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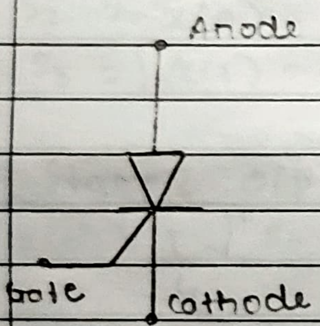
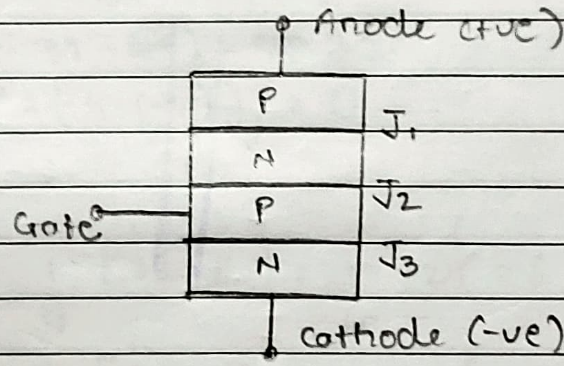
09/01/24

UNIT 1 :- STUDY OF POWER DEVICES

* **SCR (Silicon Controlled Rectifier) (Thyristor) :-**

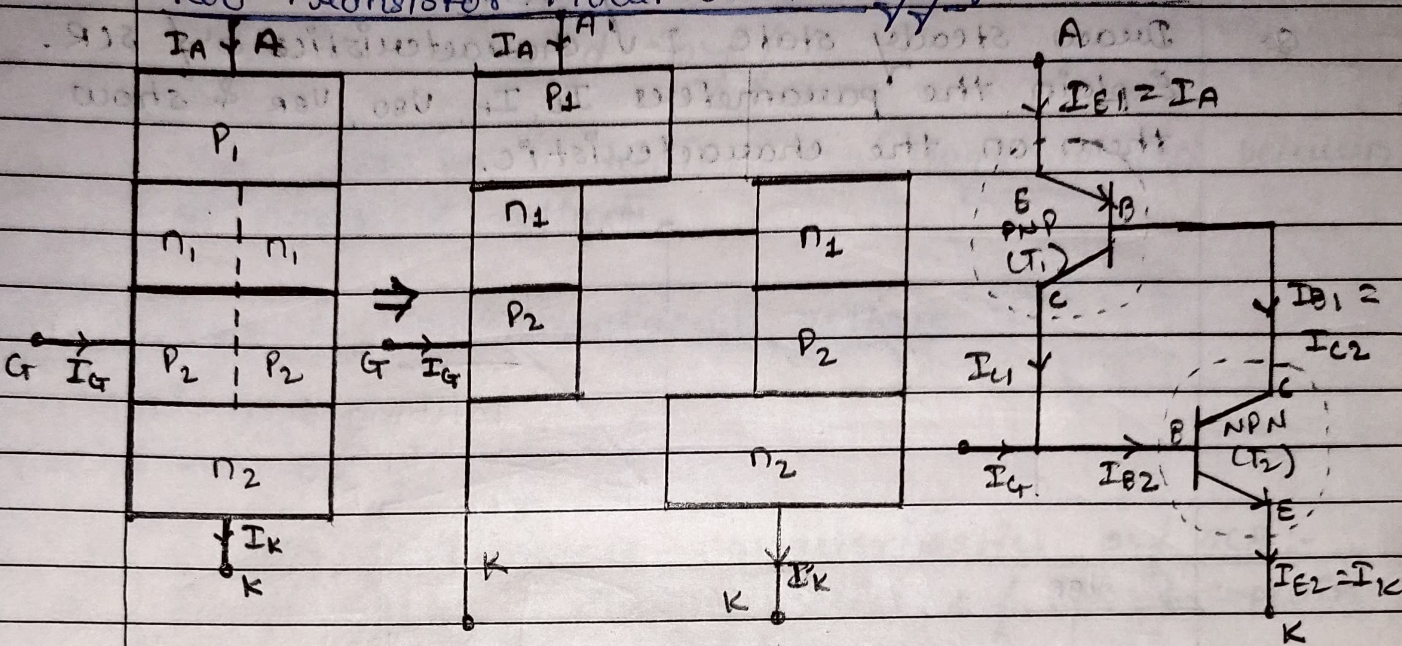
Construction :-





1. Solid state operating devices.
2. It has four layers (P, N, P, N), three junctions (J_1, J_2, J_3), three terminals (Anode, Cathode, Gate).
3. It is a current operating device.
4. In off state it has infinite resistance & in ON state it has low resistance (0.01 Ω to 1 Ω)

Two Transistor Model or Analogy :-



$$I_{E1} = I_A = \frac{\alpha_2 I_G + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$

$I_G \Rightarrow$ Gate current

$I_{CBO} \Rightarrow$ Collector Leakage Current with zero base current

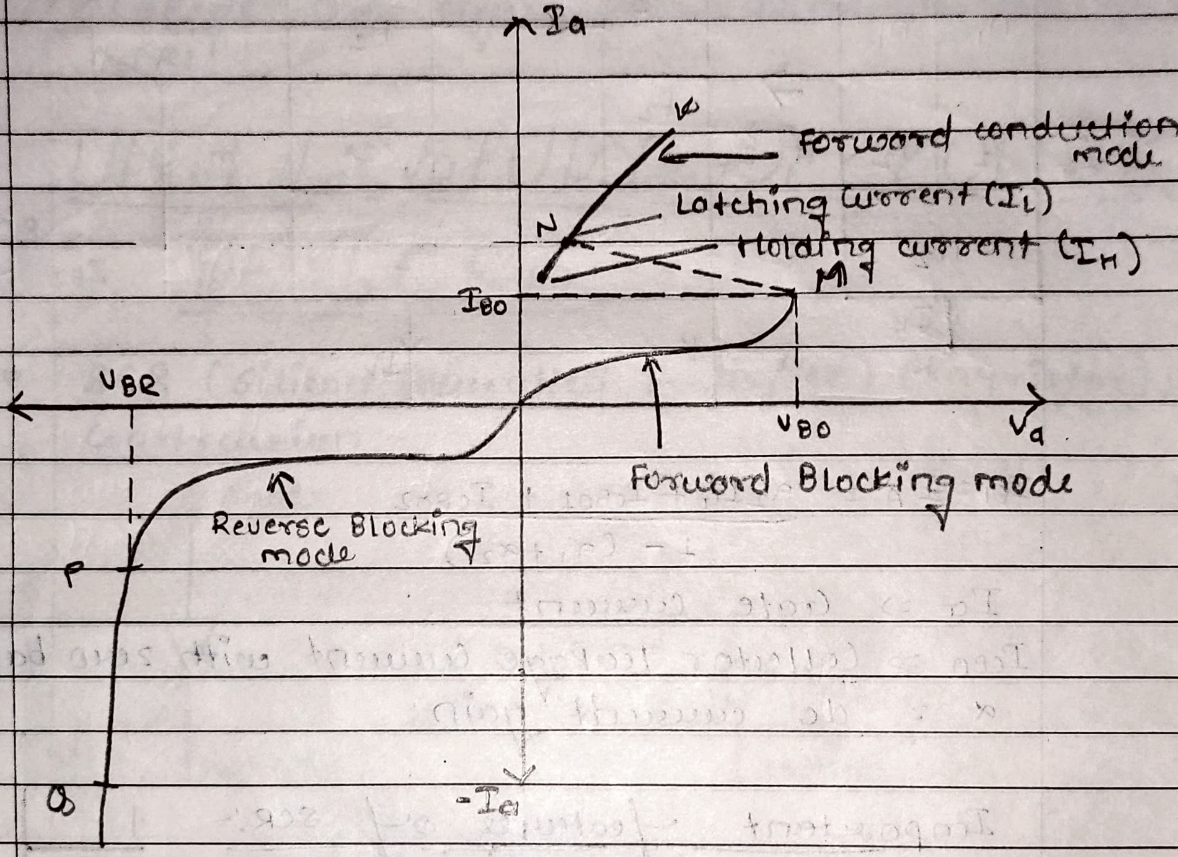
α = dc current gain

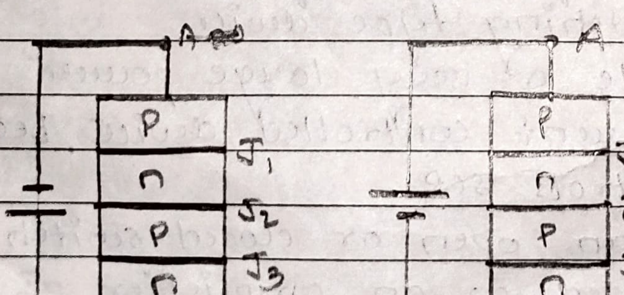
Important features of SCR:-

1. It is a latching type device.
2. It can handle a very large power.
3. It is a current controlled device, because the gate current controls SCR.
4. It acts as an open or closed switch but it cannot be used as an amplifier.
5. The on-state voltage drop is very low.
6. It can handle thousands of amperes of current.

I-V characteristics of SCR :-

Q:- Draw steady state I-V characteristics of SCR. Explain the parameters I_L, I_H, V_{BO}, V_{BR} & show them on the characteristic.





~~V_{BO}: It~~

I_L :- Minimum anode current which SCR must attain during turn-on process to maintain conduction.

~~I_L~~ I_H :- Minimum anode current below which SCR is turned off.

V_{BO} :- It is a minimum voltage applied between anode & cathode.

V_{BR} (Reverse breakdown voltage :-

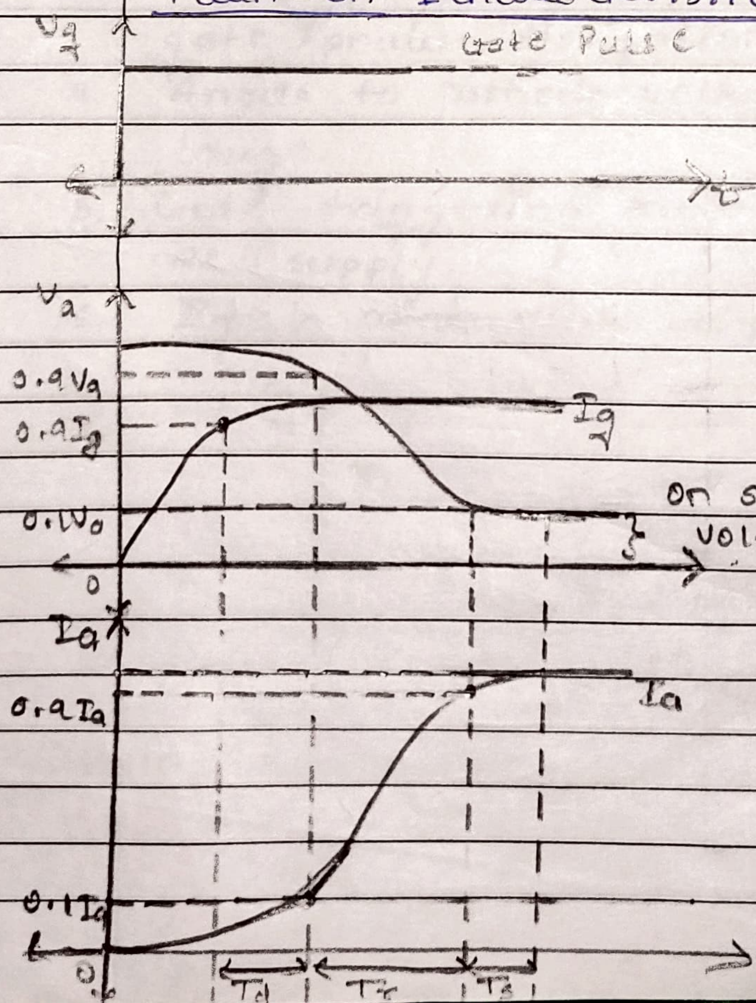
* Switching / Dynamic characteristics of SCR :-

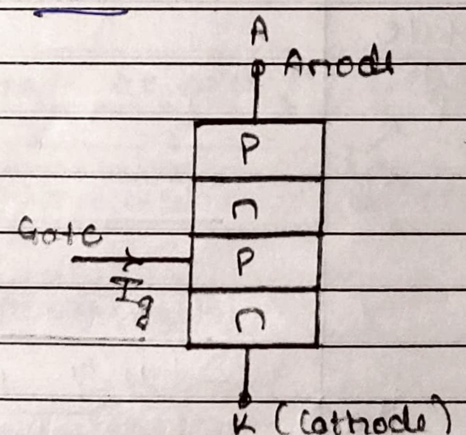
Q :- Draw dynamic characteristics of SCR & explain turn-on & turn-off process.

OR

Q :- Draw & explain switching characteristics of SCR.

Turn-on characteristics of SCR :-





* The Transition time from forward off state to on-state is SCR turn-on time.

T_d :- Gate current reaches 90% of I_g to 10% of I_a. (delay time)

T_r :- Time taken by I_a to rise from 10% to 90% I_a

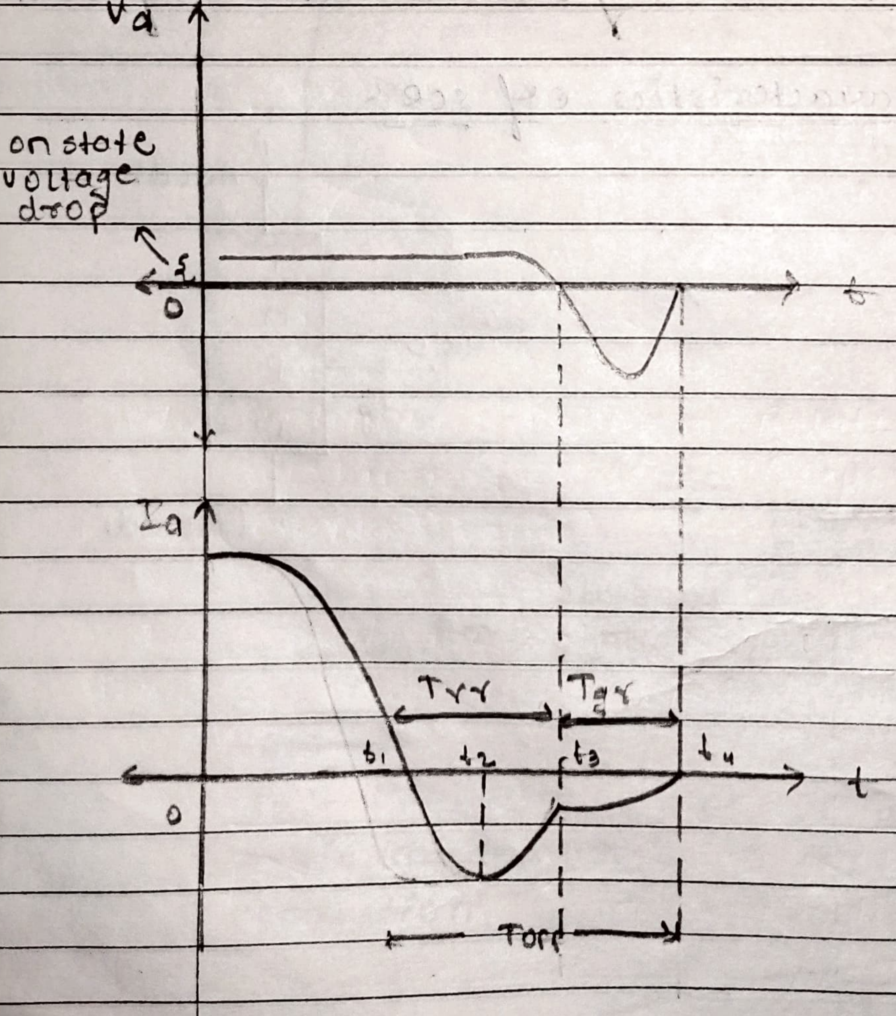
T_s :- Time taken by I_a to rise from 90% of I_a to final I_a.

~~$T_{turn-on}$ =~~

$$\boxed{T_{turn-on} = T_d + T_r + T_s}$$

Turn off characteristic of SCR :-

Time between ON to off state that is to attain forward blocking mode is turn-off time.



