وزارة التعليم العالي والبحث العلمي
الجامعة التقنية الجنوبية
المعهد التقني العما رة
قسم التقنيات الكهربائية

الحقيبة التدريسية لما دة

الكترونيات القدرة /1

المرحلة الثانية

الفصل الدراسي الاول

اع داد
ضياء داود خضير ر
معاون رئيس مهندسين

اسم المادة	لغة التدريس	السنة الدراسية	الفصل الدراسي	الفرع	الساعات الاسبوعية			الوحدات
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الكترونيات القدرة ١	الانكليزية	الثانية	الاول	القوى الكهربائية	٢	٣	٥	٥

المفردات

Week	Theoretical syllabus
1^{st}	Power electronic , electronic componts which used in high power control(power diodes , thyristor and power transistors) pevison of single phasa rectifier circuites by using diodes .
2^{nd}	Three phase rectifier circuites by using diodes , output voltage waveform , diode current waveform , output voltage equation in case of resistance lode.
3^{rd}	Using the transistor as switch , regions of operation , transistor as a switch (cut off and saturation)
4^{th}	Power transistor in (off) and (on) state , improvement of (off) and (on) time by using speed up capacitance , problems .
5^{th}	Uniplolor junction transistor , construction , theoretical operation , using the transistor as relaxation oscillator practical example .
6^{th}	Operational amplifier , description of operational amplifier (op-amp) as asparate components , zero detector , comparator .
7^{th}	The use of op-amp as astable multivibrator and amonostable multivibratir , photo conduction cells , photo diodes .
8^{th}	Light – emitting diodes (led) , photo transistor , the use of optical comparator in power electronic circuits
9^{th}	Thyristor , construction , characteristic , curves for a thyristor family , thyristor representation as adouble transistor circuit .
10^{th}	Thyristor construction methods , conduction throw the gate minimum gate current causing conduction , conduction time , conduction due to hight forward voltage rectifier (dv/dt).
11^{th}	Diac , triac characteristics , practical applications , thyristor , triggering methods , triggering on dc and ac current , pluse triggering types .
12^{th}	thyristor triggering circuit , dc and ac triggering circuit .
13^{th}	Pluse current triggering circuit , relaxation oscillator , zero detector , comparator with astable and monostable multivibrators (operational amplifiers and timer).
14^{th}	Thyristor general application introductory , ac to dc inverter dc to ac inverter , dc to dc inverter , ac to ac inverter , phase controlled halfwave rectifier with resistance and indctormace load out current and voltage waveform , output voltage equations .
15^{th}	Half controller full wave rectifire fully controlled , resistance and inductance load , generated wave forms , output voltage equation for free wheeling diode.

محاضرات الكترونيك القدرة المرحلة الثانيـــــــــــة

قســــــــم التقنيات الكهربائيـــــة المعهد التقني العمارة

الجامعة التقنية الجنوبية

بسم الله الرحمن الرحيـــــــــــــــــم

اقرأ بسم ربك الذي خلق . خلق الانسان من علق . أقرأ وربك الاكرم . الذي علم بالقلم . علم الانسان مالم يعلم .

صدق الله العظيم

المقدمـــــــــــــــــة :

إن اللغة العربية لغة العلم والعلماء فهي غنية بالمصطلحات لا تضاهيها أية لغة أخرى .لكن من المؤسف أن تفتقر مكتبتنا العربية الحديثة إلى الكتب العلمية بالأخص الهندسية منها .لقد كان لعلمائنا دور كبير في تقدم مختلف العلوم ، وما جابر بن حيان والخوارزمي وابن الهيثم وغيرهم من علمائنا الأفاضل إلا نجوم ساطعة تشهد بما قدمه أجدادنا من فضل وخير ما تزال الإنسانية ترتشف من رحيقها العذب وهذا ما يشهد به العالم اجمع .

والله من وراء القصد ومن الله التوفيق

References

1) N.Mohan, et al , Power Electronics, Converters, Applications, and Design, 3rd Edition , John Wiley and Sons,2003.

2) P.C.Sen, Principles of Electric Machines and Power Electronics, 2nd Edition , John Wiley and Sons,1997.

3) B.K.Bose, Modern Power Electronics and AC Drives, Prentice Hall Inc,2002.

4) C.W.Lander, Power Electronics, 2nd Edition, McGraw Hill, 1987.

5) M.H. Rashid, Power Electronics Handbook Devices Circuits and Applications, Academic Press, 2007.

What is Power Electronics

1. Power electronics combine power, electronics, and control.

2. Application of solid-state electronics for the control and conversion of electric power.

3. The focus in power electronics is on conversion, efficiency of conversion and control of energy.

4. Power electronics is based primarily on the switching of the power semiconductor devices.

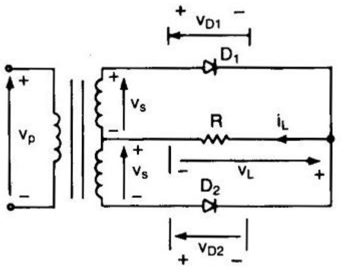
Power Semiconductor Devices:

1. **Power Diodes**
2. **Thyristors**
3. **Power Bipolar Junction Transistors (BJTs)**
4. **Power MOSFETs**
5. **Insulated-Gate Bipolar Transistors (IGBTs)**
   Static Induction transistors (SITs)

Classification of power electronic circuits:

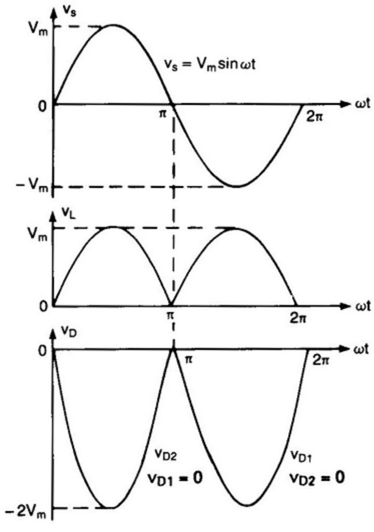
1- Diode rectifiers:

Single phase full wave Rectifier circuit with center-tapped transformer:



(a) Circuit diagram

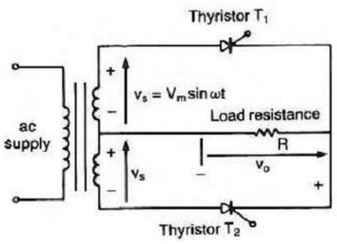
$$V_{dc} = \frac{2}{T}\int_0^{T/2} V_m \sin\omega t \; dt$$
$$= \frac{2V_m}{\pi} = 0.6366\ V_m$$

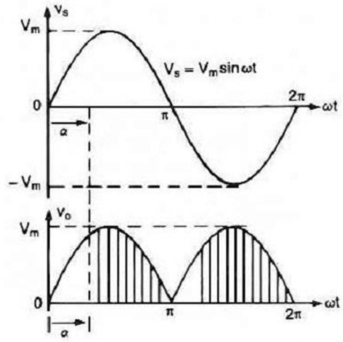


(b) Waveforms

2- AC-DC converters:

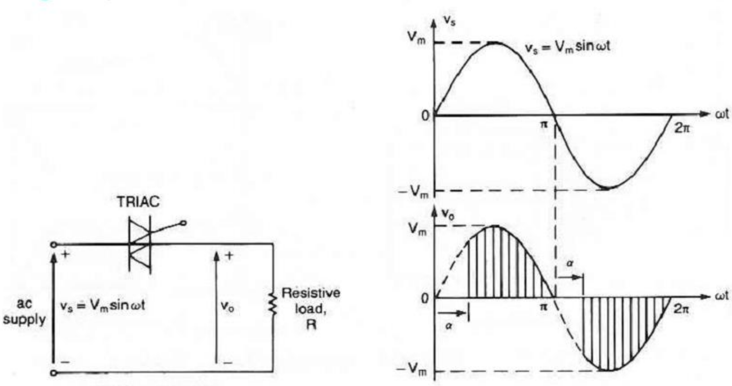
Single phase AC-DC converter:





(a) Circuit diagram (b) Voltage waveforms

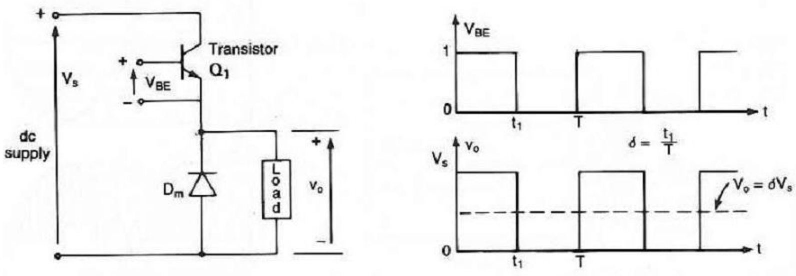
3- AC-AC converter:



(a) Circuit diagram (b) Voltage waveforms

4- DC-DC converter:

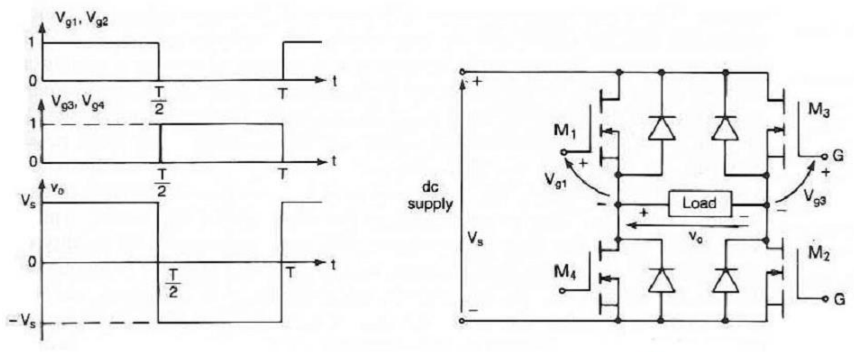
dc-dc converter



(a) Circuit diagram (b) Voltage waveforms

5- DC-AC converter:

▪ Single-phase dc-ac converter



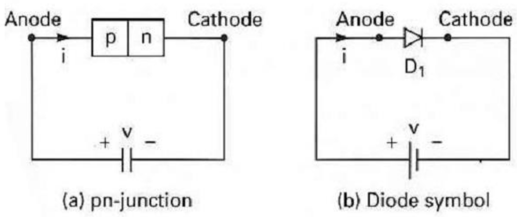
(b) Voltage waveforms (a) Circuit diagram

1- Power diode :

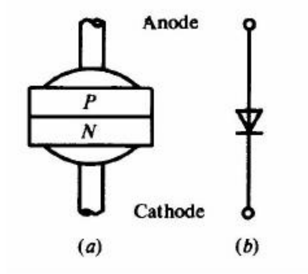
Introduction: -

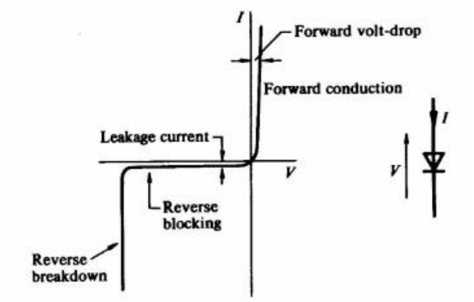
1- A power diode is designed for high forward current and high reverse breakdown voltage.
2- The area of pn junction in power diodes is much larger than in a signal diode because it is designed for large current flow.
3- The frequency response or switching speed is low compared to signal diodes.

Diode Characteristics



***pn* Junction and diode symbol**





The power diode (PN junction)

a) Structure

b) symbol

Diode characteristics

Power diode types:

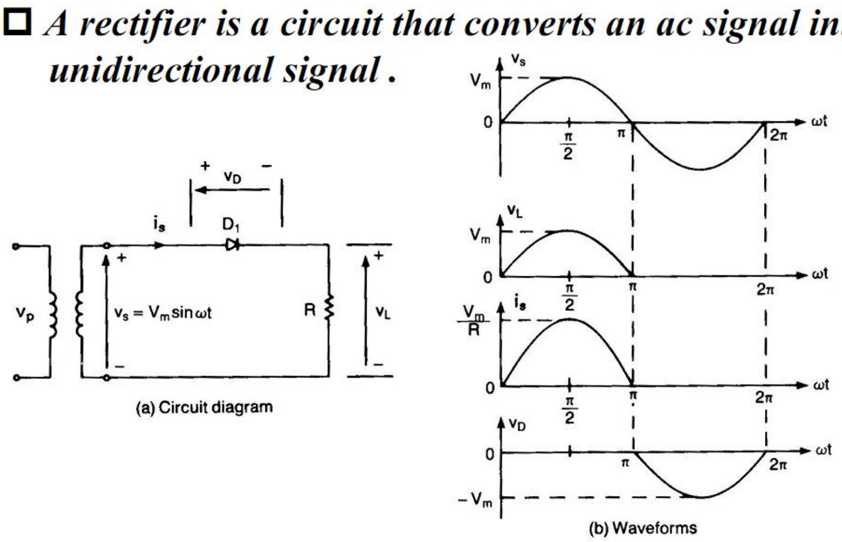
1. Standard or General-Purpose Diodes

2. Fast-Recovery Diodes

3. Schottky Diodes

Single Phase Half-wave Rectifiers:

AC-DC converters are commonly known as a rectifier and diode rectifiers provide a fixed (DC).



(a) Circuit diagram

(b) Waveforms

Fig 1

The average output voltage V_{dc} *is defined as*

$$V_{dc} = \frac{1}{T}\int_0^T v_L(t)\, dt$$

$$where,\ v_L(t) = 0 \quad for\ \ \frac{T}{2} \le t \le T \quad (figure\ in\ waveforms)$$

$$Thus,\ \ V_{dc} = \frac{V_m}{\pi} = 0.318V_m$$

$$I_{dc} = \frac{V_{dc}}{R} = \frac{0.318V_m}{R}$$

The root – mean – squre (rms) value of a periodic waveform is

$$V_{rms} = \left[\frac{1}{T}\int_0^{T/2} (V_m \sin \omega t)^2\ dt\right]^{1/2} = \frac{V_m}{2} = 0.5V_m$$

$$I_{rms} = \frac{V_{rms}}{R} = \frac{0.5V_m}{R}$$

$$P_{dc} = V_{dc} I_{dc} = \frac{(0.318V_m)^2}{R}$$

$$P_{ac} = V_{rms} I_{rms} = \frac{(0.5V_m)^2}{R}$$

Fout= Fin , $F = \frac{1}{T}$

H.W: Prove that : $I_{dc}=\frac{Im}{\pi}$ $Irms = \frac{Im}{2}$

Output voltage for the forward biased (V_D=Zero) and (R_d) is very low fig (1) explain the circuit.

Efficiency of rectifier circuit:

$$\xi = \frac{Pout}{Pin}$$

Pout = output power

Pin = input power

ξ = Efficiency

$Pout = (I_{dc})^2 . R_L$

$Pin = (Irms)^2 (r_B+R_L)$

R_B=Forward resistance for the diode

$$= \frac{(Idc)^2 .Rl}{(Irms)^2 \quad (RB+RL)}$$

If $I_{dc}=\frac{Im}{\pi}$

and $Irms = \frac{Im}{2}$

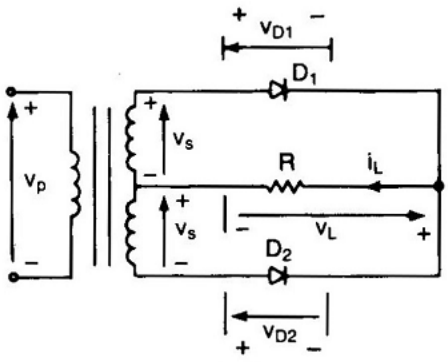
$$= \frac{(\frac{Im}{\pi})^2 \ \ RL}{(\frac{Im}{2})^2\ (RB + Rl)}$$

$$= \frac{4Rl}{(\pi)^2 \quad (RB+Rl)}$$

if (r_B) = zero

$$\xi = \quad \frac{4}{\pi^2} = 0.405 = 40.5\%$$

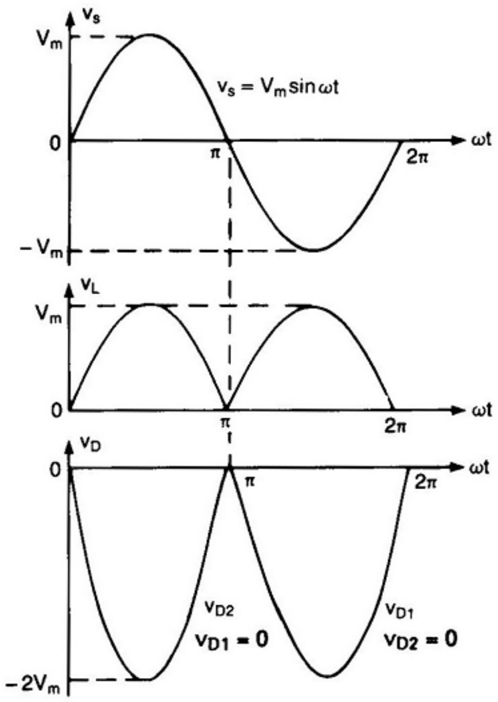
Full-wave rectifier with center-tapped transformer



(a) Circuit diagram

$$V_{dc} = \frac{2}{T}\int_0^{T/2} V_m \sin\omega t \ dt$$

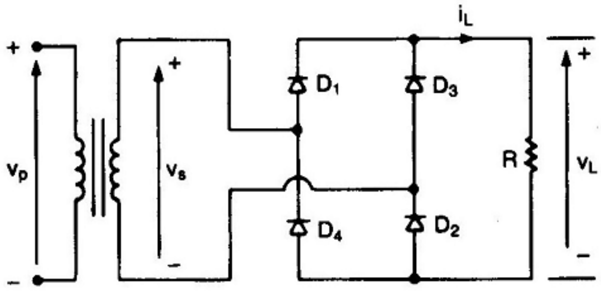
$$= \frac{2V_m}{\pi} = 0.6366\ V_m$$



(b) Waveforms

Fig 2

Full-wave bridge rectifier



(a) Circuit diagram

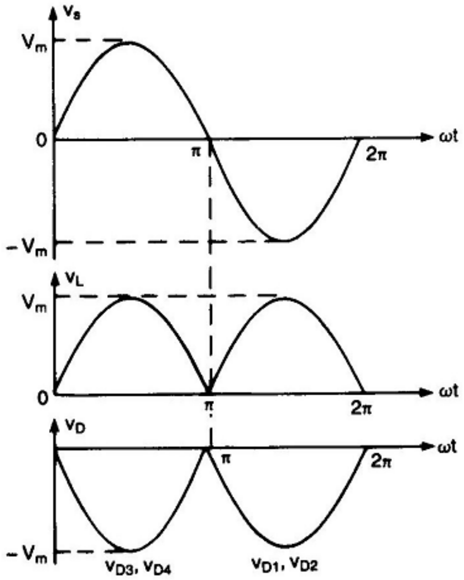


Fig 3

$$V_{dc} = \frac{2}{T}\int_0^{T/2} V_m \sin\omega t \; dt$$

$$= \frac{2V_m}{\pi} = 0.6366\, V_m$$

$\xi = \dfrac{(Idc)^2\ .Rl}{(Irms)^2\ \ (RB+RL)}$ If $I_{dc} = \dfrac{2Im}{\pi}$ and $Irms = \dfrac{Im}{\sqrt{2}}$

