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ESE – 2019 MAINS
OFFLINE TEST SERIES

ELECTRICAL ENGINEERING

TEST – 10
SOLUTIONS

All Queries related to **ESE – 2019 MAINS Test Series** Solutions are to be sent to the following email address
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1(a).

Sol: Phase voltage, $V = \dfrac{6600}{\sqrt{3}} = 3810$ V

Full-load current, I = 80 A at 0.8 p.f leading

Armature resistance per phase, $R_a = 2.2\ \Omega$

Synchronous reactance/phase, $X_s = 22\ \Omega$

Stray loss = 3200 W

(i) **E.m.f. induced, E_b:**

Power factor, $\cos\phi = 0.8$

$\cos^{-1}(0.8) = 36.9°$

Synchronous impedance/phase,

$$Z_s = \sqrt{R_a^2 + X_s^2} = \sqrt{(2.2)^2 + (22)^2}$$

$$= 22.11\Omega$$

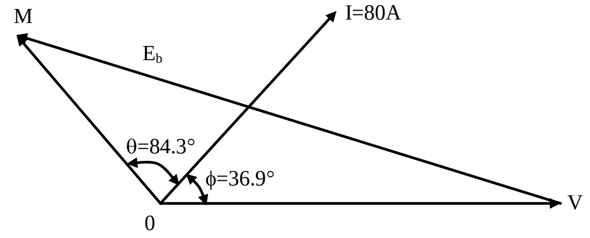
$$\tan\theta = \frac{X_s}{R_a} = \frac{22}{2.2} = 10$$

or $\theta = \tan^{-1}(10) = 84.3°$

Impedance drop/phase,

$E_r = IZ_s = 80 \times 22.11 = 1768.8$ V

The vector diagram is shown figure.



Induced e.m.f, E_b/ phase,

$$E_b = \sqrt{V^2 + E_r^2 - 2VE_r\cos(\theta+\phi)}$$

$$= \sqrt{(3810)^2 + (1768.8)^2 - 2\times 3810 \times 1768.8\cos(84.3° + 36.9°)}$$

$$= 4962.5 \text{ V}$$

Induced line e.m.f $= \sqrt{3} \times 4962.5$

= 8595 V.

(ii) Power output:

Total input = $\sqrt{3}\, E_L I_L \cos\phi$

$= \sqrt{3} \times 6600 \times 80 \times 0.8$

$= 731618$ W

Total copper losses $= 3I^2R_a$

$= 3 \times (80)^2 \times 2.2$

$= 42240$ W

Total stray losses = 3200 W

$\therefore$ Power Output = Power input – copper losses – stray losses

$= 731618 - 42240 - 3200$

= **686178 W**

1(b)

Sol: (i) Voltage–controlled power devices:

(1) Here output parameters are controlled by input voltage

(2) Ex: FET, MOSFET

(3) Low switching power losses for FET, MOSFET

Current- controlled power devices:

(1) Here output parameters are controlled by input current

(2) Ex: BJT

(3) High switching power losses for BJT

(ii) Where I_L is latching current, I_H is holding current.

Minimum Anode current required to turn on the SCR is called as latching current

Even if we remove gate pulse on reaching I_L, it will not be off. Minimum current required to turn on SCR is nothing but latching current.

Maximum current to keep the thyristor in conduction is holding current I_H.

If Thyristor current is just below this current during turn-off, Thyristor will be OFF.

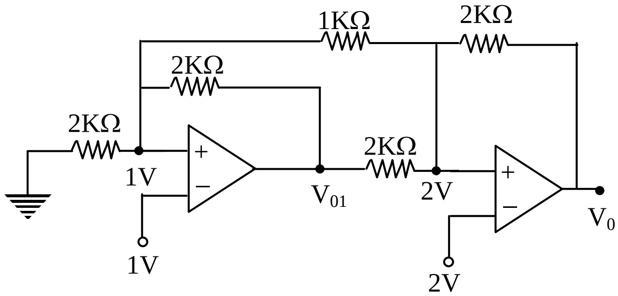
Latching current is related to Turn-on process

Holding current is related to Turn-off process

Generally $I_L > I_H$, $I_L \approx 1.5$ to 3 times of I_H

1(c)

Sol: (i)



Apply Nodal Analysis

$$\frac{1V}{2K}+\frac{1-V_{01}}{2K}+\frac{1-2}{1K}=0$$

$\therefore\ V_{01} = 0$ …….. (1)

$$\frac{2V-V_{01}}{2K}+\frac{2V-1V}{1K}+\frac{2V-V_o}{2K}=0 \qquad (\because V_{o1}=0V)$$

$$\frac{2V-V_{01}}{2K}+\frac{2V-1V}{1K}+\frac{2V-V_o}{2K}=0$$

$$\frac{2}{2}+\frac{2-1}{1}+\frac{2-V_o}{2}=0$$

$$1+1+\frac{2-V_o}{2}=0$$

$\therefore\ V_o = 6V$

(ii) $$\frac{V_0}{V_i}=\frac{-R_F}{R_1}=\frac{-R_2}{\left(R_1\|\frac{1}{C_1s}\right)}=\frac{-R_2}{\frac{R_1.\frac{1}{C_1s}}{R_1+\frac{1}{C_1s}}}=\frac{-R_2}{R_1}(R_1C_1s+1)$$

$$\therefore\ V_0=\frac{-R_2}{R_1}(R_1C_1s+1)V_i$$

$$=\frac{-R_2}{R_1}(R_1C_1s+1)\left[\frac{1}{s}-\frac{1}{s+\alpha}\right]$$

$$=\frac{-R_2}{R_1}(R_1C_1s+1)\left[\frac{s+\alpha-s}{s(s+\alpha)}\right]$$

$$= \frac{-R_2}{R_1}(R_1 C_1 s+1)\left[\frac{\alpha}{s(s+\alpha)}\right]$$

Substitute given $\alpha = \frac{1}{CR_1}$ value

$$V_0 = \frac{-R_2}{R_1}(R_1 C_1 s+1)\left[\frac{\frac{1}{CR_1}}{s\left(s+\frac{1}{CR_1}\right)}\right]$$

$$= \frac{-R_2}{R_1}(R_1 C_1 s+1)\left[\frac{1}{s(sCR_1+1)}\right]$$

If $C = C_1$ assume, then

$$V_0 = \frac{-R_2}{R_1}(R_1 C_1 s+1)\frac{1}{s(R_1 C_1 s+1)}$$

$$\therefore V_o = \frac{-R_2}{sR_1}$$

$$\therefore V_0(t) = \frac{-R_2}{R_1}u(t).$$

1(d)

Sol:

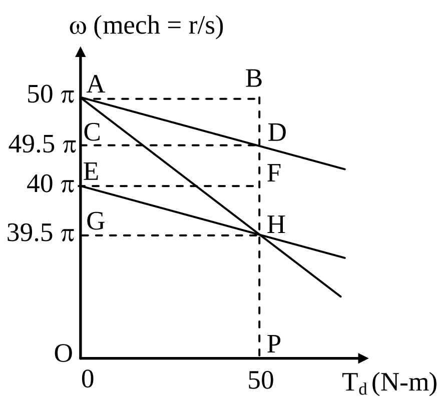


fig.2

Areas in fig.2 are referred to in the following analysis.

1. 400 V, 50 Hz operation, no external resistance introduced into the rotor phases (operation 1):

rotor input = area OPBA = $(50 \times 50\pi)$ W.

mech. Power developed = area OPDC

$= (50 \times 49.5\ \pi)$ W.

Hence rotor copper losses = $(50 \times 0.5\ \pi)$ W.

2. 400 V, 50 Hz operation, external resistance connected in series with each rotor phase for speed control = 1 Ω:

rotor input = area OPBA = $(50 \times 50\ \pi)$ W.

(Rotor input remains unchanged).

mech. Power developed = area OPHG

$= (50 \times 39.5\ \pi)$ W.

Decrease in mechanical power developed (as compared to operation 1)

$= (50 \times 10\ \pi)$ W.

Rotor copper losses = $(50 \times 10.5\ \pi)$ W.

Increase in rotor copper losses (as compared to operation 1) = $(50 \times 10\ \pi)$ W.

Remark: In the rotor resistance variation method of speed control, rotor input remains unchanged. The decrease in mechanical power developed appears as increased rotor copper losses.

3. 320 V, 40 Hz operation, (no external resistance in rotor phases) (V/f speed control):

rotor input = area OPFE = $(50 \times 40\ \pi)$ W.

mech. Power developed = area OPHG

$= (50 \times 39.5\ \pi)$ W.

Decrease in rotor input (as compared to operation 1) = $(50 \times 10\ \pi)$ W.

rotor copper losses = $(50 \times 0.5\ \pi)$ W.

increase in rotor copper losses (as compared to operation 1) = 0

decrease in mechanical Power developed (as compared to operation 1) = $(50 \times 10\ \pi)$ W.

Remark: In this method of speed control, the rotor input itself decreases by an amount equal to the decrease in mechanical power developed. Rotor copper losses remain unchanged. The method does not waste power, unlike the rotor resistance variation method.

1(e)

Sol: (i) A. 01100

The sign bit is 0. So the number is positive and the other four bits represent the true magnitude of the number, i.e., $1100_2 = 12_{10}$. Thus the decimal number is +12.

B. 11010

The sign bit is 1, so the number is negative. We can find the magnitude by negating (2's complementing) the number to convert it to its positive equivalent.

11010

2's complement of 11010 = $00110_2 \Rightarrow +6_{10}$

$\Rightarrow$ The original number 11010 must be equivalent to –6.

C. The sign bit is 1, so the number is negative. We can obtain magnitude by 2's complementing the number to convert it to it's positive equivalent.

2's complement of 10001 is $01110_2 = +14_{10}$. $\Rightarrow$ The original number 10001 must be equivalent to –14.

(ii) Because the MSB is to be used as the sign bit, there are seven bits for the magnitude. The largest negative value is

$10000000_2 = -2^7 = -128_{10}$

The largest positive value is $01111111 = 2^7 - 1 = +127_{10}$

Thus the range is –128 to 127; this is a total of 256 different values, including zero. Alternatively, because there are seven magnitude bits [N=7], then there are $2^{N+1} = 2^8 = 256$ different values.

