CLASS TEST

S.No. : 01 SK_EE_ABCD_24623

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ELECTRICAL MACHINES

ELECTRICAL ENGINEERING

Date of Test : 24/06/2023

ANSWER KEY

1.	(a)	7.	(c)	13.	(b)	19.	(a)	25.	(d)
2.	(b)	8.	(a)	14.	(b)	20.	(b)	26.	(d)
3.	(d)	9.	(b)	15.	(b)	21.	(d)	27.	(a)
4.	(c)	10.	(d)	16.	(b)	22.	(d)	28.	(c)
5.	(b)	11.	(b)	17.	(b)	23.	(b)	29.	(c)
6.	(a)	12.	(d)	18.	(b)	24.	(c)	30.	(b)

DETAILED EXPLANATIONS

1. (a)

We know for per unit loading,

$$\left(\overrightarrow{S_{f\,\text{p.u.}}{}^*}\right) \propto \frac{1}{(Z_{f\Omega})(S_{f\,\text{rated}})}$$

for first transformer produced $(Z_{j\,\Omega}) \times (S_{j\,\text{rated}})$ is lowest

i.e. $(Z_{j\,\Omega}) \times (S_{j\,\text{rated}}) = 1000 \times 2 = 2000$

So, it will reach full load first.

2. (b)

When *h.v.* side is exicted,

$$\text{core loss} = VI\cos\phi$$
$$= 1000 \times 3 \times 0.75 = 2250 \text{ W}$$

When *l.v.* side is excited,

$$\text{core loss} = VI\cos\phi = 2250 \text{ W}$$

$$I = \frac{2250}{V \times \cos\phi} = \frac{2250}{400 \times 0.75} = 7.5 \text{ A}$$

Power factor is same for a transformer.

3. (d)

We know that,

$$\frac{\text{Starting torque}}{\text{Full load torque}} = \frac{T_{st}}{T_{fl}} = x^2\left(\frac{I_{sc}}{I_{fl}}\right)^2 \times s_{fl}$$

or, $0.4 = x^2 \times (5)^2 \times 0.035$

or, $x^2 = \dfrac{0.4}{25 \times 0.035}$

$$x = \sqrt{\frac{0.4}{25 \times 0.035}} = 0.676$$

$\therefore$ The percentage of tapping is 67.6%.

4. (c)

$$\text{kVA shared} \propto \frac{1}{\text{leakage impedance}}$$

5. (b)

$$N_s \text{ (stator field)} = \frac{120 \times 50}{4} = 1500 \text{ rpm};$$

$$N_s \text{ (rotor field)} = \frac{120 \times 30}{4} = 900 \text{ rpm}$$

$\therefore$ $N_r = 1500 \pm 900 = 2400$ rpm, 600 rpm

6. (a)

Primary is star connected and secondary is delta connected.

$$(V_L)_{\text{primary}} = 11000 \text{ V}$$

$$(V_{ph})_{\text{primary}} = \frac{11000}{\sqrt{3}}$$

$$\frac{(V_{ph})_{\text{sec}}}{(V_{ph})_{\text{prim}}} = \frac{1}{5}$$

$$\therefore \quad \text{Turns ratio} = \left(\frac{\text{High voltage}}{\text{Low voltage}}\right)_{\text{phase}}$$

$$\therefore \quad (V_{ph})_{\text{sec}} = \frac{11000}{5\sqrt{3}} \text{V}$$

$$(V_{ph})_{\Delta} = (V_L)_{\Delta}$$

$$\text{Output kVA} = \sqrt{3} V_L I_L$$

$$= \sqrt{3} \times \frac{11000}{5\sqrt{3}} \times 423 = 930.6 \text{ kVA}$$

7. (c)

