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ESE – 2019 MAINS
OFFLINE TEST SERIES

ELECTRICAL ENGINEERING

TEST – 6
SOLUTIONS

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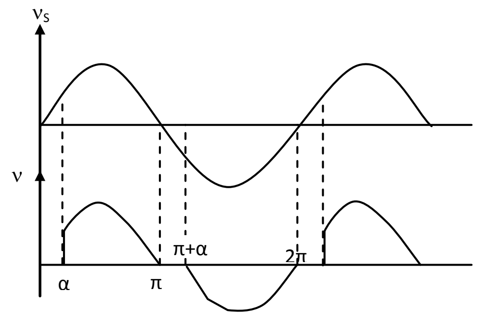
01.(a)

Sol: (i) Given that

Rms output voltage,



$$V_{or} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \, d\omega t\right]^{\frac{1}{2}}$$

$$= \frac{V_m}{\sqrt{2\pi}}\left[(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right]^{\frac{1}{2}}$$

The average power P delivered to load of resistance R,

$$P = \frac{V_{or}^2}{R}$$

$$P = \frac{V_m^2}{2\pi R}\left[(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right]$$

The power is maximum when α = 0°

$$P_{max} = \frac{V_m^2}{2\pi R}(\pi) \Rightarrow P_{max} = \frac{V_m^2}{2R}$$

(a) Power delivered = 50% of maximum power

$$P_0 = 0.5 \times \frac{V_m^2}{2R} = \frac{V_m^2}{4R}$$

$$\frac{V_m^2}{4R} = \frac{V_m^2}{2\pi R}\left[(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right]$$

$$\left[(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right] = \frac{\pi}{2}$$

By using trial and error method

$$\alpha = \frac{\pi}{2} = 90^{o}$$

(b) Power delivered = 70% of maximum power

$$P_0 = 0.7\frac{V_m^2}{2R}$$

$$0.7\frac{V_m^2}{2R} = \frac{V_m^2}{2\pi R}\left[(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right]$$

$$0.7\times\pi = (\pi-\alpha)+\frac{1}{2}\sin 2\alpha$$

$$2.20 = (\pi-\alpha)+\frac{1}{2}\sin 2\alpha$$

By trail and error method

Let $\alpha = 60°$

$$(\pi - \alpha) + \frac{1}{2}\sin 2\alpha = 2.52 \neq 2.2$$

$\alpha = 70°$

$$(\pi - \alpha) + \frac{1}{2}\sin 2\alpha = 2.24 \neq 2.2$$

$\alpha = 71°$

$$(\pi - \alpha) + \frac{1}{2}\sin 2\alpha = 2.21 \simeq 2.2$$

So the firing angle $\alpha = 71°$ (70.5° to 71.5°)

(ii) Given that

X_L=4 Ω, f=50 Hz, V_s=230 V

$$L = \frac{X_L}{2\times\pi\times f} = \frac{4}{2\times\pi\times 50}$$

$$= 12.732\times 10^{-3}\ \text{H}$$

$$\text{Max } \frac{di}{dt} = \frac{V_s}{L} = \frac{230}{12.732\times 10^{-3}}$$

$$= 18.064\ \text{kA/s}$$

01.(b)

Sol: A bipolar point to point HVDC transmission system is shown in fig(i).

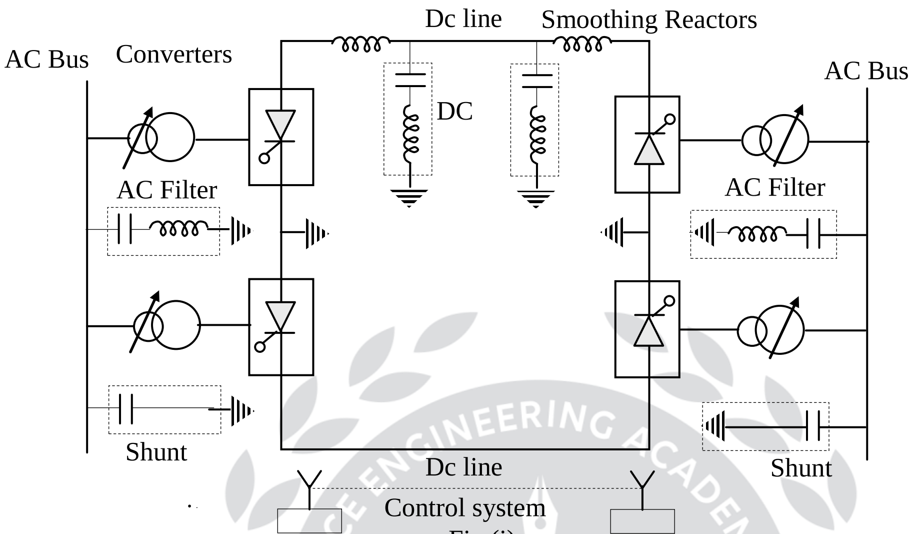


Fig (i)

Different components can be explained briefly as follows

1. Converter unit: It requires a converter system at each end. The sending end converter acts as a rectifier which converts AC to DC and receiving end converter acts as an inverter which converts DC to AC.

This unit consists of two 3-phase converters which are connected in series to form a 12 pulse converter. The converter consist of 12 thyristor valves and these valves can be packaged as single valve or double valve or quadric valve arrangements. These thyristors can be replaced by modern power electronic devices like GTOs(Gate Turn off Thyristor IGBT and Light triggered thyristors. The valves are cooled by air, water or oil.

Firing signals for these valves are generated in the converter controller and are transmitted to each thyristor in the valve through a fibre optic light guided system. The light signals are further converted into electrical signal using gate drive amplifiers with pulse transformers.

There valves are protected using snubber circuits, gapless surge arresters and protective firing circuits.

2. Filters: Frequent firings leads to generation of harmonics which lead to overheating of the equipments and interference with the communication systems. To reduce harmonics following filters are used.

(i) AC filters: They are made with passive components and provide low impedance to the harmonics (AC). Tuned as well as damped filter arrangements are generally used.

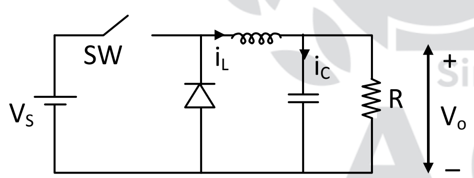
(ii) DC filters: Filters used at DC end are usually smaller and less expensive than the AC filters. Modern DC filters are designed using active components and passive components are reduced to minimum. These filters are specifically used to reduce interference with the communication lines.

(iii)High frequency filters: They suppress the high frequency currents and are connected between converter transformer and the station AC bus. Sometimes, they are connected between DC filter and DC line, and also on the neutral side.

3. Smoothing reactor: It is a large series reactor which is used on DC side to smooth the DC current. It regulates the DC current to a fixed value by opposing sudden change of the input current. It can be connected on the line side, neutral or an intermediate location.

01.(c)

Sol:



When switch is ON,

$$L\frac{di_L}{dt} = V_s - V_o \qquad \ldots\ldots\ldots(1)$$

$$C\frac{dV_o}{dt} + \frac{V_o}{R} = i_L$$

When switch is OFF,

$$L\frac{di_L}{dt} = -V_o$$

$$C\frac{dV_o}{dt}+\frac{V_o}{R} = i_L$$

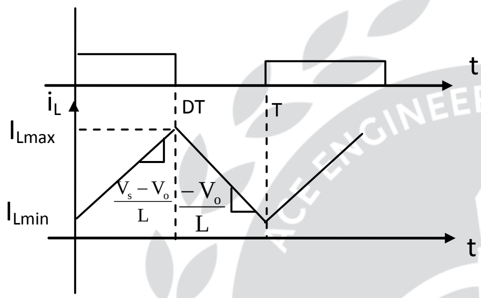
By volt-sec balance equation for L

$$\frac{1}{T}\left[L\frac{di_L}{dt}(DT)+L\frac{di_L}{dt}(1-D)T\right]=0$$

$$[(V_s-V_o)DT+(-V_o)(1-D)T]\frac{1}{T}=0$$

$$0 = V_s(D) - V_o$$

$$\Rightarrow \quad V_o = DV_S$$



From equation (1), we get $\frac{di_L}{dt}=\frac{V_s-V_o}{L}$

By integrating, we get

$$i_L=\left(\frac{V_s-V_o}{L}\right)t+I_{L\,min}$$

At $t = DT$, $i_L = I_{Lmax}$

$$I_{L\,max}=\left(\frac{V_s-DV_s}{L}\right)DT+I_{L\,min}$$

$$\Delta I_L=\frac{V_s}{L}D(1-D)T$$

$\therefore$ Peak to peak ripple current $=\frac{V_s}{L}\frac{D(1-D)}{f}$

In question he asked in terms of V_s, V_o, L, f.

As $V_o = DV_s \Rightarrow D=\frac{V_o}{V_s}$

$$\Delta I_L = \frac{V_s}{L}\left(\frac{V_o}{V_s}\right)\left(1-\frac{V_o}{V_s}\right)\frac{1}{f}$$

$$= \frac{V_o}{L}\left(1-\frac{V_o}{V_s}\right)\frac{1}{f}$$

01.(d)

Sol: Given that, 220 kV, 50 Hz

$X_L = 8\ \Omega$, $C = 0.025\ \mu F$

$R_c = 600\ \Omega$

(i) Natural frequency of oscillations,

$$f_n = \frac{1}{2\pi\sqrt{LC}}$$

$$f_n = \frac{1}{2\times 3.14}\times\frac{1}{\sqrt{\frac{8}{314}\times 0.025\times 10^{-6}}}$$

$$= 6.31\ \text{kHz}$$

(ii) Damped frequency of oscillations

$$f_d = \frac{1}{2\pi}\left[\frac{1}{LC}-\left(\frac{1}{2R_cC}\right)^2\right]^{1/2}$$

$$\Rightarrow f_d = \frac{1}{2\times 3.14}\left[\frac{1}{\frac{X_L}{2\pi\times 50}\times 0.025\times 10^{-6}}-\left(\frac{1}{2\times 600\times 0.025\times 10^{-6}}\right)^2\right]^{1/2}$$

$$\Rightarrow f_d = \frac{1}{6.28}[1570000000 - 1111111111]^{1/2}$$

$\Rightarrow f_d = 3411.09$ Hz $\Rightarrow 3.41$ kHz

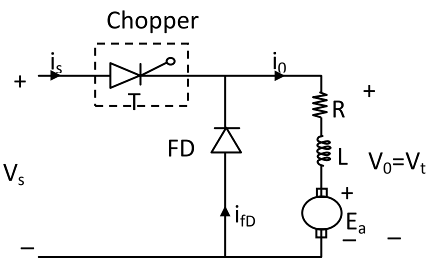
(iii) Critical resistance,

$$R = \frac{1}{2}\sqrt{\frac{L}{C}} = \frac{1}{2}\sqrt{\frac{8}{314}\times\frac{1}{0.025\times 10^{-6}}}$$

$$= 504.75\ \Omega$$

01.(e)