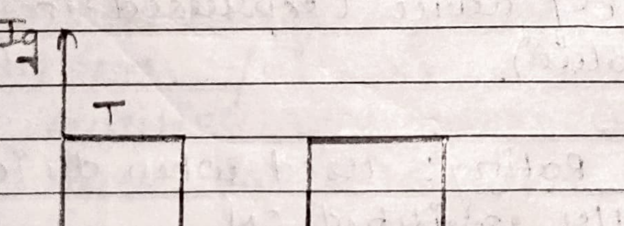
T_{rr} :- (Reverse Recovery time) :- The T_{rr} is the time required for the minority carriers to recombine with the opposite charges & get neutralized. It is the time from zero crossover point of SCR current to 25% of the peak reverse recovery current I_{rr}.

T_{gr} :- It is the time required for the recombination of excess charges in the middle p-n junction J_2. A negative reverse voltage will reduce this time.

~~Necessary conditions~~

* **Necessary conditions for SCR as a switch :-**

1. SCR must be forward biased.
2. $T \geq T_{ON}$ of SCR.
3. Average gate power dissipation < instantaneous gate power dissipation.
4. Anode to cathode voltage must be sufficiently large.
5. Gate triggering must be synchronized with AC supply.
6. I_g > ~~min~~ min. required value.



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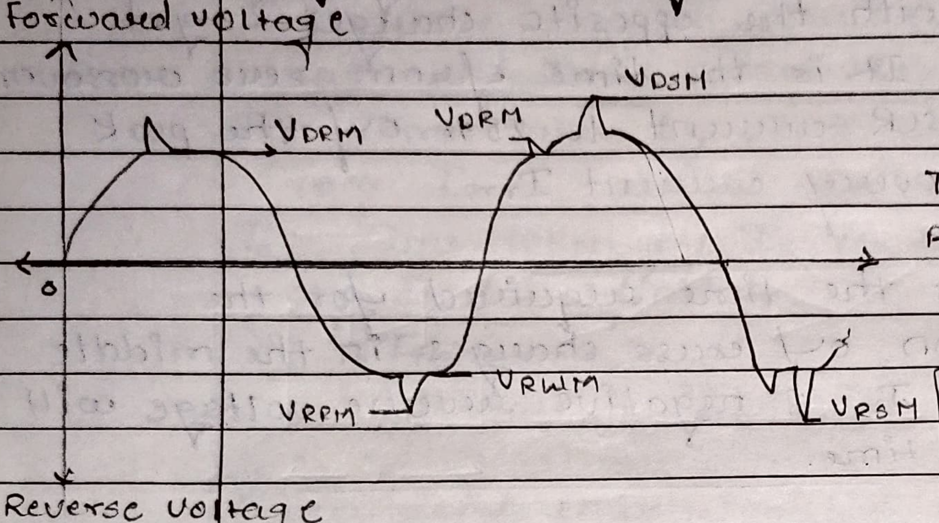
Lecture 4:- **Thyristor Ratings & Protection:-**

* **Thyristor Ratings:-**



D => Forward blocking region

T => ON, F => Forward

R = Reverse, M => Max. value

W => Working value

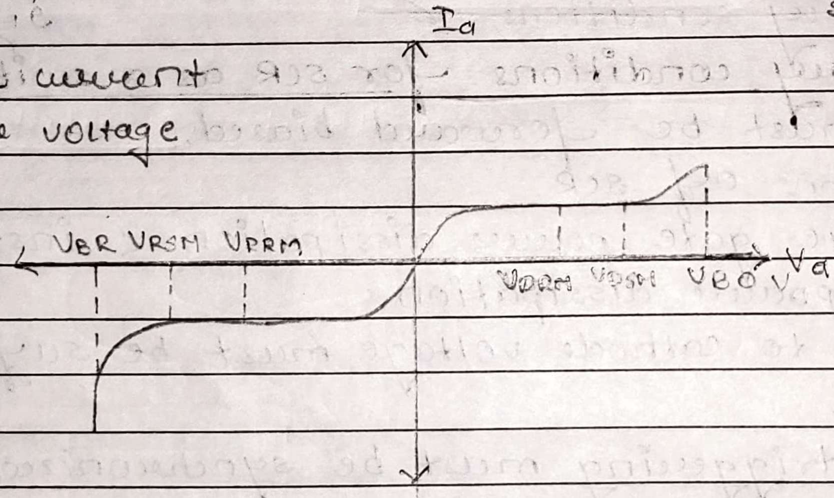
R => Repeatetive value

S => Surge (non-repeatetive)

→ 2nd term in suffix.

Ia → Anode current

Va => Anode voltage



1. **Continuous Rating:-** Related to continuous working of device (expressed in average or RMS value).

2. **Repeatetive Rating:-** used when device is periodically switched ON.

3. **Surge or Non-repeatetive:-** Related max. possible current or voltage peaks that the device can withstand during a surge.

V_{DRM} ← as per notation

V_{DRM} :- It is a peak repeatetive forward blocking voltage that a SCR can handle.

V_{RRM} :- It is a peak or max. repeatetive reverse voltage that a SCR can withstand.

V_{RWM} :- It is a ~~m~~ peak working reverse voltage that the SCR can handle.

V_{DSM} :- It is a peak surge (non-repeatetive) forward blocking voltage. It is less than V_{BO} (Forward Break over voltage).

V_{RSM} :- It is a peak surge reverse voltage. It is less than V_{BR} (Reverse Breakover voltage).

* **Thyristor Protection :-**
  If a certain specified limits of thyristor are exceded beyond its certain limits, then thyristor protection is used.

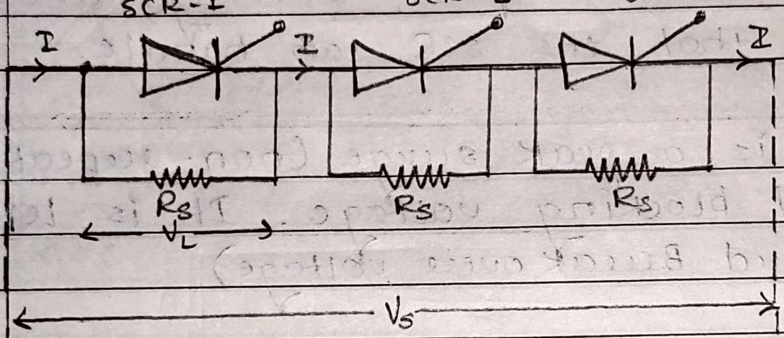
1. Over current protection :-
   i) High Repturing capacity (HRC) fuse, semi-conductors fuse or rewirable fuse.
   ii) For sensitive systems ⇒ Crowbar protection technique is used.

2. Over voltage protection :-
   i) Voltage transients are generated due to different types of switching.
   ex :- insulation breakdown, blow of fuse, free wheeling diodes, switching of the transformers etc.

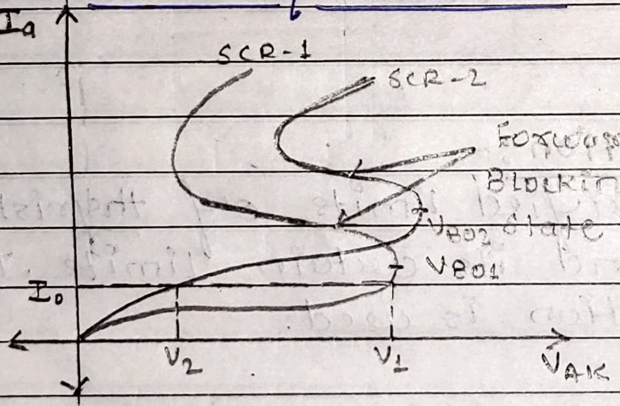
ii) use Low pass filter, zener diodes, snubber circuits etc.

Lecture 5:- **Series & Parallel connections of SCRS:-**

* **Series connection:-** Ex:- Electronic precipitators, refinories etc.



Static Equalization:-



$$R_s \leq \frac{(n_s V_D - V_s)}{(n_s - 1) I_{Dmax}}$$

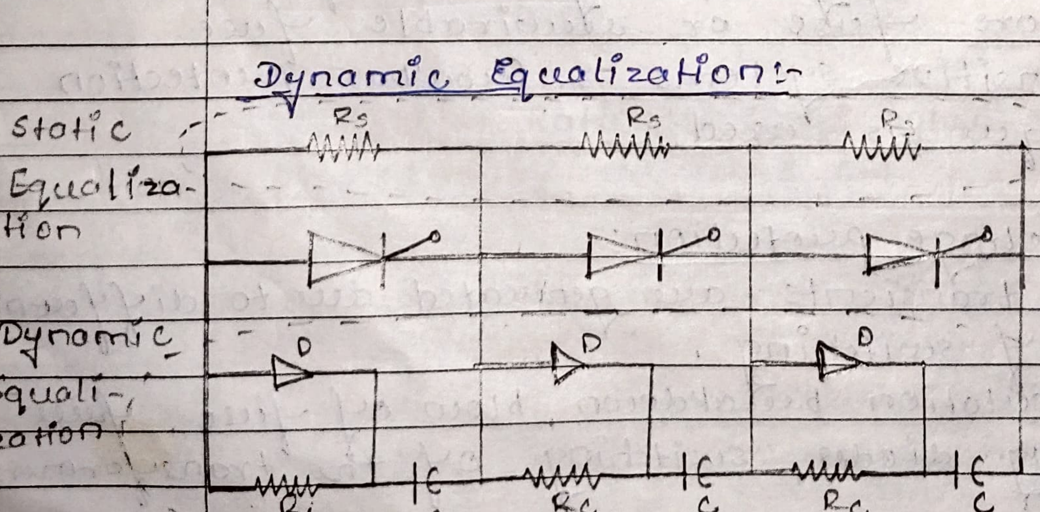
n_s => No. of series connected SCRS

V_s => String voltage

V_D => Max. blocking voltage

I_D => Max. blocking current.

Dynamic Equalization:-



If voltage requirement is more then series connection is preferred if current requirement is more then ||el connection is preferred.

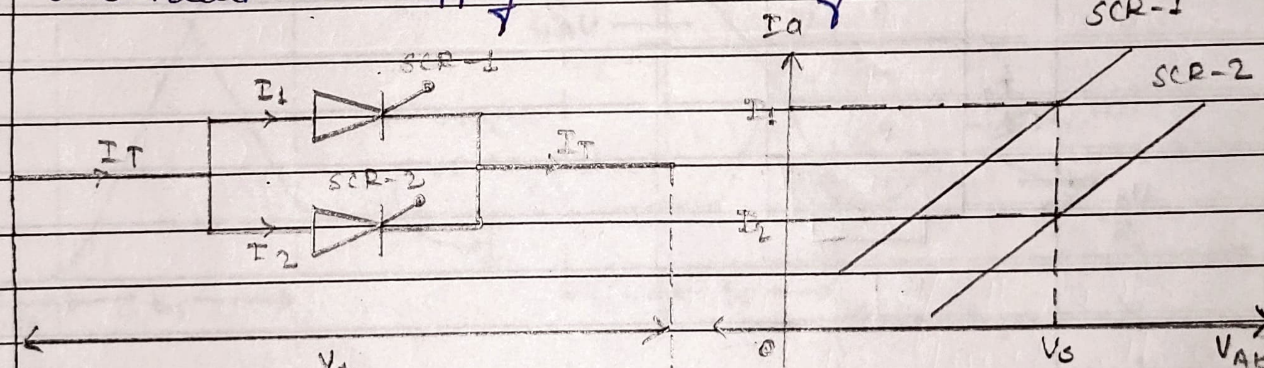
Diode (D) => i) Make 'C' more efficient in voltage equalization

ii) Limit $\frac{dV}{dt}$ across SCR.

Advantages:- SCRs of low voltage & high current ratings can be used for serial connection.

Disadvantages:- If equilization circuit fails then particular SCR may get damaged.

* Parallel connection:- Ex:- Battery chargers, overhead DC supply in railways.



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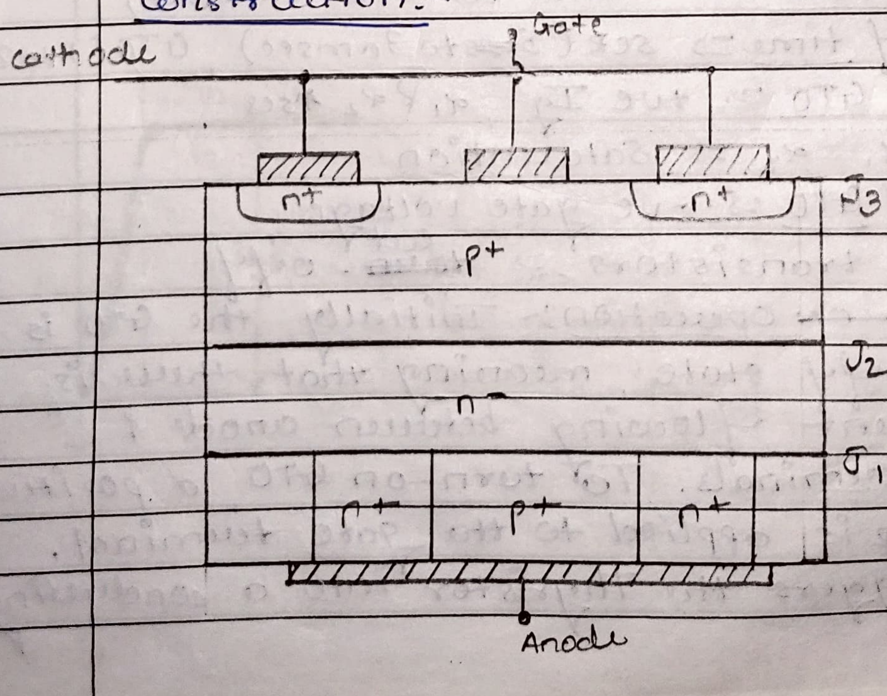
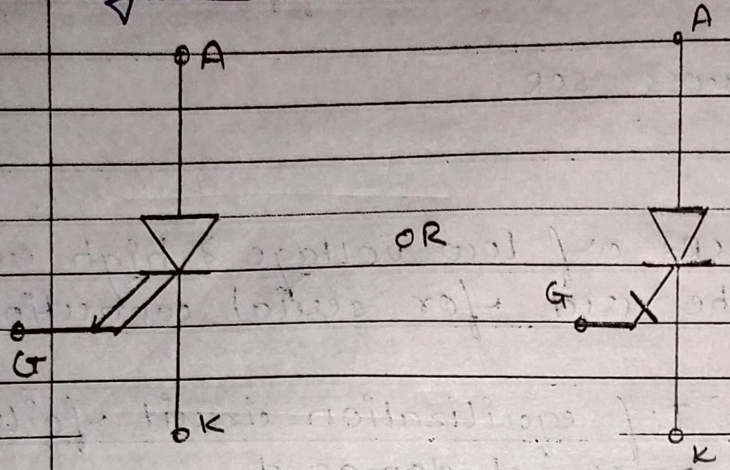
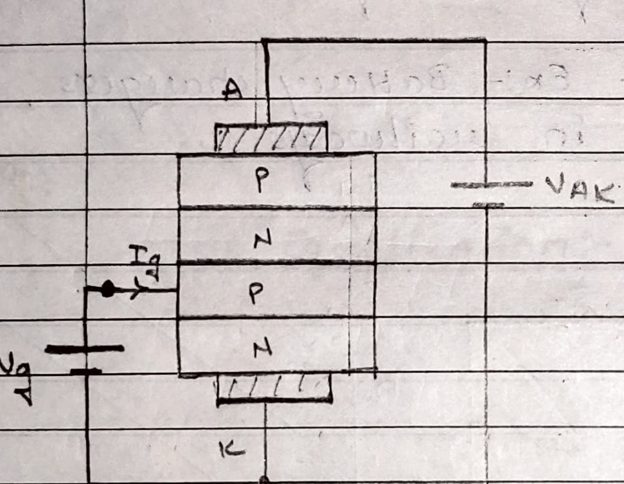
Lecture 6:- Gate Turn-off Thyristor (GTO):-

Construction:-



Symbol:-





Operation:-

Turn-ON Time => Same as SCR (1 msec)

Turn-off time => SCR (5 to 30 msec), GTO (1 to 2ms)