Transformer-1,

$$750 \text{ kVA}, Z_1 = 0.018 + j0.09 \text{ p.u. (on 750 kVA base)}$$

Transformer-2,

$$250 \text{ kVA}, Z_2 = 0.022 + j0.10 \text{ p.u. (on 250 kVA base)}$$

$$Z_{2\text{ new}} = (0.022 + j0.10) \times \frac{750}{250}$$

$$= (0.066 + j0.30) \text{ p.u (on 750 kVA base)}$$

Load shared by transformer 2 is,

$$\vec{S}_2^* = \left(\frac{\vec{Z}_1}{\vec{Z}_1 + \vec{Z}_2}\right) \vec{S}_L^*$$

$$= \frac{0.018 + j0.09}{0.084 + j0.39} \times (1000\angle - \cos^{-1}(0.8))$$

$$= 230.06\angle{-36.02°}$$

Load shared by second transformer,

$$\vec{S}_2 = 230.06\angle 36.02 \text{ kVA}$$

8. (a)

For same air gap flux, $\frac{V}{f}$ ratio should be constant

Flux, $$\phi = \frac{V}{f} = \text{constant}$$

$$\frac{V_2}{f_2} = \frac{V_1}{f_1}$$

$$V_2 = \frac{400}{50} \times 30 = 240 \text{ V}$$

Synchronous speed of motor for 50 Hz source

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

$$\text{Slip, } s_1 = \frac{1500 - 1440}{1500} = 0.04$$

At small value of slip, the electromagnetic torque is given by

$$T = \frac{3}{\omega_s} \times \frac{V^2 s}{r_2}$$

$$T \propto \frac{V^2}{f} \cdot s$$

For same torque, $$\frac{V_2^2}{f_2} \cdot s_2 = \frac{V_1^2}{f_1} \cdot s_1$$

$$\frac{(240)^2}{30} s_2 = \frac{400^2}{50} \times 0.04$$

$$\text{Slip, } s_2 = 0.067$$

Synchronous speed of motor at 30 Hz source,

$$N_{s2} = \frac{120 \times 30}{4} = 900 \text{ rpm}$$

$$\text{Rotor speed, } N = (1 - 0.067) \times 900$$

$$N = 840 \text{ rpm}$$

9. **(b)**

Point R is corresponding to maximum voltage regulation.

For maximum voltage regulation load power factor is equal to

$$\cos \phi = \frac{R}{Z}$$

$$Z = \sqrt{R^2 + X^2} = \sqrt{0.05^2 + 0.5^2}$$

Power factor, $$\cos \phi = 0.0995 \text{ lagging}$$

10. **(d)**

Synchronous speed, $$\omega_s = \frac{2}{P} \times 2\pi f = \frac{4 \times \pi \times 50}{6} = 104.72 \text{ rad/sec}$$

Starting torque, $$T_{starting} = \frac{3}{\omega_s} \cdot \frac{E_2^2 r_2'}{(r_2')^2 + (x_2')^2}$$

$$40 = \frac{3}{104.72} \times \frac{E_2^2 \times 0.32}{(0.32)^2 + (3.2)^2}$$

Rotor voltage at standstill,

$$E_2 = 212.43 \text{ V}$$

11. (b)

For first case; $\frac{V_1}{f_1} = \frac{400}{50} = 8$

For second case; $\frac{V_2}{f_2} = \frac{200}{25} = 8$

Since, $\frac{V_1}{f_1} = \frac{V_2}{f_2} = 8$; the flux density B_m remains constant

Now, Hysteresis loss, $P_h = K_1 f$

and Eddy current loss, $P_e = K_2 f^2$

Then, Iron loss, $P_i = K_1 f + K_2 f^2$

or, $\frac{P_i}{f} = K_1 + K_2 f$ ...(i)

