22 / 9 / 2019

Lecture 1

power Electronics (P.E) → power, Electronics, control

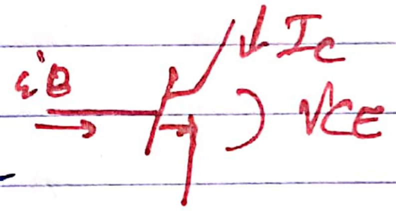
power: High values of current & voltage (power up to MWs)

— loads are: (Industrial + Transportation) drives

Electronics: High values (KA, KV).

- There is no Amplifire in power Electronics but we over drive.

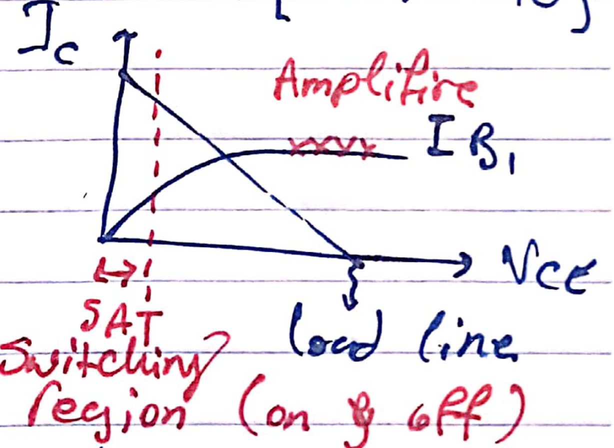
- Electronic switches with high density semi-conductors.



* $I_C \simeq \beta I_B$, β → {5, 6, ... 10}.

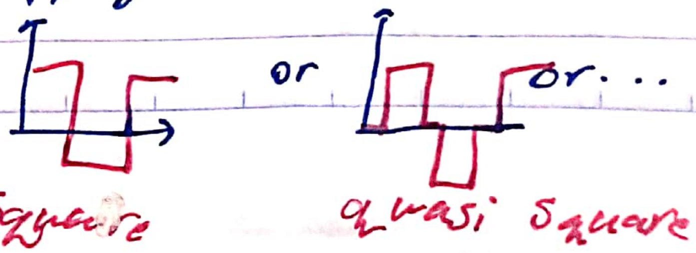
Control: using Micro-controllers to control switches

- control Topology:- could be phase delay, trigger, PWM (sin, Uniform, Multipath ...)



- for High currents we use darlington pair.

- Control also mean: to apply certain control signal stratigy:



Overall, power Electronics is Equivalent to (power conditioning system)

- control of the shape of the signal.
- control of Amplitude
  - Dc : Average.
  - Ac : fundimental component of the signal (Signal Analysis) → Fourier
- frequency control.

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lecture 2

power electronics ≡ Electric power conditioning.

⟹ The main features of the Electric conditioning:

- Shape or nature { Dc to Ac or Ac to Dc }
- Amplitude { Average for Dc & RMS, fundimental for Ac. }
- power frequency control.

power conditioning can be accomplished by

Converters: Equipment that is capable of changing one or more feature of an electric signal (Statically) ↳ no rotating parts or elements.

Converters are classified into 4 different categories :- ((Input ⟶ output.))

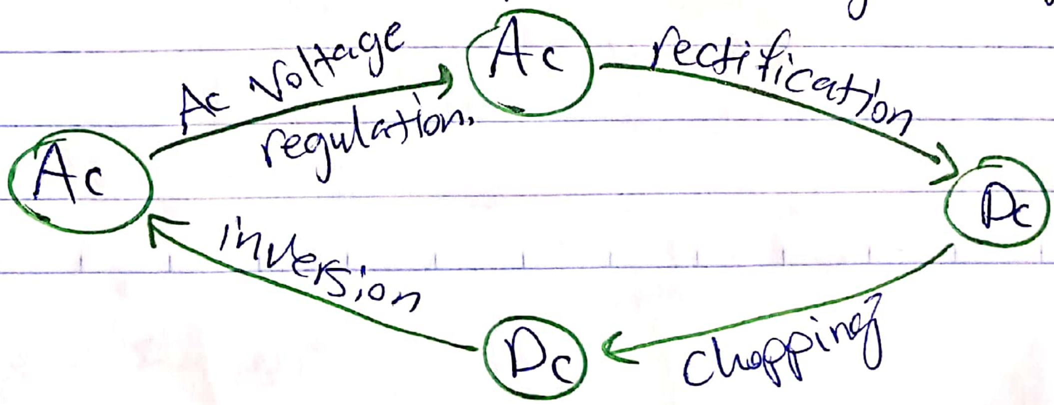
→ Rectifires (Ac to Dc converter)

→ choppers (Dc to Dc converter)

→ Inverters (Dc to Ac converter)

→ Ac Regulators (Ac to Ac converter)

* other parameters may change.

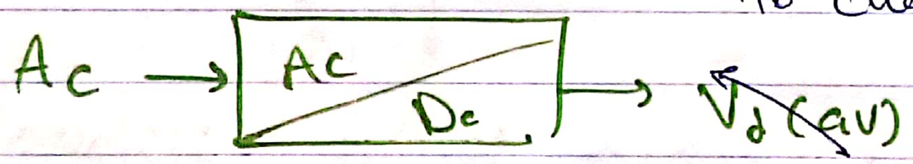


o لازم امشي بال cycle كلها عشان احول من
Ac → Ac
مع تغيير ال Frequency.

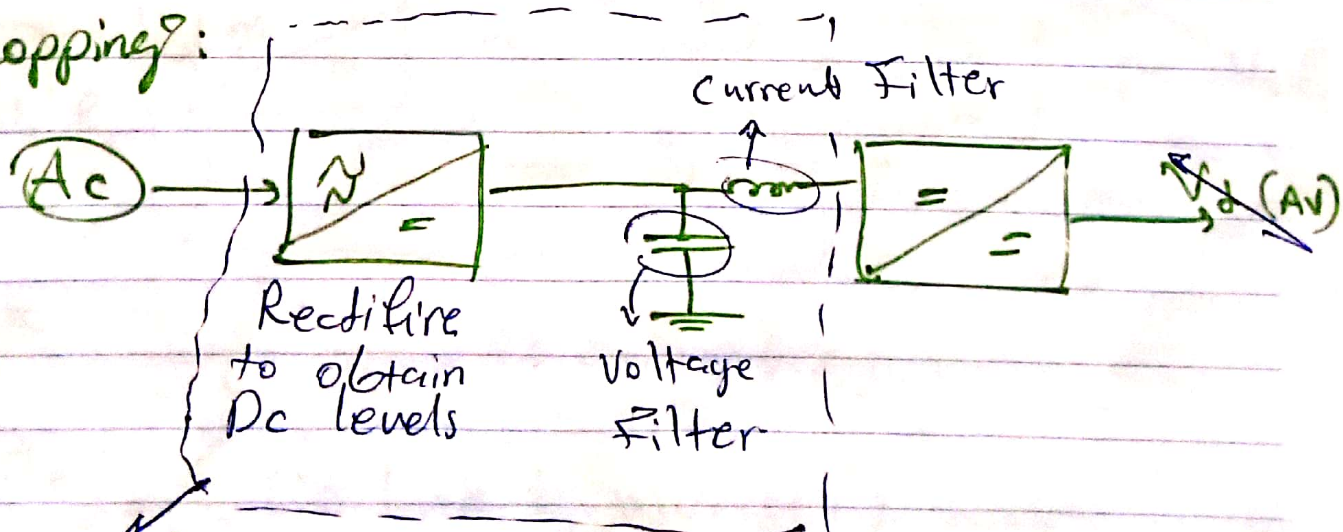
Rectifire:

Required to convert Ac into Dc with Variable amplitudes

- Control Dc Motors / Loads
- To control motor speed : ① Armature Voltage control. $V\uparrow$ on the armature to control bellow rated speed
  ② Field weakening.
  Dc voltage control to change the field.



chopping:



Dc link : توصل بين ال Ac supply
وال Dc اللي لازم يحولها لل chopper

- If you compaire the features, harmonics and the performance ; you'll find the chopper circuit with rectifire better then direct rectifire circuit.
- Rectifire circuit → Harmonics بتطلع 3rd, 5th, ...

Chopper → Harmonics بتطلع 50th Easier to filter and get rid of

3rd ↓↓ أوط

$$X_c = \frac{1}{2\pi f c}$$

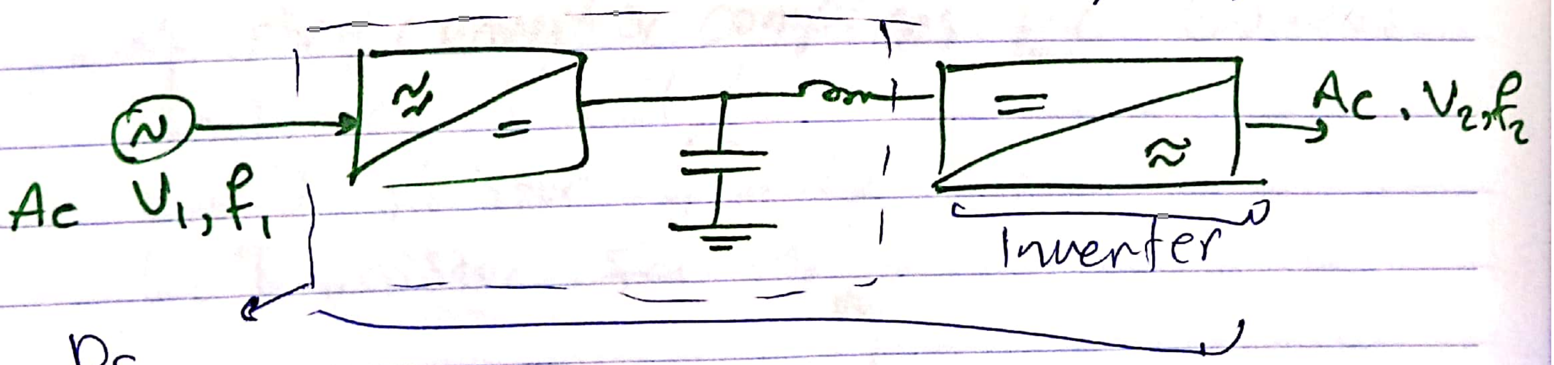
$f \uparrow, c \downarrow$ → الوزن والحجم والتكلفة أقل

$$X_L = 2\pi f L$$

كلما زاد الـ f

$f \uparrow, L \downarrow$

Inverters : is not an exact frequency converter



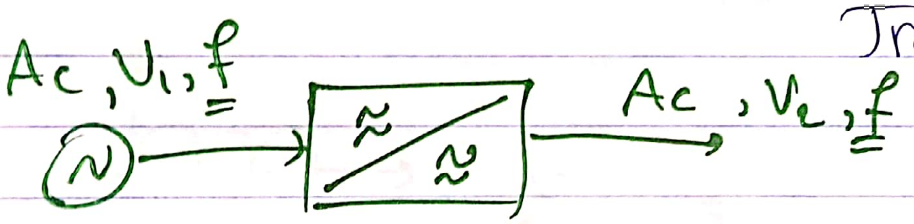
→ frequency converter :

(Dc link + inverter)

→ Rectifires Applications: Dc loads (Dc Motors)
\+ choppers

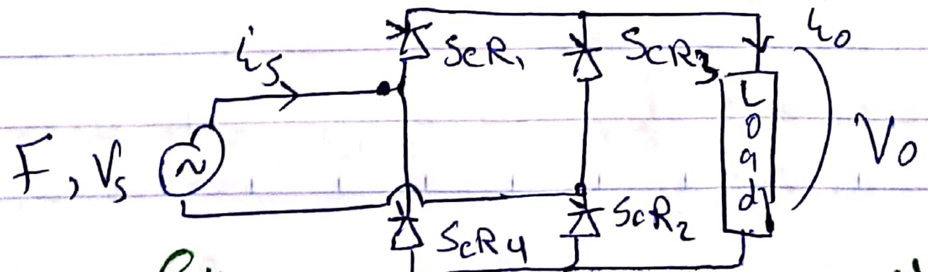
→ Inverters Applications: (1) frequency control (with Dc Link)
The Speed & Starting current of Ac Motors.
(2) PV systems: Dc (pv) → Ac (network)
علشان اشبكها بالشبكة.

Ac Voltage Regulation: (Static or Semi conductor) Transformer
↳ without affecting the frequency. (RMS control)
or
power Electronics Transformer.



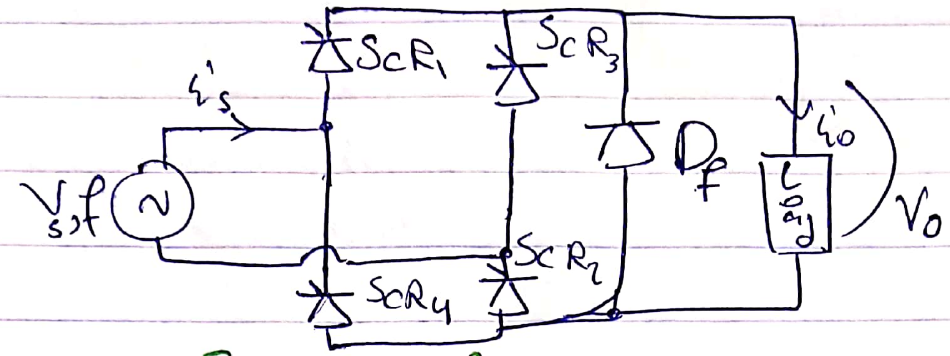
Switches — Any converter comprises P.E (Power Electronics) Switches
↳ Diode Family
↳ Thyristor Family
↳ Transistor Family

Combination of these elements means converters.



fully controlled Bridge rectifire.

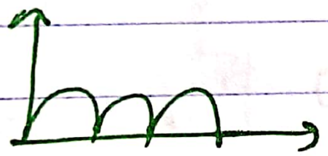
Thyristor : diode with control, sillicon controlled Rectifire (SCR)



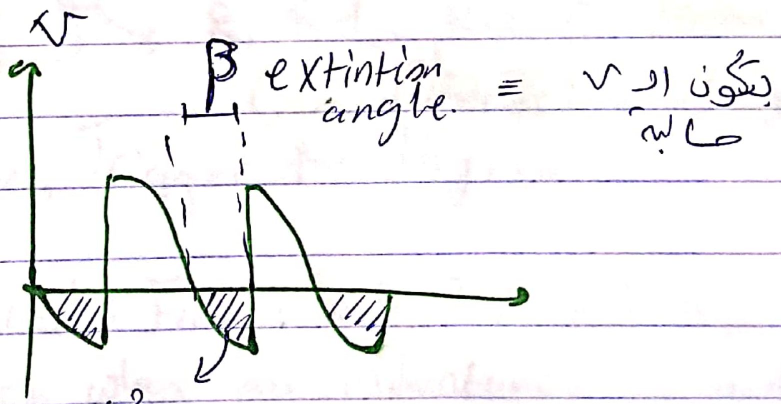
Single phase Semi-controlled bridge Rectifire.

اما اذا كان كله diodes بيسمى Uncontrolled bridge reetifire

o Before, loads were R_L resistive load.



o Now, No!
Inductive loads



جزء سالب (كاذب) اما اليكرها
بصير يكون سالب

4 للتحكم بالموتور مناطق
F.W, running & Breaking
R.V, running & Breaking

⇐ بدي الجزء السالب ، اذا بدي ركز مشتغله من
ميشيل السالب.

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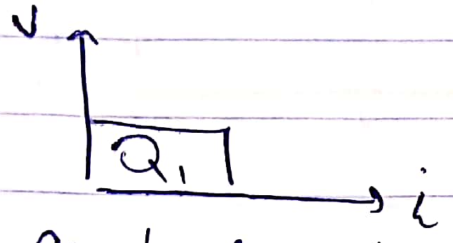
Lecture 5

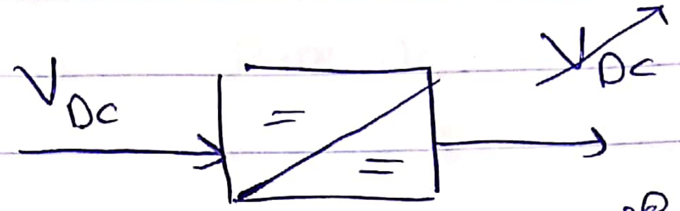
→ Transistors + diodes.

Choppers: Basic chopper → class A.



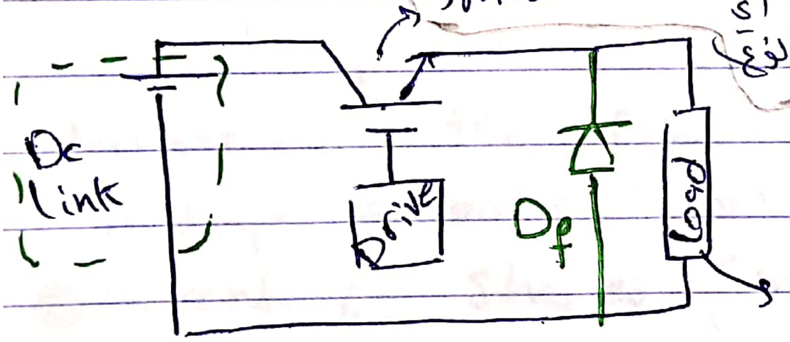
Quadrant number I

Q_1 → class A



المتغير هو ال Avg value.

- needs Dc supply
  - → Batteries
  - → Dc generator
  - → Ac supply + Rectifire circuit



Transistor من نوع ≠ Thyristor لانه مش بدائل لبعض ، مكملين لبعض.

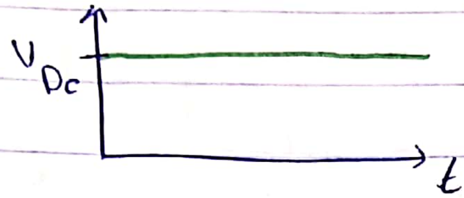
→ R, R-L, R-L-E Motor *

(ن) filter L + او بطارية *

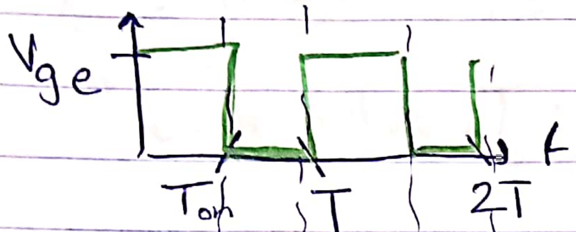
* Drive for transistor, Trigger for Thyristor.

* Df ⇒ A must (called : Free wheeling diode) to protect the main switch when an inductance is involved in the circuit. لا احتاجه اذا كان ال load مع pure resistive لكن الاحمال كبيره وغالية ومتحكم فيها بنحطه كـ Safty. لانه عدم وجوده قد يكون distructive.

Typical waveforms.



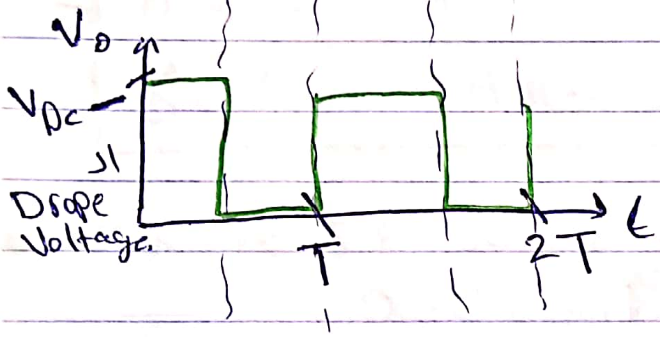
Pure dc.



control circuit / Drive. (انا بيحتاجوا)

→ control signal (must be periodic)

عملية التحكم complex ومش معجزة اذا ما كانت periodic.



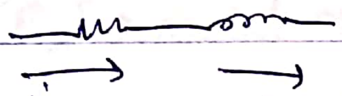
نعرف من ال control signal ال output voltage

+ ال period.

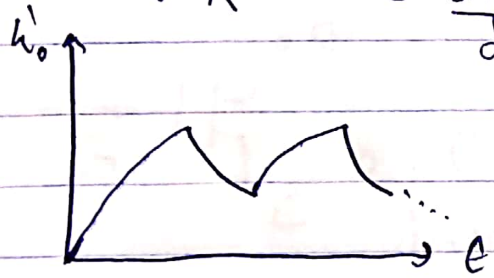
In most cases the output voltage = control signal chopped.

Current i_o shapes: (Inductivity) of (load) حتعتمد

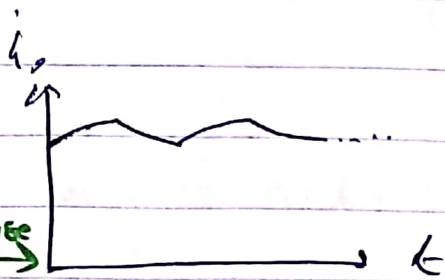
if



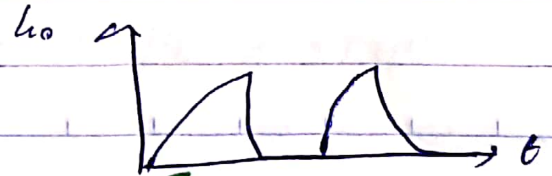
i_oR $\quad L\frac{di_o}{dt}$



or Continuous



or



discontinuous.

Control parameter : δ Modulation Index

$$\delta = \frac{T_{on}}{T} \quad , \quad f_{chopper} = \frac{1}{T} \longrightarrow f_{ch} : \text{chopping Frequency}$$

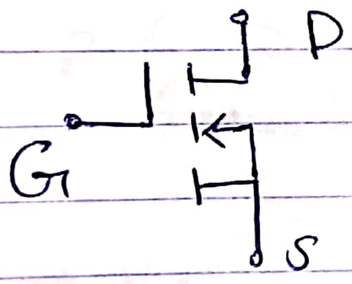
$f_{ch} = 50\,Hz \quad , T = 20\,msec.$

$f_{ch} = 1000\,Hz \, , T = 2\,msec.$ period from drive circuit to decide chopping frequency.

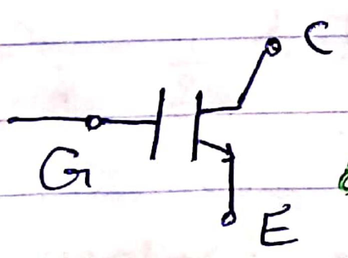
$\rightarrow 0 \leqslant \delta \leqslant 1$

$\boxed{\delta * V_{DC} = \text{AVG Voltage}}$ ⇝ بقدر اطلع عندي Variable Dc-Voltage

o Inverters : نوزة ال power electronics ⇐ بكان Dc-Generator.



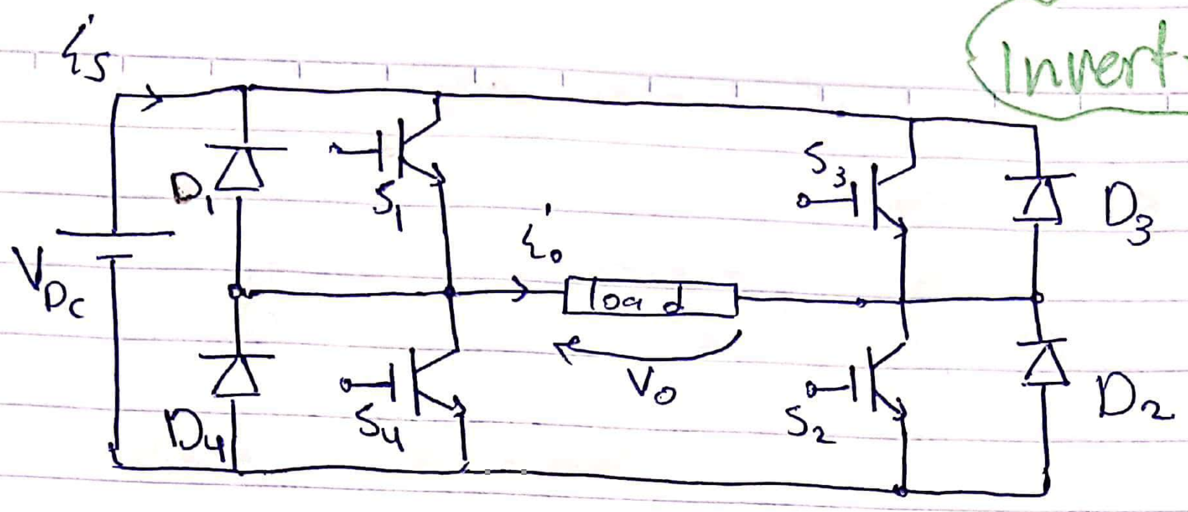
o MOSFET : metal oxide semiconductor field effect Transistor.



o IGBJT : Insulated gate Bipolar Junction Transistor.

⊛ Inverter : Use any type of transistors ≠ Thyristor.

Inverter



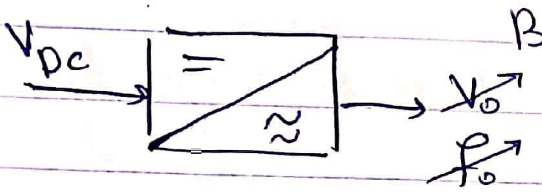
* التسمية ملهاش وضع لا convention.

* الـ Diodes ⇐ Back-to-Back

Free wheeling diodes
يعني بنوي اي diode Dc-Supply

or / and

Feed back diodes
يعني برجع الـ power للـ Supply



→ path S_1, D_3 & load:
Free wheeling → لانه مفيش Supply.

→ path D_3, Supply & D_4, load.
Feed Back.

* If diodes are not included → يحترقوا الـ switches (transistors).

$P_{Inductor} = \frac{1}{2} L I^{(2)}$ → يرجع اتيار والطاقة ويولعوا بالـ Transistors

Inverter's Applications:

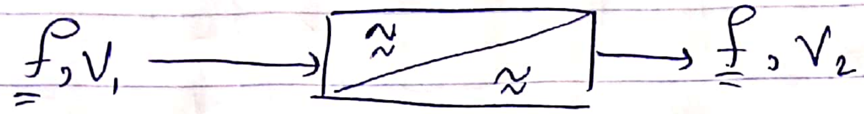
1. Variable Frequency. to control motors. $N_s = \frac{60 f}{P}$
2. PV , UPS

System (constant Frequency) (بس)   Uninterruptible power supply. (Fixed Frequency)

29/9/2019 Lecture 4

Ac Voltage regulator.

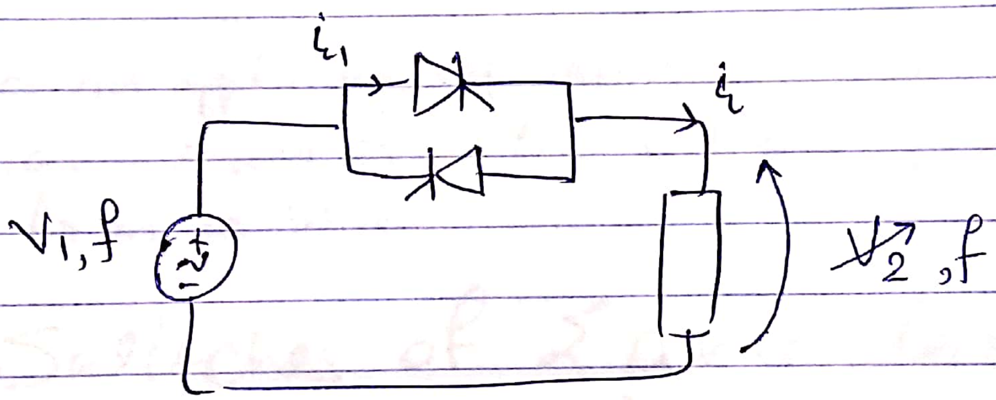
Power transformer, Static or Semiconductor Transformer



① phase Angle Control

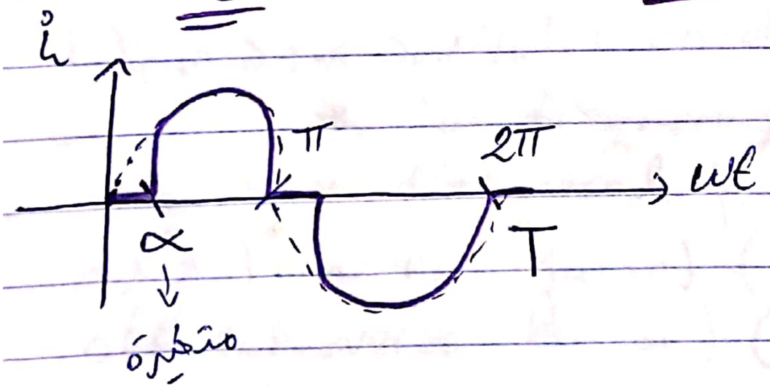
we change the RMS voltage at a certain frequency
Fixed

→ Ac Switches are Used.

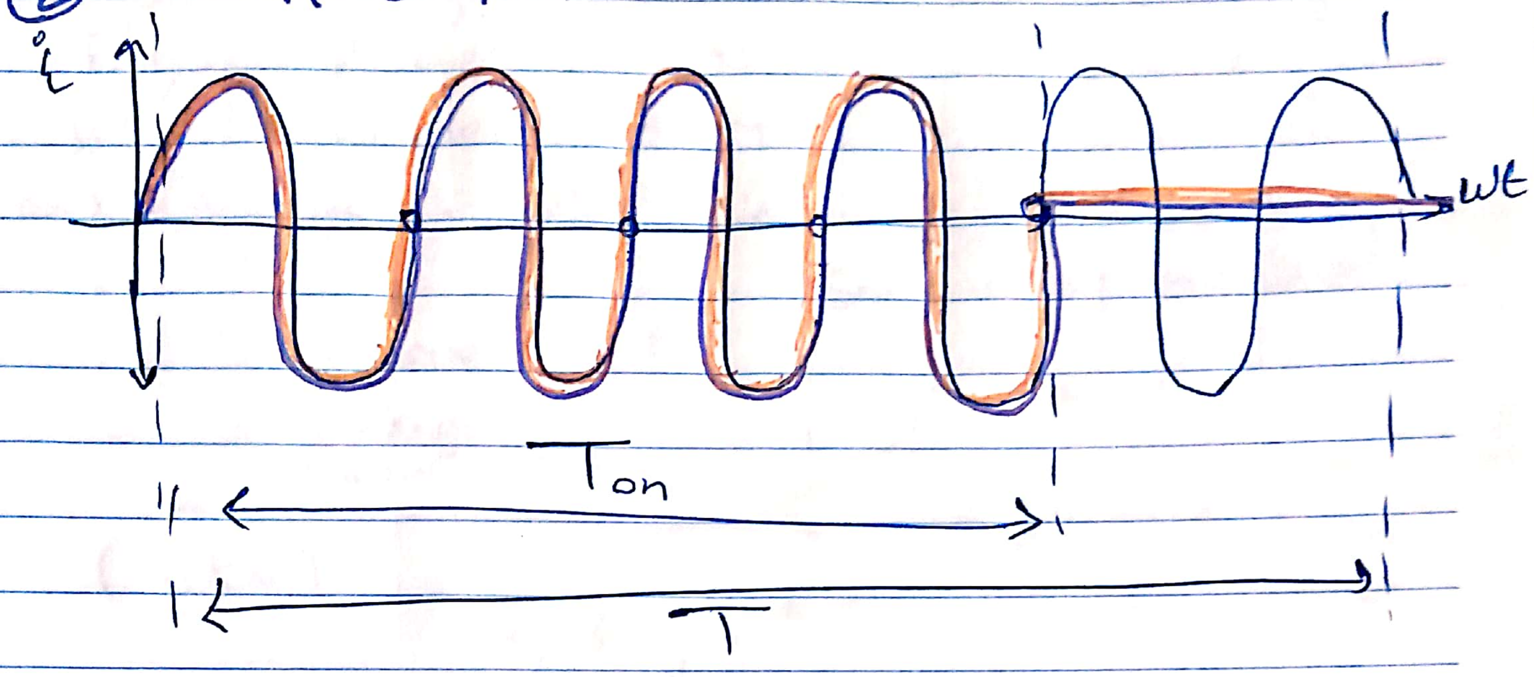


→ full output Zero output ←

$0 \leq \alpha \leq 180$



② on-off control



on-off control applications: lighting?, Motor limit Switch.

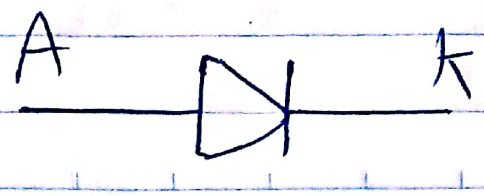
Triac : works on low voltage / power.
↳ an ac switch

Switches of {power electronics}

① Diodes ② Thyristors ③ Transistors.

Diodes: * switches on/off up to 400 HZ
* low frequency? applications.
* General purpose diodes.

oN: Forward Baised (FB)
off: Reverse Baised (RB)

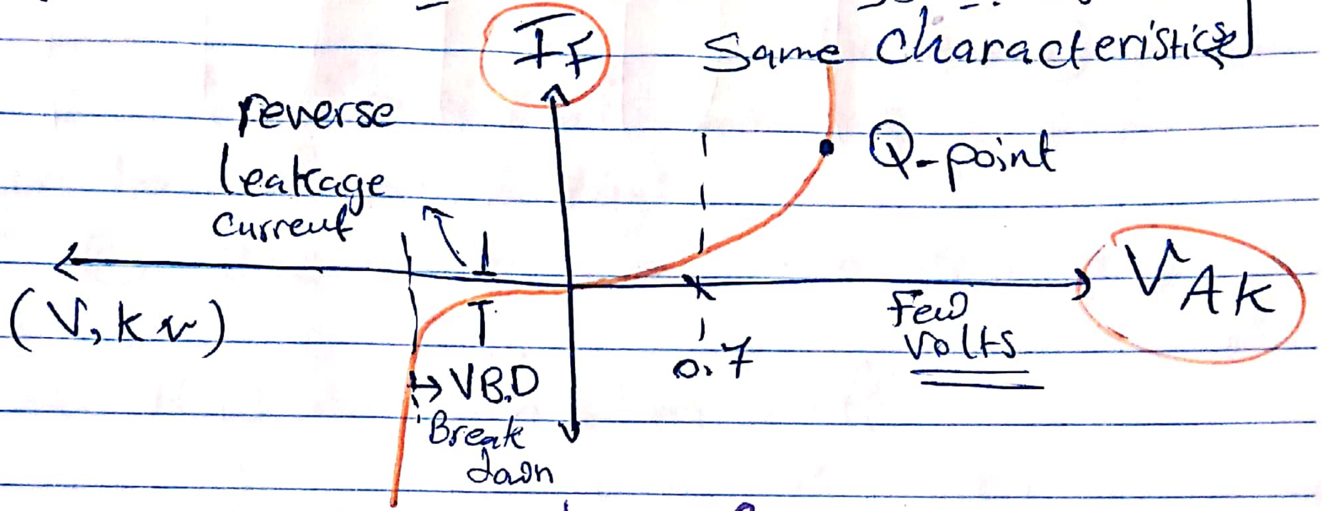


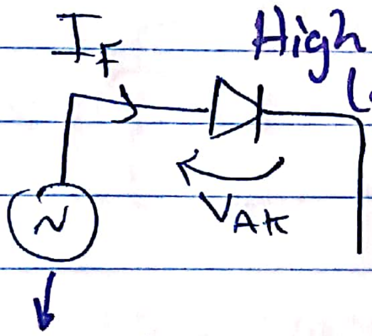
* Fast recovery diodes: * Medium to high Frequency applications.

* (ex: choppers, Inverters ...)

لا فرق بينه وبين ال diode العادي . نميزه بالرمز تبعه.

Same characteristics





High & large ⟷ few volts

different scales

$V_s = V_m \sin(\omega t)$, usually $V_m = V_{AK}$

$S.F = (2-3) * \text{rated voltage}$

Saftey Factor.

Thyristors: older than transistors (1975 → 2000)

→ SCR (1975) — Silicon controlled rectifire

MCT (2000) — Mos-controlled Thyristor.

1 / 10 / 2019 Lecture 5

- Diodes → no control
- Thyristors → control (Ac → Ac) or (Ac → Dc)
- Transistors → control (Dc → Dc) or (Dc → Ac)

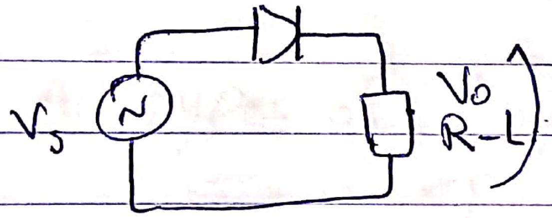
From rectifire

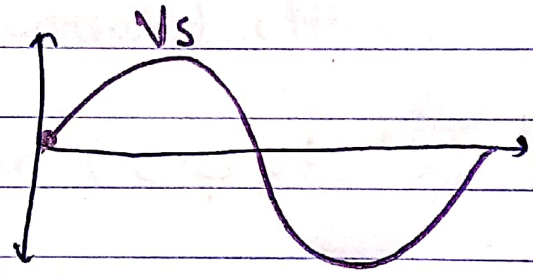
Classifications of switches.

// In terms of controllability:

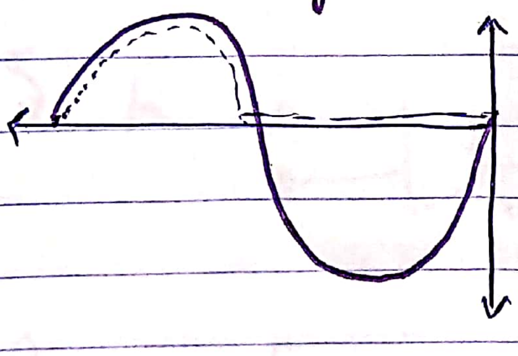
ⓐ Uncontrolled on, Uncontrolled off
Diodes

⇒ How to turn it on or off ...

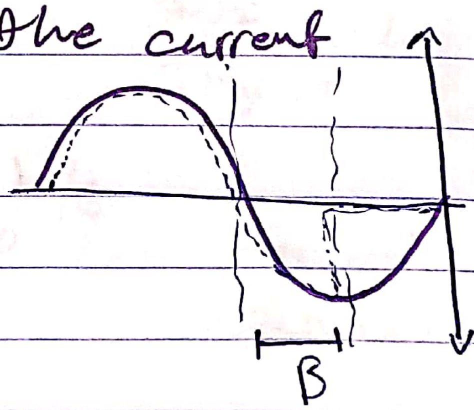




on : starts when It's Forward Baised.
off : depends on the current



resistive



inductive load

Extention Angle β : depends on inductivity

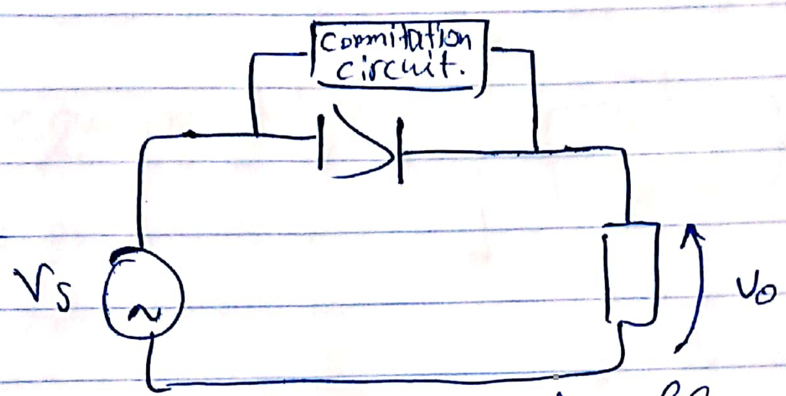
زاوية اطفاء.

$$\tau = \frac{L}{R}$$

Scanned by CamScanner

o For Thyristors α : زاوية التحكم

To stop the diode from working, we add a commitation circuit.



ⓑ controlled on & uncontrolled off.

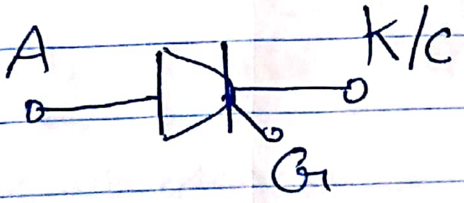
All types of Thyristor (except GTO)

Thyristors

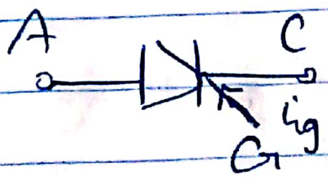
→ SCR, TRIAC, GTO, SITH, LASCR, MCT.

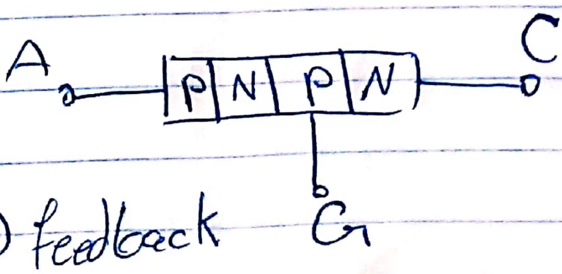
SITH: Static induction Thyristor
LASCR: light active Silicon controlled rectifire

SCR



terminals لا
مصنعين غلط

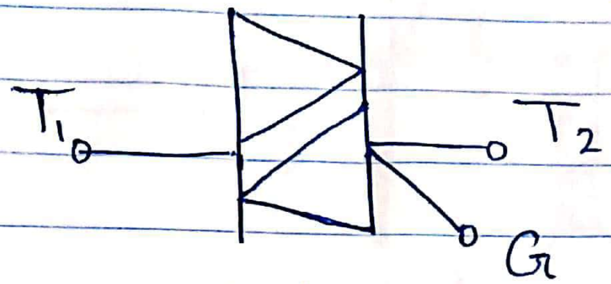




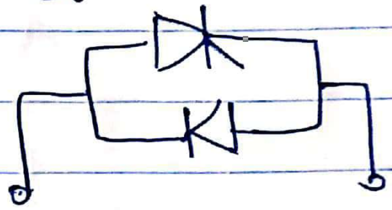
i_g : control current

(ردود) feedback

TRIAC (AC switch) // Triode for AC.



TRIAC equivalent :



RCT

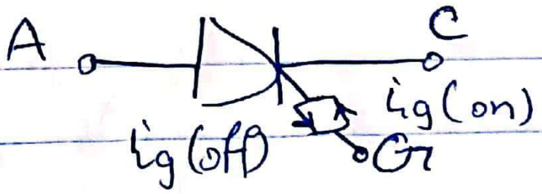
بـ act

↳ TRIAC العادي
يستعمل بحالة
low power
low voltage

العكس فيزة الـ
يستعمل بحالة
High power
High Voltage.

GTO gate turn-off Thyristor.

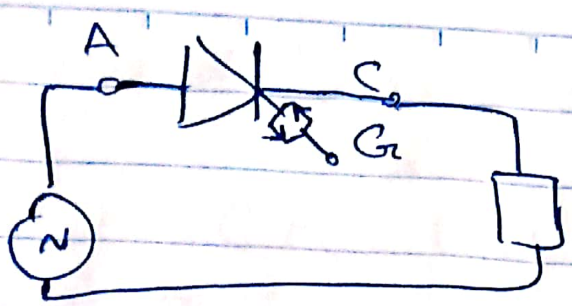
↳ for large power applications.

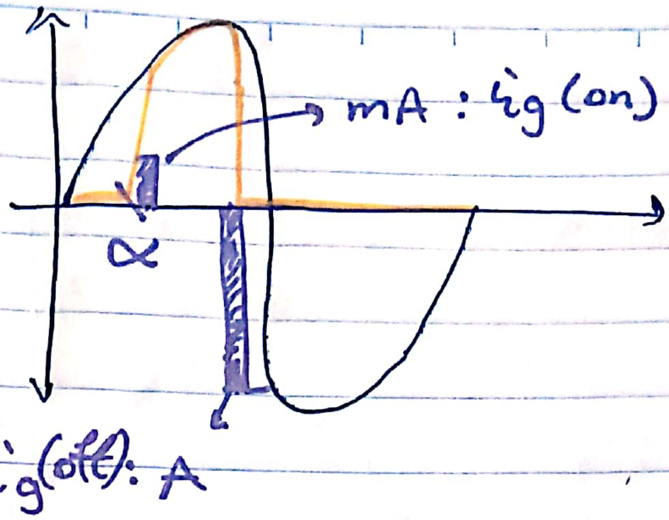


bidirectional

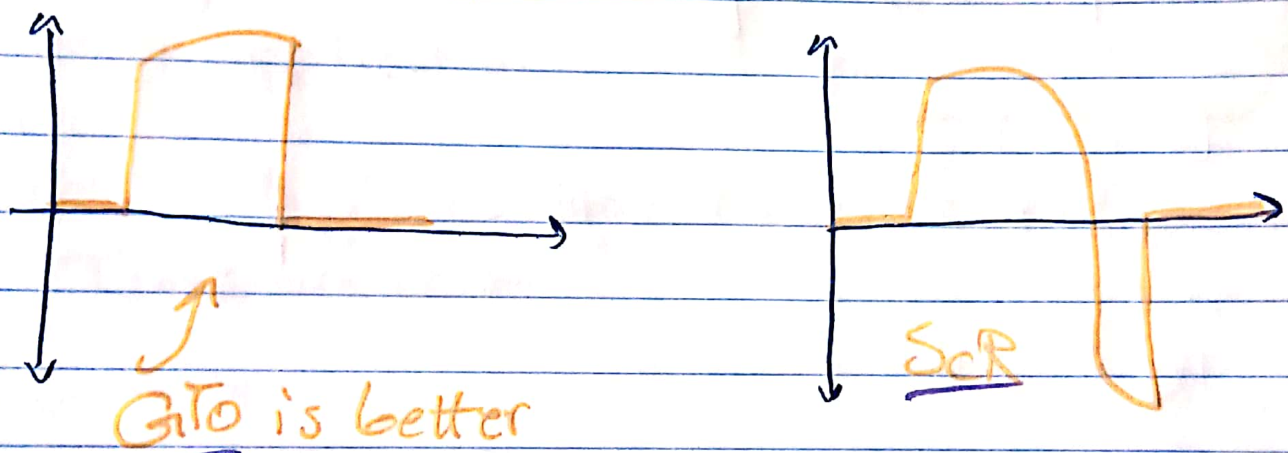
gate disadvantage → i_g(off) ≫ i_g(on)
A's mA's

o you need two control circuits "محولين كهربائيًا".





GTO Vs. SCR



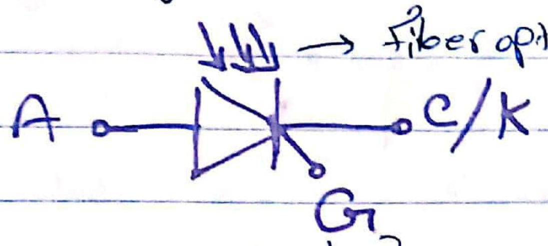
- Small positive gate current is required to switch GTO $\boxed{\text{on}}$

- Large negative gate current is required to switch GTO $\boxed{\text{off}}$

3 / 10 / 2019 Lecture 6

◎ controlled on, Un controlled off

○ LASCR → Thyristor
light activated Silicon controlled rectifire.



→ fiber optics or شعاع ليزر ضوئي

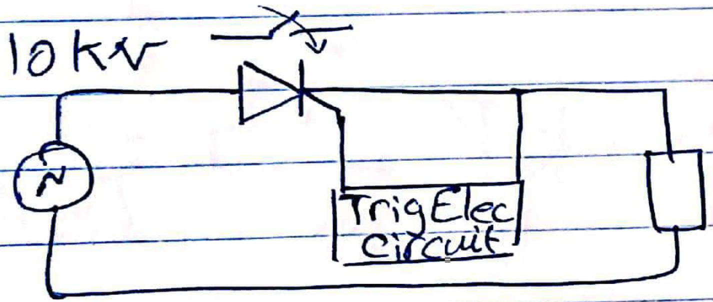
بيسلط على منطقة ال gate.

غير مستخدم ←

⊛ Very high voltage application.

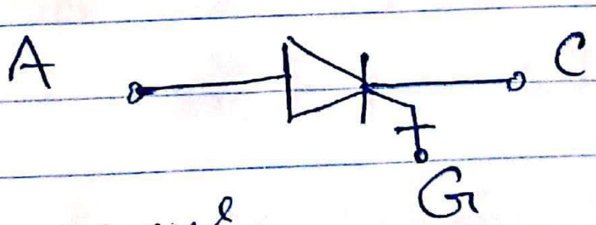
exited by light not gate current.

○ HVDCT: high voltage Direct current Transmission.



ال 10KV مسلطة على ال Triggering electric circuit.

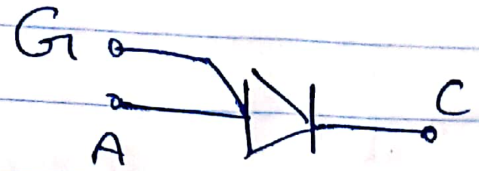
○ SITH Static Induction Thyristor.



⊛ Higher frequency applications, More than GTO or SCR
→ up to 50 kHz.

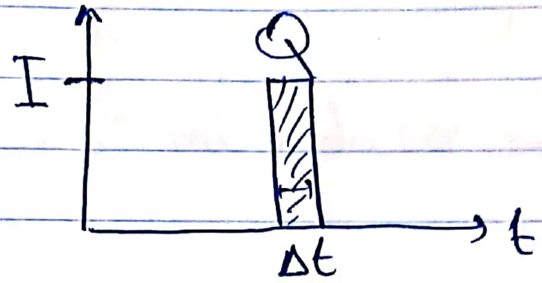
MCT

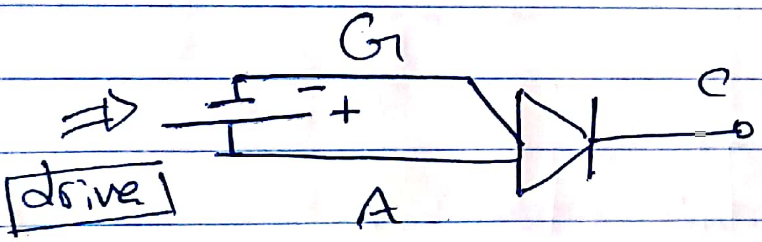
Mos - controlled Thyristor.



o to drive this switch, we apply negative gate with respect to the anode.

⇝ charge controlled all previous Thyristors except for MCT → $\boxed{\text{Voltage controlled}}$

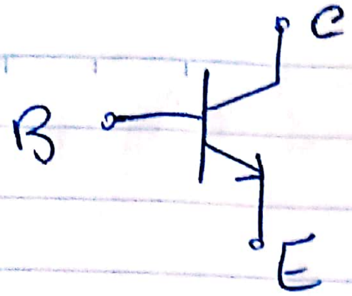




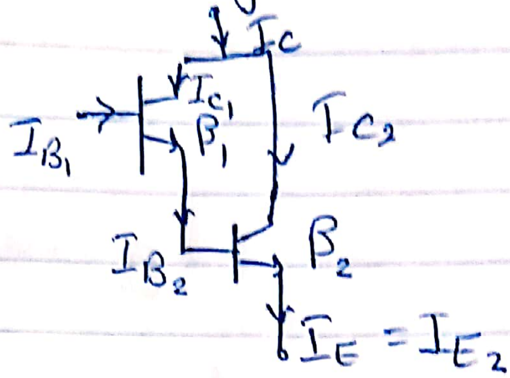
* up to 80 kHz , 2 kV , 2 kA

(C) controlled on , controlled off. (all transistors)
GTO, BJT , MOSFET , IGBT

BJT : Bipolar Junction Transistor.
↳ Base current control.



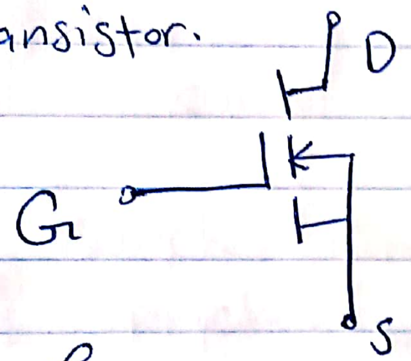
* Usually used in darlington Form.



$\beta = \beta_1 * \beta_2$ in power

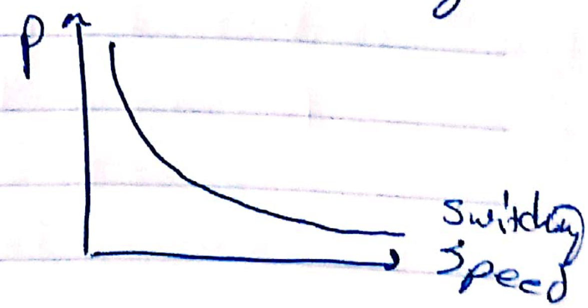
* up to 10KHZ
(ابطأ وحدة)
* up to 800V &
600 A
* Disadvantage: current controlled.

MOSFET: Metal oxide Semiconductor Field Effect Transistor.

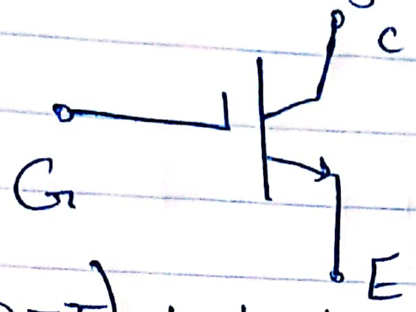


- This is the fastest switch out there!

* Voltage controlled, up to 1MHZ, Low power
⇝ switching speed $\frac{1}{\propto}$ power capability
* up to 1200V, 800A



IGBT : Insulated gate Bipolar Transistor



* (MosFET + BJT) technology.
* voltage controlled
* 100kHZ , 2.5kV , 2KA.

Classification of switchess

// In terms of the nature of the control Signal.

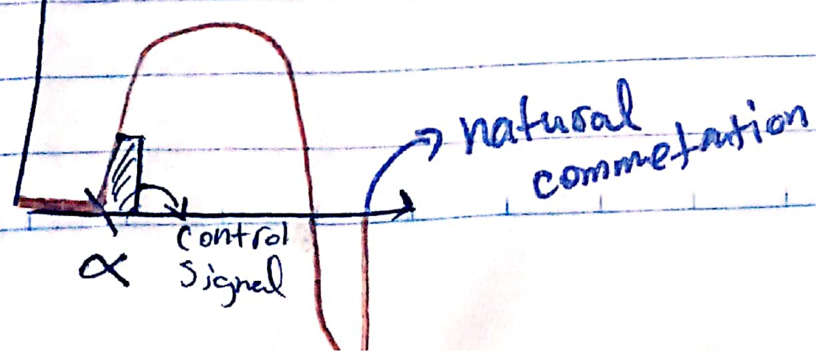
a) Latching Switches (trigger)
b) continous switches (drive)

if asked to design
1) Rectifire : SCR
2) Chopper/Inverter : IGBT

Latching Switches : (all Thyristors)

→ small , short signal is applied to switch on or off
→ when the triggering signal is removed, the switch continous conduction.

* Switching off → Forced commetation.
  → natural commetation.



Continous Switch. → (all Transistors)

(لازم تضل تعطيها
عشان تشتغل)

Drive signal:

- If on → Switch is on.
- If off → Switch is off.

Classification of switches

\\ In terms of voltage withstanding capability ≠ Amplitude.

→ polarity of the input voltage.

(a) Bi-polar.
(b) Uni-polar.

Bipolar: Ac applications.

* Rectifires + Ac Regulators

all ScR's & Thyristors are Bipolar Switches Exept for GTO. → could be bipolar (special GTO)

Unipolar: Used in inverters + Choppers.

→ all Transistors.

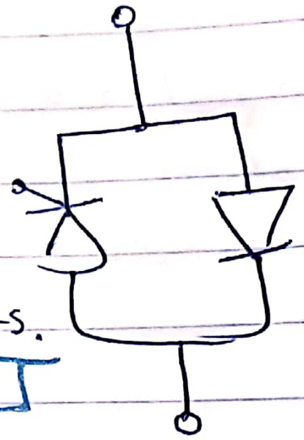
\\ In terms of current withstanding capability

→ Direction! ≠ polarity

(a) bidirectional TRIAC, RCT
(b) unidirectional all remaining switches.

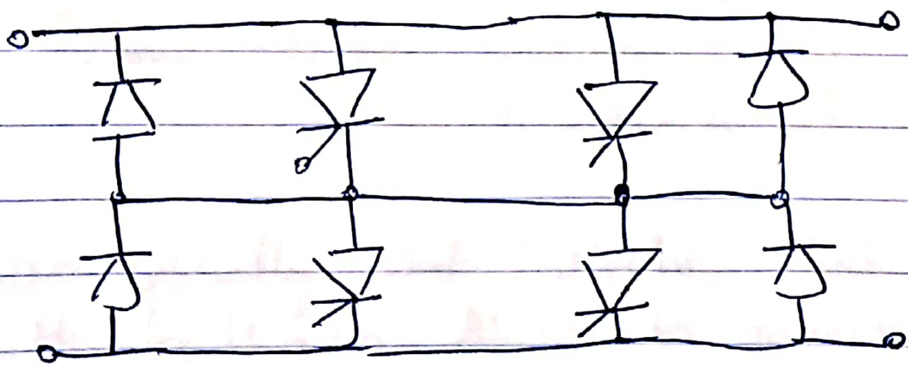
13/10/2019 Lecture 7

RCT : Reversed conducting Thyristor.
⇝ also called : Thyrode
(Thyristor + diode)

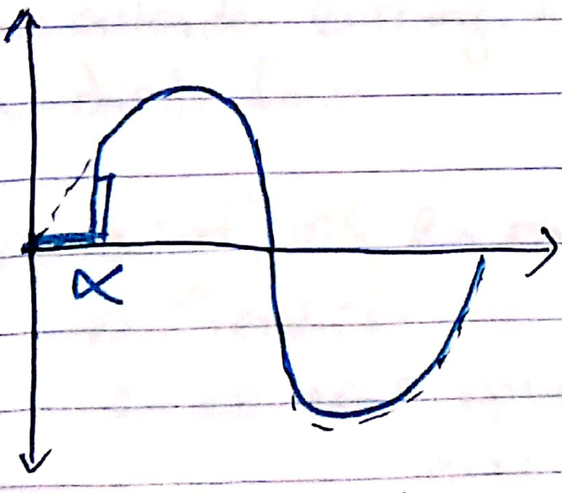


- For Ac Voltage control.
  (resistive loads)
- Unsymetrical, cause Dc components.
  burns motors.

⊛ Inverters
(Before power transistors:)



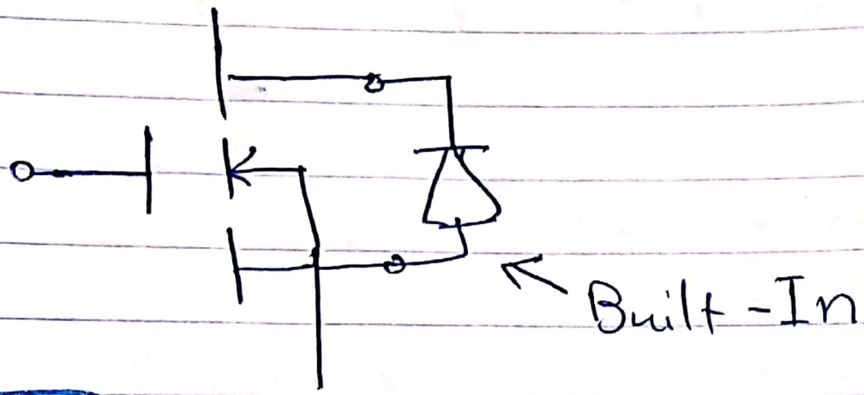
feedback & freewheeling Diodes.



So we said that all other switches are directional ... There are $\boxed{\text{Exceptions}}$

Exception bi-directional MOSFET

- this MosFET is a module , بيكونوا حاطين معه Diode.



Note: MosFET Module اذا طلب بالامتحان برسمه مع ال diode وبحطه بحالة ال bi-directional.

- we usually put Switches that are Moduled with built-In diodes in inverters (why?) to avoide burning the entire inverter when a diode fails.

Applications for power electronics.

- Services
- power supplies (rectifires + inverters + Batteries) ex: (UPS) uninterruptable power Supply. Used on critical loads : loads in which cannot accept any power stoppage (e.g Data centers, hospitals, Industrial...)

- Power systems:
  ex$_1$: (SVARC): Static Var compensation. (AC voltage regulators)
  ↳ for power factor correction

  ex$_2$: Static voltage regulators ≡ Static tap changers

  ex$_3$: (HVDCT): High voltage DC Transmission.
  (to be addressed later)
  used: ↳
  - when connecting to networks with different frequencies. (eg. USA & Canada)
  - when transmitting power for very long distances. (greater than 500 km)
  - geographical obstacles. (e.g English channel between UK & France)

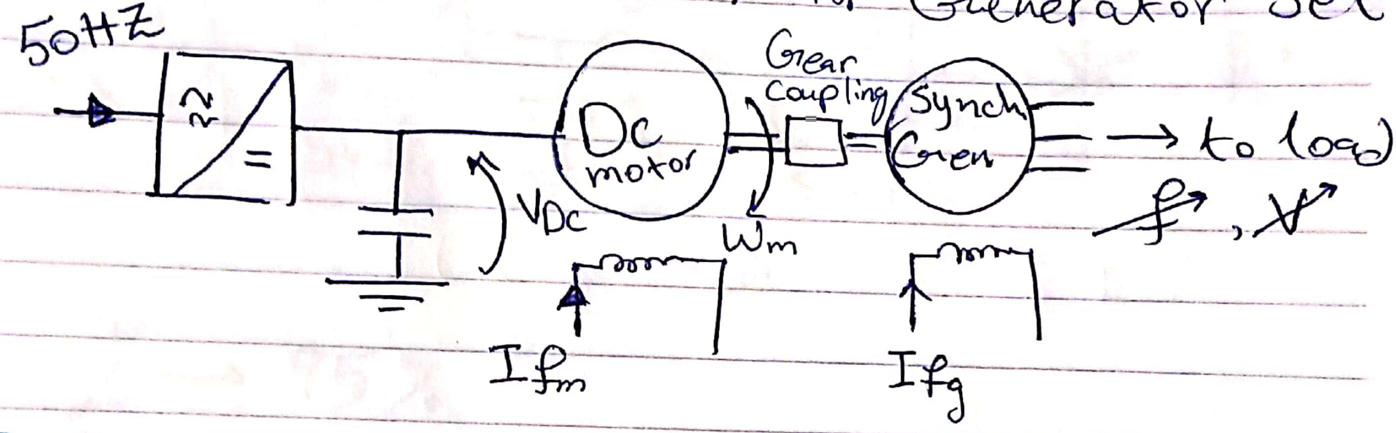
- Industrial Applications:
  - Industrial heating
  - Electric Motor Drive: motors consume up to 70% of total power consumption.

Merits & Drawbacks

Advantages — Disadvantages.