Sol: Given,



$V_s = 80V$

Rated speed = 900rpm

Rated current = 40A

$r_a = 0.25\Omega$

At rated conditions

$v_t = E + I_a r_a$

$80 = E + (40\times0.25)$

$E = 70 = k_m.\omega_m$ (where k_m is motor constant

$$k_m = \left(\frac{70}{900}\right)\frac{V}{rpm}$$

ω_m is speed of motor in radians/sec)

Given, half rated torque

N= 300rpm

$$E = K_m N = \frac{70}{900}\times 300 \text{ Volts}$$

We know that,

$T \propto \phi I_a$

$T \propto I_a$ (since separated excited motor, flux is maintained constant)

$I_a = 20A$ (as torque is reduced behalf)

$V_t = E + I_a R_a$

$$= \frac{70}{3} + 20(0.25)$$

$$\alpha V_s = \frac{85}{3}$$

$$\alpha = \left(\frac{85}{3}\right)\div 80$$

$\alpha = 0.354$

02(a)(i)

Sol: (i) E.m.f constant K_b= 0.5 V/r.p.m (given)

For separately excited d.c motor

$$E_a = K_b N$$

$$\text{and } E = V_0 - I_a R_a$$

$$= \frac{V_m}{\pi}(1+\cos\alpha)-5(2)$$

$$= \frac{230\times\sqrt{2}}{\pi}\left(1+\cos 30^o\right)-10$$

$$E = 183.20$$

$$\therefore \quad N = \frac{E}{K_b}$$

$$= \frac{183.20}{0.5}$$

= 366.4 rpm

(ii) Given 2d = 144^o $\Rightarrow$ d = 72^o

When 2d = π

V_{01max} = peak value of fundamental

$$= \frac{4V_S}{\pi} \text{ -------- (1)}$$

When 2d ≠ π

Peak value of fundamental waveform

is $\frac{4V_S}{\pi}\text{sind }\sin\frac{\pi}{2}$

Peak value of nth Harmonic

$$V_{on} = \frac{4V_S}{n\pi}\ \text{sinnd}\sin\frac{n\pi}{2}$$

For 3rd Harmonic

$$V_{03} = \frac{4V_S}{3\pi}\sin(3\times 72^o)\sin\frac{3\pi}{2} \text{------ (2)}$$

$$\frac{(2)}{(1)} = \frac{V_{03}}{V_{01}} = \frac{\sin(3\times 72^o)\ \ sin(3\times\frac{\pi}{2})}{3}$$

$$= \ 0.1959 = 19.6\%$$

(iii)Latching current may be defined as the minimum value of anode current which it must attain during turn-on process to maintain conduction when gate signal is removed.

Holding current may be defined as the minimum value of anode current below which it must fall for turning off the thyristor

- Usually latching current is two to three times that of holding current. In practice, this ratio is less than unity.
- For obtaining higher possible string efficiency, SCR connected in series/parallel string must have identical VI characteristics.

String efficiency is a term that is used for measuring the degree of utilization of SCR in a string. String efficiency of SCR's connected in series/parallel is defined as

String efficiency

$$= \frac{\text{Actual voltage /current rating of whole string}}{(\text{Individual voltage/current rating of one SCR})\times(\text{No. of SCRs in string})}$$

02(b)

Sol: Total resistance of line 100×0.1 = 10 ohms.

The inductance of the line

$$= 2\times 10^{-7}\times 100\times 1000\times \ln\frac{200}{0.75\times 0.7788}\text{H}$$

$$= 11.67\times 10^{-2}\text{ H}$$

∴ Inductive reactance

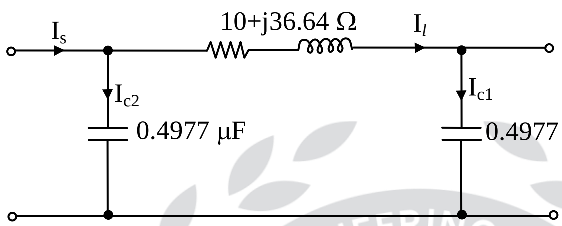
$$= 314\times 11.67\times 10^{-2} = 36.64\,\text{ohm}$$

The capacitance/phase

$$= \frac{2\pi \times 8.854 \times 10^{-12}}{\ln \frac{200}{0.75}} \times 100 \times 1000$$

$$= 9.954 \times 10^{-7} = 0.9954\,\mu F.$$

Nominal -π method: The nominal - π circuit for the problem is as follows:



For nominal -π it is preferable to take receiving end voltage as the reference phasor.

Load given as P_r(3-ϕ) = 20MW, V_r(L-L) = 66kV, cosϕ = 0.8 lag

Current $I_r = \frac{P_r(3-\phi)}{\sqrt{3} \times V_r \times \cos\phi} = 218.68A$

The current in phasor form $I_r = 218.68(0.8 - j0.6)$ A

Current $I_{c1} = j\omega CV_r = j314 \times 0.4977 \times 10^{-6} \times 38104$

$$= j5.95\,A$$

$$\therefore I_\ell = I_r + I_{c1}$$

$$= 174.94 - j131.20 + j5.95 = 174.94 - j125.25$$

$$\therefore V_s = V_r + I_\ell Z$$

$$= 38104 + (174.94 - j125.25)(10 + j36.64)$$

$$= 38104 + 1749.4 - j1252.5 + j6409.8 + 4589.16$$

$$= 44442 + j5157 \text{ volts}$$

$$\therefore |V_s| = 44740 \text{ Volts}$$

The no load receiving end voltage will be

$$\frac{44518(-j6398)}{10+j36.64-j6398}=\frac{44518(-j6398)}{10-j6361}=44985\text{ V}$$

$$\%\text{regulation}=\frac{44985-38104}{38104}\times 100$$

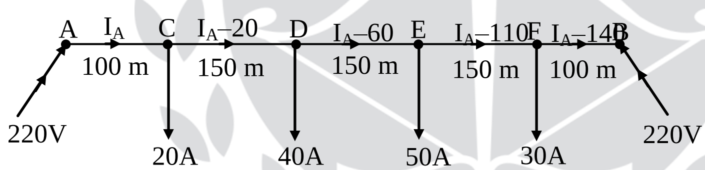
$$=18.05\%$$

The line current $I_\ell = 215.15$ Amp

$$\therefore \text{Loss}=3\times 215.15^2\times 10=1.388\,\text{MW}$$

$$\therefore\ \%\eta=\frac{20\times 100}{21.388}=93.5\%$$

Sol: (i) The figure shows the distributor with its tapped currents. Let I_A amperes be the current supplied from the feeding end A. Then currents in the various sections of the distributor are as shown in figure.



Resistance of 1m length of distributor = $2\times\frac{1.7\times 10^{-6}\times 100}{1}$ = $3.4\times 10^{-4}\ \Omega$

Resistance of section AC, $R_{AC} = (3.4\times 10^{-4})\times 100 = 0.034\ \Omega$

Resistance of section CD, $R_{CD} = (3.4\times 10^{-4})\times 150 = 0.051\ \Omega$

Resistance of section DE, $R_{DE} = (3.4\times 10^{-4})\times 150 = 0.051\ \Omega$

Resistance of section EF, $R_{EF} = (3.4\times 10^{-4})\times 100 = 0.034\ \Omega$

Resistance of section FB, $R_{FB} = (3.4\times 10^{-4})\times 100 = 0.034\ \Omega$

Voltage at B = Voltage at A – Drop over length AB

(or)

$$V_B = V_A - [I_A R_{AC} + (I_A - 20)R_{CD} + (I_A - 60)R_{DE} + (I_A - 110)R_{EF} + (I_A - 140)R_{FB}]$$

$220 = 220 - [0.034\ I_A + 0.051\ (I_A - 20) + 0.051\ (I_A - 60) + 0.034(I_A - 110) + 0.034(I_A - 140)]$

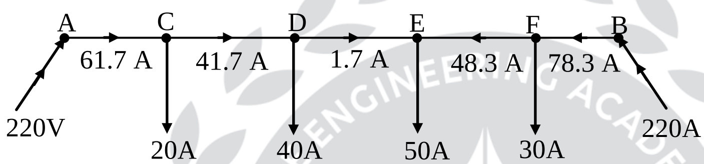
$220 = 220 - [0.204\ I_A - 12.58]$

$0.204\ I_A = 12.58$

$\therefore\ I_A = 12.58/0.204 = 61.67$ A

The actual distribution of current in the various sections of the distributor is shown in figure. It is clear that currents are coming to load point E from both sides i.e., from point D and point F. Hence, E is the point of minimum potential.

$\therefore$ Minimum consumer voltage, $V_E = V_A - [I_{AC}\ R_{AC} + I_{CD}\ R_{CD} + I_{DE}\ R_{DE}]$



$= 220 - [61.7 \times 0.034 + 41.7 \times 0.051 + 1.7 \times 0.051]$

$= 220 - 4.31$

$= 215.69$ V

(ii) Given that,

L = 0.1 H, R = 5 Ω, $v = 100 \sin(\omega t + \alpha)$

f = 50 Hz

Then, $Z = \sqrt{R^2 + \omega^2 L^2} \angle\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$

$= 31.8\angle 81°$

Let i_t = DC offset current which can be written as

$i_t = \frac{V_m}{|Z|} \sin(\theta - \alpha) e^{-\frac{R}{L}t}$

For DC offset current to be zero,

$\sin(\theta - \alpha) = 0 \Rightarrow \theta - \alpha = n\pi$ (n = 0, 1, 2,....)

