POWER ELECTRONICS

Thyristor :

Diode - uncontrolled device

Thyristor - controlled device

- parameter controlled is voltage, curnt, powe
- (They are dependent parameters)

Anode

-- Anode
- Cathod

A @ high potential w.r.t C = conduction

Thyristr

Anode (at high potential w.r.t C) = it will NOT allow the conduction unless the gate pulse is given

i.e "instead of ~~voltage~~ conduction after applying FB can be controlled"

Sir

1) "Diode is a uncontrolled device

2) Thyristor is a controlled device, where the instead of conduction can be controlled after applying the Forward Voltage. due to this out put voltage, current, and power may be controlled.

Difference b/w SCR and Thyristor :

Thyristor :- Family of devices having PNPN structure.

*** SCR :- First member of thyristor family

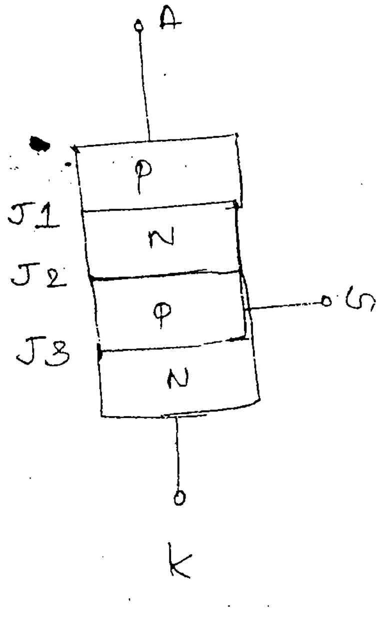
↑

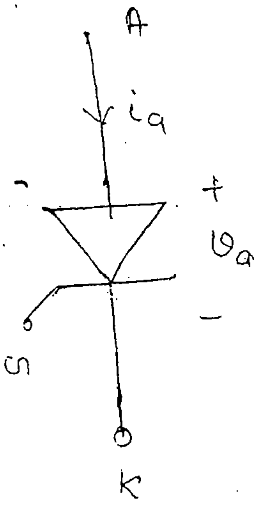
most of our discussion

Defn

" Thyristor is the Name given to Family of devices which will be used in power control application having a common structure PNPN,".

SCR. (SILICON CONTROLLED RECTIFIER)





- Four layers, 3 terminals, Anode - External P
  K — External N, Inner P → Gate
- Three junctions.

V_a = Anode voltage w.r.t cathode

i_a = Anode current (current through anode device)

= device current

Anode circuit = main circuit

Gate circuit = supporting circuit.

SCR is a 4 layer, 3 term., 3 Jn, PNPN device.

Characteristics of SCR

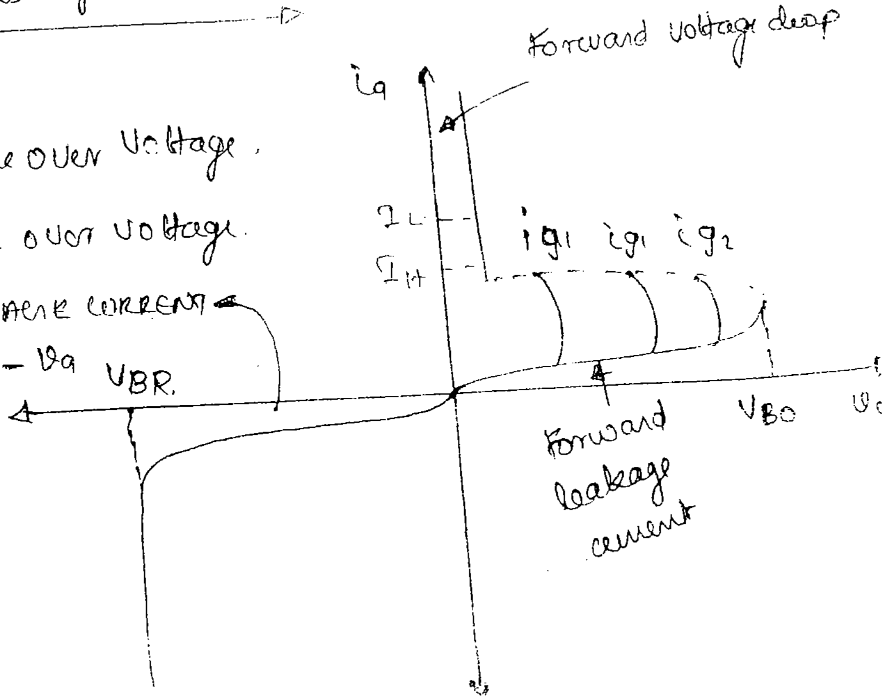
3 types

1) Static 2) Dynamic 3) gate characteristic.

Static characteristics of SCR

V_{BO} = Forward Break over Voltage.

V_{BR} = Reverse Break over Voltage.



Two parts

1) Forward charac

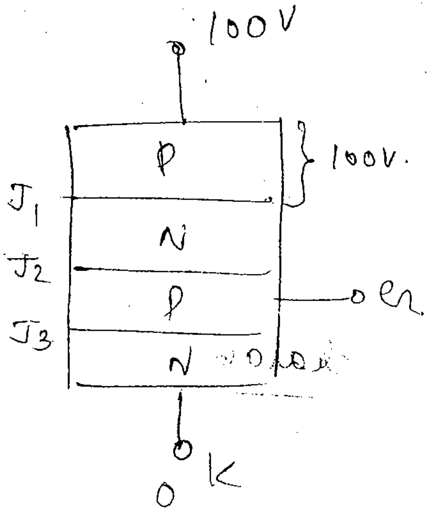
2) Reverse charac.

① Forward characteristic

- Required operation is happening here
- most Focus is here.
- Always we need SCR in Forward, we never operate in Reverse

⇒ Apply Forward V

- Anode high p Cathode



consider - Cathode = 0

- Anode = 100V

J_1 J_3 - F.B

J_2 - R.B

- 100V - distributed across 4 layers.
- I layer - 100V, II layer - defined by len - consider 70V, 3rd lay - 30V, N = 0 (Electrical Connection)

J_2 (N 70 - P30) = R.B

J_1 (P100V - N70) = F.B

J_3 (P30V - N0) = F.B

SCR TURNED 'ON' FORWARD CONDUCTION STATE

⇒ The voltage across supposed to zero!

⇒ Steady state voltage drop
⇒ Conduction voltage drop
⇒ Forward voltage drop
} Very less.

⇒ SCR is rated for 100A, If it is conducting, the ~~cur~~ scr current through the SCR will depends up on LOAD, LOAD CORRENT is passing through the SCR (Concern is it should not cross 100A, If it crosses the SCR will damage) (Current doesnot depends on Rating)

(Sir) " In Forward conduction state SCR is equivalent to CLOSED SWITCH, the voltage across the device is forward voltage drop or steady state voltage drop. The current through SCR is equal to load current.

Supply voltage available = 230 (1ϕ), 400V or 440 (3ϕ)

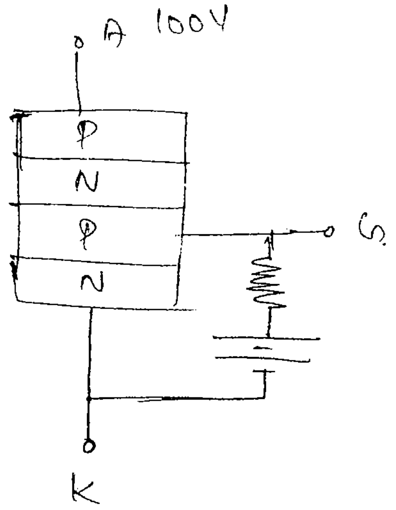
We need to get 1000V to turn ON, again we need a TRANSFORMER (undesirable requirement).

We should be able to turn ON practically if it require voltage other than the supply voltage

2) Gate triggering ***

- Method to turn ON SCR, avoiding transformer as in voltage triggering method.

- circuit diagram for gate triggering method.



- here also

1) Apply Forward voltage supply voltage (100V)

2) Voltage @ K = 0.

3) J_1 J_3 - F.B, $\boxed{J_2 - R.B}$, we need to cross J_2 junction

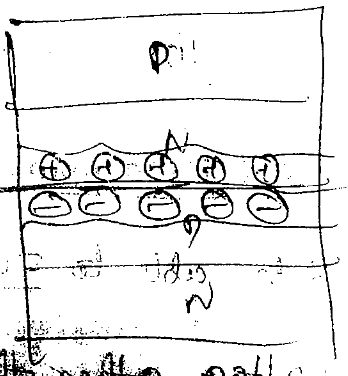
- Any R.B PN will have depletion layer.

- width of depletion layer more, Applied V↑
  less, Applied V↓

- Depletion layer - (depleted by the charge carriers)

they will have IMMOBILE IONS

{ P = -ve IONS
  N = +ve IONS } Signs



a Potential b[illegible]

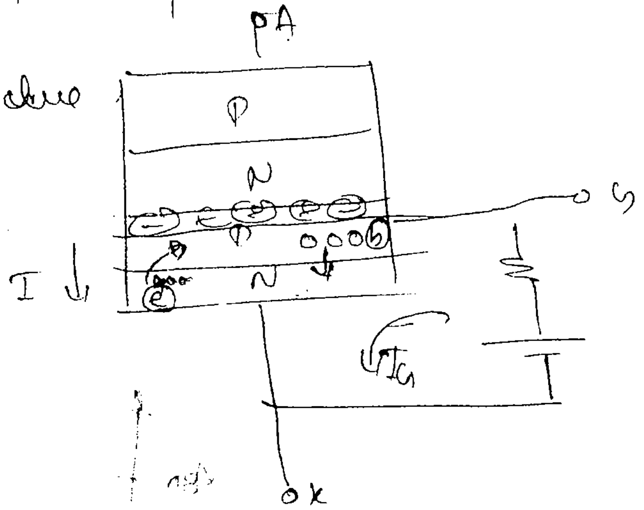
conduction is slow only [illegible] potential hill.

1) give the sufficient energy to charge carriers to cross potential hill

2) cut the potential barrier (width of depletion is decreased) with the existing energy we are able to cross the potential hill.

we are applying a dc potential at G.

current is happening due to movement of charge carriers in our desired direction



whenever holes are moving (Random direction) there is a chance to touch the ions in ⊖ IONS here Recombination takes place

Again ION → Atoms → No. of IONS decreased at the depletion layer → width of depletion layer decreased.

Q1) 4) A Forward voltage is applied across gate to cathode, terminals due to which a gate current flows The current is due to movement of charge carriers, widths of the depletion layer decreases due to Recombinations being taken place in the depl: layer.

the charge carriers are able to cross the junction with existing energy hence the device starts conduction!!

- After applying, gate trigger, graph changes.

here we took three currents i_{g1}, i_{g2}, i_{g3}

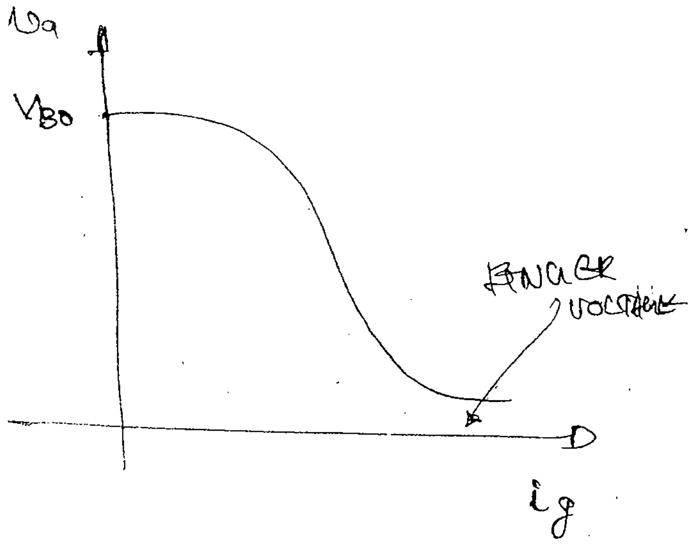
- i_{g1} shown in the graph shows, low voltage required for the SCR to turn ON, if No i_g, V_{BO} - is required

$\Rightarrow i_{g1} > i_{g2} > i_{g3}$

Conclusion

$\Rightarrow$ For higher values of gate current, the anode voltage required is LESS.

$\Rightarrow$ Anode w.r.t gate current characteristics



$i_g \rightarrow$ increases

$V_a \rightarrow$ Anode voltage decreases

$\rightarrow$ supplied voltage

$\Rightarrow i_g$ very high, '0V' Not possible to turn ON SCR

$\Rightarrow$ No supply, means close the switch, gate will NOT make any difference

FINGER VOLTAGE -

"If higher values of gate current is employed, then Anode voltage required to turn ON the SCR, decreases, A minimum forward voltage is required to TURN ON the SCR for any value of gate current and it is known as FINGER VOLTAGE.

suppose

	1Φ	3Φ
- supply voltage = 100V	= 230V	= 400
- Find ig required - trigger it - ig1	= ig2 TURN ON	= ig3. TURN ON

- 50V dc - supply => ig4 → TURN ON

Advantage of gate triggering

1) We are able to TURN ON SCR for a Range of voltage by applying the appropriate gate current

(Sn) "gate triggering allows the turn ON of SCR for a range of voltages by applying the appropriate gate currents"

3) THERMAL TRIGGERING

- As the name indicates, heat gives the required excitation for the charge carriers to cross J2, hence conduction starts.

- Applied F voltage J1 J3 - F.B
J2 - R.B

(Sn) "In this method SCR is heated up due to which energy levels of charge carriers increases, as a result they are able to cross the

... the barrier and make the conduction"

4) LIGHT TRIGGERING

LIGHT – requirement

– Intensity of the light should be high.

– Excitation is provided by light -> heat

Special app: LASCR	later

(8M) " An intensified light beam is focussed on SCR, which makes the charge carriers to be enabled as a result, they are able to cross the junction (J_2) and makes the conduction".

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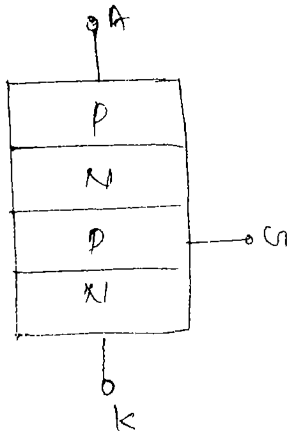
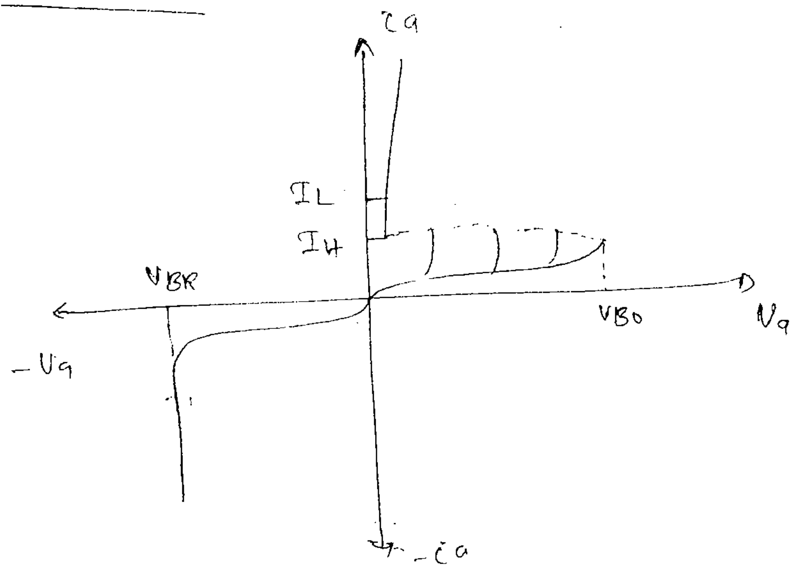
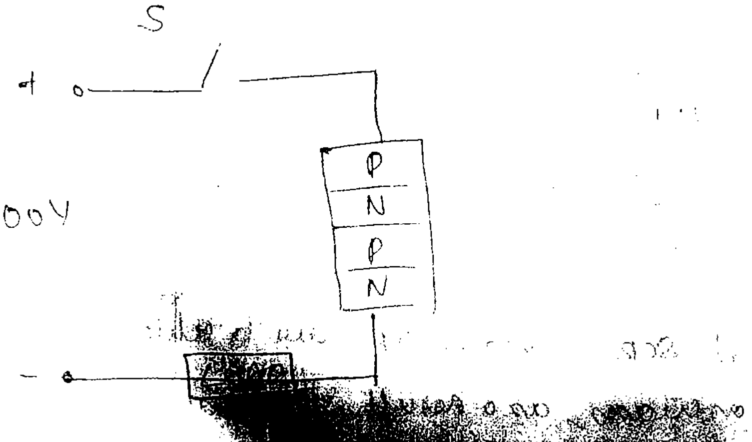
5) $\frac{dv}{dt}$ triggering ***







First differentiating this method from others

1) all discuss 1-4 are externally triggered mechanism

→ 2) here <u>INTERNALLY</u> mechanism.

- once applied F.V here SCR by its own will start the conduction.

- Applying F.V.

<u>Conduction procedure -</u>

→ S = OPEN, Voltage across the SCR = 0 = V_1

→ S = CLOSED, Voltage across the SCR ~~=100~~ = V_2 = 100

→ 0 → 100V ⇒ growth occurs.

here <u>dt = 1 ms</u> (Assume time taken from 0 - 100V).

→ F.V. applied J_1, J_2 - FB , $\boxed{J_3 - RB}$, thus R.B

junction & F.B junction offers <u>capacitance</u>

→ F.B Jn C = diffusion capacitance

R.B Jn C = transition capacitance

- generally <u>Junction capacitance</u> = <u>1N F = J_2</u>

- C → charges in " [illegible] time

⇒ $i = C\frac{dV}{dt}$ [capacitance ~~cur~~ cond, charging]

$$= 1\times10^{-6} \times \frac{100 - 0}{1\times10^{-3}}$$

*** $\boxed{i = 0.1A}$ ⟹ If this current is more than rated current ⟹ Conduction starts (width of depletion layer decreases, charge carriers cross the barrier)

⟹ Making this way TURN ON SCR is called $\frac{dv}{dt}$ triggering method.

(8M) "while applying the forward voltage sometimes SCR starts conduction. the junction capacitance subjects to rate of change of voltage ($\frac{dV}{dt}$) results in to a charging current ($I = C\frac{dV}{dt}$). If the value of the current is more than rated gate current of SCR then it starts conduction".

Not preferable why?

- control action is not here.
- It is not advised to turn ON this SCR.

$i = 0 \rightarrow$ Not possible

$i = 0.1\,A \rightarrow$ undesirable →

$i = 0.00001A \rightarrow$ desirable ---- to avoid $\frac{dv}{dt}$ triggering [illegible] value $\frac{dv}{dt}$ should be of lower value (protection

from uncontrolled conduction)

Due to lack of control action $\frac{dv}{dt}$ triggering is to be avoided. [illegible] is possible. by making lower value of $\frac{dv}{dt}$."

SCR TURN ON - PRECISE METHOD - GATE TRIGGERING

- $I_L, I_H \rightarrow$ definition of Anode current

$I_L \rightarrow$ Turn ON process (F.B → F.C)

$I_H \rightarrow$ Turn OFF process. (F.C → F.B)

= How much time gate signal required to apply?

till Anode curnt = I_L.

(Sm)

Latching current (I_L)

- "It is Associated with turn ON process"
- "It is the minimum value of current above which Anode current rises for the reliable turn ON of the SCR".

~~Hot~~ = "Gate signal should be applied, along with SCR till Anode current rises above the latching current".

Holding current

- "It is Associated with turnOFF process"
- "It is the minimum value of current below which Anode [illegible] turn OFF of the SCR"

- "It is useful to apply the reverse voltage for the ~~complete the~~ completion of turn OFF process"

Conclusion

$I_L > I_H$ (always) *** [IESQ]

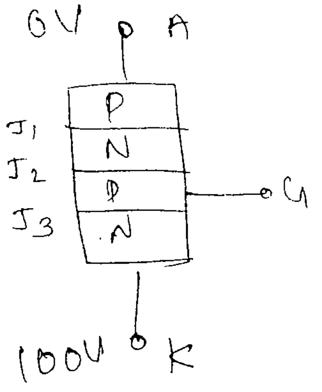
Empirical Formula.

$$\boxed{\frac{I_L}{I_H} = 2.5 \text{ to } 3}$$

(Sr) " Always latching current is more than holding current"

Reverse characteristics

- Cathode is more than Anode potential



$J_1 \ J_3$ - R.B

J_2 - F.B

- Reverse leakage current (current at NC state) at Reverse blocking state (Non conducting state)

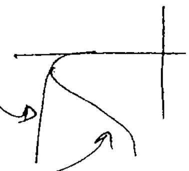
- Reverse conduction occurs = Reverse Break over Voltage
= V_{BR}

(Sr) " In Reverse Blocking state $J_1 \ J_3$ are R.B but J_2 F.B"

"The amount of R.V required to allow the conduction in Reverse direction is known as Reverse break over voltage".

Consider

- No load - only - applied voltage
- If there is load - the SCR chara bends



- (50-60V) voltage drop across SCR, for an 100V power loss↑, we cant tollerate, "why are we not using SCR for Reverse conduction Mode"

(Sn) "The Reverse voltage drop and power loss are more, so hence it is not prefereable to utilize, as Reverse conduction state".

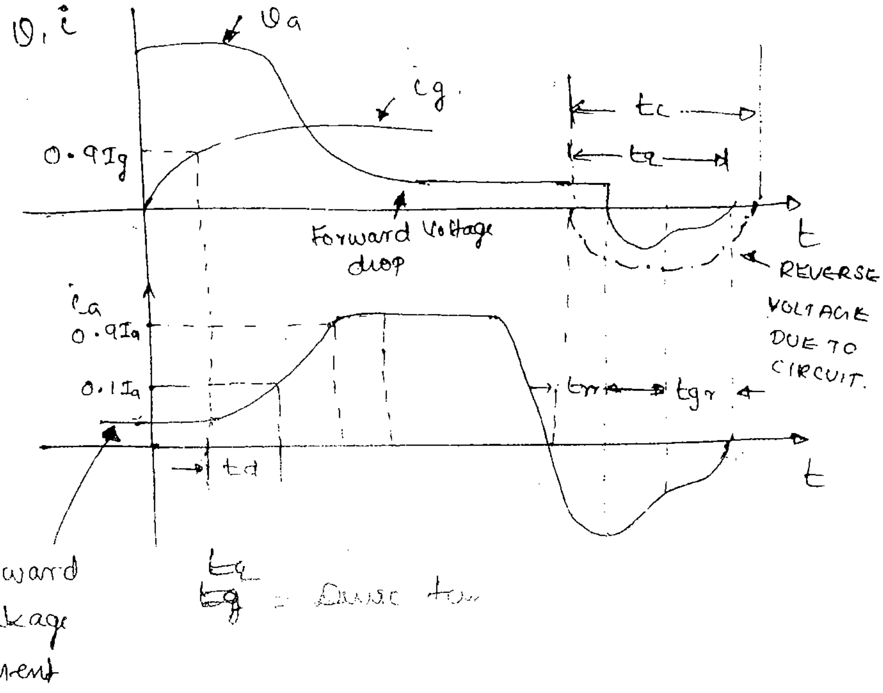
DYNAMIC OR SWITCHING CHARACTERESTICS OF SCR

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

t_d = delay time
$= 0.9 I_g - 0.I_a$

t_r = Rise time
$= 0.1 I_a - 0.9 I_a$

t_s = spread time
$= 0.9 I_a - I_a$



⇒ Static chara – Never mentioned time

⇒ Dynamic → how much time – voltage decreases

– current increases.

→ here everything w.r.t time

⇒ Two parts
- TURN ON
- TURN OFF CHAR

Consider

1) Forward Blocking state

SCR
V = Applied V.
I = leakage curr

TURNON → triggering
- ~~Voltage?~~ voltage?
- current? ✓

⇓

– Voltage CAUSE, current = EFFECT **.

- Gate voltage applied, I_a ↑ (takes time)

- Gate Response time — current taken to reach I_g

– No validity in turnon process of SCR, hence avoided in turn on time

- TURN ON → depends on, will after, we cannot start from the instant, when we apply gate voltage divided Turn ON – delay time (~~10%~~ 90% ia → ~~90%~~ 10%)

– rise time (10% ia → 90%)

(SW) "TURN ON TIME: It is the time taken by the SCR, from the instant of 90% ig to steady state value of anode current". (load current)

SCR as CHARGE CONTROLLED DEVICE

– charge carriers should be allowed to junction J2 to depletion layer to start the conduction of SCR

– charge required to turn on the SCR

– suppose $Q = I \times t$

$1\mu C = 1A \times 1\mu s$ ||ly $2A, 0.5\mu s$

(injected) ↑ required $5A, 0.2\mu s$

$$\boxed{Q = \uparrow I \times t \downarrow}$$

t = turn ON time of SCR. (should not be more than rated current of SCR)

(Q) ⇒ higher value of current, I will go reduces the anode voltage of J junction to break down

(SW) "SCR is considered to be charge controlled device. by employing higher values of gate current, turn ON time can be decreased hence the device becomes faster".

[illegible] vs conventional * * *

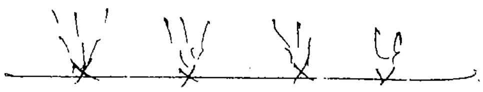
- Turn ON – Formation of local hot spots * * *

- how? influences on process?

Consider

- during turn ON process.

- cathode surface



X → areas subjected to high temp?

⇓

chance of more concentration of charge carriers compared to other area (current density ↑, power loss ↑, heat generated ↑, temperature ↑ compared to others) [NON UNIFORM CURRENT DISTRIBUTION OVER CATHODE]

- NON UNIFORM Distribution -

1) Spreading of charge carriers

- Requires time = 1 μs.

2) Rate of Rise of Anode current

Rise of Anode curr – 100 A rated } → takes 100 μs

load curr – 100 A

- Turn ON static -

- 1μs - Spreading out of charge carriers.

- 100μs - to reach rated end current

- See another 1μs - Current in device

- 1A → Linear variation

2-3A → Non linear variation

✓ If the no of carriers are LESS → CHANCE OF UNIFORM CHARGE CARRIER SPREADING.

1μs < 100μs ✓

⟹ when spreading time > rated current time ✗

100μs > 1μs ✗

⟹ Spreading is NOT COMPLETED.

- FLOODING OF CHARGE CARRIERS

- HOT SPOT FORMATION

∴ hotspot formation → depends on spreading time of charge carriers. (t_1)

Rise of anode current → depends on $\frac{di}{dt}$

✓ $\boxed{\frac{di}{dt}\downarrow}$ $t_2\uparrow$ In our control

Our requirement $t_1 < t_2 \left(\frac{di}{dt}\downarrow\right)$

CONCLUSION

$\frac{di}{dt}$ ~~should be less to~~ m

Sri

1) " during the turn ON process LOCAL HOT SPOT ~~will be~~ would be formed if $\frac{di}{dt}$ is more than the spreading velocity of charge carriers. The local hot spot ~~should~~ is be formed due to the NON-~~even~~ UNIFORM distribution of charge carriers over the cathode surface". to avoid the formation of local hot spot, the number of carriers at the time of ~~turn o~~ spreading ~~of carriers~~ process should be of lower value, it will facilitate uniform spreading of the charge carriers. t~~o avoid~~

Sri

Note:

** 2) " To avoid the formation of local hot spot rate of rise of anode current $\left(\frac{di}{dt}\right)$ should be ~~more~~ LESS than spreading velocity of charge carriers" and practically the value should be lower value.

Q) How to make $\frac{di}{dt}$ lower ?

Later in SCR protection

Practical value of $\frac{dv}{dt}$ should be lower to make controlled conduction

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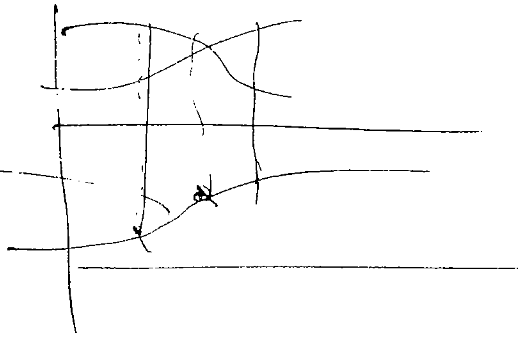
5Q) In which interval of the charac (Reverse) local hot spot More?

- when the power loss more



- In the Rise time interval
- power loss high (V×I high)

Sr) a local hot spot dominantly occurs during the rise time interval as the power loss is more in that interval.

IQ) hot spot problem and effect?

1) - degrade the performance of device
2) - life span will decrease. (useful life span)

H.W local oscillator make Notes. ***

Sr) Local hot spot may effect the device, in the following manner

- power loss increase.
- degrade the performance of the device.
- useful life span of the device decreases.

2) TURN-OFF PROCESS:

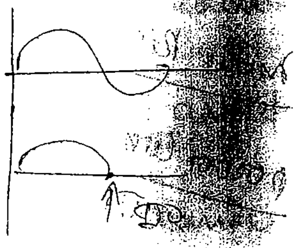
- Turn-OFF → current = 0 (SCR)

- how to bring current = 0?

- It is Not device brings current = 0

- It is the Responsibility of a circuit to bring the current = 0.

eg:-



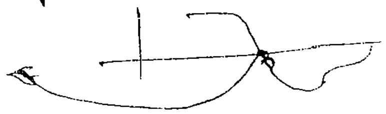
(Nature of AC).

- Consider -

  - by circuit mechanism I = 0

- See the chena - graph -

1) = Ia = 0



= Still charge carriers possess = Energy

↑ ↓

F.V → with this energy conduction can be again started.

2) Remove the energy ~~possed~~ had by the charge carrier.

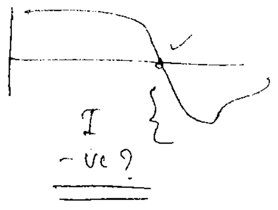
(trap the energy ~~carriers~~ from charge carriers)

Reducing Energy

1) ⇒ Removing the carrier

2) ⇒ Recombination (Reduces energy of charge carriers)

Obt

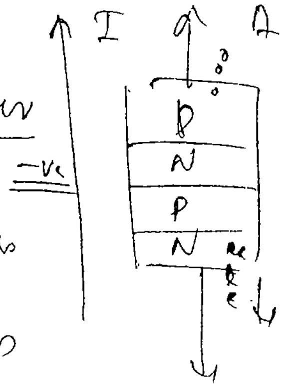


— This curr is not, Reverse conduction curr, It is not possible to maintain or sustain the conduction, It is happening only for a ~~a~~ momentary / transient time. after some time I will come to zero.

2) Why I goes -ve ?

a) — Removal carriers — External layer

— ~~Recombination~~ = ~~Internal layer~~



— While Removing the carrier curr goes to -ve side

b) Inner layer — Recombination

— Reverse voltage applied.

→ Recombination curr,

→ also helpful in Removing the carrier by attracting the carriers.

⇒ Why we apply Reverse voltage ✓

↓

SCR Regains Blocking state

↓

No conduction without TRIGGER

(311)

"The ~~following~~ conditions are to be satisfied for the turn OFF of the SCR"

1) Reduce the Anode current below the holding current.

2) Apply the Reverse voltage for sufficient duration to remove the energy possessed by the charge carriers.

- a) "The reverse voltage is useful to remove the carriers from external layer
- b) again Reverse Voltage helps in encouraging Recombination in Inner layer

"
- During trr = Reverse Recovery time, External layers will be recovered
- during gate recovery time = tg, Inner layers will be recovered
- At the end of turn OFF process SCR should Regain Blocking State."

Q) How to generate Reverse voltage ? (Commutation Circuit)

- I → Inductor — $L\frac{di}{dt} = V$
- must load = Inductive

⟹ If load = Not Inductance. } NO guarantee

= Mathematically model SCR → chance to have SELF INDUCTANCE

***

→ In practical circuit, we have special circuit, to apply the Reverse voltage, which will generate the Reverse Voltage and turn OFF SCR

(Always SCR will be with this circuit).

(Soln) " A special circuit will be employed to apply the reverse voltage during the turn OFF process and it will be called as commutation circuit "

Q) How much time we should apply Reverse Voltage ?

- See the char's graph.

- $t_c > t_q$

Q) If $t_c < t_q$ what happens ?

- Required - 10ms
- Applied - 5ms

- At the end '5ms' again F.V comes across the SCR again without trigger SCR starts to conduction

(commutation failure)

t_q = DEVICE TURNOFF TIME

" It is the time requird by the device to complete its turn OFF process

t_c CIRCUIT TURN OFF TIME,

" ~~It is~~ the time ~~requird~~ given by the circuit ~~to complete~~ for SCR to complete the turn OFF process

⇒ always $t_c > t_q$

⇒ If $t_c < t_q$ → Then the device will be failed in COMMUTATION, looses the control action.

*** 1) INVERTED GRADE SCRs

- Devices with faster turnOFF time $[t_q < 50\mu s]$ ~~are~~ known as INVERTED GRADE SCRs

- Applications :- 1) Inverters
  2) Choppers

2) CONVERTED GRADE SCRs

- Devices with slower turnOFF time $[t_q > 50$ known as converted grade SCRs

- Applications :- 1) Phase controlled rectifiers
  2) AC voltage controllers

3-5-

6-8-

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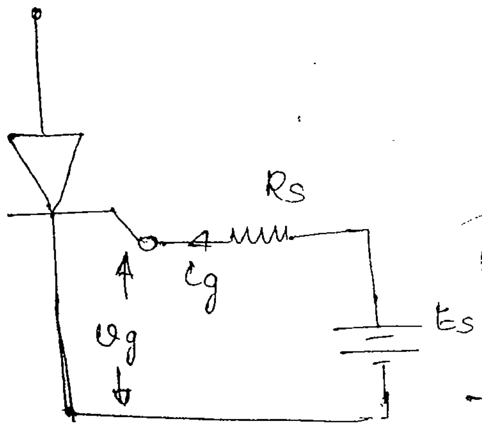
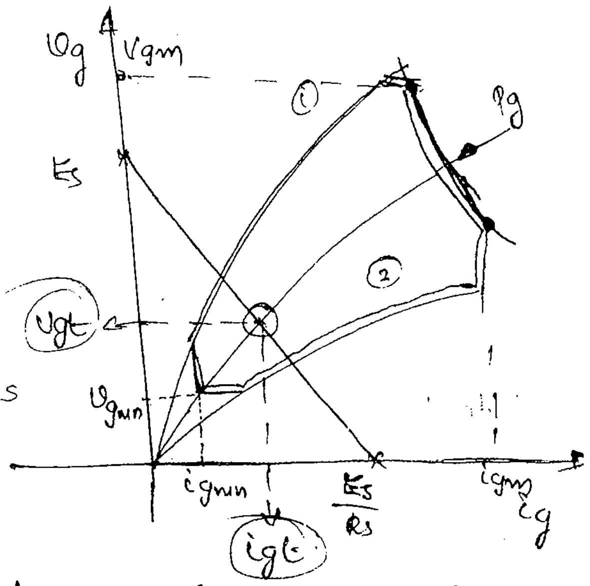
GATE ~~CHARACTERISTICS~~ CHARACTERISTICS OF SCR.





"gate characteristic of an SCR, are forward characteristics of p-n junction"

⇒ ② has more dopping concentration

Y – axis – current –

x – axis – voltage – here V is the cause – independent parameter

Char for some ckts, changed V_g and i_g axis.

⇒ V_{gm} = maximum voltage.

i_{gm} = maximum current

⇒ $P_g = V_g I_g$ [Rectangular hyperbola]

⇒ V_{gmn} = minimum voltage

i_{gmn} = minimum current.

- double lined – to show the operating point?

- Why minimum value?

  = Electromagnetic interference

  - A voltage is generated of = trigger voltage

  - Conduction starts.

  - To avoid noise signal, also SCR will not start by unstable (MAL TRIGGERING)

(8m) - ~~hence~~

"The minimum value restriction over the positioning of the operating point is to avoid MAL TRIGGERING due to noise signal".

If ~~i_g~~ = 0 OPERATING POINT (V_{gt}, I_{gt})

- $i_g = 0$, E_s on Y axis $= V_g$

- $V_g = 0$, $\frac{E_s}{R} = I_g$.

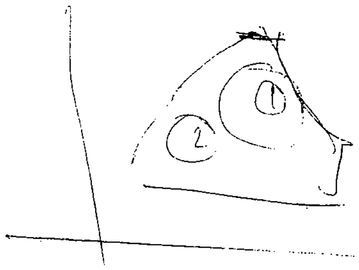
V_{gt} = trigger voltage = E_s

i_{gt} = trigger current = $\frac{E_s}{R}$

- "Can be obtained by the intersection of load line and gate to cathode characteristics.

Area preferable

- SCR should not get damaged.



- We select ①

  - operating current is more.

(Ans) "The operating point should be so selected in the given region so that the resultant gate current are higher in magnitude, It causes reduction in turn ON time and hence the device becomes faster".

KVL form fig ①

$E_s = V_g + i_g R_s.$

$P_g = V_g i_g.$

⇒ "Slope of the gate-cathode characteristic is equal to V_g/i_g"

⇒ "slope of load line = R_s"

PROTECTION OF SCR

- We will list out abnormalities to give protection.

1. over voltage protection - VARISTOR, VARIBALE CAPACITOR

2. over-current protection - CIRCUIT BREAKER, FAST ACTING CURRENT LIMITING FUSE [FACLF]

3. Thermal protection. - HEAT SINKS (ALUMINIUM).

(***)
4. $\frac{dv}{dt}$ protection - SERIES RC COMBINATION (SNUBBER CKT)

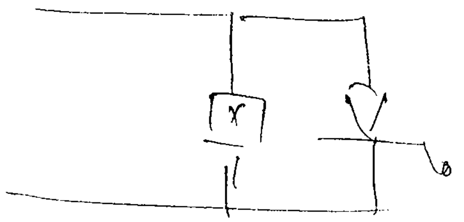
(***)
5. $\frac{di}{dt}$ protection -

1) high voltage protection

Ans:
- cause
- characteristic

- $V = L\frac{di}{dt} = \frac{1H}{1A} \xrightarrow{\text{com}}$ (1μs) suddenly turn off

$V = 1KV$



VARIABLE C'

$V\uparrow - Z\downarrow \begin{cases} R\downarrow \\ X_C\downarrow \end{cases} \Rightarrow C\uparrow \quad \&. \quad R\downarrow$

$V\downarrow - Z\uparrow \begin{cases} R\uparrow \\ X_C\uparrow \end{cases} \Rightarrow C\downarrow \quad \&. \quad R\uparrow$

VARISTOR

2). over-current protection

- Fuse - Fast acting - Semi conductor
- Rating ↑ CB.

- Normal fuse will act lately.

*** Over load – short circuit

↑ + ON-OFF PROP!　　↑

~~FUSE~~CB　　FUSE

- Fusing time (fuse) $\propto$ amount of current passing through it

$\propto I^2t$ – (Energy loss).

- R – constant

$I\uparrow$, time $\downarrow$, ⇒ energy dissipation of fuse = CONSTANT

$$\underbrace{\text{Ener}(P)}_{\text{constant}} \propto I^2 \boxed{t} \longrightarrow \text{means}$$

$$P \propto I^2\uparrow \; (t\downarrow) \quad t = \text{fusing time}$$

- Fault $(I\uparrow)$ $\boxed{t < \text{below CB operation}}$

↑ – CB need

t_{CB} { 1) Comman Relay
2) CB operate

$$t < t_{CB}$$

⇓

FUSE is GOOD –

- CB tripped – Normal fault – take a chance
- Fuse blown – do not take chance – BIG FAULT –

3) Thermal protection

- Heat sinks.
- material preferable – Aluminium.

4) $\frac{dv}{dt}$ protection

$\frac{dv}{dt}$ = Ratio ↓ - (low)

$\boxed{1)\ dt\uparrow \quad 2)\ dv\downarrow} \Rightarrow \boxed{\frac{dv}{dt}\downarrow}$ = Transient current is low also SCR = 2t. will avoid mal triggering.

dv = change in voltage.

Initially Assume V across SCR $V_1 = 0$

supply $V_2 = V_s$

- thus dv = Vs = supply voltage

- The dv ~~∝~~ supply voltage
- dv↓ = (supply voltage ↓) ∝

only one way

(dt↑) ⇒ increasing the denominator.

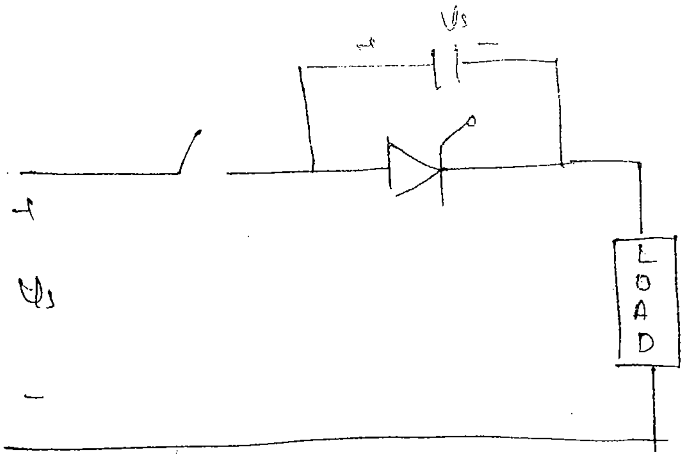
How to dt↑?

- make time 't' more to go from 0 → Vs

- we need a device, opposes the change in voltage

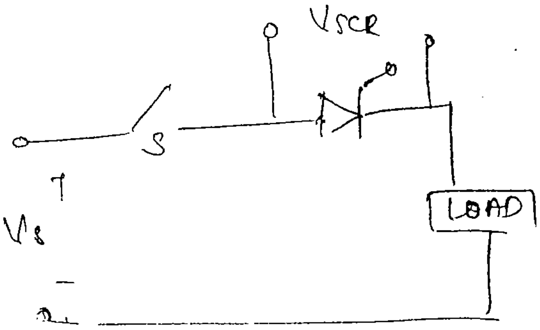
- "capacitor"

- See the diagrams



Two cases

1) No capacitor



$\Rightarrow V_s = 0$, S open.

$V_{SCR} = 0$

$\Rightarrow V_s = V_s$., S ~~closed~~ one

$V_{SCR} = V_s$ $(0 - V_s)$ = time taken is 't_1'

2) Case with capacitor

$\Rightarrow V_c = 0$, S , open.

$V_{SCR} = 0$

$\Rightarrow V_s = 0$, initially S, closed

$V_{SCR} = 0$.

$\Rightarrow$ C ↑ final voltage $V_c = V_s$ ⇓ $V_{SCR} = V_s$ } t_2 time $(0 - V_s)$

$\boxed{t_2 > t_1}$

- time is more with capacitor.

Problem:

- During discharging, SCR already conducting

⇒ Load current + discharge current = Thyristor current

⇒ chance to problem with SCR damage

~~$\frac{dV}{dt}$~~ 5) $\frac{di}{dt}$ protection

- Local hot spot formation

- $\frac{di}{dt}\downarrow$ low — $di\downarrow$ — di – Not preferable
→ $dt\uparrow$ → $dt\uparrow$ ✓

- Blocking state SCR → i_1 = leakage current ≈ 0

Conducting state → $i_2 = i_l$ load

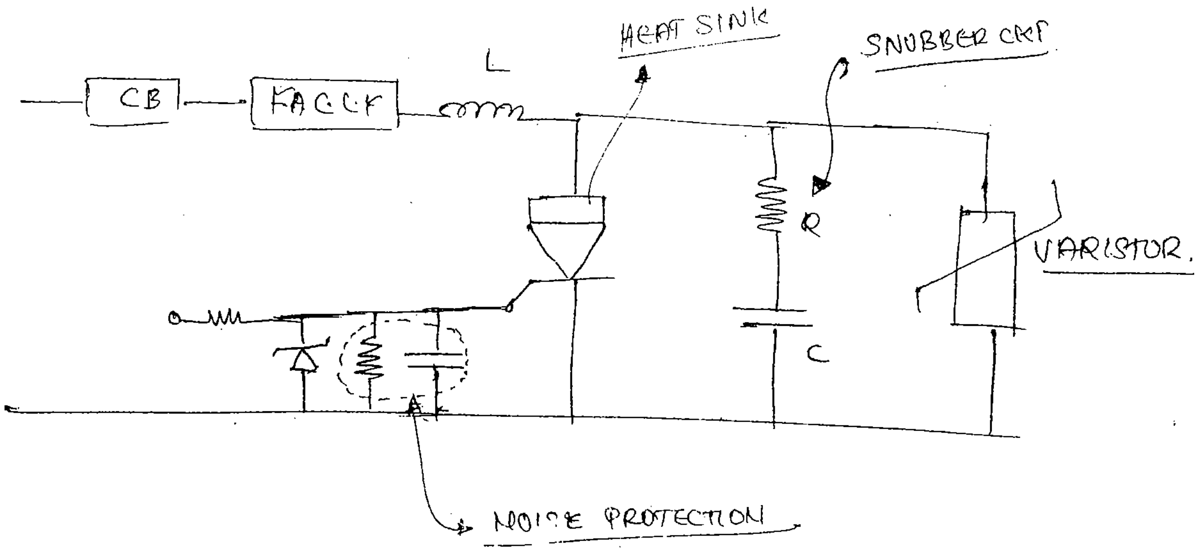
$$di = i_2 - i_1 = i_l$$

$i_l\downarrow$ → Not permitted

***

- $dt\downarrow$ ✓

- circuit → SERIES INDUCTOR



- heat sink - mechanically mounted.

(Gr) Resistor

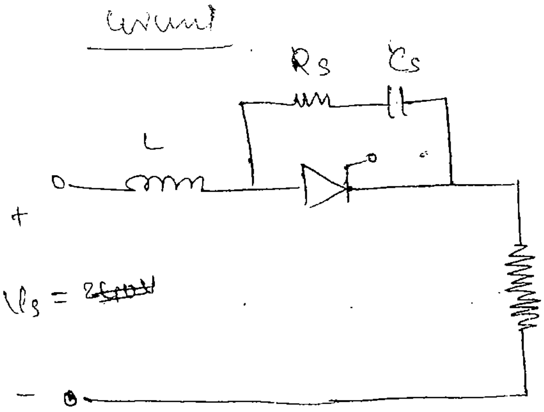
the Resistance is connected ~~across~~ across the gate to cathode terminal for NOISE PROTECTION, it increases the NOISE IMMUNITY for the SCR.

DESIGN OF SNUBBER CIRCUIT

Q) A thyristor is placed between a constant dc voltage source of 240V. and load Resistor R_L. The specified limits of $\frac{di}{dt}$ and $\frac{dv}{dt}$ of SCR are, 60 A/μs and 300 V/μs respectively determine the Snubber circuit parameters? along with $\frac{di}{dt}$ inductor. take damping ratio as $\delta = 0.5$.

Solution

Circuit



– consider dc supply given

– Initial L = S·C

C = O·C Vc = 0

$\underline{i = 0}$

SHD

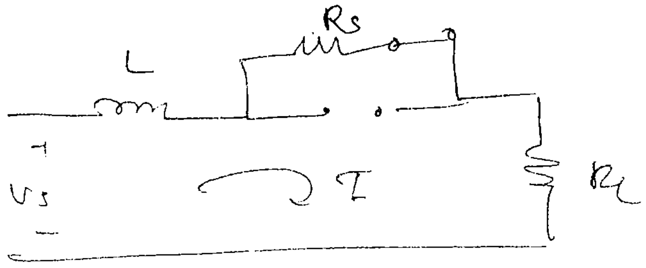
– 0^+ – i ≠ 0 =

(Vc ≠ 0 = 0) ASSUMPTION

↑ Neglected.

– Approximated Analysis.

– Considering SCR – O·C (FACT) — (Rs <<<< (||R) ser R.)



KVL ⇒ $L\frac{di}{dt} + (R_s+R_L)\,i = V_s.$

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

**

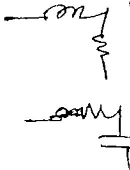
i(t) = direct answer (imp)

– Applying L.T

$$\left[S\,I(s) - 0\right] + \frac{R_s+R_L}{L}\,I(s) = \frac{V_s}{Ls}$$

$$I(s)\cdot\left[S + \frac{R_s+R_L}{L}\right] = \frac{V_s}{SL}$$

$$I(s) = \frac{V_s}{L} \cdot \frac{1}{S} * \frac{1}{S+\frac{R_s+R_L}{L}}$$



$$V/R\ (1-e^{-t/\tau})$$

$$V/R\ e^{-t/R}$$

$$= \frac{V_s}{SL\left(S+\frac{R_s+R_L}{L}\right)}$$

$$= \left[\frac{1}{S} - \frac{1}{S+\frac{R_s+R_L}{L}}\right] \frac{V_s}{L} \times \frac{L}{R_s+R_L}$$

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

t/τ

$$\tau = \frac{L}{R_s+R_L}$$

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

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

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

$$\boxed{e^{0} = 1}$$

substitute $t=0$

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

$$\boxed{L = \frac{V_s}{di/dt}} \quad ①$$

V (aux sen) = V (Resistan)

$$V = I R_s.$$

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

$$\boxed{R_s = \frac{dv/dt}{di/dt}} \quad ②$$

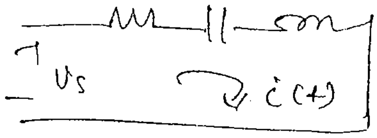
Assumed capacitor back to elevator / circuit

- correlation b/w R·L·C $\left(R = \sqrt{L/C} \right)$ – chara – fxn line

ui formula

&

- "Imagine series RLC circuit energised by DC supply, solution would be as follows":



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

$$\cancel{L\,d^2/dt^2} \quad L\frac{di^2}{dt^2} + R\frac{di}{dt} + \frac{1}{C}i = 0.$$

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

$\Updownarrow$ compare

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

$$s^2 + \underset{\cancel{2\delta w_n =}}{\frac{R}{L}}s + \frac{1}{LC} = 0.$$

$$2\delta w_n = R/L.$$

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

$$\delta = \frac{R}{L \cdot 2w_n} = \frac{R}{2L\cdot\sqrt{LC}} =$$

We need R

$$R_s = 2 \cdot \frac{L}{\sqrt{LC}}$$

R $\boxed{R_s = 2\delta\sqrt{\frac{L}{C}}}$ ✓

③

Solution

- H, F, Ω
(Scientist Name). $\Leftarrow$

Ⓐ $v = L\frac{di}{dt} \Rightarrow L = \frac{V\,S}{A} = H$

Ⓐ $i = C\frac{dv}{dt} \Rightarrow C = \frac{A \cdot S}{V} = F$

Ⓐ $R = V/I \Rightarrow R = \frac{V}{A} = \Omega.$

UPSC Interview

1) $R = \sqrt{\overset{H}{L}/\underset{\mu F}{C}}$

Ω $\sqrt{H/F} = \Omega$?

2) $\tau = \frac{L}{R}.$ 3) $\tau = RC$

$S = H/\Omega.$ $S = \Omega \cdot F$

4) $F = \frac{1}{2\pi\sqrt{LC}}$, $\frac{1}{S} = \frac{1}{\sqrt{H \cdot F}}$

5) $\sqrt{L/C} = \sqrt{H/F}$

✓ $= \sqrt{\frac{V S/A}{A \cdot S/V}}$

$= \sqrt{\frac{V^2}{A^2}} = V/A = \Omega$ ✓

Numerical data given

$V_s = 240V$, $\frac{di}{dt} = 60\,A/\mu s$, $\frac{dv}{dt} = 300V/\mu s$

$\delta = 0.5$

$L = \frac{240}{60} = \frac{V_s}{di/dt} = \boxed{4H = L}$ ✓

①

$R_s = \frac{dv/dt}{di/dt} = \frac{300V}{60A} = \boxed{5\Omega = R_s}$ ✓

$R_s = 2\delta\sqrt{\frac{L}{C}} \Rightarrow \frac{R_s^2}{4\delta^2 L} = \frac{1}{C} \Rightarrow \boxed{C = 0.16\mu F}$ ✓

⇒ Designing (good Design for better Operation)

Q1) $R_s = 5\Omega$ critical value of $R = i =$ SCR critical. (2+ mark)

R_s – greater } For more better operation
– lesser }

① $R_s = 3\Omega$, $R_s = 8\Omega$

⇒ $R_s = 3\Omega$, i through SCR ↑, dangerous op

⇒ $R_s = 8\Omega$ ✓ i (say

Q2) $\boxed{C \rightarrow C\downarrow = \text{LESS}}$ – τ = time const = ↑

C↑ – SCR = SLOW? ✓

– Protection < Protection ↑.
Performance / Response ↑

C↓ – energy loss (during discharging)

Conclusion

time constant = RC = constant = $\boxed{R\uparrow C\downarrow}$ ✓

Q3) L = ?

– First design Rande

$\boxed{L = 2 l \sqrt{4c}}$ ✓

(Sol) 4 For a better operation of SCR, Resistance can be increased and capacitance can be decreased. Substitute these values in the formula and find out L, $R_s = 2\delta\sqrt{L/C}$ 4

4 It has to seen time constant will NOT change much due to the variation of resistance and capacitance 4.

$$\therefore \underline{R_s = 8\Omega, \; C = 0.1\mu F}, \; \underbrace{R_s = 2\delta\sqrt{L/C}} = 2\times 0.5\sqrt{\frac{L}{0.1\mu F}}$$

$$\Downarrow$$

$$\boxed{L = 6.4\mu H}$$

Design of snubber circuit is over.

Capacitor enabled

— Second order (LC) equation

$R_s = 5\Omega$, we get $= 4.8\Omega$

we got

— For designing $R_s = 8\Omega$ = 'doing the simple analysis'

any way we adjust the value for better performance.

HEATING, COOLING CIRCUIT OF SCR.

— consider, SCR conducting = Powerloss = heat generated.

— This heat should be cooled for better performance of SCR.

- Maximum heat = count @ Junctions

  = most heat generated.

- casing of the device :- heat will flown from junction to casing → SCR mounted on sink → sink takes heat → 1) Natural - cooling.

  2) Forced cooling - fans, A/C, coolant (water - high rate)

  → depends on ratings of the device.

  ⇓

  surrounding medium (ambient)

"whenever SCR carries the current it produces the heat energy. The charge ~~char~~ carriers, loose some of the energy while they are passing through layers as well as junctions. Most of the heat energy will be generated at the junction. Hence junction will be at high temperature. heat flows from junction to surrounding ~~ambient~~ medium in the following sequence.

Junction → casing → sink → Ambient (medium)

Thermal parameters

— Temperature at different ~~parameters~~ areas.

— Equivalent electrical circuit for thermal application.