2(a)(i)

Sol: Given data,

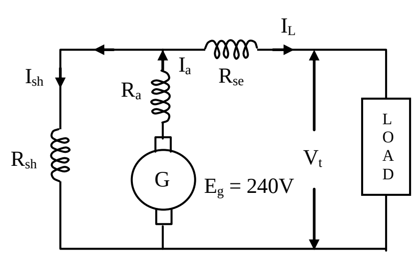
$R_a = 1\Omega$, $R_{se} = 0.5\Omega$, $R_{sh} = 100\Omega$, $P_0 = 4kW$,

$V_t = 200V$ and $V_b = 2V$

(Consider winding is lap winding)

$P_0 = V_t I_L$

$\Rightarrow I_L = 4000/200 = 20A$



A. For short shunt:

$I_a = I_{sh} + I_L$

The voltage across shunt field is

$= 200 + I_L R_{se}$

$= 200 + 20 \times 0.5$

$= 210V$

$$I_{sh} = \frac{210}{R_{sh}} = \frac{210}{100} = 2.10 \text{ A}$$

$\therefore I_a = 2.10+20=22.1$ A

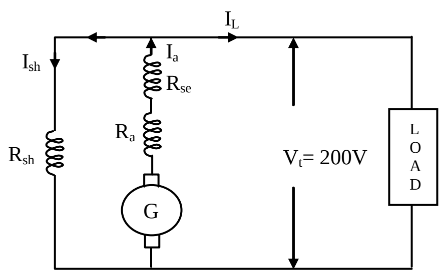
The generated emf

$E_g = I_a R_a + I_L R_{se} + V_t$ +Brush drop

$= 22.10 + 10 + 200 + 2$

$= 234.10$ V

For long shunt:



$I_a = I_L + I_{sh}$

The voltage across shunt field is 200V

$$I_{sh} = \frac{200}{100} = 2\,\text{A}$$

$I_a = I_L + I_{sh} = 20+2 = 22$ A

The generated e.m.f

$E_g = I_a R_a + I_a R_{se} + V_t + 2$

$= 22 + 22\,(0.5) + 200 + 2$

$= 235$ V

B. Given data, Z = 200, A = 4, N = 750rpm

For short shunt generator $E_g = 234.10$ V

$$E_g = \frac{\phi ZNP}{60A}$$

$$\phi_P = \frac{234.12 \times 60 \times 4}{200 \times 750 \times 4} = 93.64 \text{ mWb}$$

For long shunt Generator $E_g = 235$V

$$\phi_P = \frac{235 \times 60 \times 4}{200 \times 750 \times 4} = 94 \text{ mWb}$$

2(a)(ii)

Sol: Assume Rated output of motor = 1 pu

Then $\eta = \dfrac{\text{output}}{\text{output} + \text{losses}}$

$0.79 = \dfrac{1}{1 + \text{pu losses}} \Rightarrow \text{pu losses} = 0.265$ pu

Stator cu loss = Mechanical losses + Iron loss

= 2 Mechanical losses

($\because$ Mechanical loss = Iron loss)

Rotor cu loss = $\dfrac{1}{3} \times \text{stator cu loss}$

$= \dfrac{1}{3} \times 2$ Mechanical loss

Total pu loss = pu stator cu loss + pu Rotor cu loss + Mechanical loss + Iron loss

$\Rightarrow$ 0.265 = 2 × Mechanical losses+ $\dfrac{2}{3}$ × Mechanical loss + 2Mechanical loss

Mechanical loss = $\dfrac{0.265}{4.66} = 0.0568\,\text{pu}$

pu Rotor cu loss = $\dfrac{2}{3}$ × Mechanical loss

$= \dfrac{2}{3} \times 0.0568 = 0.0378$

pu Rotor I/P = output + Mech loss + Rotor cu loss

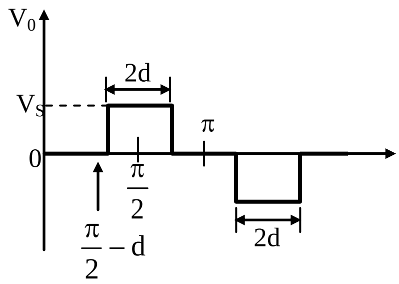
= 1 + 0.0568 + 0.0378 = 1.0946 pu

slip = $\dfrac{\text{Rotor cu loss}}{\text{Rotor I/p}} = \dfrac{0.0378}{1.0946} = 0.034\,\text{pu}$

2(b)(i)

Sol: $2d = \dfrac{\pi}{2}$ (given)

Single pulse modulation output for pulse width $2d = \dfrac{\pi}{2}$ is shown below.



From Fourier series, fundamental output voltage is

$$V_{01} = \frac{4V_S}{\pi}\sin\frac{\pi}{2}\sin d\sin\omega t$$

$$= \frac{4V_S}{\pi}\sin\frac{\pi}{4}\sin\omega t \Rightarrow \frac{4V_S}{\sqrt{2}\pi}\sin\omega t$$

$$V_{1rms} = \frac{\frac{4V_S}{\sqrt{2}\pi}}{\sqrt{2}} = \frac{2V_S}{\pi}$$

From output voltage wave form,

$$V_{rms} = \left[\frac{1}{\pi}\int_{\frac{\pi}{2}-d}^{\frac{\pi}{2}+d} V_S^2\, d\omega t\right]^{\frac{1}{2}}$$

$$= V_S\left[\frac{2d}{\pi}\right]^{\frac{1}{2}} = \frac{V_S}{\sqrt{2}}$$

$$\text{Distortion factor} = \frac{V_{1rms}}{V_{rms}} = \frac{2V_S/\pi}{V_S/\sqrt{2}} = \frac{2\sqrt{2}}{\pi} = 0.9$$

2(b)(ii)

Sol: Given data

$V_S = 330 \sin 314t$, $\alpha = \frac{\pi}{4}$, $I_0 = 5A$,

$V_0 = 140V$, $L_S = ?, \mu = ?, R_L = ?$

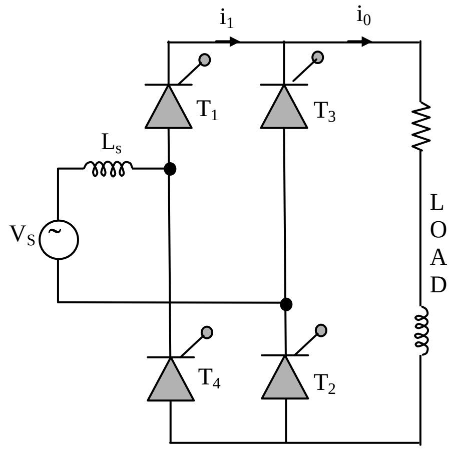


Fig: Single phase full converter with Source inductance

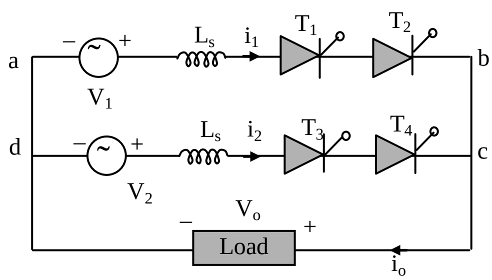


Fig. Equivalent circuit

During the commutation of T_1, T_2 and T_3, T_4 (i.e. during the overlap angle μ), KVL for the loop abcda is given as

$$V_1 - L_S \frac{di_1}{dt} = V_2 - L_S \frac{di_2}{dt}$$

$$V_1 - V_2 = L_S\left(\frac{di_1}{dt} - \frac{di_2}{dt}\right)$$

It is seen from fig. that if $V_1 = V_m \sin \omega t$ then $V_2 = -V_m \sin \omega t$

$$L_S\left(\frac{di_1}{dt} - \frac{di_2}{dt}\right) = 2V_m \sin \omega t \text{ -------- (1)}$$

and $i_1 + i_2 = I_0$

$$\frac{di_1}{dt} + \frac{di_2}{dt} = 0 \text{ ----------- (2)}$$

By solving (1) and (2)

$\frac{di_1}{dt} = \frac{V_m}{L_S}\sin\omega t$ ---------- (3)

Load current i_1 through thyristor pair T_1, T_2 builds up from zero to I_0 during the overlap angle μ.

i.e. at $\omega t = \alpha$, $i_1 = 0$

at $\omega t = (\alpha+\mu$, $i_1 = I_0)$

$$(3) \Rightarrow \int_O^{I_O} di_1 = \frac{V_m}{L_S}\int_{\alpha/\omega}^{(\alpha+\mu)/\omega}\sin\omega t\, dt$$

$$I_O = \frac{V_m}{\omega L_S}\left[\cos\alpha - \cos(\alpha+\mu)\right]$$

$$\cos(\alpha+\mu) = \cos\alpha - \frac{\omega L_S}{V_m} I_0$$

Output voltage V_0 is zero from α to $(\alpha+\mu)$

$$\therefore V_0 = \frac{V_m}{\pi}\int_{\alpha+\mu}^{\alpha+\pi}\sin\omega t \cdot d\omega t$$

$$= \frac{V_m}{\pi}\left[\cos(\alpha+\mu) - \cos(\alpha+\pi)\right]$$

$$V_0 = \frac{V_m}{\pi}\left[\cos\alpha + \cos(\alpha+\mu)\right]$$

and also $V_0 = \frac{2V_m}{\pi}\cos\alpha - \frac{\omega L_s}{\pi} I_0$

A. $140 = \frac{2\times 330}{\pi}\cos\left(\frac{\pi}{4}\right) - \frac{314\times L_S}{\pi}(5)$

$\therefore L_S = 17.1$ mH

B. $\cos(\alpha+\mu) = \cos\alpha - \frac{\omega L_s}{V_m} I_0$

$$\cos(\alpha+\mu) = \cos\left(\frac{\pi}{4}\right) - \frac{314\times 17.1\times 10^{-3}}{330}\times 5$$

$\alpha + \mu = 51.26 \Rightarrow \mu = 6.26°$

C. Load resistance $V_0 = I_0 R$

$$R = \frac{140}{5} = 28\ \Omega$$

2(c)

Sol: (i) Generator 1:

Voltage drop for 30 A = 260–220 = 40 V

$\therefore$ Voltage drop per ampere $= \frac{40}{30}$

$$= \frac{4}{3}\text{V/A}$$

Generator 2:

Voltage drop for 45A = 270–220 = 50V

$\therefore$ Voltage drop per ampere $= \frac{50}{45}$

$$= \frac{10}{9}\text{V/A}$$

Let, $I_1 =$ current output of generator 1

$I_2 =$ current output of generator 2

$V =$ bus-bar voltage

Then, for generator 1, $V = 260 - \frac{4}{3}I_1$

and for generator 2, $V = 270 - \frac{10}{9}I_2$

$\therefore 260 - \frac{4}{3}I_1 = 270 - \frac{10}{9}I_2$

or $\frac{10}{9}I_2 - \frac{4}{3}I_1 = 10$

Also $I_1 + I_2 = 65$ ………..(i)

or $I_2 = (65 - I_1)$……….(ii)

Substituting the value of I_2 in eqn. (i), we get

$\frac{10}{9}(65 - I_1) - \frac{4}{3}I_1 = 10$

$650 - 10I_1 - 12I_1 = 90$

$22I_1 = 560$

$$\therefore \quad I_1 = \frac{560}{22} = 25.45\text{A}.$$

and $\quad I_2 = 65 - I_1 = 65 - 25.45 = 39.55\text{A}.$

(ii) Output voltage of each generator,

$$V = 260 - \frac{4}{3} \times 25.45 = 226\text{V}$$

or $\quad V = 270 - \frac{10}{9} \times 39.55 = 226\text{V}.$

(iii) Output of generator 1, $P_1 = \frac{VI_1}{1000}\text{kW}$

$$= \frac{226 \times 25.45}{1000}\text{kW} = 5.75\text{kW}$$

Output of generator 2, $P_2 = \frac{VI_2}{1000}\text{kW}$

$$= \frac{226 \times 39.55}{1000}\text{kW} = 8.94\text{kW}$$

3(a)

Sol: 1. Lv load data transformation to the hv side:

Actual load voltage = 240 V.

