POWER ELECTRONICS NOTES

(Modified)

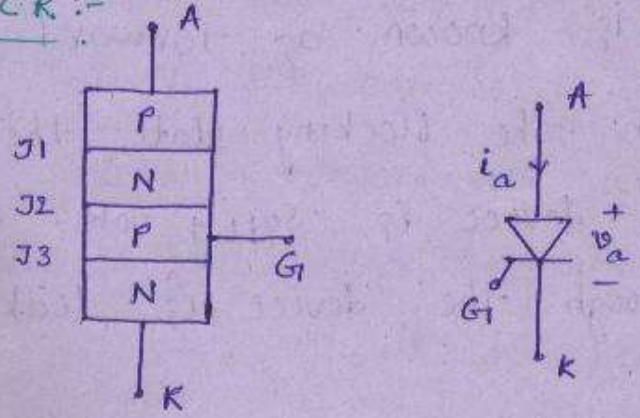
POWER ELECTRONICS

21-07-2008
(15-18) M.

→ Diode is the uncontrolled device.
Thyristor is the controlled device in which the instant of conduction can be controlled after applying forward volt. due to which the o/p. volt, current & power can be controlled.

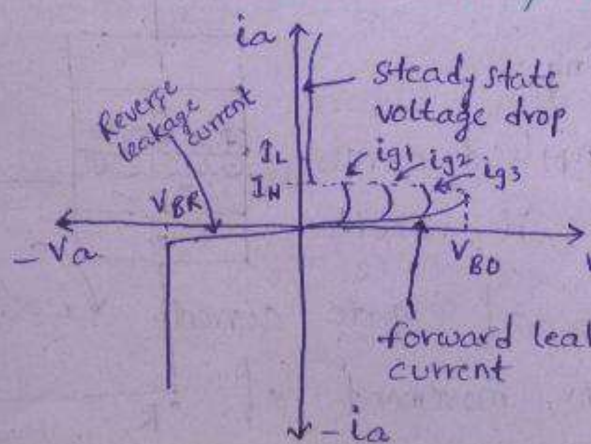
→ Thyristor is the name given to the family of devices having common structure PNPN.

SCR :-



SCR is a 4 layer, 3 terminal & 3 junction PNPN device.

Static characteristics of SCR:



V_{BO} = forward Breakover voltage

V_{BR} = Reverse BO voltage.

$i_{g_1} > i_{g_2} > i_{g_3}$

Turn on of SCR : forward blocking state to forward conduction state.

Turn off of SCR : forward conduction to forward blocking state.

1. forward voltage Triggering :

In this method, A high forward volt. is applied to the SCR, due to which reverse biased J_2 breakdown and allows the conduction.

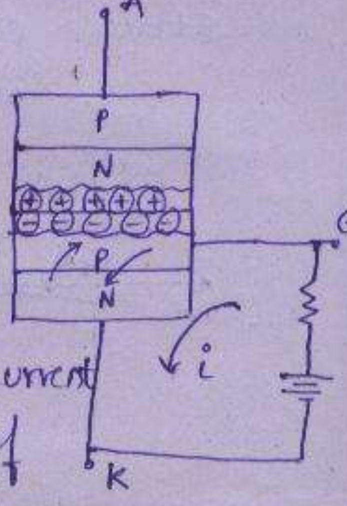
The volt. at which SCR starts conduction is known as forward BO voltage.

SCR in the blocking state, the volt. across the device is supply volt. and current through the device is leakage current.

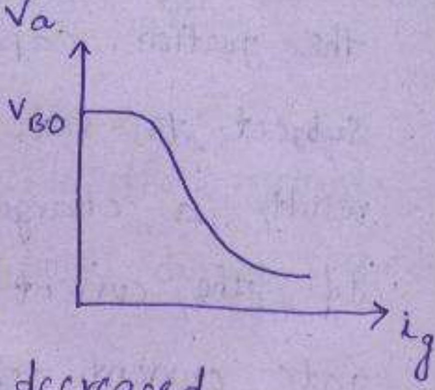
SCR in the conduction state, the volt. across the device is steady state volt. and the current is load current.

2. Gate Triggering :-

A f.v. is applied across G-K terminals, it results into a flow of gate current which is due to movement of



charge carriers. Some of the opposite charge carriers enters into depletion layer and recombination takes place then width of the depletion layer decreases and charge carriers cross the junction with the existing energy. This process allows the conduction.



By applying higher values of gate currents the anode volt. required to turn on SCR can be decreased.

A min. forward volt. is required to turn on the device for any given value of gate current and it is known as finger voltage.

3. Thermal Triggering:

In this method the SCR is heated up due to which the charge carriers are excited and as a result cross the junction and constitute the current.

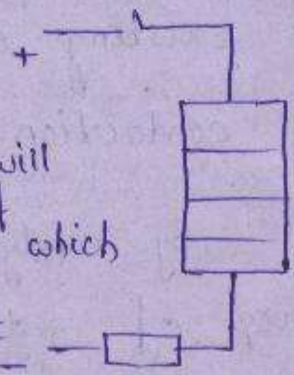
4. Light Triggering:

LASCR : Light Activated SCR.

In this, an intensified light has been focused on SCR, due to which charge carriers are excited and allows the conduction.

5. $\frac{dv}{dt}$ Triggering : $i = C \cdot \frac{dv}{dt}$

while applying f. volt. the juction capacitance will subject to rate of variation of volt. which results a charging current



If the current is more than the rated gate current of SCR then it allows conduction.

Due to lack of control action, the $\frac{dv}{dt}$ triggering is to be avoided. It is possible by making the smaller value of $\frac{dv}{dt}$, while applying the f. volt.

I_L

It is associated with turn on process. It is the min. value of the current above which the anode current should raise for the reliable turn on of the SCR.

The gate signal should be available along with SCR till the anode current raises above the latching current.

I_H

It is associated with turn off process. It is the min. value of current below which the anode current should fall for the reliable turn off of SCR.

It is useful to decide the instant for the application of r. volt. during turnoff process.

The r. volt. at which device allows conduction in reverse direction is known as r. BO. voltage.

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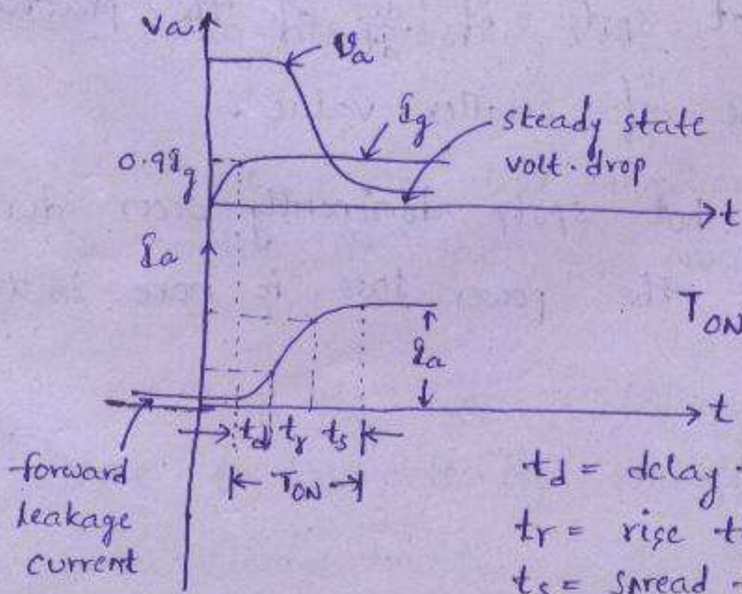
Dynamic chars (or) Switching char.s:



$T_{ON} = t_d + t_r + t_s$

t_d = delay time $\Rightarrow 0.9I_g$ to $0.1I_a$

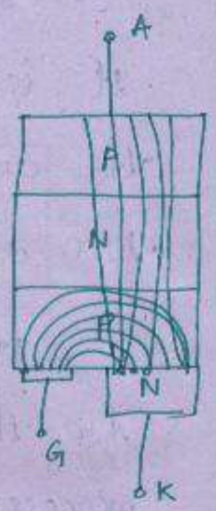
t_r = rise time $\Rightarrow 0.1I_a$ to $0.9I_a$

t_s = Spread time $\Rightarrow 0.9I_a$ to I_a.

Turn ON time :

Time interval b/w 90% of I_g to the steady state value of I_a.

SCR is a charge controlled device. By employing higher values of gate current, turn on time can be decreased.