Thermal	Electrical
1. Heat energy (J).	1. charge (C)
2. temperature difference (°C)	2. potential difference (V)
3. Rate of heat transfer (or) thermal power (J/s (or) W).	3. Electric current (A.) (Rate of charge transfer)
4. Thermal Resistance. **Unit** = (2/3) = (°C/W)	4. ~~Resis~~ Electrical Resistance (V/A) (opposing). ②/③

— Not equal, just equivalent terms, trying to correlate.

Rate of heat transfer = SAME, CONSTANT

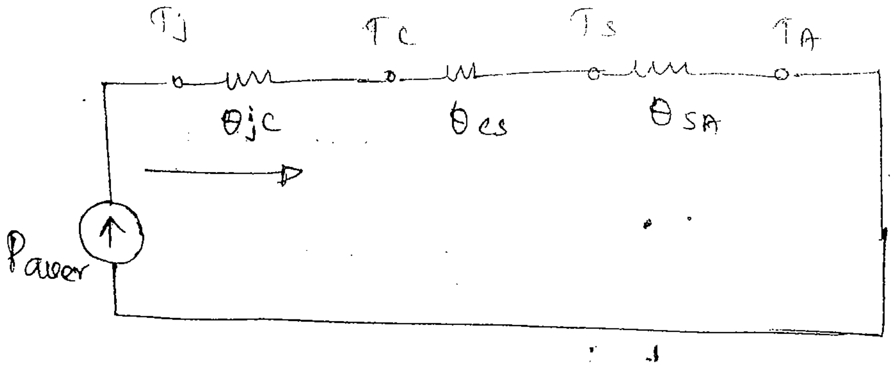
= CURREN, SAME AND CONST

THERMAL CIRUC = SERIES CIRCUIT ELECTRICAL

Ⓢⓞⓛ “In the given thermal application, Rate of heat transfer is same and constant. It can be represented as series electrical circuit”

— Nodes = 4. (Jn., casing, sink, Ambient)

= representing temperature.



- direction given, is the direction of the thermal flow.

Justification by Electrical Analogy

- $T_j > T_c > T_s > T_A$ (Voltage)
- T_j = Voltage ↑, temperature ↑ ✓
- current is correct

Thermal power / Rate of heat transfer (Paverage)

$$\boxed{P_{av} = \frac{T_j - T_c}{\theta_{jc}} = \frac{T_c - T_s}{\theta_{cs}} = \frac{T_s - T_A}{\theta_{SA}}}$$

$$\boxed{P_{avg} = \frac{T_j - T_A}{\theta_{jc} + \theta_{cs} + \theta_{SA}}}$$

$$\boxed{\begin{aligned} T_s &= T_c - P_{av}\cdot\theta_{cs} \\ &= T_A + P_{av}\cdot\theta_{SA} \end{aligned}}$$

lly for others.

Missed points   09/02/14

- θ_{jc} value depends on the material and method by which SCR is prepared.
- θ_{cs} value depends on the method of mounting and contact area with the heat sink.
- θ_{sA} value depends on the method of cooling and type of coolant employed in the cooling circuit.

SERIES, PARALLEL OPERATION OF SCR.

- Series operation of SCR is required for higher Blocking voltage capacity.
- Parallel operation of SCR is required to increase the current carrying capacity.

1) STRING EFFICIENCY η_s

$$\underset{\text{(SERIES)}}{\eta_s} = \frac{\text{Actual Voltage rating of the string}}{n_s \times \text{Actual Voltage } \cancel{\text{of SCR}} \text{ rating of SCR}}$$

$$\underset{\text{(Parallel)}}{\eta_p} = \frac{\text{Actual current rating of the string}}{n_p \times \text{actual current rating of SC}}$$

- Always $\eta_s < 1$

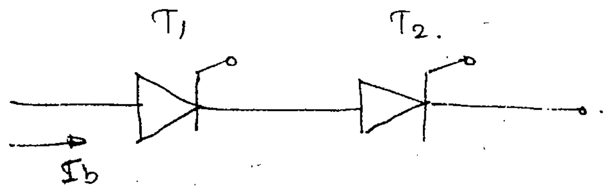
2) DERATING FACTOR (DRF)

$$= 1 - \eta_s$$

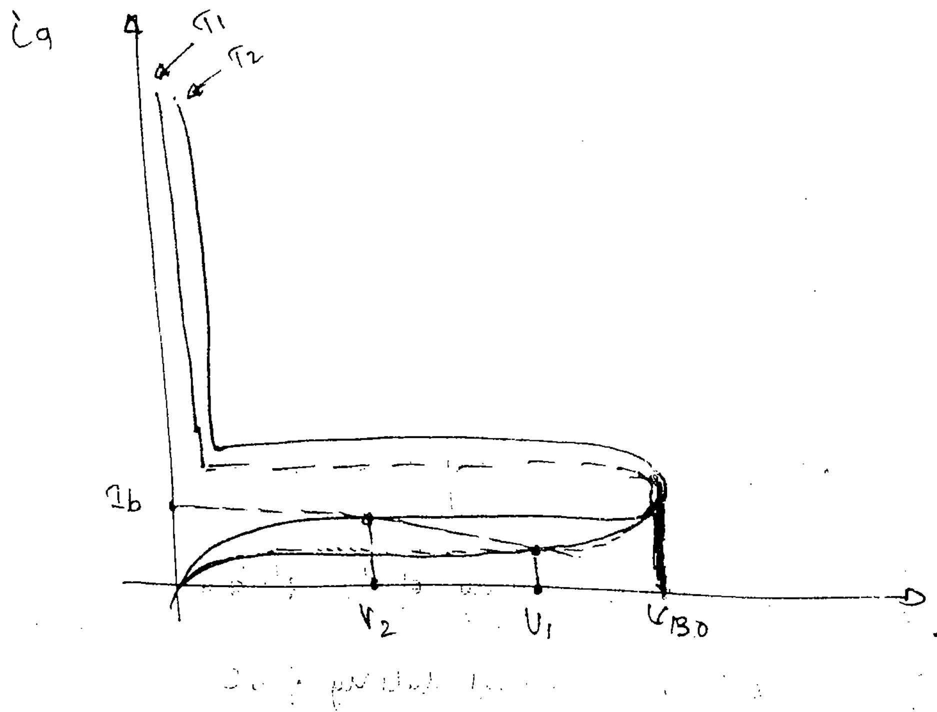
$$= 1 - \text{string efficiency.}$$

- "It is a measure of rating that is not useful for the operation of the system".

I) SERIES OPERATION OF SCR.



i) STATIC CHARA



- T_1, T_2 Rated for same V_{BO} But $V_1 > V_2$, T_1 Blocking V_1 and T_2 Blocking V_2 at I_b.

- Total Voltage blocked (practical) $= V_1 + V_2$.

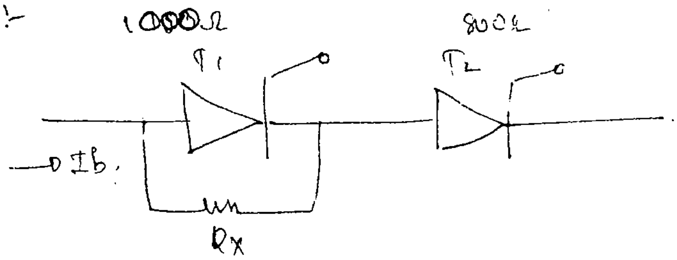
- String efficiency $\eta_s = \frac{V_1 + V_2}{2V_1} < 1$

⊛ • The difference in Static characteristics results as to unequal voltage distribution among series connected SCR.

⊛ • The unequal voltage distribution among the SCR. is because of the unequal leakage resistances offered by the SCR.

⊛ • If the SCR is having less leakage current rating, then it will block more voltage.

eg:-



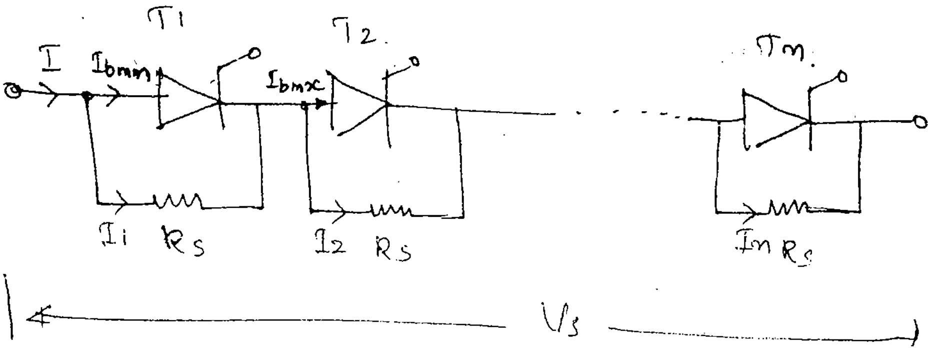
$$R_{eq}: = \frac{1}{R_x} + \frac{1}{100} = \frac{8}{700}$$

STATIC EQUALLISING RESISTOR

- To Approximately equalise the static properties

It is required to connect only one value of resistance across each and every SCR and is known as

STATIC EQUALLISING RESISTOR



$I = I_1 + I_{bmn}$.

$I = I_2 + I_{bmx}$.

Ibmn = Ib minimum First
all other = $\underline{\underline{I_{bmx}}}$

· **Deriving Rs Formula** (Rs ⇒ Static equallising Resistor)

⊛ · **Assumption**

1) Two groups of SCR

- 1st group = 1 SCR
- 2nd group = n-1 SCR.

⊛ 2). All SCR is having same current flowing through it except FIRST ONE

→ Vs = Total supply voltage = String voltage

$$V_s = I_1 R_s + I_2 R_s (n-1)$$

$$= I_1 \cdot R_s + (n-1) (\underline{\underline{I}} - I_{bmx}) (\cancel{n-1}) R_s$$

$$= I_1 R_s + (n-1) (I_1 + I_{bmn} - I_{bmx}) R_s$$

$$= I_1 R_s + (n-1)\left(I_1 - (I_{bmax} - I_{bmin})\right) R_s$$

$$= I_1 R_s + (n-1)(I_1 - \Delta I_b) R_s.$$

$$= I_1 R_s + (n-1) I_1 R_s - \Delta I_b \cdot (n-1) R_s.$$

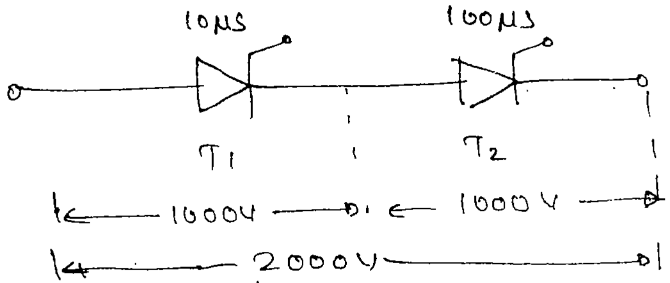
$$= n \underline{\underline{I_1 R_s}} - \Delta I_b \cdot (n-1) \cdot R_s$$

$$V_s = n V_{bm} - \Delta I_b (n-1) R_s$$

$$\Rightarrow \boxed{R_s = \frac{n V_{bm} - V_s}{(n-1)\, \Delta I_b.}} \Rightarrow$$ Approximately equal Resistance value.

$R_s \Rightarrow$ Static Equalising Resistor.

ii) DYNAMIC CHARACTERISTICS



T_1 – Turn ON time – 10 μS

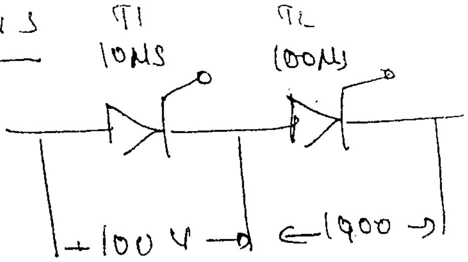
T_2 – " – 100 μS.

T_1 – Blocks – 1000 V

T_2 – " – 1000 V

- The unequal dynamic characteristics of the SCR's results as to damage of the slower devices due to the application of unequal voltage

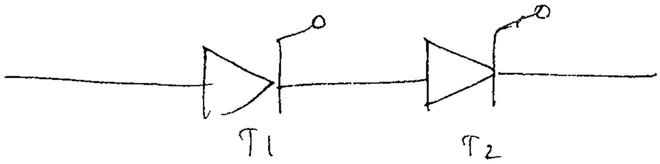
i @ 10μS



|Rating 1000V | Rating 1000V|

|total supply 2000V|.

- Difference in turn on time.



(*) charge required	= 10μC	=	100μC
i_g	= 1A	=	1A
Time required to get req: charge	= 10μs	=	100μS.
Junction capacit	= C_1	=	C_2

- The unequal dynamic properties are because of the unequal junction capacitance offered by the SCR.

(*)

- To Equalise the dynamic property one value of capacitor is connected across each and every SCR and it is known as

DYNAMIC EQUALLISING CAPACITANCE

DERIVATION :- llly to 'Rs'

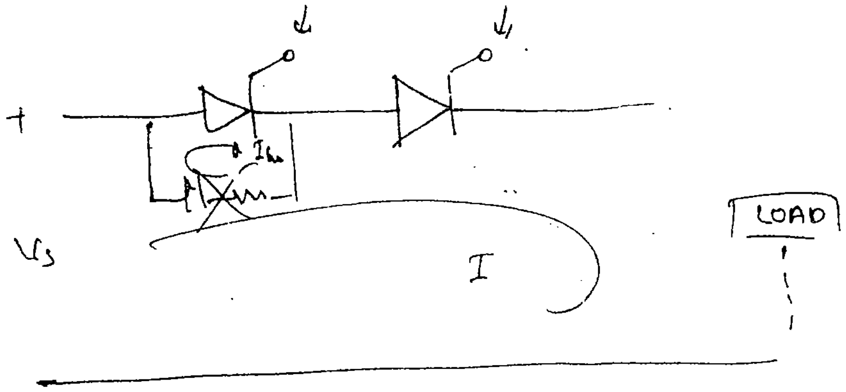
FORMULA :- $\boxed{C = \frac{(n-1)\Delta Q}{nV_{bm} - V_s}}$

$\Delta Q \Rightarrow$ difference in Reverse Recovery charge.

TIPS

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

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

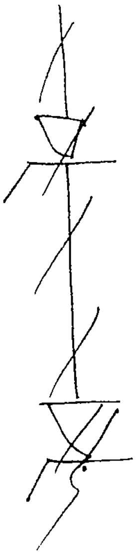


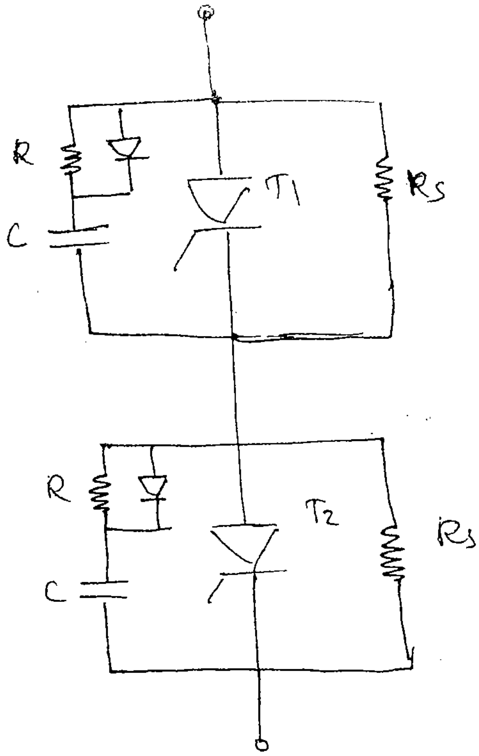
IESQ

In the series operation SNUBBER CIRCUIT is useful for following

1) dV/dt PROTECTION
2) DYNAMIC PROPERTY EQUALLISATION

2.30 – 5.30 = EDC
6 – 8.30 = PE-304





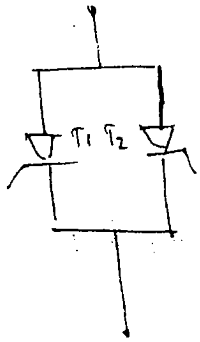
(*)

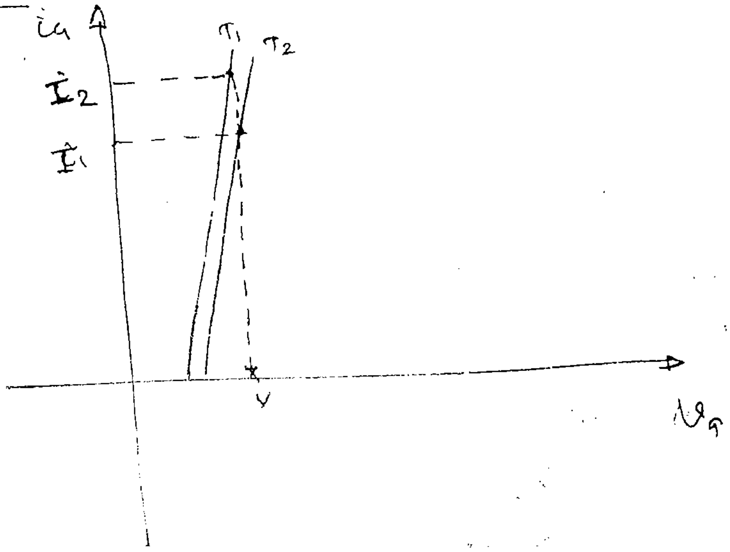
- Diode connected across the resistance. reduces the ~~thus~~ charging time constant so that device become fast.

10/02/12

II> PARALLEL OPERATION OF SCR.

i) STATIC CHARACTERESTICS.





- Blocking chara, is not required.

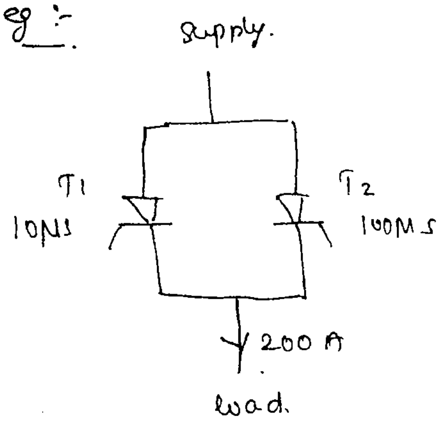
1) • String efficiency $= \frac{I_1 + I_2}{2I_1} = \eta_s$.

always $\eta_s < 1$.

• Due to the difference in static characteristic the current distribution will become unequal.

• For equallising the current distribution the devices should have overlapping static characteristics.

eg :-



$t = 0$: trigger given

$t_1 = 10NS$: T_1 ON : 1

• SCR turn ON = Min Voltage.

• $V_{T2} <$ Min switch ON voltage

• only T_1 - conducting.

• 200A pass through T_1.

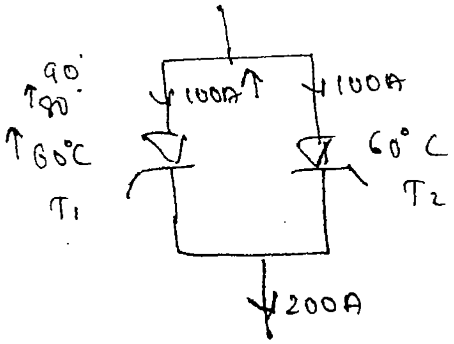
• T_1 damaged • T_2 supply V. • T_2 starts conducting · $T_2 \Rightarrow 200A$.

• Both are damaged. [CASCADE FAILURE OF DEVICE]
C.O.D

• REMEDY :- manufactures, manufacturing near by turn ON time.

• The unequal dynamic characteristic leads to cascade damage of SCR's due to the flow of high currents. To get the the satisfactory operation the devices should have ~~easy~~ VERY near values of dynamic characteristics.

ii) • Conduction



- consider T1 Temp ↑ = 70°c (due to some reason)

- T1 = -ve temp coefficent of resistance

- Temp ↑ ⟹ Resistance ↓ ⟹ current ↑. ⟹ Power loss more ⟹ 80°c

⟹ Temp ↑ THERMAL RUNAWAY occurs.

- T1 damaged, then same and shifted to T2. same

cascade failure effect.

SINK position (Remedy)

- If the parallely connected SCR's are at different temperatures

then the devices may be subjected to unequal distribution of

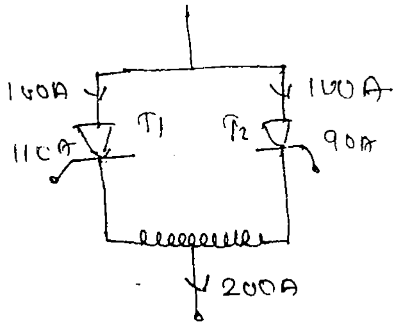
currents. some times it may lead to failure of the device.

- It is recommended to mount all the SCR's on the

same heat sink on symmetrical positions. to maintain

the same temperature.

(iii) MAGNETICALLY COUPLED CONNECTION



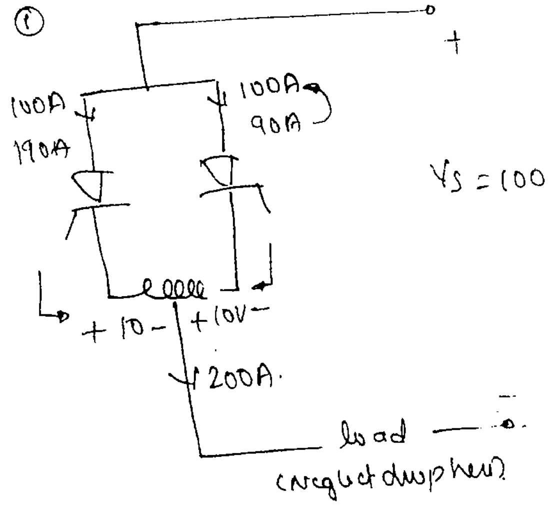
- Current $T_1 \uparrow \Rightarrow \underline{110} \Rightarrow T_2, I = \underline{90A}$

- current passing though the coil or Inductor, tries to restore the current back to 100A.

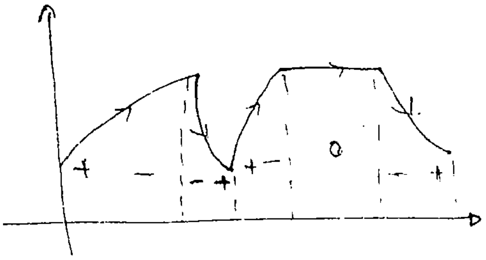
- It is preferable to couple the parallely connected SCR magnetically so as to Restore original distribution of currents if any disturbance occurs.

Note:- Inductor Properties (4).

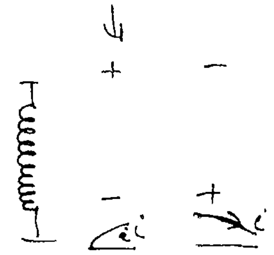
①



②



③



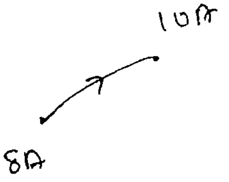
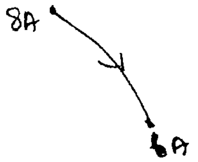
- Property of the inductance is to oppose the change in current by developing an appropriate voltage in magnitude as well as in polarity.

- Polarity of induced voltage depends on slope of variation of current.

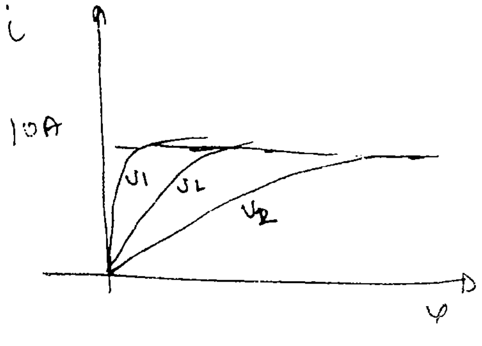
- Magnitude of voltage depends on, the value of the $L\frac{di}{dt}$.

- In a constant inductive system, instantaneous variation of current is NOT POSSIBLE.

③ ~~sts~~

	di/dt	V_L
	+ve	+ ve
	— ve	— ve
	0	0.

④



. V_1, V_2, V_3 induced voltage across inductor

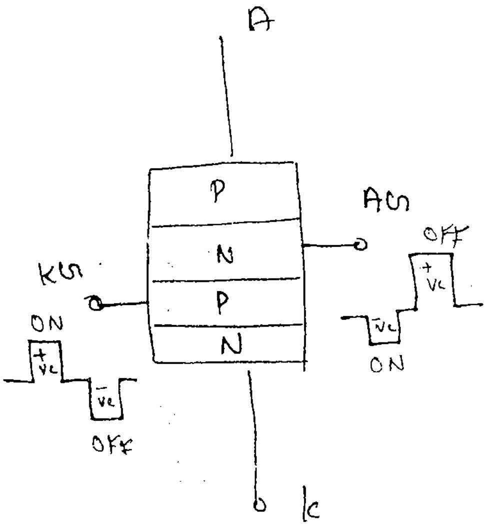
. $V_1 > V_2 > V_3$. (slope₁ > slope₂ > slope₃)

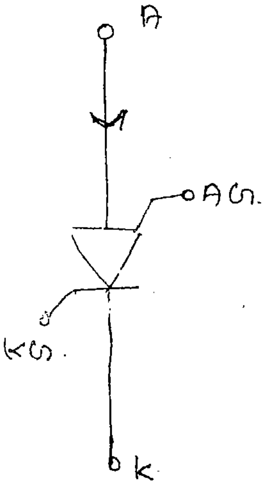
- Similar to zener diode, SUS is turn ON for a fixed value of anode to cathode voltage.

Applications

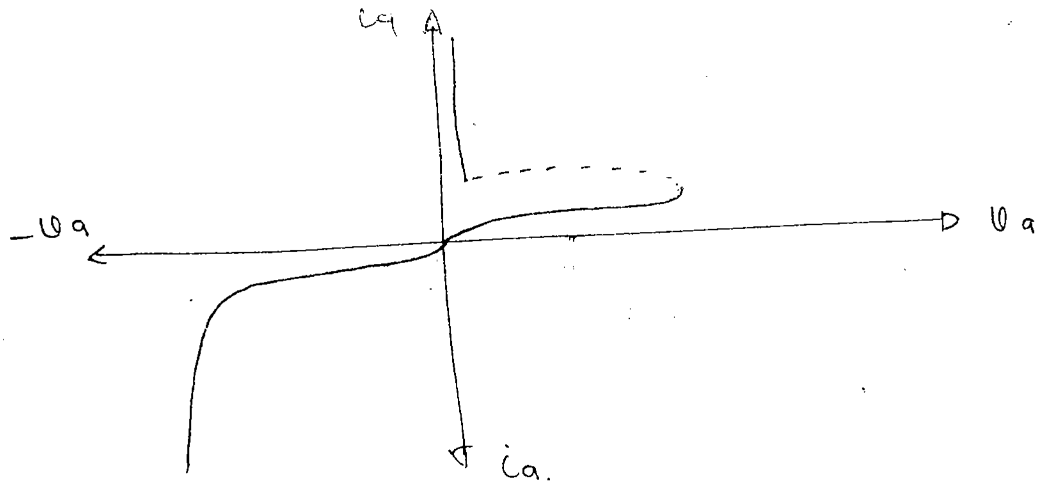
1). logic, delay, triggering circuits.

3) SCS (Silicon Controlled Switch).





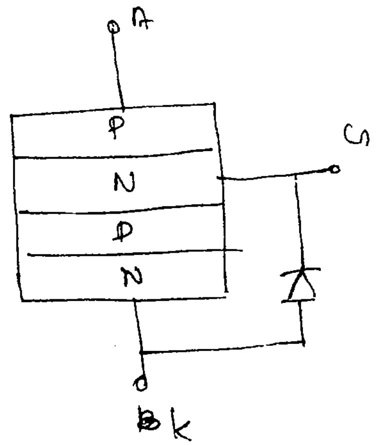
- SCS is a 4 electrode thyristor (4 terminal)
- SCS can be controlled either from i) Anode gate (OR) ii) Cathode gate.
- Opposite nature of gate currents can be employed to make turn ON and turn OFF of the device.
- It acts like a GTO, hence it is limited for low power applications.

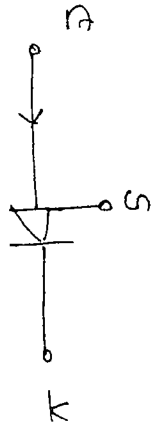


- PUT is similar to SCR. where the gate terminal is taken from inner N layer
- It is suitable for low voltage switching applications.

  1) logic circuits
  2) Time delay circuits
  3) Trigger circuits .. of SCR.

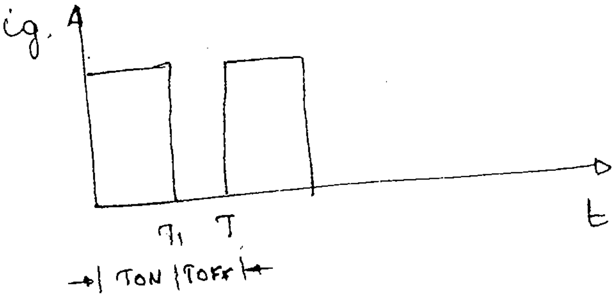
2) SUS (SILICON UNILATERAL SWITCH)





- SUS is same as the POT, But a low voltage avalanche diode is placed across Gate to Cathode terminals.

PULSE TRIGGERING OF SCR



Note :-
- Thermal time constant > Electrical time constant.

- In pulse triggering, the trigger voltage and trigger current will be applied as terms of pulses instead of continuous (dc signal) signal.
- It allows to employ higher value of gate current for the same average gate power dissipation. Due to this, TURN ON time of the SCR decreases as a result device becomes Faster.

EXPRESSIONS

$$\boxed{P_{gav} = \delta . P_{gm}.}$$

δ = Duty cycle. $\left[\frac{\text{ON TIME } (T_1)}{\text{TOTAL TIME } (T)} \right]$

$$P_{gav} = \frac{T_1}{T} . P_{gm}$$

$$\boxed{P_{agav} = f . T_1 . P_{gm}}$$

f = frequency ⇒ PULSE FREEQUENCY

Note :
Computer Terminology : $\frac{\text{mark}}{\text{space}} = 1/4$

mark ⇒ 1
space ⇒ 0

$$\boxed{\frac{\text{Mark}}{\text{Space}} = \frac{T_{ON}}{T_{OFF}}}$$

Q) 1cycle → 100A

1/2cycle → ? (surge current)

SURGE CURRENT

- The surge current rating of the SCR for different durations can be evaluated by using H. ~~energy~~ energy dissipation on the device.

$$I^2R.t = \text{constant}$$

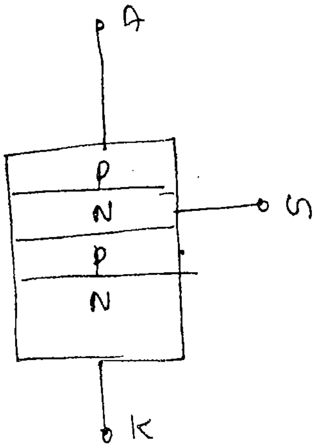
$$I_1^2.R.t_1 = I_2^2 R t_2$$

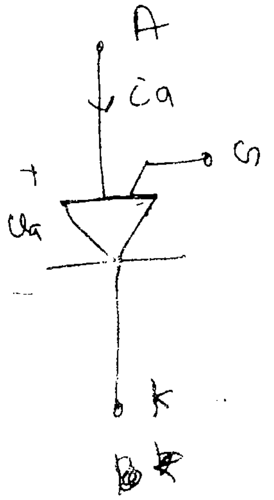
$$\boxed{I_1^2.t_1 = I_2^2.t_2}$$

OTHER MEMBERS OF THYRISTOR FAMILY

1) PUT (Programmable Unijunction Transistor)

- It is a thyristor.

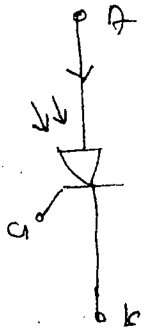




Applications

→ In oscillators, voltag sensors, Function generators. and trigger circuits

4) LA SCR (Light Activated SCR)



- LA SCR will be turned ON by using the light triggering
- The gate terminal is useful to turn ON the device, under low light intensity conditions. It is possible by applying a small gate pulse.

11-02-11

6:30 - 11:AM = PS 305

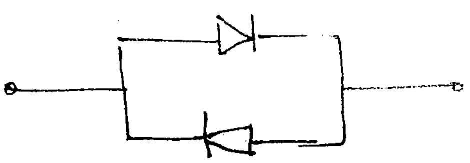
Applications

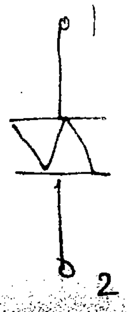
→ street lighting, highways lighting

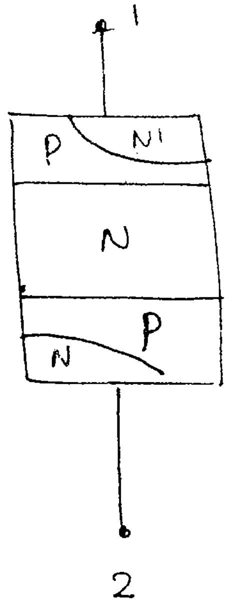
→ HVDC app:

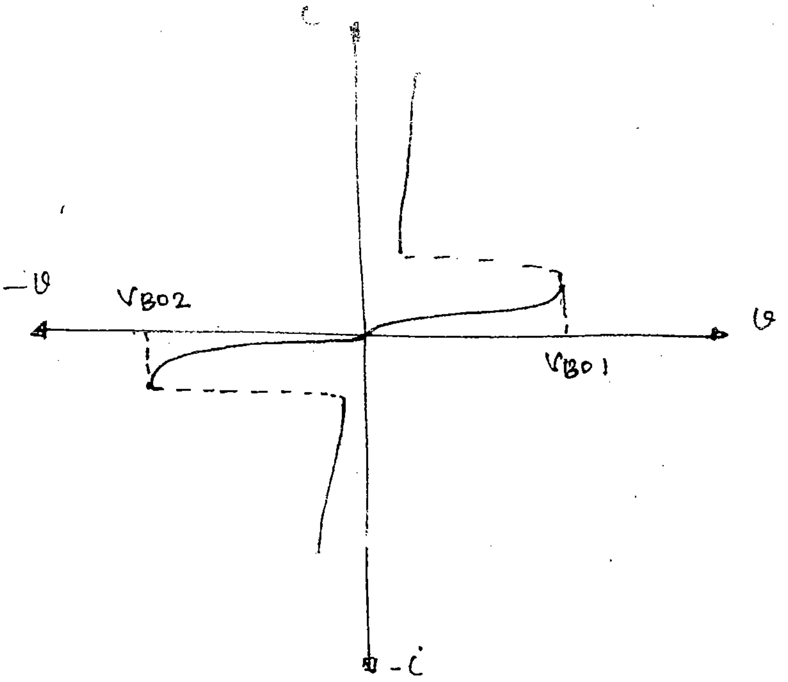
15/02/11

5) DIAC (Bi directional thyristor diode)









• Diac is electrical equivalent to antiparallel connection of diode

• If terminal '1' is at more potential w.r.t '2'. and its magnitude exceeds VBO1. and it allows the conduction from terminal 1 to 2.

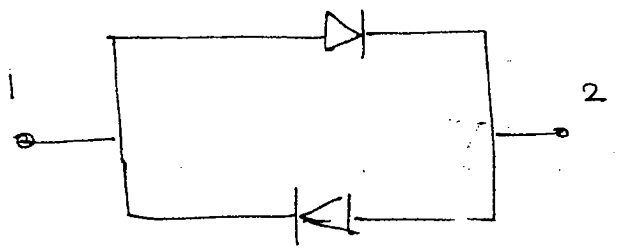
• Structure PNPN1 is activated.

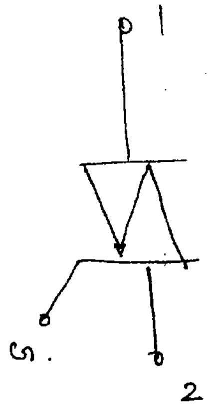
• If terminal '2' is at more potential w.r.t '1' and its magnitude exceeds VBO2. and it allows the conduction from terminal 2 to 1.

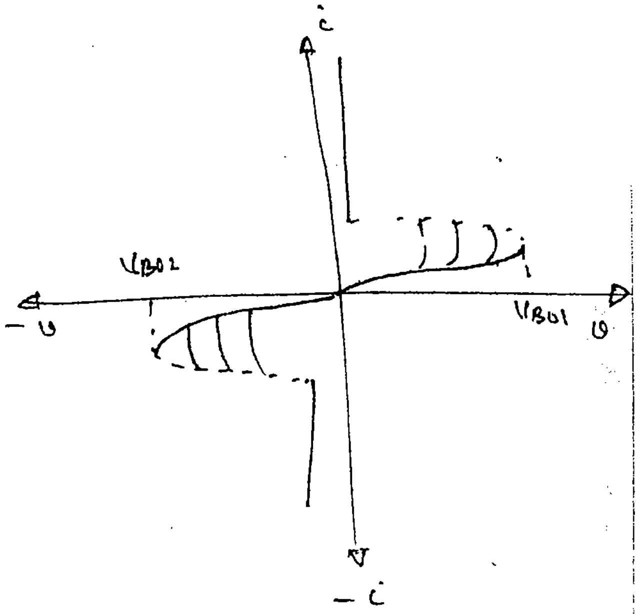
→ In this case structure PNPN' conducts

• Due to ~~lack of to~~ lack of control action DIAC finds limited App.

8) TRIAC (Bidirectional thyristor)







- Triac is electrical equivalent to antiparallel connection of SCR.
- It allows the controlled conduction in both the direction.
- The voltage, current and power ratings of the triac are less. compared to SCR. hence it is limited for medium power applications.

Appl.

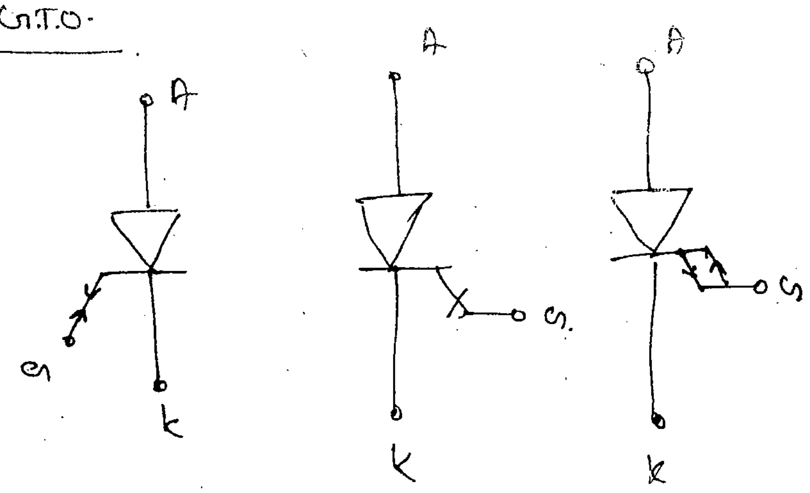
① Speed control of A/c machines

② Fan Regulators.

③ Domestic and Industrial heating circuits.

④ lighting circuits.

7) G.T.O.



- Gate turn OFF thyristor.
- It can be turned OFF by giving a negative gate current,
- The value of gate current required to turn OFF GTO is quite high (20 - 30% Anode current).
- The positive gate current required to turn ON GTO is also high compared to SCR.
- The holding and latching current magnitudes are higher in GTO.

App:

1) UPS
2) Inverter.
3) DC - DC Converter

1) A or B ?

A | B

I_g = 3mA | 1A

a) SCR | GTO

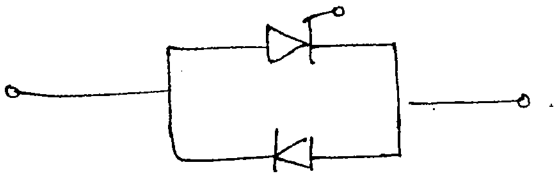
b) current gain↑ | current gain↓

2) current gain = $\frac{I_A}{I_G}$

Note:

- GTO will have the lower value of current gain since it needs higher gate current for the turn ON of the device.

8) RCT (Reverse Conducting Thyristor)



- It is electrical equivalent to antiparallel connection of SCR and diode.

(*) • The commutation of SCR (or) Thyristor will be happened by antiparallel diode

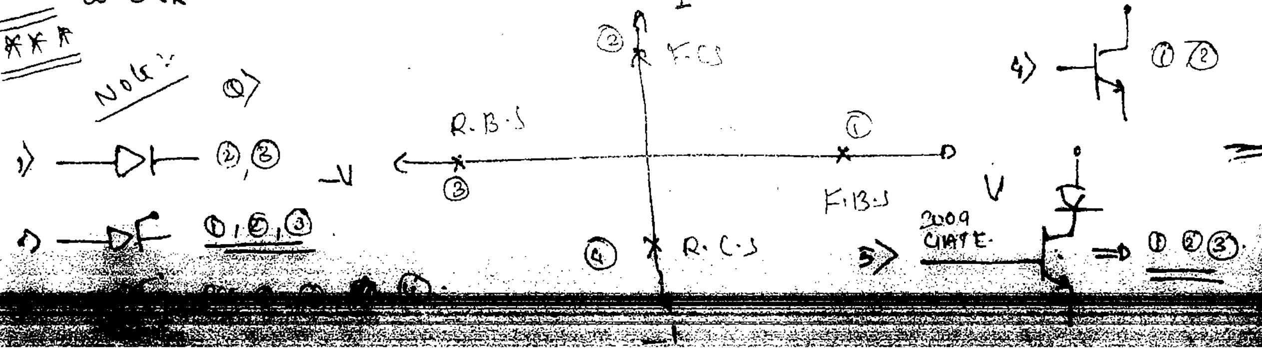
9) ASCR (Assymetrical thyristor)

- Assymetrical thyristor, if the forward characteristics of the device are optimised compared to SCR. (Reduction in turn ON time, turn OFF time and on state voltage drop).
- The reverse ~~voltage~~ properties of ASCR are inferior compared to SCR

***

Note:

Q)



08) Jc ∝ width of depletion layer

∝ Amount of ~~Vak~~ applied

$(C = \varepsilon A/\boxed{d}\uparrow)(C\downarrow)$

$V_a\uparrow$

$I_g = 12\,\mu A$

$\frac{dV}{dt}$ = ~~800~~/μs (critical)

$= 800\times10^{6}$ V/s critical

$I_c \quad \boxed{i = C_j\, dV/dt}$

$12\times10^{-6} = C_j \times 800\times10^{6}$

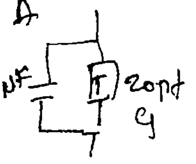
$C_j = \frac{12}{800}\times10^{-12}$

$= \underline{0.15\,pF}$

---

09) $C_{j2} = 20\,pf$ (under off state)

$I =$ ~~15μA~~ 15 mA



$= C_j + C_1$

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

$= \underline{10.02\times10^{-9}\,F}$

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

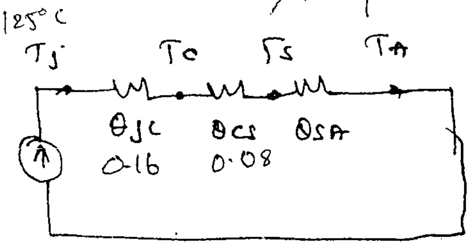
$15\times10^{-3} = 10.02\times10^{-9}\times\frac{dv}{dt}$

$\frac{dv}{dt} = \frac{15}{10.02}\times10^{6} = \approx 1.498\times10^{1}\,V/s$

$= 1.5\,V/\mu s$

10) For a thyristor

$T_j = 125°C$, 70°C/60°C



$P_{av1} = \frac{T_j - T_s}{\theta_{jc} + \theta_{cs}}$

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

$= \underline{229.16\,J/s\ (or)\ W}$

% increase in device rating

$P_{av2} = \frac{125 - 60}{0.16 + 0.08}$

$= \underline{278.8\,J/s\ (or)\ W}$

rate of generation = rate dissipation

rate heat dissipated $\propto I^2 \times P_{avg}$

$\Rightarrow I \propto \sqrt{\cancel{rate}\ P_{avg}}$

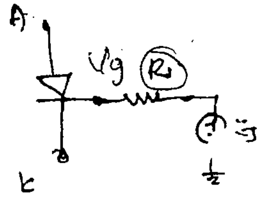
$= \underline{8.71\%}$

12) $\frac{V_g}{i_g} = 20 V/A$

$t_{ON} = 4 \mu s$

$i_g = 400 mA = 0.4 A$

~~V_g~~ $E_s = 15V$



$\frac{V_g}{\cancel{i_g}} \times \cancel{i_g} = 20 \times 0.4$

$V_g = \underline{\underline{8V}}$

$E_s = V_g + i_g R_s.$

$15 = 8 + 0.4 \times R_s$

$\underline{\underline{R_s = 17.5 \Omega}}$

Power loss

$P_{avg} = V_g \, i_g$

$= 8 \times 0.4$

$= \underline{\underline{3.2 W}}$

Pulse width = t_{ON}

$P_{avg} = 0.2 W.$

$$\boxed{P_{gavg} = \delta \cdot P_{gm}.}$$

$= \frac{T_{ON} . P_{gm}}{T.}$

$= f \cdot T_{ON} \cdot \boxed{P_{gm}}$ — $\underline{\underline{P_{gmax}}}$

⇓

Pulse frequency.

$0.2 = f \times 4 \times 10^{-6} \times 3.2$

$= \underline{\underline{15.625 kHz}}$

$P_{gmax} = 0$ when pulse is available

$\underline{P_m = 3.2 W}$

---

13) $f = 4 kHz$

$\frac{T_{ON}}{T} = 0.2$

P. ulse width = ? ✓

$P_{g avg} = 1 W.$

maximum allowable gate power

drive = ? = ✓

duty cycle $$\boxed{\delta = \frac{T_1}{T} = f \cdot T_1}$$

$0.2 = 4000 \times T_1$

$T_1 = $ ~~15T~~ $\underline{\underline{50 \mu s}}$ ✓

$P_{g avg} = \delta \cdot P_{gm}$

$1 = 0.2 \, P_{gm}$

$P_{gm} = \underline{\underline{5 (W)}}$ ✓

✗✗

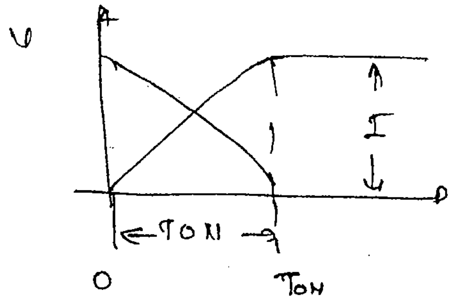
14) ~~Ear~~ V_a — 600V – 0V

I_a — 0 — 100 A

$T_{ON} = 5 \mu s$

$I_a \, V_a$ — linear variations.

$f = 100 Hz$ P_{gavg} ?



Pg/avg =(δ.2 P gm

✓ $$\boxed{P_{avg} = \frac{1}{T}\int_0^{T} P_i \, dt}$$

- After $\underline{\underline{T_{ON}}}$ $\underline{v=0}$. NO power loss.

$$P_{avg} = \frac{1}{T}\int_0^{T_{ON}} \underline{v}.\underline{\overset{o}{I}}\, dt$$

$v = V + \text{slope}$

$= V + \frac{0-V}{T_{ON}}(t)$

$$\boxed{v = V \cancel{+} -\left(\frac{V}{T_{ON}}\right)t}$$

$i = 0 + \text{slon}$

$= 0 + \left(\frac{I-0}{T_{ON}}\right)t$

$$\boxed{i = \frac{I}{T_{ON}}.t}$$

$$P_{avg} = \frac{1}{T}\int_0^{T_{ON}} \cancel{(}V-\left(\frac{V}{T_{ON}}\right)t.\frac{I}{T_{ON}}.dt$$

$$= \frac{1}{T}\int_0^{T_{ON}}\left(\frac{VI}{T_{ON}} - \frac{VI}{T_{ON}^2}\right)t^2.dt$$

$$= \frac{VI}{T}\left[\frac{1}{T_{ON}}\frac{t^2}{2} - \frac{1}{T_{ON}^2}\frac{t^3}{3}\right]_0^{T_{ON}}$$

$$= \frac{VI}{T}\left[\frac{T_{ON}^{2}}{2.T_{ON}} - \frac{1}{T_{ON}^2}\frac{T_{ON}^{3}}{3}\right.$$

$$= VI.\frac{T_{ON}}{T}\left[\frac{1}{2}-\frac{1}{3}\right]$$

$$= VI.\frac{T_{ON}}{T}.\frac{1}{6}$$

$$P_{avg} = \frac{1}{6}VI.\frac{T_{ON}}{T}$$

$$\boxed{P_{avg} = \frac{1}{6}.VIf.T_{ON}}$$

$$= \frac{1}{\cancel{6}} \times \cancel{600} \times \cancel{100} \times 5\times10^{-4}$$

$P_{avg} =$ ~~50 mW~~ $5(W)$

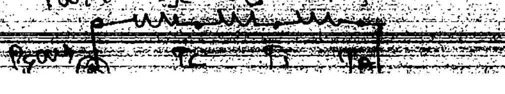
---

ii) $T_A = 50°C$ $T_{J_1} = 100°C$

$P_{avg} = 50W$. $[T_{J_2} = 40°C]$

% Reduction in thermal resistance.

100°/40°C θjc θcs θsa 50°C



$$P_{gav_1} = \frac{T_j - T_A}{(\theta_{jc} + \theta_{SA} + \theta_y) = \theta_1}$$

$$\theta = \frac{\cancel{80}^\circ\ 100^\circ - 50^\circ}{50}$$

$$= \frac{50}{50} = \underline{\underline{1\ 4AR}}$$

$$P_{avg\cancel{2}}^{50} = \frac{70-50}{\cancel{80}\ \theta_2}$$

$$= \underline{\underline{0.4\ 4AR}}$$

% reduction θ

$$= \frac{1-0.4}{1} \times 100$$

$$= \underline{\underline{60\%}}\ ✓$$

---

16) $P_{gavg} = 2W$

$P_{gm} = 20W$

$f = 2 KHz$

mark to space ratio = ρ

$$P_{gavg} = \delta \cdot P_{gm}.$$

$$\delta = \frac{2}{20} = 1/10 = \frac{T_1}{T}$$

* $\boxed{\text{mark by space} = \frac{T_{ON}}{T_{OFF}}}$

$$\delta = \frac{1}{10}$$

$$\cancel{MO}\ \frac{T_{ON}}{T_{OFF}} = \underline{\underline{1/9}}$$

---

17) 1/2 cycle $I_s = 3000A$

$f = 50 Hz$ (supply)

one cycle I_J = ?

Surge current

$$\boxed{I_1^2 t_1 = I_2^2 t_2}$$

. energy dissipation across element is going to be same

$$\frac{I_1^2}{I_2^2} = \frac{t_2}{t_1}$$

$$\frac{3000^2}{I_2^2} = \frac{t_2}{1/50} \qquad \frac{1}{50} = 20 \times 10^{-3}$$

t_1 = 1/2 cycle = 10×10^{-3}

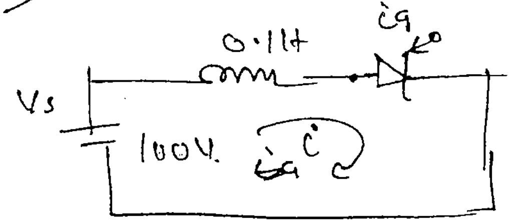
t_2 = full cycle = 20×10^{-3}

$$I_2^2 = \frac{I_1^2 t_1}{t_2}$$

$$= \frac{3000^2 \times 10 \times 10^{-3}}{20 \times 10^{-3}} = \underline{\underline{2121.320}}$$

18) $I_L = 4mA$

~~IGQ~~ TON = width of gate current



~~$I_a = I_L \Rightarrow T_{ON}$~~

~~I_g~~ ↑

~~$I_g + I_a = I_L$~~ $\Rightarrow T_{ON}$

Note

- The gate pulse should be applied to the SCR till the current reach to latching current

T=0, give pulse.

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

$$\int di = \int \frac{V_s}{L}\, dt$$

$$i = \frac{V_s}{L} \int (t) + k.$$

Initial condition

$t = 0^+$

Inductor = O.C (o+)

$i = 0.$

$$0 = \frac{V_s}{L}\, 0 + k$$

$k = 0$

here

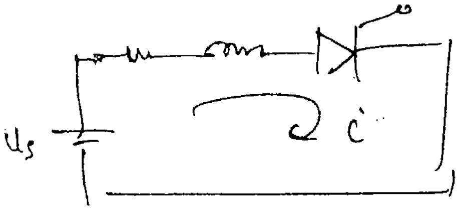
$$i = \frac{V_s}{L}.(t) = i_L$$

$$4mA = \frac{100}{0.1}.t$$

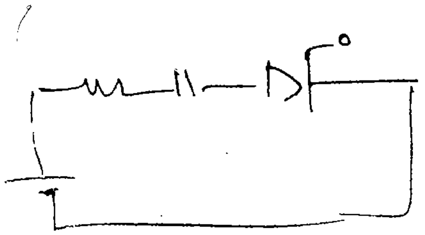
$\Rightarrow t = 4\mu s$

Comment

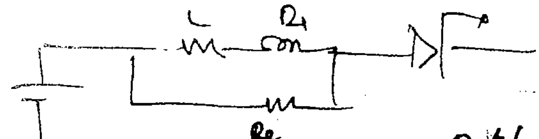
- current for 4μs, can be more should not be less



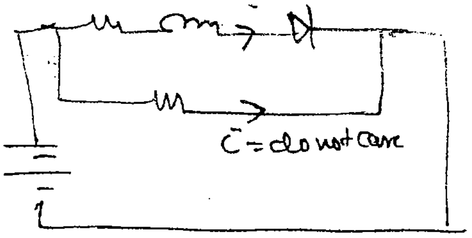
$$i = \frac{V}{R}\left(1 - e^{-Rt/L}\right)$$



$i = V/R\,(1 - e$



$$i(t) = \frac{V_s}{R} + \frac{V_s}{R_1}\left(1 - e^{-R_1t/L}\right)$$



Note :-

- Evaluate the current formula passing through the thyristor and then equate it to the latching current value, to evaluate the minimum width of the gate pulse for reliable turn ON of the SCR.