Ex: Conventional:

To convert frequency: we used (M.G) Motor-Generator Set



- Frequency controlled by N_m control.

$$N_m = \frac{60f}{P} \longrightarrow f = \frac{P}{60} N_m$$

N_m controlled by ① V_{DC} control

for $0 \leq N_m \leq N_m(\text{rated})$

② I_{fm} (field weakening control)

for $N_m(\text{rated}) \leq N_m \leq (2\text{-}3)(N_m\ \text{rated})$

((2 - 3 أضعاف))

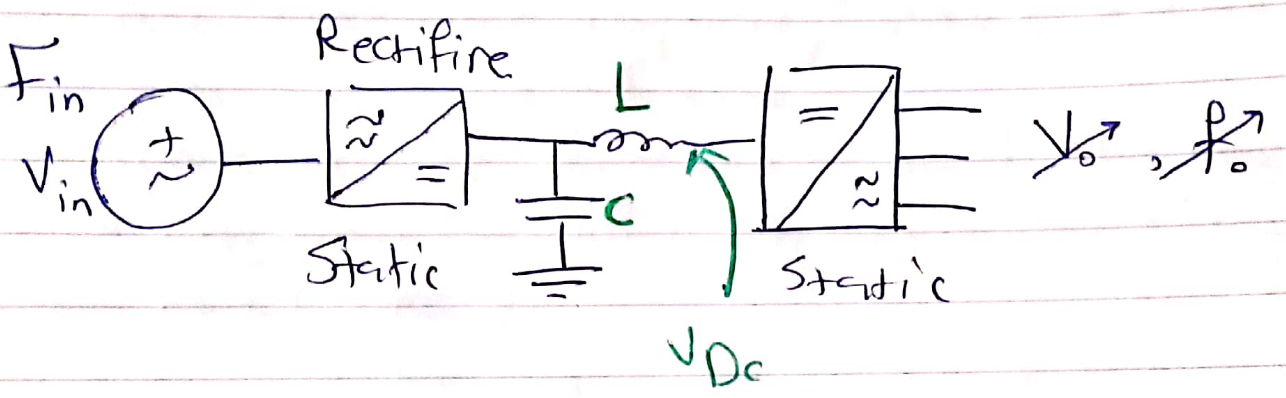
- Output Voltage Controlled by controlling I_{fg} (synchronous), $V \simeq 4.44 N_{ph} \cdot \phi_p \cdot f$

((Generator field))

15 / 10 / 2019 Lecture 8

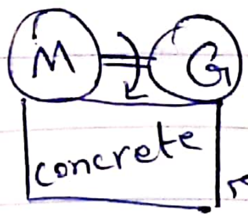
Cont. from past lecture

* Power Electronics Alternatire.



$\eta \rightarrow 95\%$

Benefits: [1] Much lower capital cost.
[2] Much higher efficiency ($\approx 95\%$ compared to $\approx 50\%$), lower running cost.
[3] Maintenance-Free
[4] Much easier control (very high controllability capabilities).
[5] less weight, size, and space.
[6] No special foundations.
[7] lower acoustic noise.



عن ربط M & G
Motor Generator

قاعده اسمنتية for vibrations.

Power Electronics Disadvantages (Drawbacks)

Compared to conventional counterparts.

[1] No over-load capacity even for a very short period of time.

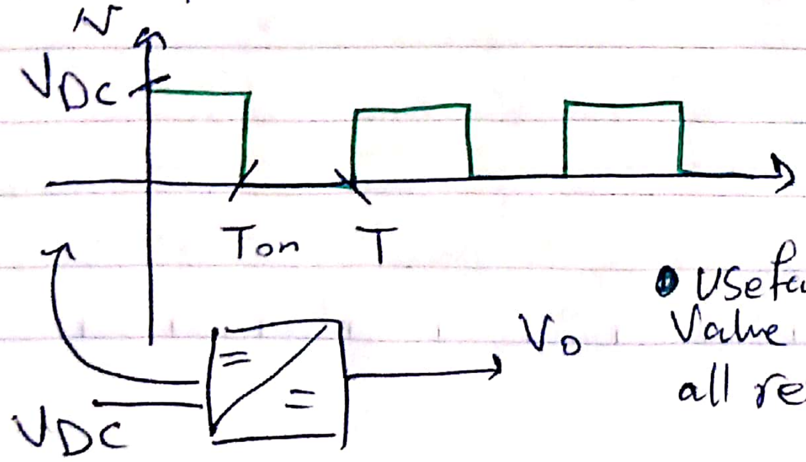
Explain → (Converters are designed to mach the maximum power required even if it happens for very short period of time.)

Ex

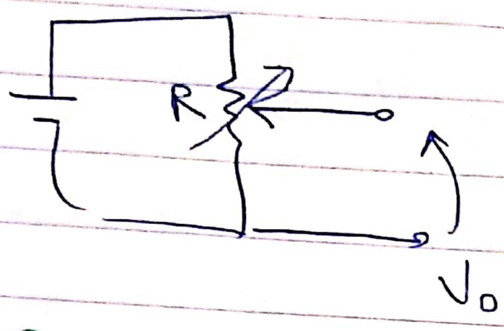
Starting a motor → the starting current ≃ $20 I_{rated}$
So the power at the begining is very high but the case is for a very short time, the motor will not heat up this fast. as for P.E, once a higher current value passes through → it will burn down.

⇝ we must over-size the P.E
Unjustified cost.

[2] Harmonics Generation: usually Voltage and currents of P.E are not ideal (not pure DC or pure Sine) ⇒ distorted waveforms



• useful component is the (AVG) Value of the signal.
all remaining are impurities.



اذا بدي اشي pure بدخل
على مقاومة وهاد على حساب
ال losses

$$V_o(t) = \begin{cases} V_{DC} , & 0 \leq t \leq T_{on} \\ 0 , & T_{on} \leq t \leq T \end{cases}$$

$$V_o(t) = \underbrace{V_{avg}}_{\text{Useful part.}} + \underbrace{\sum_{n=1,2,3\ldots}^{\infty} V_m(n) \sin(n\omega t + \Psi(n))}_{\text{Impurities}}$$

دائماً أقل من T

$$V_{avg} = \delta V_{DC} = \left(\frac{T_{ON}}{T}\right) \cdot V_{DC}$$

δ: modulation index
or
Time-to-Space ratio
or
duty cycle.

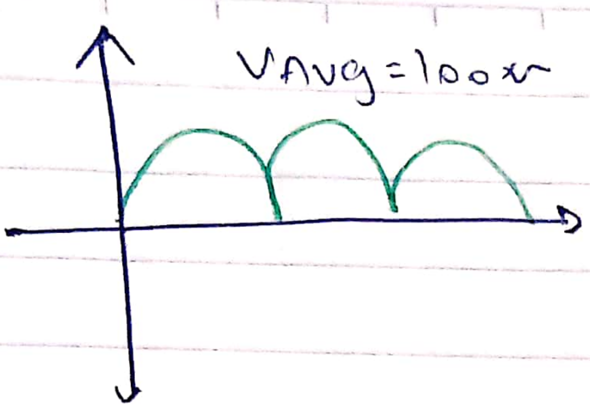
accurate.

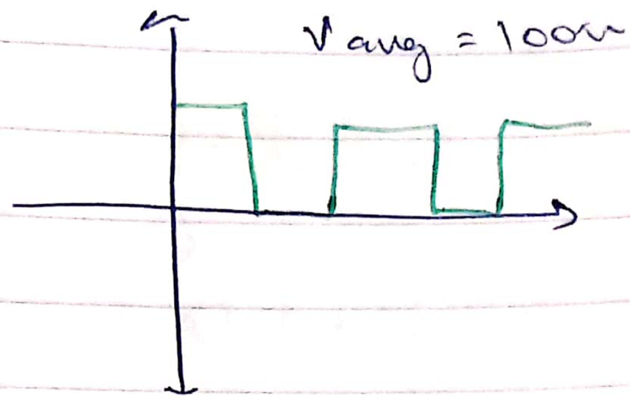
$$\boxed{V_{rms} = \sqrt{\frac{1}{T} \int_0^{T_{on}} V_{DC}^2 \, dt} = \sqrt{\delta} \cdot V_{DC}}$$

$\delta < 1 \rightarrow V_{rms} \geq V_{avg}$

$$\boxed{V_{rms} = \sqrt{V_{avg}^2 + \sum_{n=1} \left(\frac{V_m(n)}{\sqrt{2}}\right)^2}}$$

approximate





which one should we choose?

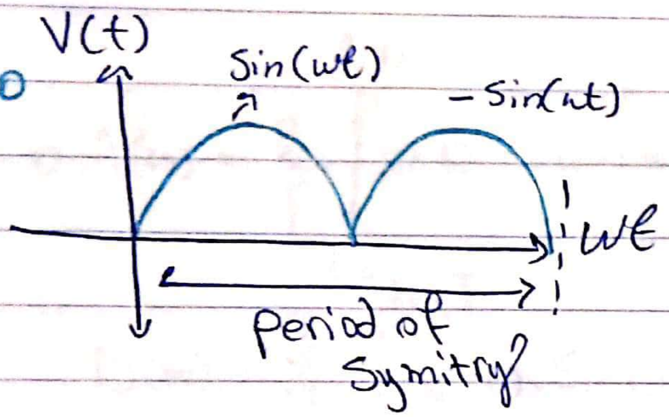
→ according to the $\boxed{\text{ripple factor}}$

17/10/2019 Lecture 9

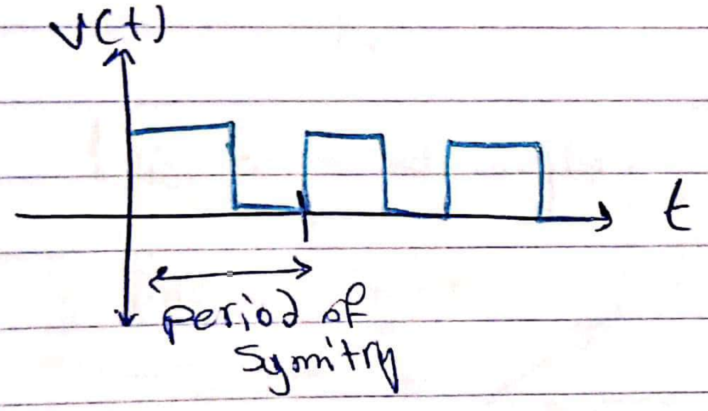
Fundamental @ $\boxed{n=1}$ ∵ Same as Supply freqancy

o $V(t) = V_{avg} + V_m(1).\sin(\omega t + \varphi(1)) + V_m(2).\sin(\ldots$
$\ldots 2\omega t + \varphi(2)) + V_m(3).\sin(3\omega t + \varphi(3)) + \ldots$
$\ldots + \ldots V_m(n).\sin(n\omega t + \varphi(n)) \ldots \infty$

o



⇐ $V_{avg} = A$.



⇐ $V_{avg} = A$.

→ when our signal is sine or cosine
شغال على (ωt) ⇐ radians.

→ if the signal isn't sine nor cosine
شغال على (t) ⇐ seconds.

o لازم ما يطلع أي اشي odd (Harmonics) يعني تكون الـ period
فقط (Period of symitry) . بس even
Harmonics.

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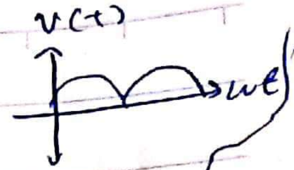
Scanned by CamScanner

$$V_{avg} = \frac{1}{T}\int_{t_0}^{t_0+T} V(t)\,.\,d\omega t$$

for 

$$V_m(n) = \sqrt{A(n)^2 + B(n)^2}$$, A & B are Fourier coefficents or Euler coefficents.

$$A(n) = \frac{2}{T}\int_{t_0}^{t_0+T} V(t).\cos(n\omega t)\,d\omega t$$

$$B(n) = \frac{2}{T}\int_{t_0}^{t_0+T} V(t).\sin(n\omega t)\,d\omega t$$

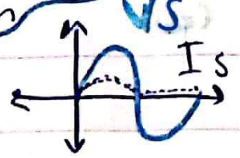
Displacement angle or phase shift

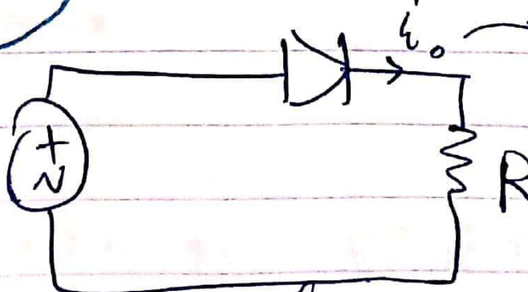
$$\boxed{\psi(n) = \tan^{-1}\left(\frac{-B(n)}{A(n)}\right)}$$

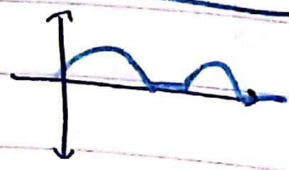
or

$$\boxed{\psi(n) = \tan^{-1}\left(\frac{A(n)}{B(n)}\right)}$$

- when $B(n) \to \sin$, $A(n) \to \cos$ ↳ $\sin/\cos \to \tan$
- when $B(n) \to \cos$, $A(n) \to \sin$ ↳ $\frac{1}{\tan}$







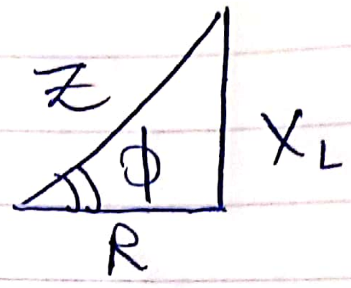
rectifire.

→ power factor & load phase angle $(\phi) = \tan^{-1}\left(\frac{\omega L}{R}\right)$

$$v_s(t) = V_m \sin(\omega t)$$

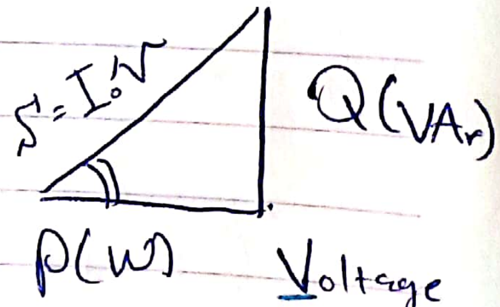
$$i_s(t) = I_{avg} + I_{m(1)} \cdot \sin(\omega t + \varphi(1)) + I_{m(2)} \cdot \sin(\ldots$$
$$\ldots 2\omega t + \varphi(2)) + I_{m(3)} \cdot \sin(3\omega t + \varphi(3)) + \cdots$$

Original definition of power factor

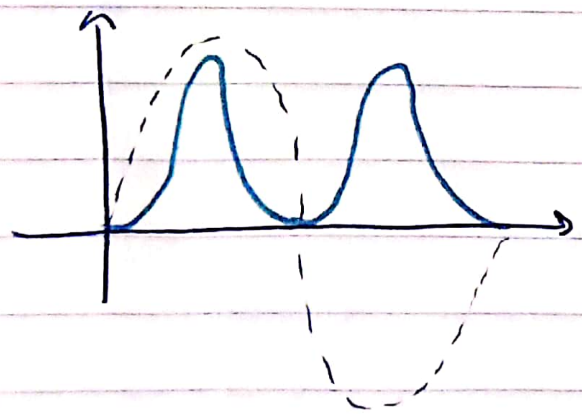


- $PF = \dfrac{\text{Real power supplied by the source}}{\text{Apparent power supplied by the same source}}$

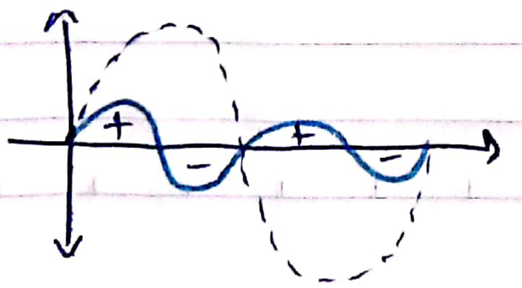
- Resistive load power



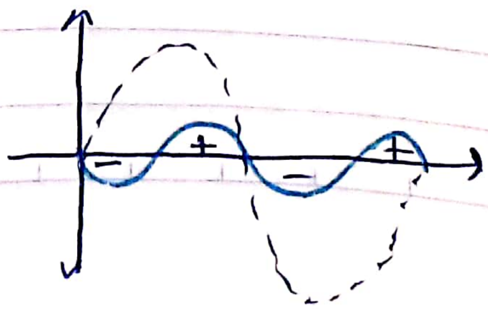
Voltage
Amper
reactive
small.



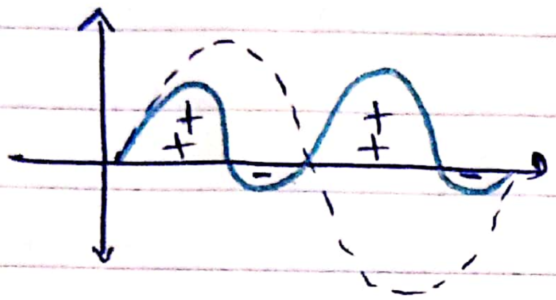
- Inductive load power



- capacitive load power

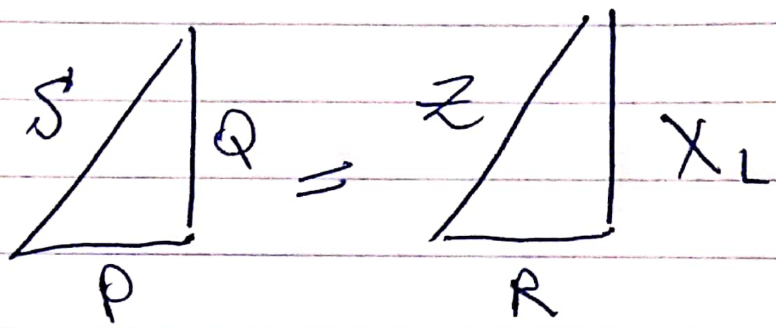


- R-L load power



for power $\omega \Rightarrow 2\omega t$
ضعف الـ frequency . ↲

Special case



- شرطها يكون ال Voltage وال Current
↳ pure Sinosoidal.

$$\cos(\phi) = PF$$

20/10/2019 Lecture 10

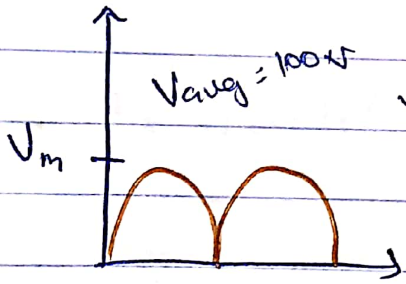
$$\text{Ripple factor} = \frac{\sqrt{V_o(rms)^2 - V_o(avg)^2}}{V_o(avg)} \quad , \; 0 \leq R.F \leq \infty$$

To compare signal 1 & signal 2, you need to Find the R.F:

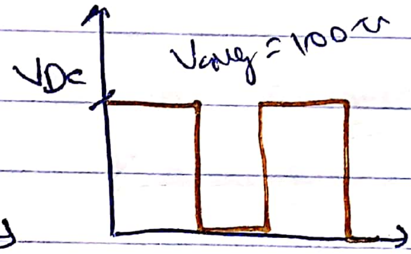
ripple factor

Pure Dc signal (Best case)

approaches ∞ when the avg value of the signal = 0, (pure Ac)
- sine &
- square wave



Signal 1



Signal 2

Signal 1

For rectified Ac, we use $V_{RMS} = \frac{V_m}{\sqrt{2}}$ (like sine & cosine) , $V_{avg} = \frac{2V_m}{\pi}$

$$V_m = \frac{V_{avg} * \pi}{2} = \frac{100\pi}{2} = 157\,v$$

$$V_{rms} = \frac{V_m}{\sqrt{2}} = 111\,v$$

$$RF = \frac{\sqrt{(111)^2 - (100)^2}}{100} = 0.48$$

Signal 2

$V_{avg} = 100$, $V_{avg} = \delta \cdot V_{Dc}$, $V_{RMS} = \sqrt{\delta} \cdot V_{Dc}$

if $V_{DC} = 150V$, $\delta = 2/3$

$V_{rms} = \sqrt{\frac{2}{3}} \cdot 150 \longrightarrow 122.4$

So, $R.F = \frac{\sqrt{(122.4)^2 - (100)^2}}{100}$

$RF = 0.7$

The Rectified Sine is better than the chopped DC signal.

$$R.F = \frac{\sqrt{V_{rms}^2 - V_{avg}^2}}{V_{avg}}$$

$$R.F = \sqrt{\left(\frac{V_{rms}}{V_{avg}}\right)^2 - 1}$$

$= \sqrt{FF^2 - 1}$, FF = Form factor $= \frac{V_{rms}}{V_{avg}}$

→ for rectified signals $FF = \frac{111}{100} = \boxed{1.11}$

اذا بالامتحان اعطاني RF or FF طلب تانيه

بستخدم القانون $\boxed{RF = \sqrt{FF^2 - 1}}$

Back to Fourier:

$V(t) = V_{avg} + V_m(1) \cdot \sin(wt + \varphi(1)) + V_m(2) \cdot \sin(\ldots$

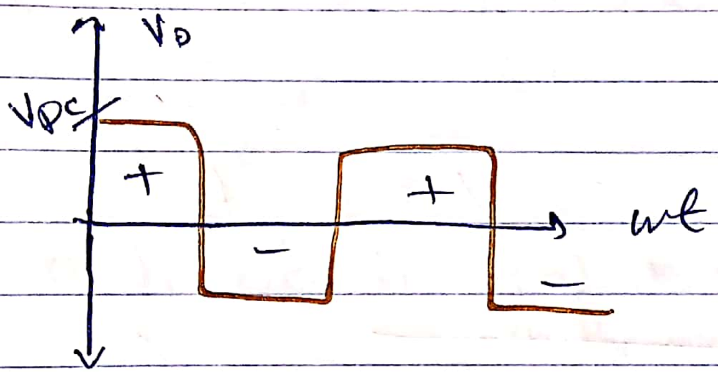
$\ldots 2wt + \varphi(2)) + V_m(3) \cdot \sin(3wt + \varphi(3)) \ldots$

$\ldots + V_m(n) \sin(nwt + \varphi(n)) + \ldots \infty$

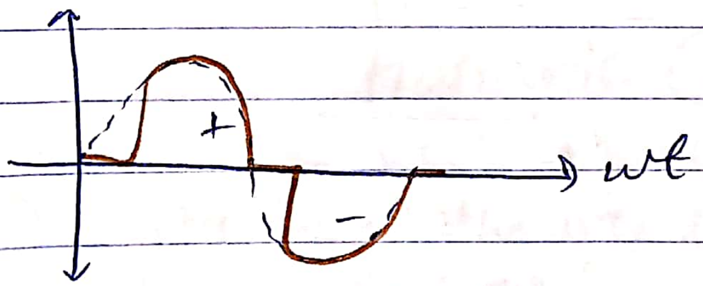
→ For Ac Signals $\boxed{V_{avg} = Zero}$
all even Harmonics = zero in Ac
n=1 ⇝ fundamental component in Ac & has the required power Value.

→ n=3 3rd Harmonic component
- pure sinosoidal ≠ pure Ac.

pure Ac → Avg = Zero



(from an inverter)



(from an Ac voltage Rectifire)

- 3rd Harmonic = Heat, losses, Torque pulsation.
  not stable
- To evaluate the signal :
  Ripple factor does not work. So, we have Quality parameters : [1] Power factor (↑ better ⇝ Unity)
  [2] Total Harmonic Distortion Factor (THDF)

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$THDF = V_{rms}^2 - V_{fundamental}^2$ (Definition)

$\rightarrow THDF = V_{rms}^2 - V_{(1)rms}^2$

$0 \leq THDF < \infty$

↳ approaching ∞

when the fundamental Component = Zero.

$V(t)$ لما تكون
$= V_{m(1)} \sin(\omega t + \varphi_{(1)})$.
pure sine #

o If $\alpha = 0 \Rightarrow$ pure sine $\boxed{\frac{V_m}{\sqrt{2}}}$

↓

عند الا شتقاق
بيطلع الشي بدلالة
$\underline{\alpha}$

o To obtain $i(n) = \frac{V_m(n)}{Z(n)}$

nth Harmonic

Harmonic Generation Impacts

① Distortion of the output signals, this leads to a load over Heating (Specially Motor loads).

ex: Dc motor

$\rightarrow i(t) = 10 + 8 \sin(2\omega t - 30°) + 5 \sin(4\omega t - 69°) + \dots$

$\rightarrow$ Find $I_{avg} = ?$ 10A

$\rightarrow I_m(2) = 8A$

$\rightarrow I_{rms}(2) = \frac{8}{\sqrt{2}} A$ ⟹ for the second Harmonic component

$\rightarrow I_m(4) = 5A$

$\rightarrow I_{rms}(4) = \frac{5}{\sqrt{2}} A$ ⟹ for the 4th component.

cont...

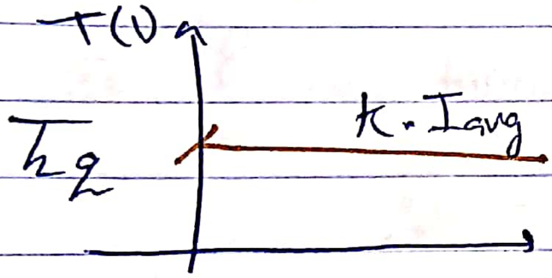
$$I_{rms} = \sqrt{10^2 + \left(\frac{8}{\sqrt{2}}\right)^2 + \left(\frac{5}{\sqrt{2}}\right)^2 + \cdots}$$

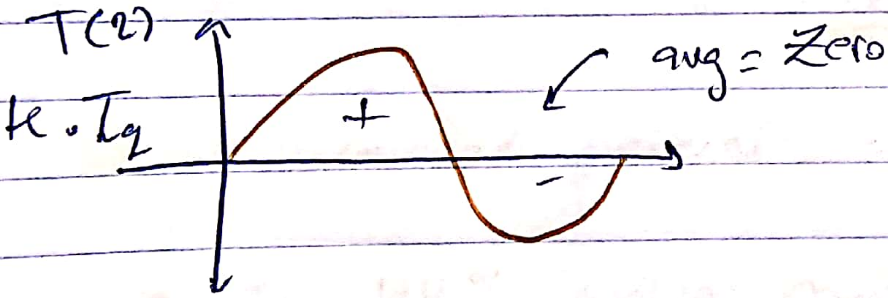
$$I_{rms} = 12 \text{ A}$$

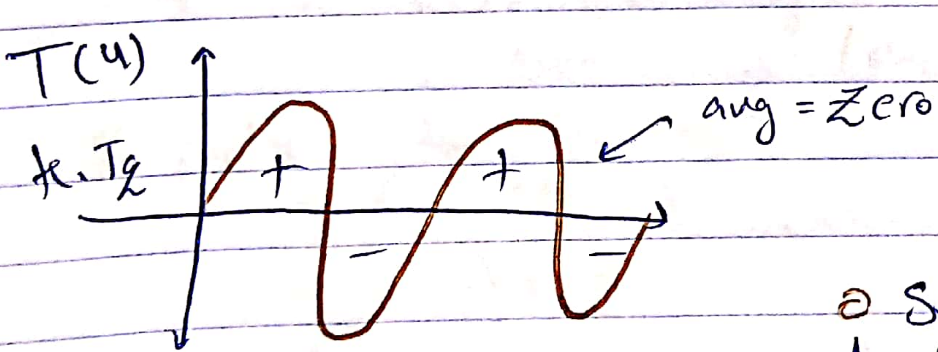
$I_{avg} = 10 \text{A}$, Torque is a function of current

→ $T_q = K_a \cdot \phi \cdot i_a$, $K_a \cdot \phi = K$

→ $T_q = K \cdot i_a$





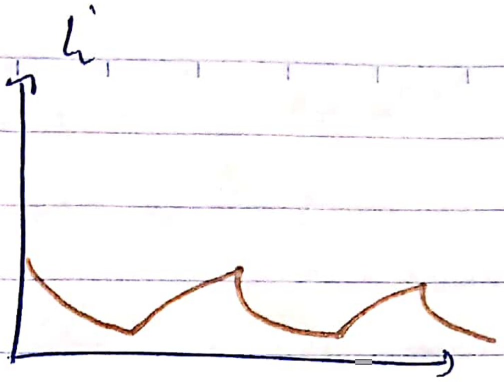


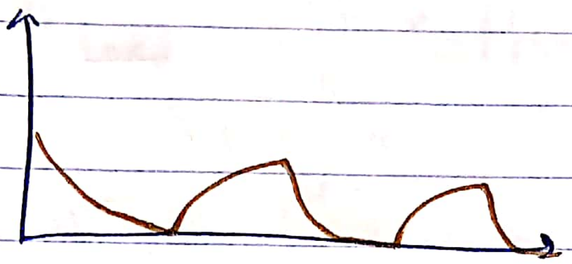
o So, Torque is only developed by $\boxed{I_{avg}}$

→ Harmonics has zero avg. developed Torque → (Torque pulsation)

Torque pulsation

CCM : continous current mode.





DCM : Discontinous current mode.

- If no Harmonics (pure Dc) : $(I_{rms} = I_{avg})$

$$P_{cu} = (I_{rms})^2 * R_a$$

copper loss (P_{cu}), armeture (R_a)

$$= 10^2 R_a = \underline{\underline{100 R_a}}$$

- if Harmoneed generated = $I_{rms} = \sqrt{\quad ---} = 12^2 R_a$

$$= \underline{\underline{144 R_a}}$$

→ so 44% extra power loss → leads to overHeating.

* ratio $\left(\frac{I_{avg}}{I_{rms}}\right)$ ⇝ called Derating Factor

From the previous Example $\frac{10}{12}$ = Derating factor

سمو دي هاد ال Derating ≡ (يعني لازم اعمل ال Motor على هذا الرقم عشان ال power تكون احسن.)

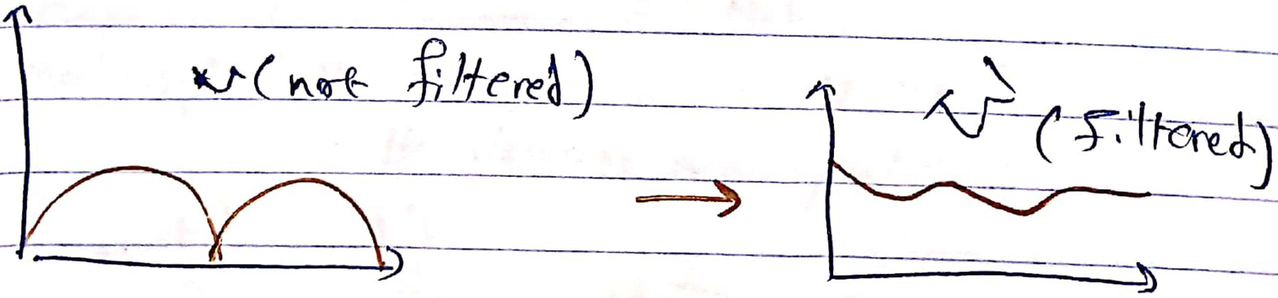
22/10/2019 Lecture 11

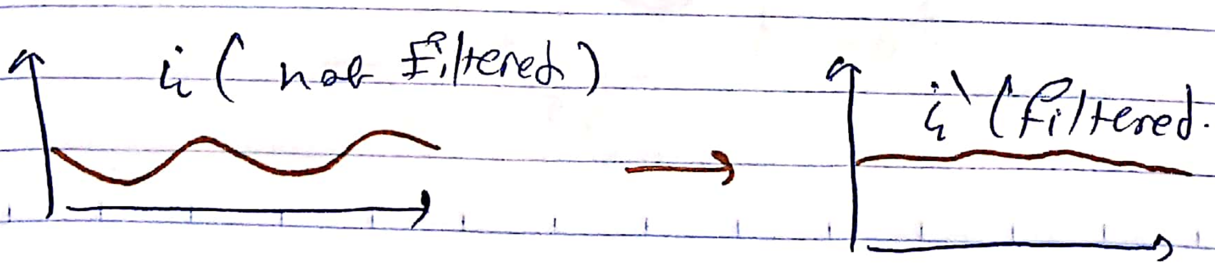
- Derating factor $= \dfrac{I_{(1)\,rms}}{I_{total\,rms}}$ (AC motors case cause power is in the fundamental)
- Derating factor $= \dfrac{I_{avg}}{I_{rms}}$ (DC motors)
- $P_{load} = \underbrace{DF}_{\text{Derating factor}} \times P_{rated}$

→ If the load power is not allowed to be reduced, then over sizing of the motor is required

- $P'_{rated} = \dfrac{P_{rated\,(orig)}}{DF}$
- DF cannot be larger than $\boxed{1}$

→ If no derating or over-sizing is required, then get rid of the harmonics (domenant current harmonics) by filtration.

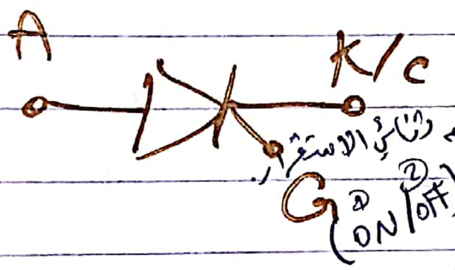




o If capacitor $C \uparrow$ values are increased ⇝ more Filteration.
o Harmonics leads to Distortion of light currents waveforms (communication & control systems).
o Harmonics leads to Supply power factor reduction even if the load is pure resistive.

SCR

Silicon controlled (controlled on) Rectifire.



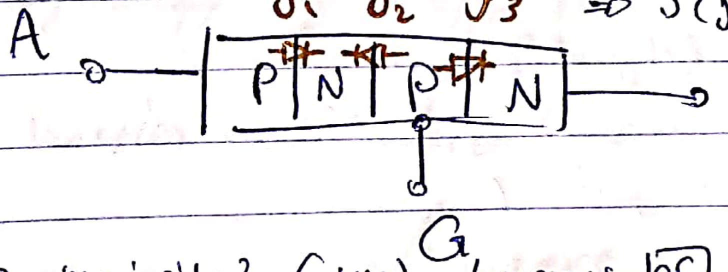
Def: a 4-layer (1), 3-terminal (2), Bi-stable (3), Semiconductor (4) Switch (5).

ثنائي الاستقرار ← (2) (ON/OFF)

ثلاثي الاستقرار ← Tri-stable (on/off) → (OFF) Forward Baised, R.B reversed Baised

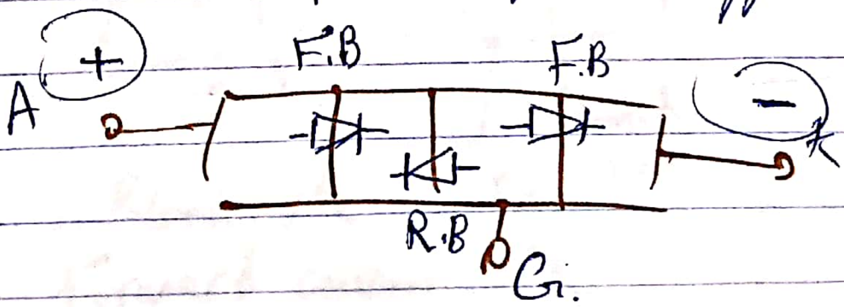
O 4-Layers: ثلاثي الاستقرار

J_1 J_2 J_3 ⇒ 3 (Junctions.)

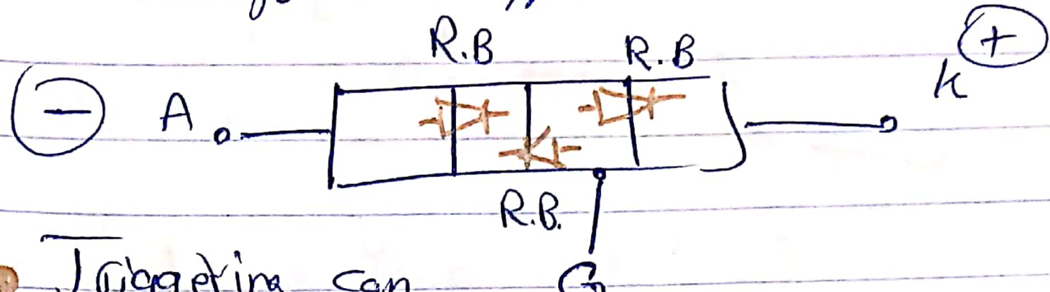


P: majority (+ve) charges or Holes.
N: majority (-ve) charges or electrons.

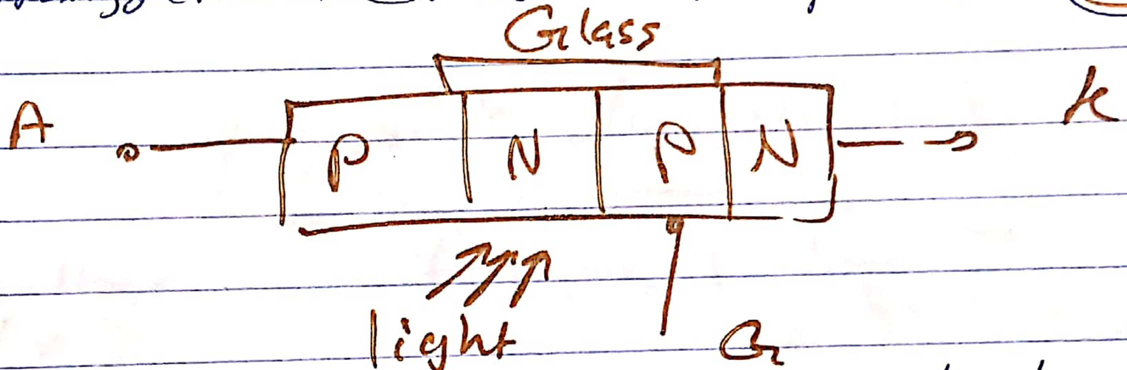
→ If Voltage was applied:



> if voltage was applied:

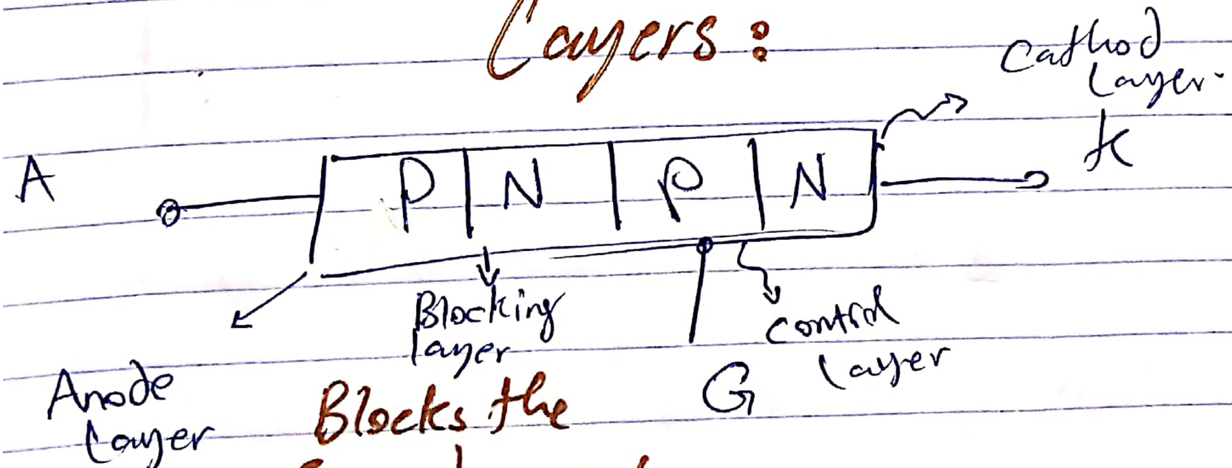


- Triggering can be applied by
  either Voltage (1) on Gate
  or making The [Np] junction in the middle transparent / Glass and apply Light (2)



(3)
- by appling V_{AK} ↑↑↑ (Voltage) → the barrier
  (very high)
  Junction will break and current will pass.

Layers:



Blocks the Forward current from flowing

Static V/I charecterstics

المستقر (حالة الاستقرار)

→ time is embedded inside.

- (i) as a function of (v)

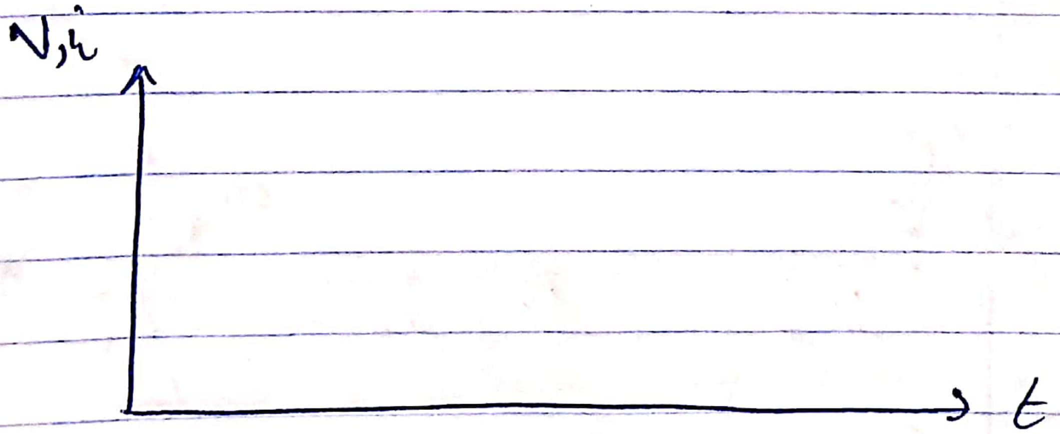
  current ... voltage

$$\boxed{i = f(v)}$$

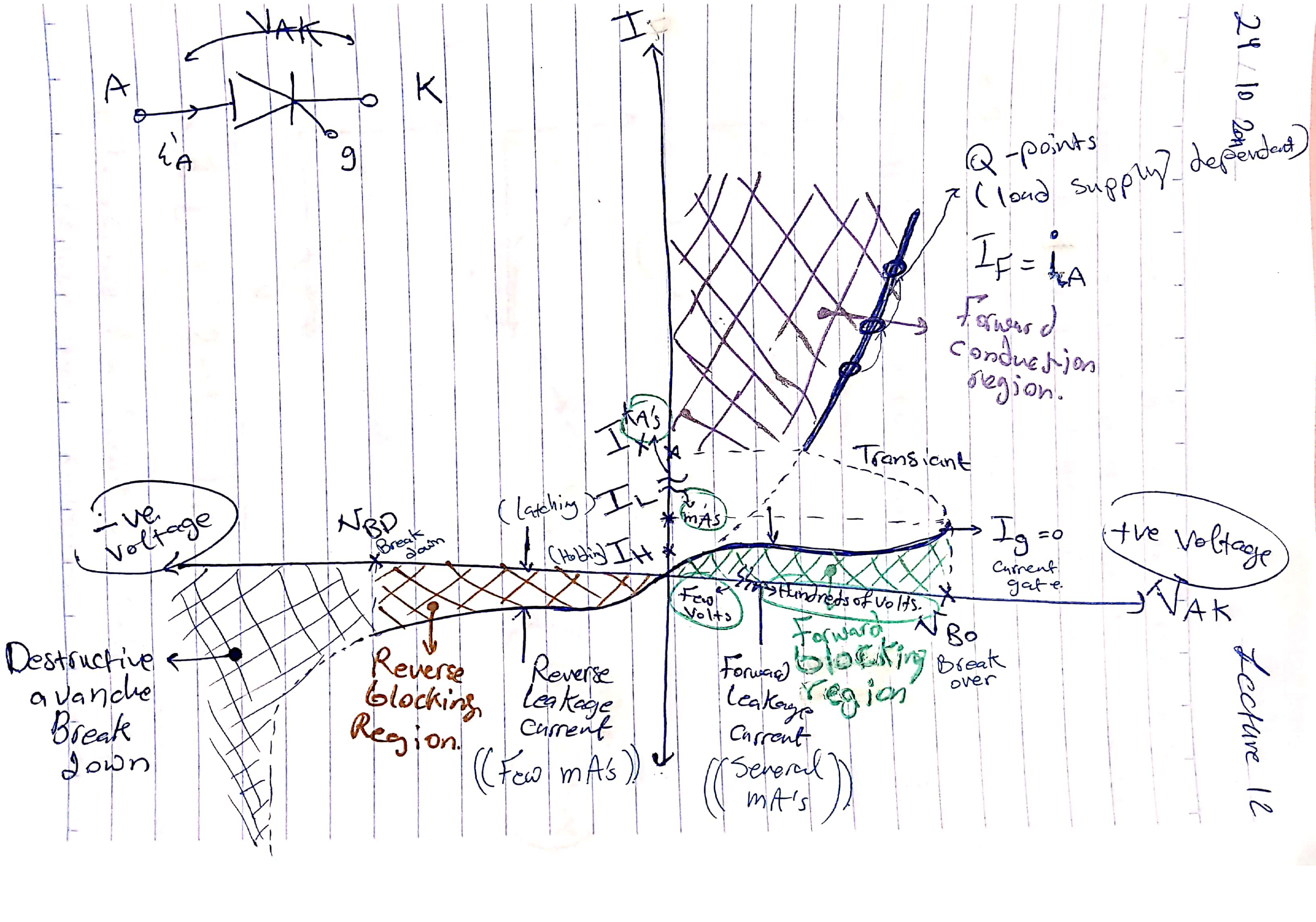
Dynamic charecterstics

- voltage (v) as a function of time (t).
- current (i) as a function of time (t).

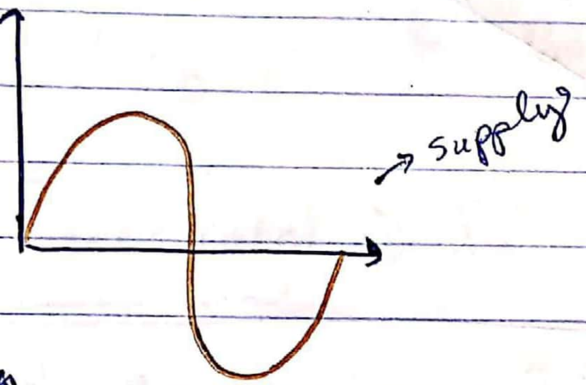
} Switching on/off

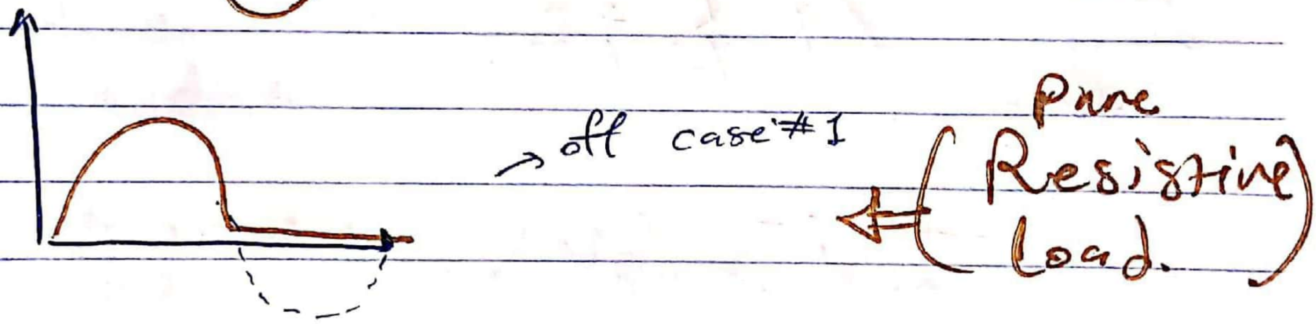


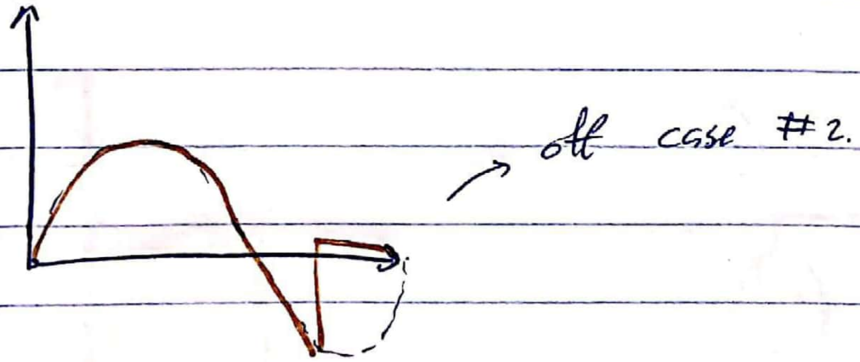
area under the curve → power dissipated.



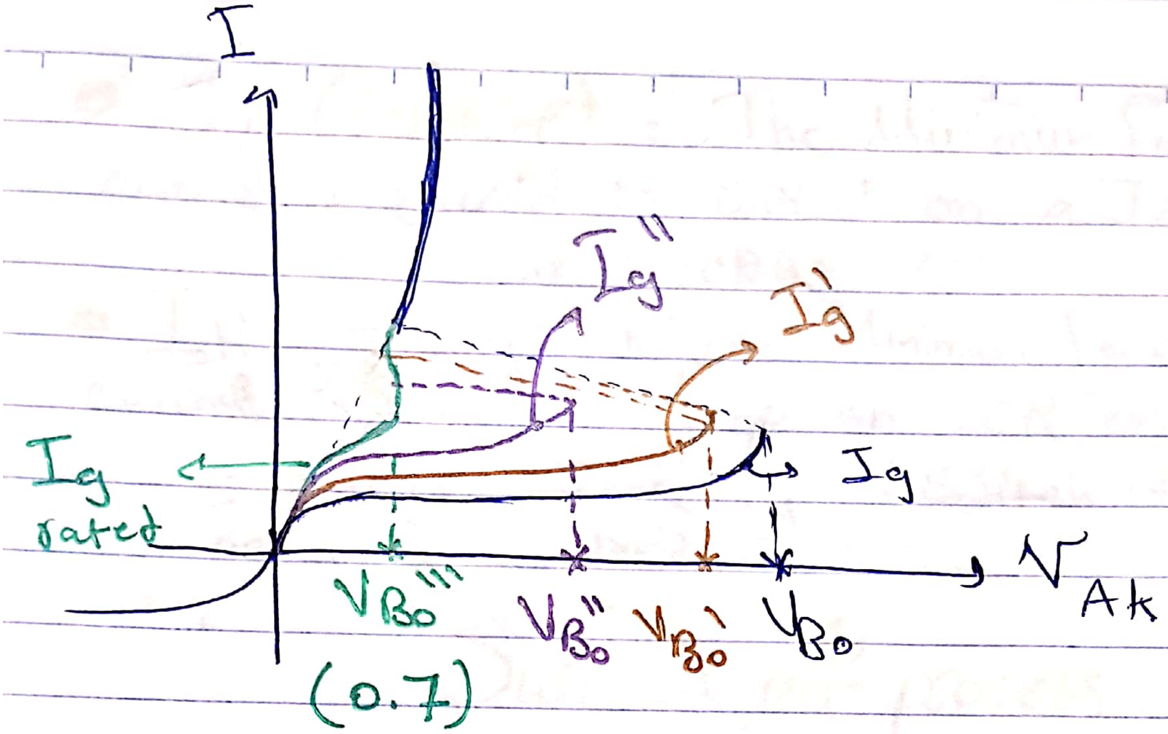
24/10
Lecture 12
VAK
A
K
iA
g
I
Q-points
(load supply dependent)
IF = iA
Forward conduction region.
mA's
IX
(Latching) IL
mA's
(Holding) IH
Transient
Ig = 0
Current gate
-ve voltage
+ve Voltage
VBD
Break down
Few Volts
Hundreds of Volts.
VBo
Break over
VAK
Destructive avanche Break down
Reverse blocking Region.
Reverse Leakage current
((Few mA's))
Forward Leakage Current
((Several mA's))
Forward blocking region

- The Voltage will decrease until the applied voltage on both load & Thyristor is equal to the supply voltage ((Transient))
- $I_L < I_X$
- I_H (Holding): to switch Thyristor off.
- 



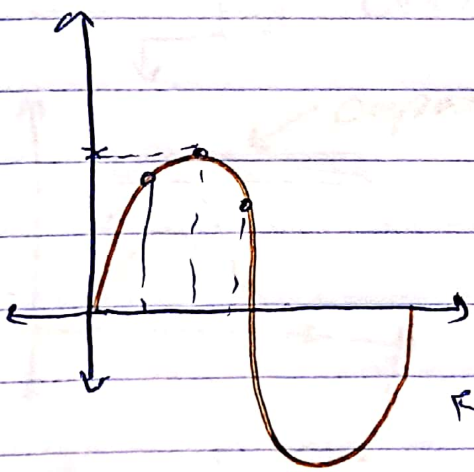


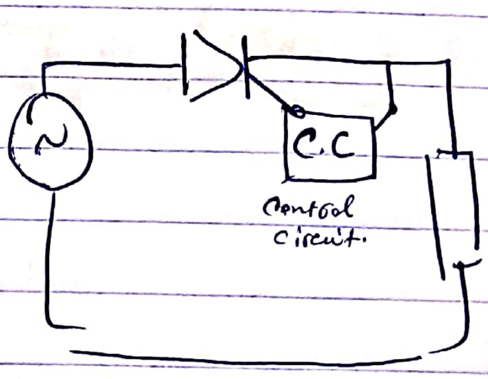
- $I_L = (2 \to 3)\, I_H$
- To reduce the Break over Voltage increase gate current.



- $\underbrace{I_{gate\ rated}}_{\text{to switch as a diode.}} > I_g'' > I_g' > I_g > 0.$

- $V_{Bo}''' < V_{Bo}'' < V_{Bo}' < V_{Bo}.$

- 



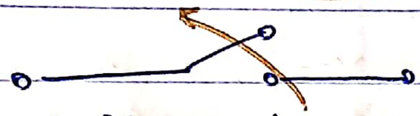
- لازم اقدر اتحكم بأي نقطة وال Voltage
  control → ما ينفخ عشان هيك بتحكم
  بال gate current.

- I_L (latching) : The Minimum Forward current required to switch on a Thyristor. or (SCR).
- I_H (Holding) : The Minimum Forward current required to keep an SCR on. or a Thyristor

→ ((if $I_{Forward} < I_H$ → Switch off action occures.))

Switch off process in SCR's.

= commutation of SCR.



السهم طالع عشان كان on

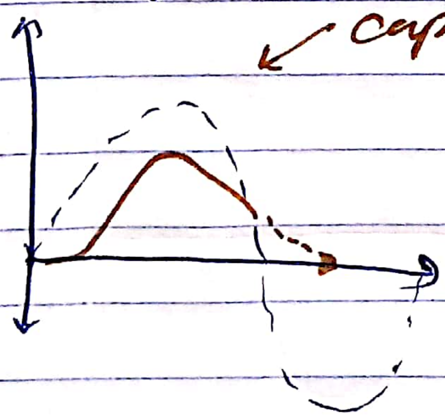
وبدي يصير off.

Types of commutation:

A. Natural commutation:

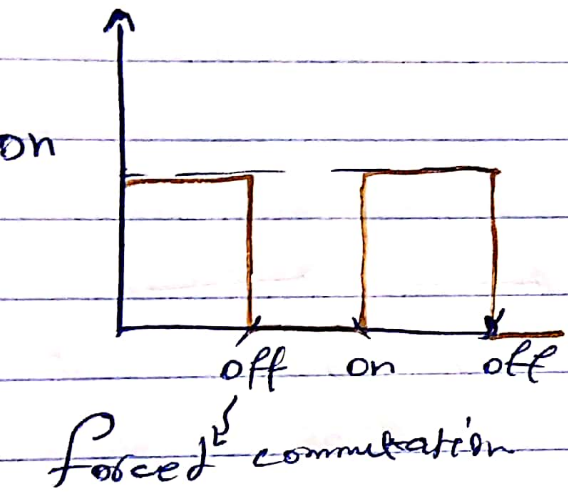
1. line commutation (Ac supply) ← from supply
2. Load commutation (capacitive load)

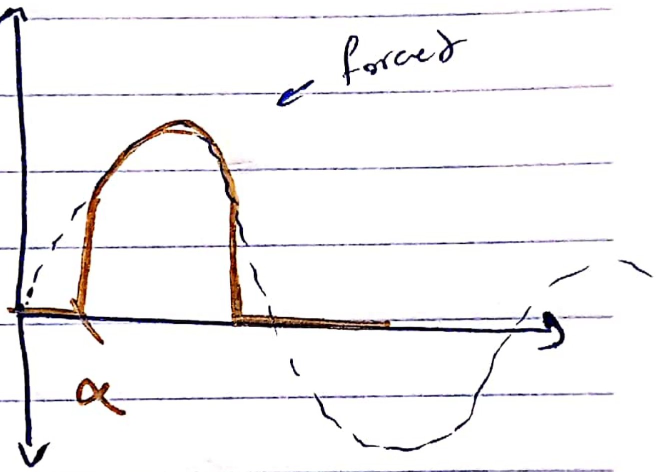
capacitive load ((i leads v)). leading power factor.



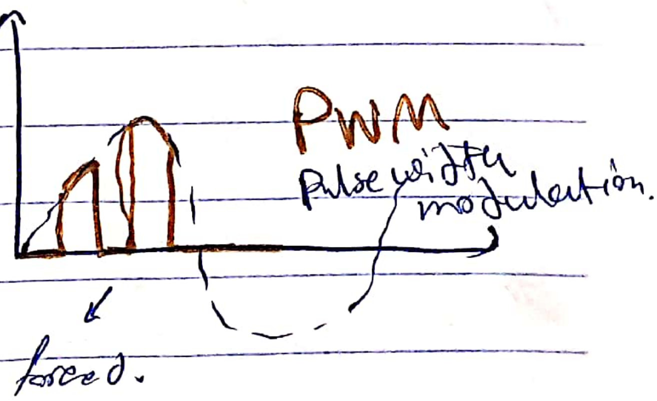
B. Forced commutation

1. To switch off DC excited SCR.
2. an AC excited SCR while being forward baised.





or

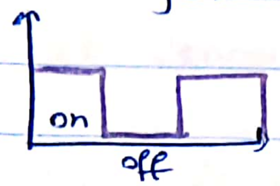


27/10/2019

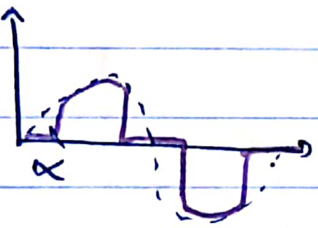
Lecture 13

Commutation

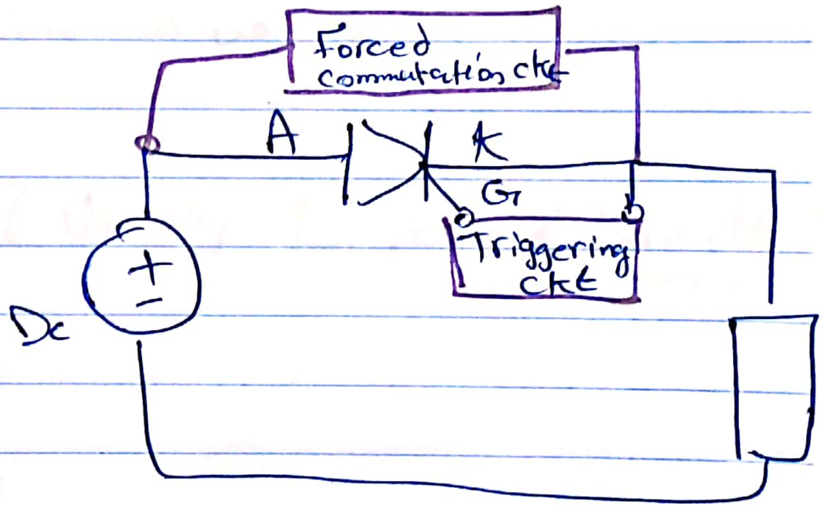
- **Forced**
  - a) Dc-Excited Systems



  - b) Ac-Excited with Switching off while Forward baised.



- **Natural**
  - Load: for capacitive loads
  - Line: for Ac-Excited Systems.



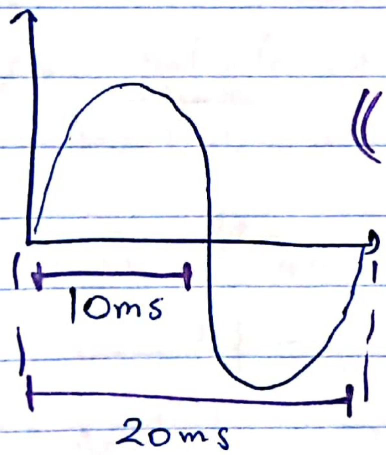
① Forced Commutation circuit (between A & K)
→ to Switch off Thyristors. (Aux SCR's, R, C, L, D)
↑ جواتها

Function: ① provides an Alternative path for SCR Forward current to decrease the current (less than I_H))

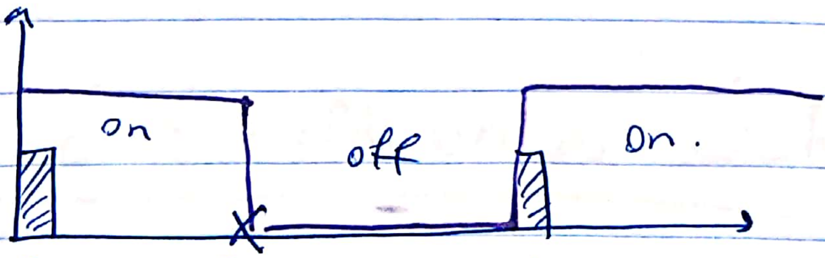
② apply Reversed Baising to The SCR for a period slightly greater Them T_{off}, where T_{off}: The →

Turn off time given by the manufacturer datasheet.
By The End of This period, The SCR is switched off and The commutation circuit is Also switched off. SCR will be back to conduction if triggered (not by the supply re-connection.)

- Turn off time : $\boxed{P}$ and $\boxed{N}$ junctions needs to recover charges (10's of μA's)
  عشان يفصل لما يطفي "كليًا" عند قطع التيار، فيه
  او تقليله عن ال I_H.

- 

((Usually Ton period < Turn off period.))

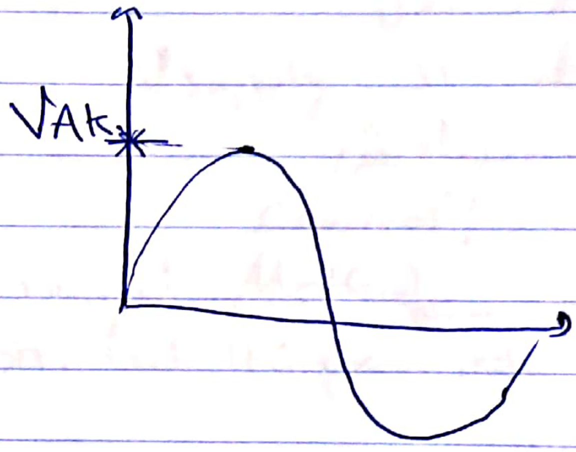


- Data Sheet information → Avg / RMS / pulse

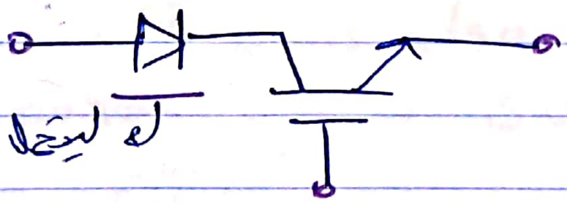
- V_{SCR} (rating) $= (2 \rightarrow 3) * PIV\ (V_{AK})$
  (peak inverse voltage)

Safty factor
(2 → 3)

← اما 2 او 3 ؛ اذا
بالامتحان 1.9 ∝ خطأ
اذا Multiple choice وفي متعتين
← نختار الاقل.



- Switch off Transistor in Ac (add diode)

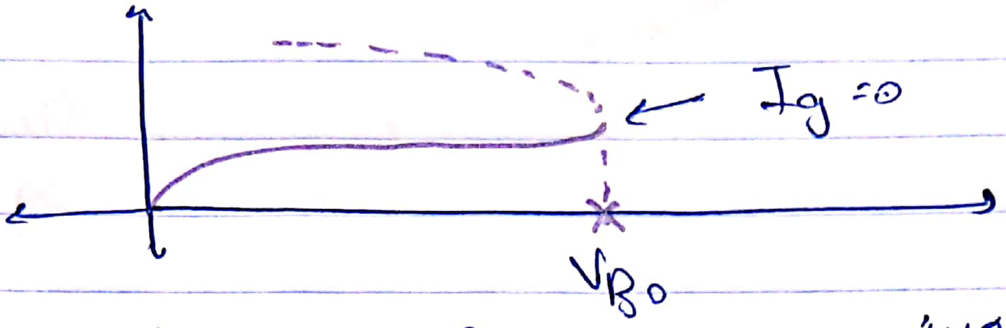


لا يتحمل ال negative voltage.