$\alpha = \theta - n\pi = 81° - n\pi$

For n = 0, $\alpha = 81°$

$$\Rightarrow t = \frac{\alpha}{\omega} = \frac{81\times\pi}{180}\times\frac{1}{2\pi\times 50} = 4.5 \text{ ms from the voltage zero crossing.}$$

For DC offset current to be negative maximum,

$\sin(\theta - \alpha) = -1$

$$\Rightarrow (\theta - \alpha) = -(2n+1)\frac{\pi}{2} \quad (n = 0, 1, 2, \ldots..)$$

$$\Rightarrow \alpha = \theta + (2n+1)\frac{\pi}{2}$$

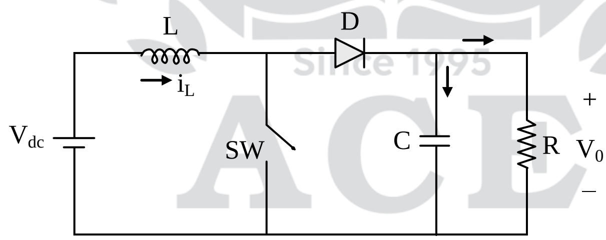
$$= 81° + (2n+1)\frac{\pi}{2}$$

For n = 0, $\alpha = 81° + 90° = 171°$

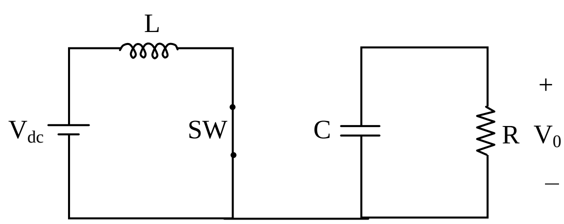
$$\Rightarrow t = \frac{\alpha}{\omega} = \frac{171\times\pi}{180}\times\frac{1}{2\pi\times 50} = 9.5 \text{ ms from the voltage zero crossing.}$$

03(a)

Sol: (i) Boost DC-DC converter:



When sw is ON (0 < t < DT)



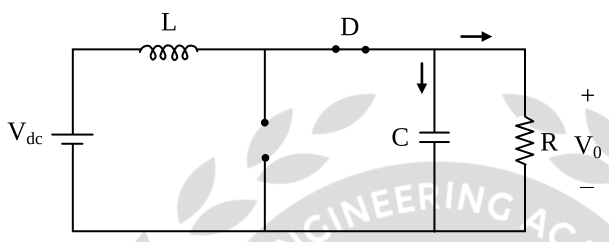
Apply KVL to the circuit

KVL: $L\frac{di}{dt} = V_{dc}$ ……..…….(1)

Apply KCL to the circuit

KCL: $C\frac{dv_0}{dt} + \frac{V_0}{R} = 0$ ...……….(2)

When sw is OFF(DT < t < T)



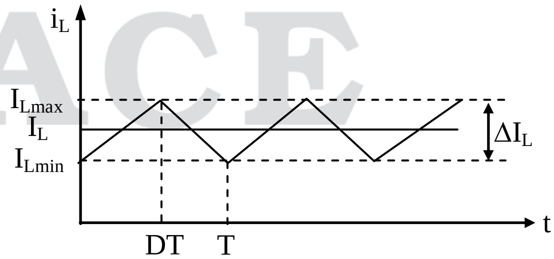
Apply KVL

$$L\frac{di_L}{dt} = V_{dc} - V_0 \quad \text{…………..(3)}$$

Apply KCL

$$C\frac{dv_0}{dt} + \frac{V_0}{R} = i_L \quad \text{…………..(4)}$$

For continuous conduction mode



Volt-sec balance equation:

$$L\frac{di_L}{dt}.DT + L\frac{di_2}{dt}(1-D)T$$

$$= V_{dc}.DT + (V_{dc} - V_0)(1-D)T$$

We know that average voltage across inductor = 0, Here LHS = 0

So, V_{dc} (D + 1–D)T – V_0 (1 – D)T = 0

$$\Rightarrow \boxed{V_0 = \frac{V_{dc}}{1-D} \text{ as } D < 1}$$

$$\boxed{V_0 > V_{dc}}$$

For discontinuous conduction mode:

For $0 < t < DT$:

$$i_L(t) = \frac{V_{dc}}{L} t \qquad \text{.........(A)}$$

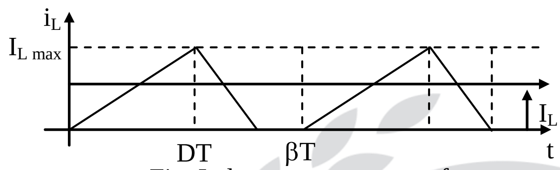


Fig. Inductor current wave form

For $DT < t < \beta T$

$$i_L(t) = I_{max} + \frac{V_{dc} - V_0}{L}(t - DT) \text{ ....(B)}$$

But at t = TD, $i_L(t) = I_{L(max)}$

From (A), $i_L(t) = \frac{V_{dc}}{L}.DT = I_{L(max)}$

From (B), if $t = \beta T \Rightarrow i_L(t) = 0$

$$= I_{L(max)} + \frac{V_{dc} - V_0}{L}(\beta T - DT)$$

$$\boxed{\Rightarrow \frac{V_{dc}}{L} DT + \frac{V_{dc} - V_0}{L}(\beta T - DT) = 0}$$

$$\Rightarrow V_0 = V_{dc}\left[\frac{\beta}{\beta - D}\right]$$

(ii) Given data

$V_S = 220V \qquad V_0 = 660V$

$T_{off} = 100\mu sec \; T_{on} = ?$

$$V_0 = V_S\left(\frac{1}{1-\alpha}\right)$$

$$660 = 220\left(\frac{1}{1-\alpha}\right)$$

$$\alpha = \frac{2}{3} \Rightarrow \frac{T_{on}}{T_{on} + T_{off}} = \frac{2}{3}$$

$3\,T_{on} = 2\,T_{on} + 2\,(100 \times 10^{-6})$

$T_{on} = 200\mu sec$

$T = 200 + 100 = 300\mu s$

If the pulse width is halved,

$T_{on} = \frac{1}{2}(200) = 100\ \mu sec$ and

And given frequency is constant

$\therefore T = T_{on} + T_{off}$

$= 100 + T_{off} = 300\ \mu sec. \Rightarrow T_{off} = 200\ \mu sec$

$V_0 = ?$

$$V_0 = V_S\left(\frac{1}{1-\alpha}\right)$$

$$= 220\left(\frac{1}{1-\frac{T_{on}}{T}}\right) = 220\left(\frac{1}{1-\frac{100}{300}}\right) = 220 \times \frac{3}{2} = 330V$$

03.(b)

Sol: (i) rms value of output voltage is

$$V_{or} = V_s\sqrt{\frac{n}{n+m}}$$

$$= 230\sqrt{\frac{6}{6+4}}$$

$$= 178.157V$$

(ii) Input pf = $\sqrt{k} = \sqrt{\frac{n}{n+m}}$

$$= \sqrt{\frac{6}{6+4}} = 0.7746 \text{ lag}$$

Also power delivered to load = $I_{or}^2 R = \frac{V_{or}^2}{R} = \frac{178.157^2}{15}$

$$= 2116 \text{ W}$$

Input VA $= 230 \times \frac{230\sqrt{0.6}}{15} = 2731.74 \text{ VA}$

$\therefore$ Input pf $= \frac{2116}{2731.74} = 0.7746 \text{ lag}$

(iii) Peak thyristor current, $I_m = \frac{230\sqrt{2}}{15} = 21.681 \text{ A}$

Average value of thyristor current, $I_{TA} = \frac{kI_m}{\pi} = \frac{0.6 \times 21.681}{\pi} = 4.1407 \text{ A}$

Rms value of thyristor current, $I_{TR} = \frac{I_m.\sqrt{k}}{2} = \frac{21.681 \times \sqrt{0.6}}{2} = 8.397 \text{ A}$

(ii) R = 2Ω, L = 10mH, E = 6V, F = 1kHz,

D = 0.1 $V_0 = DV_S$

$= 0.1 \times 220 = 22V$

$$I_0 = \frac{V_0 - E}{R} = \frac{22-6}{2} = 8A$$

$$T = \frac{1}{1000} = 1ms$$

$$T_{on} = DT = 0.1 \times 1 = 0.1 m\sec$$

$$T_a = \frac{L}{R} = \frac{10 \times 10^{-3}}{2} = 5 m\sec$$

$$I_{max} = \frac{V_s}{R}\left[\frac{1 - e^{-\frac{T_{on}}{T_a}}}{1 - e^{-\frac{T}{T_a}}}\right] - \frac{E}{R}$$

$$= \frac{220}{2}\left[\frac{1-e^{-\frac{0.1}{5}}}{1-e^{-\frac{1}{5}}}\right]-\frac{6}{2} \quad = 9.13\text{ A}$$

$$I_{min} = \frac{V_s}{R}\left[\frac{e^{\frac{T_{on}}{T_a}}-1}{e^{\frac{T}{T_a}}-1}\right]-\frac{E}{R}$$

$$= \frac{220}{2}\left[\frac{e^{\frac{0.1}{5}}-1}{e^{\frac{1}{5}}-1}\right]-\frac{6}{2} \quad = 7.036\text{ A}$$

03(c)

Sol: Given data:

Input voltage = 230V

Load values are R = 4Ω, L = 35 mH and C = 155μF

(a) The expression for output voltage is

$$V_0 = \sum_{n=1,3}^{\infty}\frac{4V_s}{n\pi}\sin n\omega t \text{ Volts}$$

$$V_0 = \frac{4V_s}{\pi}\sin\omega t + \frac{4V_s}{3\pi}\sin 3\omega t$$

$$= \frac{4\times 230}{\pi}\left[\sin\omega t + \frac{1}{3}\sin 3\omega t\right]$$

= 292.85 sin 314t +97.62 sin (3×314t)

Load impedance at frequency n.f is

$$Z_n = R + j\left(n\omega L - \frac{1}{n\omega C}\right)$$

$$Z_n = 4 + j\left(2\pi\times 50\times 35\times 10^{-3}\times n - \frac{10^6}{2\pi\times 50\times 155\times n}\right)$$

$$= 4 + j\left(11n - \frac{20.54}{n}\right)\Omega$$

$$Z_1 = \sqrt{4^2 + (11 - 20.54)^2} = 10.345\Omega$$

And $\phi_1 = \tan^{-1}\left(\frac{11 - 20.54}{4}\right) = -67.25°$

$$Z_3 = \sqrt{4^2 + \left(11 \times 3 - \frac{20.54}{3}\right)^2} = 26.46\Omega$$

And $\phi_3 = \tan^{-1}\left[\frac{33 - 20.54/3}{4}\right] = 81.3°$

Load current is given by $i_0 = \sum_{n=1,3,5}^{\infty} \frac{4V_s}{n\pi.Z_n} \sin(n\omega t - \phi_n)$

$$i_0 = \frac{292.85}{10.345}\sin(\omega t + 67.25) + \frac{97.62}{26.46}\sin(3\omega t - 81.3°)$$

$= 28.31\sin(314t + 67.25°) + 3.689\sin(3 \times 314t - 81.3°)$

(b) Rms value of fundamental load current, $I_{01} = \frac{I_{m1}}{\sqrt{2}} = \frac{28.31}{\sqrt{2}} = 20.02A$