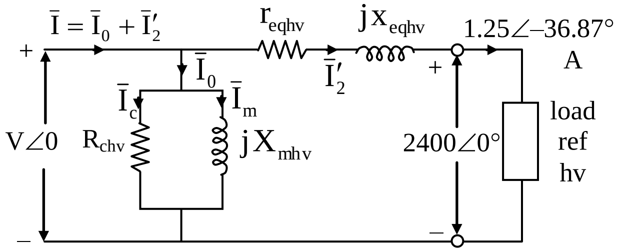
Actual load current = 12.5 A.

(hv turns/*l*v turns) = (2400/240) = a = 10.

Load voltage ref hv = 10 × 240 = 2400 V.

Load current ref hv = 12.5/10 = 1.25 A.

2. Equivalent circuit ref hv:



Approximate equivalent circuit is used phase angle of the load voltage is arbitrarily chosen.
fig.1

3. Calculation of R_{chv} and X_{mhv} from the oc test data:

$2400 \times 0.3 \times \cos\theta_0 = 230$

$\Rightarrow \cos\theta_0 = 0.3194$ and $\sin\theta_0 = 0.9476$

$I_c = 0.3\cos\theta_0 = 0.0958$ A

$I_m = 0.3\sin\theta_0 = 0.2843$ A.

$R_{chv} = (2400/I_c) = 25047\ \Omega$

$X_{mhv} = (2400/I_m) = 8442\ \Omega$.

(Note: That above I_c and I_m are valid only under the oc test conditions).

4. Calculation of r_{eqhv} and x_{eqhv} from the sc test data:

$z_{eqhv} = (70/18.8) = 3.72\ \Omega$.

$r_{eqhv} = (1050/18.8^2) = 2.97\ \Omega$.

$x_{eqhv} = \sqrt{\left(z_{eqhv}^2 - r_{eqhv}^2\right)} = 2.24\ \Omega$.

5. Calculation of $\overline{V}$ and $\overline{I}$:

$\overline{V} = 2400\angle 0° + (1.25\angle -36.87°)(2.97 + j\,2.24)$

$= 2404.7\angle 0°$ V (nearly).

Hence,

$\overline{I}_c = 0.096\angle 0°$ A.

$\overline{I}_m = 0.285\angle -90°$ A.

(Note that the new $\overline{I}_c$ and $\overline{I}_m$ are not much different from their values in the oc test).

$\overline{I} = (1.25\angle -36.87° + 0.096\angle 0°$

$+ 0.285\angle -90°)$ A.

$= (1.096 - j\,1.0348)$ A.

6. Results:

Primary voltage = 2404.7 V.

Real power input = re[2404.7 (1.096

+j 1.0348)]

= 2636 W.

Reactive power input (lagging)

= im[2404.7(1.096 + j0.0348)]

= 2488.4 VAr

Real power output = 2400× 1.25 × $\cos^{-1}(0.8)$

= 2400 W.

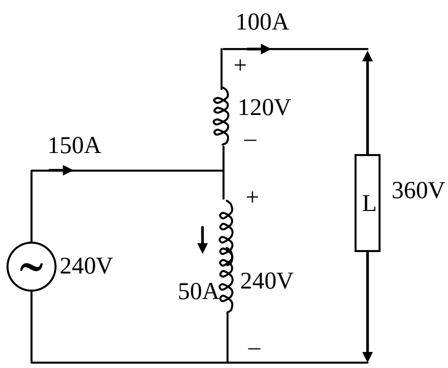
Efficiency = 91%.

3(b)(i)

Sol: In emf method of voltage regulation (VR), mmfs are transformed to their corresponding emfs, so an error is introduced in doing so. Similarly, in mmf method of VR, emfs are transformed into corresponding mmfs and likewise an error is introduced. But in Potier method, emfs are handled as voltage and mmfs are held as field ampere-turns. No errors are thus introduced due to transformation of emfs to mmfs or vice-versa. Potier method (also called zero pf method) is therefore accurate method of calculating VR of alternators.

3(b)(ii)

Sol: 240V/120V, 12kVA has rated current of 50 A/100 A. It's connected as an autotransformer as shown in figure.



Auto-transformer rating

= 360 × 100 = 36 kVA

It is 3-times then 2-winding connection.

As 2-winding connection Output, P_0

= 12 × 1 = 12 kW

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

From which find full-load loss

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

(or) $\frac{P_L}{P_0} = \frac{0.038}{0.962}$; $P_L = 12 \times \frac{0.038}{0.962} = 0.474$ kW

In auto connection full-load loss remains the same.

$P_0 = 36 \times 0.85 = 30.6$ kW

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

3(b)(iii)

Sol: Neglecting saturation & armature reaction

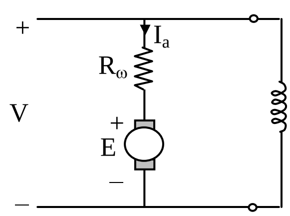


fig.1

T_d = developed torque = $KI_f I_a$ N-m/r

Induced emf = $K I_f \omega_m$ V

Where, K is a machine constant.

Mechanical power developed

$T_d \omega_m = K I_f I_a \omega_m$

$= E I_a$ = Electrical power developed = $P = (V - I_a R_a) I_a$

(Electrical power drawn by the field is used as copper losses and is neglected).

With V & R_a kept constant, P will be maximum when $\frac{dP}{dI_a} = 0$

But, $\frac{dP}{dI_a} = V - 2I_a R_a$

$\therefore \quad V = 2 I_a R_a$

$E = V - I_a R_a$

$= \frac{V}{2}$

This is the condition for maximum mechanical power developed.

3(c)(i)

Sol: A. The selectivity of a super heterodyne receiver is mainly decided by IF amplifier The tuned circuit associated with the IF amplifier operates at a fixed frequency and a fixed Bandwidth.

The value of centre frequency and bandwidth are chosen such that we get a value of Q which is reasonable and easy to design in a circuit. This leads to better selectivity.

B F_{IF}: intermediate frequency = 0.455 MHz

f_m : centre frequency of incoming signal.

f_{LO} : local oscillator freq.

Now, $f_{LO} = f_{If} + f_m$

When f_m = 0.535 MHz & f_{IF} = 0.455 MHz

f_{LO} = 0.990 MHz

When f_m = 1.605 MHz & f_{IF} = 0.455 MHz

f_{LO} = 2.06 MHz

∴ Tuning range of oscillator: 0.99 MHz to 2.06 MHz

3(c)(ii)

Sol: For AM with envelope detection and assuming 100% sinusiodal modulation, the output SNR is given by.

$$(S/N)_{0_{AM}} = \frac{1}{3}\gamma \qquad [\text{where } \gamma \text{ is } (S/N)_i]$$

For FM with sinusiodal modulation, the output SNR is given by,

$$(S/N)_{0_{FM}} = \frac{3}{2}\beta^2\gamma \quad [\beta : \text{mod ulation index of FM}]$$

Hence, we see that use of FM offers the possibility of improved SNR over AM, when

$$3/2\beta^2 > 1/3$$

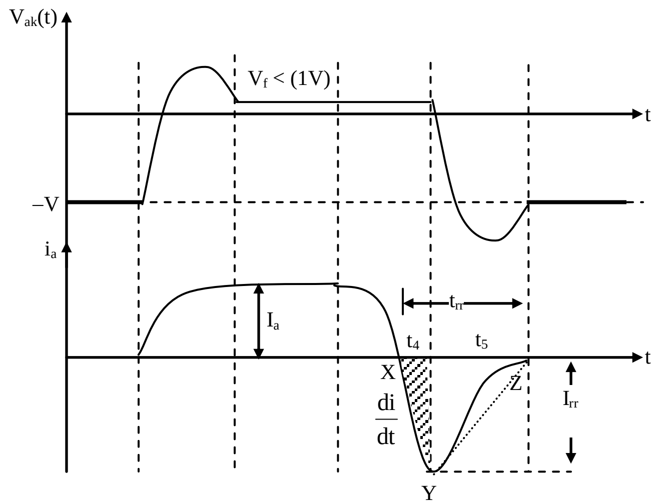
Or $\beta > 0.47$

However, a value of $\beta < 0.2$ is considered to define FM signal to be narrow band.

Hence we can conclude that narrow band FM offers no improvement in SNR over AM.

4(a)(i)

Sol: A.



Q_r = Area of ΔXYZ

$Q_r = \frac{1}{2}\times I_{rr}\times t_{rr}$

From $\Delta WXY \Rightarrow \frac{di}{dt}=\frac{I_{rr}}{t_4}$

$I_{rr} = \frac{di}{dt}\times t_4$

$\frac{t_5}{t_4} = s$, snappiness factor (or) soft factor.