Turn-ON GTO => +ve I_g, α_1 & α_2 ↑ses

when $\alpha_1 = \alpha_2$ => Saturation

Turn-off GTO => -ve gate voltage

both transistors => cut-off

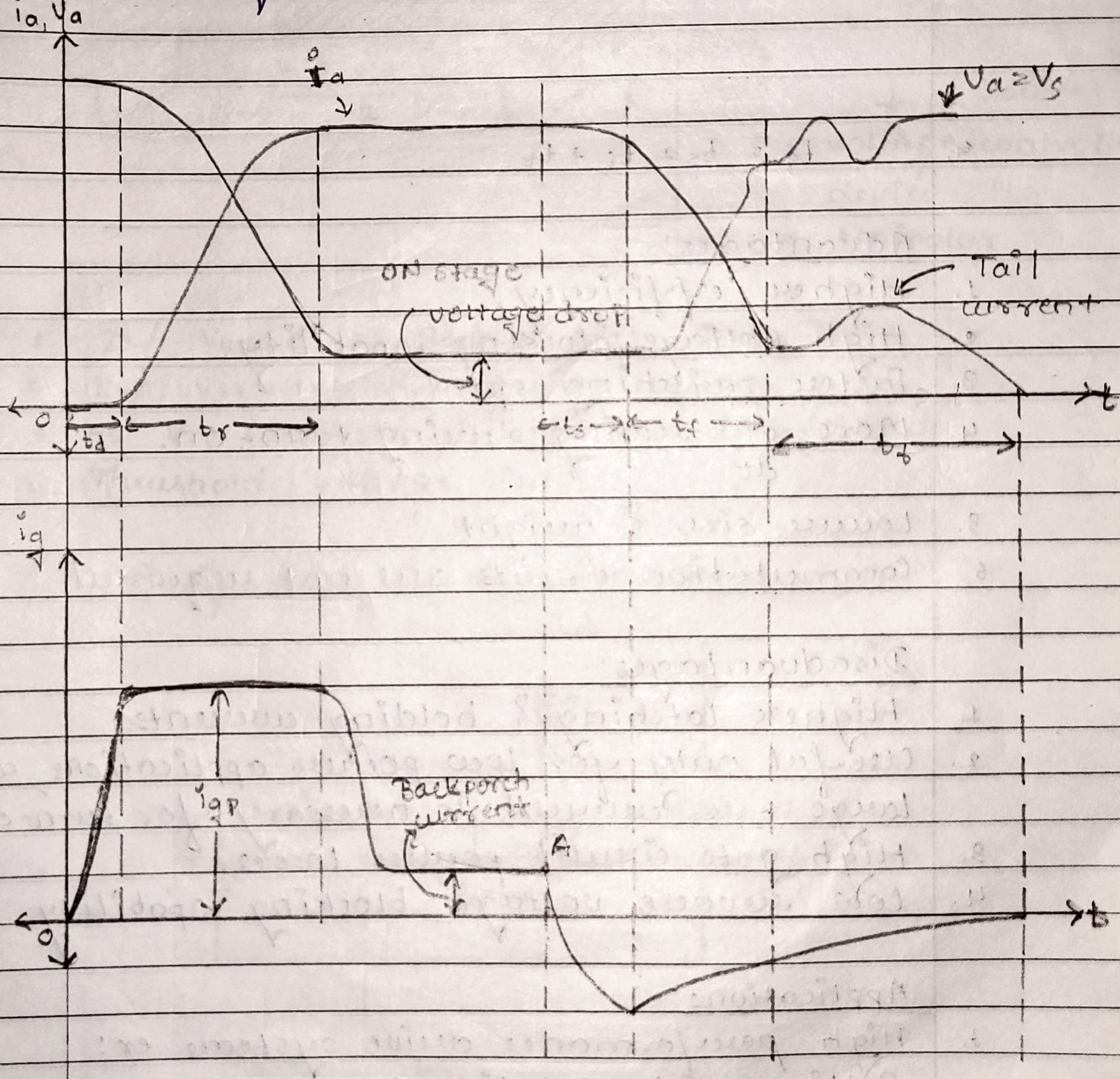
Just for explaination

1. ~~Tri Turn-ON~~ Operation:- Initially, the GTO is in the off state, meaning that there is no current flowing between anode & cathode terminals. To turn-on GTO, a positive voltage is applied to the gate terminal. This triggers the Thyristor into a conducting state.

~~Conduction:- Once the GTO is to~~

Turn-off mechanisms:- To turn-off the GTO, a negative voltage pulse is applied to the gate terminal. This negative pulse neutralizes the positive charge carriers in the thyristor, reducing the current flow to zero & turning off the device.

Switching characteristics:-



1. Storage time (t_s):- It is the time required to remove excess charge is called storage time (t_s).

2. Fall time (t_f):-

3. Tail time (t_t):-

4. $t_q = t_s + t_f + t_t$

Advantages:-

1. Higher efficiency.
2. High voltage blocking capability.
3. Faster switching speed.
4. More $\frac{di}{dt}$ rating during turn-on.
5. Lower size & weight.
6. Commutation circuits are not required.

Disadvantages:-

1. Higher latching & holding currents.
2. Useful only for low power applications as large -ve current is necessary for turn-off.
3. High gate circuit power losses.
4. Low reverse voltage blocking capability.

Applications:-

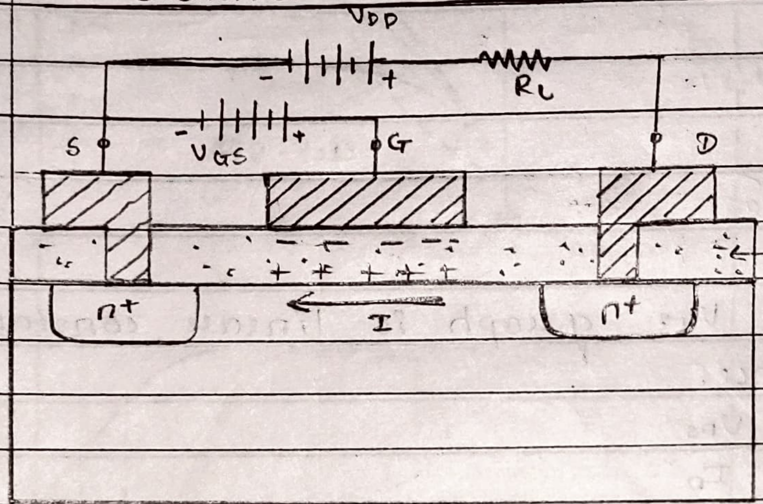
1. High performance drive systems ex: Rolling mills, Robotics, etc.

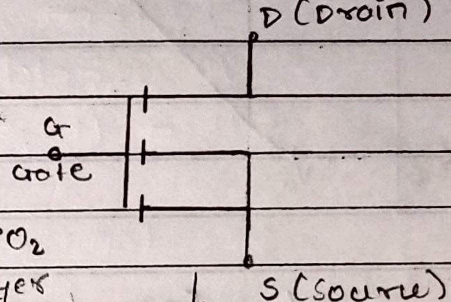
2. Counters, pulse generators, multi-vibrators.
3. Used for traction purposes.
4. Adjustable frequency inverter drives.

26/01/24 Lecture 7 :- Power MOSFET

* n-channel E-MOSFET :-

*

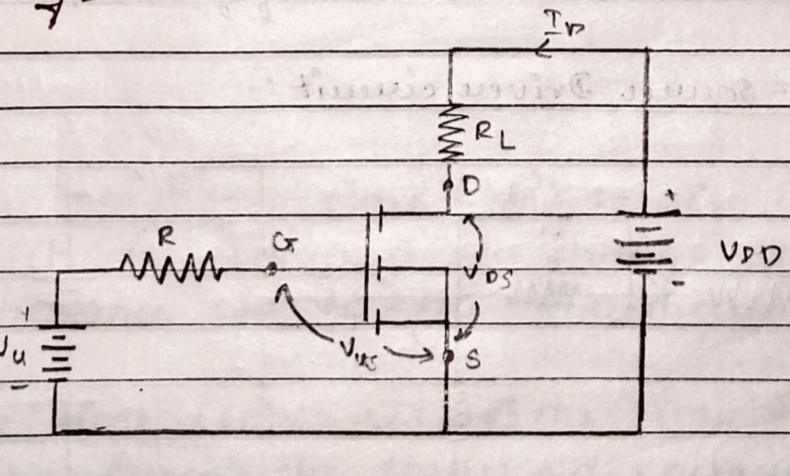




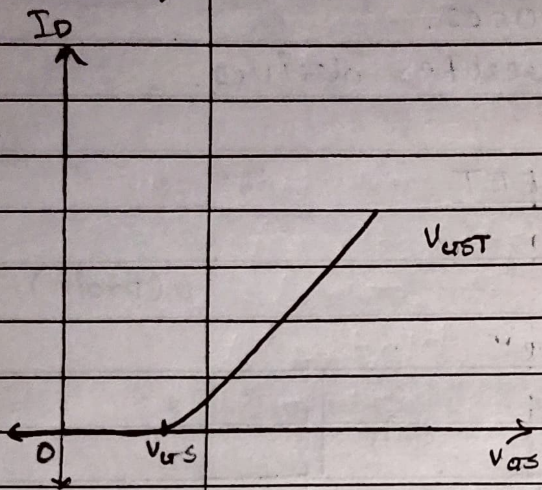
1) Voltage controlled device
2) Unipolar

1. If $V_{GS} = 0$ => Reverse bias, $I = 0$.
2. If $V_{GS} = +ve$ => depletion region.
3. As V_{GS} increases, 'n' channel is formed.
4. Threshold voltage V_{GST}.

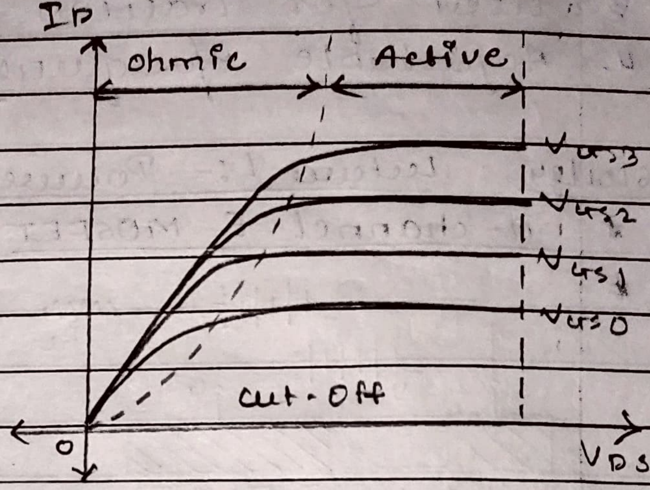
Steady - State characteristics :-



Transfer characteristics :-



Output characteristics :-



1. For lower V_{GS}, graph is linear, constant "ON" resistance.

2. $R_{DS} = \dfrac{V_{DS}}{I_D}$

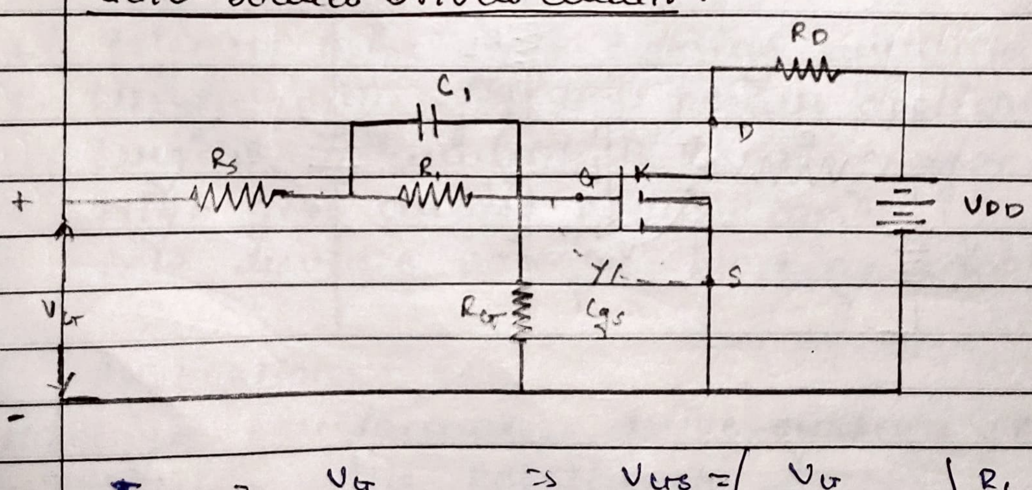
2. For given V_{GS}, if V_{DS} ↑ses, O/P is flat (I_D = const.)

3. When driven with large V_{GS}, PMOSFET is "ON".

   $V_{DS(ON)}$ is small ⇒ closed switch in ohmic region.

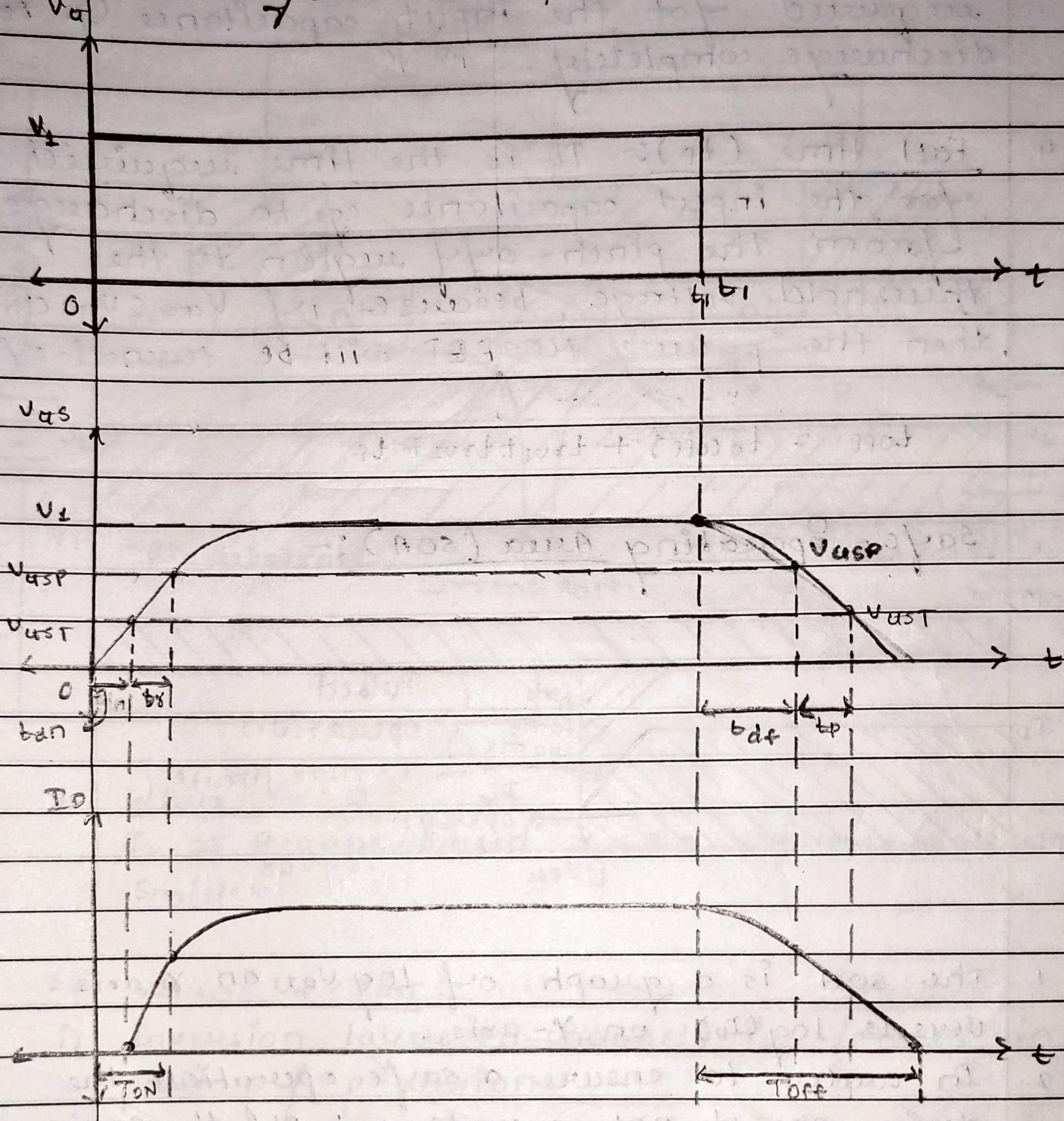
4. When $V_{GS} < V_{GST}$ ⇒ cut-off ⇒ open switch.