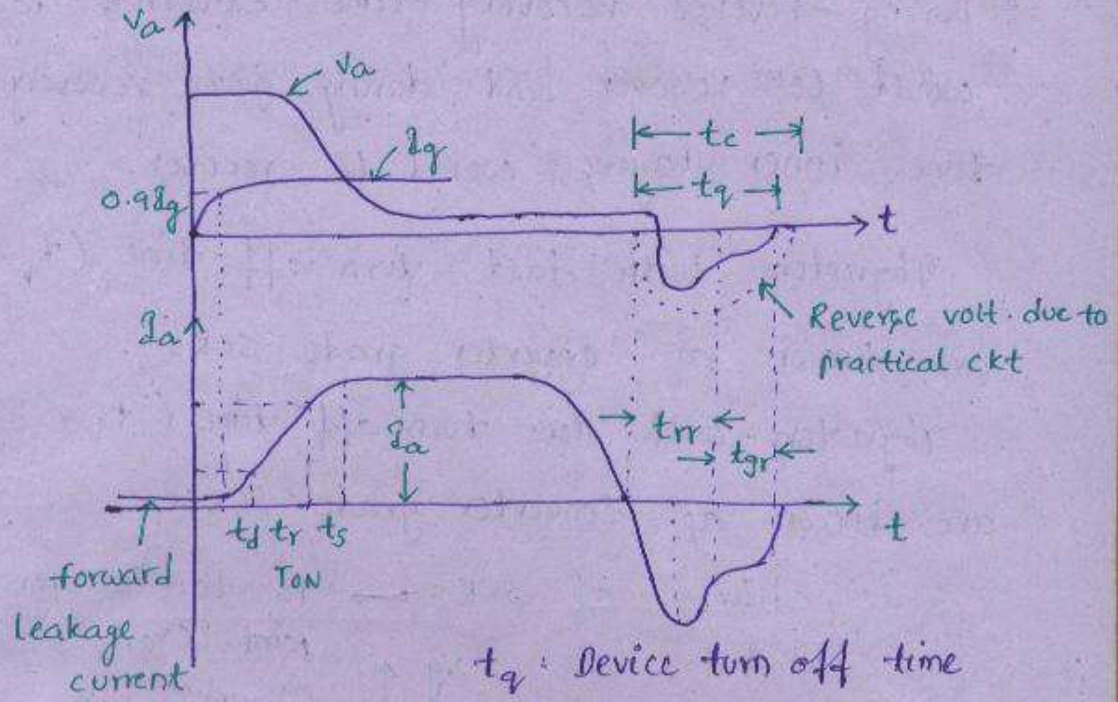


During turn on process, local hot spots could be formed, if the spreading velocity of charge carriers is less than the rate of rise of anode current. ($\frac{di_a}{dt}$).

This means $\frac{di}{dt}$ is more and time taken for the development of current is less compared to spreading time.

It is possible to avoid the formation of local hot spots if $\frac{di}{dt}$ of the practical ckt is made of smaller value.

Local hot spots dominently occur during rise time as the power loss is more in the interval.



t_q : Device turn off time

t_c : Circuit "

$t_q = t_{rr} + t_{gr}$

t_{rr} = Reverse recovery time

t_{gr} = Gate recovery time.

The following condi.s should be satisfied for the turn off of the SCR.

1. Reduce the current below the holding current
2. Apply the r. volt for sufficient duration to regain the blocking state.

t_q :

It is the time required by the device to complete its turn off process.

t_c :

It is the time alloted by the ckt for SCR for complete its turn off process.

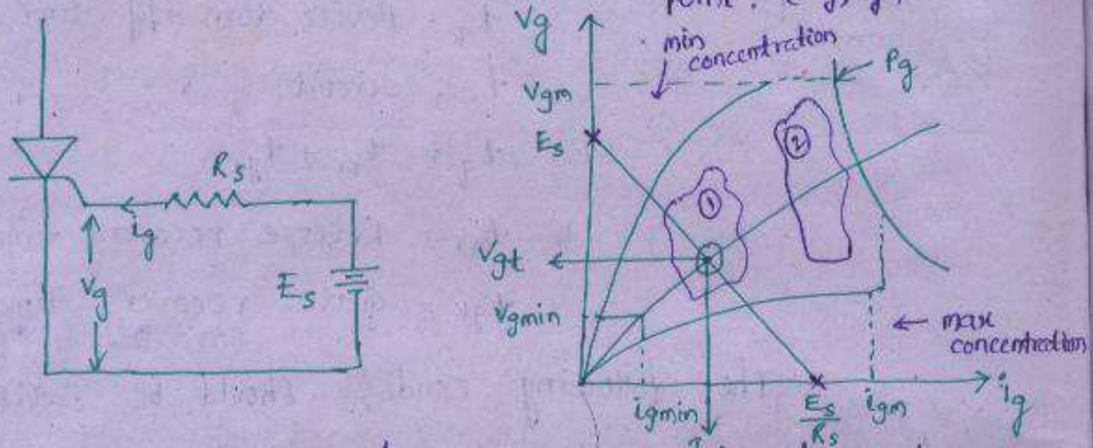
Always $t_c > t_q$.

During reverse recovery time external layers would be recover and during gate recovery time inner layers would be recover.

Thyristors with fast turn off time ($t_q < 50\mu s$) are known as Inverter grade SCRs.

Thyristors with slow turn off time ($t_q > 50\mu s$) are known as Converter grade SCRs.

Gate char.s of SCR : $\longrightarrow$ To locate operating point. (v_g, i_g).



Gate char.s of SCR are similar to forward char.s of PN junction.

The min. value restrictions over the positioning of operating point is to avoid mal triggering of SCR due to noise signals.

So V_{gmin} & $i_{g\,min}$ should be greater than that of the max. level of noise signals.

The operating point can be obtained by the intersection of gate-cathode char.s and load line. (V_{gt}, i_{gt})

The operating point should be so located that the associated gate currents are higher in magnitude, this results in the decrement of turn on time.

slope of gate-cathode char.s = $\frac{v_g}{i_g}$

slope of load line = R_s

$E_g = v_g + i_g R_s$

$P_g = v_g i_g$

Protection of SCR:

$V\uparrow \; Z\downarrow \begin{cases} R\downarrow \\ X_c\downarrow - C\uparrow \end{cases}$

$V\downarrow \; Z\uparrow \begin{cases} R\uparrow \\ X_c\uparrow - C\downarrow \end{cases}$

1. Over voltage protection
   ↳ varistors, variable capacitors
2. over current protection
   ↳ circuit breakers, fast acting current limiting fuse (F.A.C.L.F)
3. Thermal protection
   ↳ Heat sinks (AL)

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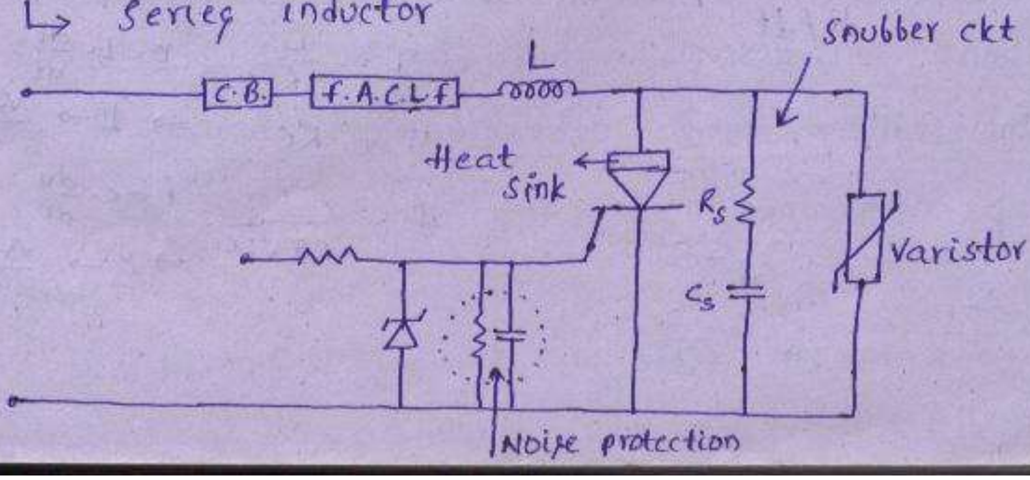
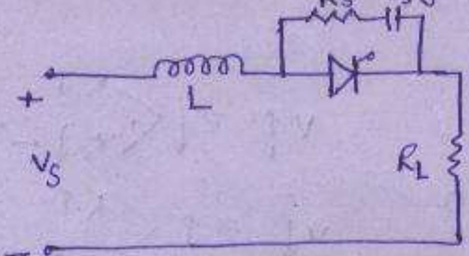
4. $\frac{dv}{dt}$ protection
   ↳ Snubber circuit (series RC combination)
5. $\frac{di}{dt}$ protection
   ↳ series inductor

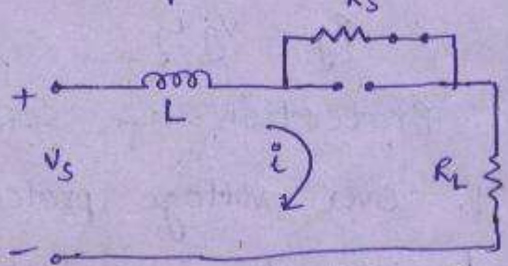


Design of snubber circuit :-

A thyristor is placed b/w a dc volt. source of $V_s = 240V$ and resistive load R_L. The specified limits for $\frac{di}{dt}$, $\frac{dv}{dt}$ of SCR are 60 A/μsec & 300 V/μsec. Find the values of snubber ckt parameters and $\frac{di}{dt}$ inductor.