To Switch on an SCR

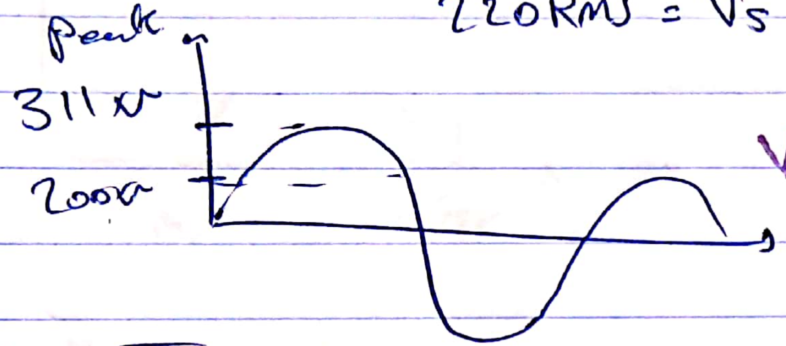
[A] By increasing The Forward leakage current, This can be done by:
(I) applying High V_{AK} Such that $V_{AK} > V_{Bo}$

○ تكبر ال V_{AK} أكبر من ال $V_{Break\ over}$



* اذا مثلاً جبنا SCR قيمة ال $V_{Bo} = 200V$

و عنا ال $V_s = 220RMS$



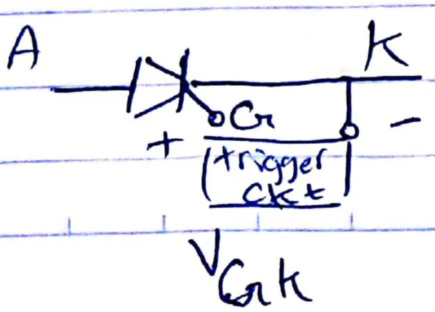
ذلك بشتغل على ال Vsupply لأنه مافيش control!

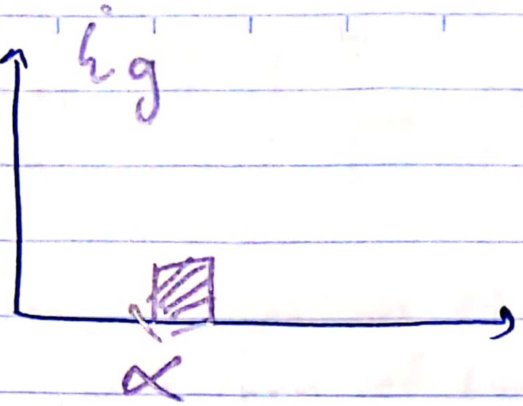
→ This is not a normal Method ← of controlling on, but it's possible.

[2] By Increasing the Ambient temprature (This is also not a normal method of controlling or switching an SCR on).

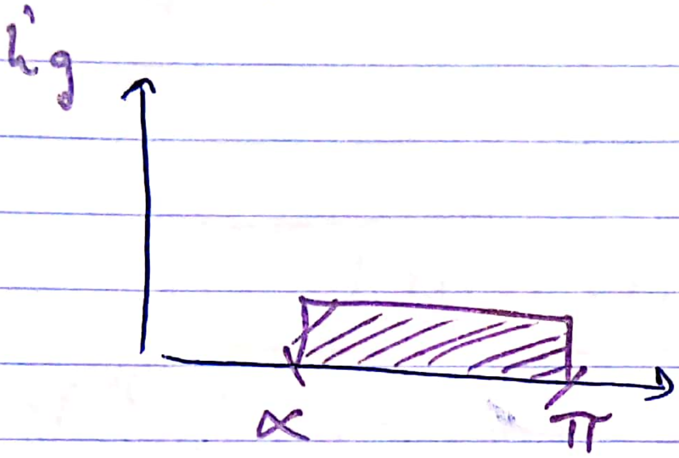
[B] By gate current:

* by appling a short pulse of current to the gate (i_g).

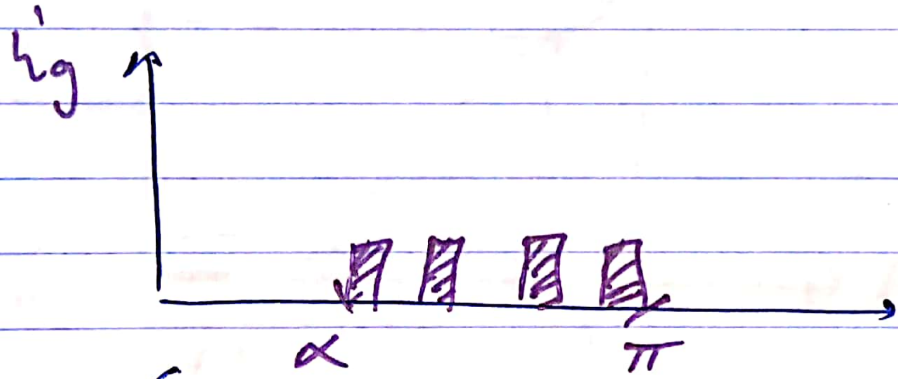




short



long



(10-20) KHZ (why?): some loads → High Inductive loads; The forward current takes time so Multiple pulses.

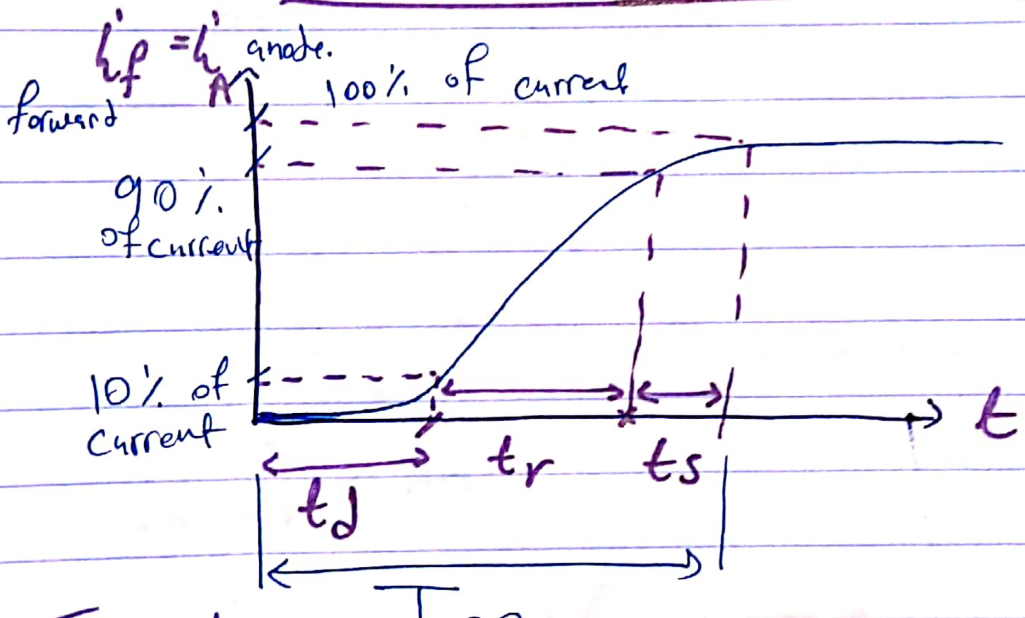
29 / 10 / 2019 Lecture 14

- $V_{AK} = f(t)$ }
  $I_f = f(t)$ } → Dynamic charecterstics.

- T_{on} : Turn on time
  T_{off} : Turn off time.

* we want T_{on} & T_{off} as small as possible.
→ Fast switching

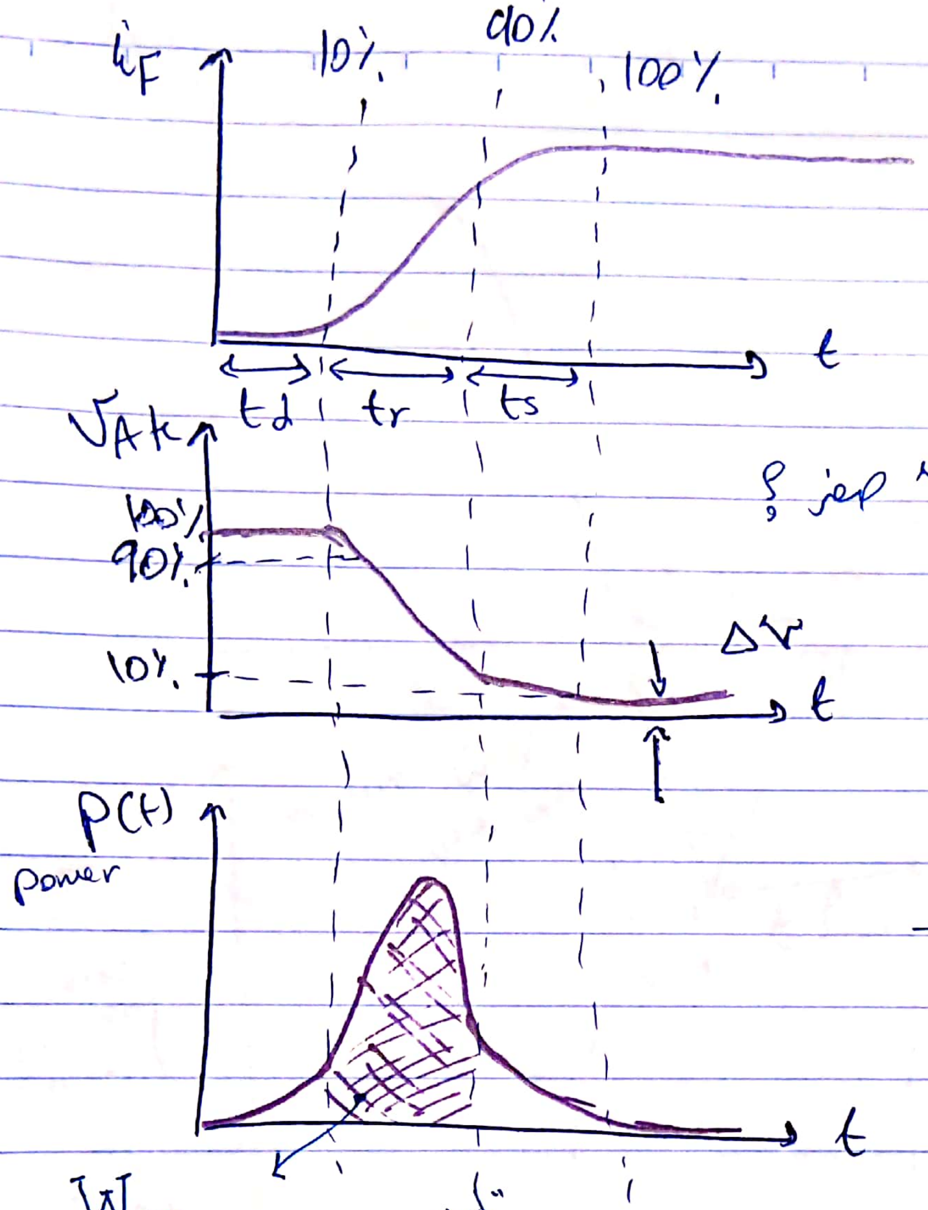
Turn on period



The Value of
- 100% of current is determined by load Impedance & the Supply Voltage.

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

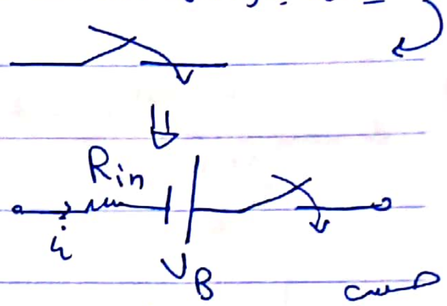
delay time, rise time, spread time.



W_{on}

"Energy in starting period"

ليه ما بتوصل ال V صفر ؟



Barrier voltage حسب $\simeq 0.7\ldots$

$\longrightarrow \Delta V_{AK} = 0.7 + R_i (i_F)$

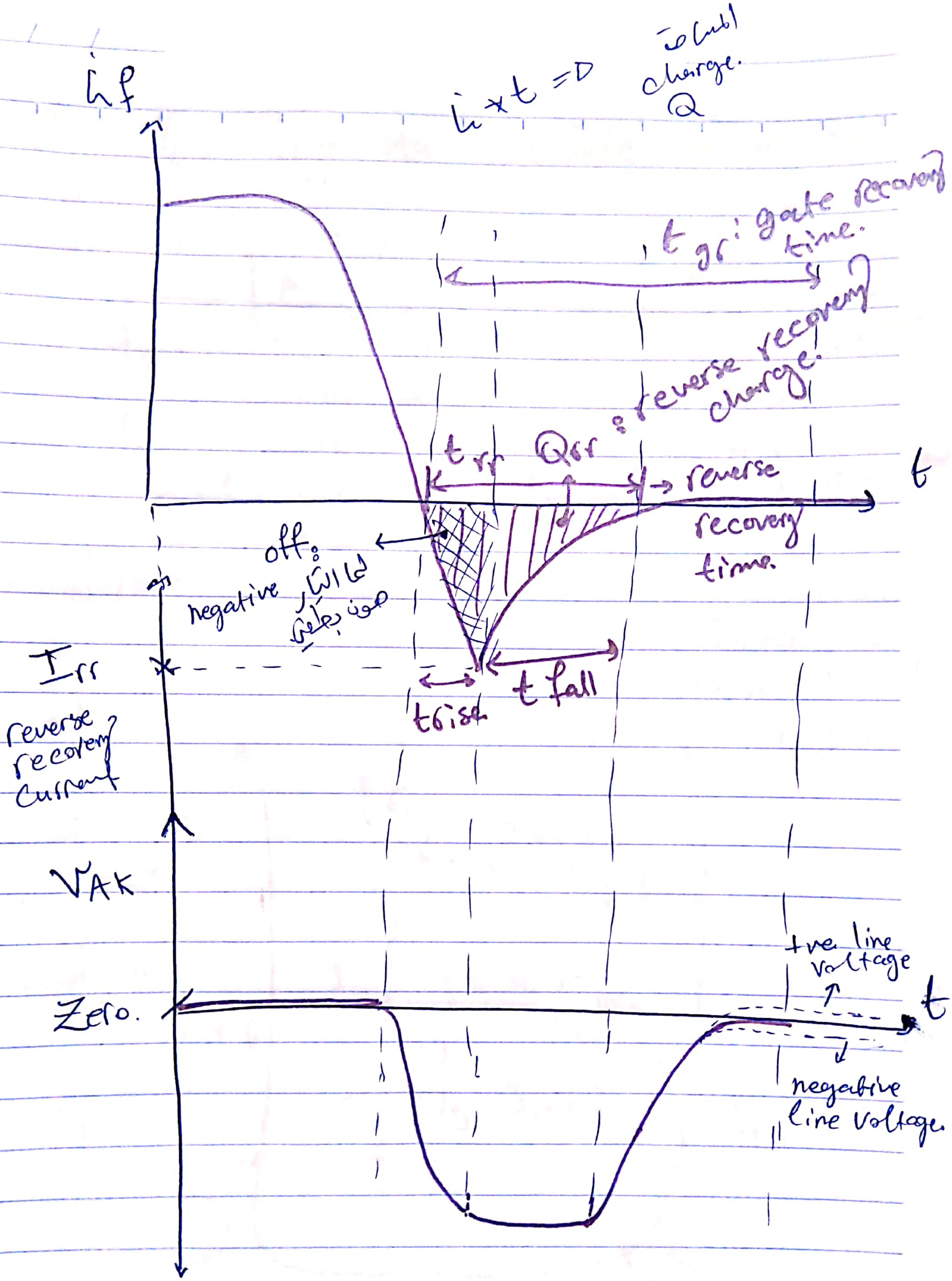
Turn off time

→ divergent أو لما
less than I_H
&
reverse baised.

Usually $T_{off} > T_{on}$.

$$T_{off} = T_{gr} + T_{rr}$$

(gate recovery) (reverse recovery ((Bulk)).

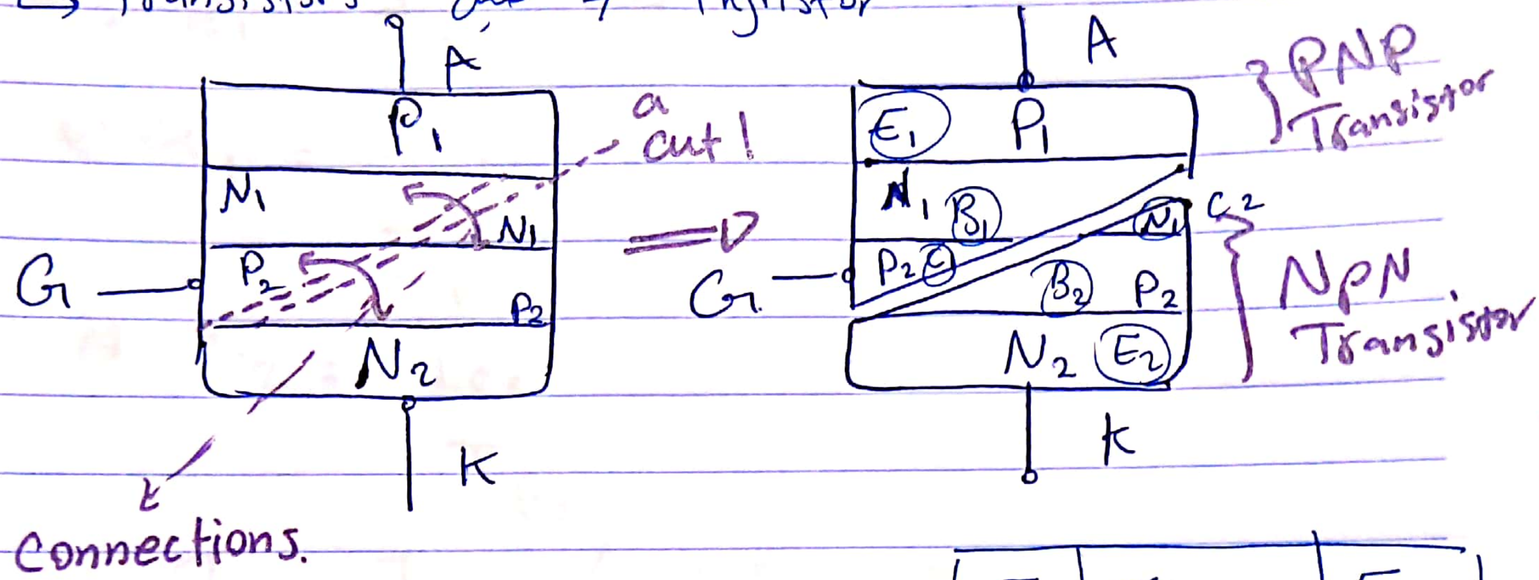


i_f
$i \times t \Rightarrow$ اجمالي charge Q
t_{gr}: gate recovery time.
Q_{rr}: reverse recovery charge.
t_{rr}
→ reverse recovery time.
t
off: لما التيار negative هو بطفي
I_{rr}
reverse recovery current
t rise
t fall
V_{AK}
Zero.
t
+ve. line voltage
negative line voltage.

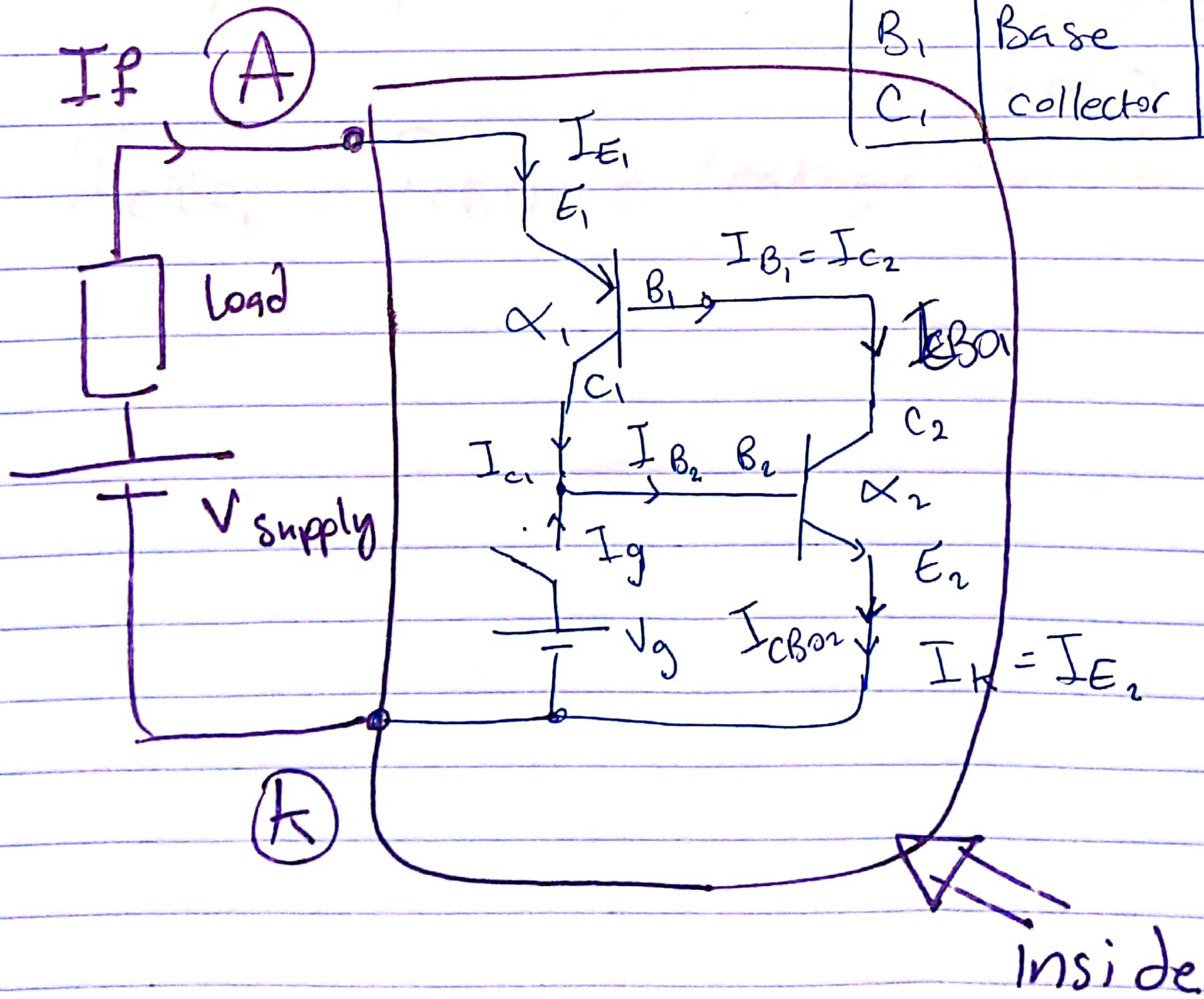
⊛ Two-Transistor Module of an SCR

محاولة في تفسير عمل ال Thyristor ، لكن اذا شبكت

→ transistors صح ≠ Thyristor



E_1	Emitter	E_2
B_1	Base	B_2
C_1	collector	C_2



- $I_{B_2} = I_g + I_{C_1}$
- $I_{E_1} = I_{E_2} - I_g$
- $\alpha_1 = \frac{I_{C_1}}{I_{E_1}}$
- $\alpha_2 = \frac{I_{C_2}}{I_{E_2}}$
- $I_A = I_F = \frac{(\alpha_2 I_G + I_{CBO_1} + I_{CBO_2})}{1 - (\alpha_1 + \alpha_2)}$

I_{CBO_1} & I_{CBO_2} = leakage current.

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- $$I_f = \frac{\alpha_2 I_g + (I_{CBO1} + I_{CBO2})}{1 - (\alpha_1 + \alpha_2)} \quad , \quad I_f > I_L$$

I_f: forward in Thyristor. I_L: latching current. $I_f > I_L$ for conduction.

$$\alpha_1 + \alpha_2 \lesssim 1$$

- To increase I_f: ① Increase $I_{CBO1} + I_{CBO2}$
  - → By V_{AK} ↑↑
  - → or (Heat) ↑↑

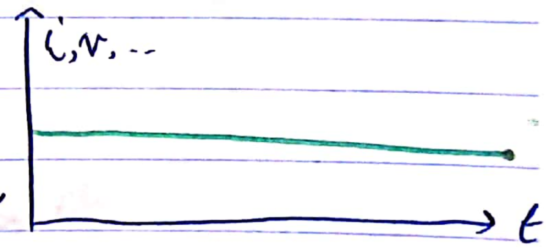
  } not normal.

② Increase I_g
→ Alternative (light beams)

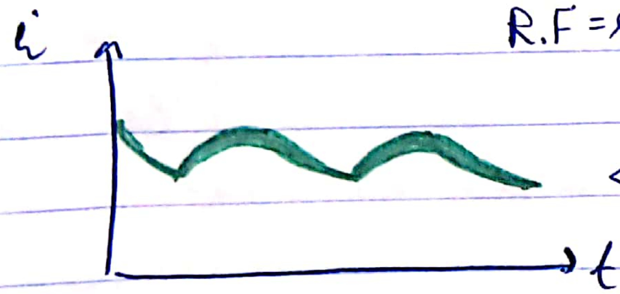
Back to the Ripple factor

→ Quality parameter for DC, V (voltage), I (current), P (power).

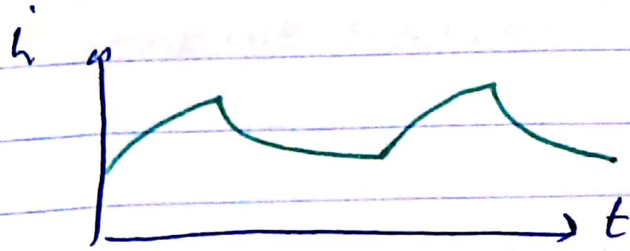
→ Optimum (Ideal) DC Signal:



Zero-Ripple
R.F = 0



Ripple ، متموّج
R.F > 0



chopper circuit output
R.F > 0

by definition

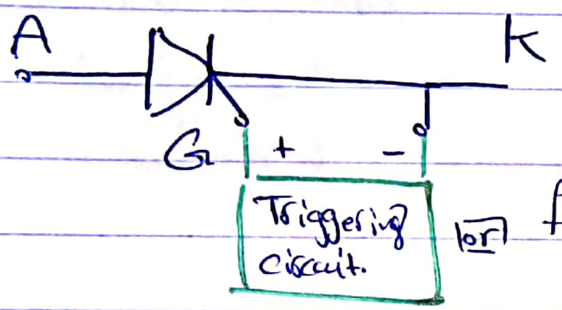
$$R.F = \frac{\sqrt{V(rms)^2 - V(avg)^2}}{V(avg)} \quad , \quad 0 \leq RF < \rightarrow \infty$$

Pure Dc
$V_{avg} = V_{rms}$
Ideal

~~pure Ac~~
not accepted

Back to the Triggering circuit

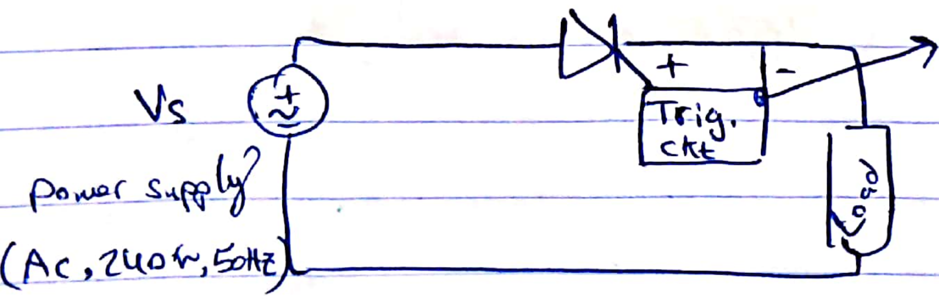
Low power Electronic circuit.



[or] firing circuit.

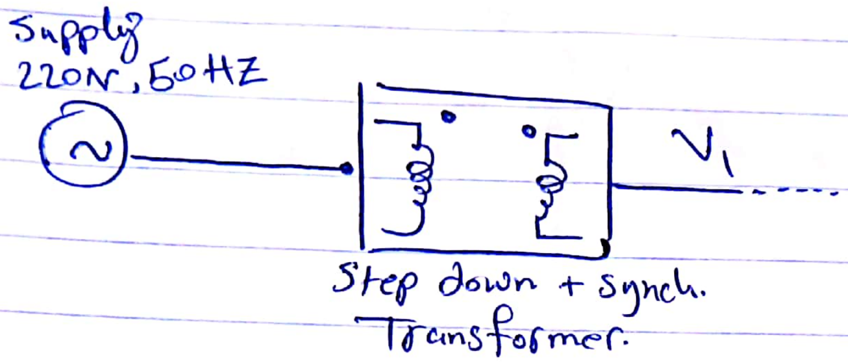
- Triggering circuit should be Synchronized with The Ac power Supply! (that is supplying the converter itself).

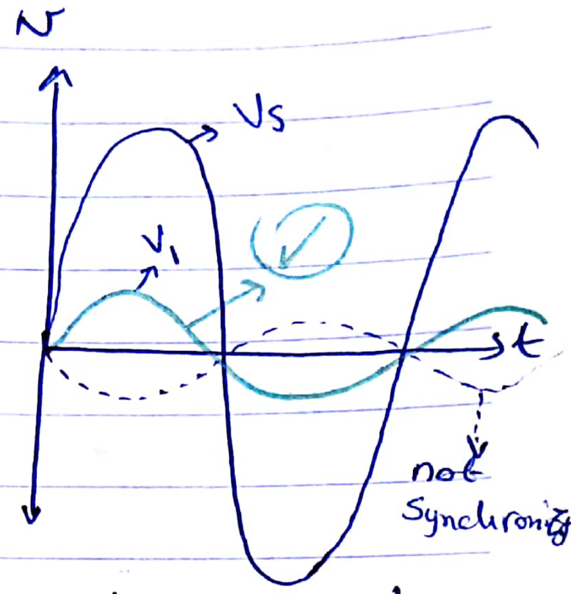
Converter



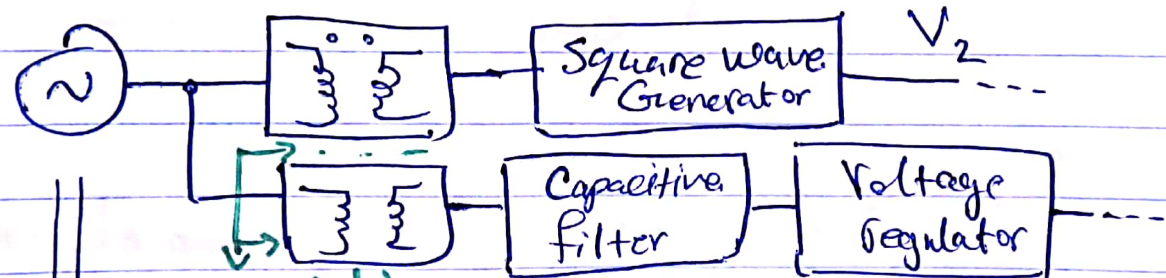
- There are electronics in the triggering circuit (needs power)

Synchronization:

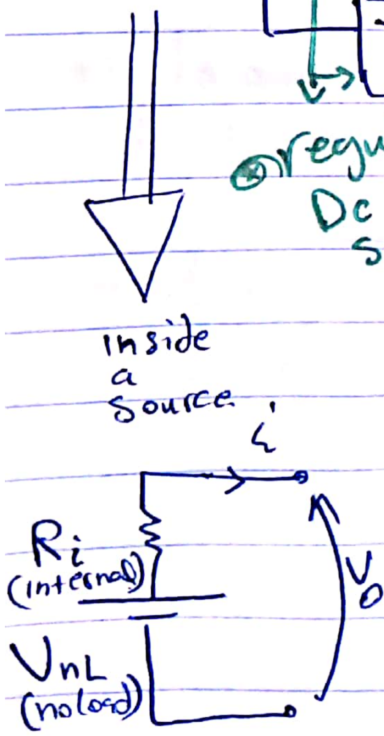




- The current is in phase with the current suppling the load.
- polarity test on the Transformer to make sure It's Synchronized ((dots))

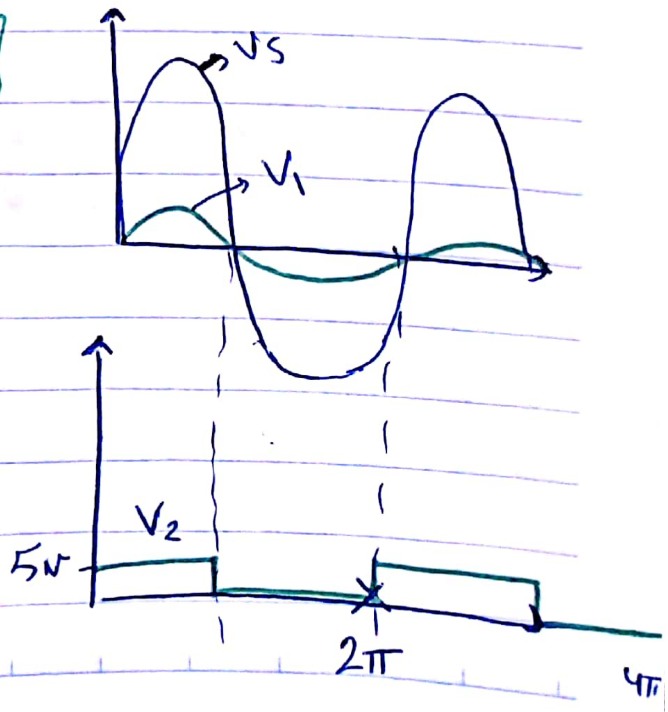


- regulated Dc power supply: to supply the triggering ckt.



$$V_o = V_{nL} - R_i * i$$

$$\boxed{V_o < V_{nL}}$$



- Voltage regulator: electronic element I_c: 7XXX

7XXX

A regulator ← 7

9 : negative (−)

8 : positive (+)

XX → Regulated voltage

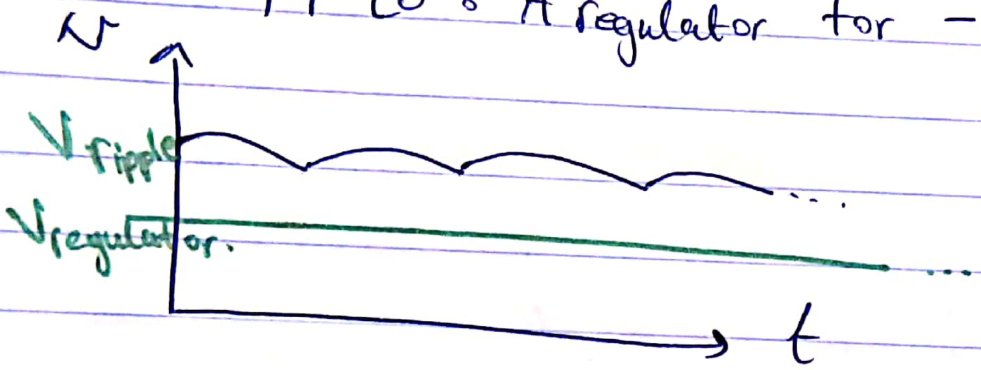
05 : 5v

09 : 9v

12 : 12v

→ ex: 7812 : A regulator for +12v.

7920 : A regulator for −20v.



Voltage regulator level must be less than the rippled Voltage.

- Triggering frequency of each switch equals that of the supply frequency.

- A regulated power supply: Zero voltage regulation (loaded or unloaded).

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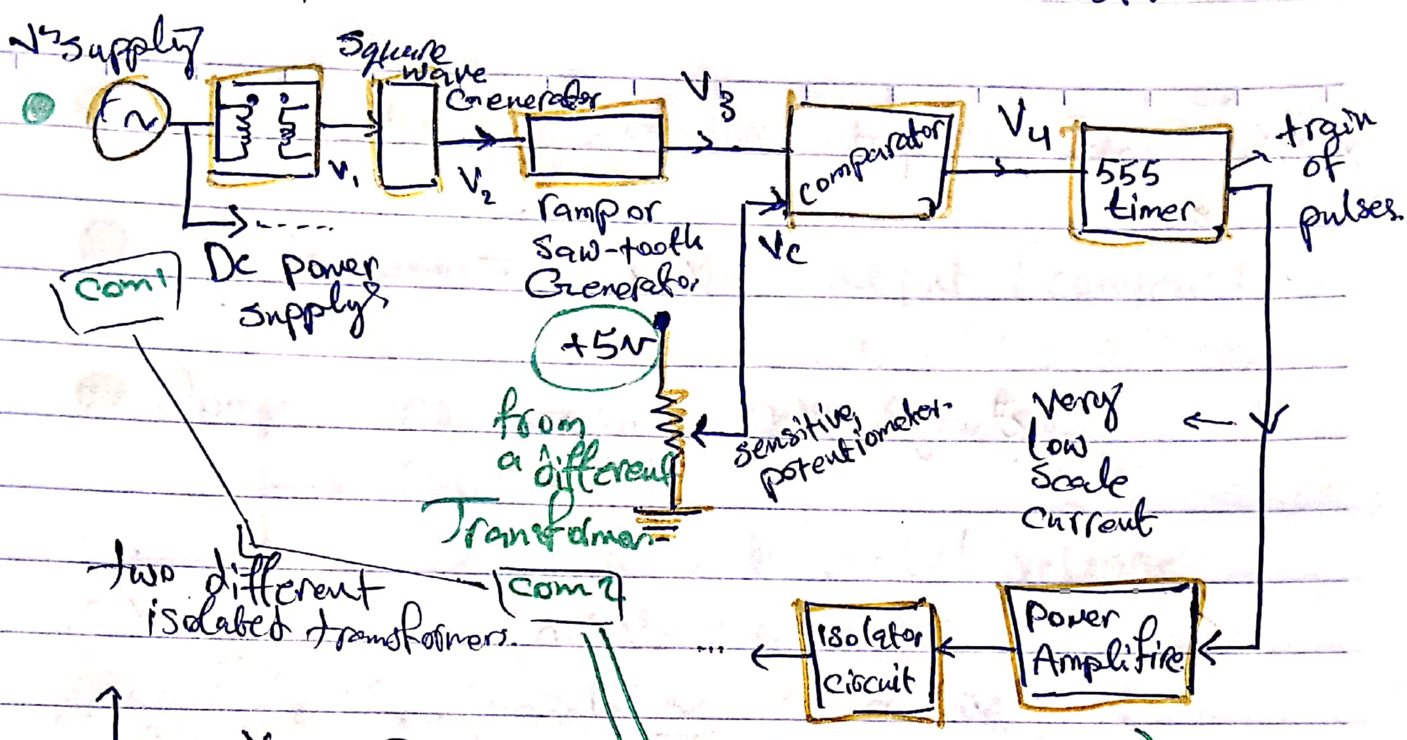
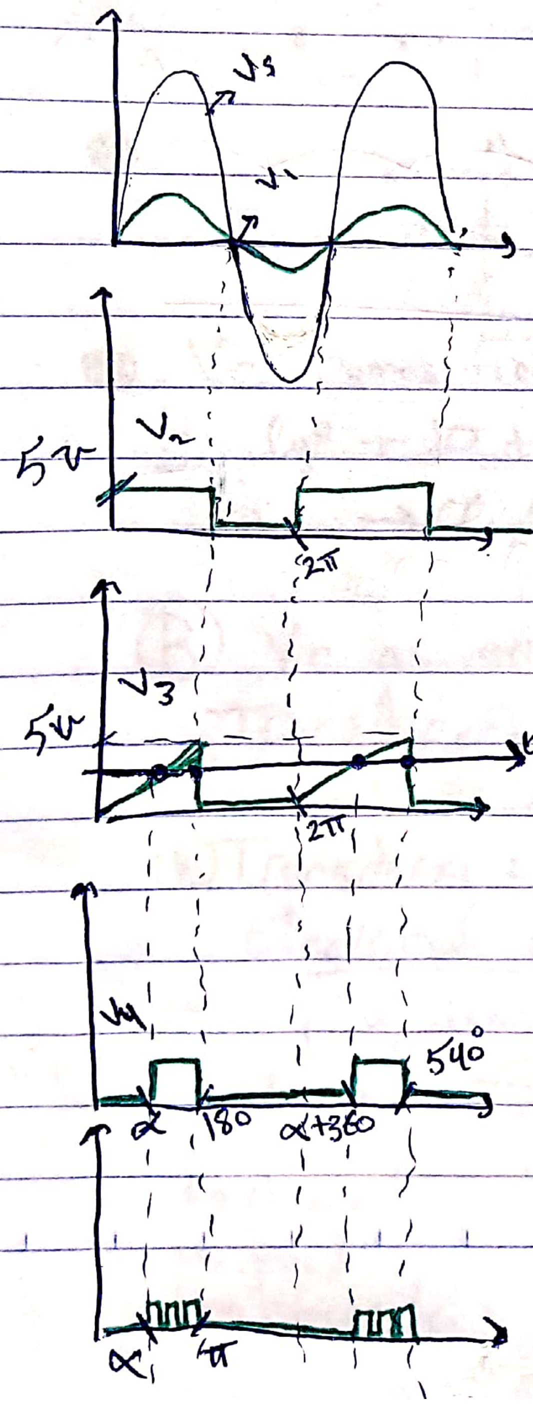
Lecture 16



we don't care if This +5v is synchronized or not.

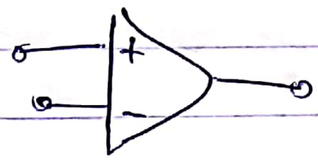


/ /

- V_3 is the output of an Integrator Op-Amp.
- V_4 is another Op-Amp output (comparator).
- Comparator: compares two signals:
  - → Saw-tooth
  - → V_c : Variable control voltage.

    $(0 \leq V_c \leq 5)$ volt.

  * Firing angle $\underline{\underline{\alpha}}$ $0 \leq \alpha \leq 180^\circ$

- 

  ⟸ comparator

  when $\alpha = 0$ then $V_c = 0$

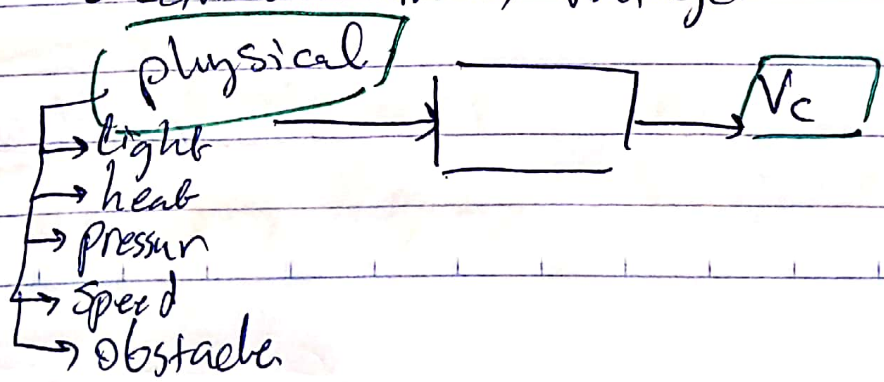
- V_c comes from: (A) Regulated 5v DC power supply + 10 turns potentiometer

  → ((Manual control of α))

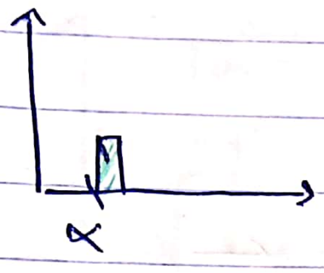
(B) V_c as an output of a certain physical Transducer.

→ ((automatic control of α))

(*) Transducer: physical Quantity to Electrical current / voltage.



Triggering pulses

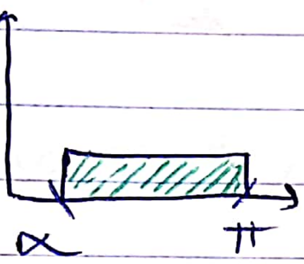


#1 ● Single short pulse.
Suitable for low inductive loads or resistive loads.

Disadvantage → Triggering isn't ensured.

Advantage → gate losses are the lowest

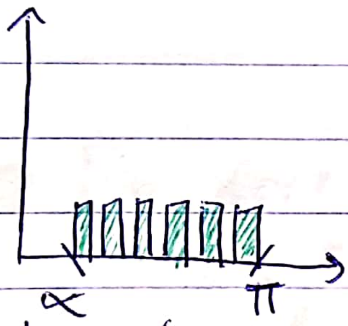
we don't prefer these two



#2 ● Continouse signal
$\alpha \leq \text{Signal} \leq \pi$

Advantage → ensure triggering

DisAdvantage → Highest gate losses.



#3 ● Train of pulses (10-20 kHz)
High frequency.

✓ → ensure triggering

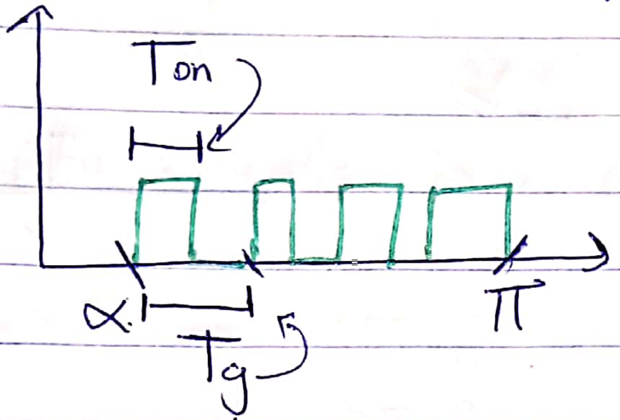
✓ → moderate gate losses. (medium).

→ to make sure that triggering occured. & to have reasonable losses values.

● To obtain the schmitt trigger pulses, use 555 timer Ic.

Homework 555 timer : ((التعريف، كيف نحلها، نتيجها)) & ((modulation index)) ((chopping frequency)) ، واختبار

- Train of pulses ⟶ period (T_g) ((10-20 KHZ modulation frequency))
  ⟶ period (T_{on}).



$T_{on} = \delta \cdot T_g$
↓
modulation index.

- power Amplifire:
  Darlington ⟹ to Amplify the current.
  → doesn't change the signal shape.

- Isolator: (A) pulse Transformer.
  (seperate two different circuits).
  excellent core material such that no saturation due to the Dc gate pulse occurs.
  → to Isolate the electronic triggering signal from the power signal.

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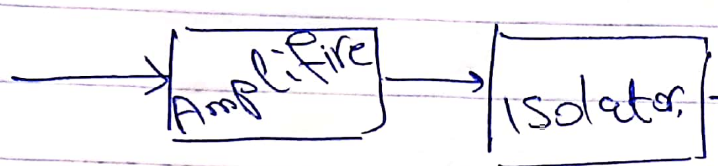
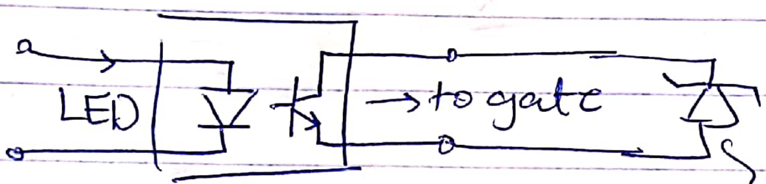
(B) Opto coupler Isolator → upto 2000V



Through voltage limiter to the gate.

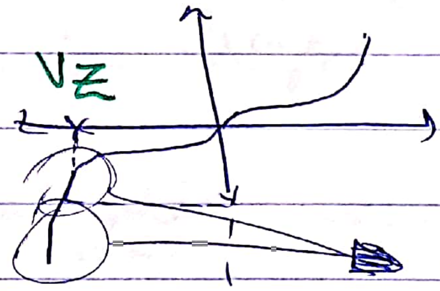
opto coupler is a light emitting diode



Zener diode.

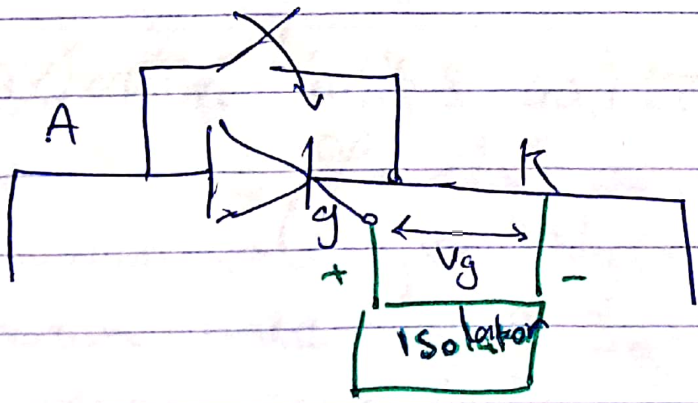
- Zener diode.

Works in the reverse & the forward baising. to limit the voltage.

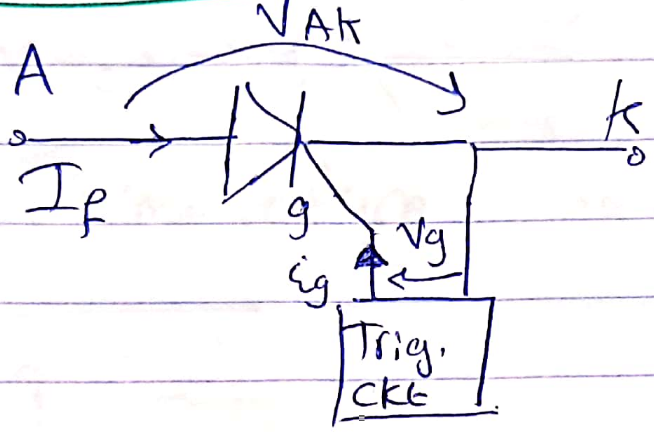


Controlled Break down.

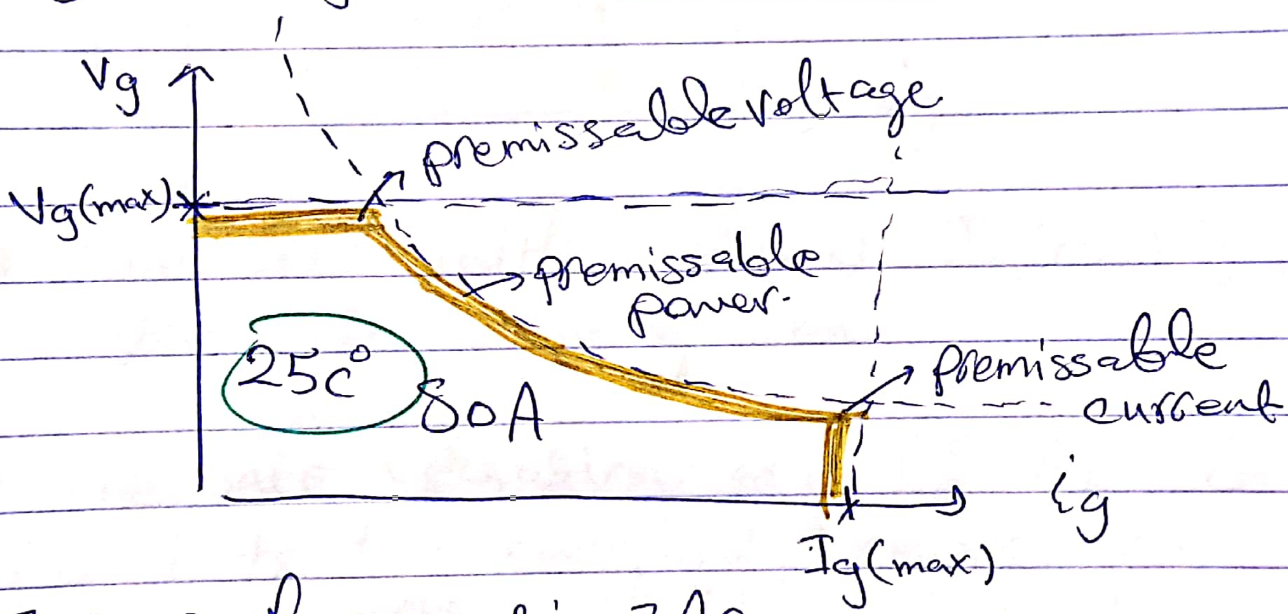
- To Isolate power part & the Electronics part from ~~each other~~.



① Gate characteristics



- $V_g = f(I_g)$ under certain ambient tempreture.



- SOA: Safe operating Area.

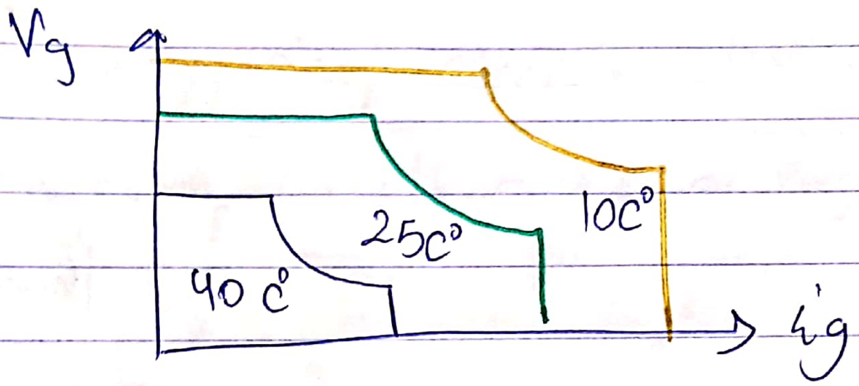
Maximum limits and tempreture effect.

(A) maximum voltage $V_{g(max)}$.
(B) maximum gate current $I_{g(max)}$.
(C) maximum power limits. $P_{g(max)}$

- Power : is a constent under a variable current

$P_{max} = V_g * I_g$, $V_g = \frac{P_{max}}{I_g}$

If Jempreture changes

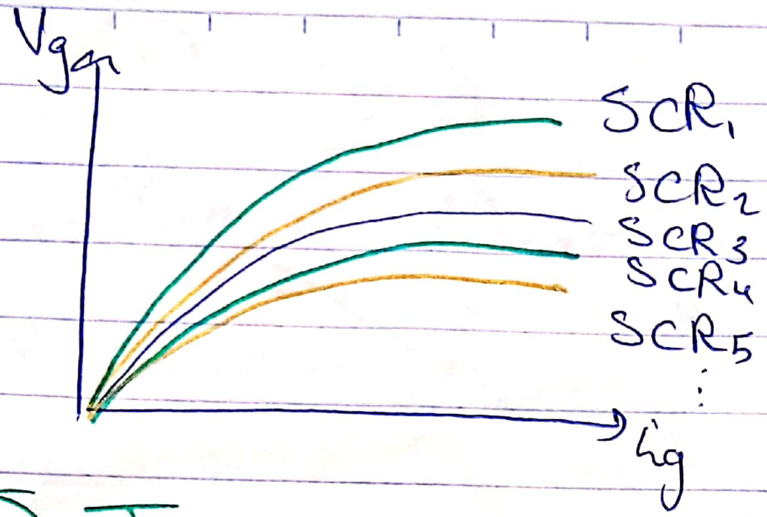


- The area within $V_{g(max)}$, $I_g(max)$ & $P_{g(max)}$ is the safe operating area.

- The safe operating area (SOA) is directly related to the ambiant tempreture.
  → SOA ↑↑ if $T_{ambiant}$ is lower.
  → SOA ↓↓ if $T_{ambiant}$ is Higher.

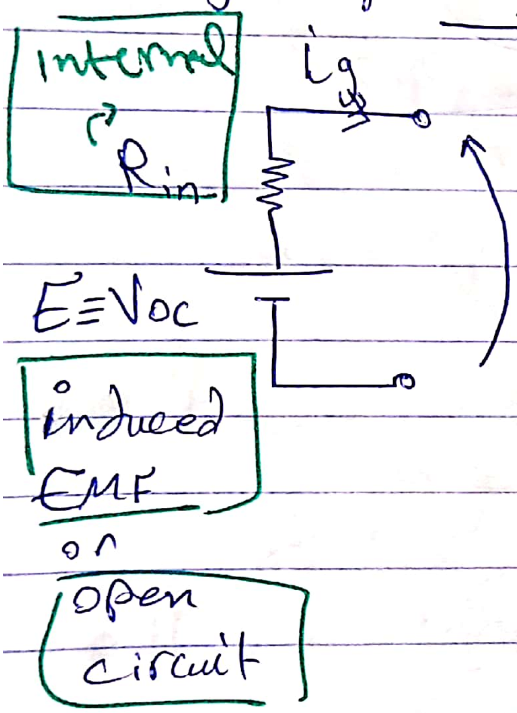
② SCR charecteristics

manufaturer's data
→ Usually a test is on a family of SCR's.

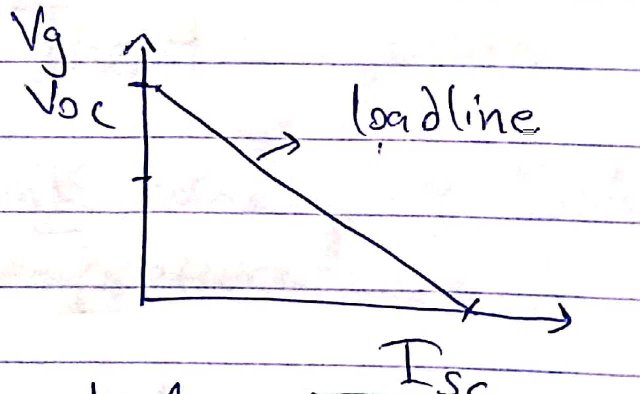


③ Triggering circuit charecterstics

- Triggering circuit is a power supply. → (Dc power supply)



$$V_g = V_{oc} - i_g R_{in}$$



(short circuit current)

- The slope is Rin dependent. (triggering circuit design dependent)

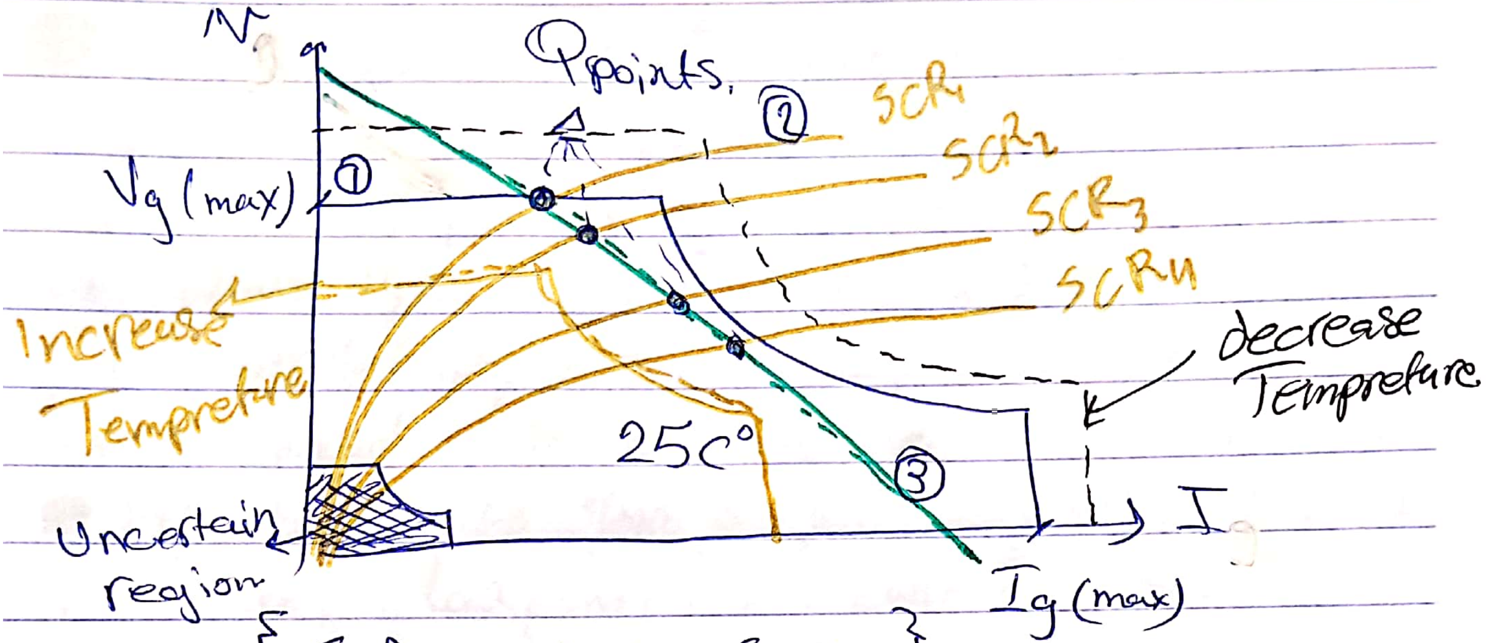
a) at no load → $i_g = \phi$, $V_g = V_{oc}$

b) Short circuit condition (SCC): $V_g = 0$

↳ $V_{oc} = I_g * R_{in}$

$= I_{sc} * R_{in} \Rightarrow R_{in} = \frac{V_{oc}}{I_{sc}}$

① ② & ③ Together.

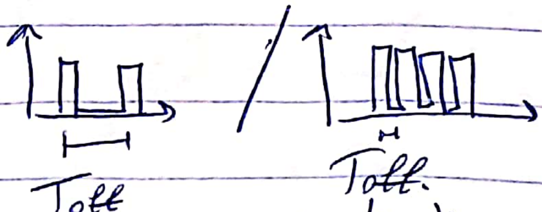


- {SCR_2 – SCR_3 - SCR_4} in The SOA.
- SCR_1 on the limit (Distractive.)

- if we decrease The temprature in black ● all SCR's will work normally in SOA.
- if we increase Temprature in yellow ● non of the SCR's will work.

→ we don't know if SCR's will work in The Uncertain region (small current values).

Duty cycle



if T_{off} long Then maximum power limits are Higher.

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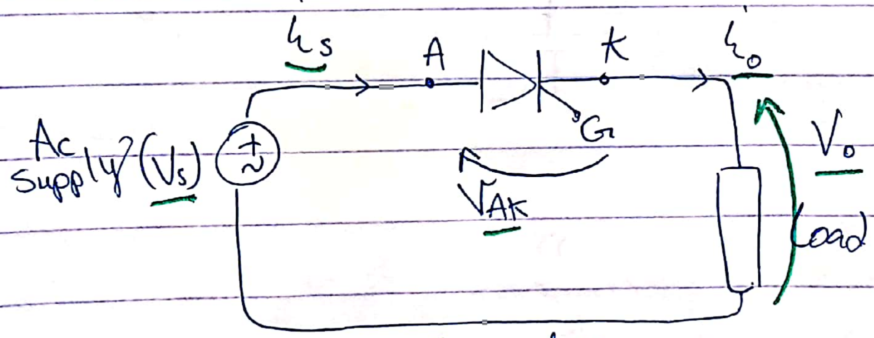
Analysis

⊛ Single-phase, half wave, controlled Rectifire

→ number of phases : single phase, three phase
→ wave type : half wave , full wave.
→ controllability : controlled , uncontrolled.
↳ uncontrolled $\alpha = 0$, controlled α has a value.