Now, from I[st] case:

$$\frac{3200}{50} = K_1 + K_2 \times 50 \quad \text{...(ii)}$$

From II[nd] case:

$$\frac{1000}{25} = K_1 + 25\,K_2 \quad \text{...(iii)}$$

From (ii) and (iii), we get

$$K_1 = 16$$

and $K_2 = \frac{24}{25}$

Hysteresis loss, $P_h = 16 \times 50 = 800$ W

and, eddy current loss, $P_e = \frac{24}{25} \times 2500 = 2400$ W

12. (d)

$$T_s = 1.5\,T_f$$
$$T_{max.} = 2\,T_f$$

For maximum torque, $s_{mT} = \frac{r_2}{x_2}$

$$\frac{T_s}{T_{max}} = \frac{1.5T_f}{2T_f} = \frac{2s_{mT}}{1+s_{mT}^2}$$

i.e. $1.5s_{mT}^2 - 4s_{mT} + 1.5 = 0$

$\therefore$ $s_{mT} = 0.45$

13. (b)

kVA supplied by *Vee* connection transformer,

$$S_{Vee} = \frac{1}{\sqrt{3}} \times S_{3-\phi} = \frac{3000}{\sqrt{3}} = 1732 \text{ kVA}$$

p.f. angle of transformer-1 = $\phi + 30° = \cos^{-1}(0.95) + 30° = 48.19°$

$\cos\phi_1 = \cos 48.19° = 0.67$ lagging

p.f. angle of transformer-2 = $\phi - 30° = \cos^{-1}(0.95) - 30° = -11.8°$

$$\cos\phi_2 = \cos 11.8° = 0.98 \text{ leading}$$
$$\vec{S}_1 = 1732\angle 48.19° \text{ kVA}$$
$$\vec{S}_2 = 1732\angle -11.8° \text{ kVA}$$

14. (b)

We know approximate voltage regulation formula,

$$\text{V.R.} = Z_{\text{p.u.}}\cos(\theta_{eq} - \phi)$$

For maximum voltage regulation,

$$\theta_{eq} - \phi = 0°$$
$$\text{V.R.} = Z_{\text{p.u.}}\cos 0° = Z_{\text{p.u.}}$$

For minimum voltage regulation,

$$\phi = -90°$$
$$\text{V.R.} = Z_{\text{p.u.}}\cos(90° + \theta_{eq}) = -Z_{\text{p.u.}}\sin(\theta_{eq}) = -X_{\text{p.u.}}$$

15. (b)

At starting slip, $s = 1$

$$I = \frac{V}{\sqrt{R_2^2 + X_2^2}}$$

$$(X_2)_{50\text{ Hz}} = X_2$$

and $(X_2)_{25\text{ Hz}} = 0.5\,X_2$

$$\text{Current, } (I)_{50\text{ Hz}} = \frac{V}{X_2\sqrt{\left(\frac{R_2}{X_2}\right)^2 + 1}}$$

and
$$\text{Current, } (I)_{25\text{ Hz}} = \frac{V}{X_2\sqrt{\left(\frac{R_2}{X_2}\right)^2 + 0.25}}$$

$$\frac{(I)_{25\text{ Hz}}}{(I)_{50\text{Hz}}} = \frac{\sqrt{s_m^2 + 1}}{\sqrt{s_m^2 + 0.25}} \qquad \left(\text{Given}, s_m = \frac{R_2}{X_2} = 0.4\right)$$

$$\frac{(I)_{25\text{ Hz}}}{(I)_{50\text{Hz}}} = \frac{\sqrt{0.4^2 + 1}}{\sqrt{0.4^2 + 0.25}} = 1.68$$

16. (b)

Given that,

$$V_{OC} = 230 \text{ V},$$
$$I_{OC} = 1.3 \text{ A},$$
$$P_{OC} = 100 \text{ W}$$
$$R_C = \frac{V_{0C}^2}{P_{0C}} = \frac{230^2}{100} = 529\ \Omega$$

Power factor angle,

$$\phi_{OC} = \cos^{-1}\left(\frac{P_{OC}}{V_{OC}I_{OC}}\right) = \cos^{-1}\left(\frac{100}{230\times 1.3}\right) = 70.46°$$

$$X_\phi = \frac{R_C}{\tan\phi_{OC}} = \frac{529}{\tan 70.46°} = 187.73\ \Omega$$

