DATE-04/08/14

Power electronics

8871453536

Topics →

(1.) Power semicond^r 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)(∵Vac) (V_o, F_o)

(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 } (P↑ – Handle highest power)
(2.) Thyristor (SCR) }
(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.

g→ (1.) Signal diode – Zener diode
LEDs
Varector diode-----

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

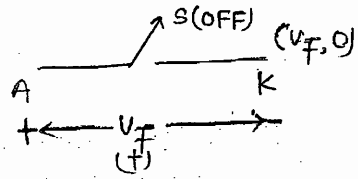
$\boxed{\text{Signal devices} - (P\downarrow, F\uparrow)}$

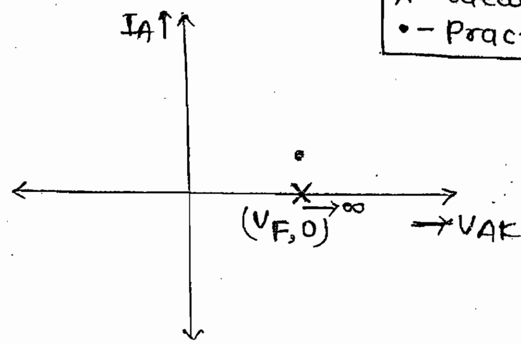
Note →
* We can't improve all the qualities in a single device, when we want to improve some of qualities the other qualities may be affected.
· We can utilize the switch is 4 diff mode but all the devices need not support all the 4 modes.

* Four modes of ideal switch →

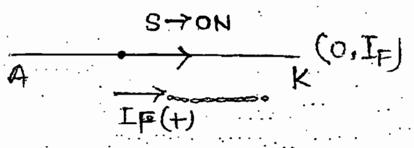
(1.) Forward blocking mode →

X – ideal
• – Practical

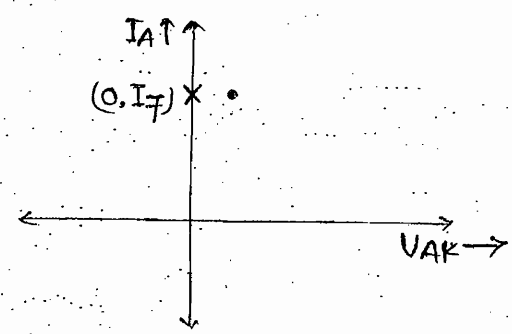




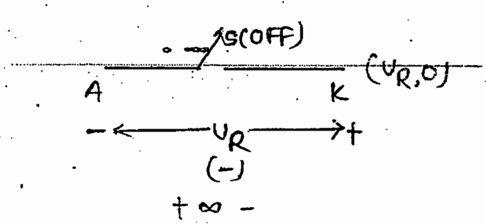
(2.) Forward Conduction mode →

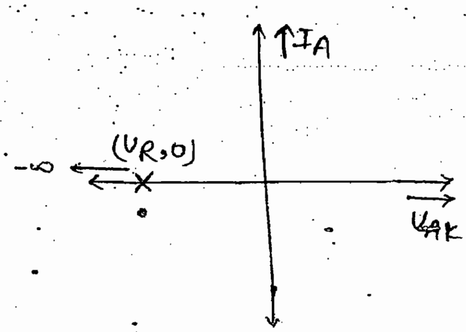


$V_{AK} = I_F \cdot R_F$
(ON state)

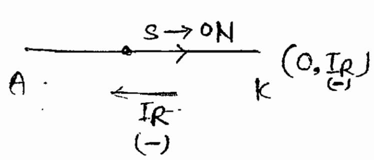


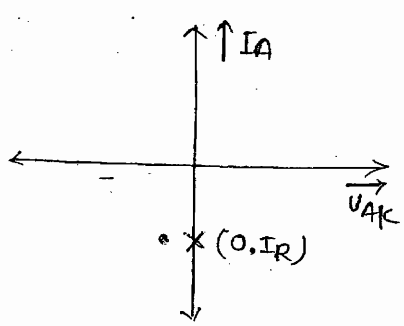
(3.) Reverse Blocking mode →



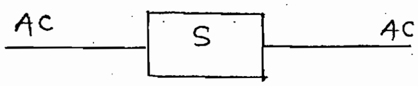


(4.) Reverse Cond^n mode →

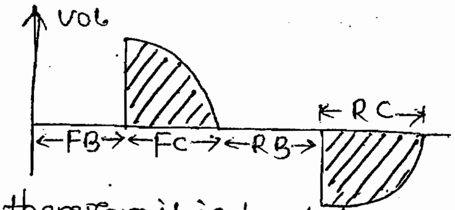




Note →

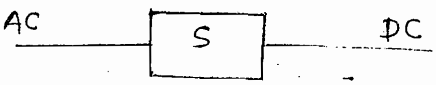
1.) 

AC switch

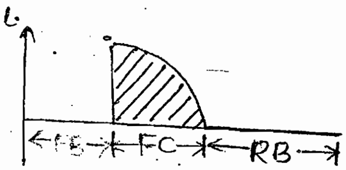


* TRIAC supports all the 4-modes therefore it is treated as an ac switch & used in AC vol. controllers.

Eg. → Fan regulator.

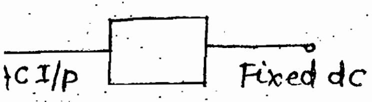
(2.) 

DC switch



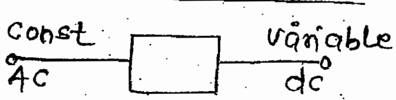
Eg. → SCR (This will support only 3 modes, RC is absent)

Diode Rectifier



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

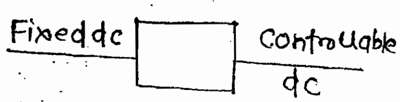
AC to dc Converters



* 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.

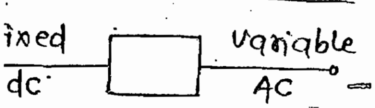
DC to dc converters



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

Appliⁿ →
① dc drives
(2) subway cars

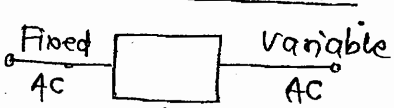
DC to AC Converters



Inverters.
Line/load/Forced commutation.

Appliⁿ →
Indⁿ/ synchronous motor
Induction Heating
UPS
HVDC

AC to AC Converter



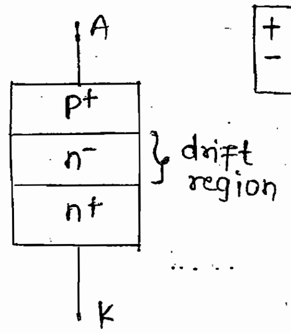
(a.) AC voltage controller
(b) Cycloconverter

↓ Slow speed large AC drive (Rotary klin)

↓ lightning (or) Speed Control

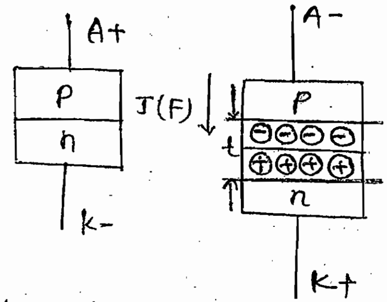
* (1.) Power Semicond^r devices →

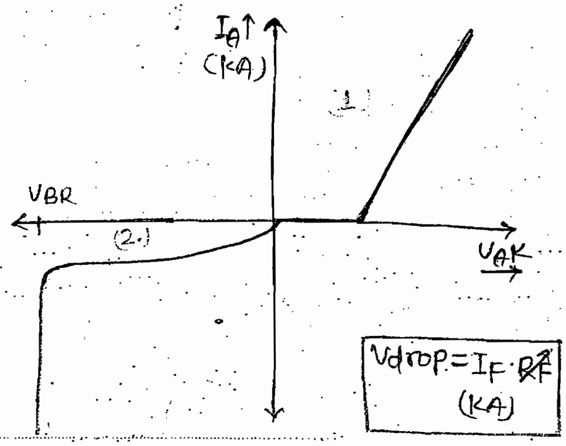
(1.) Power diode →



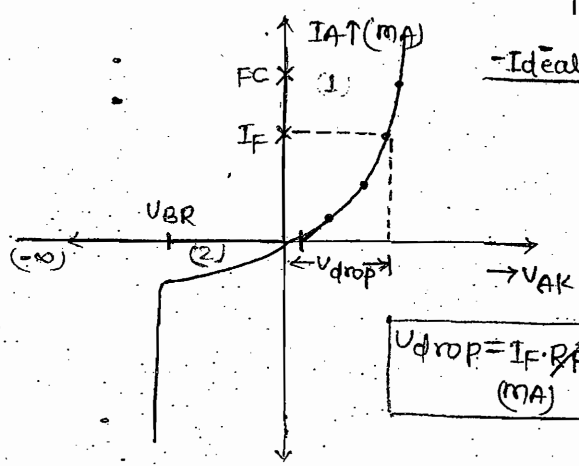
+ → Heavily dopped
− → Ligthly dopped

Signal diode





$\boxed{V_{drop} = I_F \cdot R_F}$ (kA)

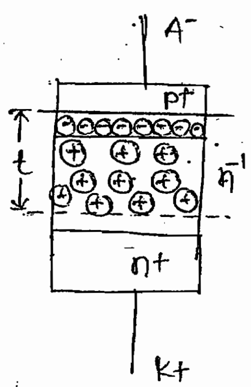


−Ideal diode

$\boxed{V_{drop} = I_F \cdot R_F}$ (mA)

* 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 →



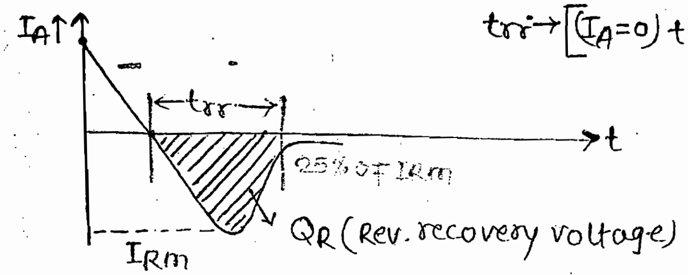
* ~~If~~ anode is made +ve wrt cathode then the depletion layer across the jun^n the depletion Layer penetrates more dipper into n^- layer in order to equalise the charge on both the size of jun^n.
* This increases the thickness of depletion layer & rev. blocking capbility of diode.

** 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.

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



* 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 states 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 →

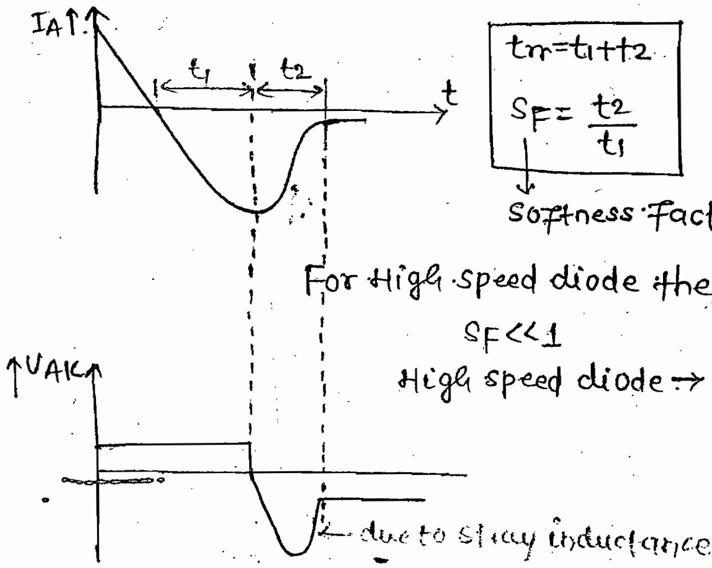
$$\boxed{Q_R = \frac{1}{2} \cdot t_{rr} \cdot I_{Rm}}$$

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

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

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

7



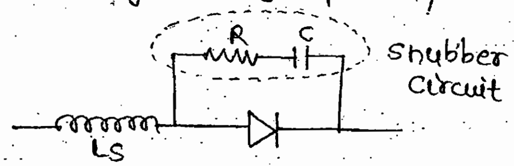
$t_{rr} = t_1 + t_2$

$S_F = \frac{t_2}{t_1}$ → 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 trr →

(1) General purpose diode → (slow diode)

(i) trr → 25 μs

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

Vrating :- 50V to 5kV

(iii) This has p-n junⁿ.

Fast recovery diode

(i) trr → 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 trr time.

* It has p-n junⁿ

Schottky diode (f↑)

(i) trr → 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 trr is very much reduced Therefore it operate with very high switching Freq.

slow diodes are used in line freq. rectifier. Therefor 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.

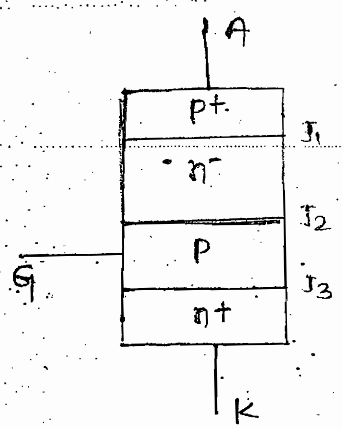
Application →

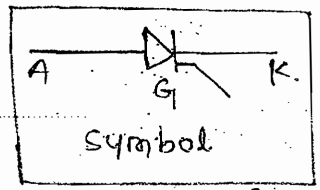
SMPS

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)

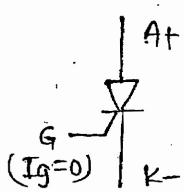
semi controlled switch

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.

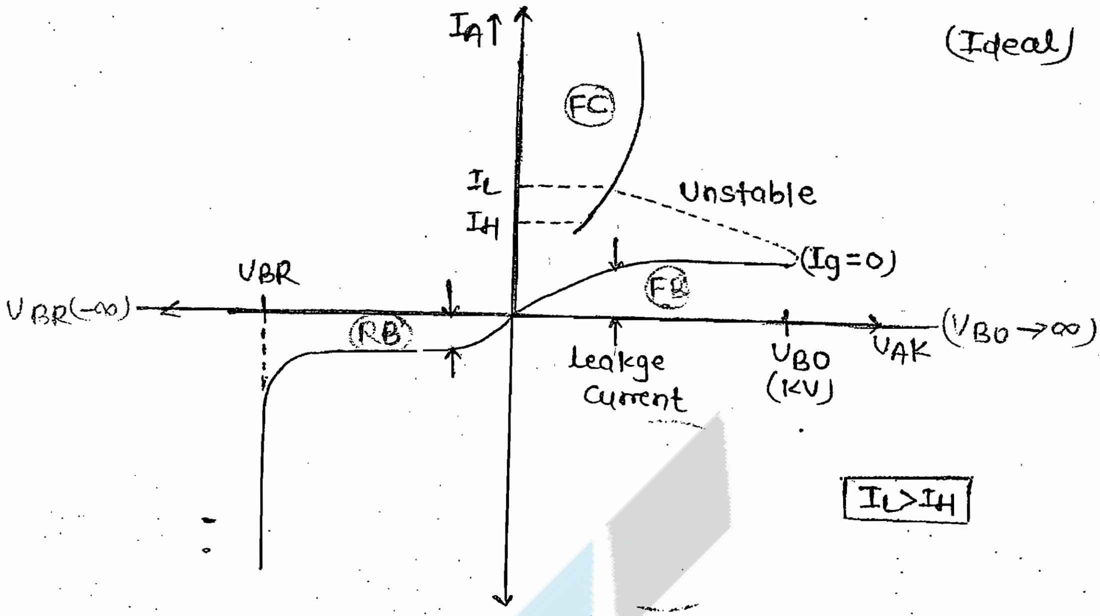
b.) Forward conduction mode →



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

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

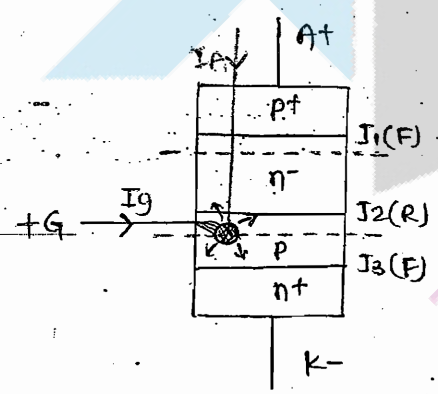
(Ideal)



$\boxed{I_L > I_H}$

* 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 →



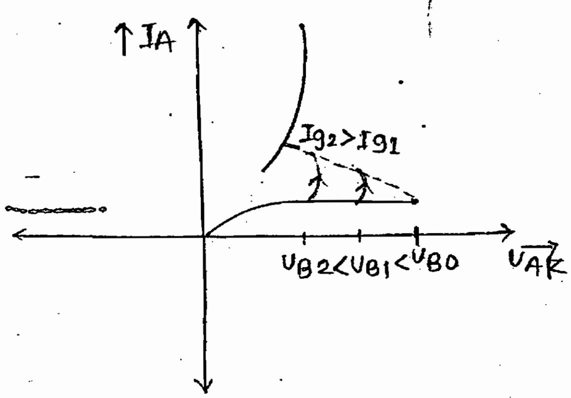
⊛ → Initial conducting area

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

$\Downarrow$

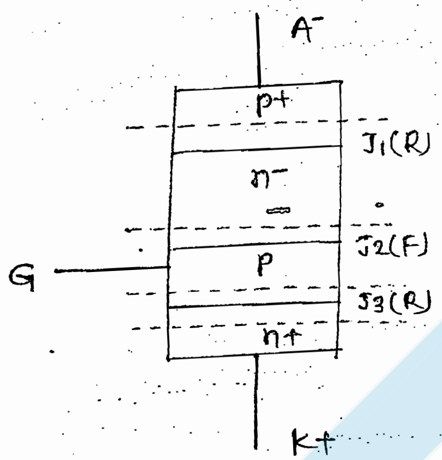
$t_{on}\downarrow$ & $V_B\downarrow$ (Breakdown voltage)

$\boxed{I_g\uparrow,\ V_B\downarrow}$



$$\boxed{\begin{array}{l} I_{g\,min} \le I_g \le I_{g\,max} \\ V_{g\,min} \le V_g \le V_{g\,max} \end{array}}$$

(C) 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.

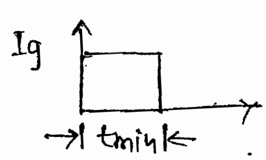
Que. → What happens if a +ve gate pulse is given to a reverse bias thyristor.

Significance of Latching Current →

Latching current is related to turn ON process.

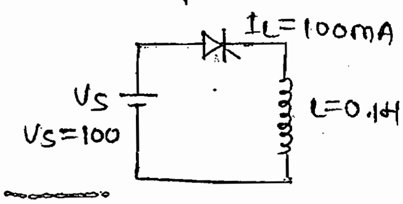
· Gate pulse initiates the turn ON process but once the thyristor is on the ON state gate looses Control on the device. Therefore we can remove the gate pulse when SCR becomes on to avoid the contineous gate power loss.

· 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.



t_{min} → min^m gate pulse required to turn ON SCR

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



Sol^n→ 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

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

$$t_{min} = \frac{I_L \cdot L}{V_S} = \frac{100\times10^{-3}\times0.1}{100}$$

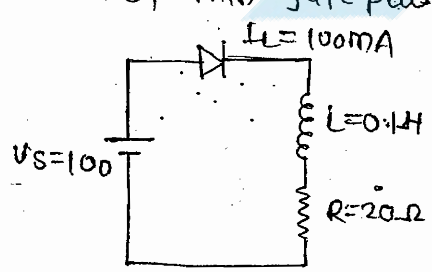
$$t_{min} = 10^{-4}\,sec$$

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

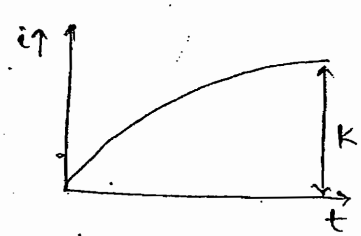
$t_{gpw} \geq t_{min}$ to turn ON the SCR.

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}

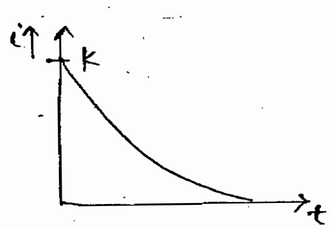
Q.→ what in the value of min^m gate pulse



Sol^n→



For inductor



For capacitor

DATE 05/08/14

$i = k(1 - e^{-t/T})$ ↑ Final value (V_s/R)

$i = k e^{-t/T}$ ↑ Initial value (V_s/R)

Applying KVL in the loop

$$V_s = R i_o + L\frac{di_o}{dt}$$

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

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

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

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

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

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

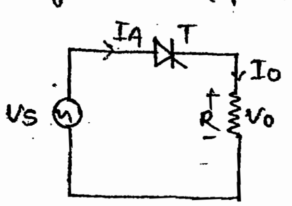
$$I_A = 5(1 - e^{-200t}), \quad I_L = 5(1 - e^{-200 t_{min}})$$

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

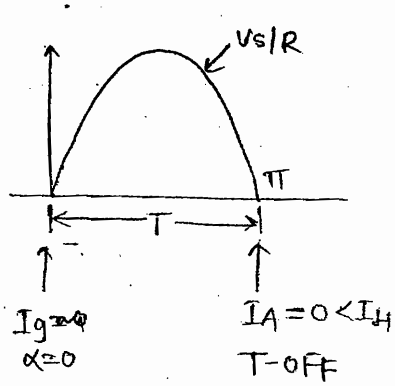
* Significance of Holding current →

* 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. $(\downarrow I_A < I_H)$

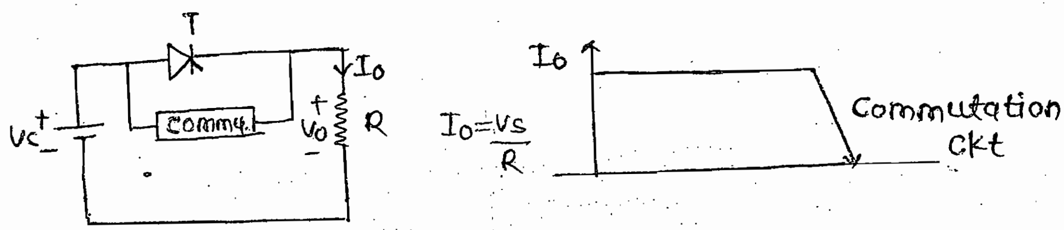
eg:- Half wave rectifier (Natural Commutation)



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



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



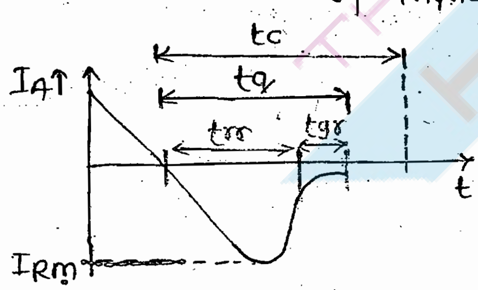
* In some of cases when supply is dc natural commutation is not possible. We have to use commutation ckt to turn OFF the SCR.

* The commutation ckt reduce the anode current below the holding current & then apply a reverse vol. across thyristor atleast for a period untill 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 (Turn-OFF C/S) → It explains the switching behaviour of thyristor from ON-state to OFF-state.



$\boxed{t_c \geq t_q}$ For succesfull Comm.

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

$\boxed{t_c = (SF/sm) \times t_q}$ 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 jun^n 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?

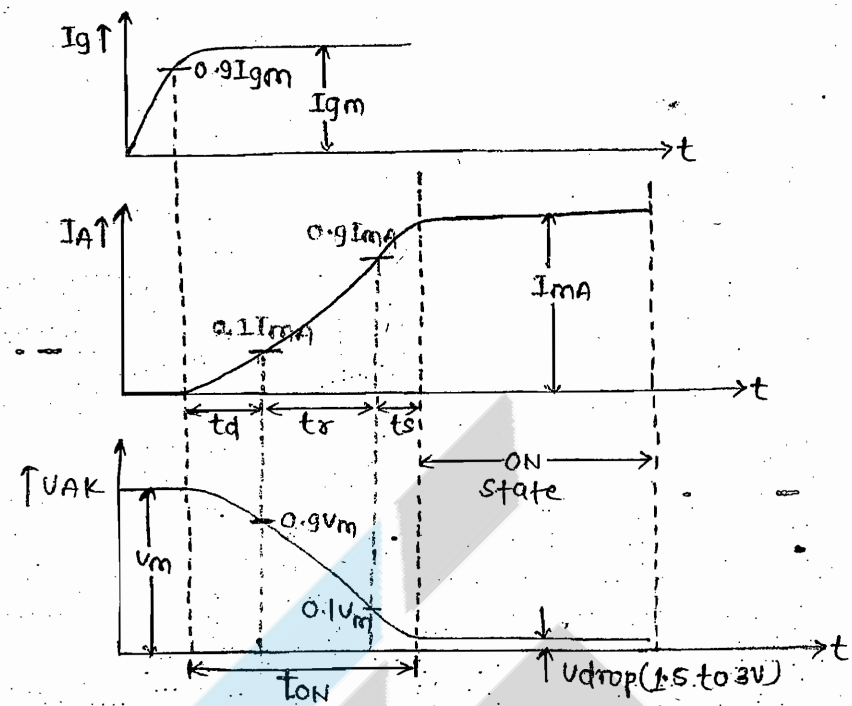
Ans → * If $t_c < t_q$ the commutation is not completed.

* some charges present still in the device.
* For the next operation if anode is +ve wrt cathode then SCR starts conducting immediately 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.



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

⇒ Initial conduction area ↑

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

⇒ $t_d \downarrow \quad \therefore t_{ON} \downarrow$

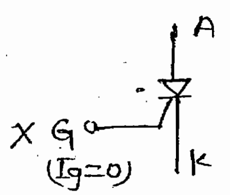
* <u>Rise time 'tr'</u> depends on the load parameters.

⇒ $L \uparrow, \ \frac{di_A}{dt} \downarrow \ \therefore t_r \uparrow \ \therefore t_{ON} \uparrow$

* <u>Spread time 'ts'</u> depends on the physical geometrical structure of thyristor.

* <u>Turn-ON topic methods of thyristor (Triggering method) →</u>

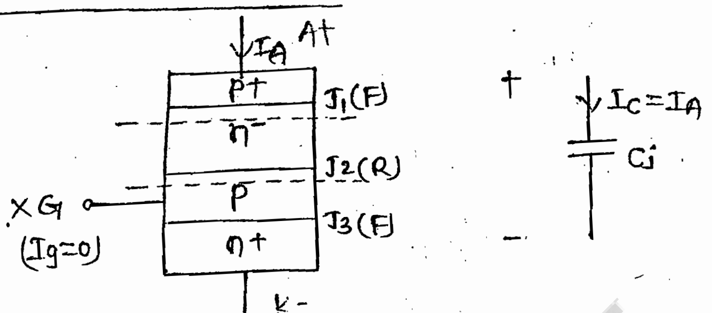
<u>(1.) Forward voltage triggering →</u>



$V_{AK} \uparrow \Rightarrow V_{BO}$, SCR→ON.

Due to high losses this is not prefered.

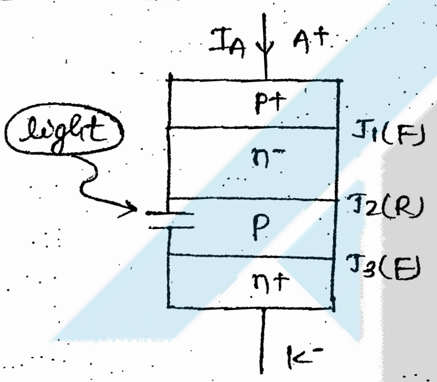
(2.) $\frac{dv}{dt}$ triggering method →



$$\uparrow I_C = C_j \frac{dv}{dt} \uparrow$$

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 junⁿ 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.

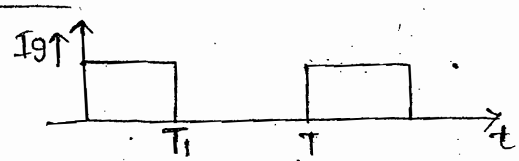
Light trigering is more efficient & reliable to trigger multiple no. of SCR simultaneously.

) 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.

i) pulse gate signal →



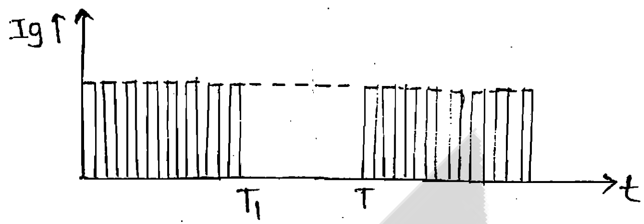
$T_1 \rightarrow$ Gate pulse

$T_1 > t_{min}$

$T \rightarrow$ time period

$\delta = \frac{T_1}{T} \rightarrow$ duty cycle

(3.) High freq. gate pulse →



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

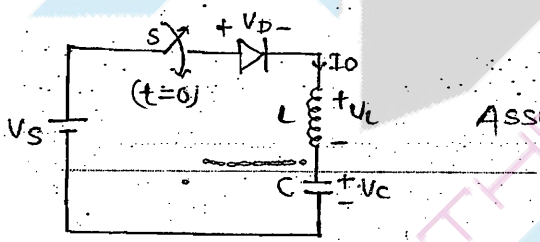
Q → what is the need of pulse Xmer in gate firing ckt?

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 $D \rightarrow ON$

$$V_S = V_D + V_L + V_C$$

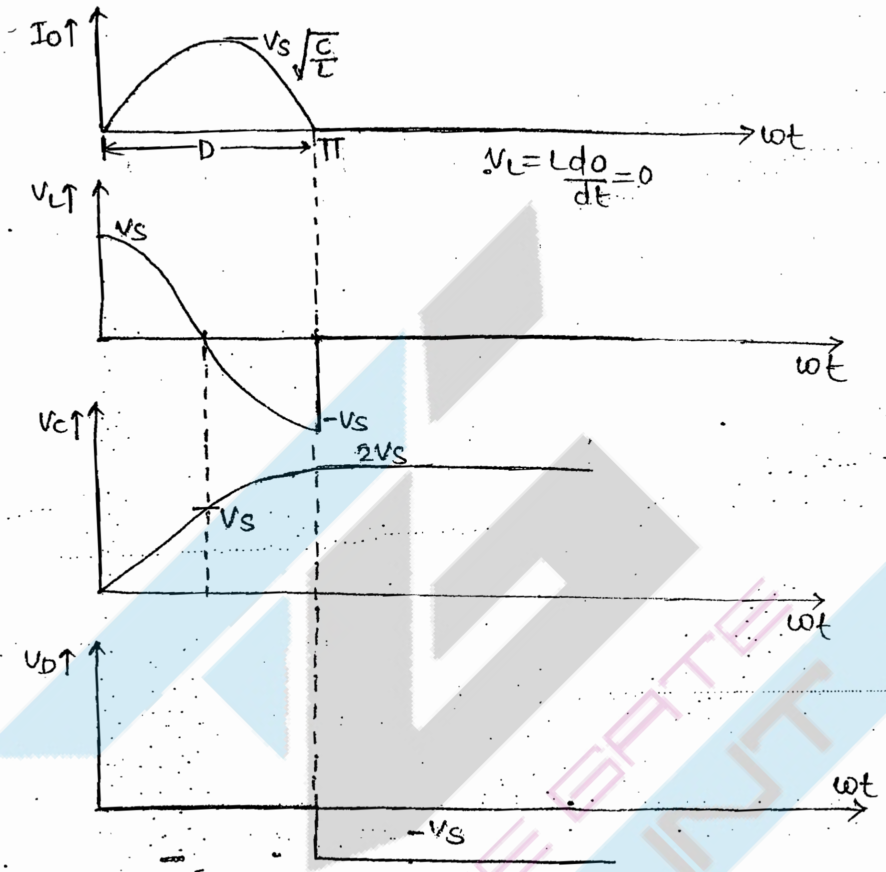
$$V_S = 0 + L\frac{di_o}{dt} + \frac{1}{C}\int i_o dt$$

$$I_0 = V_S\sqrt{\frac{C}{L}}\sin\omega_0 t$$

$$\boxed{I_0 = I_p \sin\omega_0 t}$$

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

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



$\omega_0 t = \pi$ (rad)

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

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

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

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

$V_L = V_s \cos\omega_0 t$

$V_s = V_D + V_L + V_C$

$V_s = 0 + V_L + V_C$

$V_C = V_s - V_L$

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

when D → OFF

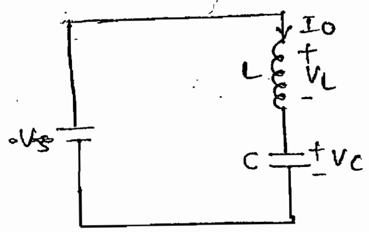
$V_L = 0$, & $\boxed{V_C = 2V_s}$

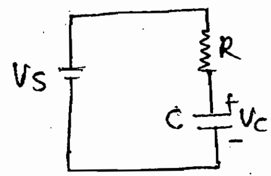
$-V_s + V_D + 0 + 2V_s = 0$

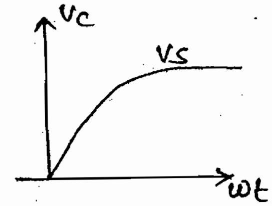
$\boxed{V_D = -V_s}$ & $\boxed{PIV = V_s}$

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

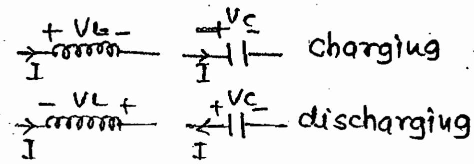
Because the value of the capacitance vol. is 2Vs means the ...







Mode(1.) → (0 to 90°)



- source ⟶ L & C ⟶ $\frac{1}{2}CV^2$

$\downarrow$ $(\frac{1}{2}Li^2)$, $i\uparrow$; $\downarrow$ $V_c\uparrow$

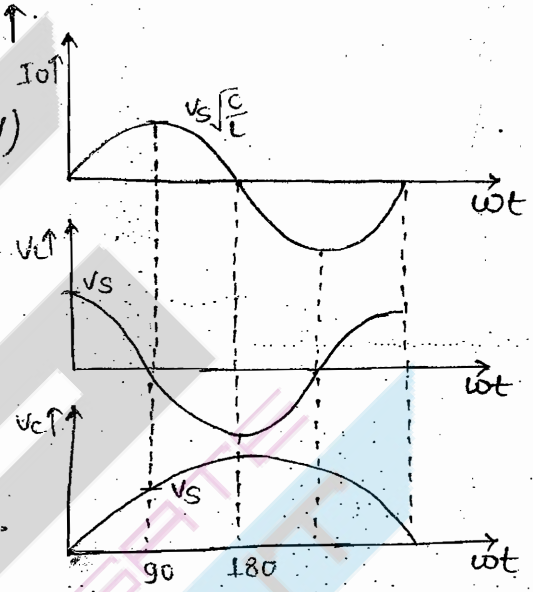
$V_s = V_L\downarrow + V_c\uparrow$ (satisfy KVL)

At $\omega t = 90°$, $V_c = V_s$ $\therefore V_L = 0$

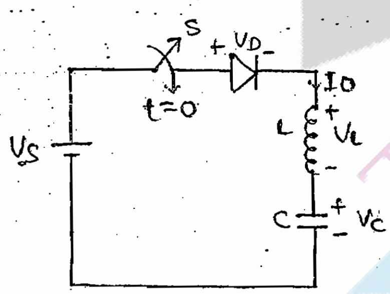
Mode(2.) → (90° to 180°)

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

$\downarrow$ $i\downarrow$; $\downarrow$ $V_c\uparrow$



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) $2V_s+V_0$

Sol^n → Applying KVL

$$V_s = V_D + V_L + V_c$$

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

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

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

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

$$V_C = V_S - V_L$$

$$\boxed{V_L = L\frac{d}{dt}(I_P \sin\omega_0 t) \quad V_L = (V_S - V_0)\cos\omega_0 t}$$

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

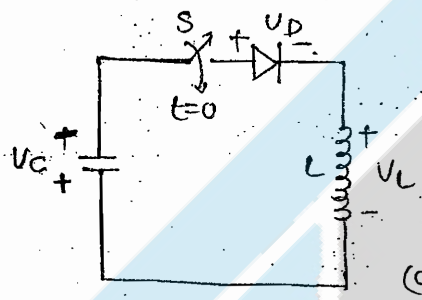
$$V_C = V_S(1 - \cos\omega_0 t) + V_0 \cos\omega_0 t$$

at $\omega t = 180^\circ$

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

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

Q.(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;

$$+V_C + V_D + V_L = 0$$

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

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

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

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

$$I_0 = I_P \sin\omega_0 t$$

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

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

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

$$= L I_P \omega_0 \cos\omega_0 t$$

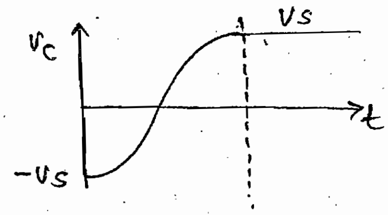
$$V_L = V_S \cos\omega_0 t$$

$$V_C + V_D + V_L = 0$$

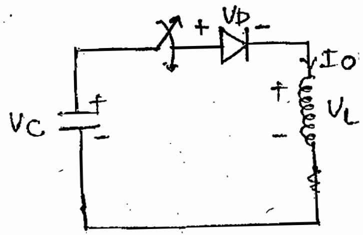
$$V_C = -V_L$$

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

$\boxed{PIV = V_S}$ $\boxed{V_C = V_S}$



Q.(4.)



Assume:- $V_C(t=0) = V_S$

$V_C = ?$

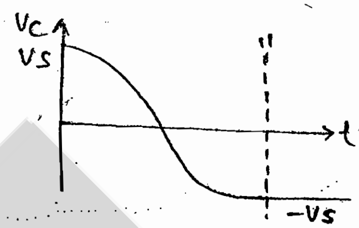
Sol^n →

$$-V_C + V_D + V_L = 0$$

$$V_C = V_L$$

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

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



$\cancel{I_0 =} I_p \sin\omega_0 t$, $I_p = V_S\sqrt{\frac{C}{L}}$, $\omega_0 = \frac{1}{\sqrt{LC}}$

& $V_C = V_L$

$$V_C = V_S \cos\omega_0 t$$

Initial vol. is V_S & final vol. will $-V_S$

$\boxed{V_C = -V_S}$

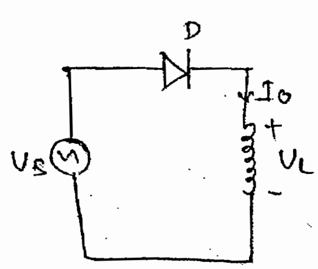
Note→ In LC ckt if capacitance is initaly charged with V_S volts then charging current of capacitor behaves as sine F^n given by

$$I_C = I_p \sin\omega_0 t$$

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°

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

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

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

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

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

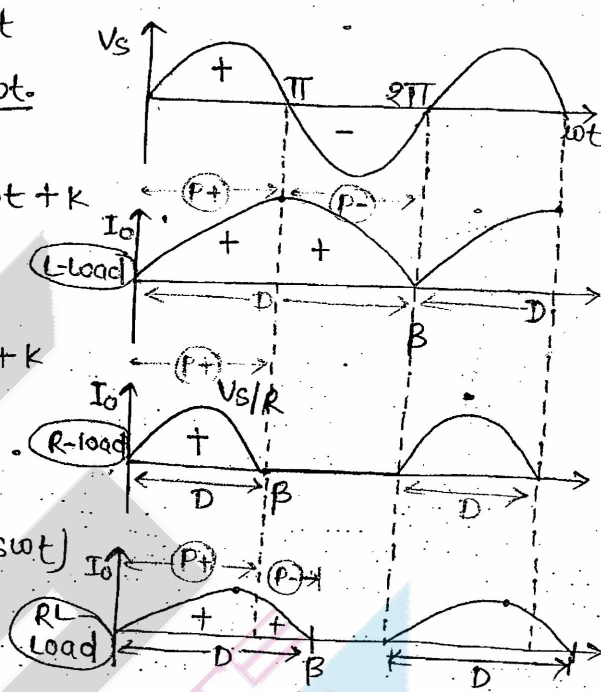
at $\omega t = 0$, $I_o = 0$

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

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

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

$\boxed{V_L = V_s \text{ For L Load}}$

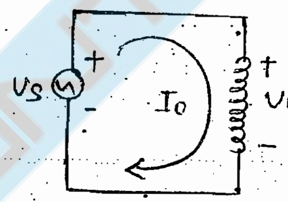


mode(1.) → 0 to 180° ⇒ P +ve

Power flow from source to load

Source $\xrightarrow{P}$ Load $(\frac{1}{2}Li^2)$

L → stores energy ($I_o \uparrow$)

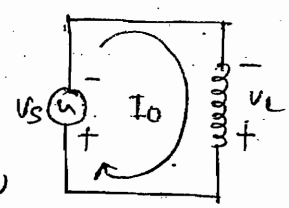


Mode(2.) → 180° to 360° ⇒ P → -ve

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.

$\boxed{\text{For pure inductor } \beta = 2\pi}$

where β = extinction angle

The angle at which current zero & diode stops conducting.

For pure Resistor;

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

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

Note →

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

$$P_o = V_o I_o = V_L I_o$$

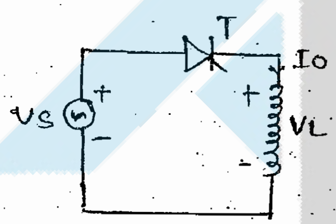
$V_o = 0$ (avg. voltage)

$I_o \neq 0$ (avg. current) [From waveform of I_o in L]

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

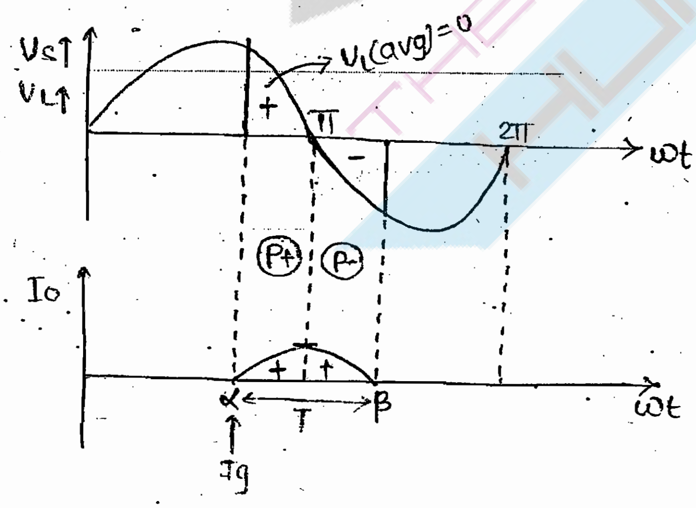
To make the avg. current 0, D is conducting for 360°

Q.(6.)



What is the value of β ?

Soln →

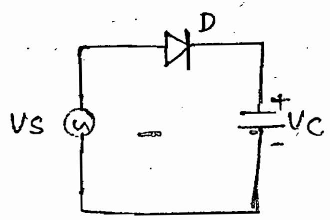


$$\beta = \pi + (\pi - \alpha)$$

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

(1.) $T\uparrow$, $\beta\uparrow$	$(T = L/R)$
(2.) $\alpha\uparrow$, $\beta\uparrow$	

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.

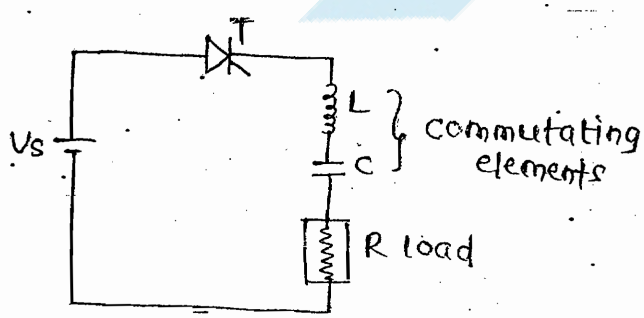
Eg. → (1.) Inverters (DC → AC)

(2.) Choppers (DC → DC)

(3.) Step up cycloconverter (AC → AC)

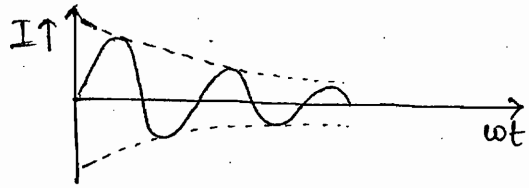
Classification of Forced Comm. →

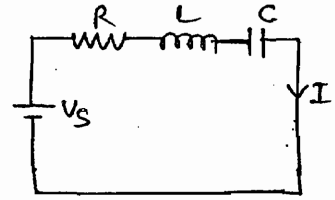
(1.) Class A →



* RLC should satisfy underdamped Condn.

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





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

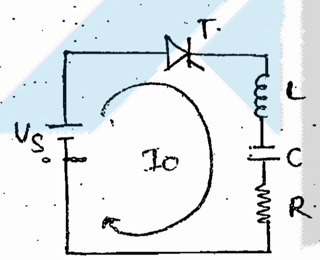
$\delta \rightarrow$ damping factor $\left(\frac{R}{2L}\right)$

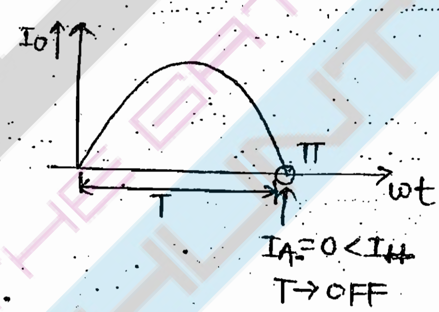
$\omega_r \rightarrow \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$ (Ringing factor)

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)

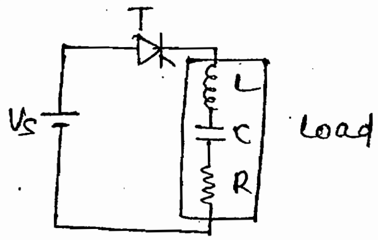
$$\boxed{t = \frac{\pi}{\omega_r} \text{ sec}}$$

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

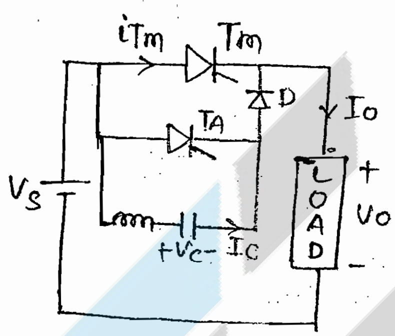
Q.→ What is load comm.?

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

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



(2.) Class-B Comm. (current comm.) →



$T_A \to$ Auxillary thyristor

$T_m \to$ main thy.

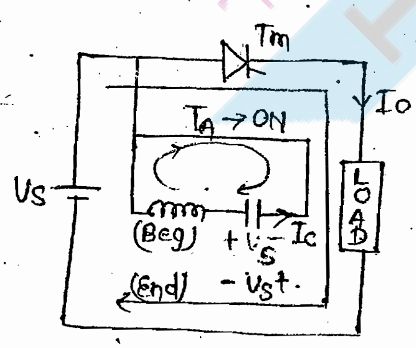
* To switch off the main thy. T_m we have to switch ON auxiliary thy. T_A

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. $(L\uparrow \; \frac{di}{dt}\downarrow)$

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

Mode (1.) → At $t=0$, $T_A \to$ ON



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

$V_C = V_S \cos \omega_0 t$

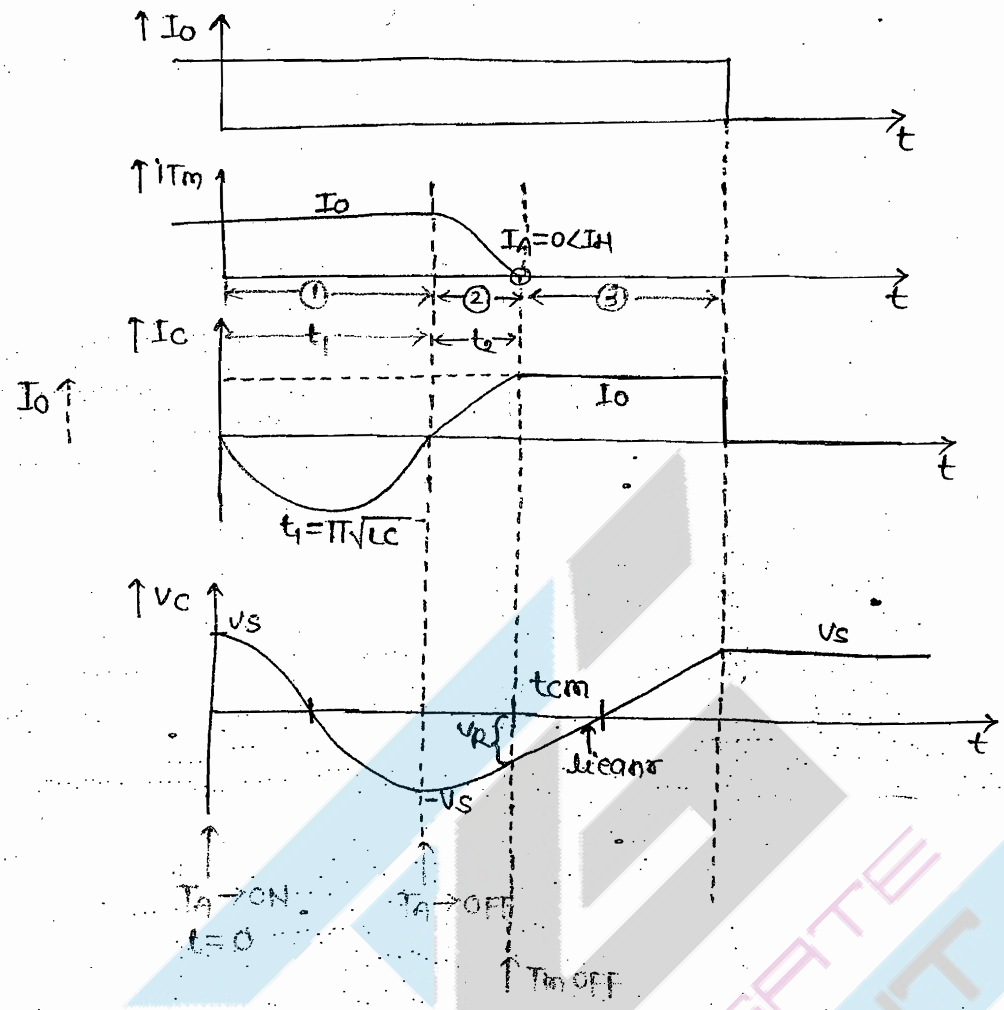
End:-

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

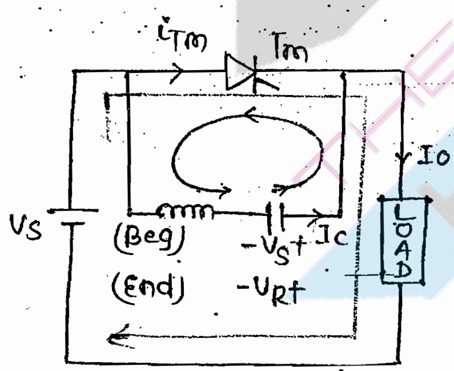
$V_C = -V_S$

$\omega_0 t_1 = \pi$

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



Mode (2)→



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

$\downarrow i_{Tm} = I_0 - I_c \uparrow$

END:- when $I_c = I_0$, $I_{Tm} = 0 < I_H$

$\therefore T_m \to OFF$

$I_c = I_0$

$I_p \sin\omega_0 t_2 = I_0$

$\omega_0 t_2 = \sin^{-1}\left(\frac{I_0}{I_p}\right)$

$t_2 = \frac{1}{\omega_0}\sin^{-1}\left(\frac{I_0}{I_p}\right)$

$$\boxed{t_2 = \sqrt{LC}\,\sin^{-1}\left(\frac{I_0}{I_p}\right)}$$

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

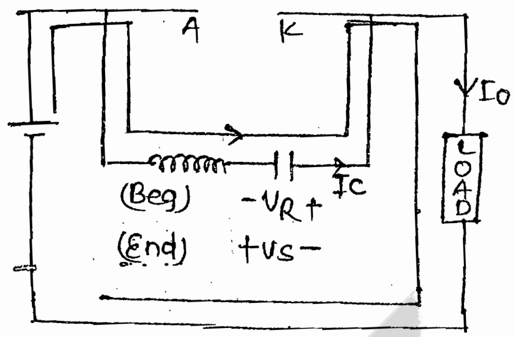
$V_c = -V_s\cos\omega_0 t_2$

$$\boxed{V_c = -V_s\cos\left[\sin^{-1}\left(\frac{I_0}{I_p}\right)\right]}$$

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

$$\boxed{V_R = V_s\cos\left[\sin^{-1}\left(\frac{I_0}{I_p}\right)\right]}$$

Mode (3.) →



$$I_C = I_o$$

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

t_{cm} = circuit turn OFF time

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

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

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

Objective question →

(1.) $(I_{TM})_{peak} = I_o$

(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 $t = t_1 + t_2$

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

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

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

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

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

$$(I_o = I_P)$$

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

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

(7.) If $I_0 > I_p$ then comm. is not possible. Therefore $I_0 \leq I_p$ (or) $I_0 = I_p$ to make comm. possible $\boxed{I_0 \leq I_p}$

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

$$\boxed{V_R = V_s \cos\left[\sin^{-1}\left(\frac{I_0}{I_p}\right)\right]}$$

(9.) $t_{cm} = \frac{C V_R}{I_0}$ (t_{cm} = circuit turn OFF time of main thy.)

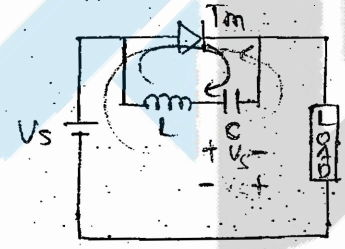
t_q = device turn off time

$\boxed{\begin{array}{l} t_{cm} > t_q \\ t_{cm} = (SF)\, t_q \end{array}}$ for succesfull commutation

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

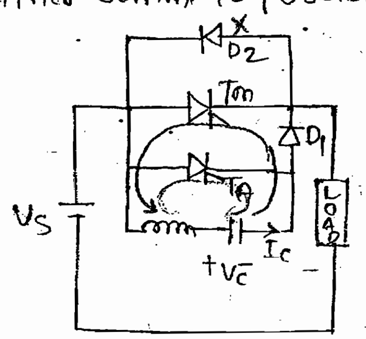
Q→ What is the purpose of diode in the comm. ckt?

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?



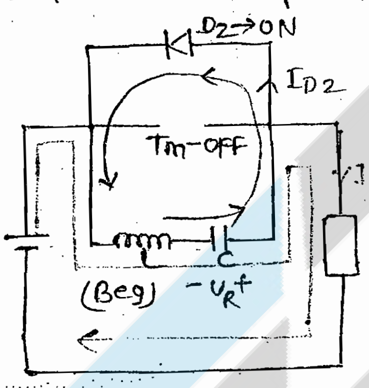
Ans→ 2 antiparallel devices can't conduct simultaneously because the vol. drop of conducting device applies a rev. vol. across the other device. Therefore the diode D2 will not conduct in the 2nd mode because main thy. is already conducting.

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?