---

19) $I_L = 12mA$

$I_H > I_L$

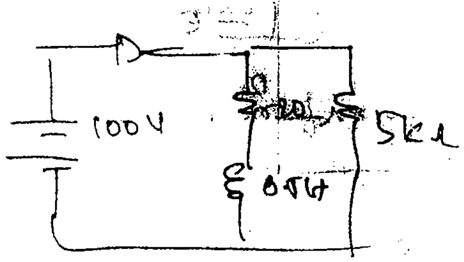
$$\boxed{\frac{I_L}{I_H} = \underline{2.5 \text{ to } 3}}$$

---

20) ✓

---

21) HW   Ton = 5μs IL = 50
IH = 40mA



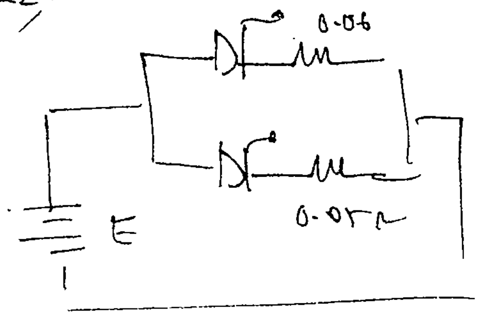
$$= \frac{100}{5\times10^3} + \frac{100}{20}\left(1 - e^{-\frac{20}{0.5}t}\right)$$

$$50mA = 0.02 + 5\left(1 - e^{-(40t)}\right)$$

$= 150\,\mu s$

---

22)



$I_n = 0.06$.

$I_n \times 0.06 = I_y \times 0.05$

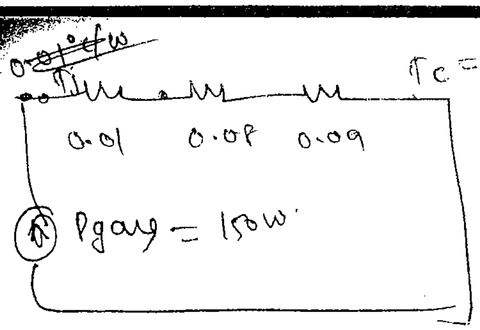
$$I_n = \frac{\overset{20}{\cancel{120}} \times 0.05}{\cancel{0.06}}$$

$= 100A$

~~23~~) 24) HW

---

32) $100A = \hat{C}_5$



$$Pgav = \frac{Tj - Tc}{\theta}$$

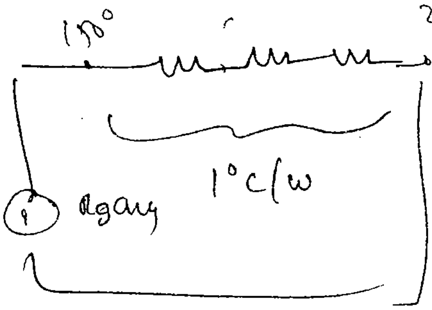
F $\theta \cdot Pgavg$ ~~+~~ $+ Tc = Tj$

$Tj = 0.18 \times 150\omega + 35°$.

$= 62°C$

---

33)

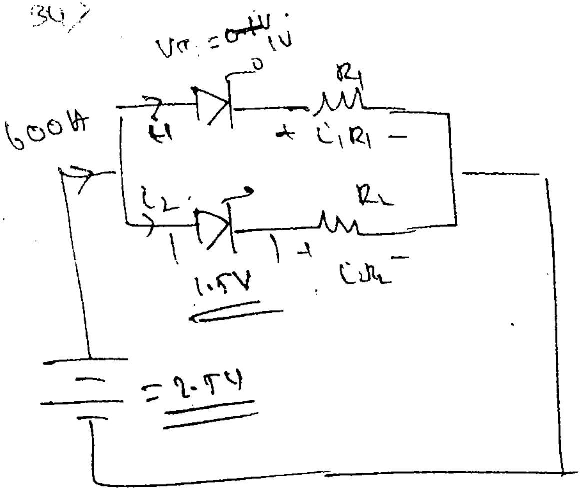


$$Pavg = \frac{150 - 25}{1}$$

$= 125 (W)$

~~Pg avg = δ Pg max~~

34)



$i_1 + i_2 = 600A$

$\omega_1 = x + 10\%$.

$= 330, 370$

⇒ drop is less ⇒ curr change is more

⇒ $i_1 = 330\ A$

⇒ $i_2 = 270\ A$

$1V + i_1R_1 = 2.5V$

$R_1 = \frac{1.5}{330}$

=

$R_2 = \frac{2.5 - 1.5}{270}$ 17

$$\boxed{330R + 1 = 270R + 1.5}$$

II / CHAPTER

1) PHASE CONTROLLED RECTIFIERS

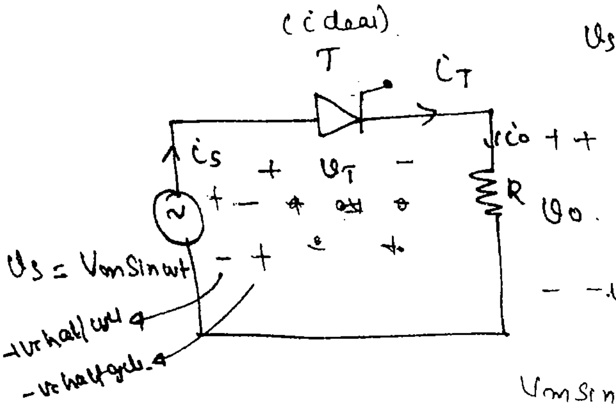
1ϕ – H.W. $\textcircled{D}$ R $\Rightarrow V_0 = \frac{V_m}{\pi} \Rightarrow D \rightarrow T \quad 0 - \frac{V_m}{\pi}$

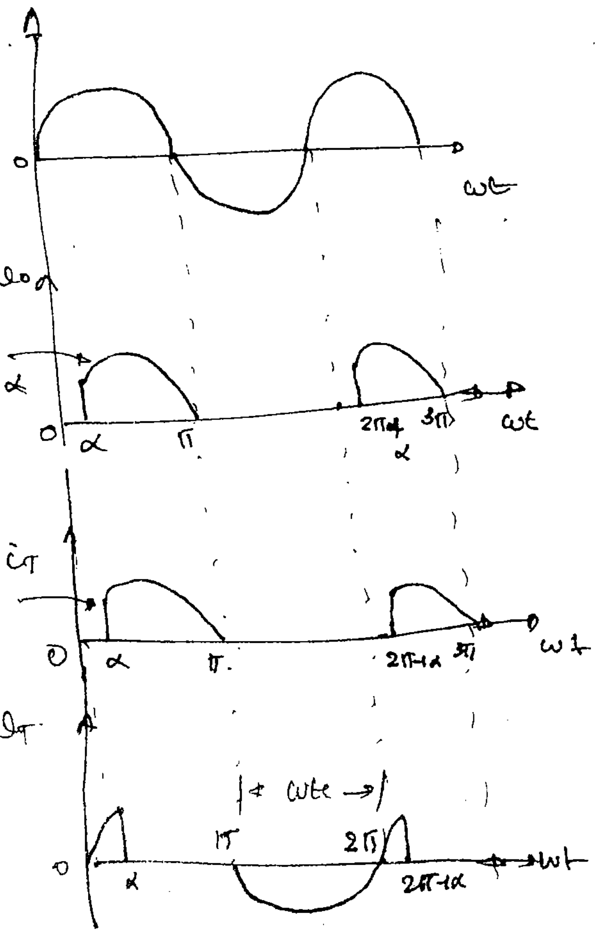
1ϕ – F.W. $\textcircled{D}$ R $\Rightarrow V_0 = \frac{2V_m}{\pi} \Rightarrow D \rightarrow T \quad 0 - \frac{2V_m}{\pi}$

⇑ Diode

*→ It is a static power electronics circuit, which converts <u>AC to variable DC.</u> ie variation in the magnitude of the voltage.

1) Single phase Halfwave Rectifier with R-load.





v_0 = o/p voltage

i_0 = o/p current

i_T = Thyristor current

i_s = source current

$i_s = i_T = i_0$ (here)

- Phase controlled rectifiers operation is based on, line (OR) Natural commutation. Natural zero of current through the SCR and application of reverse voltage are occurring by the nature of input ac supply. So it is called line (OR) Natural commutation.

- ωt_c = circuit turn OFF time

$= 2\pi - \pi$

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

⟹ If $f = 50Hz$ $t_c = 10ms$ (½ cycle). SCR which has to be used here should have more than 10ms

Note:
- The SCR is to be selected such that device turn-OFF time has to be less than the circuit turn OFF time.

$$V_{o\,avg} = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d\omega t.$$

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

$$\boxed{V_{o\,avg} = \frac{V_m}{2\pi}\left[1 + \cos\alpha\right]}$$

rms Value

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \, d\omega t} =$$

$$V_{rms}^2 = \frac{V_m^2}{2\pi}\int_{\alpha}^{\pi} \frac{1 - \cos 2\omega t}{2} \, d\omega t = \frac{V_m^2}{4\pi}\left[\omega t - \frac{1}{2}\sin 2\omega t\right]^{\pi}$$

⇒ Forward Blocking state

⇒ After Application of F. Voltage, again No Conduction

⇒ we canot say '0', due to minority carrier.

Forward leakage current (minority current, produced at the forward blocking state) (Represented in State chara graph)

Note ***

⇒ Power Electronics, we have only one - application as SWITCH.

- here Blocking state, SCR device acts as OPEN SWITCH
- Ideal chara of OPEN SWITCH

$V = V_s$ (applied)

$I = 0$

- here ideal case $V = 100V$

$$\boxed{I = 0}$$

$$\Downarrow$$

- In a STATIC SWITCH, current $I \neq 0$

(85) "In FB state $J_1 J_3$ FB, J_2 RB, In this state SCR is equivalent to OPEN SWITCH

TURNING ON SCR

Forward Blocking state $\underset{\xleftarrow{\text{OFF}}}{\xrightarrow{\text{ON}}}$ Forward conduction state

~~TURN ON and OFF~~

~~TURON~~ TURN ON of SCR means Forward Blocking state to Forward conduction state. TURN OFF means Forward conduction state to Forward Blocking state.

In Forward Blocking state to Forward conduction state

J_1 J_3 – F.B

$\boxed{J_2 - R.B}$ This is jn when conduction is blocked.

– Increase the applied voltage, a very high voltage R.B break down occurs, Avalanche Breakdown, J_2 opens hence SCR starts conduction.

The above method is called FORWARD VOLTAGE TRIGGERING

The amount of F. voltage required to turn ON SCR is called FORWARD BREAK~~DOWN~~OVER VOLTAGE

(B1) 1) FORWARD VOLTAGE TRIGGERING

A high FV is applied due to which RB. J_2 Junction gets break down (Avalanche) hence the device starts CONDUCTION.

The amount of Forward voltage required to turn ON the SCR (without GATE PULSE) is known as F. BREAKOVER VOLT

$$V_{rms}^2 = \frac{V_m^2}{4\pi}\left[\pi - \alpha + \frac{1}{2}\sin 2\alpha\right] \qquad \{\sin 2\pi = 0\}$$

18/02/11

6 — 9 AM = M-II

9.30 — 11 = 11 AM

SCCT

6 — 8.30 — PE

308

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

lly current

$$\boxed{I_{oavg} = \frac{V_o}{R}} \qquad \boxed{\underset{(\text{rms } I)}{I_{or}} = \frac{V_{or}}{R}}$$

19/02/11

- Phase angle will be supply voltage and current gets controlled with the variation of α and it is also known as <u>phase controlled Rectifier.</u>

- Alternatively powerfactor can be evaluated by equating power on dc side = Power on ac side.

→ ie $P_{ac} = P_{dc}$. ⇒ $V/I \cos\phi$ $V_s \cdot I_{sr} \cdot Pf = P_{dc}$.

$$\Rightarrow \boxed{Pf = \frac{P_{dc}}{V_s \cdot I_{sr}} = \frac{\text{Power delivered to dc load}}{\text{Source volt Amps}}}$$

***

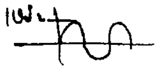
Note:

rms value ⇒ dc component + Ac component

$V_{rms} = 10V$

$V_{dc} = 10V$

avg value ⇒ dc component only



$V_{rms} = 10$

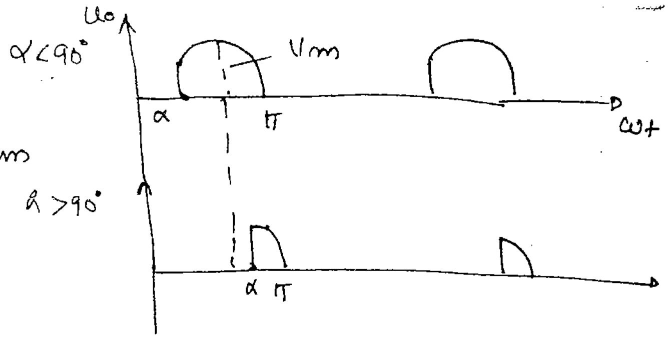
$V_{dc} = 0$

$$\Rightarrow P.f = \frac{V_{or}^2}{V_s \cdot I_{sr}} = \frac{V_{or}^2/R}{V_s \cdot V_{or}/R} = \frac{V_{or}}{V_s} \qquad \boxed{P.f = \frac{V_{or}}{V_s}}$$

***

→ In the power electronics circuit power factor may be variable with the variation of the firing angle. The starting of the current w.r.t time depends on the <u>firing angle</u> of the ckt as the firing angle changes, powerfactor also changes.

*** α and o/p Voltage



- If $\alpha < 90°$, maximum value of instantaneous output Voltage is V_m.

- If $\alpha > 90°$, the maximum value of instantaneous output voltage is $V_m \sin\alpha$

→ $V_o = \frac{V_m}{2\pi}\left[1+\cos\alpha\right]$ • Range of α ~~0-π~~ $0 < \alpha < \pi$

- $\alpha = 0 \Rightarrow V_o = \frac{V_m}{\pi}$ • $\alpha = \pi \Rightarrow V_o = 0.$ $\{\cos\pi = -1\}$

- If we are varying α from 0-π, o/p voltage varies from $\left(0 - \frac{V_m}{\pi}\right)$

- Range of firing angle (0-π), when the firing angle increases, the o/p voltage decreases. (Area under the curve decreases)

→ circuit turn OFF time = $\frac{\cancel{\omega}\pi}{\omega_c}$

Advantages of F.W.D

1) Average power consumption is increased.

2) Power factor also will be improved.

3) circuit turn OFF time would be, more (π/ω). and in the same time it is of FIXED VALUE.

- $\boxed{V_0 = \frac{V_m}{2\pi}[1+\cos\alpha]}$
- $\boxed{V_{or} = \frac{V_m}{2\sqrt{\pi}}[\pi-\alpha+\frac{1}{2}\sin 2\alpha]^{1/2}}$
- $I_0 = V_0/R$
- $I_{or} = V_{or}/R$, $\boxed{Pf = \frac{V_{or}}{V_s}}$

20/02/12
7-1 = N/w. 305
2-5.30 = P.E 308
6-8.30 = m-II 308

Note:

F.W.D

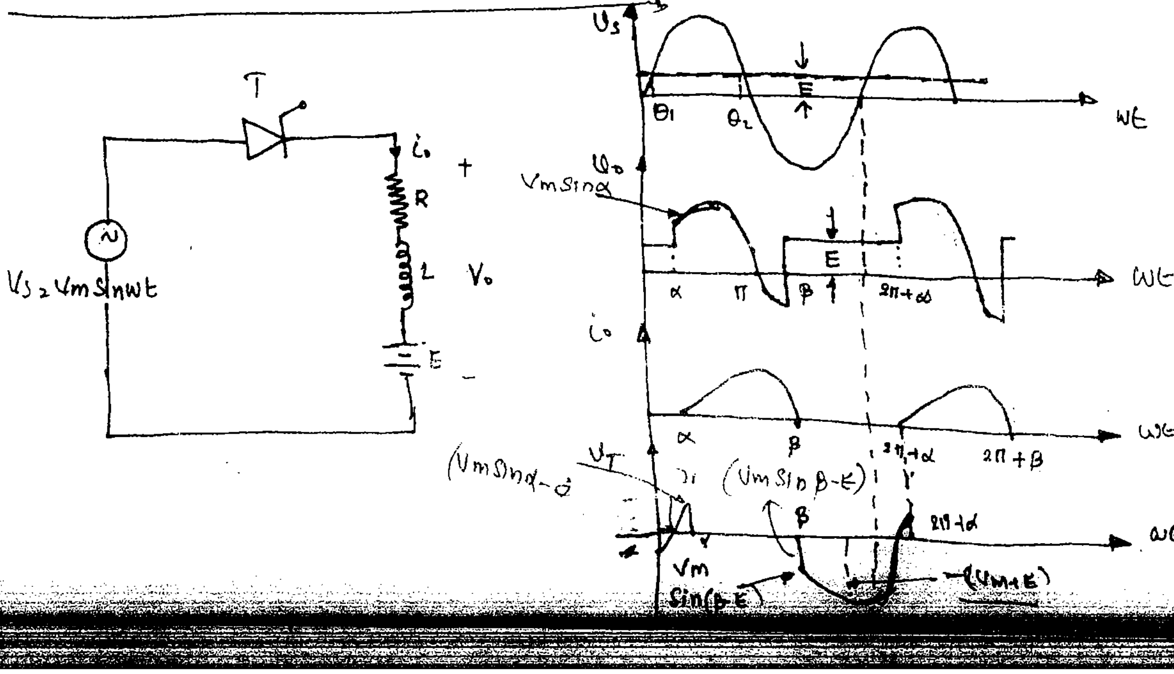
- Power diode.
- Diode is wheeling/circulating without taking any energy/power from supply lines directly, the current through the diode is determined by L.

S/r

- Diode is circulating current in the load, without consuming any energy from supply lines, it may be known as Free wheeling Diode.

02/02/11

1Φ-HALFWAVE RECTIFIER WITH RLE LOAD



- Range of Firing angle (θ_1 to θ_2).
- at θ_1 & θ_2

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

ie $V_m \sin\theta_1 = E$

$$\boxed{\begin{aligned} \theta_1 &= \sin^{-1}\left(\frac{E}{V_m}\right) \\ \Rightarrow \theta_2 &= \pi - \theta_1 \end{aligned}}$$

-OBJ Q.

- If the SCR is not in the conduction output voltage is equal to E. If the SCR is in the conduction output voltage is same as the supply voltage.

*** β Values

- In the case of RE Load $\beta = \theta_2$.
- In the case of RLE load $\beta > \theta_2$. But it may be less than π (or) greater than π.

- PIV Rating of the SCR = $(V_m + E)$.
- Voltage across SCR at the time it is starting the conduction = $(V_m \sin\alpha - E)$
- Voltage across SCR at the time it is stopped the conduction = $(V_m \sin\beta - E)$

Here

Average o/p voltage = $\boxed{V_o = E + I_o R}$

Derivation for I_o

I_o = Average o/p current

$$= \frac{1}{2\pi}\int_{\alpha}^{\beta} \frac{V_m \sin\omega t - E}{R}\, d\omega t = \frac{1\cancel{V_m}}{2\pi R}\Big[-V_m \cos\omega t - E(\omega t)\Big]_{\alpha}^{\beta}$$

$$\Rightarrow \boxed{I_o = \frac{1}{2\pi R}\Big[V_m(\cos\alpha - \cos\beta) - E(\beta - \alpha)\Big]}$$

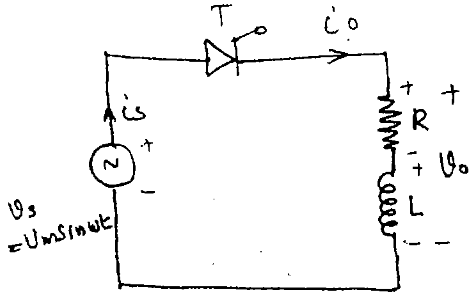
$V_o = E + I_o R.$

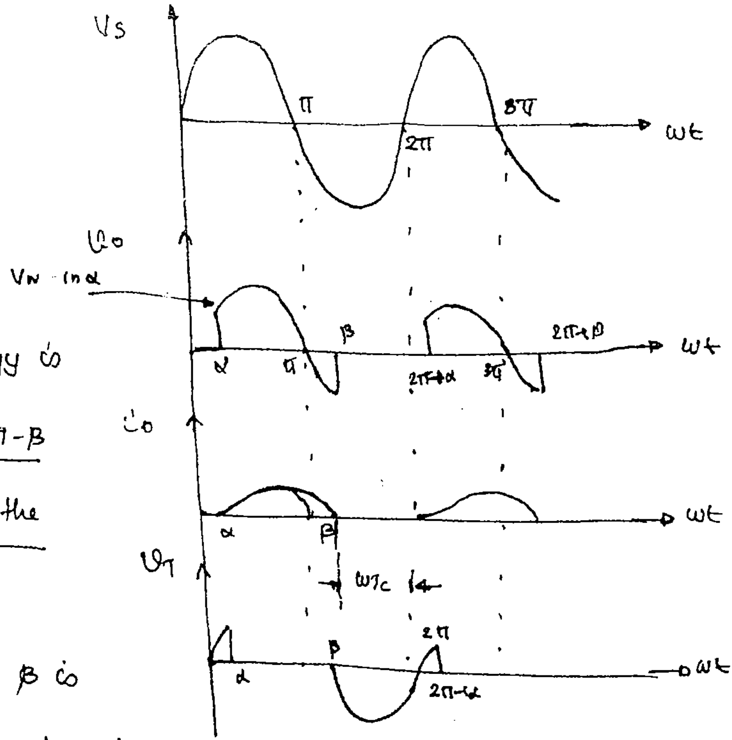
KVL at circuit

$$\Rightarrow Ri + \overset{0\ (0-2\pi)}{\cancel{L\frac{di}{dt}}} + E = V_m \sin\omega t.$$

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

II> HALF WAVE RECTIFIER WITH R-L





- During α - π conduction energy is given by the supply lines. and π-β it is given by stored energy of the inductor.

- In the case of R-L load, β is greater than π (β > π) and its value depends on the stored energy of the inductor.

- ωT_c = period in which thyristor is subjected to reverse voltage.

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

- $$V_o = \frac{1}{2\pi} \int_{\alpha}^{\beta} V_m \sin\omega t \, d(\omega t) = \frac{V_m}{\pi} \Big[-\cos\omega t \Big]_{\alpha}^{\beta}$$

$$\boxed{V_o = \frac{V_m}{2\pi} [\cos\alpha - \cos\beta]}$$

$\boxed{\beta = \text{Extinction angle}}$

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

$$V_{or}^2 = \frac{V_m^2}{4\pi} \Big[\omega t - 1/2 \sin 2\omega \Big]_{\alpha}^{\beta}$$

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

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

- $I_o = \frac{V_o}{R}$;

Note :- $Z = R + jwL$

$= R + j(2\pi f)L$

$f \Rightarrow$ wedont have cyclic frequency.

$\Rightarrow$ current varies across the device is unidirectional.

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

- Input supply pf

$$= \frac{\text{Power delivered to the load}}{\text{Source VA}}$$

$$= \frac{V_{or}^2/R}{V_s I_{sr}} = \frac{V_{or}^2/R}{V_s \cdot V_{or}/R} = \frac{V_{or}}{V_s} \Rightarrow \boxed{\text{Input supply pf} = \frac{V_{or}}{V_s}}$$

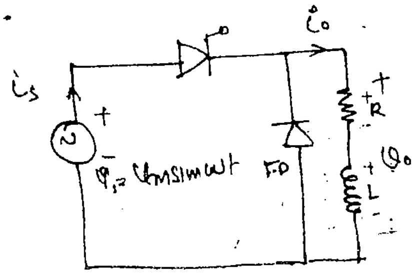
- During (α-to-π) power is +ve ($V_o \Rightarrow$ +ve, I_o is +ve) and (π to β) power is negative (V_o is -ve, I_o is +ve) hence the average power consumption would be decreased.

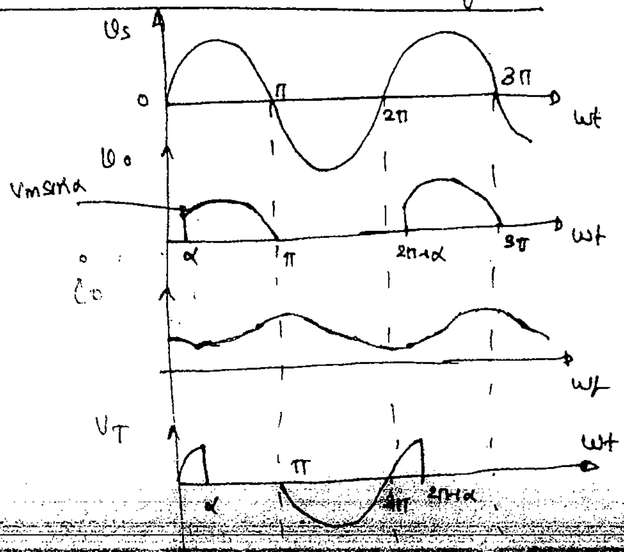
- Circuit turn off time would be less than $\frac{\pi}{\omega}$ and it is of variable.

Note:

- A Diode will be connected across the load terminal to retain the power in the load (OR) to stop the power flow to the supply lines. This diode is known as <u>FREE WHEELING DIODE</u>

III> 1ϕ HALFWAVE RECTIFIER WITH R-L LOAD and Free wheeling diode





- $wt_c = \pi$ (Turn OFF)

- $\boxed{t_c = \frac{\pi}{\omega} \text{ S}}$

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

Power Factor

$$= \frac{\text{Power delivered to load}}{\text{source volt Ampere.}}$$

(*)
- E takes average power through average value (DC component) of current.
- R takes power through rms value of current

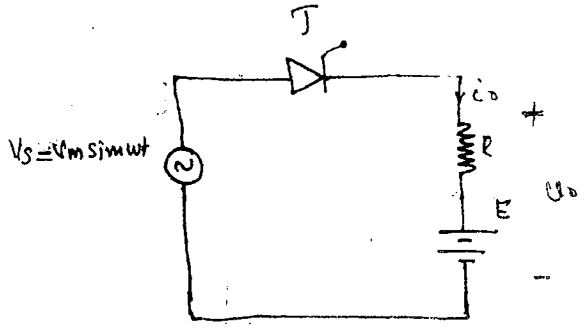
$$\boxed{P.f = \frac{E I_o + I_{or}^2 R}{V_s I_{sr}}}$$

CIRCUIT TURN OFF TIME.

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

- In the RLE load if the SCR is triggered continuosly, then it starts conduction from θ_1 onwards ($\alpha = \theta_1$)
- In the R load (or) RL load if the SCR is triggered continuosly, then $\alpha=0$.

1ϕ HALF WAVE RECTIFIER FOR R-E LOAD.



- Range of firing angle

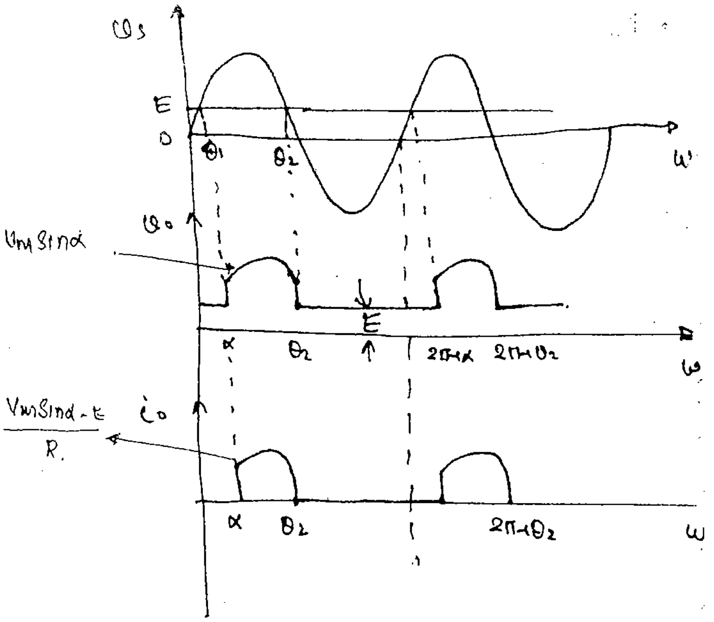
$= \theta_1 \text{ to } \theta_2$

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

$\theta_2 = \pi - \theta_1$

- Average current through $R = I_o$

$$I_o = \frac{1}{2\pi}\int_{\alpha}^{\beta=\theta_2} \frac{V_m \sin\omega t - E}{R} \cdot d\omega t$$



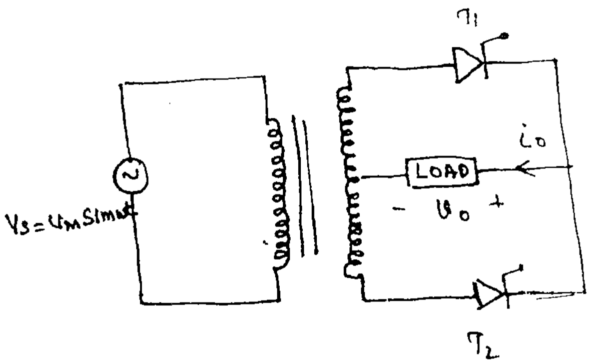
$$= \frac{1}{2\pi}\left[V_m(-\cos\omega t) - E(\omega t)\right]_{\alpha}^{\theta_2}$$

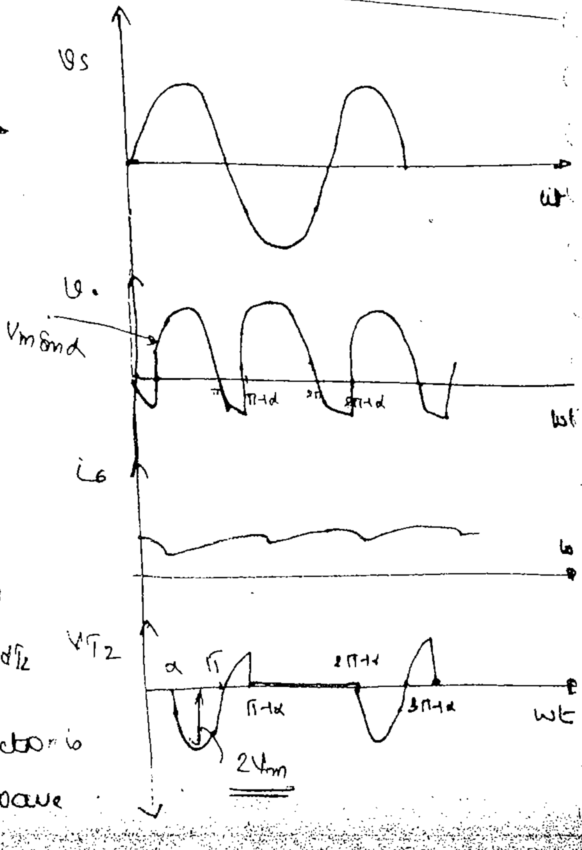
$$= \frac{1}{2\pi R}\cdot\left[V_m \cos(\alpha - \cos\theta_2) - E(\beta - \alpha)\right]$$

$V_o = E + I_oR.$

II) FULL WAVE RECTIFIER:

I) 1φ FULL WAVE MID POINT RECTIFIER





- Number of turns in the secondary is taken as such that it gives same $V_m \sin\omega t$ for T_1 and T_2

- The chance of getting the continuous conduction is more in Full wave rectifier compared to half wave rectifier.

- The O/p wave form consists of 2-pulses for one input cycle. so it is know as as single phase 2-pulse Rectifier.

- Pulse frequency obtained here is '2' times the supply frequency.

- 2Vm is the peak inverse voltage.

Vo = Average o/p voltage.

$$V_0 = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin wt \, d(wt)$$

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

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

$$\boxed{I_0 = \frac{V_0}{R}}$$

$$V_{or} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m^2 \sin^2 wt \, d(wt)}$$

$$V_{or}^2 = \frac{V_m^2}{\pi}\int_{\alpha}^{\pi+\alpha} \frac{1-\cos 2wt}{2}\, d(wt)$$

$$= \frac{V_m^2}{2\pi}\left[wt - \frac{1}{2}\sin 2wt\right]_{\alpha}^{\pi+\alpha} \qquad \left\{\sin 2\pi+\theta = \sin\alpha\right\}$$

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

$V_{or}^2 = \frac{V_m^2}{\sqrt{0}\,2}.$ $\Rightarrow$ $\boxed{V_{or} = \frac{V_m}{\sqrt{2}}}$

$V_{or} = \frac{V_m}{\sqrt{2}} = V_s.$

$I_{or} = \frac{V_{or}}{R}$ $\boxed{pf = \frac{V_{or}}{V_s}}$

Voltage Rating of SCR

- $2V_m$, $230V = V_s \Rightarrow$ Rating $= 460\sqrt{2}$.
- Cost↑
- TFR required ↑
- SCR SI&↑E

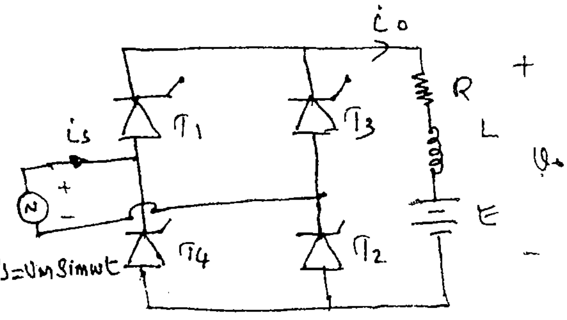
Disadvantages

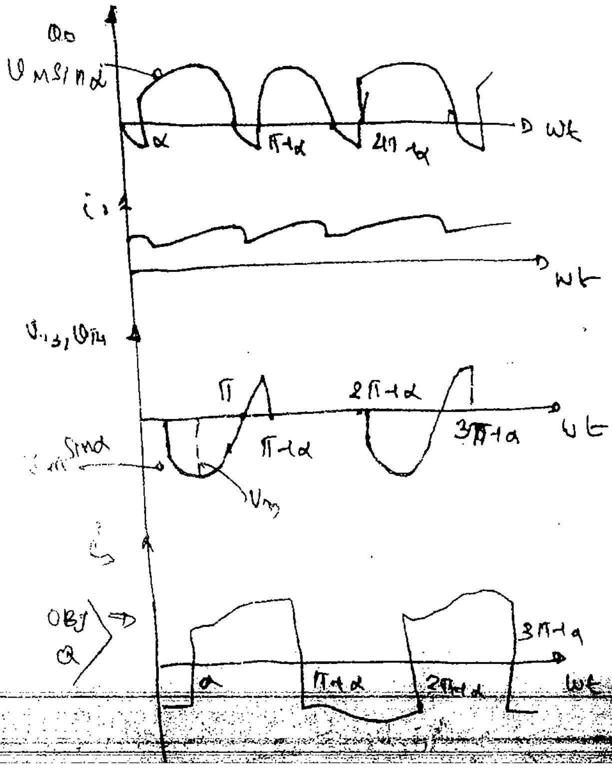
1) The PIV rating of the SCR is 2 times of the maximum value of supply voltage

2) It needs a COSTLY mid point transformer.

03/03/11

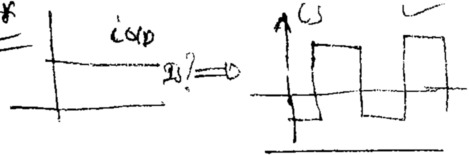
1ϕ -FULLWAVE BRIDGE RECTIFIER.





OBJQ)

✗✗



- If the o/p current is assumed to be constant then the shape of supply current would be square wave form.
- PIV rating of the SCR is same as maximum value of supply voltage.

→ Average voltage

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

$$V_{or} = V_s$$

$$I_o = \frac{V_o - E}{R.}$$

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

$$P_f = \frac{EI_o + I_{or}^2 R}{V_s I_{sr}.}$$

(RE·)

→ Motoring Application

$\alpha < 90^\circ$, $V_o > E$

→ Generator Application

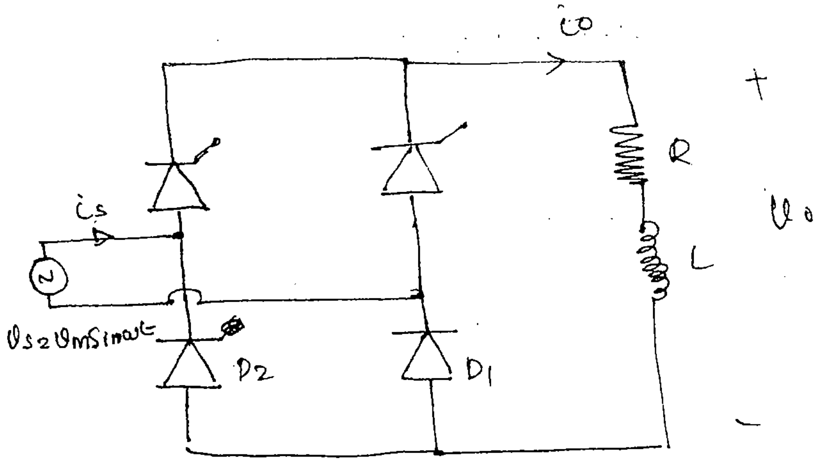
(REGENERATIVE BREAKING)

1). $\alpha > 90$ 2) E reversed. 3) $E > V$.

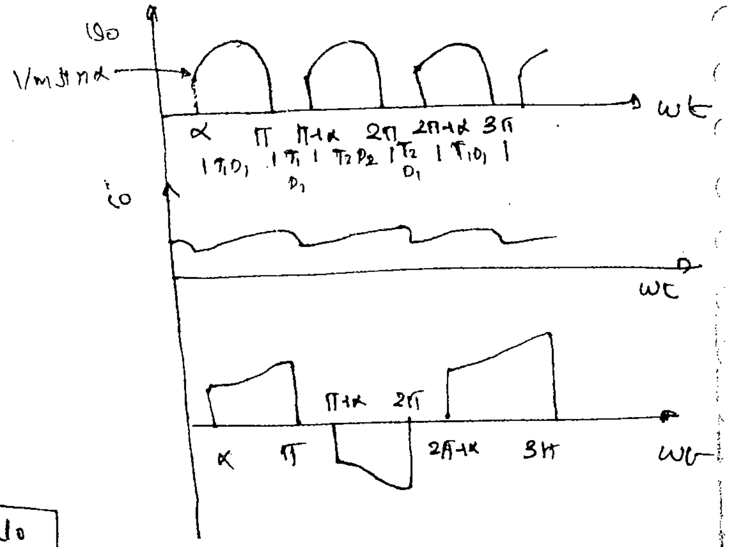
- $E = \frac{\cancel{Z}\overset{\downarrow}{\phi}\cancel{N}}{\cancel{60}} \times \frac{\cancel{P}}{\cancel{A}}$ $(\phi \Rightarrow -ve) \Rightarrow E(-ve)$
- traction N cannot make -Ve.

- If $\alpha > 90^\circ$ then the average output voltage is negative. also the average o/p power would be negative. Hence, the power flows from DC load to AC source. This operation is known as line - commutated inverter.
- Regeneration breaking employs the principle of line commutated inverter, the following conditions are to be satisfied for the Regeneration Breaking.
  - i) $\alpha > 90^\circ$
  - ii) E should reverse its polarity
  - iii) $E > V$ (generated > terminal)

1φ - SEMI CONVERTER (OR) 1φ - HALF CONTROLLED RECTIFIER.



Average voltage



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

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

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

$$\boxed{V_0 = \frac{V_m}{\pi}\left[1+\cos\alpha\right]} \quad \boxed{I_0 = \frac{V_0}{R}}$$

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

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

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

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

- Input supply

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

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

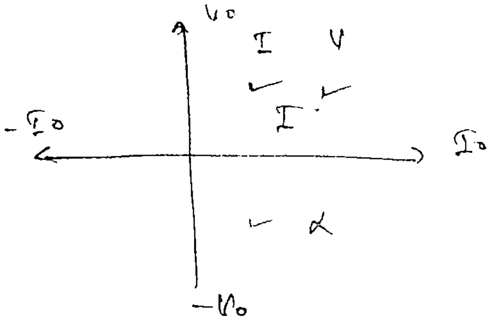
- In the semiconverter, average output voltage is always +ve. the average o/p voltage can be controlled only on positive side, so it is known as 1ϕ half controlled rectifier.

- A 1ϕ Full wave rectifier average o/p voltage can be controlled both +ve side and -ve side so it is known as single phase Fully controlled rectifier.

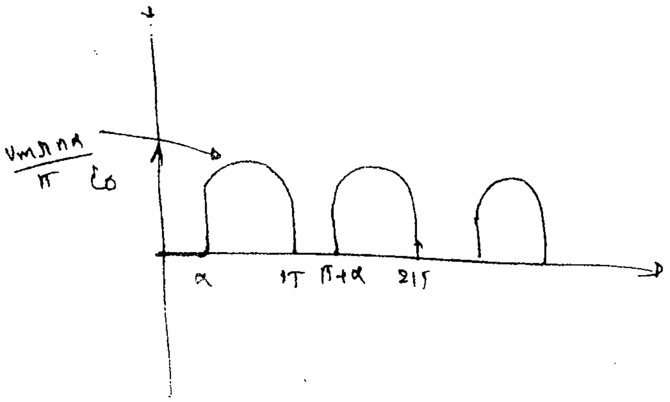
- In a Full wave bridge Rectifier a free wheeling diode is employed then it will be same as the semiconverter. and o/p voltage will always be positive.

Quadrant operation

- No ~~quade~~ -ve curr
- Vo alway +ve



1ϕ Full wave Rectifier with R-load



**

$V_0 = \frac{V_m}{\pi}(1+\cos\alpha)$ $I_0 = \frac{V_0}{R}$ $V_{or} = \frac{V_m}{\sqrt{2\pi}}\left[\pi - \alpha + \frac{1}{2}\sin 2\alpha\right]^{1/2}$

$I_{or} = \frac{V_{or}}{R}$ Input supply pf $= \frac{V_{or}}{V_s}$

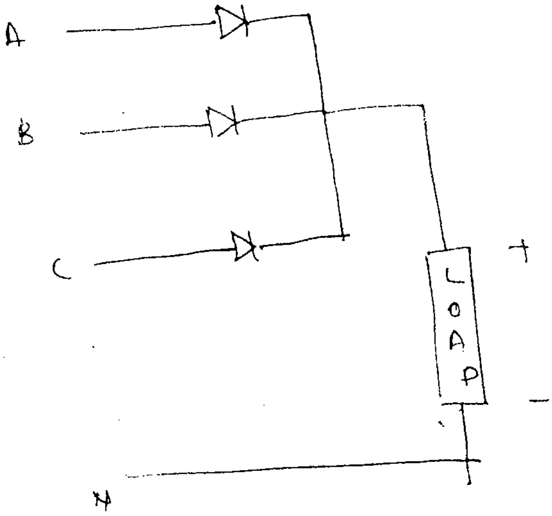
1ϕ Full wave Rectifier with R-E load. (1.10)

3ϕ HALF WAVE DIODE RECTIFIER

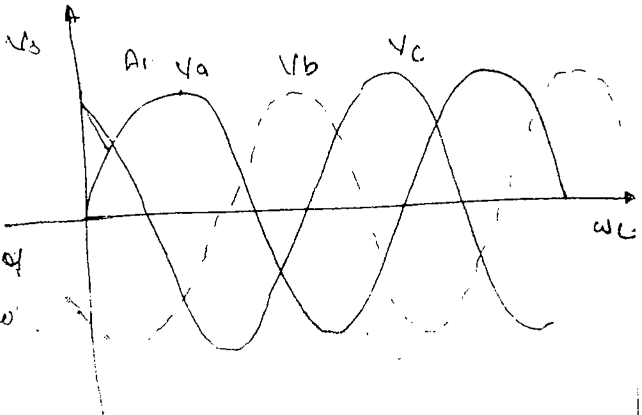
20/3/11

a) common cathode configuration b) Common anode configuration.

Common cathode configuration



- In common cathode configuration only one diode which ever is subjected to more +ve charge voltage will be in conduction.
- ~~At~~ any time the load is connected b/w. phase and neutral wires hence it subjects to phase voltages only.
- The o/p waveform to having 3 pulse for every input cycle so it is known as 3ϕ, 3pulse rectifier.
- Pulse frequency is 3 times supply frequency
- Pulse duration is 120°, conduction time of each phase is 120°, conduction time of each diode is 120°.



$$V_0 = \frac{1}{2\pi/3}\int_{30}^{150^\circ} V_{mp}\,.\sin\omega t\, d\omega t$$

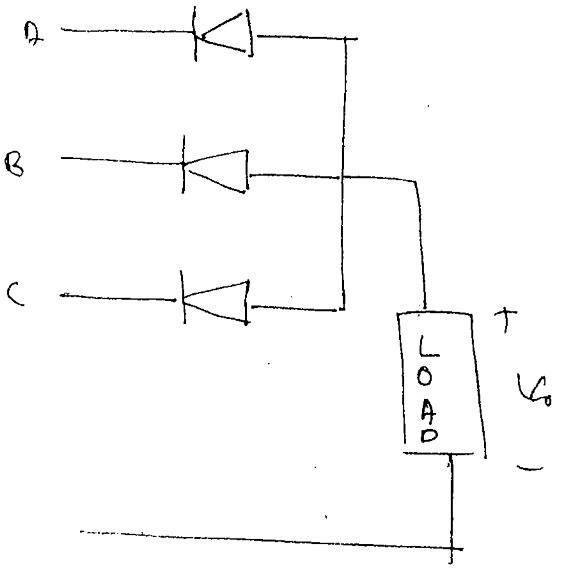
$$= \frac{3V_{mp}}{2\pi}\left[-\cos\omega t\right]_{30}^{150} = \frac{3V_{mp}}{2\pi}\left[-\cos 150 + \cos 30\right] = \frac{3V_{mp}}{2\pi}\left[2\cos 30\right]$$

$= \frac{3V_{mp}}{2\pi} \cdot 2\frac{\sqrt3}{2}$ $V_0 = \frac{3\sqrt3}{2\pi} V_{mp}$ $= V_L = \frac{3\sqrt6}{2\pi} \sqrt{2}\, V_{ph}$ $\boxed{V_0 = \frac{3\sqrt6 V_{ph}}{2\pi}}$

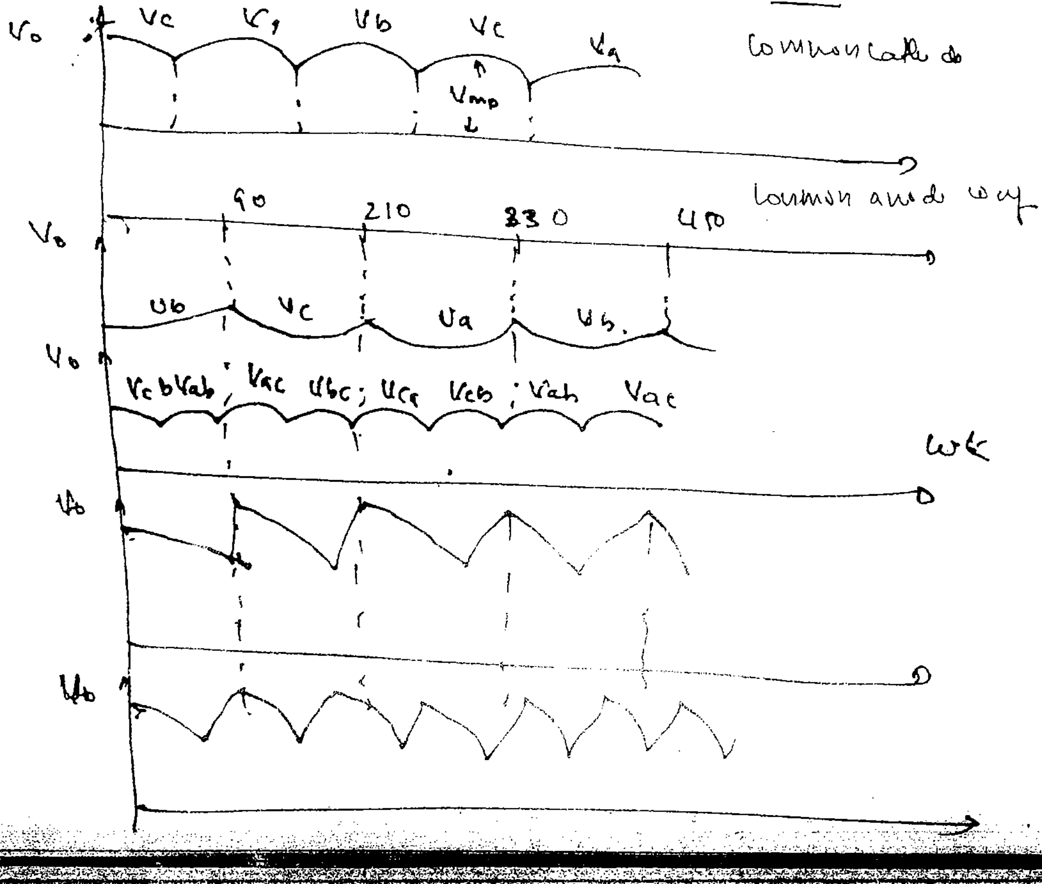
$$V_{or} = \sqrt{\frac{1}{2\pi/3}\int_{30}^{150} V_{mp}^2 \sin^2 \omega t \, d(\omega t)}$$

Common anode configuration:

- → In common anode configuration only one diode, which ever is subjected more -ve voltage will be in conduction
- → At any time load will be connected between phase and neutral wires hence, it will be subjected to phase voltages only



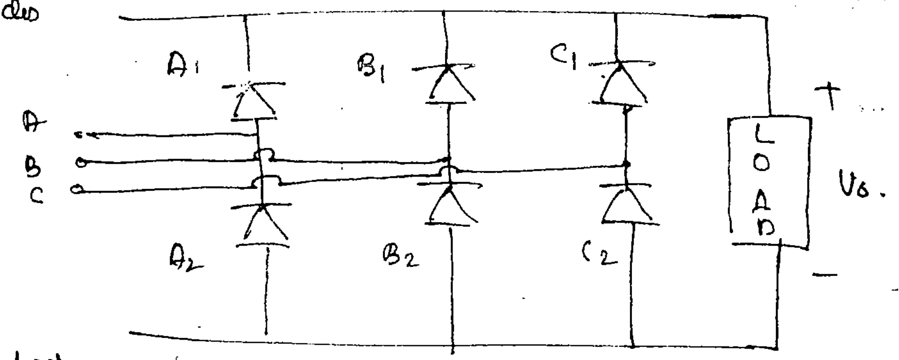
- → The polarity of the voltage is always -ve peak instantaneous o/p voltage is equal Vmp → PIV rating of diode is $\underline{V_{ml}}$.



3ϕ Full wave Diode Rectifier

→ It canbe obtained by merging common cathode and common anode configuration

- In Full wave rectifier 2diodes are conduction one diode from top group which is subjected to more positive voltage and another from bottom 2 which is subjected to more -ve voltage

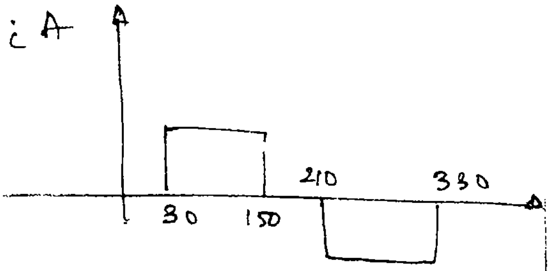


- ~~At~~ any time load is connected between 2 ~~pph~~ phase curves and hence ck subjects to less voltage.
- O/p wave form consists of 6-pulses for every input cycle so it is known as 3-ϕ 6-pulse Rectifier

1) O/p frequency = 6 fs.

2) duration of each pulse = 60°

3) conduction time of each phase = 240°



$$\to V_0 = \frac{1}{\pi/3}\int_{30^\circ}^{90^\circ} V_{ml}\sin(\omega t+30)\,d\omega t$$

$$= \frac{3V_{ml}}{\pi}\Big[-\cos(\omega t+30)\Big]_{30}^{90^\circ}$$

$$= \frac{3V_{ml}}{\pi}\Big[-\cos(90+30) - (-\cos(30+30))\Big] = \frac{3V_{ml}}{\pi}\left[\cos 60^\circ + \cos 60^\circ\right]$$

$$= \frac{3V_{ml}}{\pi}\cdot 2\cdot\cos 60^\circ = \frac{3V_{ml}}{\pi}\times 2\times 1/2$$

$$= \frac{3\sqrt{3}\,V_{mp}}{\pi} = \frac{3\sqrt{3}}{\pi}\times\sqrt{2}\,V_{ph} \Rightarrow \boxed{V_0 = \frac{3\sqrt{6}\,V_{ph}}{\pi}}$$

→ The average value of o/p voltage is 3 times of the half wave rectifier

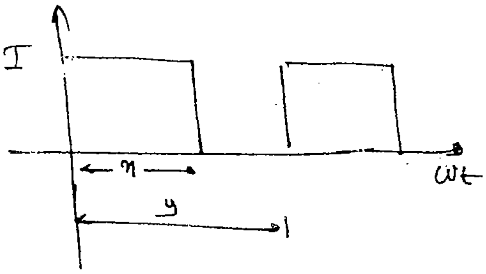
→ Peak Instantaneous o/p voltage is equal V_{ml}.

→ Peak Inverse Voltage (PIV) is equal to V_{ml}

Note :-

$i_{avg} = i \, x/y$.

$i_{rms} = i \sqrt{x/y}$



1) → In a 3φ Half wave rectifier assume that output current is constant (I) than average value of diode current (I_{DA})

→ $I_{DA} = I_{SA} = I\left(\frac{120}{360}\right) \Rightarrow \boxed{I_{DA} = \frac{I}{3}}$

• Rms value of diode current $I_{DR} = I_{SR} = I\sqrt{\frac{120}{360}}$

$$\boxed{I_{DR} = \frac{I}{\sqrt{3}}}$$

2) → In a 3φ full wave rectifier, assuming that o/p current is constant then average value of diode current $I_{DA} = I\left(\frac{120}{36}\right)$

$= \frac{I}{3}$.

→ Rms value of diode current $= \frac{I}{\sqrt{3}}$.

