Power electronics.

Topics →

(1.) Power semicondr devices.

(2.) Phase controlled rectifiers & applications (charging battery.
(AC–DC) Solar sell.
DC drives.)

(3.) Inverters (DC–AC)

(4.) Choppers (DC–DC)

(5.) AC voltage controllers & cycloconverters.
(AC–AC) (∀ fac) (Vo, Fo)

(6.) Other appn :-

⇒ AC drives

→ HVDC

→ Reactive power control

→ SMPS

Power electronics →

* It deal with control & conversion of high power appⁿ.
* Power s/c devices should be capable to handle large magnitudes of power with high η.

(1.) Power diode
(2.) Thyristor (SCR) } (P↑ – Handle highest power)
(3.) ASCR
(4.) LASCR
(5.) RCT
(6.) GTO
(8.) TRIAC
(9.) DIAC
(9.) Power transistors:-
→ Power BJT
→ Power MOSFET (F↑ – Highest switching devices)
→ IGBT.

* Signal electronics →

* It deal with control of low power appⁿ.
* Signal devices handle low power at very high switching η.

Eg → (1.) Signal diode – Zener diode
LEDs
Varector diode...

(2.) Signal transistors – BJT, MOSFET, UJT

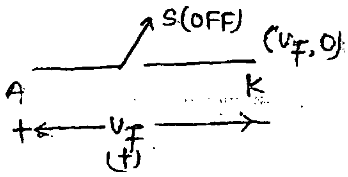
Signal devices – (P↓, F↑)

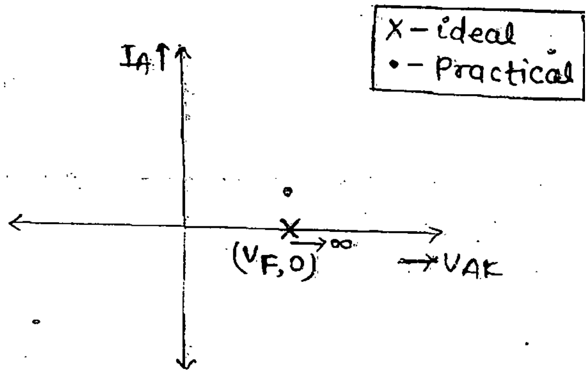
Note →

* We can't improve all the qualities in a single device, when we want to improve some of qualities the other qualities may be affected.
* We can utilize the switch is 4 diff mode but all the devices need not support all the 4 modes.

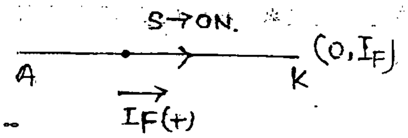
* Four modes of ideal switch →

(1) Forward blocking mode →



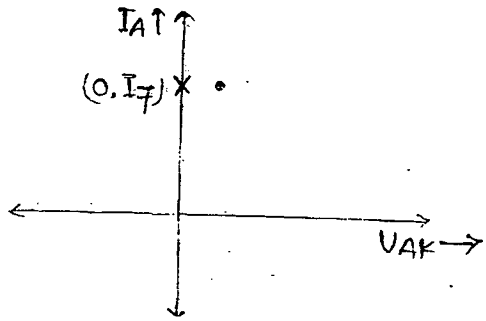


(2) Forward Conduction mode →

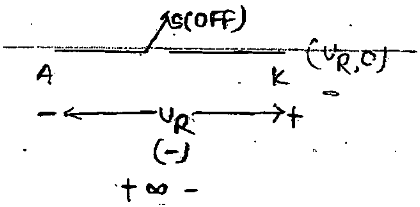


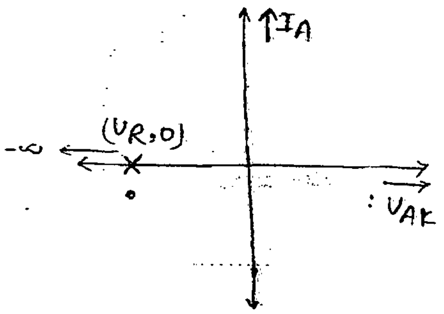
$V_{AK} = I_F \cdot R_F$

(ON state)

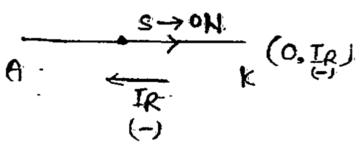


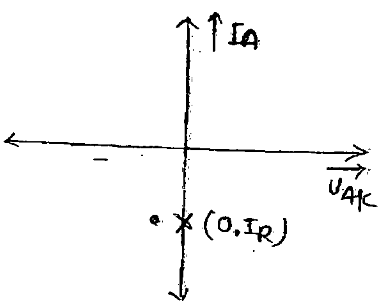
(3) Reverse Blocking mode →





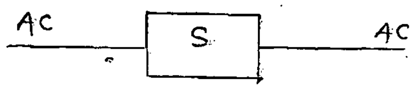
(4) Reverse Condⁿ mode →



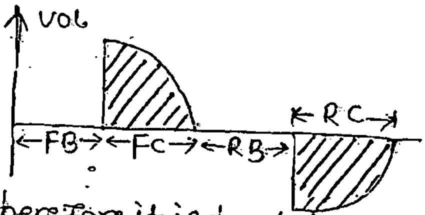


Note →

(1.)



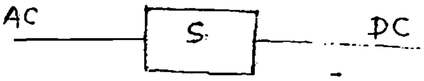
Ac switch



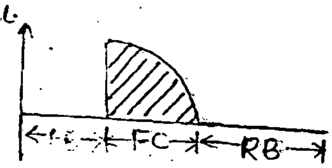
* TRIAC supports all the 4-modes therefore it is treated as an ac switch & used in Ac vol controllers.

Eg. → Fan regulator.

(2.)

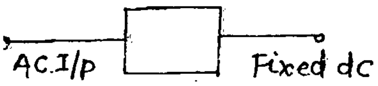


Dc switch



Eg. → SCR (This will support only 3 modes, RC is absent)

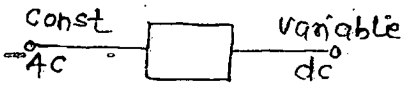
Diode Rectifier



Appliⁿ →

(1.) Electric traction
(2.) Battery charging
(3.) Electroplating
(4.) Welding
(5.) UPS (Uniterrupted Power supply)

AC to dc Converters

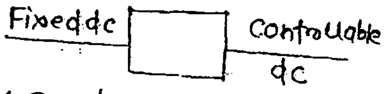


* Phase controlled Recti-
* Line/Naturally commutated Ac to dc converter (Because they use line voltage for commutation)

Appliⁿ →

(1.) DC drives
(2.) Excitation sys for Synchronous m/c.

DC to dc converters

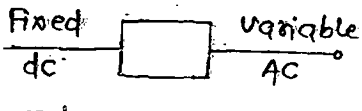


* Dc choppers
* Forced (or) load commutation.
* They may classfie as there commutation & power flow

Appliⁿ →

(1) dc drives.
(2) Subway cars

DC to AC Converters

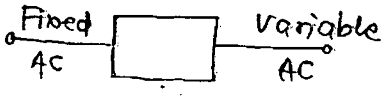


Inverters.
Line/load/Forced Commutation.

Appliⁿ →

1) Indⁿ/ synchronous motor
2) Induction Heating
3) UPS
4) HVDC

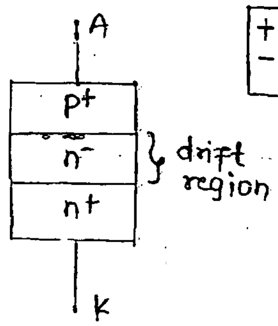
Ac to Ac Converter



(a.) AC voltage controller → lightning (or) Speed Control
(b.) Cycloconverter → Slow speed large Ac drive (Rotary kiln)

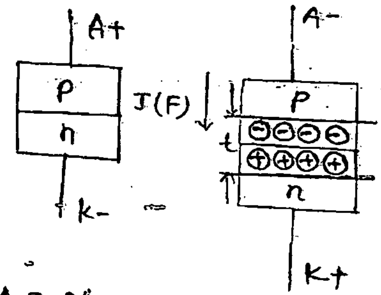
*(1) Power Semicond^r devices →

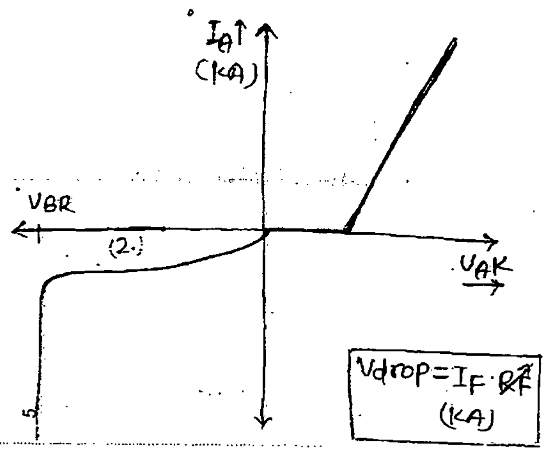
(1) Power diode →

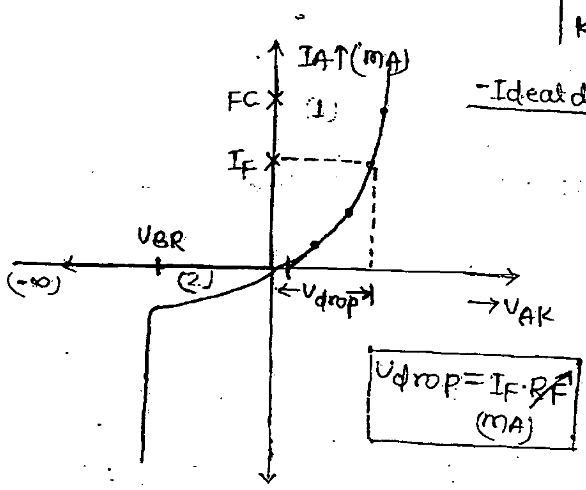


+ → Heavily dopped
− → Lightly dopped

Signal diode



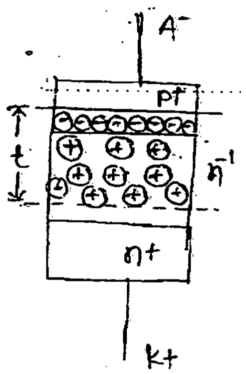




−Ideal diode

* The max^m thickness of depletion layer decides the reverse blocking capability of diode.
* Signal diode will block 20V whereas the power diode blocks 2000V (VBR)

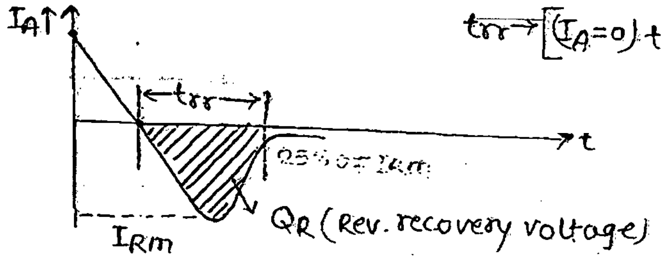
Significance of drift region →



* If anode is made +ve w.r.t cathode then the depletion layer across the jun^n the depletion layer penetrates more dipper into n⁻ layer in order to equalise the charge on both the size of jun^n.
* This increases the thickness of depletion layer & rev. blocking capbility of diode.
* Higher the thickness of n⁻¹ layer higher the rev blocking capability of diode.

* Reverse recovery c/s →

* It explain the switching behaviour of power diode from ON state to OFF state.



$t_{rr} \rightarrow [(I_A = 0) \text{ to } (I_A \rightarrow 25\% \text{ of } I_{Rm})]$

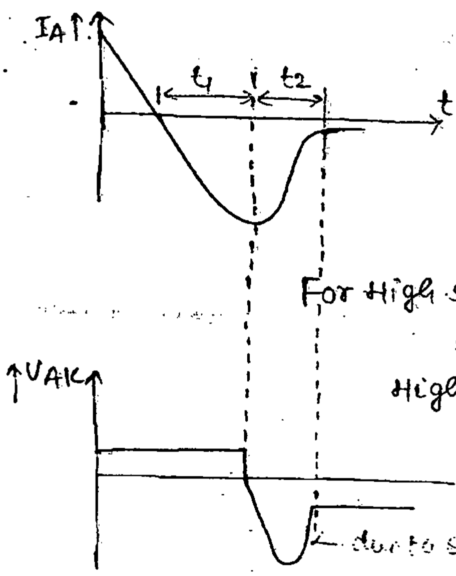
* When diode is conducting in Forward dirn some excess charge carriers are stored in the device.
* This charge carriers are mainly due to minority carriers.
* When the diode is swithing from ON state to OFF state this charge carriers are still present in the diode even after the anode current becomes 0.
* In order to remove this charge carriers & regain its eq. state or normal state recombination process begins & Hence reverse current flows in diode until all the charge carriers are completely removed.
* This process is known as rev. recovery process & the transition time during this process is known as rev. recovery time (t_{rr}).
* Area of the above Δ give →

$$Q_R = \frac{1}{2} \cdot t_{rr} \cdot I_{Rm}$$

. If the slope of the curve be (di/dt) then

$$I_{Rm} = \left[2Q_R\left(\frac{di}{dt}\right)\right]^{1/2} \quad \text{------- (i)}$$

$$t_{rr} = \left[\frac{2Q_R}{\left(\frac{di}{dt}\right)}\right]^{1/2} \quad \text{------- (ii)}$$



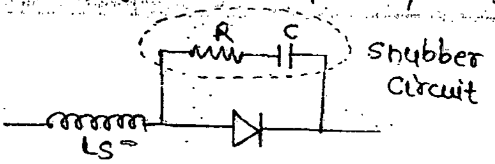
$t_{rr} = t_1 + t_2$

$S_F = \frac{t_2}{t_1}$ → Softness Factor

For High speed diode the softness factor $S_F << 1$

High speed diode → Fast recovery diode

* We have to limit this high voltage spike by using Snubber circuit.