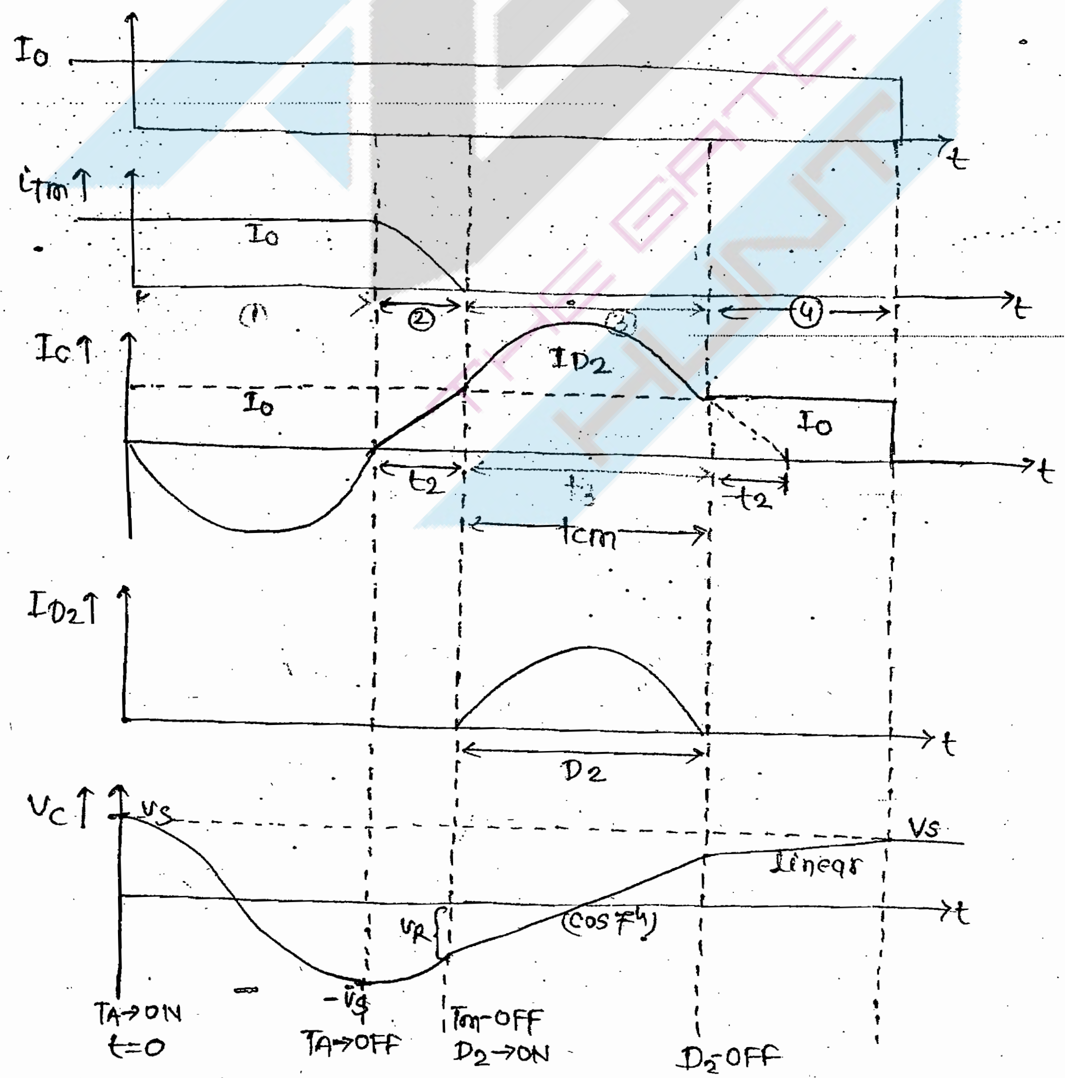
Soln→ 1st 2 modes are same as previous case.

mode ③ →



$I_C = I_0 + I_{D2}$

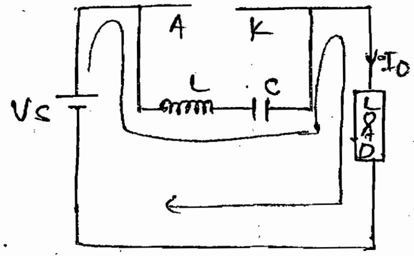
$\boxed{t_3 = \pi\sqrt{LC} - 2t_2}$



$I_C = I_O + I_{D2}$

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

mode(4) →



$I_C = I_O$

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

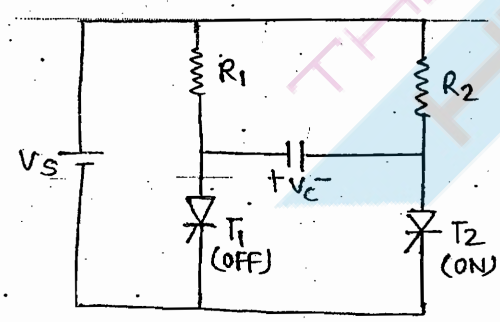
$$t_{cm} = \pi\sqrt{LC} - 2t_2$$

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

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

DATE- 07/08/14

(3.) Class C Comm. (Complementry Comm.) →



Assume:-

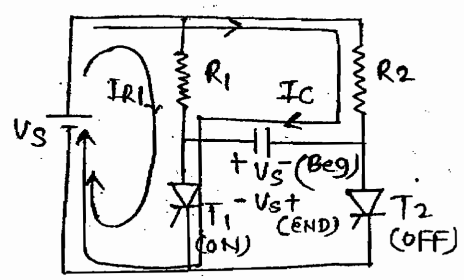
(i) $V_C(t=0) = V_S$

(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

$$I_C = k e^{-t/R_2C}$$

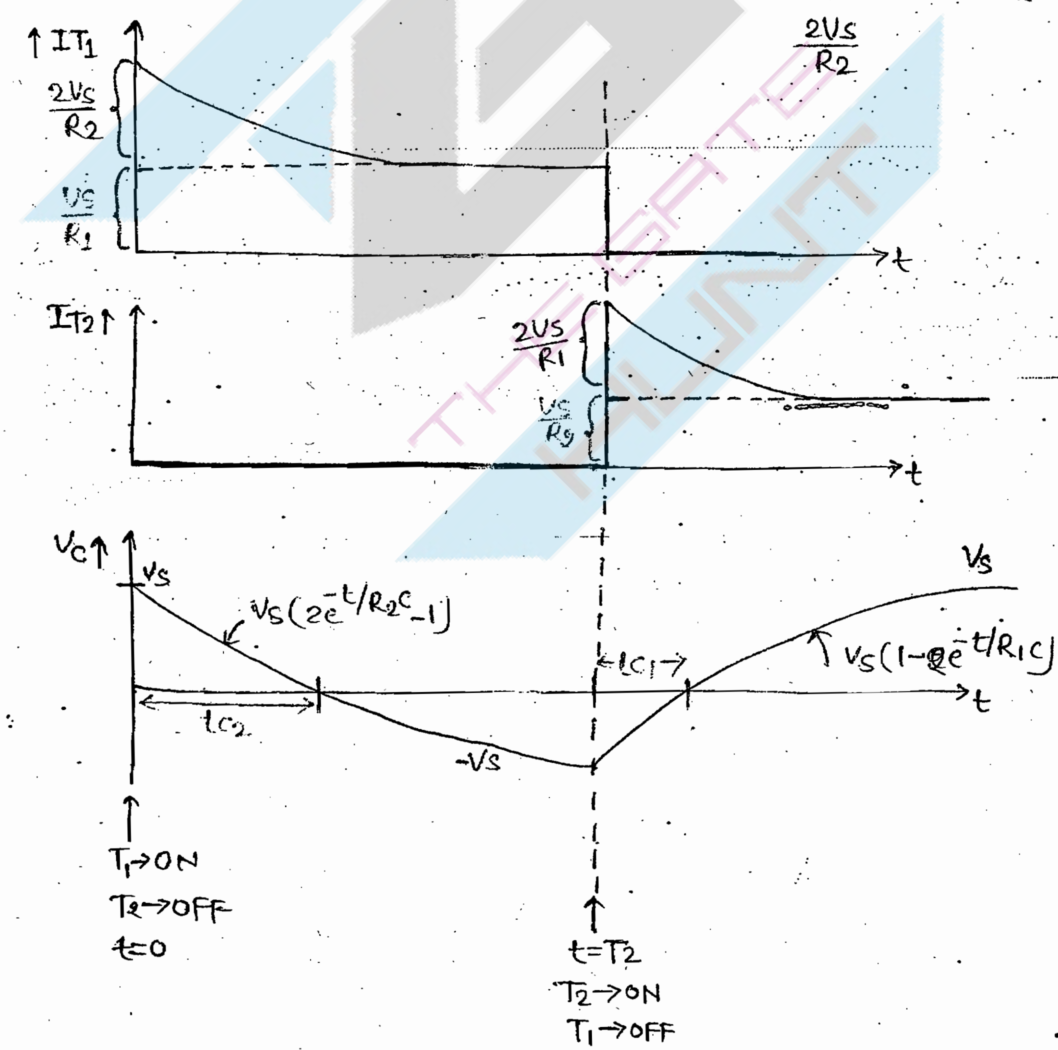
$k \rightarrow$ Initial value of current

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

$$I_C = \frac{2V_S}{R_2} e^{-t/R_2C}$$

Hence $I_{T_1} = \underbrace{\frac{V_S}{R_1}}_{\text{(Steady Current)}} + \underbrace{\frac{2V_S}{R_2} e^{-t/R_2C}}_{\text{(Transient current)}}$

initial transient ($t=0$) $\frac{2V_S}{R_2}$



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

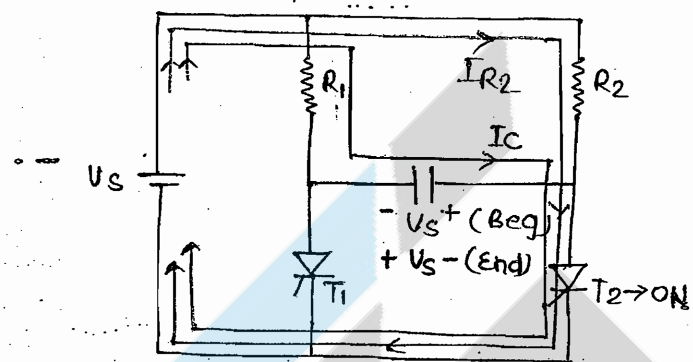
At $t = t_{c2}$

$V_C = 0$

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

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

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



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

$$I_{T2} = \underbrace{\frac{V_S}{R_2}}_{\text{Steady}} + \underbrace{\frac{2V_S}{R_1} e^{-t/R_1C}}_{\text{Transient}}$$

Circuit turn off time of 1st thy.

At $t = t_{c1}$

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

Objective questions →

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

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

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

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

From eqⁿ (ii) $$C = \frac{t_{c1}}{R_1 \ln 2}$$ $$\boxed{C = \frac{(SF)t_q}{R_1 \ln 2}} \text{ ——— (vi)}$$

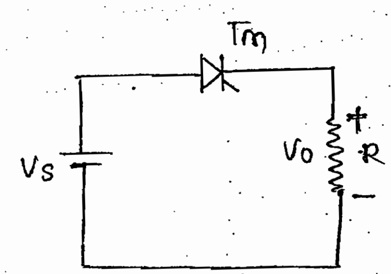
From eqⁿ (5.) & (6.) we get 2 diff. values for the commutating capacitance. We must consider the highest value to make the comm. possible.

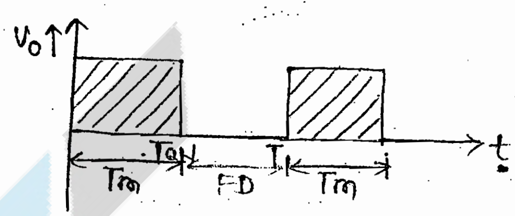
Application → Parallel inverter, Current source inverter.

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)

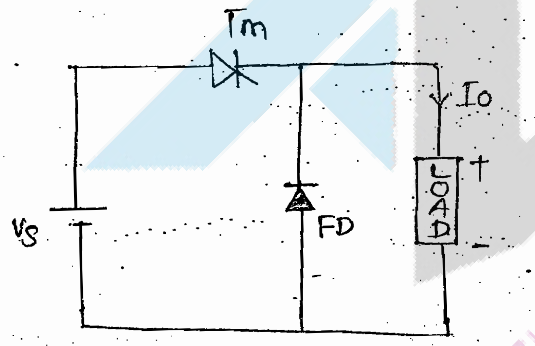




$$V_o = \frac{V_s T_{ON}}{T}$$

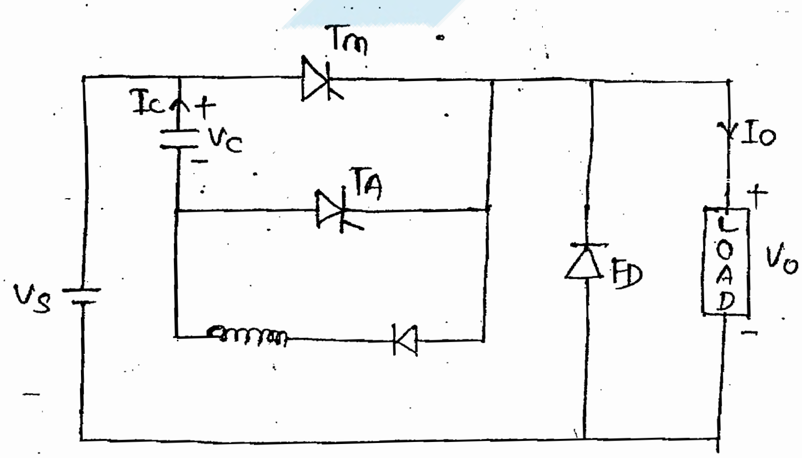
$$V_o = \alpha V_s$$

$\boxed{\alpha = \frac{T_{ON}}{T}}$ duty cycle



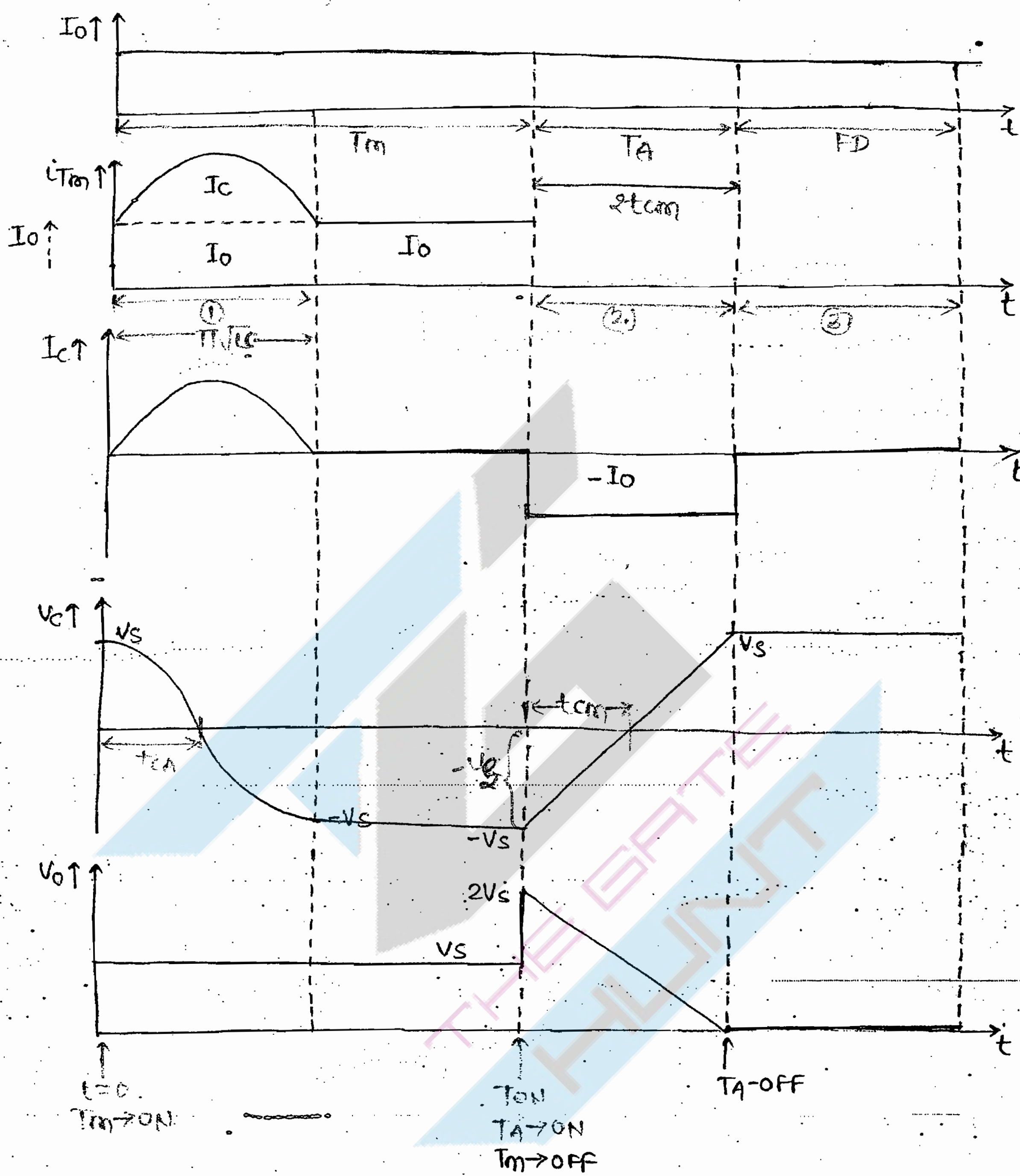
In the inductive load there is a need of FD; because the inductor will release the energy through FD.

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

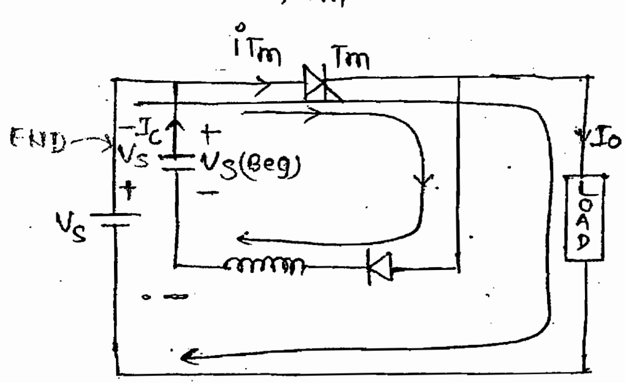


Assume:- (1.) $V_c(t=0) = V_s$

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



Mode(1) → At $t=0$, $T_m \to ON$



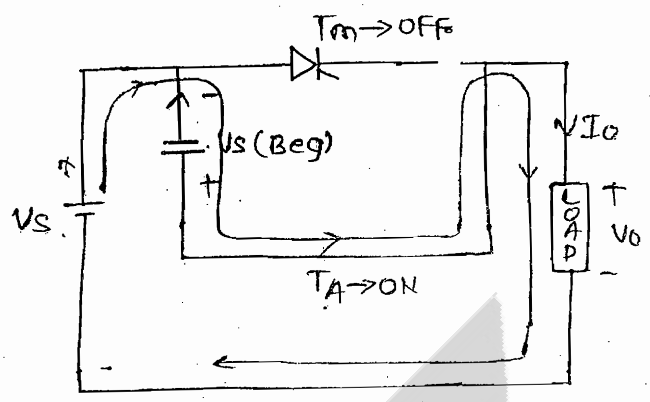
$i_{Tm} = I_o + I_c$

$I_c = I_p \sin \omega_o t$

$V_c = V_s \cos \omega_o t$

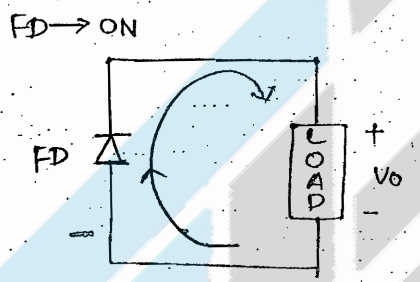
END :- $I_c = 0$, $V_c = -V_s$

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



$I_C = -I_O$
Beg. → $V_C = -V_S$
$V_O = 2V_S$
End → $V_C = V_S$
$V_O = 0$
$I_C = 0$

mode(3.) →



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

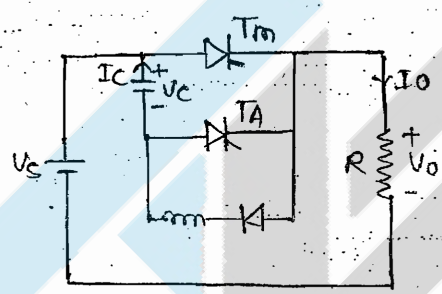
$$V_0 = V_S\left(\frac{T_{ON}+2t_{cm}}{T}\right) = \frac{V_S (T_{ON})_{eff}}{T}$$

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

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

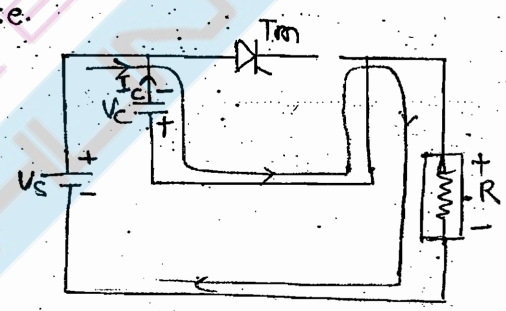
$$\boxed{(V_0)_{min} = V_S(\pi\sqrt{LC}+2t_{cm})f}$$

Q→ what is the ckt turn-off time of thy, with resistive load?



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

mode(2)→



$$I_0 = K e^{-t/RC}$$

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

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

Beg:- $V_C = -V_S$

$V_0 = 2V_S$

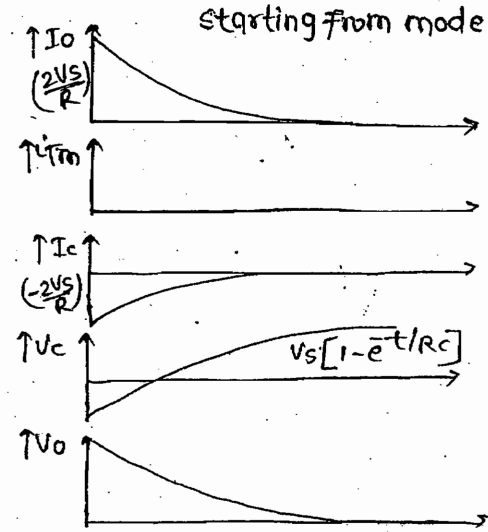
$I_0 = \dfrac{2V_S}{R}$

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

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

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

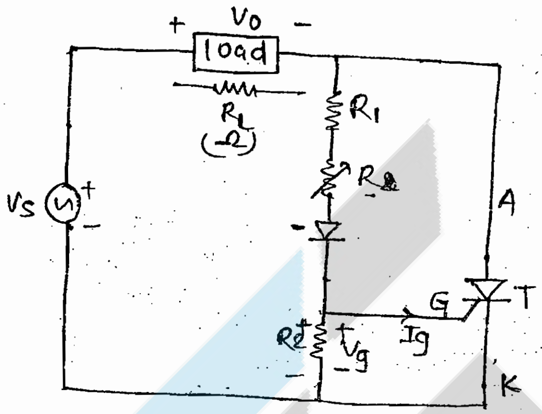
starting from mode(2·)



★ Firing Circuits → It gives the nessesary 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 $V_g \uparrow$ & it reaches V_{gt}, SCR → ON
($\omega t = \alpha$)

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

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

$\boxed{V_g = V_{gm} \cdot \sin\omega t}$ → T (OFF) then use eqⁿ

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

From above eqⁿ

$V_{gt} = V_{gm} \sin\alpha$; 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 $R = R_a$, $\alpha = \alpha_a$

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

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

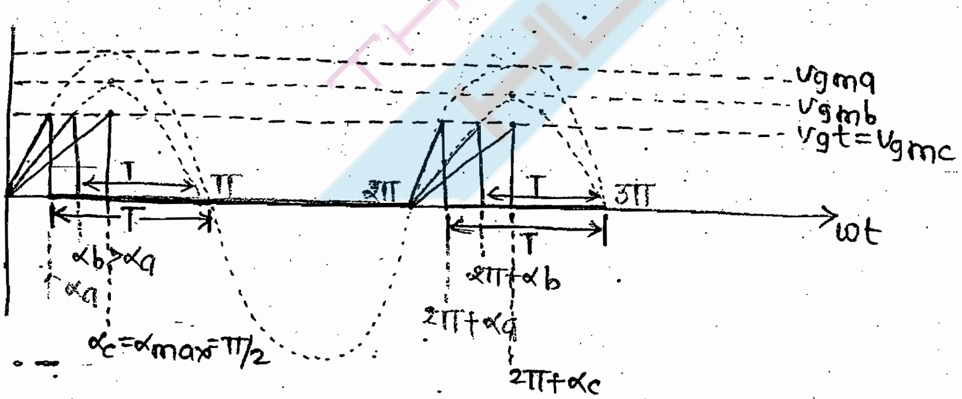
$V_{gt} \uparrow$

$V_{ga} \uparrow$

$V_{gma} \uparrow$

$V_{gb} \uparrow$

$V_{gmb} \uparrow$



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 $R = R_c$, $\alpha = \alpha_c$

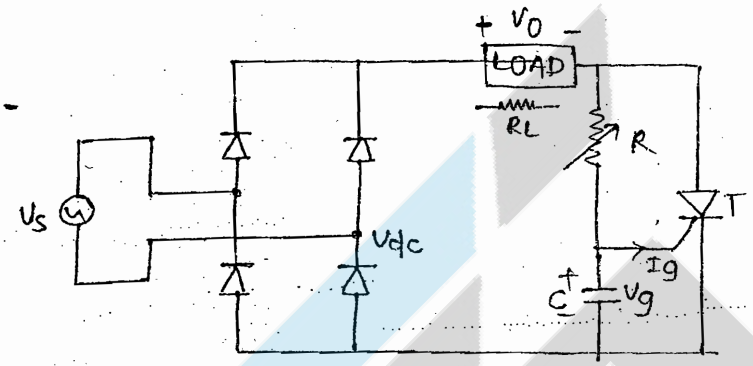
$V_{gmc} = V_{gt}$, $\alpha_{max} = \pi/2$

Drawback →

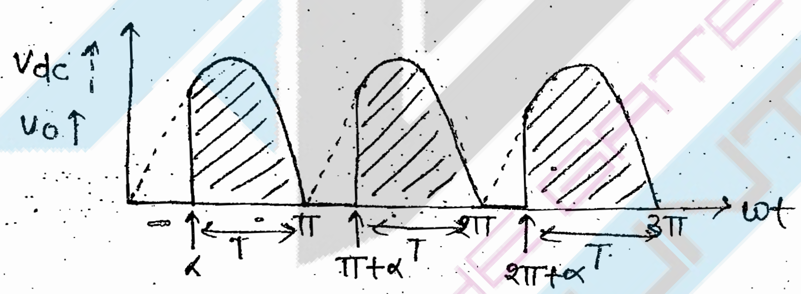
The max^m α is limited to 90°.

(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 $R = R_b > R_a$

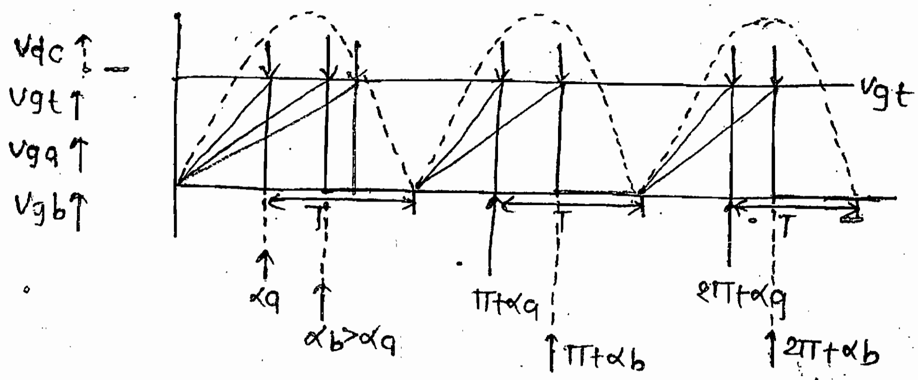
$(\alpha = \alpha_b)$

$T_b > T_a$

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

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

Hence the α will be increases.



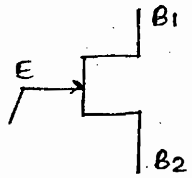
$\boxed{V_{gt}=0 \text{ (ideal SCR)}}$

$0<\alpha<180$

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

UJT

UJT

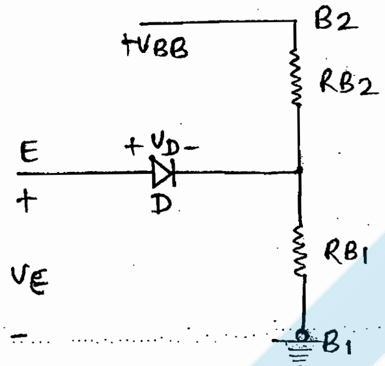


B_1 & B_2 are Base terminal

E – Emitter terminal.

UJT – unijunction transistor.

Equivalent circuit of UJT →

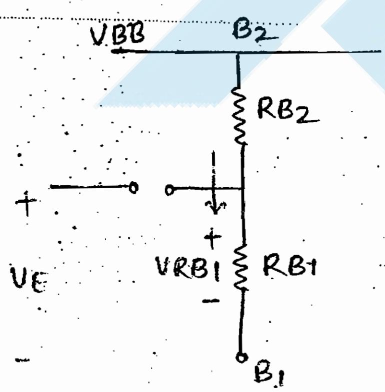


UJT

* R_{B_1} & R_{B_2} → High value (off state)

* Diode is on then UJT on
diode is off then UJT off

Suppose diode is off;



$$V_{RB_1} = \left(\frac{R_{B_1}}{R_{B_1}+R_{B_2}}\right) V_{BB}$$

$$V_{RB_1} = \eta V_{BB}$$

$$\boxed{\eta = \frac{R_{B1}}{R_{B_1}+R_{B_2}}}$$ Intrinsic stand off Ratio.

η = Intrinsic stand off ratio

Let; $V_P = V_{RB_1} + V_D$

$V_P = \eta V_{BB} + V_D$

(V_P → Peak point voltage)

↑V_E & when is reaches to V_P then the UJT will turn on

↑$V_E \Rightarrow V_P$, UJT → ON

* UJT exibits –ve resistance character.

Therefore when UJT starts conducting the base resistance R_{B1} starts decreasing.

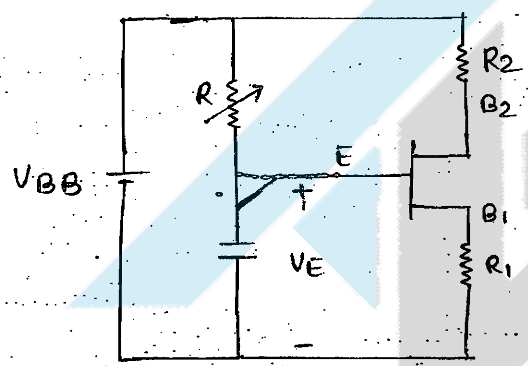
Therefore emitter vol. starts decreasing when UJT starts conducting.

$$\downarrow V_E \Rightarrow V_V, \ UJT \rightarrow OFF$$

$$V_V = \text{Value voltage}$$

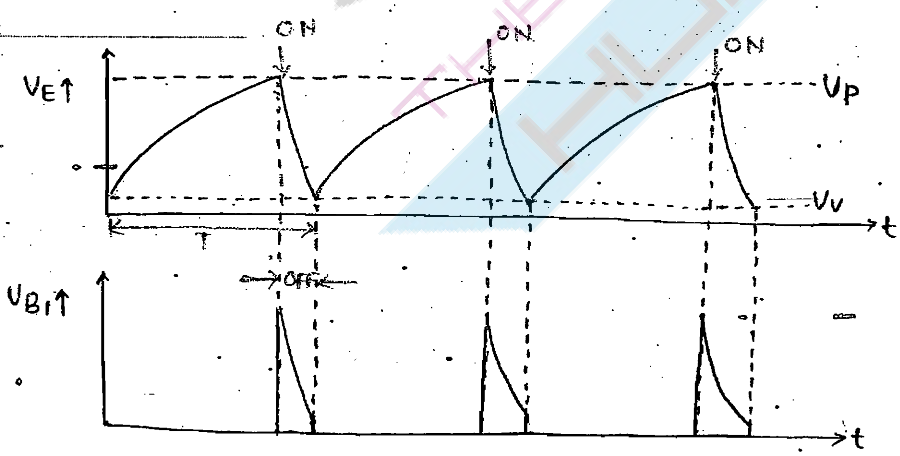
* When emitter vol. starts decreasing & reaches to V_V then UJT → OFF

* UJT working as Relaxation oscillator →



UJT → OFF, $V_{B1} = 0$

UJT → OFF, base vol. will charge the capacitor.

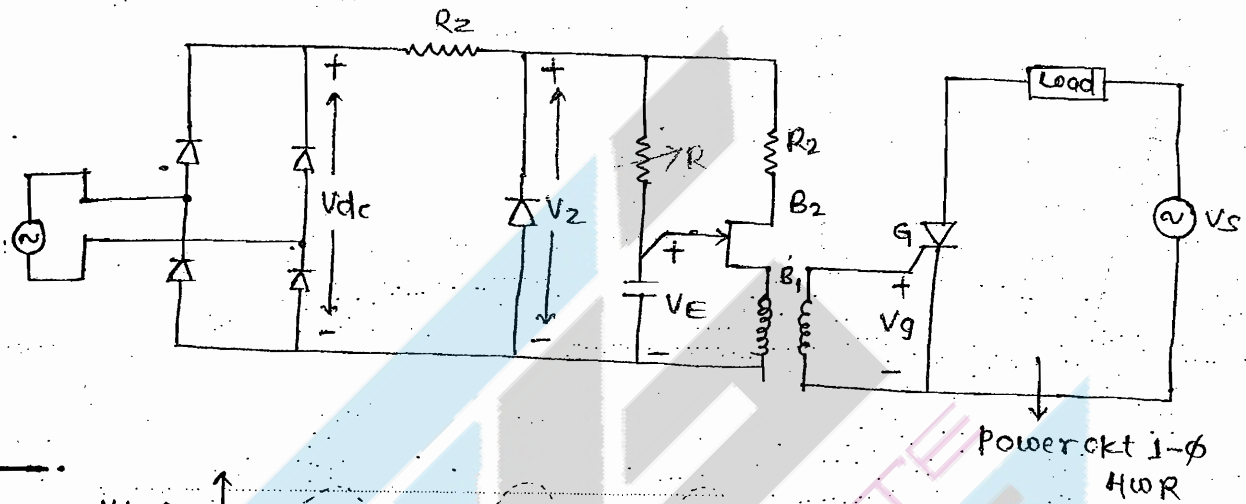


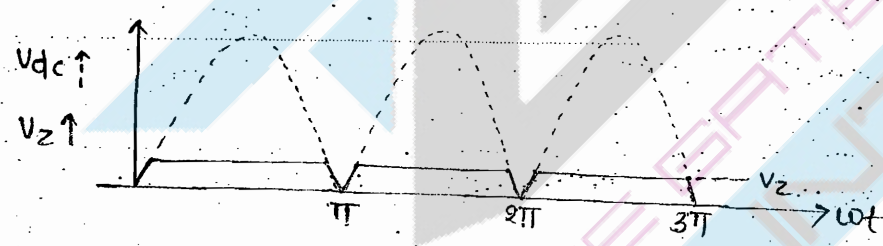
$$T = RC \ln\left(\frac{1}{1-\eta}\right)$$

$$\boxed{f = \frac{1}{RC \ln\left(\frac{1}{1-\eta}\right)}}$$

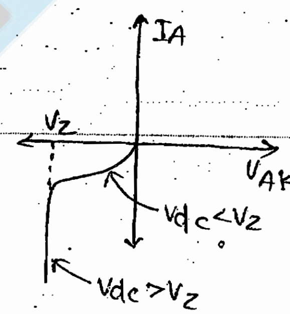
* Synchronised UJT firing ckt →

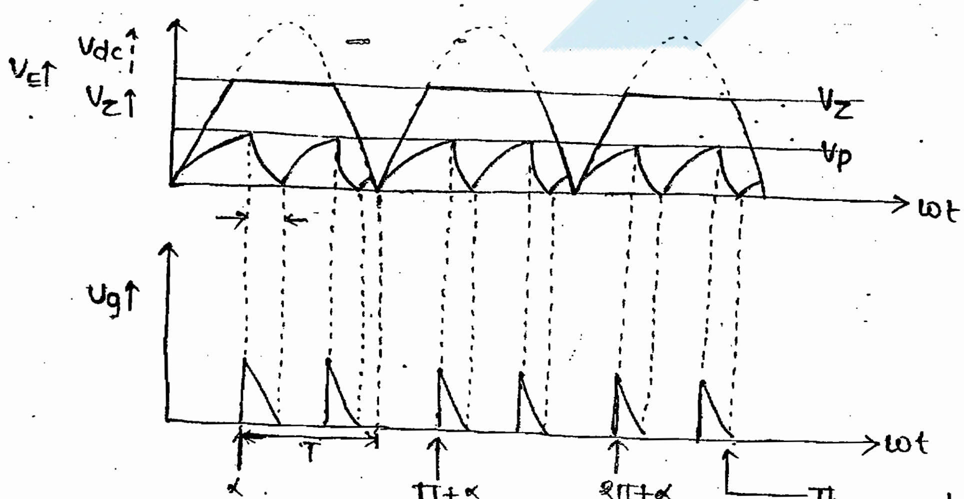
* We must synchronised the firing ckt wrt to the main ckt power supply to match the timings of gate pulse in both the ckt.
* Therefore we must use same power supply in both the ckts for the purpose of synchronisation.





(Still we are not getting the pure dc in 2% variation)



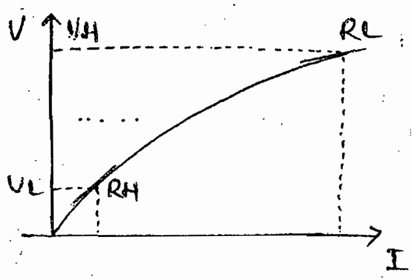


These extra gate pulse will not effect

Protection OF Thyristor

(1.) **Over Current Protection →** * We must connect either Fuse (or) CB in series with thy. for OC protection.

(2.) **Over Voltage Protection →**



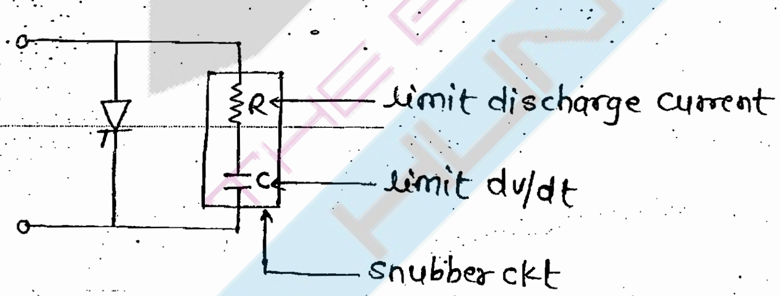
* We must connect a variastor across the thy.
* Variastor is a non-linear restiotor
* All metal oxide resistor behave as non-linear resistor.

eg:- ZnO (zink oxide)

(3.) **$\frac{dv}{dt}$ protection →**

$$\uparrow I_c = C_j \frac{dv}{dt} \uparrow \quad \& \uparrow I_c \text{ then SCR ON}$$

* At high $\frac{dv}{dt}$ the SCR may turn ON before the gate pulse is given.
* This is an accidental turn-ON.
* This unwanted turn-ON is known as False turn-ON.
* dv/dt protection is needed to avoid the False turn ON.



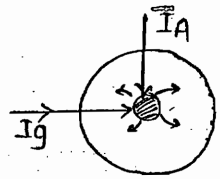
* This ckt is known as Vol. snubber because of dv/dt.

Que.→ What is a snubber ckt?

Ans→ When SCR is undergoing switching operation (ON ⇄ OFF) it is subjected to high ele. stress ($\frac{dv}{dt}$ stress, di/dt stress, overvol. etc)

* The snubber ckt will limit the ele. stress & protect the SCR during switching operations.

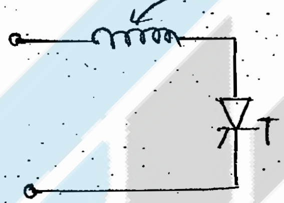
(iv) di/dt Protection →



$\uparrow \frac{di_A}{dt} >$ spread velocity of charge carrier

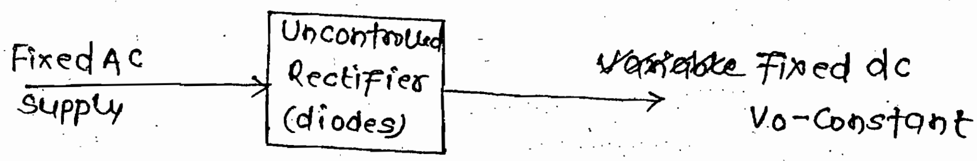
<u>effect of high di/dt</u> → * If di/dt > spread velocity of charge carriers then the charge density increases cumulatively in a small cond^n area & this results in the formation of local hotspots damaging the device

* We must connect an inductor in series with SCR for di/dt protection.

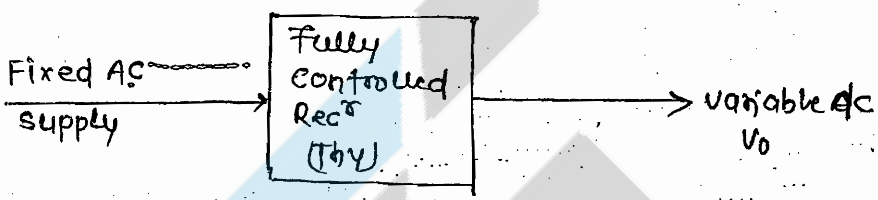


Phase Controlled Rectifier

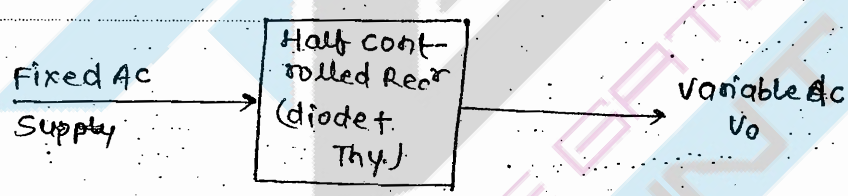
* Uncontrolled Rectifier →



Fully controlled Rectifier → (full converter)
2 quadrant operations



Half controlled Rectifier → (semiconverter)
one quadrant operation.

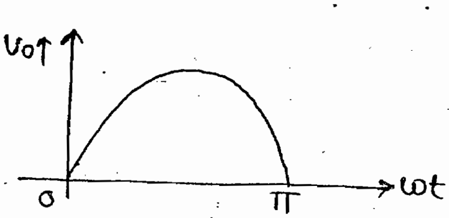


Classification of Converter based on pulse no. of the converter →

Pulse no. 'm' → pulse no. gives the no. of the o/p pulse for 1 cycle AC source voltage.

(i) One pulse con^r →

1-ϕ half wave rec^r.

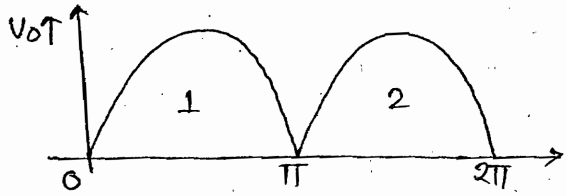


$$T_0 = \frac{2\pi}{m} = \frac{2\pi}{1} \Rightarrow T_0 = 2\pi \text{ rad.}$$

$$f_0 = f_s$$

(2.) Two pulse conr →

1-ϕ Full wave recr



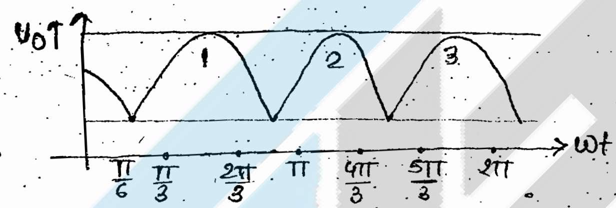
$T_o = \frac{2\pi}{2} = \pi$ rad.

$F_o = 2F_s$

T_o = Time period pulse in rad $= \frac{2\pi}{m}$ (rad)

3.) 3 pulse conr →

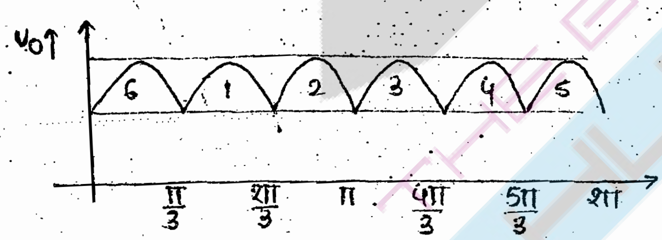
3-ϕ half wave rectifier



$T_o = \frac{2\pi}{3} = 120°$

$F_o = 3F_s$

4.) 6 pulse conr →



$T_o = \frac{2\pi}{6} = \frac{\pi}{3}$ rad.

$F_o = 6F_s$

$F_o = mF_s$

where F_o = o/p ripple Freq.

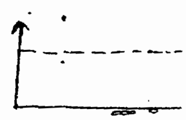
F_s = supply Freq.

$m\uparrow, T_o\downarrow, F_o\uparrow$, ripple vol. $\downarrow$ $\therefore$ Harmonics$\downarrow$

nps →

$$\underset{50Hz}{AC} \xrightarrow{(1)} DC \xrightarrow[(MOSFET)]{(2)} AC \longrightarrow \text{pure DC}$$

$F\uparrow$ (50KHz to 100KHz)

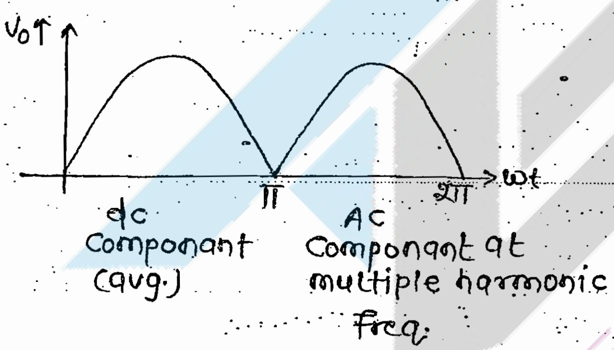


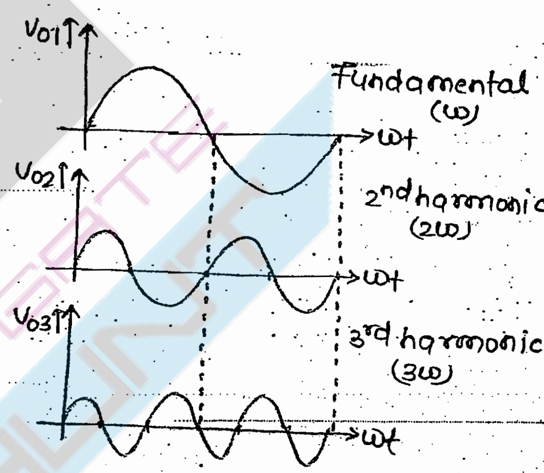
* Effect of harmonics on the performance of dc motor →

* Harmonics overheat the m/c wdg, & Hence we can't use (utilise) the m/c to its full capacity.
  Therefore we must derate the m/c when fed to conⁿ.
* Harmonics produce pulsating torque in rotor & hence smooth rotation may not be possible if it is used for power motors.
* The rotor inertia will damp for
* This pulsating torque produced by harmonics & hence smooth rotation is possible for bigger m/c.

Harmonics Analysis on the dc side of the converter →

Let us consider a 2 pulse converter





* Mathematical Formula for Fourier analysis →

$$V_0 = \underset{(avg)}{a_0} + \sum_{n=1}^{\infty} (a_n \cos\omega t + b_n \sin n\omega t)$$

$$V_0 = a_0 + \sum_{n=1}^{\infty} C_n \sin(n\omega t + \phi_n) \qquad \text{where } C_n = \sqrt{a_n^2 + b_n^2}$$

ϕ_n = nth harmonic displacement angle.

O/P RMS voltage

$$V_{or} = \sqrt{V_0^2 + V_{01}^2 + V_{02}^2 + V_{03}^2 + \cdots}$$

For all the dc loads avg. value is responsible to deliver the useful power.

$$V_{or}^2 = V_0^2 + V_{01}^2 + V_{02}^2 + \cdots$$

$$V_{or}^2 - V_0^2 = V_{01}^2 + V_{02}^2 + \cdots$$

$$\sqrt{V_{or}^2 - V_0^2} = \sqrt{V_{01}^2 + V_{02}^2 + \cdots} = V_{oH}$$

Voltage Ripple Factor (VRF) → It is a measure of harmonics on the dc side of converter.

$$VRF = \frac{\sqrt{V_{or}^2 - V_0^2}}{V_0}$$

$$\boxed{VRF = \sqrt{\left(\frac{V_{or}}{V_o}\right)^2 - 1}}$$

Form factor →

$$FF = \frac{V_{or}}{V_o}$$

$$\boxed{VRF = \sqrt{FF^2 - 1}}$$

Perfact dc → (1.) No ripple
(2.) $V_{or} = V_o$
(3.) $FF = 1$
(4) $VRF = 0$ (No harmonics)

Significance of FF :-

- Without harmonics $FF = 1$
- With harmonics $FF > 1$
- As the FF decreases & reaches to unity then smoothness of wave form is improved towards dc.
- FF gives the information on shape of waveform on dc side of converter.

Harmonics analysis of the ac side of converter →

Let us consider an inverter

* The o/p vol. waveform of the inverter may not be pure sinusoidal, it may contains harmonics.
* For all the ac loads fundamental componant is responsible to deliver usefull power.

$$V_{or} = \sqrt{V_0^2 + V_{o1}^2 + V_{o2}^2 + \cdots}$$

$$\sqrt{V_{or}^2 - V_{o1}^2} = \sqrt{V_0^2 + V_{o2}^2 + \cdots}$$

Total harmonic distortion (THD) → It is measure of harmonics on Ac side of the con^r.

$$THD = \frac{\sqrt{V_{or}^2 - V_{o1}^2}}{V_{o1}}$$

$$\boxed{THD = \sqrt{\left(\frac{V_{or}}{V_{o1}}\right)^2 - 1}}$$

Distortion factor 'g' → It gives the information of waveform on Ac sides.

$$\boxed{g = \frac{V_{o1}}{V_{or}}} \qquad \boxed{THD = \sqrt{\frac{1}{g^2} - 1}}$$

Perfact AC →

(1.) $V_{or} = V_{o1}$

(2.) $g = 1$

(3.) THD = 0 (No harmonics)

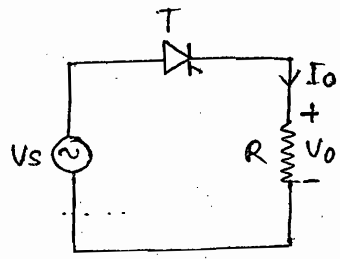
Significance of distortion factor →

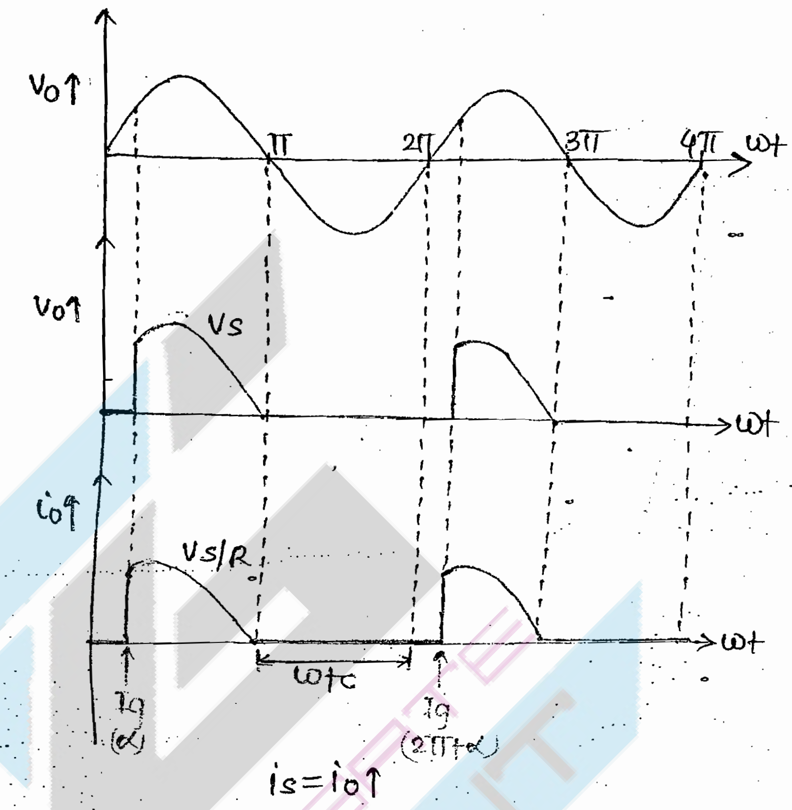
(1.) Without harmonics $g = 1$

(2.) With harmonics $g < 1$

(3.) As g value is increased & approches unity then smoothness of waveform is improved towards sinusoidal.

(1.) 1-ϕ Half wave Rectifier (One pulse converter) →





$\omega t_c = \pi$ rad

$t_c = \frac{\pi}{\omega}$ sec

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

$$= \frac{V_m}{2\pi}(-\cos\omega t)_{\alpha}^{\pi}$$

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

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

$$I_0 = \frac{V_0}{R} = \frac{V_m}{2\pi R}(1+\cos\alpha)$$

$$\boxed{I_0 = \frac{V_m}{2\pi R}(1+\cos\alpha) = (I_s)_{avg.}}$$

Drawback → The source current contains dc componants & saturates the supply T/F core.

Therefore HWR is generaly not prefered for applications.

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

$$V_{or} = \left[\frac{V_m^2}{2\pi}\left\{(\omega t)_{\alpha}^{\pi} - \frac{1}{2}(\sin 2\omega t)_{\alpha}^{\pi}\right\}\right]^{1/2}$$

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

$$\boxed{V_{or} = \frac{V_m}{\sqrt{2T_0}}\left[(U-L) + \frac{1}{2}(\sin 2L - \sin 2U)\right]^{1/2}}$$

$P_{in} = V_{sr} \cdot I_{sr}\, PF$ -------(i)

$V_s = V_m \sin\omega t$; $V_{sr} = \frac{V_m}{\sqrt{2}}$

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

$P_{in} = V_{sR}\, I_{sr} \cos\phi_1$ ----- (ii)

$P_o = V_o I_o$ ✗

i.e. For resistive load take Rms values.... i.e.;

$P_o = V_{or} \cdot I_{or}$

Assuming no losses in the thy,

$V_{sr} \cdot \cancel{I_{sr}} \cdot PF = V_{or} \cdot \cancel{I_{or}}$

$\boxed{PF = \frac{V_{or}}{V_{sr}}}$ For R load

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

(1.) The supply current contains harmonics on Ac side of the converter. In general (other then resistive load) Fundamental source current is responcible to deliver useful power on Ac side of the conr.

Fundamental displacement factor (FDF) $= \cos\phi_1$

$\cancel{V_{sr}} \cdot I_{sr} \cdot PF = \cancel{V_{sr}} \cdot I_{s1} \cos\phi_1$

$PF = \frac{I_{s1}}{I_{sr}} \cdot \cos\phi_1$

$PF = g \cdot \cos\phi_1$

$\boxed{PF = g \cdot FDF}$

(1.) PF depends on Firing angle α. As α increases PF is decreases.

(2.) PF depends on the shape of supply current waveform, i.e. it depends on Harmonics on the Ac side of con^r

$$\boxed{PF = g \cdot FDF}$$

(3.) PF also depends on type of the con^r & type of load.

Drawback of PE con^r →

(1.) The con^r injects harmonics into the supply & reduce its power quality.