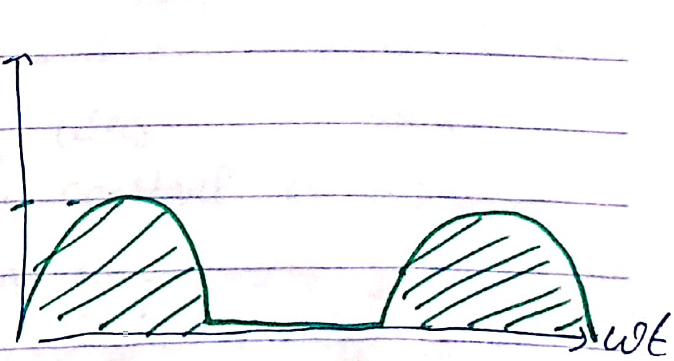
- In practical life there is no half wave. (why??)
  ↳ ripples , low power, Dc current in supply and harmonics.

power circuit (one thyristor ; simplest case).



Converter
(rectifire)

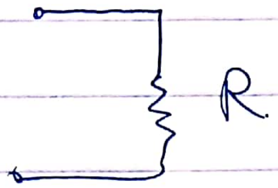
- Half-wave rectifire on a pure resistive Load



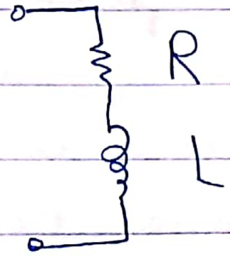
→ when choosing Thyristors
1. peak Value (most Important)
2. RMS Value
3. AVG. Value.

possible loads.

[1] Resistive load.

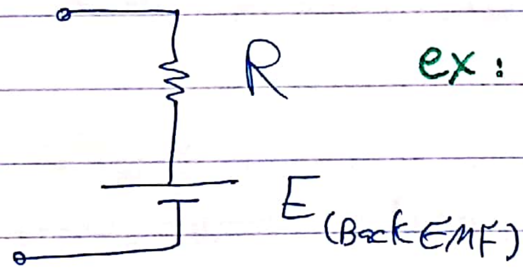


[2] R-L load



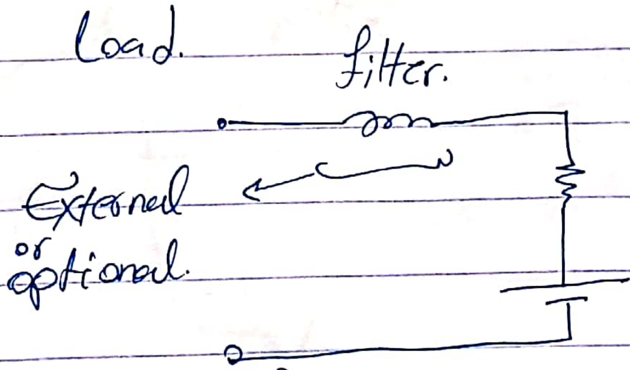
ex: • a field circuit for any machine.
• Industrial Heating system.

[3] R-E load



ex: Battery.

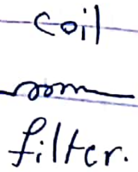
[4] R-L-E load.



ex: • Dc motor.
• Battery with Smoothing current filter in series.

⊛ in R-L-E loads, if $\underline{\underline{L}}$ was very big ⟹ vertually constant current.
⟶ So much like a pure Dc.

we should not charge a battery with ripple or Pulsating current add



Expected waveformes of intrest

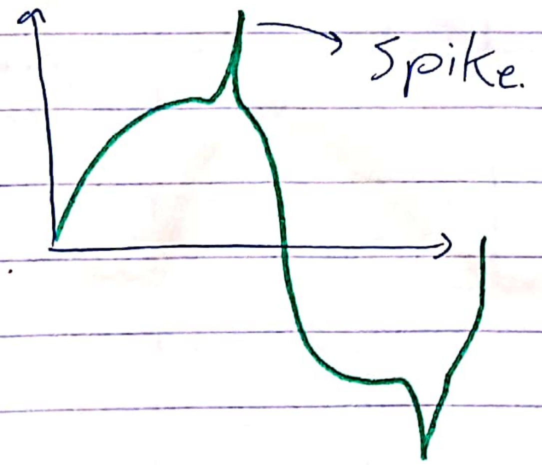
i_s, V_s, V_{AK}, i_o, V_o.

→ define α, the firing angle or triggering angle or phase delay angle.

⇒ α: the angle at which the SCR is triggered (fastly?), measured with respect to the Zero crossing point of the supply voltage. After which; the SCR becomes forward baised.

⊛ Why do we need V_{AK}?

→ optain PIV: peak inverse voltage.



- بحطله capacitor عشان نشيل ال spikes.
- The capacitor is called a Snubber.

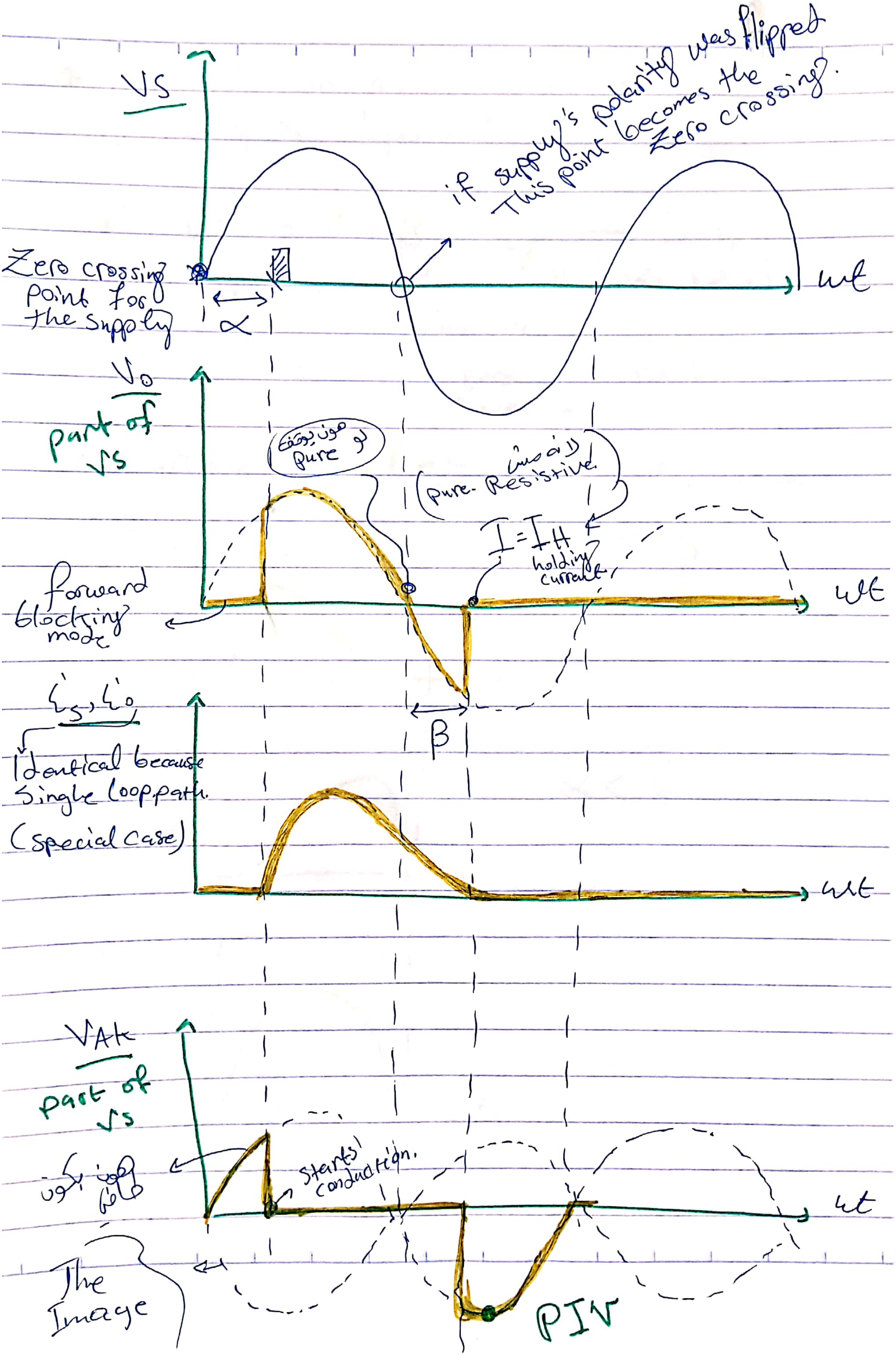
- $0 \leq \alpha \leq 180°$

0 → uncontrolled.

$180°$ → Zero output (Switch off) → if pure resistive

Inductive load, current will lag.

α: the control parameter.



Vs
if supply's polarity was flipped
This point becomes the Zero crossing.
Zero crossing point for the supply
α
ωt
Vo
part of Vs
لو pure
هون بيوقف
لانه مش
pure-Resistive.
I = IH
holding current
forward blocking mode
β
ωt
is, io
Identical because single loop path.
(special case)
ωt
VAK
part of Vs
هون بيكون
عالي
starts conduction.
ωt
The Image
PIV

① β : Extention angle. زاوية الاطفاء

→ load & α dependent.

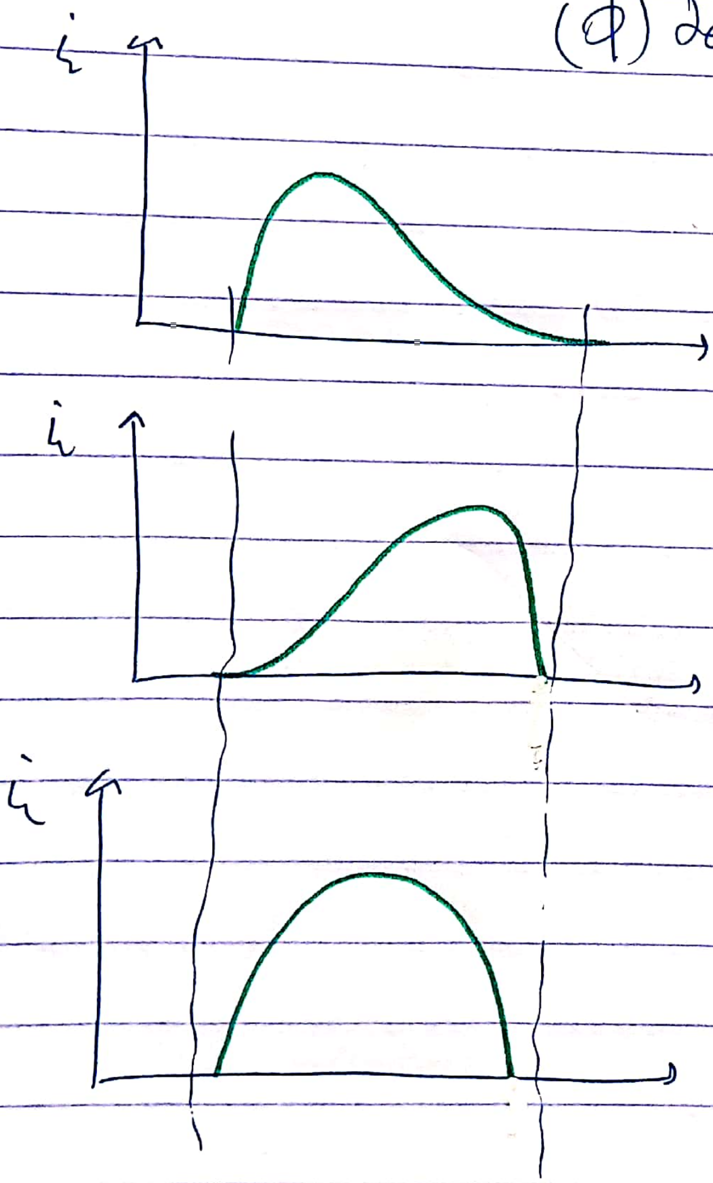
at $\omega t = \pi + \beta$, $i_f \rightarrow I_H$

[كلما كان الـ load inductive بيكون β اكبر.

اما اذا pure resistive , $\beta = 0$.

• Current can be:-

(ϕ) depends on load phase angle



$\alpha > \phi$

$\alpha < \phi$

$\alpha = \phi$

10 / 11 / 2019 Lecture 19

- In order to turn off a Thyristor we want the current to be less than I_H & Reverse baise.

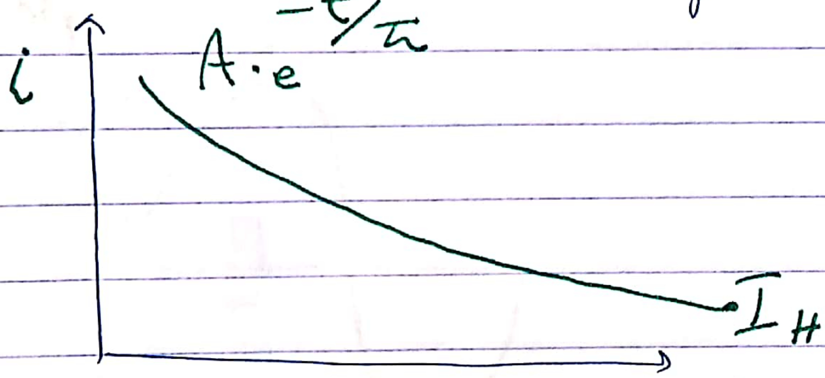
- we have two boundary limits:

primary α, $I = I$ latching

Secondary β, $I = I$ holding

} in normal case we assume both = Zero except a special case we will learn about.

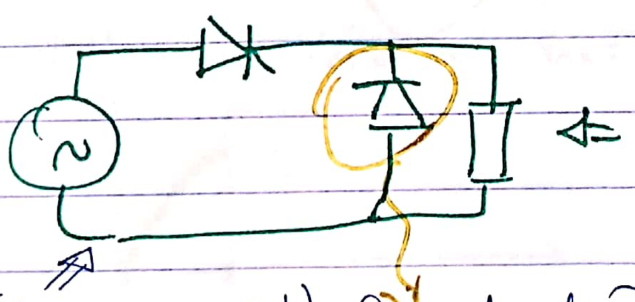
- if we have a natural decay without a forcing function (free wheeling)



$A \cdot e^{-5t}$

it will reach Zero in ∞ but I don't have ability to reach ∞.

having a free wheeling is going to Help us turn off The Thyristor in the (no forcing function) case.

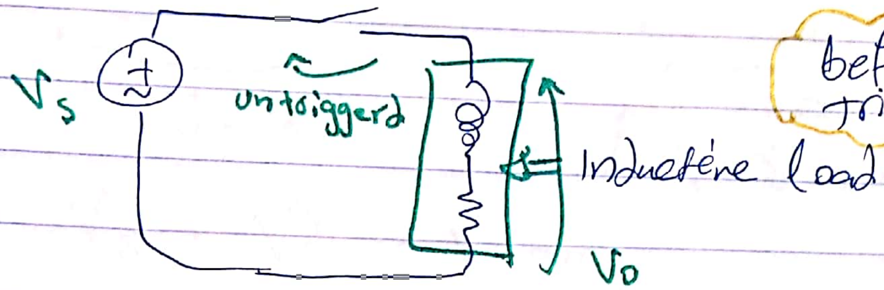


(Semi-controlled) free wheeling diode.

Analysis:

half wave Rectifire

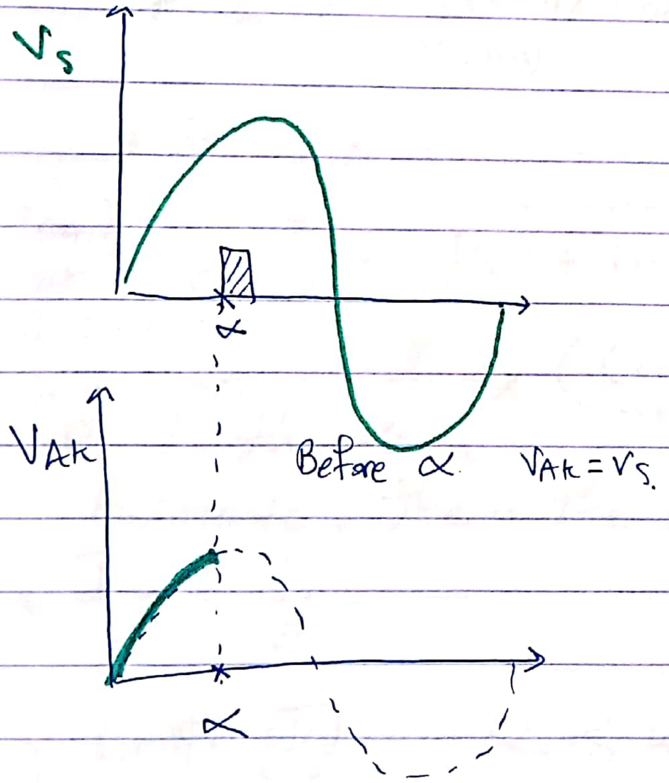
[1] $0 < \omega t < \alpha$



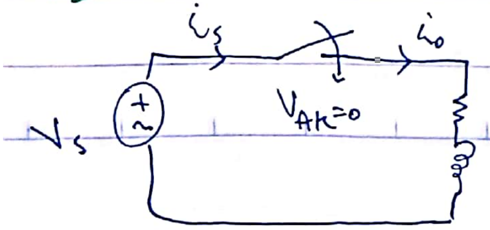
before α no triggering, The Thyristor is off

$\rightarrow$ $i_o = 0$, $V_o = 0$ $\Big\}$ $V_{AK} + \underbrace{V_o}_{Zero} = V_s$

$\therefore \boxed{V_{AK} = V_s}$

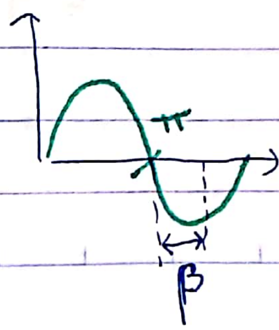


[2] $\alpha \leq \omega t < [\pi + \beta]$



$R \Rightarrow i_o R$

$L \Rightarrow L\frac{di}{dt}$



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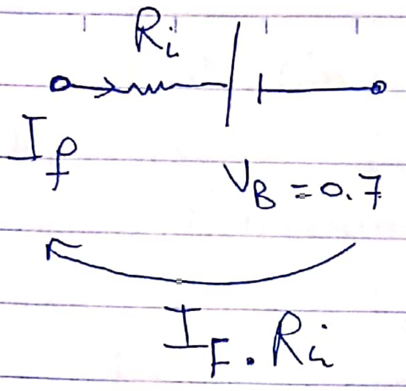

losses. أنواع ال

- SCR (switch)
  1. Turn on loss.
  2. Turn off loss.
  3. Steady state loss.

- $V_s - \cancel{V_{AK}} - V_o = 0$

$\boxed{V_o = V_s}$, $i_s = i_o = i$ #

Assume and define:-

→ $V_s = V_m \sin \omega t$

* $\omega = 2\pi f$ → supply frequency.

* $\tau = \dfrac{L \text{(Henry)}}{R \text{(ohm)}}$ load time constant (seconds)

* $Z = R + j\omega L$

load impedance at supply frequency. $= \sqrt{R^2 + (\omega L)^2} \angle \phi$, where

* (Load Phase angle at supply frequency) $\phi = \tan^{-1} \dfrac{\omega L}{R}$

- If there's a Harmonic, then the impedance will change.

* $I_m = \dfrac{V_m}{Z}$

cont. $\boxed{2}$ $\alpha \leq \omega t \leq [\pi + \beta]$

↳ KVL

$V_s = i.R + L \dfrac{di}{dt}$

$V_m \sin(\omega t) = i.R + L \, di/dt$

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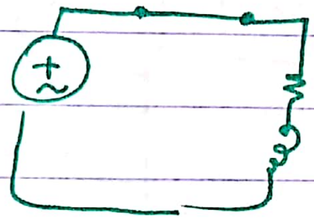
$$\boxed{V_m \sin(\omega t) = i \cdot R + L\, \frac{di}{dt}}$$

This is a 1st order non-homogenious Differantial Equation.

- $i = i_f + i_c$ (in math)
  - i_f: forced Responce
  - i_c: complementry Solution
- $i = i_S + i_n$ (in power electronics)
  - i_S: steady state
  - i_n: natural

if :



$$i = \underbrace{I_m \sin(\omega t - \phi)}_{\text{forced function.}} + \underbrace{A\, e^{-t/\tau}}_{\text{natural.}}$$

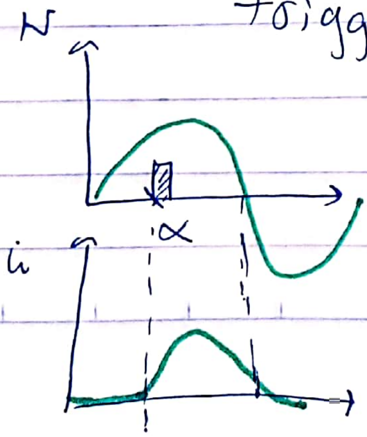
* A : integration constant
  ↳ by Applying the initial current condition.

$\Downarrow$

$i = 0$ at $\omega t = \alpha$

$0 \leq \alpha \leq 180°$

Action when triggered



$$e^{-t/\tau} \Rightarrow e^{-t/\tau} : \frac{-t}{L/R} \cdot \frac{\omega}{\omega}$$

$$\boxed{e^{-\frac{R\omega t}{\omega L}}} = \boxed{e^{\rho \omega t}}, \quad \rho = -R/\omega L$$

$$\rho = \frac{1}{\tan\phi} \qquad \text{or } \rho = -\cot\phi$$

- $e^{\rho \omega t}$ ---> $i = I_m \sin(\omega t - \phi) + A \cdot e^{\rho \omega t}$

((applying The initial condition))

$0 = I_m \cdot \sin(\alpha - \phi) + A \cdot e^{\rho \alpha}$

$\therefore A = -I_m \sin(\alpha - \phi) * e^{-\rho \alpha}$

$i = I_m \sin(\omega t - \phi) \underbrace{- I_m \sin(\alpha - \phi) e^{\rho \alpha}}_{A} \cdot e^{\rho \omega t}$

- if Resistive and un controlled $\boxed{L = 0}$, $\boxed{\alpha = 0}$

$\boxed{\phi = 0}$ in Resistive loads

... $I_m \underbrace{\sin(\phi)}_{\sin(\text{zero})} \cdot \underbrace{e^{\rho \alpha}}_{1}$

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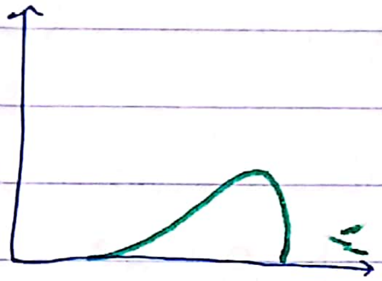
- $i = I_m \sin(\omega t - \phi) - I_m \sin(\alpha - \phi) \cdot e^{-\beta\alpha} \cdot e^{\beta\omega t}$

  $\boxed{\alpha = \phi}$ special case & usually special cases are in the Exam.

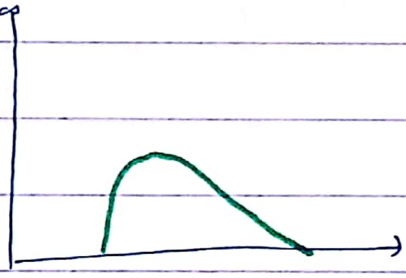
- If asked to draw Typical Waveforms:



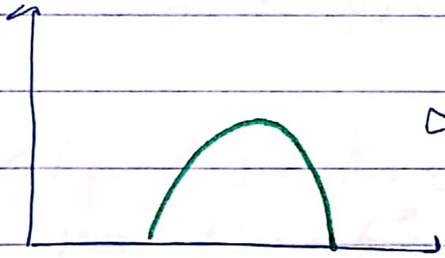
$\alpha < \phi$

Inductive $L\frac{di}{dt}$ = slow

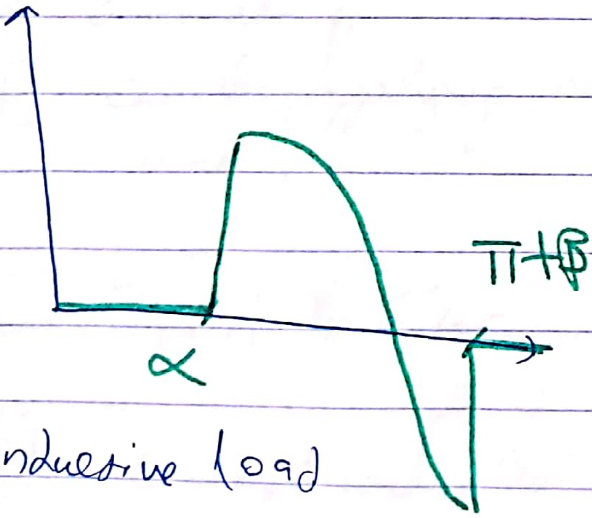
بس تصلح شغلاتها



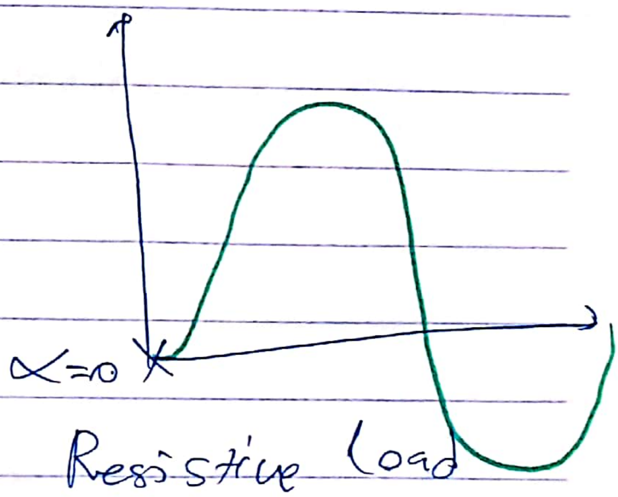
$\alpha > \phi$



$\alpha = \phi$



Inductive load



Resistive load

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/ /

- To calculate β = Apply the final current condition where $\omega t = \pi + \beta \Rightarrow \boxed{i = 0}$

So

$$i = I_m \sin(\omega t - \phi) - I_m \sin(\alpha - \phi) \cdot e^{-\rho\alpha} \cdot e^{\rho\omega t}$$

$$0 = I_m \sin(\pi + \beta - \phi) - I_m \sin(\alpha - \phi)\, e^{-\rho\alpha} \cdot e^{\rho[\pi+\beta]}$$

$$0 = -\sin(\beta - \phi) - \sin(\alpha - \phi) * e^{\rho(\pi - \alpha)} \cdot e^{\rho\beta}$$

$$\sin(\beta - \phi) = \underbrace{-\sin(\alpha - \phi) * e^{\rho[\pi - \alpha]}}_{\text{Constant}} \cdot e^{\rho\beta}$$

Constant since α & ϕ are usually given.

$$K = -\sin(\alpha - \phi) * e^{\rho[\pi - \alpha)}$$

$$\sin(\beta - \phi) = K \cdot e^{\rho\beta}$$

non-Linear Equation = transcendental Equation.

- To evaluate β
  1. can be done [applying any Numirical Technique.]
  2. Trail & Error.
  3. Graphical solution.

Graphical Solution.

Solving $\sin(\beta - \phi) = k \cdot e^{\rho\beta}$

+ve. Zero -ve

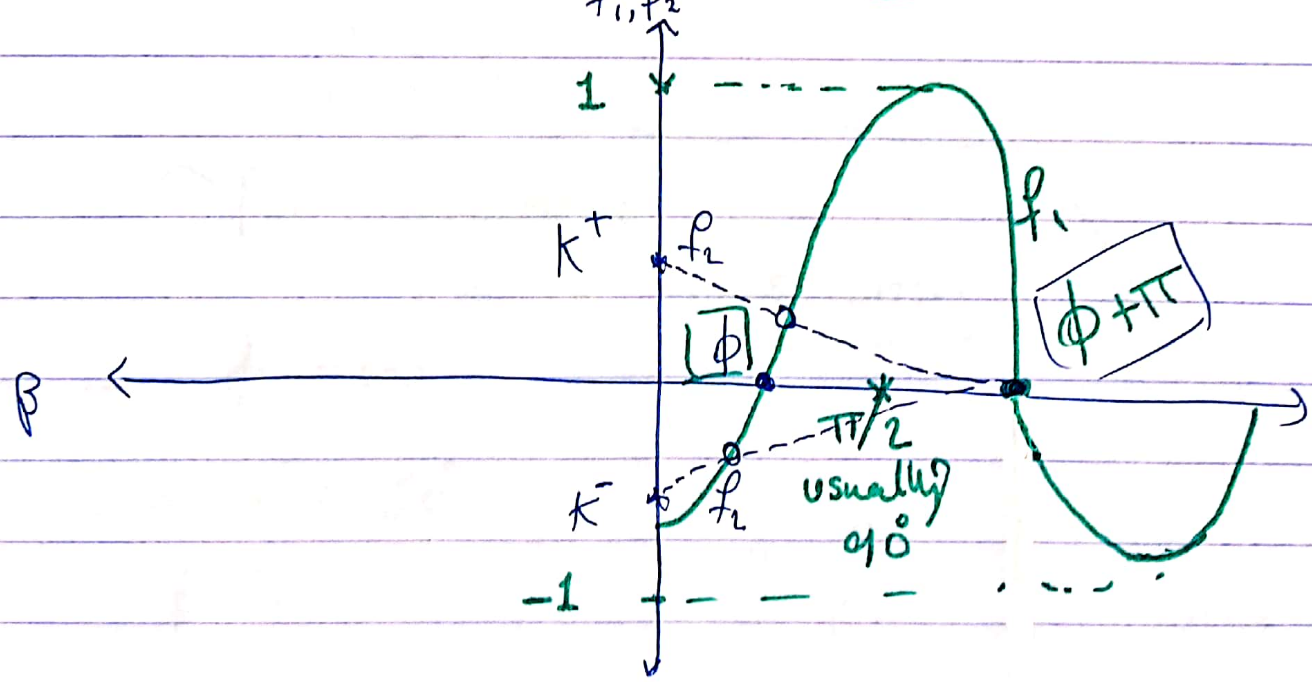
if $k = 0$, β & ϕ are equal.

- In graphical solution:

→ $\sin(\beta - \phi) = f_1$ (function)

→ $k \cdot e^{\rho\beta} = f_2$ (function)

$(f_1$ & $f_2)$ Vs β. [when they intersect. This is the solution.]



if $\beta = 0$ f_1 = exponential

- $K = (-)\sin(\alpha - \phi) \cdot \underbrace{e^{P(\pi - \alpha)}}_{\text{always +ve.}}$

  if $\alpha > \phi \Rightarrow \sin(\alpha - \phi) \Rightarrow +ve$

  and K = negative

  if $\alpha < \phi \Rightarrow \sin(\alpha - \phi) \Rightarrow -ve.$

  and K = positive.

- f_2 & f_1 in case +ve K

  The first intersect is $\beta \gtrsim \phi$

  High لم اكبر بمستوى في حالة

  inductivity.

- f_1 & f_2 case -ve K

  $\beta \lesssim \phi$

In Multiple choice Questions.

→ $\phi = 60^\circ$

→ $\alpha = 30^\circ$

β ??

a) 30
b) 60
$\boxed{\text{c) } 62}$
d) 58
e) 31.5
f) 28.7

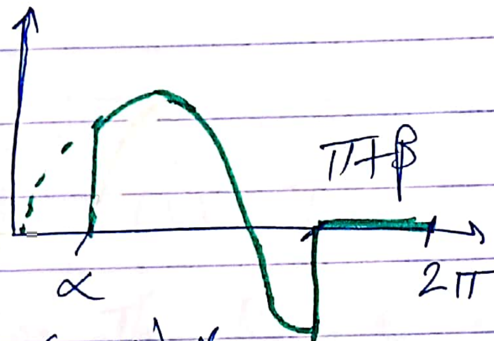
Since $\alpha < \phi$
$\phi = 60$
62 answer.

- once you find $\beta \Rightarrow$ calculate $V_o(avg)$ [integration.]

$$V_o(avg) = \frac{1}{T}\int_{t_o}^{t_o+T} V_o(t)\,dt.$$

$t \rightarrow$ radians (always.)

- period $= 2\pi$



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

$$V_o(avg) = \frac{V_m}{2\pi}\Big[-\cos(\omega t)\Big]_{\alpha}^{\pi+\beta}$$

$$\frac{V_m}{2\pi}\left[-\cos(\pi+\beta) + \cos\alpha\right]$$

$$V_o(avg) = \frac{V_m}{2\pi}(\cos\alpha + \cos\beta)$$

$$I_o(avg) = \frac{V_o(avg)}{R} \Rightarrow Z = \underline{\underline{R}} + jX$$

only R (avg DC)

$$I_o(rms) = \frac{\cancel{V_o}(rms)}{\cancel{R}\,\cancel{Z}\,\cancel{X}} \qquad \underline{\underline{so}}$$

$$V_o(\omega t) = V_o(avg) + \sum_{n=1}^{n=\infty} V_m(n) \cdot \sin(n\omega t + \Psi_n)$$

ex $60 + 40\sin(\omega t - 25^\circ) + 28\sin(2\omega t - 40^\circ) + 10\sin(3\omega t - 87^\circ)$

$$V_o(rms) = \sqrt{60^2 + \left(\frac{40}{\sqrt{2}}\right)^2 + \left(\frac{25}{\sqrt{2}}\right)^2 + \left(\frac{10}{\sqrt{2}}\right)^2}$$

If asked to find The Ripple factor:- we must find

$\Longrightarrow I_{rms}$

$V_o(rms) = \#$ رقم

$i_o(\omega t) = I_o(avg) + \sum$ ------ $\frac{60}{R}$ وبعدين اقسم , $\frac{40}{Z_1}$, ...

cont. next lecture.

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Single phase Half wave controlled Rectifier

$\rightarrow$ $V_{o\,(avg)} = \frac{V_m}{2\pi}(\cos\alpha + \cos\beta)$

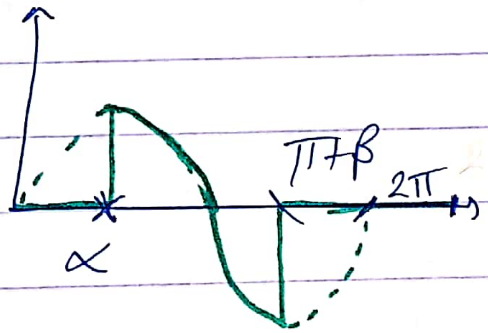
Special case (resistive load), $\beta = 0$.

$$V_{o\,(avg)} = \frac{V_m}{2\pi}(1 + \cos\alpha)$$

$$I_{o\,(avg)} = \frac{V_{o\,(avg)}}{R}, \quad I_{o\,(rms)} = ??$$

HARD.

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



$$V_{o\,(rms)} = \sqrt{\frac{V_m^2}{2\pi}\int_{\alpha}^{\pi+\beta}\left(\frac{1 - \cos 2\omega t}{2}\right) d\omega t}$$

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

$$V_{o\,(rms)} = \sqrt{\frac{V_m^2}{4\pi}\left[\pi+\beta-\alpha-\frac{1}{2}\sin(2\beta)+\frac{1}{2}\sin(2\alpha)\right]}$$

$\Rightarrow$ all α values are radians.

$\boxed{\text{or}}$

$$V_{o\,(rms)} = \sqrt{V_o\,(avg)^2 + \sum_{n=1}^{\infty}\left(\frac{V_m(n)}{\sqrt{2}}\right)^2}$$

- $$i_o(rms) = \sqrt{\left(I_{o(avg)}\right)^2 + \sum_{n=1}^{\infty}\left(\frac{I_m(n)}{\sqrt{2}}\right)^2}$$

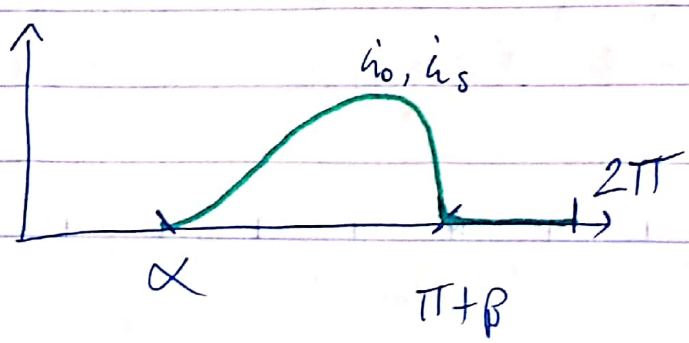
$$I_m(n) = \frac{V_m(n)}{Z(n)}$$, • $Z(n) = R + j(n)\omega L$

$$= \sqrt{R^2+(n\omega L)^2}\ \angle \tan^{-1}\left(\frac{n\omega L}{R}\right)$$

- R.F ripple factor $$= \frac{\sqrt{V_{o(rms)}^2 - V_o^2(avg)}}{V_o\,(avg)}$$

i_s and i_o are the same.

To calculate P.F power factor.



$\boxed{\cancel{P.F = \cos\phi}}$ not acceptable

$\boxed{P.F = \cos\phi}$ only The case of V_L, V_s & i_L, i_s are pure sin functions.

- $\text{Power factor} = \dfrac{\text{Real power}}{\text{apperant power}}$

- apperant power $= V_{s\,(rms)} * I_{s\,(rms)} \rightarrow$ supply?

ex:-

$V_o(t) = 120 + 80\sin(\omega t - 30^\circ) + 40\sin(2\omega t - 60^\circ)$

$+ \dots$ consider the first two components.

$\rightarrow i_o(t) = \dfrac{120}{R} + \dfrac{80}{Z_1}.\sin(\omega t - 30 - \phi_1) +$

$\dfrac{40}{Z_2}.\sin(2\omega t - 60 - \phi_2)$

ϕ_1 & ϕ_2 can be found using This Formulas

$$\boxed{\phi_{(n)} = \tan^{-1}\left(\frac{n\omega L}{R}\right)}$$

- Using Superposition ((Pout))

$V_s(t) = V_m \sin(\omega t)$

$i_o(t) = \dfrac{120}{R} + \dfrac{80}{Z_1}\sin(\omega t - 30 - \phi) + \dfrac{40}{Z_2}\sin(2\omega t - 60 - \phi_2)$

1 $\Rightarrow P_{out} = P_{supply} = P_{in} = I_{s,1(rms)} * V_{s(rms)} * \cos(30 + \phi_{(1)})$

Ideal Thyristor

so ϕ losses.

$$\phi_1 = \phi_{(v_1)} - \phi_{(is_1)}$$

$\boxed{\text{or}}$

② $P_{out} = I_{o(rms)}^2 * R.$

P_{out} in both cases should be the same.

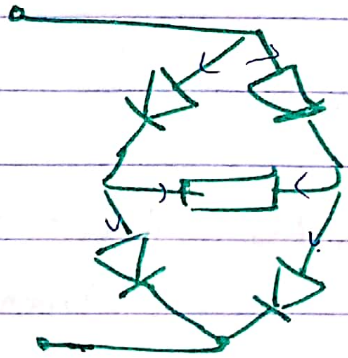
⇒ then we substitue in power factor formula #

Drawbacks of single phase rectifire circuit.

→ Supply current has Non-Zero average Value. distructive if a transformer is used due to a core saturation.

→ Reduced Voltage & power compared to the full wave rectifire

why didn't we say "reduced current"?



لانه بين اي مرحلة من المراحل
ر يمشي ويكمل بال load
فلما اشتري rectifire
in Series واطعهم
اذا واحد بتحمل $\boxed{10\ A}$, والثاني
كمان بتحمل
مع بعض $\boxed{10\ A}$
ما رح يتحملوا 20 A !!

- As for voltage :- $\frac{V_m}{2\pi}(\cos\alpha + \cos\beta)$ $\boxed{HWR}$

جيب تمام الزاوية في الإشارة

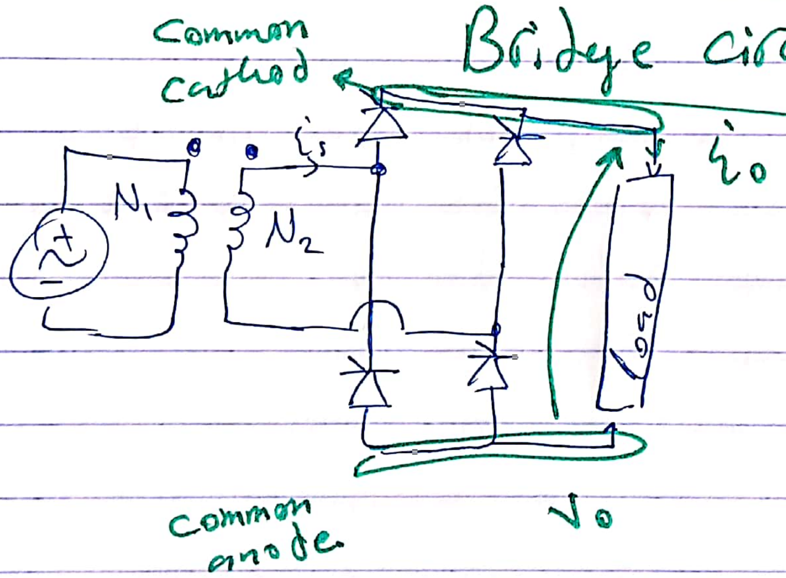
$\frac{V_m}{\pi}(\cos\alpha + \cos\beta)$ $\boxed{FWR}$

due to these drawbacks,

Single phase full wave Rectifire circuit.

→ Two configurations:
1. Bridge circuit.
2. center tapped.

Bridge circuit.



- Transformer is optional ← only used to match load voltage requirements.

- i_s, S = if transformer exist Secondary?
  if no transformer then Supply

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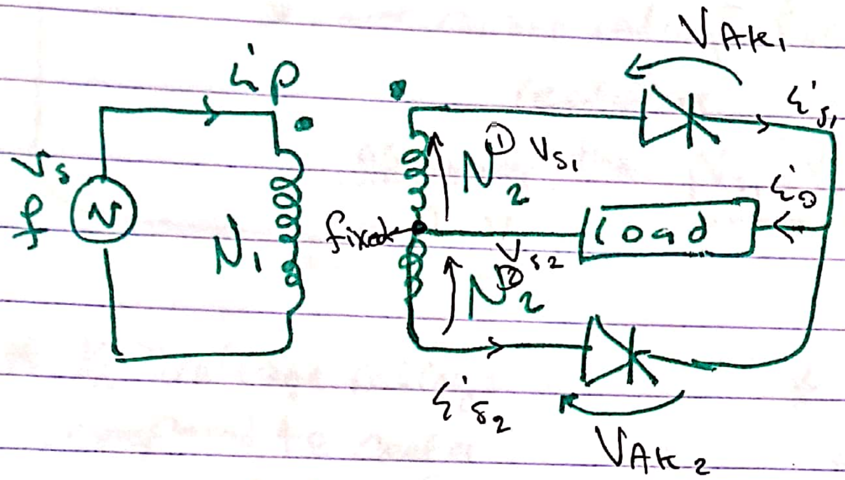
Lecture 22

- Full wave Rectifire
1) Bridge Receifire (optional Transformer)
2) Center-tapped Rectifire (Transformer is a must)



not like an autotransformer.

- V_{s_1}, V_{s_2} have the same direction because they have the same core & are wind up with the same conductor.

- When $N_2^{①}$ is on, $N_2^{②}$ is open circuit.
- Center-tapped Rectifire has more windings, weights more & Expensive compared to the Bridge Rectifire.

- $i_o = i_{s_1}$ or i_{s_2}, depending on which half cycle it's in.

- Average voltage is the same if $V_s = V_{s_1} = V_{s_2}$ in both cases, and that is usually the case.
So we choose bridge circuit.
لما نحتاج وجود ال Transformer.

Bridge rectifire	center-tapped Rectifire
* 4- Switches.	* 2- switches.

* Same current ratings for both rectifires.

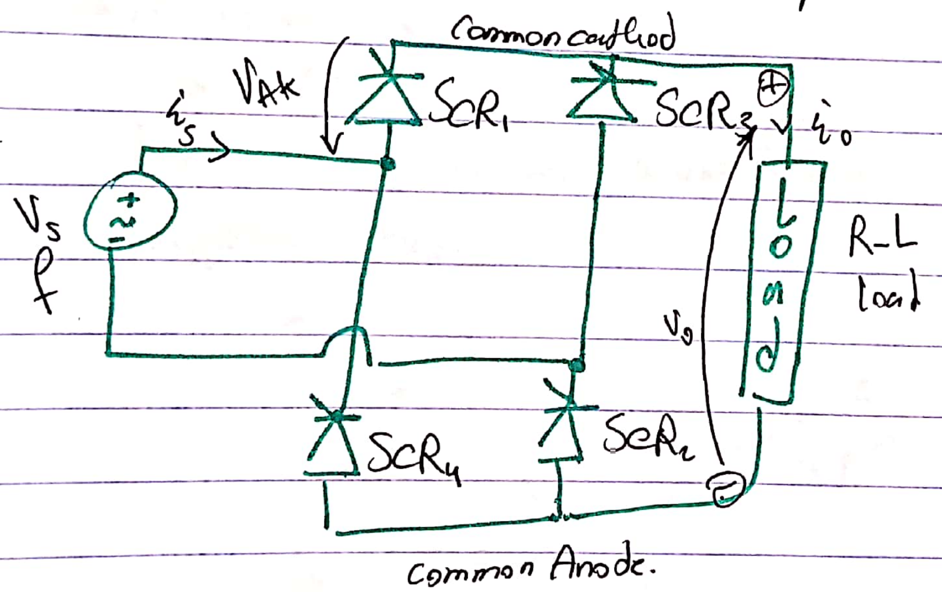
assuming that $\boxed{V_{s_1} = V_{s_2} = V_s}$ and $\boxed{V_s}$

* ½ Voltage ratings compared to center tapped Rectifire.	* double voltage ratings compared to bridge circuit.
* $PIV = V_m$ peak inverse voltage	* $PIV = 2V_m$
* cheaper SCR's	* Much Expensive SCR's. due to high voltage ratings.
* double ΔV (2 switches in series)	* ΔV is half of that of bridge circuit.
* higher power loss.	* less power loss.
* more requirements and complications.	* less triggering circuit requirements.
* transformer is optional. → Much cheaper transformer if needed.	* Transformer is a must and it's Expensive. due to double Secondary turns.

- The only Technical feature that is different between bridge & center tapped Rectifires is the PIV every thing else is the same.
- VAK →
  بتكون منصف ال Supply
  بال center tapped.

Analysis of single-phase full-wave bridge Rectifire circuit.

→ Exam Question: Sketch the power circuit of smth...



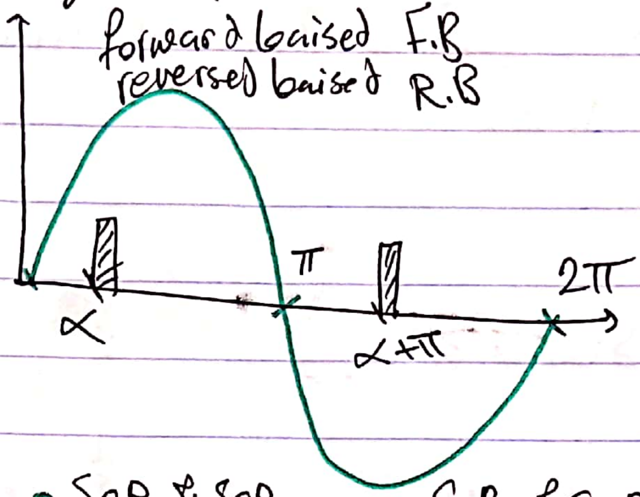
- V_o = + number or − number BUT, notation ⊕ & ⊖ never changes

- numbering of SCR's is very Important
- V_{AK} is needed for calculations of PIV
- we should trigger SCR_1 & SCR_2 Simontanously during positive half cycle.

$$0 \leq \alpha \leq 180^\circ$$

- where α is the firing angle.

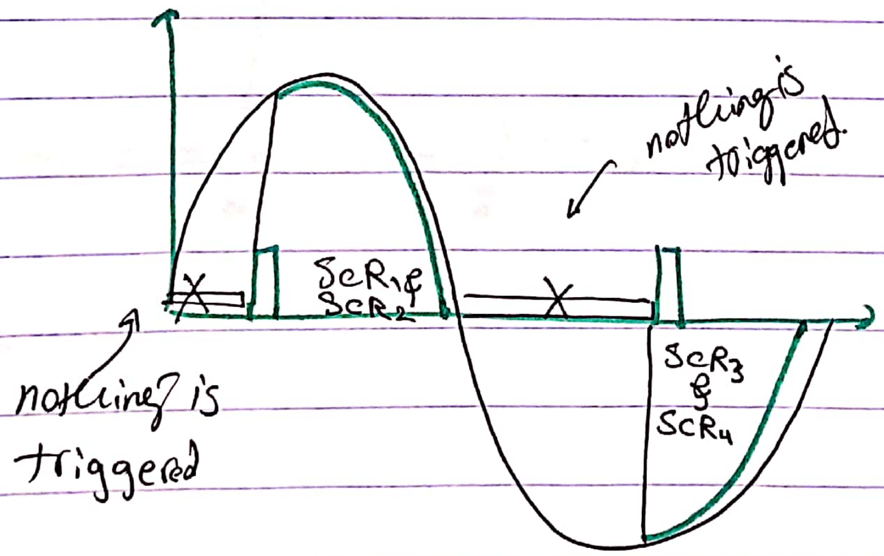
at $\omega t = \alpha$



- SCR₁ & SCR₂ F.B
- SCR₃ & SCR₄ are F.B
- SCR₃ & SCR₄ R.B
- SCR₁ & SCR₂ R.B

- if $\alpha + \pi$ was $\alpha + 150$?

Then unsymitrical waveformes ⇒ Dc Avg in the supply (BAD).



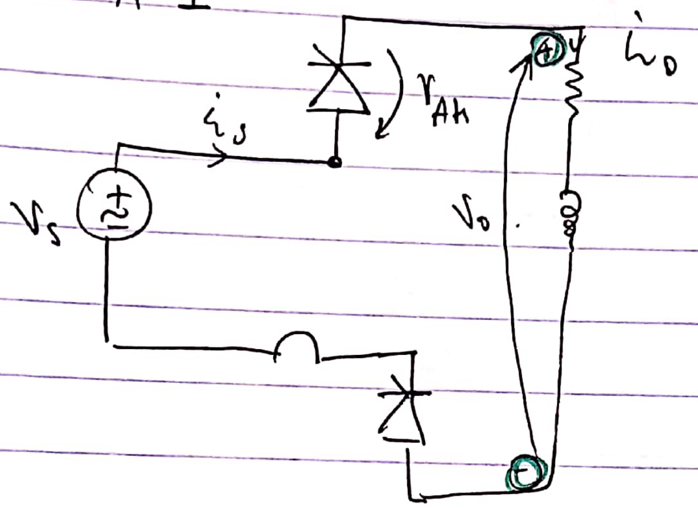
- $0 \leq \omega t \leq \alpha$, and $\pi \leq \omega t \leq \pi + \alpha$

all SCR's are off, $i_o = i_s = 0$, $V_o = 0$

- $\alpha \le \omega t \le \pi$

SCR1 , SCR2 are triggered & F.B , SCR3 , SCR4 still off.

- #1

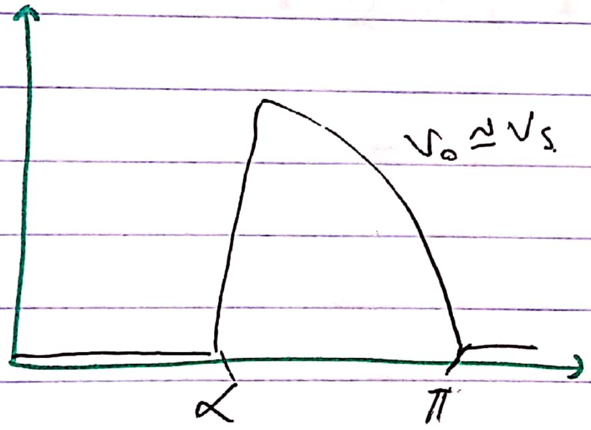


$0 \le \omega t \le \pi$

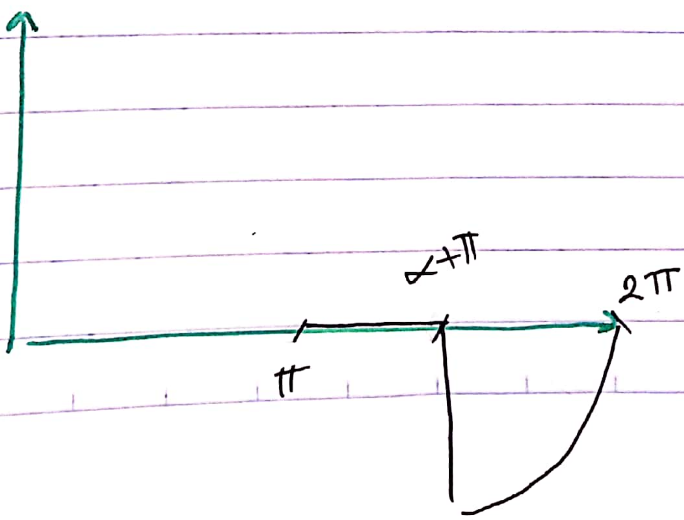
$V_o \simeq V_s$

$V_s - V_o - 2\underbrace{V_{Ak}}_{0} = 0$

$\boxed{i_o = i_s}$



- #2



$V_o \simeq -V_s.$

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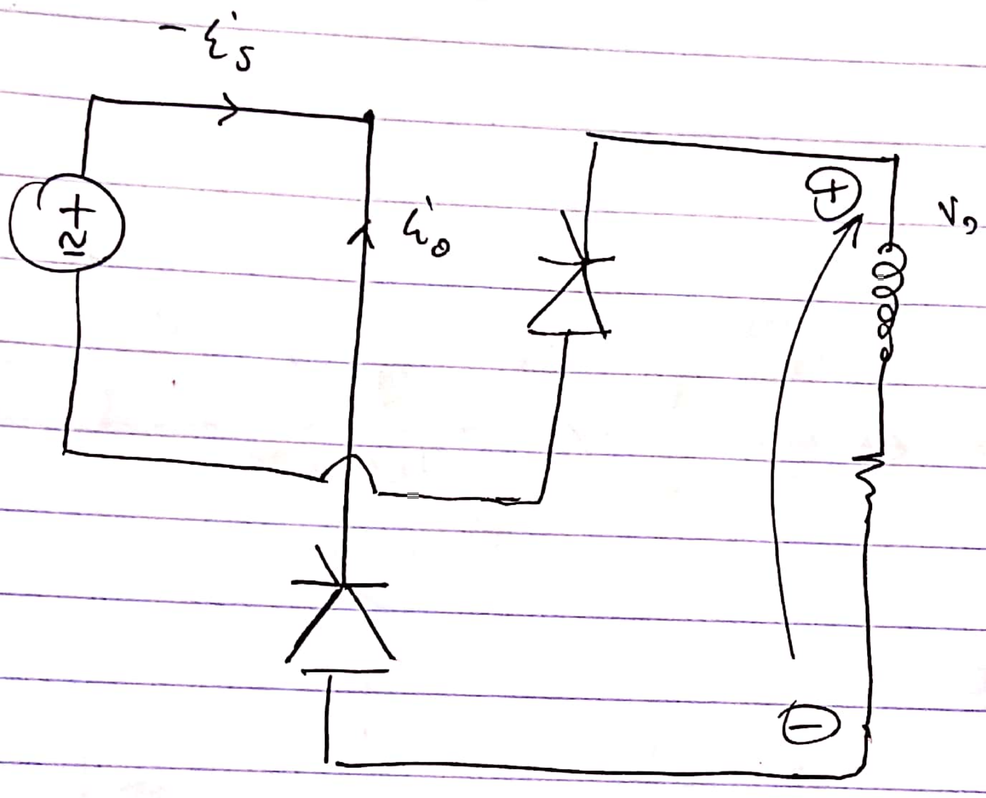
$\alpha + \pi \leq \omega t \leq 2\pi$



$$V_s + 2V_{AK} + V_o = 0$$

$$-V_s \simeq V_o$$

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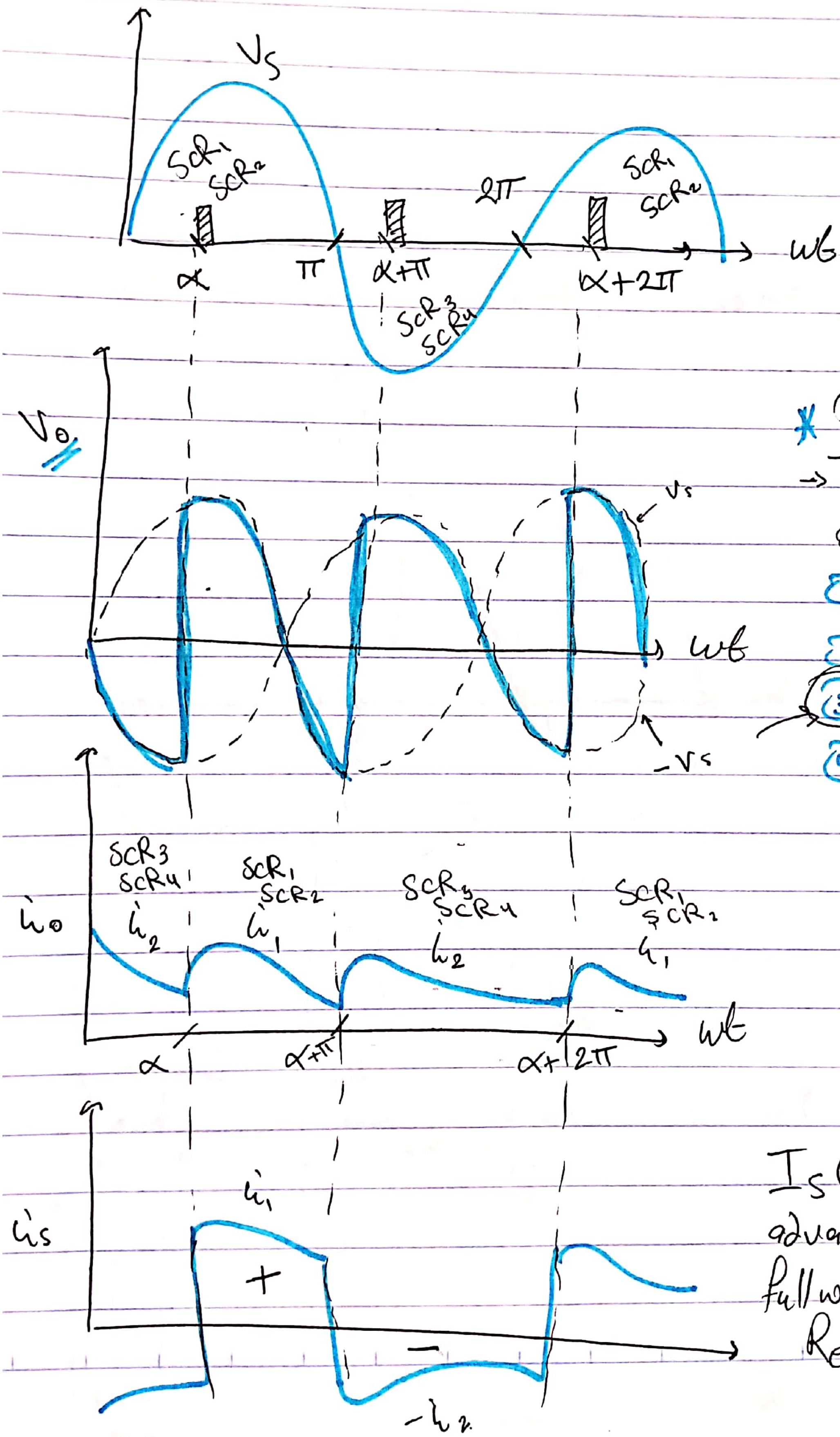
Lecture 23

- Continuous Current Mode. C.C.M

Expected WaveFormes



* Question in Exam:-

→ The frequency of one thyristor trigged

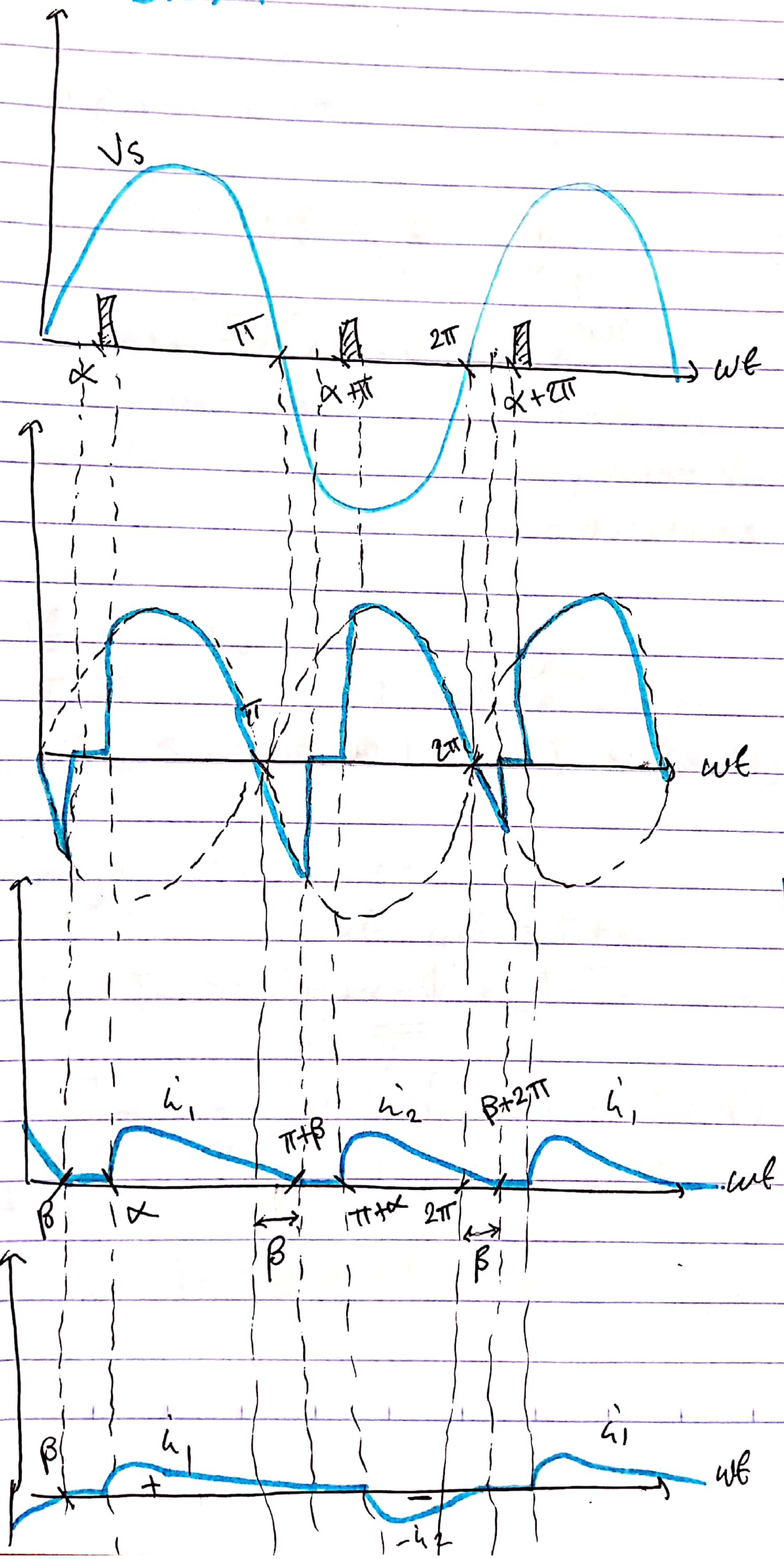
1. half of frequency of Supply
2. double of frequency of Supply
3. Same frequency of Supply
4. non - of the above

$I_s(avg) = 0$

advantage of full wave bridge Rectifire.