Gate-Source Driver circuit :-



$$I_{GSS} = \frac{V_G}{R_S + R_1 + R_G} \Rightarrow V_{GS} = \left(\frac{V_G}{R_S + R_1 + R_G}\right) R_G$$

Switching characteristics :-



1. <u>Turn on delay time (t_{dn})</u> :- It is the time which is required to charge the input capacitance C_{gs} to the threshold voltage V_{gs}.

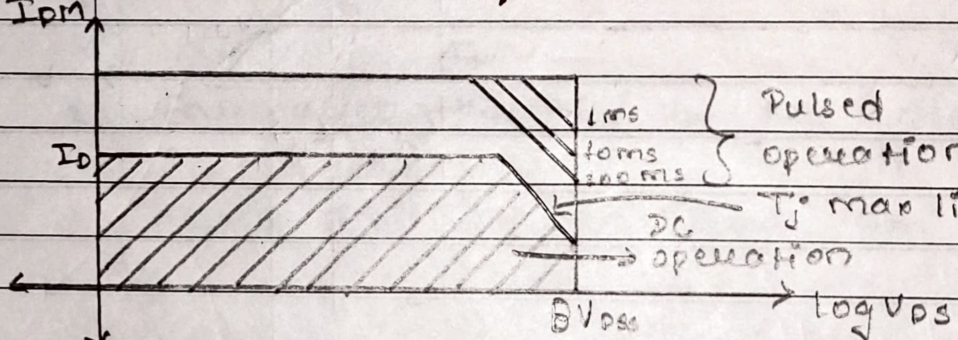
2. <u>Rise time (t_r)</u> :- It is the time taken by V_{GS} to rise from the threshold voltage $V_{GS(th)}$ to the full gate voltage (V_{GSP}).

3. Turn-off delay time (t_{df}) :- It is the time required for the input capacitance C_{gs} to discharge completely.

4. Fall time (t_f) :- It is the time required for the input capacitance C_{gs} to discharge from the pinch-off region to the threshold voltage, because if $V_{GS} \leq V_{GS(th)}$, then the power MOSFET will be turned-off.

$$t_{off} = t_{d(off)} + t_{rv1} + t_{rv2} + t_f$$

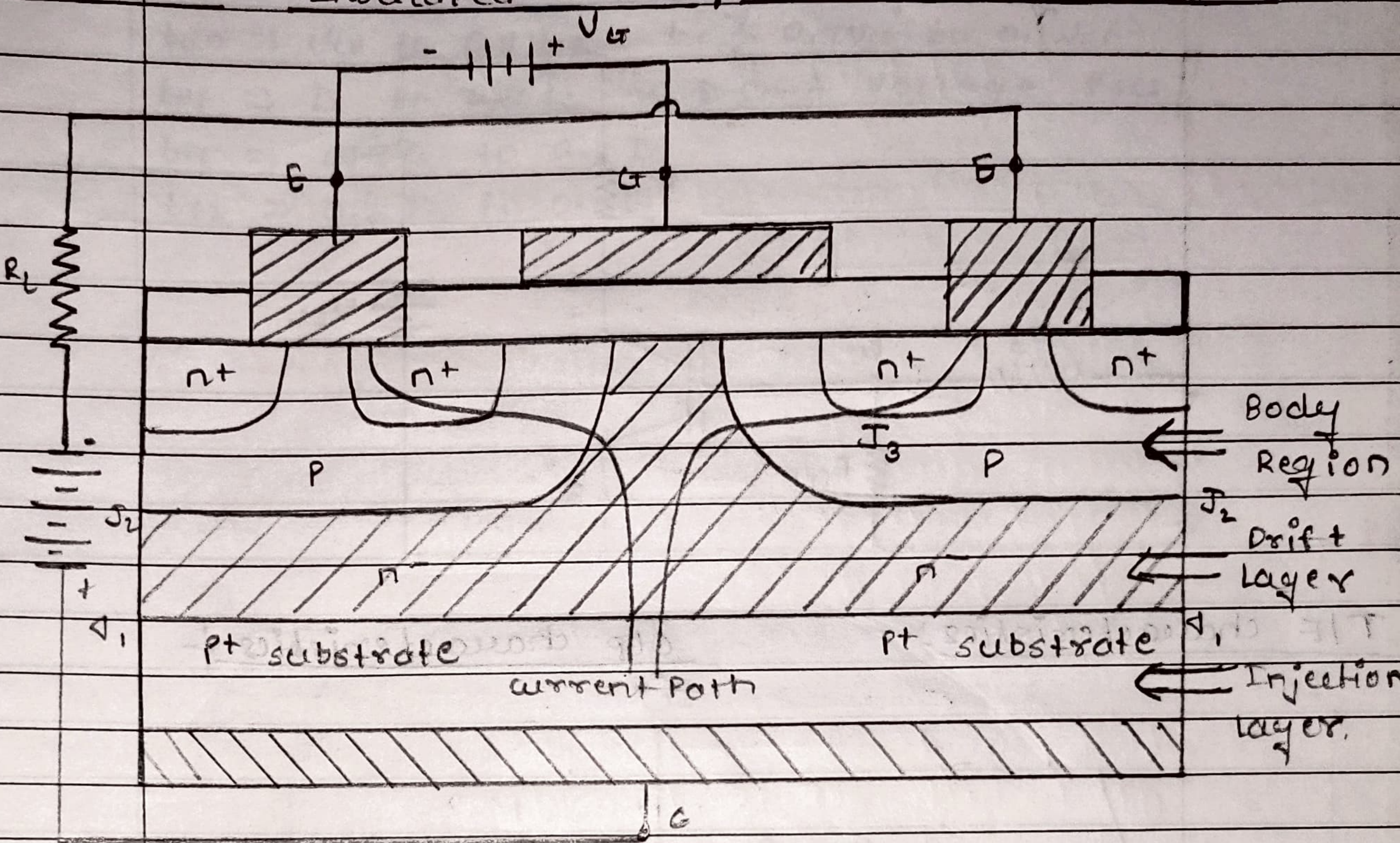
Safe-Operating Area (SOA) :-



1. The SOA is a graph of log V_{DS} on X-axis versus log (I_D) on Y-axis.
2. In order to ensure a safe operation the device should not operate out of the SOA.
3. Three factors determine the SOA, i.e.
i) I_{DM} (Max. drain current).
ii) T_j (Junction temperature).
iii) BV_{DSS} (Breakdown voltage).

Power MOSFET diagram do from sir's notes.

Lecture 8 :- Insulated Gate Bipolar Transistor (IGBT) :-



1. When $V_G = 0$:-

$J_2 \Rightarrow$ Reverse biased & $I = 0$ from collector to Emitter.

2. When $V_G > V_{GST}$:-

i) Inversion layer (n-channel) is formed in upper part of p region.

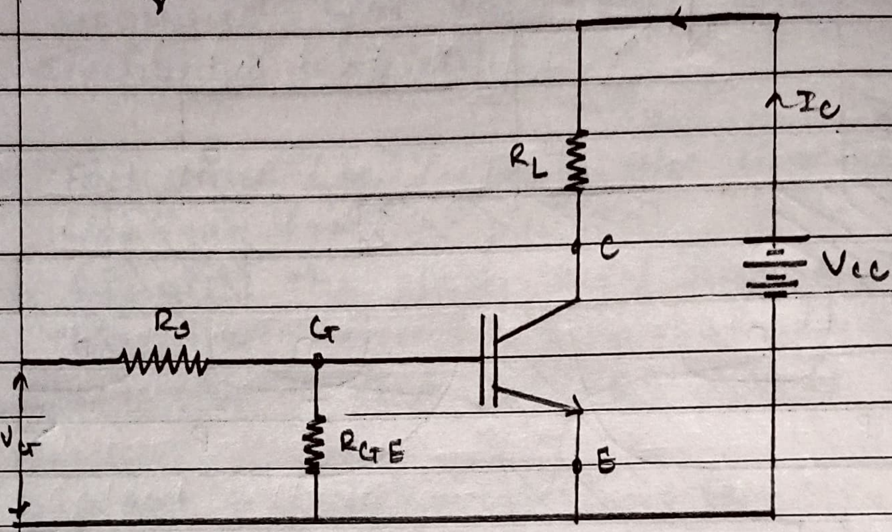
ii) It short circuits n^- region & n^+ emitter region.

iii) Electrons from n+ emitter flows to n^- drift region through n-channel.

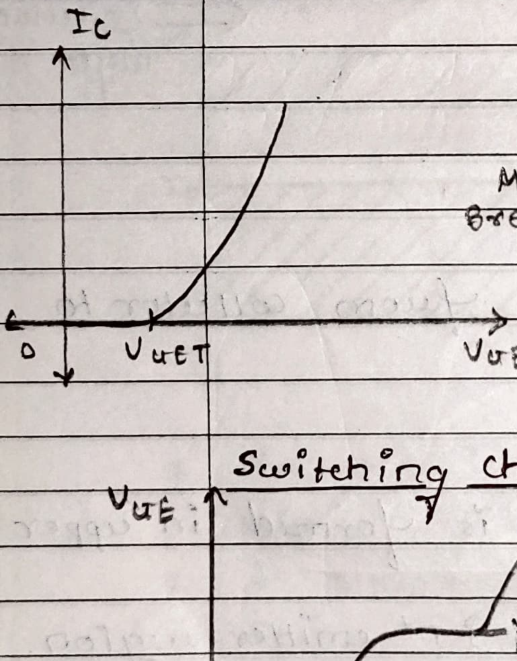
iv) Forward biased with 'collector' => +ve & 'emitter' => -ve. p+ collector injects holes into n- region.

v) Drift layer is ~~formed~~ flooded with electrons from 'p' body region & holes from p+ collector.

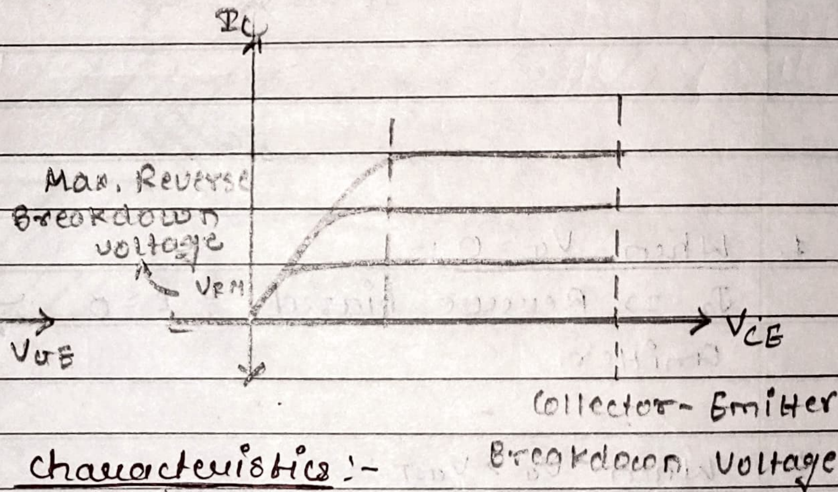
Steady - state characteristics :-



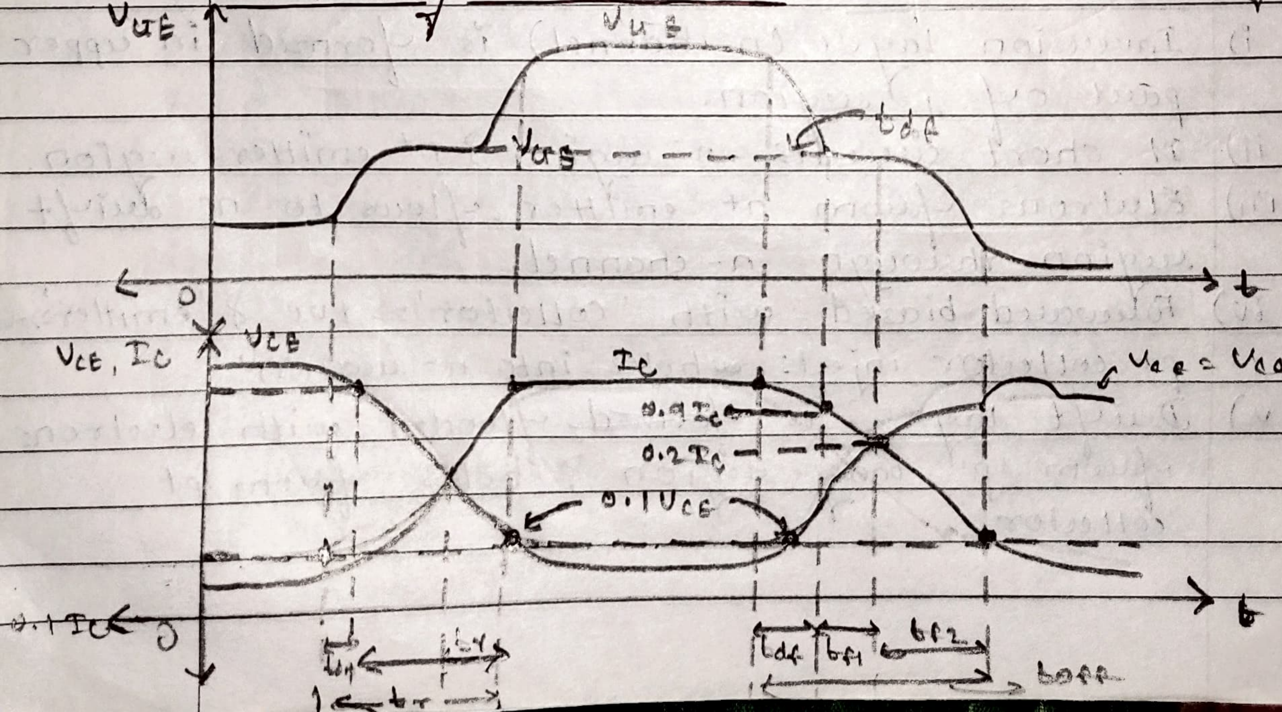
T/F characteristics :-



O/P characteristics :-



Switching characteristics :-



$t_{on} \Rightarrow$ Forward blocking to forward "ON" state

$t_{dn} \Rightarrow V_{CE}$ to $0.9 V_{CE}$, $t_r \Rightarrow 0.9 V_{CE}$ to $0.1 V_{CE}$

$t_{df} \Rightarrow I_c$ to $0.9 I_c \Rightarrow$ C-E voltage rises

$t_{f1} \Rightarrow 0.9 I_c$ to $0.2 I_c$

$t_{f2} \Rightarrow 0.2 I_c$ to $0.1 I_c$

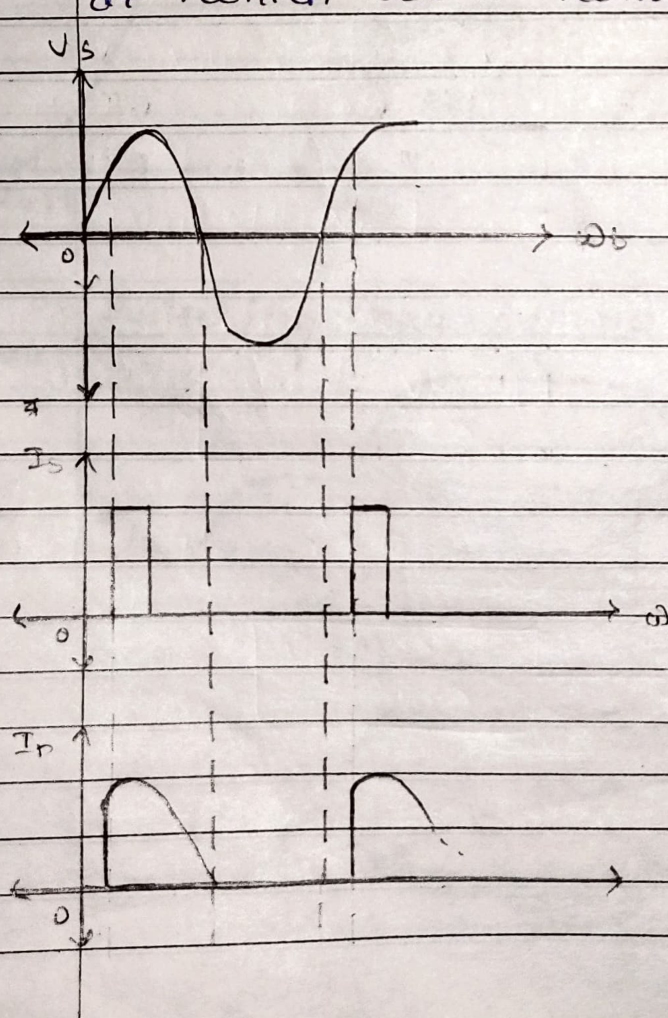
26/07/24

UNIT 2 :- AC TO DC POWER CONVERTERS

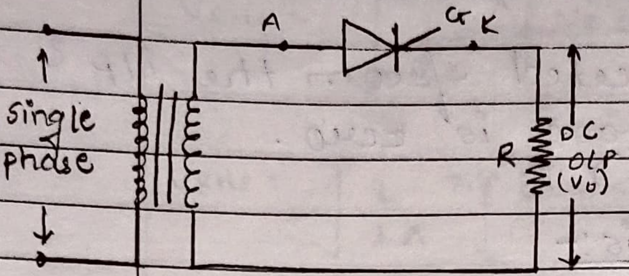
Lecture 1:- Single Phase Half Wave controlled rectifier (with R-Load) :-