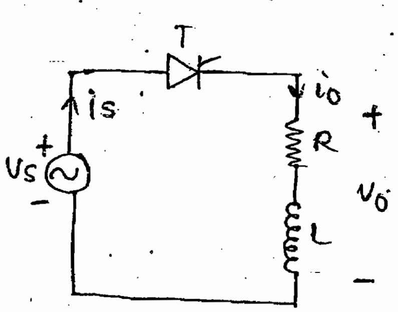
To rectify this problem we must use Ac Filter on Ac side of the con^r.

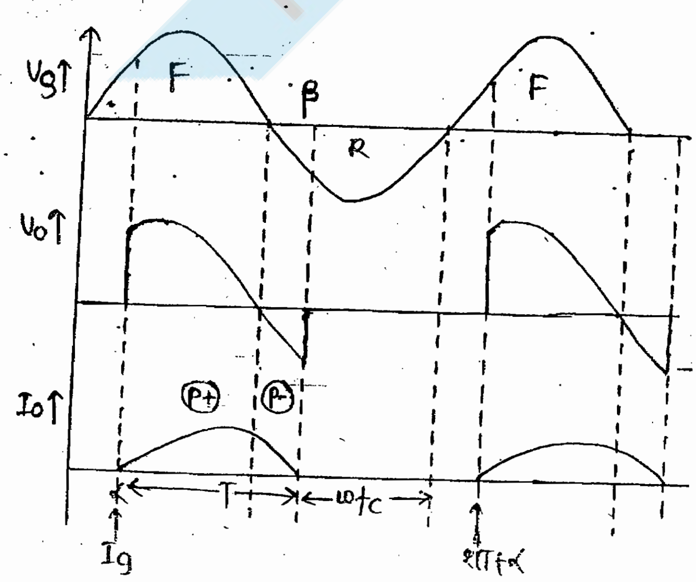
(2.) At high values of Firing angle α, the PF is very low.

Therefore it draws very high lagging reactive power from the supply.

* To rectify this problem we must connect a reactive power source on Ac side of con^r to compensate the required reactive power for the con^r operation.

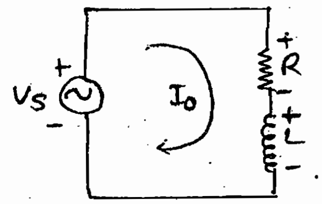
2.) 1-ϕ HWR (RL load) →





Mode(1) → (α to π)

$V_0 = V_s$



* Power Flows From Source to the load so power is +ve i.e. (P+)

Apply KVL;

$$V_s = V_m \sin\omega t = R i_0 + L\frac{di_0}{dt}$$

$$i_0 = \underset{(PI)}{I_{steady}} + \underset{(CF)}{I_{transient}}$$

$$i_0 = \frac{V_m}{|Z|}\sin(\omega t - \phi) + K e^{-t/T}$$

at $\omega t = \alpha$, $i_0 = 0$

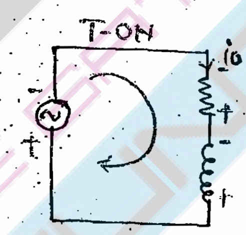
$$K = \frac{V_m}{|Z|}\left(e^{t/T}\right) \times \sin(\alpha - \phi)$$

$$\boxed{K = \frac{-V_m}{|Z|}\sin(\alpha - \phi)\, e^{\frac{-R\alpha}{\omega L}}}$$

mode(2) → (π to β)

$\frac{1}{2}Li^2 \longrightarrow$ Source & I^2R

L is releasing energy



* Here the inductance energy makes the thy. to conduct even in the -ve cycle untill it releases its complete energy at $\omega t = \beta$

$$\downarrow PF = \frac{P_0 \downarrow}{V_{sr} I_{sr}}$$

$$\omega t_c = 2\pi - \beta$$

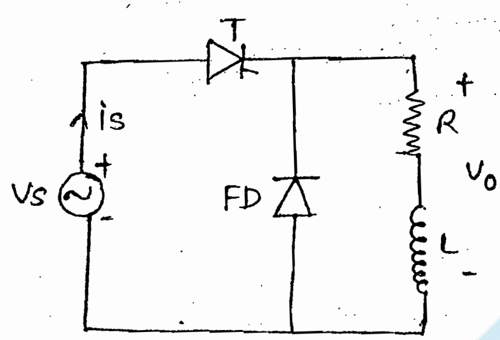
$$\boxed{t_c = \frac{2\pi - \beta}{\omega} \text{ sec}}$$

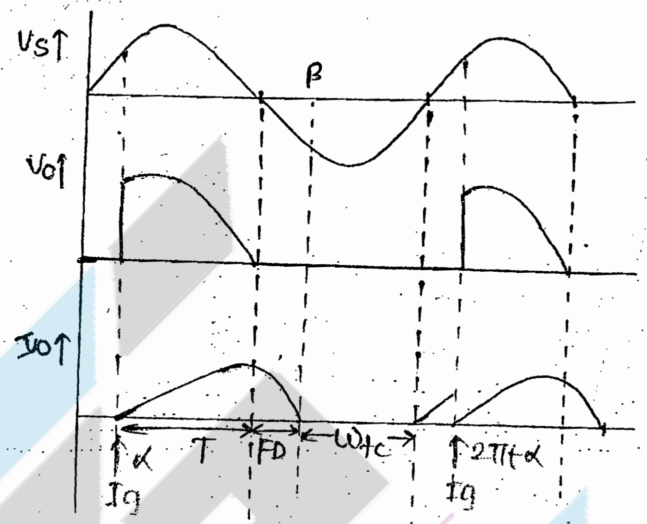
$$V_0 = \frac{1}{2\pi}\int_{\alpha}^{\beta} V_m \sin\omega t\, (d\omega t)$$

$$\boxed{V_0 = \frac{V_m}{2\pi}(\cos\alpha - \cos\beta)}$$

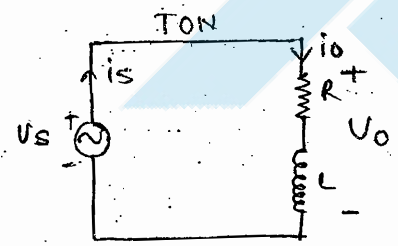
$$V_{or} = \frac{V_m}{2\sqrt{\pi}}\left[(\beta-\alpha) + \frac{1}{2}(\sin 2\alpha - \sin 2\beta)\right]^{1/2}$$

3) 1-ϕ HWR RL load with FD→

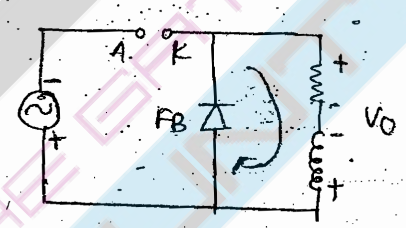




mode(1)→



mode(2)→



urce $\xrightarrow{P}$ load

$\frac{1}{2}Li^2 \rightarrow I^2R$

PF improved, $PF = \frac{P_o}{V_{sr}I_{sr}}$

$$V_o = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t\, (d\omega t)$$

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

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

$\omega t_c = \pi$ rad

$$\boxed{t_c = \frac{\pi}{\omega}}$$

* −ve power is removed i.e. avg. P_o is increased; so PF is increased.

$$\uparrow PF = \frac{P_o \uparrow}{V_{sr} I_{sr}}$$

Advantage of FD →

(1.) The PF is improved on AC side of the conʳ.

(2.) −ve Voltage spikes in the o/p voltage waveform is removed; thus increased o/p voltage, active power & PF.

(3.) The shape of the o/p current waveform is improved.

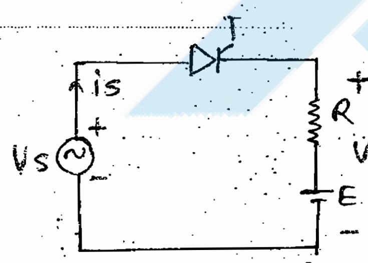
Hence the performance of the converter is improved with a FD.

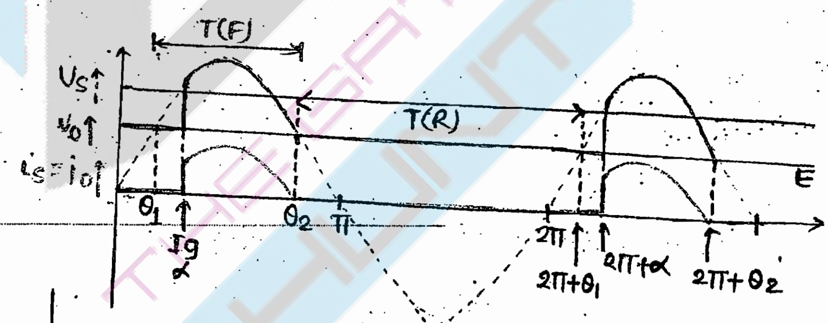
* The PF of the semiconvʳ is better than Full convʳ due to its freewheeling action.

Therefore the performance of the semiconʳ is superior to Full conʳ.

Application →

1-φ HWR charging a battery (RE load) →





$+V_s > E$, T(F)

At $\omega t = \theta_1$, $V_s = E$

$$V_m \sin\theta_1 = E$$

$$\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right)$$

$$\theta_2 = \pi - \theta_1$$

$$\theta_1 \le \alpha \le \theta_2$$

T(ON)

$V_o = V_s$

$V_s = R i_o + E$

$$i_o = \frac{V_s - E}{R}$$

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

T → (OFF)

$i_o = 0$, $V_o = E$

$$\omega t = 2\pi + \theta_1 - \theta_2$$

$$= 2\pi + \theta_1 - \pi + \theta_1$$

$$\omega t_c = \pi + 2\theta_1 \text{ rad.}$$

$$\boxed{t_c = \frac{\pi + 2\theta_1}{\omega} \text{ sec}}$$

* PIV of thyristor $= V_m + E$

$$V_{o(avg)} = \frac{1}{2\pi}\left[\int_{\alpha}^{\theta_2} V_m \sin\omega t \, d(\omega t) + \int_{\theta_2}^{2\pi+\alpha} E \, d(\omega t)\right]$$

$$V_{o(avg)} = \frac{1}{2\pi}\left[V_m(\cos\alpha - \cos\theta_2) + E\frac{(2\pi+\alpha-\theta_2)}{Rad.}\right]$$

Charging current of Battery

$$I_o = \frac{1}{2\pi}\int_{\alpha}^{\theta_2}\left(\frac{V_m \sin\omega t - E}{R}\right) d(\omega t)$$

$$I_o = \frac{1}{2\pi R}\left[V_m(\cos\alpha - \cos\theta_2) - E\frac{(\theta_2-\alpha)}{Rad}\right]$$

* when the diode rectifier is charging a battery substitute $\alpha = \theta_1$ in the above eqn to find the V_o & I_o

$$P_{in} = V_{sr} I_{sr} PF$$

$$P_o = I_{or}^2 R + E I_o$$

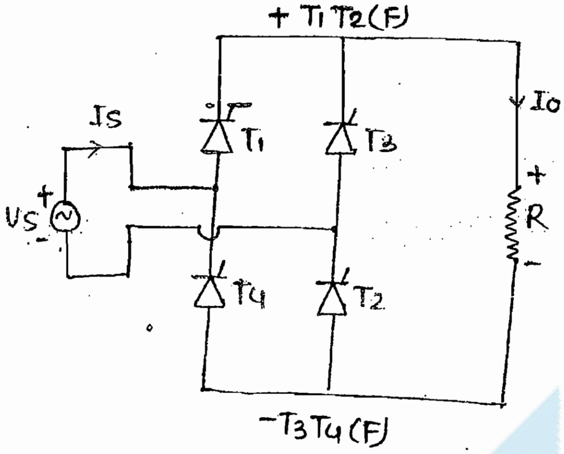
Assuming no losses in thy. i.e. we get;

$$\boxed{PF = \frac{I_{or}^2 R + E I_o}{V_{sr} I_{sr}}}$$

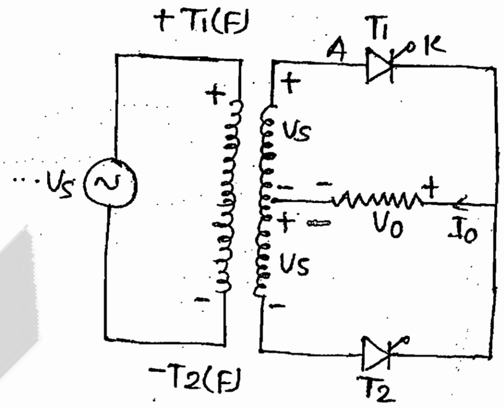
$$I_{or} = \left[\frac{1}{2\pi}\int_{\alpha}^{\theta_2}\left(\frac{V_m \sin\omega t - E}{R}\right)^2\right]^{1/2}$$

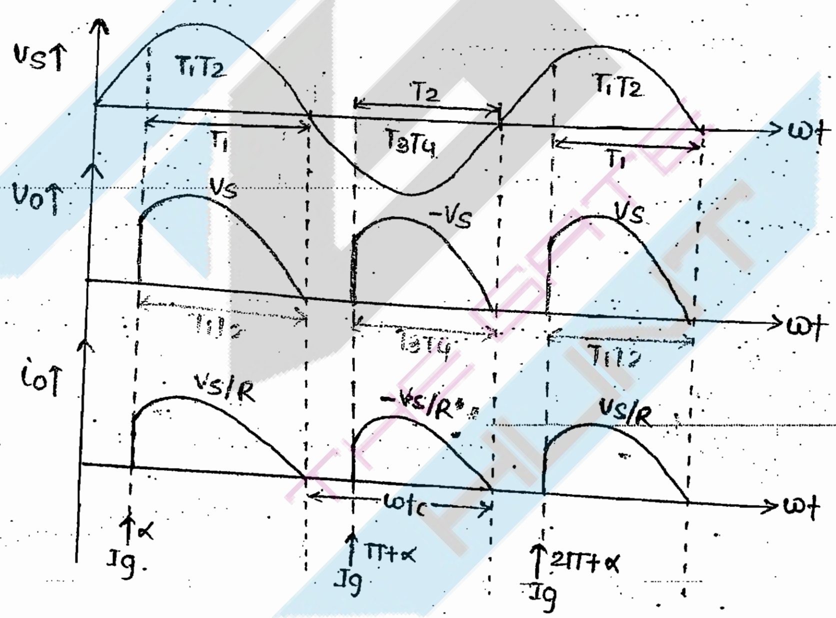
$1\text{-}\phi$ Full Wave Rectifier → (2-pulse converter)

*** Bridge Rectifier**



*** Mid point rectifier**





$T_1 T_2 \longrightarrow$ ON

i.e. $V_0 = V_S$

$i_0 = \dfrac{V_S}{R}$

$T_3 T_4 \longrightarrow$ ON

i.e. $V_0 = -V_S$

$i_0 = \dfrac{-V_S}{R}$

$T_1 \longrightarrow$ ON

i.e. $V_0 = V_S$

$i_0 = \dfrac{V_S}{R}$

$T_2 \rightarrow$ ON

$V_0 = -V_S$

$i_0 = \dfrac{-V_S}{R}$

$$\omega t_c = \pi$$

$$\boxed{t_c = \frac{\pi}{\omega}}$$

$$V_o = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d(\omega t)$$

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

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

For Resistive load; $PF = \frac{V_{or}}{V_{sr}}$

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

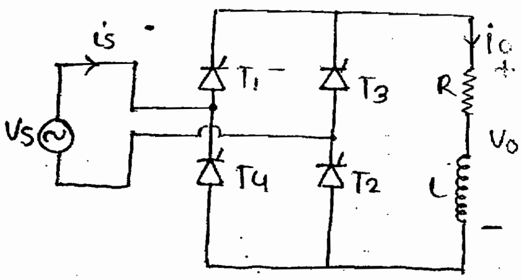
* For mid point rectifier $PIV = 2V_m$
* For bridge rectifier $PIV = V_m$.
* In mid point rectifier V_m is the peak value of upper 2° Voltage.

Advantage of bridge rectifier →

The PIV of the thy. in bridge rectifier half of that when compared to mid point rectifier.

If same thy. are used in both the conv^r then the avg. o/p vol. & power handled by bridge rectifier is double that of mid point rectifier.

Bridge Rectifier with RL load → (1ϕ fully controlled rectifier)



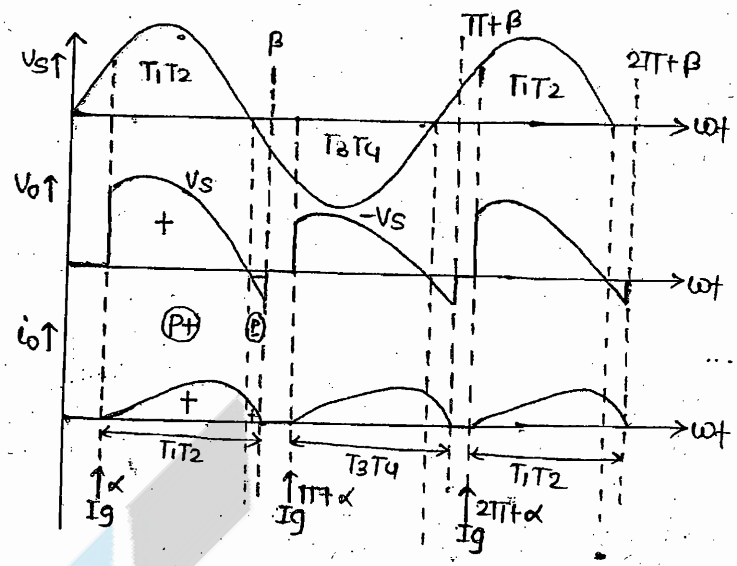
$$\omega t_c = 2\pi - \beta$$

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

$$V_0 = \frac{1}{\pi}\int_{\alpha}^{\beta} V_m \sin\omega t \, d(\omega t)$$

$$V_0 = \frac{V_m}{\pi}(\cos\alpha - \cos\beta)$$

$$\boxed{V_0 = \frac{V_m}{\pi}(\cos\alpha - \cos\beta)}$$



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

we get discontineous condn $\beta < (\pi+\alpha)$

Reasons → (1.) $L\downarrow$ $T\downarrow$ i.e. $\beta\downarrow$

$$\because \downarrow T = \frac{L\downarrow}{R\uparrow}$$

(2.) $\alpha\uparrow$ $\beta\downarrow$

(3.) If avg o/p current is less the β is also less. ($I_o \propto \beta$)

RL Load with Contineous Conduction →

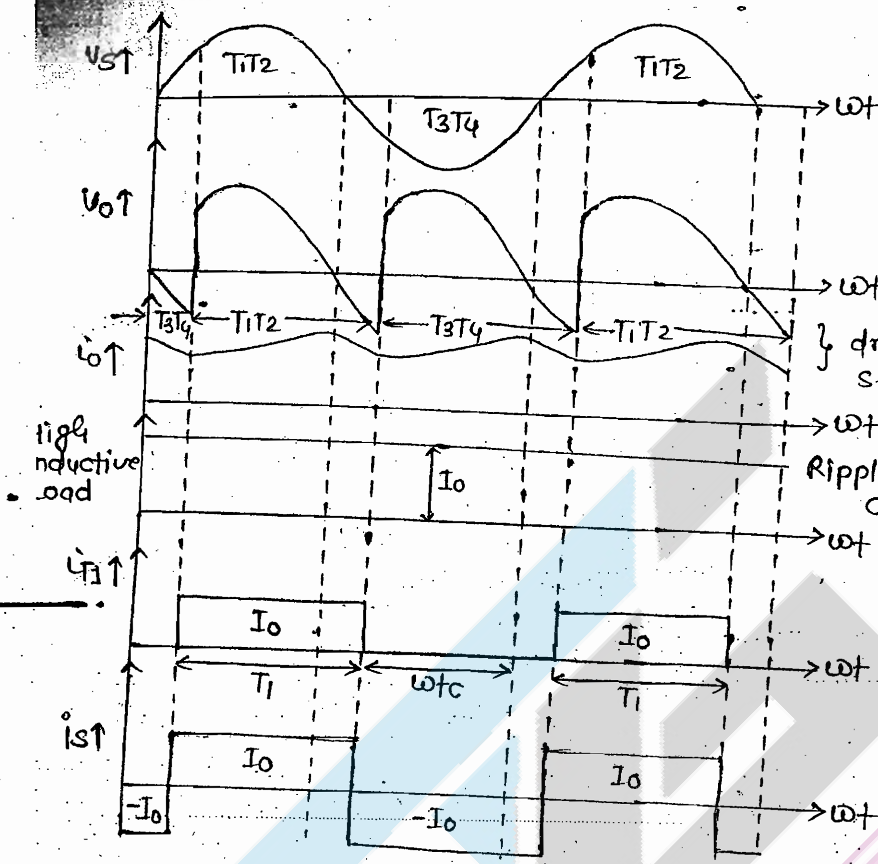
we get contineous condn when $\beta \geq (\pi+\alpha)$

Reasons → (1.) $L\uparrow$ $T\uparrow$ i.e. $\beta\uparrow$

$$\uparrow T = \frac{L\uparrow}{R\downarrow}$$

(2.) $\alpha\downarrow$ $\beta\uparrow$

(3.) $I_o\uparrow$ $\beta\uparrow$



} drawn after load attains steady state

Ripple free load current

* T_1T_2 ON
  i.e. $i_s = i_o = I_o$
* T_3T_4 ON
  i.e. $i_s = -i_o = -I_o$

$$\omega t_c = 2\pi - (\pi+\alpha)$$
$$= \pi + \alpha$$
$$\boxed{t_c = \frac{\pi-\alpha}{\omega}}$$

$$V_o = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d(\omega t)$$

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

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

$$V_{or} = \frac{V_m}{\sqrt{2}} = V_{sr}$$

$$\boxed{I_{sr} = I_o}$$

Assume high inductive load →

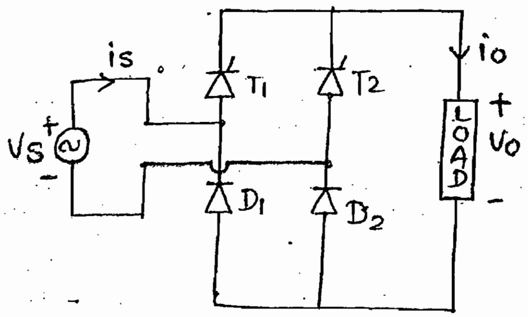
1.) Conduction angle of each thy. $= \pi$ rad for every cycle. $\{(\pi+\alpha)-\alpha\}$

2.) Avg. thy. current $(I_T)_{avg} = \frac{I_o\pi}{2\pi} = \frac{I_o}{2}$

$$(I_T)_{rms} = I_o\left(\frac{\pi}{2\pi}\right)^{1/2} = \frac{I_o}{\sqrt{2}}$$

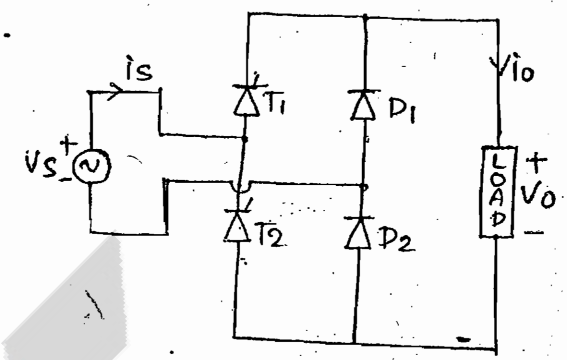
1-ϕ Half Controlled Rectifier →

Symmetrical Connection



+ $T_1 D_2$ (F)
− $T_2 D_1$ (F)

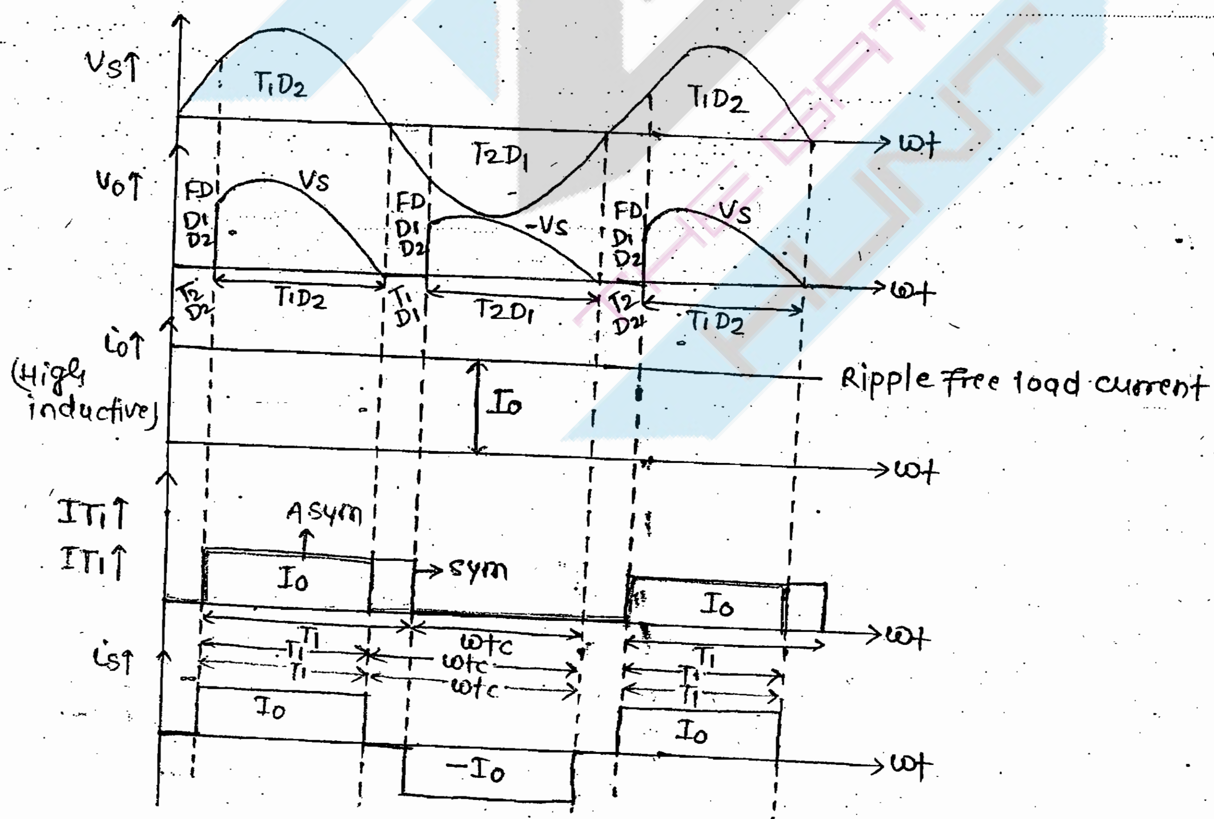
Asymmetrical Connection



+ $T_1 D_2$ (F)
− $T_2 D_1$ (F)

* During FD period the -ve spikes are removed & the source current also becomes zero.
* For resistive load waveforms are same in Full conv & semiconv.

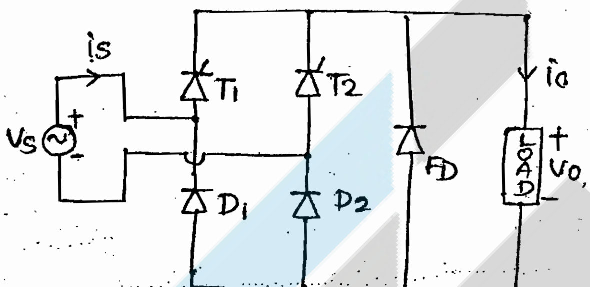
** Let us assume high inductive load.



Que → what is the problem with sym. connection ?

Ans. → * At α, $\pi+\alpha$, $2\pi+\alpha$ ------- There is a possibility of short circuit across the supply when incoming thy stats conducting before the o/p (outgoing) thy stops conducting.

* To rectify this problem we must connect a seprate FD across the load as shown in the fig. given below:-



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

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

* In the semiconverter :-

(1.) Cond^n angle of each thy. $= \pi-\alpha$ (for every 2π rad)

(2.) Avg. thy. current $(I_T)_{avg} = I_0\left(\frac{\pi-\alpha}{2\pi}\right)$

$$(I_T)_{Rms} = I_0\left(\frac{\pi-\alpha}{2\pi}\right)^{1/2}$$

(3.) Cond^n angle of FD is α rad. (for every π rad)

(4.) Avg. FD current $(I_{FD})_{avg.} = I_0\left(\frac{\alpha}{\pi}\right)$

$$(I_{FD})_{Rms} = I_0\left(\frac{\alpha}{\pi}\right)^{1/2}$$

$I_{sr} = I_0\left(\frac{\pi-\alpha}{\alpha}\right)^{1/2}$ {If you have any symm. -ve wave form we cal. for π rads}

Ratings of Thyristor →

(1.) Thyristor Rms Rating $(I_T)_{Rms}$ →

* It gives the Rms value Rating of ON state current of thy.
* $(I_t)_{Rms}$ value in conᶜ should be less than thy. Rms Rating.

(2.) Average thy. Rating $(I_T)_{avg}$ →

* It gives the avg. rating of ON state current of a thy.

$$\boxed{(I_T)_{avg} = \frac{(I_T)_{Rms}\ \text{Rating}}{FF}}$$

FF → It is a FF of thy. current waveform in a conᶜ.

Avg. Rating of thy. depends on :–

(1.) Condⁿ angle of thy. ↑ FF ↓ ⇒ $(I_T)_{avg}$ ↑

(2.) Avg. Rating depends on type of the load.

Eg. → L↑ $\frac{di}{dt}$↓ smoothness↑ ∴ FF↓ ⇒ $(I_T)_{avg}$ ↑

(3.) I^2t Rating →

* This Rating is provided for the thy. to select a proper fuse for over current protection.
* I^2t rating of thy. should always greater than fuse.

(4.) Surge Current Rating →

Surge Current Rating is specified for short duration of time.

n cycle surge current Rating (I_{sn}) → It is the surge current that the SCR can with stand for n cycle.

$$I_{sn}^2\left(\frac{nT}{2}\right) = I^2t \text{ Rating of thy.}$$

From above we can find Isn

One cycle surge current Rating (I_{s1}) → It is the surge current that the SCR can withstand for 1 cycle.

$$I_{S1}^2\left(\frac{T}{2}\right) = I_{Sn}^2 \cdot n \cdot \frac{T}{2}$$

$$\boxed{I_{S1} = \sqrt{n}\, I_{Sn}}$$

Sub cycle current Rating ($I_{S/n}$) → It is the surge current that the SCR can with stand for $\frac{1}{n}$th period of a cycle.

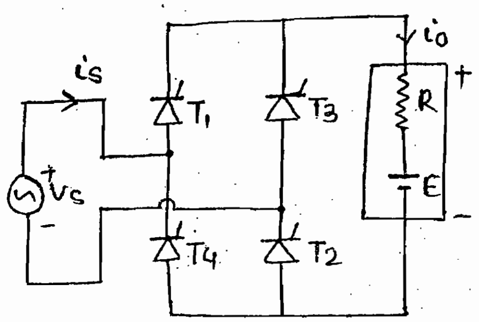
$$(I_{S/n})^2 \cdot \left(\frac{1}{n}\right) \frac{T}{2} = (I_{S1})^2 \frac{T}{2}$$

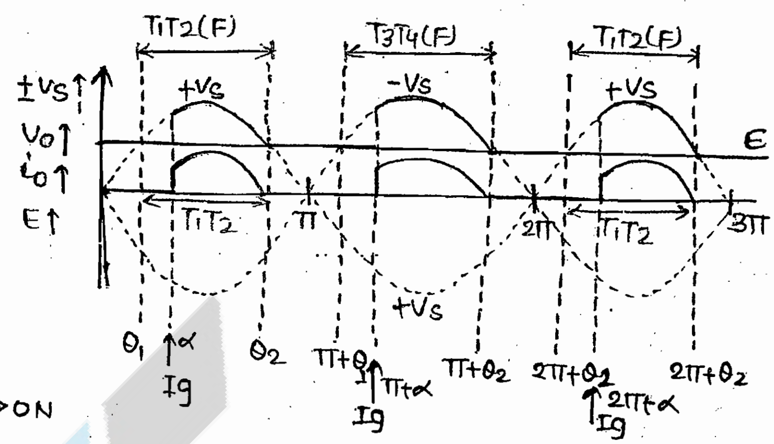
$$\boxed{(I_{S/n}) = \sqrt{n}\, I_{S1}}$$

Half cycle surge current Rating

$$(I_{S/2}) = \sqrt{2}\, I_{S1}$$

(1.) 1ϕ Full converter - Charging Battery →





+ve, $+V_s \geq E$, $T_1T_2(F)$

−ve, $-V_s > E$, $T_3T_4(F)$

$\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right)$, $\theta_2 = \pi - \theta_1$

$\theta_1 \leq \alpha \leq \theta_2$

$T_1T_2 \rightarrow ON$

$V_o = V_s$

$i_o = \frac{V_s - E}{R}$

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

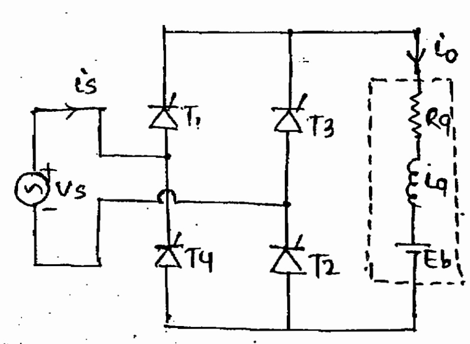
$$V_o = \frac{1}{\pi}\left[\int_{\alpha}^{\theta_2} V_m \sin\omega t \, d(\omega t) + \int_{\theta_2}^{\pi+\alpha} E \, d(\omega t)\right]$$

$$\boxed{V_o = \frac{1}{\pi}\left[V_m(\cos\alpha - \cos\theta_2) + E(\pi+\alpha-\theta_2)\right]}$$

$$I_o = \frac{1}{\pi}\left[\int_{\alpha}^{\theta_2} \frac{V_m \sin\omega t - E}{R} d(\omega t)\right]$$

$$\boxed{I_o = \frac{1}{\pi R}\left[V_m(\cos\alpha - \cos\theta_2) - E(\theta_2 - \alpha)\right]}$$

1ϕ Full converter - DC motor (RLE load) →



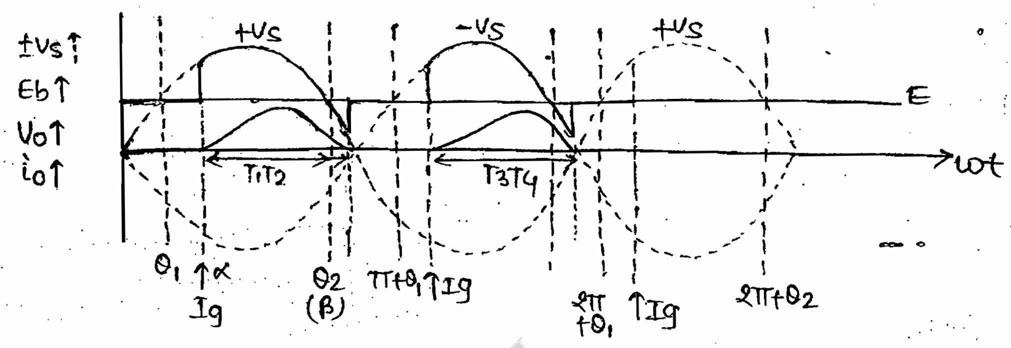
(1.) Discontineous Conduction

$\theta_2 < \beta < (\pi+\alpha)$

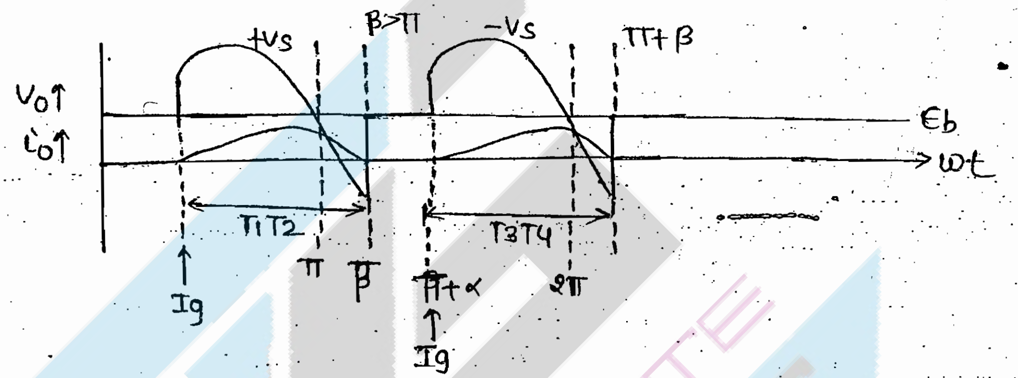
(a.) $\beta < \pi$

(b) $\beta \geq \pi$

(i) $\beta < \pi$



(ii) $\beta > \pi$



$$t_c = \frac{2\pi + \theta_1 - \beta}{\omega}$$

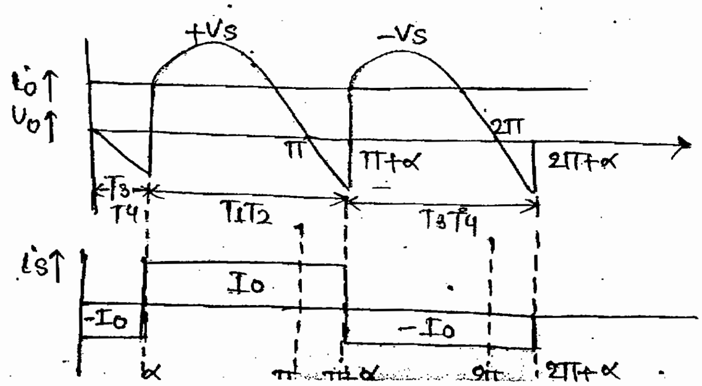
$$V_0 = \frac{1}{\pi}\left[\int_{\alpha}^{\beta} V_m \sin\omega t \, d(\omega t) + \int_{\beta}^{\pi+\alpha} E_b \, d(\omega t)\right]$$

$$\boxed{V_0 = \frac{1}{\pi}\left[V_m(\cos\alpha - \cos\beta) + E_b(\pi + \alpha - \beta)\right]}$$

(2) Contineous Conduction →

$\beta > (\pi + \alpha)$

* For contineous condⁿ there is no effect of back emf in the o/p vol. waveform therefore the o/p vol. waveform will remain same for RL & RLE load.



$$\boxed{\begin{array}{l} V_0 = \dfrac{2V_m}{\pi}\cos\alpha \\ I_{sr} = I_0 \end{array}} \rightarrow RL, RLE$$

$$I_{sr} = I_0\left(\frac{\pi+\alpha-\alpha}{\pi}\right)^{1/2}$$

$$I_{sr} = I_0$$

Harmonic analysis on Ac side of converter →

The Fourier series for supply waveform is

$$i_s = \sum_{n=1,3,5\ldots}^{\infty} \frac{4I_0}{n\pi}\sin(n\omega t+\phi_n)$$

where $\phi_n = -n\alpha$, $\phi_1 = -\alpha$

$$i_{sn} = \frac{4I_0}{n\pi}\sin(n\omega t+\phi_n)$$

$$\boxed{\begin{array}{l} i = \text{instantaneous} \\ I = \text{Rms} \end{array}}$$

$$I_{sn} = \frac{2\sqrt{2}}{n\pi} I_0$$

$$\boxed{I_{s1} = \frac{2\sqrt{2}}{\pi} I_0} \text{ ------ (i)}$$

$$FDF = \cos\phi_1$$

$$\boxed{FDF = \cos\alpha} \text{ ------ (ii)}$$

$$g = \frac{I_{s1}}{I_{sr}}$$

$$= \frac{\frac{2\sqrt{2}}{\pi} I_0}{I_0}$$

$$\boxed{g = \frac{2\sqrt{2}}{\pi}} \text{ ------ (iii)}$$

$$PF = g \cdot FDF$$

$$\boxed{PF = \frac{2\sqrt{2}}{\pi}\cos\alpha} \text{ ------ (iv)}$$

$$THD = \left(\frac{1}{g^2}-1\right)^{1/2}$$

$$= \left(\frac{\pi^2}{8}-1\right)^{1/2}$$

$$= 0.4834$$

$$\boxed{THD = 48.34\%} \text{ ------ (v)}$$

Active power (Useful power) $P = V_{sr} \cdot I_{s1} \cos\alpha$

$$P = \frac{V_m}{\cancel{\sqrt{2}}} \frac{2\cancel{\sqrt{2}}}{\pi} I_0 \cos\alpha$$

$$P = \frac{2V_m}{\pi} I_0 \cos\alpha$$

$$\boxed{P = V_0 I_0} \text{ ----(vi)} \quad \text{where; } V_0 = \frac{2V_m}{\pi} \cos\alpha$$

Reactive power

$$Q = V_{sr} \cdot I_{s1} \sin\alpha \qquad (\text{lag}) \rightarrow [\sin(-\alpha) = -\sin\alpha]$$

$$= V_{sr} \cdot I_{s1} \cdot \cos\alpha \frac{\sin\alpha}{\cos\alpha}$$

$$Q = P\tan\alpha$$

$$\boxed{Q = P\tan\alpha = V_0 I_0 \tan\alpha} \text{ ------(vii)}$$

Harmonics analysis on dc side of converter →

$$FF = \frac{V_{or}}{V_0} = \frac{V_m/\sqrt{2}}{\frac{2V_m}{\pi}\cos\alpha}$$

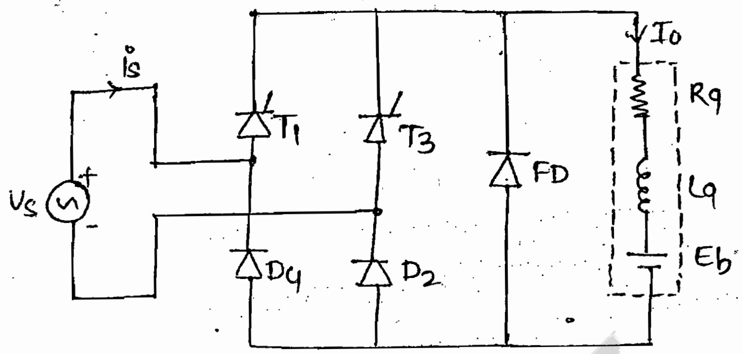
$$\boxed{FF = \frac{\pi}{2\sqrt{2}\cos\alpha}}$$

$$VRF = \sqrt{FF^2 - 1}$$

$$\boxed{VRF = \sqrt{\frac{\pi^2}{8\cos^2\alpha} - 1}}$$

1

1ϕ semi Converter →



(i) Discontineous conduction :-

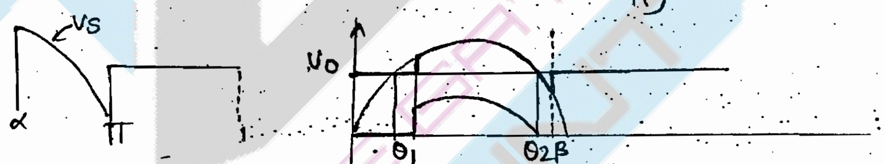
$$\theta_2 < \beta < (\pi + \alpha)$$

(a) $\beta < \pi$

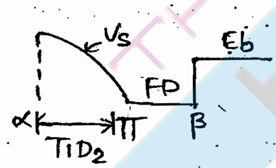
(b) $\beta > \pi$

(a) $\beta < \pi$ → * In this condition FD will not conduct (Because FD conduct after π rad i.e. due to ind^r the -ve spikes come after π)

$$\boxed{V_0 = \frac{1}{\pi}\left[V_m(\cos\alpha - \cos\beta) + E_b(\pi + \alpha - \beta)\right]}$$



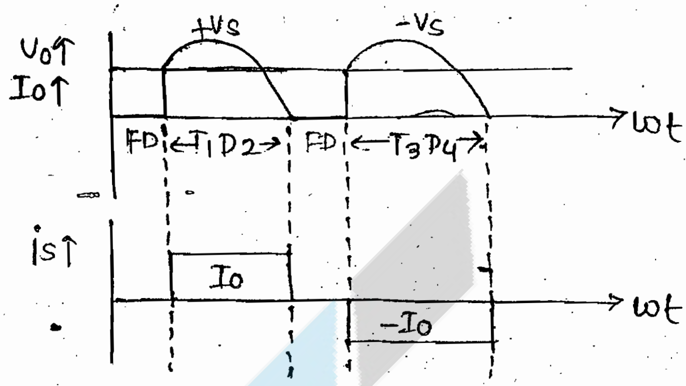
(b) $\beta > \pi$ → * In this cond^n FD will conduct from π to β



$$V_0 = \frac{1}{\pi}\left[\int_{\alpha}^{\pi} V_m \sin\omega t\, d(\omega t) + \underbrace{\int_{\pi}^{\beta} 0\, d\omega t}_{\text{FWR}} + \underbrace{\int_{\beta}^{\pi+\alpha} E_b\, d(\omega t)}_{\text{discontineous}}\right]$$

$$\boxed{V_0 = \frac{1}{\pi}\left[V_m(1 + \cos\alpha) + E_b(\pi + \alpha - \beta)\right]}$$

(ii) Contineous Conduction → $[\beta > (\pi+\alpha)]$ For this condn there is no effect of back emf for o/p vol. waveform. Therefore the o/p vol. waveform will remain same for RL & RLE load.



$$\boxed{\begin{aligned} V_o &= \frac{V_m}{\pi}(1+\cos\alpha) \\ I_{sr} &= I_o\left(\frac{\pi-\alpha}{\pi}\right)^{1/2} \end{aligned}}$$

Harmonic analysis on Ac side of Conr →

The fourier series for the supply current

$$i_s = \sum_{n=1,3,5\ldots}^{\infty} \frac{4I_o}{n\pi}\cos\frac{n\alpha}{2}\sin(n\omega t+\phi_n)$$

where $\phi_n = -\frac{n\alpha}{2}$, $\phi_1 = -\frac{\alpha}{2}$

$$i_{sn} = \frac{4I_o}{n\pi}\cos\frac{n\alpha}{2}\sin(n\omega t+\phi_n)$$

$$I_{sh} = \frac{2\sqrt{2}}{n\pi} I_o \cos\frac{n\alpha}{2}$$

$$\boxed{I_{s1} = \frac{2\sqrt{2}}{\pi} I_o \cos\frac{\alpha}{2}} \text{ ------ (i)}$$

$$\boxed{FDF = \cos\frac{\alpha}{2}} \text{ ------ (ii)}$$

$$g = \frac{I_{s1}}{I_{sr}} = \frac{\frac{2\sqrt{2}}{\pi}\cancel{I_o}\cos\frac{\alpha}{2}}{\cancel{I_o}\left(\frac{\pi-\alpha}{\pi}\right)^{1/2}}$$

$$\boxed{g = \frac{2\sqrt{2}\cos\alpha/2}{\sqrt{\pi(\pi-\alpha)}}} \text{ ------- (iii)}$$

$PF = g \cdot FDF$

$$= \frac{2\sqrt{2}\cos\alpha/2}{\sqrt{\pi(\pi-\alpha)}}\cos\alpha/2$$

$$= \frac{2\sqrt{2}\cos^2\alpha/2}{\sqrt{\pi(\pi-\alpha)}}$$

$$\boxed{PF = \frac{2\sqrt{2}(1+\cos\alpha)}{\sqrt{\pi(\pi-\alpha)}}} \text{ ------ (iv)}$$

$$THD = \left(\frac{1}{g^2}-1\right)^{1/2}$$

$$\boxed{THD = \left[\frac{\pi(\pi-\alpha)}{8\cos^2\alpha/2}-1\right]^{1/2}} \text{ ------ (v)}$$

Active Power

$P = V_{sr} \cdot I_{s1}\cos\alpha/2$

$$= \frac{V_m}{\sqrt{2}} \cdot \frac{2\sqrt{2}}{\pi} I_o \cos\frac{\alpha}{2} \cdot \cos\frac{\alpha}{2}$$

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

$= V_o I_o$

$$\boxed{P = V_{sr} \cdot I_{s1}\cos\alpha/2 = V_o I_o} \text{ ------ (vi)}$$

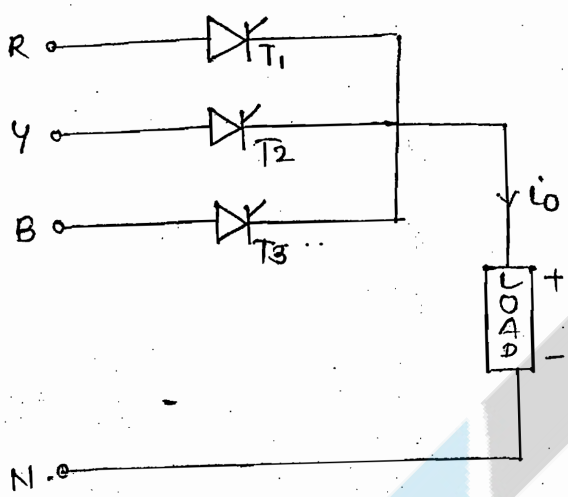
Reactive Power

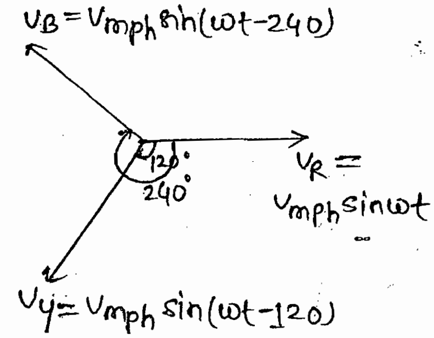
$Q = V_{sr} \cdot I_{s1} \cdot \sin\alpha/2$

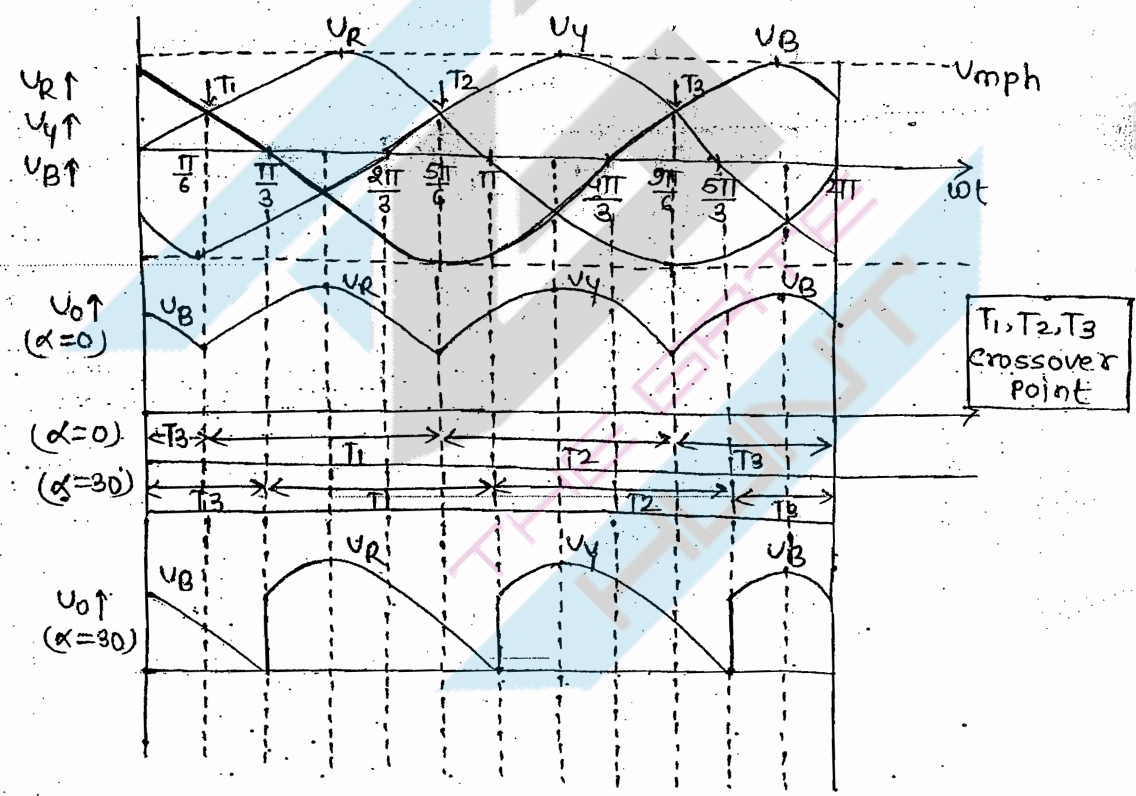
$$\boxed{Q = P\tan\alpha/2} \text{ ------ (vii)}$$

3ϕ HWR → 3 pulse converter

Phase seq. → RYB







(1.) $\alpha \le 30°$ Contineous Cond^n for R load →

$$V_o = \frac{1}{2\pi/3} \int_{\pi/6+\alpha}^{5\pi/6+\alpha} V_{mph} \sin\omega t \, d(\omega t)$$

$$\boxed{V_o = \frac{3\sqrt{3}}{2\pi} V_{mph} \cdot \cos\alpha}$$

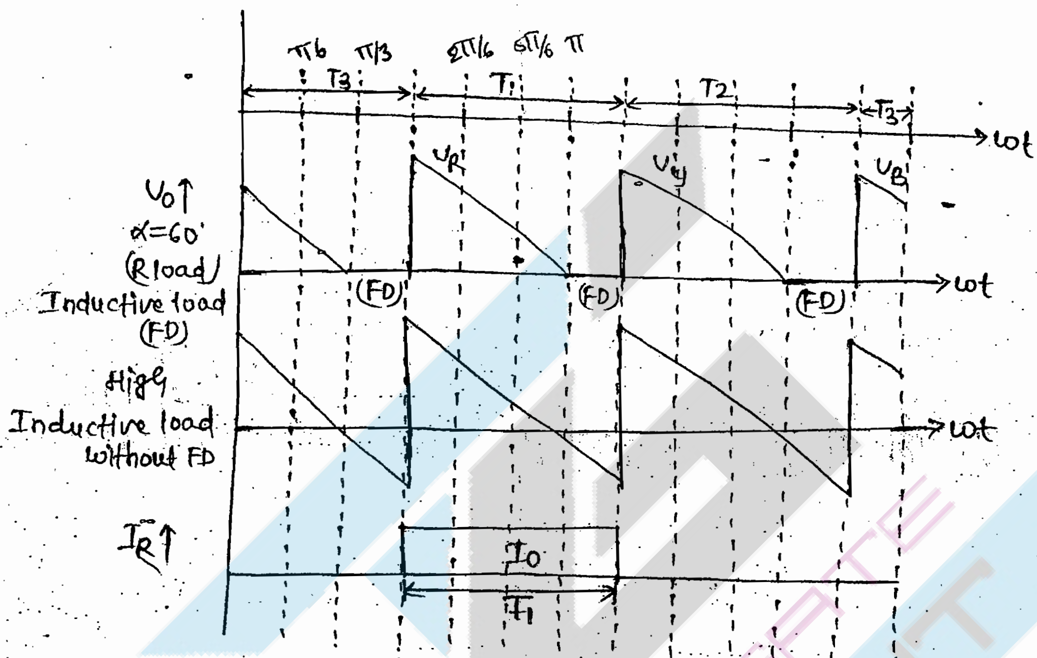
$$\boxed{V_o = \frac{3V_{mL}}{2\pi} \cos\alpha}$$

R ($\alpha \le 30°$)   RL, RLE (any α) (contineous)

$$V_{or} = \left[\frac{1}{(2\pi/3)} \int_{\pi/6+\alpha}^{5\pi/6+\alpha} V_{mph}^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

$$\boxed{V_{or} = V_{mL}\left[\frac{1}{6} + \frac{\sqrt{3}}{8\pi}\cos 2\alpha\right]^{1/2}}$$

*



(2.) $\alpha > 30°$: discontineous conduction for R load :-

$$V_o = \frac{1}{(2\pi/3)} \int_{\pi/6+\alpha}^{\pi} V_{mph} \sin\omega t \, d(\omega t)$$

$$\boxed{V_o = \frac{3V_{mph}}{2\pi}\left[1 + \cos\left(\frac{\pi}{6}+\alpha\right)\right]}$$ R ($\alpha > 30°$)
RL, RLE (with FD $\alpha > 30°$)

$$V_{or} = \left[\frac{1}{(2\pi/3)} \int_{\pi/6+\alpha}^{\pi} V_{mph}^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

$$\boxed{V_{or} = \frac{V_{mL}}{2\sqrt{\pi}}\left[\left(\frac{5\pi}{6}-\alpha\right) + \frac{1}{2}\sin\left(\frac{\pi}{3}+2\alpha\right)\right]^{1/2}}$$

Assume high inductive load with FD:-

(1.) $\alpha \leq 30$:- FD will not conduct

Conduction angle of each thy. is $\frac{2\pi}{3}$ rad [For every 2π rad]

$$(I_T = I_{ph} = I_L)_{avg} = I_0\left[\frac{2\pi/3}{2\pi}\right]$$

$$= \frac{I_0}{3}$$

$$(I_T = I_{ph} = I_L)_{rms} = \frac{I_0}{\sqrt{3}}$$

(2.) $\alpha > 30 \rightarrow$ Conduction angle of FD $= \left(\alpha - \frac{\pi}{6}\right)$ [For every $\frac{2\pi}{3}$ rad].