(c) Rms load current $I_m = \sqrt{\frac{28.31^2}{2} + \frac{3.689^2}{2}} = 20.187A$

Load power $= (20.187)^2 \times 4 = 1630.13W$

Fundamental load power, $P_{01} = I_{01}^2 \times R = (20.02)^2 \times 4 = 1603.2W$

(d) Fundamental component of current is $i_{01} = 28.31\sin(314t + 67.25°)$

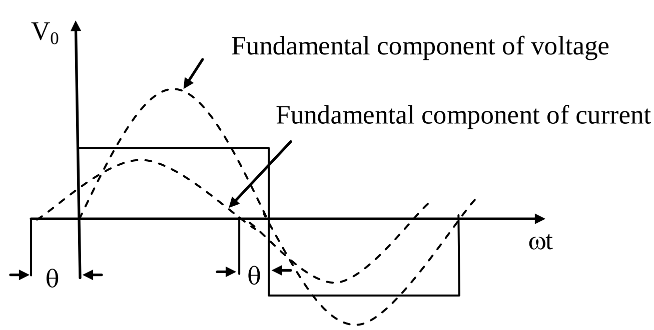


Fig.1

This current leads the fundamental voltage component by 67.25°. This means that diode conducts for 67.25° and thyristor for 180 – 67.25 = 112.75°

$\therefore$ Conduction time for thyristors $= \frac{112.75 \times \pi}{180 \times 314} = 6.267\,\text{ms}$

Conduction time for diodes = $\frac{67.25 \times \pi}{180 \times 314} = 3.738\,\text{ms}$

In case SCR turn-off time is less than 3.738 ms, load commutation will occur and no forced commutation will be required under the assumption of no harmonics.

4(a)

Sol: (i) Types of buses:

In general there are four types of buses viz

1. **Slack bus/swing bus/reference bus:** Real and reactive powers are not specified rather voltage magnitude (normally1pu) and voltage phase angle (normally set to 0) are specified This bus is assumed to represent total transmission losses.
2. **PQ Bus/Load Bus:** Net power P_i and Q_i are known because P_{Di} and Q_{Di} are known from load fore-casting and P_{Gi} and Q_{Gi} are specified. The unknowns are $|V_i|$ and δ_i for a pure load bus $P_{Gi} = Q_{Gi} = 0$. (called PQ bus). They comprise almost 80% of all the bases in the system.
3. **PV Bus/Generator Bus:** Always has a generator connected to it. These P_{Gi} and $|V_i|$ are specified. Q_i amd δ_i are unknowns. They comprise almost 10% of the buses in the system.
4. **Voltage controlled bus:** The voltage controlled bus has voltage control capabilities also and have a tap-changing transformer and/or a static variable compensator instead of a generator hence, $P_{Gi} = Q_{Gi} = 0$ and $P_i = -P_{Di}$ and $Q_i = -Q_{Di}$

   P_i , Qi and $|V_i|$ are known here whereas only unknown is δ_i

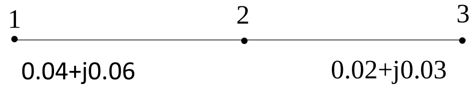
(ii) Given that, $V_1 = 1\angle 0^o$

$P_2 + jQ_2 = -5.96 + j\,1.46$

$|V_3| = 1.2$, $V_3^o = 1.02\angle 0^o$

$V_2^o = 1\angle 0^o$

Now



$$Y_{BUS} = \begin{bmatrix} \dfrac{1}{0.04+j0.06} & -\dfrac{1}{0.04+j0.06} & 0 \\ -\dfrac{1}{0.04+j0.06} & \dfrac{1}{0.04+j0.06}+\dfrac{1}{0.02+j0.03} & -\dfrac{1}{0.02+j0.03} \\ 0 & -\dfrac{1}{0.02+j0.03} & \dfrac{1}{0.02+j0.03} \end{bmatrix}$$

$$= \begin{bmatrix} \dfrac{1}{0.072\angle 56.3} & \dfrac{1\angle 180}{0.072\angle 56.3} & 0 \\ \dfrac{1\angle 180}{0.072\angle 56.3} & \dfrac{1}{0.072\angle 56.3}+\dfrac{1}{0.036\angle 56.3} & \dfrac{1\angle 180^{o}}{0.036\angle 56.3} \\ 0 & \dfrac{1\angle 180^{o}}{0.036\angle 56.3} & \dfrac{1}{0.036\angle 56.3} \end{bmatrix}$$

$$= \begin{bmatrix} 13.88\angle -56.3 & 13.88\angle 123.7 & 0 \\ 13.88\angle 123.7 & 13.88\angle -56.3 + 27.77\angle -56.3 & 27.77\angle 123.7 \\ 0 & 27.77\angle 123.7 & 27.77\angle -56.3 \end{bmatrix}$$

$$Y_{BUS} = \begin{bmatrix} 7.7 - j11.54 & -7.7 + j11.54 & 0 \\ -7.7 + j11.54 & 23.1 - j34.54 & -15.4 + j23.1 \\ 0 & -15.4 + j23.1 & 15.4 - j23.1 \end{bmatrix} \quad \ldots\ldots\ldots\ldots (1)$$

Now,

$$V_2' = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{\left(V_2^0\right)^*} - Y_{21}V_1^0 - Y_{23}V_3^0\right]$$

$$V_2' = \frac{1}{(23.1 - j34.54)}\left[\frac{-5.96 - j1.46}{1\angle 0} - (-7.7 + j11.54)\,1\angle 0^{o} - (-15.4 + j23.1)1.02\angle 0^{o}\right]$$

$$\Rightarrow V_2' = \frac{1}{41.55\angle -56.22}[6.13\angle -166.23 + 13.87\angle -56.28 + 28.31\angle -56.3]$$

$$\Rightarrow V_2' = \frac{1}{41.55\angle -56.22}[-5.95 - j1.46 + 7.7 - j11.53 + 15.7 - j23.55]$$

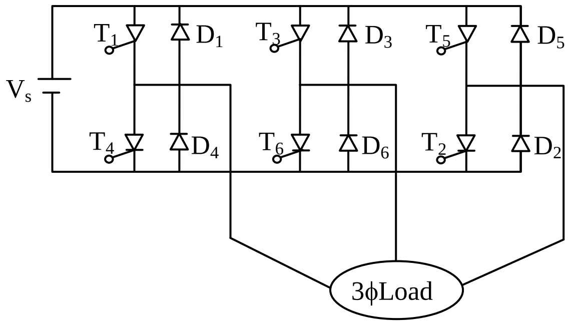
$$\Rightarrow V_2' = \frac{1}{41.55\angle -56.22}[17.45 - j36.54]$$

$$\Rightarrow V_2' = \frac{1}{41.55\angle -56.22}[40.5\angle -64.47]$$

$$V_2' = 0.97\angle -8.25^{o} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

04(b)

Sol:



In a 3-ϕ 180 degree mode VSI, each SCR conducts for 180^o of a cycle.

Thyristor pairs in each arm are turned on with time interval of 180^o. T_1 conducts for 180^o, then T_4 conductor for remaining 180^o of the cycle . Thyristor in upper group T_1, T_3, T_5 conducts at an internal of 120^o. On the basis of above firing scheme, a table is shown to know how the triggering is happening in thyristor.

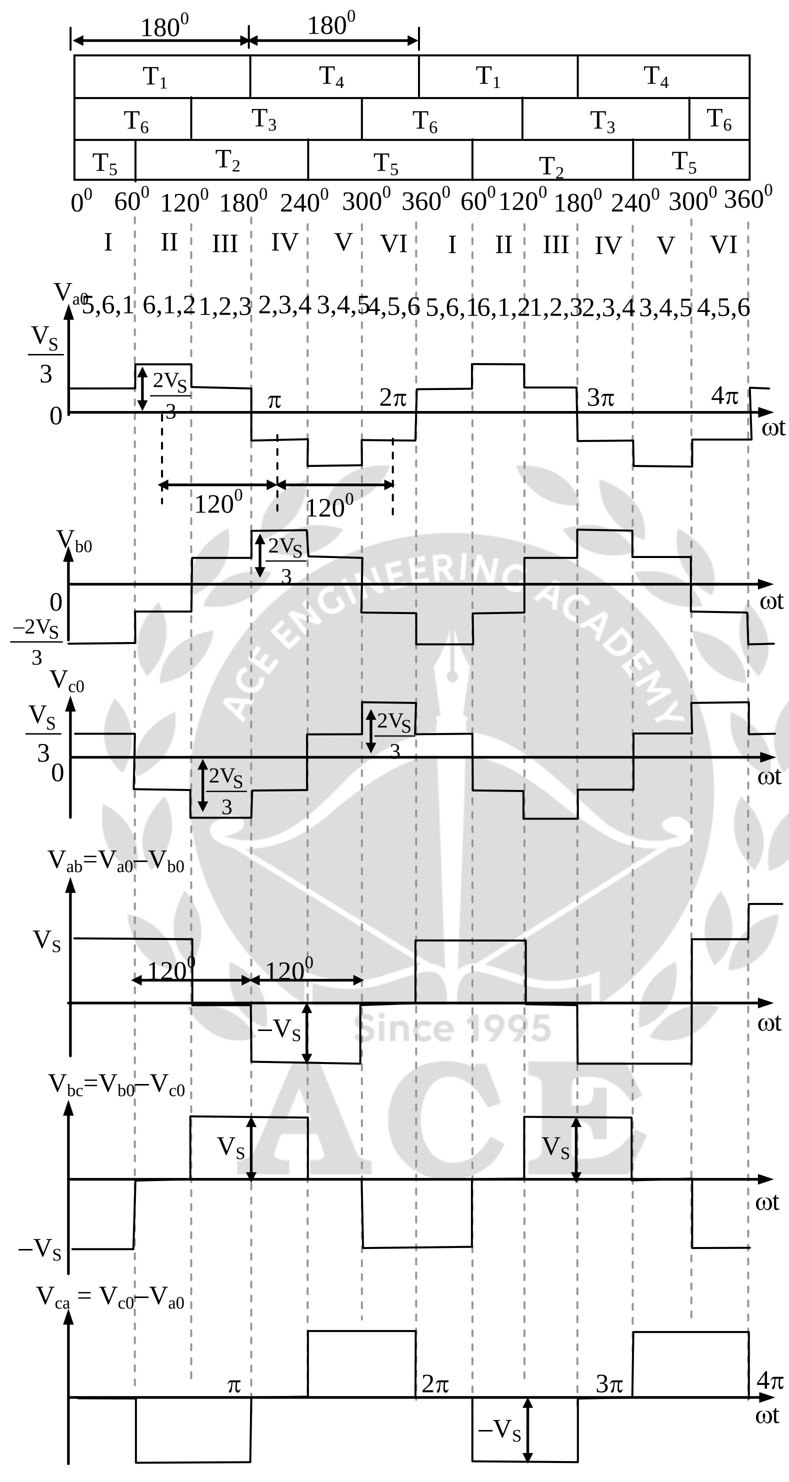
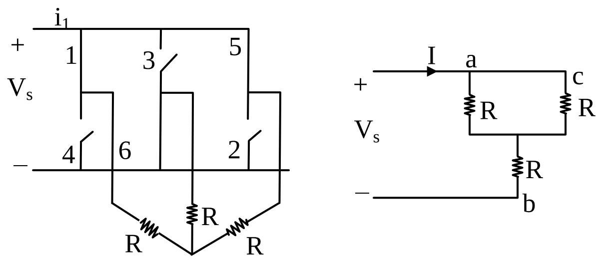


Fig. Voltage waveforms of phase voltages and line voltages

for 180^0 mode

T_1 is triggered at t = 0,T_1 conducts for 180°. After 60°, (i.e step angle) T_2 is triggered which again conductor 180°. Later after 60°, (i.e step angle) T_3 is triggered which conduct for 180°.