$\xi = \dfrac{(\frac{2Im}{\pi})^2\ .Rl}{(\frac{Im}{\sqrt{2}})^2\ \ (RB+RL)} = \dfrac{8Rl}{(\pi)^2\ \ (RB+Rl)}$ *if* R_B= zero

$$\xi = \frac{(\frac{2Im}{\pi})^2\ .Rl}{(\frac{Im}{\sqrt{2}})^2\ \ (RB+RL)} = \frac{8Rl}{(\pi)^2\ \ (RB+Rl)} = \frac{8}{(\pi)^2} = 0.81 = 81\%$$

Note: - Efficiency in full wave rectifier = 2 efficiency in half wave rectifier

Lows:

(Centre-tap) Full- wave rectifiers	Full wave bridge rectifier
$Idc = \frac{2Im}{\pi}$	$Idc = \frac{2Im}{\pi}$
$I_{rms} = \frac{Im}{\sqrt{2}}$	$I_{rms} = \frac{Im}{\sqrt{2}}$
$F_{out} = 2F_{in}$	$F_{out} = 2F_{in}$
$I_{dc} = \frac{vdc}{RL}$ $Irms = \frac{Vrms}{RL}$	$I_{dc} = \frac{vdc}{RL}$ $Irms = \frac{Vrms}{RL}$
PIV=2Vm	***PIV=Vm***

Homework 2:- Prove that: $Idc = \frac{2Im}{\pi}$, $I_{rms} = \frac{Im}{\sqrt{2}}$

Q1:**-** Calculate the efficiency for the (H.W.R) and (F.W.R)?

Q2: - Prove the efficiency in (H.W.R) equal (40.5%) and (F.W.R) equal (81%)

H.M 2:- In(H.W.R)if Vm=40v,Tin=20 msec,RL=10KΩ. **Find** Vdc,Vrms,Fin,Fout,Idc,Irms

H.M 3:- In(F.W.R)if Vm=40v,Tin=20 msec ,RL=10KΩ .**Find** Vdc,Vrms,Fin,Fout,Idc,Irm

Form factor

The form factor (FF) is defined as the ratio of the rot –mean –square (heating component) of a voltage or current its average value .

$$FF = \frac{V_L}{Vdc} \quad or \quad \frac{I_L}{Idc}$$

About half wave rectifier F.F $= \frac{0.5\,Vm}{0.318\,Vm} = 1.57$

About full wave rectifier F.F $= \frac{0.707\,Vm}{0.636\,Vm} = 1.11$

Ripple factor

The ripple factor (RF) which is a measure of the ripple content is defined as :-

RF = Vac / Vdc

Vac = $\sqrt{VL^2 - Vdc^2}$

RF = = $\sqrt{(\frac{VL}{Vdc})^2 - 1}$

RF = $\sqrt{(FF)^2 - 1}$

About half wave rectifier

RF = $\sqrt{(1.57)^2 - 1}$ = 1.21

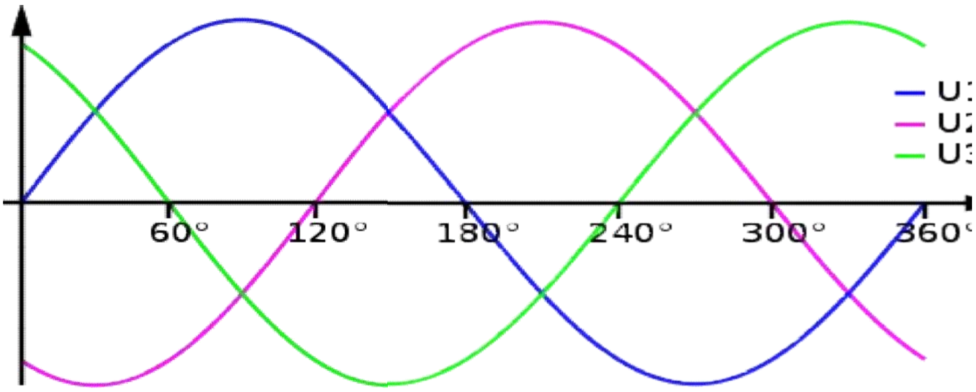
About full wave rectifier

RF = $\sqrt{(1.11)^2 - 1} = 0.482$

كلما كان عامل التموج قليل كان الموحد أفضل

Three phase rectifier

Three phase source



Three-phase Half-Wave Reactifier:

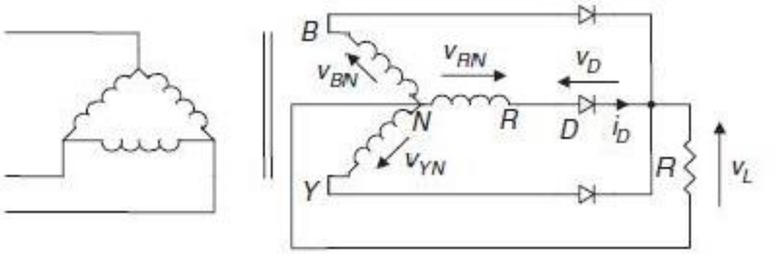


FIGURE 1-a Three-phase star rectifier.

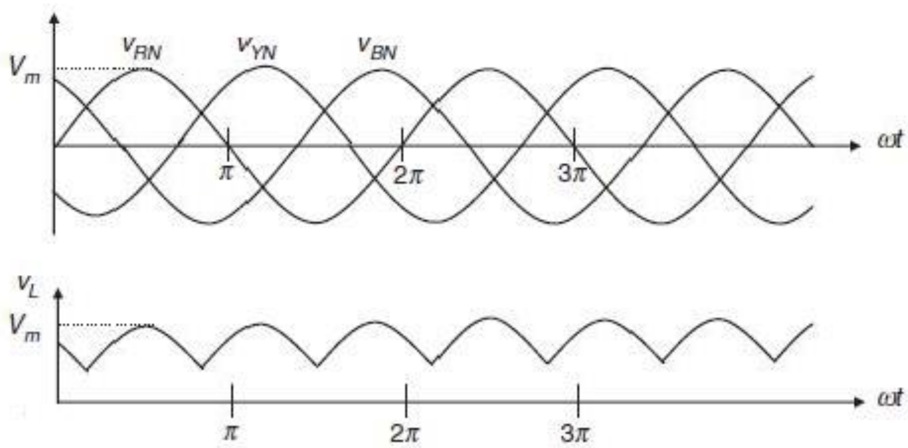


Fig 1-b input and output wave forms

Equations: -

Taking phase R as an example, diode D conducts from $\pi/6$ to $5\pi/6$.

$$V_{dc} = \frac{3}{2\pi} \int_{\pi/6}^{5\pi/6} V_m \sin\theta d\theta$$

or

$$V_{dc} = V_m \frac{3}{\pi} \frac{\sqrt{3}}{2} = 0.827 V_m$$

$$V_{rms} = \sqrt{\frac{3}{2\pi} \int_{\pi/6}^{5\pi/6} (V_m \sin\theta)^2 \, d\theta}$$

or

$$V_{rms} = V_m \sqrt{\frac{3}{2\pi} \left(\frac{\pi}{3} + \frac{\sqrt{3}}{4} \right)} = 0.84 V_m$$

Three Phase Bridge Rectifiers:

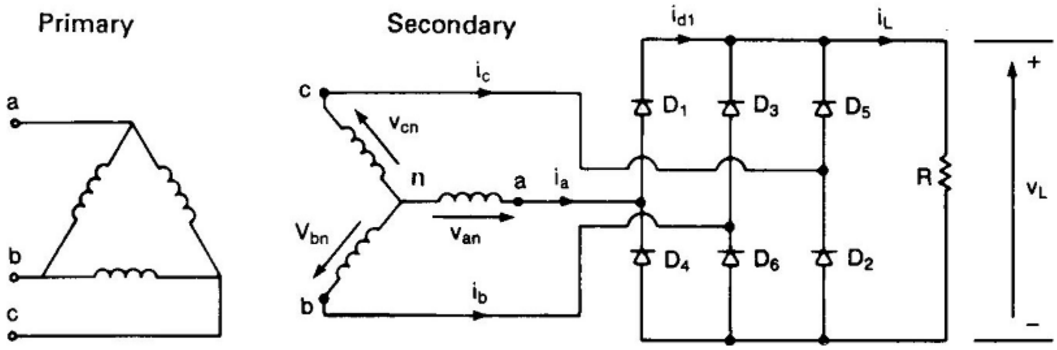
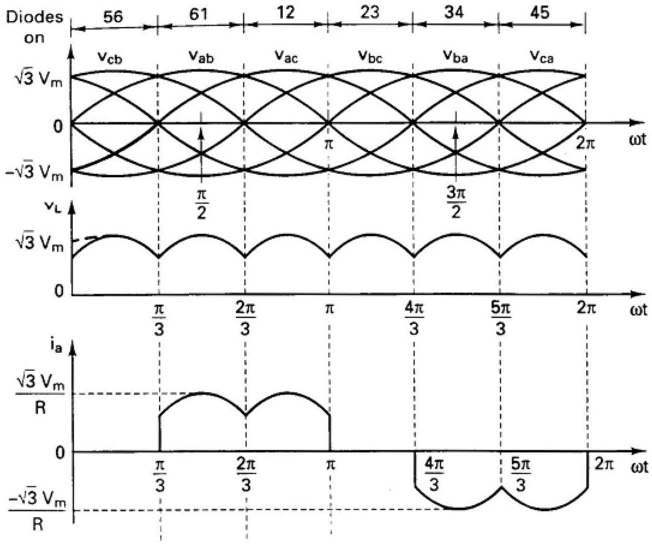