$t_5 = t_4.s \Rightarrow t_4 + t_4.s = t_{rr}$

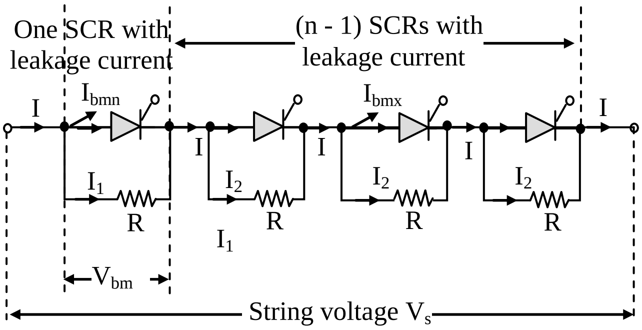
$t_4 = \frac{t_{rr}}{1+S}$

Now, $Q_r = \frac{1}{2}\times\frac{di}{dt}t_4\,t_{rr}$

$Q_r = \frac{1}{2}\times\frac{di}{dt}\times\frac{t_{rr}^2}{(1+S)}$ → slow recovery

$Q_r = \frac{1}{2}\times\frac{di}{dt}\times t_{rr}^2$ → fast recovery

B.



$I_1 = I - I_{b\,mn}$

$I_2 = I - I_{b\,mx}$

$V_s = I_1R + (n-1)\,I_2R$

$= I_1R + (n-1)\,[I - I_{bmx}]\,R$

$= I_1R + (n-1)\,[\,I_1 + I_b\,mn - I_b\,mx]\,R$

$= I_1R + (n-1)\,[\,I_1 - (I_b\,mx - I_b\,mn)]\,R$

$= I_1R + (n-1)\,I_1R - (n-1)\,\Delta I_b\,R$

$= I_1R + nI_1R - I_1R - (n-1)\,\Delta\,I_b\,R$

$= nV_{bm} - (n-1)\quad \Delta I_b\,R$

$R = \dfrac{nV_{bm} - V_s}{(n-1)\Delta I_b}$ Static equalizing Resistor

4(a)(ii)

Sol: $R_{load} = 20\Omega$,

V_{dc}= 600V, 500Hz,

rms Load voltage = 500V

A. Average power absorbed by the load

$$= \frac{V_{rms}^2}{R} = \frac{500^2}{20} = 12500\text{ W}$$

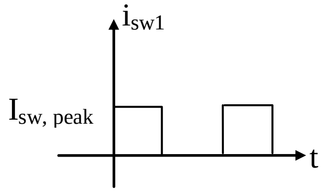
B. Average source current =?

$V_{dc}\,I_s$ = Average power absorbed by the load

$600(I_s) = 12500$

$\Rightarrow \quad I_s = 20.83$ A

C. Average current of each switch = ?



Average current of each switch

$$= \frac{1}{2} I_{sw,peak}$$

$$I_{sw,Peak} = \frac{V_{sw,RMS}}{R}$$

$$= \frac{500}{20} = 25 \text{ A}$$

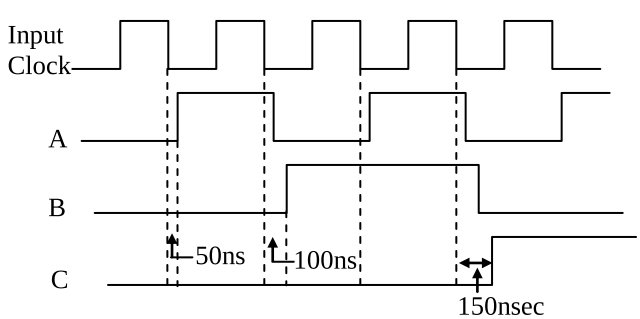
$$\therefore \text{ Average switch current } = \frac{1}{2} \times 25$$

$$= 12.5\text{A}$$

4(b)(i)

Sol: Ripple counters are the simplest type of binary counters because they require the fewest components to produce a given counting operation. However ripple counters have one major drawback, which is caused by their basic principle of operation. Each FF is triggered by the transition at the output of the preceding FF. Because of the inherent propagation delay time (t_{pd}) of each FF, this means that second FF will not respond until a time t_{pd} after the first FF receives an active clock transition. The third FF will not respond until a time equal to $2 \times t_{pd}$ after that clock transition and so on.

Consider the waveforms of a 3-bit ripple counter shown below.



Assume that each FF has a propagation delay of 50ns (t_{pd} = 50ns). Notice that the flip-flop output toggles 50ns after each input pulse. Similarly, B toggles 50ns after A goes from 1 to 0, and C toggles 50nsec after B goes from 1 to 0. As a result, when the fourth clock pulse occurs, the C output goes high after a delay of 150nsec. In this situation, the counter does operate properly in the sense that the FF's do eventually get to their correct states representing the binary count. However, the situation worsens if the input pulses are applied at a much higher frequency.

For proper counter operation we need,

$T_{clcok} \geq N.t_{pd}$

Where N = number of FF's

$$\Rightarrow f_{max} = \frac{1}{N \times t_{pd}}$$

4(b)(ii)

Sol: Assume that the set $\{\psi_n(t)\}$ is sufficient to represent the waveform.

$$\int_a^b w(t)\psi_m^*(t)dt = \int_a^b \left[\sum_n a_n\psi_n(t)\right]\psi_m^*(t)dt$$

$$= \sum_n a_n \int_a^b \psi_n(t)\psi_m^*(t)dt$$

$$= \sum_n a_n K_n \delta_{mn}$$

$$= a_n K_n$$

$$\therefore a_n = \frac{1}{K_n}\int_a^b w(t)\psi_n^*(t)dt$$

4(c)(i)

Sol: Total P = 50 kW

$\cos\phi = 0.8$; $\phi = \cos^{-1}(0.8) = 36.87°$, lag

Reactive power of load Q = P$\tan\phi$

= 50tan36.87°

= 37.5 kVAR

Real power supplied by machine 1, $P_1 = \frac{P}{2}$

$$= \frac{50}{2} = 25 \text{ kW}$$

Phase angle of machine 1 $\phi_1 = \cos^{-1}(0.9)$

$= 25.84°$,lag

Reactive power supplied by machine 1, $Q_1 = P_1 \tan\phi_1$

$= 25\tan(25.84°) = 12.10$ RVAR

Real power supplied by machine 2

$$P_2 = \frac{P}{2} = \frac{50}{2} = 25 \text{ kW}$$

Reactive power supplied by machine 2

$Q_2 = Q - Q_1$

$= 37.5 - 12.10$

$= 25.391$RVAR

Pulse angle of machine 2

$\cos\phi_2 = \cos(45.44°) = 0.701$, lag

Current supplied by machine 2

$$I_2 = \frac{P}{\sqrt{3}V_L \cos\phi_2}$$

$$= \frac{25 \times 1000}{\sqrt{3 \times 400 \times 0.701}}$$

$$= \frac{25000}{485.625} = 51.4 \text{ A}$$

4(c)(ii)

Sol: At UPF:

1. **Half full load:**

   Output = 10 kW.

   $\eta = 0.98$.

$$\text{Losses} = 10\left(\frac{1}{0.98}-1\right)\text{ kW} = 204\text{ W}$$

$$= W_i + W_{cu}$$

Where W_i = core losses

W_{cu} = copper losses at $\frac{1}{2}$ full load

2. Full load:

Output = 20 kW.

$\eta = 0.98$

$$\text{Losses} = 20\left(\frac{1}{0.98}-1\right)\text{ kW} = W_i + 4W_{cu}$$

$$= 408\text{ W}$$

Solving, W_i = **136 W** = core loses

W_{cu} = 68 W

$\therefore$ Copper losses at full load = **272 W**

3. p.u value of equivalent resistance of transformer

$$R_{pu} = \frac{\text{Full load cu losses}}{V_{rated}\, I_{rated}}$$

$$= \frac{272}{20,000}$$

= **0.0136 pu.**

5(a)(i)

Sol: $m(t) = \frac{0.8}{2j}\left(e^{j2\pi(1000\,t)} - e^{-j2\pi(1000\,t)}\right)$

$M(f) = -0.4j\delta(f-1000) + j0.4\delta(f+1000)$

Voltage spectrum of the AM signal:

$$S(f) = 250\,\delta(f-f_c) - j100\delta(f-f_c-1000) + j100\delta(f-f_c+1000)$$
$$+ 250\delta(f+f_c) - j100\delta(f+f_c-1000) + j100\delta(f+f_c+1000)$$

5(a)(ii)

Sol: $R_LC = 400 \times 10^3 \times 100 \times 10^{-12} = 4 \times 10^{-5}$ s

To avoid diagonal clipping

$$R_LC \le \frac{1}{2\pi f_m}\frac{\sqrt{1-\mu^2}}{\mu}$$

Given that $\mu = 0.75$

$$f_m \le \frac{1}{2\pi R_LC}\frac{\sqrt{1-\mu^2}}{\mu}$$

$$f_m \le \frac{1}{2\pi \times 10^{-5} \times 4}\frac{\sqrt{1-(0.75)^2}}{0.75}$$

$f_m \le 3510.8$ Hz

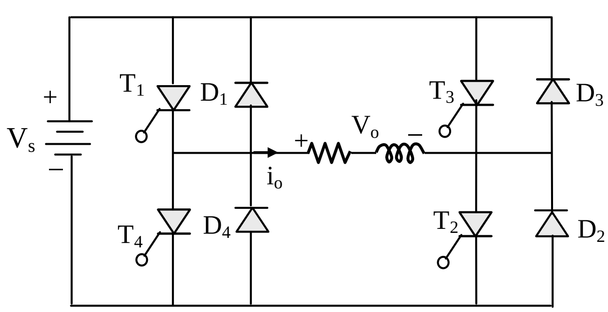
$\therefore$ maximum frequency = 3510.8 Hz

5(b)

Sol: Given data:

$V_{dc} = 100$ V; R = 10 Ω, L = 30 mH;

f = 50 Hz; ω = 100π = 314 rad/sec.