In The 1st step, T_1, T_6, T_5 conducts.



$$i_s = \frac{V_s}{R + R/2} = \frac{2}{3}\frac{V_s}{2}$$

$$V_{a0} = \frac{V_s}{3}$$

$$V_{ob} = \frac{2V_s}{3}, V_{bo} = -\frac{2V_s}{3},$$

$$V_{c0} = \frac{V_s}{3}$$

04(c)(i)

Sol: Given that, V_1 = 1pu, P = 1 pu

Now, for generator emf behind the transient reactance,

$$\because P = \frac{V_1.V}{X_{eq}}\sin\delta$$

Where, $X_{eq} = 0.1 + \frac{0.4}{2} = 0.3$

$$1 = \frac{1\times1}{0.3}\sin\delta \Rightarrow \delta = 17.45° \text{ ………. (1)}$$

Hence, $V_1 = 1\angle17.45° = 0.95 + j0.3$

Here, $I = \frac{V_1 - V}{j0.3} = \frac{0.95 + j0.3 - 1}{j0.3}$

$$I = \frac{-0.05 + j0.3}{j0.3} = 1 + j0.17 = 1.012\angle 8.73 \quad \ldots\ldots. (2)$$

Then emf E is given as,

$E = V_1 + I\ (j0.2)$

$= 1\angle 17.45° + (1.012\angle 8.73)(0.2\angle 90)$

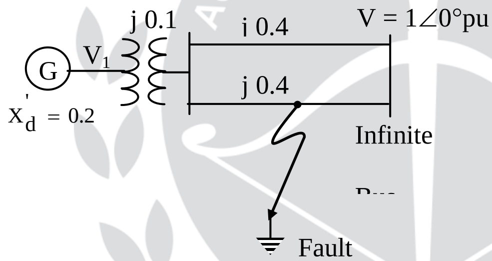
$E = 1.05\angle 28.44$ ……(3)

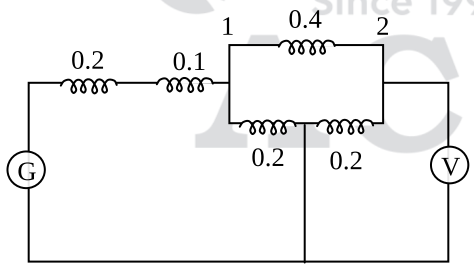
(i) Maximum power transferred when the system is operating under healthy condition

$$P_1 = \frac{E.V}{X_{eq}} = \frac{1.05\times 1}{0.5} = 2.1\text{pu} \ \ldots\ldots(4)$$

(ii) Maximum power when one line is shorted in the middle:

Consider the circuit shown in figure(i). The circuit can be redrawn to find X_{eq} by using star – delta conversion for Bus – 1 see figure(ii).





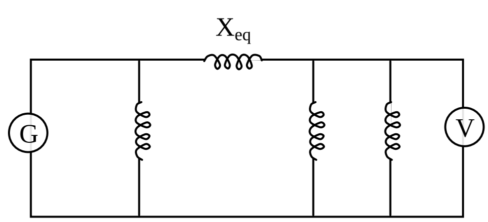


Fig (ii)

Where, $X_{eq} = 0.3 + 0.4 + \frac{(0.3)(0.4)}{(0.2)}$

$X_{eq} = 1.3$ pu

Neglecting the shunt reactances.

$$P = \frac{E \times V}{X_{eq}} = \frac{1.05 \times 1}{1.3} = 0.807 \text{ pu}$$

04(c)(ii)

Sol: J = 9000 kg-m^2

P = 2

$S = \frac{60}{0.85} = 70.588 \text{ MVA}$

f = 50 Hz

$$\omega_m = \frac{\omega}{P/2} = \frac{2\pi f}{P/2} = \frac{4\pi f}{P}$$

Kinetic Energy $W_{kin} = \frac{1}{2} J\omega^2 W - s.(\text{or } J)$

$$= \frac{1}{2} J\left(\frac{4\pi f}{P}\right)^2 W - s.(\text{or } J)$$

$$= \frac{1}{2} \times \frac{9000 \times 16\pi^2 \times (50)^2}{2^2} \text{MJ} = 444.13 \text{ MJ}$$

$\therefore$ Inertia constant $H = \frac{W_{kin}}{S}$

$$= \frac{444.13}{70.588} = 6..292 \text{ MJ/MVA}$$

05(a)

Sol: Given, V = 2200 V, $I_{3\phi}$ = 127 A,

I_{LL} = 129.5 A, I_{LG} = 190 A

Let, X_1, X_2 and X_0 be the positive, negative and zero sequence reactance of the generator respectively.

Then, $V(\text{phase}) = \dfrac{V}{\sqrt{3}}$

$\Rightarrow V_p = 1270.17$ V

Again, $\because I_{3\phi} = \dfrac{V_p}{X_1}$

$\Rightarrow X_1 = \dfrac{1270.17}{127} = 10\,\Omega$ ……….(1)

And $I_{LL} = \dfrac{\sqrt{3}\,V_p}{X_1 + X_2}$

$\Rightarrow X_1 + X_2 = \dfrac{\sqrt{3}\times 1270.17}{129.5}$

$\Rightarrow 10 + X_2 = 16.99$

$\Rightarrow X_2 = 6.99\ \Omega$ ………..(2)

And $I_{LG} = \dfrac{3V_p}{X_1 + X_2 + X_0}$

$\Rightarrow X_1 + X_2 + X_0 = \dfrac{3\times 1270.17}{190}$

$\Rightarrow 16.99 + X_0 = 20.05$

$\Rightarrow X_0 = 3.06\ \Omega$ ………(3)

Hence, $X_1 = 10\ \Omega$, $X_2 = 6.99\ \Omega$

And $X_0 = 3.06\ \Omega$

05(b)

Sol: Buchholz Relay:

Whenever a fault takes place in a transformer, the oil of the tank gets overheated and gases are formed. The generation of the gases may be slow or violent depending upon whether the fault is a minor or incipient one or heavy short circuit. The generation of gas is used as a means of fault detection.

It consists of two hinged floats in a metallic chamber, which is connected in upper side of the pipe run between the oil conservator and the transformer tank. One of the floats is near the top of the chamber and the other opposite

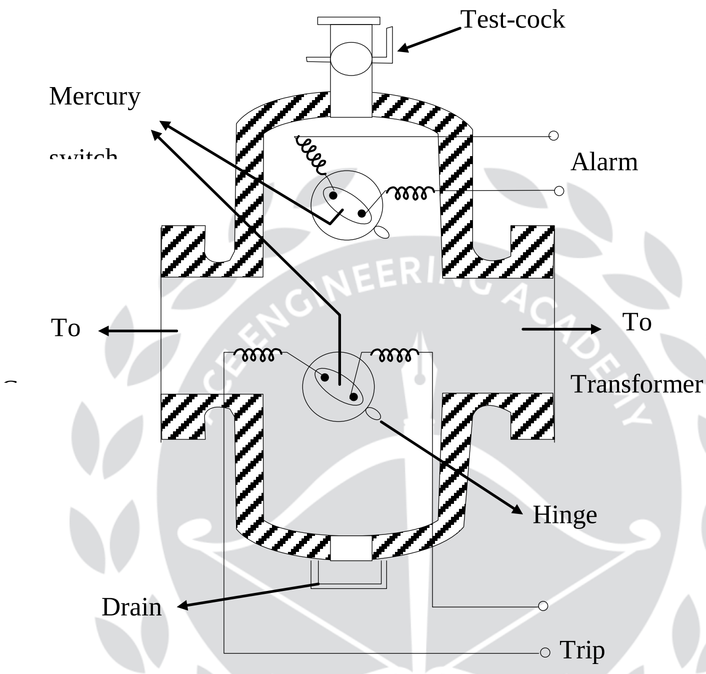


Figure (i)

The orifice of the pipe to the transformer for a minor or incipient fault, the slow generation of gas gives rise to gas bubbles which try to go to the conservator but are trapped in the upper portion of the relay chamber, thereby a fall in the oil level takes place. This disturbs the equilibrium of the gas float. The float tilts and the alarm circuit is closed through the mercury switch. For a heavy fault, large volumes of gases are generated which cause violent displacement of the oil and impinge upon the baffle plates of the lower float and thus the balance the lower float is disturbed. The lower float is tilted and the contacts are closed which are arranged to trip the transformer.

05.(c)

Sol: Heating load:

The thermal time constant is of the order of several seconds for heating loads. i.e. for heating loads, time constant is usually quite high. For such applications, almost no variation in speed or temperature will be noticed if control is achieved by connecting the load to source for some ON-cycles and then disconnecting the load for some OFF-cycles. This form of power control is called integral cycle control. So, integral cycle control consists of switching on the supply to load for an integral number of cycles and then switching off the supply for a further number of integral cycles. The integral cycle control is also known as on-off control, burst firing, zero-voltage switching, cycle selection or cycle syncopation.

Lighting load:

The time constant for lighting load is very less i.e., the light glowing responds very quickly with the changes in the supply voltage magnitude. So, for these types of loads, phase controlled ac voltage controller are very suitable.

For heating and lighting loads, however, both fundamental and harmonics are useful in producing the ac controlled power. In such applications V_{rms} and value of the output voltage (V_0) should be known.