Fig 29



Average output voltage :

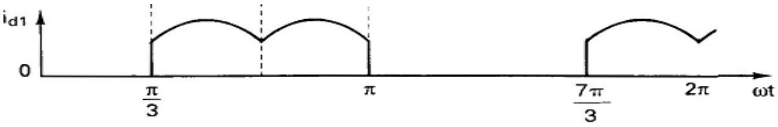
$$V_{dc} = \frac{2}{2\pi/6}\int_0^{\pi/6}\sqrt{3}\,V_m\cos\omega t\; d(\omega t)$$

$$= \frac{3\sqrt{3}}{\pi}V_m = 1.654\,V_m$$

V_m : *peak phase voltage*

***rms* output voltage :**

$$V_{rms} = \left[\frac{2}{2\pi/6}\int_0^{\pi/6} 3V_m^2\cos^2\omega t\; d(\omega t)\right]^{1/2}$$



Waveform and conduction time of diodes

$$\boldsymbol{Vrms} = \left(\frac{3}{2} + \frac{9\sqrt{3}}{4\pi}\right)^{1/2} \boldsymbol{Vm = 1.6554Vm}$$

The power transistor:

Introduction

The first transistor was discovered in 1948 by a team of physicists at the Bell Telephone Laboratories and soon became a semiconductor device of major importance. Before the transistor, amplification was achieved only with vacuum tubes. Even though there are now integrated circuits with millions of transistors, the flow and control of all the electrical energy still require single transistors. Therefore, power semiconductors switches constitute the heart of modern power electronics. Such devices should have larger voltage and current ratings, instant turn-on and turn-off characteristics, very low voltage drop when fully on, zero leakage current in blocking condition,

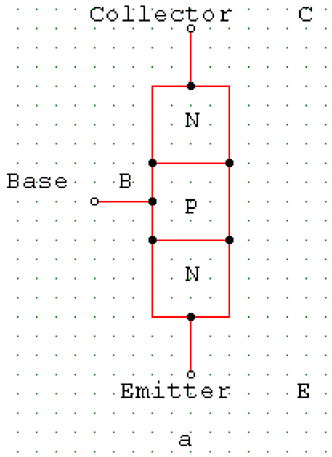
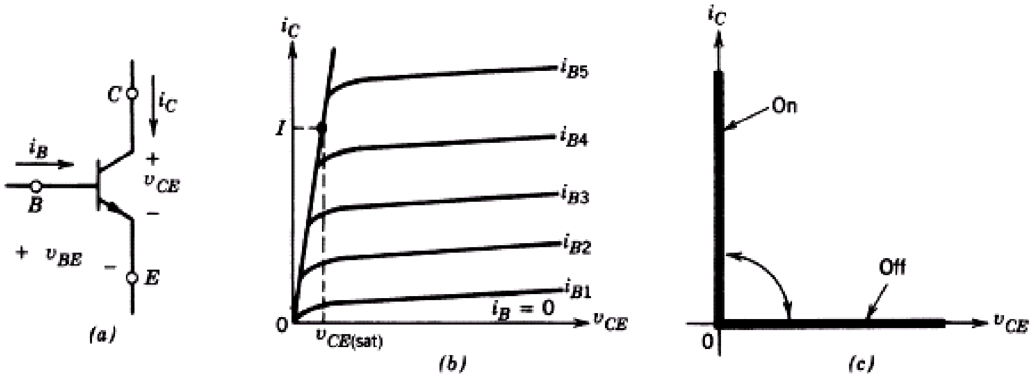


Fig 1 N-P-N Transistor a) Structure, b) Symbol with the current direction

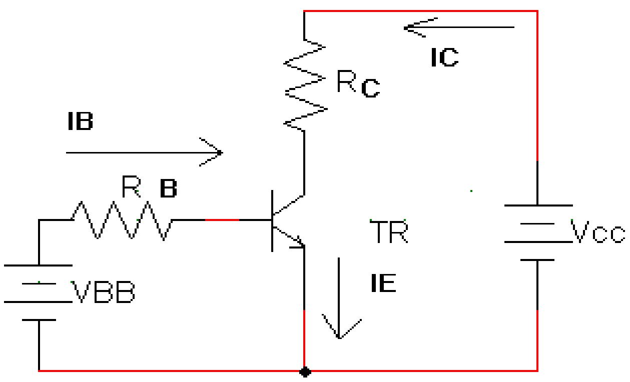


BJT (a) symbol, (b) i-v characteristics, (c) idealized characteristics

Transistor as a switch

Power transistors have controlled turn on and turn off characteristics. The transistor is operated in the saturation region, resulting in a low (in- state) voltage drop.

The switching speed of modern transistors is much higher than that of Thyristors but voltage and current rating are lower than those of Thyristors.



There are three operating regions of the transistor (cutoff, active, saturation).

In the cutoff region the transistor is off or the base current is not enough to turn it on the both junctions are reverse biased.

In the active region,the transistor acts as an amplifier .In the saturation region , the base current is sufficiently high, so that the collector – emitter voltage is low and the transistor acts as a switch.

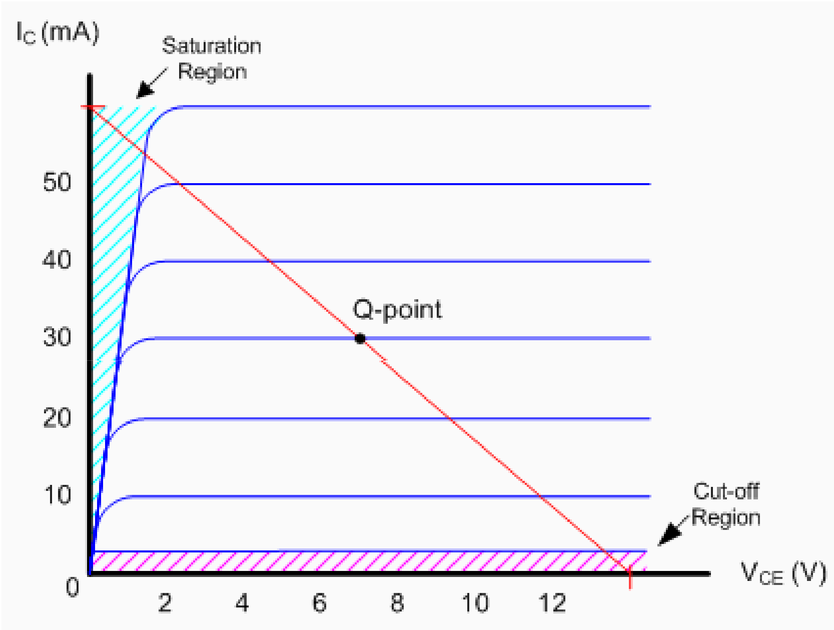


Fig 2 Characteristic curve

Transistor as switch equation:-

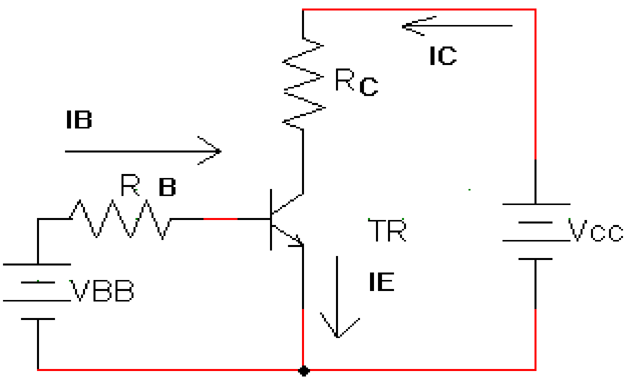
From fig (1):-

$V_{CC} = I_C \cdot R_C + V_{CE}$ ---------- (1)

$V_{BB} = I_b \cdot R_B + V_{BE}$ --------------(2)

$\beta = \frac{I_C}{I_b}$ ----------- (3)

$V_{BE} = 0.7V$



Examples

Ex1:For transistor as switch if Vcc = 10v , I_b = 10 µA , R_B= 100 kΩ , β =100 find the value of the R_C, Vin, when Vbe = 0.7 V.