- Discontinuous Current mode.

D.C.M

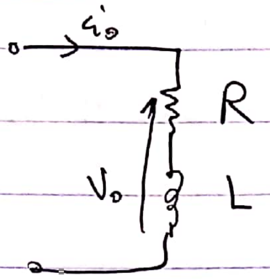


$$\boxed{\alpha - \beta = \gamma}$$

hold off angle.

Analysis assuming C.C.M

- $0 \leq \alpha \leq \alpha + \pi$, $V_o = V_s$



$$V_s = V_m \sin \omega t = i_o R + L\, di/dt$$

$$i_o = I_m \sin(\omega t - \phi) + A.e^{\rho \omega t}$$

Initial current condition : In Continuous mode $I \neq 0$ positive value. I.c.c

I.C.C — in discontinous $I = 0$.

$\omega t = \alpha$, $i_o = I$

$$I = I_m \sin(\alpha - \phi) + A \cdot e^{\rho\alpha} \longrightarrow A[I - I_m \sin(\alpha-\phi)]e^{-\rho\alpha}$$

$$i_o = I_m \sin(\omega t - \phi) + \underbrace{[I - I_m \sin(\alpha - \phi)]e^{-\rho\alpha}}_{A} \cdot e^{\rho\omega t}$$

Final current condition.

F.C.C at $\omega t = \pi + \alpha$, $i_o = I$

$$I = I_m \sin(\underbrace{\pi}_{x} + \underbrace{\alpha - \phi}_{y}) + [I - I_m \sin(\alpha - \phi)]e^{-\rho\alpha} \cdot e^{\rho(\pi+\alpha)}$$

$$I = -I_m \sin(\alpha - \phi) + [I - I_m \sin(\alpha-\phi)]e^{\rho\pi}$$

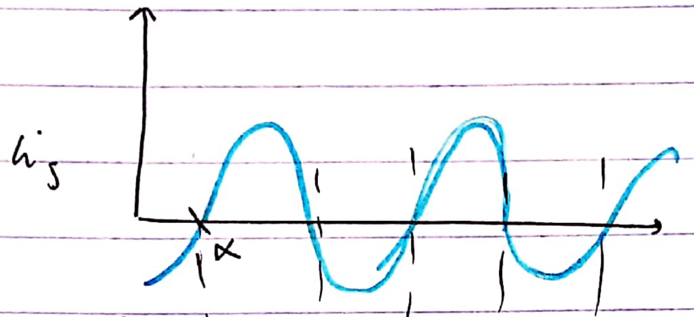
$$I[1 - e^{\rho\pi}] = -I_m \sin(\alpha - \phi)(1 + e^{\rho\pi})$$

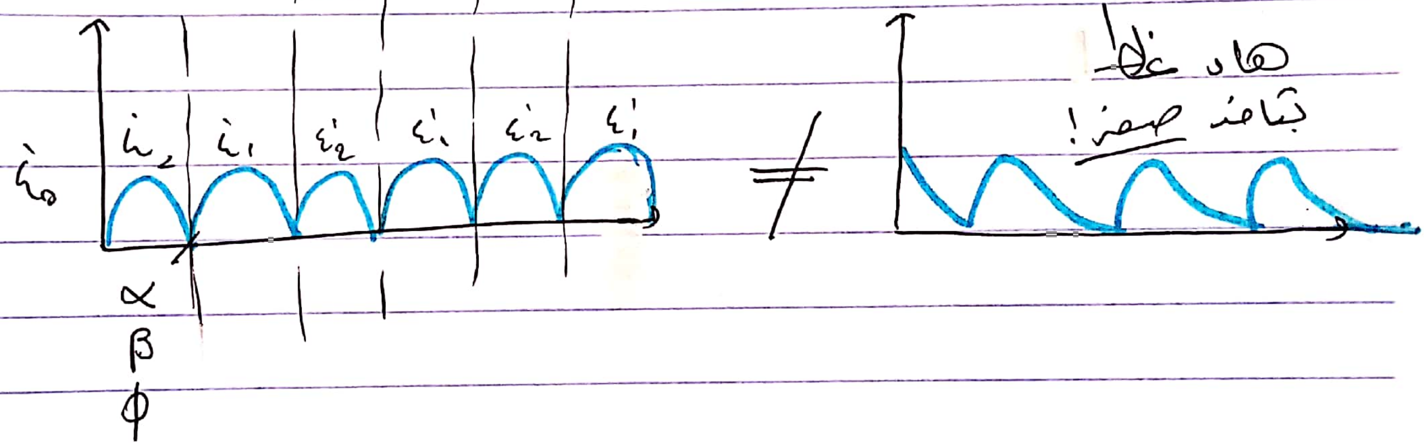
$$I = \frac{-I_m \sin(\alpha-\phi)[1 + e^{\rho\pi}]}{[1 - e^{\rho\pi}]} \Rightarrow I = -I_m \sin(\alpha - \phi) \cdot \left(\frac{1+e^{\rho\pi}}{1-e^{\rho\pi}}\right)$$

when is $I = 0$?

↳ if $\alpha = \phi$, this is the critical condition. where C.C.M & D.C.M equations apply.

$$i_o = I_m \sin(\omega t - \phi) \quad , \alpha \leq \omega t \leq \pi + \alpha$$





- $i_s = I_m \sin(\omega t - \phi) \rightarrow$ pure sinusoidal case (total harmonic distortion = Zero.)
- Voltage isn't affected.

* $I = 0$

$$\begin{cases} I < 0 \text{, Theoritical D.C.M. } \alpha > \phi. \\ I = 0 \text{, critical case } \alpha = \phi. \\ I > 0 \text{, CC.M } \alpha < \phi. \end{cases}$$

resistive discontinuous operation.

$$I = - I_m \sin(\alpha - \phi) * \left(\frac{1 + e^{\rho\pi}}{1 - e^{\rho\pi}} \right)$$

- In Exam ϕ & α are given اذا سا ا اعطانا اياها مرضي
بكون الـ ٣ خيارات التالية :.

1. $Z = 10 \angle 30 \leftarrow \phi$
2. $\boxed{OR}$ $Z = 10 + j15 \rightsquigarrow \sqrt{}\text{—} \angle \phi$
3. $\boxed{OR}$ $R, L \rightsquigarrow X_L \rightsquigarrow 2\pi f L \rightsquigarrow Z = \_\_ + j \_\_$

   for Load

   $\sqrt{}\text{—} \angle \phi$ *

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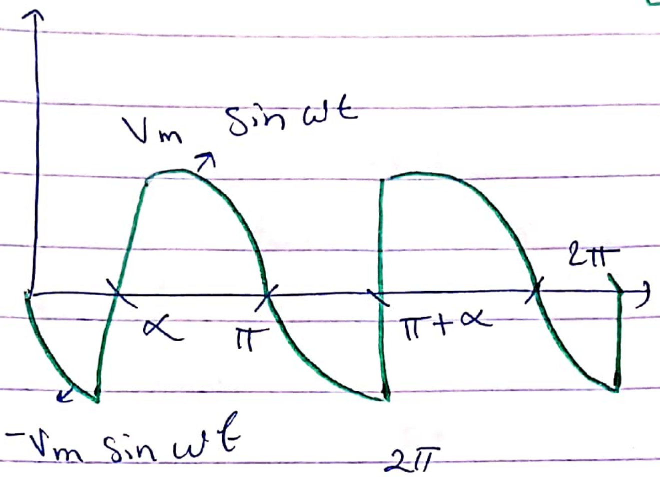
- CCM $\left.\begin{array}{l}\alpha < \phi \\ \alpha = \phi\end{array}\right\}$ $\boxed{\text{case } \alpha < \phi}$



$\rightarrow$ $V_o(avg) = \frac{1}{2\pi}\int_0^{2\pi} V_m \sin(\omega t)\, d\omega t$

$= \frac{1}{\pi}\left[\int_0^{\alpha} -V_m \sin\omega t\, d\omega t + \int_{\alpha}^{\pi} V_m \sin\omega t\, d\omega t\right]$

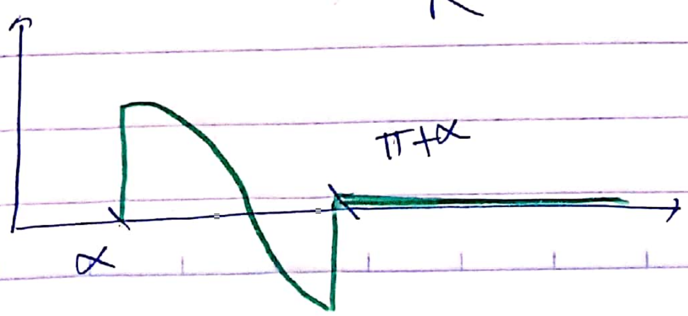
$= \frac{1}{\pi}\int_{\alpha}^{\alpha+\pi} V_m \sin\omega t\, d\omega t = \frac{V_m}{\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi+\alpha}$

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

$V_o(avg)_{\substack{CCM \\ or \\ CrCM}} = \frac{2V_m \cos\alpha}{\pi}$

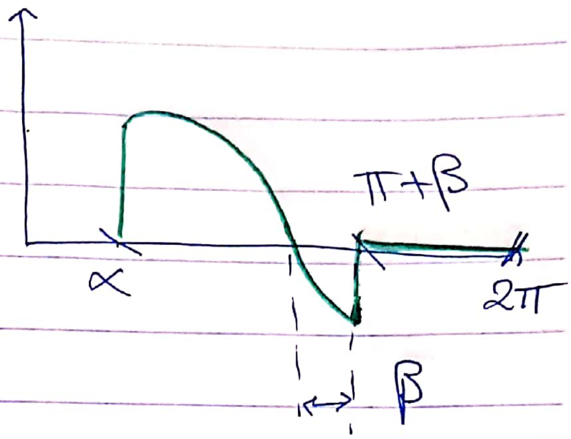
critical

- $I_o(avg) = \frac{V_o(avg)}{R}$, $I_{o(rms)} = ??$



$\rightarrow V_o(rms) = \sqrt{\dfrac{1}{\pi}\displaystyle\int_{\alpha}^{\pi+\alpha} V_m^2 \sin^2 \omega t \, d\omega t} = \boxed{\dfrac{V_m}{\sqrt{2}}}$

$\boxed{\text{Case} \quad \alpha > \phi}$ (DCM.)



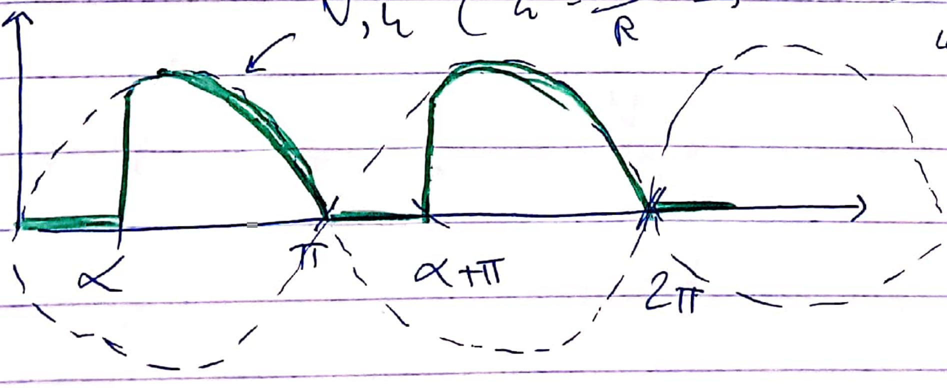
- β can be calculated using the same relationship of the HWR circuit.

$$\rightarrow \underset{DCM}{V_{o(avg)}} = \frac{1}{\pi}\int_{\alpha}^{\beta+\pi} V_m \sin \omega t \, d\omega t = \frac{V_m}{\pi}\Big[-\cos \omega t\Big]_{\alpha}^{\beta+\pi}$$

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

$$\rightarrow \underset{DCM}{I_{o(avg)}} = \frac{V_{o(avg)}}{R}$$

In pure resistive load, $\beta = 0$



→ Same waveforme but with a scaling factor R

$$I_{o(avg)} = \frac{V_{o(avg)}}{R}, \quad I_{o(rms)} = \frac{V_{o(rms)}}{R}.$$

Ex)) - Converter Single phase Full wave fully controlled Rectifire, 50 HZ, Sinonsoidal, 240 V (rms)

لو متقولش حاجة ياخدها RMS

- load $Z_L = 10 + j10\ \Omega$

- Control parameter $\alpha = 45^\circ$

1. which mode of operation the system runs in?
2. $V_o(avg) = ?$, $RF_{V_o} = ?$, $RF_{i_o} = ?$ PF_{in} ? $THDF = ?$
3. Suitable SCR ratings?

→ calculate $\phi = \tan^{-1} \frac{10}{10} = 45^\circ$

compare it with $\phi = \alpha$ ⇝ critical mode.

Calculate β if D.C.M

→ Find avg. Voltage.

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

$$= \frac{2 * 240\sqrt{2}}{\pi} . \cos\alpha$$

Very Important

$V_o = 152\,V$

→ (RMS) , $V_{o(rms)} = \frac{V_m}{\sqrt{2}} = V_s(rms) = 240\,V$

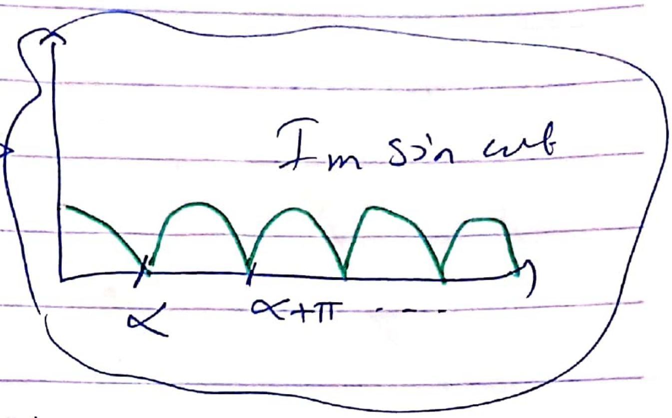
→ $RF_{V_o} = \frac{\sqrt{(240)^2 - (150)^2}}{150}$ 1.24

$$RF_{i_o} = \frac{\sqrt{I_o(rms)^2 - I_o(avg)^2}}{I_o(avg)}$$

→ $I_o(avg) = \frac{V_o(avg)}{R} \Rightarrow \frac{152}{10} = 15.2\,A$

$\Rightarrow I_o(rms) = ??$

Critical case ⇝



$I_o(avg) = \frac{2I_M}{\pi}$

because it's rectified sine.

$I_m = \frac{V_m}{Z} \Rightarrow \frac{240 * \sqrt{2}}{\sqrt{(10)^2 + (10)^2}} = \frac{240\cancel{\sqrt{2}}}{10\cancel{\sqrt{2}}} = 24A$

→ $I_o(avg) = \frac{2I_m}{\pi} = \frac{2 * 24}{\pi} = 15.2\,A$

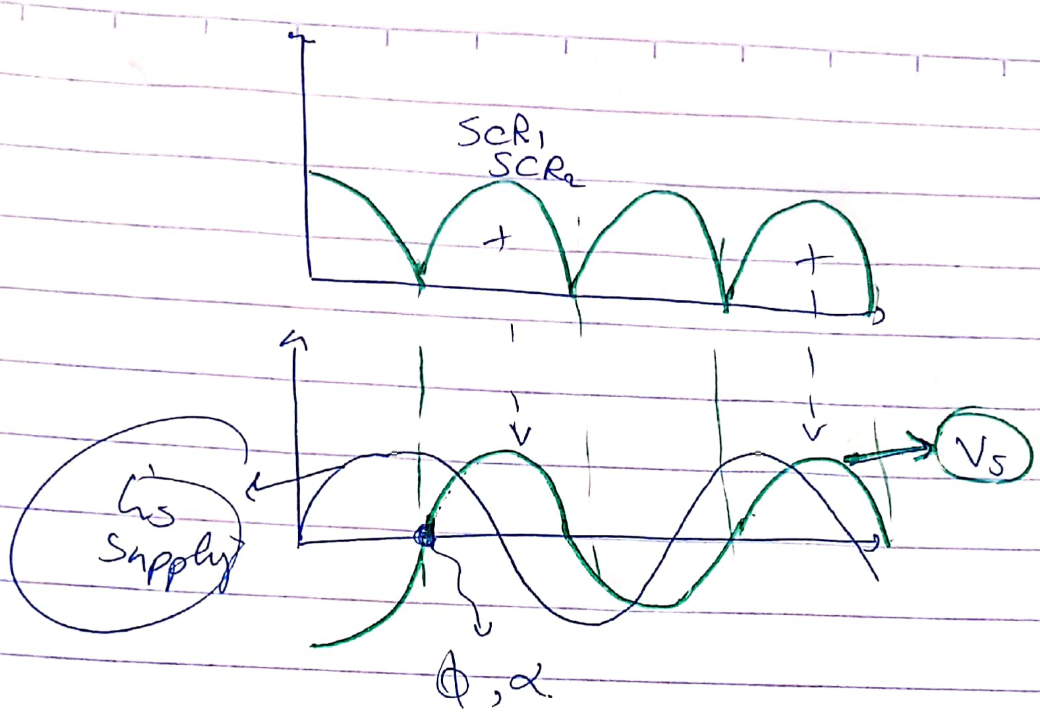
$I_o(rms) = \frac{I_m}{\sqrt{2}} = \frac{24}{\sqrt{2}} = 16.9A$

→ $RF_{i_o} = \frac{\sqrt{(16.9)^2 - (15.2)^2}}{15.2} = 0.48$

Current Quality is better (lower R.F)

→ inductive load $\underline{10 + j10}$ Coil

→ $PF_{in} \Rightarrow$ I need to draw current as filter. in supply.



→ PF in $\cos\phi = \cos\alpha = 0.707$ lag

→ $THDF = \dfrac{\sqrt{I_s(rms)^2 - I_s^2(1)}}{I_s(1)}$ fundimental

due to sine waveforme ⇓ i_s (pure sine) $I_{s(1)} = \dfrac{I_m}{\sqrt{2}}$

find fundimental

$I_s(1) = 16.9$, $THDF = Zero.$

→ SCR current & Voltage ratings:

Voltage : Safety Factor * PIV
(2 → 3) * $(\sqrt{2} * 240)$ V_m

\# Range راجع السؤال

Note

(=Zero?) Second order harmonic in Supply ⊗ لو طلب طلاب

{Might be in Exam}

SCR current Rating: I_m/π

$$I_{SCR} = \begin{cases} I_m\ (\text{peak}) = 24A \\ I_{(avg)} > 7.6A & \text{(half period of symitry)} \\ I_{(rms)} = \dfrac{I_m}{2} \rightsquigarrow 24/2 = \underline{12} \end{cases}$$

add to the Question (4)

عطى $V_o(avg) \rightsquigarrow 250\,v$: calculate α or اشي ثاني

⇒ Solution

$V_o(avg) = 250\,v$

$$250 = \frac{2V_m}{\pi}\cos\alpha \rightsquigarrow \frac{2 * 240}{\pi}\sqrt{2}\cos\alpha$$

$\cos\alpha = 1.15$!! (maximum 1!)

So this converter isn't sufficeal & cannot feed the load.

$$V_o(avg)_{max} ? = V_o(avg)_{max} = \frac{2V_m}{\pi}\cos\underline{0°}_{max}$$

$$\boxed{\neq 216\,v}$$

Transformer = طيب بدي اكثر، شو اسوي؟

⇒ Use a Transformer (step up) with

$$a = \frac{216}{250} \quad \text{اعلى اشي} = \frac{(\text{Maximum})}{(\text{load Voltage})} \quad \text{اللي بدي اياه}$$

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24 / 11 / 2019

Lecture 25

Quiz:

Single phase Rectefire $V_s = 600\,V$, $V_{DC}: 500\,V$. is the rectefire suitable to supply Such load? justify.

→ $V_{o(avg)_{max}} = \frac{2V_m}{\pi} \rightsquigarrow \frac{2 * 600\sqrt{2}}{\pi} = 540\,V$

Since $V_{o(avg)_{max}} > V_{o(avg)_{Load}}$, YES!

- Dc link is alwayes added before (rectefires and filters) choppers.

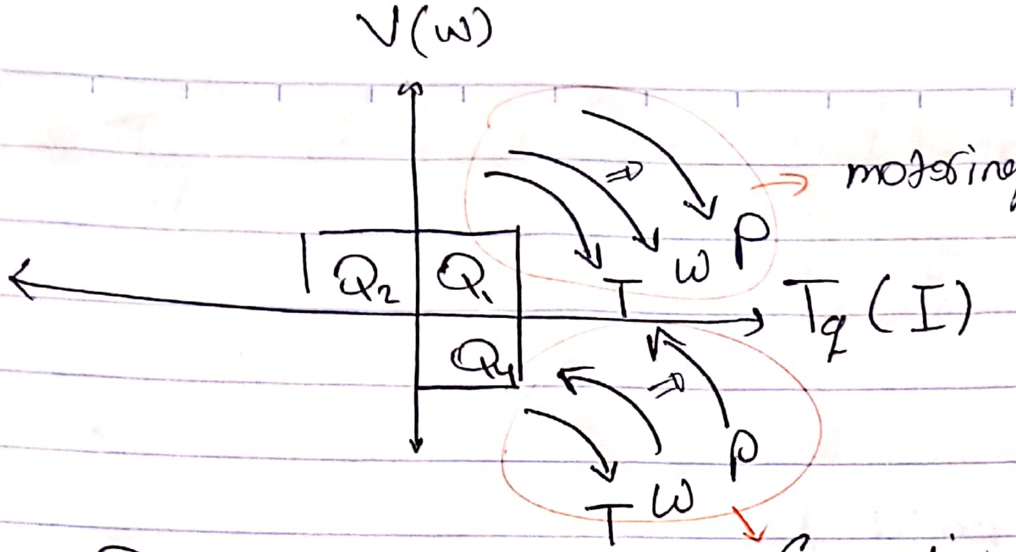
- To get maximum voltage (avg), in CCM not DCM that is why we use $V_{o(avg)}$ equation CCM

SINGLE PHASE SEMI-CONTROLLED RECTIFIRE

- اذا كان ال Torque موجب والحركة موجبة معنا يعني انه ال power موجبة.

$T = K_A \phi . I$

$EMF = K_A . \phi . \omega$

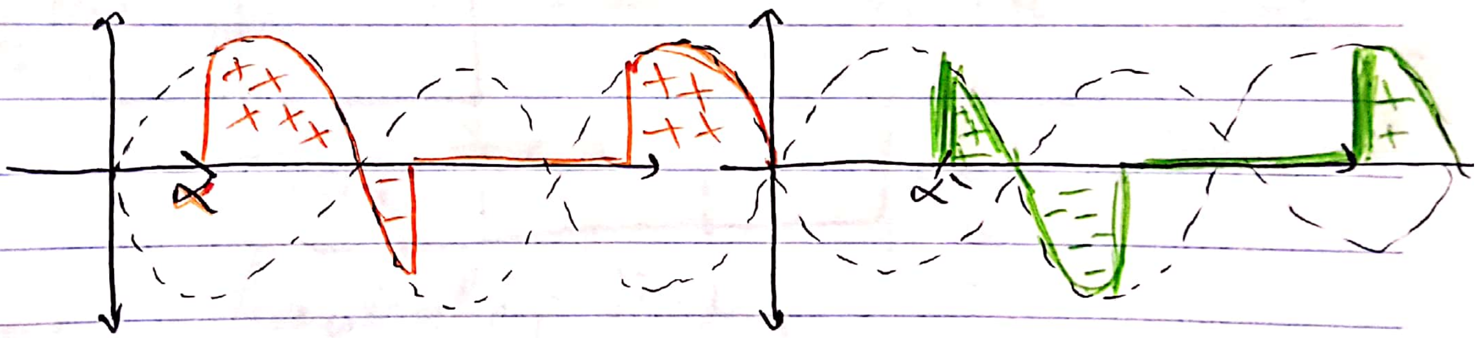


$T * w = P$

سالبة ⊖   سالبة ⊖   سالبة ⊖

Q: quadrant

ex:- عند انزال ورفع ثقل الى الاعلى او الاسفل ؛ على الجهتين لازم يكون في Torque من ارفعه ولما انزله ما يسقط سقوط حر لازم في Torque معاكس.



$V_{(avg)} > 0$
لما α اقل من 90°
"الجزء الموجب اكبر"

$V_{(avg)} < 0$
لما الـ α اكبر من 90°
"الجزء السالب اكبر"

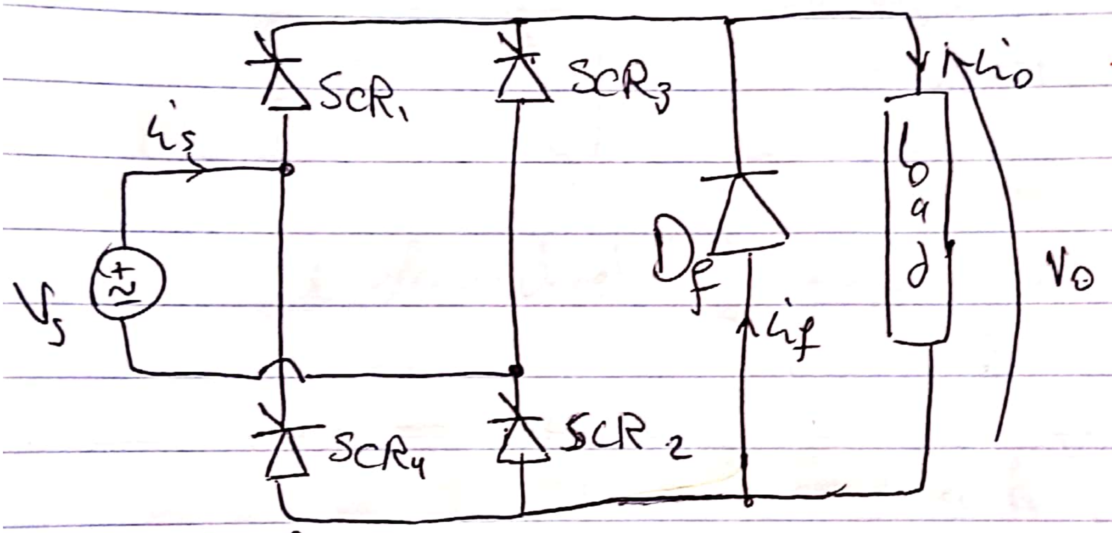
$\alpha' >> \alpha$

- If only positive avg. Voltage is required, then the negative portion of V_o should be clipped, then Semi-Controlled Rectifire is the solution.

Types of Rectifires:
- fully controlled (Thyristors only)
- Uncontrolled (Diodes only)
- Semi-controlled (Diodes & Thyristors.)

Semi-controlled Rectifire power circuit.

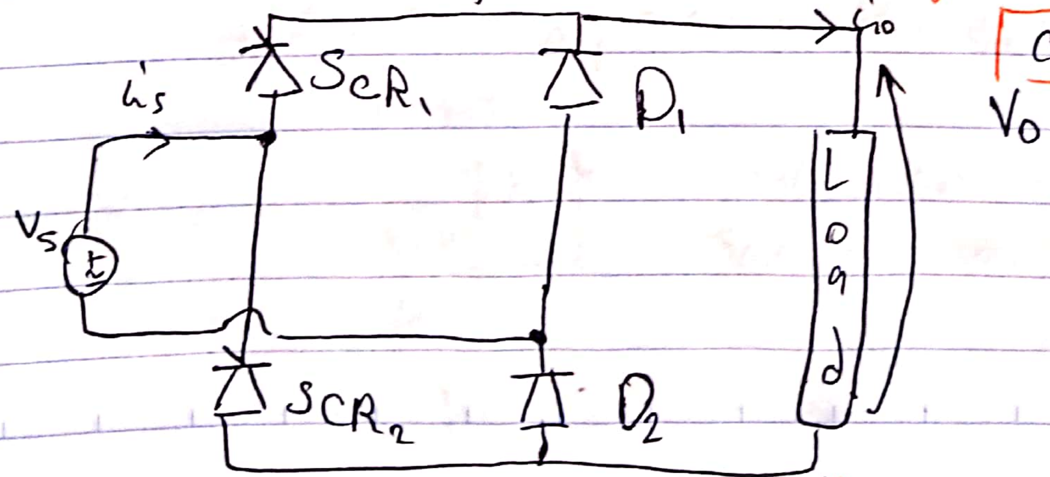
configuration #1



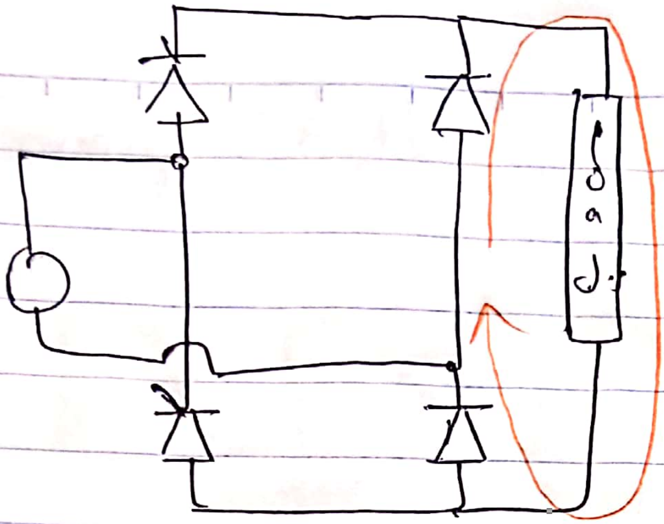
- Df = freewheeling Diode

(This configuration can become fully controlled if Df was removed)

configuration #2

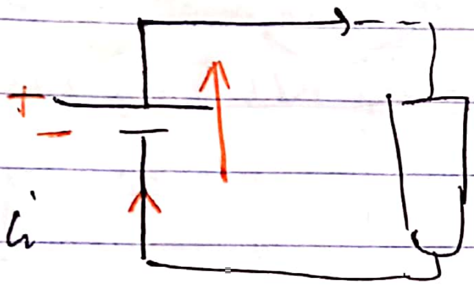


(perminant Semi-controlled)



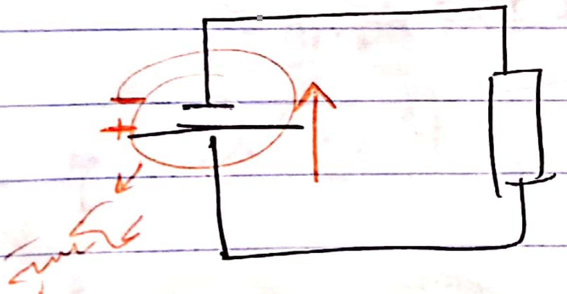
اي path لا يوجد فيها Voltage Source or a Supply

بنسميها freewheeling (free of the source)



التيار يقوم بالسير بعكس اتجاه الفولتية

The voltage is (freewheeling) Supporting the current.



feedback: لما يكون التيار معاكس للفولتية كأنه charging the battery.

The freewheeling diode is added as safety, to protect the circuit from changes

ex: 

electromechanical Relays switch on & off.

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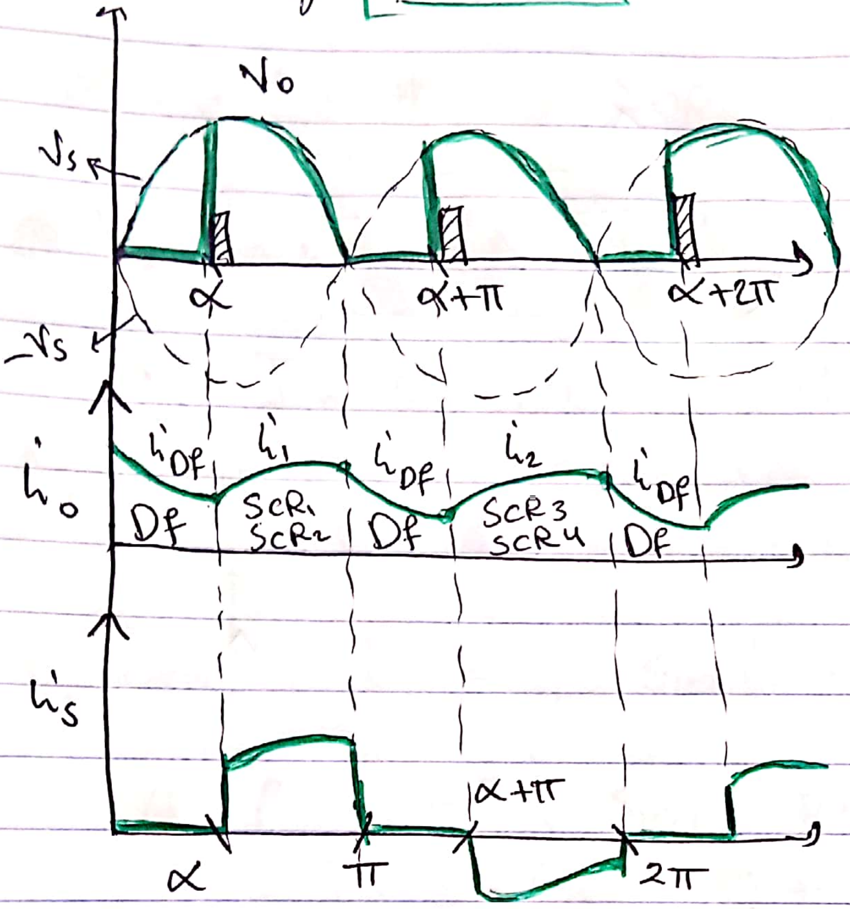
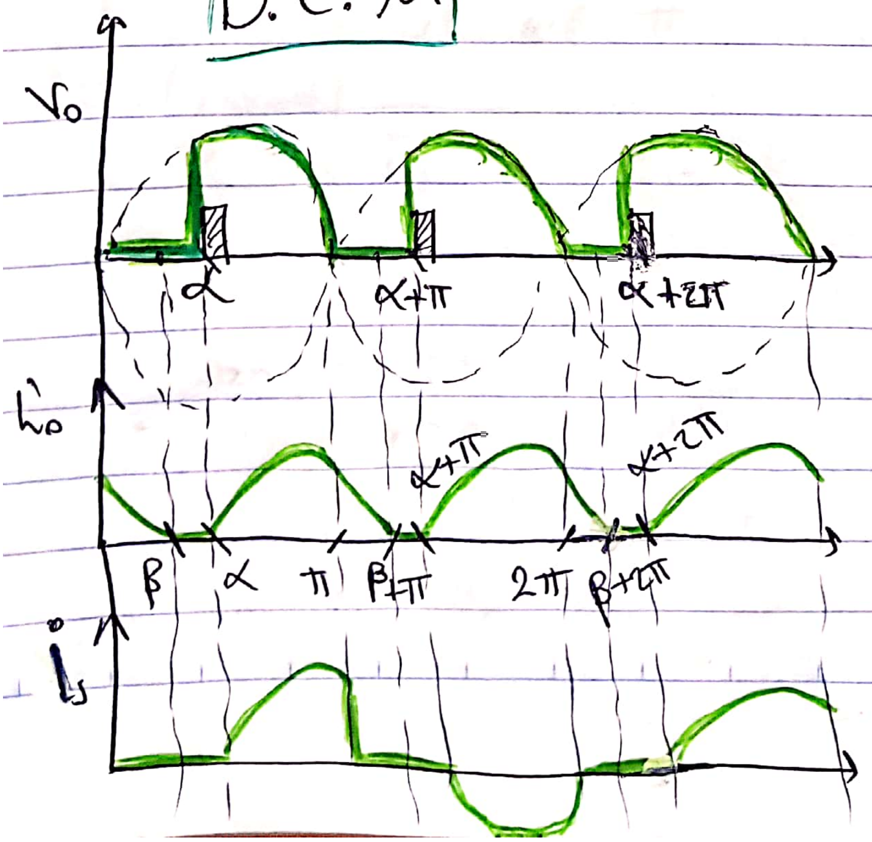
26/11/2019 Lecture 26

Assuming $\boxed{C.C.M.}$



graph ☆ 1 ☆

$\boxed{D.C.M}$



graph ☆ 2 ☆

All equations are referred to configuration #1.

$\alpha \leq \omega t \leq \pi \longrightarrow SCR_1$ & SCR_2

$$V_m \sin \omega t = iR + L\, di/dt$$

$$i = I_m \sin(\omega t - \phi) + A_o e^{\rho \omega t}$$

$\boxed{\text{I.C.C} \\ \text{Initial Current condition}}$ at $\omega t = \alpha$, $i = I_1$

$$I_1 = I_m \sin(\alpha - \phi) + A_o e^{\rho\alpha}$$

$$A = [I_1 - I_m \sin(\alpha - \phi)]\, e^{-\rho\alpha}$$

$$i = I_m \sin(\omega t - \phi) + [I_1 - I_m \sin \alpha - \phi)] \ldots$$
$$\ldots e^{-\alpha} \cdot e^{\rho \omega t}$$

$\boxed{\text{F.C.C} \\ \text{Final current Condition}}$ at $\omega t = \pi$, $i = I_2$

two unknowns we need another Equation

$$I_2 = I_m \sin(\pi - \phi) + (I_1 - I_m \sin(\alpha - \phi)] \ldots$$
$$\ldots e^{-\rho\alpha} \cdot e^{\rho(\pi)}$$

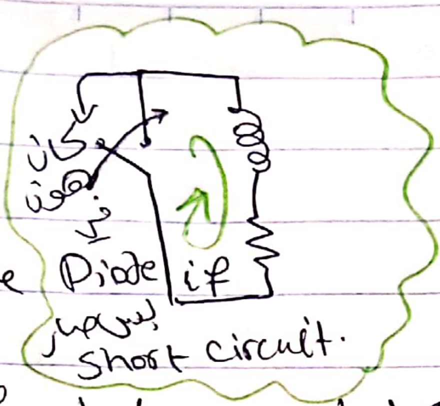
$$\sin(\pi - \phi)$$
$$\sin \pi \cos \phi - \cos(\pi) \sin(\phi)$$
$$= \sin(\phi) \text{ . So, ...}$$

$$\boxed{I_2 = I_m \sin(\phi) + [I_1 - I_m \sin(\alpha - \phi)]\, e^{-\rho\alpha} \cdot e^{\rho(\pi)}}$$

1

① $\pi \leq \omega t \leq \pi + \alpha$

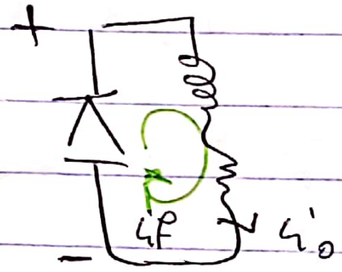
free wheeling due to having Source in the path.



note: all ωt's are referred to graph 1

→ at triggering ($\pi + \alpha$) reverse baise is applied on the diode.

→ $0 = i_f R + L \, di/dt$



$i_f = C \cdot e^{\rho \omega t}$

$i_f = I_2$ at $\omega t = \pi$

$I_2 = C \cdot e^{\rho \pi}$

$\therefore i_f = I_2 \cdot e^{-\rho \pi} \cdot e^{\rho \omega t}$

F.C.C at $\omega t = \pi + \alpha \rightsquigarrow i_f = I_1$

$I_1 = I_2 \cdot e^{-\rho \pi} \cdot e^{\rho [\pi + \alpha]}$

$$\boxed{I_1 = I_2 \cdot e^{\rho \alpha}} \text{ --- } ②$$

Substituting: ① & ② (Next page)

$$\boxed{I_2 = I_m \sin \phi + [I_1 - I_m \sin(\alpha - \phi)] \, e^{-\rho \alpha} \cdot e^{\rho \pi}} \text{ --- } ①$$

eq ≡ equation !

$$I_2 = I_m \sin\phi + [I_2 e^{\rho\alpha} - I_m \sin(\alpha-\phi)] e^{\rho\pi} \cdot e^{-\rho\alpha}$$

$$I_2 [1 - e^{\rho\pi}] = I_m [\sin\phi - \sin(\alpha-\phi) \cdot e^{\rho(\pi-\alpha)}]$$

$$\boxed{I_2 = \frac{I_m}{(1-e^{\rho\pi})} [\sin\phi - \sin(\alpha-\phi) e^{\rho(\pi-\alpha)}]}$$

memorize I_2 eq.

- Important note : remember $\rho \Rightarrow$ سالبة

$I_1 \rightarrow$ بعد التعويض $\boxed{I_1 = I_2 e^{\rho\alpha}}$

- $I_1 \longrightarrow$ approaching I_H , If $I_H = I_1$

Then it's the critical case.

$$I_1 \Rightarrow I_2 \cdot e^{\rho\alpha} = I_H$$

$$e^{\rho\alpha} = \frac{I_H}{I_2} \quad , \quad \rho\alpha = \ln [I_H / I_2]$$

already calculated

$$\alpha_{cr} = 1/\rho \cdot \ln [I_H / I_2]$$

critical

~> to solve any problem → start by $\underline{\underline{I_2}}$
to know if it's C.C.M or D.C.M

I_2 ~> α

I_H : diode (Df) holding current (أقل تيار ممكن لاستمرار التوصيل)

If $\alpha < \alpha_{cr}$ then it's C.C.M

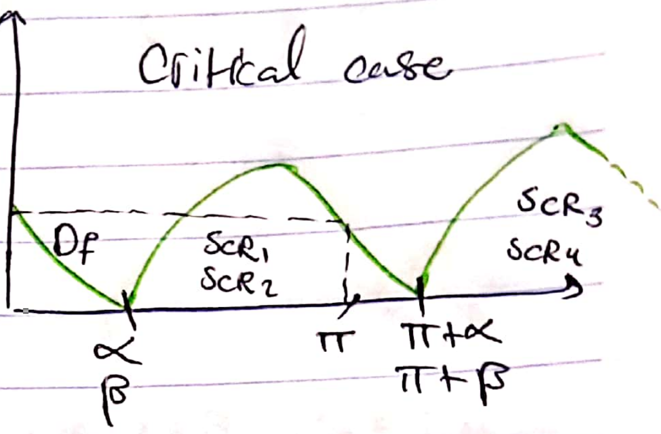
If $\alpha > \alpha_{cr}$ then it's D.C.M

$\hookrightarrow$ analyze graph 2 $\rightsquigarrow$ find β

β should be evaluated.

- DCM: to evaluate β

$i_o = I_m \sin(\omega t - \phi) + A \cdot e^{\rho \omega t}$



→ ICC at $\omega t = \alpha$, $i_o = 0$

$0 = I_m \sin(\alpha - \phi) + A\, e^{\rho \alpha}$

$A = [-I_m \sin(\alpha - \phi)] \cdot e^{-\rho \alpha}$

$i_o = I_m \sin(\omega t - \phi) - I_m \sin(\alpha - \phi) \cdot e^{-\rho \alpha} \cdot e^{\rho \omega t}$

→ at $\omega t = \pi \longrightarrow i_o = I_2$

$I_2 = I_m \sin(\pi - \phi) - I_m \sin(\alpha - \phi) \cdot e^{-\rho \alpha} \cdot e^{\rho \pi}$

$\underset{(DCM)}{I_2} = I_m \left[\sin\phi - \sin(\alpha - \phi) \cdot e^{\rho(\pi - \alpha)}\right]$

$\underset{(DCM)}{I_2} >> 0$

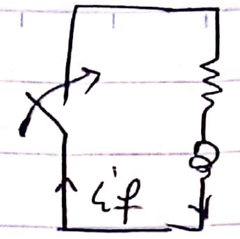
→ at $\omega t \longrightarrow \pi \leq \omega t \leq \pi + \beta$ or α

$i_f = C \cdot e^{\rho \omega t} \longrightarrow$ ICC, at $\omega t = \pi$

$i_f = \underset{(DCM)}{I_2}$

- Be careful not to find I_2 from the CCM case; I_2 must be from the $\boxed{\underline{DCM}}$.

$\rightarrow I_{2\,(DCM)} = C \cdot e^{\rho\pi}$ freewheeling current.

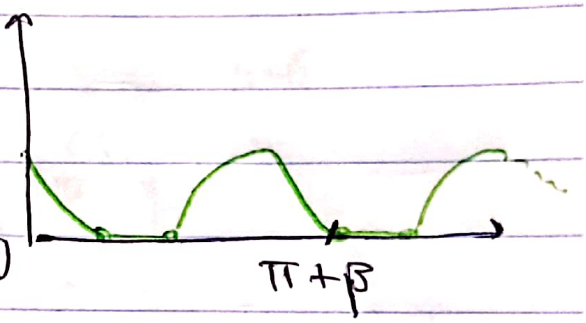


$C = I_{2\,(DCM)} \cdot e^{-\rho\pi}$

$i_f = I_{2\,(DCM)} \cdot e^{-\rho\pi} \cdot e^{\rho\omega t}$

FCC at $\omega t = \pi + \beta$, $i_f = I_H$,

The diode is turned off when the current is equal to I_H.



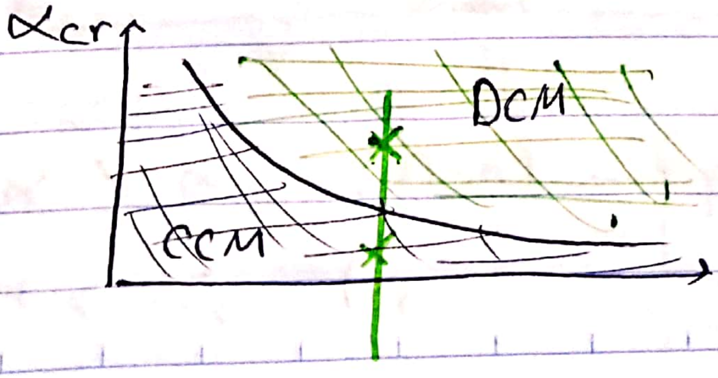
$\Longrightarrow I_H = I_{2\,(DCM)} \cdot e^{-\rho\pi} \cdot e^{\rho(\pi+\beta)}$

$I_H = I_{2\,(DCM)} \cdot e^{\rho\beta}$, $e^{\rho\beta} = \dfrac{I_H}{I_{2\,(DCM)}}$

So, $\rho\beta = \ln\left(\dfrac{I_H}{I_{2\,(DCM)}}\right)$, $\beta = \dfrac{1}{\rho} \ln\left(\dfrac{I_H}{I_{2\,(DCM)}}\right)$

$\rightarrow$ DCM $\rightsquigarrow$ $\beta < \alpha$, | But in critical f conditions $\beta = \alpha$

In case of Figured Question:



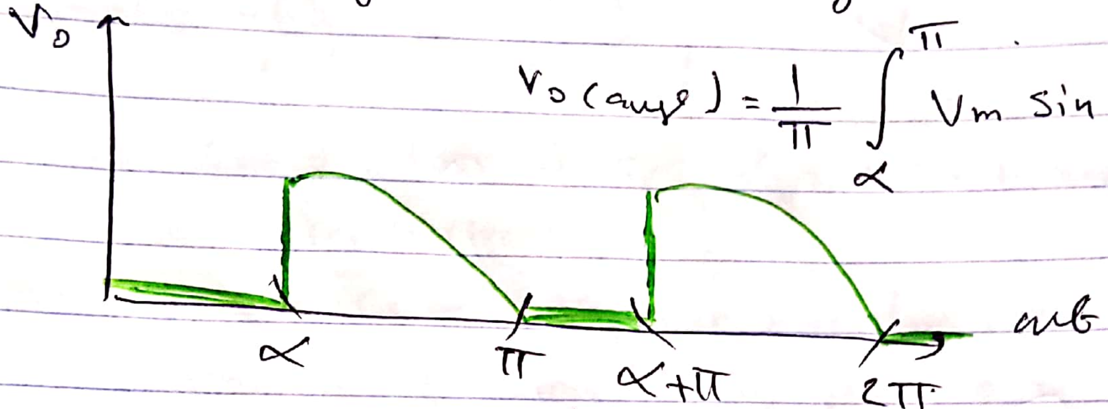
Mode بيعرف ال
(α) منه

$\underset{(DCM)}{\beta} = \underset{CCM}{\alpha_{cr}} = \frac{1}{\rho}\left[\ln\left(\frac{I_H}{I_2}\right)\right]$

نفس الاشي بس
بيختلف ال I_2
من وين احسبها
$\underset{CCM}{I_2}$ or $\underset{DCM}{I_2}$.

Average Output Voltage

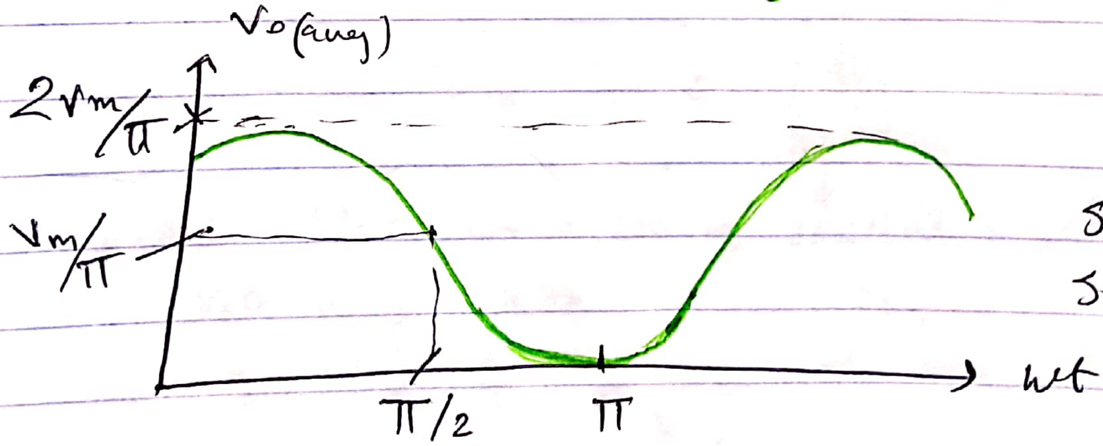
$$V_o(avg) = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \cdot d\omega t$$



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

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

$$\boxed{V_o(avg) \geq 0}$$



Shifted Sinousoidal

- $\alpha > \alpha_{cr}$ (DCM) $\rightarrow$ β, $\underset{(DCM)}{I_2}$
- $\alpha < \alpha_c$ (CCM) $\rightarrow$ I_1, $\underset{(CCM)}{I_2}$

لازم احسبهم

* Two cases : → Case ① $(\alpha = \phi)$

so... لا يجيبلنا اياها الدكتور بالامتحان

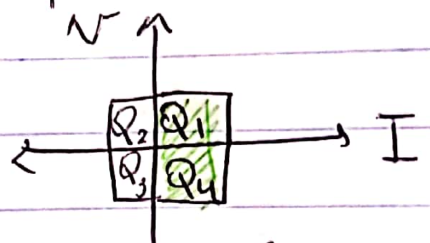
→ Case ② (special case) Highly inductive load with EMF

↳ R, L, E)) → ① Motor.

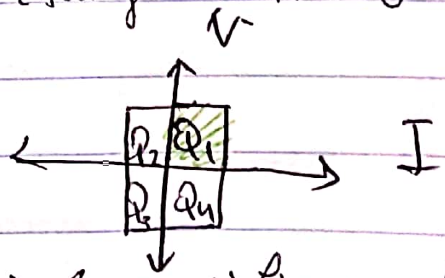
→ ② charger : {Battery + Smoothing reactor.}

Sufficiently Large L Such that the load current is ripple free (virtually constant)

- In motor case, Voltage can be positive or negative (current's always positive)

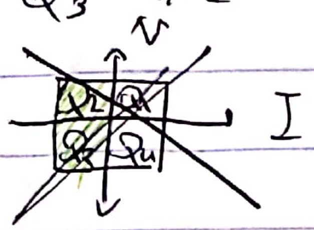


- Charger case, voltage & current are negative and we don't need a fully controlled rectifire.



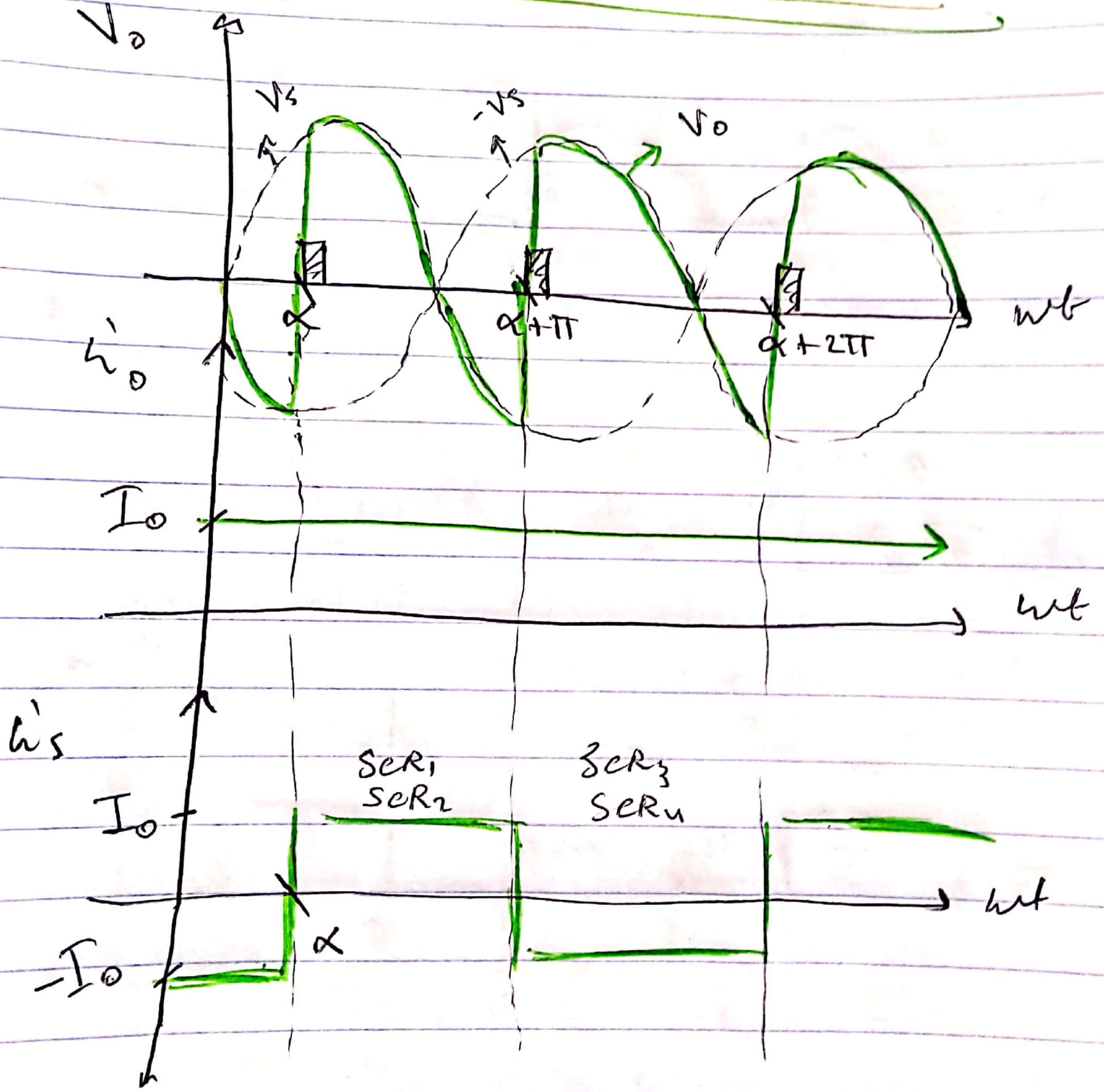
Note : Since we're using rectifires, there's no way we're negative current so Q_2 & Q_3 are not possible

wrong →

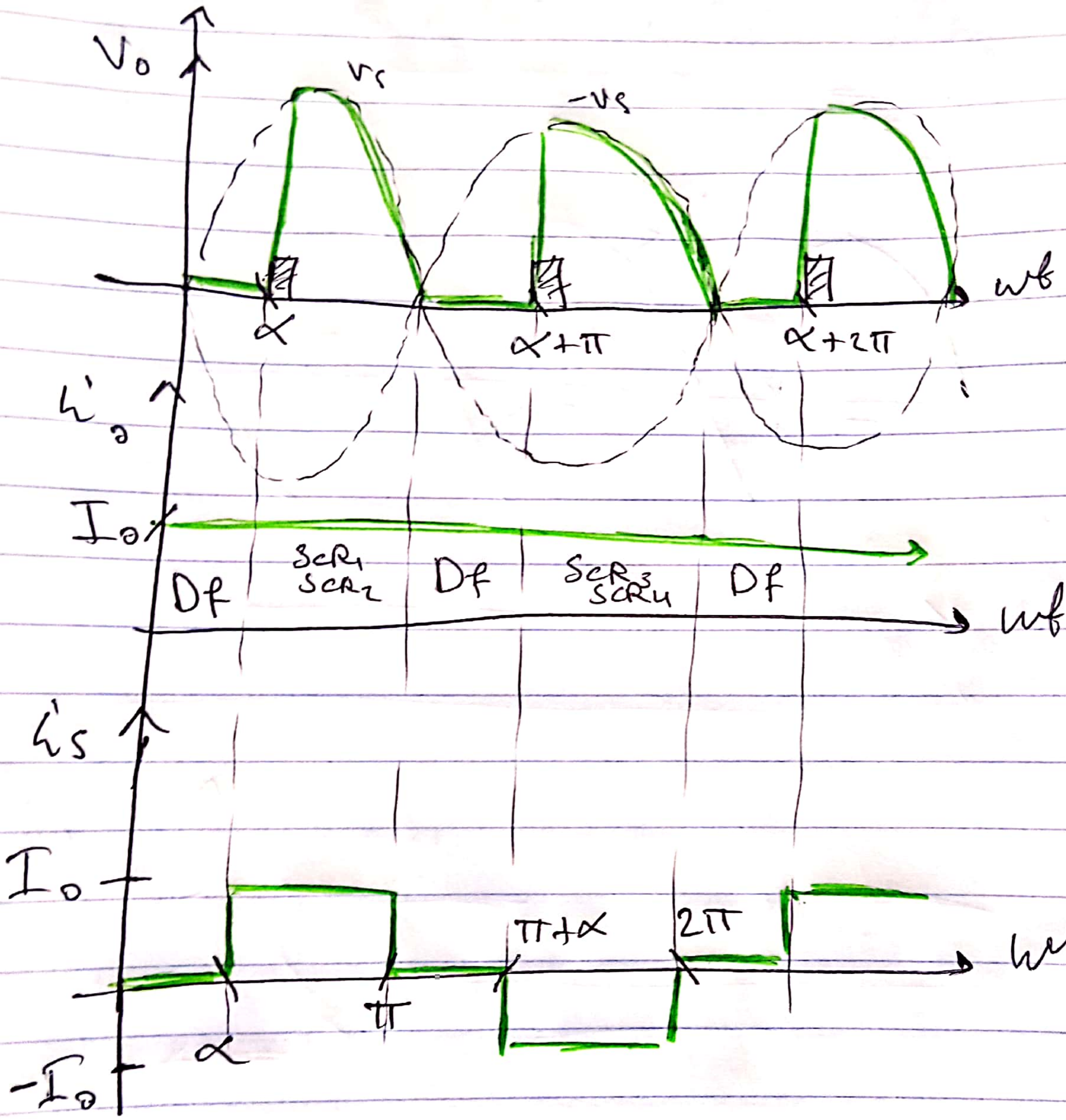


• L = Sufficiently large , coil لانه ماخذنا
بأكبر د مهم!

• Fully controlled rectifire



half / Semi - controlled rectifire



3/12/2019 Lecture 28

- Special case: harmonics ⇝ increases the current

→ $P_{cu\,(rated)} = R_a * I_{avg}^2$

$$I = \sqrt{I_{avg}^2 + \sum_{n=1}^{\infty}\left(\frac{I_{m(n)}}{\sqrt{2}}\right)^2}$$

→ $P_{cu}' = R_a * I^2$

$P_{c\,(rated)} < P_{cu}'$

- Torque is only produced by $I_{(avg)}$
(avg)

- We want a load current ripple-free (no-harmonics)

R-L-E load with (L) so larage such that the load current is ripple-free or is almost virtually constant.

- R-L-E load case is always a CCM

لم يعني ماعي داعي اروح أدور على ال β ...

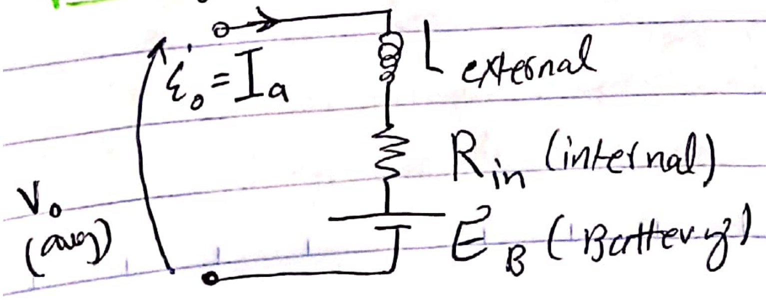
[1] Motor with large L or external L.

[2] Battery (charger) → Back EMF + current smoothing coil (external)

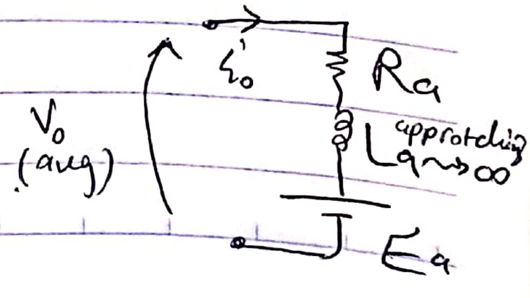
ripple factor: RF < 5 %
∴ ripple free. ✓

- why do we want a ripple-free current?
to avoid over-heating & motor derating or battery charger stress.

Battery case



Motor case



- **F.C.R** : $V_{o\,(avg)} = \dfrac{2V_m}{\pi}\cos(\alpha)$

Fully controlled Rectifire.

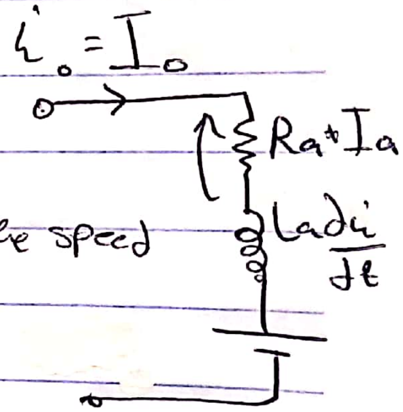
- **S.C.R** : $V_{o\,(avg)} = \dfrac{V_m}{\pi}(1+\cos\alpha)$

Semi-controlled rectifire.

→ Since it's ripple-free ; $i_o = I_o$

$$V_{o\,(avg)} = E_a + I_a R_a$$

E_a or E_B



ex. اول F.C.R

in motor case it depends on the speed

$$\frac{2V_m}{\pi}\cos(\alpha) = E_a + I_a R_a$$

$$\Rightarrow K_a \cdot \phi \cdot \omega_m + \frac{T_a}{K_a\phi} \cdot R_a$$

$\left(L_a \frac{di}{dt} = 0\right)$

لانه almost Virtually constant.