Classification of power diodes based on t_{rr} →

(1) General purpose ~~diode~~ → (slow diode)

(i) t_{rr} → 25 μs

(ii) Irating :- 1A to sevrall 1000 of A

Vrating :- 50V to 5kV

(iii) This has p-n junⁿ

Fast recovery diode

(i) t_{rr} → 5 μs or less

(ii) Irating :- 1A to severall 100 of Amp

Vrating :- 50V to 3kV

* In this diodes the layers are dopped with gold (or) Pt
* This doping reduce the life time of charge carriers & increases its recombination speed.
* This redude the t_{rr} time.
* It has p-n junⁿ

Schottky diode

(i) t_{rr} → nano sec

(ii) Irating :- 3000 A

Vrating :- 100V

* This has metal to s/c Junction diode

Al | Si (n-type)

* In this diode condⁿ is only due to majority carriers.
* Due to the absense of minority charge carriers the t_{rr} is very much reduced Therefore it operate with very high switching freq.

Slow diodes are used in line freq. rectifier. Therefore they are also known as rectifier diode.

Application →

Rectifiers

Application →

Inverters & choppers

* In this diode the rev. blocking capability is limited to 100V because the thickness of depletion layer is very small

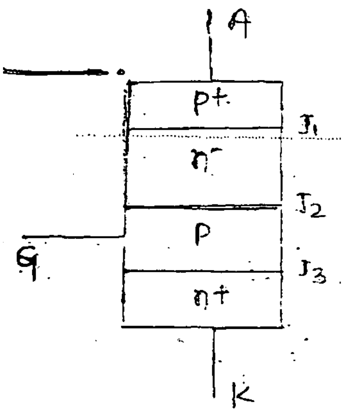
Application →

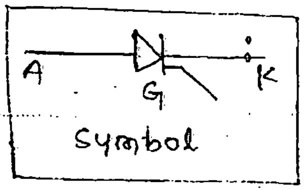
SMPS

Note →

- The t_{rr} decides the max^m switching speed of diode.
- Diode is a uncontrolled switch because there is no control terminal to decide its ON & OFF state.

(2) Silicon Controlled Rectifier →





A, K → main control

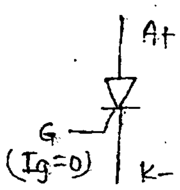
G → Control terminal (or) semi controlled switch

(a) Forward blocking mode →

* When anode is +ve w.r.t cathode then J_1, J_3 are forward & J_2 will reverse bias.

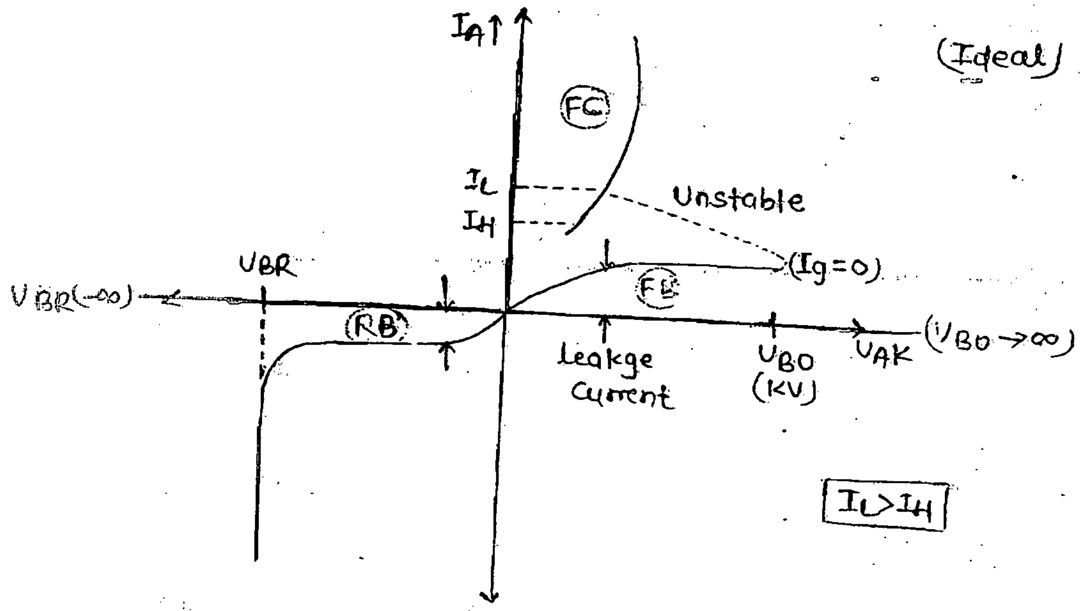
Hence the SCR will be OFF.

(b) Forward conduction mode →



$V_{AK} \uparrow \Rightarrow V_{BO}$, breakdown occurs at J_2 & SCR → ON

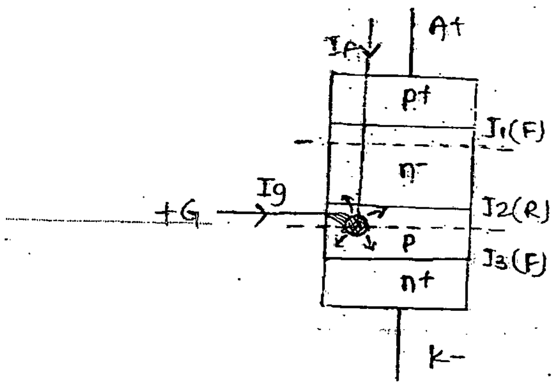
V_{BO} → Forward breakdown voltage when $I_g = 0$



$I_L > I_H$

* If breakdown occurs at such a high voltage without gate pulse then SCR may damage due to high power loss during turn ON process.

Significance of gate signal →



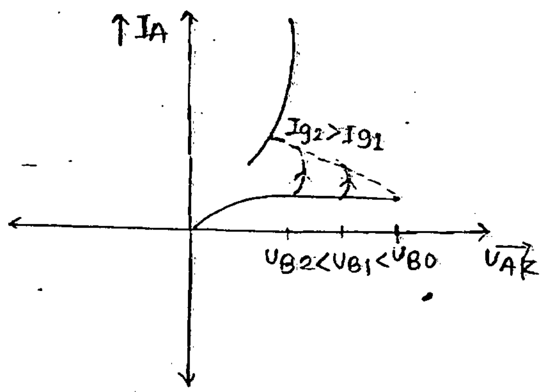
⊛ → Initial conducting area

$I_g\uparrow$ (or) $\frac{dI_g}{dt}(\uparrow) \Rightarrow \frac{dI_A}{dt}\uparrow$ (Initial Rate)

⇓

$t_{ON}\downarrow$ & $V_B\downarrow$ (Breakdown voltage)

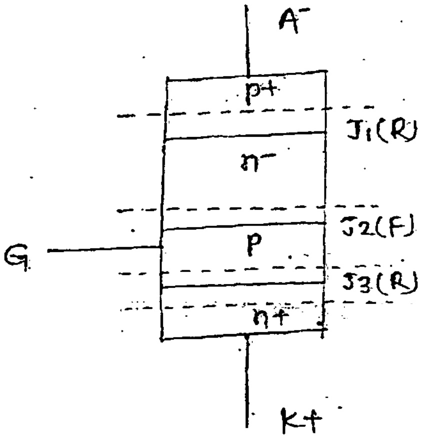
$I_g\uparrow,\ V_B\downarrow$



$Ig_{min} \leq Ig \leq Ig_{max}$

$Vg_{min} \leq Vg \leq Vg_{max}$

(ii) Reverse blocking mode →



when A -ve wrt K

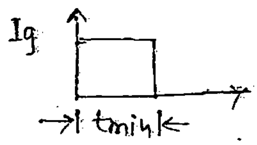
$J_2 (F)$, J_1 & $J_3 (R)$ ∴ SCR → OFF

J_1 blocks more reverse voltage compare with J_3 due to n^- layer.

(Que.) → What happens if a +ve gate pulse is given to a reverse bias thyristor.

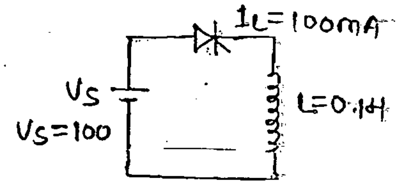
Significance of Latching Current →

* Latching current is related to turn ON process.
* Gate pulse initiates the turn ON process but once the thyristor is on the ON state gate looses control on the device. Therefore we can remove the gate pulse when SCR becomes on to avoid the contineous gate power loss.
* If gate pulse removed when anode current is less then the latching current then SCR fails to turn on. Therefore we must maintain the gate pulse width atleast for a period untill anode current reaches latching current



tmin → min^m gate pulse required to turn ON SCR

Q.→ what is the min^m gate pulse width required to turn of thyristor?



Soln→ Applying KVL at loop

$$V_S = L\frac{di_A}{dt}$$

$$\int di_A = \frac{V_S}{L}\int dt$$

$$I_A = \frac{V_S}{L}t$$

Untill the latching current = I_A the gate pulse is given

$$I_A = I_L = \frac{V_S}{L}t_{min}$$

$$t_{min} = \frac{I_L L}{V_S} = \frac{100\times10^{-3}\times 0.1}{100}$$

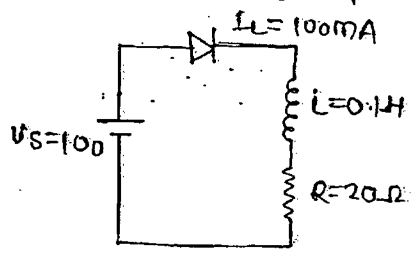
$$t_{min} = 10^{-4}\,sec$$

$$\boxed{t_{min} = 100\mu s}$$

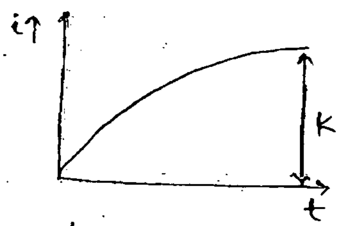
$t_{gpw} \geq t_{min}$ to turn ON the SCR.

Note→ The min^m width of the gate pulse depends on load parameter
eg→ As the load inductance increases we have to increase t_{min}

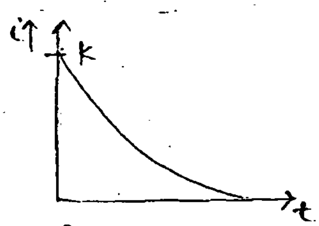
Q.→ what in the value of min^m gate pulse



Soln→



For inductor



For capacitor

$i = k(1-e^{-t/T})$

↑

Final value

(V_s/R)

$i = ke^{-t/T}$

↑

Initial value

(V_s/R)

Applying KVL in the loop

$$V_s = Ri_o + L\frac{di_o}{dt}$$

$$T = \frac{L}{R} = \frac{0.1}{20}$$

$$T = \frac{1}{200}$$

$$I_A = k(1-e^{-t/T})$$

$$I_A = \frac{V_s}{R}(1-e^{-t/T})$$

$$I_A = \frac{V_s}{R}(1-e^{-200t})$$

$$I_A = \frac{100}{20}(1-e^{-200t})$$

$$I_A = 5(1-e^{-200t}), \quad I_L = 5(1-e^{-200t_{min}})$$

$$\boxed{t_{min} = 101\,\mu s}$$

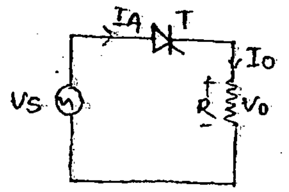
*** Significance of Holding current →**

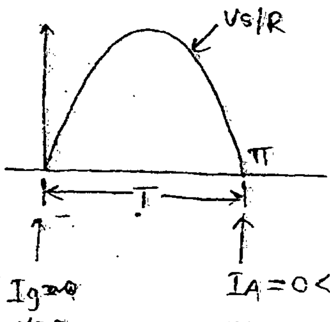
* Holding current is related to turn OFF process.

* ~~Gate has no control to turn off~~ the SCR.