Take a damping factor of 0.5.





$$V_S = (R_S + R_L)i + L\cdot\frac{di}{dt}$$

$$\left.\frac{di}{dt}\right|_{t=0} = \frac{V_s}{L}$$

$$\Rightarrow \frac{di}{dt} + \frac{(R_s+R_L)}{L}i = \frac{V_s}{L}$$

$$\therefore i(t) = \frac{V_s}{R_s+R_L}\left[1 - e^{\frac{-t(R_s+R_L)}{L}}\right]$$

$$\Rightarrow L = \frac{V_s}{di/dt}$$

$$v = iR_s$$

$$\frac{di}{dt} = \frac{V_s}{R_s+R_L}\left[0 - e^{\frac{-t(R_s+R_L)}{L}}\cdot\left\{-\frac{R_s+R_L}{L}\right\}\right]$$

$$= \frac{V_s}{L}\cdot e^{-\frac{(R_s+R_L)t}{L}}$$

$$\Rightarrow \frac{dv}{dt} = R_s\cdot\frac{di}{dt}$$

$$\Rightarrow R_s = \frac{dv/dt}{di/dt}$$

$$R = \sqrt{\frac{L}{C}} \qquad R \rightarrow \frac{V}{A}$$

$$\tau = \frac{L}{R} \qquad v = L\cdot\frac{di}{dt}$$

$$\tau = RC \qquad \Rightarrow L \rightarrow \frac{V\cdot sec}{A}$$

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad i = C\cdot\frac{dv}{dt}$$

$$\Rightarrow C \rightarrow \frac{A\cdot sec}{V}$$

when RLC energized by a dc source,

$$Ri + L.\frac{di}{dt} + \frac{1}{c}\int i\,dt = V_s$$

$$\Rightarrow L.\frac{d^2i}{dt^2} + R.\frac{di}{dt} + \frac{i}{c} = 0$$

$$\Rightarrow \frac{d^2i}{dt^2} + \frac{R}{L}.\frac{di}{dt} + \frac{1}{LC}i = 0$$

$$s^2 + (2\delta\omega_n)s + \omega_n^2 = 0$$

$$2\delta\omega_n = \frac{R}{L} \Rightarrow 2\delta\left(\frac{1}{\sqrt{LC}}\right) = \frac{R}{L} \Rightarrow R = 2\delta\sqrt{\frac{L}{C}}$$

$$\omega_n^2 = \frac{1}{LC}$$

1.3). $v_s = 240\,V$

$\frac{di}{dt} = 60\,A/\mu s$

$\frac{dv}{dt} = 300\,V/\mu s$ $\left(R = \frac{dv/dt}{di/dt}\right)$

$\delta = 0.5$

$L = \frac{240}{60} = 4\,\mu H$ $\left(v = L.\frac{di}{dt}\right)$

$R_s = \frac{300}{60} = 5\,\Omega$

$R_s = 2\delta\sqrt{\frac{L}{C}} \rightarrow 5 = 2\times 0.5\sqrt{\frac{4\times 10^{-6}}{C}}$

$\Rightarrow C = 0.16\,\mu f.$ $R = 2\xi\sqrt{\frac{L}{C}}$

for better operation of SCR, resistance should be increased and capacitance should be decreased, substitute these values into the eq $R_s = 2\delta\sqrt{\frac{L}{C}}$ for the evolvation of inductor.

$\therefore R_s = 8\,\Omega,\ C_s = 0.1\,\mu f$ then $R_s = 2\delta\sqrt{\frac{L}{C}}$

$\Rightarrow L = 6.4\,\mu H.$

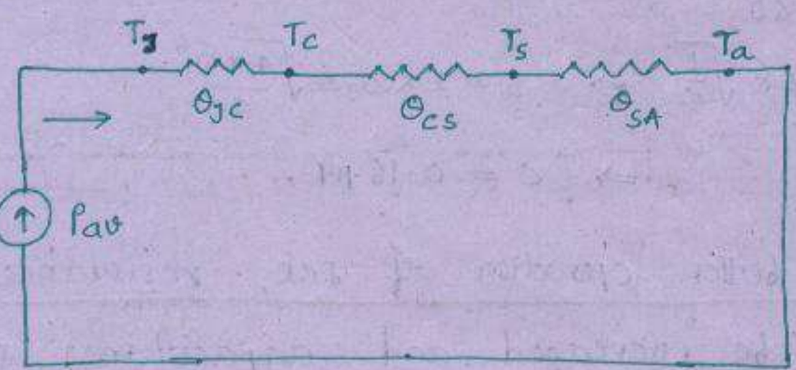
Heating, cooling circuit of SCR :-

Most of the heat generates at the junctions. This heat needs to be dissipated to the surrounding atmosphere in the following direction.

Junction → casing → heat sink → ambient

<u>Thermal</u>	<u>Electrical</u>
1. Heat energy (J)	1. charge (C)
2. Temp. difference (°C)	2. potential diff. (V)
3. Rate of heat transfer (J/sec) or (watts)	3. Electric current (A)
4. Thermal resistance (°C/W)	4. Electric resistance (V/A)

⇒ In thermal applications the rate of heat transfer is same hence it can be represented by a series electrical circuit.



$$P_{av} = \frac{T_J - T_C}{\theta_{JC}} = \frac{T_C - T_S}{\theta_{CS}} = \frac{T_S - T_a}{\theta_{SA}}$$

$$= \frac{T_J - T_S}{\theta_{JC} + \theta_{CS} + \theta_{SA}}$$

θ_{JC} value depends on the material & method by which SCR is prepared.

θ_{CS} value depends on method of mounting and contact area with the heat sink.

θ_{SA} depends on method of cooling & type of coolent employed in the cooling circuit.

Series, parallel operation of SCR's:

SCRs are required to be connected in series for higher volt. blocking capability. SCRs need to be connected in ||el for higher current carrying capacity.

$$\text{string } \eta_s = \frac{\text{Actual volt. rating of the string}}{n \times \text{Actual volt. rating of SCR}}$$

$$= \frac{\text{Actual current rating of the string}}{n \times \text{Actual current rating of SCR}}$$

Derating factor $= 1 - \eta_s$

→ ~~for continuat~~ Refer M/c-I notes for continu.

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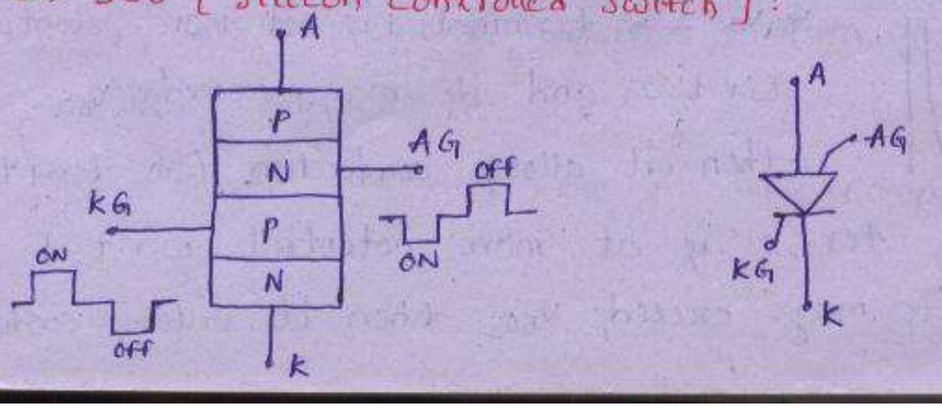
→ SCS [Silicon Controlled Switch]:



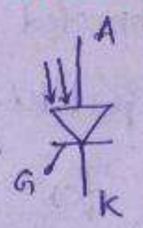
→ SCS is a tetrode.