05(d)

Sol: The given circuit is single-phase half wave thyristor circuit with R load

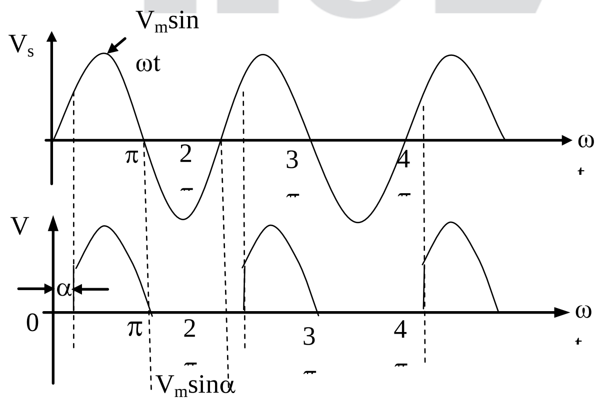


Fig. Output waveform of given circuit

(ii) V_S = 230V (rms), f = 50Hz, α = 45° and R = 100Ω

(a) Average output voltage = $\frac{V_m}{2\pi}(1+\cos\alpha) = \frac{\sqrt{2}\times 230}{2\pi}(1+\cos 45°)$

V_0 = 88.37V

Average output current = $\frac{V_0}{R} = \frac{88.37}{100} = 0.883\,A$

(b) R.M.S. value of supply current = R.M.S. value of load current

$$I_{or} = \frac{V_{or}}{R}$$

$$V_{or} = \frac{V_m}{2\sqrt{\pi}}\left[(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right]^{\frac{1}{2}}$$

$$= \frac{\sqrt{2}\times 230}{2\sqrt{\pi}}\left[\left(\pi-\frac{45\times\pi}{180}\right)+\frac{1}{2}\sin 2\times\frac{\pi}{4}\right]^{\frac{1}{2}}$$

= 155.07 V

$$\therefore I_{or} = \frac{V_{or}}{R} = \frac{155.07}{100} = 1.55A$$

05(e)

Sol: (i) Electrical power grid is the inter-connection of various generating, transmission, distribution equipments and loads.

It is achieved by maintaining the voltage and frequency of the coming machine or system as close as possible to the infinite bus.

(ii) Advantages of Electrical Power grid system:

1. It increases the reliability of power system
2. No need for partial load shedding or no need for enhancement of the capacity of a particular generating station.
3. Fluctuation of load demand of grid is much less than that of a single generating plant.

4. Maximum demand of the grid shared by the generating station is much less compared to maximum demand imposed on generating station if it runs individually. As a reason, diversity factor is improved.

(iii)Shunt reactors are used within certain desirable limits across capacitive load or lightly loaded lines to absorb some of the leading VARs (Ferranti effect). To control the voltage across the load within certain desirable limits.

Series reactor is used to reduce the current ripples and also to reduce the short circuit current.

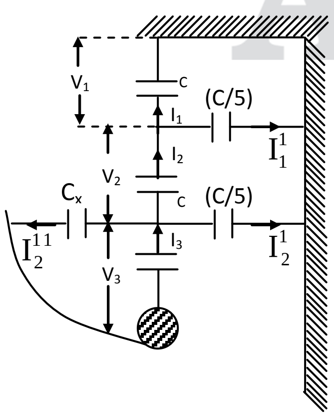
(iv) Flexible AC transmission system-FACTS

(v) Advantages of Reactive power control:

1. It helps in maintaining the desirable voltage profile of different parts of the system, thereby helping in overall voltage stability, avoiding phenomenons like voltage collapse. Also helps in preventing damage to electrical equipments due to over voltages and low voltages and reducing overall losses.
2. It helps in proper load management, thereby reducing the over all cost of the power system.
3. It helps in improving the power factor of the system, thereby increasing the overall efficiency of the system.
4. It also helps in improving the stability of the system especially transient stability.
5. It helps in proper management of real power transmitted over the transmission lines.

06(a)(i)

Sol:



Static capacitance 'C_x' of guard ring compensates the shunt capacitance(C^1) charging current.

i.e., $I_2^1 = I_2^{11}$ ………. (i)

$\therefore I_3 = I_2 \neq I_1 \; and \; V_3 = V_2 \neq V_1$ ……….. (ii)

Applying KCL at point 'a'

$I_2 = I_1 + I_1^1$

$V_2\, \omega C = V_1 \omega C + (V_1)\, \omega\left(\frac{C}{5}\right)$

$V_2 = V_1 + \frac{V_1}{5} = V_1\left(\frac{6}{5}\right) = V_3$

$\therefore V_2 = V_3 = \frac{6V_1}{5}$

Given that $V_1 + V_2 + V_3 = 20$ kV

$V_1 + 2\left(\frac{6V_1}{5}\right) = 20$ kV

$V_1\left(1 + \frac{12}{5}\right) = 20$ kV

$V_1 = 5.88$ kV

(a) $V_2 = V_3 = V_1\left(\frac{6}{5}\right) = 7.06\,kV$

(b) From equation (i)

$I_2^1 = I_2^{11}$

$(V_1 + V_2)\, \frac{\omega C}{5} = V_3\, \omega C_x$

$C_x = \left(\frac{V_1}{V_2} + 1\right) \times \frac{C}{5}$

$[\because V_2 = V_3]$

$C_x = 0.366C$

06(a)(ii)

Sol: Advantages of Nuclear power plant:

(i) The amount of the fuel required is quite small. Therefore, there is a considerable saving in the cost of fuel transportation.

(ii) A nuclear power plant requires less space as compared to any other type of the same size.

(iii) It has low running charges as a small amount of fuel is used for producing bulk electrical energy and it is very economical for producing bulk electrical power.

(iv) It can be located near the load centers because it does not require large quantities of water and need not be near coal mines. Therefore, the cost of primary distribution is reduced.

(v) There are large deposits of nuclear fuels available all over the world. Therefore, such plants can ensure continued supply of electrical energy for thousands of years.

(vi) It ensures reliability of operation.

Disadvantages:

(i) Nuclear power plants are not suitable for variable load since the reactor cannot be easily controlled to respond quickly to load changes. They are used at a load factor not less than 80%.

(ii) The capital cost on a nuclear power plant is very high as compared to other types of plants.

(iii) The fuel used is expensive and is difficult to recover.

(iv) The skilled persons are required to handle the plant therefore, maintenance cost is more.

(v) The fission-by-products are generally radio active and may cause a dangerous amount of radioactive pollution.

06(b) (i)

Sol: Given data:

Initial voltage across capacitor is $V_s = 230$ V

Load current = 300 A

$C = 20\ \mu F$ and $L = 5\ \mu H$.

Peak value of resonant current, $I_p = V_s\sqrt{\frac{C}{L}}$

$$= 230\sqrt{\frac{20}{5}} = 460 \text{ A}$$

Resonant frequency, $\omega_o = \frac{1}{\sqrt{LC}} \quad = \frac{10^6}{\sqrt{100}} = 0.1\times10^6 \text{ rad/s}$

(a) Conduction time for auxiliary thyristor $= \frac{\pi}{\omega_o} = \frac{\pi}{0.1\times10^6} = 31.416\,\mu s$

(b) $\omega t_3 = \sin^{-1}\left(\frac{I_0}{I_P}\right)$

$\omega t_3 = \sin^{-1}\left(\frac{300}{460}\right) = 40.706°\text{ or } 0.71045 \text{ rad.}$

Voltage across main thyristor, when it gets turned-off is

$$\therefore \quad V_{ab} = V_s \cos \omega t_3$$

$$= 230 \cos (40.706°)$$

$$= 174.355 \text{ V}$$

(c) Circuit turn-off time for main thyristor is

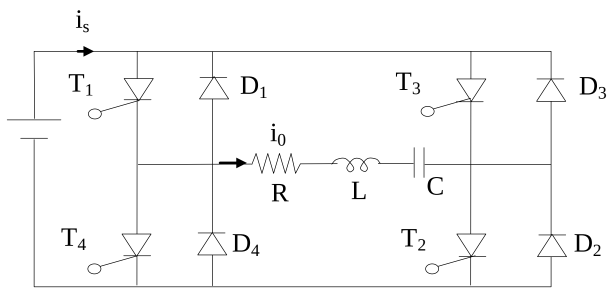
$$t_c = C\frac{V_{ab}}{I_0}$$

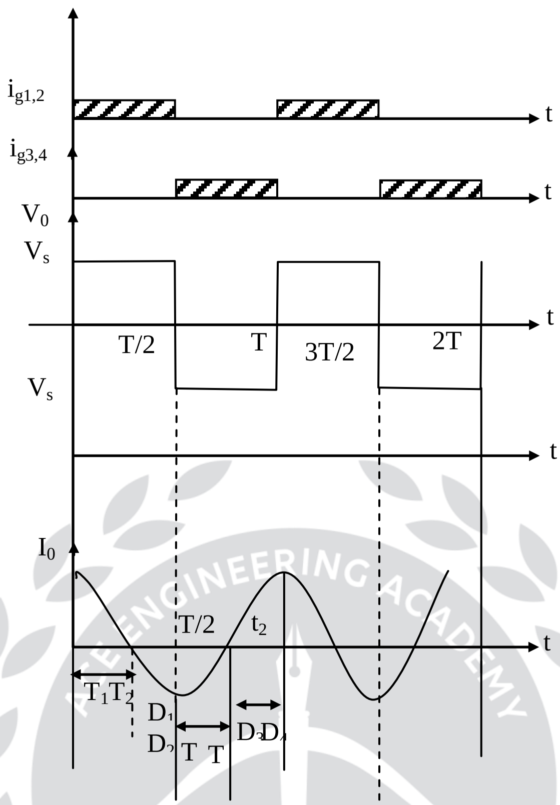
$$= 20\times10^{-6}\frac{174.355}{300}$$

$$= 11.624\,\mu s.$$

06(b)(ii)

Sol: Single phase full bridge inverter load commutation:





Load commutation is possible when load is RLC under damped.

As shown in the figure at t = 0, T1 T2 conducts. As current through T1, T2 reduces to zero at t = t1, SCR T1 T2 off before T3, T4 are gated. As T1 T2 stops conducting, current through the load reverses and is now carried by diodes D1 D2 as T3, T4 are not yet gated. The diodes D1, D2 are connected in anti parallel to T1 T2, the voltage drop in these diodes appears as reverse bias across T1 T2. If duration of this reverse bias is more than SCR turn off time tq, T1 T2 will get commutated naturally and there is no need of a commutation circuitry. This method of commutation is known as load commutation.