Conduction angle of each thy. is $\left(\frac{5\pi}{6} - \alpha\right)$ [For every 2π rad]

$$(I_T = I_{ph} = I_L)_{avg} = \frac{I_0\left[\frac{5\pi}{6} - \alpha\right]}{2\pi}$$

$$(I_T = I_{ph} = I_L)_{rms} = I_0\left[\frac{\frac{5\pi}{6} - \alpha}{2\pi}\right]^{1/2}$$

$$\boxed{(I_{FD})_{Avg} = I_0\left(\frac{\alpha - \pi/6}{2\pi/3}\right)} \qquad \boxed{(I_{FD})_{rms} = I_0\left(\frac{\alpha - \pi/6}{2\pi/3}\right)^{1/2}}$$

Assume high inductive load without FD:-

For any value of α

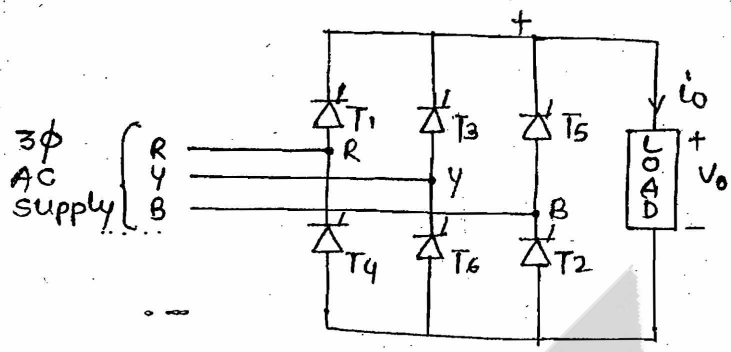
Conduction angle of each thy $= \frac{2\pi}{3}$ rad [For every 2π rad]

$$(I_T = I_{ph} = I_L)_{avg} = I_0\left(\frac{2\pi/3}{2\pi}\right) = \frac{I_0}{3}$$

Drawback $\rightarrow$ The source current contains dc componant & saturates the supply Xmer core.

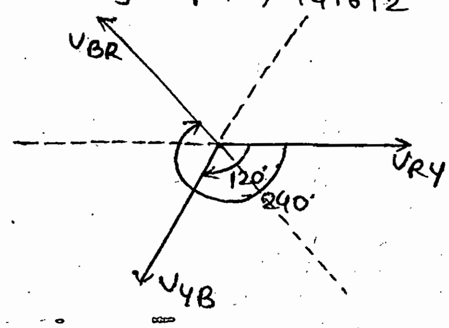
DATE - 19/08/14

* 3ϕ Fully controlled Rectifier :- (6 pulse converter) →



+ve group thy $T_1 T_3 T_5$

−ve group thy $T_4 T_6 T_2$



For 6 pulse → Line vol.

3 pulse → phase vol.

(1.) $\alpha \le 60°$:- Contineous conduction for R load →

$$V_o = \frac{1}{\pi/3} \int_{\frac{\pi}{3}+\alpha}^{\frac{2\pi}{3}+\alpha} V_{mL} \sin\omega t \cdot d(\omega t)$$

$$\boxed{V_o = \frac{3V_{mL}}{\pi} \cos\alpha}$$

→ R ($\alpha \le 60$)

→ RL, RLE (Any α) (Contineous)

$$V_{or} = \left[\frac{1}{\pi/3} \int_{\pi/3+\alpha}^{2\pi/3+\alpha} V_{mL}^2 \cdot \sin^2\omega t \, d(\omega t) \right]^{1/2}$$

$$V_{or} = \frac{V_{mL}}{\sqrt{\frac{2\pi}{3}}} \left[\frac{\pi}{3} + \frac{1}{2} \left\{ \sin\left(\frac{2\pi}{3}+2\alpha\right) - \sin\left(\frac{4\pi}{3}+2\alpha\right) \right\} \right]^{1/2}$$

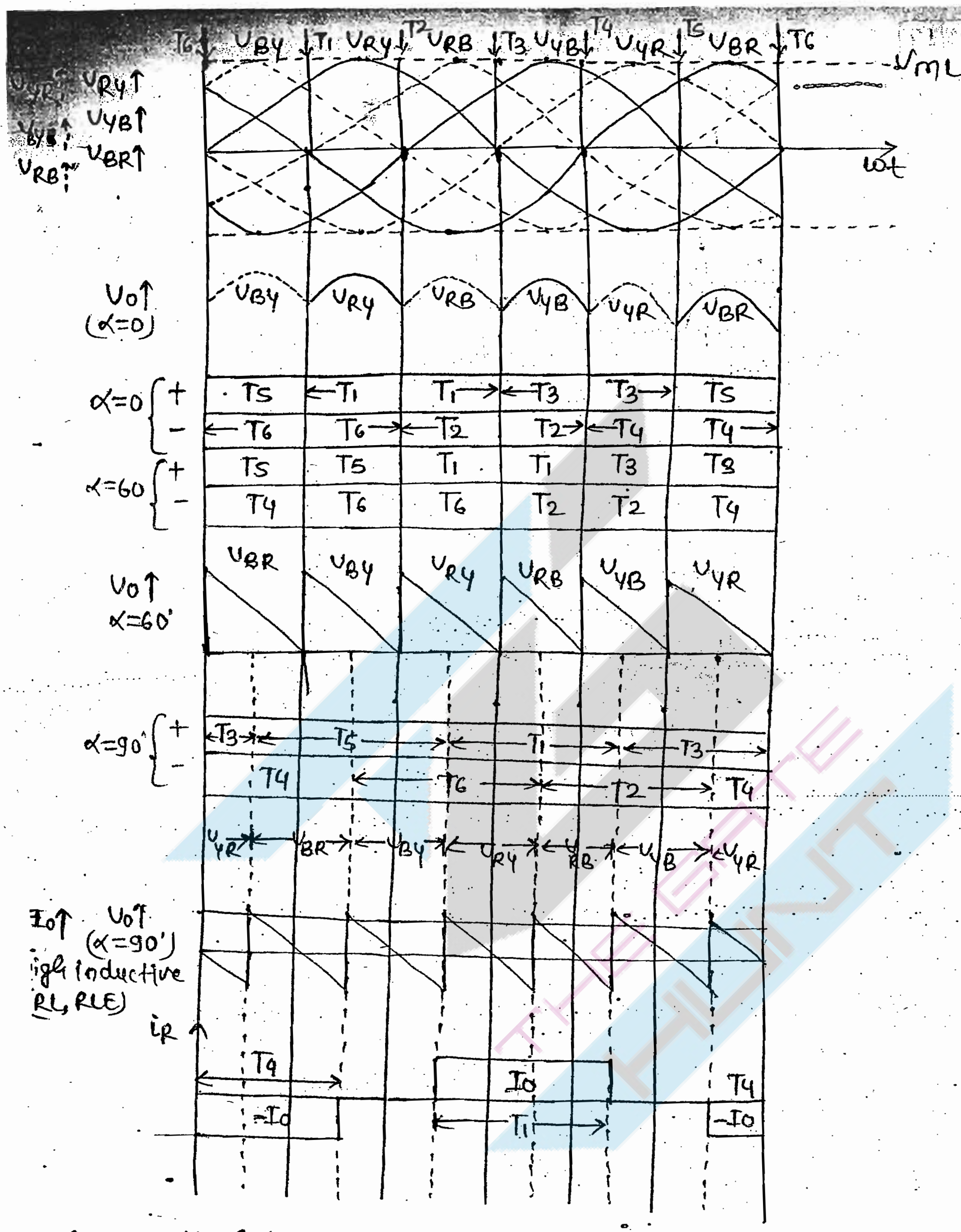
(2.) $\alpha > 60°$:- Discontineous conduction for R load →

$$V_o = \frac{1}{\pi/3} \int_{\pi/3+\alpha}^{\pi} V_{mL} \cdot \sin\omega t \cdot d(\omega t) \quad ; \quad \boxed{V_o = \frac{3V_{mL}}{\pi} \left[1 + \cos\left(\frac{\pi}{3}+\alpha\right) \right]}$$

R ($\alpha > 60°$).

$$V_{or} = \left[\frac{1}{\pi/3} \int_{\frac{\pi}{3}+\alpha}^{\pi} V_{mL}^2 \cdot \sin^2\omega t \cdot d(\omega t) \right]^{1/2}$$

$$\boxed{V_{or} = \sqrt{\frac{3}{2\pi}} \, V_{mL} \left[\left(\frac{2\pi}{3} - \alpha \right) + \frac{1}{2} \sin\left(\frac{2\pi}{3} + 2\alpha \right) \right]^{1/2}}$$



Assume High inductive load →

Conduction of angle of each thy. $= \frac{2\pi}{3}$ rad. (For every 2π rad)

$$(I_T)_{Avg} = I_o\left(\frac{2\pi/3}{2\pi}\right) = \frac{I_o}{3}$$

$$(I_T)_{rms} = \frac{I_o}{\sqrt{3}}$$

$$I_{sr} = I_o\left(\frac{2\pi/3}{\pi}\right)^{1/2} = \sqrt{\frac{2}{3}}\, I_o$$

Harmonic analysis on AC side of converter →

$$i_s = \sum_{n=1,3,5\ldots}^{\infty} \frac{4I_o}{n\pi} \sin\frac{n\pi}{3} \cdot \sin(n\omega t + \phi_n)$$

$\boxed{\phi_n = -n\alpha,\ \phi_1 = -\alpha}$

$n = 6k \pm 1$

$n = 1, 5, 7, 11, 13 \ldots\ldots$

Note:- Even & tripple harmonics are not present in the waveform

$$i_{sn} = \frac{4I_o}{n\pi} \sin\frac{n\pi}{3} \cdot \sin(n\omega t + \phi_n)$$

$$I_{sn} = \frac{4I_o}{n\pi\sqrt{2}} I_o \sin\frac{n\pi}{3} = \frac{2\sqrt{2}}{n\pi} I_o \sin\frac{n\pi}{3}$$

$$I_{s1} = \frac{2\sqrt{2}}{\pi} \cdot I_o \sin\frac{\pi}{3}$$

$$\boxed{I_{s1} = \frac{\sqrt{6}}{\pi} I_o} \text{------(i)}$$

$$\boxed{FDF = \cos\alpha} \text{------(ii)}$$

$$I_{sr} = \sqrt{\frac{2}{3}} I_o$$

$$g = \frac{I_{s1}}{I_{sr}} = \frac{\frac{\sqrt{6}}{\pi} \cancel{I_o}}{\sqrt{\frac{2}{3}} \cancel{I_o}}$$

$$\boxed{g = \frac{3}{\pi}} \text{-------(iii)}$$

$$PF = g \cdot FDF$$

$$= \frac{3}{\pi} \cos\alpha$$

$$\boxed{PF = \frac{3}{\pi} \cos\alpha} \text{-----(iv)}$$

$$THD = \left(\frac{1}{g^2} - 1\right)^{1/2} = \left(\frac{\pi^2}{9} - 1\right)^{1/2}$$

$$\boxed{THD = 0.31}$$

$$\boxed{THD = 31\%} \text{------(v)}$$

$\boxed{\begin{array}{l} m\uparrow,\ g\uparrow,\ THD\downarrow \\ m\uparrow,\ g\uparrow,\ PF\downarrow \end{array}}$

Active power →

$$P = \sqrt{3}\, V_{sr} \cdot I_{s1} \cos\alpha$$

$$= \sqrt{3} \times \frac{V_{ml}}{\sqrt{2}} \times \frac{\sqrt{6}}{\pi} I_0 \cos\alpha$$

$$= \sqrt{3} \times \frac{V_{ml}}{\sqrt{2}} \times \frac{\sqrt{2}\sqrt{3}}{\pi} I_0 \cos\alpha$$

$$= \frac{3V_{ml}}{\pi} \cos\alpha \cdot I_0$$

$$\boxed{P = \frac{3V_{ml}}{\pi} \cos\alpha \cdot I_0 = V_0 I_0} \quad \text{-------- (vi)}$$

Reactive power →

$$Q = \sqrt{3}\, V_{sr} \cdot I_{s1} \sin\alpha$$

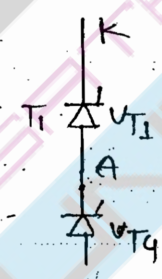
$$\boxed{Q = P \tan\alpha} \quad \text{-------- (vii)}$$

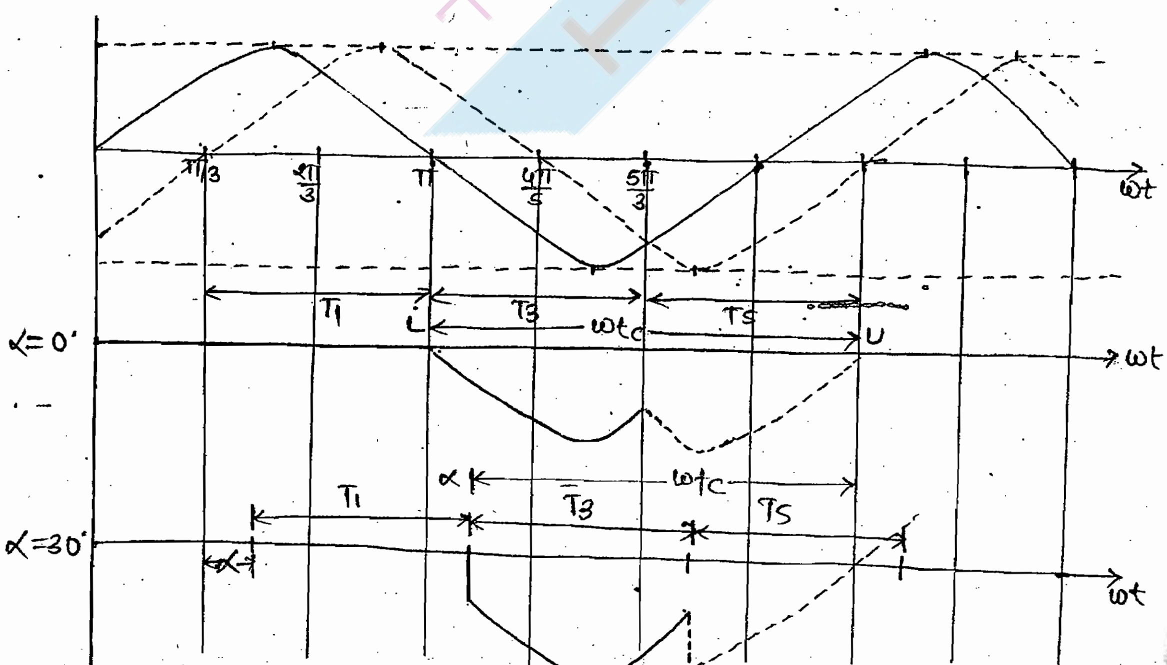
$V_{AK} \rightarrow (V_{T_1})$

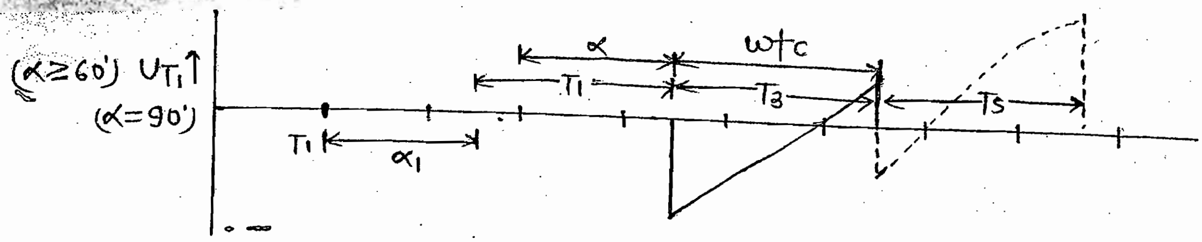
$T_1 \rightarrow ON$, $V_{T_1} = 0$

$T_3 \rightarrow ON$, $V_{T_1} = V_{RY}$

$T_5 \rightarrow ON$, $V_{T_1} = V_{RB}$







$\underline{\alpha = 0'}$

$$\omega t_c = \frac{4\pi}{3}$$

$$t_c = \frac{4\pi}{3\omega} \text{ sec}$$

$$\boxed{PIV = V_{ml}}$$

$\underline{\alpha < 60'}$

$$\alpha + \omega t_c = \frac{4\pi}{3}$$

$$\omega t_c = \frac{4\pi}{3} - \alpha$$

$$\boxed{t_c = \frac{\frac{4\pi}{3} - \alpha}{\omega}}$$

$\alpha > 60'$

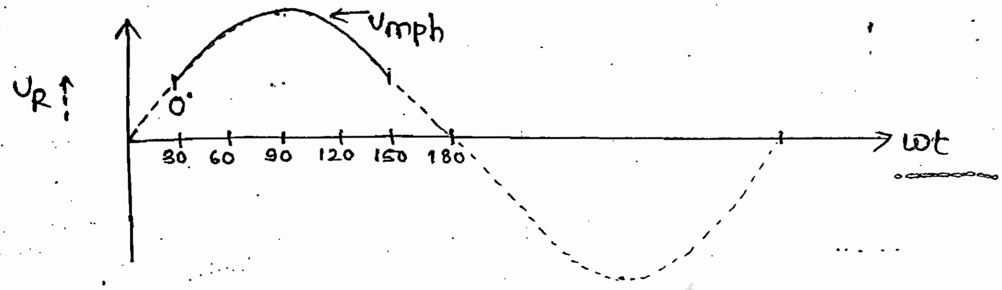
$$\alpha + \omega t_c = \frac{3\pi}{3}$$

$$\alpha + \omega t_c = \pi$$

$$\omega t_c = \pi - \alpha$$

$$\boxed{t_c = \frac{\pi - \alpha}{\omega}}$$

...nagination method for 3 pulse converter →

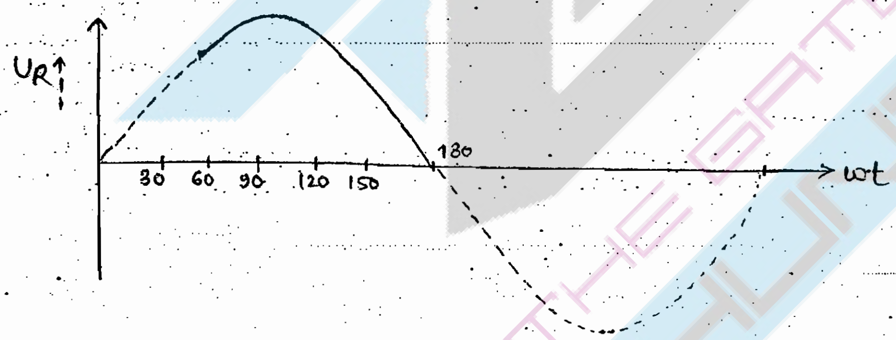


$\alpha = \omega t - 30°$

Pulse Length $= \frac{2\pi}{3}$ rad $= 120°$

$$\boxed{\begin{array}{l} 0 \le \alpha \le 150° \longrightarrow \text{R Load} \\ 0 \le \alpha \le 180° \longrightarrow \text{Inductiven load.} \end{array}}$$

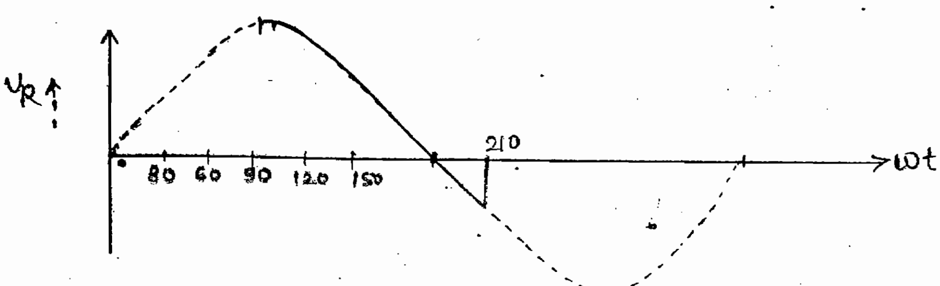
For $\alpha = 0°$, $\omega t = 30°$ (Fig (i))



$\alpha = \omega t - 30°$

Pulse length $= 120°$

For $\alpha = 30°$, $\omega t = 60°$ & $60 + 120 = 180°$



$\alpha = 60°$, $\omega t = 90°$, end $90 + 120 = 210°$

* 6 pulse converter →

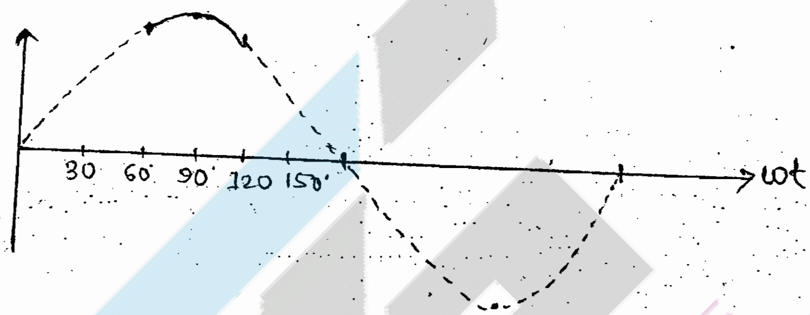
$$\alpha = \omega t - 60^\circ$$

$$\text{Pulse length} = \frac{2\pi}{6}\text{ rad} = \frac{\pi}{3}\text{ rad}$$

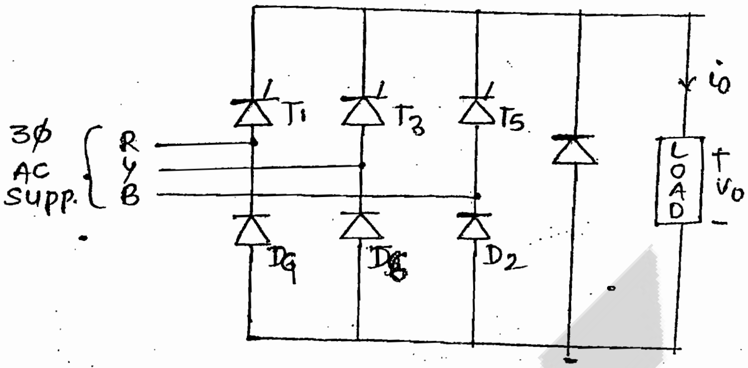
$$= 60^\circ$$

$$\boxed{\begin{array}{ll} 0 \le \alpha \le 120^\circ & R\text{ load} \\ 0 \le \alpha \le 180^\circ & L\text{ load} \end{array}}$$

$\alpha = 0^\circ$, $\omega t = 60^\circ$ & $60 + 60 = 120^\circ$



3ϕ semi conv^{r} / 3ϕ Half controlled Rectifier →



Assume High inductive load →

(1) $\alpha \le 60^\circ$ → * FD will not conduct.

* Conduction angle of each thy. $= \frac{2\pi}{3}$ rad {For every 2π rad}

$$(I_T)_{avg} = I_0\left(\frac{2\pi/3}{2\pi}\right) = \frac{I_0}{3}$$

$$(I_T)_{rms} = \frac{I_0}{\sqrt{3}}$$

$$\boxed{I_{sr} = I_0\left(\frac{2\pi/3}{\pi}\right)^{1/2} = \sqrt{\frac{2}{3}}\, I_0}$$

(2) $\alpha > 60^\circ$ → * Conduction angle of FD $= \left(\alpha - \frac{\pi}{3}\right)$ {For every $\frac{2\pi}{3}$ rad}

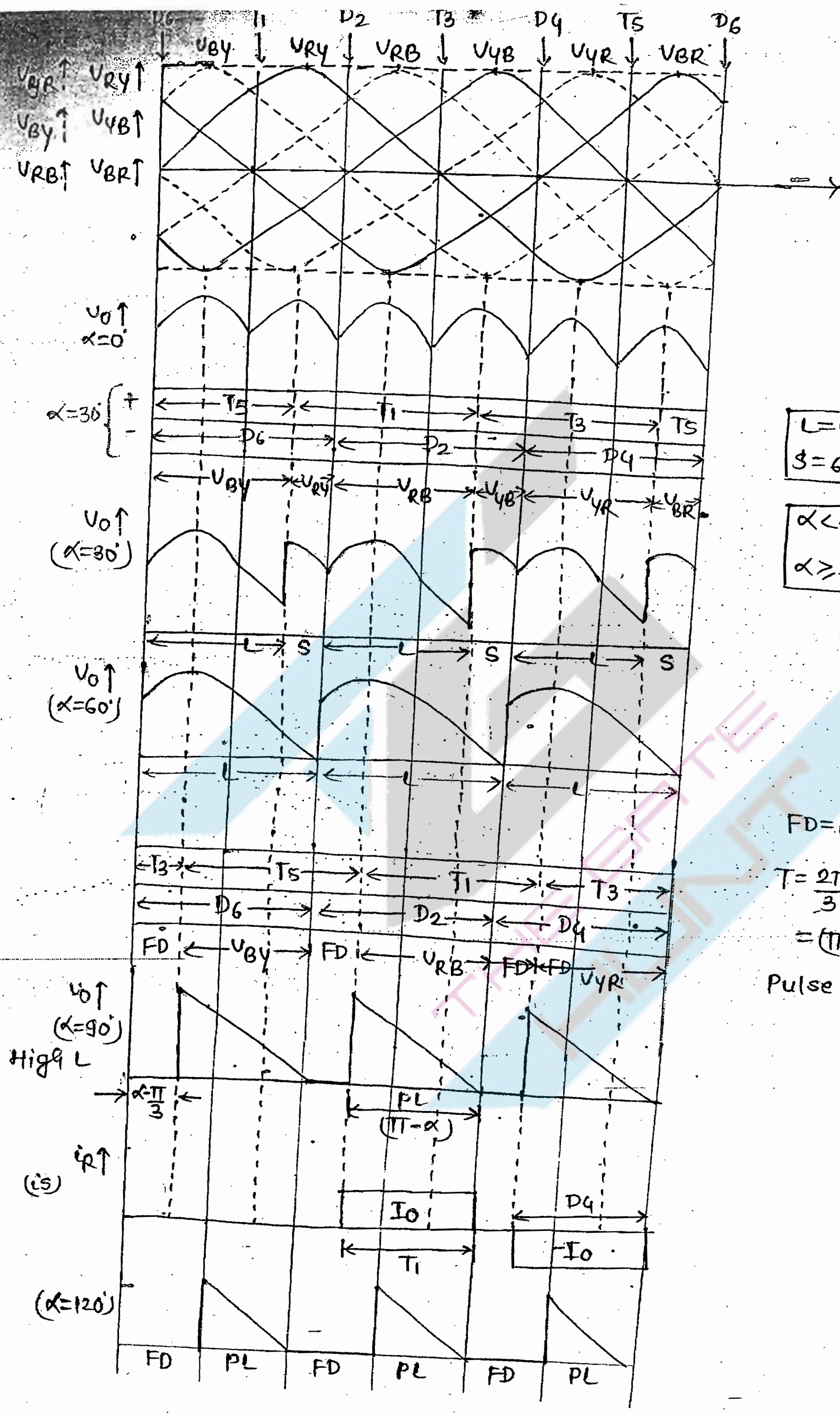
* Conduction angle of each thy. $= (\pi - \alpha)$ [For every $2\pi/3$ rad ...]

$$(I_T)_{avg} = I_0\left(\frac{\pi-\alpha}{2\pi}\right) \qquad (I_T)_{rms} = I_0\left(\frac{\pi-\alpha}{2\pi}\right)^{1/2}$$

$$\boxed{I_{sr} = I_0\left(\frac{\pi-\alpha}{\pi}\right)^{1/2}}$$

$$\boxed{(I_{FD})_{avg} = I_0\left(\frac{\alpha - \pi/3}{2\pi/3}\right)} \qquad \boxed{(I_{FD})_{rms} = I_0\left[\frac{\alpha-\pi/3}{2\pi/3}\right]^{1/2}}$$

$$\boxed{V_0 = \frac{3V_{mL}}{2\pi}(1+\cos\alpha)}$$



$$\boxed{\begin{array}{l} L = 60+\alpha \\ S = 60-\alpha \end{array}}$$

$$\boxed{\begin{array}{l} \alpha < 60 \Rightarrow 6\text{pulse} \\ \alpha \geq 60 \Rightarrow 3\text{pulse} \end{array}}$$

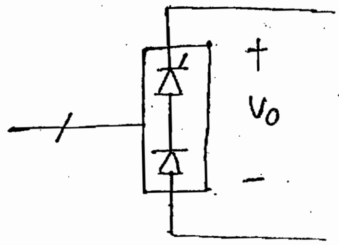
$FD = (\alpha - \pi/3)$

$T = \frac{2\pi}{3} - \left(\alpha - \frac{\pi}{3}\right)$

$= (\pi - \alpha)$

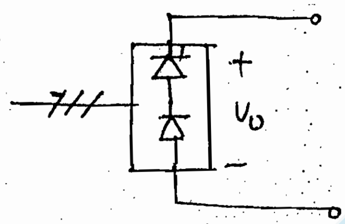
Pulse length $= T$.

1φ semiconverter →



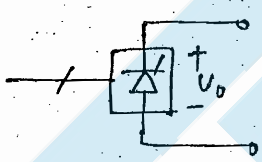
$$\boxed{V_o = \frac{V_m}{\pi}(1+\cos\alpha)}$$

3φ semiconverter →



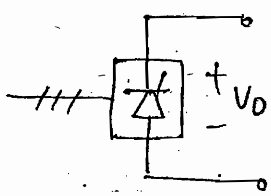
$$\boxed{V_o = \frac{V_{mL}}{2\pi/3}(1+\cos\alpha)}$$

1φ Full Condr →



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

3φ Full Convr →

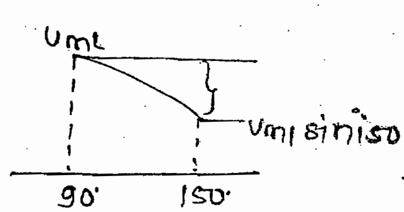


$$\boxed{V_o = \frac{3V_{ml}}{\pi}\cos\alpha}$$

T/44

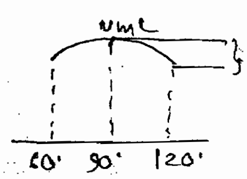
$\alpha = 30°$

$$\frac{\text{Peak to peak ripple voltage}}{\text{Peak o/p dc voltage}}$$



$$\frac{V_{mL} - V_{mL}\sin 150°}{V_{mL}} = 0.5$$

$\alpha = 0°$

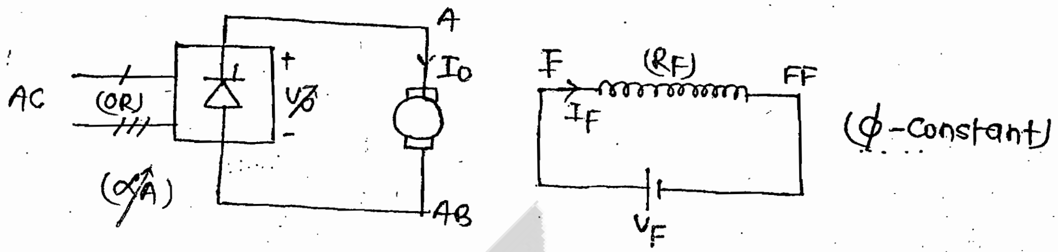


$$\frac{V_{mL} - V_{mL}\sin 120°}{V_{mL}} = 1 - \frac{\sqrt{3}}{2}$$

DATE-21/09/14

DC drives →

(1) Armature voltage control method → $(\omega < \omega_r)$



(ϕ - constant)

$$\boxed{\begin{aligned} 1\phi,\ V_0 &= \frac{2V_m}{\pi}\cos\alpha_A \\ 3\phi,\ V_0 &= \frac{3V_{mL}}{\pi}\cos\alpha_A \end{aligned}}$$

We know that;

$E_b \propto \phi N$

$E_b \propto N$ $(\because \phi \to \text{const})$

$\boxed{E_b = kN}$ → $\frac{\text{emf const (OR) motor const}}{} = \frac{V}{rpm}$

$\boxed{E_b = k\omega}$ → emf const (OR) motor const $\left(\frac{V.sec}{rad}\right)$

SI → ω rad/sec

$\omega = \frac{2\pi N}{60}$

We know that;

$T_q \propto \phi I_a$

$T_q \propto I_a$

$\boxed{T_q = k I_a}$ → motor const (OR) Torque const $\left(\frac{Nm}{A}\right)$

$$\frac{Nm}{A} = \frac{V.sec}{rad}$$

$I_a = \frac{T_a}{k}$; For motoring mode

$$V_0 = E_b + I_a R_a$$

$$V_0 = k\omega + I_a R_a$$

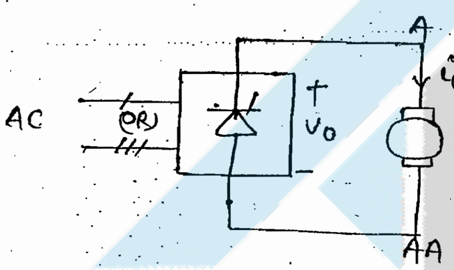
$$\cancel{\omega = \frac{V_0}{k} - \frac{R_a}{k^2} T_a}$$

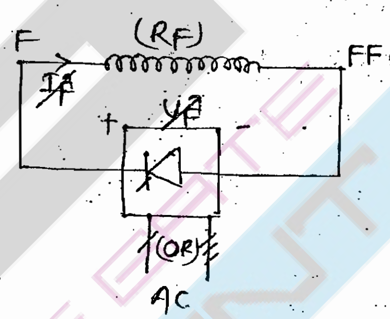
$$\omega = \frac{V_0}{k} - \frac{I_a R_a}{k}$$

$$\boxed{\omega = \frac{V_0}{k} - \frac{R_a}{k^2} T_a}$$ speed-torque eqn

$\alpha_A \uparrow, V_0 \downarrow \therefore \omega \downarrow \; (\omega < \omega_r)$

2) Field control method →





$$\boxed{\begin{array}{l} V_F = \frac{2V_m}{\pi} \cos\alpha_F \\ V_F = \frac{3V_{mL}}{\pi} \cos\alpha_F \end{array}}$$

→ 1ϕ

→ 3ϕ

$$I_F = \frac{V_F}{R_F}$$

$$\phi \propto I_F$$

$$\boxed{\phi = K_F I_F}$$ (K_F → Field constant)

$$E_b \propto \phi N$$

$$E_b = K_1 \phi N$$

$$E_b = K_1 K_F N I_F$$

$$\boxed{E_b = K I_F N}$$

K → emf const (OR) motor const $\left(\frac{V}{rpm\,A}\right)$

$\boxed{E_b = \cancel{KI_F\omega}}$ → ~~Emf const (OR) motor const~~ $\cancel{\left(\frac{V\cdot sec}{rad\cdot A}\right)}$

$T_a \propto \phi I_a$

$T_a = K_1 \phi I_a$

$T_a = K_1 (K_F I_F) I_a$

$\boxed{T_a = K I_F I_a}$ → Torque const (OR) motor const $\frac{Nm}{A^2} = \frac{V sec}{rad.A}$

$I_a = \frac{T_a}{KI_F}$; For motoring mode;

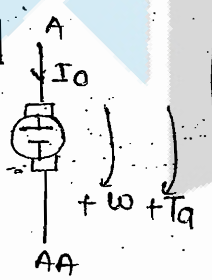
$V_a = E_b + I_a R_a$

$V_a = K I_F \omega + I_a R_a$

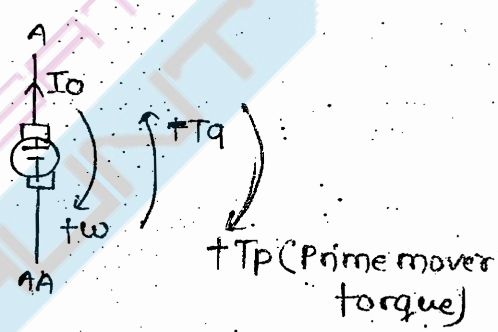
$\omega = \frac{V_a}{KI_F} - \frac{I_a R_a}{KI_F}$

$\boxed{\omega = \frac{V_a}{KI_F} - \frac{R_a}{(KI_F)^2} T_a}$ $\qquad \alpha_F\uparrow, V_F\downarrow, I_F\downarrow \therefore \omega\uparrow \ (\omega > \omega_r)$

$\boxed{\text{motoring action}}$



$\boxed{\text{Generating action}}$



Electrical Braking →

Brake energy ($\frac{1}{2}J\omega^2$) → Electrical Form

this energy is dessipated in external resestannce

(1.) Dynamic Braking (slow)

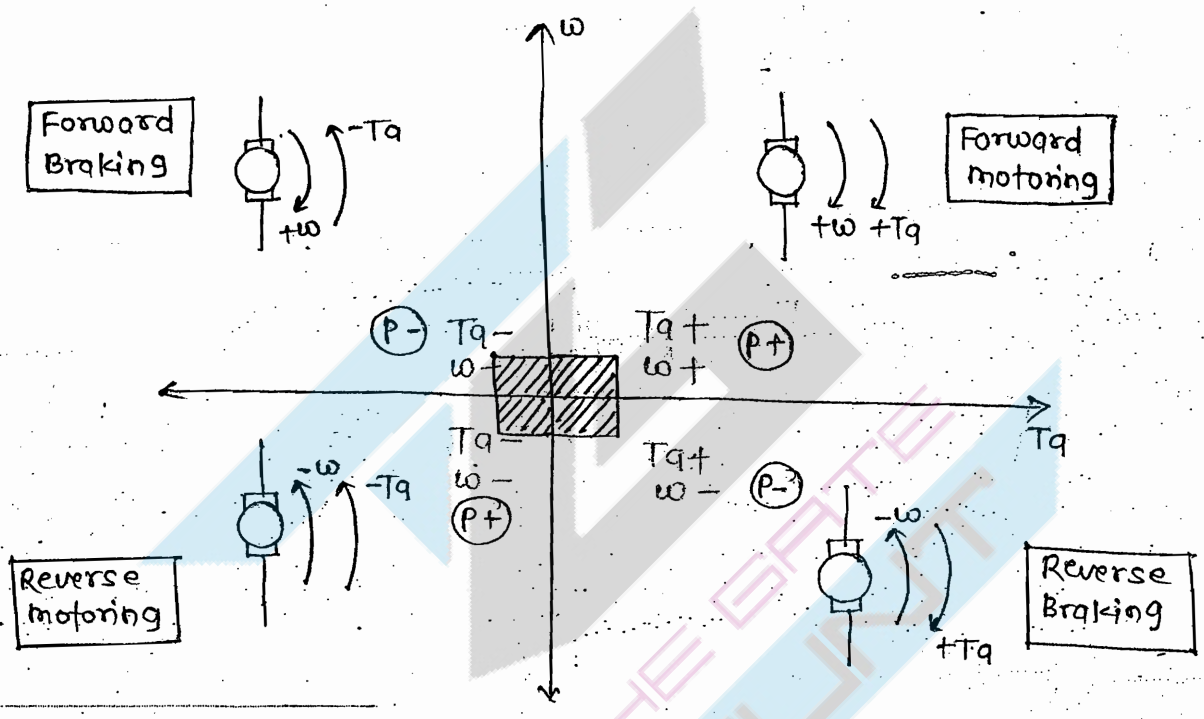
(2.) Plugging (Fast)

→ Source

(3) Regenerative Braking

* During braking the m/c behaves as generator & the brake energy available in the rotor inertia is converted into ele. form.
* If this energy is given back to the supply then it is known as regenerative braking.

* We can utilize a dc m/c in 4 modes:–



Quadrant operation of Full Converter → (Two quadrant)

1ϕ Full conv^r

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

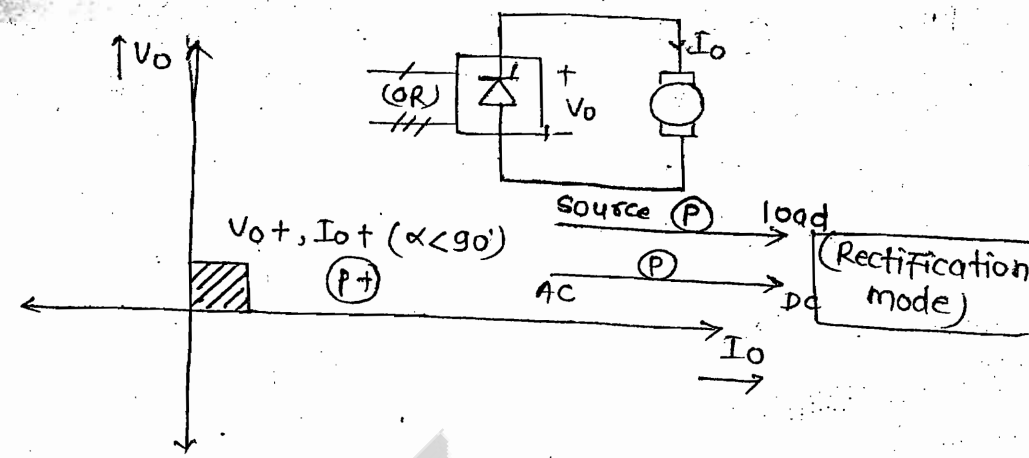
$\alpha \le 90^\circ$, $V_0 +$

$\alpha > 90^\circ$, $V_0 -$

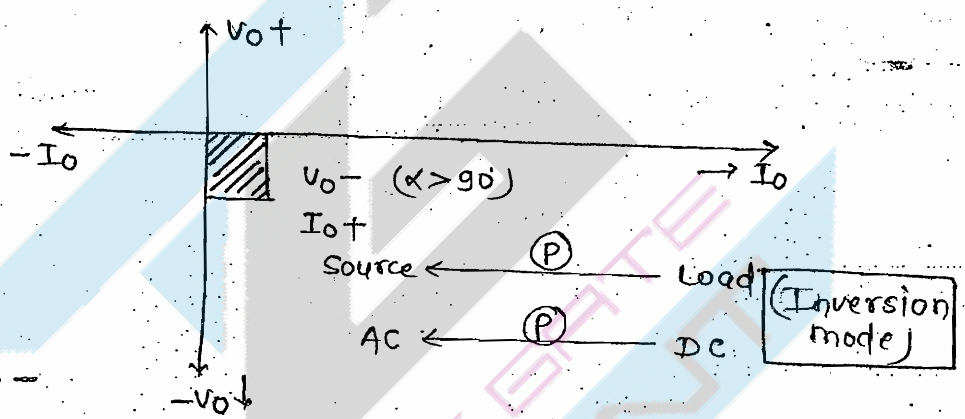
3ϕ Full conv^r

$V_0 = \frac{3V_{mL}}{\pi}\cdot\cos\alpha$

I_0 (always) +



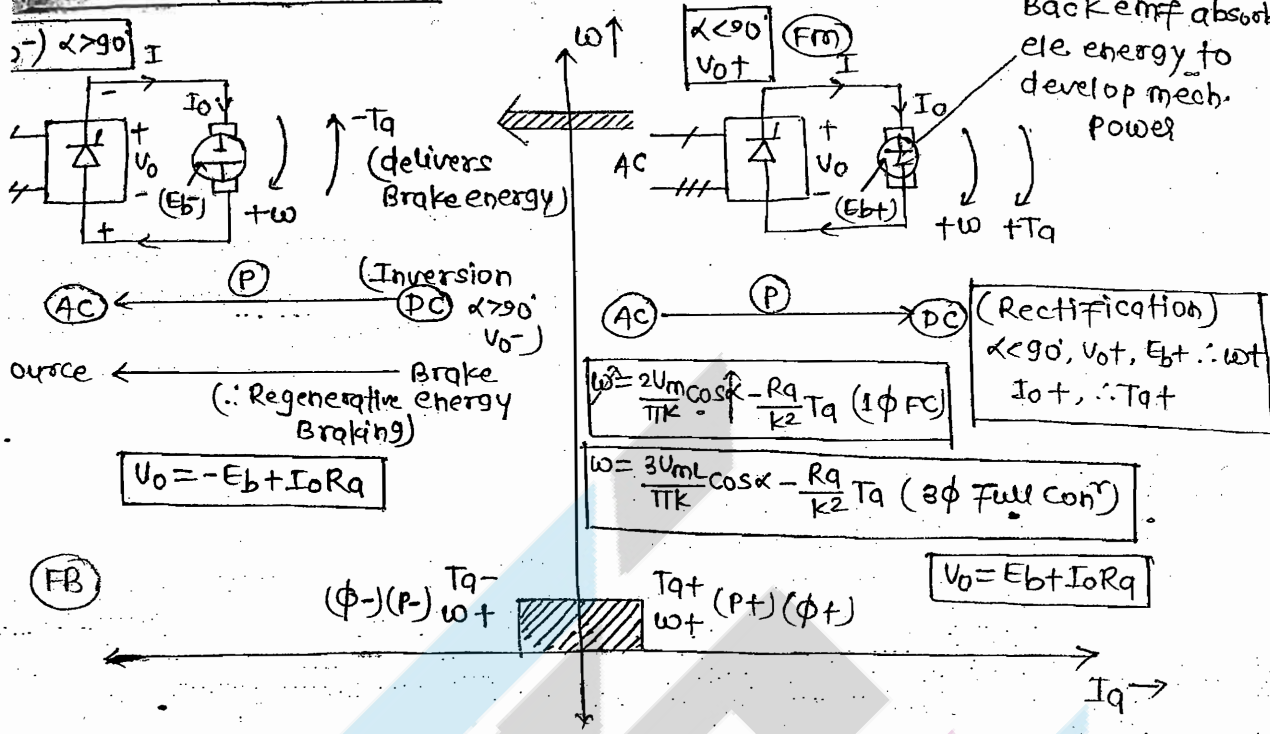
* Rectification mode can be used for motoring mode of a dc m/c & charging battery.



* Inversion mode can be used for regenerative braking of a dc m/c.

* Inversion mode is also used for solar sell.
(The solar energy stored in the form of dc is given to the AC side of conr when conr is supporting the inversion mode)

Full Conv^r Fed DC m/c →



(Solar cell) (Charging battery)

Quadrant Operation of semi converter →

1φ semi con^r	3φ semi con^r
$V_o = \frac{V_m}{\pi}(1+\cos\alpha)$	$V_o = \frac{3V_{mL}}{\pi}(1+\cos\alpha)$

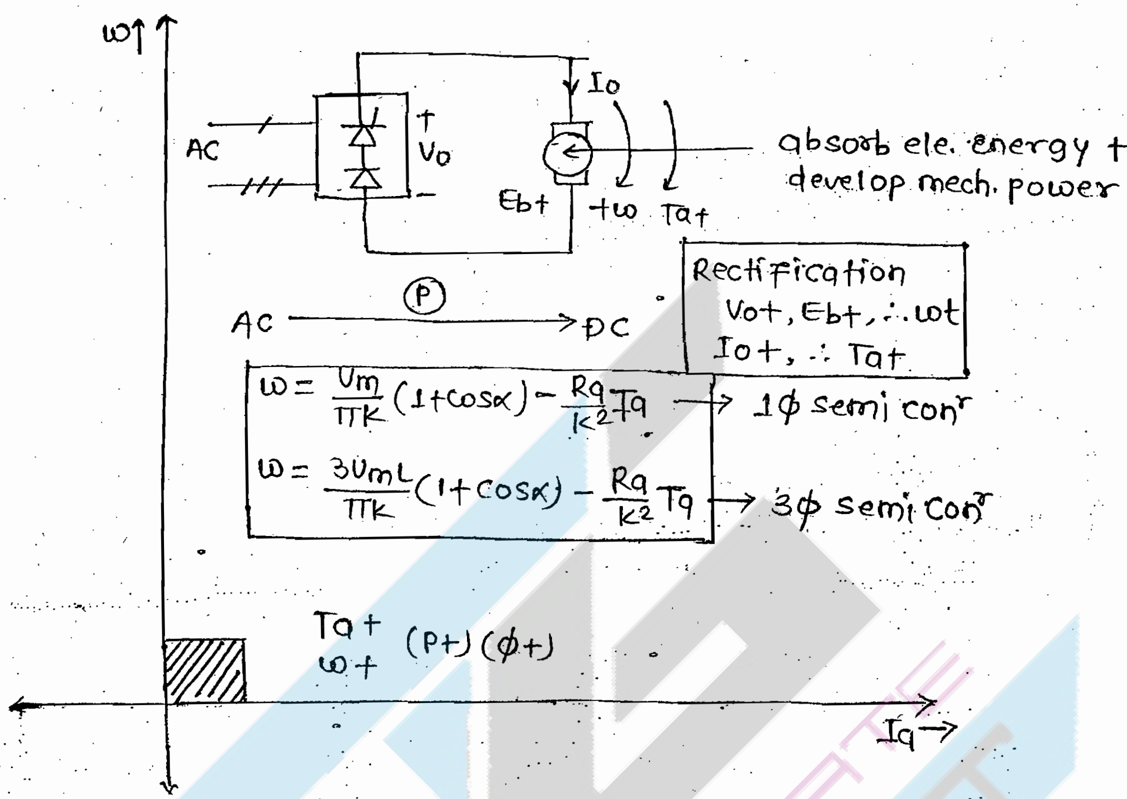
$$V_o \xrightarrow{\text{always}} +ve$$

$$I_o \xrightarrow{\text{always}} +ve$$

* Semiconverter gives only one quadrant operation.
* Inversion of semiconverter is not accepted i.e. only charging battery

application is possible with semiconv^r.

* solar cell application is not possible with semiconverter.



Rectification
Vo↑, Eb↑, ∴ ω↑
Io↑, ∴ Ta↑

AC —Ⓟ→ DC

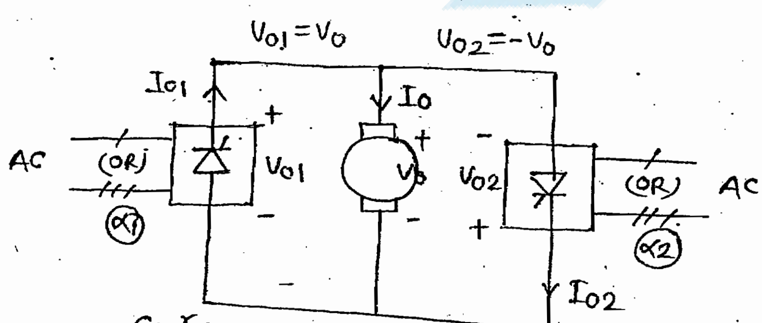
$$\omega = \frac{V_m}{\pi K}(1+\cos\alpha) - \frac{R_a}{K^2}T_a \rightarrow 1\phi \text{ semi con}^r$$

$$\omega = \frac{3V_{mL}}{\pi K}(1+\cos\alpha) - \frac{R_a}{K^2}T_a \rightarrow 3\phi \text{ semi con}^r$$

* Dual Con^r → * It gives 4 quadrant operation.

(1.) Non-circulating current type :— * In this dual con^r if one con^r is in the ON state then other con^r remains in the off state.

Advantage:— There is no circulating current b/w 2 con^r.



Con^r(1.)

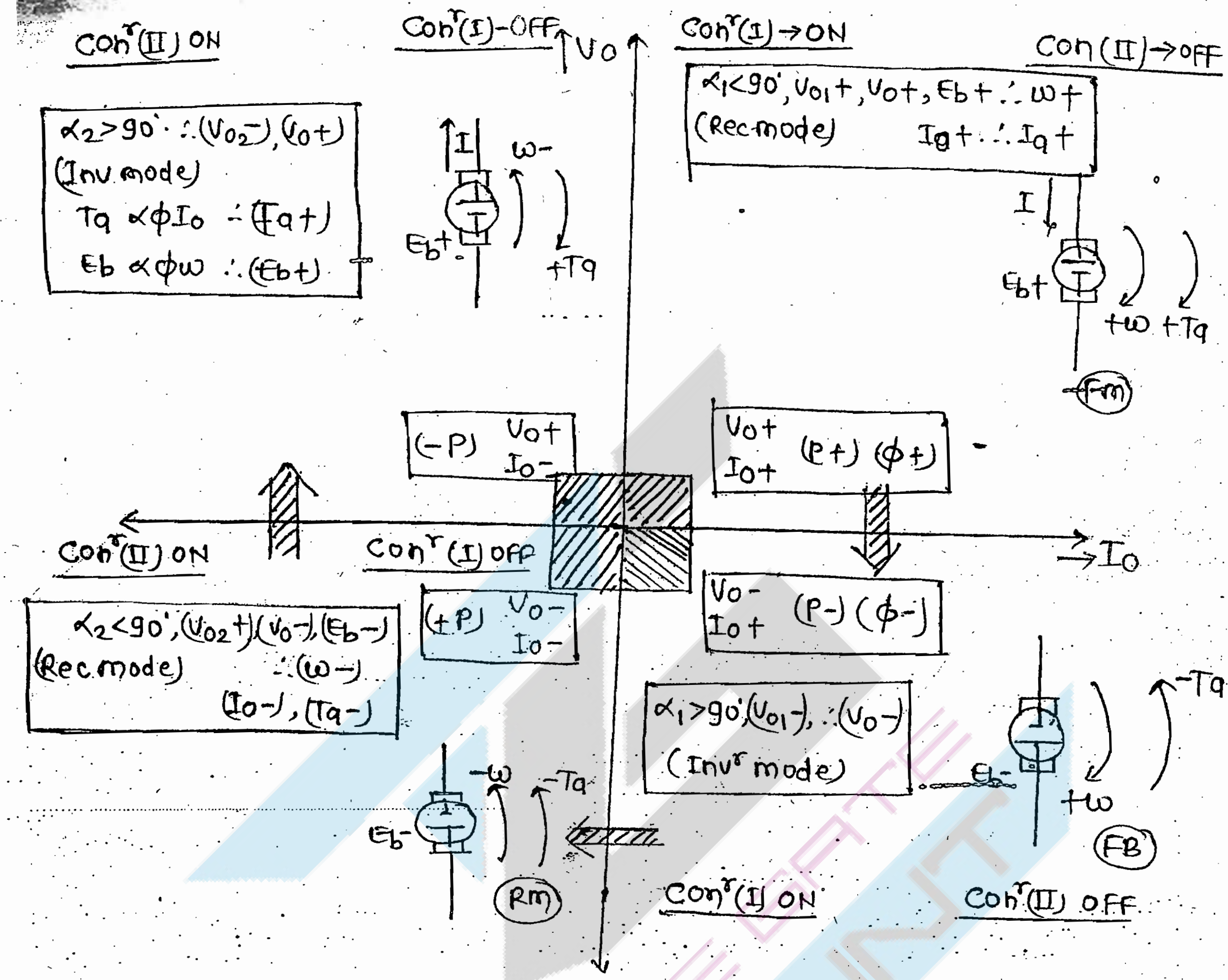
$$V_{o1} = \frac{2V_m}{\pi}\cos\alpha_1$$

$$V_{o1} = \frac{3V_{mL}}{\pi}\cos\alpha_1$$

Con^r(2)

$$V_{o2} = \frac{2V_m}{\pi}\cos\alpha_2$$

$$V_{o2} = \frac{3V_{mL}}{\pi}\cos\alpha_2$$



* <u>Disadvantage:-</u> It gives slow speed responce & the reversal of arm current is not smooth during switching operation of the con^r

* <u>Reason of slow speed responce:-</u> Here we must provide comm. delay time for outgoing con^r before the incoming con^r is switched on. to avoid high circulating current

* This comm. delay time is responsible for slow speed responce.