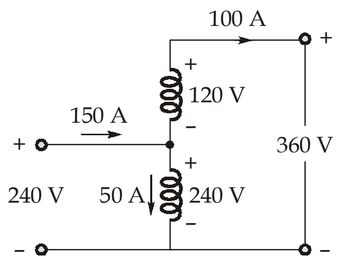
Referred to high voltage side,

$$R_C = 529\times\left(\frac{400}{230}\right)^2 = 1600\ \Omega$$

$$X_\phi = 187.73\times\left(\frac{400}{230}\right)^2 = 567.8\ \Omega$$

17. (b)

240 V/120 V, 12 kVA has rated current of 50 A/100 A.



$$\text{Auto-transformer rating} = 360 \times 100 \times 10^{-3}$$
$$= 36 \text{ kVA}$$

For 2 winding transformer,

$$\text{Output, } P_0 = 12 \times 1 = 12 \text{ kW}$$

$$\eta = \frac{P_0}{P_0 + P_L} = \frac{1}{1+\frac{P_L}{P_{L0}}} = 0.962$$

$$1 = 0.962 + 0.962\left(\frac{P_L}{P_0}\right)$$

(or) $$\frac{P_L}{P_0} = \frac{0.038}{0.962};$$

Power loss, $$P_L = \frac{12\times 0.038}{0.962} = 0.474 \text{ kW}$$

In autotransformer connection, full-load loss remains the same

At 0.85 p.f. $$P_0 = 36 \times 0.85$$
$$= 30.6 \text{ kW}$$

Efficiency, $$\eta = \frac{1}{1+\frac{0.474}{30.6}} = 0.985 \text{ (or) } 98.5\%$$

18. (b)

$$N_S = \frac{120 \times 60}{4} = 1800 \text{ rpm}$$

$$\text{Slip, } s = \frac{1800 - 1710}{1800} = 0.05$$

$$\omega_m = \frac{2 \times \pi \times 1710}{60} = 179.07 \text{ rad/s}$$

The torque developed at the rated voltage of 230 V is

$$T_d = \frac{2 \times 746}{179.07} = 8.33 \text{ N-m}$$

When the supply voltage is down by 10%, the torque developed by the motor is

$$T_{dL} = 8.33\left[\frac{0.9 \times 230}{230}\right]^2 = 6.75 \text{ N-m}$$

Similarly when the supply voltage is up by 10%, the torque developed by the motor is

$$T_{dH} = 8.33\,[1.1]^2 = 10.08 \text{ N-m}$$

Therefore torque varies from 6.75 to 10.08 N-m

19. (a)

$$\text{Equivalent impedance, } Z_e = R_e + jX_e = R_1 + R_2 + j(X_1 + X_2)$$
$$= 0.1 + 0.2 + j(0.15 + 0.25)$$
$$= 0.5\angle 53.13° \ \Omega$$

The slip at which the motor develops maximum power is,

$$S_p = \frac{R_2}{R_2 + Z_e} = \frac{0.2}{0.2 + 0.5} = 0.286 \text{ (or) } 28.6\%$$

The maximum power developed by the motor is

$$P_{dm} = \frac{3 \times 120^2}{2(0.3 + 0.5)} = 27000 \text{ W}$$
$$= 27 \text{ kW}$$

20. (b)

Given,

$$V_1 = 1000 \text{ V},$$
$$V_2 = 400 \text{ V}$$
$$\text{No load current, } I_{e1} = 3 \text{ A at 0.75 lag p.f.}$$

No load current on *l.v.* side;

$$I_{e2} = I_{e1} \times \frac{V_1}{V_2} = 3.0 \times \frac{1000}{400} = 7.5 \ A$$

At no load, the p.f. remains same on both sides;

then power factor = 0.75 lag

21. (d)