→ Acts like a GTO, but it is limited for low power applications.

→ The switching action can be controlled either from AG or KG.

→ oscillators, pulses-generator, voltage senses, logic & trigger circuits.

LASCR :-

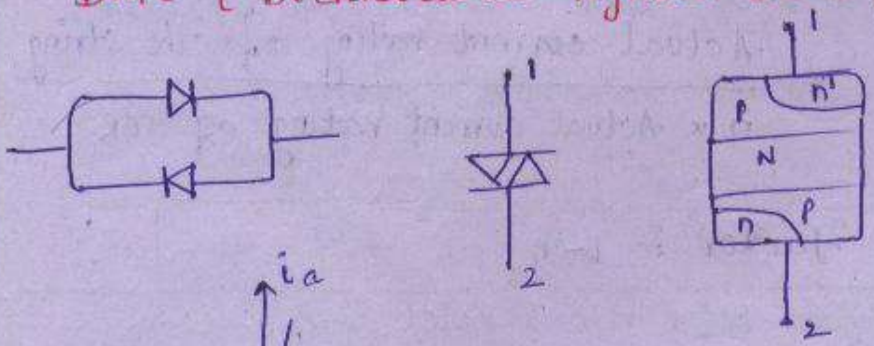


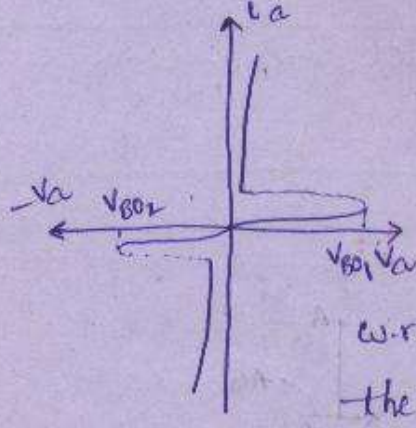
→ can turn on by light triggering.

→ Gate terminal is useful to apply mild gate pulse under low light intensity condi. to turn on the device

→ street lights, HVDC applications, static reactive power compensation.

DIAC [Bidirectional thyristor Diode] :-





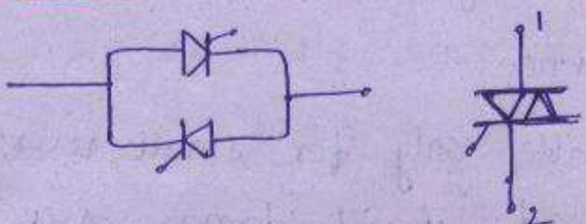
→ Anti parallel connection of diodes.

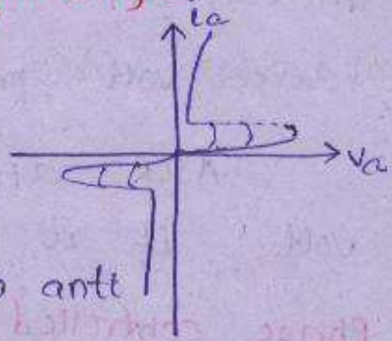
→ terminal 1 is at more potential w.r.t. 2, and its mag. exceeds V_{BO1} then it allows conduction from ter. 1 to 2

→ If ter. 2 is at more potential w.r.t. 1 and its mag. exceeds V_{BO2} then it allows condu-from ter. 2 to 1.

→ Due to lack of control action diac finds limited applications.

TRIAC : [Bidirectional Thyristor] :-





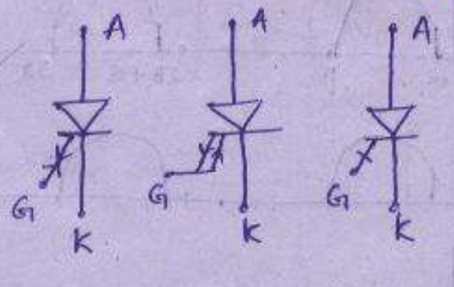
→ Electrically equivalent to anti parallel connection of SCR's.

→ Allows the control conduction in both the directions.

→ volt., current & freq. ratings are less compared to conventional SCR's. Hence limited to low and medium power applications.

→ lighting ckts, domestic & industrial heating ckts., speed control of ac motors.

GTO [Gate Turn off Thyristor] :-



→ The -ve gate current required to turn off GTO is 20 to 30% of anode current in condu. state.

→ +ve gate current required to turn on GTO is more compared to SCR.

→ I_H, I_L are also more in GTO compared to SCR.

ASCR :

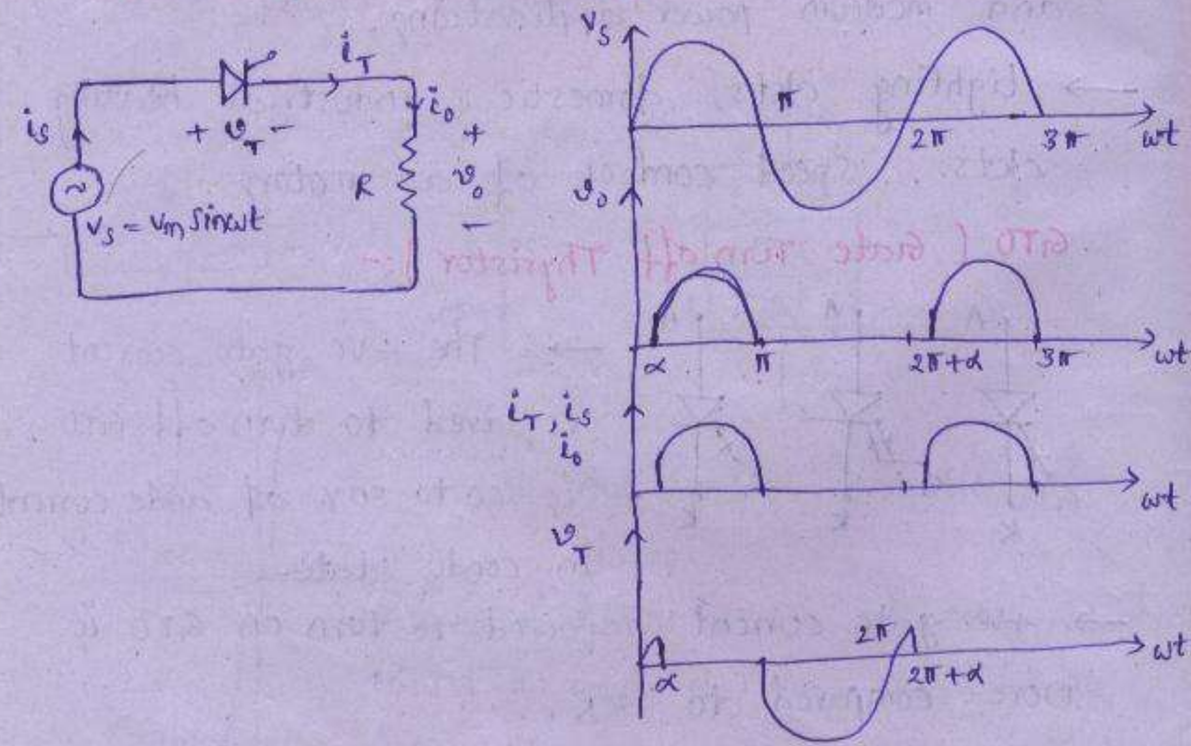
Thyristor in which more attention is given for optimization of forward char.s like reduction in ton, toff, s.s. voltage, at the cost of reverse volt. properties.

ASCR applicable only for small reverse volt., if it exceeds, it will damage ASCR.

Phase controlled Rectifiers :-

It is a static power electronics device which converts fixed ac to var. dc ie variation in magnitude of voltage.

→ 1-ø Half wave Rectifier with R- Load :-



→ ph. controlled rectifier is always based on line or natural commutation. Natural zero of current and subsequent application of reverse volt. occurs due to the nature of i/p ac supply, hence it is a line commutation.

→ $t_c = \dfrac{2\pi - \pi}{\omega} = \dfrac{\pi}{\omega}$ sec.