<u>(2) Circulating current type →</u> * In this dual con^r both the con^r are simultaneously in the on state.

<u>Disadvantage:-</u> There will be circulating current b/w 2 con^r & hence

Power Loss is responsible.

* we can reduce the circulating current if $V_{01} = -V_{02}$

$$V_{01} = -V_{02}$$

$$\frac{2V_m}{\pi}\cos\alpha_1 = -\frac{2V_m}{\pi}\cos\alpha_2$$

$$\cos\alpha_1 + \cos\alpha_2 = 0$$

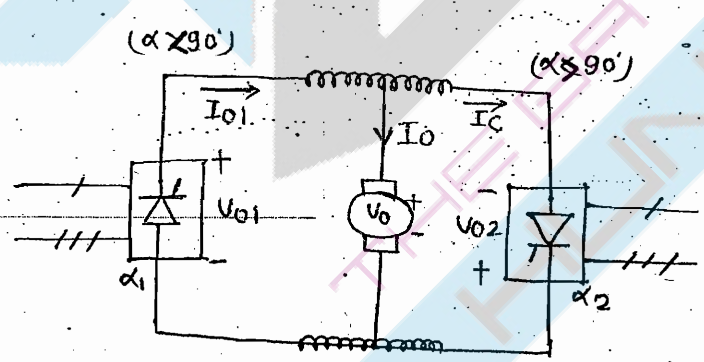
$$\cos\alpha_1 + \cos(180 - \alpha_1) = 0 \qquad (\alpha_2 = 180 - \alpha_1)$$

$$0 = 0$$

Hence $\alpha_2 = 180 - \alpha_1$

$$\boxed{\alpha_1 + \alpha_2 = 180^\circ}$$

* Even after satiesfying the condn $\alpha_1 + \alpha_2 = 180^\circ$ still there is some circulating current due to the instantaneous vol. diff. between the 2 conr.
* To reduce this circulating current we must connect a reactor b/w the 2 conr as shown in fig. given below.



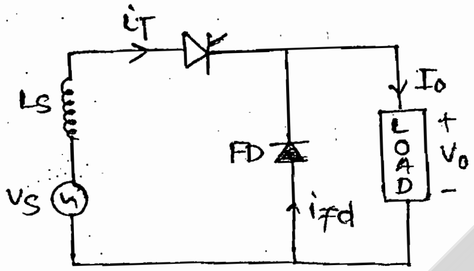
$I_{01} = I_0 + I_c$.

Advantage → It gives high speed responce & reversal of arm. current is smooth during switching operation of conr.

DATE - 22/08/14

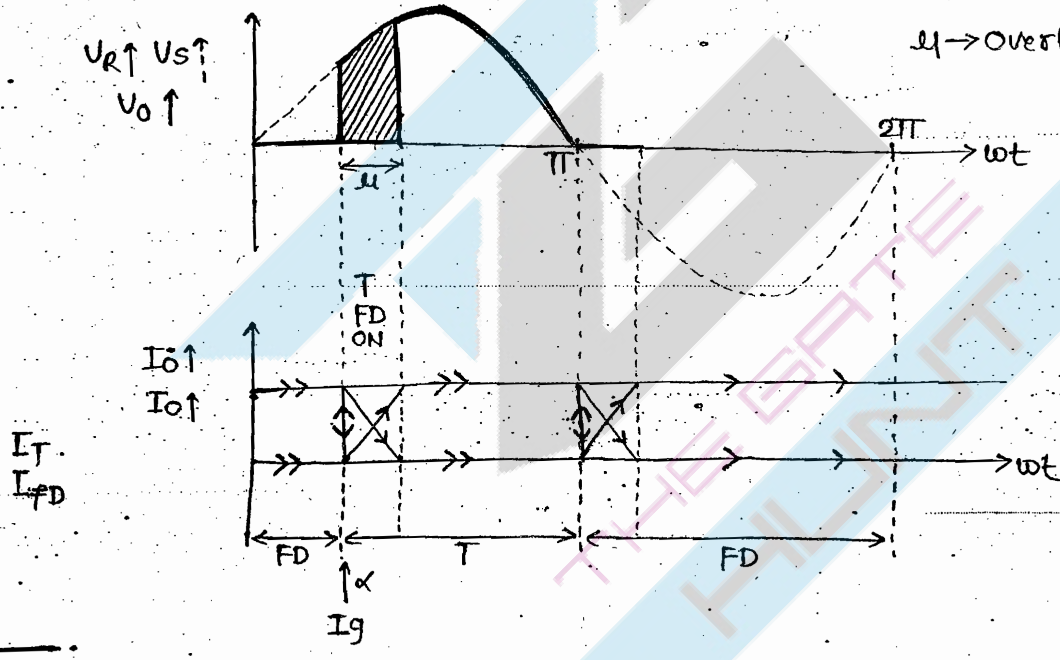
Effect of source inductance → Let Lsp the source inductance

One pulse converter →



Let us assume high inductive Load.

· without Ls (ideal source) →
· with Ls (Non-ideal source) →



μ → overlap angle

→ Reduction in V_0 due to Ls.

With Ls →

During μ, T & FD → ON state ∴ $V_0 = 0$

$\uparrow i_T + i_{FD}\downarrow = I_o$ (During μ)

The value of load current constant & value of thy. current suddenly increases. Hence $I_{FD}\downarrow$.

& $V_S = L_S \frac{di_S}{dt}$

$$V_m \sin\omega t \, dt = L_s \, di_s$$

Multiplying ω by the both sides of eqⁿ

$$V_m \sin\omega t \, dt(\omega) = L_s \omega \, di_s$$

$$V_m \sin\omega t \, d(\omega t) = L_s \omega \, di_s$$

Integrating both sides

$$\int_{\alpha}^{\alpha+\mu} V_m \sin\omega t \, d(\omega t) = \omega L_s \int_{0}^{I_0} di_s$$

$$V_m\left[\cos\alpha - \cos(\mu+\alpha)\right] = \omega L_s I_0$$

Deviding both side by 2π; then we will get average reduction in freq.

$$\frac{V_m}{2\pi}\left[\cos\alpha - \cos(\mu+\alpha)\right] = \frac{\omega L_s I_0}{2\pi}$$

$$\frac{V_m}{2\pi}\left[\cos\alpha - \cos(\mu+\alpha)\right] = f L_s I_0$$

$$\boxed{\Delta V_{do} = \frac{V_m}{2\pi}\left[\cos\alpha \mp \cos(\mu+\alpha)\right] = f L_s I_0} \text{ ------(i)}$$

Where; ΔV_{do} = average reduction in dc o/p voltage due to L_s

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

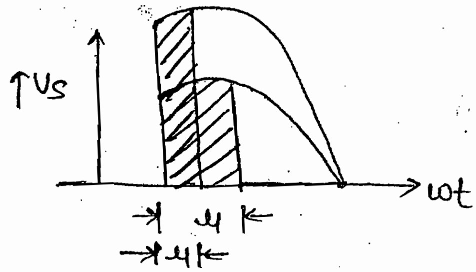
$$V_0 = \frac{V_m}{2\pi}(1+\cos\alpha) - f L_s I_0 \text{ ------(ii)}$$

$$V_0 = \frac{V_m}{2\pi}\left[1+\cos(\alpha+\mu)\right] \text{ -------(iii)}$$

ΔV_{do} does not depand on μ; it depands on $f L_s I_0$ but μ depand on the ΔV_{do}.

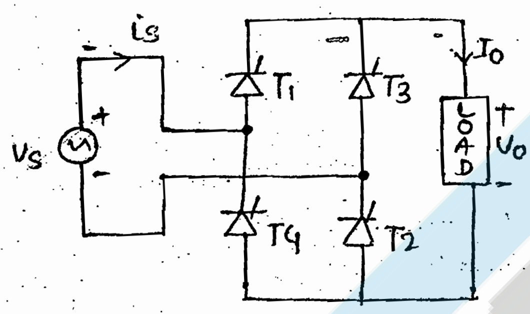
* ΔV_{do} depands only on f, L_s, I_0
* μ depands on ΔV_{do} & hence f, L_s, I_0, V_s, α
* If $f\uparrow$ (or) $L_s\uparrow$ (or) $I_0\uparrow$, without changing the ~~overlap angle~~ V_s & α then $\mu\uparrow$

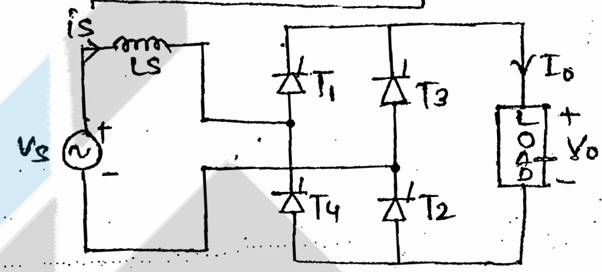
* If $V_s \uparrow$, without changing f, L_s, I_o, α then $\mu \downarrow$ to remains the area constant.

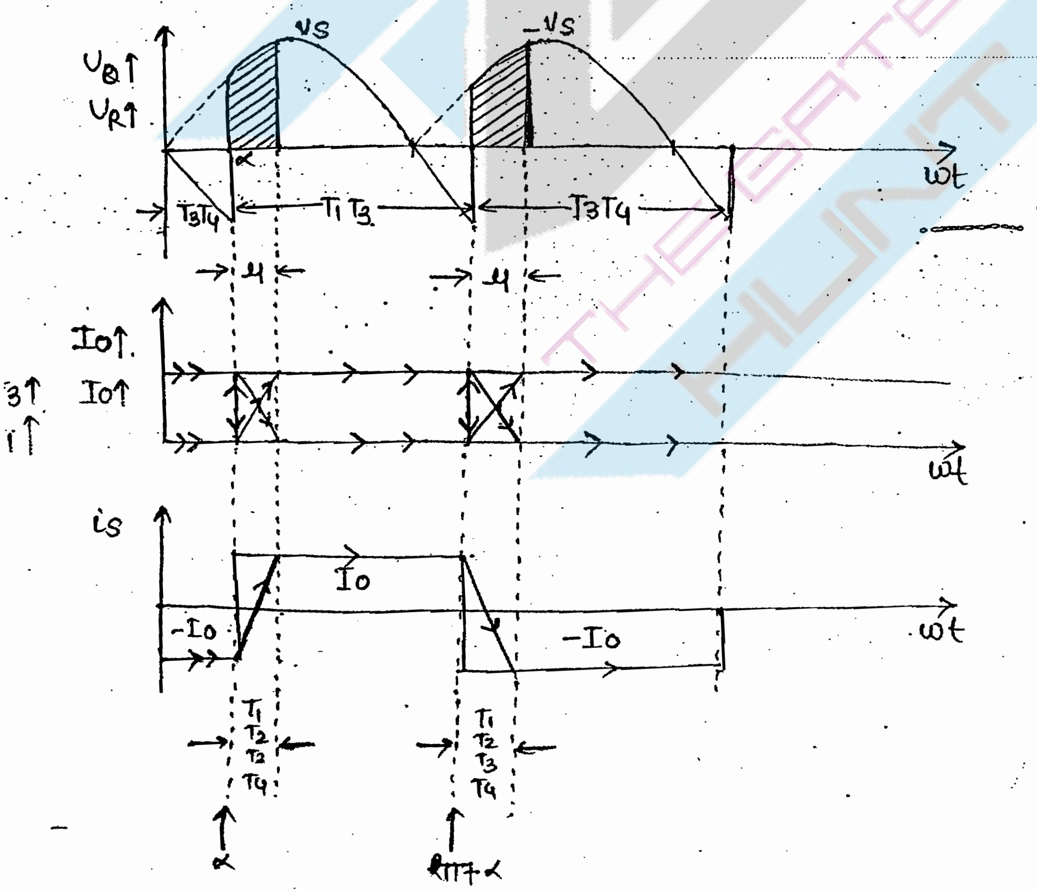


2.) Two pulse converter →

Without Ls (Ideal)
With Ls (Non-ideal)







Let $V_{do} \rightarrow (V_0)_{max}$ $\quad V_{do} = \frac{2V_m}{\pi}$ (2 pulse)

$V_{do} = \frac{3V_{mL}}{2\pi}$ (3 pulse)

$V_{do} = \frac{3V_{mL}}{\pi}$ (6 pulse)

with $L_s \rightarrow$

During μ, T_1T_2 & $T_3T_4 \rightarrow$ ON $\therefore V_0 = 0$

$$V_m \sin\omega t = L_s \frac{di_s}{dt}$$

$$V_m \sin\omega t \, dt = L_s \, di_s$$

$$V_m \sin\omega t \, d(\omega t) = \omega L_s \, di_s$$

$$\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d(\omega t) = \omega L_s \int_{-I_0}^{I_0} di_s$$

[Source current change from I_0 to $-I_0$]

$$V_m[\cos\alpha - \cos(\alpha+\mu)] = 2\omega L_s I_0$$

$$\frac{V_m}{\pi}[\cos\alpha - \cos(\alpha+\mu)] = \frac{2\omega L_s I_0}{\pi}$$

$$\boxed{\Delta V_{do} = \frac{V_m}{\pi}[\cos\alpha - \cos(\alpha+\mu)] = \frac{2\omega L_s I_0}{\pi}} \quad \text{------(i)}$$

$$\boxed{\Delta V_{do} = \frac{V_{do}}{2}[\cos\alpha - \cos(\alpha+\mu)]}$$

$m = 2, 3, 6$

***

m	ΔV_{do}
1	fL_sI_0
2	$4fL_sI_0$
3	$3fL_sI_0$
6	$6fL_sI_0$

$$V_0 = V_{do}\cos\alpha - \Delta V_{do} \quad \text{------(ii)}$$

$$\boxed{V_0 = \frac{V_{do}}{2}[\cos\alpha + \cos(\alpha+\mu)]} \quad \text{----(iii)}$$

$$-\frac{V_m}{\pi}\left[\cos\alpha-\cos(\alpha+\mu)\right]=\frac{2\omega L_s I_0}{\pi}$$

$$I_0=\frac{V_m}{2\omega L_s}\left[\cos\alpha-\cos(\alpha+\mu)\right]$$

$$I_0=I_p\left[\cos\alpha-\cos(\alpha+\mu)\right]$$

$$\boxed{\frac{I_0}{I_p}=\cos\alpha-\cos(\alpha+\mu)}$$ where $I_p=\frac{V_m}{2\omega L_s}$

Que.→ What is meant by inductive vol. regulation?

Ans.→ It is a measure of reduction is o/p vol. due to source inductance.

It is taken as a ratio of $=\frac{\Delta V_{do}}{V_{do}}$

$$=\frac{\frac{\cancel{V_{do}}}{2}\left[\cos\alpha-\cos(\mu+\alpha)\right]}{\cancel{V_{do}}}$$

$$VR^n=\left[\frac{\cos\alpha-\cos(\alpha+\mu)}{2}\right]$$

$$=\frac{1-\cos\mu_0}{2}$$

$\mu_0=$ Overlap angle at $\alpha=0°$

Que.→ What is the effect of source inductance of the performance of conr?

Ans.→ (i) It reduce the avg. o/p vol. of conr.

(ii) It limits the maxm range of firing angle.

$$\boxed{\alpha_{max}=180°-\left[\omega t_q+\mu_0°\right]}$$

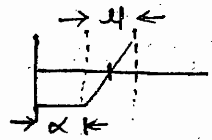
Ideal vol. source, ideal thy.. $\alpha_{max}=180°$

Ideal vol. source, practical thy. $\alpha_{max}=180-\omega t_q$

practical vol. source, practical thy. $\alpha_{max}=180°-\omega t_q-\mu$

(iii) Fundamental displacement factor

$$\boxed{FDF = \cos\left(\alpha + \frac{\mu}{2}\right)}$$

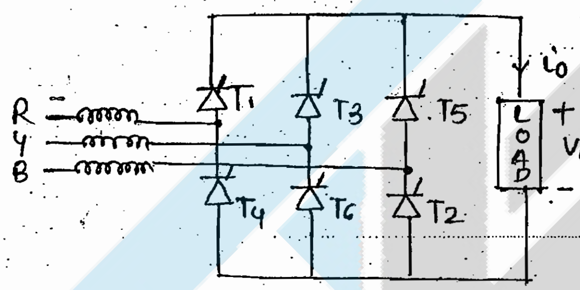


(iv) $g\uparrow$, THD $\downarrow$ ∴ Harmonic on AC side $\downarrow$
(advantage)

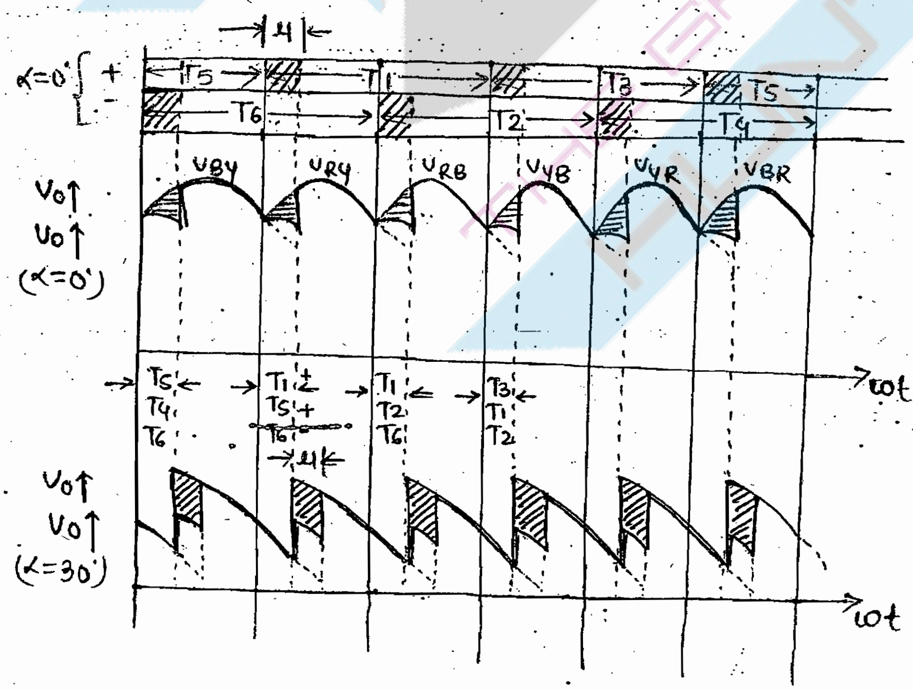
(v) $PF = g\uparrow FDF\downarrow$ (can't say)

Here the increase in g value is more than decrease in FDF
∴ the PF is slightly increased.

(3) 6 pulse converter →

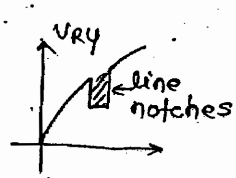


without Ls
with Ls



$\overset{+}{T_5}\overset{-}{T_6}$ & $\overset{+}{T_1}\overset{-}{T_6}$

$\frac{V_{BY} + V_{RY}}{2}$ (mean value)



Que → If α increases without changing other parameters then what happen to overlap angle?

Ans → Case(1.) $0 \le \alpha \le 90°$ $(\alpha\uparrow, \mu\downarrow)$

If $\alpha\uparrow$, without changing $\underbrace{F, L_s, I_o}_{Const}$ & V_s, then $\mu\downarrow$

$\Delta V_{do} \to$ constant

$\alpha\uparrow$ ripple vol. $\uparrow$, height of reduction $\uparrow$ $\therefore \mu\downarrow$ to maintain same area of ΔV_{do}.

Overlap angle is max^m at $\alpha = 0°$ & min^m at $\alpha = 90°$

Case② $\alpha > 90°$ $(\alpha\uparrow, \mu\uparrow)$

$\alpha\uparrow$ Ripple$\downarrow$, height$\downarrow$, $\therefore \mu\uparrow$

Conventional question →

Que. 3/48

at $\alpha = 0$, $\mu_0 = 30°$

then μ_0 at $\alpha = 30°, 60°, 90°, 120°$

$$\frac{I_o}{I_p} = \cos\alpha - \cos(\mu+\alpha)$$

For $\alpha = 0°$,

$$\frac{I_o}{I_p} = \cos 0° - \cos(30+0°)$$

$$\frac{I_o}{I_p} = 0.133$$

α	μ	
0	30°	→ max^m
30°	~~8.46~~ 12.85	$\alpha\uparrow, \mu\downarrow$
60°	~~7.61~~ 8.46	
90°	7.61	→ min^m
120°	9.21	$\alpha\uparrow, \mu\uparrow$

DATE - 25/08/14

INVERTERS

Fixed dc ⟶ Variable AC (V_0, f_0)

***Classification of inverters →**

(1) Voltage source inverter (VSI) → sq. wave inverter / PWM inverter.

* 1ϕ Half bridge Inverter.

* 1ϕ Full bridge inverter.

* 3ϕ VSI

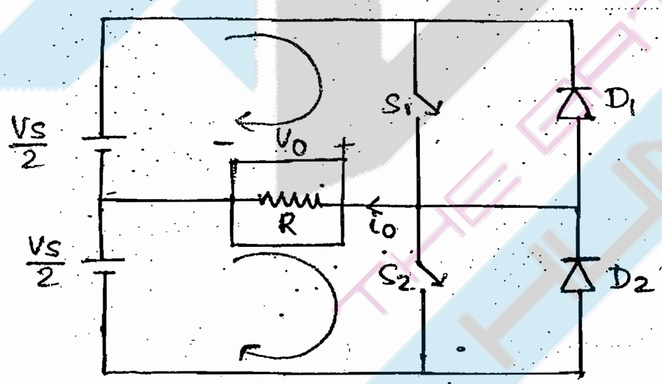
(2) Current source inverter (CSI) –

(3) Series inverter

(4) Parallel inverter.

(1) Voltage source inverter (VSI) →

(a) 1-ϕ half bridge inverter →



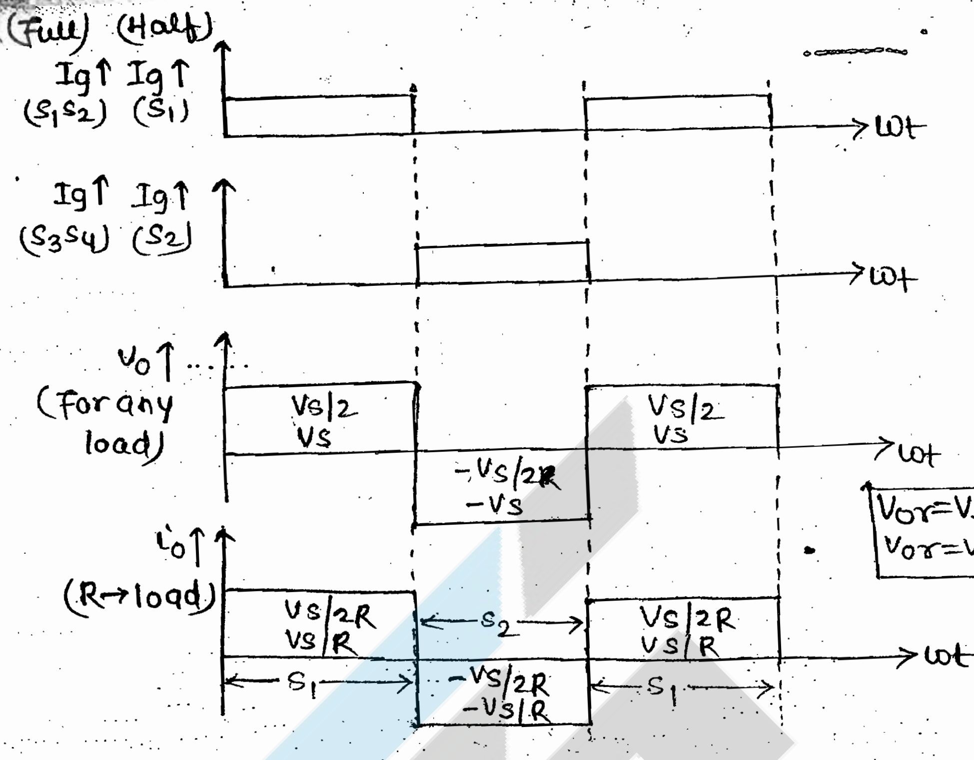
By the use of Fourier series

$$V_0 = \sum_{n=1,3,5\ldots}^{\infty} \frac{2V_s}{n\pi} \sin \omega t$$

$$V_{0n} = \frac{2V_s}{n\pi} \sin n\omega t$$

$$V_{0n} = \frac{\sqrt{2}V_s}{n\pi}$$

$$\boxed{V_{01} = \frac{\sqrt{2}V_s}{\pi}}$$



$$\boxed{\begin{aligned}V_{or} &= V_s \\ V_{or} &= V_s/2\end{aligned}}$$

$$g = \frac{V_{o1}}{V_{or}} = \frac{\frac{\sqrt{2}V_s}{\pi}}{V_s/2}$$

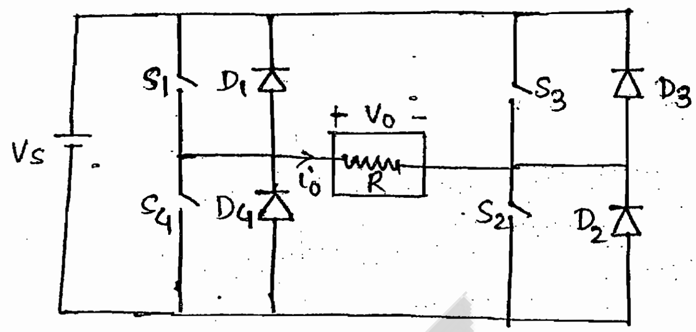
$$\boxed{g = \frac{2\sqrt{2}}{\pi}}$$

$$THD = \left(\frac{1}{g^2} - 1\right)^{1/2}$$

$$\boxed{THD = 48.34\%}$$

* For the +ve power, only R is presents & Hence F/b diode will not conducts. They will conduct only in case of -ve power
* which is found only in reactive elements (L & C)
* The shape of the V_o is not depands on the load, but the current waveform is depand on load.

(ii) 1-ϕ Full bridge inverter →



$S_1 S_2 \rightarrow ON$
$V_o \rightarrow V_s$
$i_o \rightarrow V_s/R$

$S_3 S_4 \rightarrow ON$
$V_o \rightarrow -V_s$
$i_o \rightarrow -V_s/R$

$$V_o = \sum_{n=1,3,5\ldots}^{\infty} \frac{4V_s}{n\pi} \sin n\omega t$$

$$V_{on} = \frac{4V_s}{n\pi} \sin n\omega t$$

$$V_{on} = \frac{2\sqrt{2}V_s}{n\pi}$$

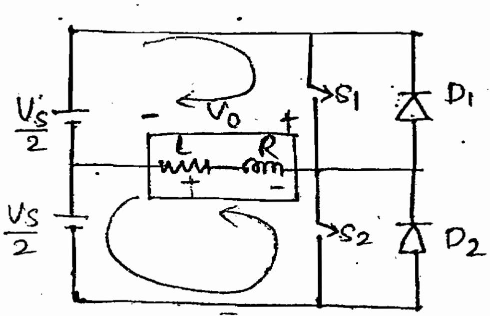
$$\boxed{V_{o1} = \frac{2\sqrt{2}V_s}{\pi}}$$

$$g = \frac{V_{o1}}{V_{or}} = \frac{\frac{2\sqrt{2}V_s}{\pi}}{V_s}$$

$$\boxed{g = \frac{2\sqrt{2}}{\pi}}$$

$$\boxed{\cancel{THD} = 48.34\%}$$

1-ϕ Half bridge inverter (Other load) →



mode (1) :- $S_1 \rightarrow ON$

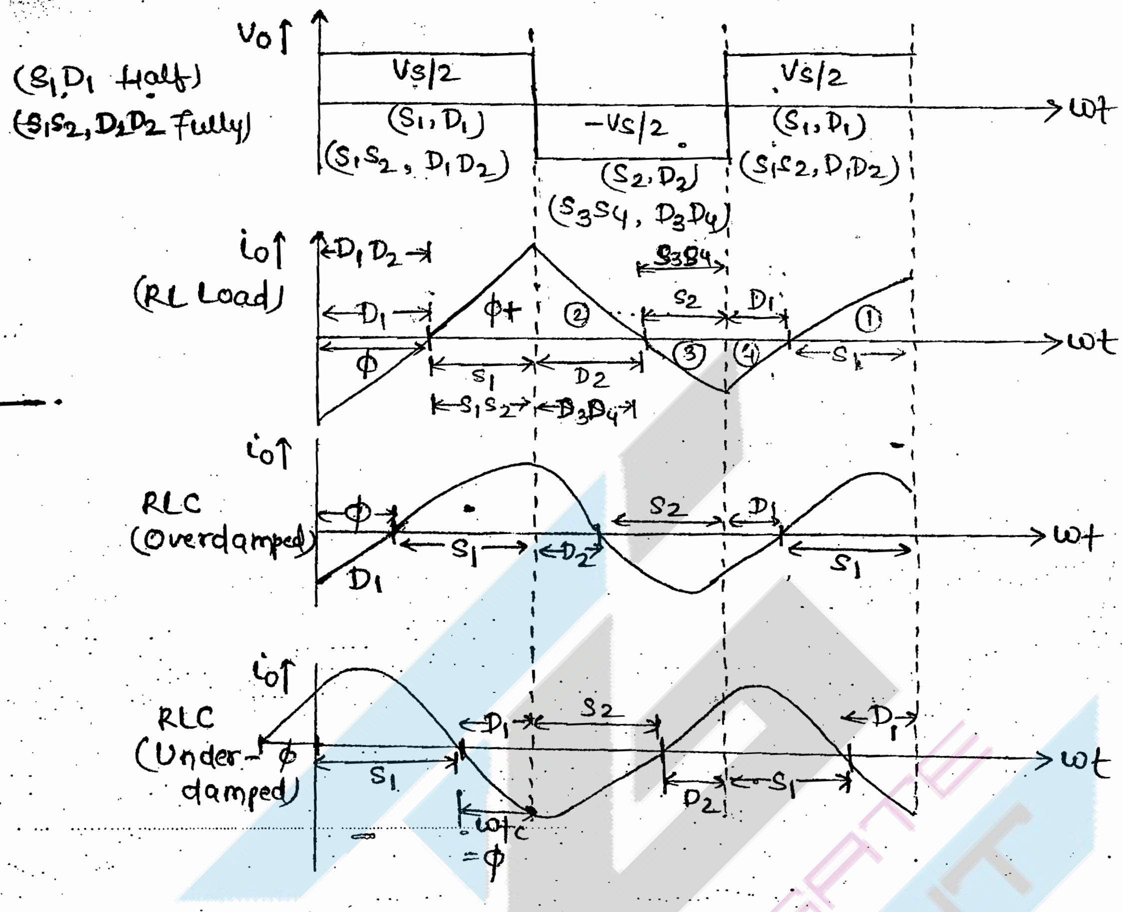
$V_o = \frac{V_s}{2}$, V_o+, i_o+, $P+$

Source $\xrightarrow{P}$ load
$(I^2R, \frac{1}{2}Li^2)$

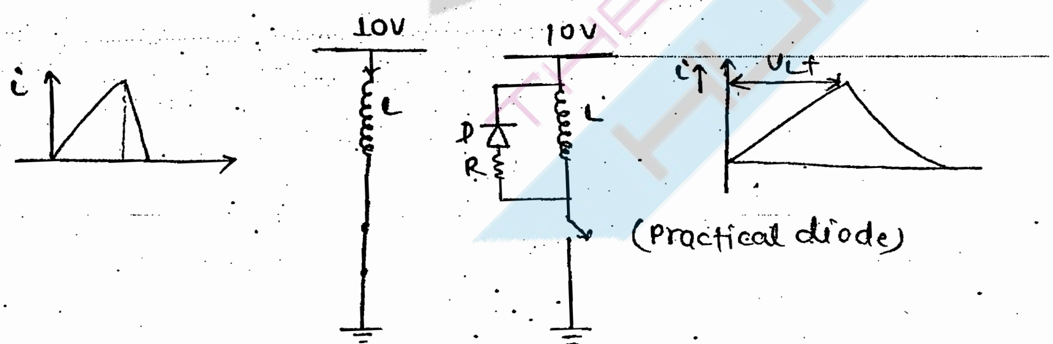
$L \rightarrow$ stores energy

mode (2) → $D_2 \rightarrow ON$

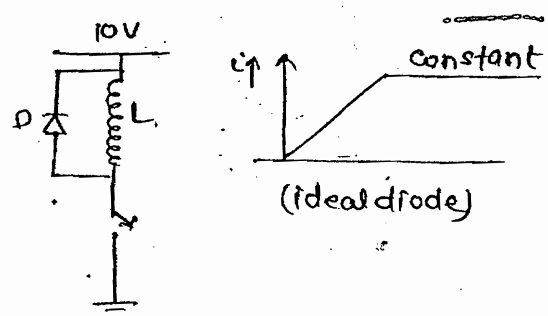
$\frac{1}{2}Li^2 \rightarrow$ sourc & i^2R
$L \rightarrow$ releasing energy



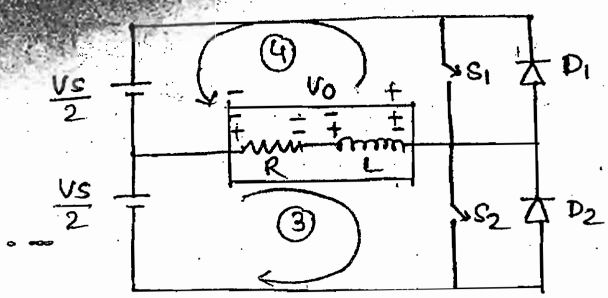
(1) RL Load → After reaching steady state, io lags by V_o by $\boxed{\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)}$



(Practical diode)



(Ideal diode)



mode(3) → $S_2 \to ON$

$V_0 = -\frac{V_S}{2}$, V_0^-, i_0^- (P+)

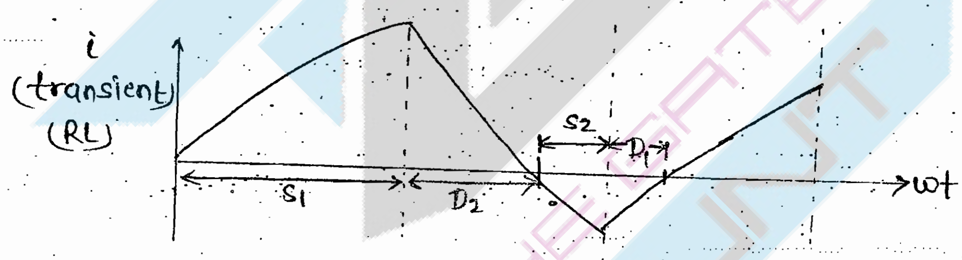
source $\xrightarrow{P}$ load (i^2R & $\frac{1}{2}Li^2$)

L → stores energy

mode(4) → $D_1 \to ON$

$\frac{1}{2}Li^2 \longrightarrow$ source & i^2R

L → releasing energy



* Inductive load will draw dc componant at the begining.

V_0	I_0	P	device
+	+	+	S_1
+	−	−	D_1
−	−	+	S_2
−	+	−	D_2

lagging load → diode

leading load → switch

(2.) RLC (Overdamped) $\rightarrow$ $(X_L > X_C)$

i_o lags v_o by $\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$

$$\boxed{\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)}$$

Forced Comm. is required.

(3.) RLC (Underdamped) $\rightarrow$

$X_C > X_L$

i_o lags v_o by $\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$

i_o leads v_o by $\boxed{\phi = \tan^{-1}\left(\frac{X_C - X_L}{R}\right)}$

Load Comm. is required

** $\boxed{\omega t_c = \phi}$

$$t_c = \frac{\phi}{\omega} = \frac{\tan^{-1}(X_C - X_L)}{R\omega}$$

If $t_c > t_q$; load Comm. is successful

$t_c < t_q$; load Comm. is fails

$\therefore$ We require forced Comm.

$$V_{on} = \frac{2V_s}{n\pi} \cdot \sin n\omega t \quad \text{(Any load)}$$

Let us consider RLC load;

$$i_{on} = \frac{V_{on}}{Z_n}$$

where $Z_n = R_n + j(X_{Ln} - X_{Cn})$.

$$= \frac{V_{on}}{|Z_n| \angle \phi_n}$$

$Z_n = |Z_n| \angle \phi_n$

$|Z_n| = \sqrt{R^2 + (X_{Ln} - X_{Cn})^2}$

$$= \frac{V_{on} \angle -\phi_n}{|Z_n|}$$

$\phi_n = \tan^{-1}\left(\frac{X_{Ln} - X_{Cn}}{R}\right)$

$$\boxed{i_{on} = \frac{2V_s}{n\pi |Z_n|} \cdot \sin(n\omega t - \phi_n)}$$

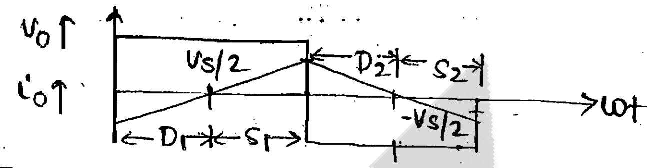
eg. – For pure inductive load

$$|Z_n| = X_{Ln} = n\omega L$$

$$\phi_n = 90°$$

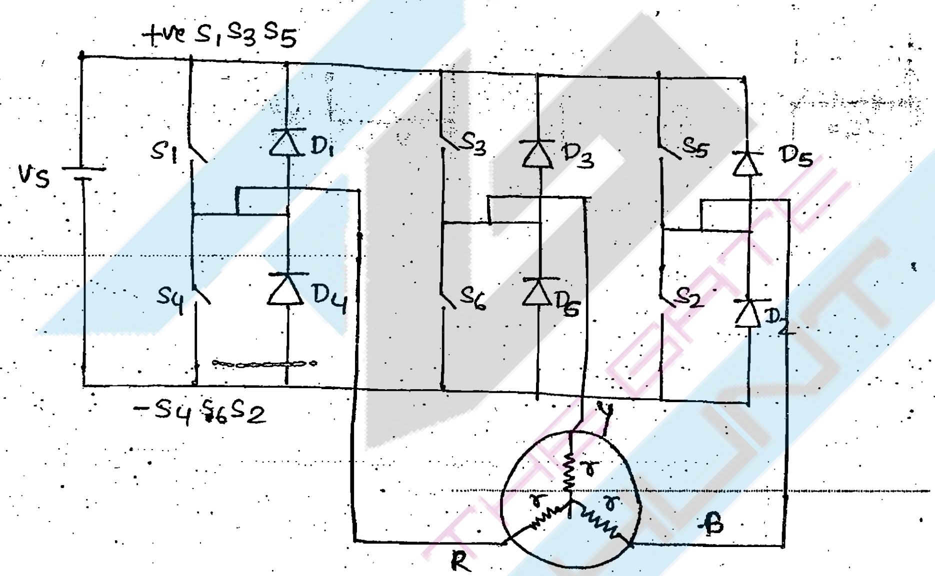
$$i_{on} = \frac{2V_s}{n\pi(n\omega L)} \cdot \sin(n\omega t - 90°)$$

$$i_{on} \propto \frac{1}{n^2}$$

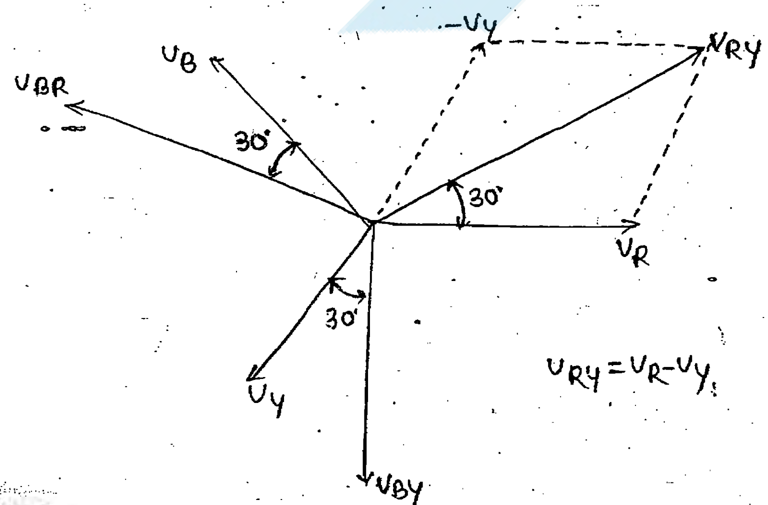


DATE-26/08/14

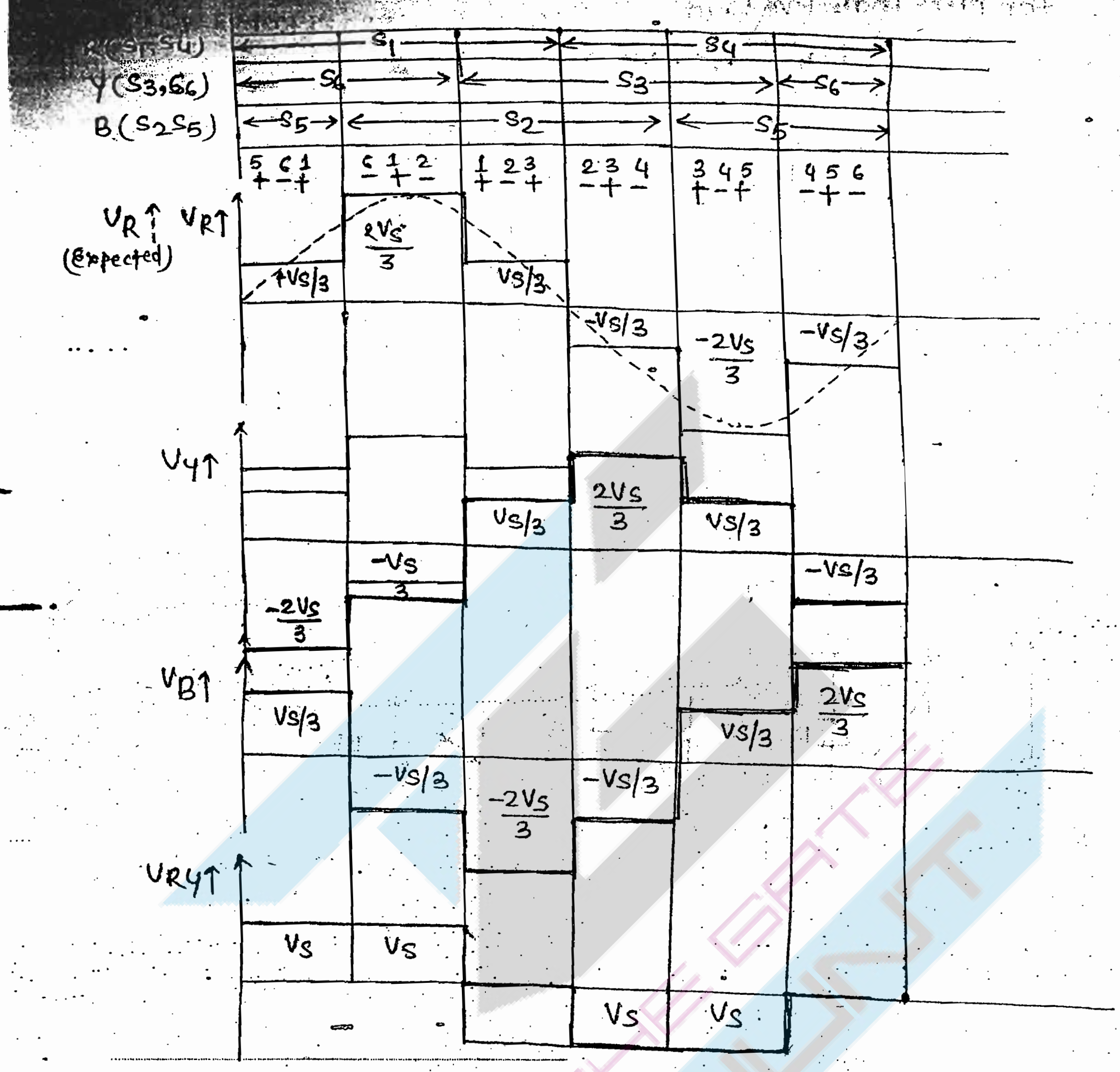
(iii) 3-ϕ VSI →



* In 180° VSI the conduction angle of switch & its antiparallel diode is 180°.

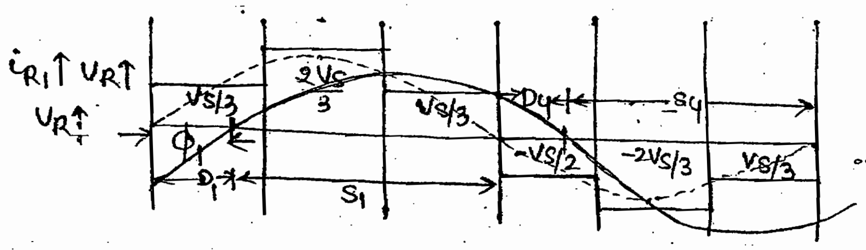


$$V_{RY} = V_R - V_Y$$



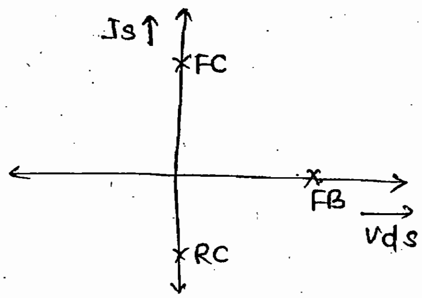
$$(V_{RY})_{Rms} = V_S\left(\frac{\frac{2\pi}{3}}{\pi}\right)^{1/2}$$

$$\boxed{V_L = \sqrt{\frac{2}{3}}\,V_S}$$



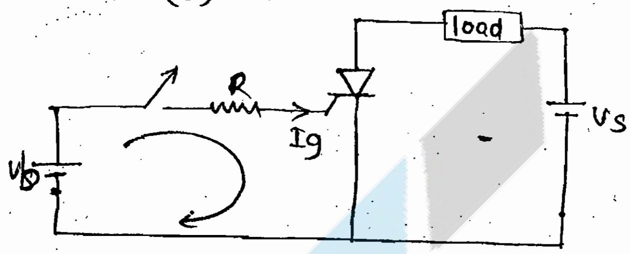
Chapter-1 Question

(1)



ans(b)

(2.)



$V_b = 12 \pm 4V$ $\quad I_{g_{min}} = 10mA$

$Ig_{min} \le Ig \le \cancel{Ig_{max}}$

For worst condn

min^m gate current

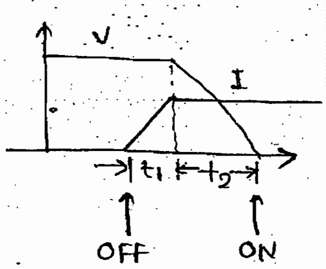
$= \frac{(V_b)_{min}}{R}$

$= \frac{12-4}{R} = \frac{8}{R} \ge Ig_{min}$

$\therefore R \le \frac{8}{Ig_{min}}$

$R \le \frac{8}{(10)\times 10^{-3}}$, $\boxed{R \le 800\Omega}$

(3.)



Turn on process

$E_{t_1} = \int_0^{t_1} V \cdot \frac{I}{t_1} t \, dt = \frac{1}{2} V I t_1$

$E_{t_1} = V(It)\,area = I \cdot \frac{V}{2} \cdot t_2$

$E_{t_2} = I(Vt)\,area$

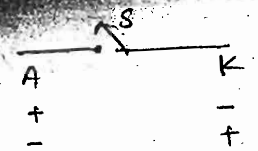
$= I\left(\frac{1}{2}\right) V t_2$

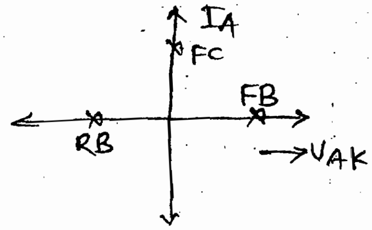
$= \frac{1}{2} V I t_2$

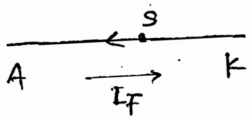
$\boxed{\text{Total } E = \frac{1}{2} V I (t_1 + t_2)}$

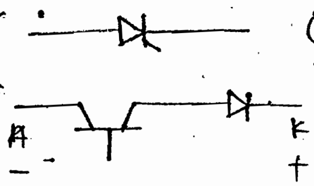
ans.(a)

(4)







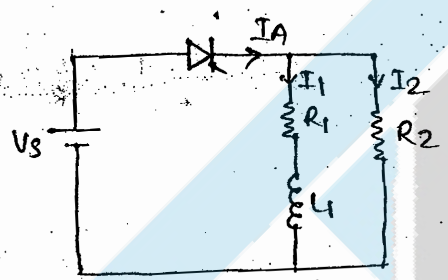
(1)  (2)

(3) (4)

Ans(C)

(5.) $C = \dfrac{S_F t_q}{R \ln 2} = \dfrac{2(50\times10^{-6})}{50 \ln 2}$ $\boxed{C = 2.88\,\mu F}$

(6.)



$I_A = I_1 + I_2$

$I_1 = \dfrac{V_S}{R_1}(1 - e^{-t/T_1}) = \dfrac{100}{20}(1 - e^{-40t})$

$I_1 = 5(1 - e^{-40t})$

$I_2 = \dfrac{V_S}{R_2} = \dfrac{100}{5\times10^3} = 20\times10^{-3}$

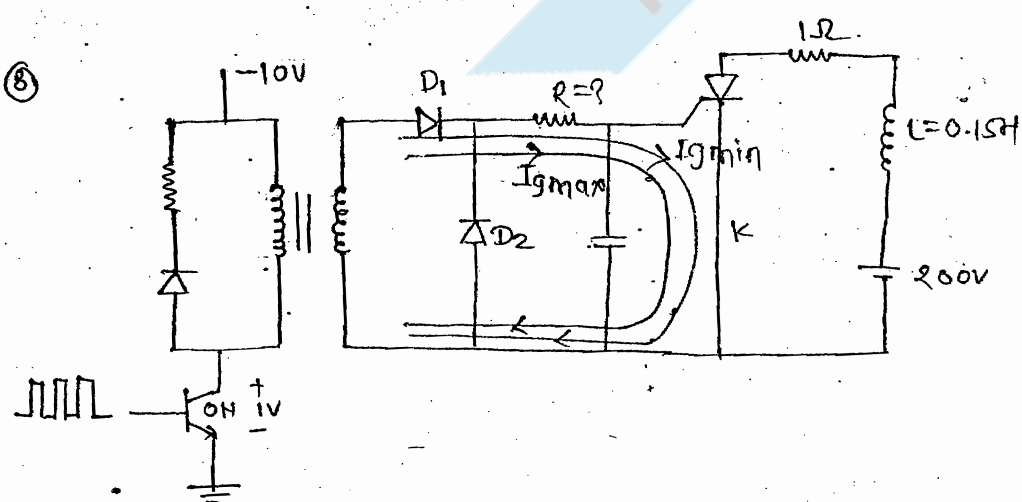
$T_1 = \dfrac{L_1}{R_1} = \dfrac{1}{40}$

$I_A = I_1 + I_2$

$I_L = 5(1 - e^{-40t}) + 20\times10^{-3}$

$\boxed{t_{min} = 150\,\mu s}$

(8)



$$9V = 1V + (I_{g\,max} R) + 1V$$

$$\boxed{R \geq 46.67\,\Omega}$$

$$9V = 1V + (I_{g\,min} R) + 1V$$

$$\boxed{R \leq 70\,\Omega}$$

If we consider both then $46.6 \leq R \leq 70\,\Omega$

Ans. (c) $47\,\Omega$

(8.) Volt sec rating of pulse Xmer $= 10 \times t_{gpw}$

- $t_{gpw} > t_{min}$

gpw = Gate Pulse width

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

$$\downarrow$$

$$I_L = \frac{200}{1}\left(1 - e^{-t_{min}/0.15}\right)$$

$$\boxed{t_{min} = 187\,\mu s}$$

$$= 10 \times t_{gpw}$$

$$= 10 \times t_{min} = 10 \times 187\,\mu Vs$$

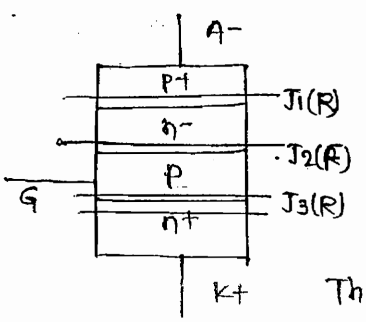
Volt sec rating of pulse Xmer $> 1870\,\mu Vs$

i.e. $2000\,\mu Vs$

(9.) (c.) (10.) MOSFET (11.) (a.) (12.) (a.) (13.) (c) (14.) $I_g \uparrow$ OR $\frac{d}{dt} I_g \uparrow$ (d)

(15.) (c.) (16.) (c.) (17.) (d.)

(17.)

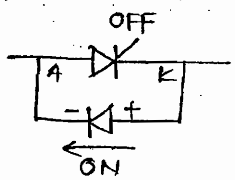


$\bar{V_R}$ +

$P\uparrow, T\uparrow, I_L\uparrow$

Thermal Runway

(18.)



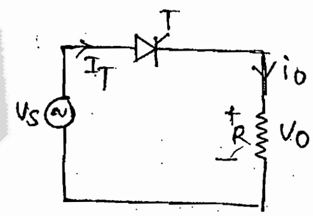
$V_R\uparrow,\ t_q\downarrow,\ \therefore P\uparrow$

$V_R\downarrow,\ t_q\uparrow,\ \therefore P\downarrow$

ans (b)

(19.) $I_S/2 = \sqrt{2}\, I_{S_1} \Rightarrow 3000 = \sqrt{2}\, I_{S_1}$, $I_{S_1} = 2121.3A$

(20.) $(I_T)_{avg.}\text{Rating} = \dfrac{(I_T)_{rms}\text{Rating}}{FF}$



$$FF = \frac{I_{T(rms)}}{(I_T)_{(avg)}} = \frac{I_{or}}{I_o}$$

$$= \frac{V_{or}/R}{V_o/R}$$

$$= \frac{V_{or}}{V_o} = \frac{\dfrac{\cancel{V_m}}{\sqrt{2.2\pi}}\left[(\pi-\alpha) + \frac{1}{2}\sin 2\alpha\right]^{1/2}}{\dfrac{\cancel{V_m}}{2\pi}\cos\alpha}$$

$$= 3.98$$

$$(I_T)_{avg}\text{ Rating} = \frac{35}{3.98}$$

$$= 8.8A$$

(21) more than 20A (22) (B.) (23.) (b.)

onventional Q.(1) (b.) –

Heat sink

J . C S A

$T_j = 125^\circ C$; $T_{s1} = 70^\circ C$

$$P_{AV_1} = \frac{T_J - T_{S1}}{\theta_{jc} + \theta_{cs}} = \frac{125-70}{0.16+0.08} = 229.16\,W$$

$\downarrow T_{S2} = 60^\circ C$ (cool down)

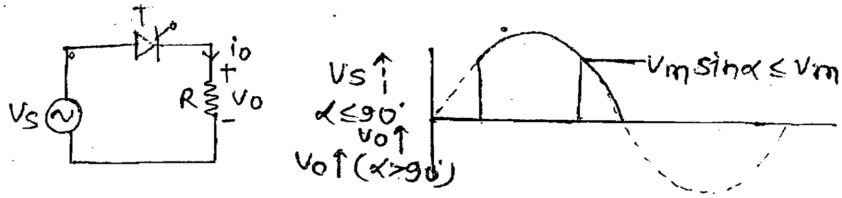
$$\therefore P_{AV_2} = \frac{125-60}{0.16+0.08} = 270.8\,W$$

$$\%\text{ increase in Rating} = \frac{\sqrt{P_{aV_2}} - \sqrt{P_{aV_1}}}{\sqrt{P_{aV_1}}} \times 100 = 8.79\%$$

Chap.(2.)