~~* The~~ thyristor stops conducting only if anode current reduces below the Holding current. $(\downarrow I_A < I_H)$

eg:- Half wave rectifier (Natural Commutation)



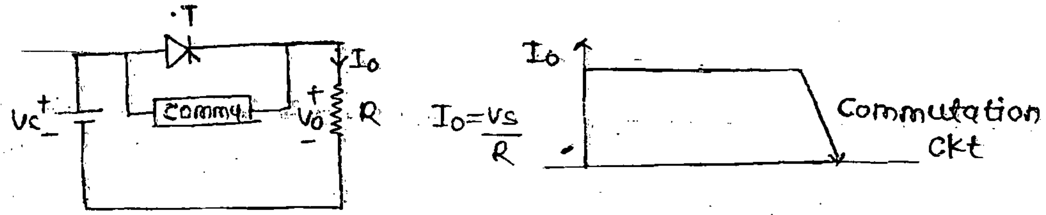


$T \to ON$, $I_o = \frac{V_s}{R} = \frac{V_m \sin\omega t}{R}$ (I_A)

$I_g \to 0$, $\alpha = 0$

$I_A = 0 < I_H$, T-OFF

* In some of the cases nature of supply supports the commutation process when supply is AC. Therefore it is known as natural Commutation.



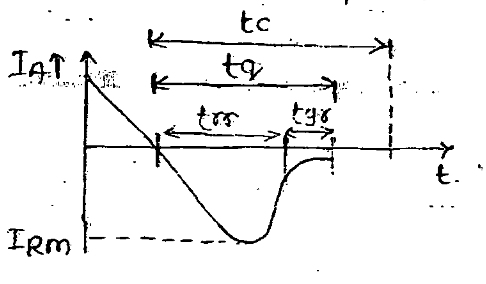
* In some of cases when supply is dc natural commutation is not possible. We have to use commutation ckt to turn off the SCR.

* The commutation ckt reduce the anode current below the holding current & then apply a reverse vol. across thyristor atleast for a period until all the charge carriers are completely removed.

* This process is known as commutation process.

* Circuit turn-OFF time (t_c) → It is the time for which the commutation circuit applies rev. vol. across thyristor after the anode current becomes 0.

* Reverse-Recovery c/s of SCR → It explains the switching behaviour of thyristor from ON-state to OFF-state
(Turn-OFF c/s)



$t_c \geq t_q$ for succesfull Comm.

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

$t_c = (SF/sm) \times t_q$ SF → safety factor >1

* During t_{rr} the excess charge carriers present in the outer layers are removed.

Gate recovery time (t_{gr}) → During this time the charges present near the gate junⁿ are in the inner layer is removed.

* Device turn off time (t_q) → * During this time all the charges are completely removed in the device.

* The device turn off time (t_q) decides the max^m switching speed of thyristor.

* Based on the t_q the thyristor may be classified as follows:-

Inverter grade thyristor	Converter grade thyristor
→ Fast thyristor	→ slow thyristor
→ t_q – (3µs to 50µs)	→ t_q – (50µs to 200µs)
Application → Inverters, choppers	Application → Rectifiers, AC voltage controller

* If $t_c < t_q$ then comm. fails.

Q → What is meant by commutation failure?

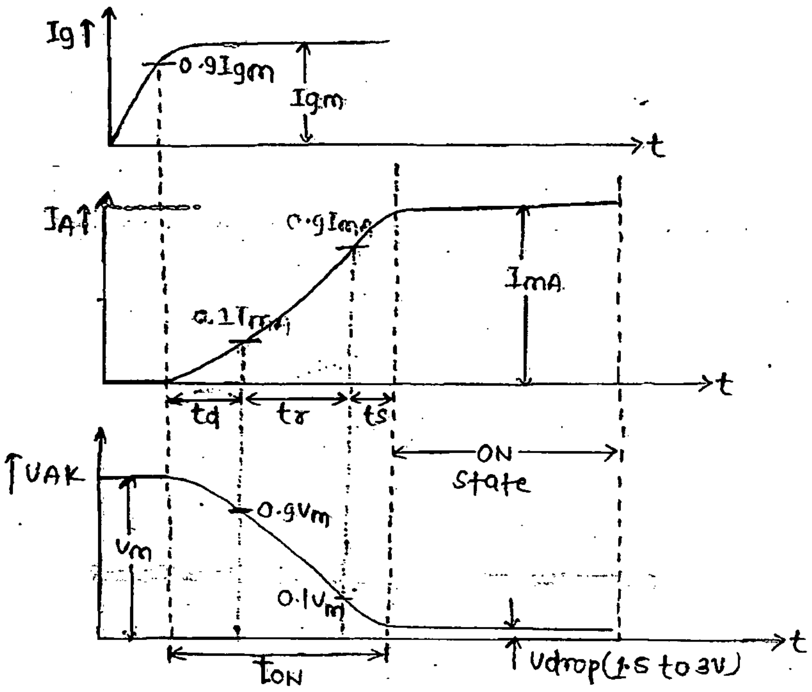
ans → * If $t_c < t_q$ the commutation is not completed.

* some charges present still in the device.
* For the next operation if anode is +ve wrt cathode then SCR starts conducting immedietly before the gate pulse is given.
* Here SCR behaves as a diode & looses the FBlocking capability.
* This is known as comm. failure.

Holding Current → * It is the min^m anode current below which SCR stops conductings.

It regain the forward blocking capability only if $t_c \geq t_q$.

Turn-ON c/s of thyristor → * It gives the switching behaviour of thyristor from OFF state to ON state.



* Delay time 'td' depends on $I_g \uparrow$ & $\frac{dI_g}{dt} \uparrow$

  ⇒ Initial conduction area ↑

  ⇒ $\left(\frac{di_A}{dt}\right) \uparrow$ initial Rate

  ⇒ td ↓ ∴ tON ↓

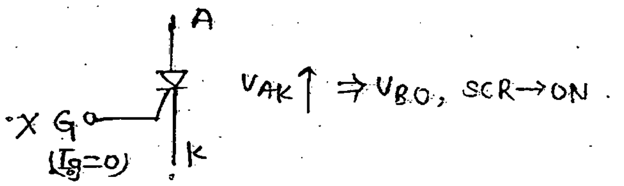
* Rise time 'tr' depends on the load parameters

  ⇒ $L \uparrow$, $\frac{di_A}{dt} \downarrow$ ∴ tr ↑ ∴ tON ↑

* Spread time 'ts' depends on the physical geometrical structure of thyristor.

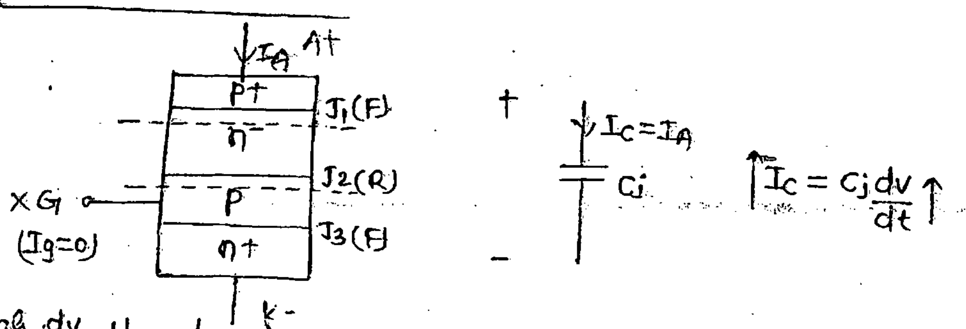
* Turn-ON topic methods of thyristor (Triggering method) →

1.) Forward voltage triggering →



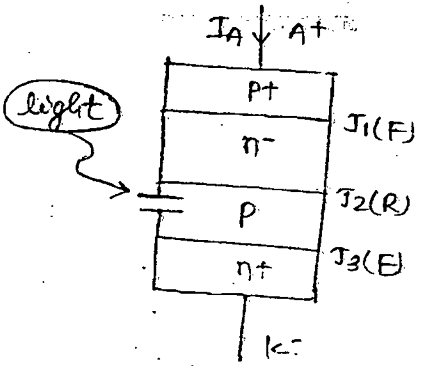
Due to high losses this is not prefered.

(2) $\frac{dv}{dt}$ triggering method →



At high $\frac{dv}{dt}$ the charging current increases. If the increasing charging current is more than latching current then SCR will turn-ON.

(3) Light trigering →



- when a light radiation is incident near the gate jun^n the depletion layer absorb the light energy & produce more no. of e⁻ hole pairs This initiates the turn ON process.

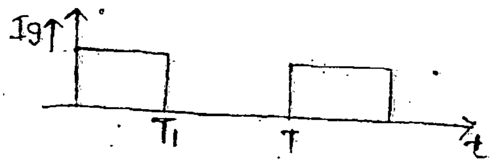
* It is used in LASCR for HVDC application.
* Light trigering is more efficient & reliable to trigger multiple no. of SCR simultaneously.

(4) Gate triggering →

(i) Contineous gate signal → Here we provide contineous gate signal untill SCR is required to be in the ON state.

* This is not an efficient method due to contineous gate power loss-

(ii) Pulse gate signal →



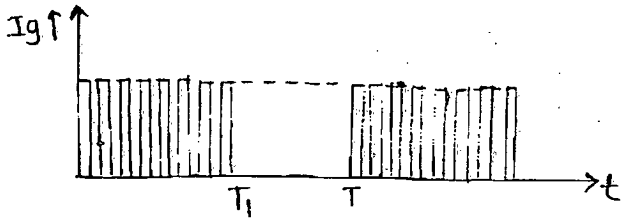
$T_1 \rightarrow$ Gate pulse

$T_1 > t_{min}$

$T \rightarrow$ time period

$\delta = \frac{T_1}{T}$ → duty cycle

(3.) High freq. gate pulse →



Advantage → We can reduce the size of pulse Xmer used in firing ckt.

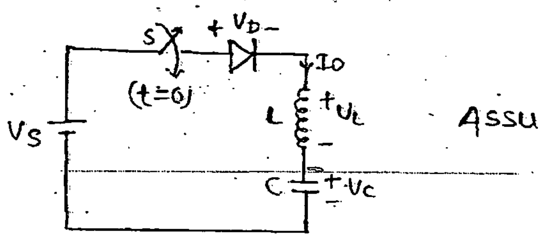
Q → What is the need of pulse Xmer in gate firing ckt?

Ans → Pulse Xmer provides ele. isolation b/w high power ckt & low power gate firing ckt.

* We can turn ON more than one SCR simultaneously at a time by using pulse Xmer.

* Diode circuits →

Q(1.)



Assume $V_C(t=0) = 0V$

(i.) When the switch is closed at t=0 sec. the diodes conducts for

(a.) $\frac{\pi}{2}\sqrt{LC}$ (b) $2\pi\sqrt{LC}$ (c) $\frac{3\pi}{2}\sqrt{LC}$ (d) $\pi\sqrt{LC}$

(ii) What is the capacitance vol. when diode stops conducting.

(a) V_S (b) $2V_S$ (c) $-V_S$ (d) $-2V_S$.

Sol^n → Applying KVL at loop then D → ON

$$V_S = V_D + V_L + V_C$$

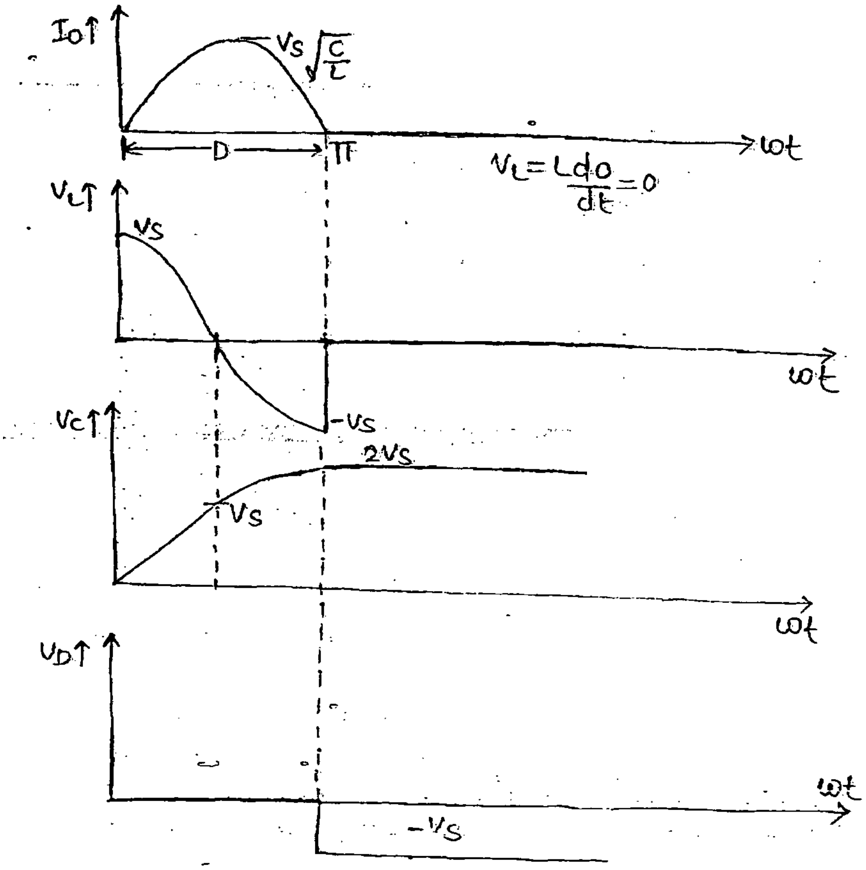
$$V_S = 0 + L\frac{di_o}{dt} + \frac{1}{C}\int i_o dt$$

$$I_o = V_S\sqrt{\frac{C}{L}}\sin\omega_o t$$

$$\boxed{I_o = I_p \sin\omega_o t}$$

where $I_p = V_s\sqrt{\frac{C}{L}}$

$$\omega_0 = \frac{1}{\sqrt{LC}} \quad \text{(Resonance freq.)}$$



$$\omega_0 t = \pi \text{(rad)}$$

$$t = \frac{\pi}{\omega_0} \qquad \omega_0 = \frac{1}{\sqrt{LC}}$$

$$\boxed{t = \pi\sqrt{LC}}$$

$$V_L = L\frac{d}{dt}(I_p \sin\omega_0 t) \qquad V_S = V_D + V_L + V_C$$

$$V_L = L I_p \omega_0 \cos\omega_0 t \qquad V_S = 0 + V_L + V_C$$

$$V_L = V_S \cos\omega_0 t \qquad V_C = V_S - V_L$$

$$V_C = V_S(1 - \cos\omega_0 t)$$

when D → OFF

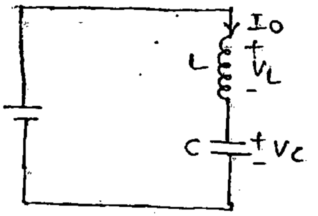
$V_L = 0$, & $\boxed{V_C = 2V_S}$

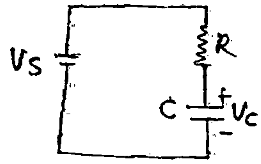
$$-V_S + V_D + 0 + 2V_S = 0$$

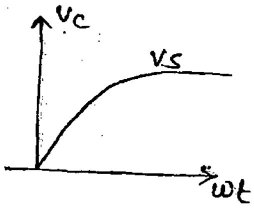
$\boxed{V_D = -V_S}$ & $\boxed{PIV = V_S}$

PIV → max^m Rev. voltage across diode when it is in OFF state.