3) Supply

$I_{avg} = 0$

$I_{rm} = I_{sr} = I\sqrt{\frac{240}{360}} = I\sqrt{2/3}$

3ϕ - Half wave thyristor Rectifier

$$V_o = \frac{1}{2\pi/3} \int_{30+\alpha}^{150+\alpha} V_{mp} \sin(\omega t)\, d\omega t$$

$$= \frac{3V_{mp}}{2\pi}\left[-\cos\omega t\right]_{30+\alpha}^{150+\alpha}$$

$$= \frac{3V_{mp}}{2\pi}\left[\cos(30+\alpha) - \cos(180-(30+\alpha))\right]$$

$$= \frac{3V_{mp}}{2\pi}\left[\cos(30+\alpha - \cos(-0-\alpha)\right]$$

$$= \frac{3V_{mp}}{2\pi} \cdot 2\cos 30 \cdot \cos\alpha = \frac{3V_{mp}}{\pi} \cdot \frac{\sqrt{3}}{2} \cdot \cos\alpha.$$

$$= \frac{3\sqrt{3}}{2\pi} \cdot V_{mp} \cos\alpha$$

$$\boxed{V_o = \frac{3\sqrt{6}}{2\pi} V_{ph} \cos\alpha}$$

3ϕ - Full wave thyristor circuit

$$V_o = \frac{1}{\pi/3} \int_{30+\alpha}^{90+\alpha} V_{ml} \sin(\omega t+30)\, d(\omega t)$$

$$= \frac{3V_{ml}}{\pi}\left[-\cos(\omega t+30)\right]_{30+\alpha}^{30+\alpha}$$

$$= \frac{3V_{ml}}{\pi}\left[\cos(60+\alpha - \cos(120+\alpha)\right]$$

$$= \frac{3V_{ml}}{\pi}\left[\cos 60 \cdot \cos\alpha - \sin 60 \sin\alpha - \cos 120 \cdot \cos\alpha \right.$$
$$\left. + \sin 120 \sin\alpha\right.$$

$$= \frac{3V_{ml}}{\pi}\, 2\cos 60 \cdot \cos\alpha$$

$$= \frac{3V_{ml}}{\pi}\cos\alpha = \frac{3\sqrt{3}\,V_{mp}}{\pi}\cos\alpha$$

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

1) In a 3φ half wave rectifier feeding R-load, α < 30° conduction is continuous conduction $V_0 = \frac{3\sqrt{6}}{2\pi}V_{ph}\cos\alpha$ for α > 30° conduction becomes discontinues

$$V_0 = \frac{1}{2\pi/3}\int_{30+\alpha}^{180^\circ} V_{mp}\sin\omega t\, d(\omega t)$$

$$= \frac{3V_{mp}}{2\pi}\Big[-\cos\omega t\Big]_{30+\alpha}^{180}$$

$$= \frac{3V_{mp}}{2\pi}\Big[\cos(30+\alpha) + \cos 180\Big]$$

$$\boxed{V_0 = \frac{3V_{mp}}{2\pi}\Big[1+\cos(30+\alpha)\Big]}$$

Chapter - 2

14/03/11

01.) R-load $P = \frac{V_{or}^2}{R}$

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

$$= \frac{220\sqrt{2}}{2\sqrt{\pi}}\Big[\pi - \overset{\text{radian}}{60\times\frac{\pi}{180}} + \frac{1}{2}\underbrace{\sin(2\times 60)}_{\text{degree}}\Big]^{1/2}$$

No problem or with radian

$= \underline{139.72V}$

$$P = \frac{139.72^2}{10\Omega}$$

$= \underline{1947 W}$

$$pf = \frac{V_{or}}{V_s} = \frac{139.72}{220} = 0.634 \text{ lag}$$

↑

By default

62) A S1 a) $V_T = V_m \sin\alpha - E$

$= 230\sqrt{2} \sin 25 - 120$

$= \underline{17.46V}$

b) at $\omega t = \beta$, $I = 0$.

$V_T = V_m \sin\beta - E$

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

$= \underline{-329V}$

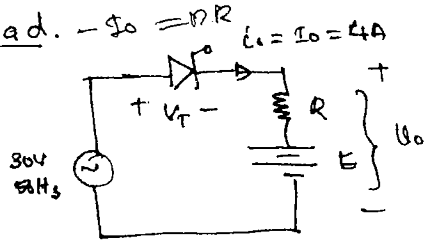
c) <u>PIV</u> $= |V_m| + |E|$

$= 230\sqrt{2} + 120$

$= \underline{445.34}$

---

03) <u>RE load.</u> − I_0 = nR $i_0 = I_0 = 4A$



$\alpha = \theta_1$

$\beta = \theta_2$

$\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right) = \sin^{-1}\left(\frac{6}{30\sqrt{2}}\right)$

$= 8.13°$

$\theta_2 = 180 - 8.13$

$= 171.87°$

IESQ

− $\alpha = 0$

$\omega t = \theta_2$

draw

derivation waveform

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

1V = drop. when conduction Practical

$$= \frac{1}{2\pi R}\Big[V_m(-\cos\omega t) - (E+V_T)\,\omega t\Big]_{\alpha}^{\beta}$$

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

$$= \frac{1}{2\pi R}\Big[30\sqrt{2}\cos 8.13 - \cos 171.87 - (6+1)(171.87 - 8.13)\frac{\pi}{180}\Big]$$

$\underline{R = 2.54}$ ⟹ write theory

OBS:

---

4) <u>RE load</u>

always $\boxed{\beta = \theta_2}$

≠ $\underline{180 - \alpha}$

$\theta_2 = 180 - \theta_1$

$\alpha = 30°$,

θ_1 = calculate

$\beta = 180 - \theta_1$

$\theta_1 = \sin^{-1}(E/V_m)$

$= \sin^{-1}(110/230\sqrt{2}) = \underline{19.76°}$

$\theta_2 = 180 - 19.76 = \underline{160.24°}$

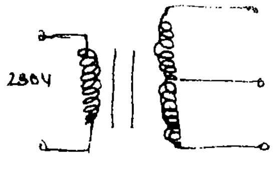
$$I_0 = \frac{1}{2\pi R}\Big[V_m(\cos\alpha - \cos\beta) - E(\beta-\alpha)\Big]$$

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

$I_0 = 5.37A$

---

5) ~~In a sing~~' <u>each</u> secondary



$\frac{N_p}{N_{S1}} = 1.25 = \frac{V_p}{V_{S1}}$

$V_S = V_p = 230V$

$\underline{R = 2\Omega}$

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

$V_0 = V_{0max}$

$\alpha = 0.$

$V_1 = V_{0max} = \frac{V_m}{\pi}(1+\cos 0)$

$= \frac{2V_m}{\pi}$

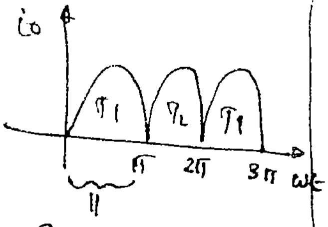
$= \frac{2 \times 260.2}{\pi}$

$= \underline{\underline{165.63V}}$

b) $I_{0max} = \frac{V_{0max}}{R} = \frac{165.63}{2}$

$= \underline{\underline{82.83A}}$

$\underline{\underline{\alpha = 0^\circ}}$



conduction angle

$(\gamma) = \underline{\underline{180^\circ}}$

Thyristor conducting here

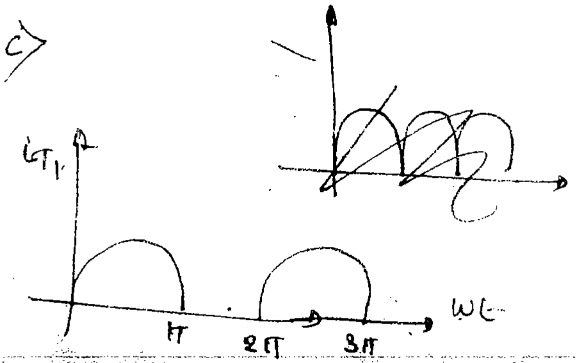
b) $PIV = 2\cancel{V_m} = 2V_{s1}$

Turn Ratio is different

$= 2 \times 260.2$

$= \underline{\underline{520.4V}}$

c)



$I_{TR} = \frac{82.83}{2} = \underline{\underline{41.41A}}$

d) $V_0 = 100V.$

$V_0 = \frac{V_m}{\pi}[1+\cos\alpha]$

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

$\alpha = \underline{\underline{78^\circ}}$

---

6) R+E load

~~Vor~~ $= \frac{V_m}{\pi} \Rightarrow$ (Semi converter)

$V_0 = \frac{V_m}{\pi}[1+\cos\alpha]$

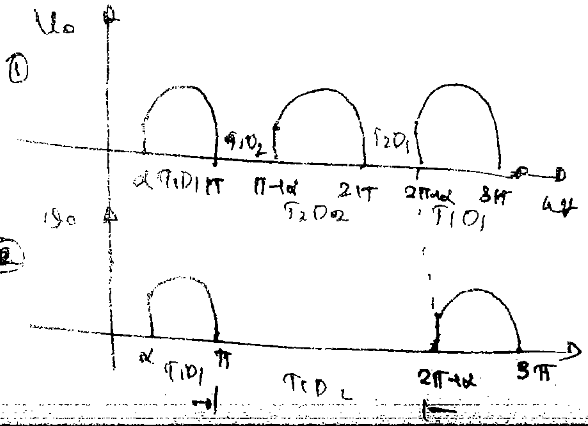
$= \frac{230\sqrt{2}}{\pi}[1+\cos 50]$

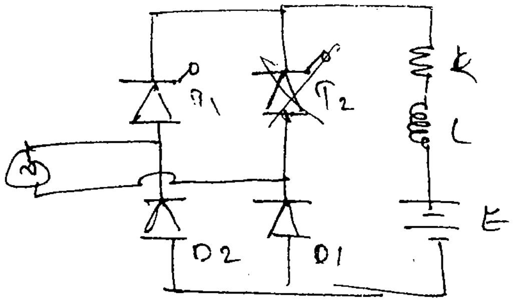
$= \underline{\underline{170V}}$

$V_0 = E + I_0R$

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

→ New value of average o/p current $\underline{\underline{I_0 = 0}}$





IES Description — show waveforms + Equivalent ckt

- T2 got damaged, ^ the available path for the currents are, free whichever path is available

· available path are T1D1 and T1D2 — Supply opposes

here current will pass through T1D2 which is equal to free wheeling path. Inductor is able to give energy from π to 2π+α (it supports) here the o/p voltage from π to 2π+α V0 is zero.

→ This wave form looks like half wave rectifier.

· do the duration of zero allow

· average value

→ $V_0 = \frac{V_m}{2\pi}[1+\cos\alpha]$ (170%.)

$= \frac{230\sqrt{2}}{2\pi}[1+\cos 30] = \underline{\underline{85V}}$

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

---

7) It is a continuous conduction since current in the load circuit is of constant

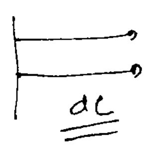
$V_0 = \frac{\textcircled{2}V_m}{\pi}\cos\alpha$ — continuous conduction (ve sign is there)

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

$= E + I_0R$

$\Rightarrow I_0 = \frac{199.3-100}{2.5} = \underline{\underline{31.72A}}$

p.f. · input pf $= \frac{EI_0 + I_{or}^2\cdot R}{V_s I_{sr}}$



$= \frac{\cancel{199}\ 100\times 31.72 + (31.72)^2\cdot(2.5)}{230\times 31.72}$

$= \underline{\underline{0.78\ \text{Lag}}}$ → By default it is zero

---

8) a) $\beta = 200^\circ$

→ Current extinguishes means the conduction is discontinuous. ~~The~~ In RLE load, here the 'L' is not capable to support the continuous flow of current. Remember.

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

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

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

$$I_o = \frac{1}{2\pi}\left[230\sqrt{2}\,(\cos 30 - \cos 200) - 100\,(200-30)\pi/180 \right]$$

$V_o = E + I_oR.$

$= 100 + (46.25 \times 2)$

$= \underline{\underline{192.5V}}.$

H.W

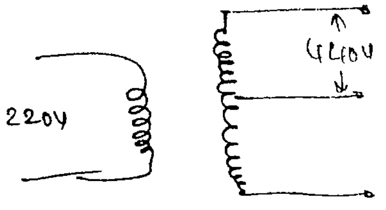
$\beta = 170^\circ$, $\underline{I_o = 56.82A \,/\, V_o = 213\text{-}1V}$

8a) $\frac{N_p}{N_{S_1}} = 1/2$

$I_o = 5A$

$\alpha = 35^\circ$

$V_p = 220V$



1:2

$V_{S_1} = \underline{\underline{440V}}$ (2 x turn Ratio)

$V_{S_1m} = 440\sqrt{2} = \underline{622V}$

– constant load current continuous conduction

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

$= \frac{2 \times 622}{\pi} \cos 35^\circ$

$= \underline{\underline{324.5V}}$

(c) $V_o = ~~V_{ph}~~ \frac{3\sqrt{6}}{2\pi} V_{ph}$

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

$= \underline{\underline{270V}}$

$I_o = \frac{V_o}{R} = \frac{270}{5} = \underline{\underline{54A}}$

---

12) $V_o = \frac{3\sqrt{6}}{2\pi} V_{ph}. \cos\alpha$

$\alpha = 0.$

$V_o = \frac{3\sqrt{6}}{2\pi} \times \frac{400}{\sqrt{3}} \times \cos 0$

$= \underline{\underline{270V}}$

$P = V_o I_o$

$= 270 \times 30$

$= \underline{\underline{8100 W}}$

b) $\alpha = 80^\circ$

$V_o = \frac{3\sqrt{6}}{2\pi} V_{ph}. \cos\alpha$

$= \frac{3\sqrt{6}}{2\pi} . \frac{400}{\sqrt{3}} . \cos 80$

$\cos\alpha = 46.9V$

$P = V_o I_o$

$= 46.9 \times 30 = \underline{\underline{1407 W}}$

13) a) $E = 110V$, $R = 0.2\Omega$, $I_o = 10A$

$V_L = 220V$.

$V_o = E + I_o R$

$= 110 + (10 \times 0.2)$

$= \underline{\underline{112V}}$

RE load

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

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

$\Rightarrow \alpha = \underline{\underline{67.8^\circ}}$

Power on dc side

$P.f = \frac{EI_o + I_{or}^2 R}{\sqrt{3} V_L I_L}$ (RE load)

Power on ac side 3φ

$= \frac{110 \times 10 + (10)^2 . (0.2)}{\sqrt{3} \times 220 \times (I_L) 10\sqrt{2/3}}$

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

14/03/12

$\boxed{pf = 0.36 \text{ Lag}}$

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

$I_o = 10A$ $\quad E = -110$

(conditions for power tfr $\alpha > 90^\circ$, E)

$V_o = E + I_o R$

$= -110 + 10 \times 0.2$

$= \underline{-108V}$

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

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

$V_{ph} = \underline{\underline{53.34}}$

$V_L = \sqrt{3} V_{ph}$

$= \sqrt{3} \times 53.34$

$= \underline{\underline{92.36V}}$

---

14) 3φ F.W.TR, $I_o = 50A$, $V_o = 230V$

$V_L = 415V$, $V_T = 1.1V$.

$V_o = 230 + 2 \times 1.1$

$= 232.2V$

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

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

a) $\alpha = \underline{\underline{65^\circ}}$

b) rms and avg SCR.

$I_{ar} = I_o \sqrt{\frac{1}{3}}$

$= 50\sqrt{1/3} = \underline{\underline{28.87A}}$

c) $I_{sr} = I_L = I_o\sqrt{2/3} = 50\sqrt{2/3}$

$= \underline{\underline{40.82A}}$

15) half controlled = SEMI CONVERTER

but full wave rectifier

1φ S.C, $R = 10\Omega$, $E = 100V$

$\alpha = 60^\circ$, $V_s = 200V$,

• RE Load $\beta = 1\cancel{80}\ \theta_2$

$\theta_2 = \overset{\pi}{180} - \theta_1$

• $\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right) = \sin^{-1}\left(\frac{100}{200\sqrt{2}}\right)$

$= \underline{20.7}$

$= 180 - 20.7$

$\theta_2 = 159.3^\circ$

$$I_o = \frac{1}{\pi}\int_{\alpha}^{\beta} V_m \sin\omega t$$

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

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

$$= \frac{1}{\pi\times 10}\left[200\sqrt{2}\,(\cos 60 - \cos 159.3\right.$$

$$- 100\,(159.3 - 60)\frac{\pi}{180}$$

$= \underline{7.4A}$

a) RLE load

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

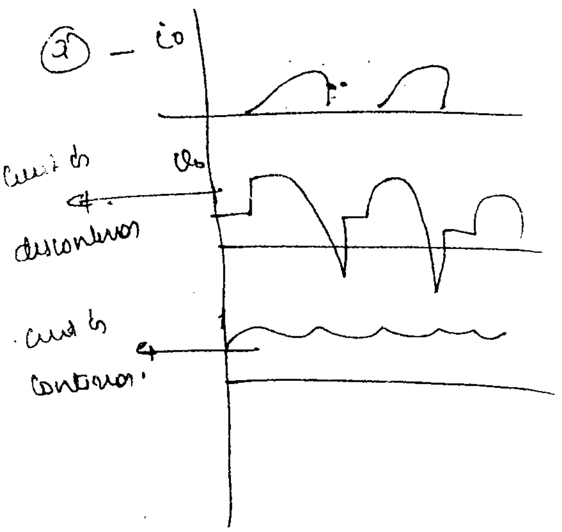
$$= \frac{200\sqrt{2}}{\pi}\left[1 + \cos 60\right]$$

$$I_o = \frac{135 - 100}{10} \quad \left(\frac{V_o - E}{R}\right)$$

$= \underline{3.5A}$

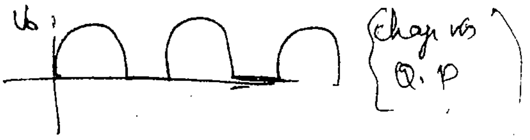
18)

(a) —



• Continuous conduction either with RL load or RLE load

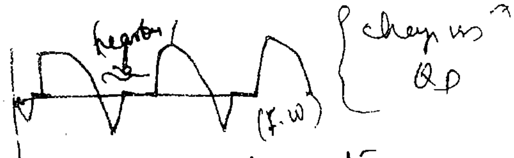
c)



? R load, $\alpha = 0$ (Ch wave)

2) 1/2 wave diode with R

d)



R-L load with discontinuous conduction

$\theta_2 = 180 - 37.94 = \underline{142^\circ}$

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

$$I_o = \frac{1}{2\pi R}\cdot\Big[V_m(-\cos\omega t) - E(\omega t)\Big]_{\alpha}^{\beta}$$

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

$$= \frac{1}{2\pi R}\Big[230\sqrt{2}\,(\cos 37.94 - \cos 142)$$
$$- 200\,(142 - 37.94)\boxed{\frac{\pi}{180}}$$

$\underline{I_o = 11.9A}$

---

25) displacement factor = $\cos\alpha$

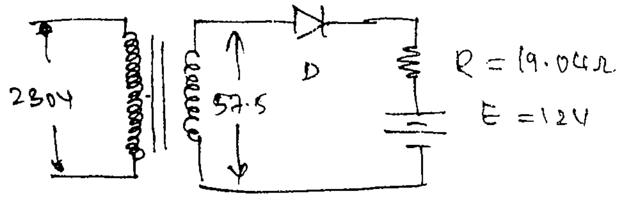
power factor = $0.92 \cos\alpha$

single phase converter

---

26) uncontrolled - diode Rectifier

*** load - RE load.



4 : 1

OBS

→ Thyristor triggered by a constant dc signal ~~supply~~ equivalent to diode circuit

→ diode circuit is here, operation is going to be same.

$$\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right) = \sin^{-1}\left(\frac{12}{57.5\sqrt{2}}\right)$$

$= \underline{8.48^\circ}$

$\theta_2 = 180 - \theta_1 = 180 - 8.48^\circ$

$= \underline{171.52^\circ}$

→ Io same derivation

$$I_o = \frac{1}{2\pi}\int_{\theta_1}^{\theta_2} \frac{V_m \sin\omega t - E}{R}\, d(\omega t)$$

$$= \frac{1}{2\pi R}\Big[V_m(\cos\theta_1 - \cos\theta_2) - E(\theta_2 - \theta_1)\Big]$$

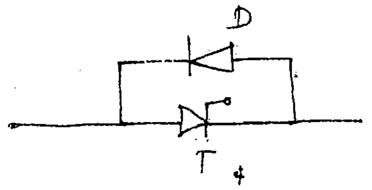
$$= \frac{1}{2\pi \times 19.04}\Big[57.5\sqrt{2}\,(\cos 8.48 - \cos 171.52) - 12(171.52 - 8.48)\frac{\pi}{180}\Big]$$

$= \underline{1.05A}$

R = 19.04 answer would be, Round figure.

---

27)

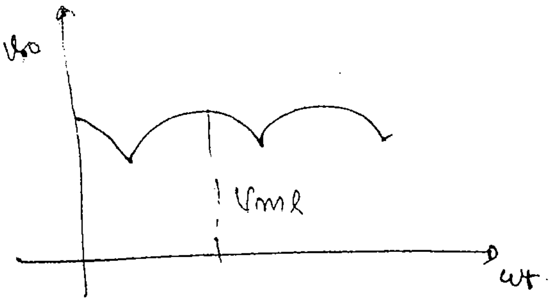


I → D conducts, thyristor gets reverse voltage so turn off obtained.

Usually diode voltage is 1V.

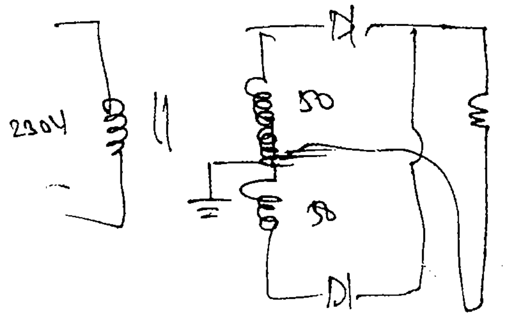
hence turn off time more, power loss decreases, turn on reduces

19)



$V_{ml} = \underline{400\sqrt{2}}$

20)



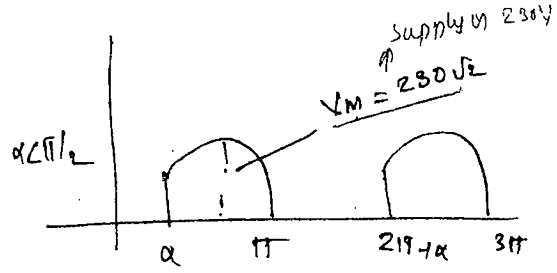
230V / 50-0-50V

. 50 - rms value   Rating are rms value

. $(50+50) = 100$

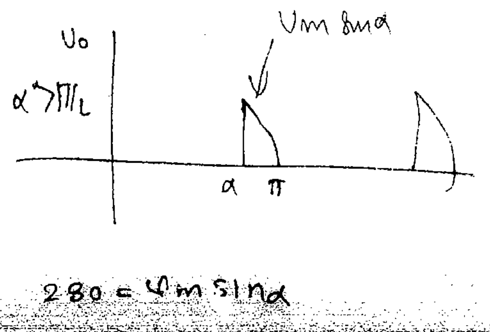
. $PIV = \underline{100\sqrt{2}}$

21)



→ given
here $PIV = \underline{230}$ Not $\underline{230\sqrt{2}}$

→ $\underline{\alpha > 90^\circ}$



$280 = V_m \sin\alpha$

$V_m = 230\sqrt{2} \sin\alpha$ α 104R 7am-1pm
- EMT (309)
6-8.30
- Power E 307

$\alpha = \sin^{-1}(1/\sqrt{2})$

$\alpha = \underline{45^\circ}$ (or) 135°

22) *** FORMULA.

~~Input~~ displacement factor = cosα

Power factor = $\underline{0.9 \cos\alpha}$

23) Inverter operation.

∴ α? $E = 350V$
$V_l = 440V$
$I_o = 20A$
$R = 0.5\Omega$

here $E = -350V$

$V_o = E + I_oR = -350 + 20 \times 0.5$
$= \underline{-340V}$

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

$-340 = \frac{3\sqrt{6}}{\pi} . \frac{440}{\sqrt{3}} . \cos\alpha$

then $\alpha = 125^\circ$.

24) RE load.

. one SCR damaged ⇒ Circuit is half wave rectifier feeding RE load.

conduction starts at θ_1 (contain DC)

. $\theta_1 = \sin^{-1}\left(\frac{E}{V_m}\right) = \sin^{-1}\left(\frac{200}{230\sqrt{2}}\right)$
$= \underline{37.94^\circ}$

28) Displacement power factor. check the answers it is given in values. $\cos 60 = 0.5$ here they meant it as power factor.

29) $I_{or} = \frac{150}{\sqrt{3}}$ · d

30) d | Commonsense

31) to work as inverter $= 90° - 180°$

d) Back emf means motor load. may back emf battery solar cell any thing to achieve line commutated operation

c) If 'c' option is not there d is the ans, but here c is the ans, c is from dc load.

Note: here commutator inverter can be used in Regenerative braking energy transfer to load to source

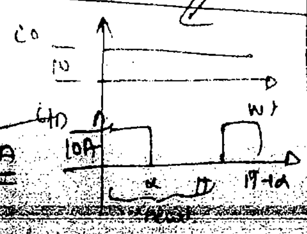
32) $V_0 = \frac{3\sqrt{6}}{\pi} V_{ph} = \frac{3\sqrt{6}}{\pi} \cdot \frac{440}{\sqrt{3}} = 594V$

33) Half controlled / semi converter Not possible to get negative voltage it is possible only in FWR

diode avg current ②

$I_{DA} = I_0 \cdot \frac{\alpha}{\pi}$

$= 10 \cdot \frac{60}{180} = 3.31A$



34) Semi converter $V_s = 120V$, $\alpha_1 = 0°$, $\alpha_2 = 180°$

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

For $\alpha = 0$ For $\alpha = 180$

$V_0 = \frac{2V_m}{\pi}$ $V_0 = 0$

$\left(\frac{2 \times 120\sqrt{2}}{\pi}, 0 \right)$

ⓐ

35) BLOWER/EXHAUST FANS :- required to be operated only in one direction. The average voltage required is only +ve. ∴ half controlled at +ve side enough. ∴ 'c' is best ans.

36 - H.W

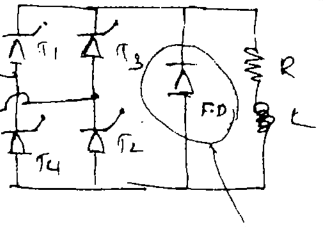
37) continuous conduction, Full wave converter

$V_0 = \frac{2V_m}{\pi} \cos\alpha = 2 \cdot \frac{230\sqrt{2}}{\pi} \cdot \cos 60° = 103.5V$

$I_0 = \frac{V_0 - E}{R} = \frac{103.5 - 50}{10} = 5.35A$
RLE

38) No negative portion same as ~~a~~ semicon ⓐ

$$\boxed{V_0 = \frac{V_m}{\pi}[1 + \cos\alpha]}$$ ①



Not the $\frac{2V_m}{\pi}\cos\alpha$

$V_0 = \frac{280\sqrt{2}}{\pi}[1 + \cos 60°] = 155.3V$

$I_0 = \frac{V_0}{R} = \frac{155.3}{15.53} = 10A$ I avg thy diode =
R-L.

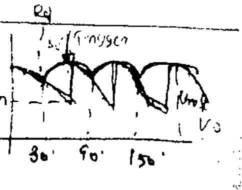
✗ Not this.

39) $\Delta V - V_{max} - V_{min} = V_{ml} - \boxed{V_{min}}$

Pulse Numbering $= V_0 = V_{ml}\sin(\omega t + 30°)$ $V_{min} = V_{ml}$

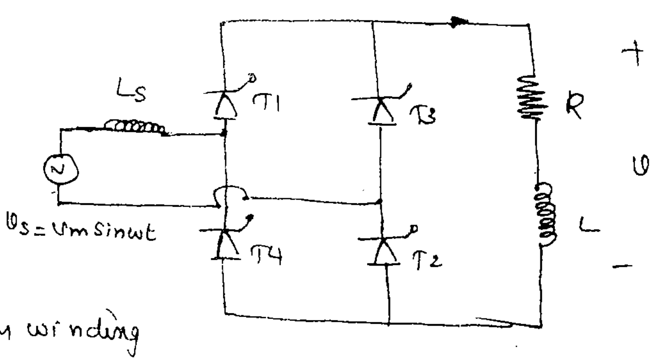
$= V_{ml}\sin(180 + 30)$
$= V_{ml} - V_{ml}\sin 150$
$= V_{ml} - 0.5V_{ml} =$

$\Delta V = 0.5V$ - Voltage ripple w.r.t peak value



EFFECT OF SOURCE INDUCTANCE ON THE PERFORMANCE OF RECTIFIER.

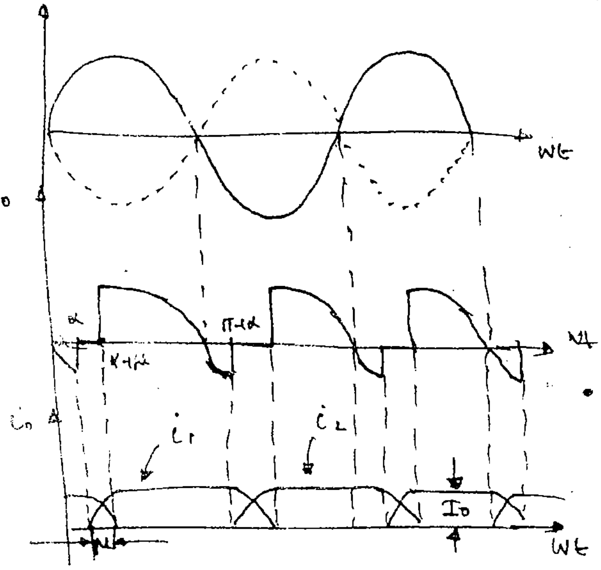
1) 1 – ϕ Rectifier



- μ = over lapping angle
- $V_1 = V_m \sin\omega t$.

$V_2 = -V_m \sin\omega t$

- Inductance generally comes from winding coils of alternator source. Assume that V_s inductance is Ls.
- Ideally if i_1 is there i_2 will not be there but due to overlapping for period of (α to $\alpha+\mu$) both of them occur at a time.



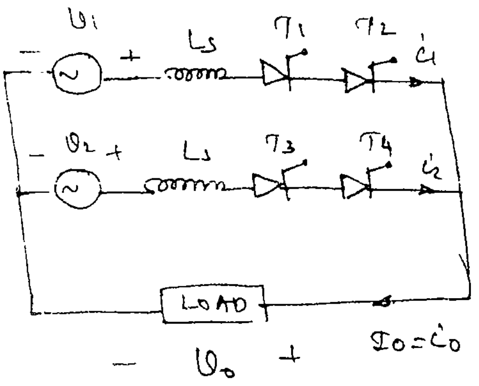
- **V_1 and V_2 – two supplies.**
- Consider supply +ve half. T_1T_2 conductors

1) KVL ⇒ $L_s \cdot \frac{di_1}{dt} + Ri_0 + L\frac{di_0}{dt}$ ①

Sup – to +

$= V_m \sin\omega t$

- here but, T_3 and T_4 conducts at (α to $\alpha+\mu$)



2) Sup + to – . T_3T_4

$$L_s\frac{di_2}{dt} + Ri_0 + L\frac{di_0}{dt} = -V_m \sin\omega t \quad ②$$

. from ① and ① Equivalent circuit is drawn

3) α to $\alpha+\mu$: $V_0 = 0$? ⇒ $V_{avg} = \frac{2V_m}{\pi}\cos\alpha - \{\ \ ?\ \ \}$

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

p a $140 = \frac{2\times 330}{\pi}\cos 45 - \frac{314 L_s}{\pi}\cdot 5$

$L_s = 17.11\,mH$

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

$\cos(45+\mu) = \cos 45 - \frac{314\times 17.11}{330}\cdot 5$

$\mu = 6.26°$

3) $\frac{V_0}{I_0} = \frac{140}{5} = 28\Omega$

12) $R = \frac{V_0}{I_0} = \frac{250}{25} = 10\Omega$

$\omega = 2\pi f$
$= 2\pi\times 50$
$= 314$

$V_0 = \frac{3\sqrt{6}}{\pi}\cdot V_{ph}\cos\alpha - \frac{3\omega L_s}{\pi}\cdot I_0$

$250V = \frac{3\sqrt{6}}{\pi}\cdot\frac{400}{\sqrt{3}}\cdot\cos 0 \quad \frac{3\times 314\cdot L_s}{\pi}$

$L_s = 2.68\,mH$? — ???

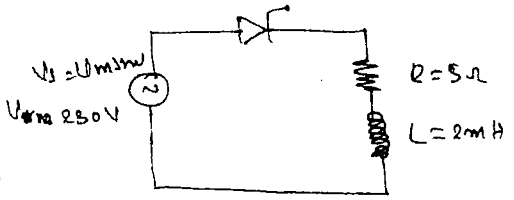
12) $\cos(\alpha+\mu) = \cos\alpha - \frac{\textcircled{2}\omega L_s}{V_{ml}}\cdot I_0$

$\mu = 4.8°$

IES2007

Q) A 230V, 50Hz, 1 pulse, SCR controlled converter is triggered at a firing angle of 40° and the load current extinguished at an angle of 120°. Find the circuit turn OFF time, average o/p voltage, average load current. for R = 5Ω and L = 2mH

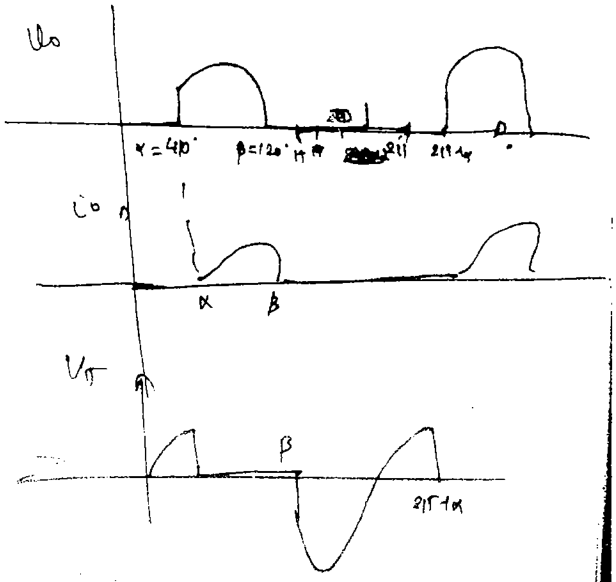
Sol:



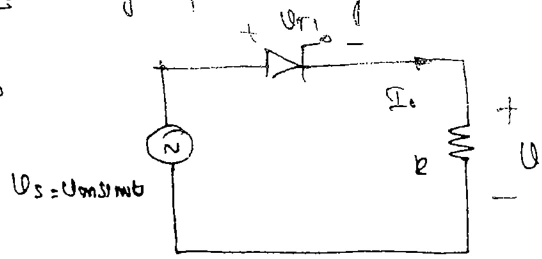
- Half wave Rectifier R-L load.
- They can stop the ~~commutation~~ Rectifier at 120° using Forced commutation. Extinction angle control.
- average V_0, I_0 is $\frac{V_m}{2\pi}(\cos\alpha - \cos\beta)$

$I_0 = \frac{V_0}{R}$

- Turn OFF time Sir will Later.



4) <u>2005</u> A single phase Thyristor converter with a resistive load as shown below



supply voltage V_s is sinusoidal at a fixed frequency

~~at a frequency~~

i) Draw the ~~already~~ wave forms for V_s, V_o and V_{T1} ~~and~~ at the firing angle $\alpha = 45°$. (Neglect leakage current)

ii) If the supply voltage is 280V (rms) ~~at~~ 50Hz, when $\alpha = 45°$ and $R = 100\Omega$ calculate,

a) Average o/p voltage and current

b) rms value of supply current

c) Ripple factor.

20 - 25 marks

derive the formula used ?

Sol:

ii) $V_s = 280V$, $\alpha = 45°$, $R = 100\Omega$.

a) $V_o = \frac{V_m}{\pi}[1 + \cos\alpha] = \frac{230\sqrt{2}}{\pi}[1 + \cos 45] = 88.37V$

$I_o = \frac{V_o}{R} = \frac{88.37}{100} = \underline{\underline{0.8837A}}$

b) rms value of supply current. ($I_o = I_s$), $V_{or} = \frac{V_m}{2\sqrt{\pi}}[\pi - \alpha + \frac{1}{2}\sin 2\alpha]^{1/2}$

$= \frac{230\sqrt{2}}{2\sqrt{\pi}}\left[\pi - 45 * \underbrace{\frac{\pi}{180}}_{\text{Radian}} + \frac{1}{2}\sin(2 \times 45)\right]^{1/2} = \underline{\underline{155V}}$

$I_{or} = \frac{V_{or}}{R} = \frac{155}{100} = \underline{\underline{1.55A}}$

c) Ripple factor = ⅄ Generally $= \frac{\text{A/c component}}{\text{d/c component (average value)}}$

A/c component = Resultant (rms and dc)

$V_{ac} = \sqrt{V_{or}^2 - V_{dc}^2}$

$V_{dc} = V_o$

The effect of source inductance is to make the simultaneous conduction of both outgoing and incoming SCes. During this period the output voltage is equal to zero and it is known as overlapping period.

ii) The net effect is to reduce the average value of o/p voltage.

Derivation

i) During overlapping period. $\alpha \le \omega t \le \alpha+\mu$. $\Rightarrow i_1 + i_2 = i_0$ constant

differentiating both sides $\frac{di_1}{dt} + \frac{di_2}{dt} = 0$ — ①

ii) From equivalent circuit during $\alpha \le \omega t \le \alpha + \mu$ then

$$v_0 = v_1 - L_s\frac{di_1}{dt} = v_2 - L_s\frac{di_2}{dt} \Rightarrow L_s\left[\frac{di_1}{dt} - \frac{di_2}{dt}\right] = v_1 - v_2$$

$$\Rightarrow L_s\left[\frac{di_1}{dt} - \frac{di_2}{dt}\right] = V_m \sin\omega t - -V_m \sin\omega t = 2V_m \sin\omega t$$

$$\Rightarrow \frac{di_1}{dt} - \frac{di_2}{dt} = \frac{2V_m}{L_s} \cdot \sin\omega t \quad — ②$$

$$① + ② \Rightarrow \cancel{2}\frac{di_1}{dt} = \frac{\cancel{2}V_m}{L_s} \cdot \sin\omega t \Rightarrow \underline{di_1 = \frac{V_m}{L_s} \cdot \sin\omega t\, dt}$$

Integrating on both sides with limits from (0 to I_0) and time $\left(\frac{\alpha}{\omega} \text{ to } \frac{\alpha+\mu}{\omega}\right)$. divide by ω to get time

$$\int_0^{I_0} di_1 = \int_{\alpha/\omega}^{(\alpha+\mu)/\omega} \frac{V_m}{L_s} \sin\omega t \cdot dt$$

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

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

here Vo : the average value of o/p voltage.

$$V_0 = \frac{1}{\pi}\int_{\alpha+\mu}^{\pi+\alpha} V_m \sin\omega t \, d\omega t = \frac{V_m}{\pi}\left[-\cos\omega t\right]_{\alpha+\mu}^{\pi+\alpha}$$

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

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

#to find o/p overlapping value

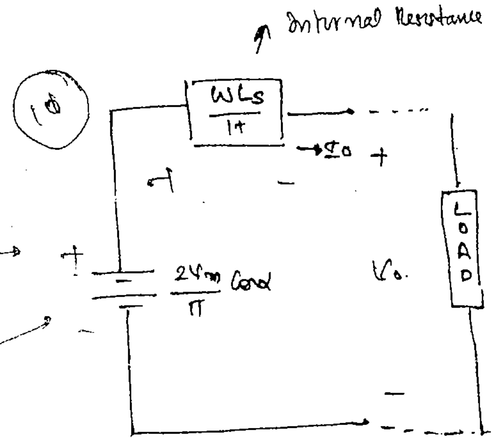
$$\Rightarrow \cos\alpha - \cos(\alpha+\mu) = \frac{\omega L_s}{V_m} \cdot I_0 \Rightarrow \boxed{\cos(\alpha+\mu) = \cos\alpha - \frac{\omega L_s}{V_m} I_0}$$

Substituting in Vo.

$$V_0 = \frac{V_m}{\pi}\left[\cos\alpha + \cos\alpha - \frac{\omega L_s}{V_m} I_0\right] = \frac{2V_m}{\pi}\cos\alpha - \frac{\omega L_s}{\pi} I_0$$

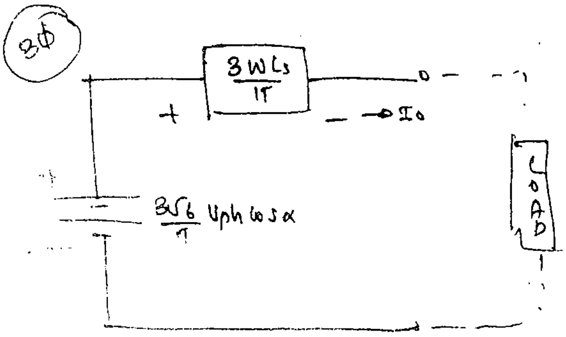
$$\boxed{V_0 = \frac{2V_m}{\pi}\cos\alpha - \frac{\omega L_s}{\pi} \cdot I_0}$$

Equivalent circuit of Vo →



⇒ 3φ - Rectifier

$$\boxed{V_0 = \frac{3\sqrt{6}V_{ph}\cos\alpha}{\pi} - \frac{3\omega L_s}{\pi} I_0}$$



$$\frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{0r}^2 - V_0^2}}{V_0} = \frac{\sqrt{155^2 - 88.39^2}}{155} \times 100\% = \underline{\underline{144\ \%}}$$

6 - 8:15 = PE
4 - 5.30 = HISTOR
6 - 8.30 = EMT
805

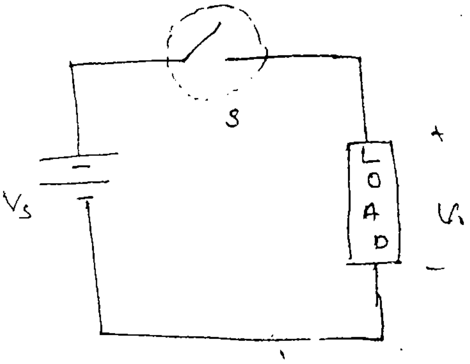
16-03-11

CHOPPERS.

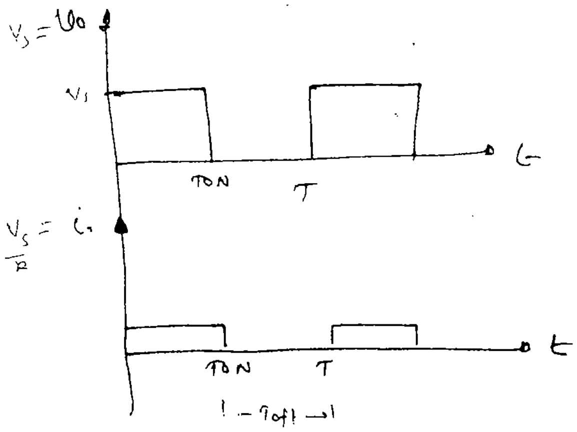
- It converts Fixed DC to Variable DC.
- It is a static power electronic circuit which converts DC to variable DC & variation in the magnitude of the voltage.
- Choppers are of two types 1) step down chopper ($V_0 < V_s$) (BUCK CHOPPER) 2) step up chopper ($V_0 > V_s$). (BOOST CHOPPER)

Realisation of chopper by a mechanical.

- Switch is ~~on and~~ opened and closed, so the V_0 avg varies at the o/p
- By varying T_{ON} and T_{OFF} time, we can vary the average o/p voltage from 0 to V_s (step down chopper).

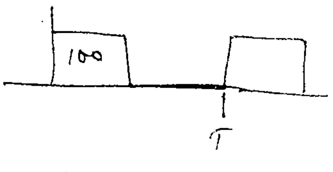


- If the time slot of T_{ON} and T_{OFF} should be 'Ns' to get a better performance of the devices.
- The switches normal, can't able to work at at Ns, here PSD CHOPPER came in to stage

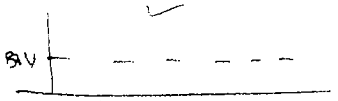


CHOPPER ↑ unidirectional switch

here

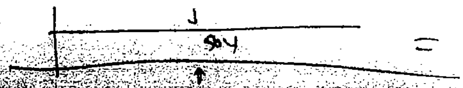
i)


=



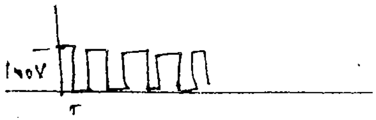
= Power Electronics

we are going to get same amount of work

ii)


= make Battery itself having No need of

3) making small pulse gives rather than waveforms just similar to 5V constant



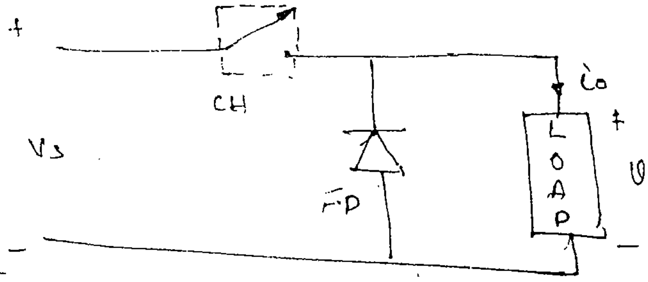
- chopper should have higher switching frequency. Time period should be high.

(S12) 1) chopper principle can be realised by using a mechanical switch, output voltage can be controlled by varying on and off ~~type of~~ times of the switch.

2) Due to limitation in the practical switches, mechanical switch should be replaced by power electronic switch that is CHOPPER. If fast switches are available, then the performance of the circuit would be better.

STEP DOWN CHOPPER (BUCK CHOPPER)

average voltage

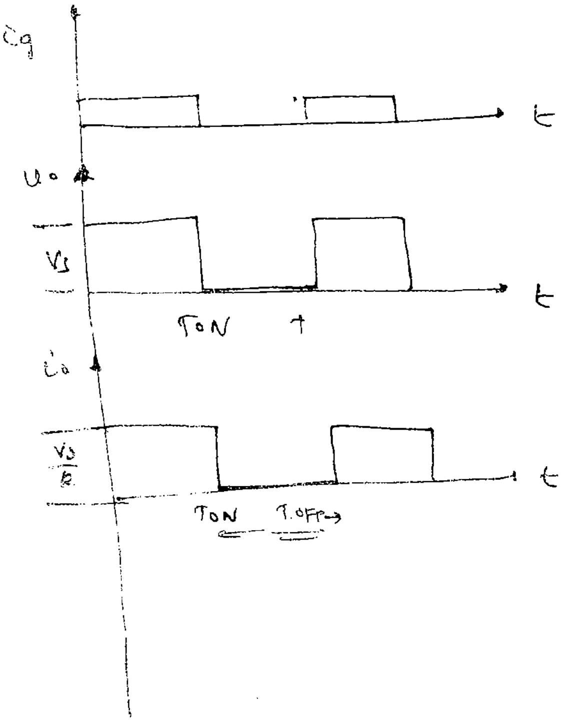


$$V_o = \frac{1}{T}\int_0^{T_{ON}} V_s\,dt$$

$$\boxed{\begin{matrix}T_{ON} = \alpha T\\ T_{OFF} = (1-\alpha)T\end{matrix}}$$

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

$$\boxed{V_o = \alpha V_s} \quad \boxed{\alpha = \text{Duty cycle} = \frac{T_{ON}}{T}}$$



other $\boxed{V_o = f \cdot T_{ON} \cdot V_s}$

where f = chopping frequency.

~~Har~~ Rms voltage

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

$$= \sqrt{\frac{1}{T} \cdot V_s^2 \cdot T_{ON}}$$

$$\boxed{V_{or} = \sqrt{\alpha}\, V_s}$$

→ Average voltage is dc component, rms value includes dc and ac, here α is always $\alpha < 1$ then $\sqrt{\alpha} > 1$

- RMS value of output voltage will be more than average value of o/p voltage. It is equivalent to resultant of a/c component as well as d/c component.

→ $I_o = \frac{V_o}{R}$, $I_{or} = \frac{V_{or}}{R}$

3) **Ripple factor** $= \frac{\text{A/C component}}{\text{DC component}} = \frac{\overrightarrow{V_{rms}} - \overrightarrow{V_{avg}}}{V_{avg}} = \frac{\sqrt{V_{or}^2 - V_o^2}}{V_o}$

$$= \frac{\sqrt{\alpha V_s^2 - \alpha^2 V_s^2}}{\alpha V_s} = \sqrt{\frac{\alpha - \alpha^2}{\alpha^2}} = \sqrt{\frac{1}{\alpha} - 1}$$

$$\boxed{= \sqrt{\frac{1}{\alpha} - 1}}$$

4) **Form Factor** $= \frac{V_{or}}{V_o} = \frac{\sqrt{\alpha}\, V_s}{\alpha V_s} = \boxed{FF = \frac{1}{\sqrt{\alpha}}}$

SIR → The output voltage can be controlled by any of the following methods,

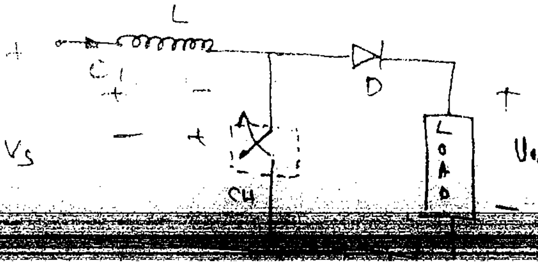
1) Pulse width Modulation :- In this method the turn ON time of the chopper gets modulated, while maintaining the frequency as constant.

2) Frequency modulation :- In this method chopping frequency gets modulated, while maintaining the turn ON time as constant.

- disadvantages
  1) It may interfere with neighbouring communication line
  2) Filter design for eliminating the harmonics will be complex because of the wide frequency variation

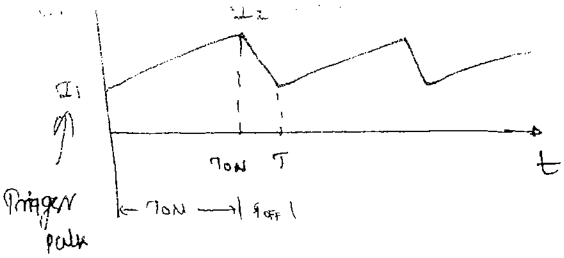
STEP UP CHOPPER (BOOST CHOPPER)

$V_s = \frac{L\,di}{dt}$ $\left\}\begin{array}{l} s - \text{closed.} \\ V_L = V_s \end{array}\right.$



$di = \frac{V_s}{L}\, dt = \frac{V_s}{L} \times t + k$

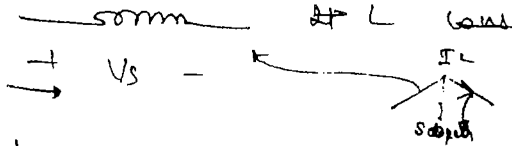
$\underbrace{i = \frac{Vs}{L} \cdot \cancel{t} + k}_{y = mx + c}$ } Linear variation



at $t = \infty$ $\quad i = \infty \Rightarrow S \cdot C$

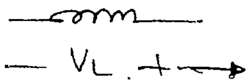
· at $t = M, n$ s $\quad i \neq \infty \quad \neq S \cdot C$

→ ~~current~~ During S closed,



~~#~~ L ~~conserves~~, stores energy

→ S-open :- current tends to decrease,



, then → delivering energy (due to change in slope)

Vs and VL are supporting. (

$-Vs - V_L + V_0 = 0 \Rightarrow \boxed{V_0 = Vs + V_L} \Rightarrow$ Vo is more than supply.

SIR

i) The extra voltage required to make the output voltage more than supply voltage will be produced by the stored energy of inductor. During 'ON' time instant, inductor stores the energy and during 'OFF' time instant it delivers the energy.

2) Expression for average o/p voltage can be obtained by equating the energy stored by the inductor and energy delivered by the inductor

During TON PERIOD

$W_{L in}$ = average voltage across inductor × Iavg (L) × $\textcircled{TON}$

$$= Vs \cdot \left(\frac{I_1 + I_2}{2}\right) \cdot TON \quad —— ①$$

During TOFF PERIOD,

$W_{L out}$ = ~~avr~~ Vavg (L) × Iavg (L) × TOFF

$$= \cancel{V_0 - Vs} \; V_L \times \frac{I_1 + I_2}{2} \times TOFF$$

Note :-

- $I_2 - I_1$ - may not be linear practically because load effect is there
- Assume $I_2 - I_1$ is LINEAR
- ~~Area~~ continuous

$= (V_0 - V_s) \cdot \frac{I_1 + I_2}{2} \cdot T_{OFF}$

Note

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

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

$= (1-\alpha)T$

① = ② ⇒ $W_{in} = W_{out}$

$V_S \cdot T_{ON} = (V_0 - V_S) T_{OFF} \Rightarrow V_S (T_{ON} + T_{OFF}) = V_0 T_{OFF}$

$V_S \cancel{T} = V_0 T_{OFF}$

$= V_0 (1-\alpha) \cancel{T}$

$\Rightarrow \boxed{V_0 = \frac{V_S}{1-\alpha}}$

OBS:

- $\alpha < 1$ always
- $1 - < 1 \Rightarrow$ ~~>1~~
- $\frac{V_S}{<1}$ ~~$\not< V_0$~~ $V_0 > V_S$.

Diode in the circuit :- consider load R(E), chopper ON, inductor should store energy, E start making the conduction through chopper.

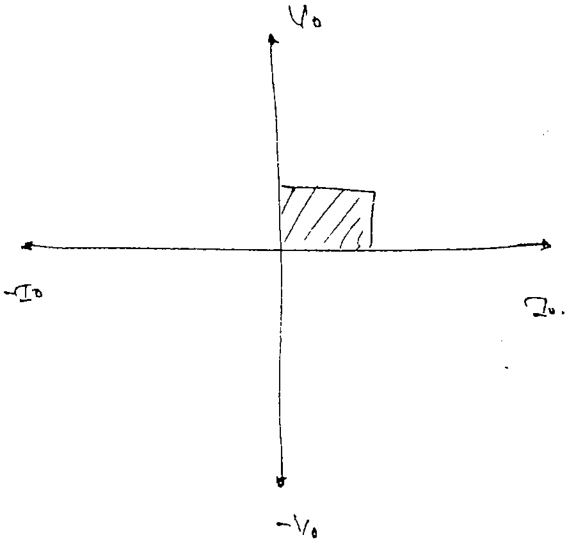
CLASSIFICATION OF CHOPPERS

- Quadrant operation :- It is best to select a suitable chopper by knowing the Quadrant operation.

eg:- we need +ve power chopper only I Quadrant is the preferred.

-ve power given app (load → source)

II or ④ - voltage negative.



- classification is useful to select a chopper suitable for required application

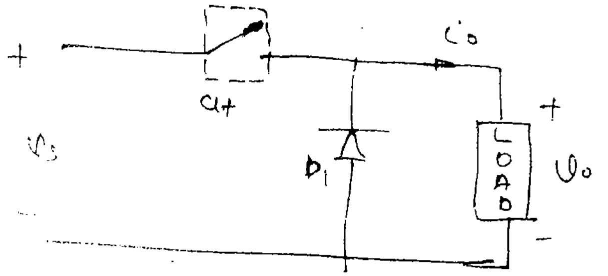
1> TYPE A CHOPPER. (I Quadrant chopper)

- Current +ve, Voltage +ve

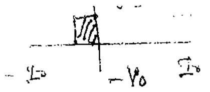
→ output power is always +ve

i.e., it flows from supply to load terminals,

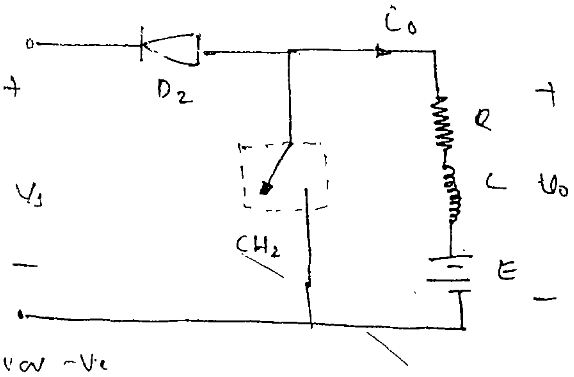
→ it is suitable only for motoring applications.