(2.) (b.) (3.) $PIV = 2V_m = 2(50)\sqrt{2} = 100\sqrt{2}$

(4.)



If $\alpha \geq 90°$, $[V_0(\omega t)]_{peak} = V_m$

If $\alpha > 90°$, $[V_0(\omega t)]_{peak} = V_m \sin\alpha = 230V$

$\Rightarrow 230\sqrt{2}\sin\alpha = 230$

$\Rightarrow \cancel{230}(\sqrt{2})\sin\alpha = \cancel{230}$

$\sin\alpha = \frac{1}{\sqrt{2}}$

$\alpha = 135°$

(5.) $\alpha = 60°$

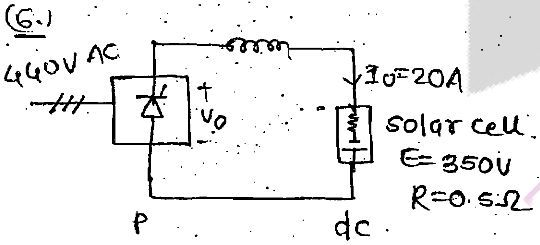
$FDF = \cos\alpha$

$= \cos 60° = 0.5$

$PF = g\cos\alpha = 0.478$

[Ans. (c)]

(6.)



AC ← DC
INV (α>90°) (Vo−)

$V_0 = -E + I_0 R$

$\frac{3V_{mL}}{\pi}\cos\alpha = -E + I_0 R$

$\frac{3(440\sqrt{2})}{\pi}\cos\alpha = -350 + (20\times 0.5)$

$\alpha = 125°$

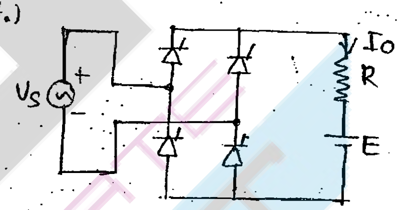
$\alpha \geq 60°$.

$\alpha + \omega t_c = \pi$

$\omega t_c = \pi - \alpha = 180° - 125°$

$\boxed{\omega t_c = 55°}$

(7.)



(α to θ_2)

$\theta_1 = \sin^{-1}\frac{E}{V_m} = 38$

$\theta_2 = \pi - \theta_1 = 142$

$I_0 = \frac{1}{2\pi R}\left[V_m(\cos\alpha - \cos\theta_2) - E(\theta_2 - \alpha)\right]$

$= \frac{1}{2\pi R}\left[V_m(\cos\theta_1 - \cos\theta_2) - E(\theta_2 - \theta_1)\right]$

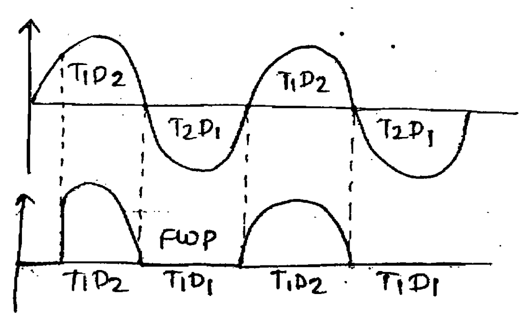
$-E(142-38)\frac{\pi}{180}$

$\boxed{I_0 = 11.9A}$

(8.) $\alpha = 25°$, $\mu = 10°$

$FDF = \cos\left(\alpha + \frac{\mu}{2}\right) = 0.866$

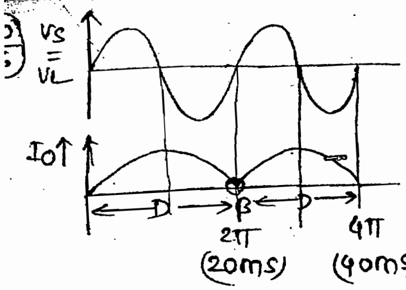
(9.)

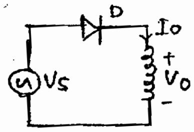


$V_S = V_L$

$F = 50Hz$

$T = 20ms$





(14/46) $V_s = 100\sqrt{2}\sin(100\pi t)$

$I_s = \underbrace{10\sqrt{2}\sin(100\pi t - \overset{\phi_1}{\tfrac{\pi}{3}})}_{I_{S1}} + \underbrace{5\sqrt{2}\sin(300\pi t + \tfrac{\pi}{4})}_{I_{S3}}$

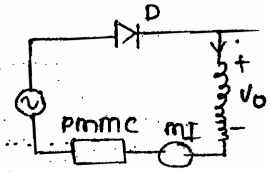
$+ \underbrace{2\sqrt{2}\sin(500\pi t - \tfrac{\pi}{6})}_{I_{S5}}$

$P = V_{sr} \cdot I_{sr}\cos\alpha = 100(2)\cos(\pi/3) = 500$

(15/46) $PF = g \cdot FDF$ $\quad g = \frac{I_{S1}}{I_{Sr}} = \frac{10}{\sqrt{10^2+5^2+2^2}}$

$PF = \frac{10}{\sqrt{129}}\cos 60° = 0.44$

*



$I_0 = \frac{V_m}{\omega L}(1-\cos\omega t)$

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

$(I_0)_{avg} = \frac{V_m}{\omega L}$; $I_{or} = 1.225\frac{V_m}{\omega L}$

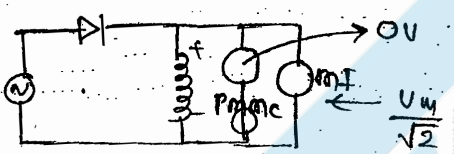
$I_{or} = \sqrt{\left(\frac{V_m}{\omega L}\right)^2 + \left(\frac{V_m}{\sqrt{2}\omega L}\right)^2} = 1.225\frac{V_m}{\omega L}$

(18/47) $V_0 = \frac{V_m}{\pi}(1+\cos\alpha)$; $(V_0)_{max} = \frac{2V_m}{\pi}$

$= I_F(100 + R_S)$

$\frac{2 \cdot 100\sqrt{2}}{\pi} = (1\times10^{-3})(100+R_S)$; $\boxed{R_S = 89.9k}$

*

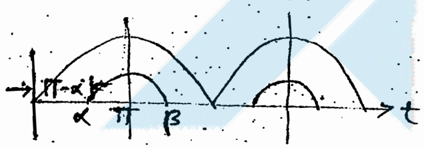


$\leftarrow \frac{V_m}{\sqrt{2}}$

(19/47) RLE load 2pulse, $\alpha = 110°$, $\mu = ?$

$\Delta V_{d0} = \frac{V_{d0}}{2}[\cos\alpha - \cos(\mu+\alpha)] = 4 f L_s I_0$

$V_{d0} = \frac{2V_m}{\pi}$; $V_0 = -E_g + I_0 R_a$ [Because of $\alpha > 90°$ INV] ---(i)



$V_0 = V_0\cos\alpha - 4fL_sI_0$ ----(ii)

$\beta = \pi + (\pi - \alpha) = 2\pi - \alpha = 360 - 120 = 240°$

$\boxed{I_0 = 35.7A}$ $\quad \boxed{\mu = 8.35°}$

AC $\xleftarrow[\text{INV }(\alpha>90°)\,(V_0)]{}$ DC

$V_0 = -E + I_0R \quad I_0 = \frac{V_0+E}{R}$

$V_0 = \frac{3V_{mL}}{\pi}\cos\alpha$; $\alpha = 90.001 = 90+$

$V_0 = (0^-)$ (Because INV not possible at $90°$)

$I_0 = \frac{0+400}{10} = \boxed{40A}$

KVA rating of Tr $= \sqrt{3}\, V_{sr} \cdot I_{sr}$

$I_{sr} = \sqrt{\frac{2}{3}}\, I_0$

$Tr = \sqrt{3} \cdot 400 \times \sqrt{\frac{2}{3}}\, I_0$

$\boxed{Tr = 22.6kVA}$

Conventional que (2) →

3 pulse : $V_{d0} = \frac{3V_{mL}}{2\pi}$

$\alpha_{max} = 180° - [(\omega t_q) + \mu_0]$ $\quad \mu_0$ = overlap angle at $\alpha = 0$

$\Delta V_{d0} = \frac{V_{d0}}{2}[\cos\alpha - \cos(\alpha+\mu)] = 3fL_sI_0$

$\frac{V_{d0}}{2}[1 - \cos\mu_0] = 3fL_sI_0$

Because at $\alpha = 0$ (Rec. mode)

$V_0 = E_b + I_0R_a$ ....(1)

$V_0 = V_{d0}\cos\alpha - 3fL_sI_0$ ....(2)

$I_0 = 14.7A$, $\boxed{\mu_0 = 17°}$

$\omega t_q = 2\pi f t_q = 2\pi \cdot 50 \cdot 250\times10^{-6} \times \frac{180}{\pi} = 4.5$

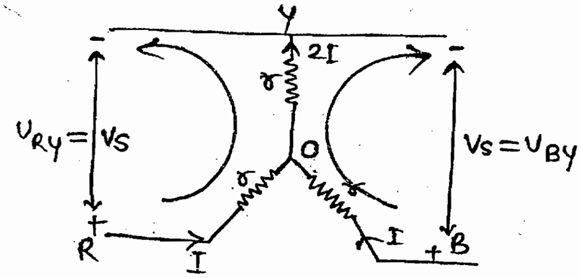
$\alpha_{max} = 180 - [\omega t_q + \mu_0] = 180 - [4.5 + 17]$

$\boxed{\alpha_{max} = 158.5}$

(1.) 0 to $\pi/3 \rightarrow$

$S_5 S_6 S_1 \rightarrow ON$
$+ \; - \; +$

$S_1 S_6$ $S_5 S_6$
$+ \; -$ $+ \; -$
R Y   B Y



By using KVL $\rightarrow$

$$V_S = Ir + 2Ir$$
$$V_S = 3Ir$$
$$Ir = \frac{V_S}{3}$$

$$V_R = +Ir = +\frac{V_S}{3}$$
$$V_Y = -2Ir = \frac{-2V_S}{3}$$
$$V_B = +Ir = +\frac{V_S}{3}$$

$$(V_R)_{Rms} = \left[\frac{1}{\pi}\left\{\left(\frac{V_S}{3}\right)^2 \times \frac{\pi}{3} + \left(\frac{2V_S}{3}\right)^2 \frac{\pi}{3} + \left(\frac{V_S}{3}\right)^2 \frac{\pi}{3}\right\}\right]^{1/2}$$

$$\boxed{V_{ph} = \frac{\sqrt{2}V_S}{3}}$$

$$\boxed{I_L = I_{ph} = \frac{V_{ph}}{r} = \frac{\sqrt{2}V_S}{3r} \, A}$$

$$(I_S)_{rms} = \left[\frac{1}{2\pi}\left\{\left(\frac{V_S}{3r}\right)^2 \frac{\pi}{3} + \left(\frac{2V_S}{3r}\right)^2 \frac{\pi}{3} + \left(\frac{V_S}{3r}\right)^2 \frac{\pi}{3}\right\}\right]^{1/2}$$

Switch

$$= \frac{V_S}{3r}$$

$$\boxed{(I_S)_{rms} = \frac{V_S}{3r}}$$

(1.) $V_{ph} = \frac{\sqrt{2}V_S}{3}$

(2.) $I_{ph} = \frac{V_{ph}}{r}$

(3) $(I_S)_{rms} = \frac{I_{ph}}{\sqrt{2}}$

(4.) $V_L = \sqrt{3} V_{ph}$

(5.) $P = 3 I_{ph}^2 r$

$$\boxed{P = \frac{3V_{ph}^2}{r}}$$

The Fourier Series of $V_R = \sum_{n=6k\pm1}^{\infty} \frac{2V_s}{n\pi} \cdot \sin n\omega t$

$n = 1, 5, 7, 11, 13, 17, 19 \ldots\ldots$

Note:- Even & tripple harmonics are not present.

$$g = \frac{3}{\pi}, \quad THD = 31\%$$

$$V_{Rn} = \frac{2V_s}{n\pi} \sin n\omega t \longrightarrow \text{Any load}$$

Let us consider RLC load in each phase & let $(X_L > X_C)$

$$i_{Rn} = \frac{V_{Rn}}{Z_n} = \frac{V_{Rn}}{|Z_n| \angle \phi_n} = \frac{V_{Rn} \angle -\phi_n}{|Z_n|}$$

$$\boxed{i_{Rn} = \frac{2V_s}{n\pi |Z_n|} \cdot \sin(\omega t - \phi_n)}$$

$$\boxed{i_{R1} = \frac{2V_s}{\pi |Z_1|} \sin(\omega t - \phi_1)}$$

* Cond^n angle of each diode $\quad D \rightarrow \phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$

* Cond^n angle of each switch $\quad S = (\pi - \phi)$

Fourier Series For line voltages:-

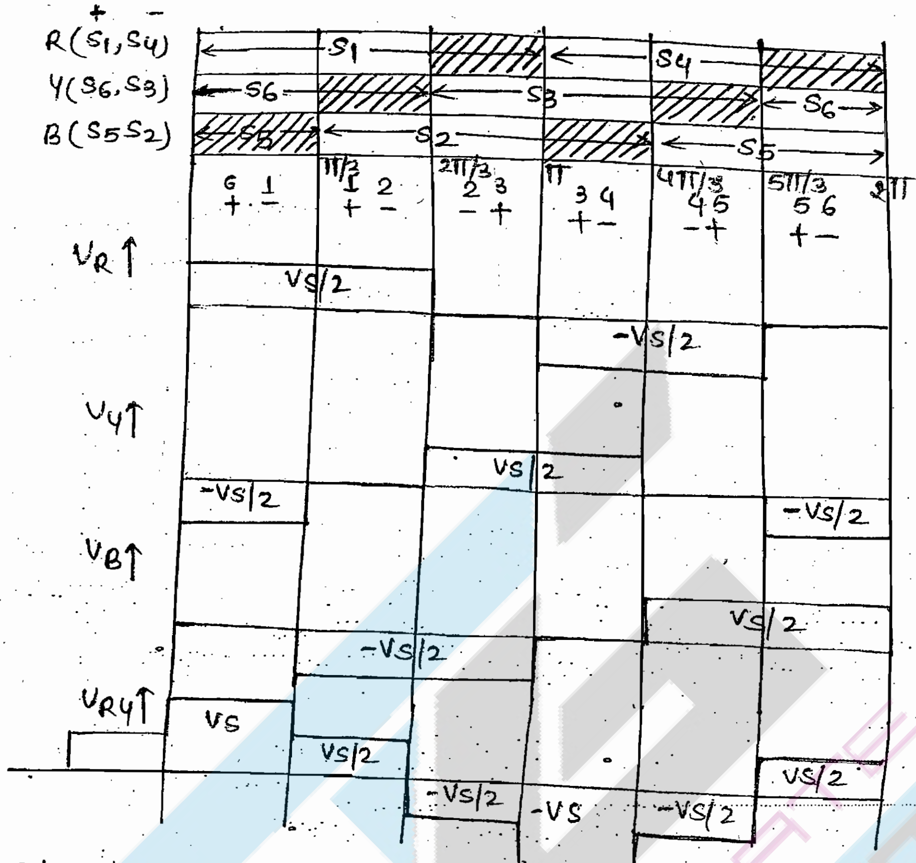
$$\boxed{V_{RY} = \sum_{\substack{n=1,3,5\ldots \\ n=6k\pm1}}^{\infty} \frac{4V_s}{n\pi} \sin\frac{n\pi}{3} \cdot \sin(\omega t + \pi/6)}$$

Note:- Even & ~~odd~~ tripple harmonics are not present.

$$\boxed{g = \frac{3}{\pi}, \quad THD = 31\%}$$

Drawback → There is a possibility of SC across the supply when the incoming switch is start conducting before the outgoing switch belonging to the same phase stops conducting.

$\underline{120^\circ \text{ VSI}} \rightarrow$ In this case a condⁿ angle of 120° is alloted for each switch & the last 60° is allotted for commutation.



$\underline{0 \text{ to } \pi/3 \rightarrow}$

$\underset{R}{\overset{+}{S_1}}\ \underset{Y}{\overset{-}{S_6}} \rightarrow$ ON

$$V_R = \frac{V_s}{2},\quad V_Y = -\frac{V_s}{2},\quad V_B = 0$$

$$* \quad (V_R)_{rms} = \frac{V_s}{2}\left[\frac{2\pi/3}{\pi}\right]^{1/2}$$

$$\boxed{(V_R)_{rms} = \frac{V_s}{\sqrt{6}}}$$

$* \quad I_{ph} = \frac{V_{ph}}{r}$ $\qquad * \quad V_L = \sqrt{3}\, V_{ph}$

$* \quad (I_s)_{rms} = \frac{I_{ph}}{\sqrt{2}}$ $\qquad * \quad P = 3 I_{ph}^2 r = \frac{3V_{ph}^2}{r}$

$$V_R = \sum_{\substack{n=1,3 \\ n=6k\pm1}}^{\infty} \frac{2V_s}{n\pi} \cdot \sin\frac{n\pi}{3} \cdot \sin\left(\omega t + \frac{\pi}{6}\right)$$

Note:- even & tripple harmonic are not present

$g = \frac{3}{\pi}$, THD = 31%

$$\boxed{V_{RY} = \sum_{n=1,3,5}^{\infty} \frac{3V_S}{n\pi} \sin n\omega t}$$

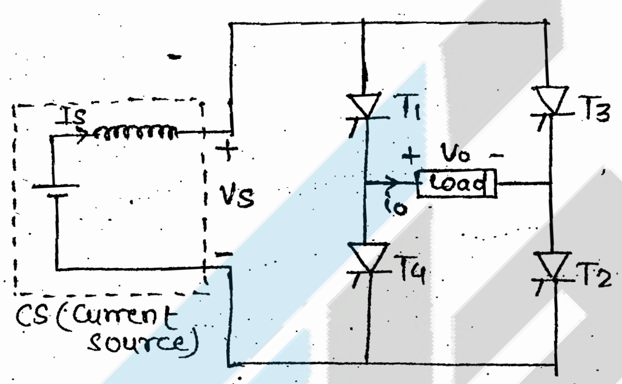
$n = 6K \pm 1$

$n = 1, 5, 7, 11, 13, 17 \ldots$

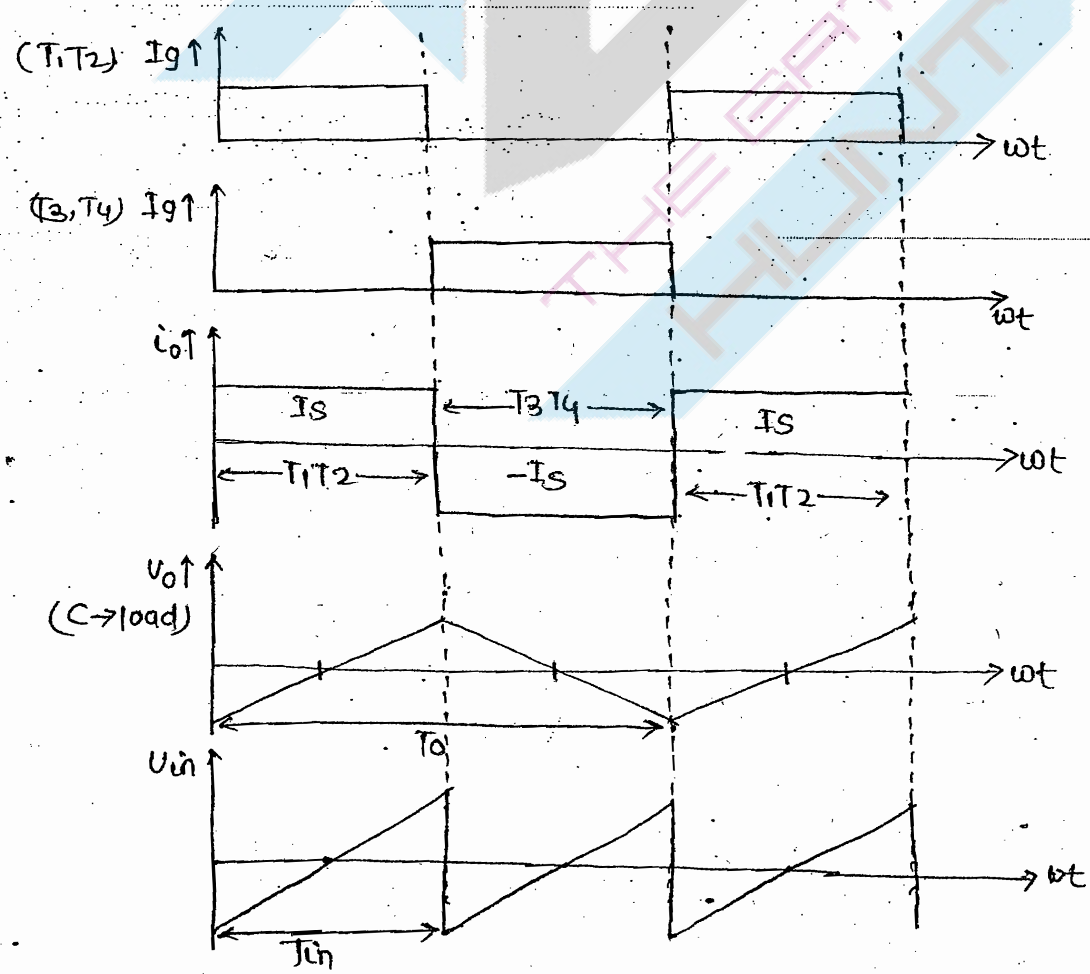
Note → even & tripple harmonic are not present.

$g = \frac{3}{\pi}$, THD = 31%

Current Source Inverter → (CSI)



$T_1T_2 \to ON$ $i_0 = I_S$
$T_3T_4 \to ON$ $i_0 = -I_S$



$$i_s = \sum_{n=1,3,\ldots}^{\infty} \frac{4I_s}{n\pi} \sin n\omega t$$

$$g = \frac{2\sqrt{2}}{\pi}, \quad THD = 48.34\%$$

$$\boxed{i_{on} = \frac{4I_s}{n\pi} \sin n\omega t}$$

Let us consider RLC Load.

$$V_{on} = i_{on} Z_{on} = i_{on} |z_n| \angle \phi_n$$

$$\boxed{V_{on} = \frac{4I_s}{n\pi} |z_n| \sin(n\omega t + \phi_n)}$$

eg:- For pure capacitive load; (load comm.)

$$|z_n| = X_{cn} = \frac{1}{n\omega C}$$

$$\phi_n = -90^\circ$$

$$V_{on} = \frac{4I_s}{n\pi} \cdot \frac{1}{n\omega C} \sin(\omega t - 90^\circ)$$

$$\boxed{V_{on} \propto \frac{1}{n^2}}$$

$T_o = 2T_{in}$

f_{in} → dc $2f_o$ → AC

$f_1 = 2f_s$

Advantage of CSI →

(1.) Feedback diodes are not req. in CSI.

(2.) Comm. is very simple.

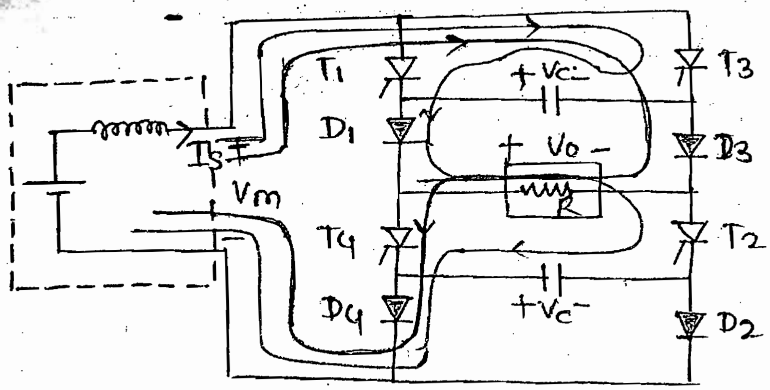
(3.) For capacitive load there is a possibility of Load Comm.

(4.) Inherently there is SC protection for the supply when the incoming thy. are switched on before the outgoing thy. becomes off.

Disadvantage → * During Comm. process the commutating capacitor (load) applies high rev. vol. across the device therefore the devices having low rev. vol. blocking capability such as GTO's, IGBT's & other transistors are generally not prefered in CSI.

* If the ~~capa~~ comm. capacitor is connected directly across the load then it will be contineouly discharging through the load.

To avoid this prob we must connect blocking diode b/n the load & commutating capacitor as shown in fig given below.



It is also called as ASCI (Auto seqential commutated inverter)

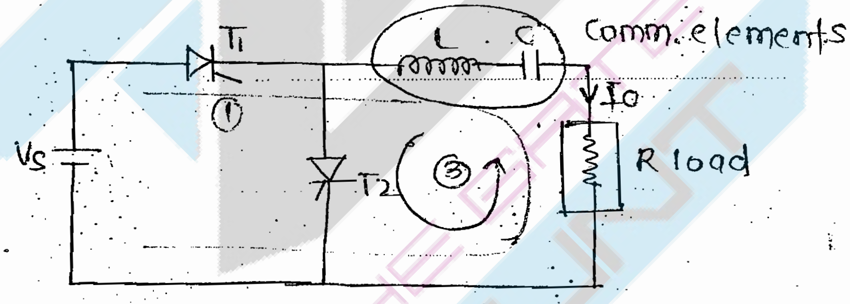
mode(1.) → ⟶ mode(2.) ⇄

mode(3.) → ⟵ (at the end of mode 2 ⟶ becomes 0)

*(2.) The commutating capacitance limits the max^m freq. of inverter

$$\therefore \boxed{f_{max} = \frac{1}{4RC}}$$

* Series Inverter →



* Here RLC should satisfy underdamped cond^n

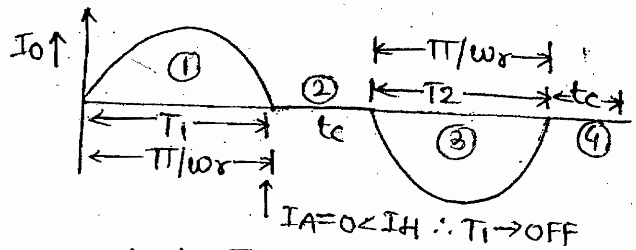
* Here the commutating device in series Hence called series inverter

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

$$\omega_r = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}} \qquad \delta = \frac{R}{2L} \qquad (\delta = \text{damping factor})$$

mode(2) In this mode we have to provide comm. time for the outgoing thy. T1 before the incoming thy. T2 is switched.

$(t_c > t_q)$



$\omega_r t = \pi$

$t = \pi/\omega_r$

$T = 2\left(\frac{\pi}{\omega_r} + t_c\right)$

$f = \frac{1}{2\left(\frac{\pi}{\omega_r} + t_c\right)}$

$\boxed{f_{max} = \frac{1}{2\left(\frac{\pi}{\omega_r} + t_c\right)}}$

For ideal thy.
$t_q = 0$

$\boxed{f_{max} = \frac{\omega_r}{2\pi}}$

& $\boxed{f_{max} < \omega_r}$

* At low freq. harmonic distortion is higher. Therefore series inverter is not benificial at low freq.

Resonant Converters (631 Bhimra) → * In this conr Comm. takes place at current 0 (or) voltage 0.

* This reduce the switching power loss even at high freq.
* If comm. takes place at current 0 then it is known as 0 current switching (ZCS)
* If comm. takes place at vol. 0 then it is known as 0 vol. switching (ZVS)
* In this conr we must use LC elements for getting current 0 (or) voltage 0.

Advantage of series inverter → In series inverter comm. takes place at current 0 & this minimise the switching power loss even at high freq.

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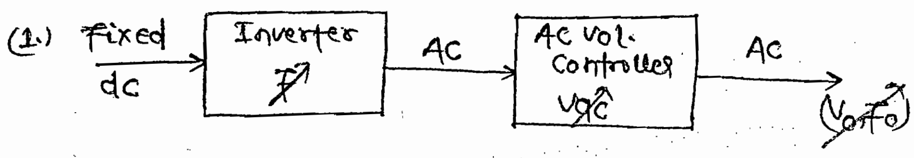
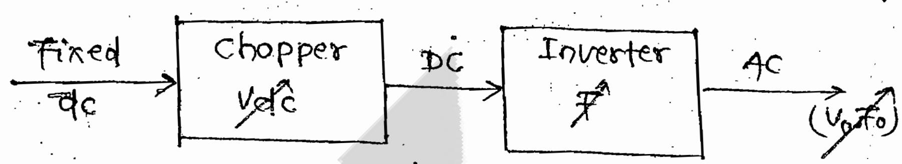
Voltage Control of inverters →

(1.) External Control →

(1.)


(2.)


Drawback → (1) As the no. of stages increases there is a increase in additional power loss along with the size & weight of the equipment.

(2) The filtering requirement becomes costlier due to the increased in harmonics as the no. of stages increased.

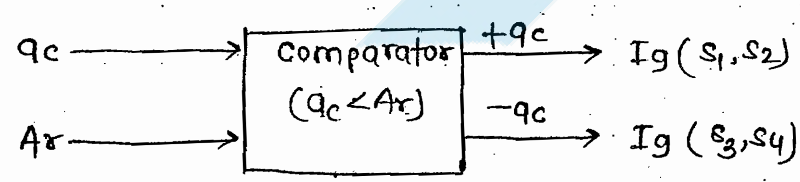
*

(2.) Internal vol. Control using PWM methods →

Advantage → (1.) We can control the vol. within the inverter itself.

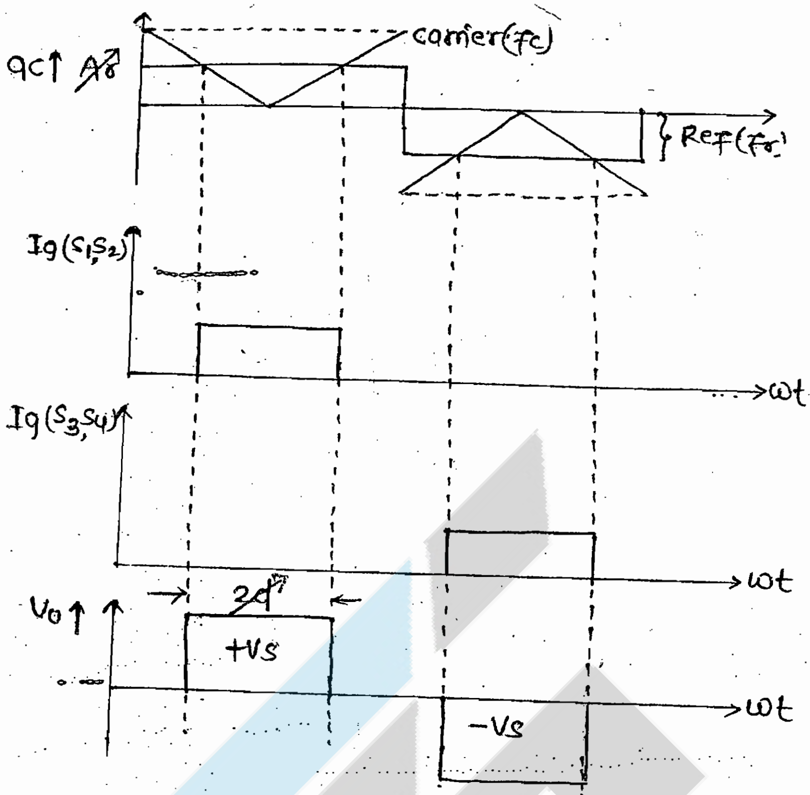
(2) We can eliminate some of the lower order harmonics & this improves the quality of o/p waveform.

(a.) Single pulse width modn tech. → Let us realize this PWM tech. for 1ϕ full bridge inverter.



$$\boxed{V_{or} = V_s\left(\frac{2d}{\pi}\right)^{1/2}}$$

2d → total pulse width in each ½ cycle



$$V_0 = \sum_{n=1,3,5\ldots}^{\infty} \frac{4V_s}{n\pi} \sin\frac{n\pi}{2} . \sin nd . \sin n\omega t$$

$$V_{on} = \frac{4V_s}{n\pi} . \sin\frac{n\pi}{2} . \sin nd . \sin n\omega t$$

$V_{on} = 0$, if $nd = \pi, 2\pi, 3\pi, \ldots$

$$d = \frac{\pi}{n}, \frac{2\pi}{n}, \frac{3\pi}{n}, \ldots$$

$$\boxed{2d = \frac{2\pi}{n}, \frac{4\pi}{n}, \frac{6\pi}{n}, \ldots}$$

Valid only if $2d \leq \pi$ ***

cond^n to eliminate the harmonic

Que→ What is the pulse width req. to eliminate the 3rd harmonic?

Ans.→ * To eliminate the 3rd harmonic...

$$2d = \frac{2\pi}{3}, \frac{4\pi}{3}, \frac{6\pi}{3} \ldots$$

$$2d = \frac{360}{3}$$

$$2d = 120^\circ$$

* To eliminate the 5th harmonic.

$$2\alpha = \frac{2\pi}{5}, \frac{4\pi}{5}, \cancel{\frac{6\pi}{5}} \ldots$$

$$2\alpha = \frac{2\pi}{5}, \frac{4\pi}{5}$$

There are only 2 option to eliminate the 5th harmonics

$$2\alpha = 72^\circ, 144^\circ$$

* Here we can eliminate the selected harmonics depanding upon the width of the pulse.
* For eliminating the low order harmonics (3rd) there is only one option.
* so there is many option to eliminate the higher order harmonics.

$$\boxed{V_{on} = \frac{2\sqrt{2}}{n\pi} V_s \sin n\alpha}$$

$$\boxed{V_{o1} = \frac{2\sqrt{2}}{\pi} V_s \sin \alpha}$$

$$g = \frac{V_{o1}}{V_{or}} = \frac{\frac{2\sqrt{2}}{\pi} \cancel{V_s} \sin\alpha}{\cancel{V_s}\left(\frac{2\alpha}{\pi}\right)^{1/2}}$$

$$\boxed{g = \frac{2\sqrt{2}\cdot\sin\alpha}{\sqrt{(2\alpha)\cdot\pi}}}$$

Radians

$$THD = \sqrt{\left(\frac{1}{g^2} - 1\right)}$$

eg:- Let $2\alpha = \frac{2\pi}{3}$ rad $= 120^\circ$

$$g = \frac{2\sqrt{2}\sin\alpha}{\sqrt{(2\alpha)\cdot\pi}} = \frac{2\sqrt{2}\cdot\sin 60^\circ}{\sqrt{\left(\frac{2\pi}{3}\right)\cdot\pi}} = \frac{3}{\pi}$$

$$THD = 31\%$$

whenever the even & 3rd order harmonics is not present then always

$$\boxed{g = \frac{3}{\pi} \quad THD = 31\%}$$

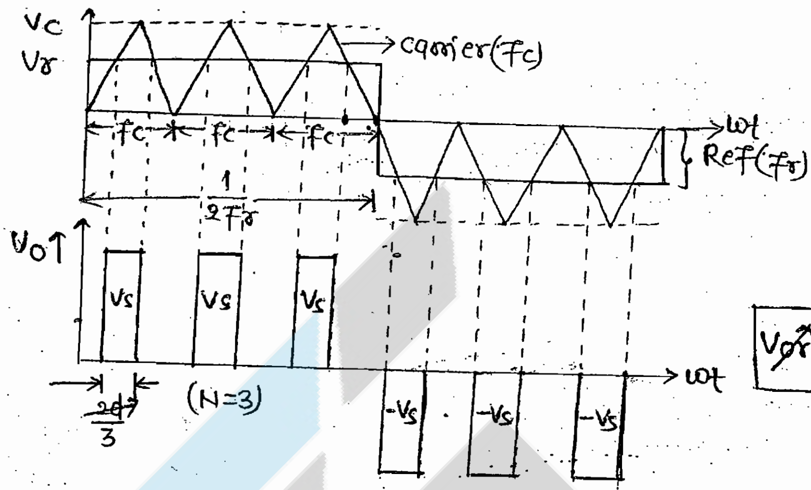
so by using pwm in 1ϕ VSI THD = 31%

$2d = 120°$

* We are using V-shape carrier, but if we use inverted V then the result is same.

V-shape carrier [carrier is high]

(2) multiple pwm tech → 3 pulse



$$\boxed{V_{or} = V_s\left(\frac{3d}{\pi}\right)^{1/2}}$$

$$\frac{3}{f_c} = \frac{1}{2f_r} \qquad \therefore 3 = \frac{f_c}{2f_r}$$

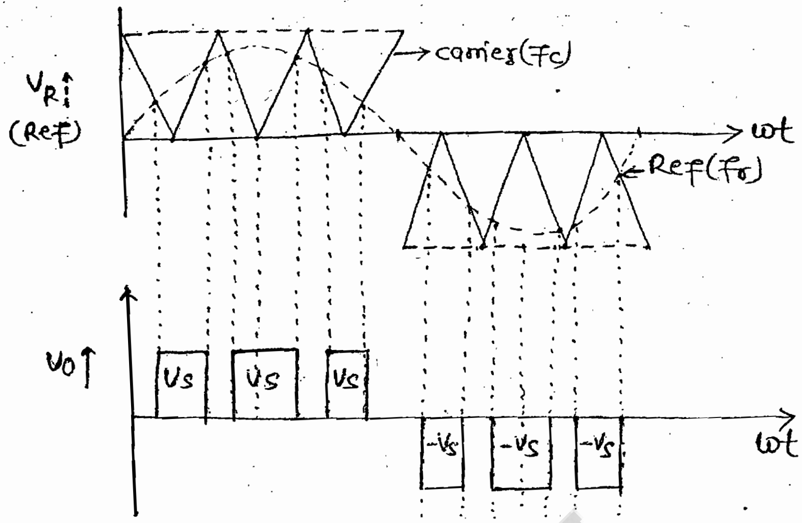
$$\boxed{N = \frac{f_c}{2f_r}}$$

$$\text{Pulse width} = \frac{2d}{N} = \left(1 - \frac{V_r}{V_c}\right)\frac{\pi}{N}$$

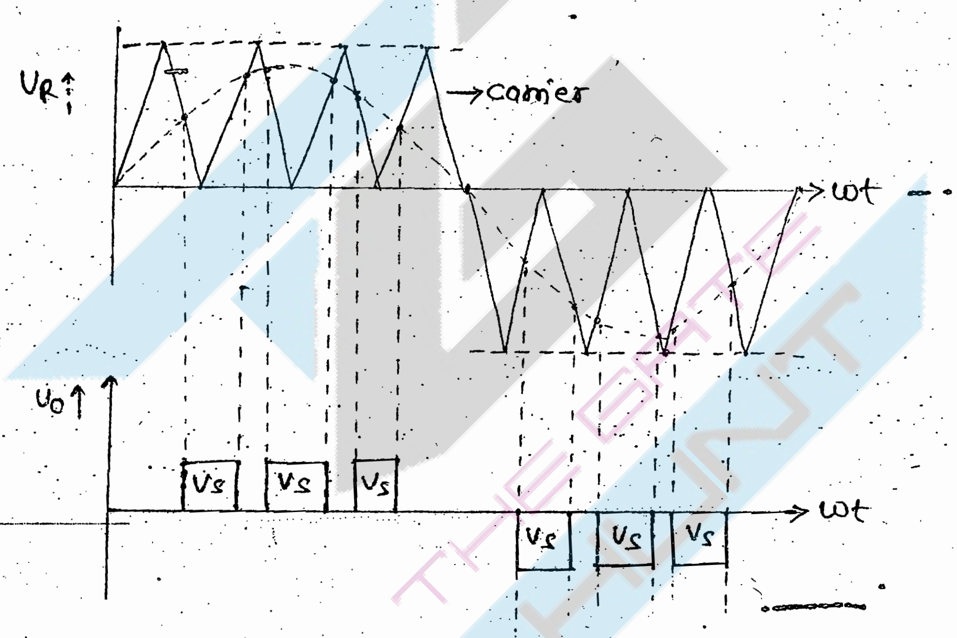
$$\boxed{P.W = \left(1 - \frac{V_r}{V_c}\right)\frac{\pi}{N}}$$

(3) Sinusoidal pwm tech →

(I) Peak carrier coincident with zero of ref :-



(II.) Zero of carrier, coincident with zero of ref:-



$$\boxed{N = \frac{f_c}{2f_r} - 1}$$

Note:- Dominant Harmonics → $2N \pm 1$

If $N=3$, $2(3)\pm1 = 5, 7$

If $N=9$, $2(9)\pm1 = 17, 19$

modulation index (MI) $= \frac{V_r}{V_c}$

* If the domination is shown by lower order it is diff. to Filter them.
* We can easily Filter the higher order dominant harmonics.
* Therefore in sinusoidal PWM tech. we increase the no. of pulses in each half cycle & increase the order of dominant harmonics. So that they can be filtered very easily.

1 PWM	Multi PWM	Sinusoidal PWM
$V_{or} = V_s\left(\frac{2d}{\pi}\right)^{1/2}$	$N = \frac{f_c}{2f_r}$	$N = \frac{f_c}{2f_r} - 1$
$V_o = \frac{4V_s}{n\pi}\sin\frac{n\pi}{2}.(\sin nd.)(\sin n\omega t)$	$PW = \left(1 - \frac{V_a}{V_c}\right)\frac{\pi}{N}$	Dominant Harmonic $= 2N \pm 1$

* $V_{on} = \frac{4V_s}{n\pi}\sin\frac{n\pi}{2}(\sin nd)(\sin n\omega t)$
* $V_{on} = 0, \quad nd = \pi, 2\pi, 3\pi$

$$d = \frac{\pi}{n}, \frac{2\pi}{n}, \frac{3\pi}{n}$$

$$2d = \frac{2\pi}{n}, \frac{4\pi}{n}, \frac{6\pi}{n} \ldots$$

If $n = 3$, $2d = 120°$

$n = 5$, $2d = 72, 144°$

* $V_{or} = \frac{4V_s}{\pi\sqrt{2}}\sin d$

$$V_{01} = \frac{2\sqrt{2}V_s \sin d}{\pi}$$

* $g = \frac{V_{or}}{V_{or}} = \frac{2\sqrt{2}V_s \sin d\,n/\pi}{V_s\left(\frac{2d}{\pi}\right)^{1/2}}$

$$g = \frac{2\sqrt{2}\sin dn}{\sqrt{(2d)\pi}}$$

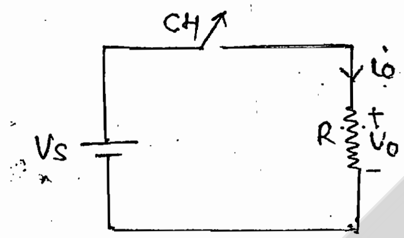
* $g = \frac{3}{\pi}$, THD $= 31\%$

Choppers

Fixed dc $\longrightarrow$ Variable dc
(V_s) (V_0)

(1.) Step down chopper → ($V_0 < V_s$). (Buck converter)

For R lod →

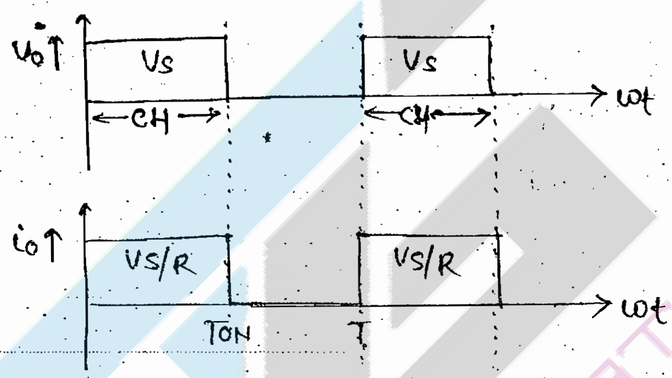


$$V_0 = V_s\left(\frac{T_{ON}}{T}\right)$$

$$\alpha = \frac{T_{ON}}{T}$$
(duty cycle)

$$V_0 = \alpha V_s$$

$$\boxed{V_{or} = \sqrt{\alpha}\, V_s}$$



Fourier Series For O/p voltage.

$$V_0 = \alpha V_s + \sum_{n=1}^{\infty} \frac{2V_s}{n\pi} \sin \pi n\alpha \cdot \sin(n\omega t + \phi_n)$$

where $\phi_n = \tan^{-1}\left(\frac{\cos n\alpha}{\sin \pi n\alpha}\right)$

$$V_{on} = \frac{2V_s}{n\pi} \sin n\pi\alpha \, \sin(n\omega t + \phi_n)$$

$V_{on} = 0$. then $n\alpha = 1$

$\boxed{\alpha = \frac{1}{n}}$ Condn to eliminate nth harmonics

$$FF = \frac{V_{or}}{V_0} = \frac{\sqrt{\alpha}\, V_s}{\alpha V_s}$$

$$\boxed{FF = \frac{1}{\sqrt{\alpha}}}$$

$$V_{RF} = \sqrt{FF^2 - 1}$$

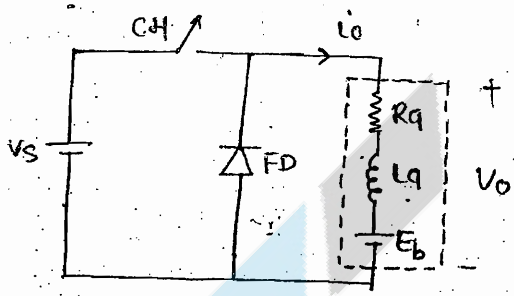
$$\downarrow VRF = \sqrt{\frac{1}{\alpha\uparrow} - 1}$$

$$\boxed{\alpha\uparrow, VRF\downarrow \therefore \text{Harmonics}\downarrow}$$

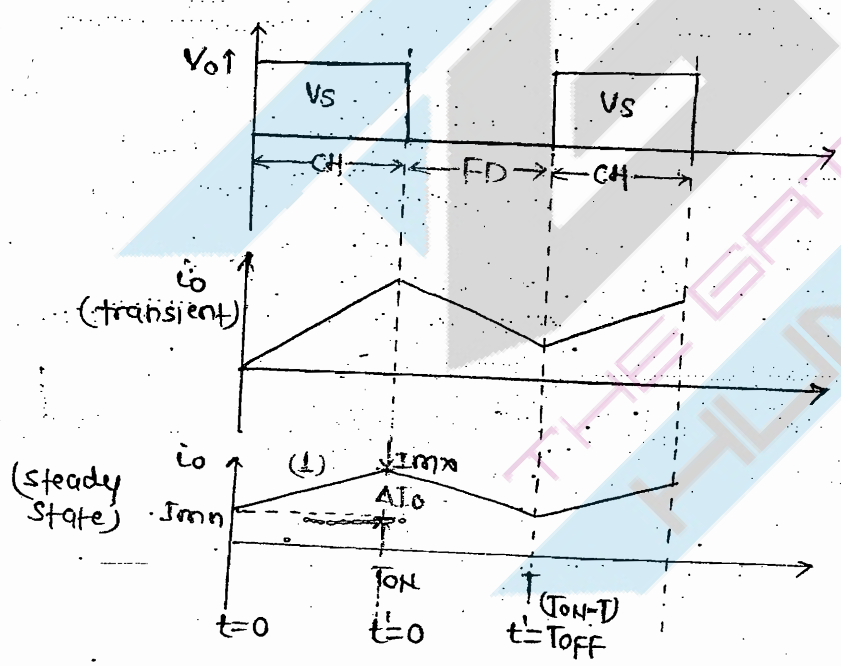
* If it is contineous conduction there is no effect of back emf in the o/p voltage waveform.

Therefore the o/p vol. waveform is remain same for RL & RLE load.

For RLE load →



DC motor



at transient the value of current will 1st starts from 0 value & then goes to steady state value

$$V_o = V_S\left(\frac{T_{ON}}{T}\right)$$

$$\left.\begin{aligned}&\boxed{V_o = \alpha V_S}\\&\boxed{V_{or} = \sqrt{\alpha}\, V_S}\end{aligned}\right\} \text{RL \& RLE}$$

$$I_o = \frac{V_o - E_b}{R_a}$$

$$\boxed{I_o = \frac{\alpha V_S - E_b}{R_a}} \rightarrow \text{RLE}$$

$$\boxed{I_o = \frac{\alpha V_S}{R_a}} \rightarrow \text{RL}$$

*** Avg. current does not depand on load inductance but the ripple current depands on the load inductance.

* **mod(I.)** $(0 \le t \le T_{ON})$

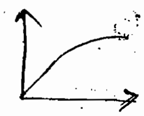
CH → ON (KVL)

$$V_s = R_a i_o + L_a \frac{di_o}{dt} + E_b$$

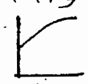
$$V_s - E_b = R_a i_o + L_a \frac{di_o}{dt}$$

$$\left(\tau_a = \frac{L_a}{R_a}\right)$$

$$i_o = \frac{V_s - E_b}{R_a}\left(1 - e^{-t/\tau_a}\right)$$ [eqn from starting to 0 (transient)]



$$i_o = \frac{V_s - E_b}{R_a}\left(1 - e^{-t/\tau_a}\right) + I_{mn} e^{-t/\tau_a} \quad \text{---(i)}$$ [From the I_{mn} value (steady state)]



$$I_{mx} = \frac{V_s - E_b}{R_a}\left(1 - e^{-T_{ON}/\tau_a}\right) + I_{mn} e^{-T_{ON}/\tau_a} \quad \text{----(ii)}$$

Mode (II) → $(T_{ON} \le t \le T)$ (or) $(0 \le t' \le T_{OFF})$

FD → ON ∴ (KVL)

$$R_a i_o + L_a \frac{di_o}{dt'} + E_b = 0$$

$$-E_b = R_a i_o + L_a \frac{di_o}{dt'}$$

$$i_o = \frac{-E_b}{R_a}\left(1 - e^{-t'/\tau_a}\right) + I_{mx} e^{-t'/\tau_a} \quad \text{-----(iii)}$$

$$I_{mn} = \frac{-E_b}{R_a}\left(1 - e^{-T_{OFF}/\tau_a}\right) + I_{mx} e^{-T_{OFF}/\tau_a} \quad \text{-----(iv)}$$

By solving the eqn (ii) & (iv) we can find the values of I_{mx} & I_{mn}

$$I_{mx} = \frac{V_s}{R_a}\left[\frac{1 - e^{-T_{ON}/\tau_a}}{1 - e^{-T/\tau_a}}\right] - \frac{E_b}{R_a} \quad \text{---(v)}$$

$$I_{mn} = \frac{V_s}{R_a}\left[\frac{e^{T_{ON}/\tau_a} - 1}{e^{T/\tau_a} - 1}\right] - \frac{E_b}{R_a} \quad \text{-----(vi)}$$

Ripple current = $I_{max} - I_{min}$

$$\Delta I_0 = \frac{V_s}{R_a}\left[\frac{(1-e^{-T_{ON}/\tau_a})}{(1-e^{-T/\tau_a})} - \frac{(e^{T_{ON}/\tau_a}-1)}{(e^{T/\tau_a}-1)}\right]$$

$$\Delta I_0 = \frac{V_s}{R_a}\left[\frac{(1-e^{-T_{ON}/\tau_a})(1-e^{-T_{OFF}/\tau_a})}{(1-e^{-T/\tau_a})}\right] \quad \boxed{(T = T_{OFF}+T_{ON})}$$

$$\Delta I_0 = \frac{V_s}{R_a}\left[\frac{(1-e^{-\alpha T/\tau_a})(1-e^{-(1-\alpha)T/\tau_a})}{1-e^{-T/\tau_a}}\right] \quad \boxed{\begin{array}{l} T_{ON} = \alpha T \\ T_{OFF} = (1-\alpha)T \end{array}}$$

For ~~max^m~~ value of the max^m Ripple current

$$\frac{d(\Delta I_0)}{d\alpha} = \frac{d}{d\alpha}\left\{\frac{V_s}{R_a}\left[\frac{(1-e^{-\alpha T/\tau_a})(1-e^{-(1-\alpha)T/\tau_a})}{(1-e^{-T/\tau_a})}\right]\right\} = 0$$

$$\boxed{\alpha = 0.5}$$

$$(\Delta I_0)_{max} = \frac{V_s}{R_a}\left[\frac{(1-e^{-0.5T/\tau_a})(1-e^{-0.5T/\tau_a})}{(1-e^{-T/\tau_a})}\right]$$

$$(\Delta I_0)_{max} = \frac{V_s}{R_a}\tanh\frac{T}{4\tau_a} \qquad (\tanh x = x)$$

$$(\Delta I_0)_{max} = \frac{V_s}{R_a}\times\frac{T}{4\tau_a} = \frac{V_s}{\cancel{R_a}}\times\frac{T}{4\times\frac{L_a}{\cancel{R_a}}} = \frac{V_s}{f}\times\frac{1}{4L_a}$$

$$\boxed{(\Delta I_0)_{max} = \frac{V_s}{4f\cdot L_a}}$$

(max^m value of Ripple current at $\alpha = 0.5$)

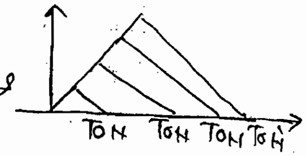
(1.) $\downarrow(\Delta I_0) \propto \dfrac{1}{f(L\uparrow)}$ (But equipment size will increase)

* By increasing the load inductance the ripple current reduce.

(2.) $\downarrow(\Delta I_0) \propto \dfrac{1}{(\uparrow f)L}$

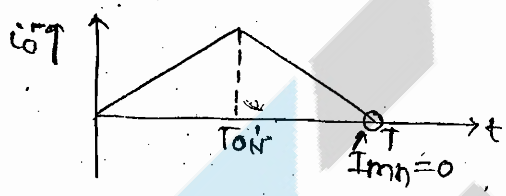
* At high chopping freq. we can eliminate the ripple current without increases the size of inductor.
* SMPS operates based on the above chopper principle.
* At low values of T_{ON} it gives discontineous.