Because the value of the capacitance vol. is 2Vs ...







Mode(1) → (0 to 90)

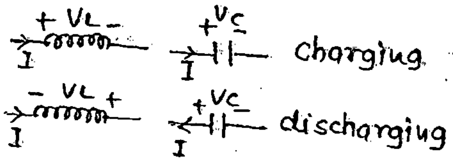
Source ⟶ L & C ⟶ $\frac{1}{2}CV^2$

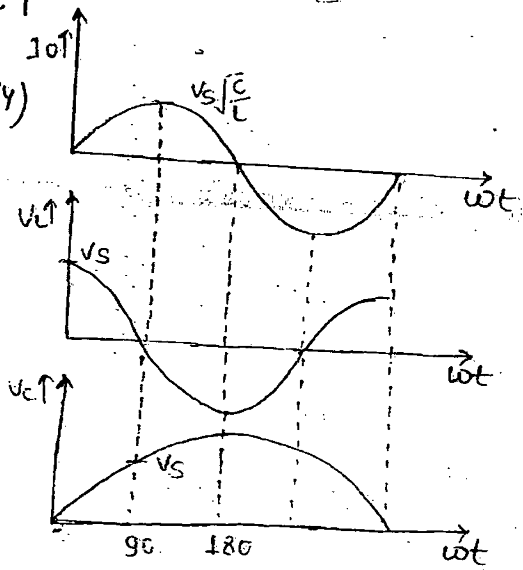
↓ ($\frac{1}{2}Li^2$) ↓ V_C ↑

i ↑

$V_S = V_L$↓ $+ V_C$↑ (Satisfy KVL)

At $\omega t = 90$, $V_C = V_S$ $V_L = 0$



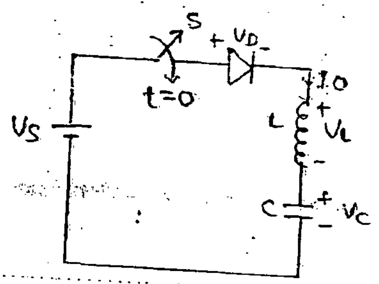


Mode(2) → (90 to 180)

(Releasing energy) $\frac{1}{2}Li^2$ ⟶ $\frac{1}{2}CV^2$

↓ i↓   ↓ V_C↑

Q.(2)



Assume: $V_C(t=0) = V_0$ volts

where ~~$V_0 > V_S$~~ $V_0 < V_S$

(i) What is the capacitance vol. when diode stops conducting?

(a) $2(V_S + V_0)$ (b) $2(V_S - V_0)$ (c) $2V_S - V_0$ (d) $2V_S + V_0$

→ Applying KVL

$$V_S = V_D + V_L + V_C$$

$$V_S = 0 + L\frac{di}{dt} + \left[\frac{1}{C}\int i\,dt + V_0\right]$$

$$V_S - V_0 = L\frac{di}{dt} + \frac{1}{C}\int i\,dt$$

$I_0 = I_p \sin\omega_0 t$, $I_p = (V_S - V_0)\sqrt{\frac{C}{L}}$

$\omega_0 = \frac{1}{\sqrt{LC}}$

$V_C = V_S - V_L$

$V_C = V_S - (V_S - V_0)\cos\omega_0 t$

$V_L = L\frac{d}{dt}(I_p \sin\omega_0 t)$

$V_L = (V_S - V_0)\cos\omega_0 t$

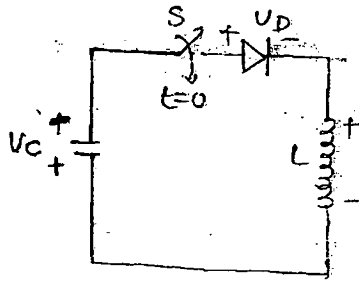
$V_C = V_S(1 - \cos\omega_0 t) + V_0 \cos\omega_0 t$

at $\omega t = 180^\circ$

$V_C = V_S(1 - \cos(180)) + V_0 \cos 180^\circ$

$\boxed{V_C = 2V_S - V_0}$

P.(3.)



Assume:- $V_C(t=0) = -V_S$
what is capacitance vol. when diode stop conducting
(a) $2V_S$ (b) $-V_S$ (c) V_S (d) $-2V_S$

Sol^n→ when we close the switch at $t=0$ then the diode will Forward biased because of $V_C(t=0) = -V_S$

Applying KVL in the loop;

$+V_C + V_D + V_L = 0$

$-V_C = V_L$

$+\left[-V_S + \frac{1}{C}\int i\,dt\right] + 0 + L\frac{di}{dt} = 0$

$+V_S - \frac{1}{C}\int i\,dt = L\frac{di}{dt}$

~~$\int i\,dt = -LC\frac{di}{dt}$~~

$V_S = \frac{1}{C}\int i\,dt + L\frac{di}{dt}$

$I_0 = I_p \sin\omega_0 t$

$I_p = V_S\sqrt{\frac{C}{L}}$

$\omega_0 = \frac{1}{\sqrt{LC}}$

$V_L = L\frac{d}{dt} I_p \sin\omega_0 t$

$= L I_p \omega_0 \cos\omega_0 t$

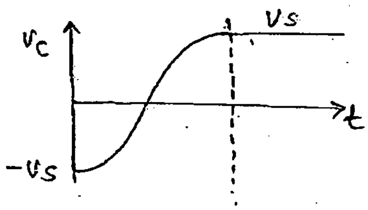
$V_L = V_S \cos\omega_0 t$

$V_c + V_D + V_L = 0$

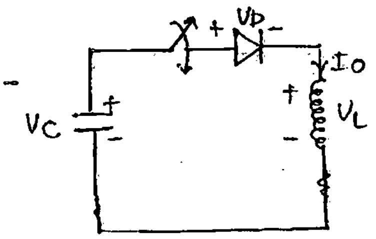
$V_c = -V_L$

$V_c = -V_s \cos \omega_0 t$

$\boxed{PIV = V_s}$ $\boxed{V_c = V_s}$



Q.(4.)



Assume:- $V_c(t=0) = V_s$

$V_c = ?$

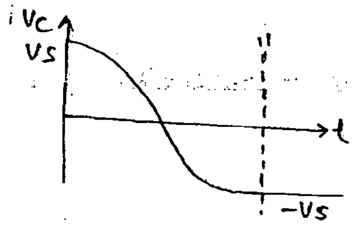
Sol^n→

$-V_c + V_D + V_L = 0$

$V_c = V_L$

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

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



$I_o = I_p \sin \omega_0 t$, $I_p = V_s\sqrt{\frac{C}{L}}$, $\omega_0 = \frac{1}{\sqrt{LC}}$

& $V_c = V_L$

$V_c = V_s \cos \omega_0 t$

Initial vol: is Vs & Final vol. will -Vs

$\boxed{V_c = -V_s}$

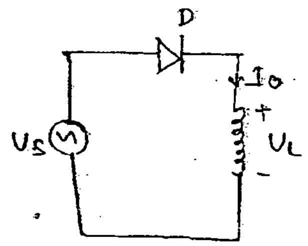
Note→In LC ckt if capacitance is initaly charged with Vs volts then charging current of capacitor behaves as sine f^n given by

& $I_c = I_p \sin \omega_0 t$

And charging vol. of capacitor behaves as cosine f^n given by

$V_c = V_s \cos \omega_0 t$

Q.(5.)



The diode conducts for

(a) 90° (b) 180° (c) 270° (d) 360°

$Sol^n \rightarrow$ Apply KVL : D → ON

$$V_s = V_m \sin\omega t = L\frac{di_o}{dt}$$

$$L\,di_o = V_m \sin\omega t$$

$$\int di_o = \int \frac{V_m \sin\omega t}{L}$$

$$I_o = \frac{-V_m}{\omega L}\cos\omega t + k$$

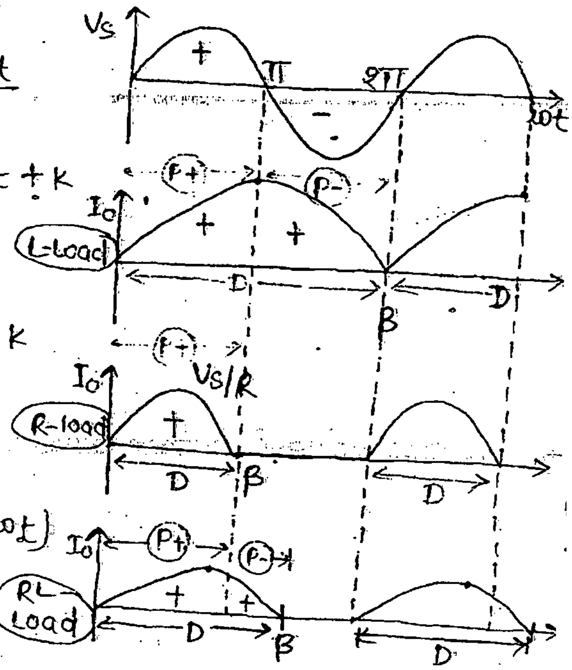
at $\omega t = 0$, $I_o = 0$

$$0 = \frac{-V_m}{\omega L}\cos 0 + k$$

$V_L = V_s$ For L Load

$$k = \frac{V_m}{\omega L}$$

$$I_o = \frac{V_m}{\omega L}(1 - \cos\omega t)$$

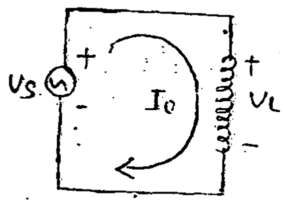


mode(1) → 0 to 180° ⇒ P +ve

Power flow from source to load

Source —P→ Load ($\frac{1}{2}Li^2$)

L → stores energy ($I_o \uparrow$)

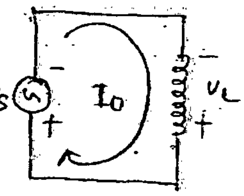


mode(2) → 180° to 360° ⇒ P → -ve

Power flow from load to source

Source ←—— load ($\frac{1}{2}Li^2$)

L → Releasing energy ($I_o \downarrow$)



Here the inductance energy makes the diode to conduct even in the -ve cycle until it releases its complete energy.

For pure inductor $\beta = 2\pi$

where β = extinction angle

The angle at which current zero & diode stops conducting.