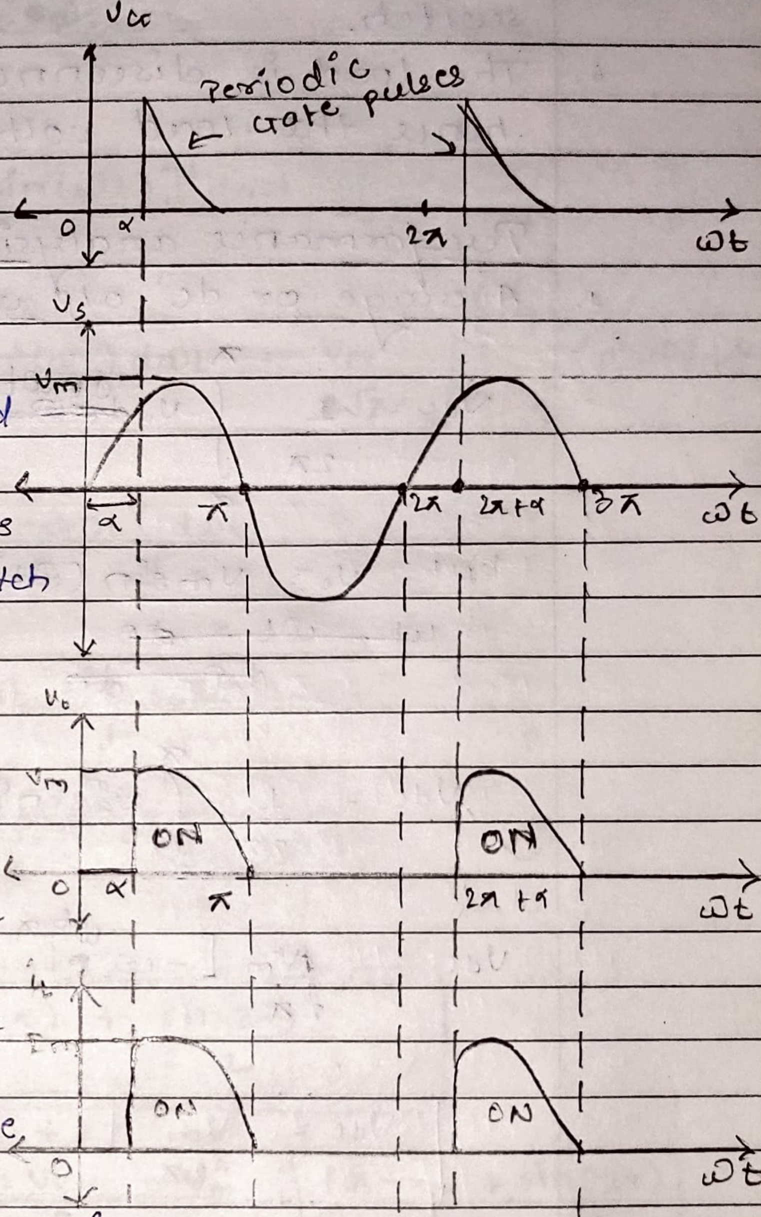
Q:- What is Phase controlled rectifier (PCR)?

→ Diode Rectifiers ⇒ uncontrolled
When diode is switched by Thyristor ⇒ PCR.
Output voltage can be controlled by changing firing angle (α)
To turn-on SCR ⇒ 1). It must be F.B.
2) Gate signal should be applied.
Firing angle (α) is the phase angle of voltage at which SCR is turned on.



* **Single Phase Half Wave Controlled Rectifier (HWCR) with R- Load :-**





Operation :-

1. When it is turned on at $\omega t = \alpha$ the thyristor acts like a closed switch & the input ac voltage appears as it is across the load.
2. Due to the resistive load, the load current is in phase with the load voltage & it has the same shape as that of the load voltage wave form.
3. The instantaneous value of load current is in phase with the load voltage & it has the same shape as that of the load voltage wave form.
4. As the load voltage ↓ses, the I_L also ↓ses & as this current reduces below the holding current of SCR_1, it is commutated due to natural commutation (at $\omega = \pi$).

5. In the negative half cycle, the thyristor is reversed biased & acts like an open switch.

6. The load is disconnected from the i/p & hence the load voltage is zero.

Performance analysis:-

1. Average or dc o/p voltage (V_{dc}):-

$$V_{dc} = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_0 \, d\omega t \quad \text{—— (1)}$$

but $V_0 = V_m \sin(\omega t)$ or $V_0 = V_m \sin\theta$

~~let $\omega t = d\theta$~~

~~$d\omega = d\theta$~~

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

$$V_{dc} = \frac{V_m}{2\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi} = \frac{V_m}{2\pi}\left[-\cos(\pi) + \cos(\alpha)\right]$$

$$\boxed{V_{dc} = \frac{V_m}{2\pi}\left[1 + \cos(\alpha)\right]} \quad \text{—— (2)}$$

~~if $\alpha = 0$~~

~~$\therefore \boxed{V_{dc} = \frac{V_m}{\pi}}$ —— (3)~~

~~directly take limits from 0 to π~~

2. RMS value of output voltage :-

$$V_{RMS} = \sqrt{\frac{1}{2\pi} \int_{\alpha}^{\pi} v_0^2 \, d\omega t}$$

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

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

$$V_{RMS} = \frac{V_m}{\sqrt{\pi}} \sqrt{\frac{1}{2} \int_{\alpha}^{\pi} \left[\frac{1 - \cos(2\omega t)}{2}\right] d\omega t}$$

$$V_{RMS} = \frac{V_m}{2\sqrt{\pi}} \sqrt{\int_{\alpha}^{\pi} d\omega t - \int_{\alpha}^{\pi} \cos(2\omega t) \, d\omega t}$$

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

$$\boxed{V_{RMS} = \frac{V_m}{2\sqrt{\pi}} \sqrt{(\pi - \alpha) + \frac{\sin(2\alpha)}{2}}}$$

* AC i/p power :- $P_i = \frac{V_{RMS}^2}{R} = \frac{V_m^2}{4\pi R} \left[(\pi - \alpha) + \frac{\sin(2\alpha)}{2}\right]$

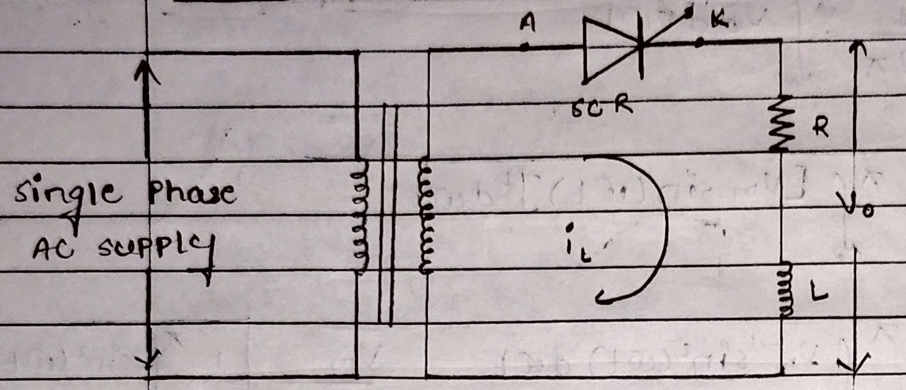
* DC o/p power :- $P_o = \frac{V_{dc}^2}{R} = \frac{V_m^2}{4\pi^2 R} (1 + \cos\alpha)^2$

* Power factor :- $\eta = \frac{P_o}{P_i} = \frac{(1 + \cos\alpha)^2}{\pi [(\pi - \alpha) + \sin(2\alpha)/2]}$

$$\eta = \frac{4}{\pi^2} \quad - [\alpha = 0 \quad \text{Max. P.F}]$$

01/02/24

Lecture 2:- Half Wave Controlled Rectifier with 'R-L' Load :-



Operation :-

1. Mode 1 (0 to α) :- Forward blocking mode
2. Mode 2 (α to π) :- SCR ON i_L is +ve & increases exponentially
3. Mode 3 (π to β) :- At π, i/p voltage is zero & after π it becomes -ve. It ~~tries~~ tries to turn-off SCR. so i_L decreases

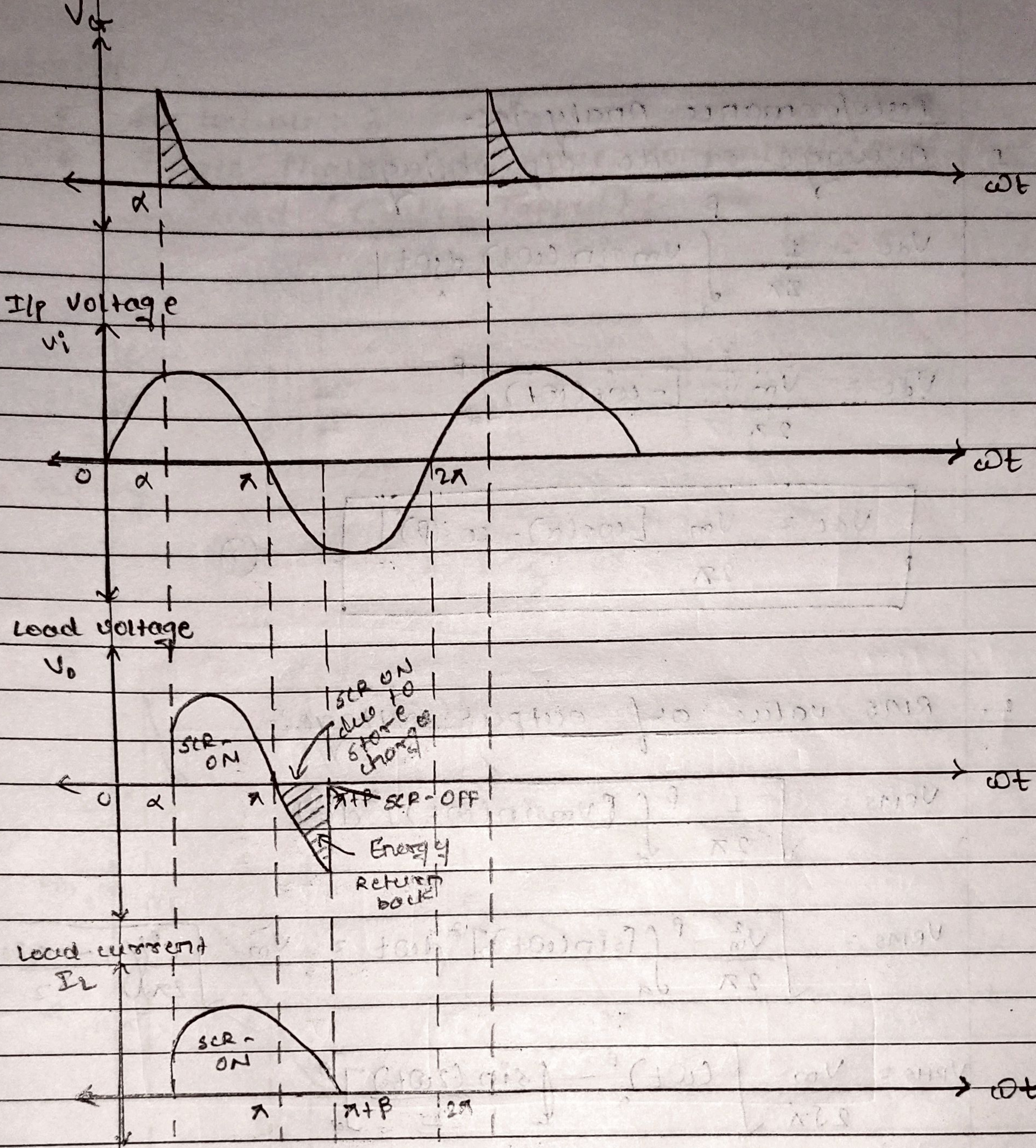
i) But inductive load induces self induced voltage & opposes this change.

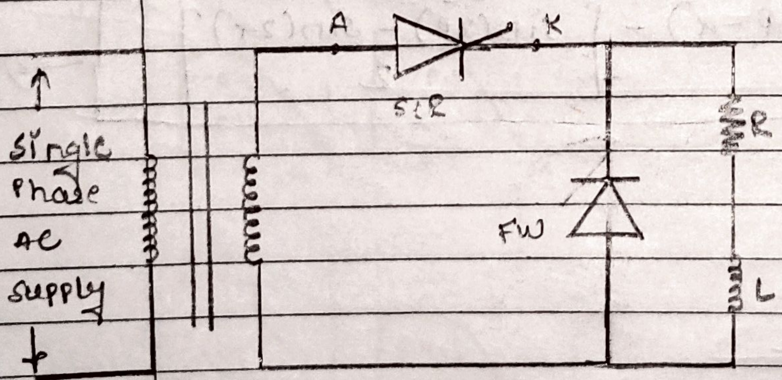
ii) 'K' voltage becomes more -ve than 'A' voltage.

iii) SCR remains in conduction from π to β.

iv) Finally I_L becomes 0 at ($\pi+\beta$) & turns-off SCR.

In the 'R-L' load as energy dissipated through 'R' so that SCR conducts for short-span in the negative half cycle the angle at which SCR stops conducting is called extension angle (β) where 'I' becomes '0' current remains +ve from α to β.





Free wheeling diode

1. i/p P.F ↑ses
2. Load current is improved.
3. More o/p voltage
4. Efficiency ↑ses
5. Conduction time ↓ses.