→ o/p wave form consists of one pulse for every i/p cycle, hence it is known as single phase one pulse rectifier, pulse freq. is same as the supply freq.

→ $$V_0 = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \cdot d(\omega t)$$

$$= \frac{1}{2\pi} V_m \left[-\cos\omega t\right]_{\alpha}^{\pi}$$

$$= \frac{V_m}{2\pi}\left[\cos\alpha - \cos\pi\right]$$

→ $$V_0 = \frac{V_m}{2\pi}\left[1+\cos\alpha\right]$$

$$V_{or} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \; d(\omega t)}$$

⇒ $$V_{or}^2 = \frac{V_m^2}{2\pi}\cdot\frac{1}{2}\int_{\alpha}^{\pi}(1-\cos 2\omega t)\cdot d(\omega t)$$

$$= \frac{V_m^2}{4\pi}\left[\omega t - \frac{1}{2}\sin 2\omega t\right]_{\alpha}^{\pi}$$

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

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

$$I_0 = \frac{V_0}{R} \; ; \; I_{or} = \frac{V_{or}}{R}$$

→ power delivered by source = power taken by load.

$\Rightarrow V_s \cdot I_{sr} \cdot \cos\phi = \frac{V_{or}^2}{R}$

$\Rightarrow pf = \frac{V_{or}^2/R}{V_s \cdot (V_{or}/R)}$

$\Rightarrow$ I/p supply pf $= \frac{V_{or}}{V_s}$.

→ phasor relationship b/w supply volt. & current gets varied with the variation of 'α' or o/p volt. then rectifier called as ph. controlled rectifier.

→ Range of 'α' → 0 to π. By varying the 'α', o/p volt. can be controlled from V_m/π to 0.

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1.1). $\frac{V_g}{i_g} = 130,$

$E_s = 15\,V$, $P_g = 0.5\,W = V_g i_g$

$\rightarrow \frac{V_g}{i_g} \times V_g i_g = 130 \times 0.5$

$\rightarrow V_g^2 = 65 \Rightarrow V_g = 8.06\,V$

$i_g = \frac{0.5}{8.06} = 0.062\,A$

$E_s = V_g + i_g R_s$

$\Rightarrow R_s = \frac{15 - 8.06}{0.062}$

$= 111.9\,\Omega$.

1.2.) $E_s = 15V, \quad R_s = 120\,\Omega, \quad i_{g\,min} = 25mA$

$P_g = i_g v_g = 0.4W$

$E_s = v_g + i_g R_s$

$\Rightarrow 15 = \frac{0.4}{i_g} + i_g (120)$

$\Rightarrow i_g = 86mA, \; 38mA$

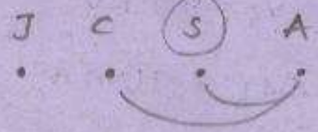
Select gate current of 86mA, which is of higher value within possible limits.

$\therefore \; i_g = 86mA, \Rightarrow v_g = \frac{0.4}{86m} = 4.63V.$

1.4). $T_c = 100°c, \quad T_J = 125°c, \quad (\theta_{cs} + \theta_{SA}) = 0.5°c/w$

$T_A = 40°c, \quad \theta_{SA} = 0.4°c/w.$

$P_{av} = \frac{T_c - T_A}{\theta_{cs} + \theta_{SA}}$



$= \frac{100 - 40}{0.5} = 120\,w$

$\Rightarrow P_{av} = \frac{T_c - T_s}{\theta_{cs}} \qquad \left(P_{av} = \frac{T_s - T_A}{\theta_{SA}} \right)$

$\Rightarrow T_s = T_c - \theta_{cs} \cdot P_{av}$

$= 100 - 120 \times 0.1 = 88°c.$

1.5).

Series	parallel
$V_s = 11\,kV$	$4\,kA$
$V_{bm} = 1800V$	$1000\,A$
$\eta_s = 0.9$	0.9
$0.9 = \frac{11000}{n_s \times 1800}$	$0.9 = \frac{4000}{n_p \times 1000}$

$\Rightarrow \quad n_s = 6.7 \qquad\qquad n_p = 4.44$

$\simeq 7 \qquad\qquad \simeq 5$

$I_{bm} = 12 \text{ mA}$

$$R_s = \frac{nV_{bm} - V_s}{(n-1)\cdot \Delta I_b}$$

$$= \frac{7\times 1800 - 11000}{6\times(12\times 10^{-3} - 0)} = 22.22\text{ k}\Omega$$

1.6).

$\Delta Q = 25\ \mu C$

$$C_s = \frac{(n-1)\Delta Q}{nV_{bm} - V_s}$$

$$= \frac{6\times 25\times 10^{-6}}{7\times 1800 - 1000} = 0.094\ \mu f.$$

1.7).

$V_s = 15\text{ kV}$

$\Delta I_b = 10\text{ mA},$

$\Delta Q = 150\ \mu C,$

$D.R.f = 0.2$

$V_{bm} = 1000\text{ V}$

$\eta_s = 1 - 0.2 = 0.8$

$$\Rightarrow 0.8 = \frac{15000}{n\times 1000} \Rightarrow n = 18.75 \simeq 19$$

$$R_s = \frac{19\times 1000 - 15000}{18\times 10\times 10^{-3}}$$

$$= 22.22\text{ k}\Omega$$

$$C_s = \frac{18\times 150\times 10^{-6}}{19\times 1000 - 15000} = 0.675\ \mu f$$

1.8). $i = 12\,\mu A$, $\frac{dv}{dt} = 800\ V/\mu s$

$C_J = ?$

$i = C_J \cdot \frac{dv}{dt} \Rightarrow C_J = 0.015\ pf$

1.9). $C_J = 20\ pf$

$i = 15\ mA$

$C_e = 0.01\,\mu f$

$C_T = 20\times10^{-12} + 0.01\times10^{-6}$

$= 10.02\times10^{-9}\ f$

$i = C_T \cdot \frac{dv}{dt}$

$\Rightarrow \frac{dv}{dt} = 1.497\times10^{6}\ V/s$

$= 1.497\ V/\mu s$.

1.10). $T_J = 125°C$, $\theta_{JC} = 0.16\ °C/W$,

$\theta_{CS} = 0.08\ °C/W$, $T_{S1} = 70°C$

$$P_{av1} = \frac{T_J - T_{S1}}{\theta_{JC} + \theta_{CS}}$$

$$= \frac{125-70}{0.16+0.08} = 229.17W$$

$T_{S2} = 60°C$

$$P_{av2} = \frac{125-60}{0.16+0.08} = 270.8\ W (or)\ J/s$$

At thermal equilibrium condi. rate of heat generation = rate of heat dissipation. Since rate of heat generation $\propto i^2$

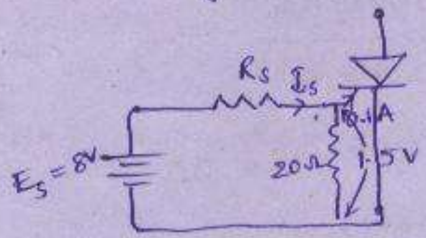
$\therefore$ $P_{av} \propto i^2 \Rightarrow i \propto \sqrt{P_{av}}$

% increase in device rating $= \dfrac{I_2 - I_1}{I_1} \times 100$

$$= \frac{\sqrt{270.8} - \sqrt{229.16}}{\sqrt{229.16}} \times 100$$

$$= 8.71\%$$

1.11). $V_g = 1.5\,V$, $i_g = 100\,mA = 0.1\,A$, $R = 20\,\Omega$



$$I_s = 0.1 + \frac{1.5}{20}$$

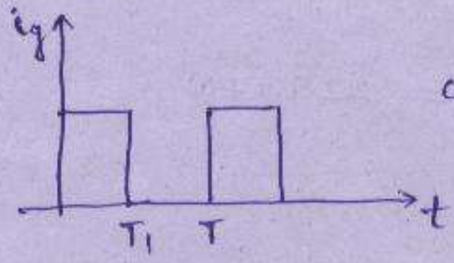
$$= 0.175\,A$$

$$R_s = \frac{E_s - V_g}{I_s} = \frac{8 - 1.5}{0.175} = 37.14\,\Omega$$

→ Pulse Triggering :-

In this method gate volt. applied to SCR is in terms of pulses rather than continuous signal.