For pure Resistor;

$$I_0 = \frac{V_s}{R} = \frac{V_m \sin\omega t}{R} \quad (\sin\pi = 0)$$

$$\boxed{\beta = \pi}$$

Note →

* We will get -ve power only for reactive load not for pure resistive load.
* And also when ↑τ, β↑ $\left(\uparrow \tau = \frac{L\uparrow}{R}\right)$ (τ = time constant)
* For pure inductor the active power is 0. $S = P + jQ$ $(P = 0)$

$$P_0 = V_0 I_0 = V_L I_0$$

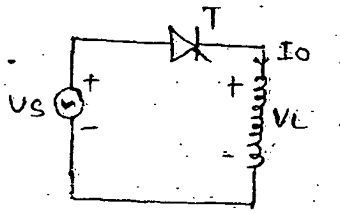
$$V_0 = 0 \text{ (avg. voltage)}$$

$$I_0 \neq 0 \text{ (avg. current)}$$ [From waveform of I_0 in L]

** $\boxed{V_L(avg.) = 0}$

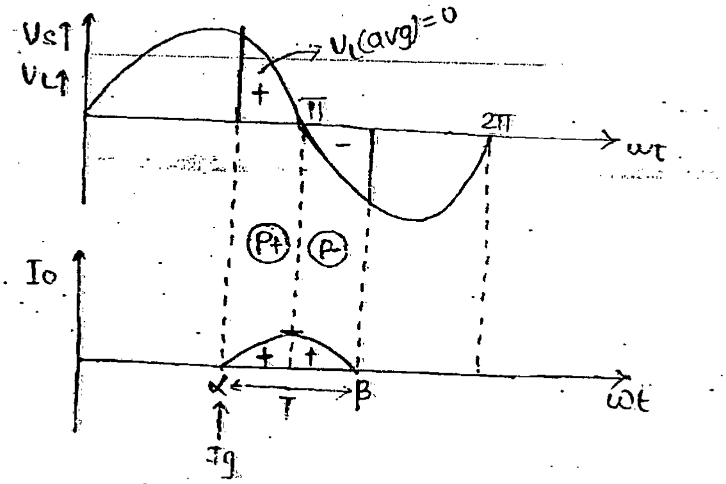
To make the avg. current 0, D is conducting for 360°

Q.(6.)



What is the value of β ?

Soln →

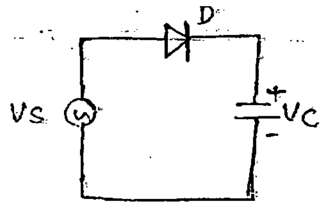


$$\beta = \pi + (\pi - \alpha)$$

$$\beta = 2\pi - \alpha$$

(1.) τ↑, β↑	$(\tau = L/R)$
(2.) α↑, β↑	

Q(7.)



$V_s = V_m \sin\omega t$

Diode conducts for

(a.) 90° (b.) 180° (c) 270° (d) 360°

*** Commutation Technique →**

(1.) Natural Commutation (Line Comm.) → If nature of the supply supports the comm. process then it is known as natural Comm.

Eg. → (1.) Rectifier (AC → DC)

(2.) AC vol. controllers (AC → AC)

(3.) Step down cycloconverter (AC → AC)

(2.) Forced Commutation → DC supply will not support the comm. process.

* We require a comm. ckt to turn off the thyristor.

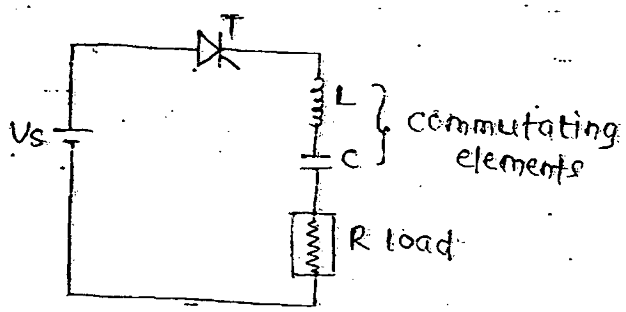
Eg. → (1.) Inverters (DC → AC)

(2.) Choppers (DC → DC)

(3.) Step up cycloconverter (AC → AC)

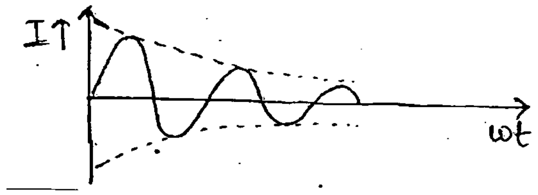
Classification of Forced Comm. →

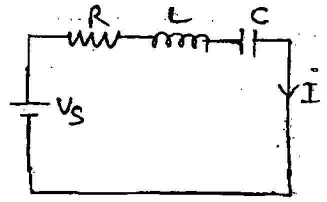
(1.) Class A →



* RLC should satisfy underdamped cond^n.

Underdamped cond^n $\left(R^2 < \frac{4L}{C}\right)$ $(X_C > X_L)$





$$\boxed{I = \frac{V_s}{\omega_r L} e^{-\delta t} \sin\omega_r t}$$

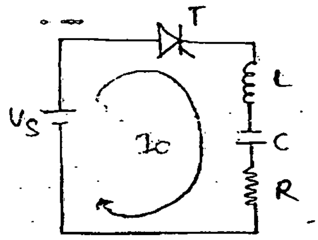
$\delta \rightarrow$ damping factor $\left(\frac{R}{2L}\right)$

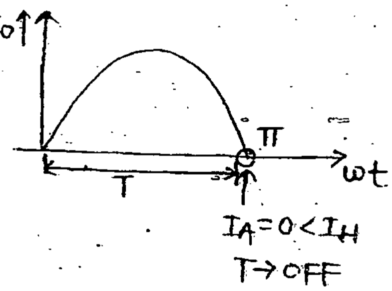
$\omega_r \rightarrow \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$ (Ringing factor)

For $R=0$, $\omega_r = \omega_0 = \frac{1}{\sqrt{LC}}$

$$I = \frac{V_s}{\omega_0 L} (1).\sin\omega_0 t$$

$$\boxed{I = V_s\sqrt{\frac{C}{L}}\sin\omega_0 t}$$





$\omega_r t = \pi$ (rad)

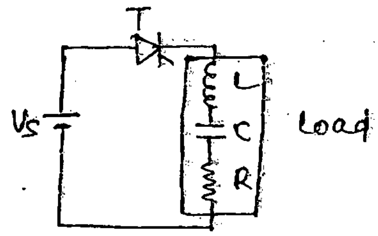
$$\boxed{t = \frac{\pi}{\omega_r} \text{ sec}}$$

Cond^n time of thyristor $= \frac{\pi}{\omega_r}$ sec

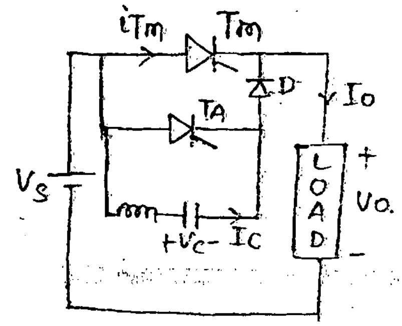
Q.→ what is load comm.?

Ans.→ If the load elements support the comm. process then it is known as load comm.

Eg.→ Consider an RLC load satiesfy underdamped cond^n as shown in fig given below.



(2) Class-B Comm. (Current Comm.) →



$T_A \rightarrow$ Auxillary thyristor

$T_m \rightarrow$ main thy.

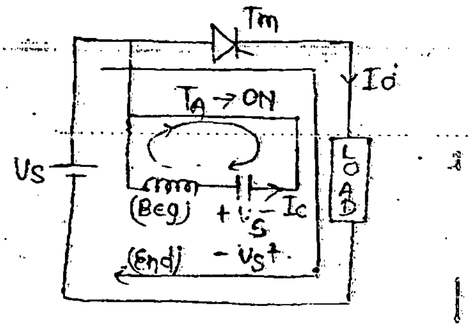
* To switch off the main thy. T_m we have to switch ON auxiliary thy. T_A

Assume :- (1) $V_C(t=0) = V_S$ (capacitor is initialy charge) with V_S)

(2) Let us consider the load to be high inductive so that the load current remains constant $\left(L\uparrow \frac{di}{dt}\downarrow\right)$

(3) $T_m \rightarrow$ ON $(t<0)$ (main thy. is on state before $t=0$)

Mode (1) → At $t=0$, $T_A \rightarrow$ ON



$i_{Tm} = I_0$, $I_C = -I_p \sin \omega_0 t$

$V_C = V_S \cos \omega_0 t$

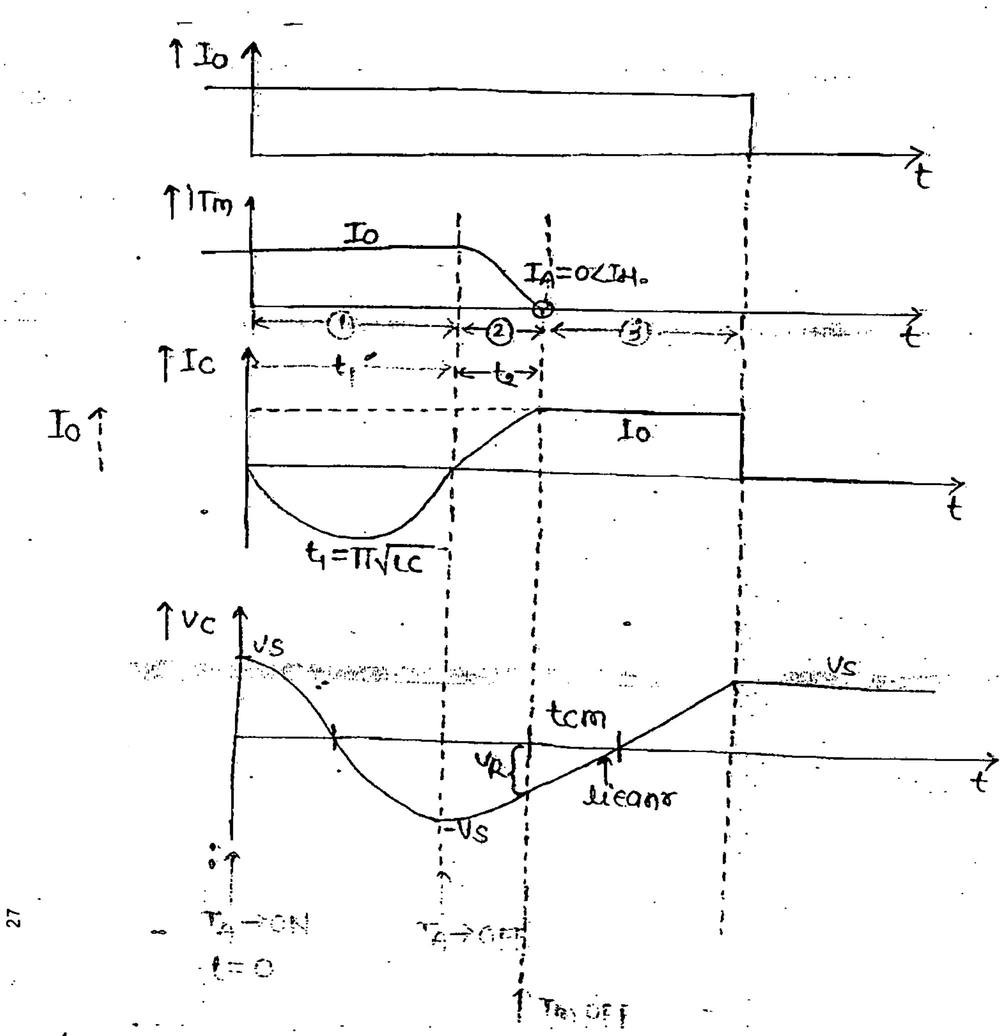
End:-

$I_C = 0$, $\therefore T_A \rightarrow$ OFF

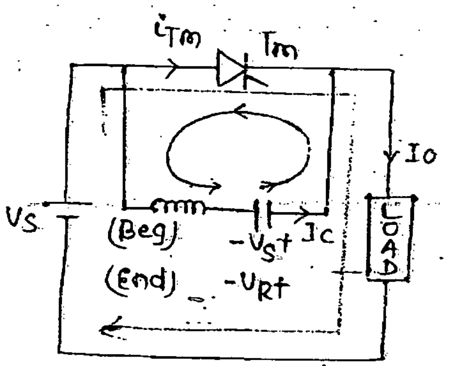
$V_C = -V_S$

$\omega_0 t_1 = \pi$

$t_1 = \frac{\pi}{\omega_0} = \pi\sqrt{LC}$



mode (2)→



The charging current is trying to reduce i_{Tm} & Hence current comm.

$\downarrow i_{Tm} = I_o - I_c \uparrow$

END:- when $I_c = I_o$, $i_{Tm} = 0 < I_H$

$\therefore T_m \to OFF$

$I_c = I_o$

$I_p \sin\omega_0 t_2 = I_o$

$\omega_0 t_2 = \sin^{-1}\left(\frac{I_o}{I_p}\right)$

$t_2 = \frac{1}{\omega_0}\sin^{-1}\left(\frac{I_o}{I_p}\right)$

$$\boxed{t_2 = \sqrt{LC}\,\sin^{-1}\left(\frac{I_o}{I_p}\right)}$$

- At the end of 2nd mode capacitance vol. $V_c = V_s \cos(\pi + \omega_0 t_2)$

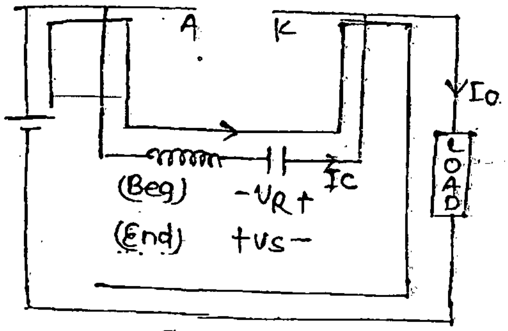
$V_c = -V_s \cos\omega_0 t_2$

$$\boxed{V_c = -V_s \cos\left[\sin^{-1}\left(\frac{I_o}{I_p}\right)\right]}$$

- Let V_R be the rev. vol. magnitude across the capacitor at the end of 2nd mode

$$\boxed{V_R = V_s \cos\left[\sin^{-1}\left(\frac{I_o}{I_p}\right)\right]}$$

Mode (3.) →



$I_C = I_0$

$V_C = \frac{1}{C}\int I_C dt = \frac{I_0}{C} t$

t_{cm} = circuit turn OFF time

$V_C = \frac{I_0}{C} t$

$V_R = \frac{I_0}{C} t_{cm}$

$$\boxed{t_{cm} = \frac{V_R C}{I_0}}$$

Objective question →

(1.) $(I_{Tm})_{peak} = I_0$

(2.) $(I_{TA})_{peak} = V_S\sqrt{\frac{C}{L}}$

(3.) Cond^n time of auxillary thy. $= \pi\sqrt{LC}$ sec.