(i) For $0 < t < \frac{T}{2}$

Under steady state conditions, at t = 0, $i_0(0) = -I_0$

Under this condition, Laplace transform of eq. $V_S = Ri_0 + L\frac{di_0}{dt}$

$$\frac{V_S}{s} = I(s)[R + Ls] + LI_0 \qquad \text{..........} \ (1)$$

Its time solution is

$$i_0(t) = \frac{V_S}{R}\left(1-e^{-\frac{R}{L}t}\right) - I_0 e^{-\frac{R}{L}t} \quad \text{.......... (2)}$$

At $t = \frac{T}{2}$, $i_0(t) = I_0$

$$i_0\left(\frac{T}{2}\right) = I_0 = \frac{V_S}{R}\left(1-e^{-\frac{RT}{2L}}\right) - I_0 e^{-\frac{RT}{2L}}$$

$$I_0 = \frac{V_S}{R}.\frac{1-e^{\frac{-RT}{2L}}}{1+e^{\frac{-RT}{2L}}}$$

$$i_0(t) = \frac{V_S}{R}\left(1-e^{-\frac{R}{L}t}\right) - \frac{V_S}{R}.\frac{1-e^{\frac{-RT}{2L}}}{1+e^{\frac{-RT}{2L}}}e^{\frac{-R}{L}t}$$

(ii) Similarly for $\frac{T}{2} < t < T$ (or) $0 < t' < \frac{T}{2}$

$$i_0(t') = \frac{-V_S}{R}\left(1-e^{-\frac{R}{L}t'}\right) + \frac{V_S}{R}.\frac{1-e^{\frac{-RT}{2L}}}{1+e^{\frac{-RT}{2L}}}e^{\frac{-R}{L}t'}$$

Where $t' = t - \frac{T}{2}$

Here $\frac{R}{L} = \frac{10}{30\times10^{-3}} = \frac{1000}{3}$

$T = \frac{1}{f} = \frac{1}{50} = 20$ ms

$$\frac{RT}{2L} = \frac{10\times0.02}{2\times30\times10^{-3}} = \frac{10}{3}$$

$\therefore$ For $0 < t < \frac{T}{2}$

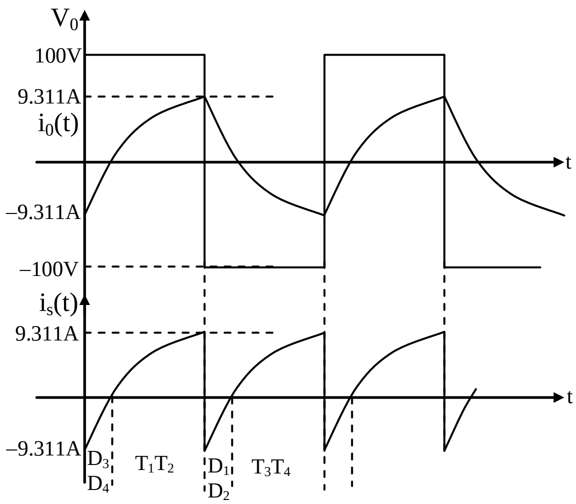
$$i_0(t) = \frac{100}{10}\left(1-e^{\frac{-1000\,t}{3}}\right) - \frac{100}{10}\left(\frac{1-e^{\frac{-10}{3}}}{1+e^{\frac{-10}{3}}}\right)e^{\frac{-1000\,t}{3}}$$

$$= 10\left(1 - e^{\frac{-1000\,t}{3}}\right) - 9.311e^{\frac{-1000\,t}{3}}$$

$$= 10 - 19.311e^{\frac{-1000\,t}{3}}$$

Similarly for $\frac{T}{2} < t < T$ (or) $0 < t' < \frac{T}{2}$

$$i_0(t') = -10 + 19.311e^{\frac{-1000\,t'}{3}}$$



5(c)

Sol: Distribution transformers are usually of 3-phase type. But since no data is given, it will be assumed that the transformer of the problem is a single-phase transformer.

1. **Turns ratio:** $\frac{\text{hv turns}}{\ell\text{v turns}} = \frac{2300}{230} = 10$.

2. The problem can be worked ref hv or ℓv. Choosing ℓv;

   Hv parameters ref ℓv :

   Resistance = $r_{1\ell v} = \frac{r_1}{100}$ = 0.0396 Ω

   reactance = $x_{1\ell v} = \frac{x_1}{100}$ = 0.158 Ω

3. Equivalent resistance and leakage reactance of the transformer ref ℓv :

$r_{eq\ell v}$ = 0.0396 + 0.0396 = 0.0792 Ω

$x_{eq\ell v}$ = 0.158 + 0.158 = 0.316 Ω.

4. Equivalent circuit ref ℓv :

Since no data is given, R_c and x_m branches are ignored.

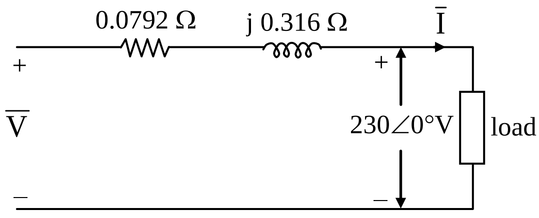


Fig.2

The load voltage is specified as 230 V. phase angle is arbitrarily selected as 0°:

Load current I in fig.1 = (10,000/230)

= 43.48 A.

$\therefore \bar{I} = 43.48\angle[-\cos^{-1}(0.8) = -36.87°]$

In fig.1, $\bar{V} = 230\angle 0° +$

$[43.48\angle -36.87°][0.0732+j0.316]$

$= 230\angle 0° + 14.1\angle 40° = 240.96\angle 2.16°$

5. Voltage that must be applied on the hv side = 2409.6 V.

$$\text{Voltage regulation} = \frac{240.96-230}{230}\times 100$$

= **4.76%**

5(d)

Sol: Given data: P_0 = 4kW, N_1 = 900rpm, I_{a1} = 20A, V_t = 230V

(i) $\tau_L \propto N^2$

Under steady state, $\tau_{em} = \tau_L$

$$\Rightarrow \qquad \frac{\phi_1 I_{a1}}{\phi_2 I_{a2}} = \left(\frac{N_1}{N_2}\right)^2$$

$$\Rightarrow \quad \frac{I_{a1}^2}{\frac{I_{a2}}{2}\times I_{a2}} = \left(\frac{N_1}{N_2}\right)^2$$

$$\Rightarrow \quad I_{a2} = \frac{\sqrt{2}I_{a1}N_2}{N_1} \qquad \text{------- (1)}$$

Since r_a and r_s are not given, $E_{b1} = E_{b2} = 230V$

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

$$\Rightarrow \quad \frac{N_1}{N_2} = \frac{\phi_2 \propto \frac{I_{a2}}{2}}{\phi_1 \propto I_{a1}}$$

$$\Rightarrow \quad \frac{N_1}{N_2} = \frac{I_{a2}}{2I_{a1}} \qquad \text{------- (2)}$$

$$\Rightarrow \quad \frac{N_1}{N_2} = \frac{\sqrt{2}I_{a1}N_2}{2I_{a1}N_1} \qquad \text{from equation-(1)}$$

$$\Rightarrow \quad \left(\frac{N_2}{N_1}\right)^2 = \sqrt{2}$$

$$\Rightarrow \quad N_2^2 = \sqrt{2}\times 900^2$$

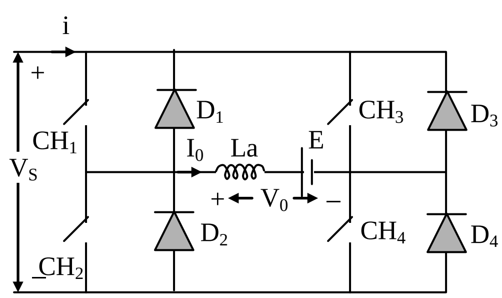
$$\therefore \quad N_2 = 1070.28 \text{ rpm}$$

From (1)

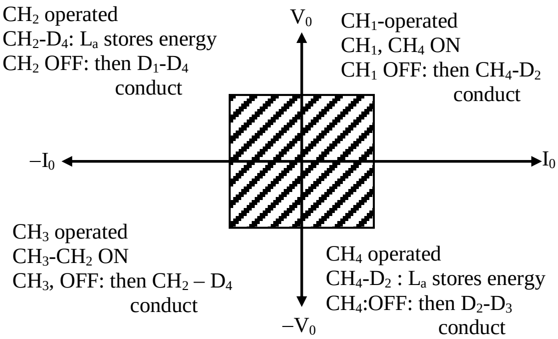
$$I_{a2} = \frac{\sqrt{2}\times I_{a1}\times N_2}{N_1} = \frac{\sqrt{2}\times 20\times 1070.28}{900} = 33.63\text{A}$$

5(e)

Sol:



From the above diagram choppers shown are switches these are self commutated by the feed back diodes shown as D_1, D_3, D_4, D_2. For duty ratio greater than 0.5 voltage is '−ve' and for < 0.5, voltage is '+ve'



Here operated means corresponding switch is get ON and OFF in that period

When $\alpha < 0.5$

First quadrant operation

CH_4 and CH_1 is ON: so current flows through $V_s – CH_1 – L_a – E – CH_4 - V_S$

So V_0 is +ve, I_0 is +ve

When CH_1 is turned off, positive current free wheels through CH_4, D_2. In this manner both V_0, I_0 can be controlled.

Second Quadrant operation

Here CH_2 operated and CH_1, CH_3 and CH_4 are kept off, with CH_2 ON, reverse (or negative) current flows through L_a, CH_2, D_4 and E. Inductance L_a stores energy during the time CH_2 ON.

In this time L_a stores energy then the load voltage $\left(V_0 = E + L\frac{di}{dt}\right) > V_S$

When CH_4 is turned off 'V_0' will turn on diode D_1, D_4 then the current is fed back to source through D_1, D_4 as load 'V_0 is +ve and I_0 is negative.

When $\alpha > 0.5$ (V_0 is negative)

Third Quadarant operation: (V_0 is –ve, I_0 is –ve). CH_1 is kept off, CH_2 is kept ON and CH_3 is operated. Polarity of load emf 'E' must be reversed for this Quadarant working $V_0 = -E_0 + I_0R$

When CH_3 ON, load gets connected to source 'V_S' so V_0 I_0 are negative leading to third Quadarant operation. When CH_3 is turned off. load voltage turn on diode D_4. Load current free wheels through CH_2, D_4

Fourth Quadrant operation: (V_0 –'Ve', I_0 '+ ve')

Here CH_4 is operated and other devices kept off. Load emf 'E' must have its polarity reversed. When CH_4 ON positive current flows through CH_4, D_2, L_a and E. Inductance L_a stores energy during this period.

This energy will turn on diodes D_2, D_3 when CH_4 turned off. So that current is fed back to source through D_2, D_3. Also power is fed back from load to source.