Solve:-

$I_C = \beta . I_b = 100*10 * 10^{-6} = 1mA$

IF $V_{CC} = I_C R_C + V_{CE}$ IF transistor as switch V_{CE}= 0

$10 = 1 * 10^{-3} . R_C + 0$

Rc= 10 K Ω

IF $V_{BB} = I_b . R_B + V_{BE}$ V_{BB}

$Vin = 10 * 10^{-6} * 100 * 10^{3} + 0.7 = 1.7 V$

EX2: Find R_B and R_C when Vcc = 10 V , Ic = 1ma , β = 100 , Vin = 10 V

Solve:-

If $V_{CC} = I_C R_C + V_{CE}$ IF transistor as switch V_{CE}= 0

$10 = 1 * 10^{-3} * R_C + 0$

$R_C = \frac{10}{1*10^{-3}} = 10\, k\Omega$, IF $V_{BB} = Ib . R_B + V_{BE}$, V_{BB} =Vin

$IB = \frac{Ic}{I\beta}$ = 0.01 mA

$10 = 0.01 * 10^{-3} R_B + 0.7$

$R_B = \frac{10 - 0.7}{0.01*10^{-3}}$

= 93 KΩ

Conditions of transistor as switch:-

Transistor as switch (OFF)	Transistor as switch (ON)
$I_c = 0$ **$V_{ce} = V_{cc}$** **$R = \infty$**	**$I_c = \frac{V_{cc}}{R_c}$** **$V_{ce} \approx 0$** **R = low**

1- When the transistor as switch in(full driven switch) case :-

$$I_{bf} = 3\ I_b$$

Ex – Find R_B , if vcc = 12 V , β = 50 , Rc = 10 k**Ω** , vin = 2V .When the transistor as switch (full driven switch). If Vbe= 0.7 V

Solve :-

IF $V_{CC} = I_C\ R_C + V_{CE}$ IF transistor as switch $V_{CE} = 0$

$$I_c = \frac{12}{10*10^3} = 1.2\ mA$$

$$I_b = \frac{I_c}{\beta} = \frac{12*10^{-3}}{50} = 24\mu A$$

Transistor as switch full driven

Ib = 3 Ib

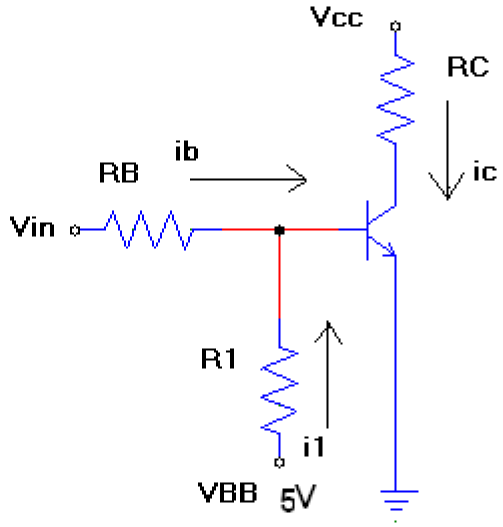
$I_b = 3 * 24 * 10^{-6}$

Ib = 72 µA

IF $V_{BB} = I_b.R_B + V_{BE}$ $V_{BB} = V_{in}$

$2 = 72*10^{-6}*R_B + 0.7$, $R_B = \frac{2-0.7}{72*10^{-6}}$ $R_B = 18.055\ K\Omega$

When the transistor as switch operate in over driven switch case :-



Ex: - In a transistor as switch circuit show in above operate in over driven switch At Vin = 1v. Find R_1 ,R_B when β=50 and Vbe = 0.65v,Rc = 500Ω ,V_{CC}=15v,V_{BB}=5V .

Solve: -

$V_{CE} = 0$

$$IC = \frac{V_{CC}}{R_C} = \frac{15}{500} = 0.003\ A = 3mA$$

$$\beta = \frac{I_C}{I_b}$$

$$Ib = \frac{I_C}{\beta} = \frac{30*10^{-3}}{50} = 600\mu A$$

Transistor as switch in over driven swatch

$I_1 = 2I_b$

$I_1 = 2(600*10^{-6}) = 1200\ \mu A = 1.2mA$

$V_{BB} = I_1 R_1 + V_{be}$

$R_1 = 3.625\ K\Omega$

$Vi\ n = I_b R_b + V_{be}$

$R_b = 583\ \Omega$

The equation above can be used to ***draw the dc load line*** *by choosing two points as follows:*

1- At cut off region :

Ic I_C *(cut off) = 0*

V_{CE} *(cut off) =*V_{CC}

2- At saturation region: V_{CE} *(sat)=0*

$$I_C(sat) = \frac{V_{CC}}{Rc}$$

$$\beta = \frac{Ic\ (sat)}{Ib\ (sat)}$$

Dynamic Switching Characteristics:

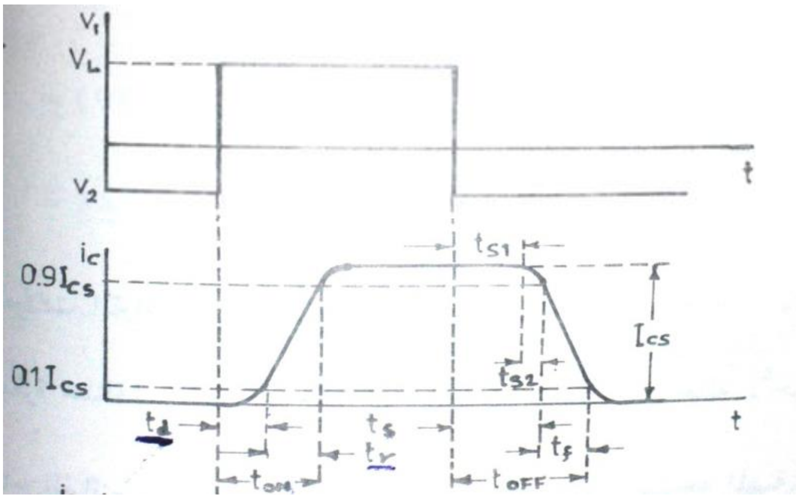
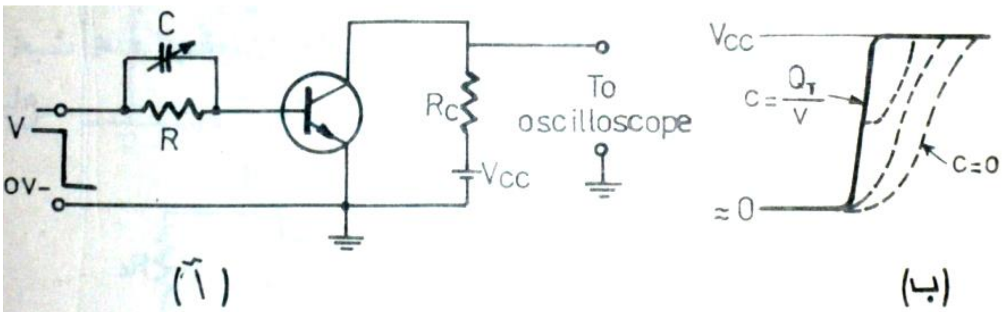


Fig. Resistive Load dynamic response

Conduction time (t on) = td + tr

Cut off time (t off): Toff = ts + tf

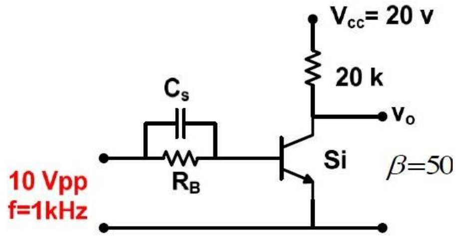
Improvement of Switching Time:



$QT = C\,V \qquad C = \frac{QT}{V}$

لكي يتم الاستجابة بسرعة لعملية تشغيل الترانزستور يجب ربط متسعة متغيرة على التوازي مع مقاومة Base للتخلص من الشحنات الفائضة التي تخزن في قاعدة الترانزستور وتسمى هذه المتسعة بمتسعة التسارع

EX :- For the cct. Shown , what are the values of R_B and C_s



Solution :- when the i/p is (high 10 v) transistor is in saturation

$I_C(sat)=V_{CC}/(R_C)=20/(20k)=1mA$

$\beta d.c = I_C / I_B$

$I_B = I_C / \beta = (1\ mA)/50 = 20\mu A$

$Vin=V_{BB}=I_B R_B - V_{BE}$, $R_B = (Vin-V_{BE})/I_B$

$= (5-0.7)/(20*10^{-6}) = 215\ K\Omega$

$Cs = \frac{tp}{5RB}$

$T = \frac{1}{f} = 1/(1*10^{-3})$

$T = 1\ msec$

$Tp = \frac{T}{2} = (1*10^{-3})/2$

$T = 0.5\ msec$

$Cs = (0.5*10^{-3})/(5*215*10^{-3}) = 0.4\ nf$

UNIJUNCTION TRANSISTOR (UJT):