Given, turn ratio $= \dfrac{\text{No. of turns in H.V. winding}}{\text{No. of turns in L.V. winding}}$

$$a = \frac{2750}{2500} = 1.1$$

Rating of two winding transformer;

$$S_{TW} = 25 \text{ kVA}$$

Rating of auto transformer;

$$S_{\text{auto}} = \left(\frac{a_{\text{auto}}}{a_{\text{auto}} - 1}\right) \times S_{TW}$$

$$= \frac{1.1}{1.1 - 1} \times 25 = 275 \text{ kVA}$$

Power transferred conductively

$$= \left(\frac{1}{a_{\text{auto}}}\right) s_{\text{auto}} = \frac{27.5}{1.1} = 250 \text{ kVA}$$

and power transferred inductively

$$= \left(1 - \frac{1}{a_{\text{auto}}}\right) = \left(1 - \frac{1}{1.1}\right) \times 275 = 25 \text{ kVA}$$

22. (d)

The total power input in sumpner's test or back to back test is sum of individual iron and full load copper losses P_i and P_{cu} respectively. Hence the total input power will be twice of (P_i + P_{cu}) individual losses of identical transformer. Hence option (d) is correct.

23. (b)

As we can write:

Voltage regulation; $V.R = Z_{pu} \cdot \cos(\theta_{eq} - \phi)$

For leading power factor angle = –30°

$$V.R. = 0.1 \cos(90° + 30°)$$

If resistance is negligible;

then $\theta_{eq} = 90°$

therefore; $V.R. = 0.1\{-\sin 30°\}$

$$= -0.1 \times 0.5 = -0.05$$

$$\% \text{ V.R.} = -5\%$$

24. (c)

Given,

Emf per turn on each side = 9 volts/turn

No. of turns at secondary side,

$$= \frac{\text{Secondary voltage}}{\text{Voltage per turn}} = \frac{210}{9} \simeq 24$$

$$\therefore \quad E_{phase} = 4.44\, f\, N_{ph} \times \phi_{max}$$

$$\phi_{max} = \frac{(E_{Phase} / N_{ph})}{4.44\, f}$$

At secondary side,

$$\phi_{max} = \frac{9}{4.44 \times 50} = 0.0405 \text{ Wb}$$

$\therefore$ We know that;

$$\phi_{max} = B_{max} \times A_c$$

$$A_c = \frac{\phi_{max}}{B_{max}} = \frac{0.0405}{1.2}$$

$$A_c = 337.5 \text{ cm}^2$$

25. (d)

The torque developed in induction motor, is proportional to V^2

$$T \propto V^2$$

or,

$$\frac{T_1}{T_2} = \frac{V_1^2}{V_2^2}$$

$$T_2 = \left(\frac{V_2}{V_1}\right)^2 \times T_1$$

$$T_2 = \left(\frac{200}{400}\right)^2 \times 100 = 25 \text{ N-m}$$

26. (d)

Given;

$$T_{max} = 4 \times T_{fl}$$

and

$$T_{st} = 1.6\, T_{fl}$$

as we know,

$$\frac{T_{st}}{T_{max}} = \frac{2}{\frac{s_{max,T}}{1} + \frac{1}{s_{max,T}}}$$

or

$$\frac{1.6}{4} = \frac{2}{\frac{s_{max,T}}{1} + \frac{1}{s_{max,T}}}$$

$$0.4 = \frac{2 s_{max,T}}{s_{max,T}^2 + 1}$$

or $\quad s_{max,T}^2 - 5 s_{max,T} + 1 = 0$

This yields, $\quad s_{max,\,T} = \dfrac{5 \pm \sqrt{21}}{2}$

Neglecting the higher values;