Pulse triggering allows to employ higher value of gate current which will reduce T_{on} (turn ON time).



$$P_{g\,av} = \delta\, P_{gm}$$

where δ = Duty cycle

$$= \frac{T_{ON}}{T} = \frac{T_1}{T}$$

$$= f \cdot T_1$$

$$\Rightarrow P_{g\,av} = f \cdot T_1\, P_{gm}$$

where f = pulse freq.

1.12) $\frac{V_g}{i_g} = 20\ V/A$, $T_{ON} = 4\ \mu s$, $i_g = 400\ mA$
$= 0.4\ A$

$E_s = 15\ V.$

$V_g = 20 \times 0.4 = 8\ V$

$E_S = V_g + i_g R_S \Rightarrow R_S = 17.5\ \Omega$

$P_g = V_g i_g = 8 \times 0.4$
$= 3.2\ W$

$T_1 = 4\ \mu s$

$P_{gav} = 0.2\ W$

$P_{gav} = f T_1 \times P_{gm}$

$\Rightarrow f = 15.615\ KHz.$

1.13) $f = 4000\ Hz$, $\delta = 0.2$

$\delta = f \cdot T_1$

$\Rightarrow T_1 = \frac{0.2}{4000} = 50\ \mu s.$

$P_{gav} = 1\ W$

$P_{gm} = \frac{P_{gav}}{\delta} = \frac{1}{0.2} = 5\ W.$

→ 1-ϕ Half wave Rectifier with RL load :-

* In RL load conduction is supported by supply from α to π and by inductor from π to β.

* In RL load extinction angle β is always $> \pi$

power delivered by source = power taken by load

$\Rightarrow \quad P_s = P_L$

$\rightarrow \quad V_s \times I_{sr} \times pf = \dfrac{V_{or}^2}{R}$

$\rightarrow \quad pf = \left(\dfrac{V_{or}}{R}\right) / \left(\dfrac{V_s \cdot V_{or}}{R}\right)$

$= \dfrac{V_{or}}{V_s}$

→ 1-ϕ HWR with RL load with free wheeling diode:-

⇒ During α to π o/p power is +ve (V_o & $I_o \Rightarrow$ +ve).

During π to β : o/p power is −ve ($V_o \rightarrow$ −ve & $I_o \rightarrow$ +ve). So avg. power consumption of load decreases.

→ To improve the performance of load a diode is connected across the load and it allows the circulation of power in the load itself. It is known as free wheeling diode.

Advantages :-

1. probability of getting conti. conduction is more with f.w. diode provided inductor should have strength to support condu. from π to $2\pi+\alpha$.
2. power consumption is improved.
3. t_c is fixed and more than pure RL load

⟹ HWR with RLE load :-

* Range of firing angle : θ_1 to θ_2.

At $\omega t = \theta_1 \Rightarrow V_s = E$.

$V_m \sin\theta_1 = E$

$\Rightarrow \theta_1 = \sin^{-1}\frac{E}{V_m}$.

and $\theta_2 = \pi - \theta_1$

* If the thyristor in blocking state o/p volt = E.

In condu. state o/p volt. = Supply volt.

* In the case RE load extinction angle $\beta = \theta_2$

RLE load " $\beta > \pi$ $\alpha < \pi$

but it is always $> \theta_2$.

In the case of RL load, $\beta > \pi$.

* $$Ri + \cancel{L \cdot \frac{di}{dt}}^{\to 0} + E = V_m \sin \omega t$$

[The avg. volt during 2π interval is zero across inductor].

$$\Rightarrow i = \frac{V_m \sin\omega t - E}{R}$$

$$I_o = \frac{1}{2\pi}\int_{\alpha}^{\beta} \frac{V_m \sin\omega t - E}{R} \, d(\omega t)$$

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

$$I_{or} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\beta}\left(\frac{V_m \sin\omega t - E}{R}\right)^2 \cdot d(\omega t)}$$

$$\text{I/P Supply pf} = \frac{\text{power delivered to load}}{\text{source VA}}$$

$$= \frac{I_{or}^2 R + I_o E}{V_s \cdot I_{or}}$$

2.1. $R = 10\Omega,\quad V_s = 220V,\quad \alpha = 60^\circ$

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

$$= \frac{220\times\sqrt{2}}{2\sqrt{\pi}}\left[(\underset{180^\circ}{\pi} - 60^\circ)\frac{\pi}{180} + \frac{\sin 120}{2}\right]^{1/2}$$

$$= 139.7\,V$$

$$P = \frac{(V_{or})^2}{R} = \frac{(139.7)^2}{10} = 1947\,\omega.$$

$$pf = \frac{V_{or}}{V_s} = \frac{139.7}{220}$$

$$= 0.634 \text{ lag}.$$

2.2. $V_S = 230V,\quad R = 2\Omega,\quad L = 1mH,\quad E = 120V.$

$\beta = 220^\circ,\quad \alpha = 25^\circ.$

(a). $V_T = V_m \sin\alpha - E$

$$= 230\times\sqrt{2}\cdot\sin 25^\circ - 120$$

$$= 17.46\,V$$

(b). $V_T = V_m \sin\beta - E$

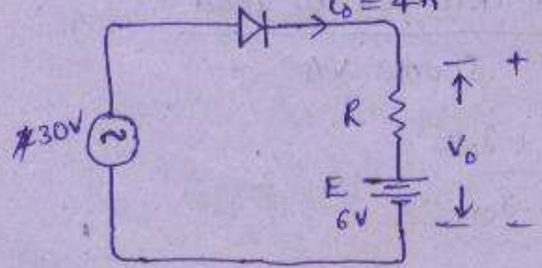
$$= 230\times\sqrt{2}\times\sin 220 - 120$$

$$= -329\,V$$

(c). $PIV = V_m + E$

$$= 230\sqrt{2} + 120 = 445.3\,V$$

2.3.



$\alpha = \theta_1$

$\beta = \theta_2$

$$\theta_1 = \sin^{-1}\left[\frac{E}{V_m}\right]$$

$$= \sin^{-1}\left[\frac{6}{30\sqrt{2}}\right]$$

$$= 8.13^\circ$$

$\beta = \theta_2$

$= 180 - 8.13 = 171.87^\circ$

$$I_0 = \frac{1}{2\pi} \int_\alpha^\beta \frac{V_m \sin\omega t - (E + V_T)}{R} \, d(\omega t)$$

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

$$\Rightarrow 4 = \frac{1}{2\pi R} \left[30\sqrt{2} (\cos 8.13 - \cos 171.87) - (6+1) (171.87 - 8.13) \times \frac{\pi}{180} \right]$$

$\Rightarrow R = 2.54\ \Omega.$

2.4.

$R = 10\Omega, \quad E = 110V, \quad \alpha = 30^\circ, \quad V_s = 230V$

$\beta = \theta_2$

$\theta_1 = \sin^{-1}\left(\frac{110}{230\sqrt{2}} \right) = 19.76^\circ$

$\theta_2 = \pi - 19.76 = 160.24^\circ$

$$I_0 = \frac{1}{2\pi R} \left[V_m (\cos\alpha - \cos\beta) - E(\beta - \alpha) \right]$$

$$= \frac{1}{2\pi \times 10} \left[230\sqrt{2} (\cos 30 - \cos 160.24) - 110 (160.24 - 30) \cdot \frac{\pi}{180} \right]$$

$= 5.4\ A.$

2.5.

$\frac{N_P}{N_{S1}} = 1.25$

$V_P = 230V$

$R = 2\Omega$

$\frac{N_P}{N_{S1}} = \frac{V_P}{V_{S1}} = 1.25$

1-ϕ Semi Converter:

→ The o/p volt. is always +ve. Since o/p voltage can be controlled in only +ve direction Hence it is known as 1-ϕ half controlled rectifier.

→ If load requires only +ve o/p voltage, then semi converter is preferable.

→ If load demands both +ve & -ve o/p voltages, then it is required to employ 1-ϕ full wave bridge rectifier.

$\Rightarrow V_{S1} = \frac{230}{1.25} = 184\,V$

$V_{S1m} = 184 \times \sqrt{2} = 260.2\,V$

(a). $V_0 = \frac{V_m}{\pi}(1+\cos\alpha)$

If $\alpha = 0$, $V_0 = V_{0m}$

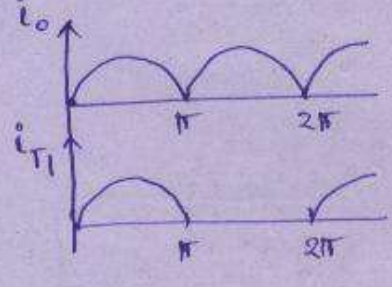
$V_{0m} = \frac{2V_m}{\pi} = \frac{2 \times 260.2}{\pi} = 165.63\,V$

$I_{0m} = \frac{V_{0m}}{R} = 82.85\,A$

Conduction angle $(\gamma) = 180$

(b). $PIV = 2 \times 260.2 = 520.4\,V$

(c).



