiency \( (\eta_n) = \eta_g \times \eta_{aux} \)
\[ = 33.9 \times (1 - 0.09) \]
Net efficiency \(, \eta_n = 30.8\% \)

06.
Sol: Given,
Total volume of water \( (V) \)
\[ = 1 \text{ million cubic meters} \]
Density of water \( (P_w) = 993 \text{ kg/m}^3 \)
Mean head \( (H) = 50\text{m} \)
Losses = negligible
\[ \Rightarrow \text{Efficiency} = 100\% \]
Energy produced by the water is
\[ E_0 = \eta mgH \]
\[ E_0 = \eta (PV) gH \]
\[ = (1.0) (993 \times 10^6) \times 9.8 \times 50 \]
\[ = 4.8657 \times 10^{11} \text{J} \]
\[ = 4.8657 \times 10^5 \text{ MJ} \]
\[ = 135.16 \text{ MWh} \]
Energy output \( = 135.16 \text{ MWh} \)

07.
Sol: Given,
Annual load factor (PLF) \( = 0.75 \)
Annual capacity factor (pcf) \( = 0.6 \)
Plant use factor (puf) \( = 0.65 \)
Maximum demand \( (P_m) = 60\text{Mw} \)
Let, \( C = \) plant capacity

(a) \[ PLF = \frac{\text{Average demand}}{\text{Maximum demand}} \]
\[ = 0.75 \times \frac{60}{45} \]
\[ = \frac{45}{45} \times 60 \]
\[ = 45 \times 60 = 394200 \text{ MWh} \]
\[ E_0 = 394.2 \times 10^6 \text{ KWh} \]

(b) \[ PCF = \frac{\text{Average load}}{\text{Plant capacity}} \]
\[ = \frac{45}{75} \]
\[ = \frac{45}{75} \times 10^6 \text{ KWh} \]

(c) \[ PUF = \frac{\text{Energy generated per year}}{\text{Plant capacity} \times \text{hours in operation}} \]
\[ = \frac{45}{75} \times 8760 \times 0.65 \]
\[ = 135 \times 8760 \times 0.65 \]
\[ = 81.34 \times 10^6 \text{ KWh} \]
08. 

Sol: Given,
Peak load \( P_P \) = 60MW

Maximum demand of load 1 is \( P_1 \)
\[ = 30 \text{MW} \]

Maximum demand of load 2 is \( P_2 \)
\[ = 20 \text{MW} \]

Maximum demand of load 3 is \( P_3 \)
\[ = 10 \text{MW} \]

Maximum demand of load 4 is \( P_4 \)
\[ = 14 \text{MW} \]

Annual load factor (PLF) = 0.5

(a) \[
\text{PLF} = \frac{\text{Average load}}{\text{Peak load}} = \frac{30}{60} = 0.5
\]

(b) Energy supplied \( E_0 \)
\[ = \text{Average load} \times \text{time (h)} \]
\[ E_0 = 30 \times 10^6 \times 8760 \]

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
\[ C_c t_c = 1 \]
\[ 2 \times t_c = 1 \]
\[ t_c = 0.5 \text{ hours} \]

(b) \[
\text{Ah} = I_c t_c = 10 \times 0.5 \]
\[ \text{Ah} = 5 \text{Ah} \]
(c) \( Ah = I_d t_d \)
\[
5 = I_d t_d \\
\text{But, } C_d + t_d = 1 \\
0.2 \times t_d = 1 \\
t_d = 5 \text{ hours} \quad ------(d) \\
\therefore 5 = I_d \times t_d \\
I_d = \frac{5}{5} = 1 \text{ A} \\
I_d = 1 \text{ A} \\

10. 

Sol: Given, Source voltage \( (V_s) = 10 \text{ V} \)
Ampere hour of each battery \( (Ah) = 10 \text{ Ah} \)
Terminal voltage of battery \( (V_b) = 2 \text{ V} \)
Load resistance, \( (R_L) = 1.9 \Omega \)

Internal resistance during charging \( (r_c) \) 
\[
= 0.25 \Omega \\
\]

Internal resistance during discharging \( (r_d) \) 
\[
= 0.4 \Omega \\
\]

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,
\[
I_c = \frac{V_s - V_{beq}}{r_{eq}} \\
= \frac{10 - 8}{1} \\
I_c = 2 \text{ A} \\
\]
(b) \( Ah = I_c t_c = I_d t_d \)
\[
10 = 2 \times t_c \\
t_c = 5 \text{ hours} \\
C_c t_c = C_d t_d = 1 \\
C_c \times 5 = 1 \\
C_c = 0.2 \text{ C rate} \\
\]
(c) \( Ah \text{ stored} = 10 \text{ Ah} \) (given)
\[
\text{Wh stored} = V_b \times Ah \\
= 2 \times 10 \\
\text{Wh stored} = 20 \text{ Wh} \]
(d) Circuit during discharge is as follows,

\[ I_d = 0.25A \]

\[ IL = \frac{V_d}{r_{eq} + R_L} \]

\[ IL = \frac{2}{0.1 + 1.9} \]

\[ IL = 1A \]

(e) \( Ah = I_d t_d \)

\[ 10 = (0.25) t_d \]

\[ t_d = 40 \text{ hours} \]

\[ C_d t_d = 1 \]

\[ C_d \times 40 = 1 \]

\[ C_d = 0.025 \text{ C rate} \]

(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 (\( \eta \))

\[ \frac{E_d}{E_s} = 76\% \]