K_1 : $\dfrac{K_a \phi\, 2\pi}{60} = K_1$

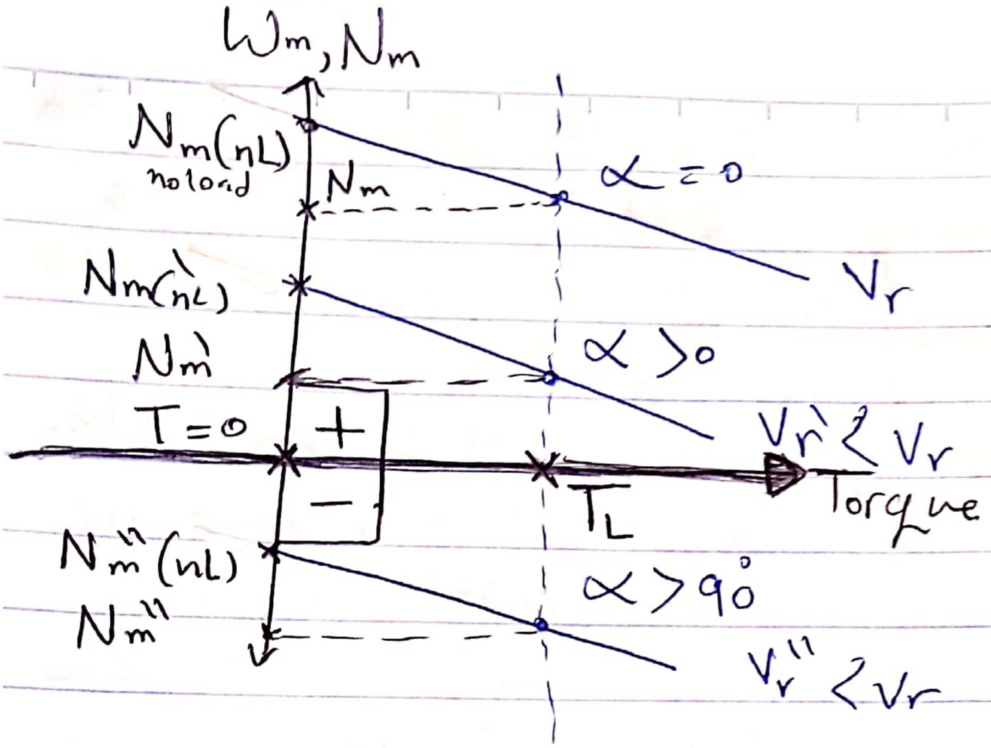
K_2 : $\dfrac{R_a}{K_a\phi} = K2$

$$\boxed{K_1 \cdot N_m + K_2 T_a = \frac{2V_m}{\pi}\cos(\alpha)}$$

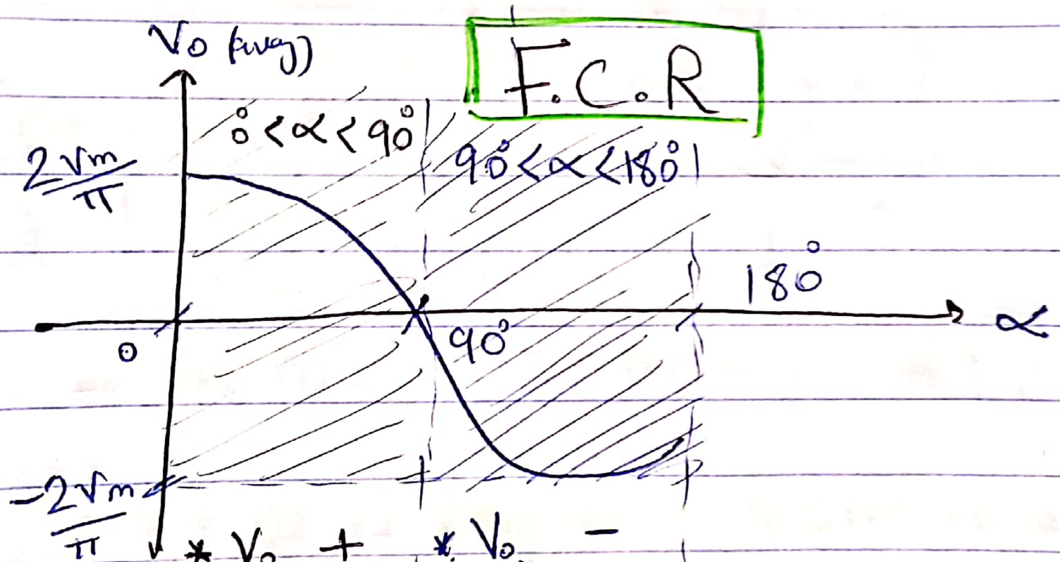
قد يكون موجب او سالب

دائماً موجب لانه التيار لا ينعكس بال Thyristor

هادا الجزء قد يكون موجب او سالب حسب قيمة α



$\boxed{\text{F.C.R}}$



$0° < \alpha < 90°$		$90° < \alpha < 180°$	
* V_o (avg)	+	* V_o (avg)	−
* I_o (avg)	+	* I_o (avg)	+
* T_q	+	* T_q	+
* N_m	+	* N_m	−
* $P = T_q \omega_m$		* $-P$	

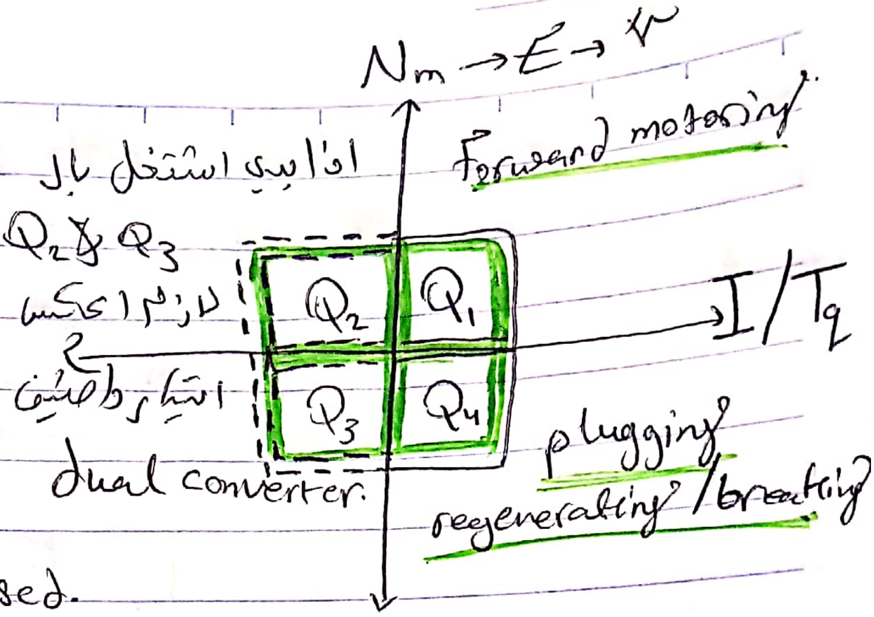
- motoring action (Rectification) mode
- (Forward motoring)

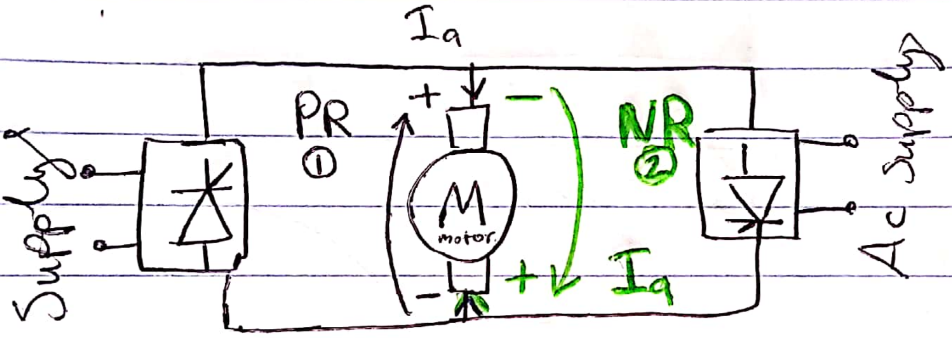
- (Blugging / Breaking)
- (Inversion mode @ Supply frequency) generating action.

كمان اميز بينه
وبين ال Inverter
العادي

Dual Converter

- to run at all 4 Quadrants (1 ⟶ 4) dual converter is used.



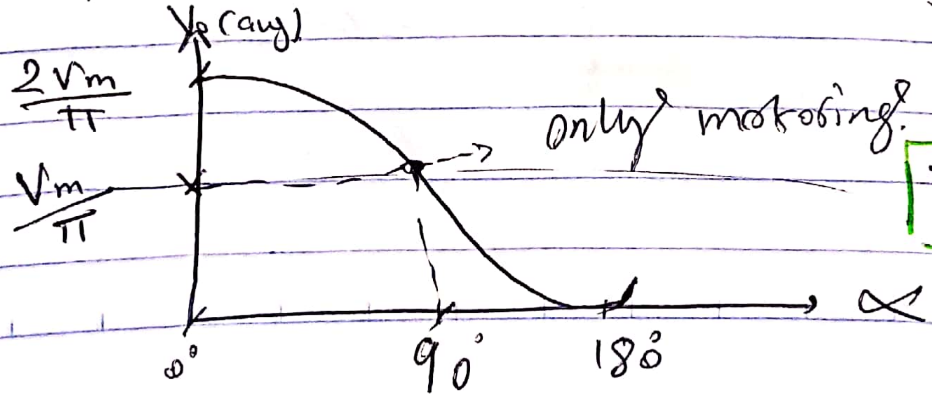


*) PR ① : (positive Rectifire) ← I_a direction

*) NR ② : (Negative Rectifire)

- In dual converter one of the back-to-back connected rectifires work. but if $\alpha_1 + \alpha_2 = 180$, then they can work together.

ex: $\alpha_1 = 60°$, $\alpha_2 = 120°$. PR & NR work

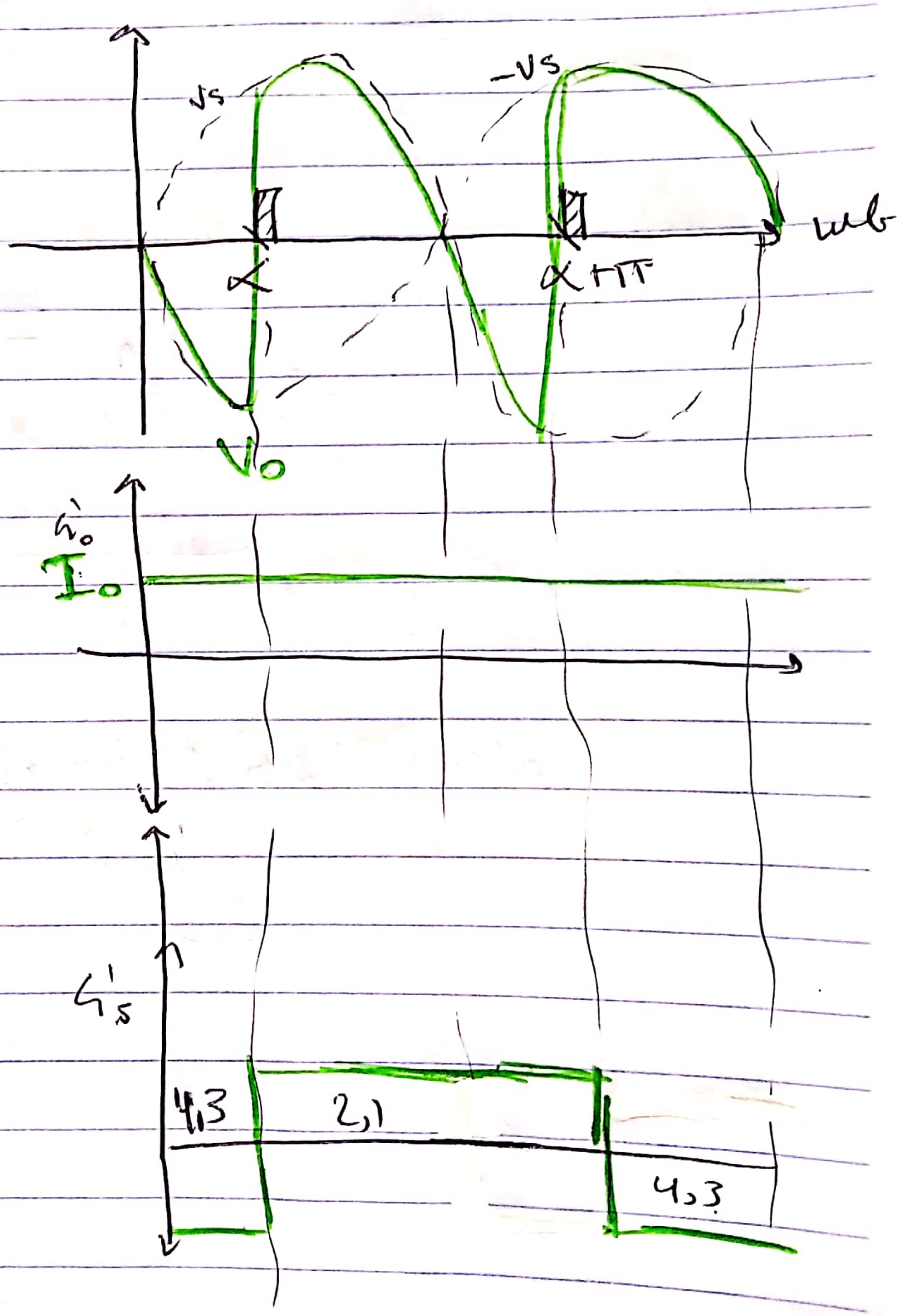


$$\boxed{\frac{V_m}{\pi} \cdot \cos(\alpha + 1)}$$

5 / 12 / 2019 Lecture 29

Quiz : Sketch the load / supply, current and voltage waveformes for a full wave fully controlled rectifier for an L-R-E load with $L \to \infty$ (very large):

→ $i_o = I_o$

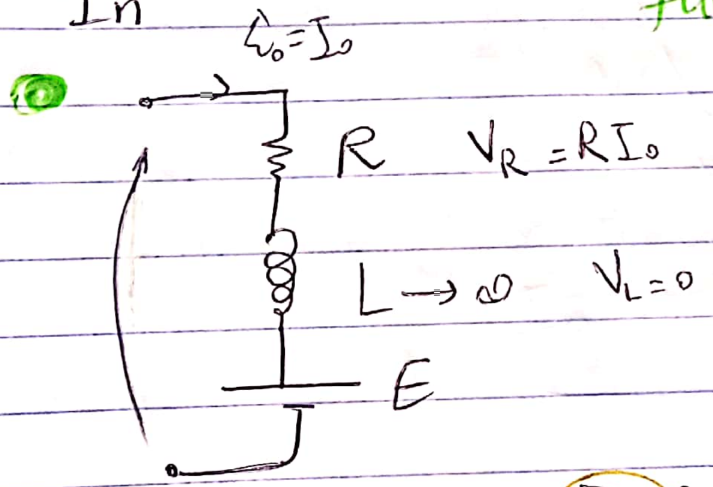


Q) controller Single-phase full wave fully controlled bridge rectifire. Supply: 230 V, 50 HZ Sinousodal. Load: series R-L-E Load with R equal to 0.5 Ω, $L \to \infty$,

a) $E = +65$ V. (motoring) b) -75 V (generating)

For $I_o = 10$ A, Find: α, RF, RF_{V_o}, $THDF_{I_o}$, PF_{I_n}: I_s

• note in Questions like this I_o or α is given



V_o (Avg) $= I_oR + E$

ممكن نقول عن السرعة بالإشارة مرتبطة بال E

او عن ال Torque مرتبطة بال I_o

Contious mode of operation: $\frac{2V_m}{\pi} \cos\alpha = 10 * 0.5 + 65$

$\frac{2V_m}{\pi} \cos\alpha = 70$ V

$\cos\alpha = \frac{70 * \pi}{2(\sqrt{2}) * 230} \Rightarrow \alpha = 70.8^\circ$

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- $RF_{V_o} = \dfrac{\sqrt{V_{o\,rms}^2 - V_{o\,avg}^2}}{V_{o\,avg}}$, $V_o(rms) = V_{s\,rms}$ CCM is دائماً

$V_o(avg) = 70\text{v}$

So, $RF = \dfrac{\sqrt{(230)^2 - (70)^2}}{70} = 3.1\ pu$

or

310%

- $RF_{I_o} = \text{Zero}$ (pure DC)

- $THDF_{i_s}$: HARMONIC Analysis

odd symmetry $\rightarrow n = 1, 3, 5, 7, \ldots$

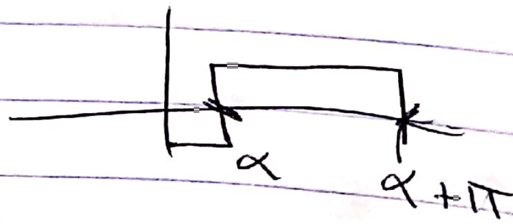
even symmetry $\rightarrow n = 2, 4, 6, \ldots$

$C(n) = 0$

$$A(n) = \frac{2}{T}\int_{t_o}^{t_o+T} i_s(t)\cdot\cos(n\omega t)\, d\omega t \quad , n = 1, 2, 3, 4.$$

Symmetry is being taken into consideration

$$= \frac{4}{T}\int_{t_o}^{t_o+T/2} i_s(t)\cdot\cos(n\omega t)\, d\omega t \quad , n = 1, 3, 5$$



$$\frac{4}{2\pi}\int_{\alpha}^{\alpha+\pi} I_o\cos(n\omega t)\, d\omega t$$

$$= \frac{4 I_o}{2\pi n}\Big[\sin(n\omega t)\Big]_{\alpha}^{\alpha+\pi}$$

$$= \frac{4I_0}{2n\pi}\left[\underbrace{\sin(n\alpha + n\pi)} - \sin(n\alpha)\right]$$

$$\sin(n\alpha + n\pi) = \sin(n\alpha)\underbrace{\cos(n\pi)}_{-1} + \cos\alpha \,\underbrace{\cancel{\sin n\pi}}_{0}$$

$$= (-\sin n\alpha)$$

$$A(n) = \frac{-4I_0}{n\pi}\sin(n\alpha) \;\#$$

$$\rightarrow B(n) = \frac{4}{2\pi}\int_{\alpha}^{\alpha+\pi} I_0 \sin(n\omega t)\, d\omega t$$

$$= \frac{-4I_0}{2\pi n}\cdot\left[\cos(n\omega t)\right]_{\alpha}^{\alpha+\pi}$$

$$= \frac{4I_0}{2\pi n}\left[\underbrace{-\cos(n\alpha + n\pi)} + \cos(n\alpha)\right]$$

$$-\cos(n\alpha + n\pi) = -\underbrace{\cos(n\alpha)\cos(n\pi)}_{+1} + \sin(n\alpha)\underbrace{\cancel{\sin(\pi)}}_{0}$$

$$\frac{4I_0}{n\pi}\cos n\alpha = B(n)$$

$$\rightarrow C(n) = \frac{4I_0}{n\pi}\sqrt{\sin^2(n\alpha) + \cos^2(n\alpha)}$$

$C(n) = \frac{4I_0}{n\pi}$ peak Amplitude for n^{th} harmonic.

$$\rightarrow \psi_{(n)} = \tan^{-1}\left(\frac{-B(n)}{A(n)}\right) \text{ or } \tan^{-1}\left(\frac{A(n)}{B(n)}\right)$$

desplacement angle / Phase shift

Using this :

$$= \tan^{-1}\left(\frac{\frac{-4 \cancel{I_o}}{n\pi}\sin(n\alpha)}{\frac{4\cancel{I_o}}{\cancel{n\pi}}\cos(n\alpha)}\right)$$

$$= \tan^{-1}\left(-\tan(n\alpha)\right)$$

$$\psi(n) = -n\alpha$$

$$\boxed{I_s / i_s = \sum_{n=1,3,5,7,\ldots} \frac{4 I_o}{n\pi} \cdot \sin(n\omega t - n\alpha)}$$

تكملة المحاضرة القادمة.

- $C(n) = \frac{4I_o}{n\pi}$, $i_s(n) = \frac{4I_o}{n\pi} \sin(n\omega t - n\alpha)$

  $* \; n = 1, 3, 5, \ldots$

$$i_s = \sum_{n=1,3,5,7,\ldots} \frac{4I_o}{n\pi} \sin(n\omega t - n\alpha)$$

- Power Factor

$V_s = V_m \sin(\omega t)$

$$i = \frac{4I_o}{\pi} \sin(\omega t - \alpha) + \frac{4I_o}{3\pi} \sin(3\omega t - 3\alpha) \ldots$$

$$\ldots + \frac{4I_o}{5\pi} \sin(5\omega t - 5\alpha) + \ldots$$

avg value = zero

- $P_{in} = ??$

$$P_{(1)} = \frac{V_m}{\sqrt{2}} * \frac{4I_o}{\pi\sqrt{2}} * \cos(\omega t - \omega t + \alpha)$$

fundimental

$$P(1) = V_s(rms) * I_{s(1)}(rms) \cos(\alpha)$$

$P(3) = 0$, $P(5) = 0$,

$$P_{in} = P_s = V_s(rms) * I_s(1)(rms) \cdot \cos(\alpha).$$

$$PF_{in} = \frac{P_s\,(real)}{P_s\,(apperant)} = \frac{P_s}{S_s}$$

$$\tilde{S} = V_{s(rms)} I_{s(rms)}$$

$$\boxed{I_{s(rms)} \neq I_{s(1)\,rms}}$$

$$\Rightarrow P_{in} = \frac{P_s}{\tilde{S}}$$

$$\Downarrow$$

$$\left(V_{s(rms)} I_{(1)(rms)} \cdot \cos(\alpha)\right)$$

$$P_{in} = \frac{V_{s(rms)} I_{s(1)(rms)} \cos(\alpha)}{V_{s(rms)} I_{s(rms)}} = \frac{I_{s(1)(rms)}}{I_{s(rms)}} * \cos\alpha$$

Distoration factor ≠ Total harmonic distration factor.

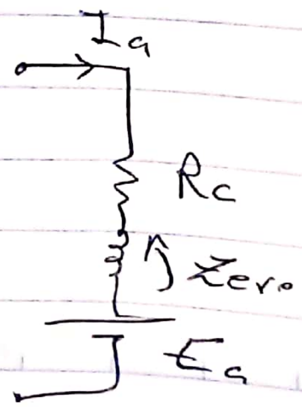
- $P_{in} = DTF * DPF$

Displacement factor = cos(angle between fundimental voltage & fundimental current)

[or] alternatinly → $PF_{in} = \frac{P_s}{\tilde{S}_s} = \frac{P_o}{\tilde{S}_s}$

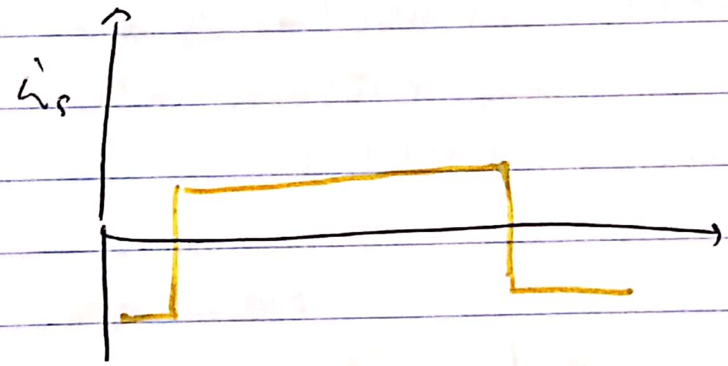
supply

$$= \frac{I_a^2 R + (I_a E_a)}{\tilde{S}_s}$$



$$= \frac{I_o[E_a + I_o R]}{V_s(rms)\, I_s(rms)} = \frac{I_o V_o(avg)}{V_s(rms)\, I_s(rms)}$$

Relationship between I_o & $I_s(rms)$



They have same RMS Value.

$I_s(rms) = I_o$

$$= \frac{\cancel{I_o} V_o(avg)}{V_s(rms)\, \cancel{I_s(rms)}} = \boxed{\frac{V_o(avg)}{V_s(rms)} = PF_{in}}$$

Cont. Question solution ...

$$I_{s(1)} = \frac{4 I_o}{\pi \sqrt{2}} = \frac{4 \times 10}{\pi \sqrt{2}} = 9A$$

$$PF_{in} = \frac{70}{230} = 0.304 \text{ (lagging)}$$

$$DTF = 9/10 = 0.9$$

$$DPF = \cos\alpha = \cos(70.2) = 0.34$$

check

PF_{in} in the new way:

$$Pf_{in} = 0.9 \times 0.342 = 0.307$$

$\boxed{\text{PART 2}}$ -75 v

$E_f / E_a = -$ negative: motor is changing direction.

→ Current will never change direction because of the rectifire positive current (always)

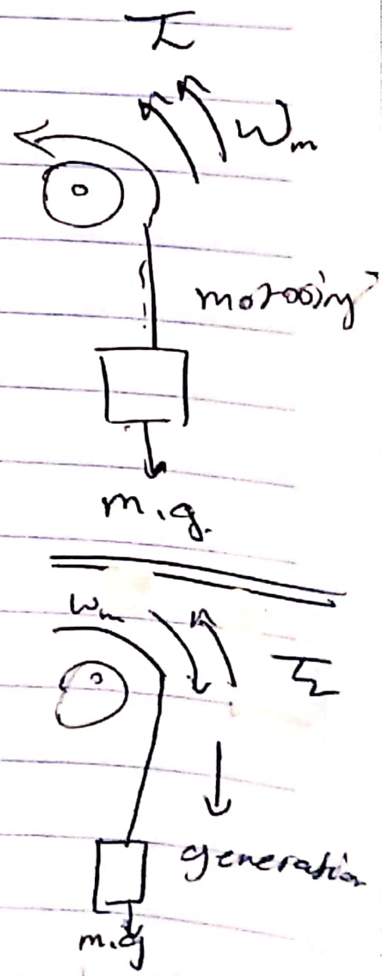
(blugging / breaking) case

- solution:

$$V_{o(avg)} = E_a + I_o R_a$$
$$= -75 + 10 \times 0.5 = -70\ V$$
$$\cos\alpha = \frac{-70 \times \pi}{2V_m}$$
$$\boxed{\alpha = 109.7°}$$

$$PF_{in} = \frac{V_{o\,(avg)}}{V_{(rms)}} = \frac{-70}{230} = -0.304$$

↓ means generation



Homework 220V, 50 HZ, Sinosoidal, RL-series load, $R = 10\Omega$, $L = 55.13\ mH$, $\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$

$\alpha = \phi$ critical case.

$\alpha = 60^\circ$

$\omega L = 2\pi * 50 * 55.133 * 10^{-3}$ ----

Calculate all performance parameters of load & supply

① draw waveforms ⓔ after ϕ calculation.

② load $RF_{v_{load}}$, $RF_{i_{load}}$

③ supply $THDF_{i_s}$, $PF_{in\ supply}$

10/12/2019

Lecture 31

- fully controlled rectifier, supply 220, 50 Hz, sinusoidal, R-L load, R = 10, L = 55.133 mH

Solution

$V_{o(avg)} = \frac{2V_m}{\pi}\cos\alpha$, $\tan^{-1}\left(\frac{\omega L}{R}\right) = \phi$

CCM

$X_L = \omega L = 2\pi * 5 * 55.133 * 10^{-3} = 17.3$

$\phi = 60^\circ$ $\boxed{\text{CC mode}}$

$\Rightarrow V_{o(avg)} = \frac{2 * 220 * \sqrt{2}}{\pi}\cos 60^\circ$

$I_{o(avg)} = \frac{1}{\pi}\int_{\alpha}^{\alpha+\pi} I_m \sin(\omega t)\, d\omega t = \frac{V_{o(avg)}}{R}$

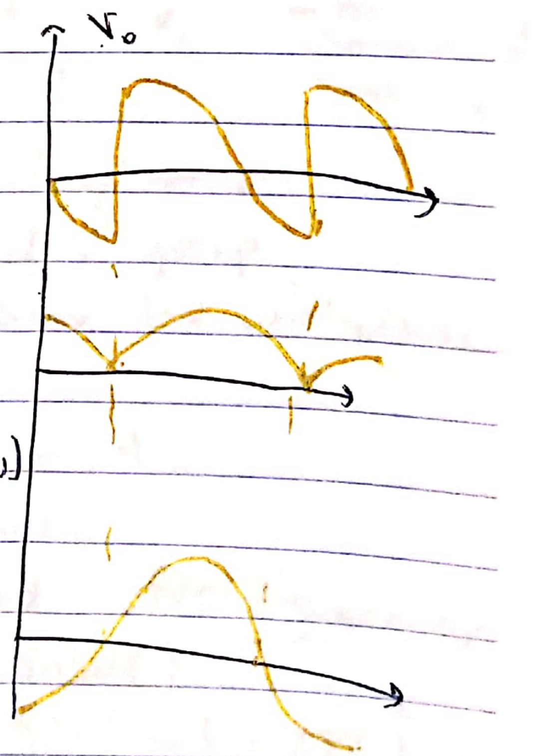
$I_m = \frac{V_m}{Z} = \frac{220\sqrt{2}}{\sqrt{10^2 + 17.3^2}}$

$I_{o(rms)} = \frac{I_m}{\sqrt{2}}$

- $A(n), B(n) = ??$ $\boxed{\text{Home-work}}$

$i_o = I_{o(avg)} + \sum_{n=2,4,6,\ldots} I_{o(n)} \cdot \sin(n\omega_0 t + \varphi(n))$

$I_{o(n)} = \sqrt{A(n)^2 + B(n)^2} = C(n)$



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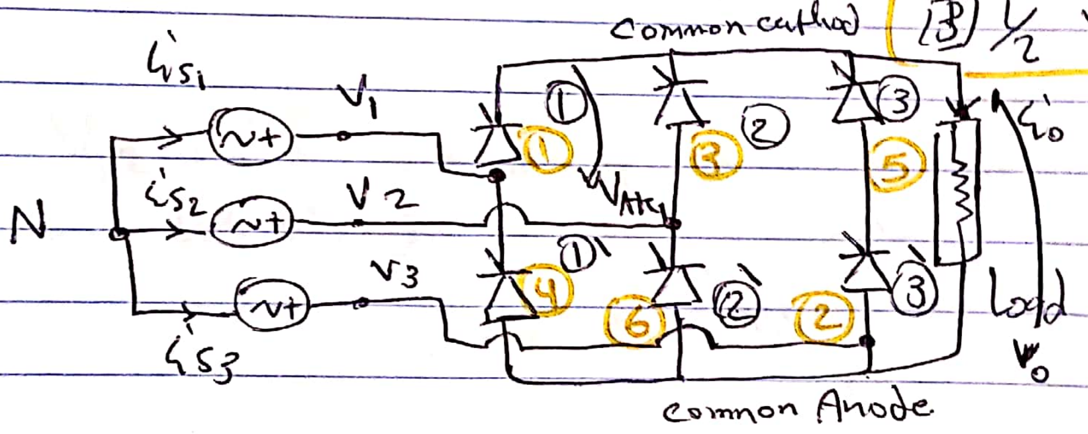
3-phase-rectifires.

- pure resistive load : power circuit → full wave, → half wave.
  - Real numbering for Later.
  - Y-connected ⇒ avoid harmonics. & circulating current.

Disadvantages:
1. Dc in supply
2. low power
3. ½ voltage



Real numbering
— non-conventional numbering

- Common cathod ≡ positive rectifying group.
- common Anode ≡ negative rectifying group
- V_{AK_1}, V_{AK_2}, ---- are the same but with phase shift.
- الرســمة مهمة جداً مع الأرقام الحقيقية والتفاصيل كلها.

- Supply: (3-phase balanced (+ve Sequence)

Referance → $V_1 = V_m \sin(\omega t)$

$V_2 = V_m \sin(\omega t - 2\pi/3)$

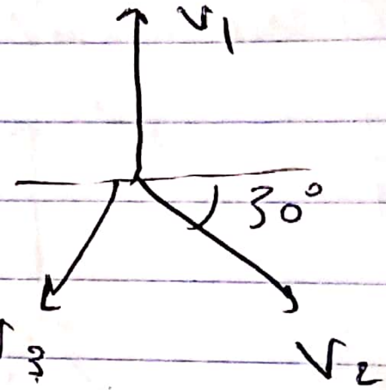
$V_3 = V_m \sin(\omega t - 4\pi/3)$

→ for a balanced supply: →

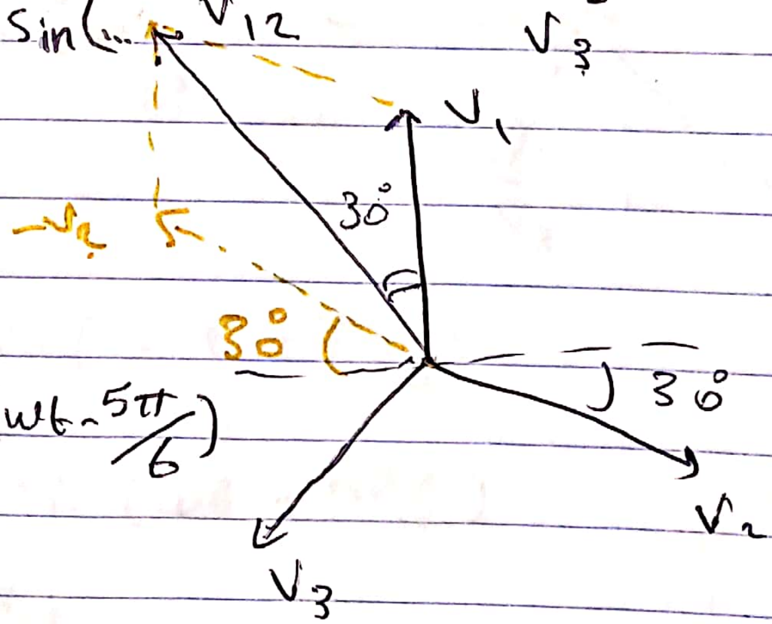
[1] V_m's are equal (peak)
[2] ωt's are equal
[3] 120° shift between one voltage and another.

- $V_{12} = V_1 - V_2 = V_m \sin \omega t - V_m \sin \omega t \ldots$ -----

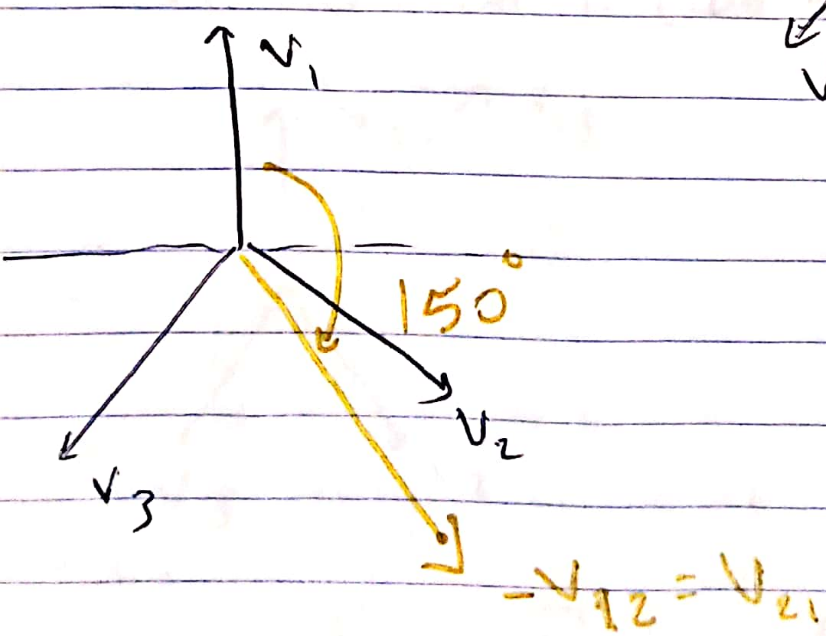
Graphically:-



$V_{12} = \sqrt{3}\, V_m \sin(\ldots$
$\ldots \omega t + \pi/6)$



$V_{21} = \sqrt{3}\, V_m \sin(\omega t - \frac{5\pi}{6})$



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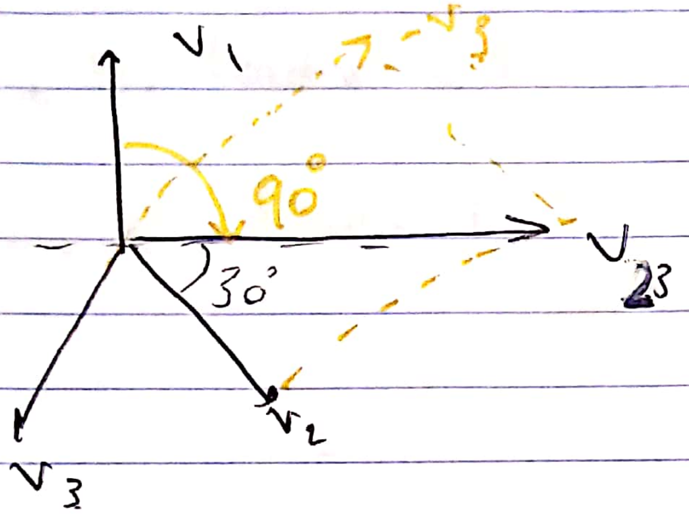
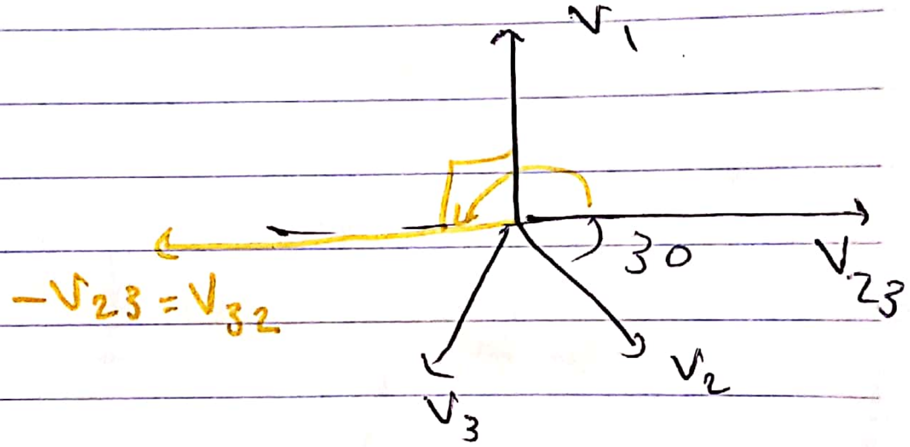
$$V_{23} = \sqrt{3}\, V_m \sin(\omega t - \pi/2)$$



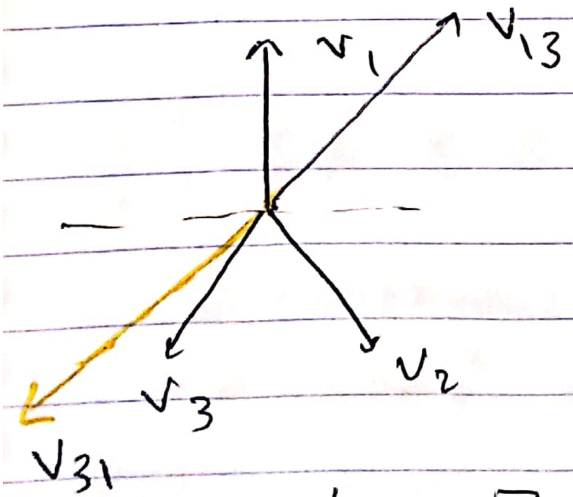
$$V_{32} = \sqrt{3}\, V_m \sin(\omega t + \pi/2)$$

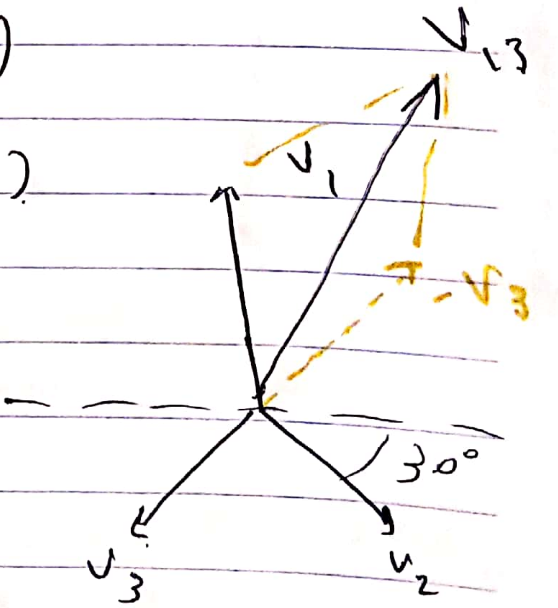


$$V_{31} = \sqrt{3}\, V_m \sin(\omega t - 7\pi/6)$$

or

$$V_{31} = \sqrt{3}\, V_m \sin(\omega t + 5\pi/6)$$

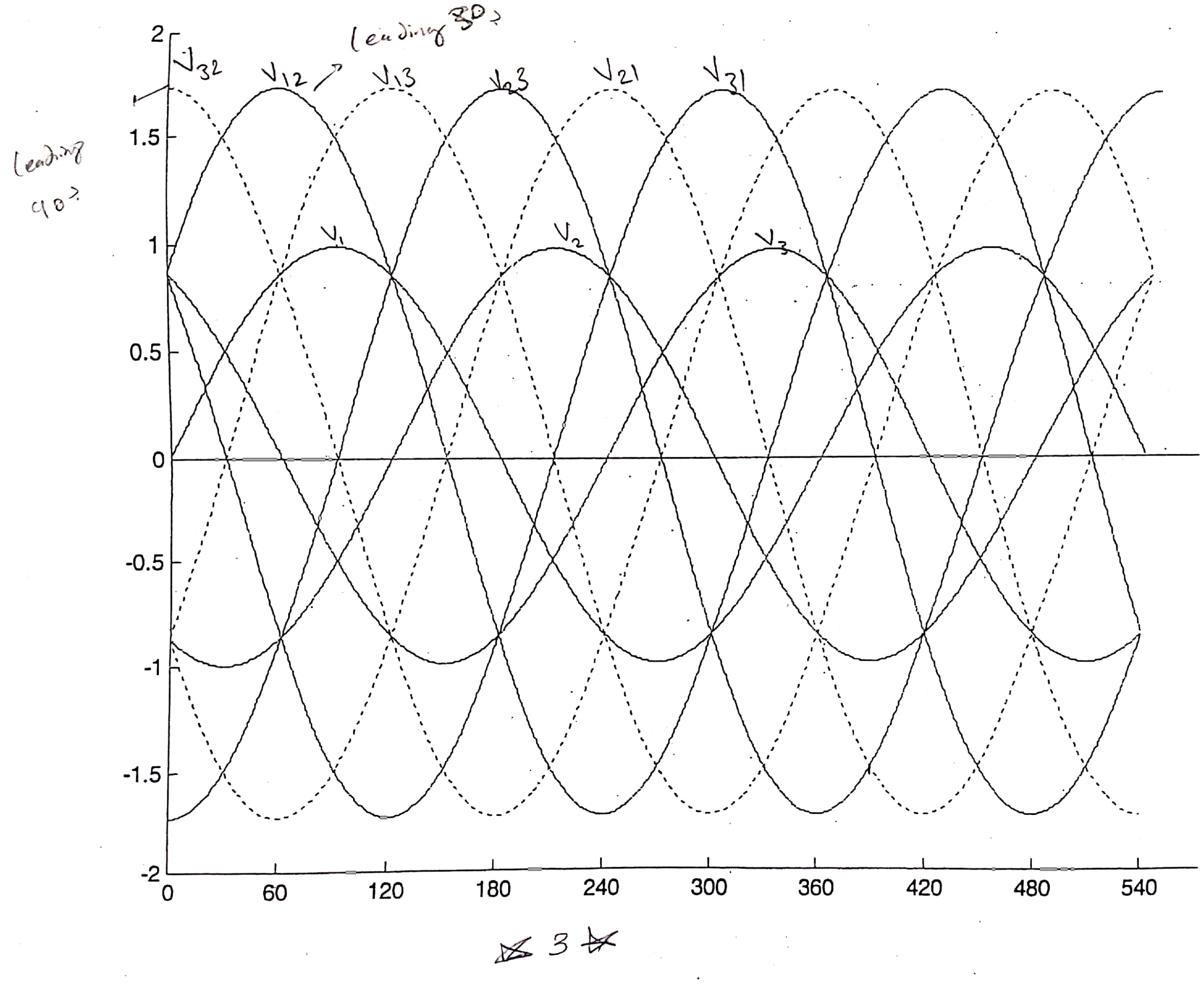




$$V_{13} = \sqrt{3}\, V_m \sin(\omega t - \pi/6)$$

$\boxed{\text{or}}$

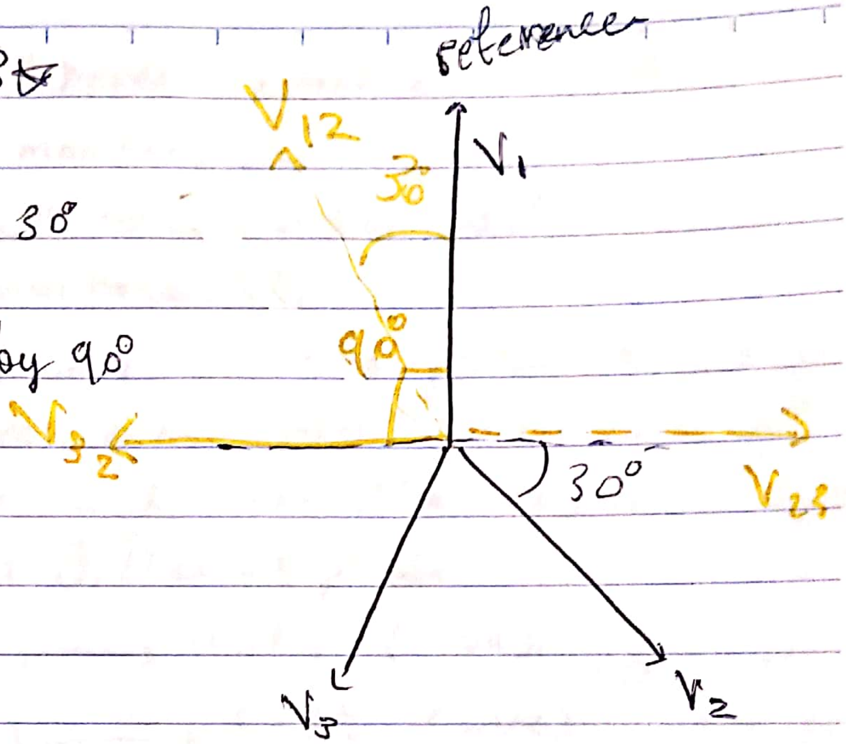
$$V_{13} = \sqrt{3}\, V_m \sin(\omega t + 11\pi/6)$$

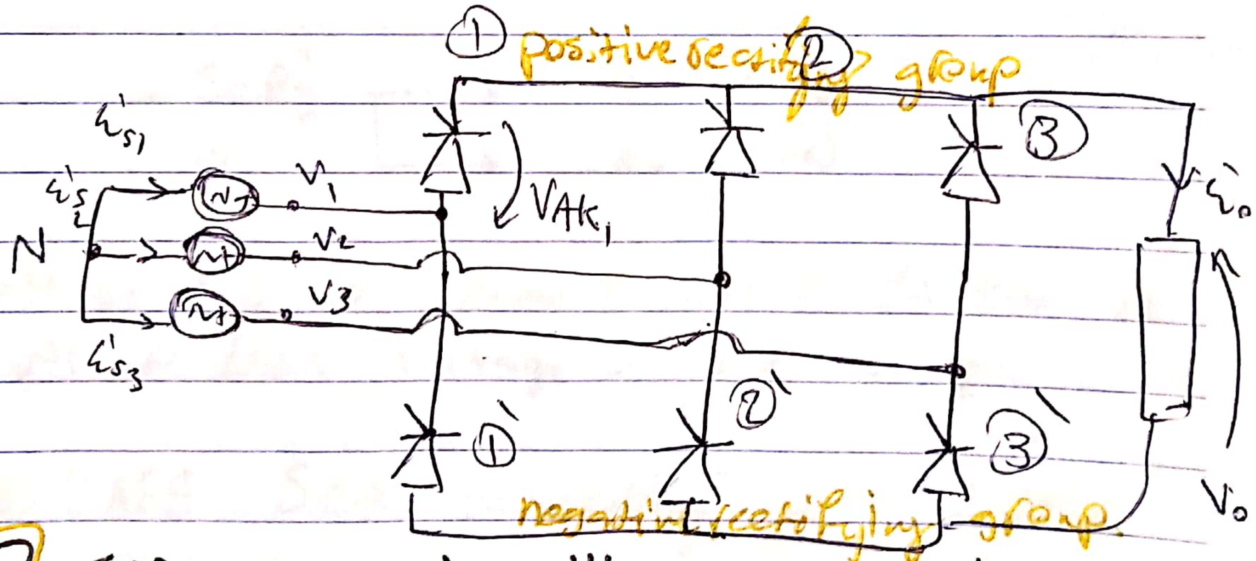

leading 80°
V_{32}
V_{12}
V_{13}
V_{23}
V_{21}
V_{31}
leading 40°
V_1
V_2
V_3
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
60
120
180
240
300
360
420
480
540
3

referring to ~~Δ~~ 3ϕ

→ V_{12} leading by $30°$

→ V_{32} leading by $90°$





[1] SCR_1 & SCR_1' will never conduct simontanously & the same for SCR_2 and SCR_2', SCR_3 and SCR_3'.

[2] any Thyristor of the positive group will never conduct with another SCR in the same group.

eg.:- + SCR(1) will never conduct with SCR(2) or SCR(3) simontanously.

+ SCR(1) will never conduct with SCR(1) or SCR(3) simontanously.

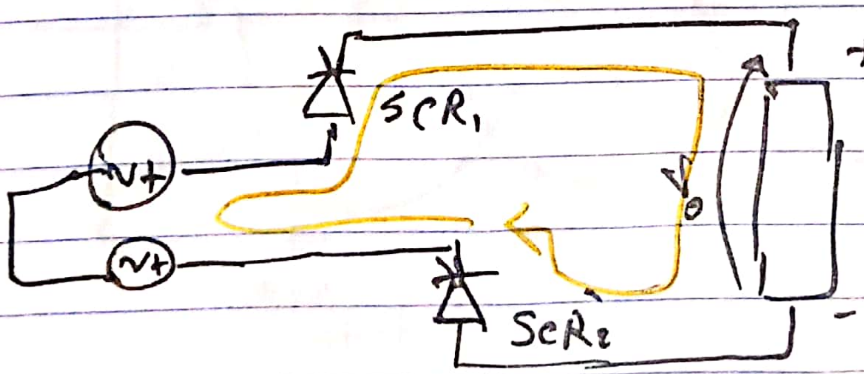
[3] any Thyristor at the positive group should share conduction simontanously with another SCR from the negative group but belongs to different phase.

eg.:- + SCR_1 (+ve) → SCR_2' (-ve), → SCR_3' (-ve) $\neq SCR_1'$ Same phase!

+ SCR_2' (-ve) → SCR_1 (+ve), → SCR_3 (+ve)

• هلأ على اي اساس بختار ؟ حسب ال Voltage ؛ اللي اله قيمة ال Voltage اكال هو اللي بمشي فيه.

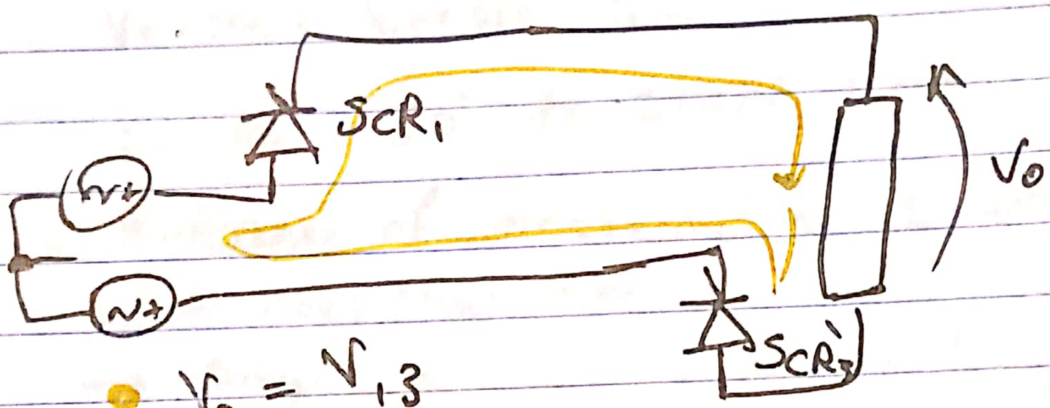
• CASE SCR_1 conducting with SCR_2'



• $V_1 - V_0 - V_2 = 0$

$V_0 = V_{12}$

● CASE SCR_1 conducting with SCR_3'

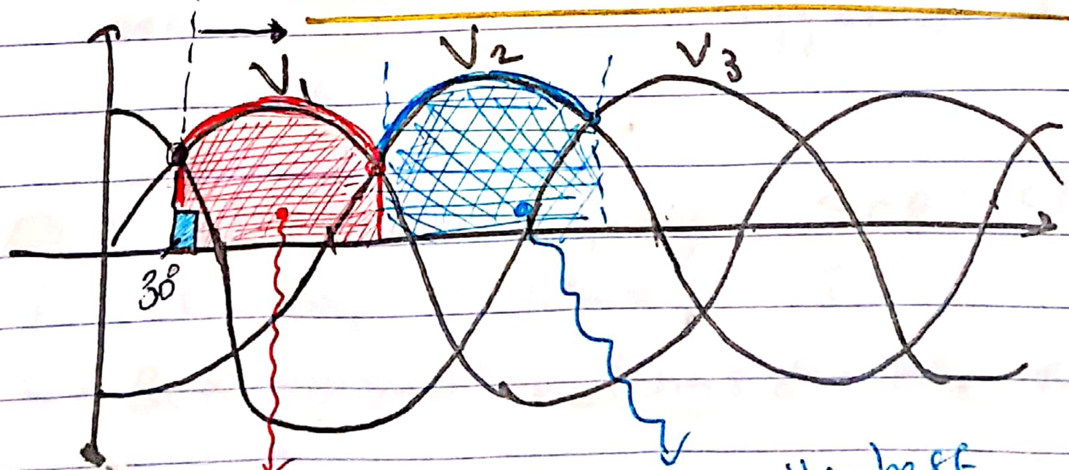


● $V_0 = V_{13}$

● The voltage across the Load is parts of The line voltages, not the (phase) voltages

e.g :- $V_{12}, V_{23}, V_{32}, V_{21}, \dots$

$\omega t = \pi/6 = 30^\circ$ **Reference of measuring α**



+ve group

V_1 هون

Highest in polarity

عشان هيك بقدر اشغل ال SCR_1

* قبلها ما رح يشتغل.

V_1 : Highest

→ triggering SCR_2 Here.

- $0^\circ \rightarrow 30^\circ$, we can't conduct SCR_1 because V_1 isn't the highest in voltage before 30°.

So $\alpha = 30^\circ$ to start SCR_1

* Reference of measuring α is $\omega t = \pi/6$, what does that mean?

→ Say $\alpha = 30$, SCR_1 is triggered at $\omega t = ??$ $\boxed{60^\circ = \omega t \longrightarrow \alpha = 30^\circ}$

- Each SCR is capable of conducting 120° at maximum.

- If SCR_1 is triggered at $\boxed{\omega t = X}$, SCR_2 should be triggered at $\boxed{\omega t = X + 120^\circ}$ and SCR_3 will be triggered at $\boxed{\omega t = X + 240^\circ}$

- For the negative group, SCR_1' should be triggered at $\boxed{\omega t = X + 180^\circ}$

↳ SCR_1 & SCR_1' belongs to the same phase.

15/12/2019 Lecture 33

3-phase Rectifires

Waveform construction.

$\alpha = 0 \rightarrow$ equivalent to uncontrolled rectifire.