$I_{Tm} = \frac{82.83}{2} = 41.41\,A$

(d). $V_0 = 100V$

$100 = \frac{260.2}{\pi}[1+\cos\alpha]$

$\Rightarrow \alpha = 78°$.

2.6. $R = 5\Omega$

$L = 10\,mH$

$E = 80\,V$

$V_s = 230\,V$

$\alpha = 50^\circ$

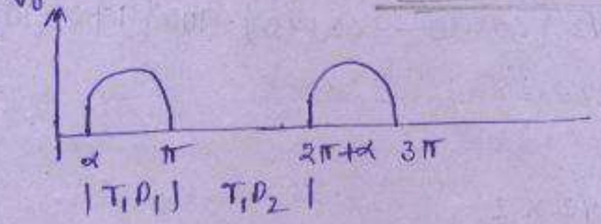
$V_0 = \frac{V_m}{\pi}(1+\cos\alpha)$

$= \frac{230\sqrt{2}}{\pi}(1+\cos 50^\circ)$

$= 170\,V$

$I_0 = \frac{V_0 - E}{R} = \frac{170-80}{5} = 18\,A$

(b).



$V_0 = \frac{V_m}{2\pi}(1+\cos\alpha)$

$= \frac{230\sqrt{2}}{2\pi}(1+\cos 50) = 85\,V$

$I_0 = \frac{V_0 - E}{R} = \frac{85-80}{5} = 1\,A$

2.7. $V_s = 230\,V$

$R = 2.5\,\Omega$

$E = 100\,V$

$\alpha = 30^\circ$

(a). $V_0 = \frac{2V_m}{\pi}\cos\alpha$

$= \frac{2\times 230\sqrt{2}}{\pi}\cos 30^\circ$

$= 179.3\,V$

$I_0 = \frac{V_0 - E}{R} = \frac{179.3-100}{2.5}\,A$

$= 31.72\,A$

Input p.f $= \frac{E I_0 + I_{or}^2 R}{V_s \cdot I_{sr}}$

$= \frac{100\times 31.72 + (31.72)^2 \cdot 2.5}{230\times 31.72}$

$= 0.78$ lag.

2.8. $V_s = 230\,V$

$R = 2\,\Omega$

$L = 10\,mH$

$E = 100\,V$

$\alpha = 30^\circ$

(a). $\beta = 200^\circ$

$I_0 = \frac{1}{\pi}\int_\alpha^\beta \frac{V_m \sin\omega t - E}{R}\, d(\omega t)$

$= \frac{1}{\pi R}\left[V_m(\cos\alpha - \cos\beta) - E(\beta-\alpha)\right]$

$$I_0 = \frac{1}{\pi \times 2}\left[230\sqrt{2}\,[\cos 30 - \cos 200] - 100[200-30]\frac{\pi}{180}\right]$$

$$= 46.25\ A$$

$$V_0 = E + I_0 R = 100 + 46.25 \times 2 = 192.5\ V$$

(b). $\beta = 170^\circ$

$$I_0 = \frac{1}{\pi \times 2}\left[230\sqrt{2}\,[\cos 30 - \cos 170] - 100[170-30]\cdot\frac{\pi}{180}\right]$$

$$= 56.92\ A$$

$$V_0 = 100 + 56.92 \times 2$$

$$= 213.8\ V$$

2.9. $I_0 = 5A,\ \alpha = 35^\circ,\ V_p = 220V,$

$$\frac{N_p}{N_{S1}} = \frac{1}{2} = \frac{V_p}{V_{S1}}$$

$$\Rightarrow V_{S1} = 2V_p$$

$$= 2 \times 220 = 440V$$

$$V_{S1m} = 440 \times \sqrt{2} = 622.2V.$$

$$V_0 = \frac{2V_m}{\pi}\cos\alpha$$

$$= \frac{2 \times 622.2}{\pi}\cos 35^\circ$$

$$= 324.8\ V$$

2.10. $R = 5\Omega,\ L = 3mH,\ V_L = 400V$

$$V_0 = \frac{3\sqrt{6}}{2\pi}\cdot V_{ph}$$

$$= \frac{3\sqrt{6}}{2\pi} \times \frac{400}{\sqrt{3}} = 270V$$

$$I_0 = \frac{V_0}{R} = \frac{270}{5} = 54\ A$$

2.11. $I_0 = 30\,A, \quad \alpha = 0^\circ \text{ to } 80^\circ, \quad V_L = 400V$

(a). $V_0 = \dfrac{3\sqrt{6}}{2\pi} V_{ph} \cos\alpha$

for $\alpha = 0^\circ$, $= \dfrac{3\sqrt{6}}{2\pi} \times \dfrac{400}{\sqrt{3}} \times \cos 0^\circ = 270\,V$

$P = V_0 I_0 = 270 \times 30 = 8100\,W$

(b). for $\alpha = 80^\circ$,

$V_0 = \dfrac{3\sqrt{6}}{2\pi} \times \dfrac{400}{\sqrt{3}} \times \cos 80^\circ$

$= 46.8\,V$

$P = 46.8 \times 30 = 1406\,W$

imp

2.12. $E = 110V, \quad R = 0.2\,\Omega, \quad I_0 = 10A, \quad V_L = 220V$

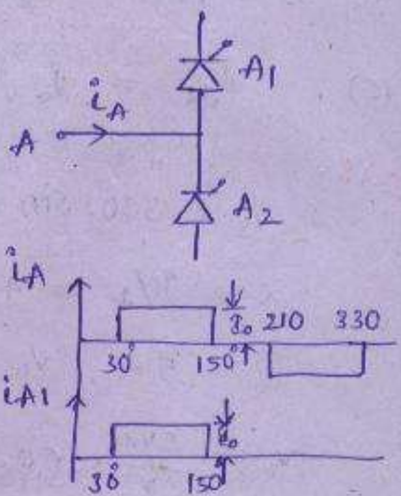
(a). $V_0 = E + I_0 R$

$= 110 + 10 \times 0.2 = 112\,V$

$V_0 = \dfrac{3\sqrt{6}}{\pi} V_{ph} \cos\alpha$

$\Rightarrow 112 = \dfrac{3\sqrt{6}}{\pi} \times \dfrac{220}{\sqrt{3}} \times \cos\alpha$

$\Rightarrow \alpha = 67.8^\circ$



$p.f. = \dfrac{E I_0 + I_{or}^2 \cdot R}{\sqrt{3} V_L \cdot I_L}$

$I_{Tr} = I_0 \sqrt{\dfrac{120}{360}} = I_0 \sqrt{1/3}$

(?) $I_{sr} = I_L = I_0 \sqrt{\dfrac{240}{360}} = I_0 \sqrt{\dfrac{2}{3}}$.

$\therefore pf = \dfrac{110 \times 10 + (10)^2 \times 0.2}{\sqrt{3} \times 220 \times 10\sqrt{2/3}} = 0.35.$

(b). $\alpha = 150^\circ$

$I_0 = 10A$

$E = -110V$

$V_0 = E + I_0 R$

$= -110 + 10 \times 0.2$

$= -108\,V$

$$V_0 = \frac{3\sqrt{6}}{\pi} V_{ph} . \cos\alpha$$

$$\Rightarrow -108 = \frac{3\sqrt{6}}{\pi} . V_{ph} . \cos 150$$

$$\Rightarrow V_{ph} = 53.3V$$

$$V_L = \sqrt{3} V_{ph} = \sqrt{3} \times 53.3 = 92.36V.$$

2.16. $I_0 = 50\ A, \quad V_0 = 230V, \quad V_L = 415V, \quad V_T = 1.1V$

$V_0 = 230 + 2(1.1)$ → At a time 2 thyristors are in conduction.

$= 232.2V$

$$V_0 = \frac{3\sqrt{6}}{\pi} V_{ph} \cdot \cos\alpha$$

$$\Rightarrow 232.2 = \frac{3\sqrt{6}}{\pi} \cdot \frac{415}{\sqrt{3}} \cdot \cos\alpha$$

$$\Rightarrow \alpha = 65^\circ.$$

(b). $I_{Tr} = I_0\sqrt{1/3} = 50\sqrt{1/3} = 28.86\ A$

(c). $I_{sr} = I_0\sqrt{2/3} = 50\sqrt{2/3} = 40.82\ A$

2.18.