Performance Analysis:-

1. Average or dc o/p voltage:-

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

$$V_{dc} = \frac{V_m}{2\pi}\left[-\cos(\omega t)\right]_{\alpha}^{\beta}$$

$$\boxed{V_{dc} = \frac{V_m}{2\pi}\left[\cos(\alpha) - \cos(\beta)\right]} \quad (1)$$

2. RMS value of output voltage:-

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

$$V_{RMS} = \sqrt{\frac{V_m^2}{2\pi}\int_{\alpha}^{\beta}\left[\sin(\omega t)\right]^2 d\omega t} = V_m\sqrt{\frac{1}{2\pi}\int_{\alpha}^{\beta}\left(\frac{1-\cos 2\omega t}{2}\right)}$$

$$V_{RMS} = \frac{V_m}{2\sqrt{\pi}}\sqrt{(\omega t)_{\alpha}^{\beta} - \left[\frac{\sin(2\omega t)}{2}\right]_{\alpha}^{\beta}}$$

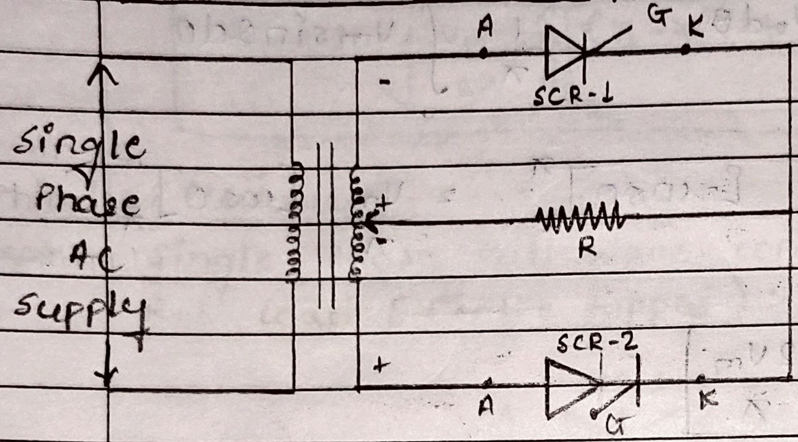
$$\boxed{V_{RMS} = \frac{V_m}{2\sqrt{\pi}}\sqrt{(\beta-\alpha) - \left[\frac{\sin(2\beta) - \sin(2\alpha)}{2}\right]}} \quad (2)$$

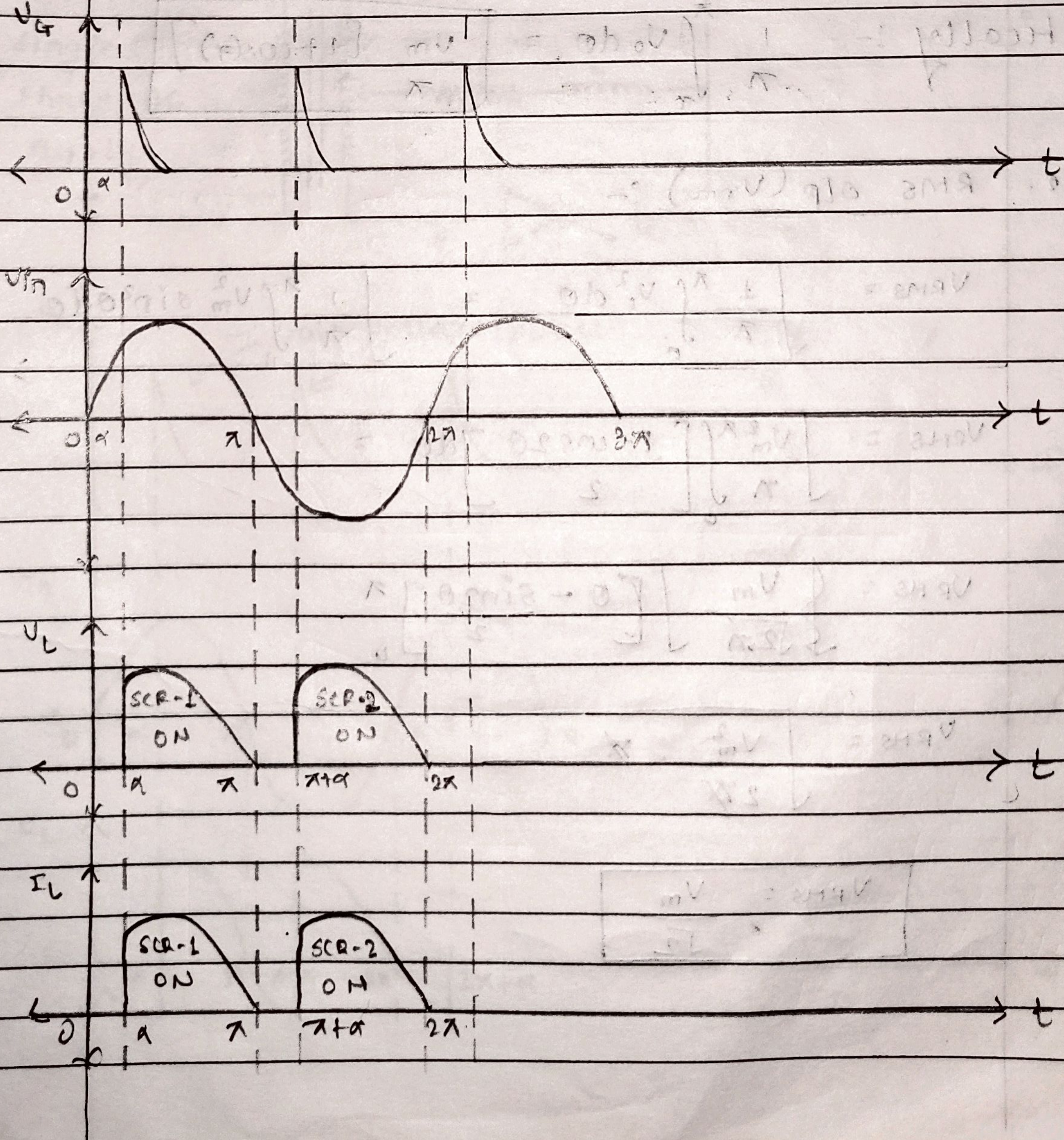
04/02/24

* Lecture :- 3

* **Single Phase Full Wave controlled Rectifier with R- Load (Centre Tapped) :-**

(FWCR) → H-2





Analysis :-

1. Average or dc output voltage :-

ideal

$$V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_o\, d\theta = \frac{1}{\pi}\int_0^{\pi} V_m \sin\theta\, d\theta$$

$$V_{dc} = \frac{V_m}{\pi}\left[-\cos\theta\right]_0^{\pi} = \frac{V_m}{\pi}\left[\cos\theta\right]_{\pi}^{0}$$

$$\boxed{V_{dc} = \frac{2V_m}{\pi}}$$

Practically :- $\frac{1}{\pi}\int_{\alpha}^{\pi} V_o\, d\theta = \boxed{\frac{V_m}{\pi}\left[1+\cos(\alpha)\right]}$

2. RMS o/p (V_{rms}) :-

$$V_{RMS} = \sqrt{\frac{1}{\pi}\int_0^{\pi} V_o^2\, d\theta} = \sqrt{\frac{1}{\pi}\int_0^{\pi} V_m^2 \sin^2\theta\, d\theta}$$

$$V_{RMS} = \sqrt{\frac{V_m^2}{\pi}\int_0^{\pi}\left[\frac{1-\cos 2\theta}{2}\right]d\theta} =$$

$$V_{RMS} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\left[\theta - \frac{\sin 2\theta}{2}\right]_0^{\pi}}$$

$$V_{RMS} = \sqrt{\frac{V_m^2}{2\cancel{\pi}} \cdot \cancel{\pi}}$$

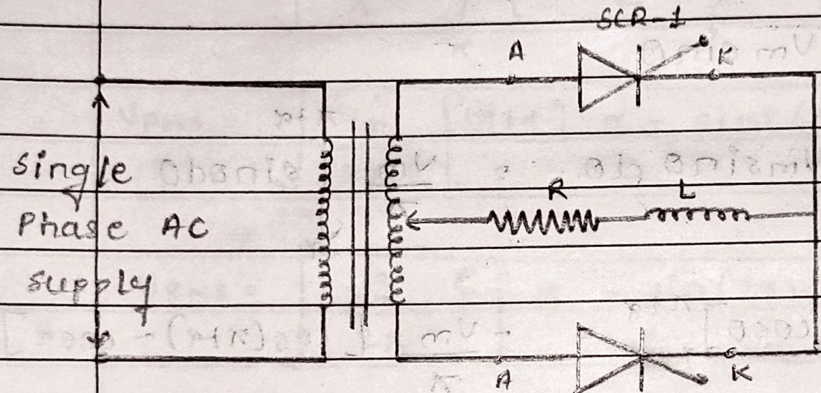
$$\boxed{V_{RMS} = \frac{V_m}{\sqrt{2}}}$$

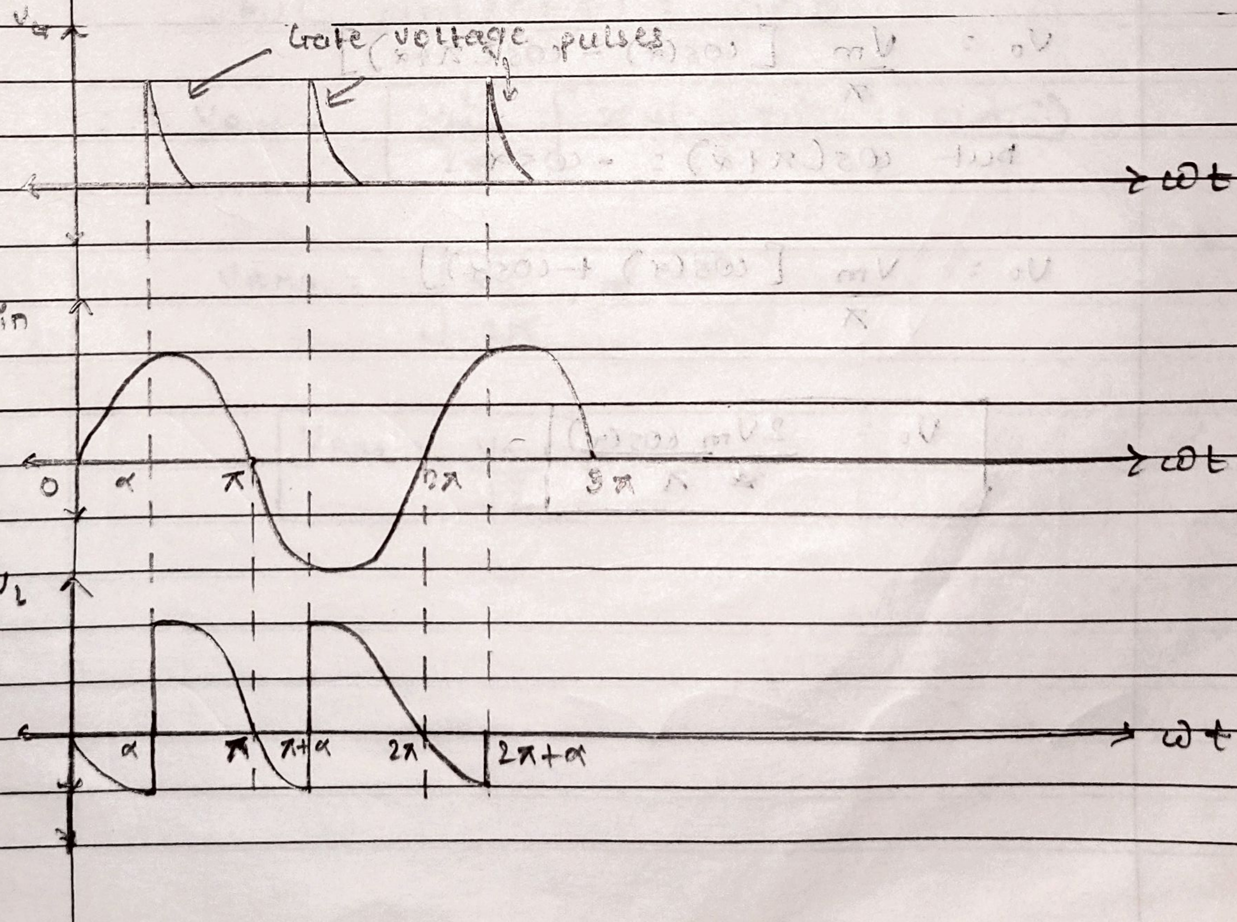
Practically :- $V_{RMS} = \sqrt{\dfrac{V_m^2}{2\pi}\left[\theta - \dfrac{\sin 2\theta}{2}\right]_{\alpha}^{\pi}}$

$$\boxed{V_{RMS} = \sqrt{\dfrac{V_m^2}{2\pi}\left\{\left[(\pi-\alpha) + \dfrac{\sin(2\alpha)}{2}\right]\right.}}$$

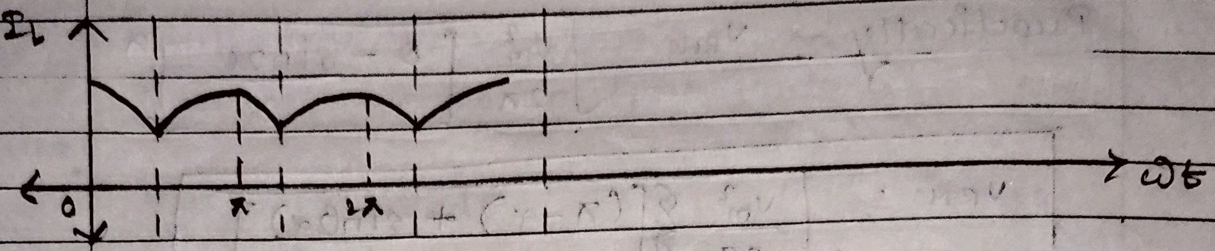
07/02/24 Lecture 4:-

* **Single Phase Full Wave-controlled Rectifier with R-L Load (Centre tapped) :-**





It is also called M-2 or FWCR



Performance Analysis:-

1. Average o/p voltage :-

$$V_0 = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_{in}\, d\theta \quad \text{--- (1)}$$

but $V_{in} = V_m \sin\theta$

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

$$V_0 = -\frac{V_m}{\pi}\left[\cos\theta\right]_{\alpha}^{\pi+\alpha} = -\frac{V_m}{\pi}\left[\cos(\pi+\alpha) - \cos\alpha\right]$$

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

but $\cos(\pi+\alpha) = -\cos\alpha$

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

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

2. **RMS o/p voltage (V_{RMS}):-**

$$V_{RMS} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} v_{in}^2 \, d\theta} \quad \text{but } v_{in} = V_m \sin\theta$$

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

$$V_{RMS} = \sqrt{\frac{V_m^2}{\pi}\int_{\alpha}^{\pi+\alpha} \left(\frac{1-\cos 2\theta}{2}\right) d\theta} = \sqrt{\frac{V_m^2}{2\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_{\alpha}^{\pi+\alpha}}$$

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

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

but $\sin(2\pi + \phi) = \sin\phi$

$$\therefore \quad V_{RMS} = \sqrt{\frac{V_m^2}{2\pi}\left[\pi + \frac{\cancel{(-\sin(2\alpha)} + \cancel{\sin 2\alpha)}}{2}\right]}$$

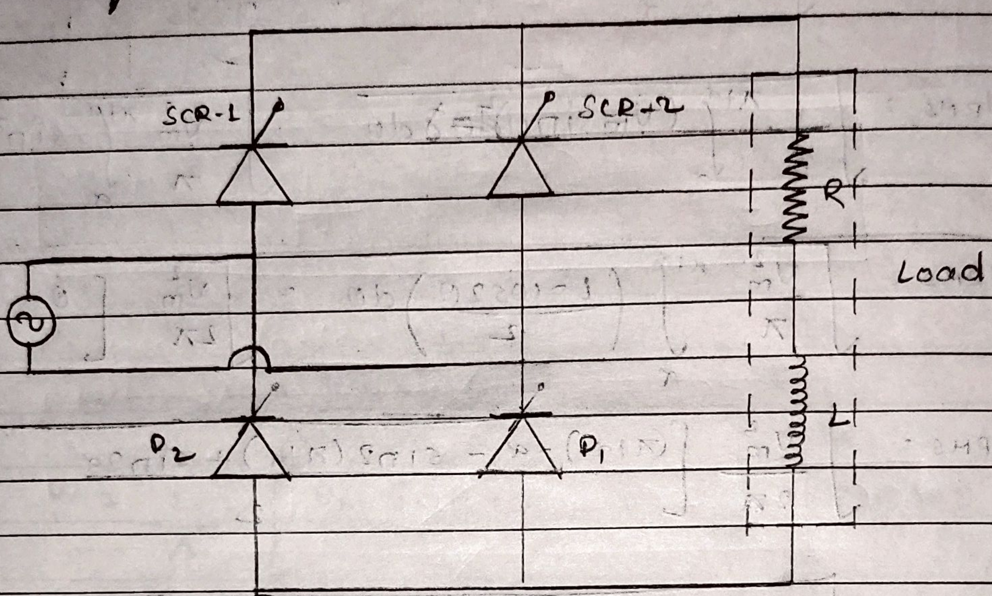
$$V_{RMS} = \sqrt{\frac{V_m^2}{2\cancel{\pi}} \cdot \cancel{\pi}}$$