SCR No.	Starts conduction at $\omega t =$	Ends conduction at $\omega t =$
1	$\alpha + 30$	$(\alpha + 30) + 120 = \alpha + 150$
1'	$(\alpha + 30) + 180 = \alpha + 210$	$\alpha + 210 + 120 = \alpha + 330$
2	$(\alpha + 30) + 120 = \alpha + 150$	$\alpha + 150 + 120 = \alpha + 270$
2'	$(\alpha + 150) + 180 = \alpha + 330$	$\alpha + 330 + 120 = \alpha + 450$; $\alpha + 360$, $0 \rightarrow 90^\circ$
3	$(\alpha + 150) + 120 = \alpha + 270$	$\alpha + 270 + 120 = \alpha + 390$; $\alpha + 360$, $0 \rightarrow 30^\circ$
3'	$\alpha + 270 + 180 = \alpha + 450$; 90°	$\alpha + 90 + 120 = \alpha + 210$

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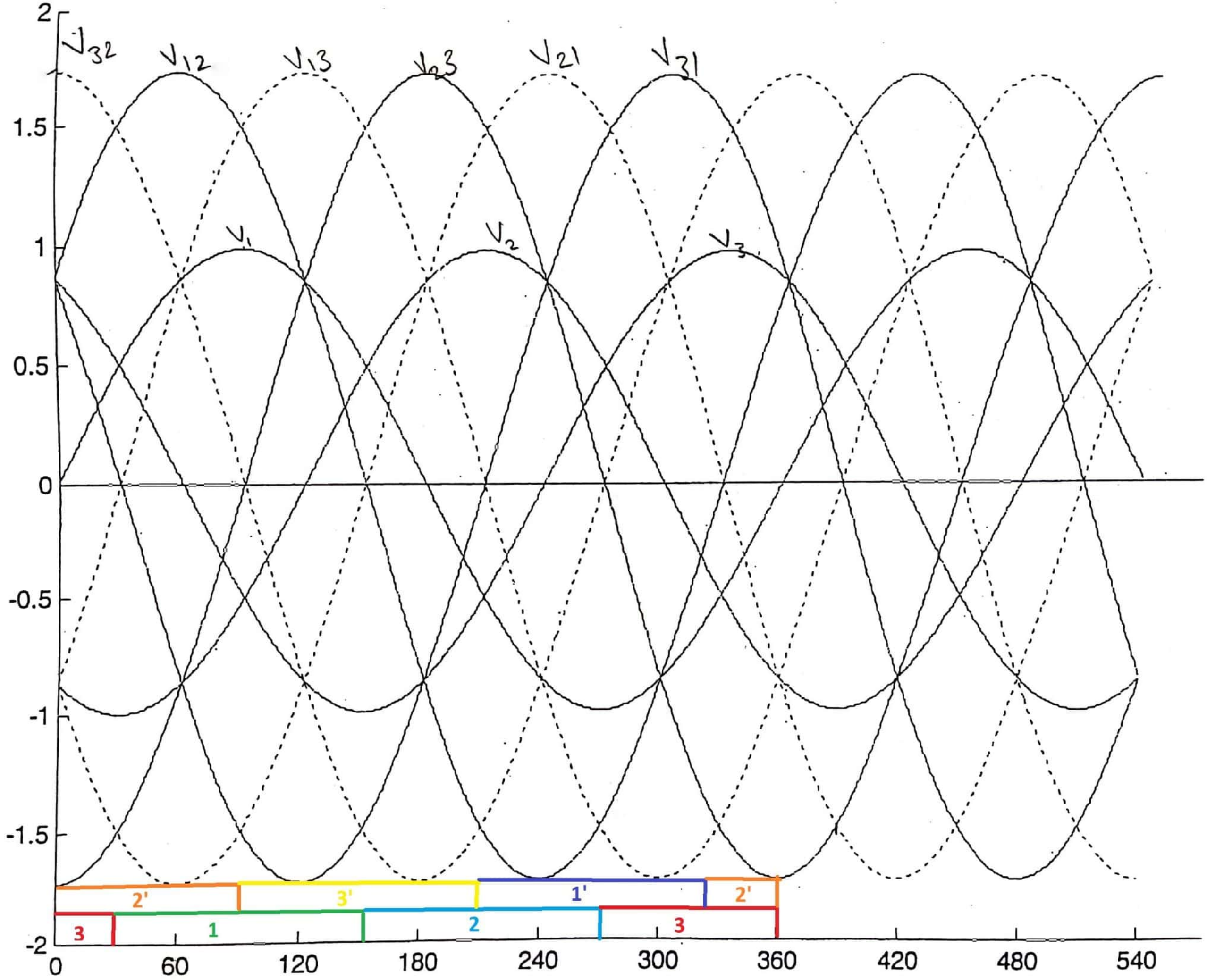
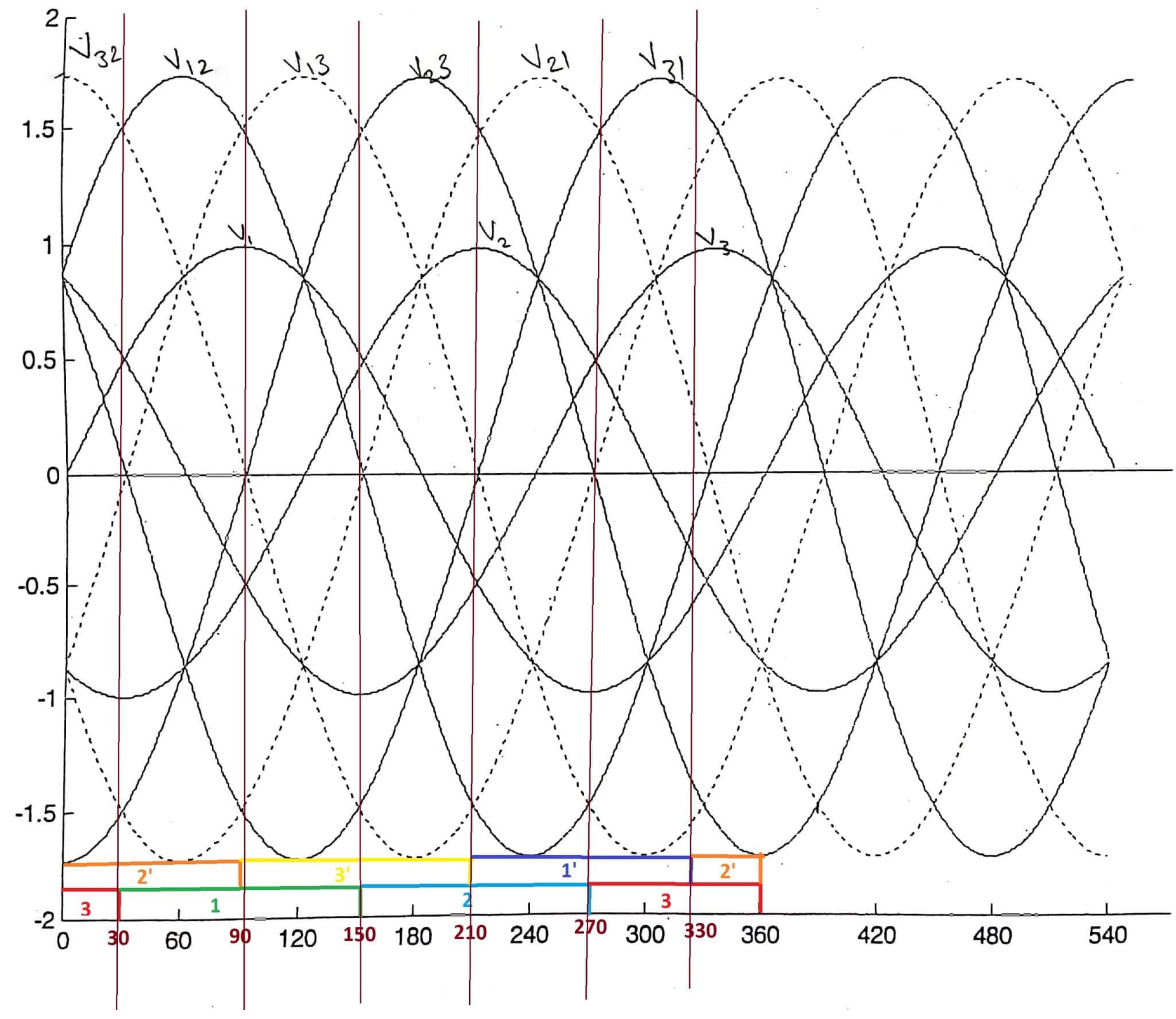
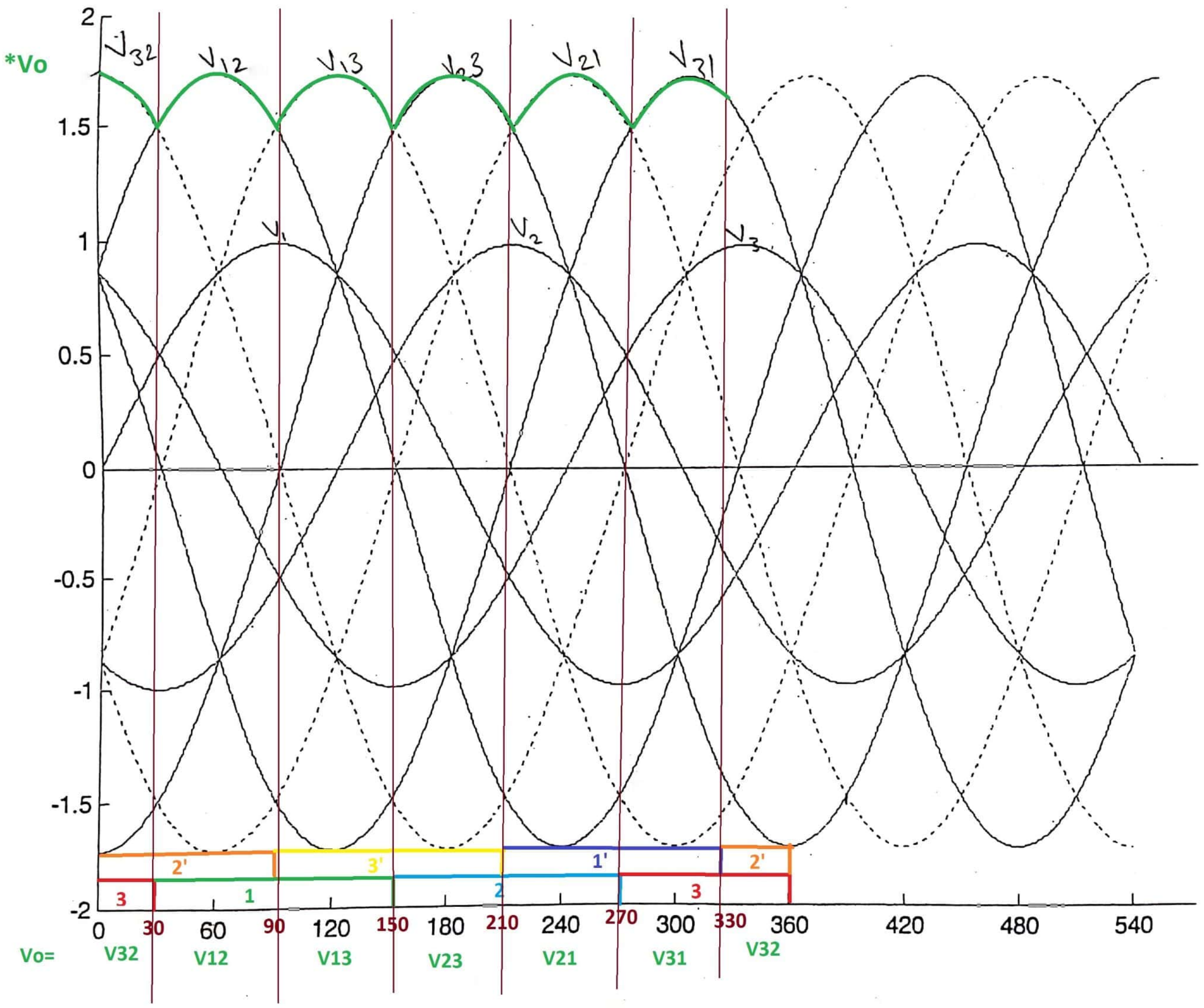
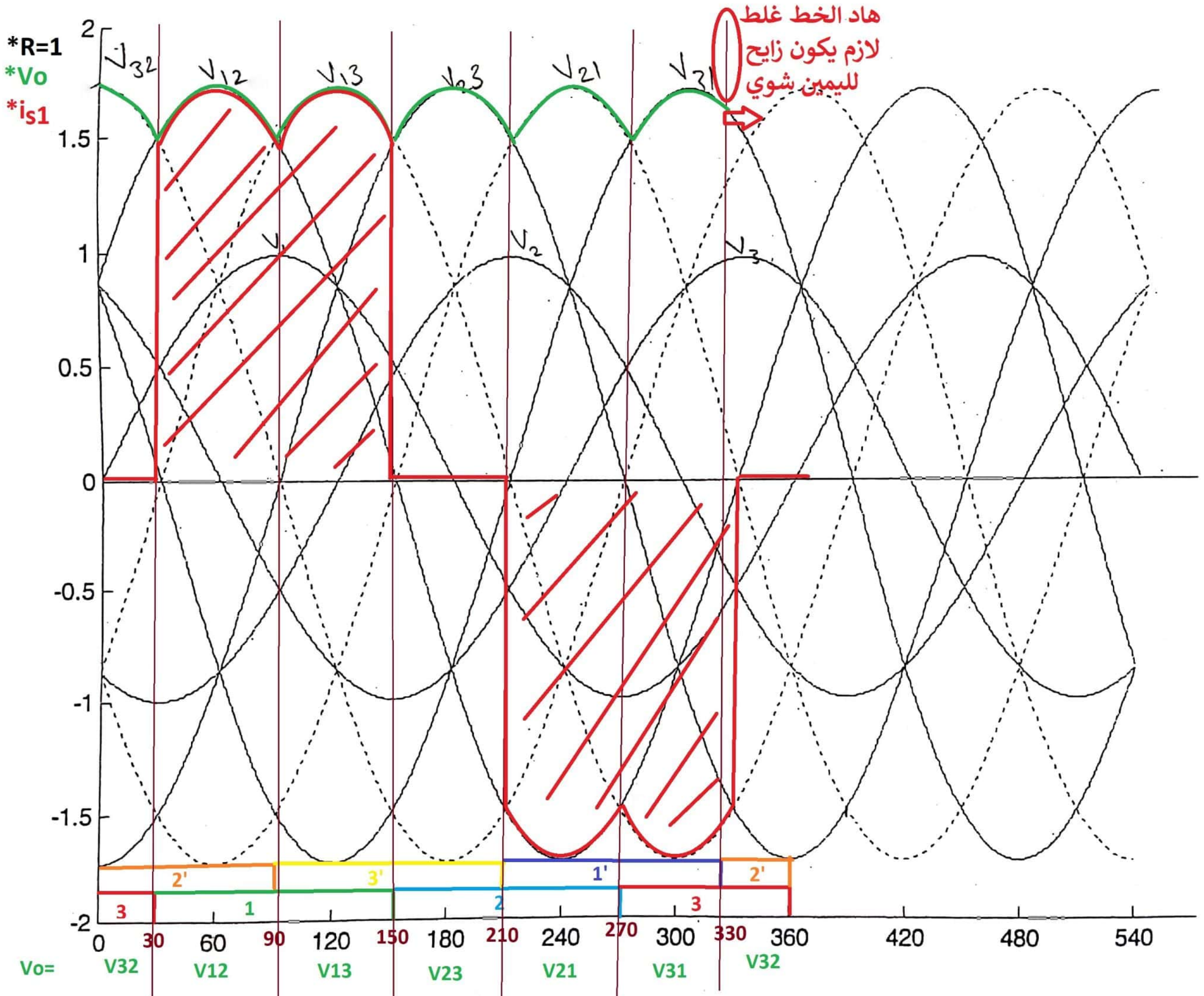


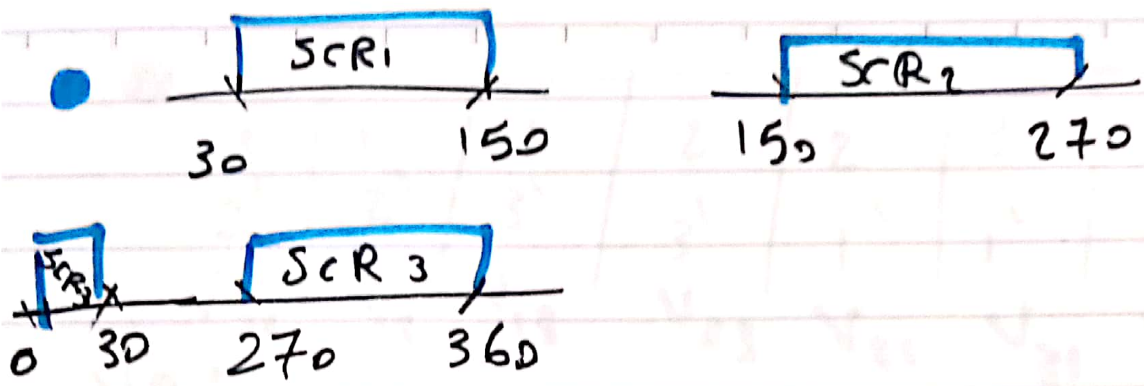
V32
V12
V13
V23
V21
V31
V1
V2
V3
2'
3'
1'
2'
3
1
2
3

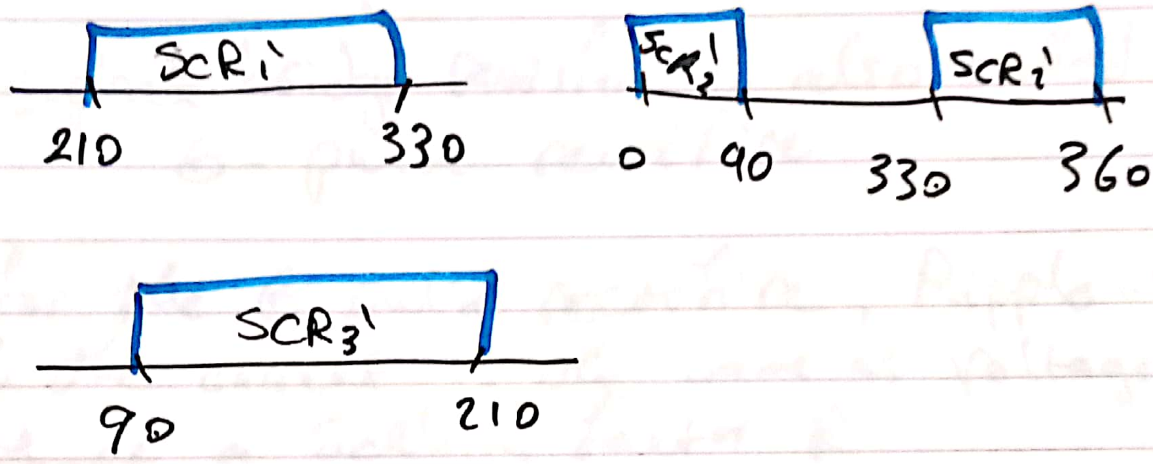


V32
V12
V13
V23
V21
V31
V1
V2
V3
2'
3'
1'
2'
3
1
2
3
30
90
150
210
270
330


*Vo
Vo=
V32
V12
V13
V23
V21
V31
V32
0
30
60
90
120
150
180
210
240
270
300
330
360
420
480
540
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2


*R=1
*Vo
*is1
هاد الخط غلط
لازم يكون زايح
لليمين شوي
Vo=
V32
V12
V13
V23
V21
V31
V32
0
30
60
90
120
150
180
210
240
270
300
330
360
420
480
540
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2





- conventional numbering (fto)

$1 \longrightarrow 1$

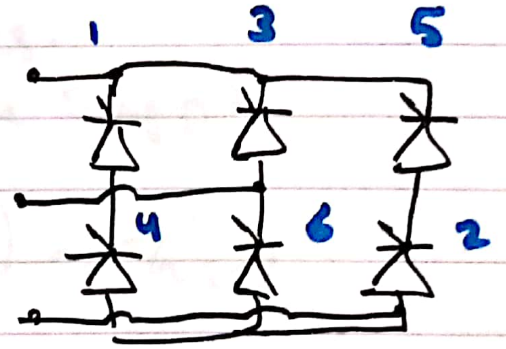
$2 \longrightarrow 3'$

$3 \longrightarrow 2$

$4 \longrightarrow 1'$

$5 \longrightarrow 3$

$6 \longrightarrow 2'$



numbering according to the sequence of triggering/switching.

$\rightarrow$ $V_o = V_{32} \left[\begin{matrix} 3 \\ 2' \end{matrix} \right]$, $V_o = V_{13} \left[\begin{matrix} 1 \\ 3' \end{matrix} \right]$

$V_o = V_{12} \left[\begin{matrix} 1 \\ 2' \end{matrix} \right]$

3	1	1	2	2	3	3
2'	2'	3'	3'	1'	1'	2'
V_{32}	V_{12}	V_{13}	V_{23}	V_{21}	V_{31}	V_{32}

$V_o =$

- 3-phase bridge recetifire is also called 6- pulse rectifire.

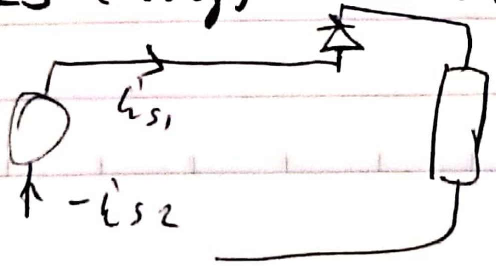
- for the 6-pulse recotfire, Ripple = 4%. & the current is the same as voltage Exept a Scalling factor $\underline{\underline{R}}$

- 3-phase recetifire advantages :-
  - Higher Voltage $\simeq 3 * V$ (٣-اضعاف)
  - power $\simeq 3 * P$ (٣ اضعاف)
  - better Harmonics.
  - No Dc in the Supply

- i_o is either (i_{s1}) or $(-i_{s2})$

$$I_{s1} = \sqrt{\frac{2}{3}}\, I_o(rms)$$

$I_s(avg) = 0$ ⟶ Zero always in supply.



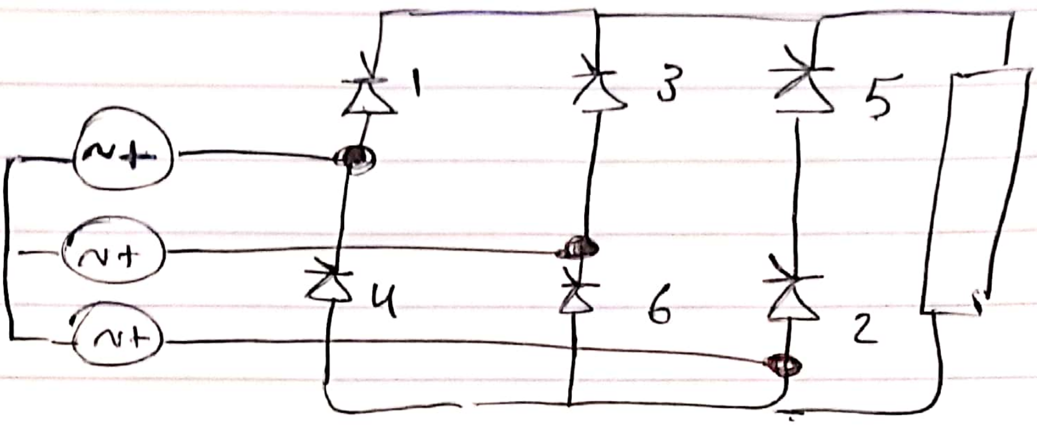
17 / 12 / 2019 Lecture 34

Example ①, $\alpha = 30$, SCR is triggered at
$\omega t = 30 + \alpha = \underline{60^\circ}$

Mode: CCM

R = 1

i_{S_2} draw



check Example 1 Solution in Next pages

Example ② $\alpha = 60$ single phase resistive load $\alpha_{cr} = 0$

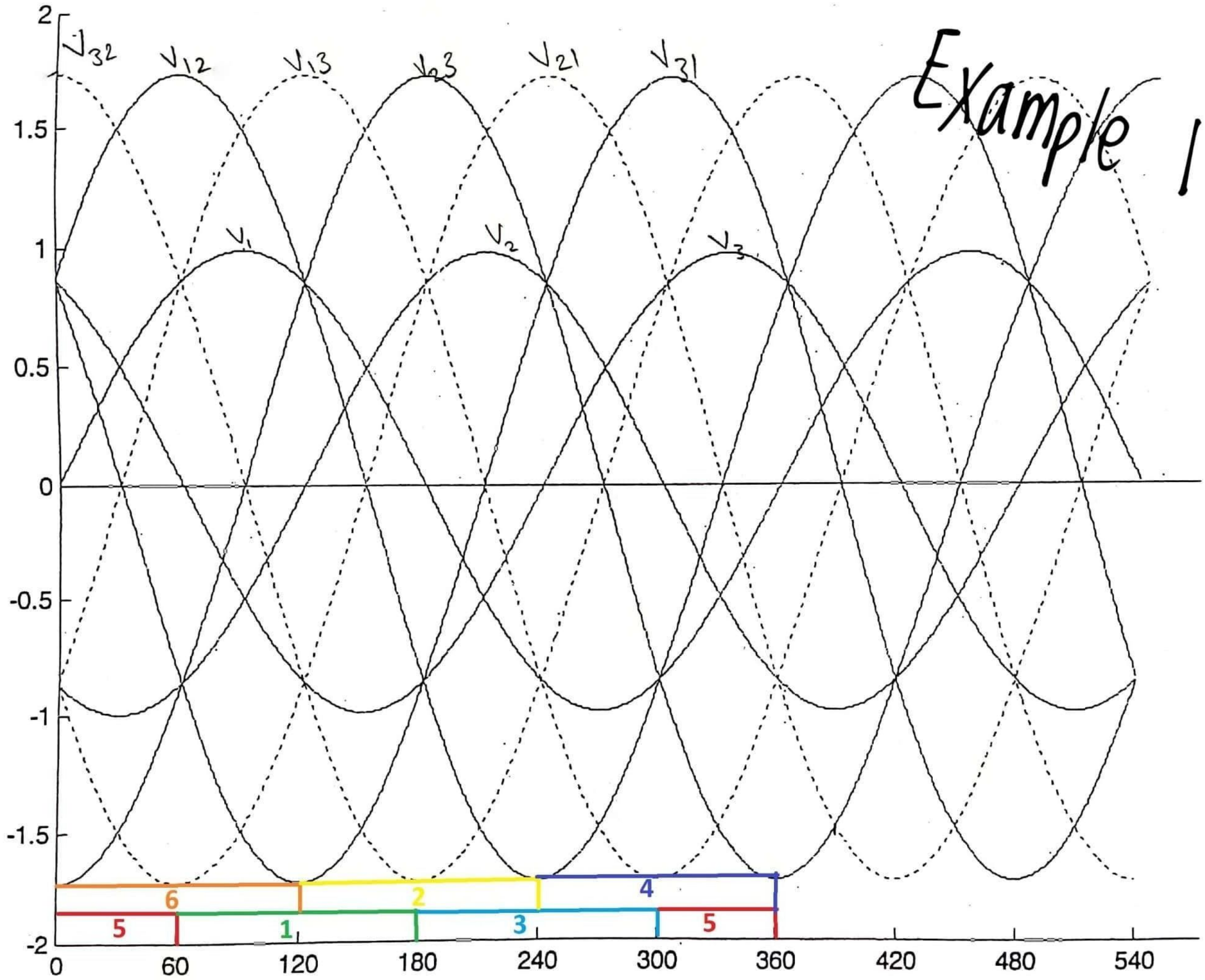
$\phi = \alpha_{cr} = 0$

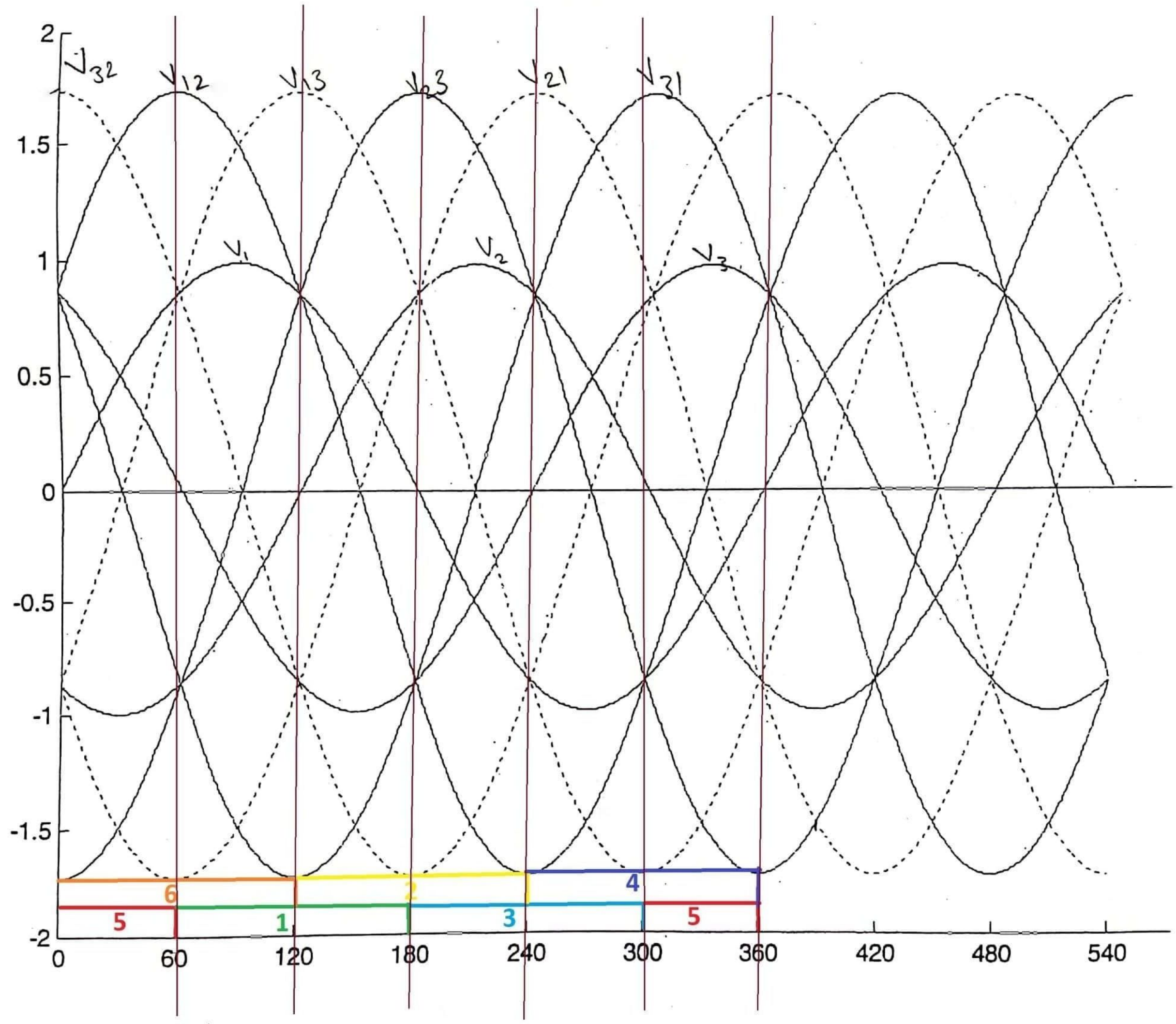
$\omega t = 30 + 60 = 120$ (Starts SCR_1

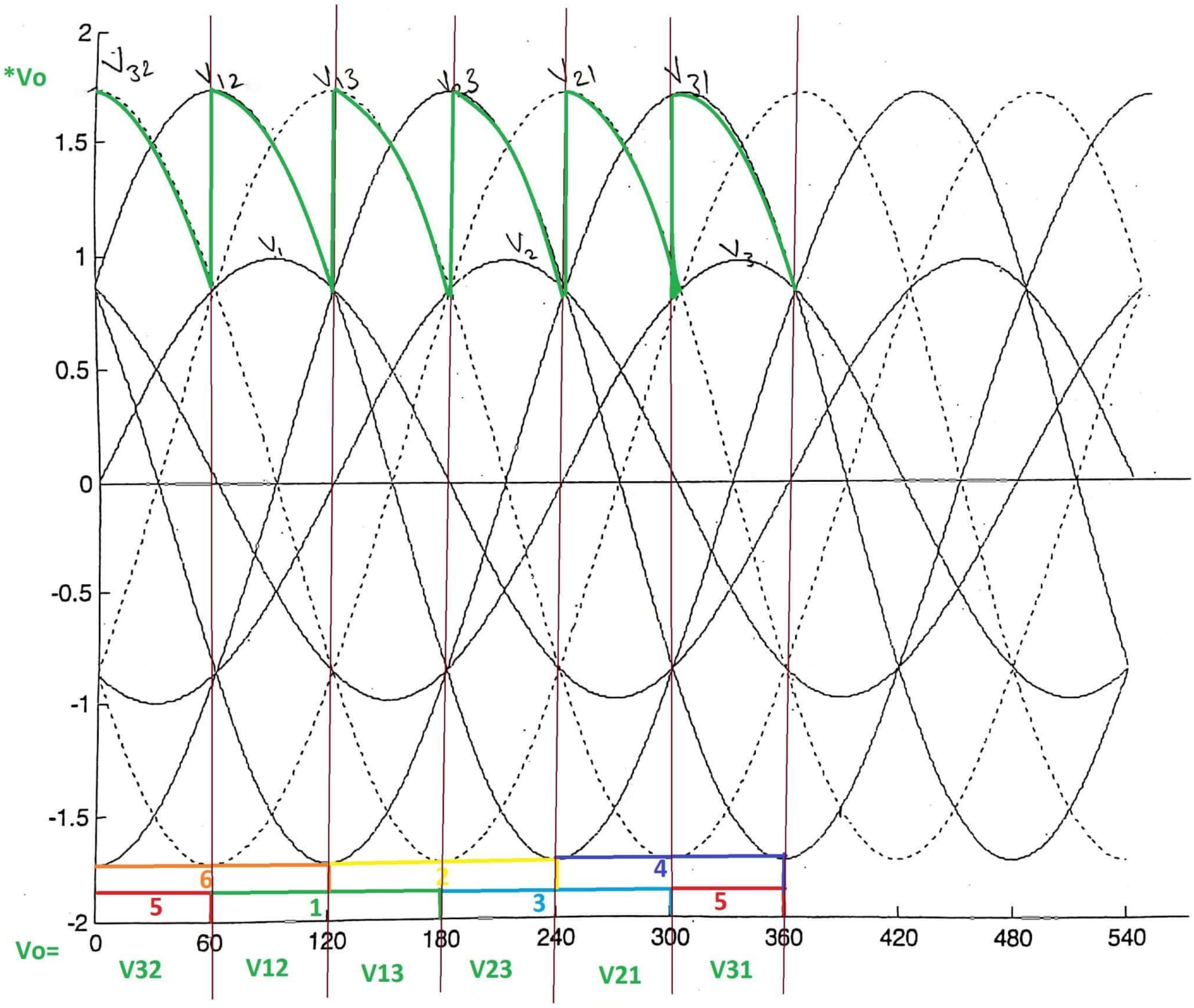
conducts: 90 → 120
1, 5, 6

check solution in The next pages.

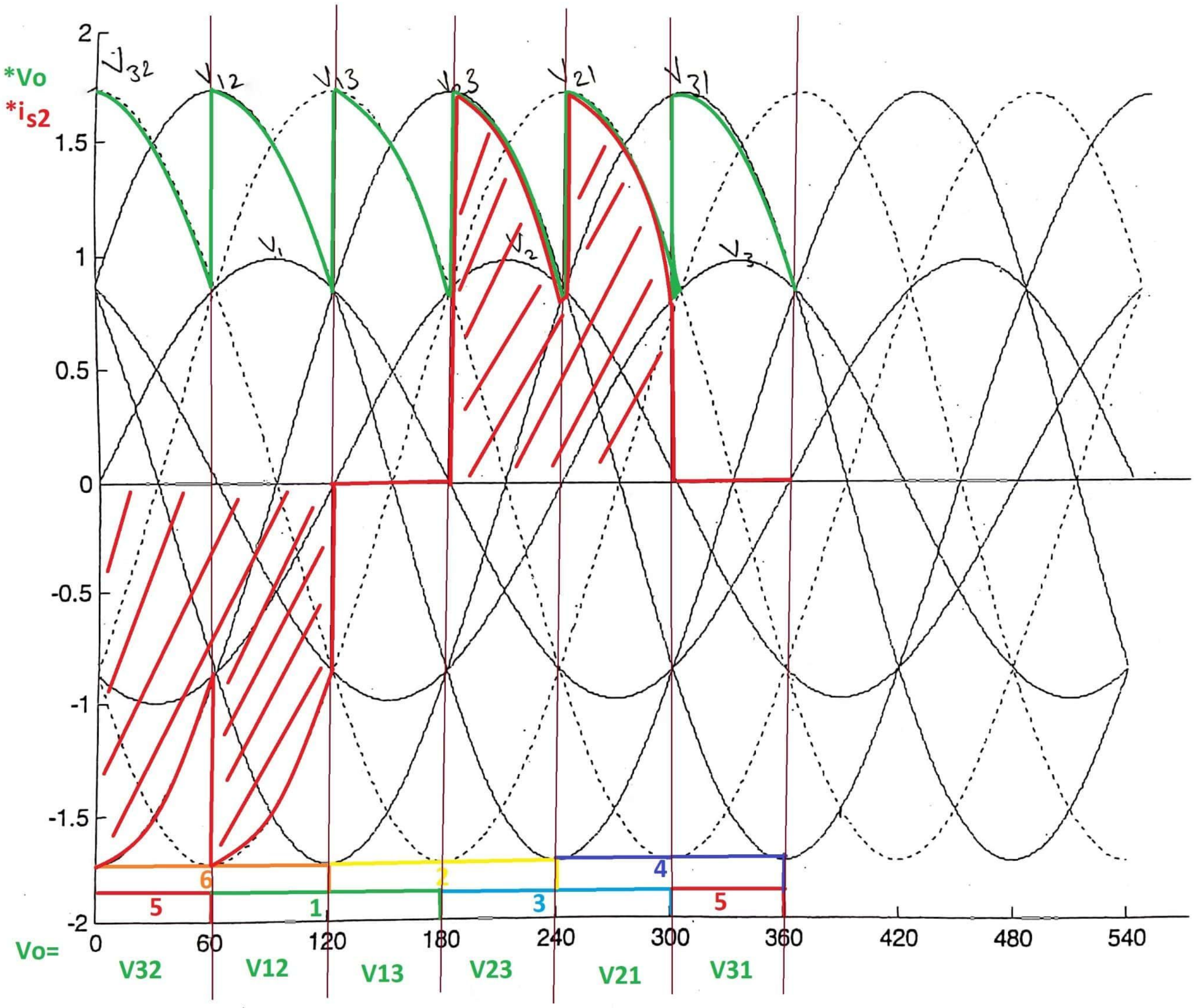
Example 1


v_{32}
v_{12}
v_{13}
v_{23}
v_{21}
v_{31}
v_1
v_2
v_3
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
6
2
4
5
1
3
5
0
60
120
180
240
300
360
420
480
540


v_{32}
v_{12}
v_{13}
v_{23}
v_{21}
v_{31}
v_1
v_2
v_3
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
6
2
4
5
1
3
5
0
60
120
180
240
300
360
420
480
540

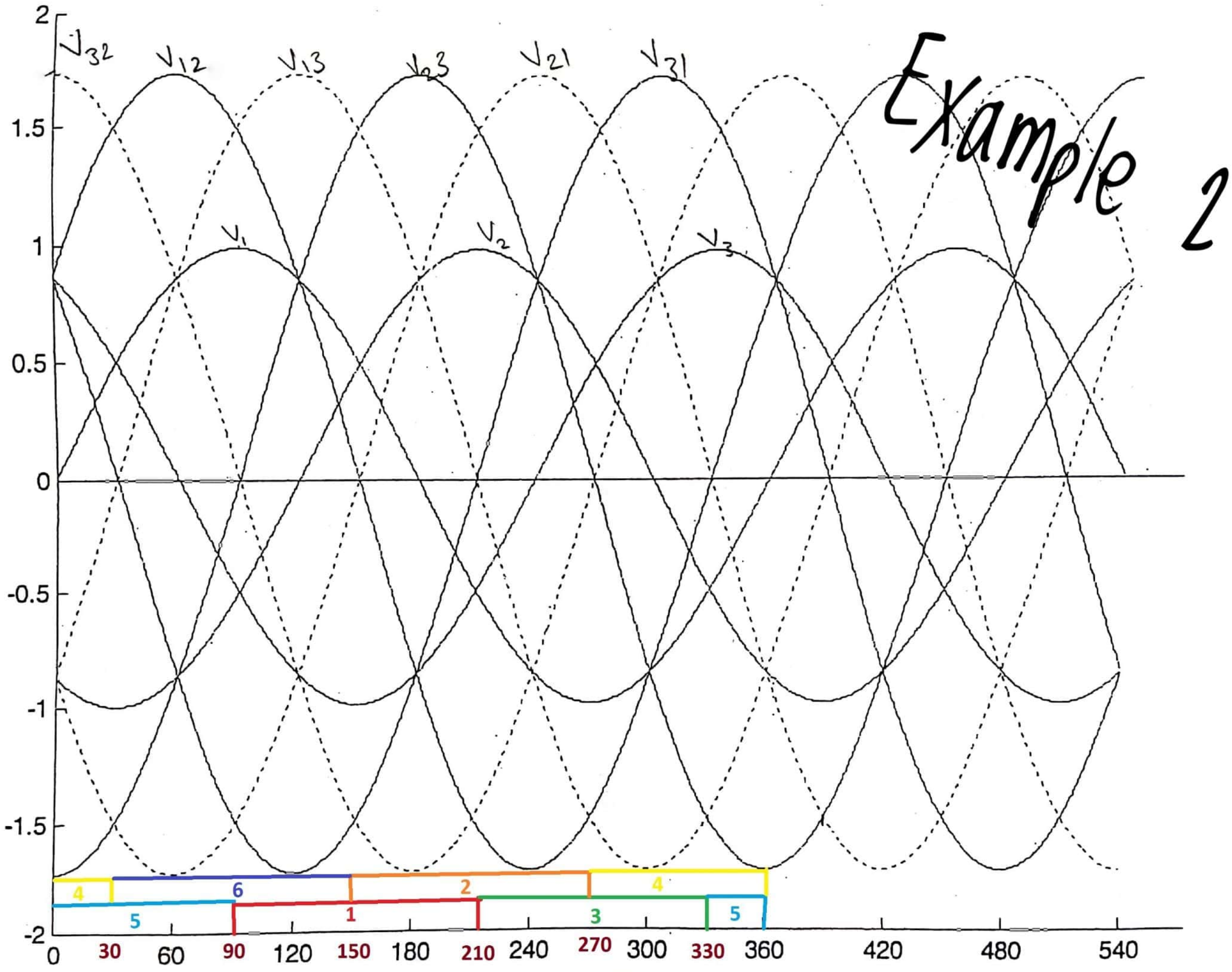


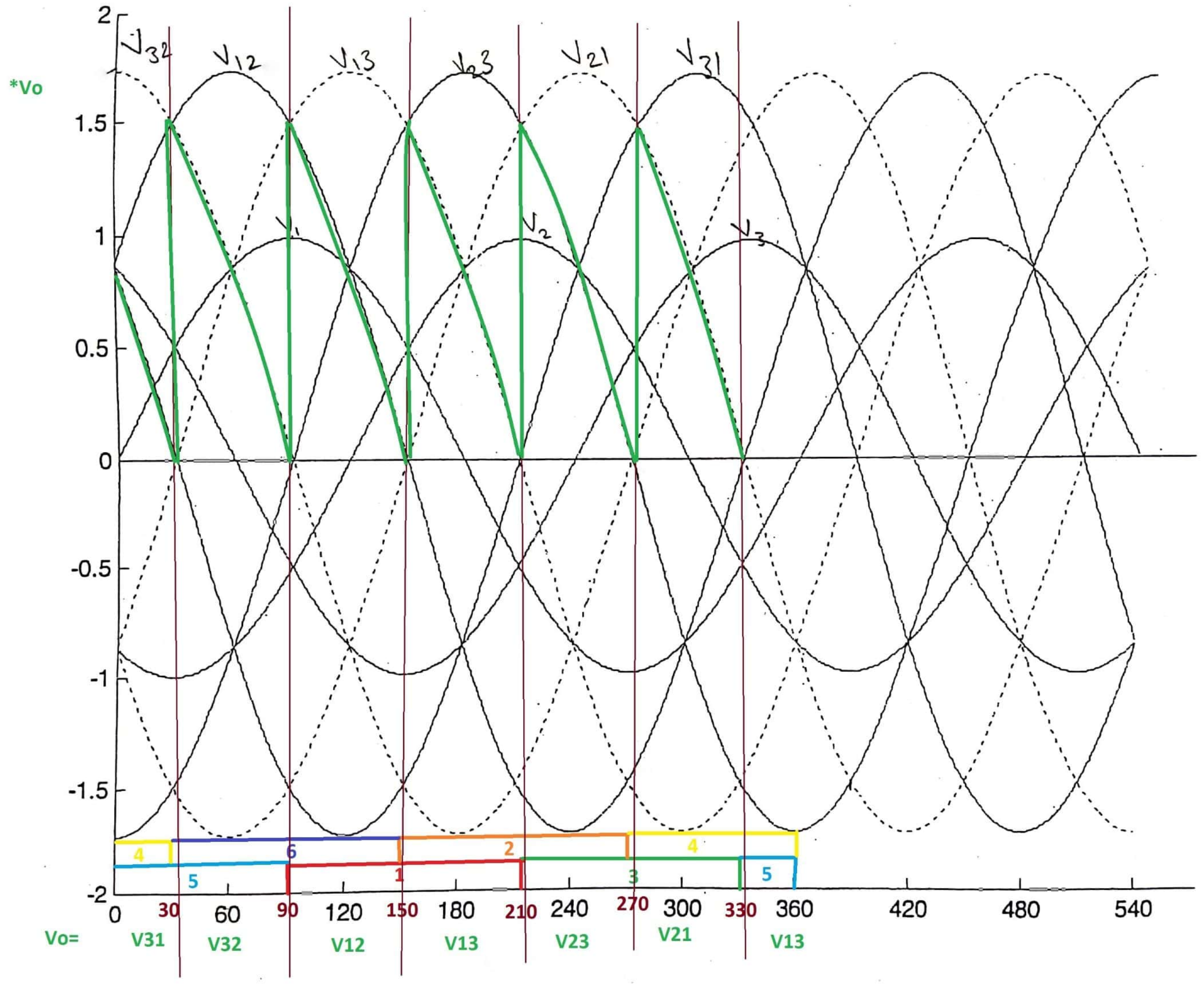
*Vo
V32
V12
V13
V23
V21
V31
Vo=



*Vo
*is2
V32
V12
V13
V23
V21
V31
Vo=

Example 2





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Homework find V_o & i_s for $\alpha = 45°$

Example 8

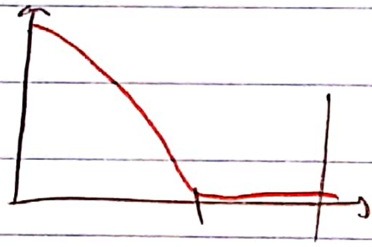
$\alpha = 90°$

$SCR_1 \rightarrow \omega t = 30° + 90° = 120° \longrightarrow 240°$ conduction

Mode : DCM

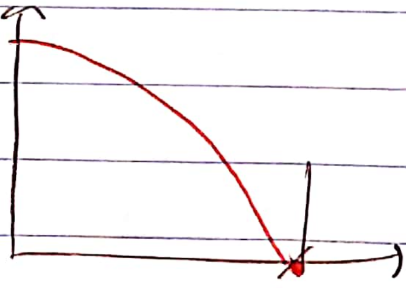
(*) check solution in next pages ...

- if $\alpha < 90°$



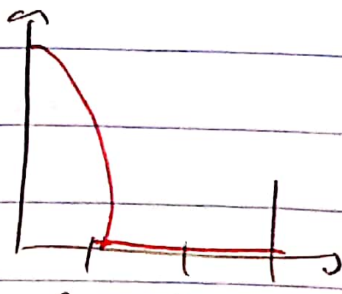
60

if $\alpha > 90°$



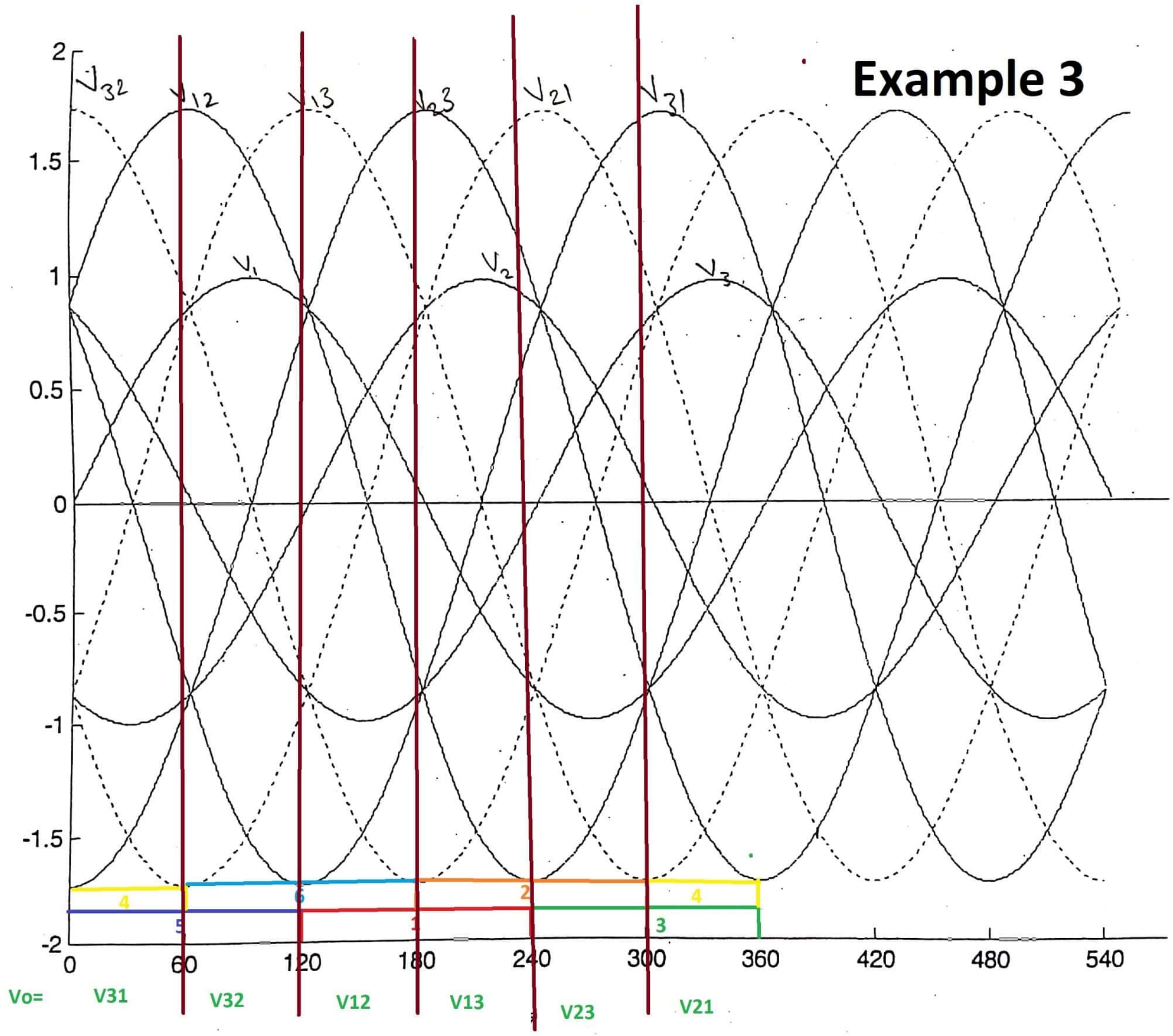
60

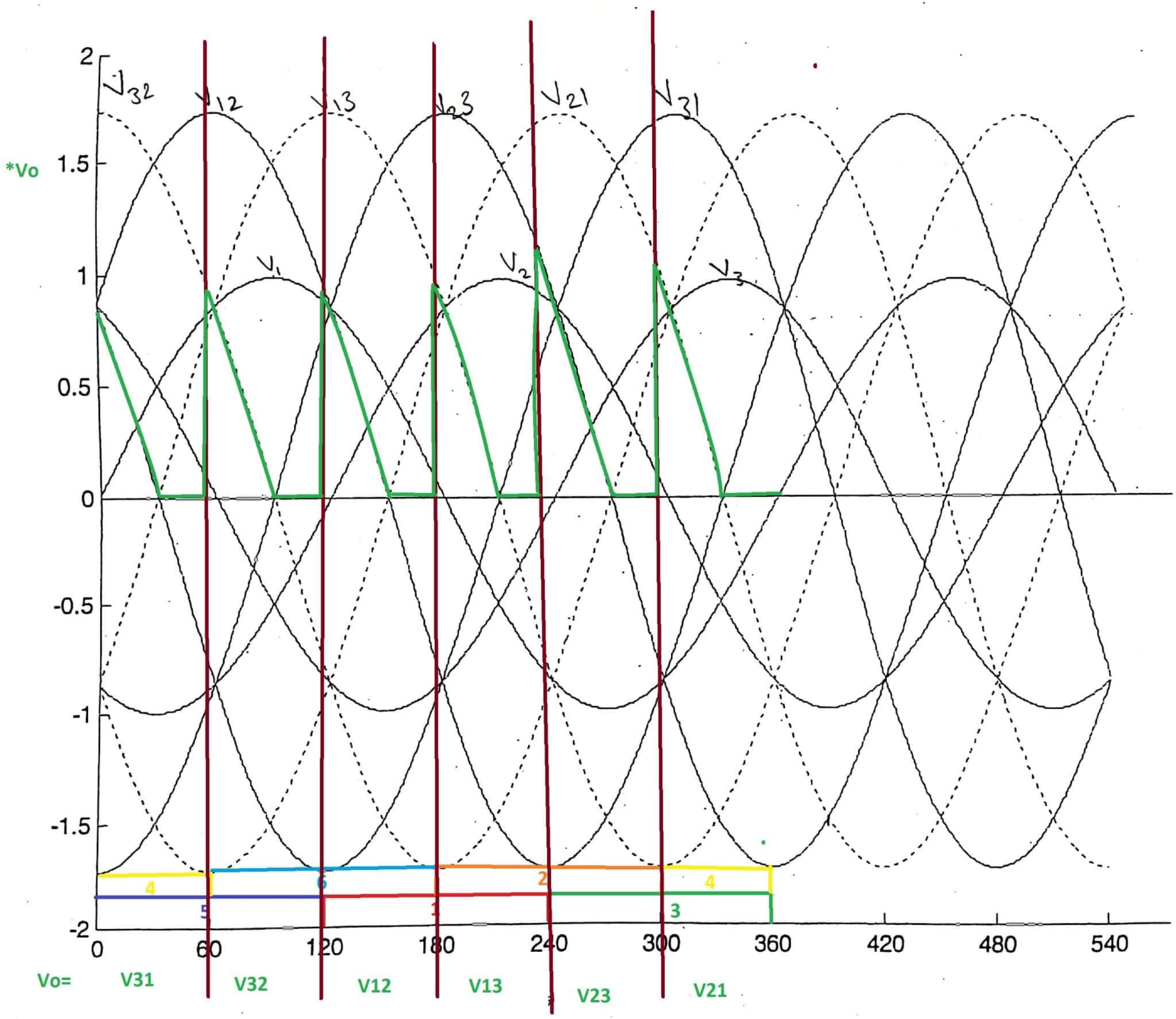
if $90° < \alpha < 120°$



30 60

Example 3





- In DCM CASE:

SCR₁ must be triggered twice → @ 30 & 60°
or else it won't re-conduct ⇒ $\boxed{\text{HWR}}$

- This doesn't happen in CCM.

- To avoid error in the output signal, each SCR should be triggered twice:
  - $\boxed{SCR_1}$ $(30+\alpha)$ & $((30+\alpha)+60)$
  - $\boxed{SCR_2}$ $(30+\alpha+60)$ & $((30+\alpha+60)+60)$
  - $\boxed{SCR_3}$ $(30+\alpha+120)$ & $((30+\alpha+120)+60)$

⋮

& so ON

* Exam Question:

$\alpha = 75°$, SCR_2 is triggered at $\omega t = ??$

Sol:

SCR_2 $(30+75+60) = 165°$

$((30+75+60)+60) = 225°$

answer: at 165° $\boxed{\text{and}}$ 225°.

Ep

- $V_{o(avg)} = ??$

two modes of operation CCM & DCM

CCM:- $(0 \leq \alpha \leq 60) \Rightarrow$ critical mode included.

$$V_{o(avg)\,CCM} = \frac{1}{(2\pi/6)} \int_{(\alpha+\pi/6)}^{(\alpha+\pi/6)+(\pi/3)} V_{12} \cdot d\omega t$$

→ نهاية الـ pulse هو الفرق بين البداية ، النهاية

اول pulse بالرسمة ((Curves))

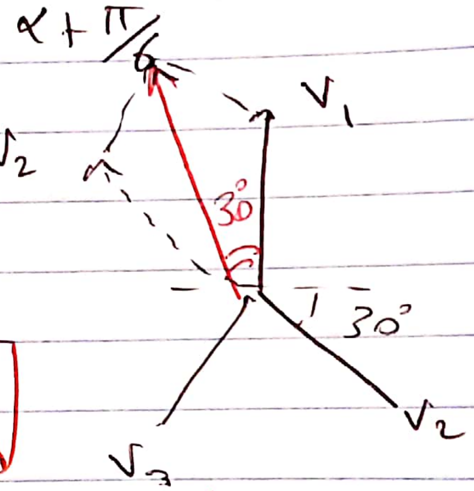
بدء ا SCR_1 من $\alpha+30°$

6-pulses بكامل وحدة وبنقسم على 6

So, $\left(\alpha + \frac{\pi}{6} + \frac{\pi}{3}\right) \Rightarrow \pi/2$

$$V_{o\,(avg)\,CCM} = \frac{1}{(2\pi/6)} \int_{\alpha+\pi/6} V_{12} \cdot d\omega t = \frac{3}{\pi} \int^{\alpha+\frac{\pi}{2}} \sqrt{3}\, V_m \sin\left(\omega t + \frac{\pi}{6}\right) d\omega t$$

$$= \frac{3\sqrt{3}\, V_m}{\pi} \Big[-\cos\left(\omega t + \pi/6\right) \Big]_{\alpha+\pi/6}$$



$$= \frac{3\sqrt{3}\, V_m}{\pi} \Big[-\cos(\alpha + 120^\circ) + \dots$$

$$\dots \cos(\alpha + 60^\circ) \Big]$$

$$\boxed{V_{o\,(avg)\,CCM} = \frac{3\sqrt{3}\, V_m}{\pi} \cos\alpha}$$

V_m → peak value of the phase voltage. NOT the line voltage.

$= 1.65\, V_m \cos\alpha$

→ compared to single phase

$V_{o(avg)} = \frac{2V_m}{\pi} \cos\alpha \Rightarrow 0.63\, V_m \cos\alpha$

(1.65 $V_m \cos\alpha$ 3phase ال اضعاف ٣ "تقريبا")

DCM! $(5\pi/6) \rightarrow 150^\circ$ ∴ not a function of α!

$$V_{o\,(avg)\,DCM} = \frac{1}{(2\pi/6)} \int_{\alpha+\pi/6} V_{12}\, d\omega t$$

- V_{12} always ends conduction at <u>150°</u> fixed

$$\Rightarrow V_{o(avg)\,DCM} = \int_{\alpha+\pi/6}^{5\pi/6} \sqrt{3}\, V_m \sin(\omega t + \pi/6)\, d\omega t$$

$$= \frac{3\sqrt{3}}{\pi} V_m \left[-\cos\left(\omega t + \frac{\pi}{6}\right)\right]_{\alpha+\pi/6}^{5\pi/6}$$

$$= \frac{3\sqrt{3}\, V_m}{\pi} \left[-\cos(\pi) + \cos\left(\alpha + \frac{\pi}{3}\right)\right]$$

$$\boxed{V_{o(avg)\,DCM} = \frac{3\sqrt{3}\, V_m}{\pi} \left[1 + \cos\left(\alpha + \frac{\pi}{3}\right)\right]}$$

- $V_{o(avg)\,DCM} = 1.65\, V_m \left[1 + \cos\left(\alpha + \frac{\pi}{3}\right)\right]$

For critical case.

- $$V_{o(avg)\,cr\,Mode} = \frac{3\sqrt{3}\, V_m}{\pi} \cos(60°) = \frac{3\sqrt{3}\, V_m}{2\pi}$$

$\boxed{\text{or}}$

SAME → CCM, DCM equations

- $$\frac{3\sqrt{3}\, V_m}{\pi} \left[1 + \cos(120°)\right] = \frac{3\sqrt{3}\, V_m}{2\pi}$$

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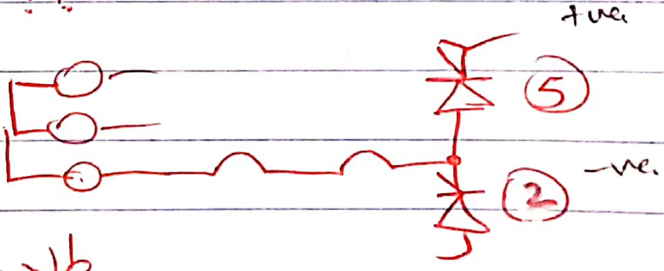
- If asked for a certain Voltage value : which mode to choose?
- Calculate the critical mode then.
  - if $V_{o(avg)} > V_{o(avg)\,cr} \longrightarrow$ CCM
  - if $V_{o(avg)} < V_{o(avg)\,cr} \longrightarrow$ DCM.

To calculate & draw the current waveform.

Example 3 المثال 6 ملاحظة . ارسم i_{s5} هو بيطلب اي

$\longrightarrow$ draw i_{s3} ....

بيروح على V_{s3} وبشوف ع مين شغال ال SCR بال positive group ??

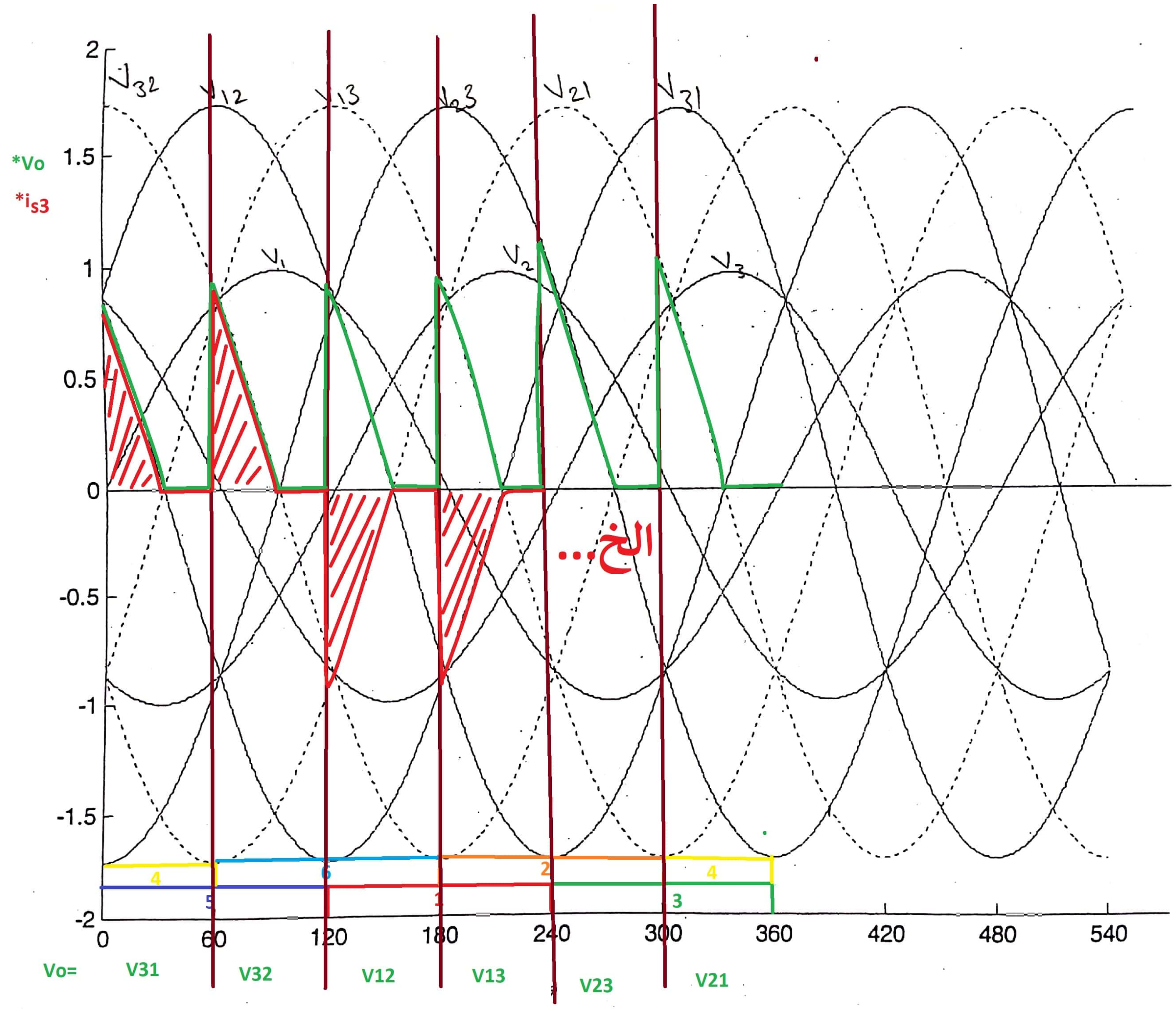


$\longrightarrow$ 5 طلع شغال ع

So, back to the graph $\longrightarrow$ بيشوف وين شغال ال SCR_5 $\Leftarrow$ $(0 \longrightarrow 120^\circ)$

ويكمل ...

Check solution in next page



*Vo
*is3
V32
V12
V13
V23
V21
V31
V1
V2
V3
الخ...
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
60
120
180
240
300
360
420
480
540
4
5
6
1
2
4
3
Vo=
V31
V32
V12
V13
V23
V21

- $\alpha_{max} = ??$

for both CCM & DCM. but we calculate from DCM because small avg. voltag values are in the DCM.

→ when $V_o(avg) = Zero$, $\alpha = max$

so, $0 = \frac{3\sqrt{3}V_m}{\pi}\left[1 + \cos\left(\alpha_{max} + \pi/3\right)\right]$

$$\left[1 + \cos\left(\alpha_{max} + \pi/3\right)\right] = 0$$

$$\cos\underbrace{\left(\alpha_{max} + \pi/3\right)}_{\text{الي الزاوية كلها}} = 1$$

180° = لازم

$$\alpha_{max} + \pi/3 = \pi$$

- $\boxed{\alpha_{max}} = \frac{2\pi}{3}$ or $120°$ #

22/12/2019

Lecture 36

Choppers : Classifications: (A) in terms of Vo : Vi

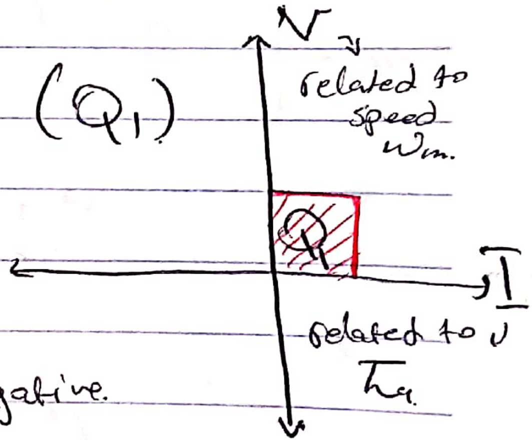
mainly needed for Regulated DC power Supplies
(variable Voltage power supply)

- Step-down → Buck chopper
- Step-up → Boost chopper
- Step up / Step down → Buck / Boost.

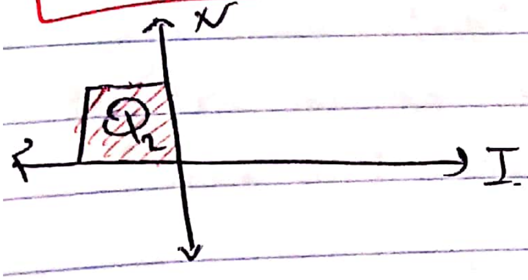
(B) In terms of polarity of V and direction of I

4-types:-

$\boxed{\text{Class A chopper}}$ Positive I & V (Q_1)
- direction:- drive in forward



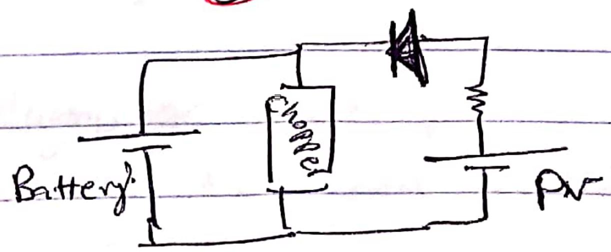
$\boxed{\text{Class B chopper}}$



V positive & I negative.

- Ex:-

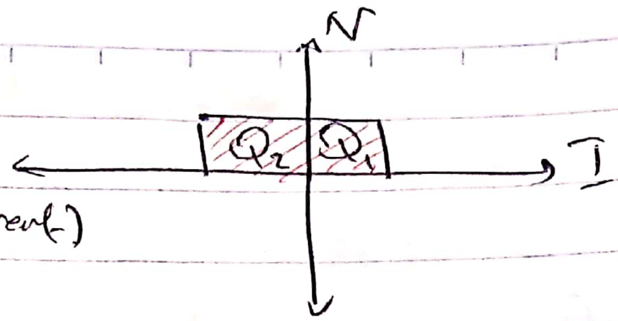
(1) Solar Cells → charging battery



(2) motor → Generator
Breaking action.