6(a)(i)

Sol: Given

200V, 875 rpm, I_a =150A, r_a = 0.06

$V_{rms} = 240$

A. At rated conditions

Let us find Back EMF,

$V_t = E_b + I_aR_a$

$E_b = 200 - 150(.06)$

$E_b = 191$ V

At rated torque, current will be rated I_a = 150 A

At 750 rpm,

$E_b \propto N$

$$\frac{875}{750} = \frac{191}{x}$$

$$\Rightarrow x = \frac{191 \times 750}{875} \text{V}$$

For fully controlled bridge rectifier

$$V_o = \frac{2V_m}{\pi}\cos\alpha$$

$$\frac{2V_m}{\pi}\cos\alpha = E_{b_2} + I_aR_a$$

$$\frac{2}{\pi} \times 240\sqrt{2}\cos\alpha = \frac{191 \times 750}{875} + 150(0.06)$$

$\Rightarrow \alpha = 36.93°$

$\therefore$ firing angle, α = 36.93°

B. At rated torque, –500 rpm

$N \propto E_b$

$$\frac{875}{-500} = \frac{191}{x}$$

$$\Rightarrow x = \frac{191 \times -500}{875} V$$

$$V = E_b + I_a R_a$$

$$\frac{2}{\pi} \times 240\sqrt{2}\cos\alpha = \frac{191 \times -500}{875} + 150(0.06)$$

$\alpha = 117.61°$

$\therefore$ firing angle, $\alpha = 117.61°$

6(a)(ii)

Sol: Given data:

Source voltage V_s = 230 V

Firing angle = 40°

Extinguishes at an angle = 210°.

A. The circuit turn off time t_c is

$$= \frac{2\pi - \beta}{\omega}$$

$$= \frac{(360 - 210)\pi}{180 \times 2\pi \times 50} = 8.333 \text{ ms}$$

Average output voltage is $V_o = \frac{V_m}{2\pi}[\cos\alpha - \cos\beta]$

$$V_o = \frac{\sqrt{2}.230}{2\pi}[\cos 40° - \cos 210°] = 84.477 \text{ V}$$

Average load current $I_o = \frac{V_o}{R}$

$$= \frac{84.477}{5} = 16.8954 A.$$

B. The circuit turn-off time is

$$t_c = \frac{2\pi + \theta \ -\beta}{\omega}$$

Here $\theta = \sin^{-1}\frac{E}{V} = \sin^{-1}\frac{110}{\sqrt{2}\times 230} = 19.77°$

$\therefore$ $t_c = \frac{(360+19.77-210)\pi}{180\times 2\pi\times 50} = 9.432\,\text{ms}$

The average load voltage

$$V_o = \frac{1}{2\pi}\left[V_m(\cos\alpha - \cos\beta) + E(2\pi+\alpha-\beta)\times\frac{\pi}{180}\right]$$

$$V_o = \frac{1}{2\pi}\left[\sqrt{2}.230(\cos 40° - \cos 210°) + 110(360+40-210)\frac{\pi}{180}\right]$$

$$= 142.544\ \text{V}$$

$\therefore$ Average charging current $I_o = \frac{V_0 - E}{R}$

$$= \frac{142.54-110}{5}$$

= 6.508 A.

6(b)

Sol: (i).20 kW, 500 V dc shunt motor:

These ratings mean that the full-load output = 20 kW.

With a full-load efficiency = 90%,

Full load input = $\frac{20,000}{0.9}$

= 22,222 W.

$\therefore$ Full load losses = 2222 W,

From given data full load armature copper losses = 2,222 × 0.4

= 888.8 W

(ii).Full-load line current = $\frac{20,000}{0.9\times 500}$ = 44.4 A

Field current (constant) = $\frac{500}{500}$ = 1A

$\therefore$ Full load armature current = 43.4 A

Armature resistance $r_a = \frac{888.8}{43.4^2} = 0.472\ \Omega$

(iii)The problem specifies starting current. It is assumed that it refers to starting line current.

Minimum starting line current

$= 1.2 \times 44.4 = 53.3$ A

Maximum starting line current

$= 2.5 \times 44.4 = 111$ A

$\therefore$ Minimum starting armature current

$= 52.3 \text{ A} = I_{a2}$

Maximum starting armature current

$= 110 \text{ A} = I_{a1}$

(iv)Design of a 4-section starter:

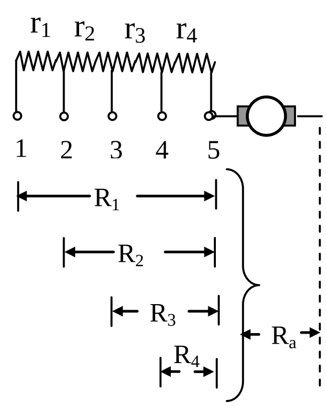


Fig. 4-section starter of dc machine

$\alpha = \frac{I_{a2}}{I_{a1}} = \frac{52.3}{110} = 0.475.$

Also, $\frac{500}{r_1 + r_2 + r_3 + r_4 + r_a} = \frac{500}{R_1} = 110$

$\Rightarrow R_1 = 4.54\ \Omega$

We have,

$r_1 = R_1(1 - \alpha) = 4.54(0.525) = 2.383\ \Omega.$

$r_2 = \alpha r_1 = 0.475 \times 2.383 = 1.132\ \Omega$

$r_3 = \alpha r_2 = 0.475 \times 1.132 = 0.537\ \Omega$

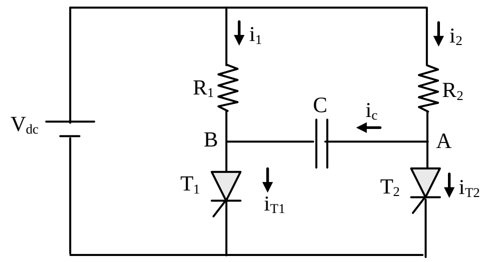
$r_4 = \alpha\, r_3 = 0.475 \times 0.537 = 0.255\ \Omega$

6(c)(i)

Sol: Complementary commutation:

In this type of commutation a thyristor carrying load current is commutated by transforming its load current to another incoming thyristor.

Figure below shows a complementary commutation.



When 'T_1' is ON

voltage across 'T_2' reverse Bias

When 'T_2' is ON

voltage across 'T_1' reverse Bias

At t = 0, 'T_1' is trigger

When T_1 is ON (t = 0)

$i_1 = \frac{V_{dc}}{R_1}$

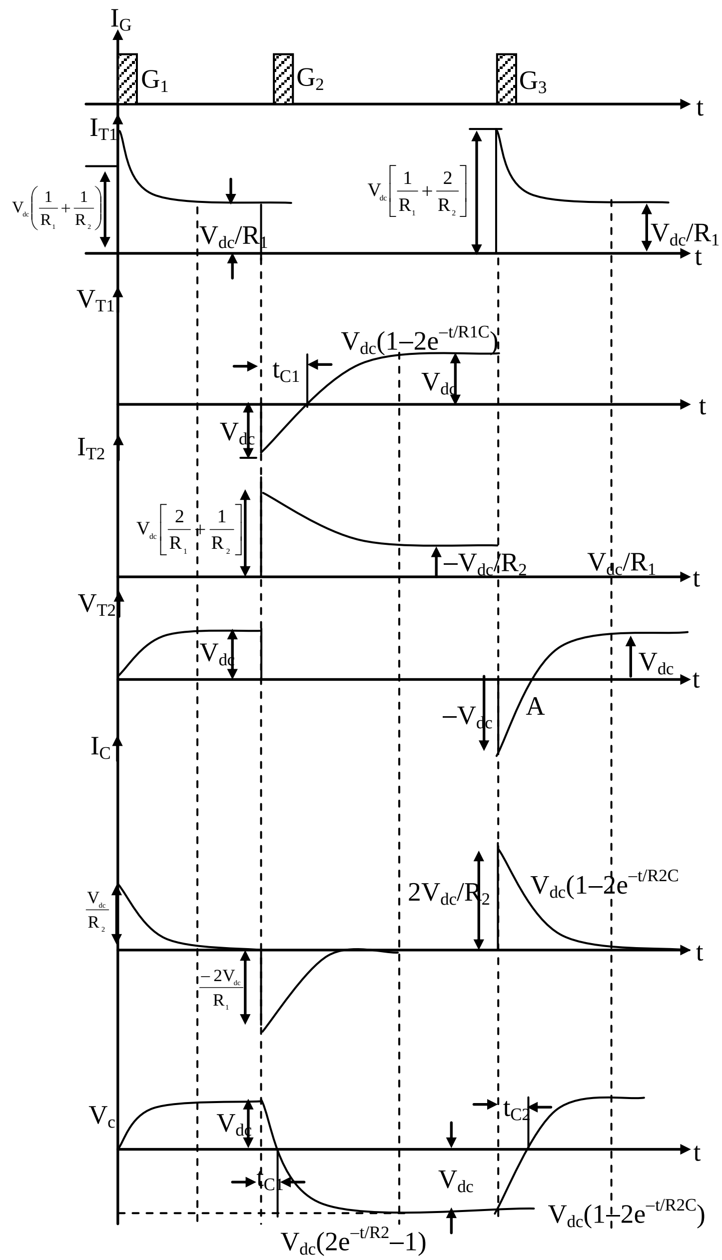
$V_{dc} = R_2 i_2 + \frac{1}{C}\int i_2 dt \quad (i_2 = i_c)$

$\Rightarrow \frac{V_{dc}}{s} = \left[R_2 + \frac{1}{Cs}\right] I_c(s)$

$I_C(s) = \frac{V_{dc}}{s} \times \frac{Cs}{R_2 Cs + 1}$

$= \frac{V_{dc}}{R_2} \frac{1}{(s + 1/\tau)}$

Solution of above equation



$$i_c(t) = \frac{V_{dc}}{R_2} e^{-t/R_2C}$$

Voltage across capacitor

$$V_C(t) = V_{dc}\left[1 - e^{-t/R_2C}\right] \quad (\because V_C = V_{dc} - R_2 i)$$

$$i_{T1} = i_1 + i_2 = \frac{V_{dc}}{R_1} + \frac{V_{dc}}{R_2}$$

When T_2 ON: $(t = t_2)$

Voltage across $(T_1) \Rightarrow V_{T1} = V_{BA} = -V_{dc}$ at $t = t_2$

In this case path of current $i_2 = \frac{V_{dc}}{2}$

Direction of capacitor current B to A

$V_{dc} = R_1 i_1 + \frac{1}{C}\int i_1 dt$

Apply Laplace transform

$$\frac{V_{dc}}{s} = R_1 I_1(s) + \frac{I_1(s)}{Cs} - \frac{V_{dc}}{s}$$

$$I_1(s) = \frac{2V_{dc}}{s} \times \frac{1}{R_1 + Cs}$$

Apply ILT

$$i_1(t) = \frac{2V_{dc}}{R_1} e^{-t/R_1C}$$

at $t = t_2$

$$i_1 = \frac{2V_{dc}}{R_1}$$

(at $t = t_2$ instant the capacitor current direction is changed)