(4.) The time taken to turn-off the main thy. after the auxillary thy. is switched on $t = t_1 + t_2$

$$\boxed{t = \pi\sqrt{LC} + \sqrt{LC}\sin^{-1}\left(\frac{I_0}{I_P}\right)}$$

(5.) The min^m time taken to turn off the main thy. $= \pi\sqrt{LC}$ sec.

$\downarrow t_2 = \sqrt{LC}\sin^{-1}\left(\frac{I_0\downarrow}{I_P}\right)$

(6.) The max^m time req. to turn-off the main thy. after the auxillary thy. is switched on.

$t_{max} = \pi\sqrt{LC} + \frac{\pi}{2}\sqrt{LC}$

$(I_0 = I_P)$

$\sqrt{LC}\sin^{-1}\left(\frac{I_0}{I_P}\right) = \sqrt{LC}\frac{\pi}{2}$

$$\boxed{t_{max} = \frac{3\pi}{2}\sqrt{LC}}$$

(7.) If $I_o > I_p$ then comm. is not possible. Therefore $I_o \le I_p$ (or) $I_o = I_p$ to make comm. possible $\boxed{I_o \le I_p}$

(8.) The max^m rev. vol. across the main thy. when it is in the OFF state $= V_R$.

$$\boxed{V_R = V_s \cos\left[\sin^{-1}\left(\frac{I_o}{I_p}\right)\right]}$$

(9.) $t_{cm} = \frac{C V_R}{I_o}$ (t_{cm} = circuit turn OFF time of main thy.)

t_q = device turn off time

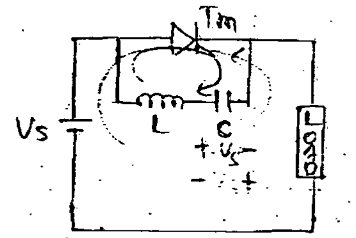
$t_{cm} > t_q$

$t_{cm} = (SF) t_q$ for succesfull commutation

(10.) We must consider the above eq^n (7.), (8) & (9) to design the commutating elements L & C.

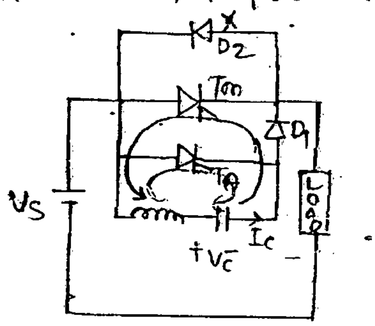
Q → what is the purpose of diode in the comm. ckt?

Ans →



* without a diode auxillary thy has no control on the comm. process.
* The comm. takes place automaticaly before the auxillary thy. is switched on.

Q → Check weather comm. is possible or not in the following ckt?



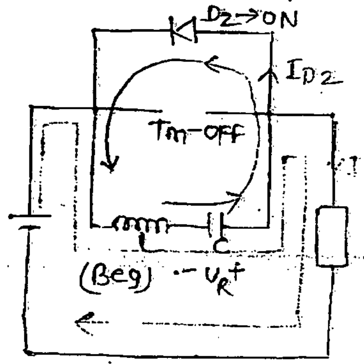
Ans → 2 antiparallel devices can't conduct simultaneously because the vol. drop of conducting device applies a rev. vol. across the other device. Therefore the diode D_2 will not conduct in the 2nd mode because main thy. is already conducting.

Therefore 1st 2 ~~case~~ modes are same as previous case. Hence comm. is possible.

Q→ what is ckt turn-OFF time of main thy. in the above comm ckt?

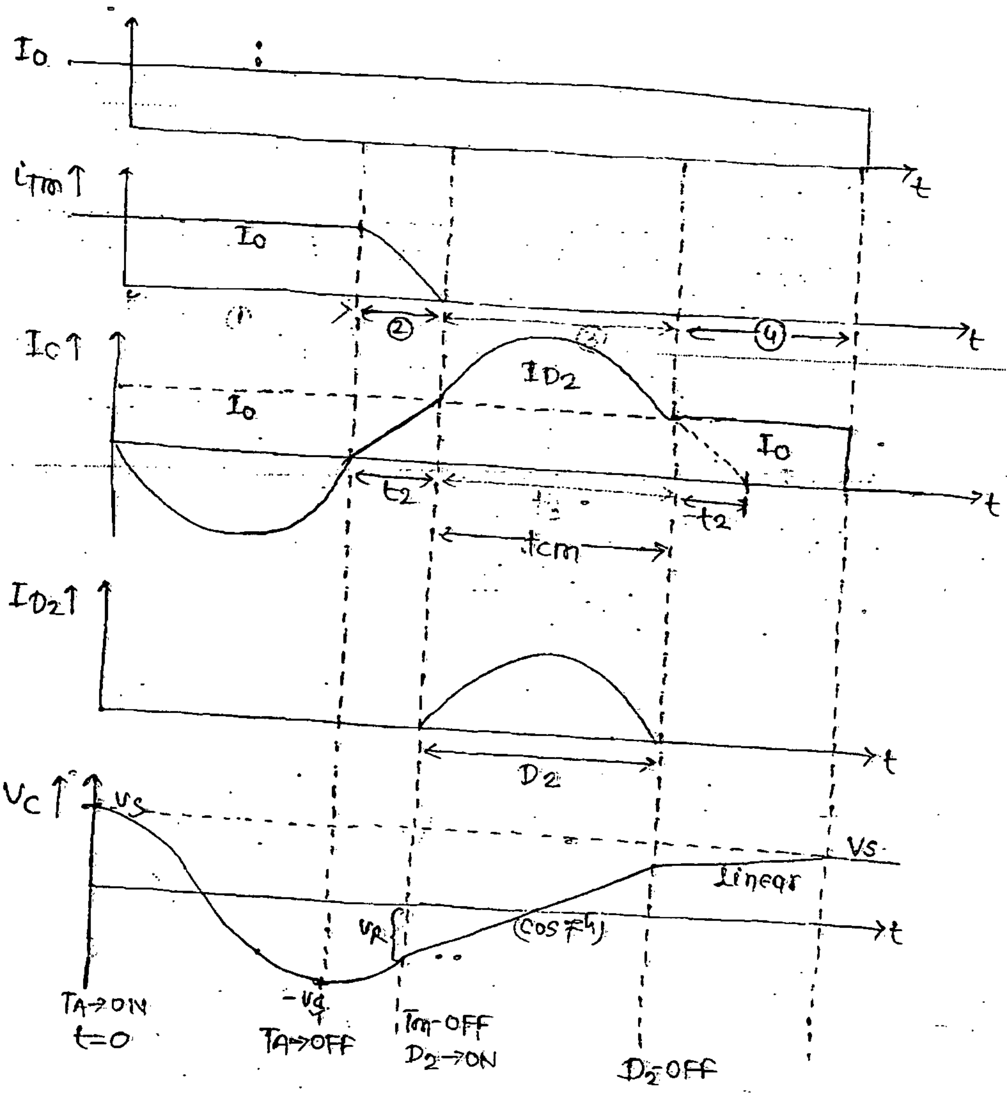
Sol^n→ 1st 2 modes are same as previous case.

mode③ →



$I_c = I_0 + I_{D2}$

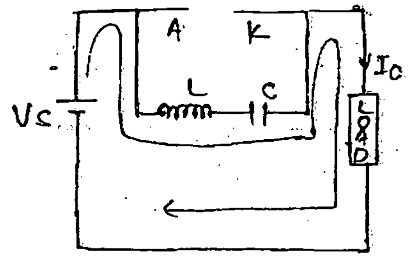
$t_3 = \pi\sqrt{LC} - 2t_2$



$I_C = I_0 + I_{D2}$

END:- when $I_C = I_0$, $I_{D2} = 0$ ∴ $D_2 \rightarrow$ OFF

mode(4)→



$I_C = I_0$

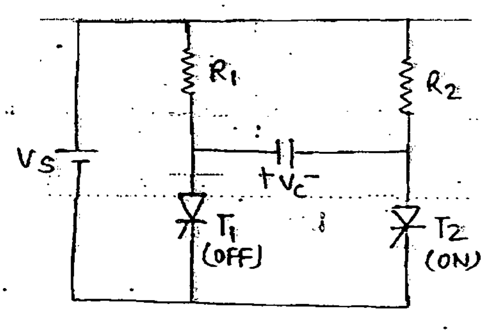
* In the 3rd mode the vol. drop of the diode D_2 applies a rev. voltage across main thy. Therefore the cond^n time of diode D_2 ~~applies a rev. vo~~ gives the ckt turn OFF time of main thy.

$$t_{cm} = \pi\sqrt{LC} - 2t_2$$

$$\boxed{t_{cm} = \pi\sqrt{LC} - 2\sqrt{LC}\sin^{-1}\left(\frac{I_0}{I_P}\right)}$$

Application→ This type of comm. technique is used in stepdown chopper. Therefore it is also known as current comm. chopper.

(3) Class C Comm. (complementry comm.)→



Assume:-

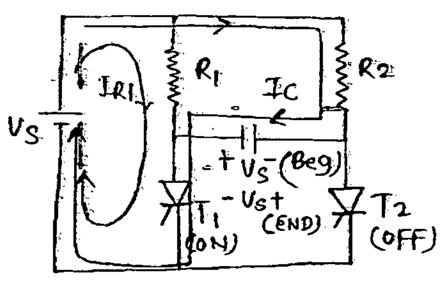
(i) $V_C(t=0) = V_S$

(ii) $T_2 \rightarrow$ ON, $T_1 \rightarrow$ OFF } $(t<0)$

mode(1)→ At $t=0$, $T_1 \rightarrow$ ON, $T_2 \rightarrow$ OFF

Resultant current through T_1

$I_{T_1} = I_{R_1} + I_C$



Because the resistance (R_2) & capacitance value C the value of the current will exponantialy decay

$$I_C = k e^{-t/R_2 C}$$

↓

Initial value of current

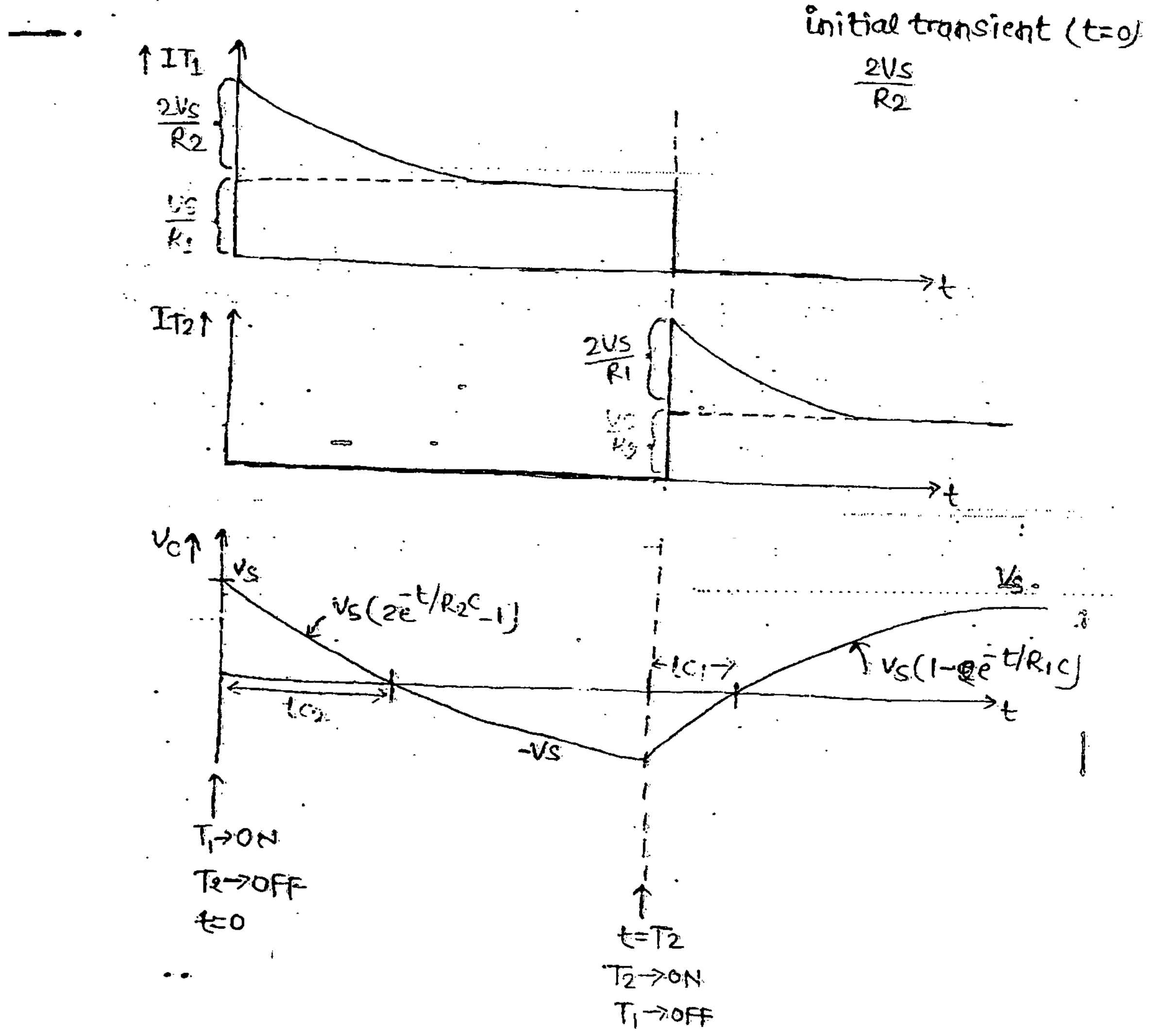
$$k = \frac{2V_S}{R_2}$$

$$I_C = \frac{2V_S}{R_2} e^{-t/R_2 C}$$

Hence $I_{T_1} = \frac{V_S}{R_1} + \frac{2V_S}{R_2} e^{-t/R_2 C}$

$\frac{V_S}{R_1}$ → (Steady Current)

$\frac{2V_S}{R_2} e^{-t/R_2 C}$ → (Transient current)



Now, the circuit turn off time of 2nd thy.