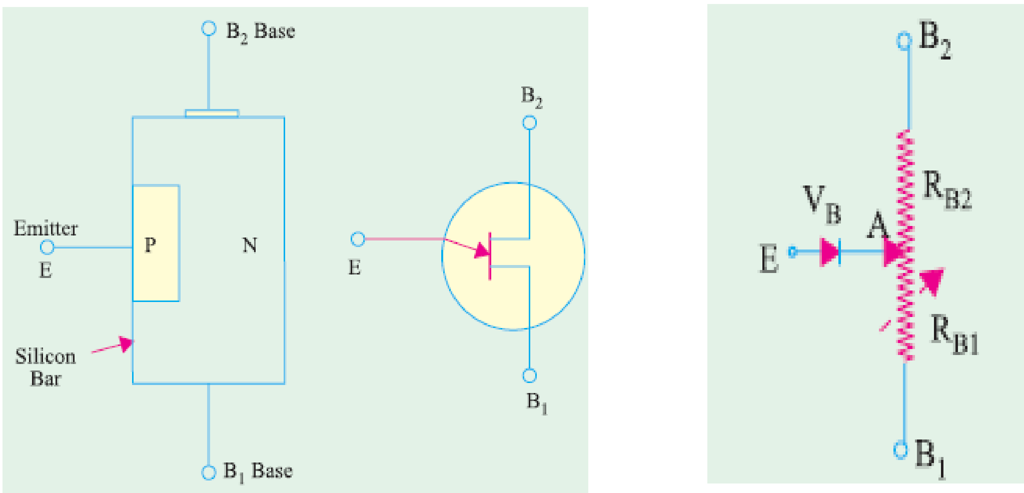


Fig 3:* *Construction. ***Symbol of UJT*** ***Equivalent** circuit.*

The UJT has been just like two resistances in series from B_1 to B_2 and a diode connected to the junction of the two resistors as shown in fig.3

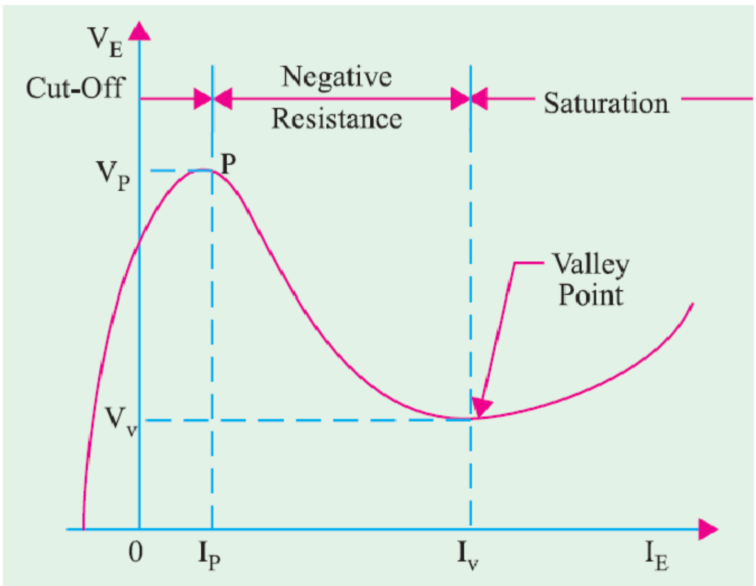


Fig 4 characteristics of UJT

In $I_E=0$ the voltage at no point is equal to ηV_{BB}, $\eta = R_{B1}/R_{BB}$

When $V_E< \eta V_{BB}$ ∴ PN is reverse biased and I_E is minus.

When $V_E > \eta V_{BB}$ ∴ PN is forward biased and I_E is placed

η = نسبة الموازنة الحقيقية يسلط جهد قاعدة ثابت VBB بين B_1 و B_2 .

When B_2 open circuit & I_{B2} =0 the relation between V_E & I_E is like the relation in PN.

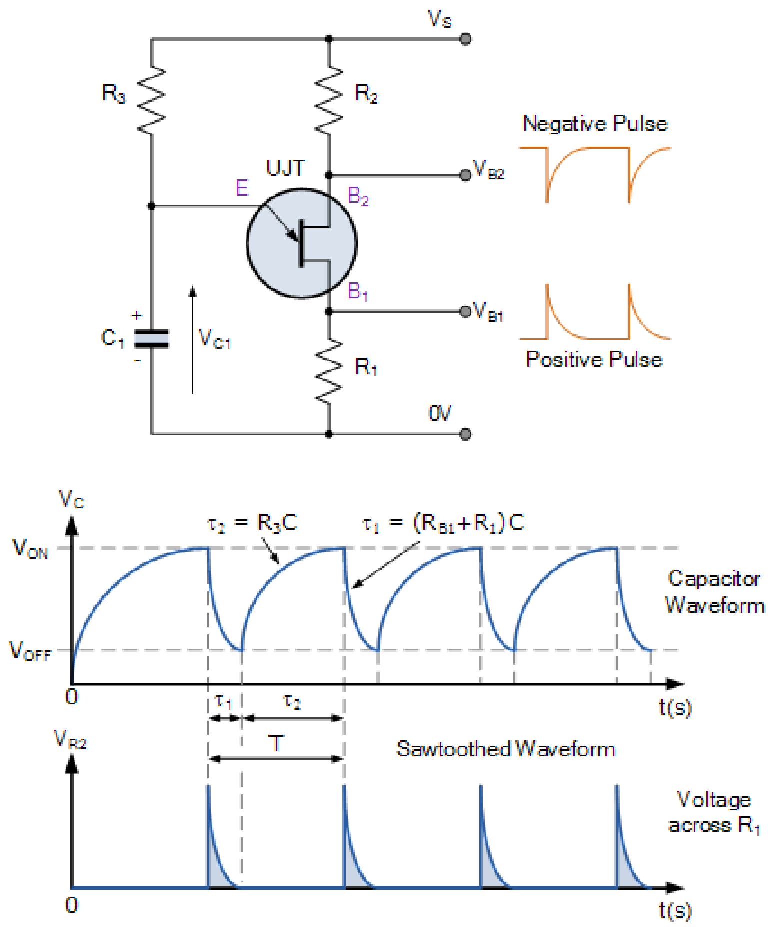
$R_{BB} = R_{B1}+R_{B2}$

$V_P= \xi V_{BB} +V_v$

.

***UJT Applications**: The UJT is often used as a trigger device for Thyristors and relaxation Triacs other applications include non-sinusoidal oscillators, oscillators (saw tooth generator), pulse control, and timing circuits*

1-Relaxation oscillator circuit.
2-A stable circuit with controllable (ON ,OFF) time.
3- Used the (UJT) in triggering circuit.
4- Phase control.
5- Switching circuit .
6- Pulse generator.
7- Sin wave generator .
8- Saw tooth generator.
9- Voltage and current regulator supplies.



Relaxation oscillator circuit (sawtooth generator)

$T_1 = RC \; Ln \frac{1}{1-\eta}$,

$\boldsymbol{\tau} = R\,C$, $f = \frac{1}{T}$

Ex: In relaxation circuit show in fig (1). find (F_{max} , F_{min} and VC) .When V_{CC} = 12 v,(ξ=0.65),Vv=0.4v and then draw the output waveform and vc.

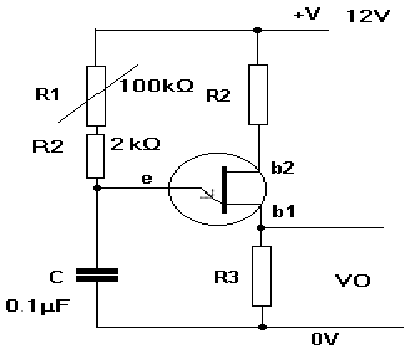


Fig (1)

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

If $R_1 = 0$

$$T_{min} = RC\,Ln\frac{1}{1-\pounds} = (R_1+R_2)*(0.1*10^{-6})Ln\frac{1}{1-\pounds}$$

$$= (0+2*10^{3})(0.1*10^{-6})\quad Ln(\frac{1}{1-0.65}) = (0.2*10^{-3})Ln\ 2.857$$

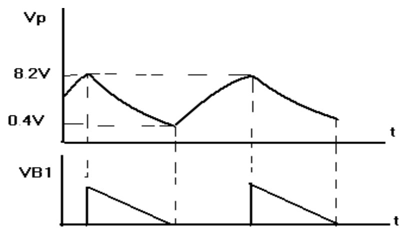
$$= 0.20\ msec$$

If R_1= 100 KΩ then $T_{max} = (R_1+R_2)*(0.1*10^{-6})\,Ln\frac{1}{1-0.65}$

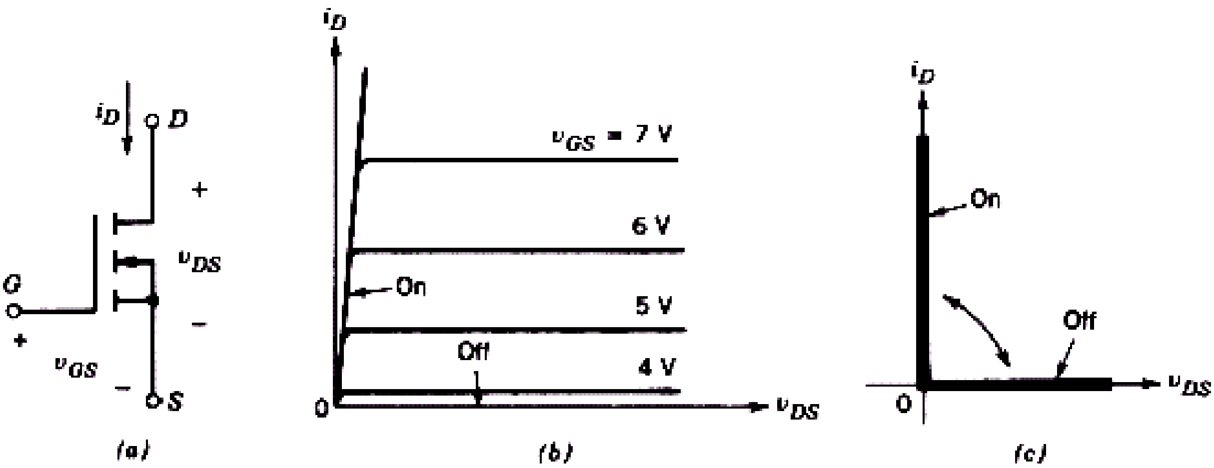
$$=(100*10^{3}+2*10^{3})(0.1*10^{-6})\,Ln\frac{1}{1-0.65} = 10.707\ m\ sec$$

$$F_{max} = \frac{1}{T\ min} = \frac{1}{0.20*10^{-3}} = 5\ KHz$$

$$F_{min} = \frac{1}{T\ max} = \frac{1}{10.707*10^{-3}} = 93\ KHz$$



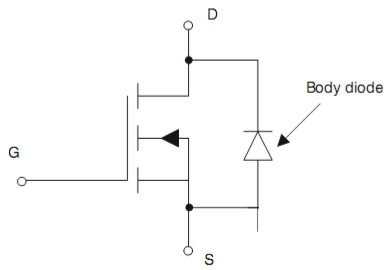
MOSFET:

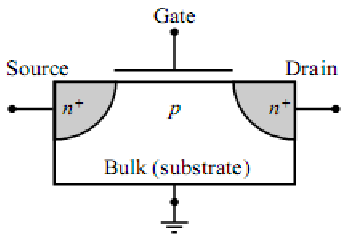


MOSFET: (a) symbol, (b) i-v characteristics, (c) idealized

Characteristics of the MOSFT:

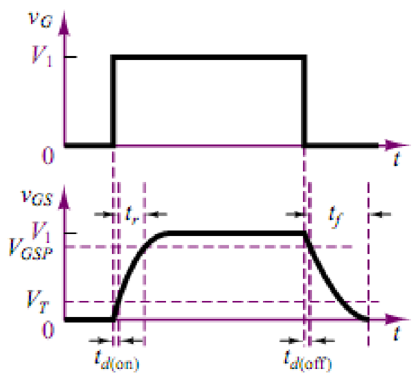
A very low value of the drain-source voltage the device has a constant resistance Characteristic but at the higher values of the drain-source voltage the current is determined by the gate.





Internal body diode *channel construction*

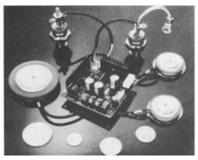
Switching time of MOSFT:



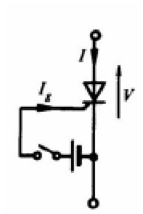
Thyristors

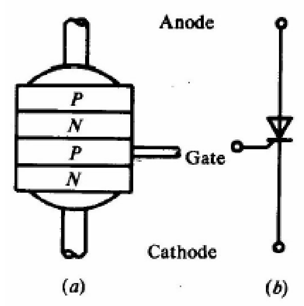
The thyristor, also called a silicon-controlled rectifier (SCR), is basically a four- layer three-junction *pnpn* device. It has three terminals: anode, cathode, and gate. The device is turned on by applying a short pulse across the gate and cathode. Once the device turns on, the gate loses its control to turn off the device. The turn-off is achieved by applying a reverse voltage across the anode and cathode. The thyristor symbol and its volt-ampere characteristics are shown in Fig. below.

1. **Forced-commutated thyristor**
2. **Line-commutated thyristor**
3. **Gate-turn-off thyristor (GTO)**
4. **Reverse-conducting thyristor (RCT)**
5. **Static induction thyristor (SITH)**
6. **Gate-assisted turn-off thyristor (GATT)**
7. **Light-activated silicon-controlled rectifier (LASCR)**
8. **MOS-controlled thyristor (MCT)**



Introduction:

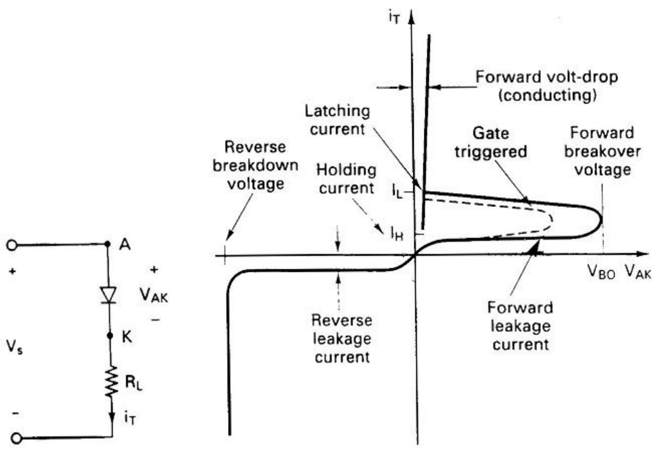




Thyristor A) Structure B) Symbol

Circuit and V & I characteristic

For $I_G = 0$



The characteristic curve of the Thyristor

Thyristors are highly rugged devices in terms of transient currents, *di/dt*, and *dv/dt* capability. The forward voltage drop in thyristors is about 1.5 to 2 V, and even at higher currents of the order of 1000 A, it seldom exceeds 3 V. While the forward voltage determines the on-state power loss of the device at any given current, the switching power loss becomes a dominating factor affecting the device junction temperature at high operating frequencies. Because of this, the maximum switching frequencies possible using thyristors are limited in comparison with other power devices considered in this section.

Thyristor Family

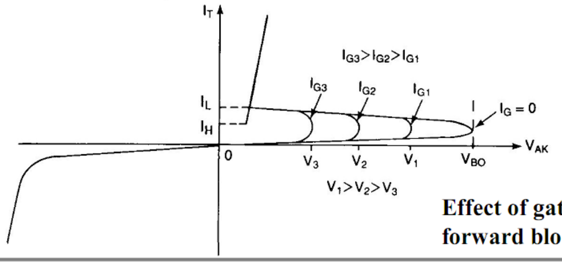
- Silicon Controlled Rectifier (SCR).
- TRIAC.
- DIAC.
- Gate Turn-Off Thyristor (GTO).

Important Symbols:

I_{GT}: Gate Current
V_{GT}: Minimum Gate Voltage
I_H: Holding Current
I_L: Latching Current
V_{BO}: Break over Voltage
V_{AK}: Anode-Cathode Voltage
I_{AK}: Anode-Cathode Curren

Thyristor Turn-On:

A thyristor is turned on by increasing the anode current.
This can be accomplished in one of the following ways.



Effect of gate current on forward blocking voltage.

Thyristor conduction methods:

With anode positive with respect to the cathode, a thyristor can be turned on by any one of the following techniques:

(a) Forward voltage triggering
(b) gate triggering
(c) dv/dt triggering
(d) Temperature triggering
(e) Light triggering

These methods of turning-on a thyristor are now discussed:

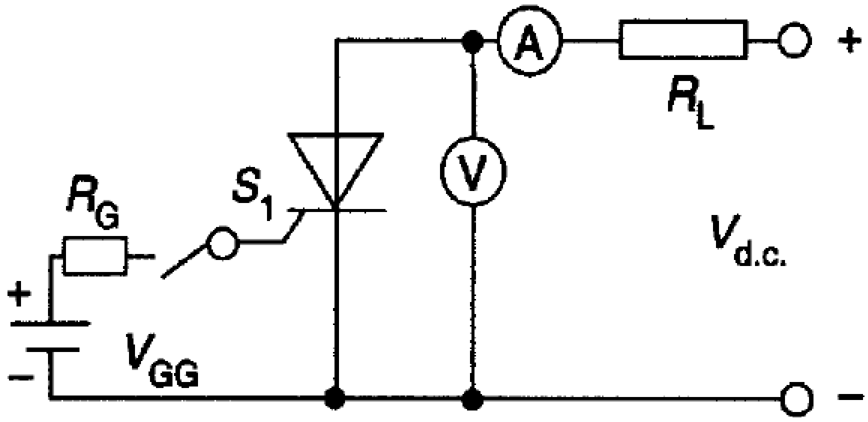
Forward Voltage Triggering:
When anode to cathode forward voltage is increased with gate circuit open, the reverse biased junction J_2 will break. This is known as avalanche breakdown and the voltage at which avalanche occurs is called forward break over voltage V_{B0}. At this voltage, thyristor changes from off-state (high voltage with low leakage current) to on-state characteristic by low voltage across thyristor with large forward current. As other junctions J_1, J_3 are already forward biased, breakdown of junction J_2 allows free movement of carriers across three junctions and as a result, large forward anode-current flows. As stated before, this forward current is limited by the load impedance. In practice, the transition from off-state to the on - state obtained by exceeding V_{B0} is never employed as it may destroy the device.

The magnitudes of forward and reverse break over voltages are nearly the same and both are temperature dependent. In practice, it is found that V_{BR} is slightly more than V_{B0}. Therefore, forward break over voltage is taken as the final voltage rating of the device during the design of SCR applications.

After the avalanche breakdown, junction J_2 loses its reverse blocking capability. Therefore, if the anode voltage is reduced below V_{B0} SCR will continue conduction of the current. The SCR can now be turned off only by reducing the anode current below a certain value called holding current (defined later).