$i_{T2} = i_1 + i_2$

Voltage across capacitor (V_c) = source voltage $-$drop across R_1

$= V_{dc}(2e^{-t/RC} - 1)$

($\because$ Voltage across 'A' w.r.t 'V')

When T_1 is ON in second time $(t = t_3)$:

$$i_1 = \frac{V_{dc}}{R_1}$$

$$\frac{V_{dc}}{s} = R_2 I_2(s) + \frac{I_2(s)}{Cs} - \frac{V_{dc}}{s}$$

$$i_2 = \frac{2 \times V_{dc}}{R_2} e^{-t/R_2C} = i_C \text{ (Direction A} \rightarrow \text{B)}$$

Voltage across (V_C) = source voltage $-$ drop across 'R_2'

$= V_{dc} - R_2 i_2$

$= V_{dc}(1-2e^{-t/R2C})$

Voltage across $T_2 = (V_{T2}) = V_{AB}$

Conclusion: When one SCR's trigged other SCR is RB

6(c)(ii)

Sol: Given data:

Supply voltage $V_s = 230$ V

Battery emf = 200 V

The battery terminal voltage $V_o = E + I_0R$

$$V_0 = 200+20\times0.5 = 210 \text{ V}$$

But $V_o = \frac{3V_{ml}}{\pi}\cos\alpha = 210\,\text{V}$

$$\therefore \alpha = \cos^{-1}\frac{210\times\pi}{3\sqrt{2}\times230} = 47.453°.$$

Constant load current $(I_o) = 20$ A

Rms value of output current , $I_{or} = 20$ A

Power delivered to load $= EI_o + I_{or}^2.R$

$$= 200 \times 20 + (20)^2 \times 0.5 = 4200\text{W}$$

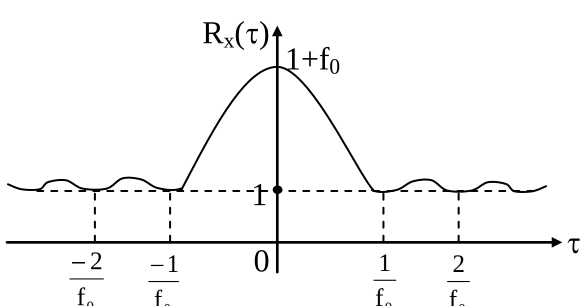
7(a)(i)

Sol: A. The power spectral density consists of 2 components

(1) A delta function $\delta(t)$ at the origin, whose inverse Fourier transform is one.

(2) A triangular component of unit amplitude and width $2f_0$, centered at the origin: the inverse Fourier transform of this component is $f_0 \text{ sinc}^2 (f_0 \tau)$

$R_X(\tau) = 1 + f_0 \sin c^2(f_0 \tau)$



B. Since $R_X(\tau)$ contains a constant component of amplitude 1, it follows that the dc power contained in X(t) is 1.

C. The mean-square value of X(t) is given by $E[X^2(t)] = R_X(0)$

$$= 1 + f_0$$

AC power = Total power – DC power

$$= E[X^2(t)] - 1 = 1 + f_0 - 1 = f_0$$

The AC power contained in X(f) is therefore equal to f_0.

7(a)(ii)

Sol: A. For a unity rolloff, raised cosine pulse spectrum, the bandwidth B equals 1/T, where T is the pulse length. Therefore, T in this case 1/12kHz. Quarternary PAM ensures 2 bits per pulse, so the rate of information is $\frac{2\,\text{bits}}{T} = 24$ kilobits per second.

B. For 128 quantizing levels, 7 bits are required to transmit an amplitude. The additional bit for synchronization makes each code word 8 bits. The signal is transmitted at 24 kilobits/s, so it must be sampled at

$$\frac{24\ \text{kbits/s}}{8\,\text{bits/sample}} = 3\ \text{kHz}\ .$$

The maximum possible value for the signal's highest frequency component is 1.5 kHz, in order to avoid aliasing.

7(b)

Sol: (i) **V_r, f_r operation:**

synchronous speed = $\frac{4\pi f_r}{P} = \omega_{sr}$ r/s (mech).

actual rotor speed = ω_1 r/s (mech).

slip = $s_1 = \frac{\omega_{sr} - \omega_1}{\omega_{sr}}$

dev.torque $T_{d_1} = \dfrac{3V_r^2 r_2}{s_1\omega_{sr}\left[\dfrac{r_2^2}{s_1^2} + x_2^2\right]}$

(neglecting stator impedance).

V,f operation, f = kf$_r$, V = kV$_r$ (V/f = V$_r$/f$_r$). (k some constant):

synchronous speed = $\dfrac{4\pi k f_r}{P} = k\omega_{sr}$ rad/s.

Let actual speed = ω_2 rad/s

slip = $s_2 = \dfrac{k\omega_{sr} - \omega_2}{k\omega_{sr}}$

It is given that the drop in speed is the same in both cases. So $(\omega_{sr} - \omega_1) = (k\omega_{sr} - \omega_2)$

$\therefore\ s_2 = \dfrac{\omega_{sr} - \omega_1}{k\omega_{sr}} = \dfrac{s_1}{k}$, and

$$T_{d_2} = \frac{3.k^2 V_r^2 r_2}{\dfrac{s_1}{k} k\omega_{sr}\left[\dfrac{r_2^2 k^2}{s_1^2} + k^2 x_2^2\right]}$$

$$= \frac{3V_r^2 r_2}{s_1\omega_{sr}\left[\dfrac{r_2^2}{s_1^2} + x_2^2\right]} = T_{d_1}$$

(ii) 1. Circuit element to be connected in parallel with the load (to improve overall power factor): Capacitor

2. Current drawn by the motor before any power factor improving device is connected:

Let voltage applied to the motor = $200\angle 0°$V.

Let current drawn by it be $\bar{I}_m = I_m(\cos\theta - j\sin\theta) = I_m(0.8 - j\,0.6) = I_m\angle{-36.87°}$.

Rating of the motor is given as 1 kW. Usually, this refers to the full load output. In the absence of necessary data regarding losses, assume that input to the motor = 1 kW. Then

$200 \times I_m \times 0.8 = 1000$.

$I_m = (1000/160) = 6.25$ A.

This is shown in fig.1.

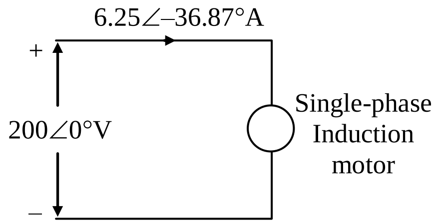


fig.1

3. Circuit and analysis after the capacitor is connected:

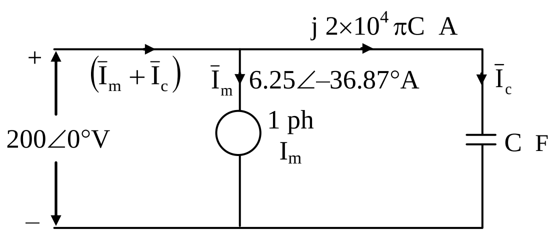


fig.2

From fig.2,

$(\bar{I}_m + \bar{I}_c)$= current delivered by the supply

$= 5 + j\,(20{,}000\,\pi C - 3.75)$ A.

It lags the supply by an angle

Since the overall current is lagging $\Rightarrow 20000\pi C < 3.75$

Hence, $\tan^{-1}\dfrac{3.75 - 20{,}000\,\pi C}{5} = \cos^{-1}(0.95) = 18.2°$

$\therefore \dfrac{3.75 - 20{,}000\,\pi C}{5} = \tan 18.2^\circ = 0.3287$

From which $C = 33.44\ \mu F$.

7(c)(i)

Sol: A. $(0111011110)_2$

$= (2^8 \times 1) + (2^7 \times 1) + (2^6 \times 1) + (2^4 \times 1) + (2^3 \times 1) + (2^2 \times 1) + (2^1 \times 1)$

$= 256 + 128 + 64 + 16 + 8 + 4 + 2 = 478$

B. $(1011100111)_2$

$= (2^9 \times 1) + (2^7 \times 1) + (2^6 \times 1) + (2^5 \times 1) + (2^2 \times 1) + (2^1 \times 1) + (2^0 \times 1)$

$= 512 + 128 + 64 + 32 + 4 + 2 + 1 = 743$

C. $(3751)_8$

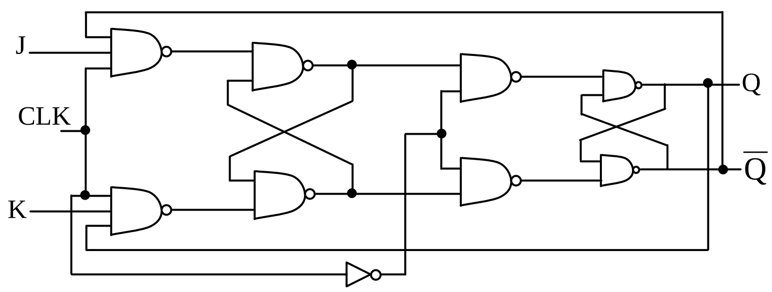
$= (8^3 \times 3) + (8^2 \times 7) + (8 \times 5) + (8^0 \times 1)$

$= 1536 + 448 + 40 + 1 = 2025$

7(c)(ii)

Sol: A. In all digital systems and circuits two logic levels are defined, HIGH and LOW, sometimes called "1" and "0". Taking the example of two voltage levels, in positive logic, HIGH level is denoted by higher voltage and LOW level is denoted by lower voltage. eg., 5 volts and 0 volts. In negative logic, on the other hand, HIGH level is denoted by lower voltage and LOW level is by higher voltage eg., 0 volts and 5 volts. In other words, the two are dual of each other, for example, an AND gate in positive logic will represent an OR gate in negative logic.