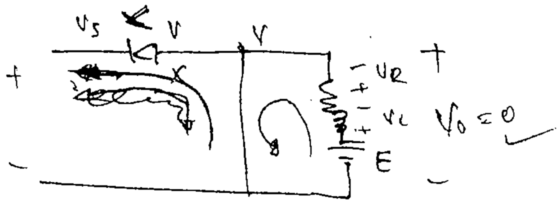
2) Type B chopper : II Quadrant chopper



- Load must be of RLE in Nature.



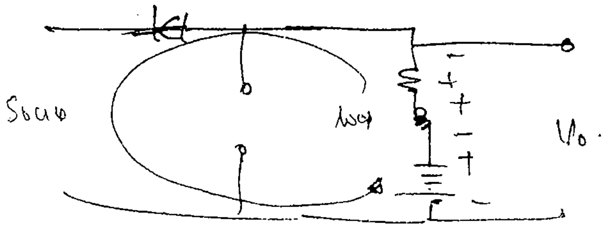
- **CH2 closed**



$V_0 = 0$

- Current is always -ve, whether voltage +ve or -ve

→ Power is -ve, Flows from Load - source, It is suitable only for Regenerative braking applications.



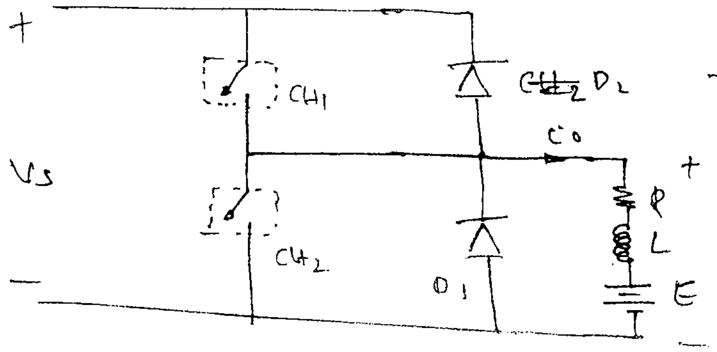
Note:-

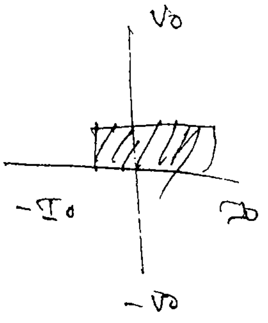
Regenerative Application the formula to be employed for the average output voltage is same as the step up chopper.

$$\left[V_0 = \frac{V_s}{1-\alpha} \right]$$

3) Type C chopper : Two Quadrant type A chopper

- Type C chopper can be obtained by merging type A and type B choppers.





- o/p power can be +ve as well as -ve i.e power flows in both the directions. It is suitable for both motoring as well as Regenerative Braking applications.

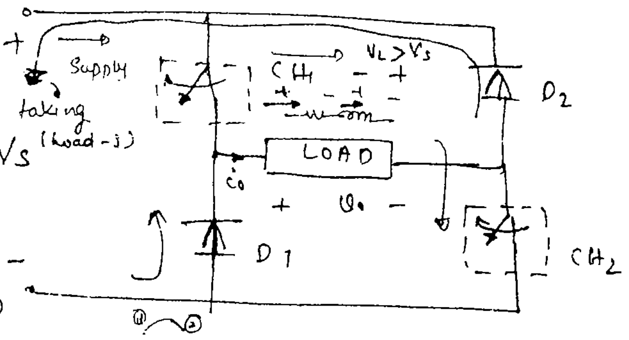
4) Type D chopper, two Quadrant type B chopper

CH1 + CH2 - closed

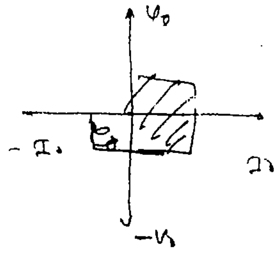
$V_o = V_s = +ve$

CH1 + CH2 - open

D1 D2 conducts to L.



1) output power can be +ve as well as -ve i.e. it flows in both the direction. It is suitable for motoring as well as Regenerative braking appl:



- V_L depends on slow the ckt ②.

→ If -com should be there.

---

5) Type E chopper

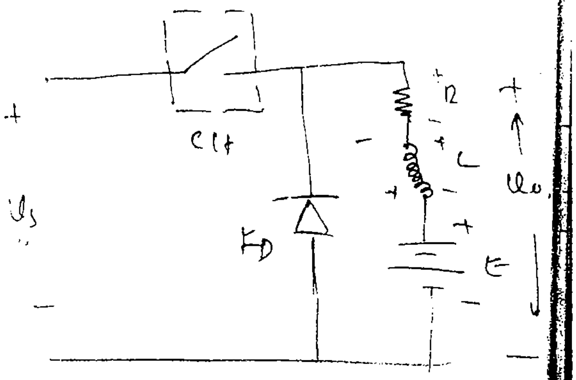
20/03/11 2

- Type E chopper can be obtained by merging either '2' type C, or '2' type 'D' choppers

---

6) Steady state analysis of type A chopper

- The value of inductance is so selected such that it is capable to support the conduction, through out Toff time interval then the conduction is continuous (If conduction dis continuous $V_o \neq 0$ $v_o = E$)



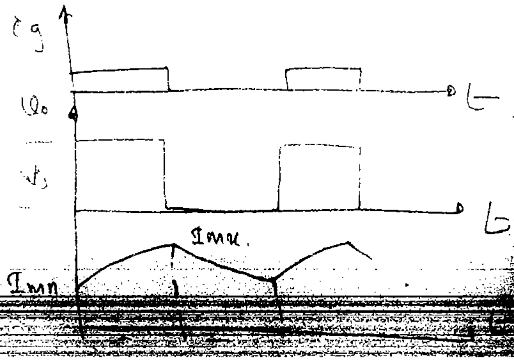
- $V_o = \alpha V_s$

$V_{or} = \sqrt{\alpha} V_s$

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

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

H.W Derivation



$\Delta I = I_{max} - I_{min}$ (T_a = Load time constant = L/R

$$= \frac{V_s}{R}\left[\frac{(1-e^{-T_{ON}/T_a})}{1-e^{-T/T_a}} - \frac{e^{T_{ON}/T_a}-1}{e^{T/T_a}-1}\right]$$

$$= \frac{V_s}{R}\left[\left(\frac{(1-e^{-T_{ON}/T_a}}{(1-e^{-T/T_a}}\right) - \frac{e^{T_{ON}/T_a}\left(1-e^{-T_{ON}/T_a}\right)}{e^{T/T_a}\left(1-e^{-T/T_a}\right)}\right]$$

$$= \frac{V_s}{R}\left[\frac{1-e^{-T_{ON}/T_a}}{1-e^{-T/T_a}}\right]\left[\frac{e^{T/T_a}-e^{T_{ON}/T_a}}{e^{T/T_a}}\right]$$

$$= \frac{V_s}{R}\left[\frac{1-e^{-T_{ON}/T_a}}{1-e^{-T/T_a}} - e^{-(T-T_{ON})/T_a}\left(\frac{1-e^{-T_{ON}/T_a}}{1-e^{-T/T_a}}\right)\right]$$

$$= \frac{V_s}{R}\left[\frac{1-e^{-T_{ON}/T_a}}{1-e^{-T/T_a}} - \frac{e^{-T_{OFF}/T_a}\left(1-e^{-T_{ON}/T_a}\right)}{1-e^{-T/T_a}}\right]$$

$$\Delta I = \frac{V_s}{R}\left[\frac{(1-e^{-T_{ON}/T_a})(1-e^{-T_{OFF}/T_a}}{1-e^{-T/T_a}}\right]$$

$$\text{Current Ripple} = (\Delta I) = \frac{V_s}{R}\left[\frac{(1-e^{-T_{ON}/T_a})(1-e^{-T_{OFF}/T_a})}{(1-e^{-T/T_a})}\right]$$

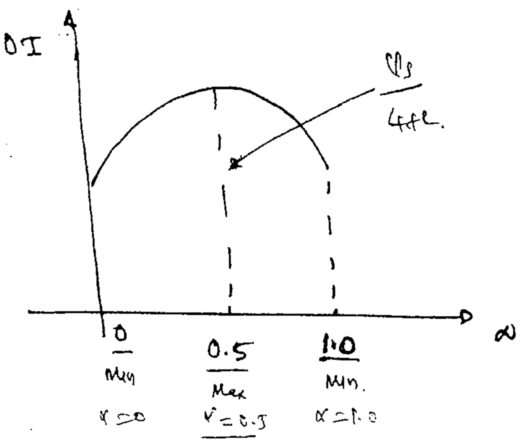
$$\text{Per unit Ripple} = \frac{\Delta I}{V_s/R} = \frac{\left(1-e^{-T_{ON}/T_a}\right)\left(1-e^{-T_{OFF}/T_a}\right)}{1-e^{-T/T_a}}$$

$T_{ON} = \alpha T$; $T_{OFF} = (1-\alpha) T$

$$\Delta I = \frac{V_s}{R}\left[\frac{\left(1-e^{-\alpha T/T_a}\right)\left(1-e^{-(1-\alpha)T/T_a}\right)}{\left(1-e^{-T/T_a}\right)}\right]$$

pu ripple as a function of duty cycle.

graph curnt ripple w.r.t duty cycle



- ripple or pu ripple varies with the value of α
- ripple is minimum at α=0, increases and reaches maximum at α=0.5, then decreases to minimum at α=1.0.
- For α=0.5, ripple will be maximum

$$(\Delta I)_{max} = \frac{V_s}{R}\left[\frac{\left(1-e^{-0.5T/T_a}\right)\left(1-e^{-0.5T/T_a}\right)}{1-e^{T/T_a}}\right]$$

Let $\frac{T}{T_a} = x$

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

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

$$= \frac{V_s}{R}\cdot \tanh\cdot\frac{1}{4}x$$

$$= \frac{V_s}{R}\cdot \tanh\cdot\frac{T}{T_a}\cdot\frac{1}{4} =$$

$$(\Delta I)_{max} = \frac{V_s}{R}\tanh\left(1/f\cdot L/L\cdot 1/4\right) = \frac{V_s}{R}\tanh R/4fL$$

$$(\Delta I)_{max} \simeq \frac{V_s}{R}\cdot\frac{R}{4fL} = \frac{V_s}{4fL} \qquad \left\{ \begin{matrix} \theta \to 0 \\ \tan\theta = \theta \end{matrix} \right\}$$

$$\boxed{(\Delta I)_{max} = \frac{V_s}{4fL}} \quad ***$$

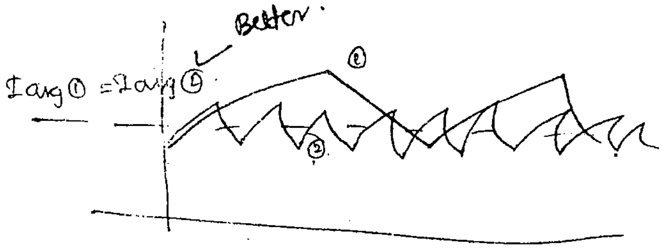
Ripple.
(ΔI_{max}) Reduction

i) $(\Delta I)_{max} \propto \frac{1}{f}$, increase the chopping frequency the ripple is less, the time period is less.

Physically in waveform

→ $I_{avg_①}$ ripple > $I_{avg_②}$ ripple

$I_{avg}① = I_{avg}②$

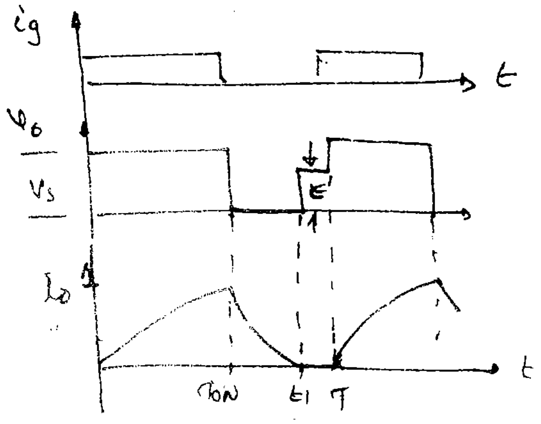


→ here $I_{avg}②$ current is better.

SIR

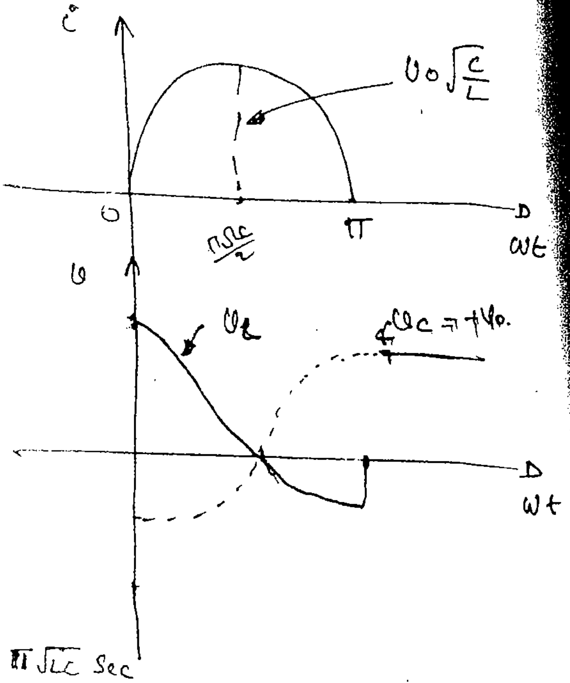
i) To reduce the current ripple, it is preferable to employ, higher value of chopping frequency. Hence faster devices may be utilized in the chopper.

DISCONTINUOUS CONDUCTION.



• The value of inductance in load circuit is unable to support the conduction throughout 'off' time interval, then conduction becomes discontinuous. In this period

• in -ve half cycle after π diode is in blocking state hence -ve conduction stops. only +ve half cycle conduction occurs.



$$\boxed{\omega_0 t = \pi = \text{Conduction time}}$$

$$\frac{1}{\sqrt{LC}} \times t = \pi \Rightarrow \boxed{t = \pi\sqrt{LC} \text{ sec}}$$

RESULTS OF THE TANK CIRCUIT

> Nature of current = Sinusoidal

> Peak value of current = $V_0 \cdot \sqrt{\frac{C}{L}}$

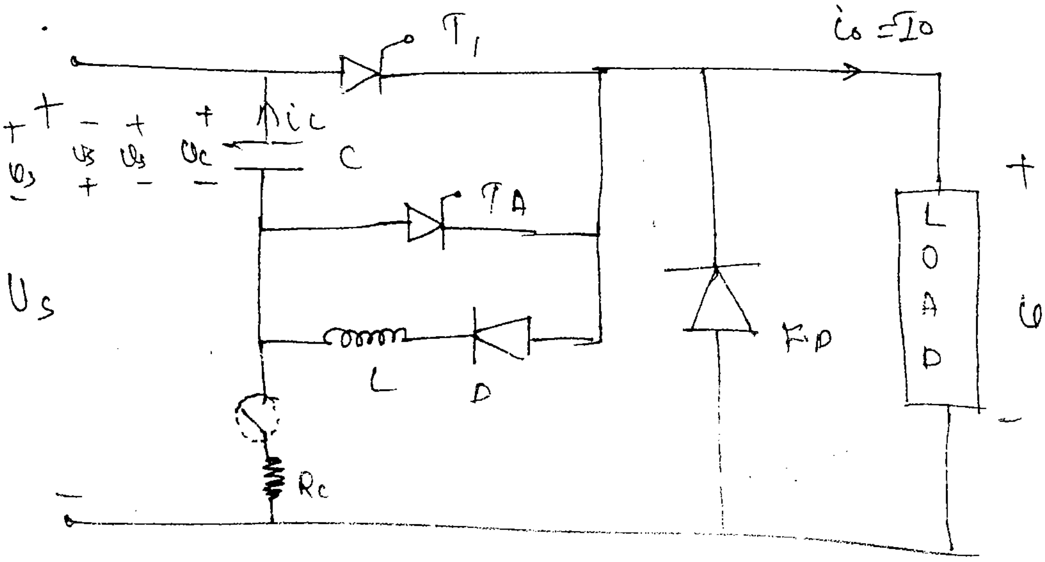
*

> Conduction duration of the circuit π rad = $\pi\sqrt{LC}$ sec

**

> At the end of conduction, the voltage across the capacitor gets REVERSED.

VOLTAGE COMMUTATED CHOPPER



KVL ⇒ $\cancel{I(s)\left[sL + 1/Cs\right]}$ $I(s) \cdot Ls$.

$$+ \frac{I(s)}{Cs} = V_0(s).$$

$$I(s)\left[Ls + \frac{1}{Cs}\right] = \frac{V_0(s)}{s.}$$

Time varying voltage. $v(t)$

$$I(s) \cdot \frac{L}{s}\left[s^2 + \frac{1}{LC}\right] = \frac{V_0}{s.}$$

$$I(s) = \frac{V_0}{L} \cdot \frac{1}{s^2 + 1/LC}$$

$$= \frac{V_0}{L} \cdot \frac{1}{s^2 + \omega_0^2} \quad \text{when} \quad \frac{1}{LC} = \omega_0^2$$

$$= \frac{V_0 \cdot}{\omega_0 L} \frac{\omega_0}{s^2 + \omega_0}$$

$$\boxed{\begin{aligned} i(t) &= \frac{V_0}{\omega_0 L} \cdot \sin \omega_0 t \\ i(t) &= V_0 \sqrt{C/L} \sin \omega_0 t \end{aligned}}$$

$$\omega_0 L = \frac{1}{\sqrt{LC}} \times L = \sqrt{L/c}$$

$$v_c = \frac{1}{c}\int i\,dt = \frac{1}{c} \cdot \frac{V_0}{\omega_0 L}\left(\frac{-\cos\omega_0 t}{\omega_0}\right) + k$$

$$v_c = -V_0 \cos \omega_0 t + k$$

~~At~~ At $t = 0^+$, $v_c = -V_0$ $\quad -V_0 = -V_0 + k$

$k = 0$ $\quad \boxed{v_c = -V_0 \cos \omega_0 t}$

The o/p voltage is equal to E

then

i> average voltage Vo

$$V_o = \frac{\text{Area Total}}{\text{Time period Total}} = \frac{1}{T}\left[V_s \times T_{ON} + E(T - t_1)\right]$$

$$\boxed{V_o = \alpha V_s + E\left(1 - \frac{t_1}{T}\right)}$$

OBS:-

i> The average value of o/p voltage is more in discontinuous conduction compared to continuous conduction.

FOURIER ANALYSIS OF OUTPUT VOLTAGE (CONTINOUS CONDUCTION)

$$V_o = \alpha V_s$$

$$V_{or} = \sqrt{\alpha} V_s .$$

$$v_o = V_o + \sum_{n=1,2\ldots}^{\infty} v_n \quad \text{where} \quad V_o = \alpha V_s .$$

Not time varying   Time varying function

$$v_{on} = \underbrace{\left\{ \frac{2V_s}{n\pi} \sin(n\pi\alpha) \right\}}_{V_{mn}} \underline{\sin(\omega t - \theta_n)}$$

$$V_{rms} = \left.\frac{V_{mn}}{\sqrt{2}}\right|_{n=1} = \frac{2V_s}{\pi\sqrt{2}} \cdot \sin(\pi\alpha) \quad \boxed{V_{01} = \frac{\sqrt{2}V_s}{\pi} \sin(\pi\alpha)}$$

fundamental

- Choppers operation is based on forced commutation. There are two types of forced commutation

  i> Voltage commutation

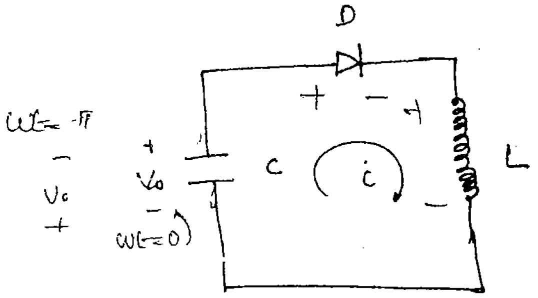
  2> current commutation.

TANK CIRCUIT

- It is the main elemement to realize the forced commutation ckt.
- Tank circuit consists of Inductor, Capacitor and UNIDIRECTIONAL DEVICE (Diode (or) Thyristor).

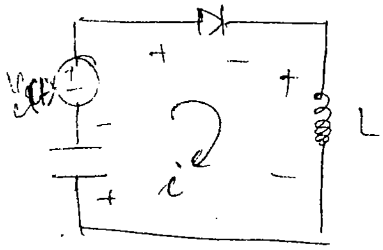
THEORY OF TANK CIRCUIT

- V_0 = initial voltage of C
- due to that 'D' F.B
- current i flows



$$L\frac{di}{dt} - \frac{1}{C}\int i\,dt \neq 0.$$

$$L\frac{di}{dt} = \frac{1}{C}\int i\,dt \quad \text{SIR}$$



~~$L\frac{di}{dt} + \frac{1}{C}\int i\,dt = \overset{0}{V_0} \cdot V_c(t)$~~

~~$SL.I(s) + \frac{1}{CS}I(s)$~~ $= V_0$

~~Apply L.T~~

~~$L[SI(s) - 0] + \frac{1}{C}[$~~

Note:

$i = \frac{dq}{dt}$ $\qquad C = \frac{Q}{V}$

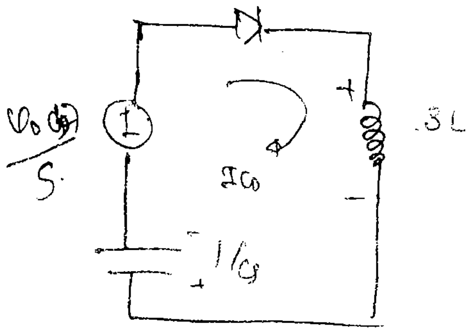
$dq = i\,dt$ $\qquad Q = CV.$

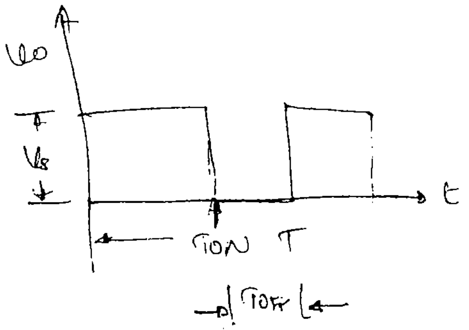
$q = \int i\,dt$

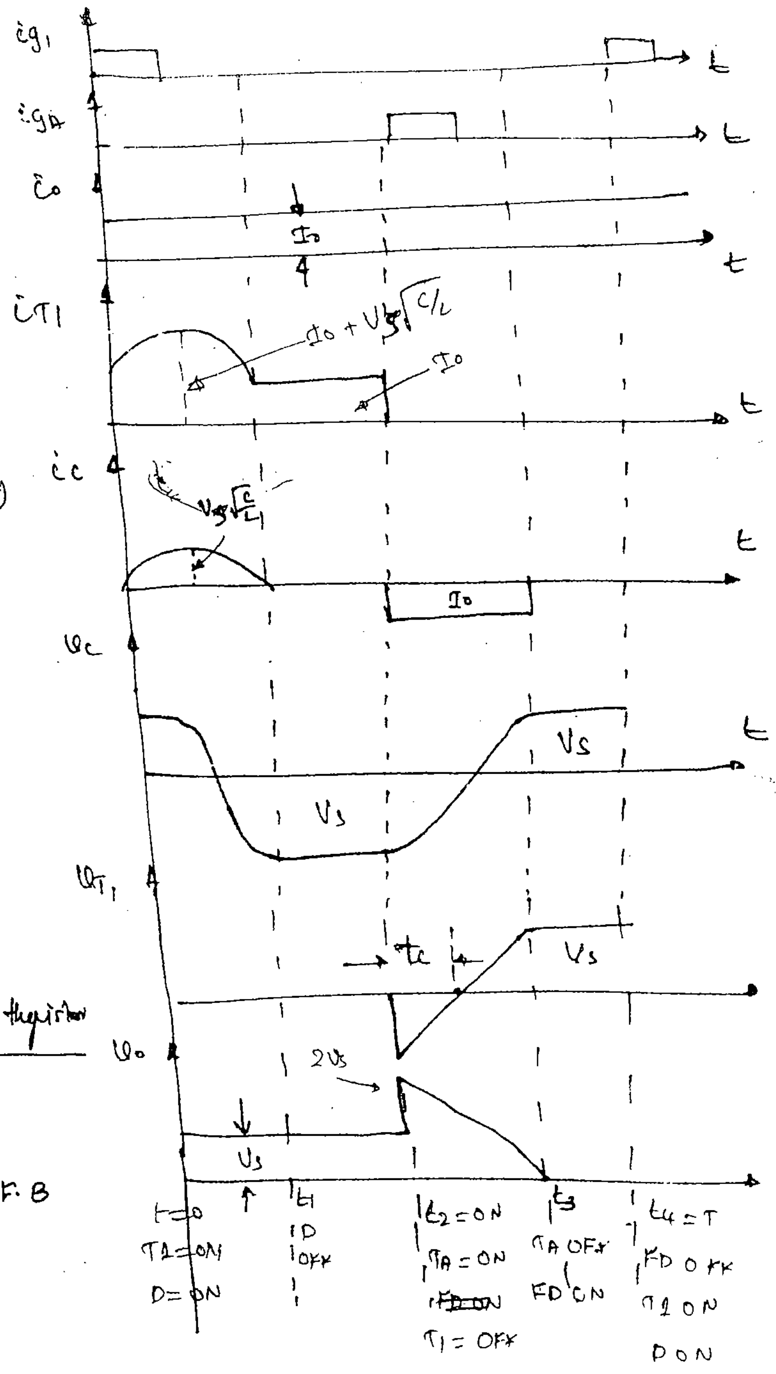
$\int v\,dt$ = flux linkage

$\int v\,dt = \psi$
$= Li.$

S-Plane







- Io assumed constant.
- T1, TA – Thyristor
  (main) (auxiliary charge)
- L, C – commutator (Tank circuit)
- D – supporting D.
- Rc – charging Resistor.

1) S-closed (Initial condition)

C ⟶ Vs thru Rc-C.

vc = Vs. (after some t)

2) S-open – t=0, triggers T1 main thyristor

- Vo = Vs
- Because of Vc = Vs. diode F.B conduction starts giving ic.
- T1 holds – Io + ic
- For ic = L, C, Diode. (Tank circuit).

Tank circuit

- ic = sinusoidal.

time of ic = π√LC sec.

. end conduction 'C' reverse the polarity

$i_{T_1} = I_o + i_c$.

$i_{T_1} = I_o + V_o\sqrt{\frac{C}{L}}$

from tank circuit (gate 2011)

- After π√LC second or π radians Vc = 0.
- diode – RB

3) at $t=0$, T_1 - ON, up to T_{ON} ~~circuit~~ is Not disturbed.

So conduction through T_1 continues up to T_{ON} time. at

<u>$T = T_{ON}$</u> , <u>T_1 = Needs to be OFF</u>

Turn OFF T_1

⇒ Turn ON the auxiliary thyristor T_A.

- Trigger is given to T_A. ⇒ T_1 got reverse voltage. ⇒ T_1 stops the conduction.
- Hence VOLTAGE COMMUTATION (Applying a Reverse voltage)

IMPULSE COMMUTATION.

↳ short duration high voltage by T_A. V↑↑, I time is less.

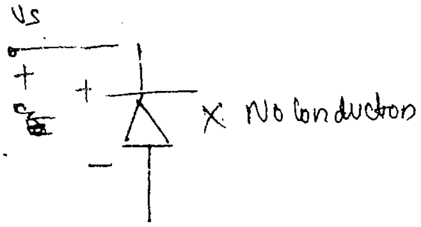
- $i_{T_1} = 0$

4) I_0 = constant ?

T_1 - stopped ~~and~~ conduction

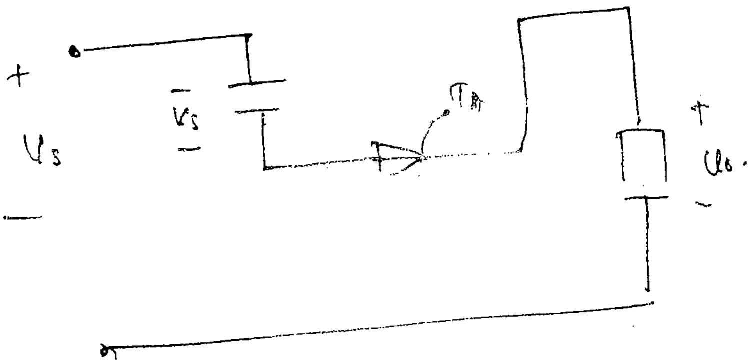
D - stopped conduction.

$\boxed{\text{F.D} = \text{Should Help}}$ ⇒



. T_A = Conducts.

I_0 ⇒ <u>path</u> supply + C + T_A + load.

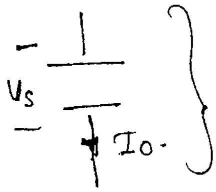


By KVL

$$-V_s - V_s + V_0 = 0 \Rightarrow \boxed{V_0 = 2V_s}$$

· If I_0 constant

$\Rightarrow I_C = \text{const}$ $I_0 = -i_c$.



} discharging V_s decreases gradually due and after some time 'τ' it becomes zero.

→ V_c

· No the voltage is linear . , I_0 = constant

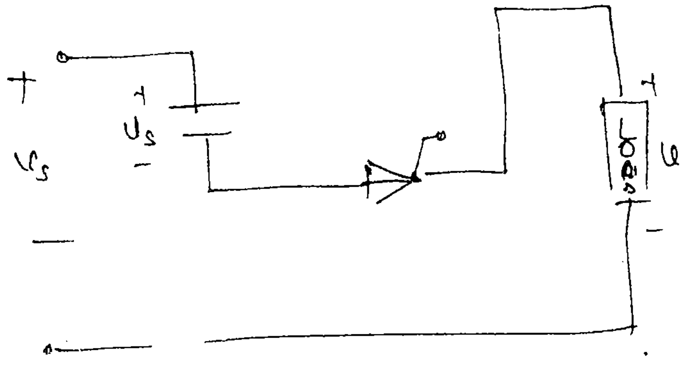
· $i = C\frac{dV}{dt} \Rightarrow \frac{-I_0}{\text{constant}} = \underset{\text{constant}}{C}\frac{dv}{dt} \Rightarrow$ constant = slope = constant = linear curve.

· agains $V_c = V_s$

KVL

$\Rightarrow -V_s + V_s + V_0 = 0$

$$\boxed{V_0 = 0}$$



TA

· TA stops the conduction when $V_c = V_s$.

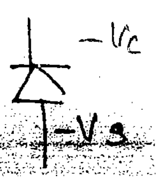
F.D

· Now F.D coming as to conduction

· $V_c > V_s$ (assumption) (check above) it is possible as LC

This extra voltage is given by transfer of energy from L to C.

· So FD



$-V_c < -V_s$

conduction starts [illegible] FD

- at $t = T$, trigger is given to T_1 , cycle repeats.

OBS:-

1) No need to close the switch S again to give charging voltage It is already present on V_c.

2) If $V_c > V_s$ at ~~t0E~~. (Io continuous, load is heavy Inductance) Io → slows ⟹ load L ⟹ produces a voltage. which makes the FD conduction occurs.

3) t_c = circuit turnOFF time of T_1. Time taken to $i_{T1} = 0$ after applying the reverse voltage. (Specification of T_1 to be used)

4) peak value of current through thyristor $I_0 = V_s \sqrt{C/L}$

HIGHCITATION (SIR)

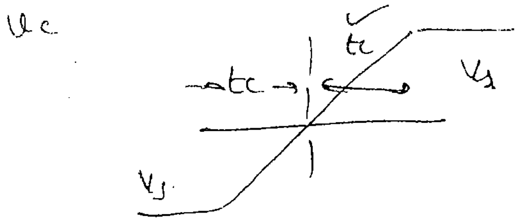
- In this commutation, a high reverse voltage will be applied across the main thyristor due to which current comes to zero. It is also known as IMPULSE COMMUTATION. since turn OFF of SCR occurs in a short duration due to a larger voltage.

Equations for C and L values

1) Commutating capacitor

- Its value will be calculated based on circuit turn off time.

$i = C\frac{dv_c}{dt}$



$\rightarrow I_0 = C \times \frac{2V_s}{2t_c}$

$$\boxed{C = \frac{I_0 \times t_c}{V_s}}$$

2) Commutating Inductor

- Its value is calculated based on peak current through main thyristor

i> peak current through main thyristor $I_{T1P} = I_0 + V_s\sqrt{\frac{C}{L}}$

gate 2014, IES 2012

given by the examiner

Important points

*** i> peak current through auxiliary thyristor $= I_0$.

ii> peak current through ~~Diode~~ Capacitor $= i_c$

$= V_s\sqrt{\frac{C}{L}}$ or I_0.

(whichever is higher)

Note :- if $\underbrace{V_s\sqrt{\frac{C}{L}}}_{\text{peak}} > I_0$.

- Otherwise I_0.

Rating is taken by this

ii> peak diode current $= V_s\sqrt{\frac{C}{L}}$ only

Note :- I_0 will not conduct through D

iii> peak instantaneous o/p voltage $= 2V_s$.

Disadvantage

i> T_1 — main thyristor $I_{peak\,T_1} = \underline{\underline{I_0}} + V_s\sqrt{C/L}$

[illegible]

mains thyristor required to be rated for more than load current. cost of T1 is high.

2) V_0 = o/p voltage. ~~[illegible]~~ is more than Calculated.

eg:- $\alpha = 0.5$, $V_s = 100\,V$

$V_0 = 50V$ But here $V_0 > 50$ (due to peak $2V_s$ occuring)

Then $\alpha = 0.45$ is choosen in Practical circuit.

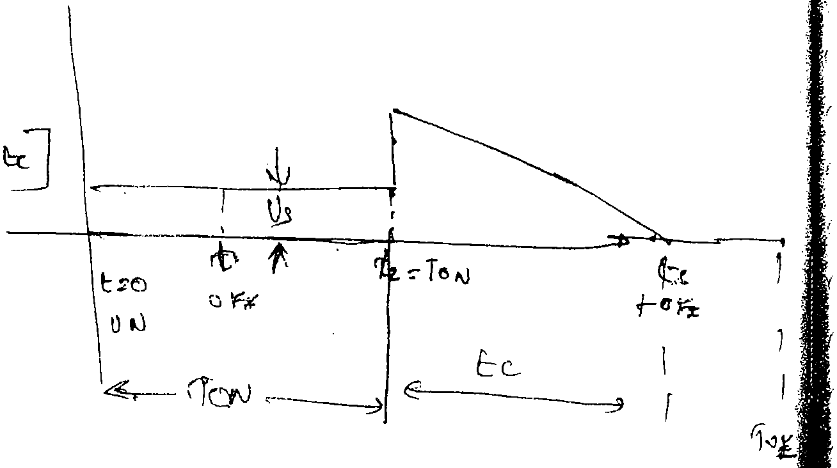
SIR

① Main thyristor will carry more than load current hence the main thyristor is required to be rated for more than load current rating.

② The average value of o/p voltage is more in practical circuit compared to theoretical calculations.

V_0 Calculations

$$V_0 = \frac{1}{T}\left[V_s \times T_{ON} + \frac{1}{2} \times 2V_s \times 2t_c\right]$$



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

$$= \frac{V_s}{T}\left[T_{ON} + 2\frac{CV_s}{I_0}\right]$$

$$\boxed{V_0 = \frac{V_s}{T}\left[T_{ON} + 2\frac{CV_s}{I_0}\right]}$$

$V_0 = \frac{V_s}{T} T_{ON}'$ where $T_{ON}' = T_{ON} + \frac{2CV_s}{I_0}$

T_{ON}' => effective turn on.

$$V_0 = V_s \times \frac{T_{on}'}{T}$$

$\boxed{V_0 = \alpha' V_s}$ α' = effective duty cycle.

OBS:

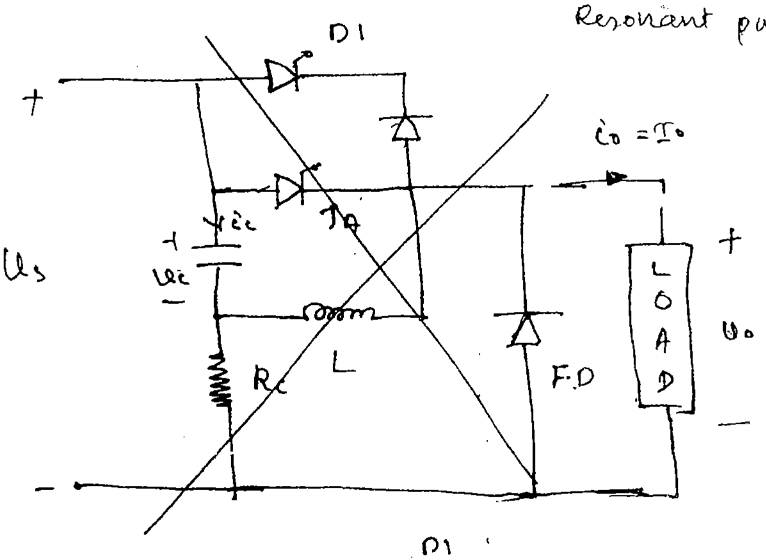
1) $\pi^C = \pi\sqrt{LC}$ is the minimum time T_1 should be ON condition before that we cannot OFF the chopper.

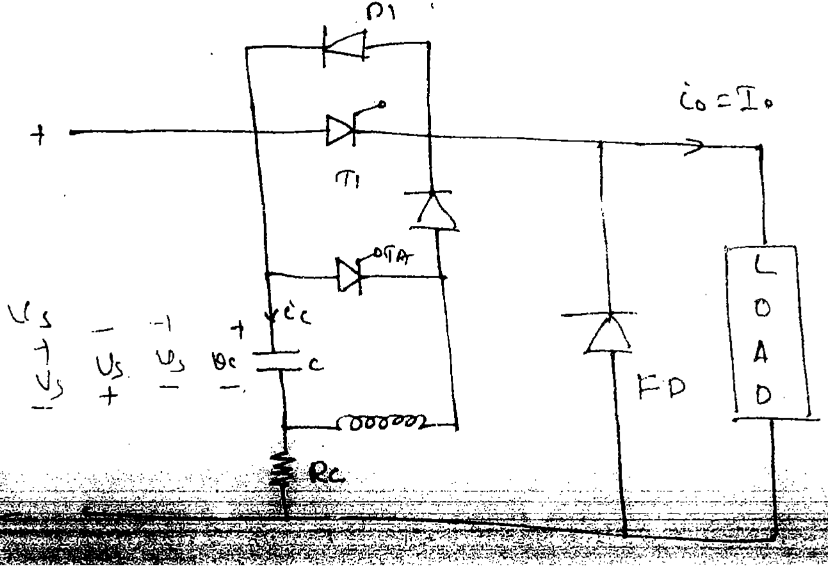
→ Minimum turn ON time of the chopper = $\pi\sqrt{LC}$ seconds

gate 2009

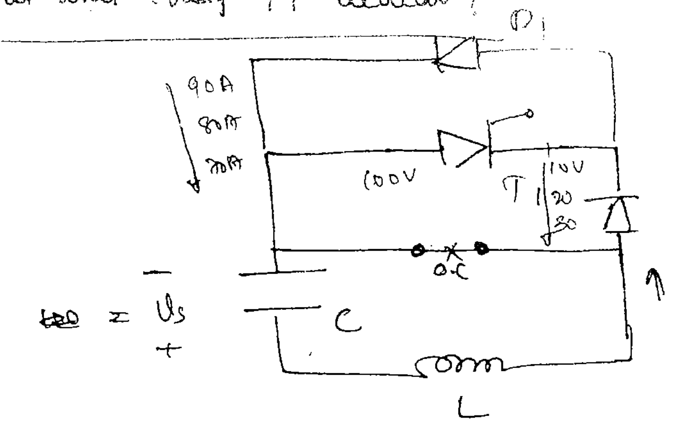
II> CURRENT COMMUTATED CHOPPER (Step down chopper)

Resonant pulse commutation





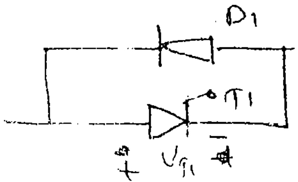
• How net amt through T1 decrease?



• 'V_s/V_C' voltage is opposing the supply V_s, hence due to capacitor effect net voltage across ~~the~~ T_1 gradually decreases and the net current comes to zero. (Voltage commutation its instantaneous)

• Here the application of reverse voltage is gradual, TOFF time is more.

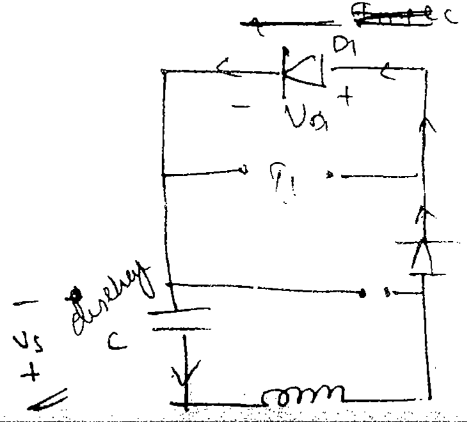
• D_1 doesnot conduct?



- Antiparallel connection D_1 and T_1, unidirectional device.
- 'V_{T_1}' small acts as reverse voltage for D_1

• Reverse voltage across T_1 after $i_{T_1} = 0$

• once $i_{T_1} = 0$, D_1 starts conducting.



• V_{D1} gives the reverse voltage to T_1

$I_{cp} > I_0$.

• $I_{cp} - I_0$ = passes through D_1

• D_1 conducting.

- V_{D1} is very less, again T_1 is turn off slowly.

~~2)~~ ~~3)~~ ∘ V_c reaches to zero when conducting through D1 occurs.

- V_C charges towards V_s.

~~3) at t3~~

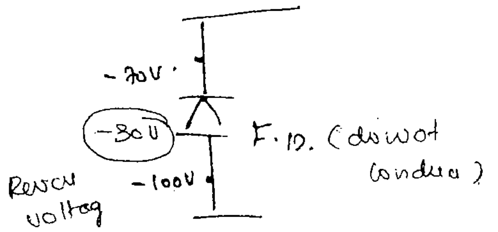
3) at t4 $V_c < V_s$ because still current is I_o. To make next cycle V_c needs to be ~~st~~ charged to V_s.

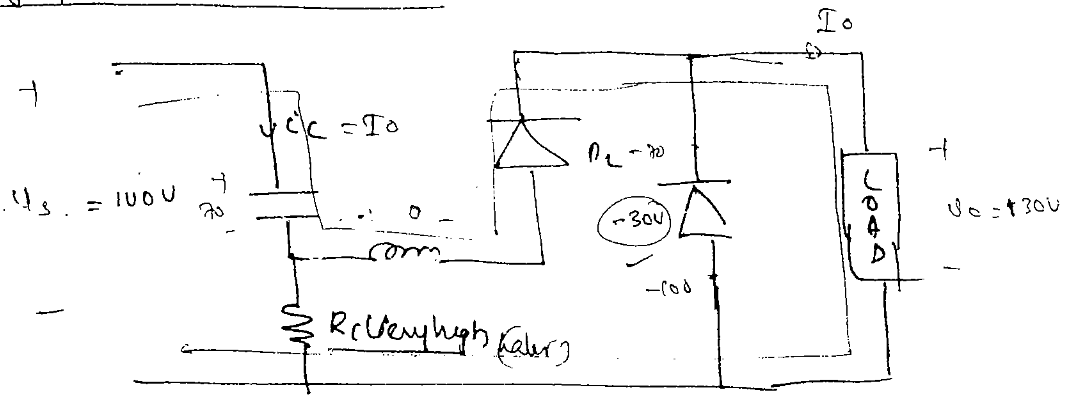
- Assumption I_o = constant

- FD doesn't conduct

- Existing path should support

$V_s = 100$





By KVL

$$-100 + 70 + V_o = 0 \Rightarrow V_o = 30V$$

.i.e V_s drops.

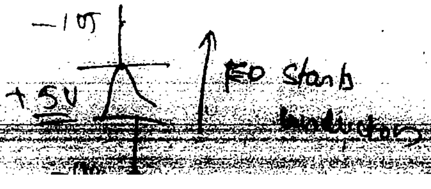
- $I_o = C\frac{dv}{dt}$ C - constant, I_o - constant $\frac{dv}{dt}$ = varies linearly $\longrightarrow$ V_s

4) at t5

→ • $V_c > V_s$? (Because of ~~l~~ d energy from L c)

105 100

- FD starts conduction

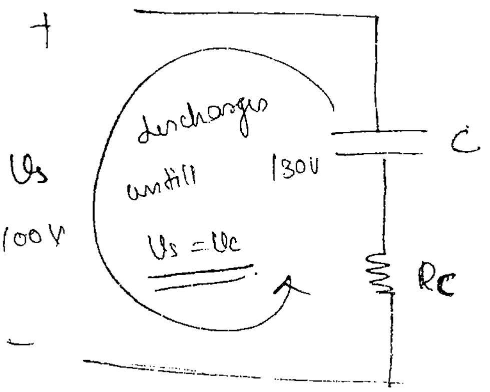


⇒ ~~So~~ So ic gradually reach to zero hence capacitor ~~vo~~ voltage reaches Vcp highest value, due to prolonged conduction.
(130V)

- $V_c > V_s$.

- For next cycle we need to bring back $V_c = V_s$

5) at t6



Design of Rc

. It will not hamper operation of cycle.

6) at t = t7

. FD OFF

. T_1 ON

. $V_c = V_s$

SIR

- In this commutation, an opposite current pulse is passing through the main thyristor due to which net current through SCR gradually decreases and finally comes to zero.
- It is also known as Resonant pulse commutation since an LC circuit will be connected across the thyristor at the time of commutation.

Anti parallel diode across the thyristor is useful to apply the reverse voltage after the current through thyristor comes to zero. Due to the lower value of reverse voltage it takes more time to turn OFF hence the turn OFF time increases and turn OFF power loss decreases.

- Main thyristor is required to carry only load current
- The main thyristor will stop the conduction, whenever both the currents (I_o, i_c) are equal

Calculations of L & C.

$v = L\frac{di}{dt}$

$i = c\frac{dv_c}{dt}$

$$L = \frac{V_s \times t_c}{(x I_o)\left[\pi - 2\sin^{-1}(1/x)\right]}$$

$$C = \frac{x I_o \times t_c}{V_s\left[\pi - 2\sin^{-1}(1/x)\right]}$$

when $x = \frac{I_{cp}}{I_o}$ always > 1

$$V_{cp} = V_s + I_o\sqrt{\frac{L}{C}}$$

occurs due to energy transfer from c to L.

Stored energy of C = stored energy L

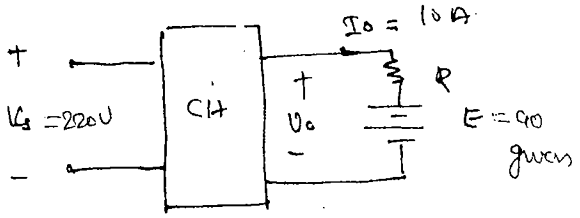
$\frac{1}{2}Li^2 = \frac{1}{2}CV^2$

$V = i\sqrt{\frac{L}{C}}$

$V = I_o\sqrt{\frac{L}{C}}$

material page No: 11.- chapter 3

1) RE load



a) $E = 90V$ then $V_o = E + I_oR$.

$V_o = 90 + 10 \times 1 = 100V$

$V_o = \alpha V_s$

$\alpha = \frac{V_o}{V_s} = \frac{100}{220} = 0.4545 = \frac{T_{ON}}{T}$

5) $E = 122V$

$V_o = 122 \times 10 \times 1$

$= 132V$

$\alpha = \frac{V_o}{V_s} = \frac{132}{220} = 0.6$

Range of α (0.45 to 0.6)

ii/ $\alpha = 0.3$

$V_0 = \alpha V_s$

$V_0 = \underline{\underline{0.3 V_s}}$ ✓

$V_{rm} = \sqrt{\alpha} V_s$

$= \sqrt{0.3} V_s$

$= \underline{\underline{0.8 V_s}}$

ii) $\text{Power} = \dfrac{V_{or}^2}{R}$

$= \dfrac{(\sqrt{0.3} V_s)^2}{R}$

$= \dfrac{0.3 V_s^2}{R}$

(iii) Ripple factor

$= \sqrt{\frac{1}{\alpha} - 1}$

$= \sqrt{\frac{1}{0.3} - 1}$

$= \underline{\underline{1.526}}$

$\alpha = 0.8$

$V_0 = \underline{\underline{0.8 V_s}}$ ✓

$V_{rms} = \sqrt{0.8} V_s$

$= \underline{\underline{0.894 V_s}}$

$\text{Power} = \dfrac{V_{or}^2}{R}$

$= \underline{\underline{\dfrac{0.8 V_s^2}{R}}}$.

$= \sqrt{\frac{1}{0.8} - 1}$

$= \underline{\underline{0.5}}$.

3) $V_{s\,dc} = 230V$

$R = 10\Omega$

$V_{T1} = 2V$ (ON)

$\alpha = 0.4$

$V_0 = \alpha V_s' = \alpha (V_s - V_{T1})$

$= 0.4 (230 - 2)$

$= \underline{91.2V}$

$V_{or} = \sqrt{\alpha} (V_s - V_{T1})$

$= \sqrt{0.4} (230 - 2)$

$= \underline{\underline{144.2V}}$

Q4) $f = 500Hz$

$R = 30\Omega$

$L = 9mH$

$E\ V_s = 48V$.

$\alpha = 0.5$

a) Peak load current

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

$T = \dfrac{1}{f} = \dfrac{1}{500} =$

$T = 0.2ms$, $T_{ON} = \alpha T = 1ms$, $T_a = \frac{L}{R}$

$T_a = $ Time const $= \underline{\underline{0.3ms}}$

$= \dfrac{48}{30}\left[\dfrac{1 - e^{-1\times10^{-3}/\cancel{0.2ms}\ 0.3}}{1 - e^{-0.2ms/0.3ms}}\right] - \dfrac{\cancel{4}8V}{\cancel{R}\ 30\Omega}$

$= \underline{\underline{1.544A}}$

b) $I_{min} = \dfrac{V_s}{R}\left[\dfrac{e^{T_{ON}/T_a} - 1}{e^{T/T_a} - 1}\right] - \dfrac{E}{R}$

$= \dfrac{48}{30}\left[\dfrac{e^{1/0.3} - 1}{e^{2/0.3} - 1}\right] - \dfrac{48}{30}$

$= \underline{\underline{0.048A}} = \underline{\underline{~~[illegible]~~}}$?
$\underline{0.055}$

c) Average load voltage $V_0 = \alpha V_s$

$= 0.5 \times 48$

$= \underline{\underline{24.0V}}$

d) Average load curr

$\underset{(R\text{-}L\ \text{load})}{I_0} = \underset{(\text{dc only})}{\dfrac{24}{30}} = \underline{\underline{0.8A}}$

e) CURRENT EXCURSION = Curr Rip.

$\Delta I = I_{max} - I_{min} = 1.544 - 0.048$

$= 1.488A$

) RLE load. $R = 2\Omega, L = 10mH$

$E = 6V$

$f = 1KHz$

$\gamma = 0.1$

$V_s = 220V$

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

$T_{ON} = \alpha T = 0.1 \times 1$

$= \underline{0.1ms}$

$T_a = \frac{L}{R} = \frac{10}{2} = \underline{5S}$

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

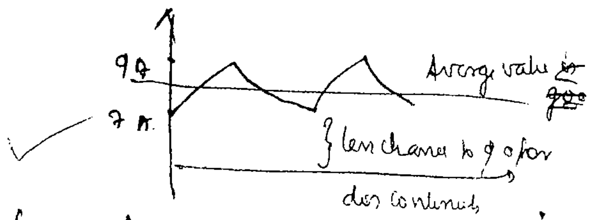
$$= \frac{220}{2}\left[\frac{1 - e^{-0.1/5}}{1 - e^{-1/5}}\right] - \frac{6}{2}$$

$$= \underline{9.016A}$$

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

$$= \frac{220}{2}\left[\frac{e^{0.1/5} - 1}{e^{1/5} - 1}\right] - \frac{6}{2}$$

$$\boxed{= 7.036A}$$



Comment:

- Best wave forms.