α' = duty cycle limit for ~~contineous~~



* Duty cycle limit for contineous conduction →

* α' is the duty cycle at the boundary between contineous & discontineous conduction.



$$\alpha' = \frac{T_{ON}'}{T}$$

at $t = T$, $I_{mn} = 0$

$$\frac{V_s}{R_a}\left[\frac{e^{T_{ON}'/\tau_a}-1}{e^{T/\tau_a}-1}\right] - \frac{E_b}{R_a} = 0$$

$$\frac{V_s}{\cancel{R_a}}\left[\frac{e^{T_{ON}'/\tau_a}-1}{e^{T/\tau_a}-1}\right] = \frac{E_b}{\cancel{R_a}}$$

$$\left[\frac{e^{T_{ON}'/\tau_a}-1}{e^{T/\tau_a}-1}\right] = \frac{E_b}{V_s}$$

$$(e^{T_{ON}'/\tau_a}-1) = m(e^{T/\tau_a}-1) \qquad \left(\frac{E_b}{V_s} = m\right)$$

$$e^{(T_{ON}'/\tau_a)} = 1 + m(e^{T/\tau_a}-1)$$

$$\frac{T_{ON}'}{\tau_a} = \ln\left[1 + m(e^{T/\tau_a}-1)\right]$$

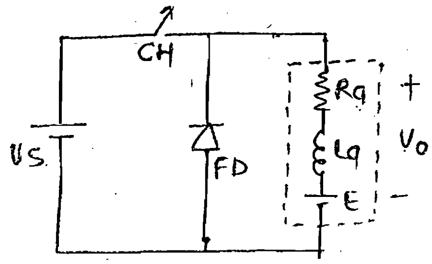
$$\frac{T_{ON}'}{T} = \frac{\tau_a}{T}\ln\left[1 + m(e^{T/\tau_a}-1)\right]$$

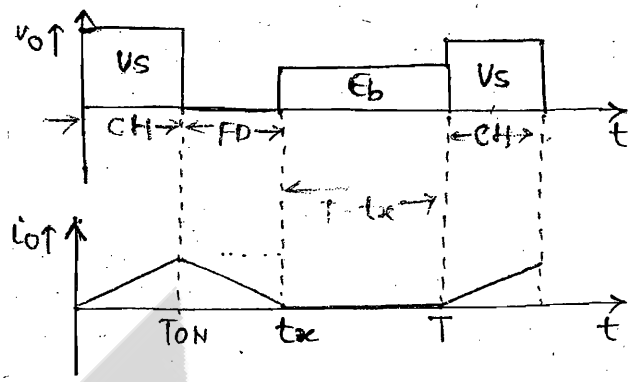
$$\boxed{\alpha' = \frac{T_{ON}'}{T} = \frac{\tau_a}{T}\ln\left[1 + m(e^{T/\tau_a}-1)\right]}$$

$\alpha < \alpha' \longrightarrow$ discontineous

$\alpha > \alpha' \longrightarrow$ Contineous

* Discontineous Conduction →





$$V_0 = V_S\left(\frac{T_{ON}}{T}\right) + E_b\left(\frac{T-t_x}{T}\right)$$

($t_x \rightarrow$ extinction time)

$$\boxed{V_0 = V_S\alpha + E_b\left(1-\frac{t_x}{T}\right)}$$

$$V_{or} = \left[V_S^2\left(\frac{T_{ON}}{T}\right) + E_b^2\left(\frac{T-t_x}{T}\right)\right]^{1/2}$$

$$\boxed{V_{or} = \left[\alpha V_S^2 + E_b^2\left(1-\frac{t_x}{T}\right)\right]^{1/2}}$$

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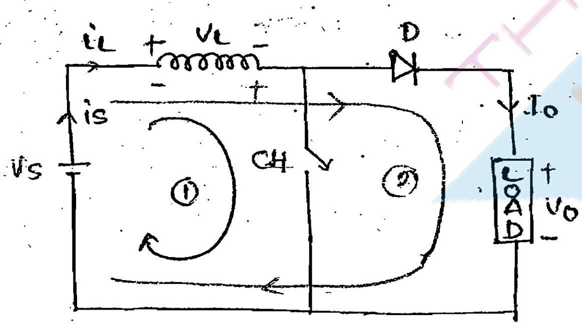
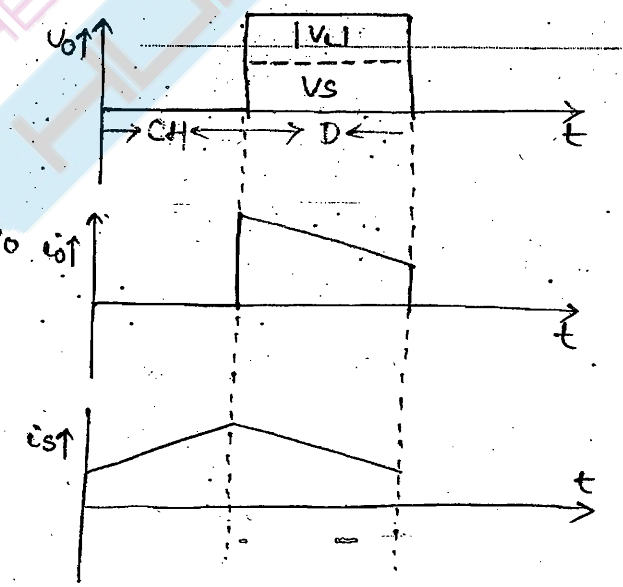
Step up chopper →





(I) $0 \le t \le T_{ON}$ →

CH → ON, D → OFF, $V_0 = 0$

$i_0 = 0$

$$V_S = V_L = L\frac{di_S}{dt}$$

L → stores energy

Step up chopper
Boost converter

(II.) $T_{ON} \le t \le T \rightarrow$

CH $\rightarrow$ OFF, D $\rightarrow$ ON, $i_s = i_o$

$$\left.\begin{array}{c}\text{Source} \\ \& \\ \frac{1}{2}Li^2\end{array}\right\} \xrightarrow{P} \text{Load}$$

L $\rightarrow$ Releasing energy

$V_0 = V_s + |V_L|$

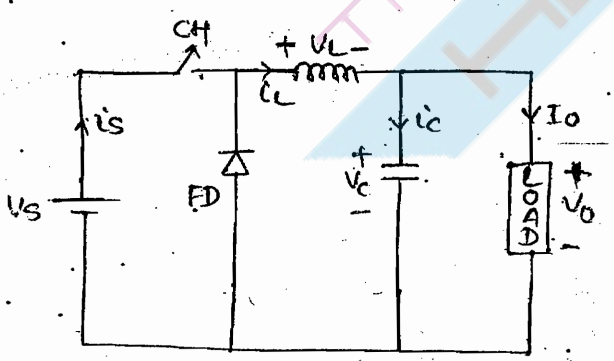
$$\boxed{V_0 = \frac{V_s}{1-\alpha}}$$

$\alpha < 1$, $V_0 > V_s$

* In step up chopper power flows from low vol. side to high voltage side
* Step up chopper principle can be used for regenerative braking of dc m/c.

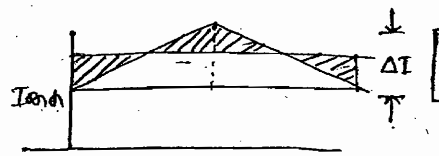
Choppers with Filters $\rightarrow$ * In order to reduce the harmonics & improve the quality of o/p waveform we have to use filters.

Step down chopper (Buck converter) $\rightarrow$ For 1st order low pass filter we use resistance but in the resistance power loss occurs.



i_L $\rightarrow$ DC Componant $(I_L)_{avg}$

i_L $\rightarrow$ AC Componant (At multiple Harmonic freq.)



$$\boxed{\text{Area} = \frac{\Delta I}{2} + I_{mn}}$$

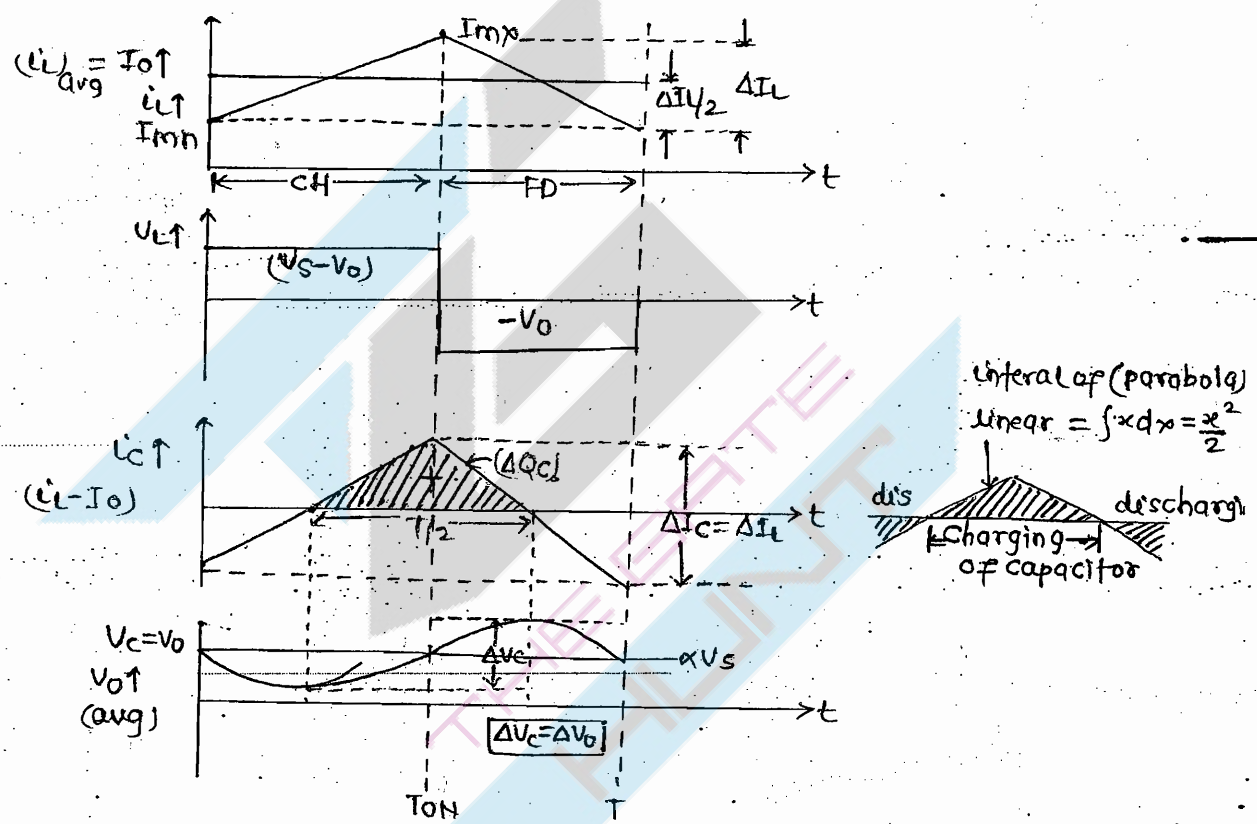
* Let us assume very large value of filter capacitance. So that the o/p vol remains almost constant.

$$X_C = \frac{1}{\omega C\uparrow} \simeq 0 \text{ (Ac comp) (short circuited)}$$

$$X_C = \frac{1}{\omega C} \simeq \infty \text{ (dc comp.) (open circuited)}$$

* Capacitor will only allow only AC comp. (Ripple)
* All the AC comp. will bypass through capacitor then;

$$\boxed{(\Delta I_L) = (\Delta I_C)}$$



(1.) $0 \le t \le T_{ON} \rightarrow$ CH $\rightarrow$ ON

$$-V_S + V_L + V_o = 0$$

$$V_L = V_S - V_o$$

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

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

$$\int_{I_{mn}}^{I_{mx}} di_L = \frac{V_S - V_o}{L}\int_0^{T_{ON}} dt$$

$$\Delta I_L = \frac{V_S - V_o}{L} \cdot T_{ON}$$

$$\left\{ T_{ON} = \alpha T = \frac{\alpha}{f} \right\}$$

$$= \frac{V_S - \alpha V_S}{L} \cdot \frac{\alpha}{f}$$

$$\boxed{\Delta I_L = \frac{\alpha(1-\alpha)V_S}{fL}}$$

$$\boxed{(\Delta I_L)_{max} = \frac{V_S}{4fL}} \rightarrow \text{at } \alpha = 0.5$$

(II.) $T_{ON} \le t \le T \rightarrow$ CH → OFF, FD → ON

$$+V_L + V_0 = 0$$

$$V_L = -V_0$$

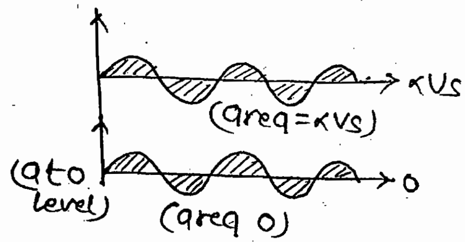
$$(V_L)_{avg} = 0$$

+ve area + (-ve) area = 0

$$(V_S - V_0)T_{ON} + V_0 T_{OFF} = 0$$

$$V_S T_{ON} = V_0[T_{ON} + T_{OFF}]$$

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



From the area of Δ in the waveform

$$\Delta Q = C \cdot \Delta V_C$$

$$\Delta V_C = \frac{\Delta Q}{C}$$

where $\Delta Q = \frac{1}{2} \cdot \frac{T}{2} \cdot \frac{\Delta I_L}{2}$

$$\Delta Q = \frac{\Delta I_L}{8f}$$

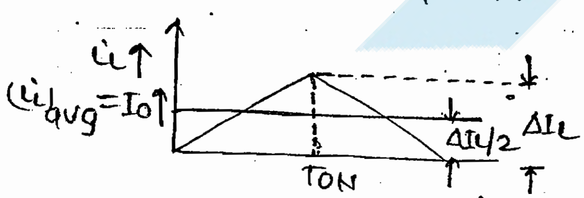
$$\boxed{\Delta V_C = \frac{\Delta I_L}{8fC}}$$

$$\boxed{\Delta V_C \downarrow = \frac{\alpha(1-\alpha)V_S}{8f^2 \uparrow LC}} \quad \text{-----(2.)}$$

✱ If we increase the value of f↑ then ΔV_C will decrease, & we will get pure dc current ($\Delta V_C = 0$)

Critical inductance → (L_C) It is the value of inductance at which I_L waveform is just discontineous.

If L



$$I_0 = \frac{\Delta I_L}{2}$$

$$\frac{\alpha V_S}{R} = \frac{\alpha(1-\alpha)V_S}{2fLC}$$

$$\boxed{L_C = \frac{(1-\alpha)R}{2f}} \quad \text{-----(3.)}$$

*Critical capacitance → It is the value of capacitance at which the V_C waveform is just discontineous.
(C_c)

$$V_0 = \frac{\Delta V_C}{2} \text{ (at } C_c)$$

$$V_0 = \frac{\alpha(1-\alpha)V_S}{16f^2LC}$$

$$\alpha V_S = \frac{\alpha(1-\alpha)V_S}{16f^2LC_c}$$

$$\boxed{C_c = \frac{(1-\alpha)}{16f^2LC}} \quad \text{------(4.)}$$

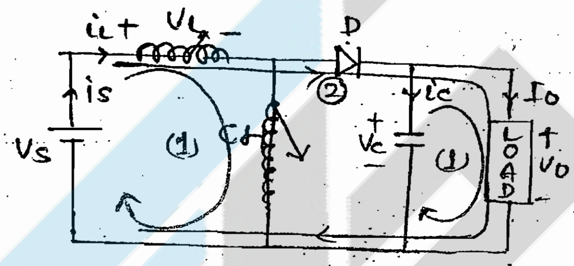
$$P_0 = P_{in}$$

$$V_0 I_0 = V_S I_S$$

$$\frac{V_0}{V_S} = \frac{I_S}{I_0} = \alpha$$

$$\boxed{I_S = \alpha I_0}$$

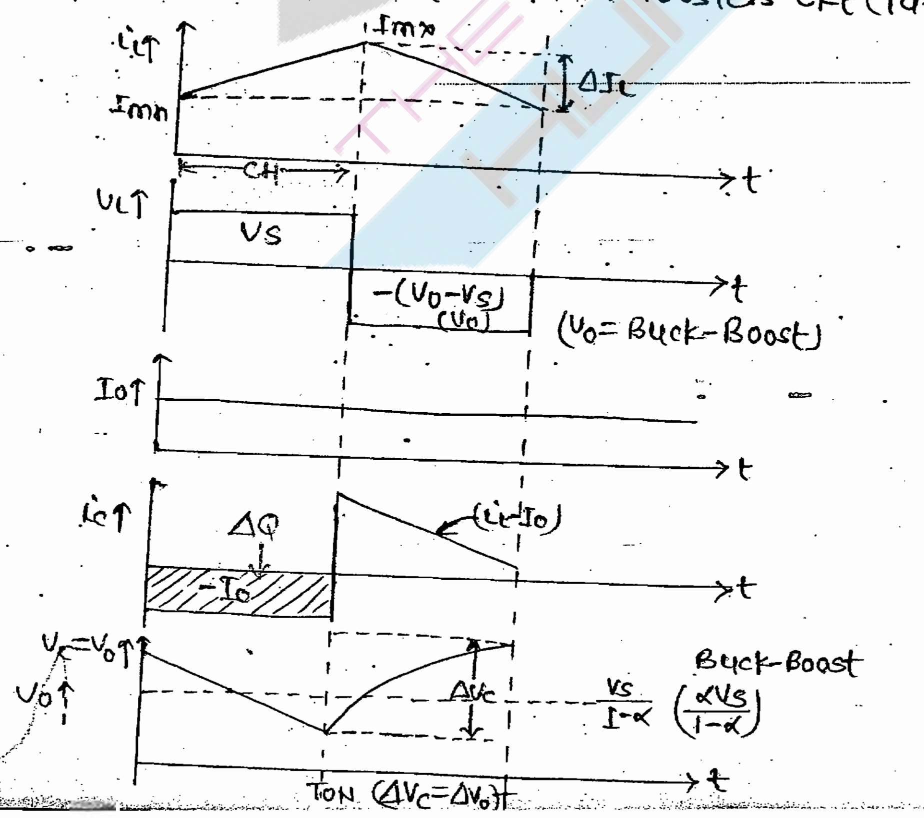
*Step up chopper (Boost converter) →



$i_L = i_c + i_o$
$(I_L)_{min} > (I_o)$

*Let us assume large value of filter capacitance. So that the o/p vol. remains const

*Let us assume const load current & it is a lossless ckt (ideal ckt)



(I.) $0 \le t \le T_{ON} \rightarrow$

CH → ON, D → OFF

$$\boxed{i_c = -I_0}$$

$$V_L = V_s$$

$$L\frac{di_L}{dt} = V_s$$

$$\int_{I_{mn}}^{I_{mx}} di_L = \int_0^{T_{ON}} \frac{V_s}{L}\, dt$$

$$\Delta I_L = \frac{V_s}{L} \cdot T_{ON}$$

$$\boxed{\Delta I_L = \frac{\alpha V_s}{f L}} \text{ ---- (1)}$$

(II.) $T_{ON} \le t \le T \rightarrow$

CH → OFF ; D → ON

$$\boxed{i_L = i_c + I_0}$$

$$-V_s + V_L + V_0 = 0$$

$$V_L = V_s - V_0$$

$$* \; V_L = -(V_s - V_0)$$

* $(V_0 > V_s)$ step up

$$(V_L)_{avg} = 0$$

$$V_s T_{ON} = (V_0 - V_s) T_{OFF} = 0$$

$$V_s(T_{ON} + T_{OFF}) = V_0 T_{OFF}$$

$$V_s \cancel{T} = V_0 (1-\alpha) \cancel{T}$$

$$\boxed{V_0 = \frac{V_s}{1-\alpha}}$$

$$P_0 = P_{in}$$

$$V_0 I_0 = V_s I_s$$

$$\boxed{\frac{V_0}{V_s} = \frac{I_s}{I_0} = \frac{1}{(1-\alpha)}}$$

$$\boxed{I_s = \frac{I_0}{(1-\alpha)}}$$

$$\Delta Q = C \Delta V_C$$

$$\Delta V_C = \frac{\Delta Q}{C} = \frac{I_0 T_{ON}}{C}$$

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

$$\boxed{\Delta V_C = \frac{\alpha I_0}{f C}} \text{ ---- (2)}$$

Critical inductance (L_c) →

$$I_o = \frac{\Delta I_L}{2} \text{ (at } L_c)$$

$$\frac{V_s}{(1-\alpha)R} = \frac{\alpha V_s}{2 f L_c}$$

$$\boxed{L_c = \frac{\alpha(1-\alpha)R}{2f}} \text{ - - - - - (3.)}$$

Critical capacitance (C_c) →

$$V_o = \frac{\Delta V_c}{2}$$

$$I_o R = \frac{\alpha I_o}{2 f C_c}$$

$$\boxed{C_c = \frac{\alpha}{2 f R}} \text{ - - - - - (4.)}$$

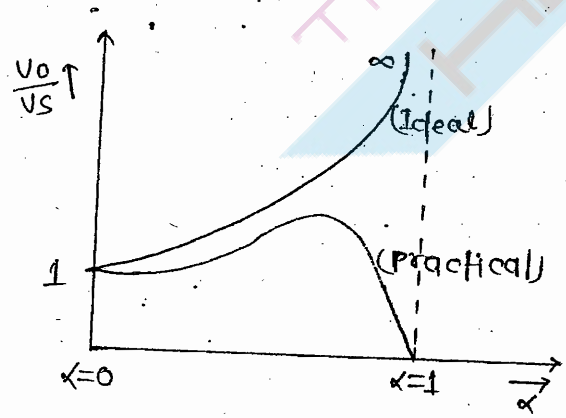
Non-ideal case → (Practical)

r → internal resistance of inductance

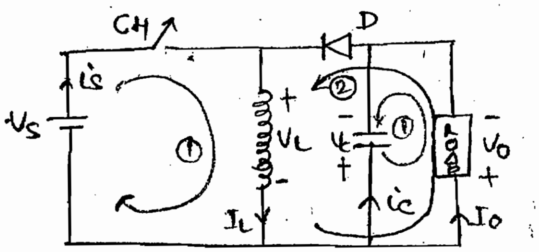
R → Load resistance.

$$\boxed{V_o = \frac{V_s(1-\alpha)}{\frac{r}{R} + (1-\alpha)^2}}$$ (Not in syllabus)

If question is ask in the form of internal ~~inductance~~ resistor of inductance



Step down/up chopper (Buck-Boost Converter) →



* Let us assume constant o/p vol. & current & it is a lossless ckt.

(I) $0 \le t \le T_{ON}$ → CH → ON, D → OFF

$$i_c = -I_o$$

$$V_L = V_s$$

$$L\frac{di_L}{dt} = V_s$$

$$\int_{I_{mn}}^{I_{mx}} di_L = \frac{V_s}{L}\int_0^{T_{ON}} dt$$

$$\boxed{\Delta I_L = \frac{\alpha V_s}{fL}} \quad \text{----(i)}$$

(II) $T_{ON} \le t \le T$ →

CH → OFF, D → ON

$$i_L = i_c + I_o$$

$$+V_L + V_o = 0$$

$$V_L = -V_o$$

$$(V_L)_{avg} = 0$$

$$V_s T_{ON} - V_o T_{OFF} = 0$$

$$V_s T_{ON} = V_o T_{OFF}$$

$$V_s(\alpha T) = V_o(1-\alpha)T$$

$$\boxed{V_o = \frac{\alpha V_s}{(1-\alpha)}}$$

$$\Delta Q = C \cdot \Delta V_C$$

$$\Delta V_C = \frac{\Delta Q}{C} = \frac{I_o T_{ON}}{C}$$

$$\boxed{\Delta V_C = \frac{\alpha I_o}{fC}} \quad \text{——(ii)}$$

$$V_o I_o = V_s I_s$$

$$\boxed{\frac{V_o}{V_s} = \frac{I_s}{I_o} = \frac{\alpha}{(1-\alpha)}}$$

$$\boxed{I_s = \frac{\alpha I_o}{(1-\alpha)}}$$

Critical inductance (L_c) →

$$I_o = \frac{\Delta I_L}{2} \text{ (at } L_c)$$

$$\frac{\alpha V_s}{(1-\alpha)R} = \frac{\alpha V_s}{2fL_c}$$

$$\boxed{L_c = \frac{(1-\alpha)R}{2f}} \quad \text{---- (3)}$$

Critical Capacitance (C_c) →

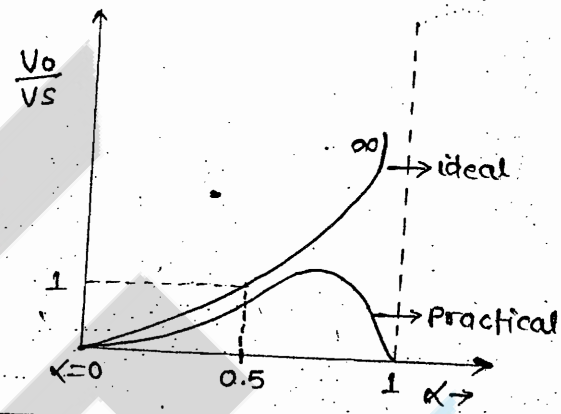
$$V_o = \frac{\Delta V_c}{2}$$

$$I_oR = \frac{\alpha I_o}{2fC_c}$$

$$\boxed{C_c = \frac{\alpha}{2fR}} \quad \text{---- (4.)}$$

Non-ideal case →

$$\boxed{V_o = \frac{V_s\alpha(1-\alpha)}{\frac{r}{R}+(1-\alpha)^2}}$$



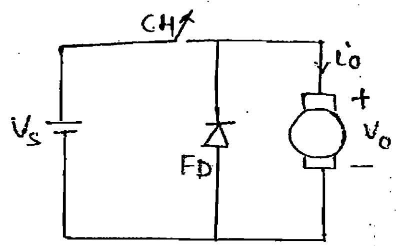
$$\boxed{\begin{array}{l} \alpha < 0.5,\ V_o < V_s \\ \alpha > 0.5,\ V_o > V_s \end{array}}$$

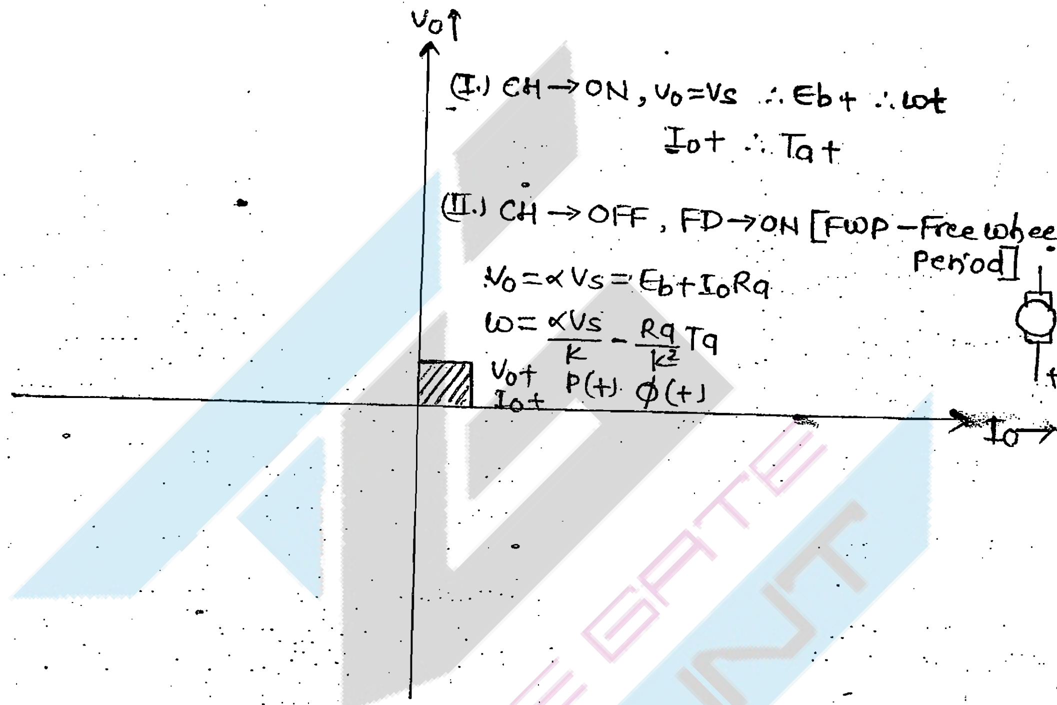
Parameters	Step down (Buck Con^r)	Step up chopper (Boost Con^r)	Step up/down chopper (Buck-Boost Con^r)
* ΔI_L	$\frac{\alpha(1-\alpha)V_s}{fL}$	$\frac{\alpha V_s}{fL}$	$\frac{\alpha V_s}{fL}$
* $(\Delta I_L)_{max}$ $(\alpha=0.5)$	$\frac{V_s}{4fL}$	$\frac{V_s}{2fL}$	$\frac{V_s}{2fL}$
** V_0	αV_s	$\frac{V_s}{(1-\alpha)}$	$\frac{\alpha V_s}{(1-\alpha)}$
* ΔQ_c -	$\frac{\Delta I_L}{8f}$	—	—
* ΔV_c	$\frac{\alpha(1-\alpha)V_s}{8f^2LC}$	$\frac{\alpha I_0}{fC}$	$\frac{\alpha I_0}{fC}$
* L_c	$\frac{(1-\alpha)R}{2f}$	$\frac{\alpha(1-\alpha)R}{2f}$	$\frac{(1-\alpha)R}{2f}$
* C_c	$\frac{(1-\alpha)}{16f^2LC}$	$\frac{\alpha}{2fR}$	$\frac{\alpha}{2fR}$
** Ratio	$\frac{V_0}{V_s}=\frac{I_s}{I_0}=\alpha$	$\frac{V_0}{V_s}=\frac{I_s}{I_0}=\frac{1}{(1-\alpha)}$	$\frac{V_0}{V_s}=\frac{I_s}{I_0}=\frac{\alpha}{1-\alpha}$
** I_s	αI_0	$I_0\left(\frac{1}{1-\alpha}\right)$	$\frac{\alpha I_0}{(1-\alpha)}$
* V_0 (practical)	~~V_s/α~~ —	$\frac{V_s(1-\alpha)}{\frac{r}{R}+(1-\alpha)^2}$	$\frac{V_s\alpha(1-\alpha)}{\frac{r}{R}+(1-\alpha)^2}$

DATE - 29/08/19

Classification of chopper based on quadrant operation →

(1.) First quadrant chopper : (Type A) → (Step down chopper)





(I.) $CH \rightarrow ON$, $V_o = V_s$ ∴ E_b+ ∴ $\omega+$

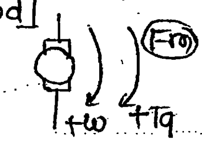
I_o+ ∴ T_a+

(II.) $CH \rightarrow OFF$, $FD \rightarrow ON$ [FWP − Free wheeling Period]

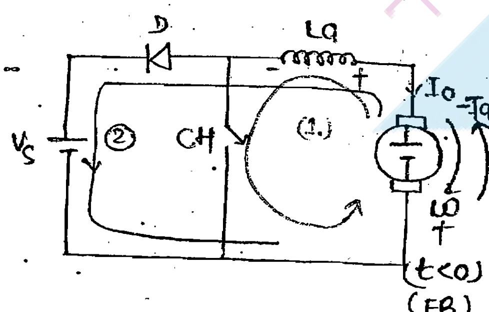
$V_o = \alpha V_s = E_b + I_o R_a$

$\omega = \frac{\alpha V_s}{K} - \frac{R_a}{K^2} T_a$

V_o+ $P(+)$ $\phi(+)$
I_o+



(2.) 2nd quadrant Chopper (Type B) →



Let us assume that the m/c is running at rated speed in the forward dir^n before t=0.

Brake energy at t=0 = $\frac{1}{2}J\omega^2$

(I.) $0 \le t \le T_{ON}$ →

$CH \rightarrow ON$, $D \rightarrow OFF$

$(V_o = 0)$ ∵ (I_o^-), ∵ $(T_a -)$

$\frac{1}{2}J\omega^2 \rightarrow \frac{1}{2}Li^2$

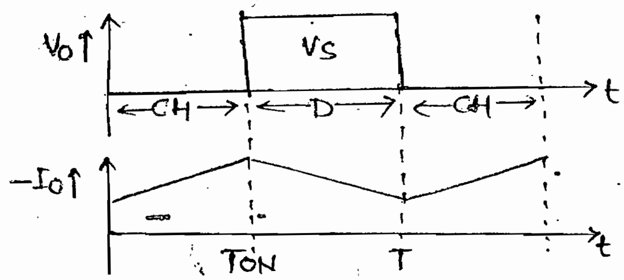
(II.) $T_{ON} \le t \le T$ →

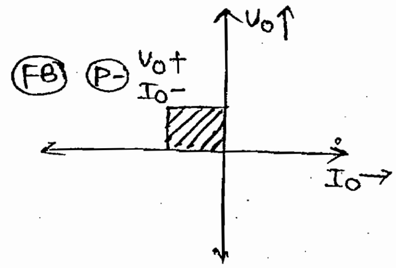
$CH \rightarrow OFF$, $D \rightarrow ON$

$\frac{1}{2}Li^2 \longrightarrow$ Source

$L \rightarrow$ releasing energy

$V_o = V_s$





Source $\xleftarrow{(P)}$ Brake energy

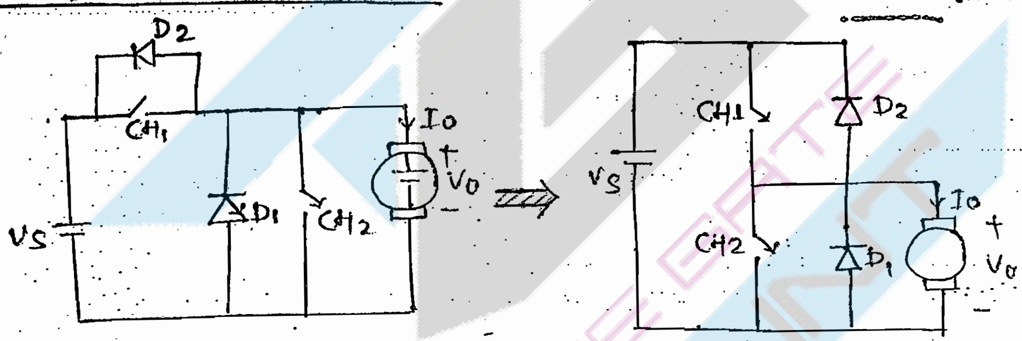
∴ Regenerative Braking

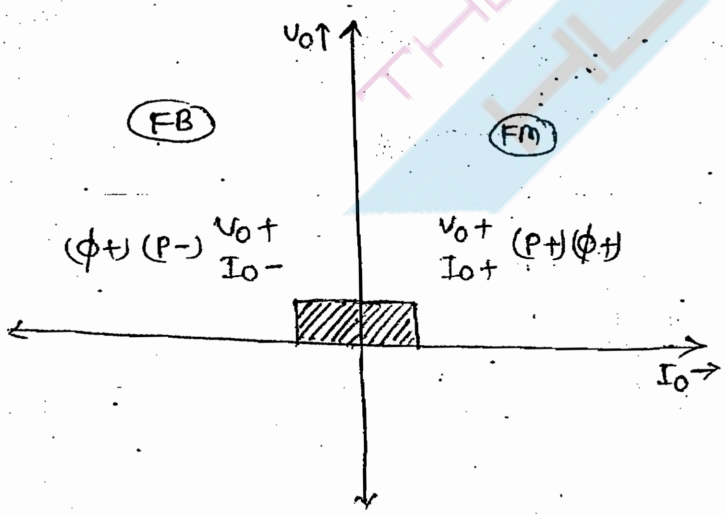
HV ← LV

$$\text{Regenerative Power} = V_o I_o \quad (V_o < V_s)$$

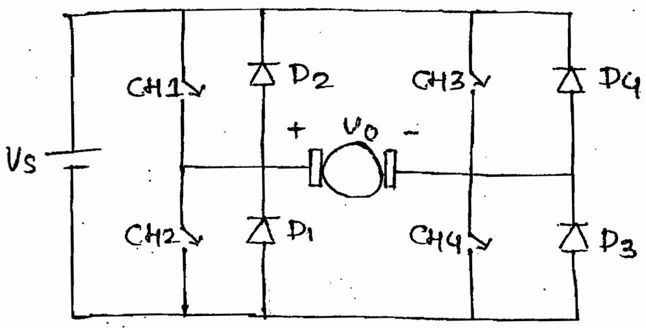
$$= (1-\alpha) V_s \cdot I_o$$

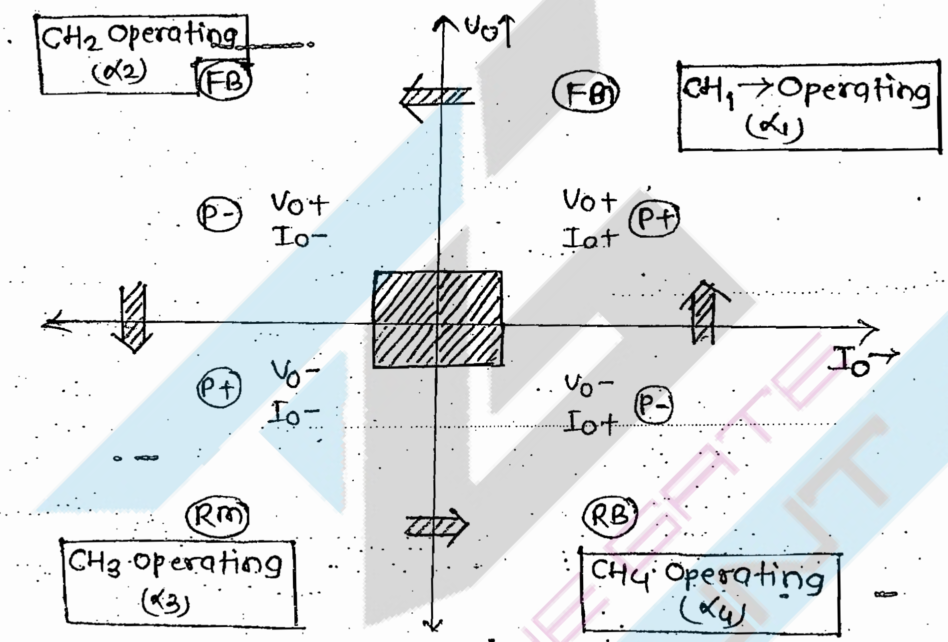
3.) Two quadrant Chopper→





(4) Four Quadrant Chopper →





(1) $CH_2, D_3 \to ON$

$V_0 = 0$, ∴ I_o-, ∴ T_a-

$1/2 J\omega^2 \to 1/2 Li^2$

(2) $CH_2 \to OFF$

$D_2, D_3 \to ON$

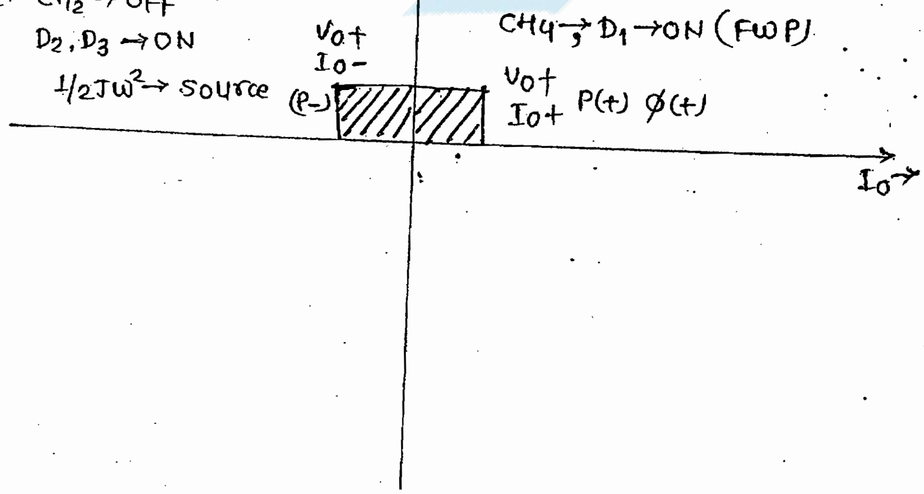
$1/2 J\omega^2 \to$ source

(1) $CH_1, CH_4 \to ON$, $V_0 = V_s$, ∴ E_b+, ∴ $\omega+$

I_o+, ∴ T_a+

(2) $CH_1 \to OFF$

$CH_4, D_1 \to ON$ (FWP)



AC Voltage Controller

Fixed AC ⟶ Variable AC

$\cancel{V_0}$

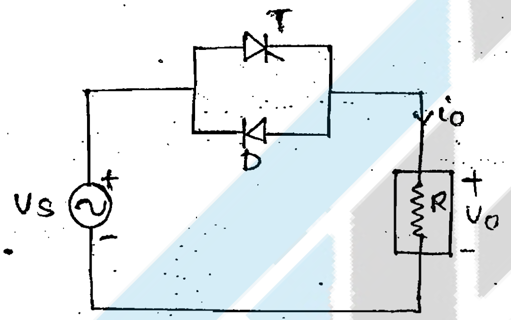
f(const)

(1.) Phase Control tech.

(2.) Integral cycle control (ON/OFF)

(1.) Phase Control tech →

(i) Single phase half controlled AC vol. Controller →

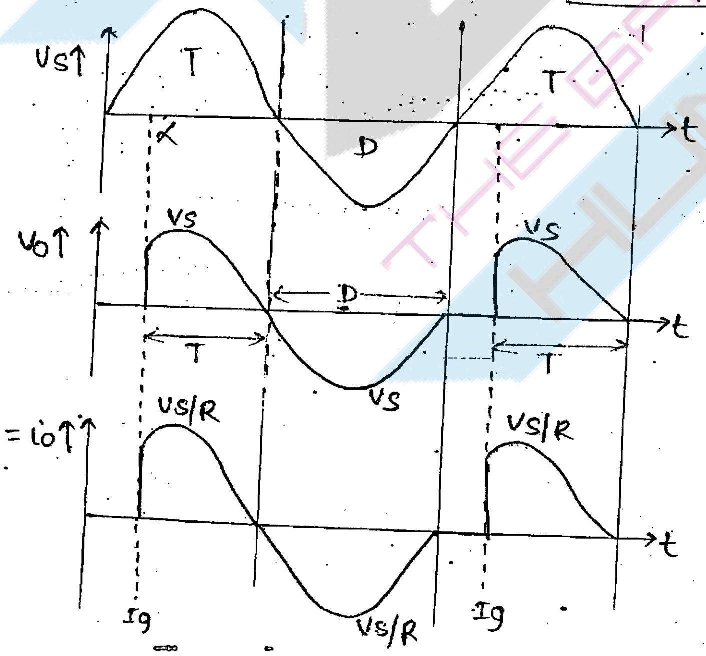


$$V_0 = \frac{1}{2\pi}\int_{\alpha}^{2\pi} V_m \sin\omega t \cdot d(\omega t)$$

$$\boxed{V_0 = \frac{V_m}{2\pi}[\cos\alpha - 1]}$$

$$\boxed{(I_s)_{avg} = I_0 = \frac{V_m}{2\pi R}[\cos\alpha - 1]}$$

(I_s) ↓ Dc comp.



Drawback →

* The source current contains dc comp. & saturates the supply Xmer core. Therefore this type of AC vol. controllers are not prefered in applications.

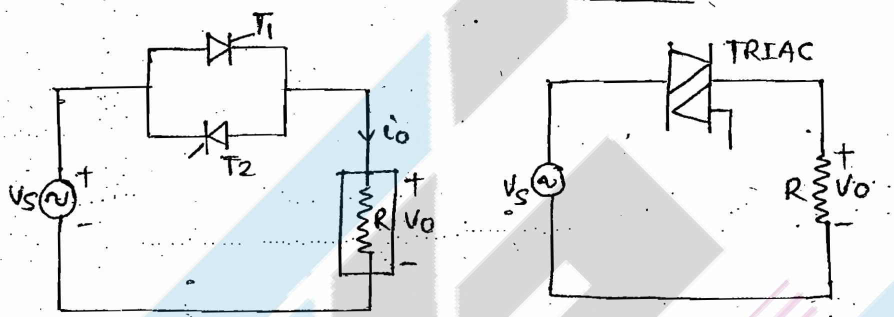
$$V_{or} = \left\{ \frac{1}{2\pi} \int_{\alpha}^{2\pi} V_m^2 \sin^2\omega t \cdot d(\omega t) \right\}^{1/2}$$

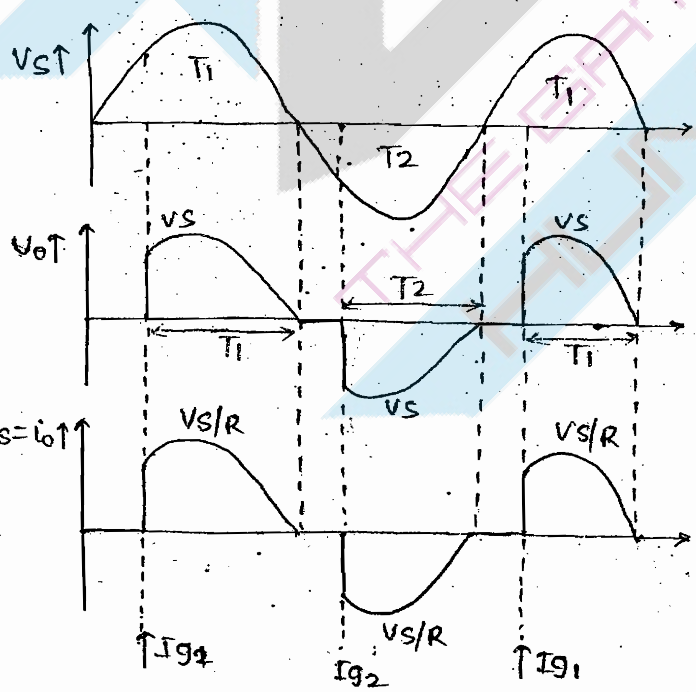
$$V_{or} = \frac{V_m}{2\sqrt{\pi}} \left\{ (2\pi - \alpha) + 1/2 \sin 2\alpha \right\}^{1/2}$$

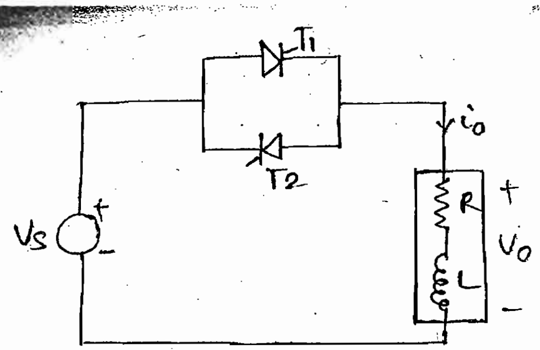
For R Load →

$$PF = \frac{V_{or}}{V_{sr}} = \frac{1}{\sqrt{2\pi}} \left\{ (2\pi - \alpha) + \frac{1}{2} \sin 2\alpha \right\}^{1/2}$$

(2) 1ϕ Full Controlled AC Voltage Controller →



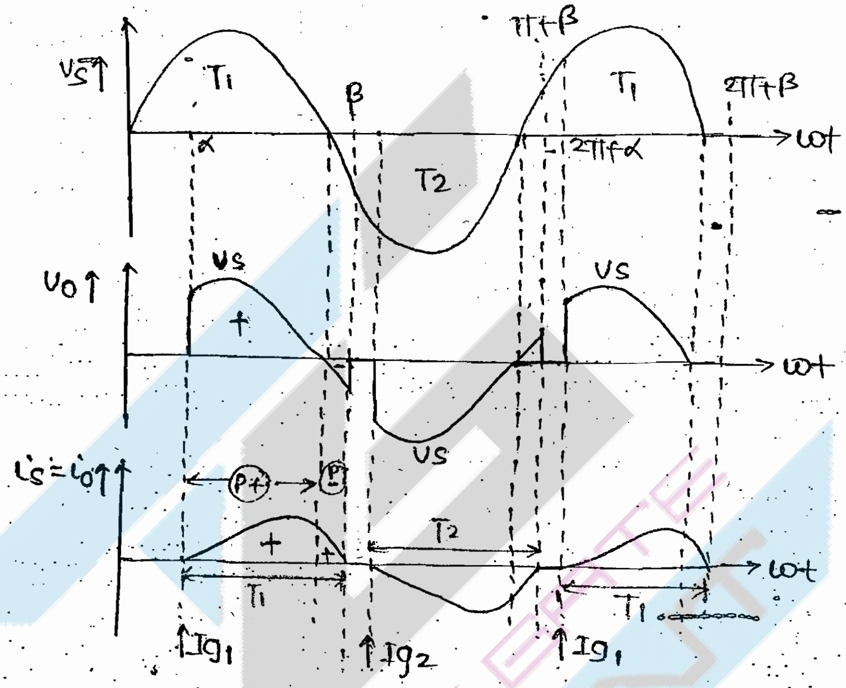




After reaching steady state,
i_o lags V_o by $\phi = \tan^{-1}\frac{\omega L}{R}$

(i) $\alpha > \phi$, V_o is controlled

(ii) $\alpha \le \phi$, V_o is uncontrolled.



(i) $\alpha > \phi$, V_o is controlled →

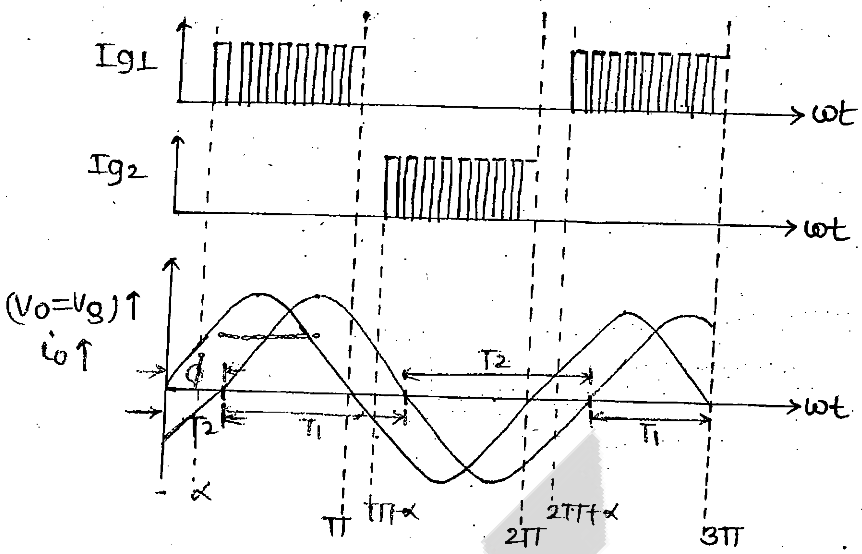
$$V_{or} = \frac{V_m}{\sqrt{2\pi}}\left[(\beta - \alpha) + \frac{1}{2}(\sin 2\alpha - \sin 2\beta)\right]^{1/2}$$

$$I_{or} = \frac{V_{or}}{|Z|} \qquad \text{where } |Z| = \sqrt{R^2 + (\omega L)^2}$$

(ii) $\alpha \le \phi$, V_o is Uncontrolled →

$$\boxed{(V_{or})_{max} = V_{sr} = \frac{V_m}{\sqrt{2}}}$$

$$\boxed{(I_{or})_{max} = \frac{(V_{or})_{max}}{|Z|}}$$

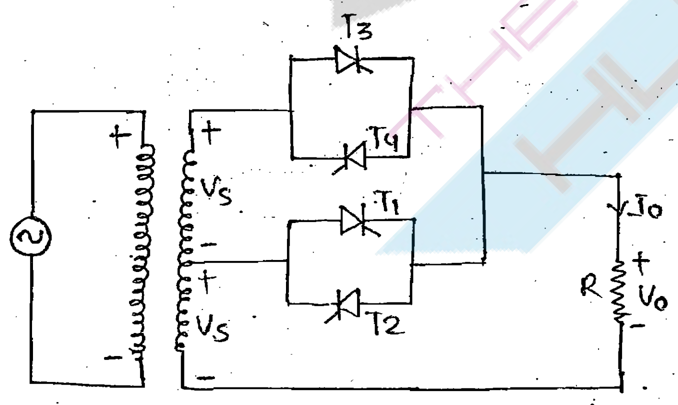


* If pulse gate signal is given tho thy. in AC vol. controller with inductive load then it may behave like half wave rectifier.

To rectify this prob. we must provide contineous gate pulse (or) high freq. gate pulse as shown in fig.

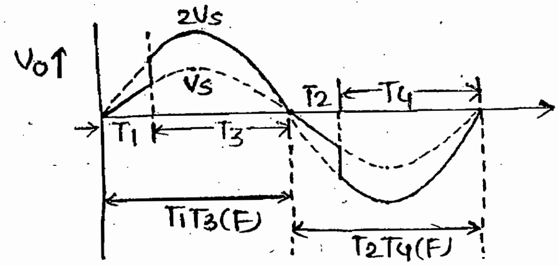
Drawback → In phase control tech. at high values of α harmonics distortion is higher & is operates at ~~high~~ low PF.

* Two-stage AC vol. Controller →



+ve $T_1 T_3$ (F)

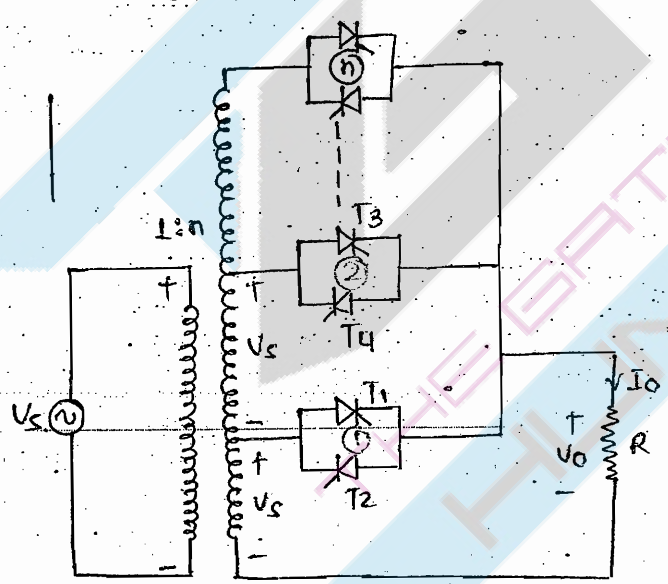
−ve $T_2 T_4$ (F)

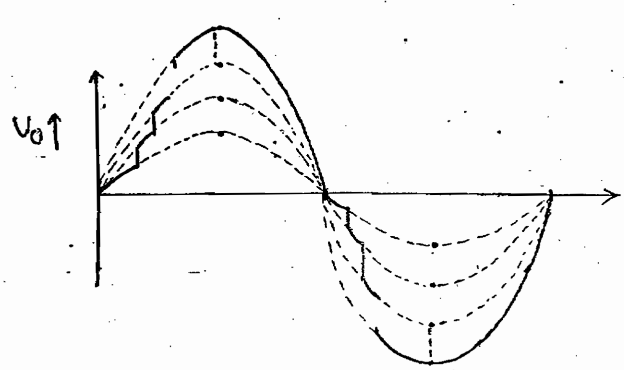


$$V_{or} = \left\{ \frac{1}{\pi} \left[\int_0^{\alpha} V_m^2 \cdot \sin^2\omega t \cdot d(\omega t) + \int_{\alpha}^{\pi} 4V_m^2 \sin^2\omega t \cdot d(\omega t) \right] \right\}^{1/2}$$

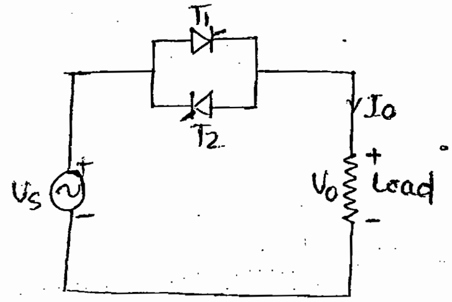
$$V_{or} = \frac{V_m}{\sqrt{2\pi}} \left\{ \left[\alpha - \tfrac{1}{2}\sin 2\alpha \right] + 4\left[(\pi-\alpha) + \tfrac{1}{2}\sin 2\alpha \right] \right\}^{1/2}$$

Multi-stage Ac Voltage Controller →



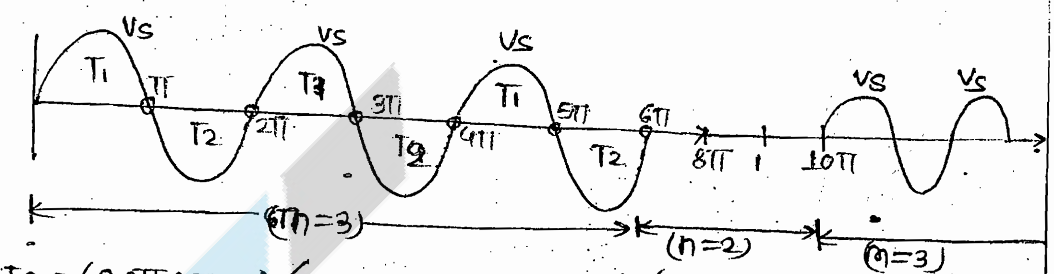


2. Integral Cycle Control → (ON/OFF)



m cycles → ON ($V_0 = V_s$) let m=3

n cycles → OFF ($V_0 = 0$) n=2



$I_{g1} = (0, 2\pi, 4\pi, \cancel{6\pi}, \cancel{8\pi}, 10\pi, 12\pi, 14\pi, \cancel{16\pi}, \cancel{18\pi} \ldots\ldots)$

$I_{g2} = (\pi, 3\pi, 5\pi, \cancel{7\pi}, \cancel{9\pi}, 11\pi, 13\pi, \cancel{17\pi}, \cancel{19\pi}, 21\pi \ldots\ldots)$

$$V_{or} = V_{sr}\left(\frac{m}{m+n}\right)^{1/2}$$

$$\boxed{V_{or} = \sqrt{K}\, V_{sr}} \qquad \left(K = \frac{m}{m+n}\right)$$

$$\boxed{PF = \sqrt{K}}$$

Application → It can be used for the AC loads with high time constant.
For eg:- It can be used for Indⁿ motor with high MI ψi mech. time constant.