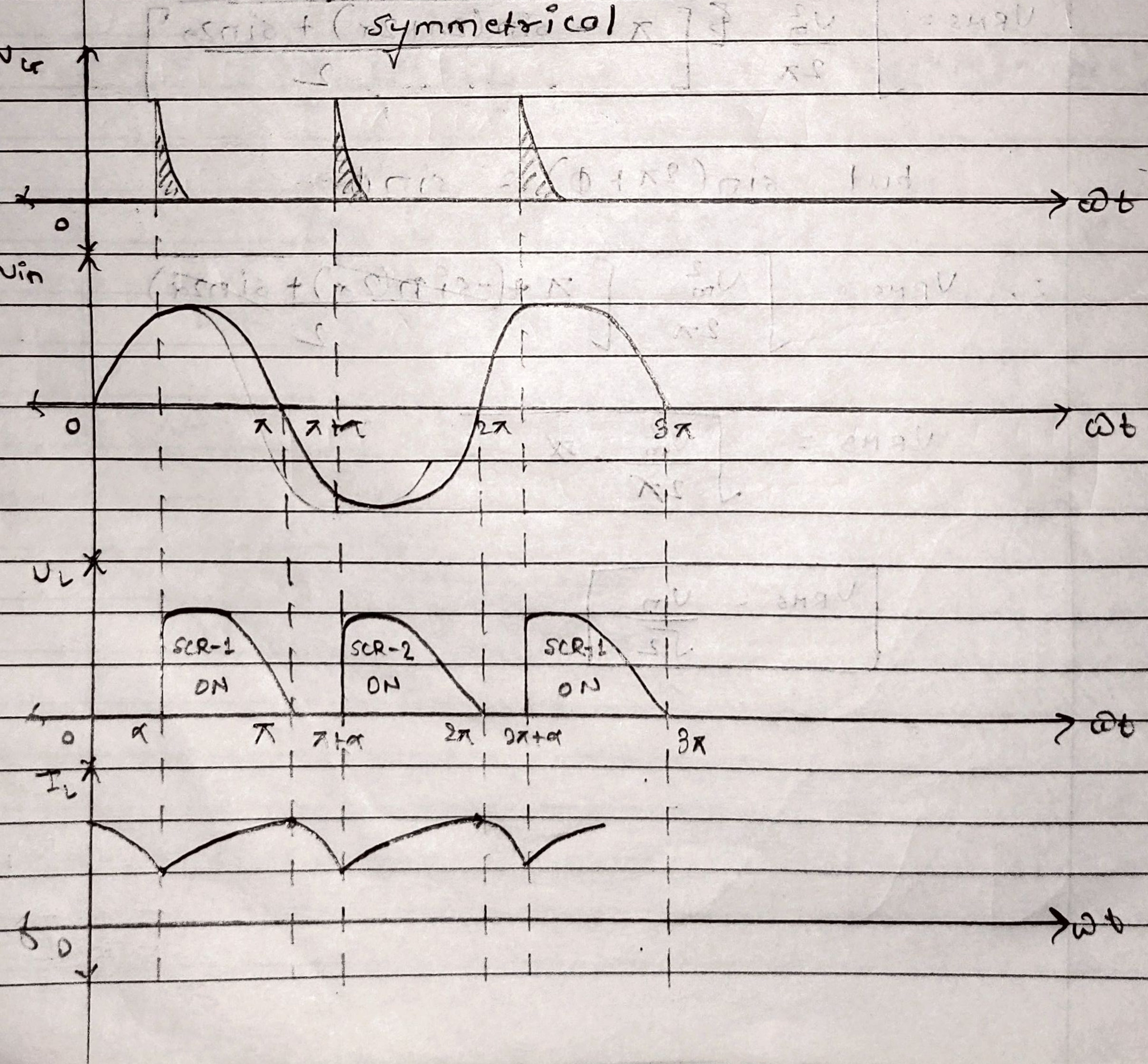
$$\boxed{V_{RMS} = \frac{V_m}{\sqrt{2}}}$$

08/02/24 Lecture 5 :- Semiconverter

* ~~Half~~ Half controlled converter (Semiconverter) :-

Single Phase full wave half controlled bridge converter :-





Operation:-

~~Mode~~

Mode	I	II	III	IV
	$(\alpha - \pi)$	$[\pi - (\pi+\alpha)]$	$[(\pi+\alpha)-2\pi]$	$[0-\alpha]$
conducting devices	SCR1 - D_1	DFW	$S_2 D_2$	DFW
Load voltage	Positive	zero	Positive	zero
Load current	Positive	Positive	Positive	Positive
Power flow	Source to Load	Free-wheeling	source to Load	Free-wheeling

Performance analysis:-

1. Average output voltage (V_0):-

$$V_0 = \frac{1}{\pi}\int_{\alpha}^{\pi} v_{in} d\theta$$

but $v_{in} = V_m \sin\theta$

$$V_0 = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\theta \, d\theta = \frac{V_m}{\pi}\left[-\cos\theta\right]_{\alpha}^{\pi}$$

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

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

2. RMS voltage (V_{RMS}):-

$$V_{RMS} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} v_{in}^2 d\theta} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\theta \, d\theta}$$

$$V_{RMS} = \sqrt{\frac{V_m^2}{\pi}\int_{\alpha}^{\pi}\left(\frac{1-\cos 2\theta}{2}\right) d\theta}$$

$$V_{RMS} = \sqrt{\frac{V_m^2}{2\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_\alpha^\pi}$$

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

$$\boxed{V_{RMS} = \frac{V_m}{\sqrt{2\pi}}\sqrt{(\pi-\alpha) + \frac{\sin(2\alpha)}{2}}}$$

3. Power factor (P.F) :-

$$P.F = \frac{V_0^2}{V_{RMS}^2} = \frac{\frac{\cancel{V_m^2}}{\pi^{\cancel{2}}}(1+\cos\alpha)^2}{\frac{\cancel{V_m^2}}{2\cancel{\pi}}\left\{(\pi-\alpha) + \frac{\sin(2\alpha)}{2}\right\}^2}$$

$$P.F = \frac{2}{\pi}\frac{[1+\cos(\alpha)]^2}{[(\pi-\alpha) + \sin(2\alpha)/2]}$$

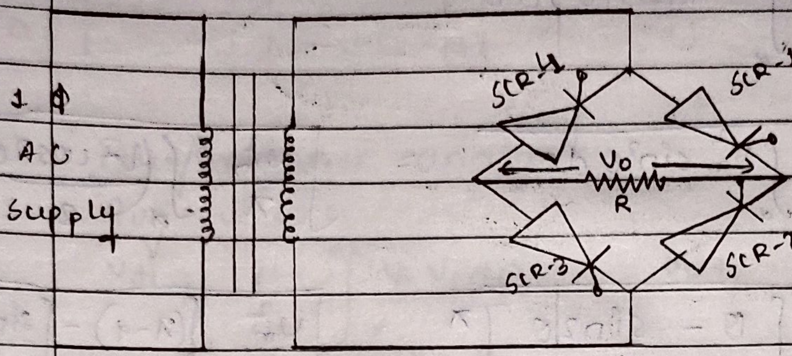
if $\alpha = 0$

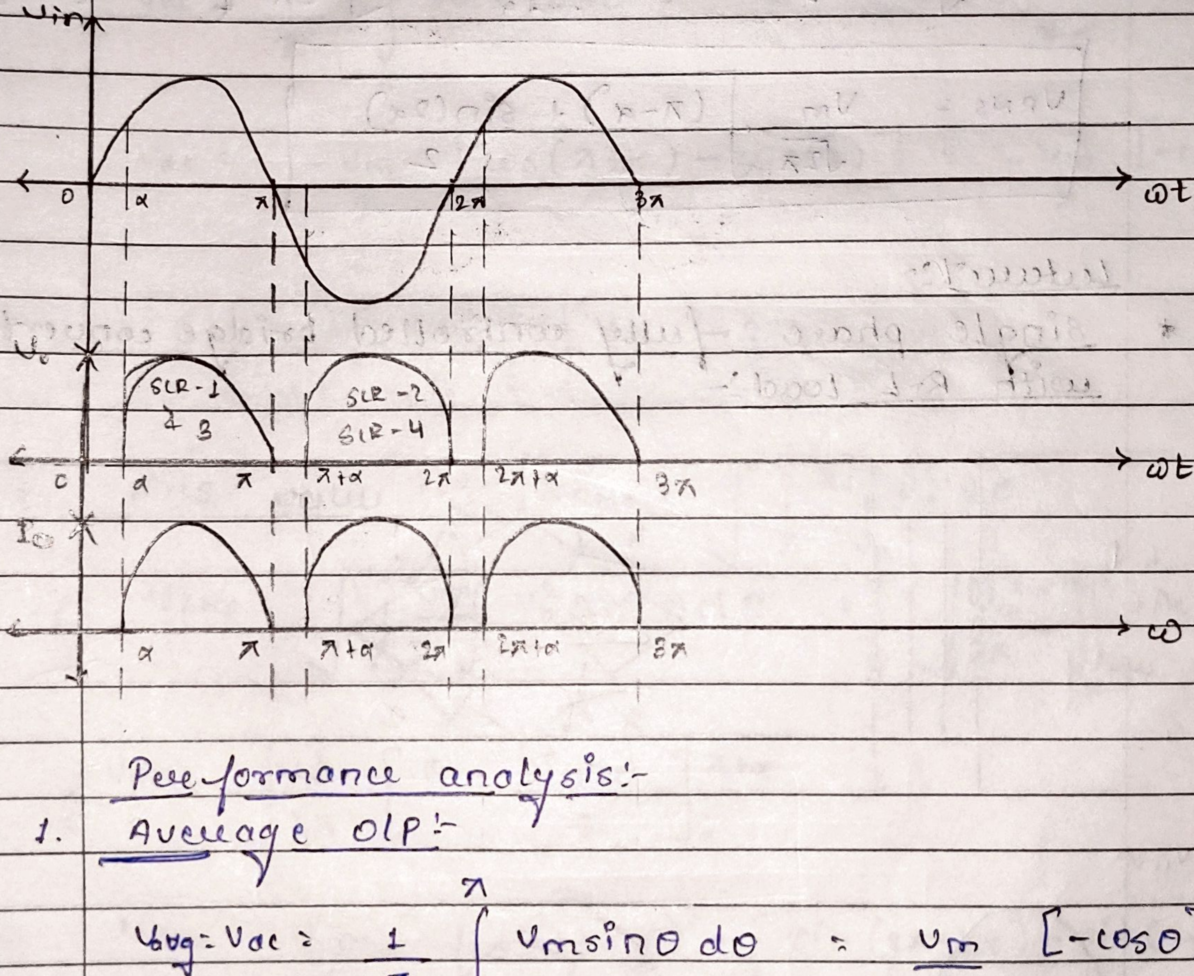
$$P.F = \frac{2}{\pi} \cdot \frac{4}{\cancel{2}\pi}$$

$$\boxed{P.F = \frac{8}{\pi^2}} \left[\begin{array}{l}\text{Max. value of P.F} \\ \text{provided } \alpha = 0\end{array}\right]$$

19/02/24 Lecture 6 :-

* Single phase fully controlled rectifier for R- Load :- (Bridge converter) :-





Performance analysis :-

1. Average O/P :-

$$V_{avg} = V_{dc} = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\theta \, d\theta = \frac{V_m}{\pi}\left[-\cos\theta\right]_{\alpha}^{\pi}$$

$$V_{dc} = \frac{-V_m}{\pi}\left[\cos(\pi) - \cos(\alpha)\right]$$

$$\boxed{V_{dc} = \frac{V_m}{\pi}\left[1 + \cos(\alpha)\right]}$$

2. RMS o/p voltage :- $V_{RMS} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} V_0^2 \, d\theta}$

$$V_{RMS} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} (V_m \sin\theta) \, d\theta}$$

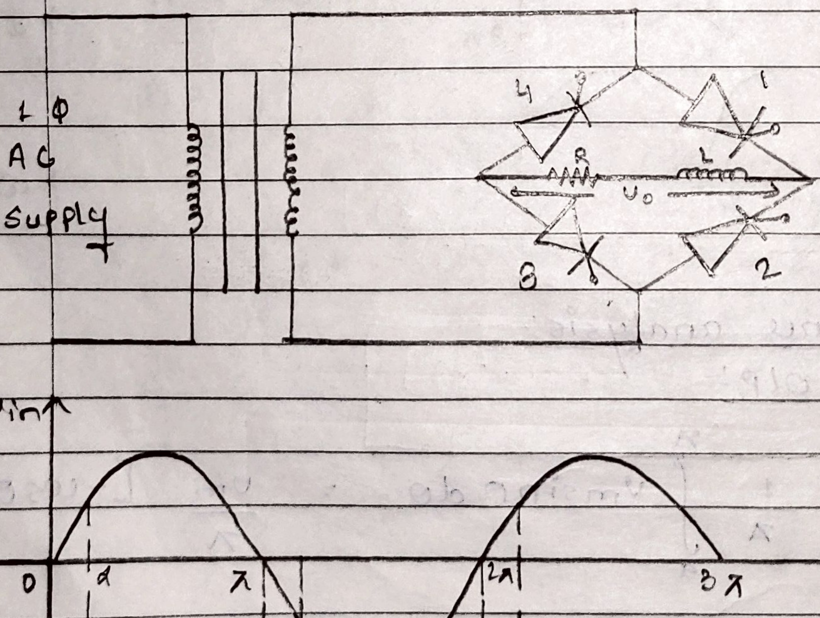
$$V_{RMS} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\theta \, d\theta} = \sqrt{\frac{V_m^2}{\pi}\int_{\alpha}^{\pi}\left(\frac{1-\cos 2\theta}{2}\right) d\theta}$$

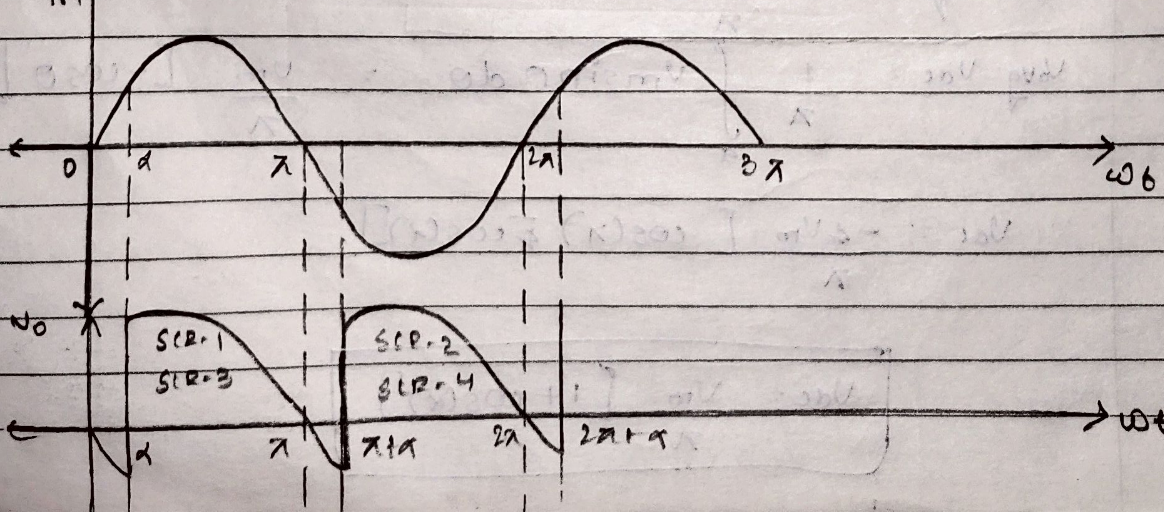
$$V_{RMS} = \sqrt{\frac{V_m^2}{2\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_{\alpha}^{\pi}} = \sqrt{\frac{V_m^2}{2\pi}\left\{(\pi-\alpha) - \left[\frac{\sin 2\pi - \sin 2\alpha}{2}\right]\right\}}$$

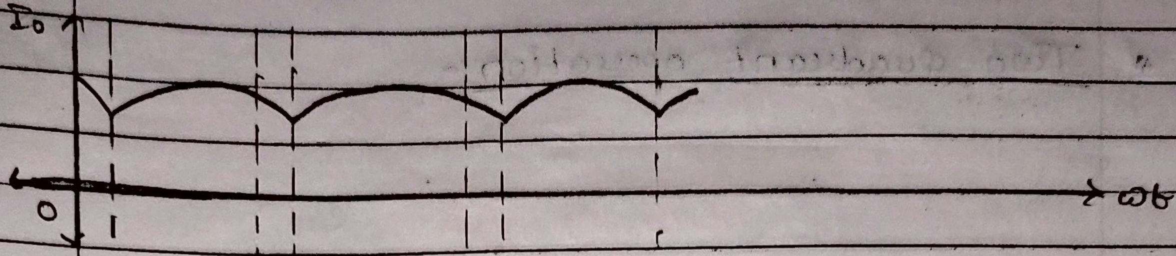
$$\boxed{V_{RMS} = \frac{V_m}{\sqrt{2\pi}}\sqrt{(\pi-\alpha) + \frac{\sin(2\alpha)}{2}}}$$