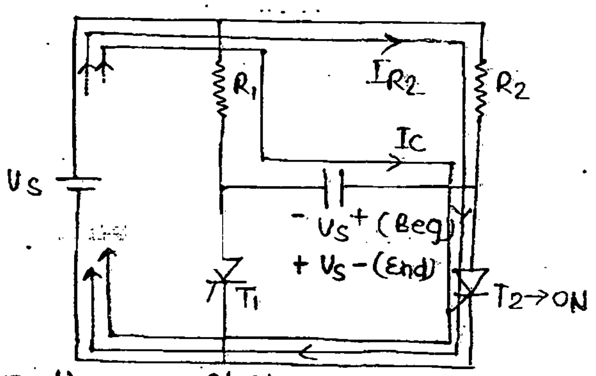
$$\text{At } t = t_{c2}$$

$$V_C = 0$$

$$V_S\left(2e^{-t_{c2}/R_2C} - 1\right) = 0$$

$$\boxed{t_{c2} = R_2 C \cdot \ln 2} \quad \text{---(i)}$$

Mode (2.) → At $t = t_2$, $T_2 \rightarrow ON$



$$I_{T2} = I_{R2} + I_C$$

$$I_{T2} = \frac{V_S}{R_2} + \frac{2V_S}{R_1} e^{-t/R_1C}$$

$\frac{V_S}{R_2}$ → Steady, $\frac{2V_S}{R_1} e^{-t/R_1C}$ → Transient

Circuit turn off time of 1st thy.

$$\text{At } t = t_{c1}$$

$$\boxed{t_{c1} = R_1 C \ln 2} \quad \text{---(ii)}$$

Objective questions →

(1.) $$(I_{T1})_{peak} = \frac{V_S}{R_1} + \frac{2V_S}{R_2} \quad \text{---- (3.)}$$

(2.) $$(I_{T2})_{Peak} = \frac{V_S}{R_2} + \frac{2V_S}{R_1} \quad \text{------ (iv)}$$

From eqn (i) $$C = \frac{t_{c2}}{R_2 \ln 2}$$

$$\boxed{C = \frac{(SF)t_q}{R_2 \ln 2}} \quad \text{---(v)} \qquad t_c = (SF)t_q$$

From eqn (ii) $$C = \frac{t_{c1}}{R_1 \ln 2}$$

$$\boxed{C = \frac{(SF)t_q}{R_1 \ln 2}} \quad \text{---(vi)}$$

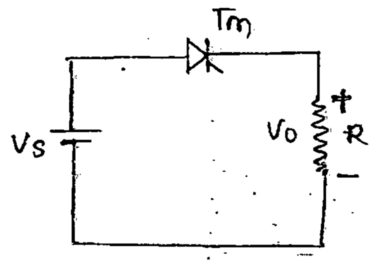
From eqn (5.) & (6.) we get 2 diff. values for the commutating capacitance. We must consider the highest value to make the comm. possible.

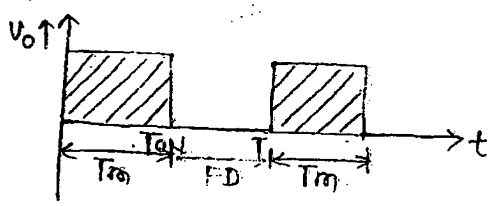
Application → Parallel inverter, Current source inverter.

Class D (Voltage Comm.) →

* This type of comm. technique is prefered in step down chopper. Therefore it is also known as vol. comm. chopper.

Step down chopper → (without Comm. ckt)

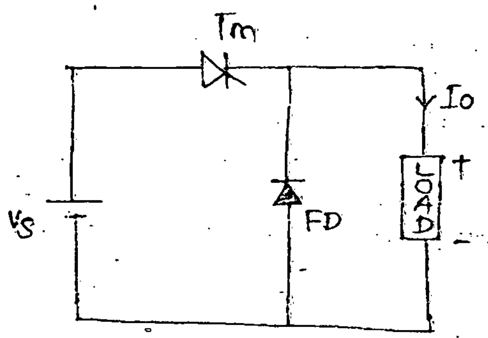




$$V_0 = \frac{V_s T_{ON}}{T}$$

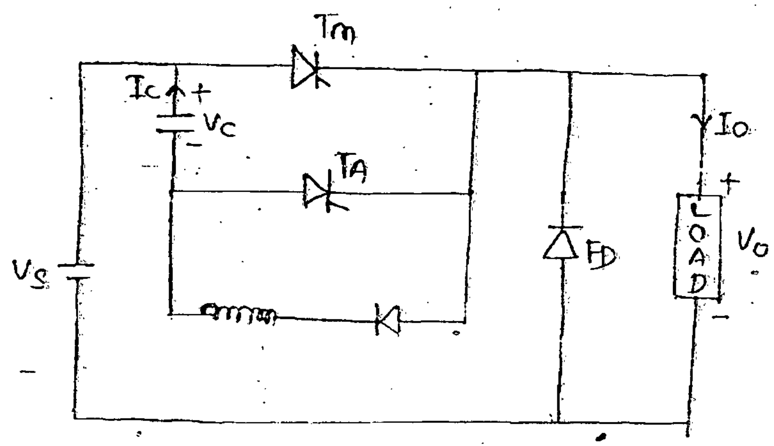
$$V_0 = \alpha V_s \qquad \boxed{\alpha = \frac{T_{ON}}{T}}$$

duty cycle



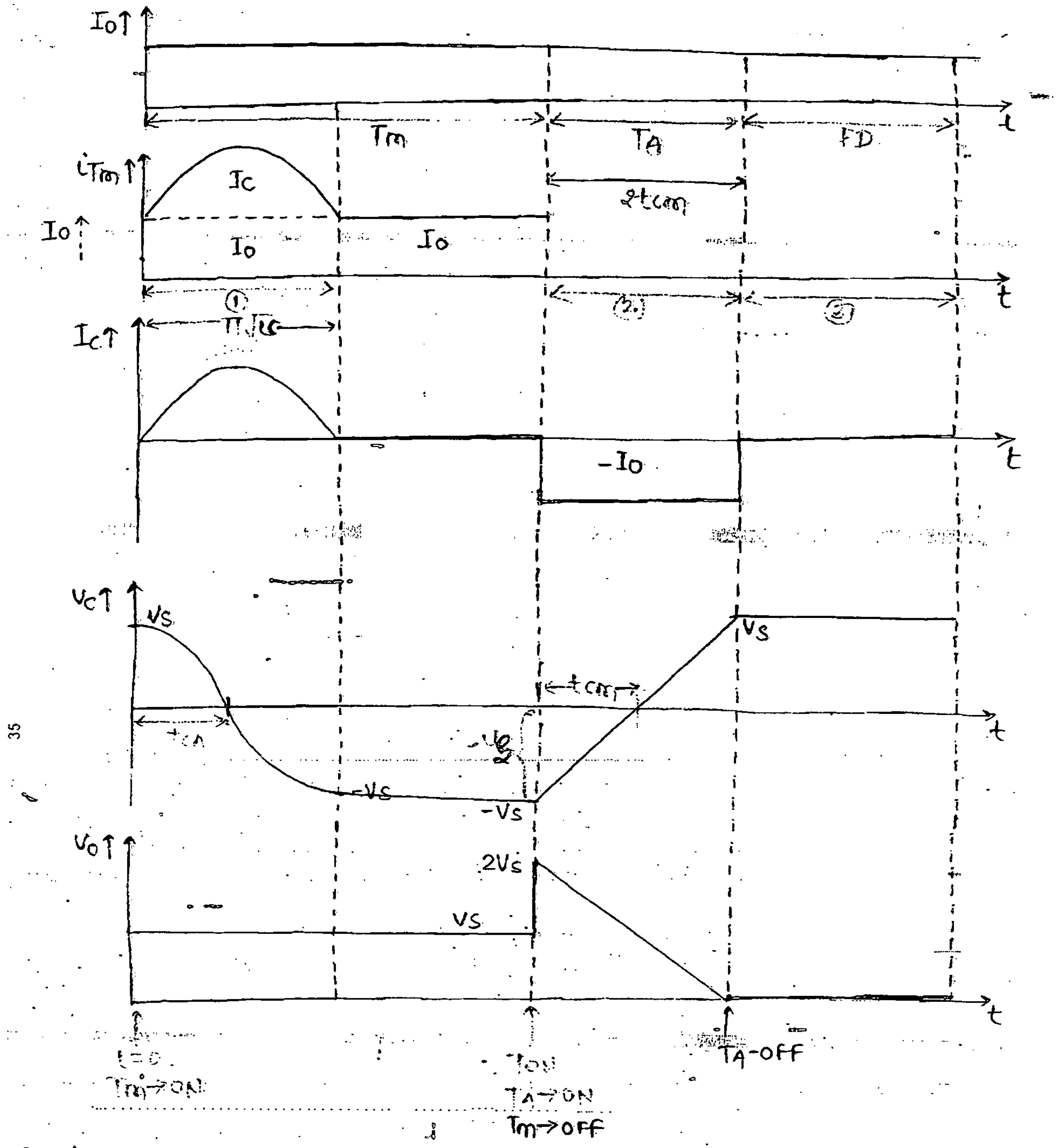
In the inductive load there is a need of FD; because the inductor will release the energy through FD.

Step down chopper / Vol. Comm. chopper (with comm. ckt) →

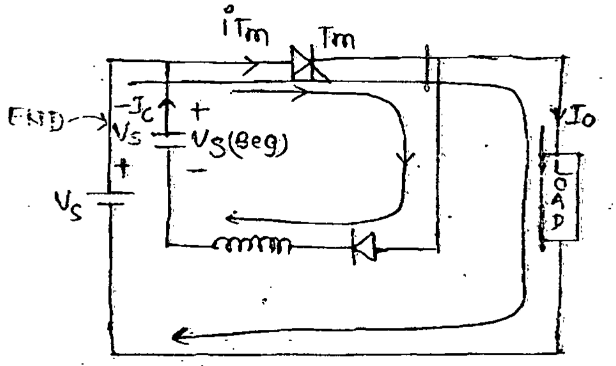


Assume:- (1) $V_c(t=0) = V_s$

(2) $I_o \rightarrow$ const (High inductive load)



Mode(1)→ At $t=0$, $T_m \to ON$



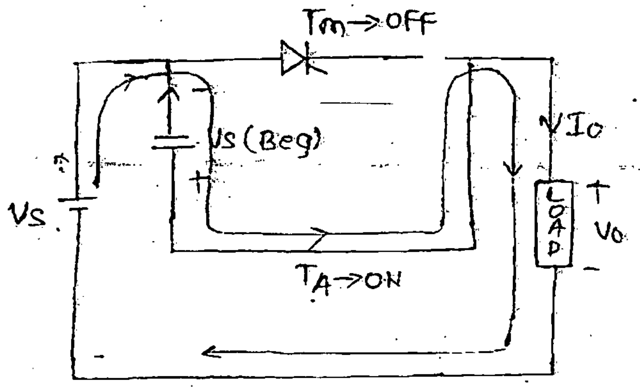
$i_{Tm} = I_o + I_c$

$I_c = I_p \sin\omega_o t$

$V_c = V_s \cos\omega_o t$

END:- $I_c = 0$, $V_c = -V_s$

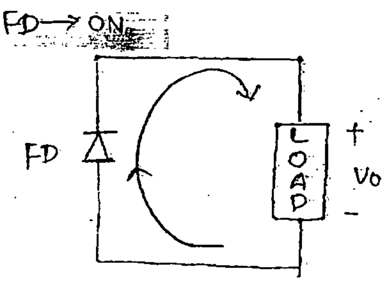
mode(2)→ At $t = T_{ON}$, $T_A \to ON$



$I_c = -I_o$
Beg.→ $V_c = -V_s$
$V_o = 2V_s$
End→ $V_c = V_s$
$V_o = 0$
$I_c = 0$

mode(3)→

FD→ON



without comm. of the 1st mode we can't turn-off the main thy. therefore $(T_{ON})_{min}$ of $T_m = \pi\sqrt{LC}$

$$\alpha_{min} = \frac{\pi\sqrt{LC}}{T} = \pi\sqrt{LC}\cdot f$$

(2) $(I_{Tm})_{peak} = I_o + I_p = I_o + V_s\sqrt{\frac{C}{L}}$

(3) $(I_{TA})_{peak} = I_o$

(4) PIV of FD $= 2V_s$

(5) PIV of $T_m = V_s$

(6) $t_{cm} = \frac{CV_s}{I_o} = T_{OFF}$

(7) $t_{cA} = \frac{\pi}{2}\sqrt{LC}$

(8) Conduction time of T_A $= 2t_{cm}$

(9) Comm. iterval $= 2t_{cm}$
It is a time for which or It is the time taken to disconnect the load from supply after the Tm stops conducting.