06) Step up chopper

$V_o = \cancel{2V_s}\ 2V_s$

$= 4V_s.$

$V_o = \frac{V_s}{1-\alpha} \Rightarrow 2V = \frac{V_s}{1-\alpha}$

$1-\alpha = 1/2$

$\alpha = 1/2$

$\frac{T_{ON}}{\cancel{T_{OFF}}} = 1/2$

$T_{ON} = 0.5\, T_{OFF}$

~~$T_{OFF} = 2T_{ON}$~~ $= 2x$ $\frac{T_{ON}}{T} = \alpha$

i) $T_{OFF} = \frac{1}{2} \cdot 500 = \underline{250\mu s}$
$(1-\alpha)T$

ii) $T_{OFF} = (1-\alpha)T = \frac{1}{4} \times 500$

$= 125\mu s$

07) $V_s = 200Vdc$, $R = 40\Omega$

$I_0 = 30A$, $f = 400Hz$

$V_o = I_0 R = 40 \times 30 = \underline{1200V}$

$V_o = \frac{V_s}{1-\alpha}$ $\left.\begin{matrix} V_s = 200V \\ V_o = 1200V \end{matrix}\right\}$ stepup chopper

$1-\alpha = \frac{200}{1200} \Rightarrow 1-\alpha = \frac{1}{6}$

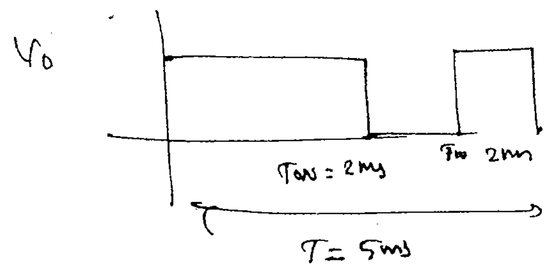
$\frac{T_{ON}}{T} = \alpha \Rightarrow T_{ON} = T \times \alpha$

$= \frac{5}{6} \times 2T$

$= \underline{2.083ms}$

$T_{OFF} = (1-\alpha)T = \underline{0.417ms}$

08) $V_s = 200V$, type A - stepdown



$$\alpha = \frac{T_0}{T} = \frac{2}{5} = \underline{\underline{0.4}}$$

a) $r = \frac{1}{\sqrt{\alpha}} \cdot \sqrt{\frac{1}{\alpha} - 1}$

$$= \sqrt{\frac{1}{0.4} - 1}$$

$$= \underline{\underline{1.2249}}$$

b) $V_0 = \alpha V_s = 0.4 \times 200$

$$= \underline{\underline{80V}}$$

$V_{or} = \sqrt{\alpha} V_s = \sqrt{0.4} \overset{200}{V_s} = 126.5V$

c) V_{rms} fundament $= \frac{\sqrt{2} V_s}{\pi} \sin(\pi\alpha)$

$$= \frac{\sqrt{2} \times 200}{\pi} \sin(180 \cdot \times 0.4)$$

$$= \underline{\underline{85.63V}}$$

d) <u>Ac ripple voltage</u>

AC. = Ripple factor x dc component

Ripple fact = $\frac{\text{AC compo}}{\text{DC compo}}$ =>

AC = 1.2249 x 80 = 97.99V

09) voltage commutated chopper

$V_s = 220V$

<u>Load ckt</u>

$R = 0.5\Omega$
$L = 0.2 mH$
$E = 40V.$

<u>Commut ckt</u>

$L = 20 \mu H$
$C = 50 \mu F$
$T_{ON} = 800 \mu s.$
$T = 2000 \mu s.$

$I_0 = 80A$ (constant) (given)

a) <u>Effective on period</u>

$$T'_{on} = T_{ON} + 2 \cdot \frac{C V_s}{I_0}$$

$$= 800 \times 10^{-6} + 2 \times \frac{50 \times 10^{-6} \times 220}{80}$$

$$= \underline{\underline{1075 \mu s}}$$

5) <u>i_{T1peak}, i_{TApeak}</u>

$$i_{T1peak} = I_0 + V_s \sqrt{\frac{C}{L}}$$

$$= 80 + 220 \sqrt{\frac{50}{20}}$$

$$= \underline{427.85A}$$

$i_{TApeak} = I_0 = \underline{\underline{80A}}$

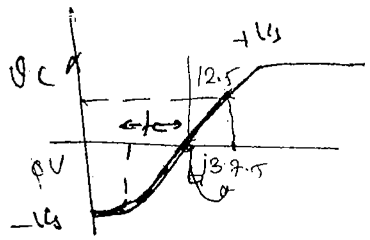
gate 2011

c) Turn OFF time for T_1

$$t_c = \frac{CV_s}{I_0} = \frac{50\times10^{-6}\times 220}{80}$$

$= 137.5\ \mu s$

d) V_c.



$t_c = 137.5\ \mu s.$

$t = 150$

$t_1 = 12.5\mu$

Linear variation

~~t~~ $V = 0V \xrightarrow{V_x} V$

$t = 137.5 \xrightarrow{12.5\mu s} 150$

$$V_c = \frac{220}{137.5} \times 12.5$$

$= 20V$

-6-9 → DC M/c - 305

9.30 - 1 → MP - 305

2 - 5.30 → ND - 305

6 - 8.30 - PE - 304

22/03/11

10) $f = 500Hz$ $\alpha = 0.5$, $I_0 = 20$ Amps

$V_s = 100V.$

a) circuit turn OFF time

$$t_{OFF} = \frac{CV_s}{I_0} = \frac{6\times10^{-6}\times100}{20}$$

$= 30\mu s$

b) L

$I_{max} = 1.80 \times I_L$

$= 1.8 \times 20$

$= 36A$

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

$36A = I_0 + V_s\sqrt{\frac{C}{L}}$

$= ~~20~~ .$

$\Rightarrow V_s\sqrt{\frac{C}{L}} = 0.8 I_0$

~~L=0~~ $t=$

~~0=~~ $= 100\sqrt{\frac{6\times10^{-6}}{L}} = 0.8\times20.$

$L = 234.375\mu H$

c) $V_m = 2V_s. = 2\times100 = 200V$

---

11) $I_{cp} = 2I_0$. main SCR $t_{OFF} = 30\mu s$

$V_s = 230V$ dc. $t_c = 30\mu s$

$I_0 = 200A$ F.S = 2

$t_c = 2\times30 = 60\mu s$

$L = \frac{V_s \times t_c}{(2I_0)\ [\pi - 2\sin^{-1}(V_0)]}$

$$x = \frac{I_{cp}}{I_o} = 2$$

$$L = \frac{230 \times 60 \times 10^{-6}}{2 \times 200 \left[\pi - 2\sin^{-1}(1/2) \times \boxed{\frac{\pi}{180}}\right]}$$

radians

$$= \underline{\underline{16.47 \mu H}}$$

$$C = \frac{(x I_o)(t_c)}{V_s\left[\pi - 2\sin^{-1}\left(\frac{1}{x}\right)\right]}$$

$$= \frac{2 \times 200 \times 60 \times 10^{-6}}{230\left[\pi - 2\sin^{-1}(1/2) \times \frac{\pi}{180}\right]}$$

$$= \underline{\underline{49.82 \mu F}}$$

b) $V_{c\,max}$?

Energy tfr from L to C

$$V_{cp} = V_s + \underline{I_o\sqrt{\frac{L}{C}}}$$

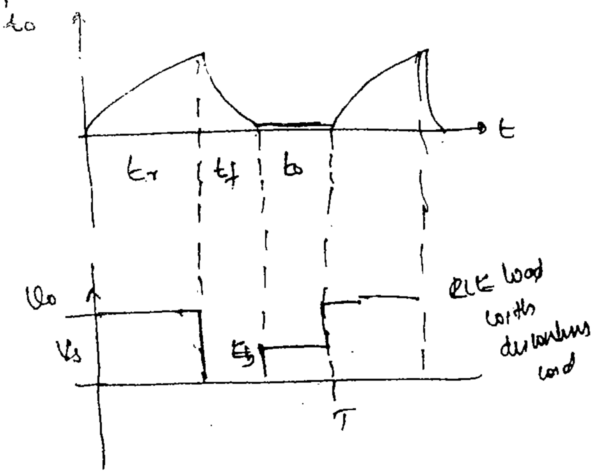
$$= \overset{230}{\cancel{200}} + 200\sqrt{\frac{16.47}{49.82}}$$

$$= \underline{\underline{345 V}}$$

c) $I_{cp} = 2 \cdot 200$

$$= \underline{\underline{400 A}}$$

11> load RLE — fall to zero.



$$V_o = \frac{V_s \times t_r + E_b \times t_o}{t_r + t_f + t_o}$$

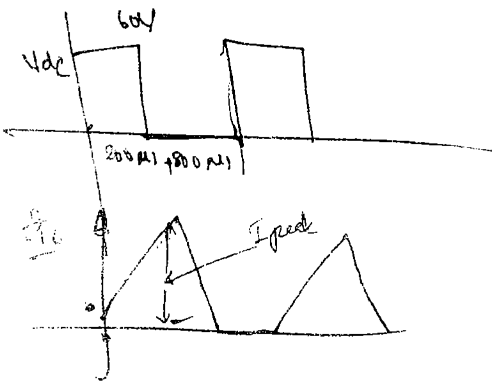
1[illegible]> step down chopper fed by RLE load and conduction is discontinuous.

13> $I_o = 5A$, $\alpha = 0.2$

load = LE load

consider E is not the L load

~~Vdc~~ $V = 60V$
$t_{ON} = 200 \mu s$
$t_{OFF} = 800 \mu s$. } given



dc given to pure conductor or a linear variation.

$i = \frac{V_s}{L} t$

considering E

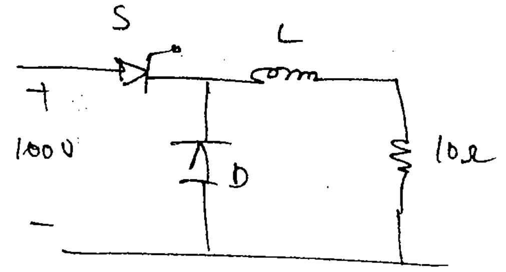
$\Rightarrow i = \frac{V_s - E}{L} \times t_{ON}$

$= \frac{\cancel{B} \cdot 60 - 12}{20 \times 10^{-3}} \times 0.2 ms.$

$= \underline{\underline{0.48 A}}$

---

14)



$V_s = 100V$

$\alpha = 0.8$

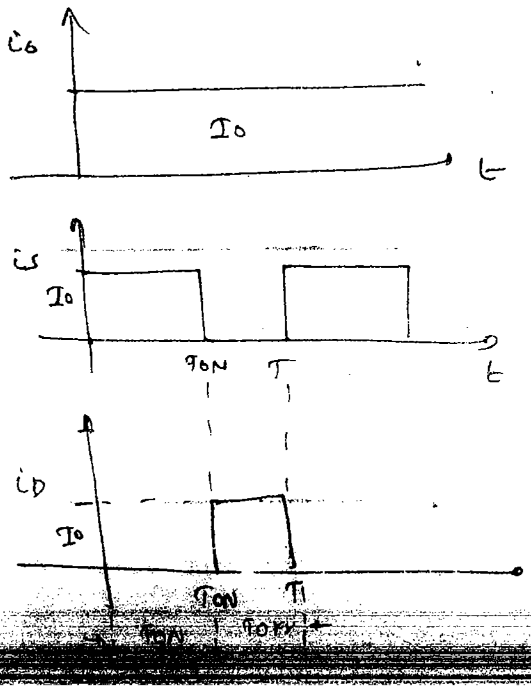
$V_0 = \alpha V_s$

$= 0.8 \times 100$

$= 80V$

$I_0 = \frac{V_0}{R} = \frac{80}{10}$

$\underline{\underline{I_0 = 8A}}$



$\boxed{I_{DA} = I_0 \times \frac{T_{OFF}}{T}}$ ***

$= 8 \times \frac{(1-\alpha)\cancel{T}}{\cancel{T}} = 8(1-0.8)$

$\underline{\underline{I_{DA} = 1.6A}}$

extra

$\boxed{\text{Switch average current} = I_0 \cdot \frac{\cancel{V_0}\, T_{ON}}{T}}$ ***

$= \underline{\underline{6.4A}}$

---

15) whenever S_2 is trigger across the S_1 only capacitor is given.

$I_{SIP} = I_0 + V_s \sqrt{\frac{C}{L}}$

$= 20 + 200 \sqrt{\frac{2\mu}{200\mu}}$

$= \underline{\underline{40A}}$

---

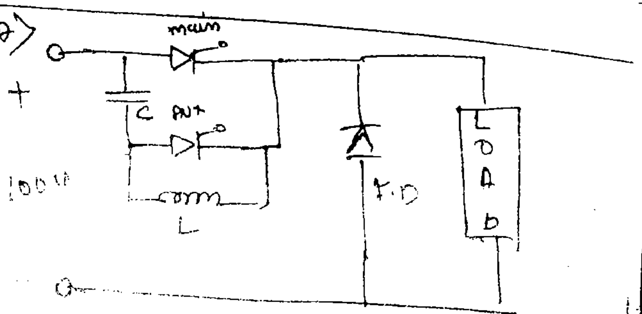
16) Imax p-p ripple $= \frac{V_s}{4fL} = \frac{100}{4 \times 1000 \times 200mH}$

$= \frac{1}{8}$

$= \underline{\underline{0.125A}}$

---

17)



minimum time = $\underline{\underline{\pi\sqrt{LC}\ sec}}$ should turn ON

$= 140 ms$

$V_0 = \frac{V_s}{T}\left[T_{ON}'\right]$

$\leftarrow \frac{V_s}{T}\left[T_{ON} + 2 \cdot \frac{CV_s}{I_0}\right]$

→

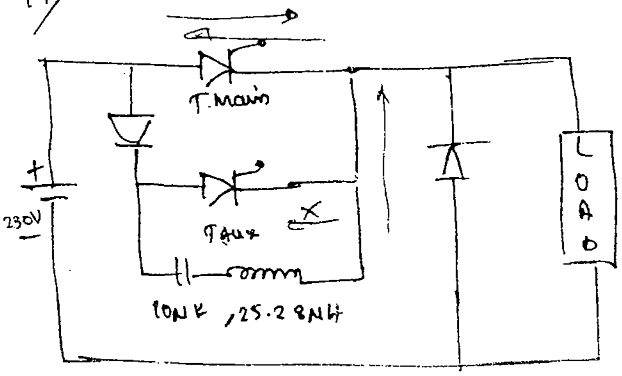
f = 1kHz

T = 1ms

→ $V_0 = \left[T_{ON} + \frac{2CV_s}{I}\right] = \underline{\underline{42.5V}}$

---

19)

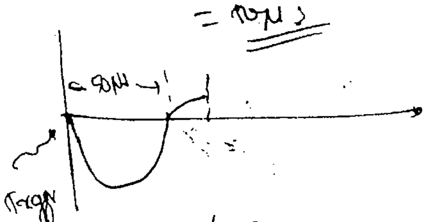


$\underline{t=0}$

· $\pi\sqrt{LC}$ ~~Load~~ Tmain surely remains ON

$\pi\sqrt{LC} = \pi\sqrt{10\times10^{-6}\times25.28\times10^{-6}}$

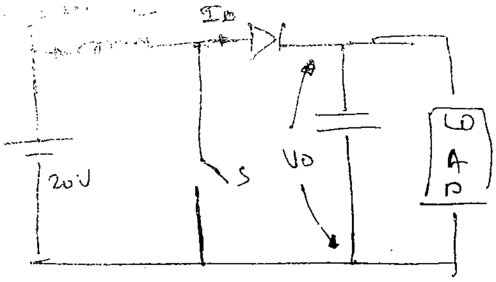
$= \underline{\underline{50\mu s}}$



$\underline{\underline{t > 50\mu s}}$

---

20)



Step up chopper.

S parallel, L series

Note :

Series inductor, parallel capacitor

purpose is to make conduction smooth

· OFF period diode conducts

$(\overline{S})$

$I_{DA} = \underset{\text{current given}}{I_L} \times \frac{T_{OFF}}{T}$

$= 4 \times (1-0.5)$

$I_{DA} = \underline{\underline{2A}}$

$V_0 = \frac{V_s}{1-\alpha} = \frac{20}{1-0.5} = \underline{\underline{40V}}$

---

21) Step down chopper

$V_1 = \alpha V_s$

$= 0.8\times100$

$= \underline{80V}$

$I_0 = \frac{V_1}{R} = \frac{80}{5}$

$= \underline{\underline{16A}}$

$\frac{dv}{dt} = t =$

$I_0 = C \times D \Rightarrow C = \underline{\underline{0.2\mu F}}$

Step up chopper

$V_0 = 660V$

$V_S = 220V$

$t_{OFF} = 100\mu s$

$$V_0 = \frac{V_s}{1-\alpha}$$

$$660 = \frac{220}{1-\alpha}$$

$$1-\alpha = \frac{1}{3}$$

$$\alpha = 2/3$$

Pulsewidth = TON

$T_{ON} = \alpha T$

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

$$T = \frac{100}{1-2/3} = 300\mu s$$

$$T_{ON} = 300 \times \frac{2}{3} = 200\mu s$$

23) $R_L = 10\Omega$ $f = 1kHz$

$V_s = 220V$ $\boxed{2V} = E_b$

$\alpha = 0.5$

$V_0 = \alpha(V_s - V_T) = 0.5(220-2)$

$= 109$

24) Boost regulator - step up chopper.

$V_S = 5V$, $V_0 = 15V$

$$15 = \frac{5}{1-\alpha} \quad 1-\alpha = 1/3,\ \alpha = 2/3$$

25) Current commutated, diode

~~[illegible]~~

auxiliary L and C.

$$T_1 = I_0 = \frac{V_s}{R} \text{ only}$$

$$T_A = V_s\sqrt{\frac{C}{L}} = (\text{fault current})$$

26) $L = 5\mu H$, $C = 20\mu F$

$V_C = 200V$

at $t=0$. ~~Io and~~

$$I_p = \cancel{V_0\sqrt{\frac{C}{L}}}\ V_s\sqrt{\frac{C}{L}}$$

$$= 200\sqrt{\frac{20}{5}}$$

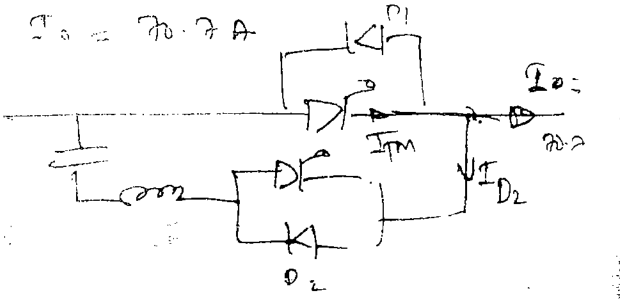
$= 400A$

fault ckt

$$t_{cm}\ t = \frac{\pi\sqrt{LC}}{2} = 15.70$$

27) L&C connected across main when

Fmain ON = current commutation



$$I_{max} = 70.7 + 200\sqrt{\frac{16}{64}} = 170.7A$$

28/ f = 500Hz , Vs = 60V

R = 3Ω , L = 9mH

20 08(ES)

$\frac{T_{on}}{T_{off}} = \frac{1}{1}$

$\alpha = 0.5$ Step down commonly using here we have, if no thing is given step down.

$V_0 = \alpha V_s$

$= 0.5 \times 60$

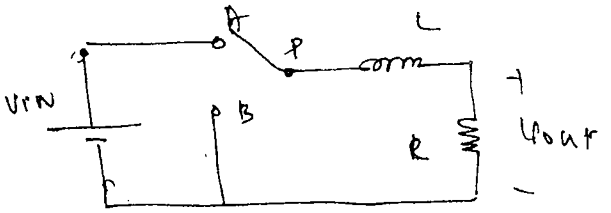
$= 30V$

$I_0 = V_0/R = 30/3 = 10A$

---

29). Rectifier X d_{in} – dc

d_o – dc.

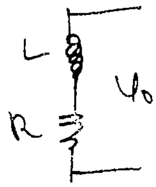


. PA = VIN = L — store

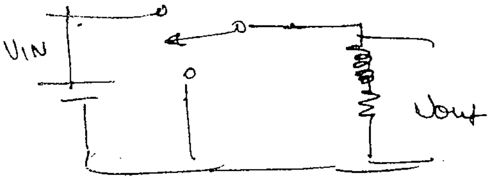
R – dissipate

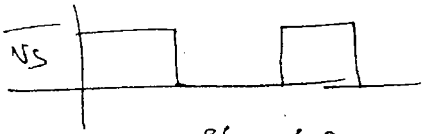
. PB = VIN=0, L – dissipates this R

. Vout only across R



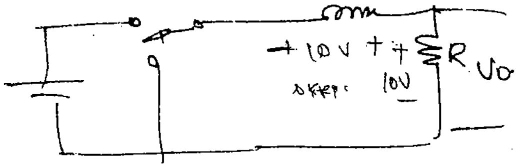
V_0 } =n Step down

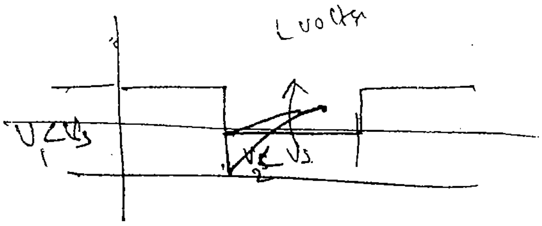




Step up

here





Vary ∠Vs

. Step down chopper

---

30) Regeneration braking mode

└ step up to transfer power

$\alpha = 0.7$,

$V_s = 600V$

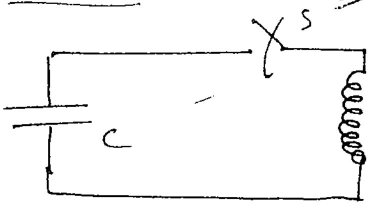
$V_0 = \frac{V_s}{1-\alpha}$

$= \frac{600}{1-0.7} = 2000V$

$V = 2000 \times 9 = 18\,kW$

2009 gate.

21/03/11



23/03/11

$i = V_0 \sqrt{\frac{C}{L}} \sin \omega_0 t$

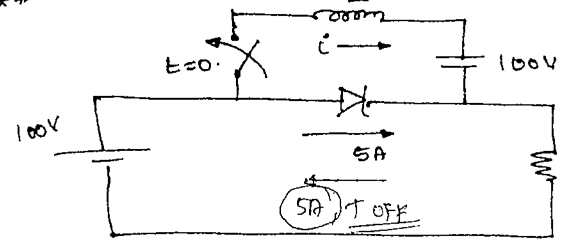
$$\boxed{i = V_0 \sqrt{\frac{C}{L}} \sin \underbrace{\frac{1}{\sqrt{LC}}}_{\omega_0} \cdot t}$$

$L = 1mH$
$C = 10\mu F$ } 9

$i = 10 \sin 10^4 t$ A

***

32)



. current commutation

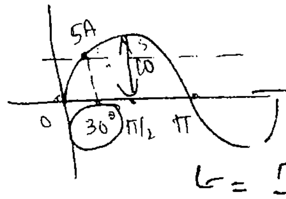
$. \; i = V_0 \sqrt{\frac{C}{L}} \cdot \sin \frac{1}{\sqrt{LC}} \cdot t$

$i = 10 \sin 10^4 t = 5$

$t = ?$

$t = 52 \mu s$

another method



$t = \frac{\pi\sqrt{LC}}{6} = 52 \mu s$

IES Q material chopper

) $R = 20\Omega$, $V_{in} = 200V$, $E_T = 1.5V$

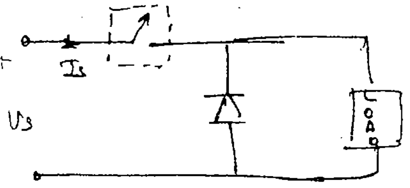
$f = 2kHz$, $\alpha = 0.5$ IES 2009

$V_{or} = \sqrt{\alpha}\,(V_s - V_T)$

$= \sqrt{0.5}\,(200 - 1.5)$

$\cong 140.3V$

Power $= \frac{V_{or}^2}{R} = \frac{(140.3)^2}{20} = 985$ watt



$V_0 = \alpha\,(V_s - V_T)$

$= 0.5(200 - 1.5)$

$= 99.25V$

$I_0 = \frac{99.25}{20} = 4.9625A$

22/03/11

$f = 500$ -

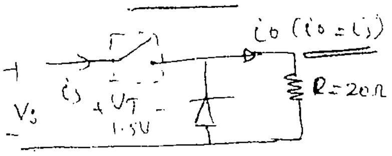
$T = 0.5 ms$

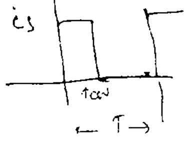
$T = 500 \mu s.$

Next class

R-LOAD

28/03/11 clarification





$i_s = \frac{V_s - V_T}{R} \Rightarrow I_{SA} = \left(\frac{V_s - V_T}{R}\right) \cdot \frac{T_{ON}}{T}$

$= \alpha\left(\frac{V_s - V_T}{R}\right)$

$= 0.5\left(\frac{200 - 1.5}{20}\right)$

$= 4.96A$

$P_i = 200 \times 4.96$

$= 992W$

$P_0 = 985W$

$\eta = \frac{985}{992} = 99.2\%$

02) c) $T_{OFF} = 100\mu s$

IES 2007

$T_{ON} = 200\mu s$

$$V_0 = \frac{V_s}{1-\alpha}$$

$$660 = \frac{220}{1-\alpha} \Rightarrow 1-\alpha = 1/3$$

$$\alpha = 2/3$$

$$T_{OFF} = (1-\alpha)t = \frac{1}{3} \times T$$

$T = 300\mu s$

$T_{ON} = 200\mu s.$

Pulse width halved

$$T_{ON} = \frac{200\mu s}{2} = 100\mu s$$

f - same

$T = 300\mu s$

$$\alpha = \frac{100}{300} = \frac{1}{3}$$

$$V_0 = \frac{V_s}{1-\alpha} = \frac{3}{2} 220 = 330V$$

Q3) ~~Q5)~~ 2003

(a) Step up chopper

$\alpha = 0.5$, $V_0 =$

'2V' can be obtained.

---

b) $V_0 = 600V$

$V_s = 200V$

$T_{OFF} = 50\mu s.$

$T_{ON} = ?$

$$6000 = \frac{200}{1-\alpha}$$

$$1-\alpha = 1/3$$

$$\alpha = 2/3$$

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

$$50 = \frac{1}{3} \times T$$

$T = 150\mu s$

$T_{ON} = 100\mu s$

→ T_{ON} for f - same

$V_0 = 300V$

$T =$ same $= 150\mu s$

~~$T_{ON} =$~~

$$V_0 = \frac{V_s}{1-\alpha} = \frac{200}{1-\alpha} = 300$$

$$1-\alpha = 2/3$$

$$\alpha = 1/3$$

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

$$= \frac{1}{3} \cdot 150$$

$$= 50\mu s$$

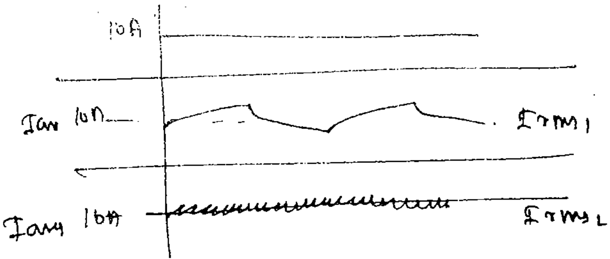
4> chopping frequency

ii). increase the chopping frequency

i> frequency ↑

→ stepdown

·If L replace C, operation not feasible (reason).



$I_{rm1} > I_{rm2}$

· good performance.

· Form factor = 1 powde $\boxed{\frac{I_{rm}}{I_{av}} = 1}$

· Formfactor → 1

6-9-DC M/c-307
4 8.30-PE-307

5> Later at DC drives speed control.

INVERTER

23/03/11

· line commutated inverter	Forced commutated inverter
· designed based on Appl:	· It is automatically ON when P-S is not there.
· make it ON whenever P-S Not available	· It is having control over f, Vout No of phases
· cannot feed the load directly	· Can be feed the load directly.

Phase controlled Rectifiers. ~~can~~ when operated with $\alpha > 90°$, they are known as line commutated inverters.

· It transfers the energy from dc to an existing ac supply network.

· The o/p voltage, frequency and No: of phases cannot be controlled.

→ INVERTER :- It is a static power electronic circuit, which converts dc to variable ac, ie variation in magnitude of voltage, frequency and No: of phases.

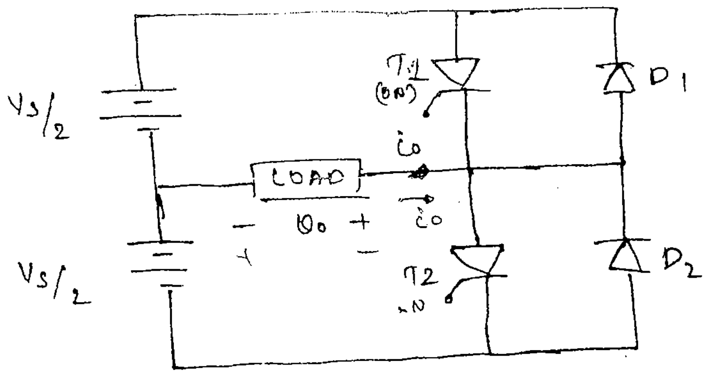
17) (1-ϕ) Half Bridge Inverter

- If supply across the load
- frequency.

Std :- 50Hz

T :- 20ms

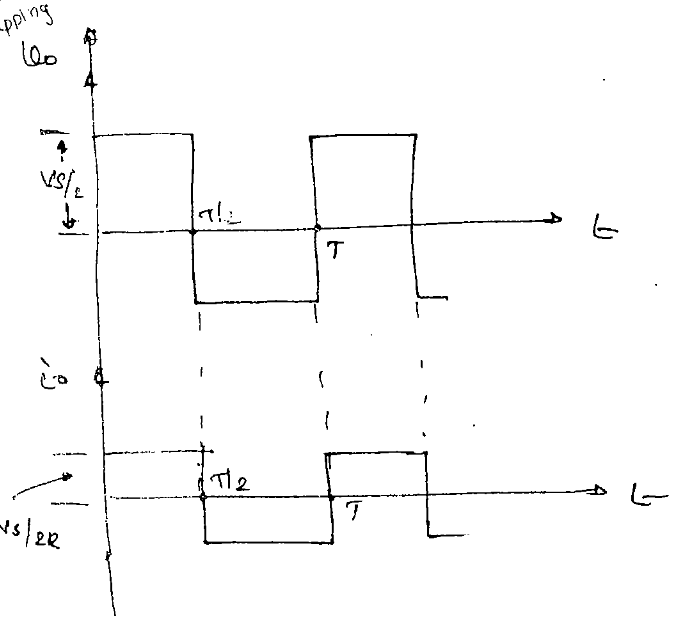
$\boxed{T/2 :- 10ms}$



: centre tapping a Vs/2

- For every 10ms we need +ve -ve transition.

→ T1 T2 are FB - (If triggered both dead S.C occurs)(careful)



1) T1 - Triggered. ON.

- $V_o = V_s/2$
- $i_o = V_s/2R$

} +ve { this direction convention }

- ON Conduction TON = 10ms. for T1
- at 10ms T1 - OFF.

2) Triggering T2 - ON

- $V_o = -V_s/2$
- $i_o = -V_s/2R$

{ -ve opposite to conventional dir.

3) Again T2 - OFF
T1 - triggered ON. } given Vo's graph

OBS

1) o/p is square wave changing (Alternating) voltage or current (This is the possible wave form).

- Passed through Filter to eliminate unwanted harmonics

2) Forced commutation.

- i/p dc voltage never comes to zero.
- Voltage/current commutation applied (do not show here)

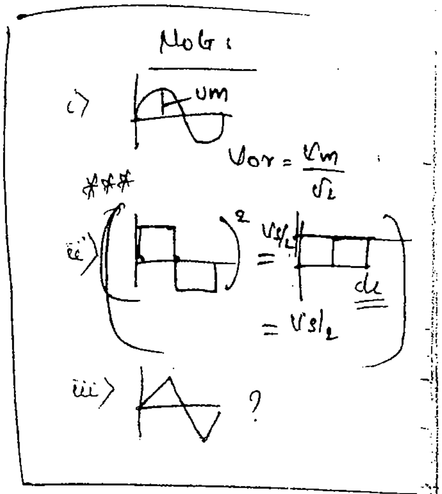
3) Diodes D_1 and D_2

- D_1 and D_2 are required for RL load, RLC load

12 Inverter operation is based on forced commutation. o/p wave forms are square wave forms. These will be passed thru filter to eliminate unwanted Harmonics. The anti parallel diodes are required for all the loads except 'R load'

Average & rms value.

- Average value $V_o = 0$.
- RMS value $\boxed{V_{or} = \frac{V_s}{2}}$ For square waveform

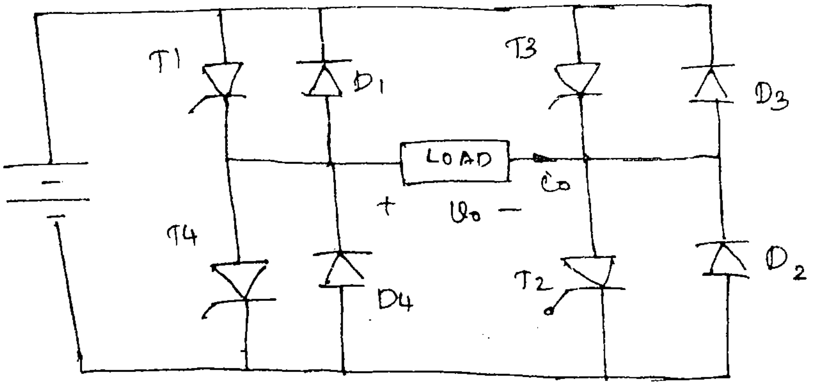


Disadvantage.

1) At any time o/p voltage is half of the available supply voltage hence source utilization factor would be 50%.

---

2) 1ϕ - Full Bridge Inverter -

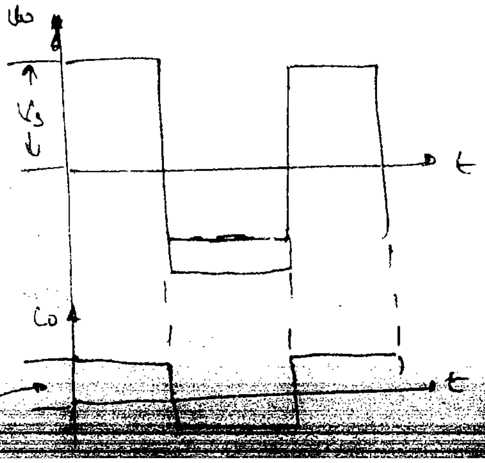


4 SCR, 4 diode.

dc i/p, load = A/c with $f = 50Hz$
$T = 20mS$
$T/2 = 10mS$.

(T 1, T 2, T 3, T 4) ⇒ All are Forward Biased

CAUTION :- while triggering thyristor
other wise S.C



[illegible]

· T1 T2 – triggered ON – $+v_0 = v_s$

+ve chosen $\xrightarrow{i_0} = \frac{v_s}{R}$ Ⓡ Assume R load. } cycle Repeats.

·2) $T/2 = 10ms$, T3 T4 – trigger ON – – $v_0 + = -v_s$

$\xleftarrow{i_0} = -\frac{v_s}{R}$

OBS

1) o/p wave form square ⇒ Filtered ⇒ sinusoidal

2) commutation forced.

3) Diode D1 D2 D3 D4 – Other than R Load

** 4) $\boxed{V_{or} = V_s}$ *** ADVANTAGE – At any time o/p voltage is same as the supply voltage, hence load utilization factor is 100%

5) $f_1 = 50Hz$, $T = 20ms$, $T/2 = 10ms$

$f_2 = 100Hz$, $T = 10ms$, $T/2 = 5ms$

$f_3 = 200Hz$, $T = 5ms$, $T/2 = 2.5ms$

Frequ varied (o/p) ⟹ vary the conduction time of thyristor

· The o/p frequency of the a/c waveform, can be controlled by varying the conduction times of thyristor.

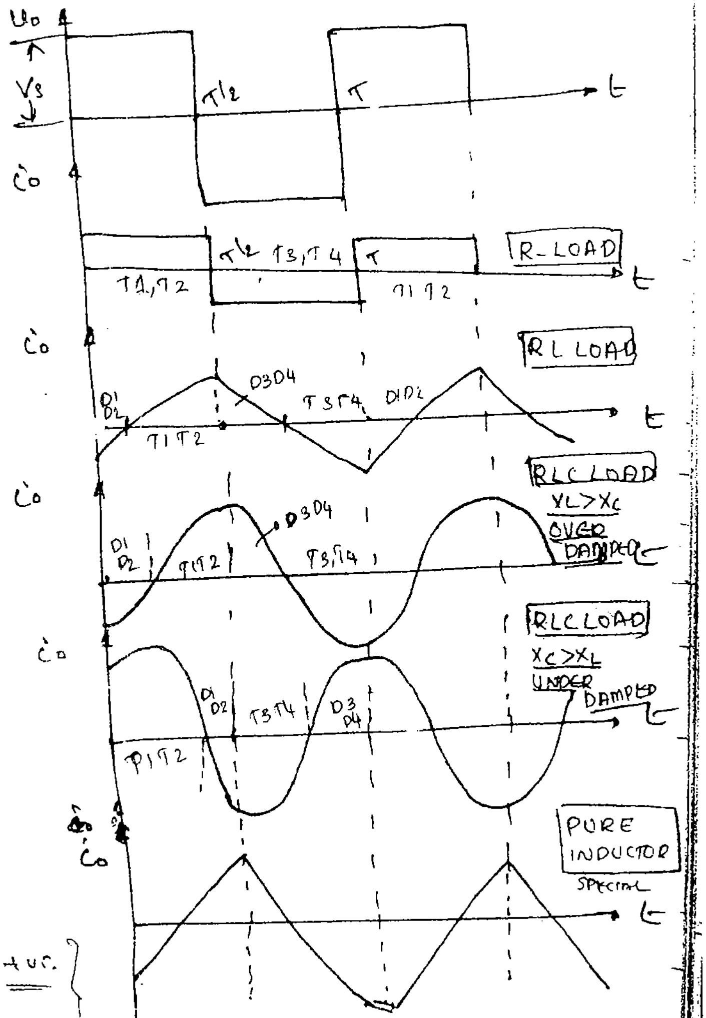
·6) given supply, R-load, o/p voltage and o/p power in F Bridge inverter compare to 1/2 Bridge relation.

~~P F.B =~~ $V_{o\,FB} = ② \times V_{o\,1/2\,Bridge}$

$P_{o\,FB} = ④ \times P_{o\,1/2\,Bridge}$

- The output voltage is 2 times and output power is 4 times as full bridge inverter compared to half bridge inverter.

Steady state analysis of 1ϕ - Full bridge inverter.



1) R load current discussed above.

Sign convention (general)

	$-U_o$	i_o
T1T2	+ve	+ve
T1 T3	-ve	-ve

2) R-L load current

i) Lagging current.

ii) shape :- DC given to R-L load, exponential variation of current. (exponential rise and decay).

- By sign convention

+ve ⟹ T1, T2

-ve ⟹ T3, T4

- Voltage +ve, i = -ve (diode).

1) D1 D2 - conduction $+ \, v_o \, - = \underline{\underline{+ve}}$ $\overleftarrow{i_o} = \underline{\underline{-ve}}$ }

~~2) D3 D4~~

2) D3 D4 - conduction $- \, v_o \, + = -ve$ $\overrightarrow{i_o} = +ve$ }

(Later: diode conduction situation)

8) R-L-C load XL > Xc (overdamped) (Lagging i)

- Constant dc supplied to R-L-C, second order equation, which gives the shape of o/p current as sinusoidal.
- XL > Xc mean lagging.

R-L-C - Xc > XL (leading i) (under damped)

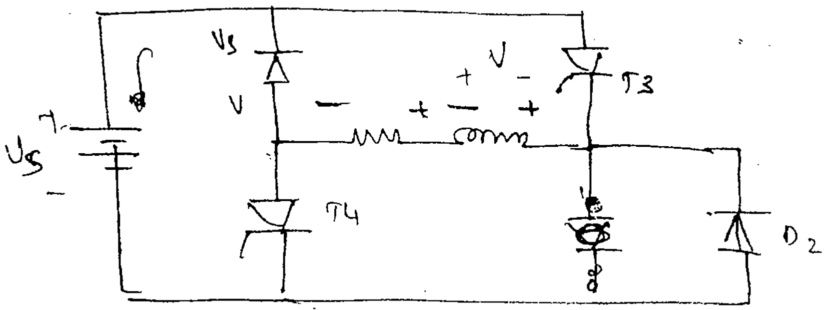
[illegible]

- D1D2 conducting ⟹ FB = $V_A > \frac{V_K}{V_s}$ ⟹ $V_A > V_s$

i) RL load

- waveforms, before D1D2 ~~was~~ as conduction T3T4 as conduction.

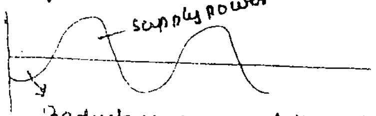
- which means



- when T3T4 – turned OFF, current ~~polarity~~ changes and has to become zero hence gives a slope, Inductor voltage ~~has~~ reversed and produces a a $V_o > V_s$ by the $\frac{di}{dt}$ which happens while T3T4 gets OFF

- Power = – Negative power
  - Instantaneous

Note:-
i) No Regenerative motor braking only happens when average power = 0 –V.
e)



Inductance power delivered.

OBS:-

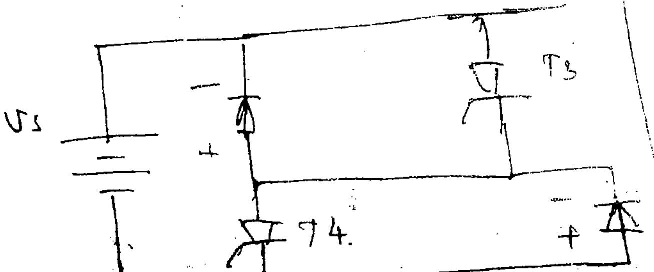
i) Commutation

- ~~1 to 4 loads required Forced commutation~~

i) LOAD COMMUTATION

a) RLC load $X_L > X_C$ and $X_C > X_L$

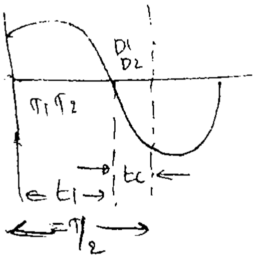
- Diodes D1D2 conduction then T1T2.



RLC / $X_C >> X_L$

- here load commutation :- commutation –Vc voltage is coming because of the nature of the load.

- condition



→ tc is the time when we apply reverse voltage across T1 T2 after its current becomes zero.

$$\boxed{\frac{T}{2} - t_1 = t_c > t_q}$$

→ $T/2 - t_1 >$ Total turn OFF times of T ~~1~~ and T2.

$X_c > X_L$

SIR

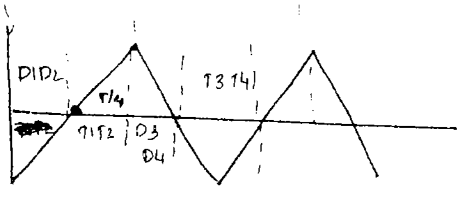
1) • In under damped loading condition when $X_c > X_L$ load commutation can be achieved. It is possible only when anti-parallel diodes conducts for a ~~time~~ duration $\left[\underline{(T/2 - t_1) = t_c} \; ~~t_q~~ \right]$ ~~tq~~ is the duration device turn off time t

2) The current through thyristor is coming to zero and immediate application of reverse voltage are happening due to the nature of the load so it is known as <u>LOAD COMMUTATION</u>.

5> SPECIAL LOAD (PURE INVERTER)

• due to pure inductor, current variation is always linear.

• slope +ve ⇒ $V_0 = +V_C$
• slope −ve ⇒ $V_0 = -V_C$.
} Δ^{lr} waveform.



→ 90° lag, T/2 crossover.

→ Average power = 0 (symmetrical)

~~Ipeak~~ = 3) 0 to peak time required = T/4

4> Peak - Peak ~~time~~ = T/2.

OBJ *** ~~5~~ 5> Conduction time = T/4 (for T and D)

• If the inverter is feeding a pure inductive load, following are the points w.r.t o/p waveforms.

1> Nature of o/p current = Δ^{lar} 2> Nature of o/p voltage = square wave form

3) Slope of current variation = V_s/L

$$\boxed{4) \text{ Peak value of current } I_{peak} = \frac{V_s}{L} \cdot T/4}$$

5) peak to peak error = 2 I peak = $\frac{V_s}{L} \cdot T/2$.

6) Conduction duration of either thyristor or diode ~~for~~ a cycle = $T/4$.

FILTERED OUTPUT

1ϕ 1) $V_{or_1} = \frac{V_s}{2}$ ⟹ Filtered (Removed unwanted Harmonics) ⟹ $\underline{\underline{V_{or_2}}}$.

1ϕ Illy 2) $V_{or_1} = V_s$ ⟹ Filtered (Removed unwanted H) ⟹ V_{or_2}.

Fourier Analysis of 1ϕ INVERTERS.

1)

$$V_0 = \underbrace{\sum_{n=1,3}^{\infty}}_{\text{Symmetrical wave form}} \left\{ \frac{2\,V_s}{n\pi} \right\} \sin nwt$$

$$i_0 = \sum_{n=1,3}^{\infty} \left\{ \frac{2\,V_s}{n\pi \underbrace{Z_n}_{\text{Impedance offered by nth harmonic}}} \right\} \sin(nwt - \underbrace{\phi_n}_{\text{phase angle}})$$

} 1ϕ - Half Bridge Inverter.

Illy 2)

$$V_0 = \sum_{n=1,3}^{\infty} \left\{ \frac{4\,V_s}{n\pi} \right\} \sin nwt$$

$$i_0 = \sum_{n=1,3}^{\infty} \left\{ \frac{4\,V_s}{n\pi Z_n} \right\} \sin(nwt - \phi_n)$$

} 1ϕ – Full Bridge Inverter.

Generally

$$V_0 = \boxed{V_m} \sin nwt$$

$$i_0 = \boxed{I_m} \sin nwt$$

Fundamental component

1) Half Bridge inverter $V = \frac{2V_s}{n\pi\sqrt{2}}$ others |||ly

where $Z_n = \sqrt{R^2 + \left(nX_L - \frac{X_C}{n}\right)^2}$

$$\phi_n = \tan^{-1}\left(\frac{nX_L - \frac{X_C}{n}}{R}\right)$$

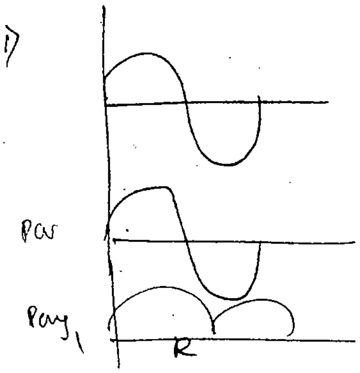
Note :

→ at nth harmony
$f = nf.$
$= n \times$ fundamental.

→ hence $X_L = nX_L.$
$X_C = \frac{X_C}{n}.$

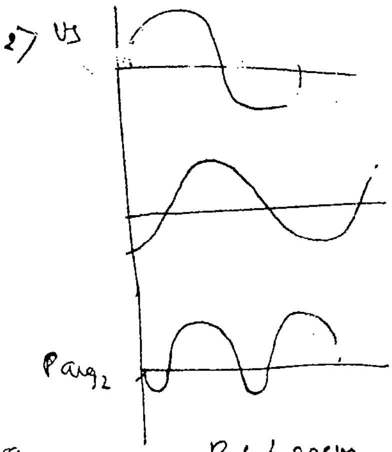
Note :- Power curves

1)



Pavg1 > Pvg2

2)



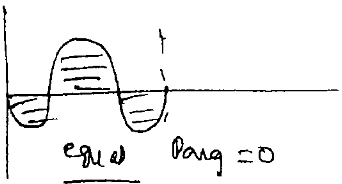
R-L Lagging

Pf ↑ ⇒ Pavg ↓

$P_{max} = V I \cos\theta$

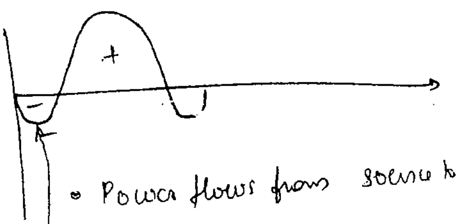
$\phi = 90°$

3)



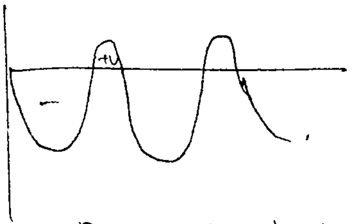
equal Pavg = 0

4)



- Power flows from source to load (Pavg +ve)
- No Regenerative Breaking only instantaneous power −ve
- Net power supply from source to load.

4)



- Regenerative braking
- Net power load to source
- Pavg = −ve

3) order of harmonics increases, Zn also increases

· At electronics — f = MHz, kHz — impedance of the coil is very high hence draws a very less current (RF coil)

SIR · As the order of the harmonics increases, in RLC load, impedance increases.

4) Harmonic Factor of nth harmonics. (Hfn) :- It is the measure of individual harmonics present in o/p voltage w.r.t fundamental component

$$\boxed{Hf_n = \frac{V_n}{V_1}}$$

{ · used to find out other harmonics in fundamental (which we required. }

5) Total harmonic distortion (T.H.D) :- It is the measure of resultant of all harmonics w.r.t Fundamental harmonics.

$$\boxed{THD = \frac{\sqrt{\sum_{n=2,3}^{\infty} V_n^2}}{V_1}}$$

· How to evaluate infinite individual components after fundamental.

1) Calculate the fundamental.

2) Total harmonics = 1000 V

Fundam = 80 V

$$= \sqrt{1000^2 - 80^2}$$

Remaining harmonics other than Fundamental / Fundamental

$$= \boxed{\frac{\sqrt{V_{or}^2 - V_1^2}}{V_1} = \frac{\sqrt{\sum_{n=2,3}^{\infty} V_n^2}}{V_1} = THD}$$

b) distribution factor of nth harmonic

$$\boxed{(D.Fn) = \frac{V_n}{n^2 V_1}}$$

24/03/11

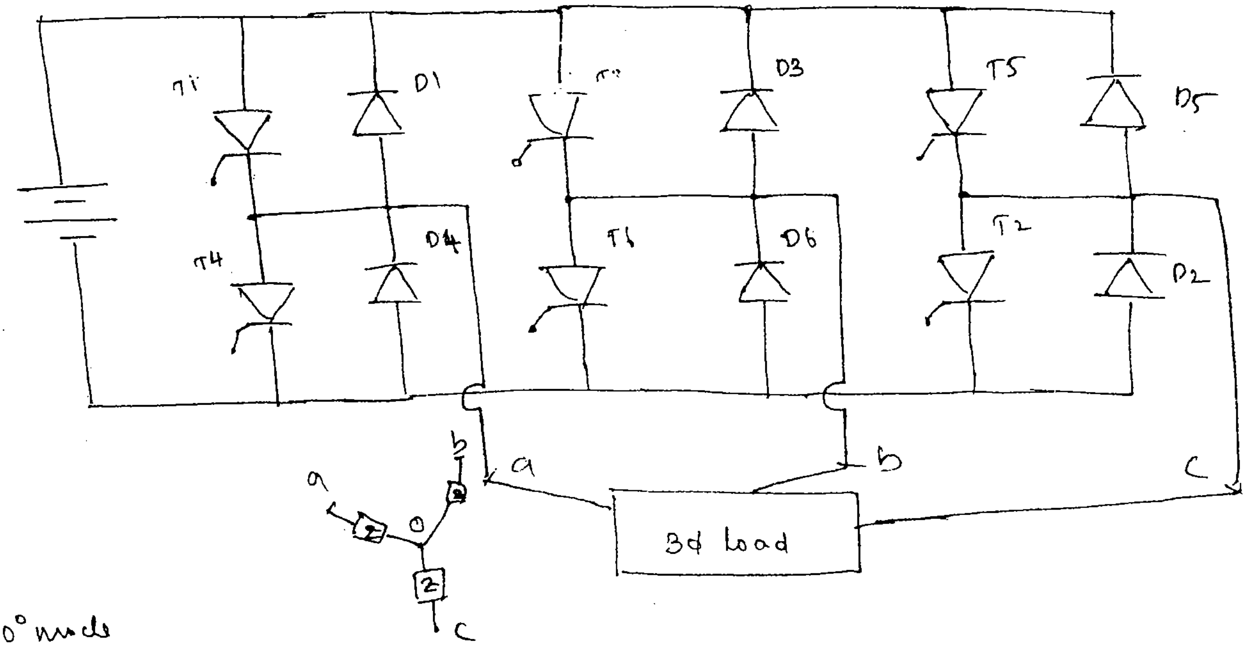
6 - 8 = M/C II

6 pm - 9.10 = PE

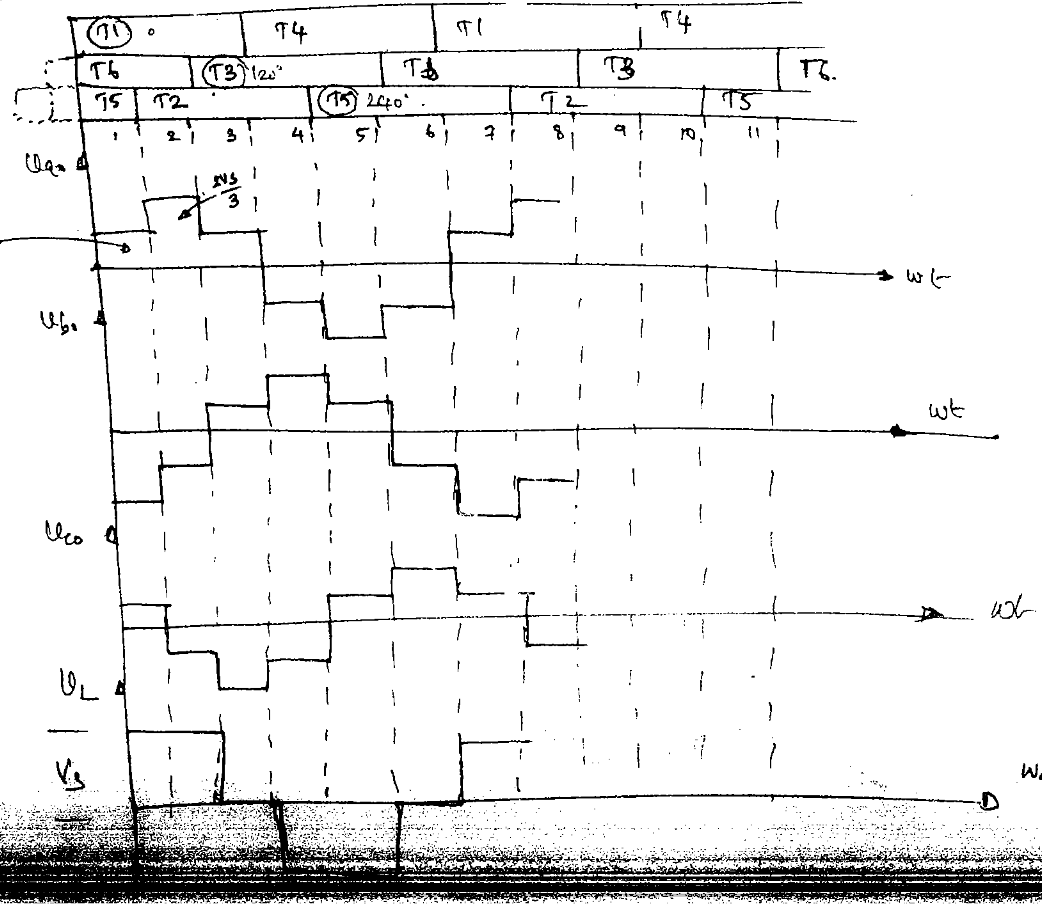
302

3φ - BRIDGE INVERTER → IES Q

24/03/11



180° mode



nditions of 3ϕ

1> 120° displacement between a b c

2> Conduction time 180°

- Numbering of the Thyristor and diode take care

1> Vs supply, All 'T' are FB, Based on requirement trigger is given.

2> Two modes of operation 180° mode and 120° mode

a) conduction time of each SCR = 180°.

b) phase angle b/w two sequential thyristors from top group or bottom group is 120°

1) each SCR conducts for 180°

2) phase angle b/w two sequential thyristor (1,3) (3,5) (5,1) is 120° (to obtain 120° phase difference).