Conduction of various circuit elements:

From $t = 0$ to $t = t_1$, T1 T2 conducts

$t = t_1$ to $t = T/2$, D1 D2 conducts

From t = T/2 to t = t2, T3, T4 conducts

$t = t_2$ to $t = T$, D3 T4 conducts

06(c)

Sol: (i) (a) The gate characteristics of thyristor is same as forward characteristics of P-N junction

(b) Positioning of gate characteristics in V-I plane depends on doping concentrations employed in making that PN junction (J_3) of thyristor.

(c) The gate characteristics would be drawn considering following extreme/ boundary condition of operation.

(i) Maximum doping concentration

(ii) Minimum doping concentration

(iii) Maximum gate voltage and gate current.

(iv) Minimum gate voltage and gate current

(v) Maximum gate power loss

(d) ate characteristics of thyristor can be drawn as follows:

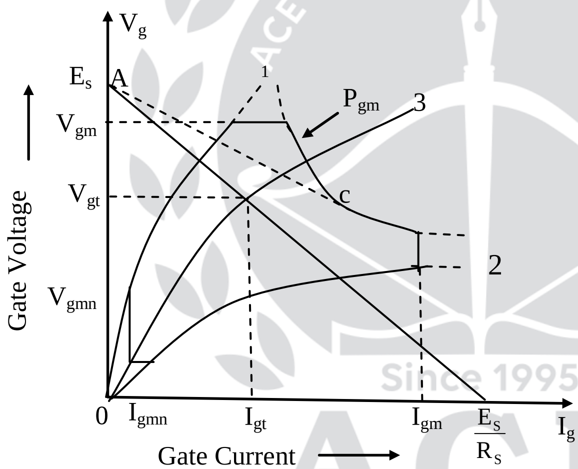


Fig. 1

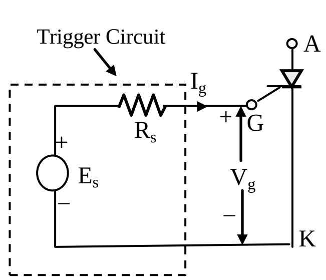


Fig. 2

Curve-1 ⇒ Gate characteristics corresponding to maximum doping concentration.

Curve-2 ⇒ Gate characteristics corresponding to minimum doping concentration.

Curve-3 ⇒ Gate characteristics corresponding to given concentration of thyristor.

(e) Gate operating point (V_{gt}, I_{gt}) can be obtained by intersection of gate characteristics and load line.

Gate characteristics relevancy in design of gate drive circuit:

(f) Positioning of gate characteristics decide the gate operating point (V_{gt}, I_{gt}) and hence the values of V_{gt}, I_{gt}.

(g) The gate drive circuit in fig. 2 is useful to apply V_{gt}, I_{gt} as and when thyristor is to be turned ON.

(h) The value of resistance R_S is to be selected so that required voltage and current are applied at the gate function.

(ii) Problem

Pulse triggering:

(i) The gate current can be applied as continuous signal or in terms of pulses.

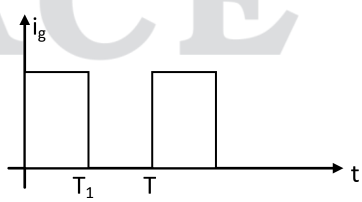
(ii) The advantage of pulse triggering is to apply gate current in pulses can have higher amplitude for same average power dissipation.

(iii) Pulse triggering allows turn on of device in less time and faster the device.

$P_{gm} = DP_{gm}$

Where D = Duty cycle

$$D = \frac{T_1}{T}$$



$P_{g(avg)} = V_g I_{g\,(avg)}$

$= V_g\ I_{g\,(peak)}\ D$

$0.4 = (1).\ I_{g\,(peak)}\ (0.5)$

$I_{g\,(peak)} = 0.8$ A

07(a)

Sol: (i) Comparison of steam power plant with hydroelectric power plant from the economic point of view:

Thermal Plants	Hydro-electric plants
The capital cost/initial cost is less comparatively.	The capital cost/initial cost is very high. Because hydro plants require large scale displacement, rehabilitation and resettlement of the potential land source.
The running cost/fuel cost is high comparatively. eg. The cost of coal in case of coal thermal power plants.	The running cost/fuel cost is negligible comparatively. Because electrical energy is generated by using the potential energy of the water head.
The maintenance cost is also comparatively high because of the complexity of system (very high operating boiler temperature) and safety to the man power.	The maintenance cost is comparatively low because of the simple process for electrical energy generation.
The cost of fuel transportation is quiet high(eg:coal transportation)	The cost of fuel transportation is zero. (The potential energy/kinetic energy of the water is freely available.
Thermal plants are not suitable for peak loads as they require a substantial time for achieving the critical temperature for generating the power.	The hydro electric plants can be used for both base load and peak load because they do not required any time lag for power generation. Therefore their overall performance is comparatively more economical.

(ii) Given that, $\frac{dC_1}{dP_1} = 0.2P_1 + 50$ Rs/MWh

$$\frac{dC_2}{dP_2} = 0.24P_2 + 40 \text{ Rs/MWh}$$

As $\frac{dC_1}{dP_1} = 76$ Rs/MWh

$\Rightarrow 0.2P_1 + 50 = 76$

$$P_1 = 130 \text{ MW}$$

As $\frac{dC_2}{dP_2} = 68.8$ Rs/MWh

$\Rightarrow 0.24\,P_2 + 40 = 68.8$

$$P_2 = 120 \text{ MW}$$

Total load $P_1 + P_2 = 250$ ……….. (1)

to minimize the total cost, $\frac{dC_1}{dP_1} = \frac{dC_2}{dP_2}$

$$0.2P_1 + 50 = 0.24P_2 + 40$$

$\Rightarrow 0.2P_1 - 0.24P_2 = -10$ ………. (2)

By solving equations (1) and (2)

$P_1 = 113.636$ MW

$P_2 = 136.364$ MW

07(b)

Sol: (i) (a) Air-blast circuit breakers:

Advantages:

- The risk of fire is eliminated
- The arcing products are completely removed by the blast whereas the oil deteriorates with successive operations, the expense of regular oil replacement is avoided

- The arcing time very small due to the rapid buildup of dielectric strength between contacts. Therefore, the arc energy is only a fraction of that in oil circuit-breaker, thus resulting in less burning of contact
- The growth of dielectric strength is so rapid that final contact gap needed for arc extinction is very small.
- Due to lesser arc energy, air-blast circuit breakers are very suitable for conditions where frequent operation is required.

Limitations:

- The air has relatively inferior arc extinguishing properties.
- The air-blast circuit breakers are very sensitive to the variations in the rate of rise of restriking voltage.
- *Considerable maintenance is required for the compressor plant which supplies the air-blast.*

(ii) The suitable circuit breaker for given application would be SF_6 circuit breaker whose specifications are given below.

Nominal system voltage = 220 kV

Highest system voltage = 245 kV

Power frequency withstand voltage =460 kV

Impulse voltage level = 1050 kV

Rated frequency = 50 Hz

Braking current $= \dfrac{500\times1000}{\sqrt{3}\times220}$

$= 1312.16\text{ A}$

Rated current = 1500 A

Making current = 2.55 × 1312.16

= 3346 A

Short time rating = 1312.16 A for 3 sec.

Circuit breaker along its specifications used SF_6 circuit breaker.

(iii)Adjustable load flow: For simulating the behaviour of equipments with automatic control this method is used for example on load tap changing transformer, area interchange control, generator bus Q violations and switched capacitors etc.

The major impact of this method is on the speed of the convergence of the solution.

Unadjustable load flow: In this method the behaviour of equipments with automatic control is not modelled. This is the conventional method having slow speed of convergence.

More accurate method: The unadjustable load flow solution gives the more accurate results at the cost of speed.

07(c)

Sol: **(i)** A simple differential relay may maloperate under due to the following reasons.

(1) Magnetic inrush currents during the charging of a transformer.

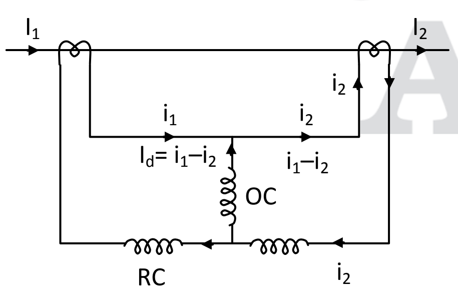
(2) Due to transformer no load current

(3) Mismatch of CT ratios

(4) Saturation of CT etc.

So in the above circumstances a simple differential relay(without a restraining coil) will maloperate i.e., operation of relay despite no fault.

So to avoid same or all of the above constrains, a differential relay is provided with a restraining coil along with an operating coil as shown below.



OC = operating coil

RC = restrain coil

The actuating current in RC is not same and hence it is taken as the average of both currents known as bias current

$$I_b = \frac{i_1 + i_2}{2}$$

$I_d = i_1 - i_2$ = differential current

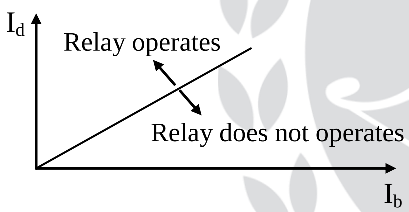
Relay operates when torque of OC > torque of RC

$$n_{OC}(i_1 - i_2) > n_{RC}\left(\frac{i_1 + i_2}{2}\right)$$

$$\frac{(i_1 - i_2)}{\left(\frac{i_1 + i_2}{2}\right)} > \frac{n_{RC}}{n_{OC}}$$

$$\frac{I_d}{I_b} > B(\text{constant})$$

$I_d > BI_b \Rightarrow$ Relay operated



Analysis of inrush currents indicates that inrush currents is rich in 2nd harmonic and current during over fluxing (saturation) has a large 5th harmonic component. Therefore a 2nd harmonic restraining is provided in transformer differential protection. Usually the setting of 2nd harmonic restraining is kept at 20% which means that if the 2nd harmonic component in the deferential relay is more than 20% of I_d, then the relay will not trip.