Lecture 7 :-

* Single phase fully controlled bridge converter with R-L Load :-







Performance analysis:-

1. Avg. value:-

$$V_{dc} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_o \, d\theta \qquad \text{but} \qquad V_o = V_m \sin\theta$$

$$V_{dc} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\theta \, d\theta = \frac{V_m}{\pi}\left[-\cos\theta\right]_{\alpha}^{\pi+\alpha}$$

$$V_{dc} = -\frac{V_m}{\pi}\left[\cos(\pi+\alpha) - \cos(\alpha)\right] = -\frac{V_m}{\pi}\left[-\cos\alpha - \cos\alpha\right]$$

$$\boxed{\cancel{V_{dc} = \frac{2V_m}{\pi}}} \qquad \boxed{V_{dc} = \frac{2V_m\cos(\alpha)}{\pi}}$$

2. RMS value :- $V_{RMS} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_o^2 \, d\theta}$

$$V_{RMS} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m^2 \sin^2\theta \, d\theta} = \sqrt{\frac{V_m^2}{\pi}\int_{\alpha}^{\pi+\alpha}\left[\frac{1-\cos(2\theta)}{2}\right]d\theta}$$

$$V_{RMS} = \sqrt{\frac{V_m^2}{2\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_{\alpha}^{\pi+\alpha}}$$

$$V_{RMS} = \frac{V_m}{\sqrt{2\pi}}\sqrt{(\pi+\cancel{\alpha}-\cancel{\alpha}) - \left\{\frac{\sin(2\pi+2\alpha) - \sin(2\alpha)}{2}\right\}}$$

$$V_{RMS} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\pi - \left\{\frac{\cancel{\sin(2\alpha) - \sin(2\alpha)}}{2}\right\}} = V_m\sqrt{\frac{1}{2\cancel{\pi}} \times \cancel{\pi}}$$

$$\boxed{V_{RMS} = \frac{V_m}{\sqrt{2}}}$$

Lecture 8:-

* **Solved Problems of semiconverters (Half):-**

1) $V_{iRMS} = \frac{V_m}{\sqrt{2}}$ 2) $V_{ov} = \frac{V_m}{\pi}[1+\cos(\alpha)]$

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

4) $D.F = \cos\left(\frac{-\alpha}{2}\right)$ 5) $I_{SRMS} = I_0\sqrt{\frac{(\pi-\alpha)}{\pi}}$

6) $I_{nRMS} = \frac{2\sqrt{2}\,I_0}{n\pi}\cos\left(\frac{n\alpha}{2}\right)$ 7) $Radian = \frac{\pi}{180} \times degree$

Q:1 A single phase semiconverter with highly inductive load is feed from 120V AC mains & fired at $\alpha = 90°$. calculate i) Average load voltage ii) RMS load voltage iii) Displacement factor.

→ $V_{iRMS} = 120V$, $\alpha = 90°$

$V_{iRMS} = \frac{V_m}{\sqrt{2}}$ ∴ $\boxed{V_m = 120\sqrt{2}}$

$V_{av} = \frac{V_m}{\pi}(1+\cos\alpha) = \frac{120\sqrt{2}}{\pi}(1+\cos 90°)$

$\boxed{V_{oav} = 54.0189\,V}$

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

$\alpha = 90° \Rightarrow Radian = \frac{\pi}{\cancel{180}_2} \times \cancel{90} = \frac{\pi}{2}$

$$V_{ORMS} = \sqrt{\frac{(120\sqrt{2})^2}{2\pi}\left\{\left(\pi - \frac{\pi}{2}\right) + \frac{\sin(2\times 90)}{2}\right\}}$$

$$V_{ORMS} = \sqrt{\frac{\cancel{14400}^{7200} \times \cancel{2}}{\cancel{2}\cancel{\pi}} \times \frac{\cancel{\pi}}{\cancel{2}}}$$

$$\boxed{V_{ORMS} = 84.8528\ V}$$

$$D.F = \cos\left(\frac{-\alpha}{2}\right) = \cos\left(\frac{-90}{2}\right)$$

$$\boxed{D.F = 0.7071}$$

Q:2 A single phase half controlled bridge rectifier supplies a ripple free load current of 10A & operates from 110V, 60Hz mains. If average o/p voltage is 75V. Calculate.

i) Firing angle ii) RMS o/p voltage iii) RMS supply current iv) RMS 3rd harmonic supply current.

→ $I_o = 10V$, $V_{irms} = 110V$, $V_{av} = 75V$

i) $\alpha = ?$

$$V_{irms} = \frac{V_m}{\sqrt{2}} \Rightarrow \boxed{V_m = 110\sqrt{2}}$$

$$V_{av} = \frac{V_m}{\pi}(1+\cos\alpha) \Rightarrow 75 = \frac{110\sqrt{2}}{\pi}[1+\cos(\alpha)]$$

$$1+\cos(\alpha) = \frac{75\pi}{110\sqrt{2}} \Rightarrow \cos(\alpha) = \frac{75\pi}{110\sqrt{2}} - 1$$

$$\alpha = \cos^{-1}\left(\frac{75\pi}{110\sqrt{2}} - 1\right)$$

$$\boxed{\alpha = 59.0279^\circ} = \frac{59.0279\pi}{180}$$

$$\boxed{\alpha = 1.0302\ rad}$$

2. $V_{ORMS} = \sqrt{\frac{110\sqrt{2}}{2\pi}\left\{\left(\cancel{1.030}\pi - \cancel{0}1.0302\right) + \frac{\sin(2\times 59.02)}{2}\right\}}$

$$\boxed{V_{ORMS} = 99.1557\,V}$$

3. $I_{SRMS} = I_0\sqrt{\frac{(\pi-\alpha)}{\pi}} = 10\sqrt{\frac{(\pi - 1.0302)}{\pi}}$

$$\boxed{I_{SRMS} = 8.1980\,A}$$

4. $I_{nRMS} = \frac{2\sqrt{2}\,I_0}{n\pi}\cos\left(\frac{n\alpha}{2}\right) = \frac{2\sqrt{2}\times 10}{3\pi}\cos\left(\frac{3\times 59.02}{2}\right)$

$$\boxed{I_{nRMS} = 0.0769\,A}$$

Lecture 9:- Full converter using SCR (solved Problems)

R-load

1. $V_m = \sqrt{2}\,V_{iRMS}$ 2. $V_{o(av)} = \frac{V_m}{\pi}[1+\cos(\alpha)]$

3. $V_{ORMS} = \frac{V_m}{\sqrt{2\pi}}\sqrt{(\pi-\alpha) + \frac{\sin(2\alpha)}{2}}$

4. $I_{o(av)} = \frac{V_{o(av)}}{R}$ 5. $I_{o(RMS)} = \frac{V_{o(RMS)}}{R}$

6. $F.F = \frac{V_{o(RMS)}}{V_{o(av)}}$ 7. $R.F = \sqrt{F.F^2 - 1}$

Q:1 A 1ϕ full controlled converter with resistive load ($R = 10\Omega$) & i/p voltage 230V. Calculate for $\alpha = 60°$

i) Average load voltage ii) RMS load voltage

iii) Average & RMS load current.

iv) Form factor & Ripple factor.

→ $R = 10\,\Omega$, $V_{irms} = 230V$, $\alpha = 60^\circ = \frac{\pi}{3}$

$\sqrt{2}\,V_{irms} = V_m \Rightarrow V_m = 230\sqrt{2}$

i) $\cancel{I_{av}} = V_{av} = \frac{V_m}{\pi}\left[1+\cos(\alpha)\right] = \frac{230\sqrt{2}}{\pi}\left[1+\cos\left(\frac{\pi}{3}\right)\right]$

$\cancel{V_{av} = \frac{230\sqrt{2}}{\pi}}$ $\boxed{V_{av} = 155.3045V}$

ii) $\cancel{V_{ORMS} = \sqrt{\frac{V_m^2}{\sqrt{2}}}}$

ii) $V_{ORMS} = \frac{V_m}{\sqrt{2\pi}}\sqrt{(\pi-\alpha) + \frac{\sin(2\alpha)}{2}}$

$V_{ORMS} = \frac{230\sqrt{2}}{\sqrt{2\pi}}\sqrt{\left(\pi-\frac{\pi}{3}\right) + \cancel{\frac{\sin(120^\circ)}{2}}\ \frac{\sin(2\times 60)}{2}}$

$\boxed{V_{ORMS} = 206.2958\,V}$

iii) $I_{av} = \frac{V_{av}}{R} = \frac{155.3045}{10} = 15.53\,A$

$I_{ORMS} = \frac{V_{O(RMS)}}{R} = \frac{206.2958}{10} = 20.62\,A$

iv) $F.F = \frac{V_{O(RMS)}}{V_{O(av)}} = \frac{206.2958}{155.3045} = 1.3283$

$R.F = \sqrt{(F.F)^2 - 1} = \sqrt{}\ 0.8743$

$P.F = \cos(\alpha) = \cos(60^\circ) = \frac{1}{2}$

Power factor

$V_m = \sqrt{2}\, V_{iRMS}$, $V_{oav} = \frac{2V_m}{\pi}\cos\alpha$ P.F (Fundamental) $= \cos(-\alpha)$

P.F (supply) $= \frac{2\sqrt{2}}{\pi}\cos(\alpha)$

Q12 A single phase fully controlled bridge converter supplies an inductive load. Assume I_o is constant. Determine the following if $V_{in} = 230V$, $\alpha = \frac{\pi}{6}$

i) Average o/p voltage ii) Fundamental P.F

iii) Supply P.F

→ ~~$V_{iRMS} = 230V$, $\alpha = \frac{\pi}{6} = 30°$~~

~~$V_{iRMS} = \frac{V_m}{\sqrt{2}} \Rightarrow V_m = 230\sqrt{2}\,V$~~

~~i) $V_{oav} = \frac{V_m}{\pi}[1+\cos(\alpha)] = \frac{230\sqrt{2}}{\pi}\left[1+\cos\left(\frac{\pi}{6}\right)\right]$~~

~~$\boxed{V_{oav} = 193.2015\,V}$~~

→ $V_{iRMS} = 230V$, $\alpha = \frac{\pi}{6} = 30°$, $V_m = \sqrt{2}\,V_{iRMS}$

& $V_m = 230\sqrt{2}\,V$

i) $V_{oav} = \frac{2V_m}{\pi}\cos(\alpha) = \frac{2\times 230\sqrt{2}}{\pi}\cos(30°)$

$\boxed{V_{oav} = 179.33\,V}$

ii) P.F $= \cos(-\alpha) = \cos(-30°) = 0.8668$ (lagging)

iii) P.F $= \frac{2\sqrt{2}}{\pi}\cos(30°) = 0.78$ (lagging)

Q:3 A 3ϕ full converter from 3ϕ stare connected 208 V, 60Hz supply with 'R' load of 10 Ω. It is required to obtain 50% of max. possible o/p voltage. ~~Calc~~ Calculate i) Delay angle ii) RMS & avg. current.

~~$V_{RMS} = 208V$, $R = 10\Omega$~~

~~to~~ 3ϕ

1. $V_{m(line)} = \sqrt{3} \times \sqrt{2}\, V_{m(ph)}$ 2. $V_{Ldc(max)} = \dfrac{3V_{m(line)}}{\pi}$

3. $V_{Ldc} = \dfrac{3V_{m(line)} \cos(\alpha)}{\pi}$ 4. $I_{dc} = \dfrac{V_{LDC}}{R_L}$ 5. $I_{LRMS} = \dfrac{V_{LRMS}}{R}$

& $V_{L(RMS)} = V_{m(line)} \sqrt{\dfrac{1}{2} + \dfrac{3\sqrt{3}}{4\pi} \cos(2\alpha)}$

$V_{m(ph)} = 208V$

$V_{m(line)} = \sqrt{3} \times \sqrt{2} \times 208 \Rightarrow V_{m(line)} = 208\sqrt{6}$

$$\boxed{V_{m(line)} = 509.4938\,V}$$

$V_{Ldc(max)} = \dfrac{3V_{m(line)}}{\pi} = \dfrac{3 \times 509.4938}{\pi}$

$$\boxed{V_{Ldc(max)} = 486.53\,V}$$

50% of $V_{Ldc(max)} = \dfrac{50}{100} \times 486.53$

$= 243.26\,V$

$243.26 = \dfrac{3 \times 509.49}{\pi} \cos(\alpha) \Rightarrow \cos(\alpha) = \dfrac{243.26\pi}{3 \times 509.49}$

$$\boxed{\alpha = 60^\circ}$$

2. $I_{Ldc} = \dfrac{V_{Ldc}}{R} = \dfrac{243.26}{10} \Rightarrow \boxed{I_{Ldc} = 24.326A}$

Q. $I_{L RMS} = \frac{V_{L(RMS)}}{R}$

$V_{L(RMS)} = 509.49 \sqrt{\frac{1}{2} + \frac{3\sqrt{3}}{4\pi} \cos(2\times 60°)}$

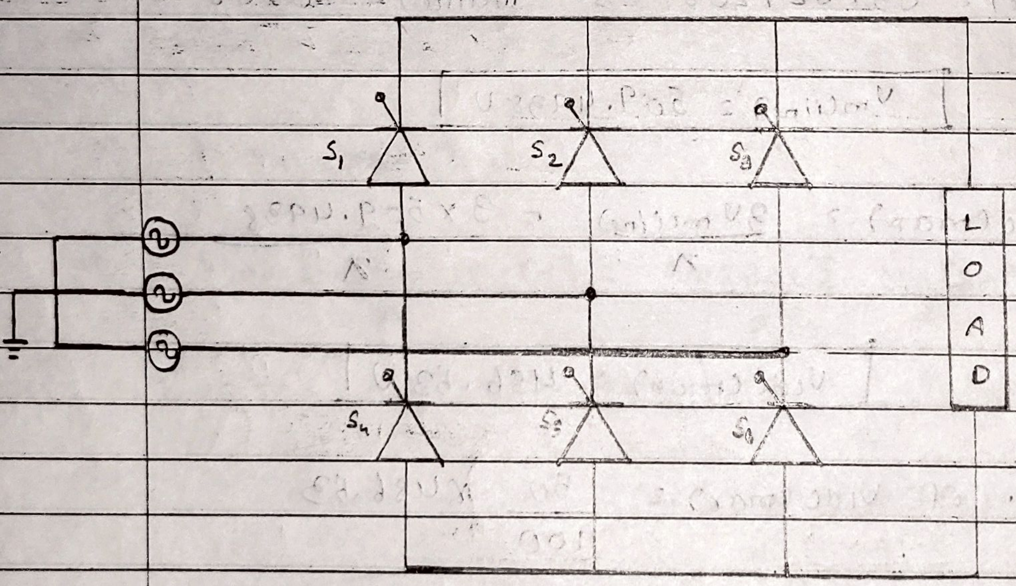
$\boxed{V_{LRMS} = 275.9026\ V}$

$I_{LRMS} = \frac{275.9026}{10}$

$\boxed{I_{LRMS} = 27.59\ A}$

25/02/24 **Lecture 10:-**

* **Three Phase Full converter using SCR with R-Load:-**



Interval	I	II	III	IV	V	VI
Conducting pair	1, 5	1, 6	2, 6	2, 4	3, 4	3, 5
Load Voltage	V_{RY}	V_{RB}	V_{YB}	V_{YR}	V_{BR}	V_{BY}

R – Y – B

Just for understanding

Steps for drawing waveform:-

1. Mark 5 horizontal lines.
2. Mark L, M, N on line-2 (Phase cross-over points on +ve side)
3. Place points on centre of these points on line-1. (Peak voltage points on +ve side).
4. Mark same points on line 4 (O, P, Q)
5. Place points at centre of O, P, Q on line 5 (Peak voltage points on -ve side)
6. Join the points using sine wave.

Waveforms:-