(10) Effective turn ON time of chopper

$$\boxed{(T_{ON})_{eff} = T_{ON} + 2t_{cm}}$$

(11.) Avg. voltage $V_0 = \dfrac{(V_S T_{ON}) + \left(\frac{1}{2} \cdot 2t_{cm} \cdot 2V_S\right)}{T}$

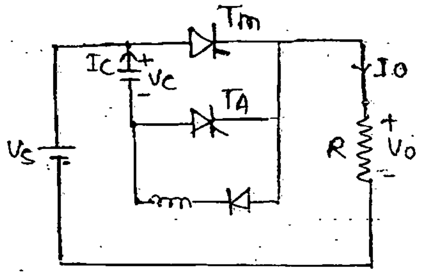
$$V_0 = V_S\left(\frac{T_{ON} + 2t_{cm}}{T}\right) = \frac{V_S (T_{ON})_{eff}}{T}$$

$$\boxed{V_0 = \frac{V_S (T_{ON})_{eff.}}{T}}$$

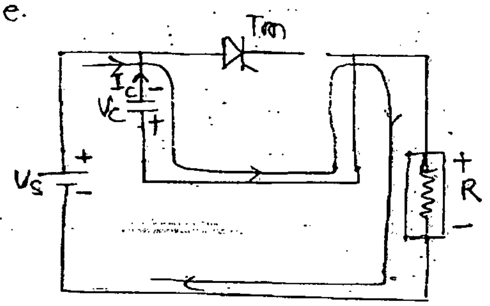
(12.) $(V_0)_{min} = V_S\left[\dfrac{\pi\sqrt{LC} + 2t_{cm}}{T}\right]$

$$\boxed{(V_0)_{min} = V_S(\pi\sqrt{LC} + 2t_{cm})f}$$

Q→ what is the ckt turn-OFF time of thy. with resistive load?



Ans.→ 1^{st} mode same as previous case.



mode(2.)→ $I_0 = Ke^{-t/RC}$

$$I_0 = \frac{2V_S}{R} e^{-t/RC}$$

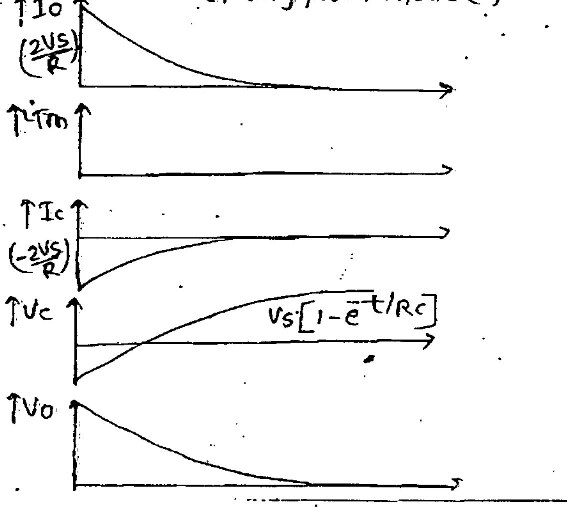
$$I_c = \frac{-2V_S}{R} e^{-t/RC}$$

Beg:- $V_c = -V_S$

$V_0 = 2V_S$

$I_0 = \dfrac{2V_S}{R}$

starting from mode(2.)



At $t = t_{cm}$, $V_c = 0$

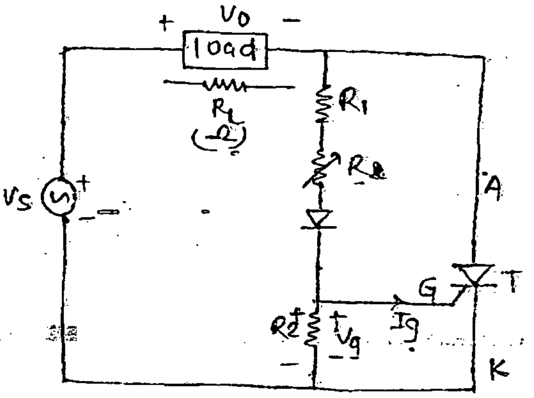
$$V_S(1 - e^{-t_{cm}/RC}) = 0$$

$$\boxed{t_{cm} = RC\ln 2}$$

* **Firing Circuits →** It gives the nessesory gate signal to turn ON the SCR.

(i) **Resistance firing ckt →** It is also known as R-firing ckt

main ckt → 1ϕ HWR



$R_L <<< (R_1+R+R_2)$
(Ω) KΩ

$I_{g\,min} \le I_g \le I_{g\,max}$

$V_{g\,min} \le V_g \le V_{g\,max}$
(Gate specification)

* R_1 is added to limit the gate current within the max^m value.
* For worst cond^n the max^m gate current

$$I_{g\,max} \ge \frac{V_m}{R_1}$$

$$\boxed{R_1 \ge \frac{V_m}{I_{g\,max}}}$$

* Degin R_2 to limit the gate vol. below the specified max^m value.
* For worst cond^n the max^m gate vol. $= \boxed{\left(\frac{V_m}{R_1+R_2}\right) R_2 \le V_{g\,max}}$

From above eq^n we can design value of R_2

* Variable resistor is used to vary the firing angle α.
* Diode is used to avoid the −ve gate pulse in the −ve cycle.

V_{gt} = Gate turn on voltage

It is the gate vol. at which SCR will turn on.

when V_g↑ & it reaches V_{gt}, SCR → ON
($\omega t = \alpha$)

$$V_g = \left(\frac{V_m \sin\omega t}{R_1+R+R_2}\right) \cdot R_2$$

$$V_g = \left(\frac{V_m R_2}{R_1 + R + R_2}\right) \sin\omega t$$

$$\boxed{V_g = V_{gm} \cdot \sin\omega t} \rightarrow T\text{(OFF) then use eq}^n$$

where; $V_{gm} = \frac{V_m R_2}{R_1 + R + R_2}$ (Peak value of gate vol.)

From above eq^n

$V_{gt} = V_{gm} \sin\alpha$; SCR → ON

$$\sin\alpha = \frac{V_{gt}}{V_{gm}}$$

$$\boxed{\alpha = \sin^{-1}\left(\frac{V_{gt}}{V_{gm}}\right)}$$

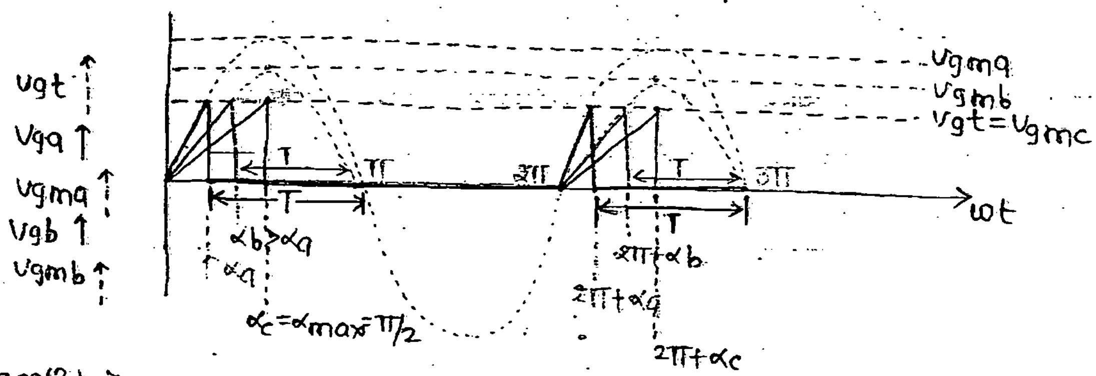
If $R\uparrow$, $V_{gm}\downarrow$ $\therefore \alpha\uparrow$ (By increasing the variable resistor $\alpha\uparrow$)

Case(1) →

Let $R = R_a$, $\alpha = \alpha_a$

$V_{ga} = V_{gma} \cdot \sin\omega t$

$$V_{gma} = \frac{V_m R_2}{R_1 + R_a + R_2}$$



Case(2) →

Let $R = R_b$, $\alpha = \alpha_b$ $\quad R = R_b > R_a$

$V_{gb} = V_{gmb} \sin\omega t$

$V_{gmb} < V_{gma}$

Case(3.) → Let $R=R_c$, $\alpha=\alpha_c$

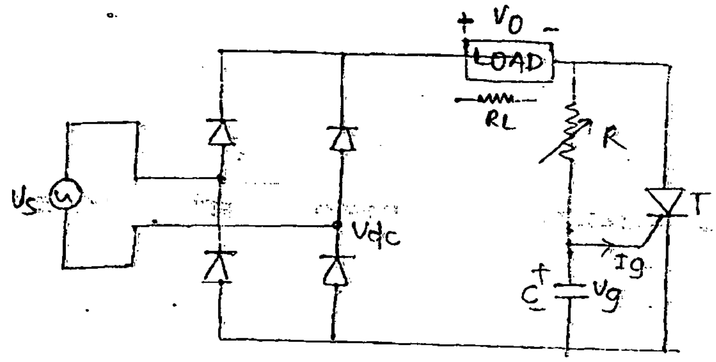
$V_{gmc}=V_{gt}$, $\alpha_{max}=\pi/2$

Drawback →

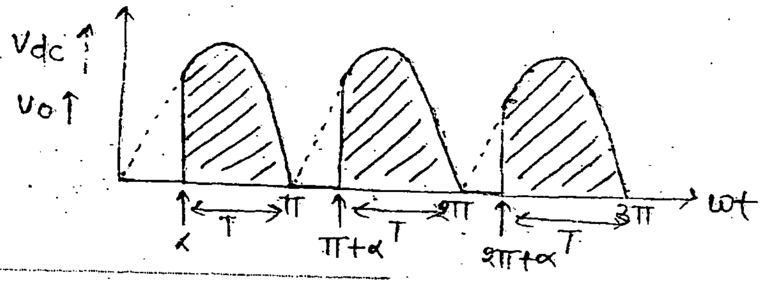
The max^m α is limited to 90°.

(ii) RC Firing ckt →

Main ckt :- 1φ FWR



$R_L << R$
(Ω) (kΩ)



Case(1.) → Let $R=R_a$, $\alpha=\alpha_a$

$T_a = R_a C$

Case(2.) → Let $R=R_b>R_a$

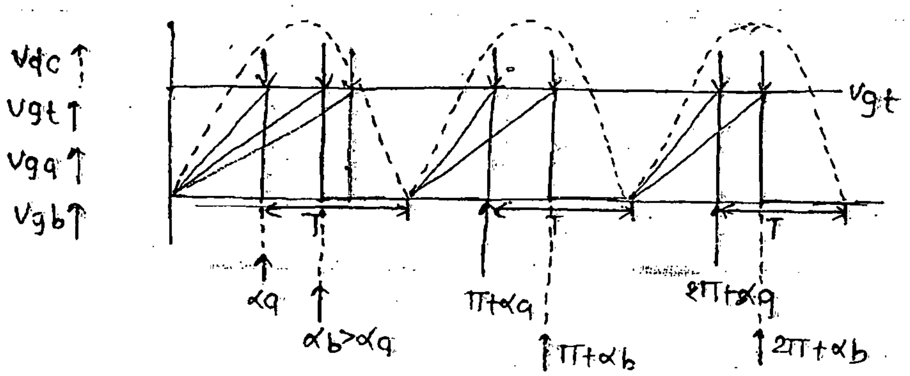
($\alpha=\alpha_b$)

$T_b > T_a$

$T_b = R_b C$ $R\uparrow, T\uparrow \therefore \alpha\uparrow$

Because of the increasing the value of time constant the wav will take more time to take V_{gt}.

Hence the α will be increases.



$V_{gt} = 0$. (ideal SCR)

$0 < \alpha < 180$

$(5 \text{ to } 7°) \le \alpha \le (165° \text{ to } 175°) \Rightarrow$ (Practical SCR)

UJT