We get, $\quad s_{max,\,T} = 0.21$

27. **(a)**

Line current taken from the supply;

$$I_{st} = x^2 I_{sc} \quad \text{...(i)}$$

The supply line current at start

$$= 2 I_{fl}$$

$$\text{short circuit current, } I_{sc} = 5 I_{fl}$$

From equation (i),

$$2 I_{fl} = x^2 \times 5 I_{fl}$$

$$x^2 = \frac{2}{5}$$

or, $$x = 0.6324 \approx 63.24\%$$

28. **(c)**

Given,

$$R_{e\,(\text{p.u.})} = 0.015 \text{ p.u.}$$

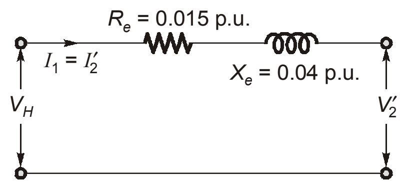
and $$X_{e(\,\text{p.u.})} = 0.04 \text{ p.u.}$$

$$\text{Let us take base voltage} = 3300 \text{ V}$$

then, $$V_H = 1 \text{ p.u.}$$

$$\text{Full load current} = 1.0\angle{-36.86^\circ} \text{ p.u.}$$

The equivalent circuit diagram on h.v. side can be drawn as below (neglecting shunt parameters)



∴ From circuit diagram,

$$V_H = V_2' + I_2'(R_e \cos\theta + X_e \sin\theta)$$

$$V_2' = 1 - 1(0.015 \times 0.8 + 0.04 \times 0.6)$$

$$V_2' = 0.964 \text{ p.u.}$$

Secondary voltage on secondary side;

$$V_2 = 230 \times 0.964 = 221.72 \text{ V}$$

29. **(c)**

From the given diagram,

$$N_1 : N_2 : N_3 = 9 : 3 : 1$$

$$\text{Induced emf} = 400\angle 0^\circ \text{ V}$$

As we know that; $$\frac{E_1}{E_2} = \frac{N_1}{N_2}$$

$$\Rightarrow \quad E_2 = \frac{N_2}{N_1}E_1 = \left(\frac{3}{9}\right)\times 400\angle 0^\circ = \frac{400}{3}\angle 0^\circ \text{ V}$$

and $$\frac{E_1}{E_3} = \frac{N_1}{N_3}$$

$$\Rightarrow \quad E_3 = \left(\frac{1}{9}\right)400\angle 0^\circ = \frac{400}{9}\angle 0^\circ \text{ V}$$

Current in secondary winding;

$$\Rightarrow \qquad I_2 = \frac{E_2}{R} = \frac{400/3}{20} = \frac{20}{3}\text{ A}$$

Current in tertiary winding;

$$\Rightarrow \qquad I_3 = \frac{E_3}{-jX_c} = \frac{400/9}{-j5} = \frac{80}{9}\angle 90^\circ\text{ A}$$

I_2 referred to primary side,

$$I_2' = \left(\frac{N_2}{N_1}\right) I_2 = \left(\frac{3}{9}\right)\times\frac{20}{3} = \frac{20}{9}\angle 0^\circ\text{ A}$$

I_3 referred to primary side,

$$I_3' = \left(\frac{N_3}{N_1}\right) I_3 = \frac{1}{9}\times\frac{80}{9}\angle 90^\circ\text{ A} = \frac{80}{81}\angle 90^\circ\text{ A}$$

Then supply current, $I_1 = \frac{20}{9}\angle 0^\circ + \frac{80}{81}\angle 90^\circ$

$$= \frac{20}{81}(9 + j4)\text{ A}$$

30. (b)

Given, N_r (rotor speed) = 1400 rpm

Synchronous speed, $N_s = \frac{120\times 50}{4} = 1500$ rpm

$\Rightarrow$ Slip at N_r $\quad s = \frac{1500-1400}{1500} = \frac{1}{15}$

Rotor impedance at slip, $s = \frac{1}{15}$

$$Z_{2s} = R_2 + jsX_{20}$$

$$= 1 + j\times\frac{1}{15}\times 4$$

$$= 1 + j\,0.2667 = 1.0349\angle 14.93^\circ\ \Omega$$

Power factor at 1400 rpm is

$$= \cos 14.93^\circ = 0.9662 \text{ (lag)}$$

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