Limitation → We can't get wide range of voltage control with this method.

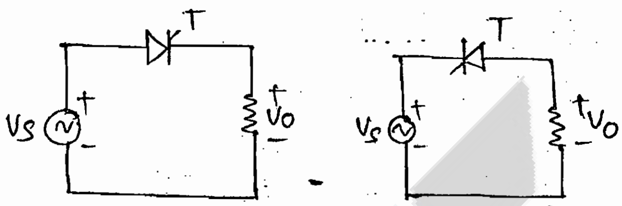
* Cycloconverter →

Cycloconverter

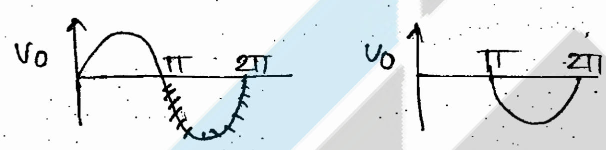
Fixed AC ⟶ variable AC
(V_s, f_s) (V_o, f_o)

$f_o < f_s$ → step down cyclocon^{r}

$f_o > f_s$ → step up cyclocon^{r}

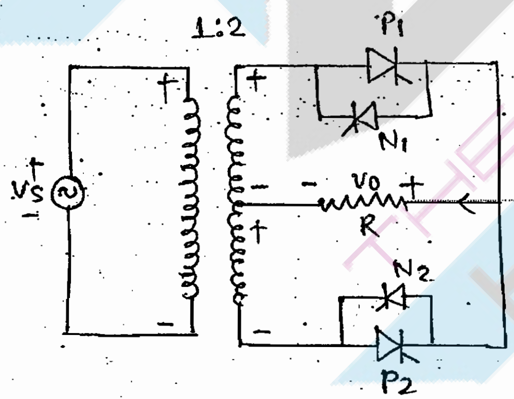


AC ⟶ DC   AC ⟶ DC



+ve rectifier   -ve rectifier

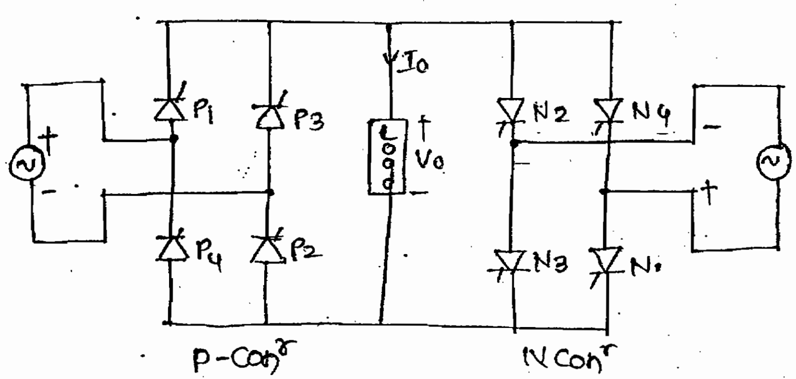
* Mid point cycloconverter →



+ve, P_1N_2(F)

-ve, P_2N_1(F)

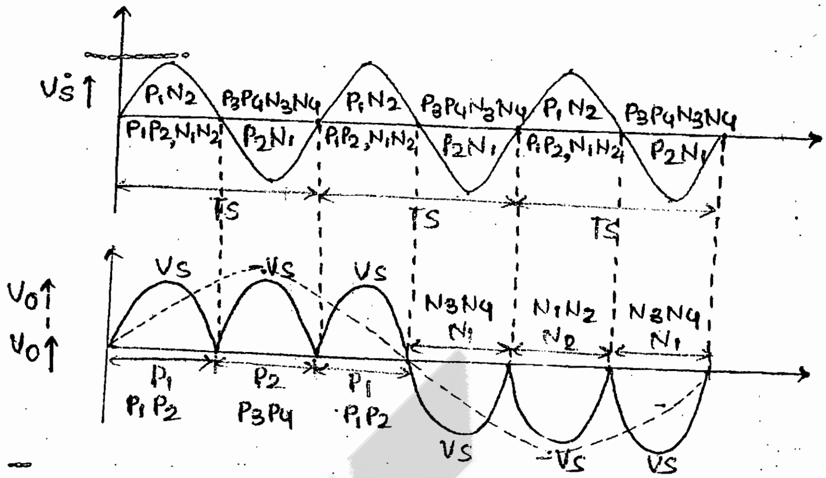
* Bridge cycloconverter →



+ve P_1P_2, N_1N_2(F)

-ve P_3P_4, N_3N_4(F)

Stepdown cyclo $[f_o < f_s]$ → Let $f_o = \frac{1}{3} f_s$, $T_o = 3T_s$



$f_o = \frac{1}{3} f_s$	$P_1 P_2 P_1$ $+ - +$	$N_1 N_2 N_3$ $- + -$
$f_o = \frac{1}{4} f_s$	$P_1 P_2 P_1 P_2$ $+ - + -$	$N_2 N_1 N_2 N_1$ $+ - + -$

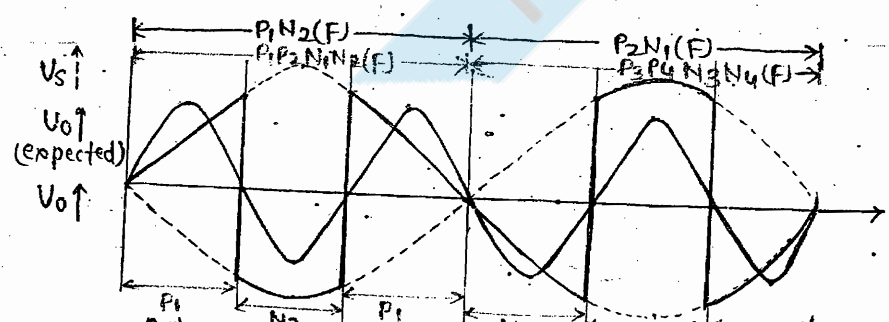
R Load →

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

RL Load →

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

Stepup cycloconverter → $(f_o > f_s)$ Let $f_o = 3f_s$, $T_s = 3T_o$



* Forced comm. is required in step up cyclo.
* Harmonic distortion is high in cyclocon^r therefore it operates with low PF.

Application → It is used for high power, low speed & reversefull AC drives.

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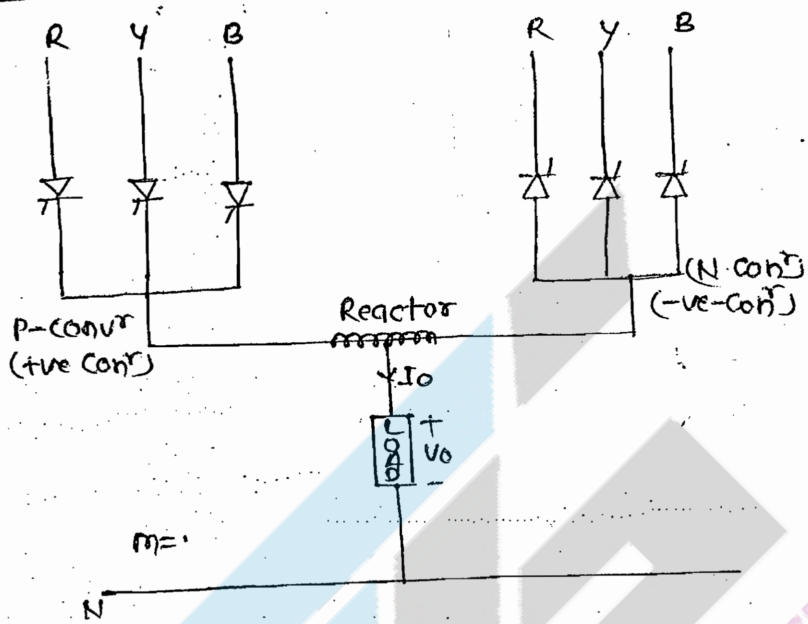
★3ϕ to 1ϕ cycloconverter →

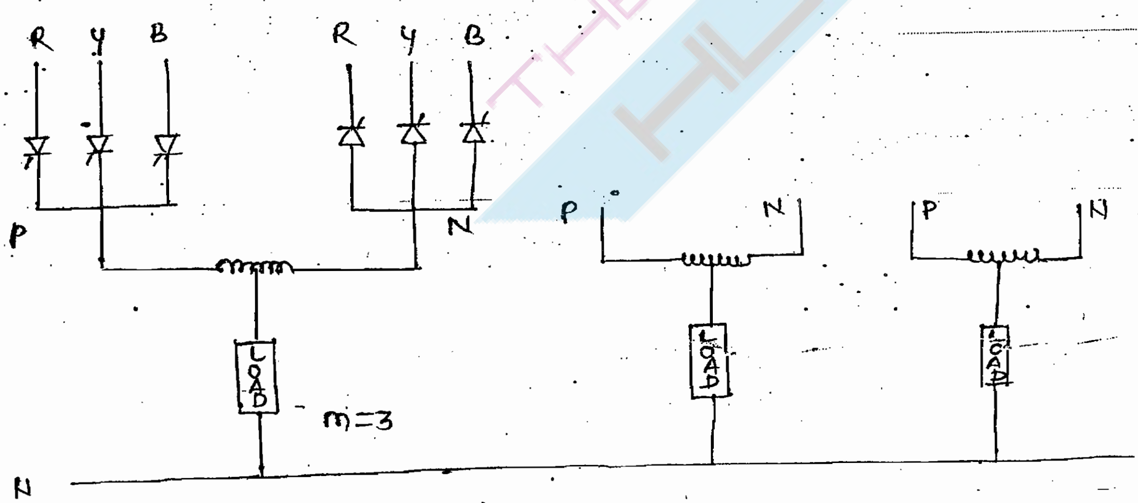


(1.) $\alpha_P + \alpha_N = 180°$

(2) Reactor

$$\boxed{V_{01} = V_{ph} \cdot \frac{m}{\pi} \cdot \sin\frac{\pi}{m} \cdot \cos\alpha}$$

3ϕ to 3ϕ cycloconverter → (18 thy. cycloconverter)



$$\boxed{V_{01}/\text{phase} = V_{ph} \cdot \frac{m}{\pi} \sin\frac{\pi}{m} \cdot \cos\alpha}$$

* If 6 pulse conʳ is used in 3ph to 3ph. cycloconverter then we require 36 thy.

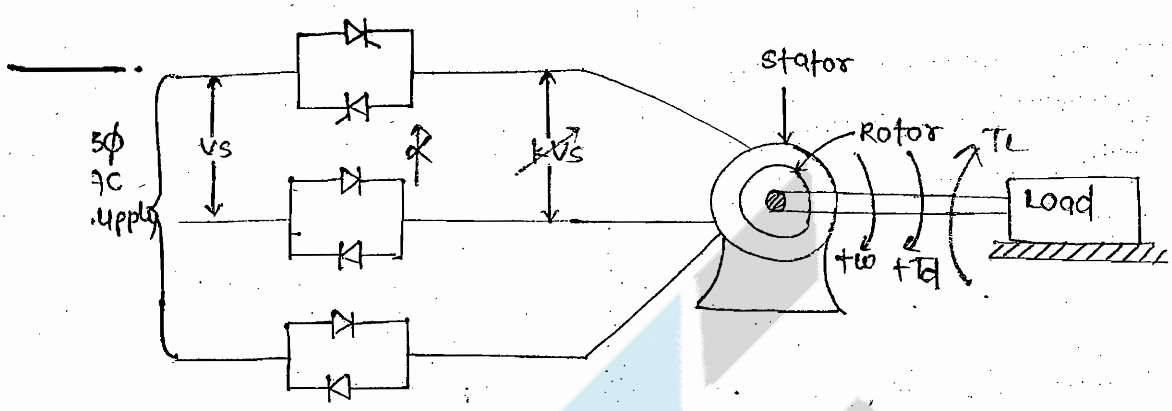
Therefore it is also known as 36 thy. cyclo.

$$\boxed{V_{01}/\text{phase} = V_L \cdot \frac{m}{\pi} \sin\frac{\pi}{m} \cdot \cos\alpha}$$

Applications of Power electronics

Ac drives →

(1.) Stator voltage control of IM, using AC voltage controllers:-



* At starting, $T_d > T_L$ ∴ $\omega \uparrow$
* After reaching steady state speed, $T_d = T_L$
* If developed torque(T_d) $< T_L$, $\omega \downarrow$ (m/c retard).

Mech Loads:-

(1.) $T_L = $ const (Load torque is independant of speed)

(ii.) $T_L \propto \frac{1}{\omega}$ [($T_L \cdot \omega = 1$) Constant power load]

(iii) $T_L \propto \omega^2$

(iv) $T_L \propto \omega$

2.) Check weather the constant torque loads are suitable (or) not for the given ele. drive? case(I.) $T_L = $ const.

Ans:- * Let us consider that the m/c is running at rated load & rated speed.

If $(KV_s) \downarrow$, $T_d \downarrow$, ($T_d < T_L$) ∴ $\omega \downarrow$, $s \downarrow$, $I \uparrow$.

* Here the m/c will slow down & draws more current from supply to build up the torque untill $T_d = T_L$
* Here the m/c draws more current from the supply to build up the torque this overheats the m/c wdgs & much dearating is required for const. torque loads

Therefore this type of mech. loads are not prefered for a given ele. drive.

Case(2) $T_L \propto \omega^2 \rightarrow$

$(kVs)\downarrow, T_d\downarrow, (T_d < T_L) \therefore \omega\downarrow, T_L\downarrow$

* Here the m/c will slowdown until $T_L = T_d$
* Here T_L reduces along with the speed & developed torque.
Therefore there is no necessity to build up the torque
* Hence the m/c will not draw more current from supply.
Therefore much derating is not required & hence this type of mech. loads can be used for given ele. drives. Eg:- Fan loads, compressers, reciprocating pmp

Case(3) $T_L \propto \omega \rightarrow$

Case(2) & case(3) are same; but in case(3) speed is less as compare to above.

Case(4) $T_L \propto \frac{1}{\omega} \rightarrow$

$\uparrow T_L \propto \frac{1}{\omega\downarrow}$

(2) Stator Frequency Control $\rightarrow$

(a) $\omega < \omega_r$:- $\frac{V}{F}$ control

$\downarrow N_s = \frac{120 F\downarrow}{P}$ $\downarrow N = (1-S) N_s \downarrow$ $\downarrow V_s \propto \phi F \downarrow$ $\frac{V\downarrow}{\downarrow F} \rightarrow$ constant $\therefore \phi \rightarrow$ const

* In this case V/F ratio should be kept constant in the entire range of speed control in order to maintain constant flux.
* We can realise the V/F control by using cycloconverter.
* With cyclo. the max^M speed is limited to 40% of its rated value.
* We can also use pwm inverter for V/F control of IM.

$\downarrow P_d = T_d \cdot \omega \downarrow$

(b) $\omega > \omega_r \rightarrow$

$\uparrow V_s \propto \phi\downarrow F\uparrow$ $\underset{(const)}{P_d} = \downarrow T_d \cdot \omega \uparrow$

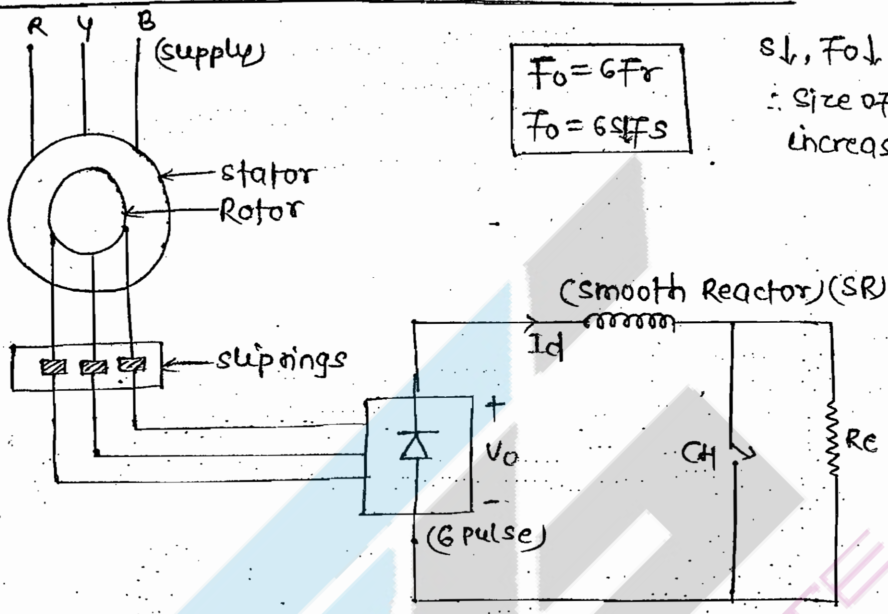
* In this case V/F ratio can't be kept constant because we can't increase the stator vol. more then its rated value.

Therefore the stator vol. is fixed that its rated value.

* To increase the speed ($\omega\uparrow$), $F\uparrow$ $\therefore \phi\downarrow$ ($\because V_s \to$ Rated value) $\therefore T_d\downarrow$

* In this case we can we sq. wave inverter or PWM ~~inverter~~.

3.) Static resistance control (using chopper control) →



$\boxed{F_o = 6F_r \\ F_o = 6sF_s}$

$s\downarrow, F_o\downarrow \therefore$ Ripple in $I_d\uparrow$

$\therefore$ Size of the SR should be increased.

Total cu loss $= 3I_r^2R_r + I_d^2(1-\alpha)R_e$ $\quad \boxed{(1-\alpha)R_e = R_{eff}}$

$$I_{sr} = \sqrt{\frac{2}{3}}I_o$$

$$I_r = \sqrt{\frac{2}{3}}I_d$$

$$I_d = \sqrt{\frac{3}{2}}I_r$$

Total cu loss $= 3I_r^2R_r + \left(\frac{3}{2}\right)I_r^2(1-\alpha)R_e$

$$sP_g = 3I_r^2\left[R_r + 0.5(1-\alpha)R_e\right]$$

$\therefore$ Effective resistance connected in series with rotor ckt $= 0.5(1-\alpha)R_e$

$\frac{12}{57}$

$$\text{Avg. Resistance} = \text{Series } R + [0.5(1-\alpha)R_e]$$

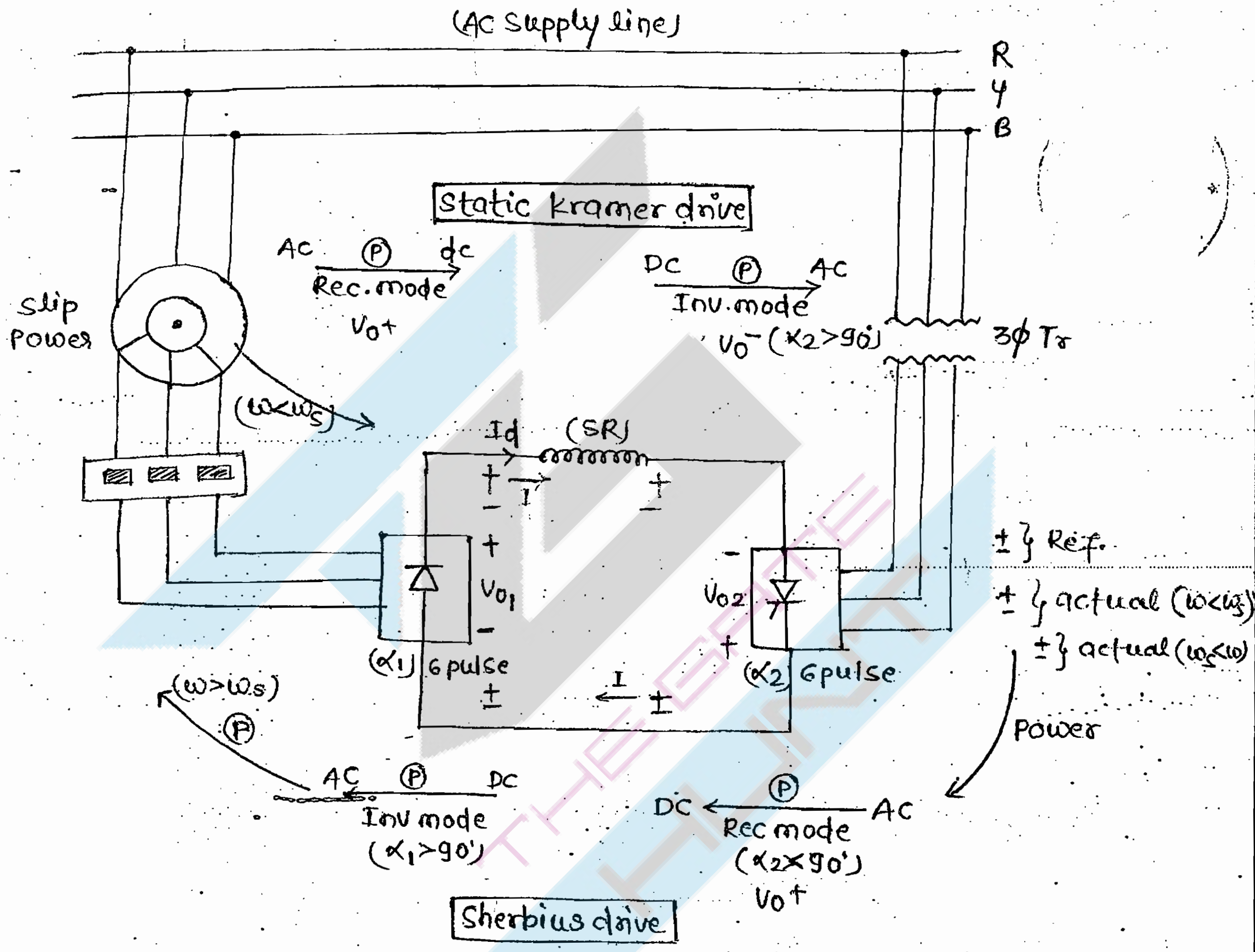
$$= 2 + [0.5(1-\alpha)4]$$

$$(1-\alpha) = \frac{T_{OFF}}{T} = T_{OFF}\cdot f = 4\times10^{-3}\times 200 = 0.8$$

$$\text{Avg. resistance} = 2 + [0.5\times0.8\times4] = 18/5$$

* This is not an efficient method because the slip power is dessipated in the external resistance in order to slow down the speed.

4.) Slip power recovery method → * This is an efficient method & ~~the~~ because the slip power is recovered & it can be utilised to the load itself (or) given back to the supply line.



HVDC

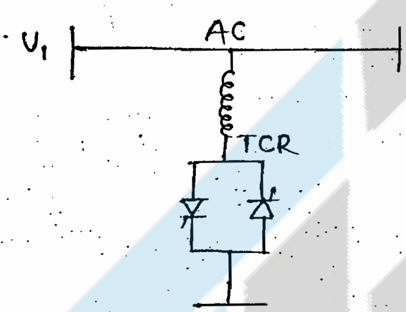
* We can xmit the power by using EHVAC (or) HVDC.

Features of AC lines :-

(1.) The power flow magnitude & dirⁿ can't be quickly & easily control.

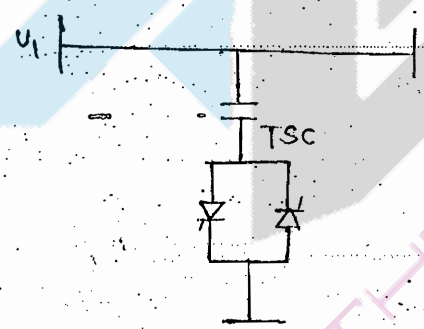
(2.) The transient stability limit is lesser in the AC line when compared with dc line.

(3.) The other prob. associated with AC lines are skin effect; corona losses, radio & TV interference b/n the comm. lines & power lines.



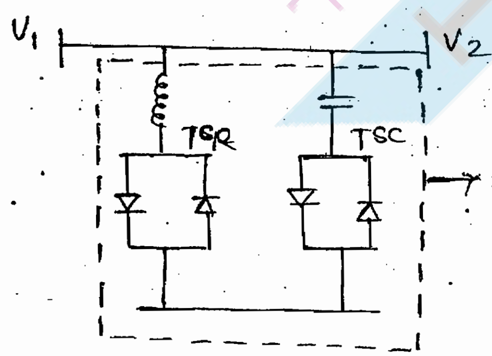
V_2 lightly loaded $V_2\uparrow$

TCR → thyristorised Control Reactor



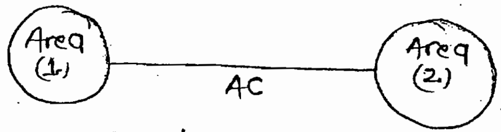
(Highly loaded $V_2\downarrow$)

TSC → Thyristorised switch capacitance

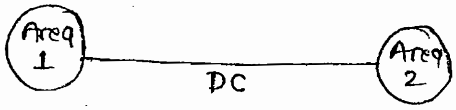


→ SVC (Static vars Compensating)

(4.) Intermediate substation are installed in the ac line to compensate the reactive power automatically as per the requirement of the line.



Synchronous tie [Frequencies must be same]



Asynchronous tie [Freq. need not be same]

5) The sys. disturbance in one of area results in power swings. If the power swings are unstable then it may lead to cascading of tripping the alternators & this results in large scale blackouts.

(6.) With ac interconnection the freq. disturbance in one area is transfered to other area.

(7.) If multiple no. of areas is interconnected by ac line then the fault level of the system increases.

★ HVDC → It is economical to Xmit bulk power over long distance.

Advantages →

(1.) The power flow magnitude & dirn can be quickly & easily controlled.

(2.) The transient stability limit is improved in the dc line.

(3.) There is no skin effect prob. in the dc line.

(4.) The other prob. likes corona losses, radio & tv interfererance is very much reduced in the dc lines.

(5.) HVDC is used for underground (or) submarine cables even for short distance (because dc cables will not charge contineously)

(6.) HVDC can utilised earth for its return path.

(7.) The power xn capacity of a bipolar HVDC line is almost same as that of 3ϕ single ckt ac line.

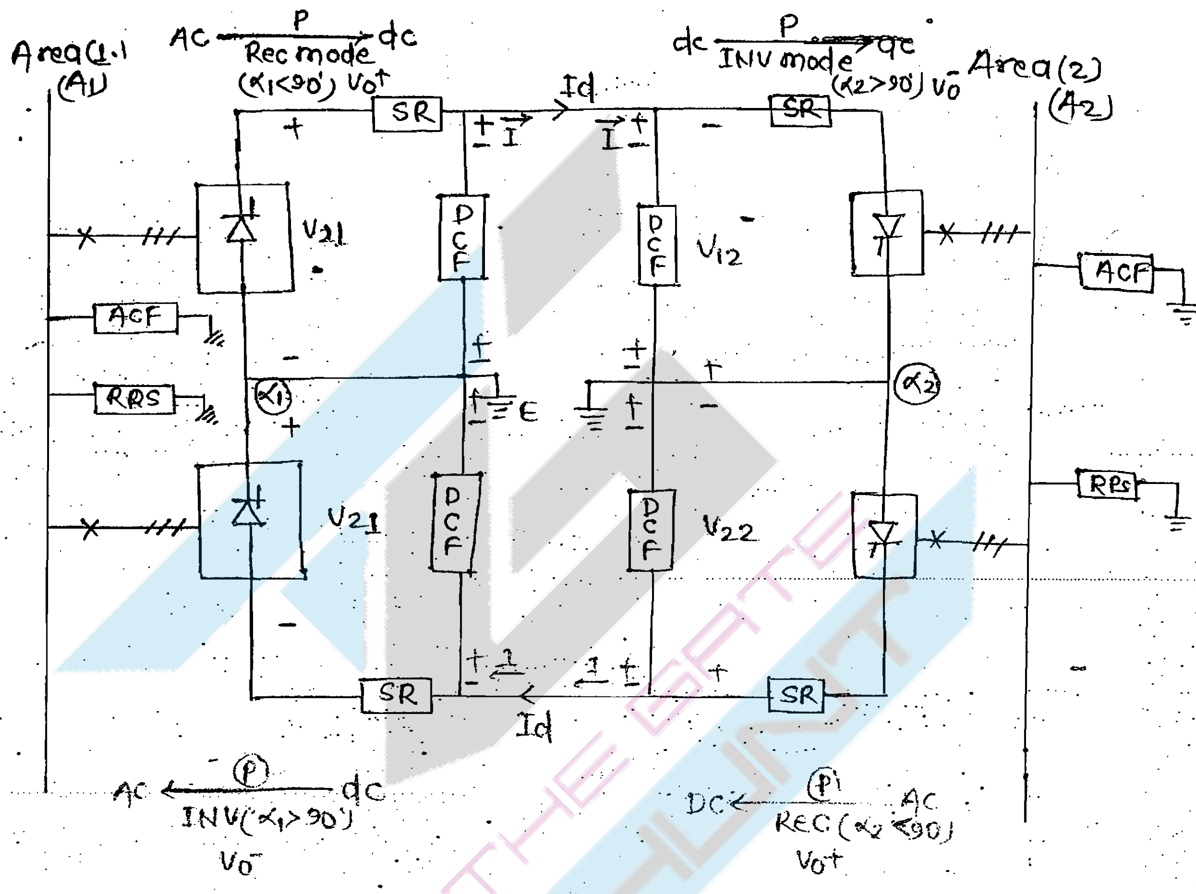
(8.) We can interconnect 2 independant areas at different freq. because it is an asynchronous type.

(9.) With dc interconnection the freq. disturbance in one area can't be Xfered to other area.

(10) If multiple no. of areas are interconnected with dc line then the fault level of the sys. will not be subtansily increased.

Type of HVDC →

(1) Bipolar HVDC →



SR → smoothning Reactor

DCF → DC Filter

ACF → AC Filter

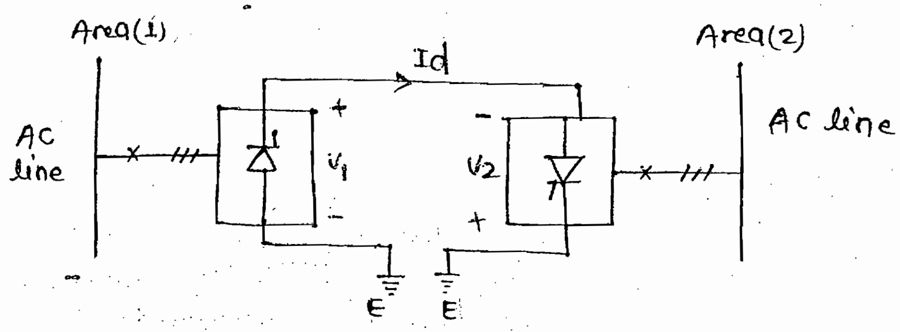
RPS → Reactive power source (To compensate the required Power for converter operation)

{± Ref

{± Actual ($A_1 \xrightarrow{P} A_2$)

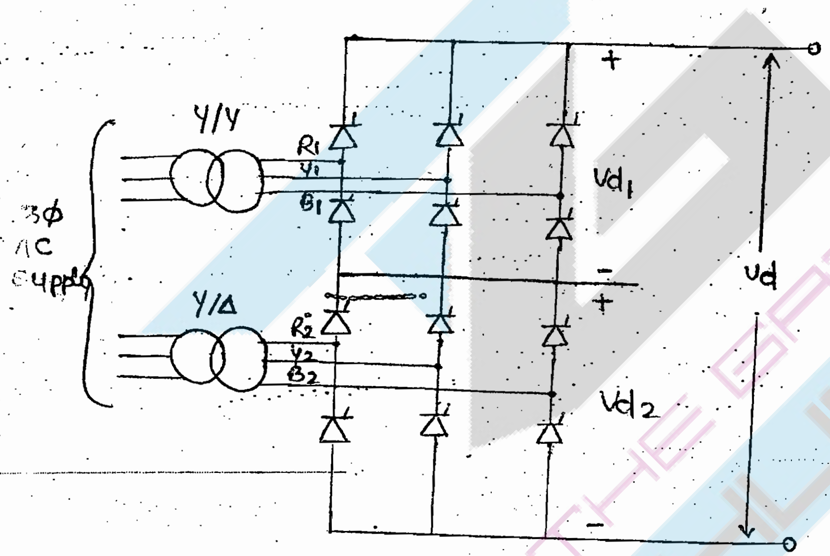
{± Actual ($A_1 \xleftarrow{P} A_2$)

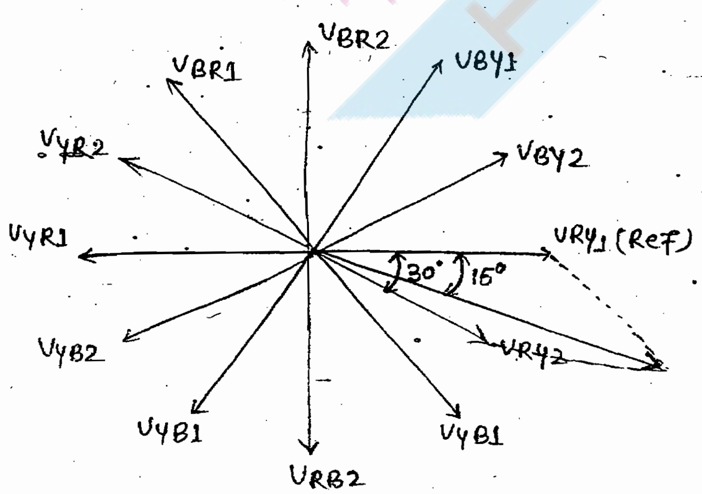
2.1 Monopolar HVDC →



* In order to reduce the harmonics the 6 pulse conʳ is replaced by the 12 pulse conʳ.

12 pulse converter →





Inverter Question

1/49

$2\alpha = 120^\circ$

$\alpha = 60^\circ$

$V_{on} = \frac{2\sqrt{2}}{n\pi} \sin n\alpha \; V_s$

$V_{o1} = \frac{2\sqrt{2}}{\pi} \sin\alpha \cdot V_s$

$= \frac{2\sqrt{2}}{\pi} \cdot 1 \cdot \sin\alpha$

$= 0.78V$

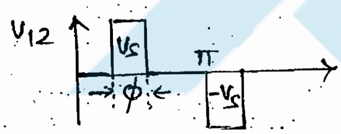
4/49

$\frac{V_{o3}}{(V_{o1})_{max}} = \frac{\frac{2\sqrt{2}}{3\pi} V_s \sin 3\alpha}{\frac{2\sqrt{2}}{\pi} V_s}$

$= \frac{\sin 3\alpha}{3} = 19.6\%$

11/50

$V_{12} = V_1 - V_2$



$V_{12} = V_s\left(\frac{\phi}{\pi}\right)^{1/2}$

13/51

$D \rightarrow \phi = \tan^{-1}\frac{X_L - X_C}{R}$

$= \tan^{-1}\left(\frac{X_L - 0}{0}\right) = 90^\circ$

$\omega t = \pi/2 \; rad$

$t = \pi/2\omega \; rad = \frac{1}{4f} sec$

$t = 5ms$

5/49

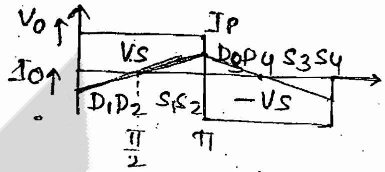
$g = \frac{2\sqrt{2} \sin\alpha}{\sqrt{(2\alpha) \cdot \pi}}$ $\quad 2\alpha = 150 = \frac{5\pi}{6} rad$

$\alpha = 75$

$g = \frac{2\sqrt{2} \cdot \sin 75}{\sqrt{\frac{5\pi}{6} \cdot \pi}}$ $\quad g = 0.95$

$THD = 31.8\%$

7/50



$\pi/2$ to π ; $S_1S_2 \rightarrow ON$, $V_o = V_s$

$L\frac{di}{dt} = V_s$; $\int_0^{I_p} di = \frac{V_s}{\omega L}\int_{\pi/2}^{\pi} d(\omega t)$

$I_p = \frac{V_s}{\omega L} \cdot \frac{\pi}{2} = \frac{V_s}{4fL} = 10A$

12/50

$|Z_n| = X_{Ln} = n\omega L$

$V_{on} = \alpha_n \cdot V_{o1}$ $(\alpha_n < 1)$

$I_{on} = \frac{V_{on}}{|Z_n|} = \frac{\alpha_n V_{o1}}{n \cdot \omega L} = \frac{\alpha_n}{n} I_{o1}$

CONV. (1) →

(1) RLC ; $\omega t_c = \phi = \tan^{-1}\frac{X_C - X_L}{R}$; $\omega = \frac{2\pi}{T} = \frac{2\pi}{0.2\times10^{-3}}$

$\tan(\omega t_c) = \frac{X_C - X_L}{R}$ $\quad t_c = (SF)\, t_q = 2(12)\times10^{-6} = 24\times10^{-6}$

$\tan\left[\frac{2\pi}{0.2\times10^{-3}} \times 24\times10^{-6} \times \left(\frac{180}{\pi}\right)\right] = \frac{X_C - 12}{3}$

$X_C = 14.7\Omega$, $\frac{1}{\omega C} = 14.7$

$C = 2.15\mu F$

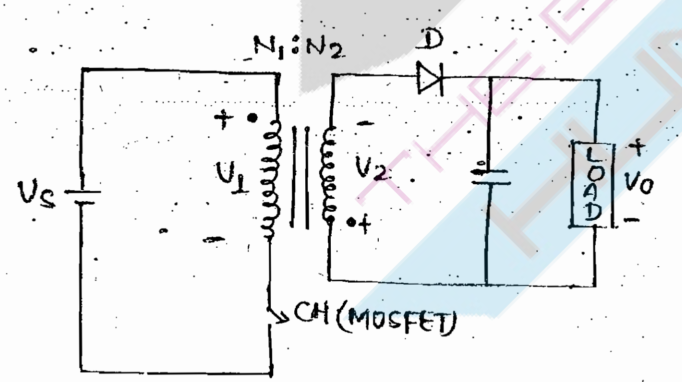
SMPS

* In SMPS the transistor operates in the switch mode in very high freq. (Cut off region is used for off state & saturation region is used for ON state).
* At such an high freq. we can reduce the size of filter as well as Xmer.
* Here we use ferrite core for high freq. Xmer used in SMPS.
* With the availability of high speed device like power MOSFET SMPS is populary used in now a days.
* SMPS is highly efficient & compact in size.
* In linear power supply the transistor operates in the active region & therefore it is not efficient power supply & it occupy more space & weight (because we use 50 Hz Xmer in linear power supply)

*Types of SMPS →

1.) Flyback Converter → * It is derived from Buck-Boost converter.
* It is also known as isolated Buck-Boost converter.

* Here in place of the indctor we are use Xmer here because both stores megnatic energy.



mode(I) → $0 \le t \le T_{ON}$

CH → ON

Xmer stores energy in the form of megnatic field

$V_1 = V_S$

$V_2 = \frac{N_2}{N_1} V_1$

$V_2 = a V_S$

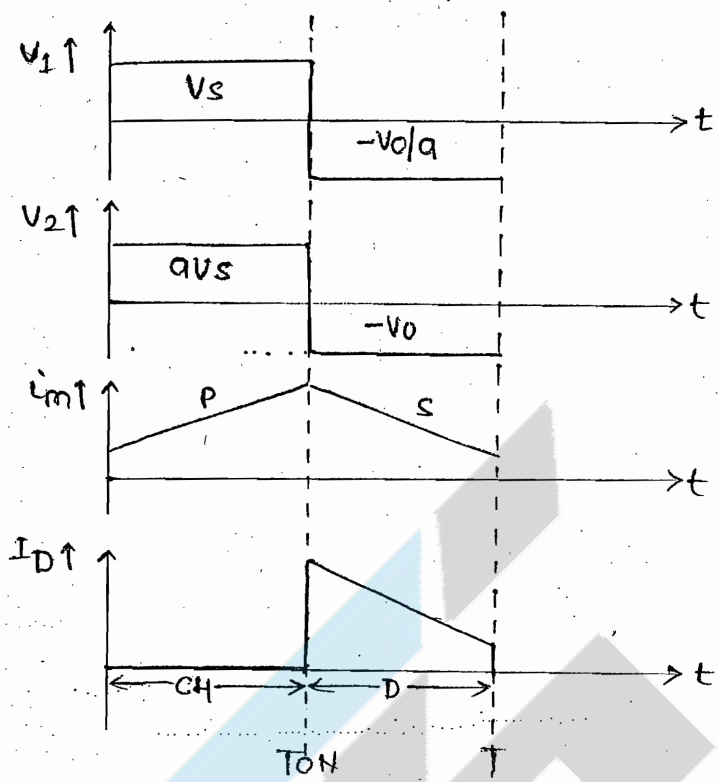
mode(2) → $T_{ON} \le t \le T$

CH → OFF, D → ON

$V_2 = -V_0$

$V_1 = \frac{N_1}{N_2} V_2$

$V_1 = -\frac{V_0}{a}$



$$\boxed{V_0 = \frac{a \cdot \alpha V_s}{(1-\alpha)}}$$

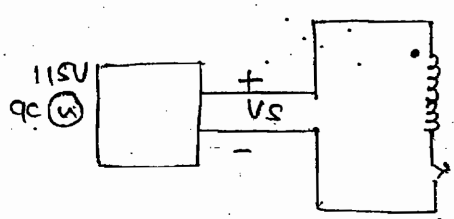
*** The peak forward blocking voltage of CH switch $= V_s + \frac{V_0}{a}$

Note:- The o/p voltage of front end rectifier without voltage doubling $= V_m$

V_m (Peak value of ac i/p vol.)

o/p voltage of front end rectifier with voltage doubling $= 2V_m$

(3/59)



$V_s = 115\sqrt{2}$ (peak)

$V_0 = \frac{a \cdot \alpha V_s}{1-\alpha}$

$35 = \frac{a \times 0.3 \times 115\sqrt{2}}{(1-0.3)}$

$a = 0.5$

Forward blocking vol. $= V_s + \frac{V_0}{a} = 115\sqrt{2} + \frac{35}{0.5}$

$= 232.5V$

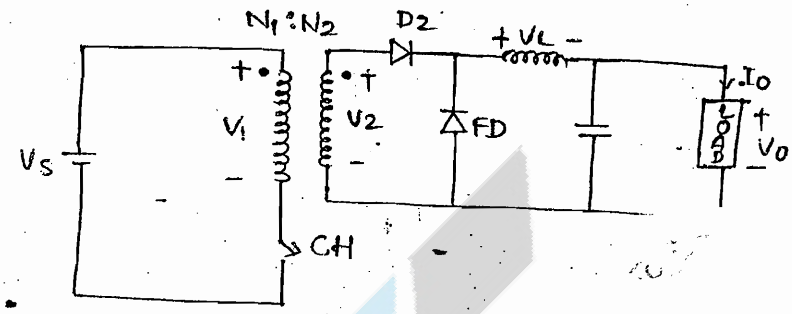
(2) Forward Converter → * It is derived from Buck Conr.

Case (1) → Ideal Xmer;

→ $I_m = 0$

→ No Losses

→ No leakage inductance



Mode (1) → $0 \le t \le T_{ON}$

CH → ON

$V_1 = V_S$; $V_2 = \frac{N_2}{N_1} V_1$

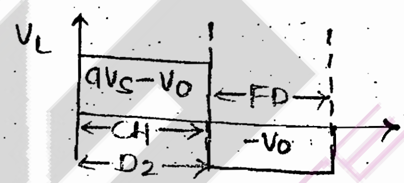
$V_2 = a \cdot V_S$

Applying KVL;

$-V_2 + V_L + V_o = 0$

$V_L = V_2 - V_o$

$V_L = aV_S - V_o$



Mode (2) → $T_{ON} \le t \le T$

CH → OFF, D_2 → OFF

FD → ON

$+V_L + V_o = 0$

$V_L = -V_o$

$(V_L)_{avg} = 0$

$(aV_S - V_o) T_{ON} - V_o T_{OFF} = 0$

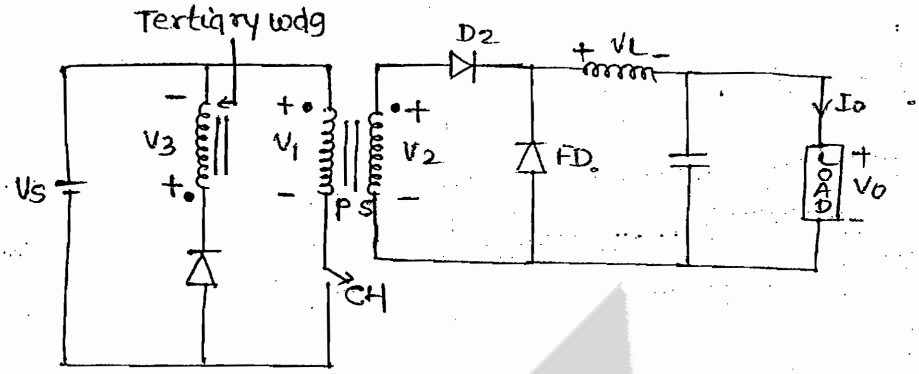
$aV_S T_{ON} = V_o T$

$V_o = a \cdot \frac{T_{ON}}{T} \cdot V_S$

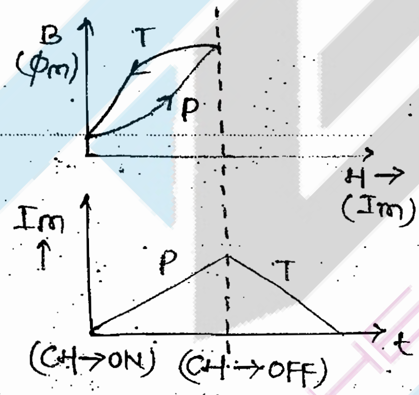
$\boxed{V_o = a\alpha \cdot V_S}$

Case (2) → For non-ideal Xmer

→ $I_m \neq 0$



* Tertiary wdg is used to provide a path to magnetising current when the CH switch becomes OFF
* Here Xmer magnetises through 1° wdg & demagnetises through 3° wdg.



* In Flyback & Forward Converters the Xmer is excited only in one dir^n.

It is called unidirectional core excitatation.

(3) Push-Pull Converter → * In this con^r the Xmer core is excited bi-directionaly.

Therefore it is called bidirectional core excitation.

Fig is que $\frac{5}{59}$.

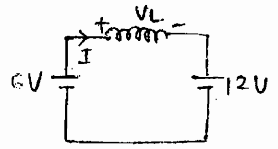
$$V_o = 2 \cdot a \alpha V_s$$

$$V_o = 2 \cdot \frac{N_2}{N_1} \cdot \frac{T_{ON}}{T_{ON} + T_{OFF}} \cdot V_s$$

Chopper Question

(1/52) 0 to T_{ON}

$V_{dc} = 60V$



KVL →

$$-60 + V_L + 12 = 0$$

$$V_L = 48$$

$$L\frac{dI}{dt} = 48$$

$$\int_{I_{min}}^{I_{max}} dI = \frac{48}{L}\int_0^{T_{ON}} dt \qquad \Delta I = \frac{48}{L}T_{ON} = 0.48A.$$

(2/52) $I_0 = \frac{\alpha V_S}{R} = \frac{0.8\times100}{10} = 8A$

$$(I_D)_{avg} = I_0\left(\frac{T_{OFF}}{T}\right) = I_0(1-\alpha) = 8(1-0.8) = 1.6A$$

(3/52) $(t_{om})_{min} = \cancel{\frac{CV_S}{R}} = \cancel{1\times10^{-6}\times250} \qquad \pi\sqrt{LC} = 140\mu s.$

(4/52) $V_o)_{min} = V_S\frac{(T_{ON})_{eff}}{T} = 47.5V$

(5/52) $(i_m)_{max} = I_0 + V_S\sqrt{\frac{C}{L}} = 12A, \quad (i_A)_{max} = I_0 = 10A$

Conventional question →

(a.) (i) $(T_{ON})_{eff} = T_{ON} + 2t_{cm}$ $\qquad$ (ii) $t_{cm} = \frac{CV_S}{I_0} = 137.5\mu s$

$$= 1075\mu s$$

(b.) $(i_m)_{max} = I_0 + V_S\sqrt{\frac{C}{L}}$ & $(i_A)_{max} = I_0$

(c.) $t_{cA} = \frac{\pi}{2}\sqrt{LC} = 49\mu s$ & $t_{cm} = \frac{CV_S}{I_0}$

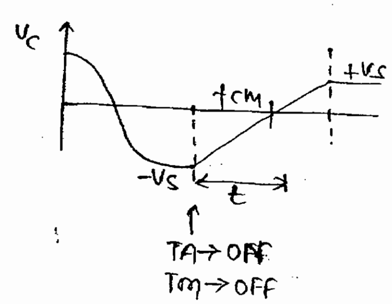
(d.) $2t_{cm} = 275\mu s$

(e.)

$$V_C = \frac{V_S}{t_{cm}}t - V_S$$

$$= \frac{220}{137.5}(150) - 220$$

$$V_C = 20V$$



(9.) $T_{ON}' = T_a \ln\left[1+m\left(e^{T/\tau_a}-1\right)\right]$

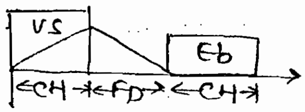
(10.) $t_{min} \le t \le t_{max}$

$\pi\sqrt{LC} \le t \le \frac{3\pi}{2}\sqrt{LC}$

$50\mu s \le t \le 75\mu s.$

(11) $I_o + I_p \sin\omega t$

(12.)



$$V_0 = \frac{V_s t_r + E_b t_r}{t_r + t_f + t_o}$$

(13.) $I_{max} = I_o + \frac{\Delta I_c}{2}$

$= 5 + \frac{1.6}{2}$

$= 5.8A$

1-φ Half Wave Rectifier

Rectifier Load	V_o	V_{or}	t_c	I_o	Other
R	$\frac{V_m}{2\pi}(1+\cos\alpha)$	$\frac{V_m}{2\sqrt{\pi}}\left[(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right]^{1/2}$	$\frac{\pi}{\omega}$	$(I_s)_{avg}=\frac{V_m}{2\pi R}(1+\cos\alpha)$	$I_{sr}=I_{or}=\frac{V_{or}}{R}$ $V_{sr}=\frac{V_m}{\sqrt{2}}$
R-L	$\frac{V_m}{2\pi}(\cos\alpha-\cos\beta)$	$\frac{V_m}{2\sqrt{\pi}}\left[(\beta-\alpha)+\frac{1}{2}(\sin 2\alpha-\sin 2\beta)\right]^{1/2}$	$\frac{2\pi-\beta}{\omega}$	$i_o=\frac{V_m}{\lvert Z\rvert}\sin(\omega t-\phi)+Ke^{-t/\tau}$	$K=\frac{-V_m}{\lvert Z\rvert}\sin(\alpha-\phi)e^{\frac{-R\alpha}{\omega L}}$
RL+FD	$\frac{V_m}{2\pi}(1+\cos\alpha)$	$\frac{V_m}{2\sqrt{\pi}}\left[(\pi-\alpha)+\frac{1}{2}\sin 2\alpha\right]^{1/2}$	$\frac{\pi}{\omega}$		$PF=\frac{P_o}{V_{sr}.I_{sr}}$
RE	$(V_o)_{avg}=\frac{1}{2\pi}\left[V_m(\cos\alpha-\cos\theta_2)+E(2\pi+\alpha-\theta_2)\right]$		$\frac{\pi+2\theta_1}{\omega}$	$\frac{1}{2\pi R}\left[V_m(\cos\alpha-\cos\theta_2)-E(\theta_2-\alpha)\right]$	(1.) $PF=\frac{I_{or}^2R+EI_o}{V_{sr}I_{sr}}$ (2.) $I_{or}=\left[\frac{1}{2\pi}\int_\alpha^{\theta_2}\left(\frac{V_m\sin\omega t-E}{R}\right)^2\right]^{1/2}$ (3.) PIV of thy. $=V_m+E$ $\theta_1=\sin^{-1}\left(\frac{E}{V_m}\right)$ $\theta_2=\pi-\theta_1$

spec:	1ϕ-full converter	1ϕ semi-converter	$3\text{-}\phi$ full conv
i_s	$\frac{4I_o}{n\pi}\sin(n\omega t+\phi_n)$	$\frac{4I_o}{n\pi}\cos\frac{n\alpha}{2}\sin(n\omega t+\phi_n')$	$\frac{4I_o}{n\pi}\sin\frac{n\pi}{2}\sin(n\omega t+\phi_n)$
I_{s1}	$\frac{2\sqrt{2}}{\pi}I_o$	$\frac{2\sqrt{2}}{\pi}I_o\cos\frac{\alpha}{2}$	$\frac{2\sqrt{2}}{\pi}I_o\sin\frac{\pi}{3}=\frac{\sqrt{6}}{\pi}I_o$
FDF	$\cos\alpha$	$\cos\frac{\alpha}{2}$	$\cos\alpha$
g	$\frac{2\sqrt{2}}{\pi}$	$\frac{2\sqrt{2}\cos\alpha/2}{\sqrt{\pi(\pi-\alpha)}}$	$\frac{3}{\pi}$
PF	$\frac{2\sqrt{2}}{\pi}\cos\alpha$	$\frac{\sqrt{2}(1+\cos\alpha)}{\sqrt{\pi(\pi-\alpha)}}$	$\frac{3}{\pi}\cos\alpha$
THD	48.34%	$\left[\frac{\pi(\pi-\alpha)}{8\cos^2\frac{\alpha}{2}}-1\right]^{1/2}$	31%

Specifi.	Current Commutated chopper (class B)	Voltage Commutated Chopper (Class D)
*$(I_{Tm})_{peak}$	I_o	$I_o + I_p = I_o + V_s\sqrt{\frac{C}{L}}$
*$(I_{TA})_{peak}$	$I_p = V_s\sqrt{\frac{C}{L}}$	I_o
*Condn time of the TA	$\pi\sqrt{LC}$	$2t_{cm}$
* t_{cm}	$\frac{V_R C}{I_o}$	$\frac{V_s C}{I_o}$ $RC\ln 2$ (with R load)
*Time req. to turn off Tm after TA is ON (total)	$t_1+t_2 = \pi\sqrt{LC} + \sqrt{LC}\sin^{-1}\left(\frac{I_o}{I_p}\right)$	
*$(T_{on})_{min}$ = tmin(min) time req. to turn off the Tm after TA ON	$\pi\sqrt{LC}$	
* t_{max}	$\frac{3\pi}{2}\sqrt{LC}$	
*Reverse vol.	$V_R = V_s\cos\left[\sin^{-1}\left(\frac{I_o}{I_p}\right)\right]$	
* $(T_{ON})_{min}$		$\pi\sqrt{LC}$
* PIV of FD		$2V_s$
* PIV of Tm		V_s
* t_{cA}		$\frac{\pi}{2}\sqrt{LC}$
* commutation interval		$2t_{cm}$
* $(T_{ON})_{eff}$		$T_{ON}+2t_{cm}$
* V_o		$V_s\frac{(T_{ON})_{eff}}{T}$
* $(V_o)_{min}$		$V_s(\pi\sqrt{LC}+2t_{cm})f$