(ii) The connections of the CTs on both the sides of the transformers are shown in fig(i)

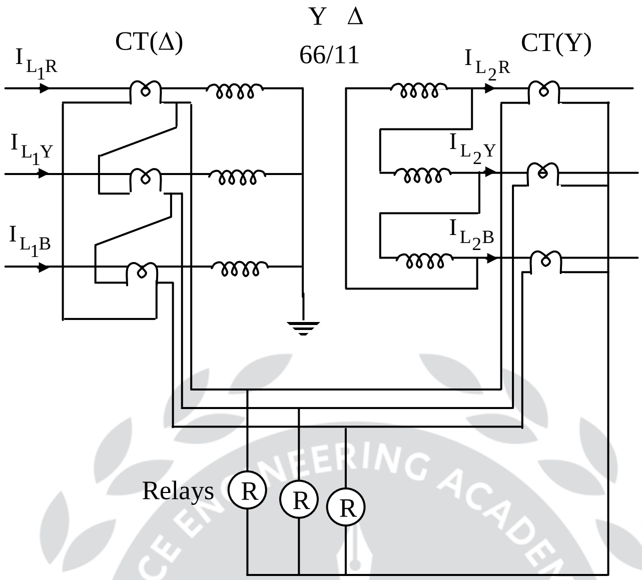


fig (i)

Let the line currents on the primary and secondary sides of the transformer be I_{L1} and I_{L2} respectively,

So that,

$$\sqrt{3}V_{L_1}I_{L_1} = \sqrt{3}V_{L_2}I_{L_2}$$

$$\Rightarrow \sqrt{3}\times 66\times I_{L_1} = \sqrt{3}\times 11\times I_{L_2}$$

$$\Rightarrow I_{L_1} = \frac{1}{6}I_{L_2} \qquad \text{……..…………(1)}$$

11 kV transformer has CT ratio of 250/5

Hence, for I_{L2} = 250 A

$I_{L1} = \dfrac{1}{6} = 250 = 41.67\,\text{A}$

Secondary of CTs at 11 kV side have currents of 5A

For secondary of CTs at 66 kV side the currents would be $\dfrac{5}{\sqrt{3}}$ (Δ-connection) 1

Hence,

CT ratio on HV side (66 kV)

$$= \frac{41.67}{5/\sqrt{3}} = \frac{72.15}{5}$$

08(a)

Sol: (i) Output voltage waveform for a p-pulse controlled converter:

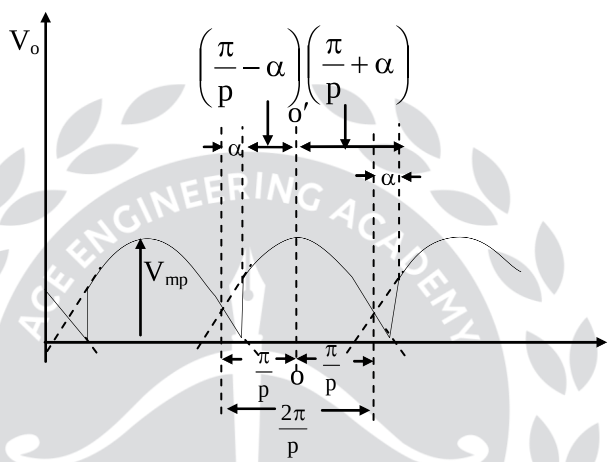


Figure illustrates the output voltage waveform for a p-pulse controlled converter. The origin is taken at oo′, the peak value of the instantaneous output voltage V_o. Firing angle must be measured from the intersection of phase voltage waveforms as shown. Therefore, the limits of integration are from $-\left(\frac{\pi}{p}-\alpha\right)$ to $\left(\frac{\pi}{p}+\alpha\right)$

∴ Average output voltage, $V_o = \frac{p}{2\pi}\int_{-\left(\frac{\pi}{p}-\alpha\right)}^{\frac{\pi}{p}+\alpha} V_{mp}\cos\omega t.d(\omega t)$

$$= \frac{p.V_{mp}}{2\pi}\left|(\sin\omega t)\right|_{-\left(\frac{\pi}{p}-\alpha\right)}^{\frac{\pi}{p}+\alpha}$$

$$V_o = V_{mp}\left(\frac{p}{\pi}\right)\sin\left(\frac{\pi}{p}\right)\cos\alpha$$

(ii) Given data: $V_{SL} = 440V$, $V_{ml} = 440\sqrt{2}$, $R_a = 0.05\Omega$/Phase and $\omega L = 0.3\Omega$ /phase

For firing advance angle of 35°,

$\Rightarrow \alpha = 180–35 = 145°$.

$I_0 = 60A$, $V_T = 2$ Volts

V_0 = Average output voltage $= \frac{3V_{ml}}{\pi}\cos\alpha$

$$V_0 = -E + 2I_0 r_s + 2V_T + \frac{3\omega L_s}{\pi} I_o$$

$$\frac{3\times(440\sqrt{2})}{\pi}\cos(145) = -E + (2\times 60\times 0.05) + (2\times 2) + \frac{3\times 0.3\times 60}{\pi}$$

E = 513.93 V

$\therefore$ Average generated voltage = 513.936 V

08. (b)

Sol: (i) $\vec{E}_R = \overrightarrow{E_{R0}} + \overrightarrow{E_{R1}} + \overrightarrow{E_{R2}}$

$3 = (0.5 - j\,0.8666) + 2 + \overrightarrow{E_{R2}}$

$\therefore$ Negative sequence component in R-phase is

$$\overrightarrow{E_{R2}} = 0.5 + j\,0.866 = 1\angle 60^\circ \text{ V}$$

In polar form, $\overrightarrow{E_{R0}} = 0.5 - j0.866 = 1\angle -60^\circ$ V

Now $\overrightarrow{E_Y} = \overrightarrow{E_{R0}} + a^2\,\overrightarrow{E_{R1}} + a\,\overrightarrow{E_{R2}}$

$= [1\angle -60^\circ] + [1\angle 240^\circ \times 2\angle 0^\circ] + [1\angle 120^\circ \times 1\angle 60^\circ]$

$= 1\angle -60^\circ + 2\angle 240^\circ + 1\angle 180^\circ$

$= (0.5 - j\,0.866) + (-1 - j\,1.732) + (-1 + j\,0)$

$= -1.5 - j\,2.598$

$= 3\angle -120^\circ$ volts

$\overrightarrow{E_B} = \overrightarrow{E_{R0}} + a\,\overrightarrow{E_{R1}} + a^2\,\overrightarrow{E_{R2}}$

$= [1\angle -60^\circ] + [1\angle 120^\circ \times 2\angle 0^\circ] + [1\angle 240^\circ \times 1\angle 60^\circ]$

$= 1\angle -60^\circ + 2\angle 120^\circ + 1\angle 300^\circ$

$= (0.5 - j\,0.866) + (-1 + j\,1.732) + (0.5 - j\,0.866)$

$= 0$ volt;

$\overrightarrow{I_{Y1}} = \overrightarrow{I_Y} = 90\angle 240^0$ A;

$\overrightarrow{I_{B1}} = \overrightarrow{I_B} = 90\angle 120^0$ A

(ii) Given data

$I_a = 1\angle -90°$ p.u

$I_{b_2} = 4\angle -150^o$ p.u

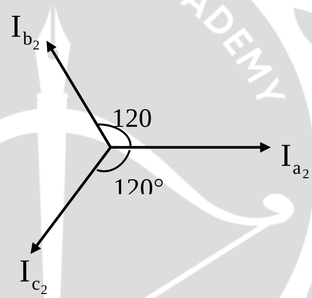
$I_{c_0} = 3\angle 90^o$ p.u

magnitude of phase current I_b in p.u = ?

$|I_b| = ?$

$I_b = I_{b_0} + I_{b_1} + I_{b_2}$

$I_a = I_{a_0} + I_{a_1} + I_{a_2}$



$I_{b_2} = \alpha . I_{a_2}$

$I_{a_2} = \dfrac{I_{b_2}}{\alpha}$

$I_{a_0} = I_{b_0} = I_{c_0}$

$I_a = I_{a_0} + I_{a_1} + I_{a_2}$

$I_{a_1} = I_a - (I_{a_0} + I_{a_2})$

$= I_a - \left(I_{a_0} + \left(\dfrac{I_{b_2}}{\alpha}\right)\right)$

$$1\angle -90^o - \left[3\angle 90^o + \frac{4\angle -150^o}{1\angle 120^o}\right]$$

$I_{a_1} = 8\angle -90^o$ p.u

$I_{b_1} = \alpha^2 I_{a_1}$

$= 1(1\angle 240°)\,(8\angle -90°)$

$= 8\angle 150°$ p.u

$I_b = 3\angle 90° + 8\angle 150° + 4\angle -150°$

$= 11.53\angle 154.3$

Therefore magnitude of I_b is 11.53 pu.

(iii) Given that,

Current setting = 125%

TMS = 0.6, CT ratio = 400/5,

$I_f = 4000A$

Now,

$$PSM = \frac{\text{Primary fault current}}{\text{CT ratio} \times \text{Relay current setting}} = \frac{4000}{\frac{400}{5} \times 1.25 \times 5} = 8$$

For PSM = 8, T = 3.4 sec

Actual operating time = 3.4 × 0.6 = 2.04 sec

08(c)

Sol: Given data:

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

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

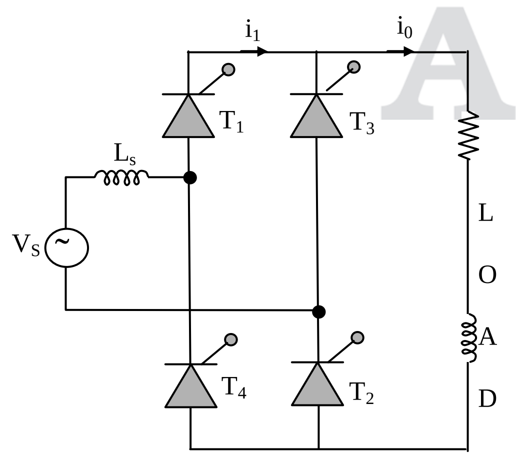


Fig: Single phase full converter with Source inductance

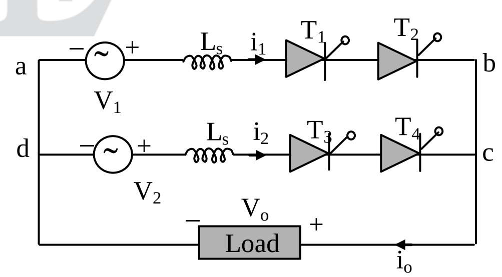


Fig. Equivalent circuit

During the commutation of T_1, T_2 and T_3, T_4 (i.e. during the overlap angleμ), 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 $V_2 = -V_m \sin \omega t$

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

and $i_1 + i_2 = I_0$

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

By solving (1) and (2)

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

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

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

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

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

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

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

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

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

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

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

$\therefore L_S = 17.1$ mH

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

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

$\alpha + \mu = 51.26$

$\Rightarrow \mu = 6.26°$

(iii)Load resistance $V_0 = I_0 R$

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