- 120° mode
- Each SCR conducts for 120°
- 180 - 120 = 60° time is given to turn OFF the SCR.

3> graph, each interval of 60°, 3 ϕ are shown as 3 lines.

I>
i> ~~at~~ T1 = Triggered (t=0) - 180° conduction. ii> T4 - triggered - 180° - conduct

iii> T1 - triggered (180°) iv> T4 - triggered (180°) = 1 CYCLE

II> T3 ⇒ Triggered at (t = 120°) (180° conduction), T6, T3, T6 ----

0-120° = T3

III> T5 ⇒ triggered at (t = 240°) (180° conduction) T2, T5, T2.

0-240° = T2

4> At any time 3 SCR's will be in conduction.

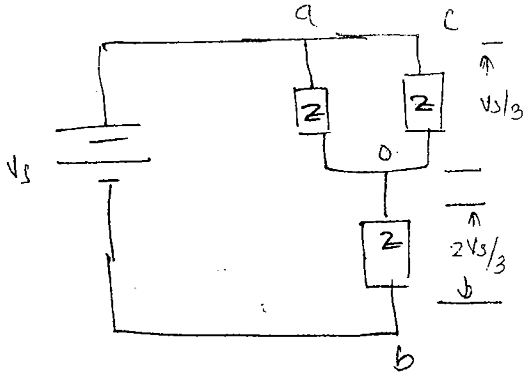
5> Consider a star connected load. (balanced load) with impedance Z.

6) T1 conducting → a → connected to +ve

T6 → b → -ve

T5 → c → +ve

Now draw the equivalent circuit for (0-60°)



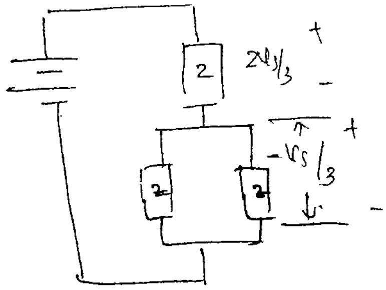
(0- 60°)

- calculate Vphase

. Va phase = Vs/3 Vc phase = Vs/3 } Plotted on the graph
. Vb phase = -2Vs/3.

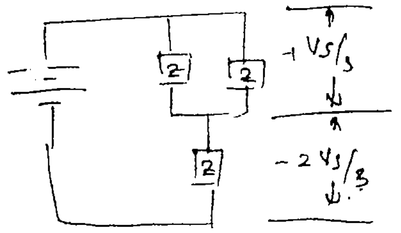
⇒ (Va phase + Vc phase + Vb phase) at any time
= 0

ii) 60–120° (T1 T6 T2)
a b c
+Vc -Vc -Vc



} Plot the graph.

iii) 120 – 180° (T1 T3 T2)
a b c
+Vc +Vc -Vc



} Plot the graph

6) Line voltage Vab

$V_{ab} = V_{ao} - V_{bo}$

$= \left\{ \frac{V_s}{3} - \left(-\frac{2V_s}{3} \right) \right\} \quad \left\{ \frac{2V_s}{3} - \frac{V_s}{3} - \frac{V_s}{3} \right.$

7) shape of the waveform

OBJ i) shape of the phase voltage is 3 stepped waveform.

ii) Shape of line voltage Quasi - square waveform.

8) Disadvantage.

→ at 180°, T1 – turned OFF at zero time, T4 triggered. If T1 is not correctly switched off. T1 may go conduction.

→ 120°, mode

i) In 180° mode of operation, there is 'NO time gap' between commutation of outgoing SCR and conduction of incoming SCR. It may leads to short circuit of the supply due to simultaneous conduction of both the SCRs. Hence 120° mode is preferable.

9) Numbering Sequence

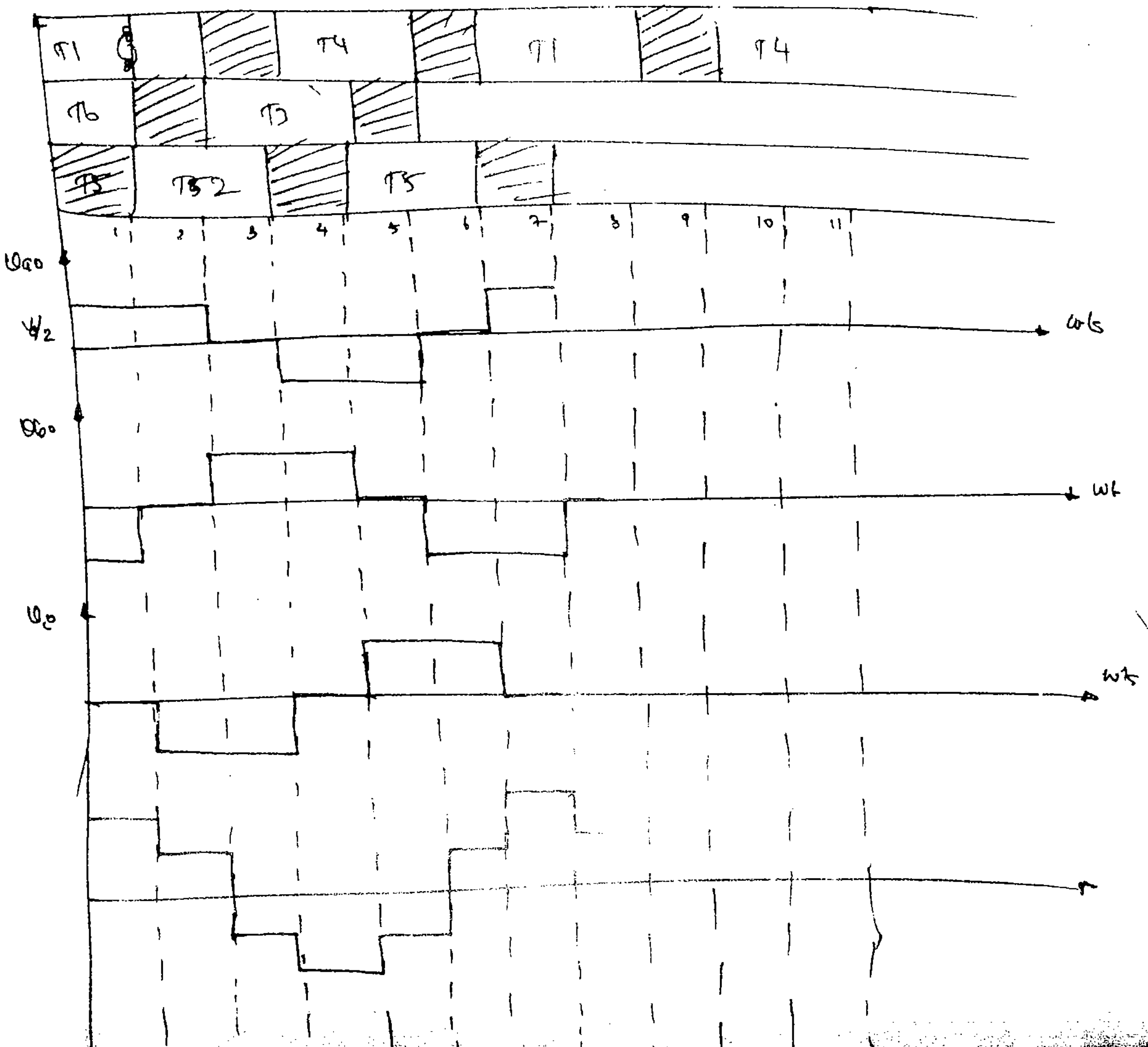
- wt = 0 ⟹ T1 only (T6, T5 already conducting)

ly wt = 60 ⟹ T2, wt = 120 ⟹ T3, wt = 180 ⟹ T4, wt = 240 ⟹ T5

wt = 300 ⟹ T6)

- The thyristors have been numbered in the sequence, they are getting the trigger pulses.

II) 120° mode.



1) Conditions

1) Conduction time $\underline{120^\circ}$

2) phase angle b/w two sequential SCR = $\underline{\underline{120^\circ}}$

- Conduction time of each SCR is equal to 120°
- Phase angle b/w two sequential SCR is ~~120°~~ either from top group or from bottom group = $\underline{\underline{120^\circ}}$

- After 120°, the next 60°, in one phase there will not be any conduction
- The time (60°) is given to the SCR to reach the off state clearly.

2) - we are starting to divide the time slot as upper line

IES OBJ

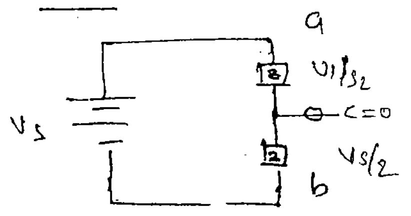
- At any time only '2 SCR's' will be in conduction.

3) ~~Draw~~ Equivalent circuit

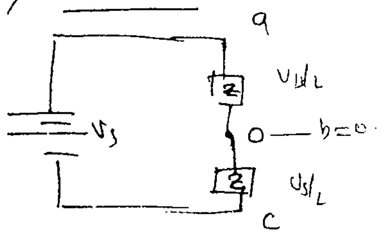
- Consider $\overset{a\quad b}{\curlyvee}_{c}$ connected load with impedance Z.

phase voltage

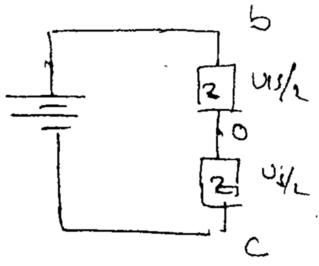
i) 0 – 60°



ii) 60 – 120°



iii) 120 – 180°



4) Line voltages

$V_{ab} = V_{ao} - V_{bo}$

4) shape of ~~wave~~ voltage

- Shape of the phase voltage is Quasi square wave, ~~shape of line~~
- shape of the line voltage 3-stepped waveform

5) Disadvantage

- Any time 't' only two phases are supplied. If the load is unbalanced, the voltage occurs (uncertain voltage), for other phase.
- At any time ~~only 2 phases~~ one of the phase is neither connected to +ve plate ~~nor to negative plate hence the particular phase voltage is tied for~~

[illegible]

II) Mathematical Expression.

- In both mode ~~as~~ Vphase is calculated means Vline can be calculated.
- a in Quasi square wave it is easy to do integration

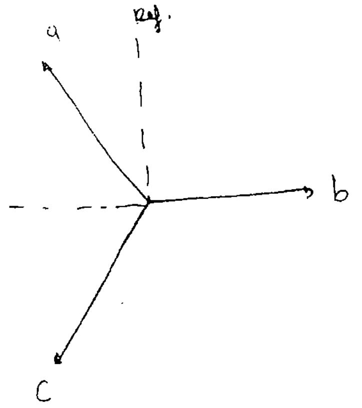
I) 180° mode

$$V_{ab} = \sum_{n=1,3}^{\infty} \left\{ \frac{4V_s}{n\pi} \cos\frac{n\pi}{6} \right\} \sin n(\omega t + \pi/6)$$

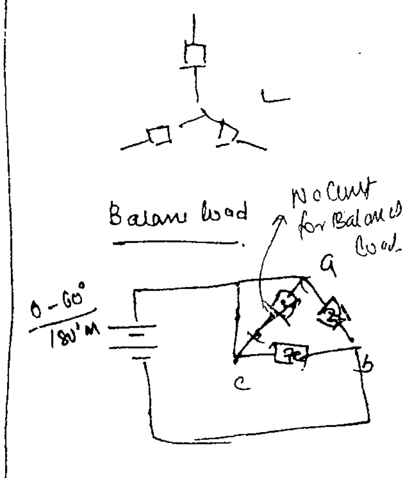
$$V_{bc} = \sum_{n=1,3}^{\infty} \left\{ \frac{4V_s}{n\pi} \cos\frac{n\pi}{6} \right] \sin n(\omega t - \pi/2)$$

$$V_{ca} = \sum_{n=1,3}^{\infty} \left\{ \frac{4V_s}{n\pi} \cos\frac{n\pi}{6} \right] \sin n(\omega t + 5\pi/6).$$

Vector diagram



Note :-



i) OBS ① ~~All multiple~~ for $n = 3$, $\cos\frac{n\pi}{6} = 0$, hence all the line voltages are free from triple n (3n) harmonics.

ii) → Rms value of line voltage $(V_L) = V_s \sqrt{\frac{120°}{180°}} = V_s\sqrt{\frac{2}{3}} = 0.8165V_s$

$$\boxed{V_{L\,rms} = 0.8165V_s}$$

b) Rms value of phase voltage $\frac{V_L}{\sqrt{3}} = V_{ph} = \frac{0.8165}{\sqrt{3}}$ $\boxed{V_{ph} = 0.4714V_s}$

120° mode

$$v_{ao} = \sum_{n=1,3}^{\infty} \left\{ \frac{2V_s}{n\pi} \cos\frac{n\pi}{6} \right\} \sin n\left(\omega t + \pi/6\right)$$

$$v_{bo} = \sum_{n=1,3}^{\infty} \left\{ \frac{2V_s}{n\pi} \cos\frac{n\pi}{6} \right\} \sin n\left(\omega t - \pi/2\right)$$

$$v_{co} = \sum_{n=1,3}^{\infty} \left\{ \frac{2V_s}{n\pi} \cos\frac{n\pi}{6} \right\} \sin n\left(\omega t + 5\pi/6\right).$$

1) For $n = 3$, $\cos\frac{n\pi}{6} = 0$, hence all phase voltages are free from triplen harmonics (3n harmonics).

2) i) Rms value of phase voltage $(V_{ph}) = \frac{V_s}{2}\sqrt{\frac{120}{180}}$.

$$\boxed{V_{ph} = 0.4082 V_s}$$

ii) Rms value of line voltage $(V_L) = V_{ph}\cdot\sqrt{3} = 0.4082 \times \sqrt{3}\, V_s$

$$\boxed{V_L = 0.7071 V_s.}$$

DS :- * * *

i) For a given dc supply more o/p voltage can be obtained from single phase inverter even compared to 3 ϕ inverter.

II) CONTROLLING MAGNITUDE OF OUTPUT VOLTAGE (0 to Vmax)

I) VOLTAGE CONTROL IN 1ϕ INVERTERS. IES ② 20 marks

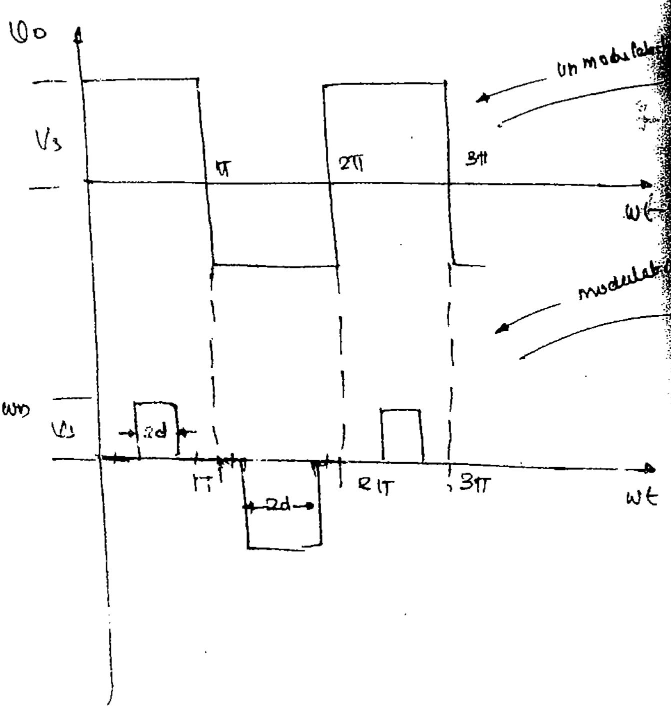
Introduction: O/p voltage of the inverter can be controlled by any of the following methods. 1) External control of A/c o/p voltage :- In this method an a/c voltage controller will be employed at the o/p of the inverter to make a c to variable magnitude a/c voltage.

2) External control of dc i/p voltage :- A dc chopper will be connected at the i/p of the inverter to make the dc to variable dc voltage.

3/ Internal control of inverter :- in this method Pulse width modulation (PWM) techniques are employed to control the output voltage. *** Repeat IGQ

- In PWM method, width of the o/p pulse will be controlled to achieve the o/p voltage achieved.

i) Single pulse modulation



- For every half cycle of unmodulated wave there is only one pulse is there. in o/p wave form
- o/p voltage waveform having only one pulse per half cycle. hence known as single pulse modulation

1) Vrms $V_{or} = \boxed{V_s\sqrt{\frac{2d}{\pi}}}$ ***

- conventional → derive the equation

$$V_{or} = \sqrt{\frac{1}{\pi}\int_{\pi/2-d}^{\pi/2+d} V_s^2 \, d(\omega t)}$$

- Limits of Integration

$$2d + 2x = \pi$$

$$2x = \pi - 2d$$

$$x_1 = \frac{\pi}{2} - d.$$

$$x_2 = \pi/2 + d.$$

- Symmetrically placed $\underset{0}{|}\!\!-\!\!\!\!|\overset{2d}{\boxed{}}\!|\!\!-\!\!\underset{\pi}{/}$ to avoid harmonics.

$$V_{or} = \sqrt{\frac{V_s^2}{\pi}\left[\omega t\right]_{\pi/2-d}^{\pi/2+d}} =$$

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

OBS

i) $|V_{o}|$ varied ~~using~~ by varying '2d' (or width)

i) Minimum width of pulse = 0

$2d = 0$

$V_{or} = 0$

$\boxed{0 \leq V_{or} \leq V_s}$

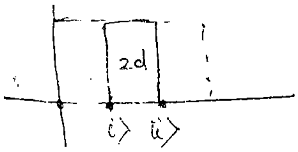
ii) Maximum width of pulse = π

$2d = \pi$

$V_{or} = V_s$

2> To control the width of the pulse

i> delay the firing of the thyristor
+
ii> Advance the commutation



→ The width of the o/p pulse can be controlled by varying firing delay angle and advancement of commutation.

3> Fourier Analysis Expression

6.30 - 10.30 PM - IM - 305
2 - PM - 5.30 - Analy 304
6 - 8.30 - DC M/c 304

$$V_o = \sum_{n=1,3}^{\infty} \left\{ \frac{4V_s}{n\pi} \sin\frac{n\pi}{2} \sin nd \right\} \sin n\omega t.$$

$$\boxed{V_{or\,1} = \left\{ \frac{4V_s}{\pi} \sin\overset{1}{\frac{\pi}{2}} . \sin d . \right\} 1/\sqrt{2}}$$

4> Harmonic Elimination. (nth from o/p waveform)

- For $n=3$, $V_{or(3)} \cancel{\neq 0} = 0$ $\Rightarrow$ $\sin 3d = 0$ $\boxed{2d = \frac{2\pi}{3}} = \cancel{72°}\ 120°$
- generally $\sin nd = 0$ $\Rightarrow$ $nd = \pi$ (take only π), Not 0)
  d = 0 no meaning

$$d = \pi/n$$

$$\boxed{2d = 2\pi/n}$$

a By properly selecting the width of the pulse one of the harmonics in the o/p waveform can be eliminated. It is possible only when amplitude is equal to zero for that value of 'n'.

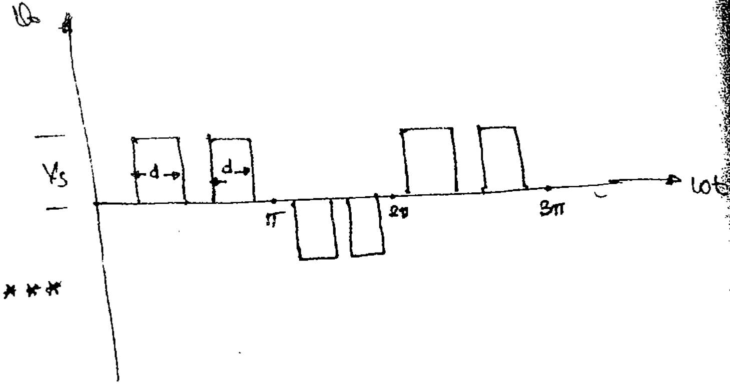
eg :- 3rd Harmonics can be eliminated by making the width of the pulse $2d = 2\pi/3 = 120°$

5> Disadvantage

- The o/p waveform will have the large amount of harmonics particularly at low o/p voltage levels. Hence multiple pulse modulation is more preferable

ii) Simple multiple pulse modulation

- All the pulses are having equal (height = Vs) width, hence called simple multiple pulse modulation.



- Vor = rms value of o/p voltage

$$\boxed{V_{or} = V_s\sqrt{\frac{d+d}{\pi}} = V_s\sqrt{\frac{2d}{\pi}}}$$ ***

- Realising two pulses by T_1T_2 ON and OFF, here two times.

n pulses ⟹ n times ON and OFF of T_1T_2.

⟹ Short interval, switching ~~frequency~~ duty high.

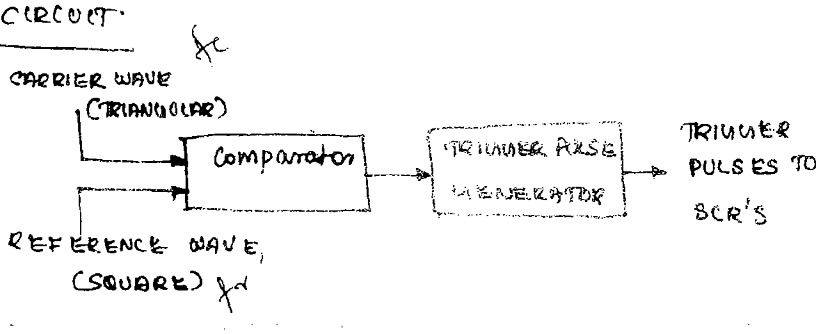
⟹ Harmonics becomes less, high spans decreases. So average and ECONOMICALLY Number of pulses are selected.

(312)
Q. If the number of pulses per half cycle are made more then switching duty on the thyristor increases, hence optimum number of pulses will be selected to reduce the harmonics as well as minimizing the switching duty.

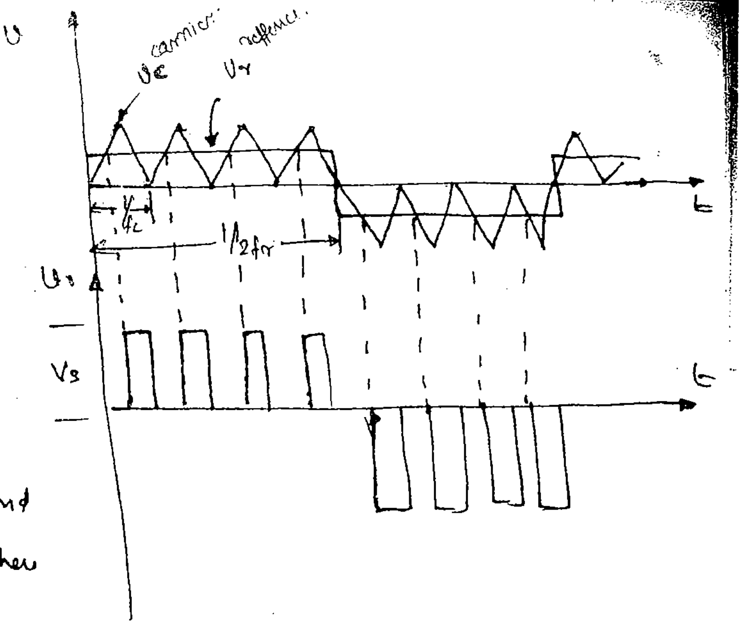
OBJ Q> The amplitudes of lower order harmonics will be decreased, at some of the higher order harmonics will be increased significantly, these are easy to filter out. (Size of the filter required to eliminate higher order frequency are less, $f = 2\pi\sqrt{LC}$, $\frac{L \to \text{small},\ C \to \text{small})}{f\,\text{small}}$.

IMPLEMENTATION OF SINGLE MULTIPLE PULSE

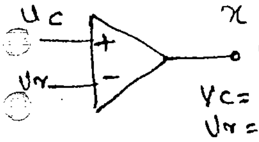
CONTROL CIRCUIT:



carrier wave f_c > Reference wave f_r.
~~(for sinusoidal Vo)~~
(it is square wave)



Comparator



(o/p high ⟹ Triggering).

Vc = Non inverting
Vr = inverting.

Vc > Vr   x ⟹ HIGH ⟹ pulse generated

- Width d is same on all pulses, because square is having a constant magnitude and time was for Vc > Vr is same everywhere
- Time period of carrier = $\frac{1}{f_c}$
- Time period of reference = $\frac{1}{2f_r}$
- carrier wave is an high frequency triangular waveform, Reference wave is an low frequency square waveform, so
- No: of pulses/half cycle

$$\boxed{N = \frac{\text{Width of one half cycle of reference wave.}}{\text{width of one cycle of carrier waveform.}}}$$

we

$$N = \frac{1/2f_r}{1/\cancel{2}f_c.} = \frac{f_c}{2f_r} \qquad \boxed{N = \frac{f_c}{2f_r}}$$

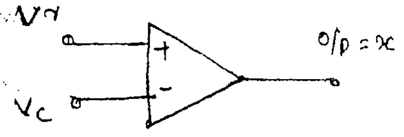
IES 2010 Q

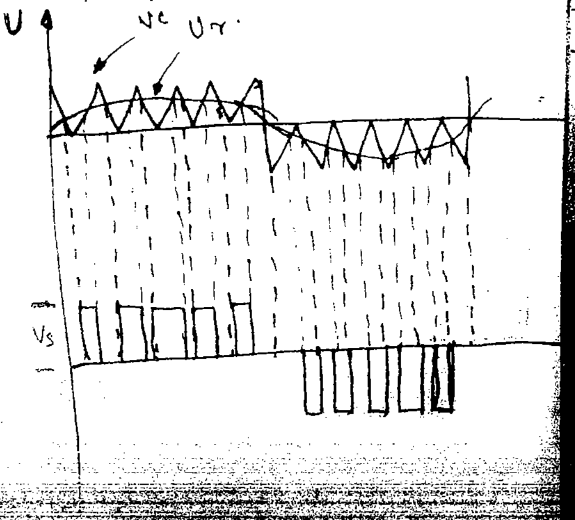
ii) SINUSOIDAL PULSE WIDTH MODULATION. (Elaborate Study)

i) CARRIER WAVE :- High frequency triangular waveform

ii) REFERENCE WAVE :- Low frequency sinusoidal waveform

- Width of the o/p pulses :- it varies in accordance with the magnitude of sinusoidal waveform.





- here note that Vc = inverting
  Vr = Non inverting
- Vr > Vc ⟹ x HIGH ⟹ PULSE

- Time ($V_r > V_c$) ∝ width of the pulse
- Amplitude here is V_s, input dc.

No of pulses/ cycle = N (2 cases)

1) peak of carrier coincident with zero of reference, then the Number of pulse / half cycle $\boxed{N = \frac{f_c}{2f_r}}$ ≅ simple multiple modulator.

2) If zero of carrier, coincident with zero of reference. then $\boxed{N = \frac{f_c}{2f_r} - 1}$ { 1 pulse less }

- So we choose the ~~Reference~~ carrier from maximum and reference from zero.

Modulation Index $\boxed{MI = \frac{V_r}{V_c}}$ · physically how much carrier is available as the reference given.

** OBJQ

1) $MI < 1 \Rightarrow \boxed{|V_r| < |V_c|}$

- Largest harmonic amplitude in the o/p waveform are associated of the order $(2N \pm 1)$ N⇒ No: of pulses/half cycle.
- By increasing the value of 'N' the order of the harmonic frequency will increase. which is easy to filter.

→ Vo shown here is the comparator o/p which are called power waveforms which in turn enables the trigger pulses to produce the triggering to the thyristor T_1 and T_2.

→ Vo, width is giving a series for ~~time~~ cut for which time the thyristor is ON.

→ Using Vo power waveforms, we can generate proper commutations for the T_1 and T_2 by analysing the time period / width of Vo.

SERIES INVERTER

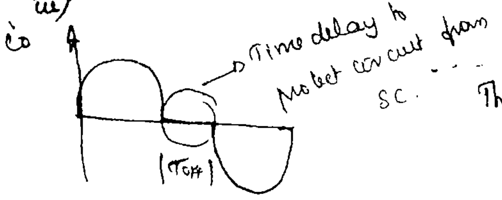
2) For any combination of load, Total load circuit is RLC.

i) T1 triggered, conducting.

ii) Supply dc given to RLC parameters i_0 = sinusoidal (2nd order equation)

-ve half produced by RLC and i_0 will be blocked by T1.

iii)



Then after some time T_2 trigger conducting

$\boxed{T_{off} > T_q \text{ (device turn off time)}}$

-ve half cycle is produced. This continued.

3) Commutation :- Load Commutation (Load circuits are responsible to make the current to zero)

SR → Series inverter employs load commutation. The current comes to zero due to the Nature of load circuit, so it is a load commutation.

OBS :-

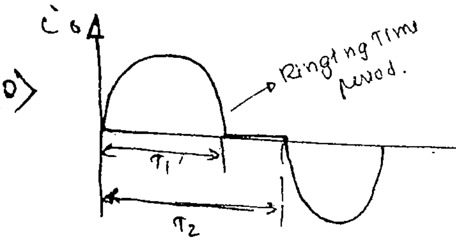
1) $T_{off} > T_q \Rightarrow T_{off} = \frac{\pi}{\omega} - \frac{\pi}{\omega_r} = \frac{\pi}{2\pi f} - \frac{\pi}{2\pi f_r}$

$$\boxed{T_{off} = \frac{1}{2}\left[\frac{1}{f} - \frac{1}{f_r}\right]}$$

$f \Rightarrow$ o/p frequency

$f_r \Rightarrow$ RINGING FREEQUENCY.

2)



$\frac{1}{f_r} = T_r$ = Fixed once RLC parameters defined (Natural conduction of ckt)

$\frac{1}{f} = T_2$ = depends on T_{off} (By convention)

$\left.\begin{array}{l} T_r < T_2 \\ f_r > f \end{array}\right\}$ o/p frequency < to Ringing frequency

OBJ Q

. RINGING FREEQUENCY :- Natural frequency of RLC circuit.

iv> TRAPEZOIDAL PULSE WIDTH MODULATION

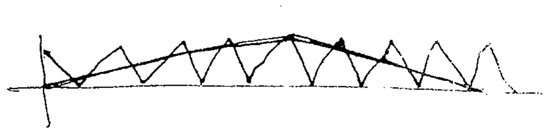
- width of the V_0 ∝ trapezoidal waveform, & ~~Carrier wave~~

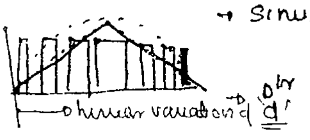
1> carrier wave :- high frequency triangular 2> Reference wave :- low frequency Trapezoidal wave form

3> width of the output pulses varies in accordance to the magnitude of trapezoidal wave form

v> Triangular pulse width modulation

1> Carrier wave :- High frequency triangular 2> Reference wave :- low frequency Δ^{lar}.





→ Sinusoidal = Non-linear variation of width (V_0)

= linear variation of width for pulses. (V_0)

2> width of the o/p pulses varies in accordance with the magnitude of Reference triangular waveform

SELECTION OF MODULATION TECHNIQUE

1> Usually depends up on type of load and harmonics effects on load.

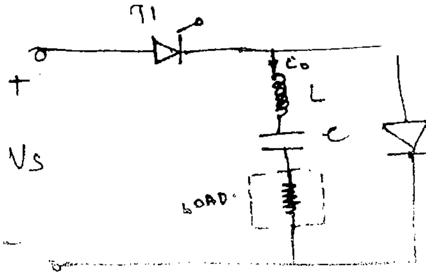
- Induction motor :- Eliminate 7th harmonic :- Take best method.
- Heater :- simple heater do not worry about harmonics :- Take simple method.
- In general the best commutation is sinusoidal

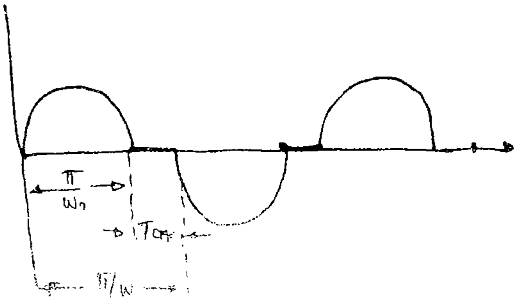
- The type of modulation technique to be employed depends on the type of load and its capability to accommodate the harmonics.

IES Problems

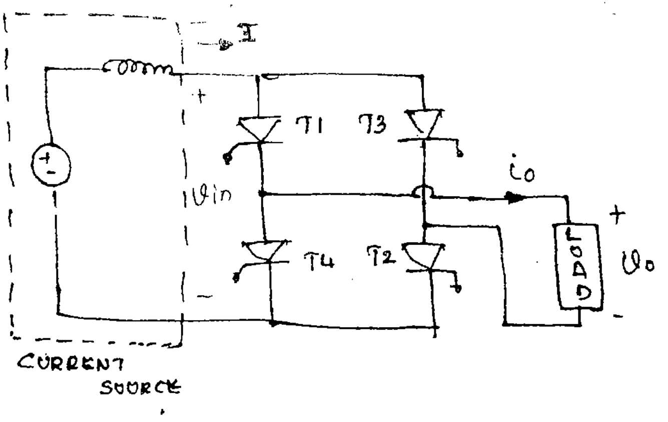
1> Later 2> ~~Lea~~ ✓ Formula given 3> Later 4> ✓ Theory 5> ✓ Theory

SERIES INVERTER. ~~(T1 & T2 connected in series)~~





CURRENT SOURCE INVERTER



- Current source

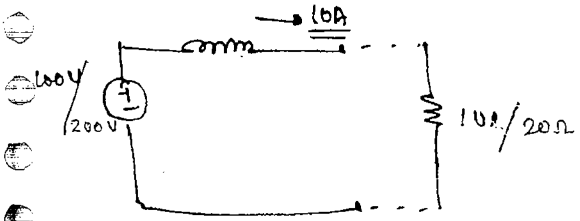
Symbol :

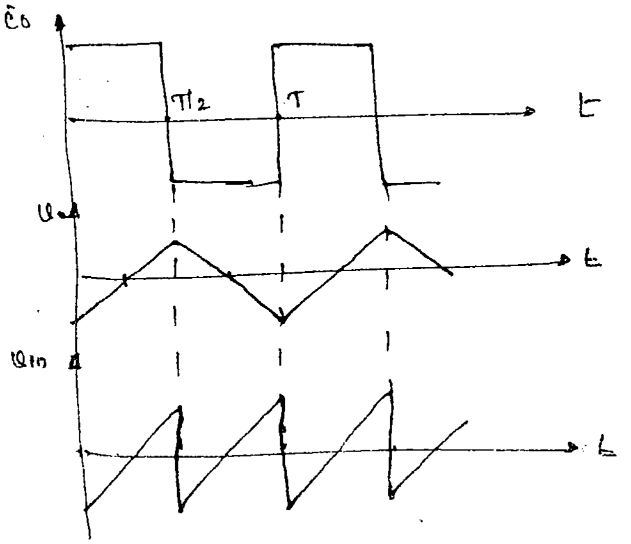
Natural = voltage source

current source we are made. A constant current flowing through the load with out any change w.r.t load.

Realising Current Source

- voltage source and a HIGH VALUE OF INDUCTOR IN SERIES.





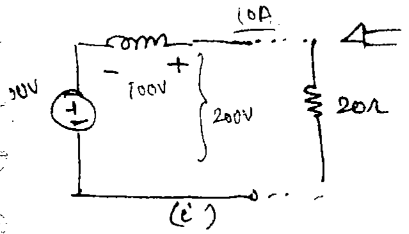
Assum: S.S

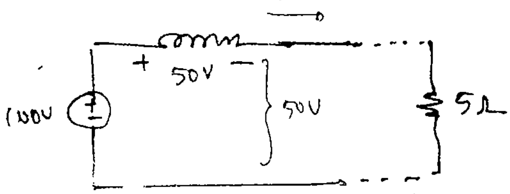
i) Increasing 10 Ω to 20Ω

10A tends to decreas slope = -ve

$\frac{di}{dt}$ = -ve

$L\frac{di}{dt}$ = -ve voltage





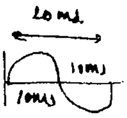
ii) Reducing 10Ω to 5Ω

10A tends to increase slope = +ve, di/dt = +ve, L di/dt = +ve voltage

2) I constant, our reference is current, frequency expected = 50Hz

T = 20ms

T/2 = 10ms.



i) T1 T2 ON for T/2 duration = 10ms, io flows I, + Vo - ⟹ +ve.

ii) T1T2 Turn OFF, T3 T4 Triggerd ON for T/2 duration = 10ms, io opposite - I, - Vo + ⟹ -ve

3) 'Vo' ⟹ depend by the load connected.

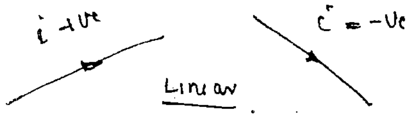
⇒ R load ⟹ same square wave.

4) load given are Not inductive ~~at~~ shorted load Vc used.
pure.

✓ 5) pure capacitor pulse ~~Response are not expected~~.

calculations

→ $i = \overset{constant}{\overbrace{C}}\frac{dv}{dt}$ ⟹ linear variation



→ $V_0 = V_C = \frac{1}{C}\int i_C\,dt = \frac{\cancel{i_c = I}}{C}$

→ slope · $\frac{dV_C}{dt} = \frac{I}{C}$ →

{ • Voltage

(S/C) • current source inverter feeds a pure capacitor load, when the following points are relevant

1) shape of o/p current = Square wave.

2) shape of o/p voltage = Triangular wave.

3) slope of o/p voltage $= \frac{I}{c}$.

4) peak value of o/p voltage = $V_{peak} = \frac{I}{c} \cdot \frac{T}{4}$

5) peak-peak voltage = $V_{pp} = \frac{I_0}{C} \cdot \frac{T}{2}$.

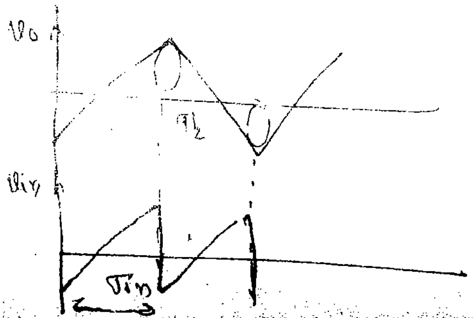
Variation of input Voltage Vi & keep I constant

1) T_1T_2 - conducting. Vin^{+}_{-} ← Polarity ← $^{+}_{-}$ load Vo.

⟹ $\underline{\underline{Vin = V_0}}$ - defining

2) T_3T_4 - conducting, we need $V_0{}^{+}_{-}$ ⟹ $V\bar{i}n^{-}_{+}$ (-ve Voltage)
defining.

*** ⟹ $\underline{\underline{Vin = -V_0}}$



$\boxed{Tin = T/2.}$

$fin = 2f_0$ ← Feet VIMP

: To produce a o/p at 50Hz frequency, the i/p voltage to the inverter is required to be varied at $\underline{\underline{100Hz}}$ It is because, whenever T_1, T_2 conducting $V_{in} = V_0$, whenever T_3, T_4 are conducting ~~to~~ $V_{in} = -V_0$.

Q1) <u>Page 06, chapter 4</u>

$\omega L = X_L = 8\Omega$, $\frac{1}{\omega C} = X_C = 7\Omega$

a) $i_0 = \sum_{n=1,3}^{\alpha} \left\{ \frac{4V_s}{n\pi Z_n} \right\} \sin(n\omega t - \phi_n)$

$$\boxed{I_{01} = \frac{4V_s}{\pi Z_1} \times \frac{1}{\sqrt{2}}}$$ Fundamental.

$$Z_1 = \sqrt{R^2 + (X_L - X_C)^2}$$

$$Z_1 = \sqrt{(1.2)^2 + (8-7)^2} = \underline{\underline{1.56\Omega}}$$

$$I_{01} = \frac{4V_s}{\pi Z_1} \times \frac{1}{\sqrt{2}} = \frac{4 \times 230}{\pi \times 1.56} \times \frac{1}{\sqrt{2}}$$

$= 132.56A$

b) $P_1 = I_{01}^2 R$

$= (132.9)^2 \times 1.2$

$= \underline{21.1kW}$

Turn on, Proof

c) $\underline{\underline{X_L > X_C}}$ ~~Forced~~ since, $X_L > X_C$

Forced commutation is required

Q2) a) $$\boxed{V_{01} = \frac{2V_s}{\pi} \cdot \frac{1}{\sqrt{2}}}$$ Fundamental

$$= \frac{2 \times 48}{\pi \sqrt{2}} = \underline{\underline{21.6V}}$$

b) <u>o/p power</u> $= P = \frac{V_{or}^2}{R} = \frac{V_s/2}{R \text{ (given)}}$

~~Fun~~ Total o/p power

$$= \frac{(48/2)^2}{2.4} = \underline{\underline{240W}}$$

c) [illegible]

Q3) Half Bridge inverter.

$R = 10\Omega$, $V_s = 400V$. ~~$V_{or} = 200V$~~

Fundamental frequency.

$$V_{01} = \frac{2V_s}{\pi\sqrt{2}} = \frac{2 \times 400}{\pi\sqrt{2}} = \underline{\underline{180V}}$$

$$I_{01} = \frac{V_{01}}{R} = \frac{180}{10} = \underline{\underline{18A}}$$

*** Q) Full Bridge inverter, load $= R = 3$, L ($X_L = 12$), C. ϕ

periodicity $=$ Time period $= \underline{\underline{0.2ms}}$, $t_q = 12\mu s$

F.S = 2

→ load commutation $X_C > X_L$.

→ circuit $T_{OFF} = 2 \times$ device turn OFF

$= 2 \times 12\mu s = 24\mu s$

Factor of safety.

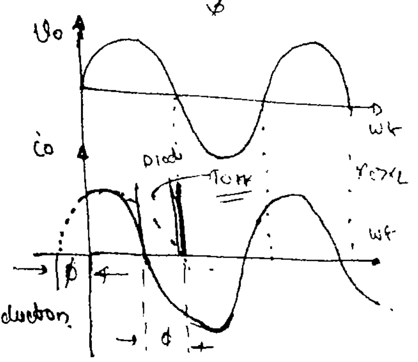
$\phi = $ p.f angle

$= \phi \Rightarrow T_{OFF}$

$\underline{\tan\phi} = \frac{\boxed{X_C} - X_L \text{ given}}{R \text{ given}}$

$\underline{\underline{\phi ?}}$

→ Anti parallel diodes are in conduction



$\underline{\phi = \omega t_c}$

For Reliable commutation

$\underline{\underline{\omega t_c}} = $ angle

• During the period antiparallel diodes are conducting and applying the reverse voltage (ωt_c) = p.f angle of the circuit. $\therefore \phi = \omega t_c$

$\phi = 2\pi f t_c \Rightarrow \phi = \frac{2\pi t_c}{T = 0.2ms \text{ (given)}} = \frac{2\pi \times 5000 \times 24 \times 10^{-6}}{}$ (3.14) $T_c = T_{OFF}$

$= \underline{0.95 rad}$

$= \underline{\underline{43.2°}}$

$\tan 43.2° = \frac{X_C - X_L}{R = 3}$ ($X_L = 12$) $\Rightarrow X_C = 14.8\Omega = \frac{1}{\omega C}$

$$\frac{1}{2\pi \times 5000 \times C} = 14.8 \Rightarrow \boxed{C = 2.15\mu F}$$ Ans

C < 2 ✓ Ans

$C < 2.15$ <u>Reliability</u> 4

to select a capacitance, which is LESS THAN THE CRITICAL VALUE.

5) $R = 15\Omega/\text{pha}$, $V_s = 420V$, 3ϕ BI $\begin{cases}180^\circ \\ 120^\circ\end{cases}$

180° mode

i) $V_{ph} = 0.4714 V_s$

$= 0.4714 \times 420$

$= \cancel{198.9}\ 197.9V$

$I_{ph} = \frac{V_{ph}}{R} = \frac{197.9V}{15}$

$= 13.2A = I_{L_{rms}} \{Y\}$

ii) $I_{T\,rms} = I_p \sqrt{\frac{180}{360}}$

$= 13.2 \sqrt{\frac{180}{360}}$

$= 9.33A$

iii) R-Load

Power $= V_{ph}\, I_{ph} \times 3$

$= 3 \times 197.9 \times 13.2$

$= 7.82kW$

120° mode

i) $V_{ph} = 0.4082 V_s$

$= 0.4012 \times 420$

$= 171.4V$

$I_{ph} = \frac{V_{ph}}{R} = \frac{171.4}{15} = 11.43A$

$I_{L\,rm} = 11.43$

ii) $I_{T\,rm} = 11.43 \sqrt{\frac{120}{360}}$

$= \cancel{7.54A}\ 11.43$

iii) R-load

Power $= V_{ph}\, I_{ph} \times 3$

$= 3 \times 171.4 \times 6.59$

$= \cancel{8}\ 11\ 100$

6) 1ϕ FB. V_{01} — single pulse modulation. — 110V

$2d$? V_{or}? , $V_s = 220V$

$$V_0 = \sum_{n=1,3}^{\infty} \left\{ \frac{4V_s}{n\pi} \cdot \sin\frac{n\pi}{2} \cdot \sin nd \right\} \sin n\omega t$$

$$V_{01\,rms} = \frac{\left\{ \frac{4V_s}{\pi} \sin\frac{\pi}{2} \cdot \sin d \right\} \text{max value}}{\sqrt{2}}$$

$$110 = \frac{4 \times 220}{\pi\sqrt{2}} \cdot \sin d.$$

$d = 33.73^\circ$

p.ulse width $2d = 67.46^\circ$

$V_{or} = \text{Total o/p } V_0\ rm = V_s\sqrt{\frac{2d}{\pi}}$

$= 220\sqrt{\frac{67.46^\circ}{180}} = 184.7V$

$\frac{1}{f} = \frac{1}{200} = 5\,\text{msec}$

08) $\alpha = 120^\circ$.

$$V_{01} = \frac{4V_s}{\pi} \cancel{\Sigma} \left(\sin\frac{\pi}{2} \sin d\right) \times \frac{1}{\sqrt{2}}$$

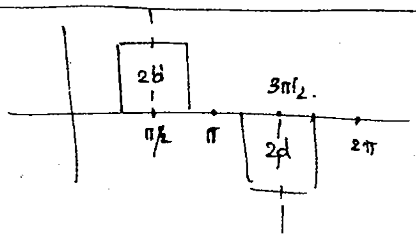
$$= \frac{4 \times (V_s = \text{given})}{\pi} \left(1 \times \sin\frac{120}{2}\right) \times \frac{1}{\sqrt{2}}$$

$= 0.78V$

09) Eliminate 5th harmonic

$2d = \frac{2\pi}{n} \Rightarrow 2\alpha = \frac{2 \times 180}{5} = 72^\circ$

10)



$\frac{2d = 144^\circ}{72^\circ} \Rightarrow 5^{th} = 0.$

$$\frac{V_{03}}{V_{01}\cancel{max}} = \frac{\frac{4V_s}{3\pi} \times \underbrace{\sin\frac{3\pi}{2}}_{-1} \times \sin(3 \times 72) \cdot \frac{1}{\sqrt{2}}}{\frac{4V_s}{\pi} \times \underbrace{\sin\pi/2}_{1} \cdot \sin 72^\circ \cdot \frac{1}{\sqrt{2}}}$$

$= \frac{1}{3} \times \frac{-1}{1} \times \frac{\sin 3 \times 72}{\sin 72} \times 100\%$

$= 20.6\% \cong 19.6$ from list

Now consider V_{01max}

- $\frac{V_{03max}}{V_{01max}}$ = Ans same as above ✗
- $\frac{V_{03}}{V_{01max}} = \frac{(rms)\,1/\sqrt{2}}{\text{max value}} = \frac{20.6}{\sqrt{2}} = 14.4$ ✗

V_{01max} is at $\underset{d=90^\circ}{90^\circ}$. (Instead of $\sin 72$, $\sin 90^\circ$)

$$\frac{V_{03}}{V_{01max}} = \frac{\frac{4V_s}{3\pi} \times \sin 3\pi/2 \times \sin 3 \times 72 \cdot 1/\sqrt{2}}{\frac{4V_s}{\pi} \times \sin\pi/2 \cdot \sin 90^\circ \cdot 1/\sqrt{2}}$$

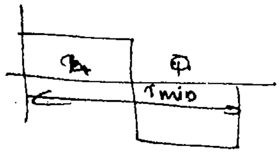
$= 19.6$

11> $\frac{V_S}{L} \times \frac{I}{4} = I_{peak} = \underline{10A}$

12> current sequential inverter.

- frequency max $= \frac{1}{\text{minimum time period}}$

- Time period $\Rightarrow$ +ve half + -ve half.



Path $\underset{ON}{T2}$, $\underset{ON}{T2}$ ON — T1, 0.1μF, 10 R3, D

D4, 0.1μF T2.

$\tau = R C_{eq} = 10 \times 0.05 \mu s$

$= \underline{0.5 \mu s}$

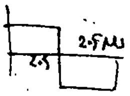
- Steady state response $5\tau \Rightarrow$ error 0.1%.

$4\tau \Rightarrow$ error 0.2%.

Consider 5τ

$\Rightarrow 5 \times 0.5 = 2.5 \mu s = \frac{1}{2}$ cycle

Time period $= 5 \mu s$



$f = \frac{1}{5\mu s} = \underline{200 kHz}$

Ans Not in options

Consider 4τ

$\Rightarrow 4 \times 0.5 = 2.0 \mu s = \frac{1}{2}$ cycle

Time period $=$ ~~0~~ $4\mu s$.

$f = \frac{1}{4 \mu s} = \boxed{250 kHz}$ ✓

Ans is given in the options

3> $V_{or} = V_s \sqrt{\frac{2d}{T}} = 220 \sqrt{\frac{120}{180}}$

$= \underline{179.63V}$

4> $\frac{V_{05}}{V_{01}} = \frac{\frac{4V_s}{5\pi} \cdot \cancel{\frac{1}{\sqrt{2}}}}{\frac{4V_s}{\pi} \cdot \cancel{\frac{1}{\sqrt{2}}}} \times 100 = \underline{20\%}$

5> c | 16> $V_s = 48V$, $R = 2.4$

$V_{01} = \frac{4V_s}{\pi\sqrt{2}} = \frac{4 \times 48}{\pi\sqrt{2}} = 9$

[illegible] deragw [illegible] load valus

main circuit and

left h Al is commutating ckt

L&C commutating elements.

· modification is done in the commutation circuit

· We assumed that Io constant. +Io, -Io A/c

· +ve half cycle = +Io

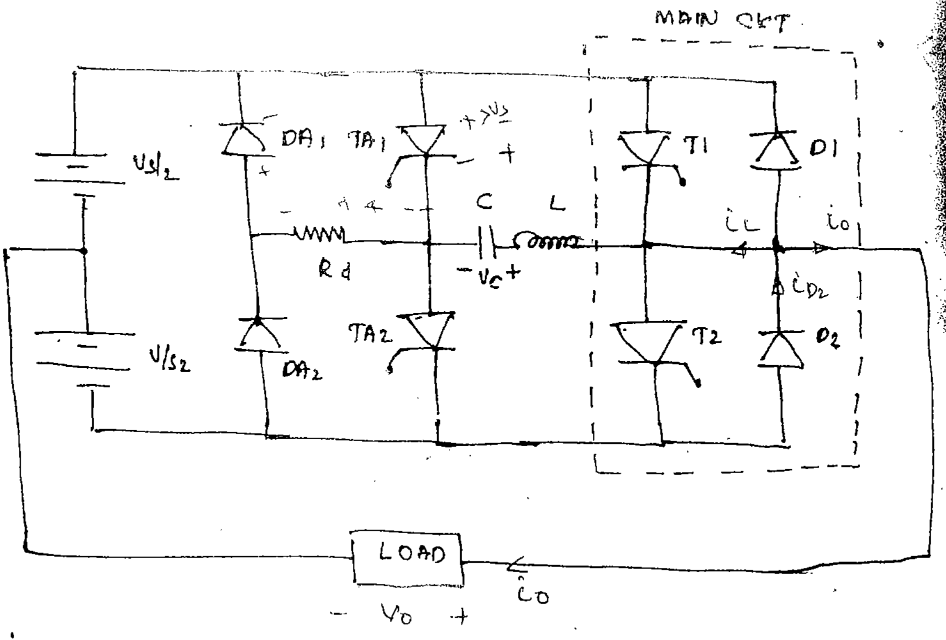
-ve half cycle = -Io.

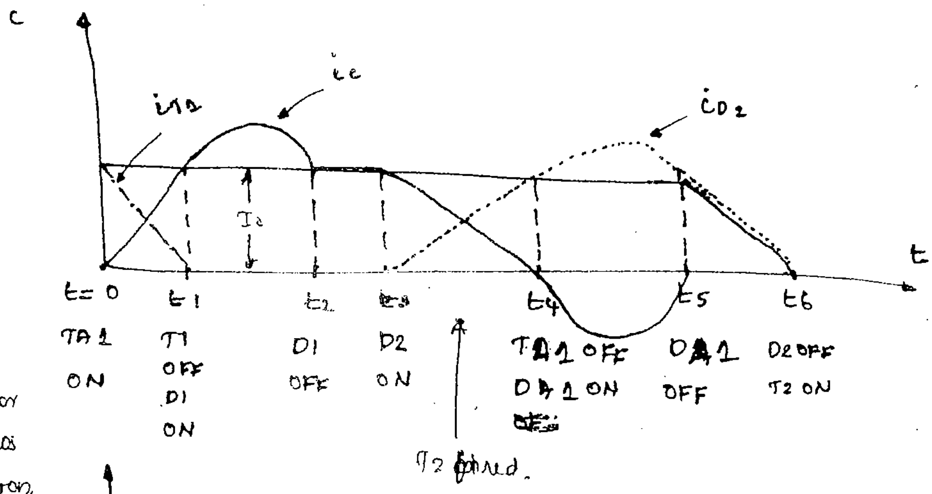
→ Voltage across the capacitor = Vc = Vs (Initially)

1) T1 - Triggering ON
Vc = +Vs.