$V_s = 330 \sin 314t$

$\alpha = \pi/4 = 45^\circ$

$I_0 = 5A, \quad V_0 = 140\ V$

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

$$140 = \frac{2 \times 330}{\pi} \times \cos 45^\circ - \frac{314 \times L_s}{\pi} \times 5$$

$$\Rightarrow L_s = 17.11\ mH$$

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

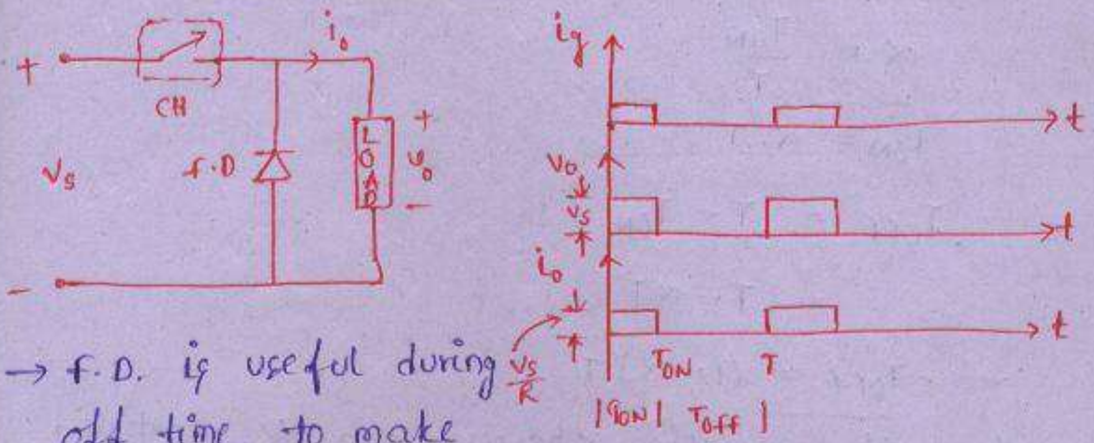
$$\Rightarrow \cos(\alpha+\mu) = \cos 45^\circ - \frac{314 \times 17.11 \times 10^{-3}}{330} \times 5$$

$$\Rightarrow \mu = 6.3^\circ$$

$$R = \frac{V_0}{I_0} = \frac{140}{5} = 28\,\Omega.$$

CHOPPERS

→ step down chopper:



→ F.D. is useful during off time, to make current to be continuous provided load consists of inductance.

$$V_0 = \frac{1}{T}\cdot\int_0^{T_{ON}} V_s\,.dt$$

$$= V_s\cdot\frac{T_{ON}}{T}$$

$$\Rightarrow V_0 = \alpha\cdot V_s\,,\quad \alpha - \text{duty cycle.}$$

$$\alpha = f\cdot T_{ON}\,,\quad f - \text{chopping frequency.}$$

$$V_0 = f\cdot T_{ON}\cdot V_s$$

$$V_{0r} = \sqrt{\frac{1}{T}\int_0^{T_{ON}} V_s^2\,.dt}$$

$$= \sqrt{V_s^2\cdot\frac{T_{ON}}{T}}$$

$$V_{0r} = \sqrt{\alpha}\cdot V_s\,,$$

In chopper always $V_{0r} > V_0$ (rms, avg).

Ripple ~~component~~ factor $= \frac{V_{ac}}{V_{dc}}$

$$= \frac{\sqrt{V_{0r}^2 - V_0^2}}{V_0}$$

$$= \frac{\sqrt{\alpha V_s^2 - \alpha^2 V_s^2}}{\alpha V_s}$$

$$= \sqrt{\frac{\alpha - \alpha^2}{\alpha^2}}$$

$\rightarrow$ Ripple factor $= \sqrt{\frac{1}{\alpha} - 1}$

$$\alpha = \frac{T_{ON}}{T}$$

$$T_{ON} = \alpha . T$$

$$T_{OFF} = T - T_{ON}$$

$$= T - \alpha T$$

$$\rightarrow T_{OFF} = (1 - \alpha) T .$$

o/p volt. of the chopper can be controlled by, (i). pulse width modulation:

In this, T_{ON} gets varied while maintaing f as const.

(ii). freq. modulation :

In this, chopping freq gets modulated while maintaining pulse width is const.

Dis.

(1). There is a chance of interference with neibouring comm. lines.

(2). Filter design for wide freq. variation is quite difficult.

for $\alpha = 0.5$

$$(\Delta i)_{max} = \frac{V_s}{R}\left[\frac{(1-e^{-0.5x})(1-e^{-0.5x})}{(1-e^{-x})}\right]$$

where $x = T/T_a$.

$$= \frac{V_s}{R}\left[\frac{(1-e^{-0.5x})(1-e^{-0.5x})}{(1+e^{-0.5x})(1-e^{-0.5x})}\right]$$

$$= \frac{V_s}{R} \tanh 0.25x$$

$$\simeq \frac{V_s}{R} \times 0.25 \times x$$

$$\simeq \frac{V_s}{R} \times \frac{1}{4} \times \frac{T}{T_a}$$

$$\simeq \frac{V_s}{R} \times \frac{1}{4} \times \frac{1}{f} \times \frac{R}{L} = \frac{V_s}{4fL}.$$

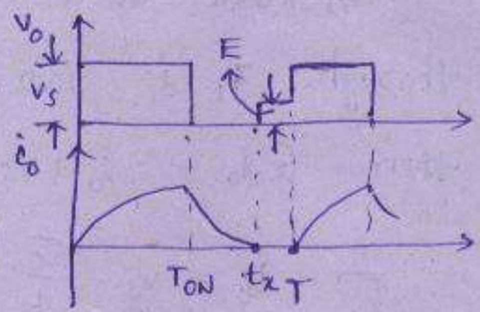
By employing higher values of chopping freq. the ripple can be made smaller value and o/p current would be of more continuous.

Discontinous conduction :-

for RLE :

$$V_o = \frac{V_s \cdot T_{ON} + E(T - t_x)}{T}$$

$$\Rightarrow V_o = \alpha V_s + E\left[1 - \frac{t_x}{T}\right]$$



→ The main element of forced commutation circuit is Tank circuit.

Dis. adv.s of Voltage commu. chopper :

→ peak value of current through main SCR $= I_o + V_s \cdot \sqrt{\frac{C}{L}}$.

→ Practical avg. o/p volt is more than theoritical o/p volt.

→ peak instantaneous volt. for the load $= 2V_s$.

commutative capacitor

Its value is calc.d based on ckt turn off time.

$$i = C \cdot \frac{dv}{dt}$$

$$\Rightarrow I_0 = C \cdot \frac{2V_s}{2t_c}$$

$$\Rightarrow C = \frac{I_0 * t_c}{V_s}.$$

Commutating Inductor:

Its value is calc.d based on peak value of current through main thyristor T_1.

$$I_{T_1 p} = I_0 + V_s \cdot \sqrt{\frac{C}{L}}$$

Assume that peak value of current through T_1 is two times of o/p current,

then $2I_0 = I_0 + V_s \cdot \sqrt{\frac{C}{L}}$

$$\Rightarrow I_0 = V_s \cdot \sqrt{\frac{C}{L}}$$

$$\Rightarrow L = \left(\frac{V_s}{I_0}\right)^2 \cdot C.$$

peak diode current $= V_s \cdot \sqrt{\frac{C}{L}}$.

peak voltage across FD $= 2V_s$.

Avg. o/p. voltage $= \frac{(V_s \times T_{ON}) + (\frac{1}{2} \times 2V_s \times 2t_c)}{T}$

$$= \frac{V_s}{T}\left[T_{ON} + 2t_c\right]$$

$$\Rightarrow V_0 = \frac{V_S}{T}\left[T_{ON} + 2.\frac{CV_S}{I_0}\right]$$

$$= \frac{V_S}{T}\left[T'_{ON}\right]$$

T'_{ON} = effective Turn ON time

$$V_0 = V_S * \frac{T'_{ON}}{T}$$

$$\Rightarrow V_0 = \alpha' V_S.$$

where α' = effective duty cycle = $\frac{T'_{ON}}{T}$

Minimum T_{ON} for chopper = $\pi\sqrt{LC}$ sec.
(turn ON time)

jnrao.k@gmail.com

Contact: 09966715471