B. Master - slave JK flip-flop:



Master-slave flip-flop is a set of two identical flip flops. The clocks of the two flip-flops are of opposite phases i.e., if the clock of the master is HIGH, that of the slave is LOW and vice versa. When there is a change in the input of the master-slave unit, the output of the master changes when its clock is HIGH. This change can not be immediately transmitted to the slave as its clock is LOW. When the clock of the master becomes LOW, the clock of the slave becomes HIGH and changes in the output of the master is transmitted to the output of slave, which is the output of the master-slave unit. The purpose of this arrangement to make sure that the output of the flip-flop changes only once in a clock cycle, irrespective of the number of changes in the input.

8(a)(i)

Sol: Comparison between GTO and thyristor:

A GTO has the following disadvantages as compared to a thyristor:

(i) Magnitude of latching and holding current is more in a GTO.

(ii) On state voltage drop and the associated loss is more in a GTO.

(iii) Gate drive circuit losses are more.

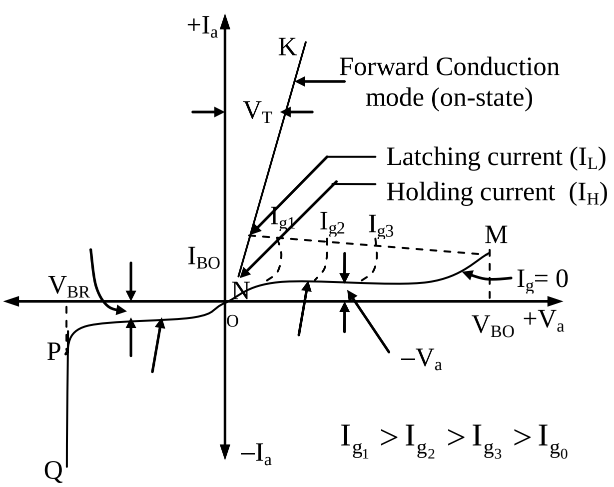
GTO has the following advantages over an SCR:

(i) GTO has faster switching speed.

(ii) Its surge current capability is comparable with SCR.

(iii) It has more di/dt rating at turn-on.

(iv) GTO circuit configuration has lower size and weight as compared to thyristor circuit unit.

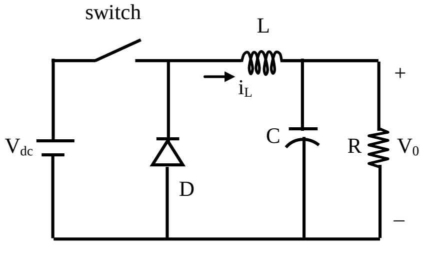


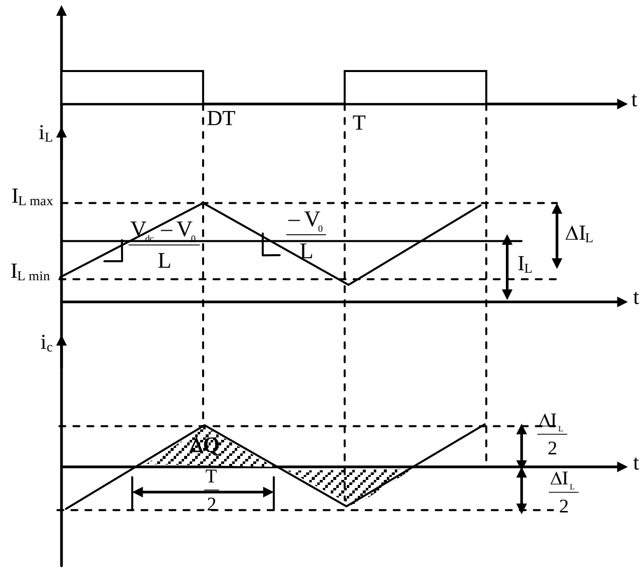
$I_{g_1} > I_{g_2} > I_{g_3} > I_{g_0}$

V –I characteristic of SCR

8(a)(ii)

Sol:





Expression for ripple current (ΔI_L):

$0 < t < DT$:

$$i_L(t) = \frac{V_{dc} - V_0}{L} t + I_{L\,min}$$

If $t = DT \Rightarrow i_L(t) = I_{L\,max}$

$$\therefore\ I_{L\,max} = \left[\frac{V_{dc} - V_0}{L}\right] DT + I_{L\,min}$$

$$I_{L\,max} - I_{L\,min} = \Delta I_L = \frac{V_{dc} - DV_{dc}}{L} DT$$

Ripple in inductor $\Delta I_L = \frac{V_{dc}}{L} D(1-D)T$

ΔI_L is maximum $\frac{d\Delta I_L}{dD} = 0 \Rightarrow D = \frac{1}{2}$

If $D = \frac{1}{2}$ peak-peak inductor current (ΔI_L) is maximum

$$\Delta I_{L\,max} = \frac{V_{dc}}{4Lf}$$

High switching will give less ripple, So high switching frequency gives only MOSFET

Expression for ΔV_0:

$$\Delta V_0 = \frac{\Delta Q}{C} = \frac{\frac{1}{2}\times\frac{\Delta I_L}{2}\times\frac{T}{2}}{C}$$

$$= \frac{1}{8C}\frac{V_{dc}}{L}D(1-D)T^2$$

ΔV_0 is max when $\frac{d\Delta V_0}{dD} = 0$

$1 - 2D = 0$, $D = \frac{1}{2}$

$$\Delta V_0 \max = \frac{V_{dc}}{32\,LCf^{\,2}}$$

8(b)(i)

Sol: Let x be a binomial random variable

A. $p(x > 1) = 1 - p(x = 0) - p(x = 1)$

$$= 1 - {}^{10}c_0(0.01)^0(0.99)^{10} - {}^{10}c_1(0.01)^1(0.99)^9$$

$\therefore p(x > 1) = 0.0042$

B. According to poisson distribution,

$$p(x = k) = e^{-np_e}\frac{(np_e)k}{k!} \quad np_e = 10(0.01)$$

$$np_e = 0.1$$

$p(x > 1) = 1 - p(x = 0) - p(x = 1)$

$$= 1 - e^{-0.1}\frac{(0.1)^0}{0!} - e^{-0.1}\frac{(0.1)^1}{1!}$$

$\therefore p(x>1) = 0.0047$

8(b)(ii)

Sol: The minimum number of bits per sample is “7” for a signal to quantization noise ratio of 40 dB.

The number of samples in a duration of

10 seconds = 8000×10

$= 8 \times 10^4$ samples

The minimum storage is = $7 \times 8 \times 10^4$

= 560 k bits

8(b)(iii)

Sol: $B = \frac{R}{2}(1+\alpha)$

B = 75 kHz

$R = \frac{1}{10\mu} = 100\,\text{kHz}$

$\frac{75 \times 2}{100} = 1 + \alpha$

$\alpha = 0.5$

8(c)(i)

Sol: Mechanical loss $= \frac{30}{100} \times 3000 = 900\,\text{W}$

Stator core loss = Power input at no-load – Mechanical loss– stator I^2R loss at no load

Neglecting stator I^2R loss,

Stator core loss = 3000 – 900 = 2100 W

Power input during blocked rotor test

= stator I^2R loss + Rotor I^2R loss = 4000 W

$\therefore$ Stator I^2R loss = Rotor I^2R loss

$= \frac{4000}{2} = 2000\,\text{W}$

A. At rated load, air-gap power,

P_g = Output power + mechanical loss + rotor I^2R loss

$\therefore$ P_g =60,000 +900+2000 = 62900W

But rotor I^2R loss = 2000 W = $s.P_g$

$\therefore$ Slip at rated load, $s = \frac{2000}{62900} = 0.0318$

B. At rated voltage, power input to motor during blocked rotor test

$$= 4 \times \left(\frac{100}{30}\right)^2 = 44.444\,\text{kW}$$

Air-gap power,

P_g=Power input– stator core loss – stator I^2R loss

$= 44444 - 2100 - 2000$

$= 40344$ Watt

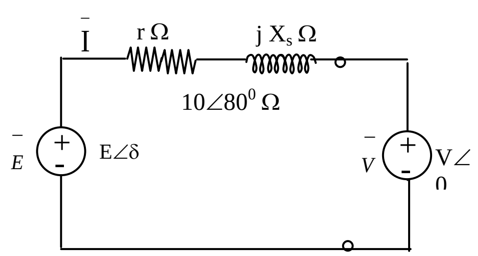
Synchronous speed,

$$\omega_s = \frac{4\pi f}{P} = \frac{4\pi \times 50}{4} = 50\pi\,\text{rad/s}$$

$\therefore$ Starting torque $= \dfrac{P_g}{\omega_s} = \dfrac{40344}{50\pi} = 256.84\,\text{Nm}.$

8(c)(ii)

Sol: A. Equivalent circuit per phase is shown in figure.



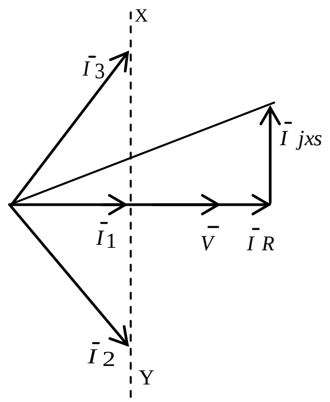
Since generator operation is being considered, $\bar{E}$ is shown as leading $\bar{V}$ (assuming δ is +ve). (For motor operation, $\bar{E}$ would lag $\bar{V}$). Reference direction for $\bar{I}$ is chosen to represent generator operation.

$$\bar{I} = \frac{E\angle\delta - V\angle 0}{10\angle 80^0} = \frac{E}{10}\angle(\delta - 80^0) - \frac{V}{10}\angle -80^0 \quad \bar{I}^* = \frac{E}{10}\angle(80^0 - \delta) - \frac{V}{10}\angle 80^0$$

Power received by the bus $= \text{Re}\,\bar{V} I^* = \dfrac{EV}{10}\cos\left(80^0 - \delta\right) - \dfrac{V^2}{10}\cos 80^0$

This will remain constant as E and δ change if E cos (80^0 - δ) remains constant (rest of the terms in the above expression are constants).

B.



For the same power received by the bus, the tip of the current phasor must lie on the line XY in the phasor diagram. In the phasor diagram, phase currents $\bar{I}_1$, $\bar{I}_2$ and $\bar{I}_3$ all give same power to bus but lead to different values of $\bar{E}$ and different excitations. So to have power constant, the prime mover power input to the generator must be held constant except for any changes in losses. (Friction losses do no change copper losses may change by a small amount). Change of power cannot be obtained by changing excitation.