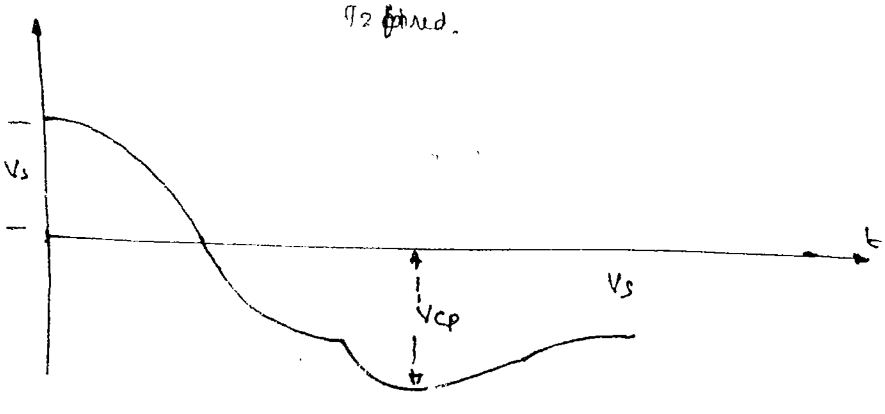
T2 - Triggerin ON
Vc = -Vs.

must for continuous conduction. Then gives Facility for turn OFF.





1) ~~t=0~~, T1 conducting
io constant.
- Vo +
Vs/2



→ Vc = +Vs. (we set).

→ conduction time = As per our requirement.

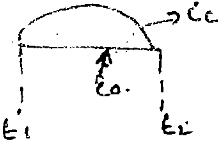
→ half cycle is completed, to go to next ~~part~~ half cycle, TA1 should OFF T2 should ON.

2). TA1 - triggered ON. $\overrightarrow{i_C}$ +Vc, $\underrightarrow{i_C = I_o \Rightarrow i_{T1} = 0}$. both same and opposite
(t = t1).

· Reverse voltage when D1 conducts. (when T1 is OFF) Then gives reverse voltage for T2

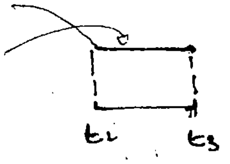
~~Turn OFF completed~~

- Designed $i_c > i_o$ to pass the extra current through D1



- T1 OFF, $\xrightarrow{i_c}$ −||+ $\xrightarrow{i_c}$ $V_s \downarrow$ at t_2 $\underline{V_C = 0}$

3) $t_2 \rightarrow t_3 \Rightarrow V_C < V_S$ (by TA1 ct charged), to maintain i_o constant, whenever $\underline{i_c = i_o}$ (chosen)



$\Rightarrow V_C > V_s$
little.

4). After $\pi\sqrt{LC}$ second T2 is triggered ..., i_c passes through inductor and gradually decreases $i_c = 0$, $i_{T2} \uparrow\uparrow \cong \rightarrow i_{T2} = i_o$. $\underline{t_3 \rightarrow t_4}$, prolonged charging

$\underline{V_C > V_S}$ Extra energy is transferred to C & inductor.

5) $\underline{t_4}$:- current thus i_c tends to go in -ve direction, path available is Rd and DA1 $\underset{\text{by } i_c}{\underline{V_{Rd} + V_{DA1}}} \Rightarrow$ Reverse voltage for TA1, TA1 ensured for OFF.

i_c +||− discharging it reaches '−Vs'.

6) t_5, $V_C = -V_S$, DA1 OFF

7) $\underline{t_6 - D2 \text{ OFF}, T2 \text{ ON}}$ Next TA2 triggered and cycle repeats T2 gets OFF

Modification of Bridge

1) Ensuring the Turn OFF of TA1 and TA2.

Sol:

1) Half Bridge Inverter operation is based on current commutation, modification of the circuit is useful to ensure the turn OFF of auxiliary thyristors by applying the reverse voltage

2) Anti parallel diode D1 is useful to apply the reverse voltage across T1 after its current comes to zero.

CALCULATIONS

1) Capacitance formula $\boxed{C = 0.892 \dfrac{t_c \times I_{om}}{V_{mm}}}$ 2) Inductance $\boxed{L = 0.3964 \dfrac{t_c \times V_{mm}}{I_{om}}}$

3) Damping Resistance $\boxed{R_d = 2\sqrt{\dfrac{L}{C}}}$

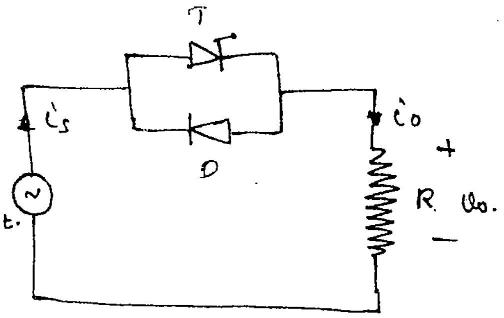
where, t_c = circuit turn OFF time.
V_{mm} = minimum supply voltage.
I_{om} = maximum output current.

A/C VOLTAGE [illegible]

Def :- It is a static power electronics circuit, which converts AC to variable AC i.e. variation in the magnitude of the voltage

1) 1ϕ Half wave AC Voltage Controller.

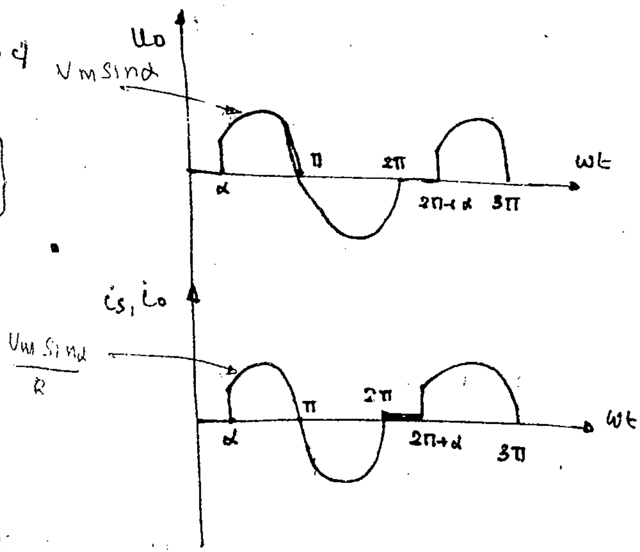
- i/p AC supply
- T & D connected in antiparallel
- $i_s = i_o$



- Considering R load

1) +ve half cycle T - F.Voltage | α triggered. acts
D - R.Voltage | as a closed switch. upto π (α to π = Vm sin α) V ; (0 to α = 0 V)

$i_s, i_o = \frac{V_m \sin \alpha}{R}$ $\begin{cases} 0 \text{ to } \alpha = 0\ A \\ \alpha \text{ to } \pi = \frac{V_m \sin \alpha}{\pi} \end{cases}$



2) π - 2π :- D = F.B. → starts conducting at π.

V_o = −ve same as V_s } upto 2π
i_o = −ve ~~same~~.

3) To maintain symmetry after a delay 'α' from 2π T again triggered ON.

(here)

Ⓢ⓪ • A/C voltage controller employs line (or) Natural commutation.
• ~~Commutation~~

• Output of A/C

V_o period = 2π,

1) RMS value

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

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

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

$$= \frac{V_m^2}{4\pi}\left[2\pi - \alpha + 1/_2 \sin 2\alpha\right]$$

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

2) Rms current

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

3) Input supply pf = $\frac{\text{Power delivered to load}}{\text{Source VA}}$

$$= \frac{V_{or}^2/R}{V_s \cdot I_{sr}} = \frac{V_{or}^2/R}{V_s \cdot V_{or}/R}$$

$$\boxed{PF = \frac{V_{or}}{V_s}}$$

Disadvantage

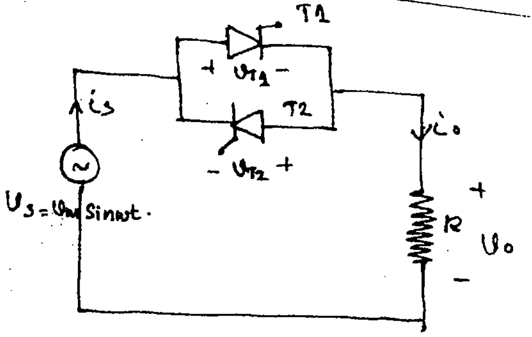
1) o/p wave forms are Not-symmetrical, so they consist of All types of harmonics

2) o/p voltage can be controlled only during +ve half cycle.

---

2) 1 ϕ Full wave AC voltage controller

- i/p A/c.
- A TRIAC, can be employed in the place of antiparallel connection of SCR's to realise full wave AC voltage control.



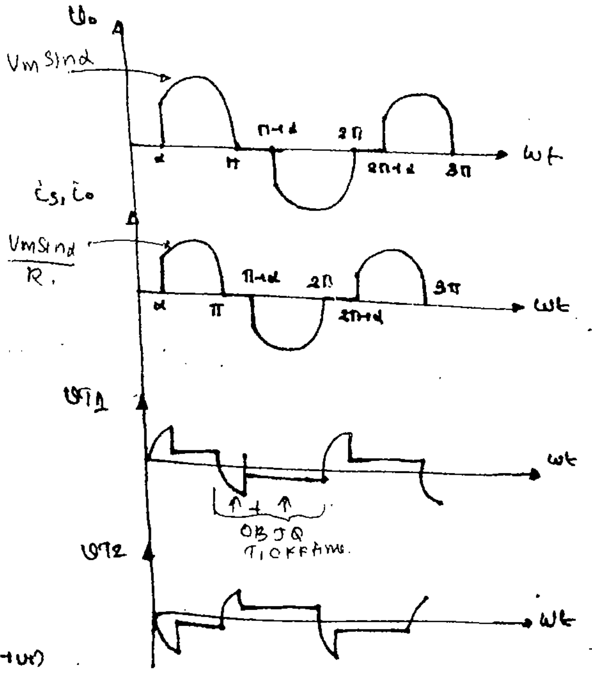
- Consider R load

1) +ve half cycle, T1 − Forward at α − Trigged ⟹ $V_o = V_m \sin\alpha$ (α − π)

(α − π) − T1 conducts.

2) −ve half cycle, T2 − Forward, T1 − Reverse } To maintain Symmetry T2 triggerd at π+α. −ve conduction occurs. (π+α − 2π) T2 conducts

Same cycle repeats.



3) $\frac{V_{T1}}{V_{T2}}$ 1) 0 − α. T1 = +ve voltage, T2 = −ve voltage } same as V_s

2) α − π. T1 conducting = $^{+}V_{T1}^{-}$ small. (+ve)

T2 Non conducting = $^{-}V_{T1}^{+}$ small (−ve)

3) π to π+α → −ve half cycle } same as V_s

V_{T1} = −ve

V_{T2} = +ve.

4) circuit T1 OFF time = $\underbrace{\pi \text{ to } \pi+\alpha}_{\text{Supply } -ve}$ to $\underbrace{\pi+\alpha \text{ to } 2\pi}_{V_{T2} \text{ small drop coming across } V_{T1}.}$ = $\underline{\underline{\pi \text{ to } 2\pi}}$

$$\boxed{L = \frac{\quad}{\omega . I_{f1}}}$$

$$\frac{\quad}{X_L} = \frac{V_s}{X_L} = \frac{V_s}{\omega L}$$

$$\boxed{Q = \frac{V_s^2}{\omega L}}$$

2) For $\alpha > 90°$, I_s would be less But its fundamental component I_{f1} lags the supply voltage by 90°.

- The value of I_{f1} ~~would~~ will ~~increase~~ decrease with the increment of firing angle from 90°. The effective Inductance will increase and reactive power will decrease.

$$\boxed{I_{f1} = \frac{V_s}{\pi \omega L}\left[2\pi - 2\alpha + \sin 2\alpha\right]}$$

at $\alpha = 90°$

$I_{f1} = \frac{V_s}{X_L}$ [substitute]

$$Q = V_s . I_{f1} = V_s . \frac{V_s}{\pi \omega L}\left[2\pi - 2\alpha + \sin 2\alpha\right]$$

$$\boxed{Q = \frac{V_s^2}{\omega L} \frac{1}{\pi}\left[2\pi - 2\alpha + \sin 2\alpha\right]}$$

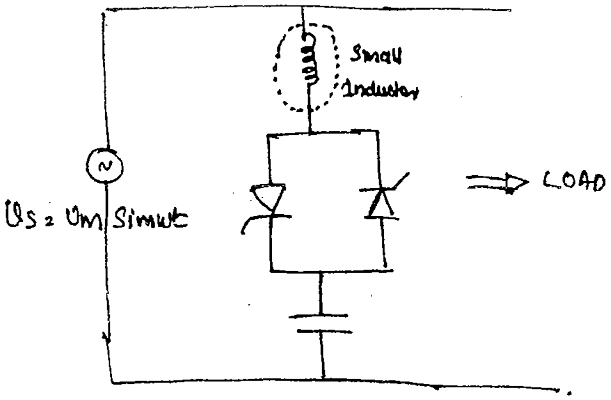
→ • For $\alpha \leq 90°$ Reactive power will be MAXIMUM $(Q = Q_{max})$

→ • For $\alpha \simeq 180°$ Reactive power will be 0. $(Q = 0)$

	X_L	I_{f1}	Q.
$\alpha \leq 90°$	ωL (MINIMUM)	$V_s/\omega L$ (MAXIMUMUM)	V_s^2/X_L (MAX)
$\alpha > 90°$	INCREASE.	DECREASE	DECREASE
$\alpha \simeq 180°$	∞	0.	0

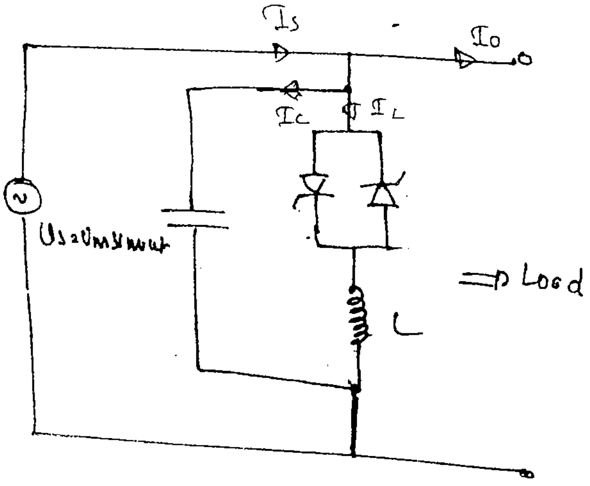
⟹ Ideally

7) Thyristor switched capacitors.



- TSC ~~means~~ makes the availability or non-availability of the capacitor on the supply system. i.e. It switches the capacitor on to the supply system.
- TSC employs integral cycle control to connect the capacitance.
- A small inductor will be connected ~~also~~ in series with the TSC to avoid the short circuit of the supply through capacitors. { i(ωt) transient }.

8). Static VAR Compensator (SVC)



- SVC consists of A Fixed capacitor connected across TCR. This combination controls the VAR requirement on the supply system to maintain the power factor at the desired value.

1) leading VAR compensated $= \frac{V_s^2}{X_c}$ rms
(Fixed always)

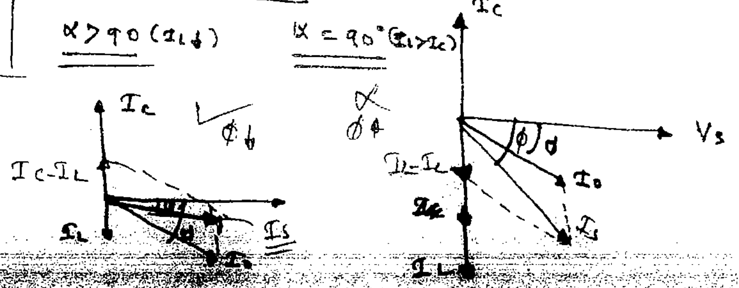
$$= \frac{V_s^2}{1/wc} = \underline{\underline{V_s^2 \cdot wc.}}$$

2) Maximum lagging VAR $= \frac{V_s^2}{X_L} = \frac{V_s^2}{\omega L}$ rms.
(variable)

3) L & C values of the compensator will be selected in such a fashion that

rms $\boxed{\frac{V^2}{wL} > V^2 \cdot wC}$

4) Phasor diagram



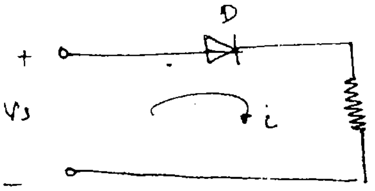
=> SVC supplies the required VAR on the supply systems to adjust the power factor near to unity value.

◆> In a 3ϕ circuit TCR should be connected in Δ fashion so that the (3n) tripple n harmonics would be restricted inside the Δ, they will not inject on to the supply systems.

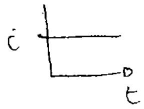
28/03/11

POWER DIODE CIRCUITS.

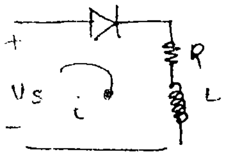
i)



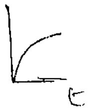
$i = \frac{V_s}{R}.$



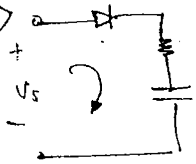
ii)

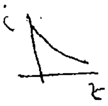


$i = \frac{V_s}{R}[1 - e^{-Rt/L}]$



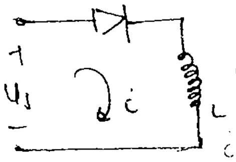
iii)



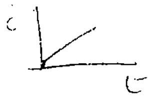


$i = \frac{V_s}{R}[1 - e^{-t/RC}]$

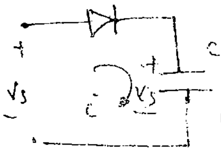
iv)



$i = \frac{V_s}{L} t$



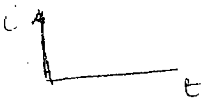
v)



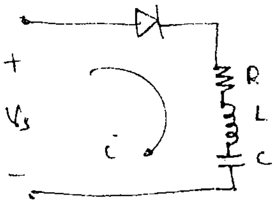
i = IMPULSE CURRENT.

$\begin{pmatrix} \tau = 0 \\ R = 0 \end{pmatrix}$

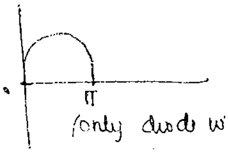
Achieves 1A/ 0 ohm



vi)



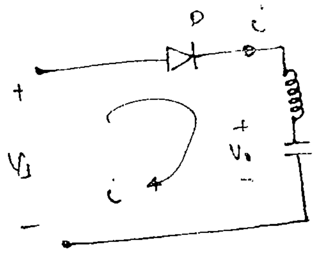
i = SINUSOIDAL



(only diode will Not allow −ve)

(conduction will be stopped by π, one half cycle).

vii)



→ $V_s > V_0$ − Diode − FB − Conduction starts.

KUL

$$\Rightarrow L\frac{di}{dt} + \frac{1}{C}\int i\,dt = V_s(t)$$

(V_0 is initial condition we will substitute later).

- Applying L.T $$L[sI(s) - \underset{\substack{\uparrow \\ \text{initial}}}{0}] + \frac{1}{C}\left[\frac{I(s)}{s} + \frac{CV_0}{s}\right] = \frac{V_s}{s}.$$

$$I(s)\left[sL + \frac{1}{Cs}\right] = \frac{V_s}{s} - \frac{V_0}{s} = \frac{V_s - V_0}{s}$$

$$I(s) \times \frac{L}{s}\left[s^2 + \frac{1}{LC}\right] = \frac{V_s - V_0}{s}$$

$$I(s) = \frac{V_s - V_0}{L} \cdot \frac{1}{s^2 + \boxed{\frac{1}{LC}}}$$ ω_0^2 Substitute

$$I(s) = \frac{V_s - V_0}{L} \frac{1}{s^2 + \omega_0^2}$$ where $\omega_0^2 = \frac{1}{LC}$ $\quad \omega_0 = \frac{1}{\sqrt{LC}}.$

$$= \frac{V_s - V_0}{\omega_0 L} \cdot \frac{\omega_0}{s^2 + \omega_0^2}$$

Invow LP

1)

$$\boxed{\begin{aligned} i(t) &= \frac{V_s - V_0}{\omega_0 L} \sin \omega_0 t \\ i(t) &= (V_s - V_0)\sqrt{\frac{C}{L}} \sin \omega_0 t \end{aligned}}$$

$$\left\{ \omega_0 L = \frac{1}{\sqrt{LC}} \times L = \sqrt{\frac{L}{C}} \right\}$$

2) Inductor voltage $= L\frac{di}{dt} = \cancel{L} \cdot \frac{(V_s\ V_0)}{\cancel{\omega_0} \cancel{L}} \cdot \cos \omega_0 t \times \cancel{\omega_0}.$

$$\boxed{v_L = (V_s - V_0 \cos \omega_0 t}$$

3) capacitor voltage $(v_c) = \frac{1}{C}\int i\,dt = \frac{1}{C} \cdot \frac{V_s - V_0}{\omega_0 L} \times \frac{-\cos \omega_0 t}{\omega_0} + K.$ $\quad \left\{ \omega_0^2 = \frac{1}{LC}. \right\}$

$$= -(V_s - V_0) \cos \omega_0 t + K.$$

Initial condition $t = 0^+,\ v_c = V_0.$

$$V_0 = -(V_s - V_0) \times 1 + k$$

$$k = \cancel{V_0} + V_s - \cancel{V_0} \Rightarrow \boxed{k = V_s}$$ substituting -

$$v_c = -(V_s - V_0) \cos \omega_0 t + V_s$$

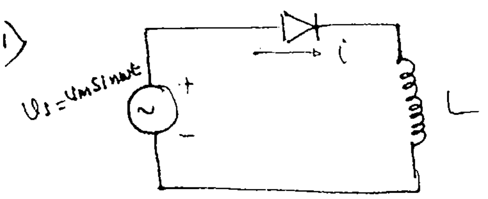
$$\boxed{v_c = V_s - (V_s - V_0) \cos \omega_0 t}$$

- consider initially conditions $V_0 = 0$ $\quad V_c = V_s - V_s \cos \omega_0 t$ $\quad$ ~~$i_{max} = V_s$~~

- conduction allowed only for 'π' values $\quad \omega_0 t = \pi.$ $\quad \boxed{t = \pi\sqrt{LC}}$

	Initial condit	I peak	Final voltage across capacitor	Conduction duration
1)	$V_0 = 0$	$V_s\sqrt{\frac{C}{L}}$	$2V_s$	$\pi\sqrt{LC}$ S
2)	$V_0 = +ve$	$(V_s - V_0)\sqrt{\frac{C}{L}}$	$2V_s - V_0$	$\pi\sqrt{LC}$ S.
3)	$V_0 = -ve$	$(V_s + V_0)\sqrt{\frac{C}{L}}$	$2V_s + V_0$	$\pi\sqrt{LC}$ S.

viii)



By KVL at +ve half cycle

$$L \Rightarrow L\frac{di}{dt} = V_m \sin\omega t$$

$$di = \frac{V_m}{L}\sin\omega t \, dt$$

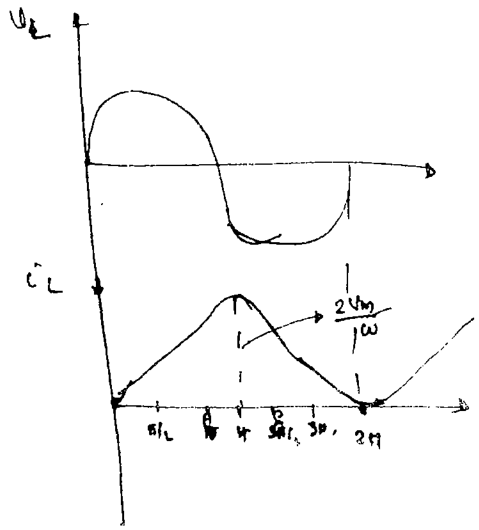
Integrating $i = -\frac{V_m}{\omega L}\cos\omega t + \underline{k}$ — initial condition.

- at $\underline{t=0} \Rightarrow i = 0$ $(I = n.o.c)$ $0 = -\frac{V_m}{\omega L} + k \Rightarrow \boxed{k = \frac{V_m}{\omega L}}$

$$i = -\frac{V_m}{\omega L}\cos\omega t + \frac{V_m}{\omega L} = \frac{V_m}{\omega L}\left[1 - \cos\omega t\right]$$

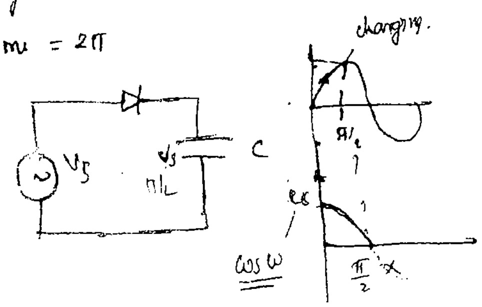
$$\boxed{i = \frac{V_m}{\omega L}\left[1 - \cos\omega t\right]}$$

$\left.\begin{array}{l}\cos\omega t = -1 \ +ve \\ \cos\omega t = +1 \ +ve\end{array}\right\} i = +ve$ always



		$(\cos\pi = -1)$		
$\omega t = 0$	$\omega t = \pi/2$	$\omega t = \pi$	$\omega t = \frac{3\pi}{2}$	$\omega t = 2\pi$
$i = 0$	$i = \frac{V_m}{\omega L}$	$i = \frac{2V_m}{\omega L}$	$i = \frac{V_m}{\omega L}$	$i = 0$

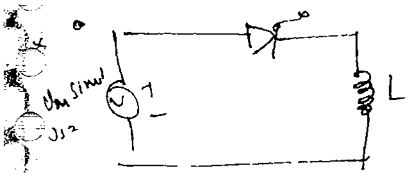
- Current always = +ve
- Conduction time = 2π



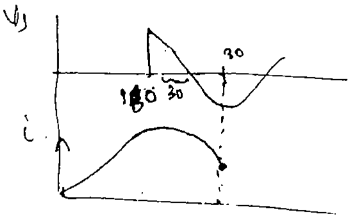
- Conduction duration of the circuit is equal to 2π.

Note:- • If the circuit is feeding a pure resistor, then conduction time is equal to π.

• If the circuit is feeding pure capacitor, then the conduction time = $\pi/2$.

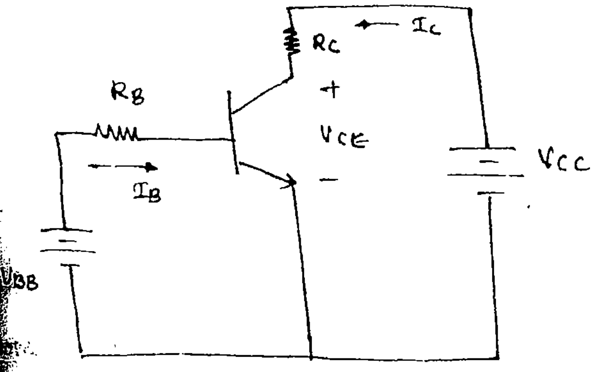


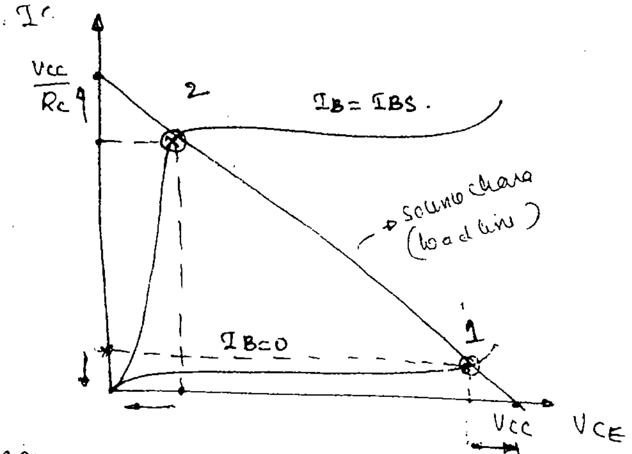
$\omega t = \alpha$ (initial)



II> POWER BJT current controlled switch.

• Power BJT as n-p-n configuration and common emitter connectivity is suitable for power control applications.





I_C = load current

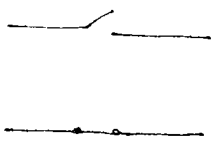
R_C = Load.

V_{CC} = Supply voltage.

V_{CE} = Voltage across the switch.

I_B = Control signal

OPERATION :-



$I = 0$, $V = V_s$ } 1. OFF STATE/OPEN S/W

$V = 0$, $I = I_L$ } 2 ONSTATE/OFF S/W.

Loadline

• $V_{CE} = 0$, $I_C = \frac{V_{CC}}{R_C}$

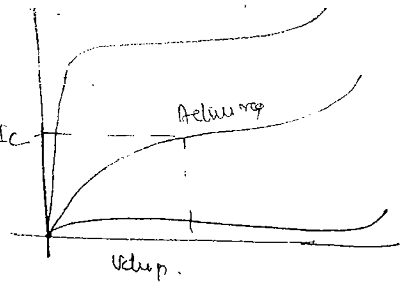
• $I_C = 0$, $V_{CE} = V_{CC}$.

I_{BS} : Base current corresponding to saturation

Power BJT in cut off region acts as a open switch, In saturation region it acts as closed switch.

Power BJT being controlled by base current, it is known as current controlled device.

- Power BJT should not operate on the active region as it leads to more voltage drop and power loss across the switch.



1) $I_C = \frac{V_{CC} - V_{CES}}{R_C}$ saturated VCE

2) $I_B = \frac{V_{BB} - V_{BES}}{R_B}$ saturated VBE

3) $\beta = \frac{I_C}{I_B}$ = current gain.

control signal is there as long as switch is ON

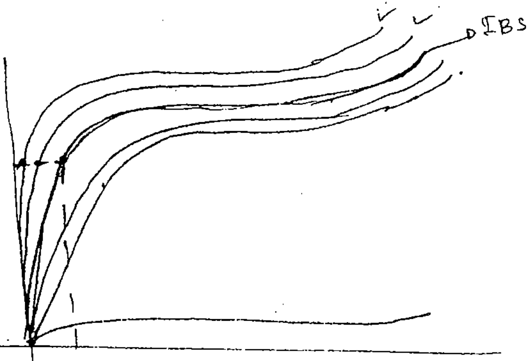
IMPT

$$\boxed{4)\ \text{Power loss in switch} = V_{CES} I_C + V_{BES} \cdot I_B}$$

6) OVER DRIVE FACTOR

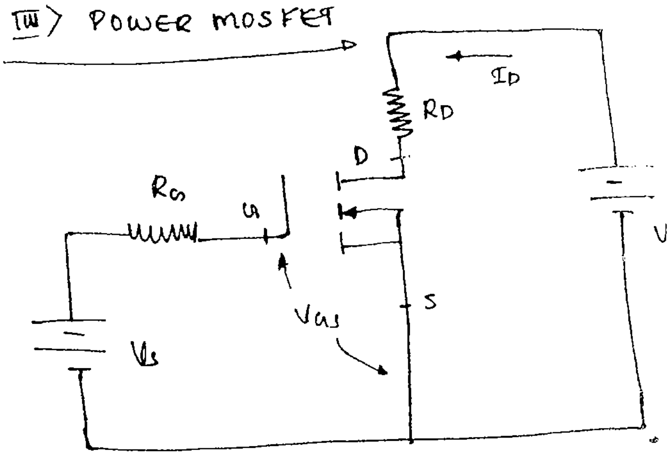
$= \frac{I_B}{I_{BS}}$

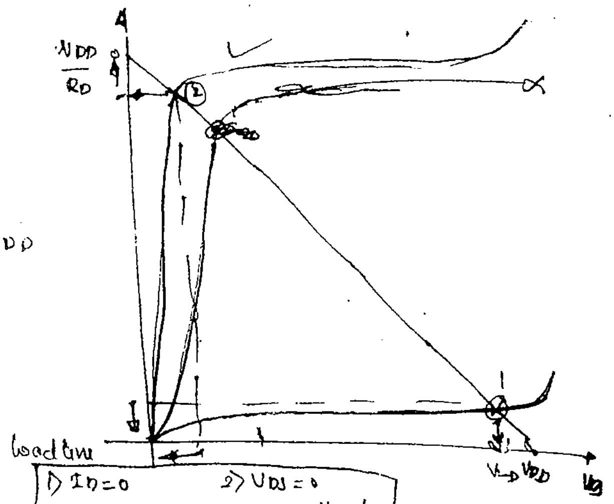
5) Applied $I_B > I_{BS}$.



Some times transistor will be driven with higher value of base current, then switching performance would be improved. At this condition, Transistor is said to be <u>HARD DRIVEN TRANSISTOR</u> (or) <u>OVER DRIVEN TRANSISTOR.</u>

III) POWER MOSFET





1) ID=0
VDS=VDD

2) VDS=0
ID=VDD/RD

1) N channel MOSFET in common source configuration is the best suitable for power control applications.

2) ID = load current, RD = load, VDD = supply voltage, <u>VGS = control signal</u>

- $I_D = \frac{V_{DD}}{R_D}$ = ideal load current

3) Power MOSFET in cut-off region acts as a open switch and in saturation region it acts as a closed switch.

4) MOSFET being controlled by voltage across gate to source junction (V_{GS}) it is known as voltage controlled switch.

5) It is having the faster switching time and switching loss will be less steady state voltage drop and conduction power loss could be more as MOSFET compared to BJT.

6) Power MOSFE is best suitable for parallel operation since it is possessing +ve temperature coefficient of resistance.

- IGBT has been developed by eliminating the limitations of transistor and MOSFET families. (BJT + MOSFET Family)

- IGBT is free from second breakdown problem that is present in BJT and conduction losses would be less compared to MOSFET.

POWER DEVICES IN THE DESCENDIN ORDER IN THEIR SPEEDS OF OPERATION ARE AS FOLLOWS

MOSFET > IGBT > BJT > THYRISTOR

~~ELEC~~ DC DRIVES.

29/03/11

- DC drive consists of DC motor, power electronic converter (rectifier or chopper), speed sensing mechanism (Tachometer), intelligent system (µP or µC)
- The following dc motors are suitable for speed control applications
  1) Separately excited dc motor
  2) dc series motor.

- during the speed control application load remains constant i.e; armature current is assumed to be constant

Note : · DC shunt motor is not preferable for speed control applications since, independent variation of armature voltage and field flux cannot be ~~pu~~ possible.

1) Induced Emf.

$$E_a = \frac{Z\phi N}{60} \cdot \frac{P}{A} \Rightarrow Z\phi n \times \frac{P}{A} \quad \overset{E_a}{\cancel{Rev}}/s.$$

$\omega_m = 2\pi n$ when $n = \frac{\omega_m}{2\pi}$ so $E_a = Z\phi . \frac{\omega_m}{2\pi} \times \frac{P}{A}$

$$E_a = \underbrace{\left(\frac{Z\phi}{2\pi}\ \frac{\cancel{2\pi} P}{A}\right)}_{K_a} . \phi\,\omega_m.$$

$$\boxed{E_a = K_a \phi \omega_m} \quad \text{where } K_a = \frac{ZP}{2\pi A}$$

2) Torque. mechanical power = Electrical power (By energy conservation)

$$T_e \omega_m = E_a I_a .$$

$$T_e = \frac{E_a I_a}{\omega_m} = K_a \phi \cancel{\omega_m} \times \frac{I_a}{\cancel{\omega_m}}$$

$$\boxed{T_e = K_a \phi I_a .}$$

i) → Separately excited DC Motor.

a) $\boxed{E_a = K_a \phi \omega_m}$ where $K_m = K_a \phi$ $\boxed{K_m = \left(\frac{V.S}{rad}\right)}$

Same ***

$T_e = K_a \phi I_a$

b) $\boxed{T_e = K_m I_a .}$ $K_m = K_a\phi$ ** $\boxed{K_m = \left(\frac{Nm}{A}\right)}$

ii) DC Series motor.

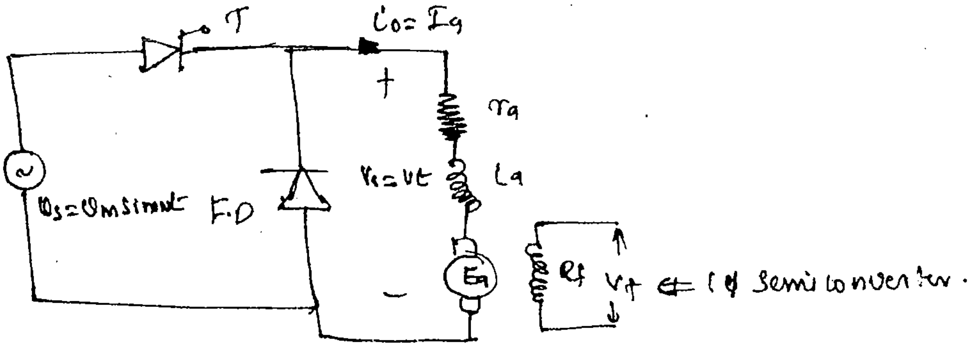
$E_a = K_a \phi \omega_m .$

$\phi \propto I_a \Rightarrow \phi = C . I_a$ again $E_a = K_a C \phi \omega_m$

1) $\boxed{E_a = K_1 I_a \omega_m}$ $\boxed{K_1 = \frac{V.S}{rad}}$ #

b) $T_e = K_a \phi I_a = K_a C I_a I_a = K_1 I_a^2$ $\boxed{T_e = K_1 I_a^2}$ $K_1 = \frac{Nm}{A^2}$

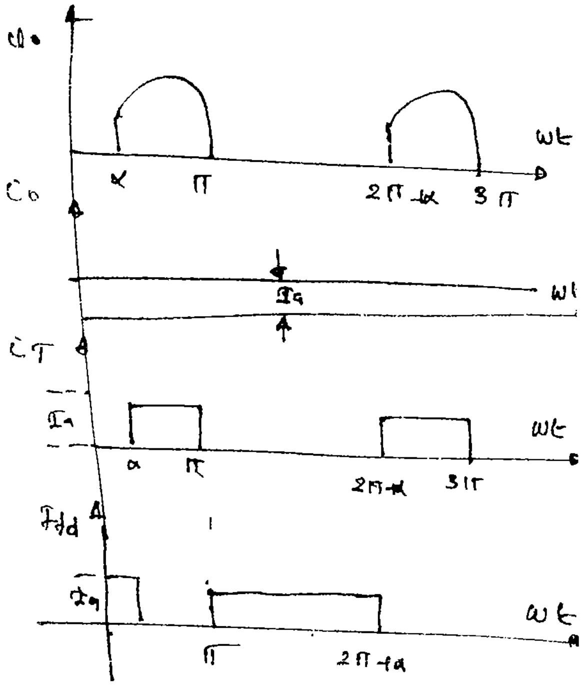
SINGLE PHASE HALF WAVE RECTIFIER DRIVE.



Note:

Solving Numerical. Find V_o of terminal side is asked find V_t of the Quantor is on T or F.D, V_s.

- $i_T = i_s$. ($\alpha - \pi$ and $2\pi+\alpha$ 3π)
- i_{fd} ($0-\alpha$, π to $2\pi+\alpha$).



1) $V_o = V_t = \frac{V_m}{\pi}\left[1 + \cos \alpha_1\right]$ — armature $\alpha_1 \Downarrow$

2) $V_f = \frac{V_m}{\pi}\left[1 + \cos \alpha_2\right]$ $\alpha_2 \Rightarrow$ converter.

3) $I_{sr} = I_{Tr} = I_a \sqrt{\frac{\pi - \alpha_1}{2\pi}}$

4) $I_{FDr} = I_a \sqrt{\frac{\pi + \alpha}{2\pi}}$

RLE load.

5) Armature p.f (or) Input p.f $= \frac{E_a I_a + I_a^2 r_a}{V_s I_{sr}}$ → Power loss in the resistance. $V_s I_{sr}$ → ~~Input~~

$\left\{ I_{sr} = I_{avg} \right\}$

$= \frac{I_a \overbrace{(E_a + I_a r_a)}^{V_t}}{V_s I_{sr}}$

$$\boxed{p.f = \frac{V_t I_a}{V_s I_{sr}}}$$

Q1> S.Ex.DC , 1ϕ HWR

$V_s = 230V$, $r_a = 0.5$

$\frac{V-S}{r} = K_m = 0.4$.

$T_L = T_e = 20\ N\text{-}m$, $N = 1500$.

$\underline{\underline{I_a = \text{constant}}}$

Sol:

- T given ⇒ I_a we can calculate

$T_e = K_m I_a$

$I_a = \frac{20}{0.4} = \underline{\underline{50A}}$ — constant

i) Firing angle (converter side)

Start Numerical from motor side

$V_t = \cancel{V}E_a + I_a r_a$

⇓ separately excited motor

$= K_m \omega_m + I_a r_a$

$= 0.4 \times \overset{\frac{2\pi N}{60}}{2\pi \times \frac{1500}{60}} + 50 \times 0.5$

$= \underline{\underline{87.84}}$

$\Rightarrow \frac{V_m}{2\pi}[1+\cos\alpha] = V_t$

$\frac{230\sqrt{2}}{2\pi}[1+\cos\alpha] = 87.8$

$\boxed{\alpha = 45.8°}$

ii) $i_s = i_T$

$I_{sr} = I_a\sqrt{\frac{\pi-\alpha}{2\pi}}$ ratio we can keep in deg

$= 50\sqrt{\frac{\cancel{\pi}\ 180 - 45.8}{360}}$

$= \underline{\underline{30.52A}}$

iii) $P_f = \frac{V_t I_a}{V_s I_{sr}}$

$= \frac{87.8 \times 50}{230 \times 30.52}$

$\boxed{P_f = 0.625\ \text{lag}}$

Q2> S.E

$N = 1400 rpm$.

$V_s = 330 \sin 314t$

$E_b = 80V$.

$\alpha = 30°$

$R_a = 4\Omega$.

$I_a = ?$, $T = ?$

$\longrightarrow$ This way calculate

$V_0 = \frac{V_m}{\pi}[1+\cos\alpha]$

$= \frac{330}{\pi}[1+\cos 30]$

$V_0 = 196V$ $V_0 = V_t = E_a + I_a r_a$.

$\overset{V_0}{196} = \overbrace{80 + I_a \times 4}^{V_t}$

$I_a = 29A$

$T_e = K_m \cdot I_a$

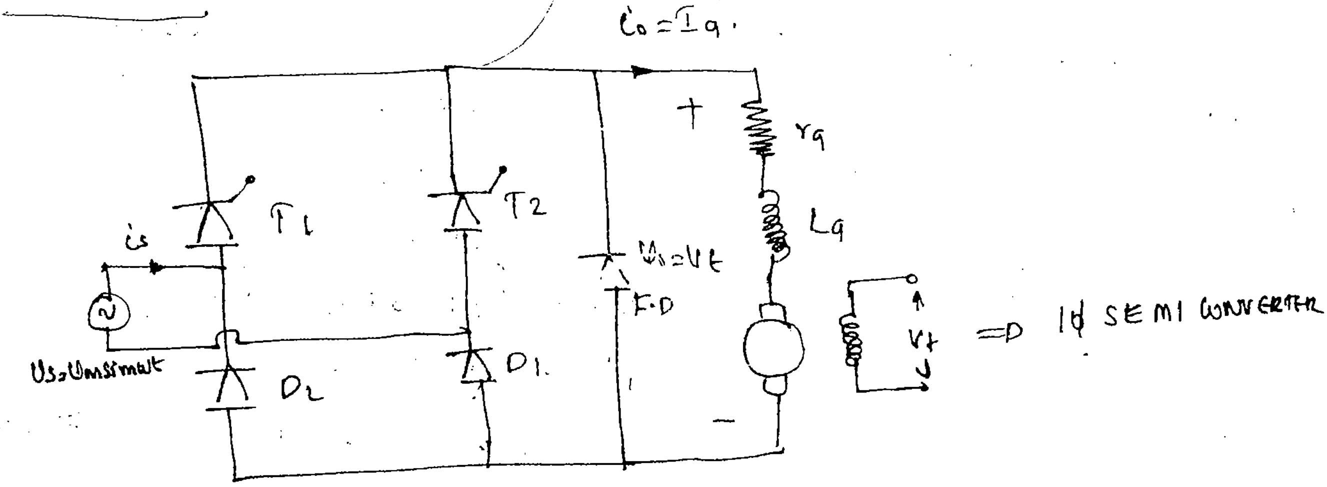
$E_a = K_m \omega_m$

$K_m = \frac{80}{2\pi \times \frac{1400}{60}} = 0.545\ \frac{V\text{-}s}{rad}$

$T_e = 0.545 \times 29 = \underline{\underline{0.83\ N\text{-}m}}$

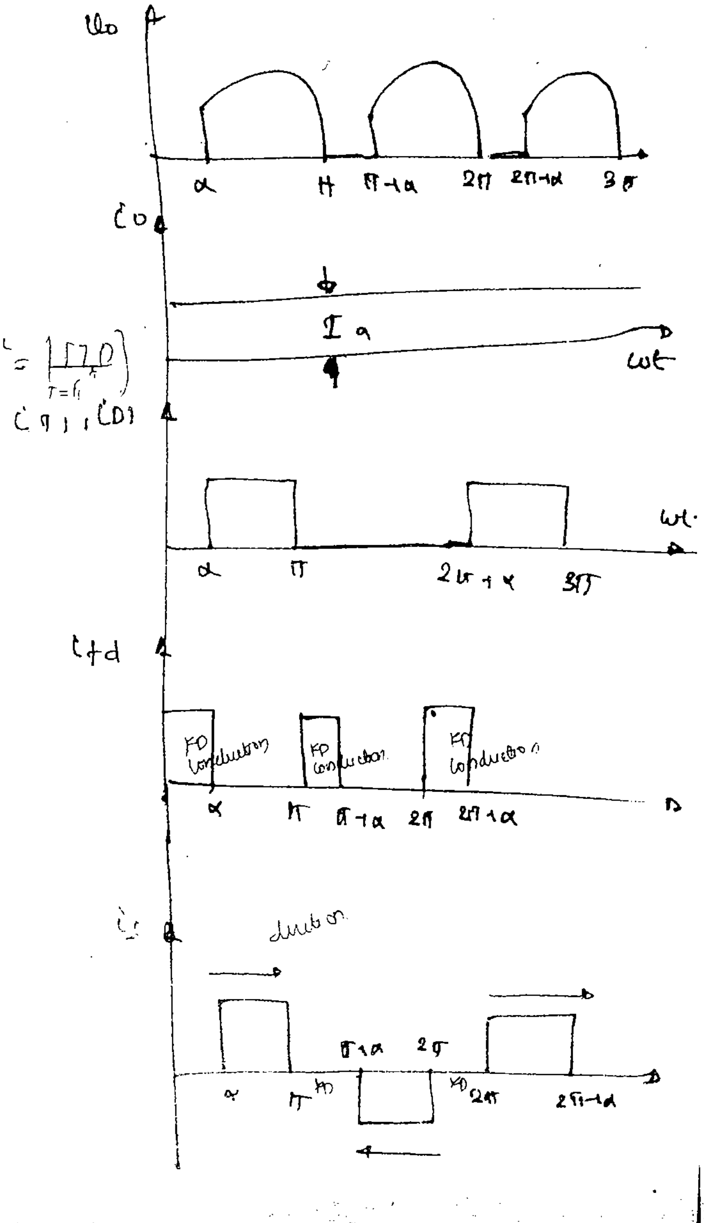
2) ~~1φ Half controlled / converter drive.~~

II) 1φ - SEMI CONVERTER DRIVE / 1-φ HALF CONTROLLED CONVERTER DRIVE :



- $V_o = V_t = \frac{V_m}{\pi}[1 + \cos\alpha_1]$
- $V_f = \frac{V_m}{\pi}[1 + \cos\alpha_2]$
- $I_{Tr} = I_{Dr} = I_a\sqrt{\frac{\pi - \alpha}{2\pi}}$
- $I_{Sr} = I_a\sqrt{\frac{\pi - \alpha_1}{\pi}}$ (rms =

- $I_{FDr} = I_a\sqrt{\frac{\alpha_1}{\pi}}$



03) DC Series motor (220V, 1000rpm) motor rating

$r_a + r_s = 0.2\Omega$

$N = 1000 rpm$, $K_1 = 0.03 \frac{Nm}{A^2}$

K_1

$V_s = 250V$

- Rating of the motor is useful to evaluate the motor constant.

- Current and torque are on motor side

start from convertor side.

$$V_0 = \frac{V_m}{\pi}[1+\cos\alpha]$$

$$= \frac{250\sqrt{2}}{\pi}[1+\cos 30]$$

$$= 210 V$$

$E_a = K_1 I_a \omega_m$

$$V_t = V_t \Rightarrow 210 = E_a + I_a(\overset{r_a+r_s}{\cancel{R_a+R_s}})$$

$$V_0 = K_1 I_a W_m + I_a(r_a+r_s)$$

$$= 0.03 \times I_a \times \frac{2\pi\times1000}{60} + I_a \times 0.2$$

$$210 = 0.03 \times I_a \times \frac{2\pi\times1000}{60} \times I_a \times 0.2$$

$I_a = 62.84$

$$T = K_1 I_a^2$$

$$= 0.3 \times (62.84)^2$$

$T = 1184.6 Nm$

04) 220V, 1500rpm, 10A
(V_t) N I_a

- separately excited dc motor.

- $r_a = 1\Omega$

- Fully controlled bridge rectifier

$V_s = 230V$

$f = 50Hz$

- Continuous load current

a) $\alpha = 30°$, $T = 5 Nm$, $N = ?$

$$V_t = E_a + I_a r_a.$$

$$220V = K_m \omega_m + I_a r_a = K_m \cdot \frac{2\pi\cdot1500}{60} + (10\times1)$$

$K_m = 1.337 \frac{V.s}{rad}$ (Keep up to 3 digits)

$$I_a = \frac{T_e}{K_m} = \frac{5}{1.337} = 3.74 A$$

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

$$= \frac{2\times230\sqrt{2}}{\pi}\cos 30 = 179.33V$$

$$V_t = V_t \Rightarrow K_m\omega_m + I_a r_a = 179.33$$

$$179.33 = 1.337 \times \frac{2\pi\times N}{60} + 3.74\times1\Omega$$

$N = 1254.95$

b) $\alpha = 45°$, $N = 1000 rpm$

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

$$= \frac{2\times230\sqrt{2}}{\pi}\times\cos45$$

$$= 146$$

$$146 = K_m\omega_m + I_a r_a$$

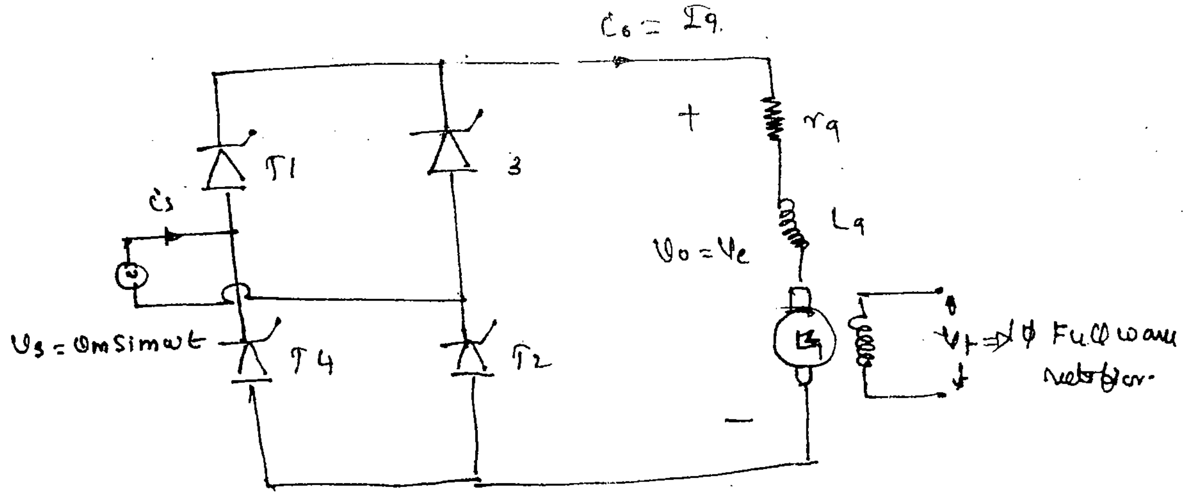
$$= 1.337\times\frac{2\pi\times1000}{60} + I_a$$

$I_a =$ ~~5.939~~ 6.4A

$T_a = K_m I_a = 1.337 \times 6.4$

$= 8.7 Nm$

III> 1-φ - Full wave rectifier wave.



- Full wave Rectifier is specially used when motor + REGENERATIVE BRAKING MODE.

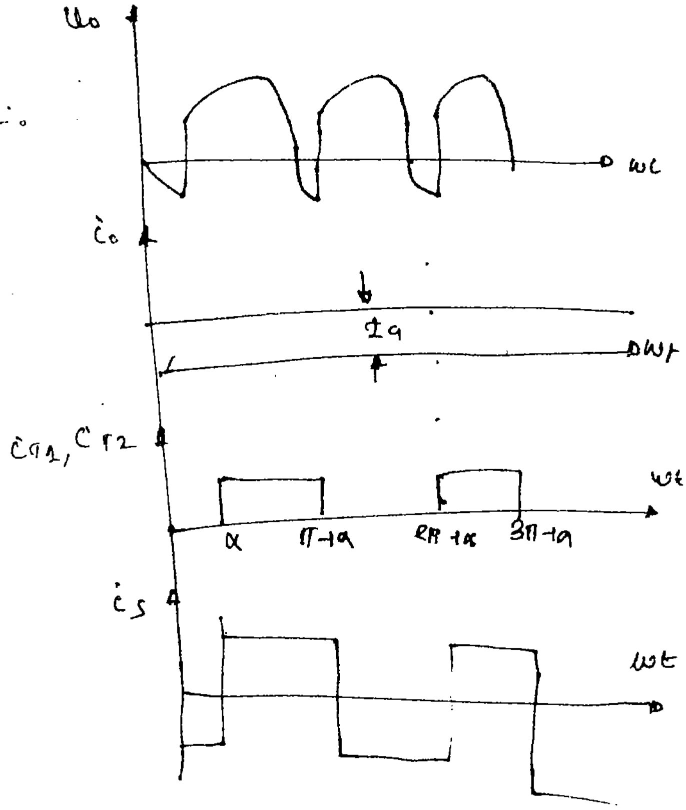
1) $V_0 = V_E = \frac{2V_m}{\pi} \cos\alpha_1$

2) $V_f = \frac{2V_m}{\pi} \cos\alpha_2$

3) $I_{Tr} = I_a \sqrt{\frac{\pi}{2\pi}} = \frac{I_a}{\sqrt{2}}$

4) $I_{sr} = I_a$

5) $P_f = \frac{V_E I_a}{V_s I_{sr}}$



8125387847

Q57 200V
1500
10A } motoring (separately excited)

$V_s = 230V, f = 50Hz$

$r_a = 1\Omega$

I_a = continuous.

a) I_a = rated = 10A for Torque rated

$V_t = E_a + I_a R_a$

$200 = K_m \omega_m + 10 \times 1$

$200 = \frac{2\pi \times 100}{60} \times K_m + 10$

$K_m = 1.815$ V.s/rad.

12000
600
11400

114
8

30 - 9.30 = N/W (302)

11 - 11.30 = N/W Sgn.

1 pm - 1.30 = History.

THE D

The End