Class C chopper

- Positive V & (+ve and -ve current)
- Q_2 & Q_1
  Breaking , F.W motoring

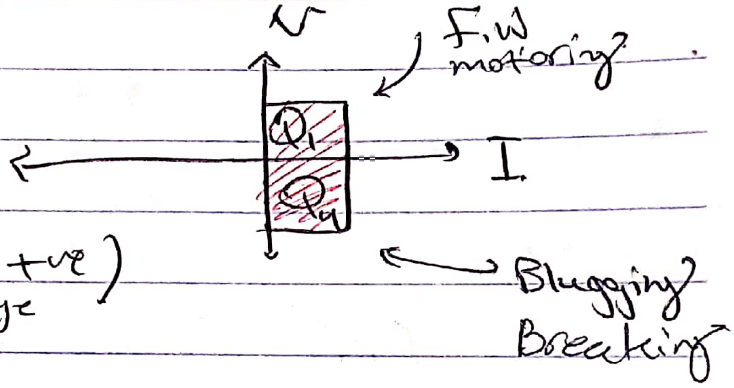


- Drive (motoring & Breaking (regeneration action))

⟹ $Q_3 \equiv Q_1$

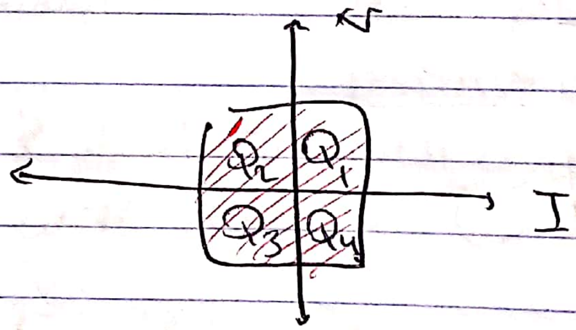
Class D chopper

positive Current & (-ve and +ve voltage)



Class E chopper

* Does everything,
Ma shaa Allah!
* (+ve and -ve I) & (+ve and -ve V)



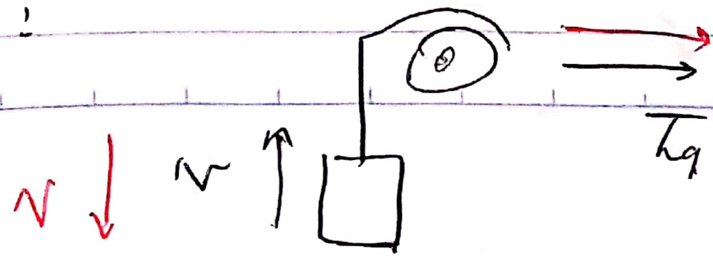
Blugging Breaking

is equivent to Full wave reactifire when

$90^\circ > \alpha$: Q_4

$90^\circ < \alpha$: Q_1

ex :



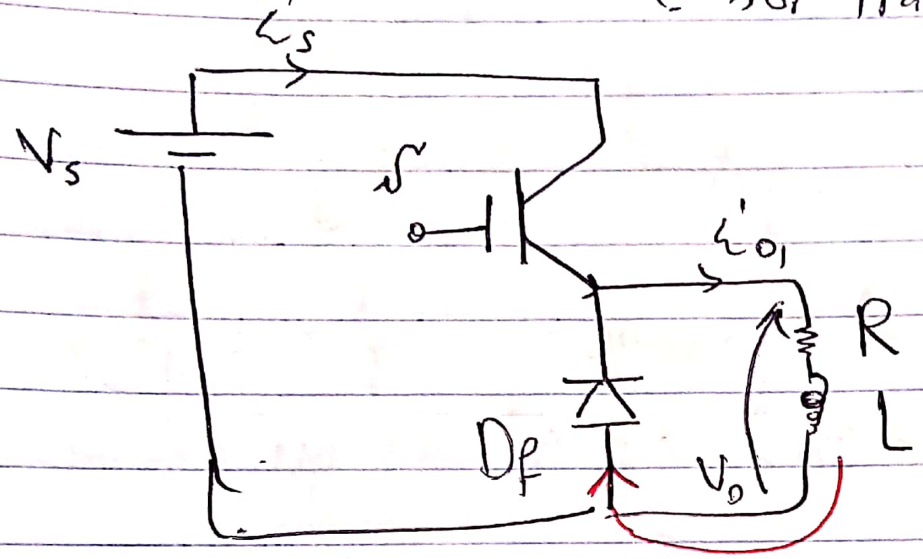
* حالة تنزيل Bulk

* حالة رفع Bulk

Class A chopper

We use transistors, not thyristors (why?)

(1) The input is DC. (2) Thyristors needs forced commutation. (3) We need driving circuit (for transistors only).



$\Rightarrow P = \frac{1}{2} \cdot L \cdot i_{o1}^2$

i_f

freewheeling

(*) في حالة load ليس resistive

سوف يحرق الدائرة التيار المتولد في مصدر L

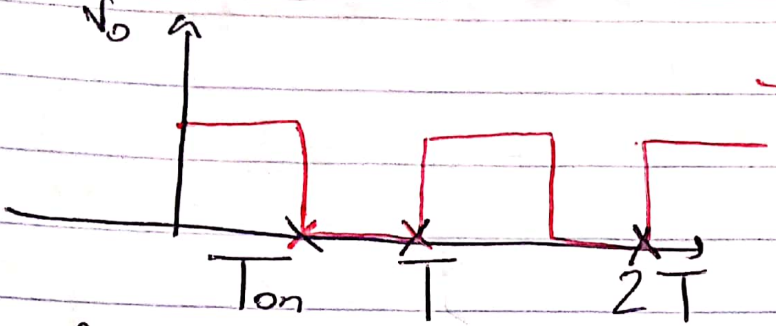
(*) D_f: nothing to do with resistive loads.

Question in Exam: Freewheeling Diode D_f is very important in DC to DC converters irrespective of load; The above statement is ...

→ Incorrect / wrong, since D_f is only active when the load is inductive, otherwise no current runs in it.

Control Topology

1) pulse Width Modulation (PWM)



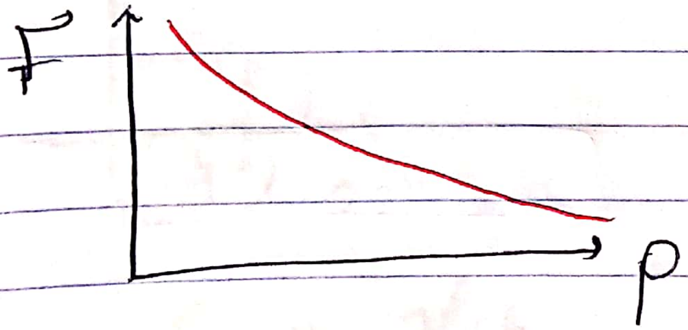
→ T: period of the input Signal.

→ $f_{ch.} = \frac{1}{T}$; chopping frequency or f_m (modulation)

↳ up to 1 MHz (10^6) ⇒ MOSFET

* High Switching frequency
* less harmonics
* Small size (without current filter)

frequency / power



inversly proportional (to avoid large Switching losses).

$$V_{o\,(avg)} = \left(\frac{T_{on}}{T}\right) \cdot V_s \quad , \quad \delta \cdot V_s .$$

δ : modulation index , $0 < \delta < 1$ → $T_{on} = T$ Pure Dc.

Transistor is not active.

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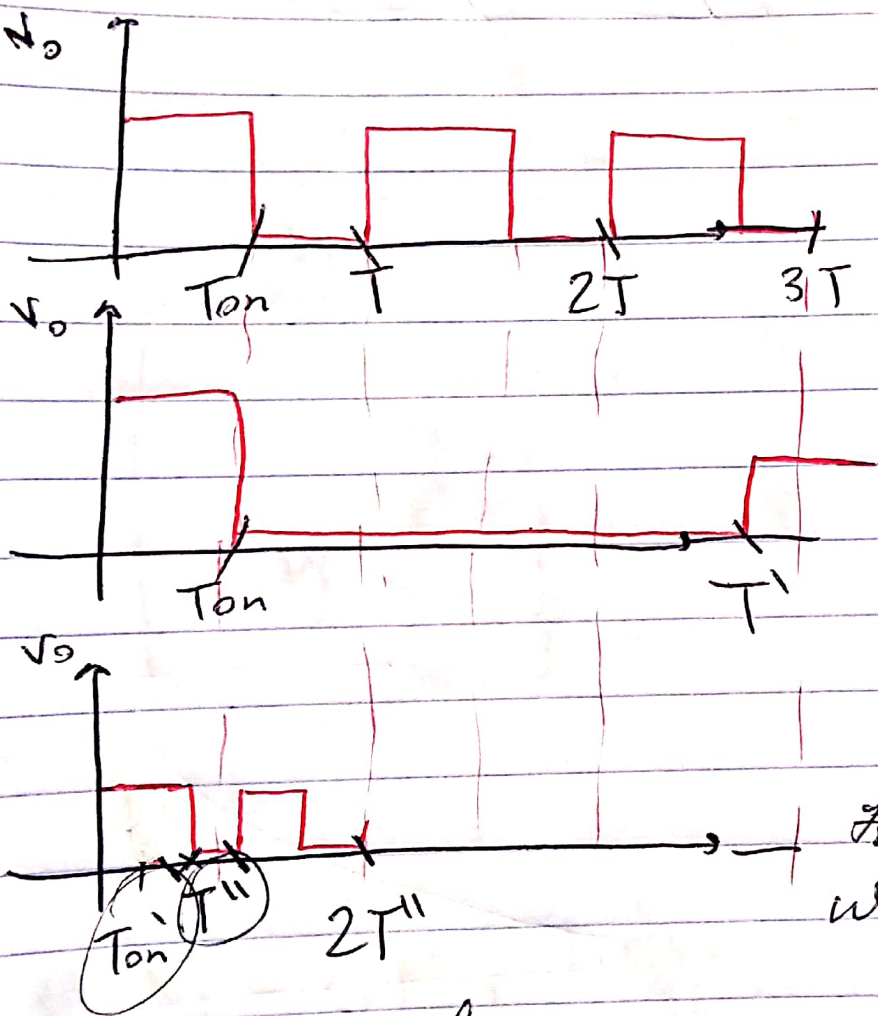
$$I_{(avg)} = \frac{V_{(avg)}}{R}$$

② Frequency Modulation (FM)

$$f_{ch} = \frac{1}{T}$$



$$f_{ch}' = \frac{1}{T'}$$

$$f_{ch}' = \frac{f_{ch}}{3}$$

Frequency Modulation when Ton is fixed.

$$f_{ch}'' = 2 f_{ch}$$

Usually: PWM + FM are used simultaneously for advanced control.

- Analysis assuming C.C.M:-

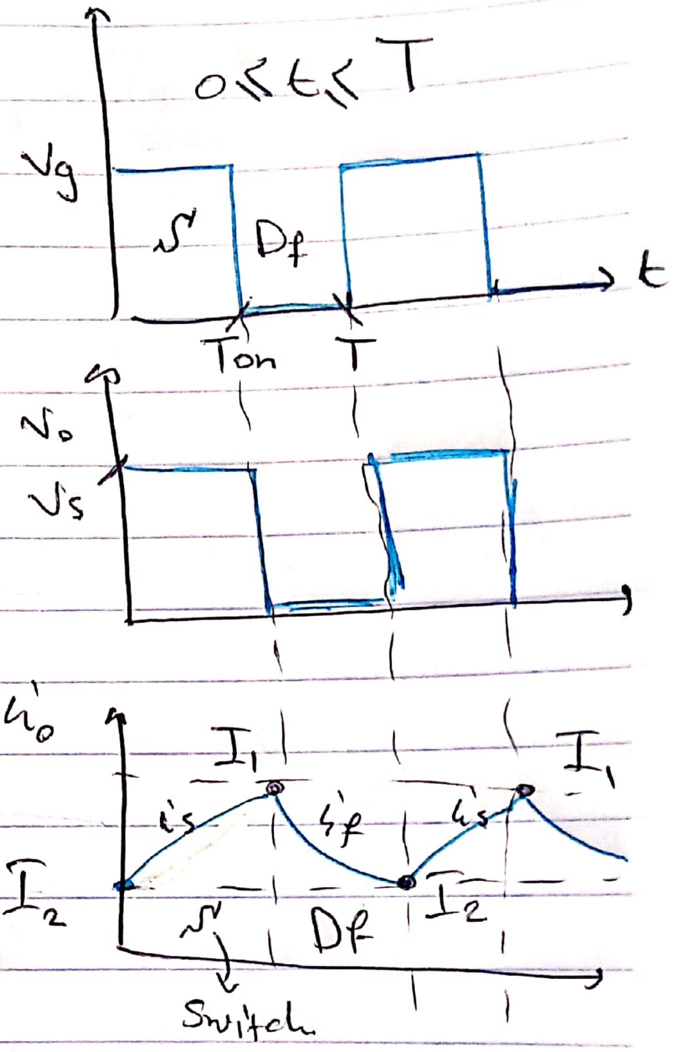
$V_g \; (-20 \longrightarrow +20)$

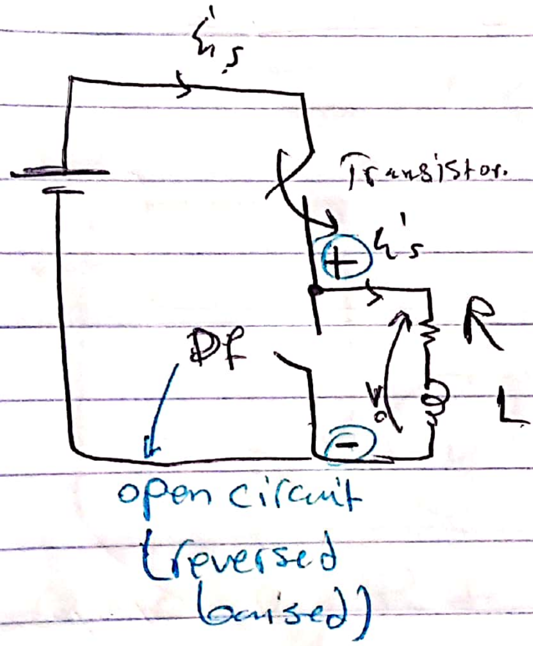
$\delta = \frac{T_o}{T}, \; \frac{1}{f_{ch}} = T = \frac{1}{f_m}$

$0 \leq \delta \leq 1$

Zero output → 0; 1 → full output

$0 \leq t \leq T$





- $V_s = i_s R + L\frac{di_s}{dt}$

$i_s = \frac{V_s}{R} + A \cdot e^{-t/\tau}$

Steady State current (fixed) ← $\frac{V_s}{R}$

so, $\boxed{\frac{V_s}{R} = I_s}$

I.C.C at $t=0$, $i_s = I_2$

$$I_2 = I_s + A \cdot e^{-t/\tau}$$

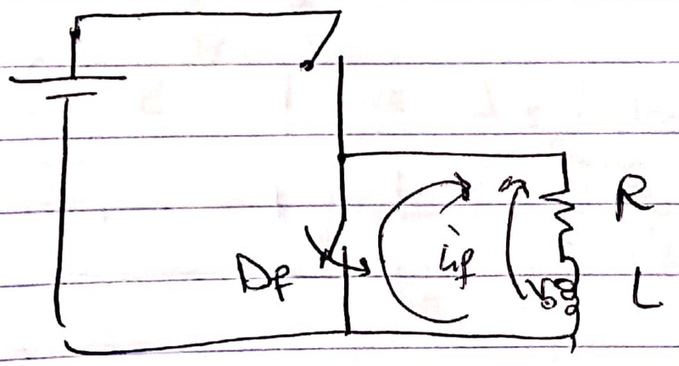
$$A = I_2 - I_s \longrightarrow i_s = I_s + (I_2 - I_s) \cdot e^{-t/\tau}$$

$$= I_s(1 - e^{-t/\tau}) + I_2 \cdot e^{-t/\tau}$$

F.C.C at $t = T_{on}$, $i_s = I_1$

$$\boxed{I_1 = I_s(1 - e^{-T_{on}/\tau}) + I_2 \cdot e^{-T_{on}/\tau}} \quad (1)$$

$$T_{on} \leq t \leq T$$



$$\Rightarrow 0 = i_f R + L \frac{di_f}{dt}$$

$$\boxed{i_f = B \cdot e^{-t/\tau}}$$

I.C.C at $t = T_{on} \longrightarrow i_f = I_1$

$$I_1 = B \cdot e^{-T_{on}/\tau}$$

$$\therefore i_f = (I_1 \cdot e^{T_{on}/\tau}) \cdot e^{-t/\tau}$$

$$I_1 = B \cdot e^{-T_{on}/\tau} \longrightarrow B = I_1 \cdot e^{T_{on}/\tau}$$

$$\therefore i_f = (I_1 \cdot e^{T_{on}/\tau}) \cdot e^{-t/\tau}$$

F.C.C at $t = T$, $i_f = I_2$

$$\boxed{I_2 = I_1 \cdot e^{T_{on}/\tau} \cdot e^{-T/\tau}} \quad (2)$$

from (1) & (2) $\rightsquigarrow$ $I_1 = I_s(1 - e^{-T_{on}/\tau}) + \ldots$

$$\ldots I_1 e^{T_{on}/\tau} \cdot e^{-T/\tau}) \cdot e^{-T_{on}/\tau}$$

$$I_1 = I_s(1 - e^{-T_{on}/\tau}) + ((I_1 e^{T_{on}/\tau} \cdot e^{-T/\tau}) \cdot e^{-T_{on}/\tau})$$

$$I_1(1 - e^{-T/\tau}) = I_s(1 - e^{-T_{on}/\tau})$$

$$I_1 = I_s \left[\frac{1 - e^{-T_{on}/\tau}}{1 - e^{-T/\tau}}\right]$$

I_1 is always positive

$$I_2 = I_s \left[\frac{1 - e^{-T_{on}/\tau}}{1 - e^{-T/\tau}}\right] \cdot e^{\frac{T_{on}}{\tau}} \cdot e^{-T/\tau}$$

$$I_2 = I_s \left[\frac{1 - e^{-T_{on}/\tau}}{1 - e^{-T/\tau}}\right] \cdot \frac{e^{T_{on}/\tau}}{e^{T/\tau}}$$

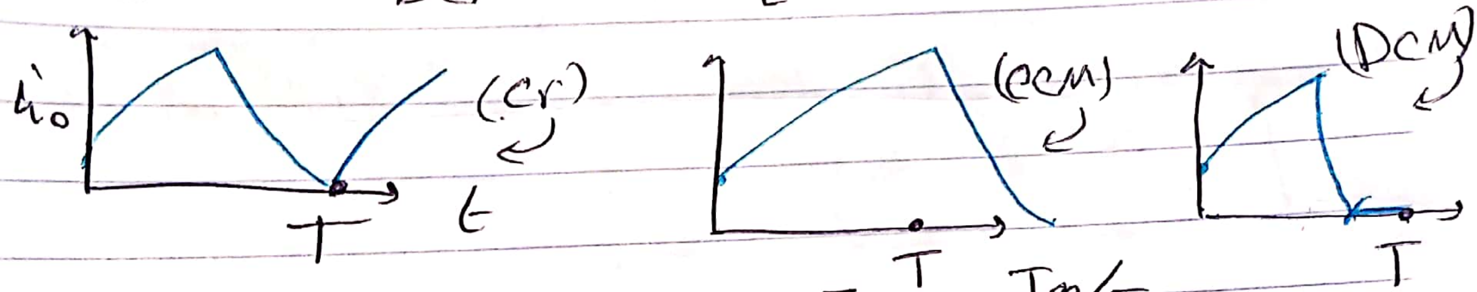
$$I_2 = I_s \left[\frac{e^{T_{on}/\tau} - 1}{e^{T/\tau} - 1}\right]$$

$$I_2 = I_s \left[\frac{1 - e^{T_{on}/\tau_L}}{1 - e^{T/\tau_L}} \right]$$

could be +ve or -ve.

Critical case

CCM $\longrightarrow$ DCM. , $I_2 = 0$



$$I_2 = I_{H(DF)} = I_s \left[\frac{1 - e^{T_{on}/\tau_L}}{1 - e^{T/\tau_L}} \right]$$

$$\frac{I_{H(DF)}}{I_s} \cdot \left(1 - e^{T/\tau_L}\right) = 1 - e^{T_{on}/\tau_L}$$

$$e^{T_{on}/\tau_L} = \left[1 - \frac{I_{H(DF)}}{I_s} \left(1 - e^{T/\tau_L}\right) \right]$$

$$\frac{T_{on}}{\tau_L} = \ln \left[1 - \frac{I_{H(DF)}}{I_s} \left(1 - e^{T/\tau_L}\right) \right]$$

$$T_{on\,(cr)} = \tau_L \cdot \ln \left[1 - \frac{I_{H(DF)}}{I_s} \left(1 - e^{T/\tau_L}\right) \right]$$

load time constant.

ex) $\delta = 0.5$??

ccm / DCM

continous or Discontinous?

$$\delta_{cr} = \frac{T_{on\,(cr)}}{T}$$

$\rightarrow$ find $\delta\,(cr)$

$\delta(cr) < \delta$ CCM

$\delta(cr) > \delta$ DCM

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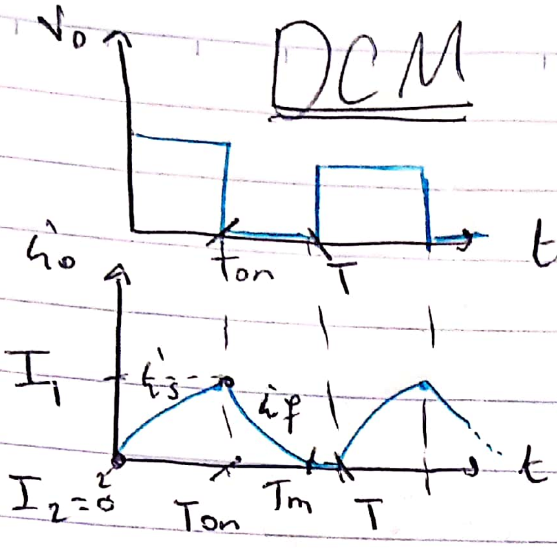
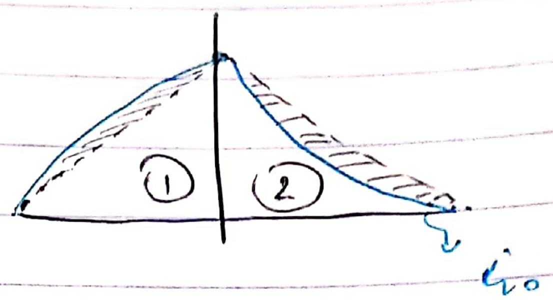
26/12/2019 Lecture 38

DCM



$T_m = ??$



{ الزيادة في ① = النقصان
في ② بس كأنه مثلث
متساوي الاضلاع. }

- $i_f' \rightarrow I_H$ at $t = T_m$

$$i_s' = I_s + A \cdot e^{-t/\tau}, \quad t=0 \longrightarrow \boxed{i_s' = 0}$$

$$0 = I_s + A \rightsquigarrow A = -I_s$$

$$i_s' = I_s - I_s e^{-t/\tau} = I_s\left[1 - e^{-t/\tau}\right]$$

$$i_f' = B \cdot e^{-t/\tau}$$

- F.C.C. at $T = T_{on}$, $\boxed{i_s' = I_2}$

$$I_1 = I_s\left(1 - e^{-T_{on}/\tau}\right)$$

$$i_f' = B \cdot e^{-t/\tau}$$

I.C.C at T_{on}, $\boxed{i_f' = I_1}$

$$I_1 = B \cdot e^{-T_{on}/\tau} \longrightarrow B = I_1 \cdot e^{T_{on}/\tau}$$

$$i_f' = I_1 \cdot e^{T_{on}/\tau} \cdot e^{-t/\tau}$$

$$t = T_m \longrightarrow i_f = I_H$$

$$I_H = I_1 \cdot e^{T_{on}/\tau} \cdot e^{-T_m/\tau}$$

$$e^{-T_m/\tau} = \frac{I_H}{I_1} \cdot e^{-T_{on}/\tau}$$

$$-\frac{T_m}{\tau} = \ln\left(\frac{I_H \cdot e^{-T_{on}/\tau}}{I_1\ (DCM)}\right)$$

$$T_m = -\tau \cdot \ln\left[\frac{I_H \cdot e^{-T_{on}/\tau}}{I_1\ (DCM)}\right]$$

- $V_{o\,(avg)} = \frac{1}{T}\int_0^{T_{on}} V_s \cdot dt \Rightarrow \boxed{\delta \cdot V_s = V_{o\,(avg)}}$

- $V_{o\,(rms)} = \sqrt{\frac{1}{T}\int_0^{T_{on}} V_s^2 \cdot dt} \Rightarrow V_{o\,(rms)} = \sqrt{\delta} \cdot V_s$

- $RF = \frac{\sqrt{\delta V_s^2 - \delta^2 V_s^2}}{\delta \cdot V_s} \Rightarrow RF = \sqrt{\frac{1}{\delta} - 1}$

- **Voltage Harmonics** $\psi(n) = \frac{\pi}{2} - n\pi\delta$

$\rightarrow A(n) = \frac{2}{T}\int_0^{T_{on}} V_s \cdot \cos n\omega t \; dt = \frac{2V_s}{T} \cdot \frac{1}{n\omega} \sin(n\omega t)\Big|_0^{T_{on}}$

$\rightarrow B(n) = \frac{2}{T}\int_0^{T_{on}} V_s \cdot \sin n\omega t \; d\omega t$ ....

$\rightarrow C(n) = \frac{2V_s}{n\pi} \cdot \sin(n\pi\delta)$ ....

?

ex: $\delta = 1$, fundimental $\rightarrow 0$
$\delta = 0.5$, fundimental $\rightarrow$ MAX.

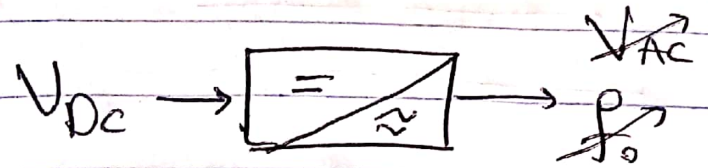
- The previous $A(n), B(n), C(n)$ Equations are for both $\rightsquigarrow$ CCM & DCM.

- $I_{(avg)} = \dfrac{V_{(avg)}}{R}$

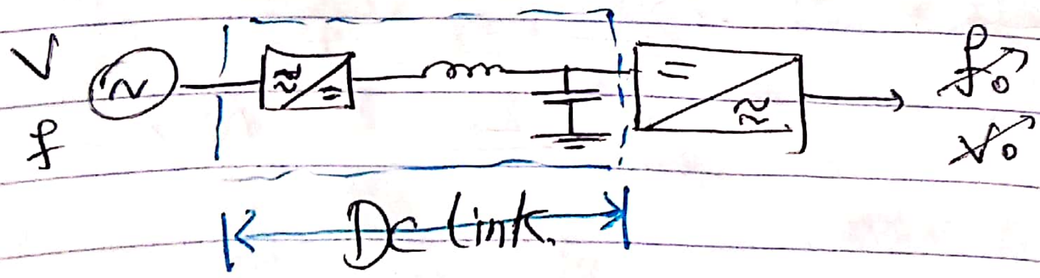
- $f_{ch} \uparrow\uparrow \rightsquigarrow$ Harmonics $\downarrow\downarrow$
- $L \uparrow\uparrow \rightsquigarrow$ Harmonise $\downarrow\downarrow$

$\Rightarrow$ chopper's disadvantages $\rightsquigarrow$ more switching losses.

Inverters



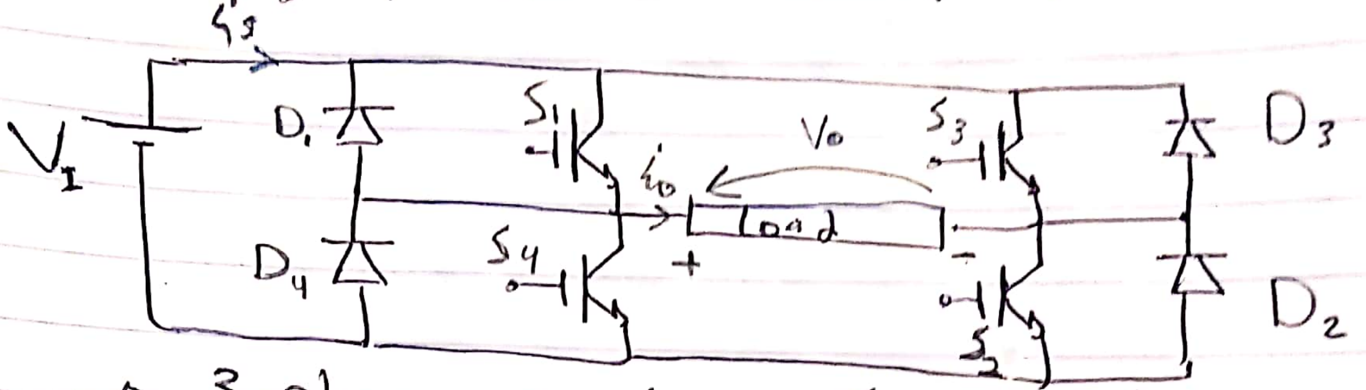
((Ac-to-Ac converter))



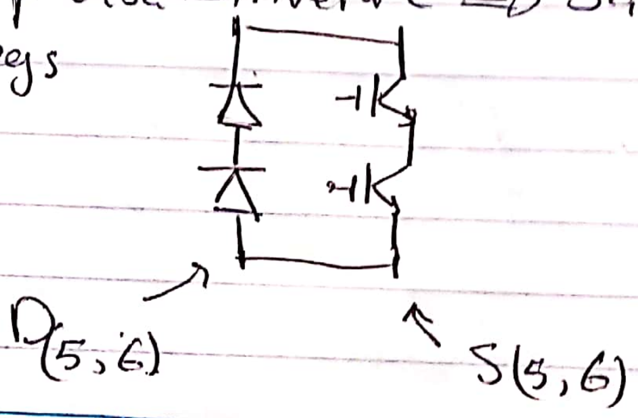
- The Best switching elements are Transistors to avoide forced commutation of SCR's.

$\rightarrow$ Transistors + fast recovery Diodes.

• Single phase - Inverter (power circuit).

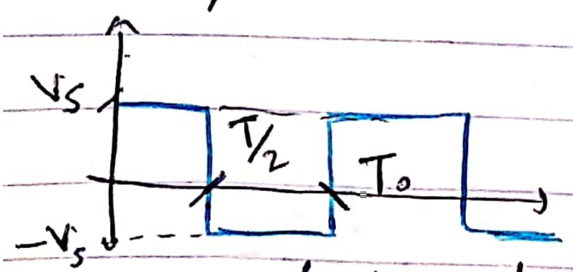


⇒ 3-phase - Inverter ⇒ Same + two new legs



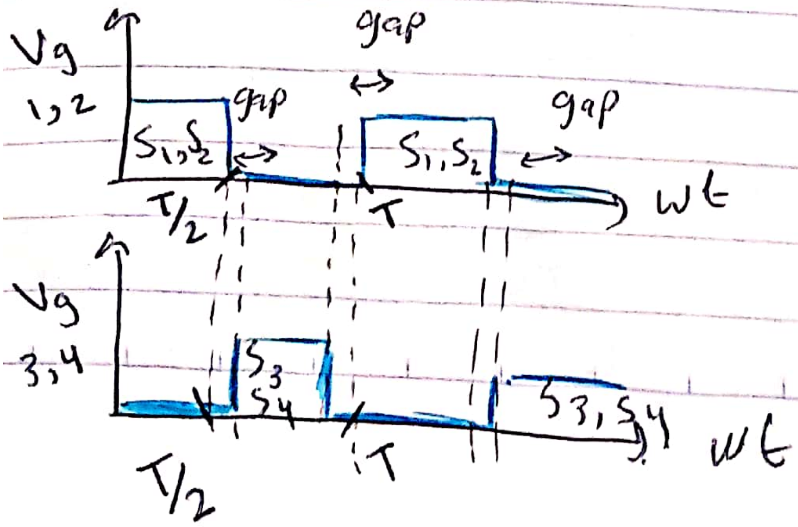
Control Topology

① Square-wave Inverter , $f_o = \frac{1}{T}$



⇒ Control T by a microcontroller to obtain the required frequency.

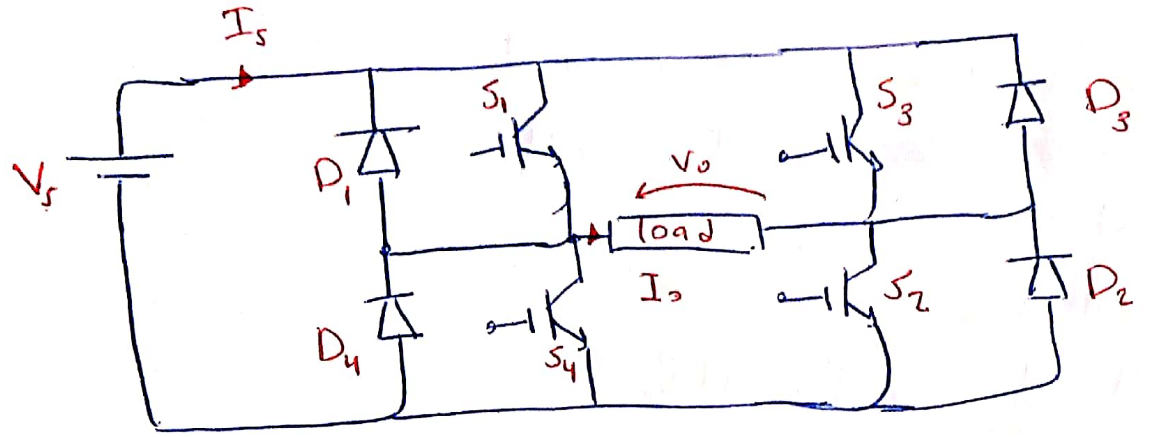
Control signals



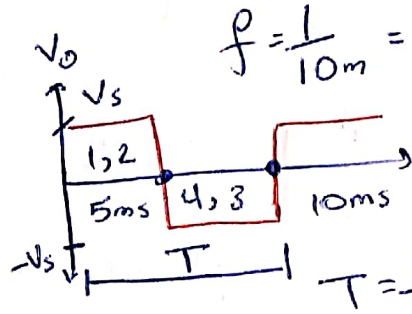
• We keep a gap (delay) to prevent short circuiting the 4-transistors when over-lapping

Lecture 39

29/12/2019



Control topology

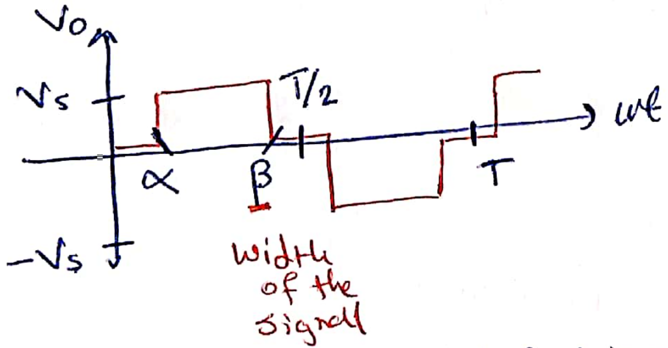


$f = \frac{1}{10m} = 100\ Hz$

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

① Square-wave
- f_o controlled by selection of switching times of the inverter switches
- V_o controlled by V_s, Dc link with controlled rectifire

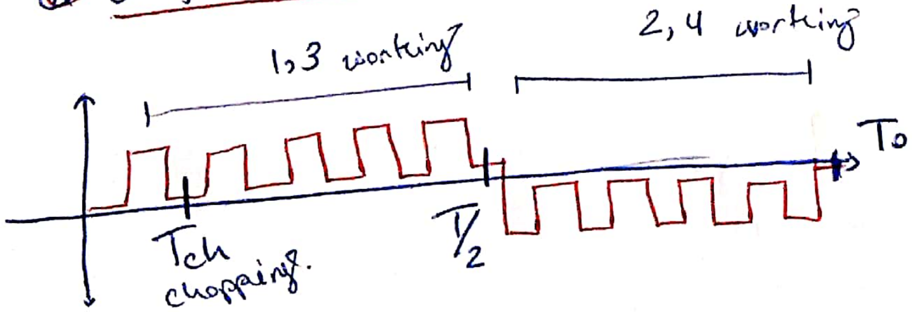
② Quasi-square-wave (Single pulse-width modulation)



- V_o controlled by the inverter switching action

③ Pulse width modulation (PWM) → Sinosoidal PWM
→ Uniform PWM.

④ Uniform PWM



4PWM, $f_{ch} = \frac{1}{T_{ch}}$

$f_o = f(f_{ch})$

① Number of pulses per half cycle N.

② Number of pulses per full cycle M.

$M = 2N$

$T_o = M * T_{ch}$

$\frac{1}{f_{ch}} * M = \frac{1}{f_o} \Rightarrow f_{ch} = M f_o$

$= 2N f_o$

Question in Exam

→ Pulse width modulation Technique, $f_{ch} = \ldots$ HZ, pulse # No. $= \ldots$

find power frequency $\underline{\underline{f_o}} = ??$

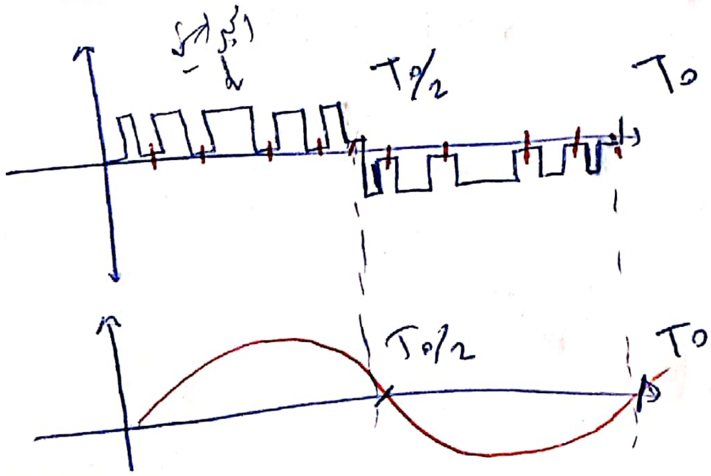
ex) Microcontroller:-

$f_{ch} = 5000$ HZ, $f_o = 100$ HZ ⇝ find # of pulses, $\frac{5000}{100} = 5$ pulses

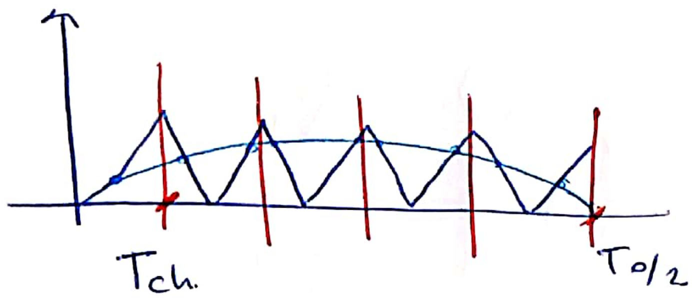
each half cycle $= 25$ pulse

→ in $10m \Rightarrow \frac{1}{100}$ ⇝ each pulse $\frac{10m}{25}$ = time for each pulse ....

④ Sinusoidal PWM : for better performance.

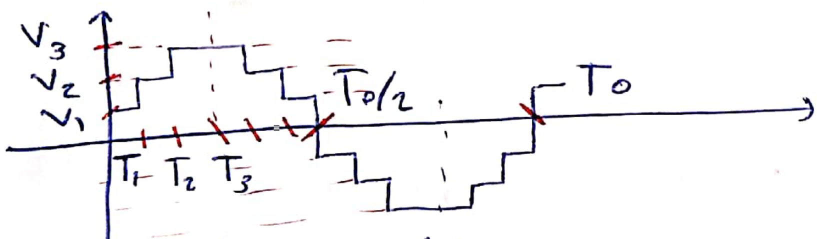


in microcontroller I generate triangular signal then we get Dc modulation signal and compair it :-



(4) Multilevel Voltage Source inverter :

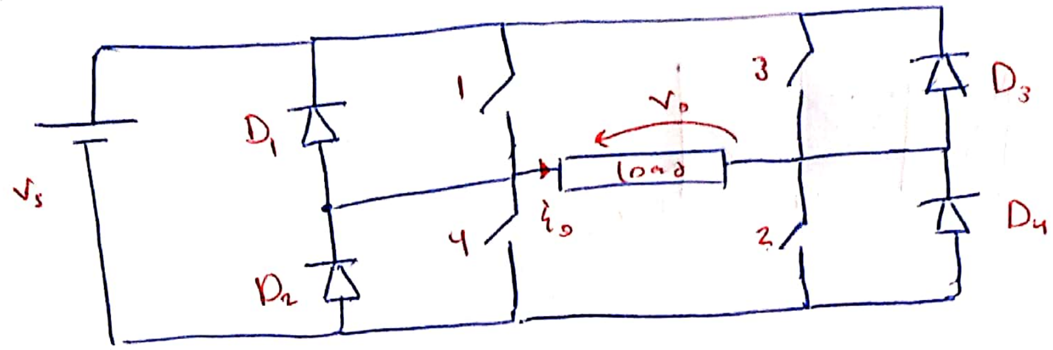
→ complex in design & more expensive but Great performance.



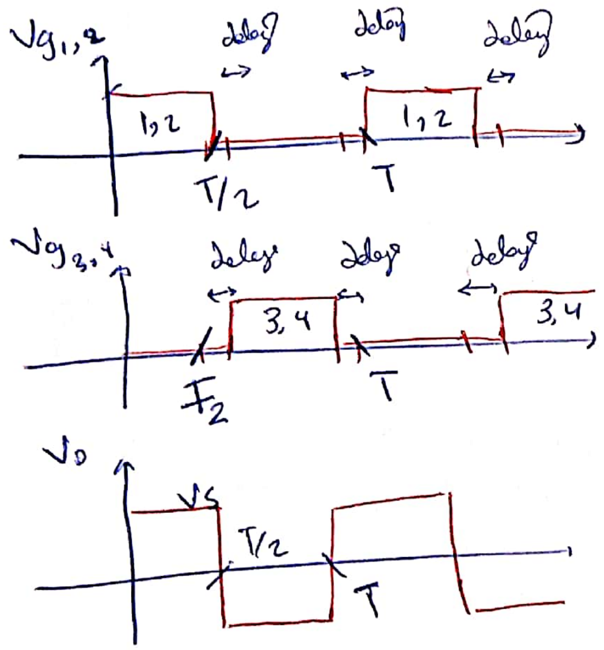
fundimental supplye
$V(1) = 240$ RMS
$V(3) = 0$
$V(5) = 0$
$V(7) = 0$

→ sitting in computer to generate equations.

31/12/2019 Lecture 40



Square-Wave inverter



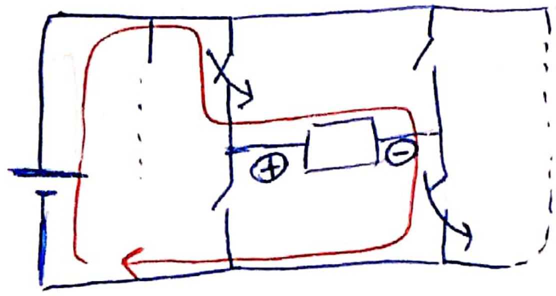
- T is decided by f_o

ex) $500\ HZ = f_o$

$T = \frac{1}{500} = 2\,msec$

→ each switch will work for 1 msec.

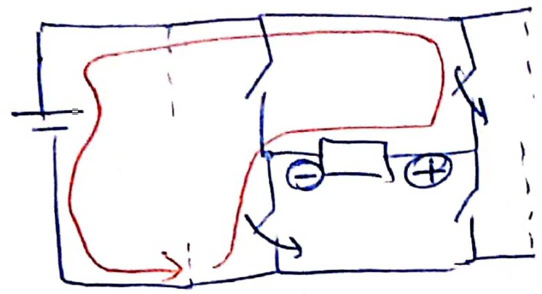
when SCR_1 & SCR_2 are on, $V_s = i_o R + L\frac{di_o}{dt}$ => زي ال chopper

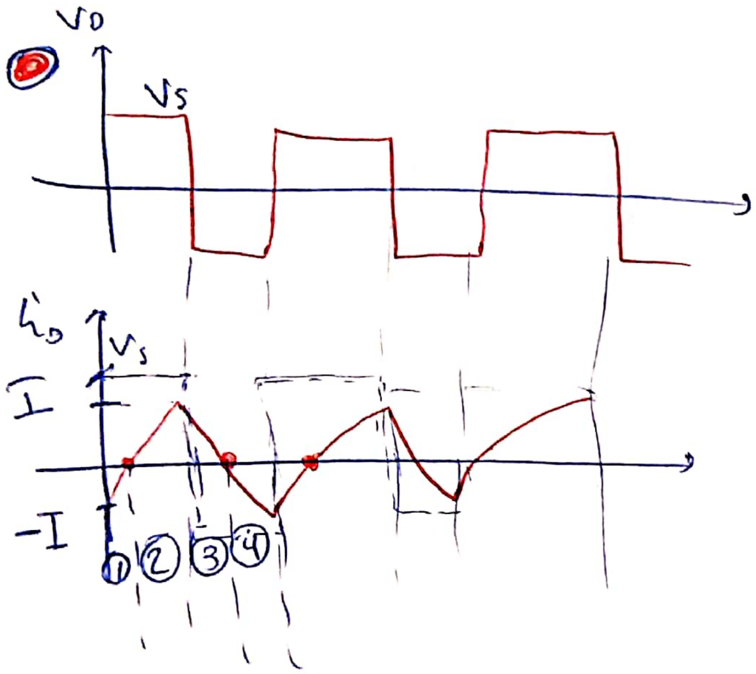


$0 \leq t \leq T/2$

In the second cycle

* ح تنقلب الإشارة.





(F.B)

① : D_1 & D_2, V_o^+, I_o^-

② : S_1, S_2, V_o^+, I_o^+

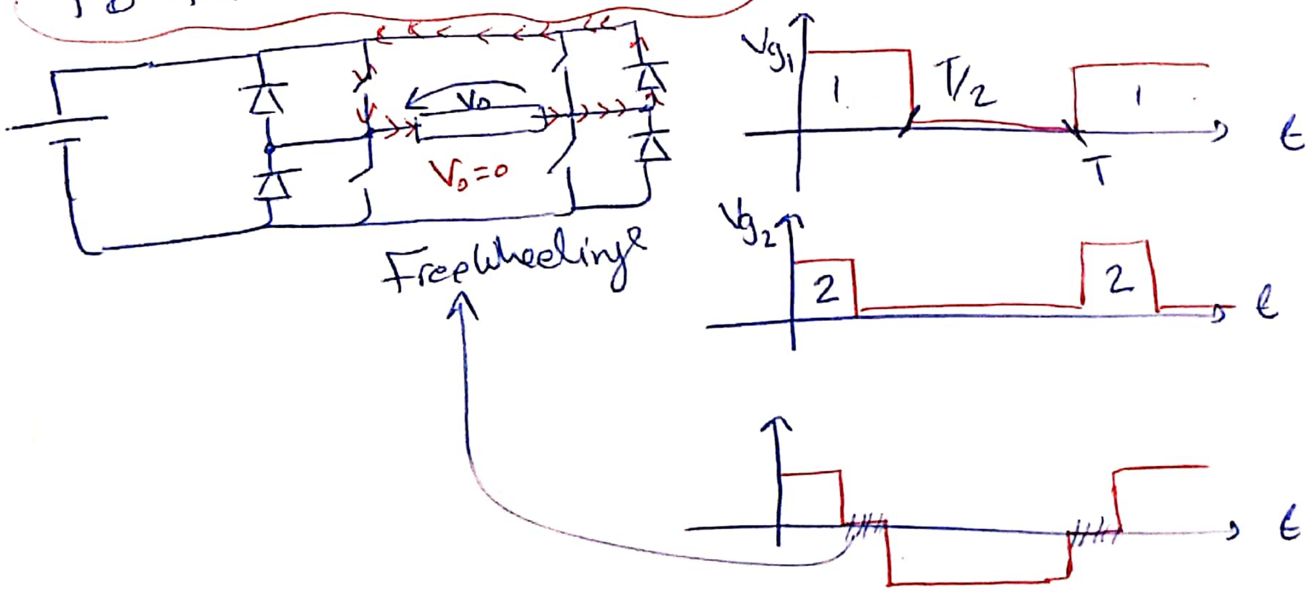
③ : V_o^-, I_o^+, D_3 & D_4 (F.B)

④ : S_3, S_4, V_o^-, I_o^-

• Power $= \frac{1}{2} I^2 L$ بترجع للـ Supply من خلال ال Feedback diodes.

⇒ Question in the Exam: In Square-Wave Inverters, Diodes are used for feedback or free wheeling? (A) feedback.

To Force Zero Voltage:



- in PWM Techniques (including quasi-square-wave)

⇒ $D_1 \rightarrow D_4 \longrightarrow$ freeWheeling / feed back Diodes

(work as both F.B & F.W!)

2/1/2020 Lecture 41

3-ph Rectifire (Questions in Exam:

- Waveform construction (V_o, i_s)

ex)) given α $\longrightarrow$ SCR 4 triggered at ??
45°

1 $\longrightarrow$ $\alpha + 30 = 75$

2 $\longrightarrow$ 135

ex)) given $\omega t = 240$ SCR_3 triggerd at $\alpha = ??$

3 $\to$ 240
$\downarrow$
2 $\to$ 180
$\downarrow$
1 $\to$ 120 $\rightsquigarrow$ $120 = \alpha + 30$, $\alpha = 90°$

ex)) $V_s = V_L / V_{ph}$, 3ph - supply, given $\alpha \longrightarrow$ find :-
380/220

RF_{v_o, i_o}, PF_{in} = ??

Q))) 3ph Rectifire, $V_{ph} = 220v$, $VL = 380v$, $f = 50HZ$
$RL = 10\Omega$, RF_{v_o} = ?? , PF_{in} = ?? at $\alpha = 0$, $\alpha = 30$ $\to$ CCM
$\alpha = 90°$ $\to$ DCM

Sol)) $\alpha = 30$ $\alpha < \alpha_{cr.} \to$ CCM.

$$V_{o(avg)} = \frac{3\sqrt{3}\, V_m \cos\alpha}{\pi} = \frac{3 * \sqrt{3} * \sqrt{2} * 220}{\pi} \cos(30°)$$

$V_{o(avg)} = 445.656v$

$$V_{o(rms)} = \sqrt{\frac{1}{2\pi/6} \int_{\alpha+\pi/6}^{\alpha+\pi/2} \left[\left(\sqrt{3} \cdot V_{max} \sin(\omega t + \pi/6)\right]^2 \cdot d\omega t\right.}$$

X Don't Do This !! takes time ...

$$V_{o(rms)} = 3V_m \left[\frac{1}{6} + \frac{\sqrt{3}}{4\pi} \cos 2\alpha \right]^{1/2}$$ #

$$\Rightarrow \boxed{V_{o(rms)} = 453.034\,V} > V_{o(avg)}$$

$$RF = \frac{\sqrt{V_{rms}^2 - V_{avg}^2}}{V_{avg}} = 18.27\,\%$$

$$PF_{in} = \frac{P_{in}(W)\ \text{watt}}{S_{in}(VA)} = \frac{P_o(W)\ \text{Watt}}{S_{in}(VA)}$$ ← لان ما فيش Losses.

$$P_o(W) = I_{o\,(rms)}^2 * R \to \text{given.}$$

$$\boxed{I_{o(rms)} = \frac{V_{o(avg)}}{R}} \Rightarrow$$ only for resistive loads +
ولانه اصلا غير صحيح !

$$I_{o(avg)} = \frac{V_{o(avg)}}{R}$$

$$S_{in}(VA) = 3V_{s\,rms}(ph) * I_{s\,rms}(ph)$$

$$3 * 220 * \text{-----}$$

$$\boxed{I_{s\,rms}(ph) = \sqrt{\frac{240^\circ}{360^\circ}} * I_{o(rms)} = \sqrt{\frac{2}{3}} * I_{o(rms)}}$$

$I_{s(avg)} = ??$ ⇝ Zero ∫ +ve و -ve
بيلغوا بعض

$$\left.\begin{aligned} I_{o(rms)} &= 45.3034\,A \\ I_{s(rms)} &= 36.99\,A \\ P_{in} = P_o &= 20524\,W \\ S_{in} &= 24413.4\,VA \\ PF &= 0.8407\ \text{lag} \end{aligned}\right\}$$ = الاجابة

→ when $\alpha = 90°$

$\alpha > 60° \longrightarrow$ DCM.

$$V_{o\,(avg)} = \frac{3\sqrt{3}\,V_m}{\pi}\left(1+\cos\left(\alpha+\pi/3\right)\right)$$

$$V_{o\,(avg)} = 68.94\ V$$

$$V_{o\,(rms)} = 3V_m\left[\frac{1}{3} - \frac{\alpha}{2\pi} + \frac{1}{4\pi}\sin\left(2\alpha + \frac{2\pi}{2}\right)\right]^{1/2}$$

must be in radians! مهم

$V_{o(rms)} = 112.07\ V$

$RF_{V_o} = 128.16\%$

$I_{s(rms)} = 9.1507\ A$

$PF_{in} = 0.208$ lag

الحل كامل

PIV

بدون شك رح يجي عليه سؤال

- PIV in 3-ph rectifires $= \sqrt{3}\,V_m$

  peak inverse voltage

- PIV, single phase - half wave $= V_m$
- PIV, single phase - full wave → Bridge $= V_m$
  → Center tapped $= 2V_m$

Voltage rating $= PIV * (2-3)$

min

max

Single ph - Rectifire

① R-L-load ⤳ critical case:-

$\boxed{\alpha = \phi}$

② $\alpha \neq \phi \rightarrow \phi = 60,\ \alpha = 30$ ⤳ Find $RF_{V_o} = ??$

$Z = 10 + j10\ \Omega$ ⤳ (rectangular form)

or $R = \_\_\_$ and $X = \_\_\_$

or $Z = 10\sqrt{2}\ \angle 45°\ \Omega$ (polar form)

$\phi = \tan^{-1}\left(\frac{X}{R}\right)$

CCM :-

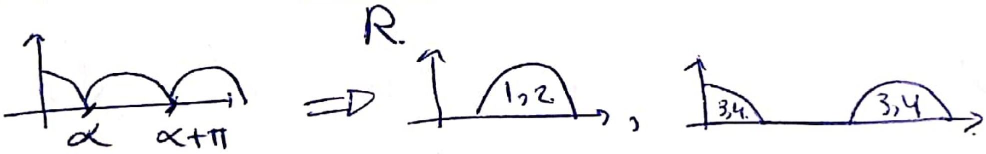
- $V_o = \frac{2V_m}{\pi} \cos(\alpha)$

- $V_{rms} = V_s\,(rms) = \frac{V_m}{\sqrt{2}}$

- $RF_{V_o} = \frac{\sqrt{V_o^2 - V_{avg}^2}}{V_{avg}}$

- $I_o\,(avg) = ??$ $\longrightarrow \frac{V_o\,(avg)}{R}$

- critical :



$$\begin{cases} I_{avg}(SCR) = \frac{1}{2} I_{(avg)} \\ I_{rms}(SCR) = \frac{I_{o(rms)}}{\sqrt{2}} \\ I_{peak}(SCR) = I_m = V_m/2 \end{cases}$$

⟵ current ratings of SCR.

⤳ choose Peak, (لما يجور)

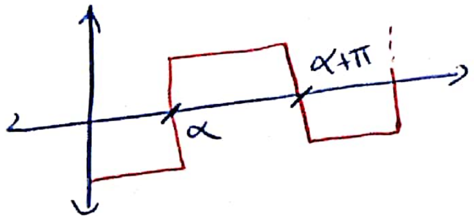
what is the (avg) of the SCR (Question in Exam صدقني)

ans : → (Load avg./2)

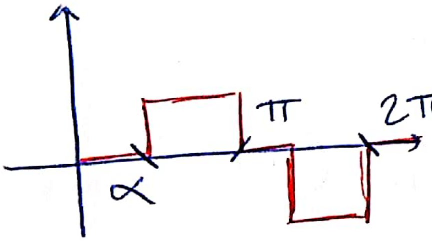
⤳ Rms?? (Load RMS/2)

Questions can also be:-

- R-L-E, L so large such that I_o is ripple free:-



Fully controlled.



Semi-controlled

- IN FULLY CONTROLLED:

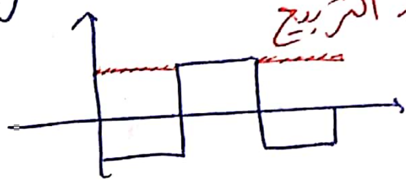
$RF_{I_o} = Zero$, $i_s = \sum_{1,3,5,\dots} \frac{4 I_o}{n\pi} \sin(n\omega t - n\alpha)$ → $\psi = n\alpha$

has harmonics → peak value.

$\rightarrow I_{1(rms)} = \frac{4 I_o}{\pi\sqrt{2}}$ (fundamental)

$$\boxed{I_{s\,(rms)} = I_o = I_{o(rms)}}$$

عند التربيع



- IN SEMI-CONTROLLED:

$I_{s\,(rms)} = I_{o(rms)} * \sqrt{\frac{180^\circ - \alpha}{180^\circ}}$ → α in degrees or حط 180° بدل π وحل radians.

$$i_s = \sum_{1,3,5,\dots} \frac{4 I_o}{n\pi} \cos\left(\frac{n\alpha}{2}\right) \sin\left(n\omega t - \frac{n\alpha}{2}\right)$$

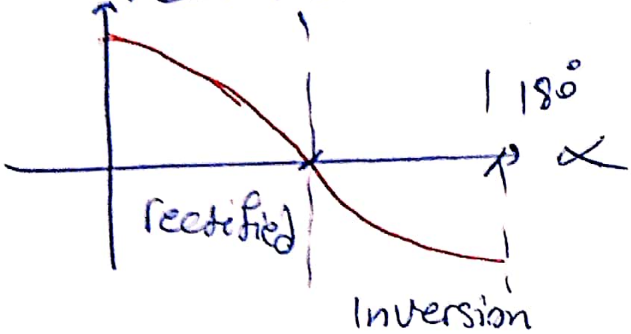
Question in the Exam Find:

RF_{V_o}, PF_{in}, $THDF$ = ?? then add a freewheeling diode connected to the load:

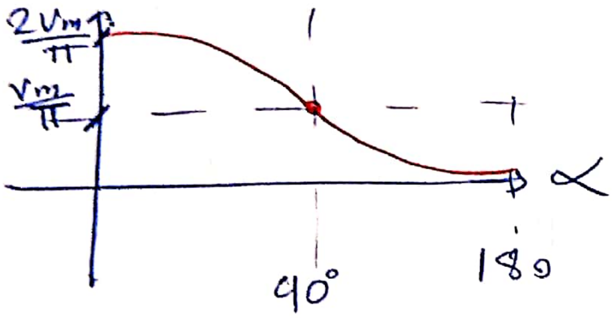
Recalculate them then compare the results.

→ Draw α Vs. $V_{o(avg)}$ for the previous two cases: →

Case ①))
Fully controlled rectifire. , $V_o(avg) = \frac{2V_m}{\pi}\cos\alpha$



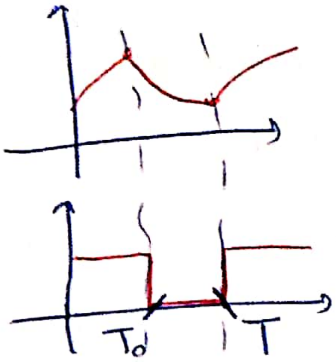
Case ②))
Semi-controlled rectifire , $V_o(avg) = \frac{V_m}{\pi}(1+\cos\alpha)$



● another Question: Semi-controlled R-L-Load, is it CCM or DCM??
⇝ (I_1 & I_2 for CCM & DCM, you should know them)
$I_1 > 0$ ⇝ CCM, $I_1 < 0$ ⇝ DCM.

Choppers

R-L-Load, f_{ch} (f_m), V_s (DC), δ given, or, $V_o(avg)$
⇝ Find $RF_{V_o} = ??$ CCM/DCM = ??

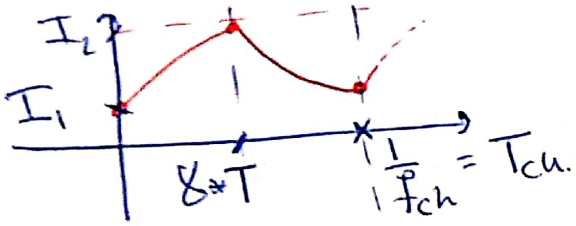


$\delta = T_o/T$, $\delta_{cr} = ??$ you must find it
$\delta_{cr} < \delta \Rightarrow$ CCM.
$\delta_{cr} > \delta \Rightarrow$ DCM.

$V_{o(avg)} = \delta * V_s$

$V_{o(rms)} = \sqrt{\delta} * V_s$

$I_1, I_2 \longrightarrow$ Sketch to scale



$RF_{i_o} = ??$

بيحطلنا عدد ال Harmonics
اللي لازم اهتم بيهم بالاعتبار

$$i_o = I_{o(avg)} + \sum_{n=1,2,3,\ldots} \frac{2V_s}{n\pi} \cdot \sin(2\pi\delta n)\sin\left(n\omega t + \frac{\pi}{2} + n\pi\delta\right)$$

$$\varphi(n) = \pi/2 - n\pi\delta$$

if $n=1$, find i_o or $n \rightarrow 3$ ....

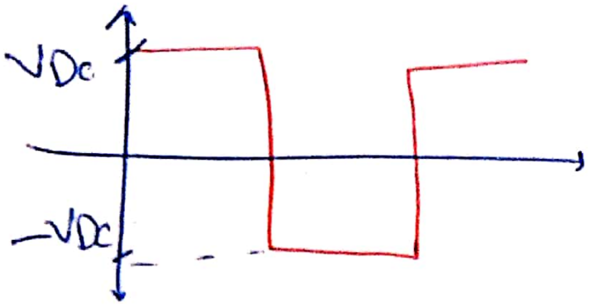
1^{st} RMS value $\rightsquigarrow \frac{2V_s}{\pi\sqrt{2}} = I_{1(rms)}$

2^{nd} RMS value $\rightsquigarrow \frac{2V_s}{2\pi\sqrt{2}}$

$$V_o = V_{o(avg)} + \sum_{n=1,2,3,\ldots} \frac{2V_s}{n\pi} \cdot \sin(2\pi n\delta)\sin(n\omega t - \pi/2 + n\pi\delta)$$

INVERTER

Questions:
- power circuit
- typical waveformes.
- conduction pattern: where SCR 1, 2, 3 .... & D 1, 2, 3 ....
- control signal بيشتغلوا؟
- PWM, F_m & f_o relations.



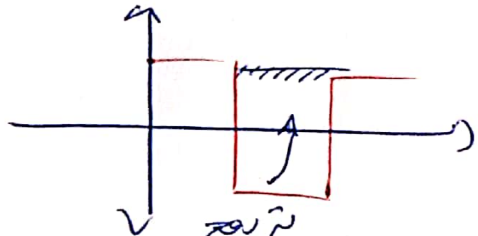
$$V_o = \begin{cases} +V_{DC}, & 0 \leq \omega t \leq 180^\circ \\ -V_{DC}, & 180^\circ \leq \omega t \leq 360^\circ \end{cases}$$

$$\boxed{V_{o\,(avg)}(t) = \sum_{n=1,3,5,\ldots} \frac{4V_{DC}}{n\pi} \sin(n\omega t)} \quad , \quad \boxed{\psi(n) = 0}$$

مهم   مهم

$$\boxed{i_o(t) = \sum_{n=1,3,5,\ldots} \frac{4V_{DC}}{n\pi\, Z(n)} \cdot \sin(n\omega t)}$$

$$V_{o\,(rms)} = V_{DC}$$



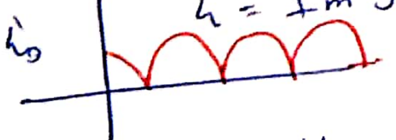
تربيع
وكذا ...

Q)) find V_{DC} such that $V_{o_1(rms)} = 240\,V$??

fundimental الهرمونك الأول

$$V_{o_1(rms)} = \frac{4V_{DC}}{1\pi\sqrt{2}} \Rightarrow 240 = \frac{4V_{DC}}{\pi\sqrt{2}} \quad , \quad V_{DC} = ??$$

Homework أخذنا ، كان يا مكان في قديم الزمان   8 Cr. case:-



$i = I_m \sin(\omega t - \phi)$

$RF_{i_o} = ??$, $I_{o\,(rms)} = \frac{I_m}{\sqrt{2}}$, $I_{o\,(avg)} = \frac{2I_m}{\pi}$ هاد اللي بيجي

$$A(n) = \frac{4}{2\pi} \int_{\alpha}^{\alpha+\pi} I_m * \sin(\omega t - \phi) \cdot \cos(n\omega t)$$

يحوله ل $\sin(X) \cdot \cos(Y)$

$= \frac{1}{2}\left[\text{ـ البصير بيطلع ـ} \right]$ ـــ ويكمل

على الاغلب ما رح يجي ، بس اذا اجا انا كثير مسؤولة ...