(a) Gate Triggering:

Turning on of thyristors by gate triggering is simple, reliable and efficient, it is therefore the most usual method of firing the forward biased SCRs. A thyristor with a forward break over voltage (say 800 V) higher than the normal working voltage (say 400 V) is chosen. This means that thyristor will remain in forward blocking state with normal working voltage across anode and cathode and with gate open. However, when turn-on of a thyristor is required, a positive gate voltage between gate and cathode is applied. With gate current, thus established, charges are injected into the inner p layer and voltage at which forward break over occurs is reduced. The forward voltage at which the device switches to on-state depends upon the magnitude of gate current. Higher the gate current, lower is the forward break over voltage



When positive gate current is applied, gate P layer is flooded with electrons from the cathode. This is because the cathode N layer is heavily doped as compared to gate P layer. As the thyristor is forward biased, some of these electrons reach junction J_2. As a result, the width of the depletion layer around junction J_2 is reduced. This causes the junction J_2 to break down at an applied voltage lower than forward breakover voltage V_{B0}. If the magnitude of gate current is increased, more electrons will reach junction J_2 ,as a consequence thyristor will get turned on at a much lower forward applied voltage.

(b) dv/dt Triggering:

The rate of rise of off-state voltage (*dv* /*dt*) depends on the resistance *RGK* connected between the gate and the cathode and the reverse bias applied between the gate and the cathode.

(c) Temperature Triggering:

During forward blocking, most of the applied voltage appears across reverse biased junction J_2. This voltage across junction J_2 associated with leakage current may raise the temperature of this junction. With increase in temperature, leakage current through junction J_2 further increases. This cumulative process may turn on the SCR at some high temperature.

(d) Light Triggering:

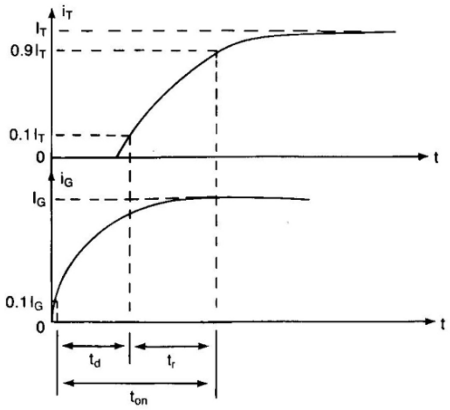
For light-triggered SCRs, a recess (or niche) is made in the inner p-layer. When this recess is irradiated, free charge carriers (holes and electrons) are generated just like when gate signal is applied between gate and cathode. The pulse of light, of appropriate wavelength is guided by optical fibres for irradiation. If the intensity of this light thrown on the recess exceeds a certain value, forward-biased SCR is turned on. Such a thyristor is known as light-activated SCR (LASCR).

LASER may be triggered with a light source or with a gate signal. Sometimes a combination of both light source and gate signal is used to trigger an SCR. For this, the gate is biased with voltage or current slightly less than that required to turn it on, now a beam of light directed at the inner p-layer junction turns on the SCR. The light intensity required to turn-on the SCR depends upon the voltage bias given to the gate. Higher the voltage (or current) bias, lower the light intensity required.

Light-triggered thyristors have now been used in high-voltage direct current (HVDC) transmission systems. In these several SCRs are connected in series-parallel combination and their light-triggering has the advantage of electrical isolation between power and control circuits.

***T*urn on Thyristor characteristics**:

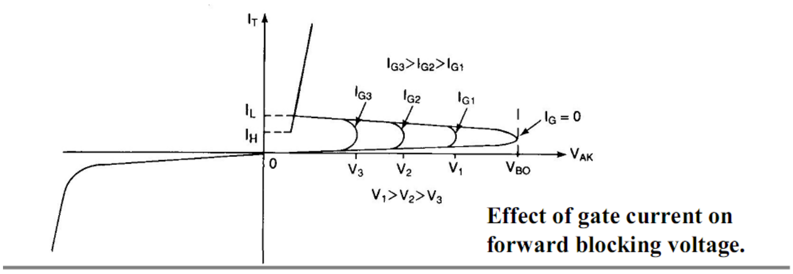
1. ***The gate signal should be removed after the thyristor is turned on. A continuous gating signal would increase the power loss in the gate junction.***
2. ***While the thyristor is reversed biased, there should be no gate signal ; otherwise, the thyristor may fail due to an increased leakage current.***
3. ***The width of gate pulse t_G must be longer than the time required for the anode current to rise to holding current value I_H. In practice,the pulse width t_G is normally made more than the turn-on time ton of the thyristor.***



Thyristor Turn-Off

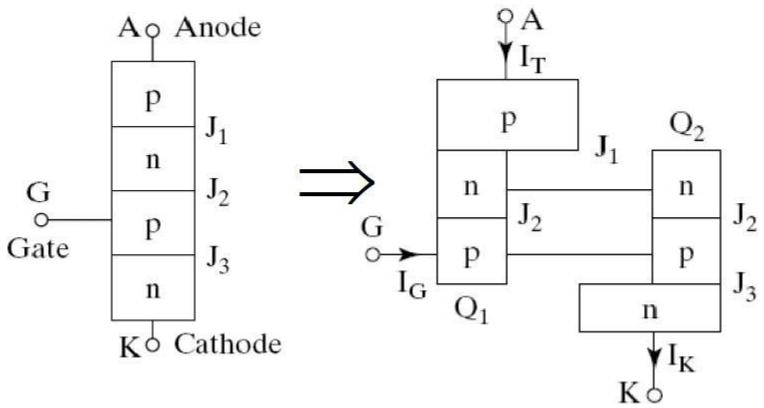
1

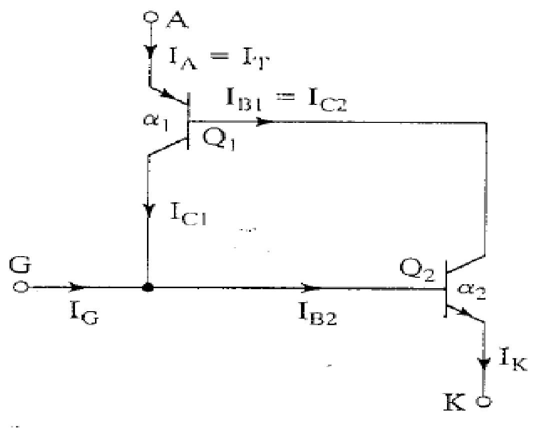
1. *A thyristor which is in the on-state can be turned off by reducing the forward current to a level below the holding current I_H.*
2. *In all the commutation techniques, the anode current is maintained below the holding current for a sufficiently long time, so that all the excess carriers in the four layers are swept*



Effect of gate current on forward blocking voltage.

Thyristor representation as a double transistor circuit





Equivalent circuit

Prove I_A

The collector current I_C of a transistor is related to the emitter current I_E and the leakage current of the collector base junction I_{CBO} as

$$I_C = \propto I_E + I_{CBO}$$

The emitter current of transistor Q_1 is the anode current I_A of the thyristor and collector current I_{C1} is given by:-

$$I_{C1} = \propto_1 I_A + I_{CBO1} \text{ ——————(1)}$$

$$I_{C2} = \propto_2 I_K + I_{CBO2} \text{ ———————(2)}$$

Combining the two collector currents I_{C1} and I_{C2} yields

$I_A = I_{C1} + I_{C2}$ −−−−−−(3) put (1) and (2) in (3)

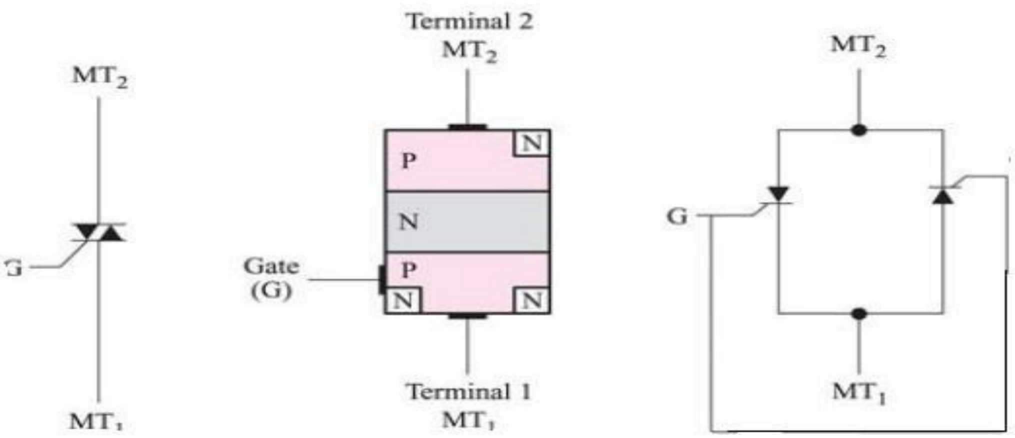
$$I_A = \propto_1 I_A + I_{CBO1} + \propto_2 I_K + I_{CBO2}$$

When a gate current I_G is applied to the thyristor

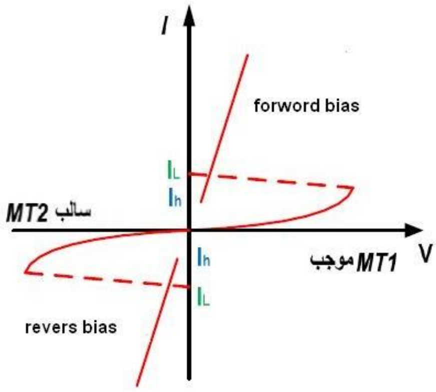
$$I_K = I_A + I_G$$

$$I_A = \frac{\propto_2 I_G + I_{CBO1} + I_{CBO2}}{1 - (\propto_1 + \propto_2)}$$

Bidirectional Triode Thyristors (TRIAC)



1- symbol of TRIAC 2-construction of TRIAC



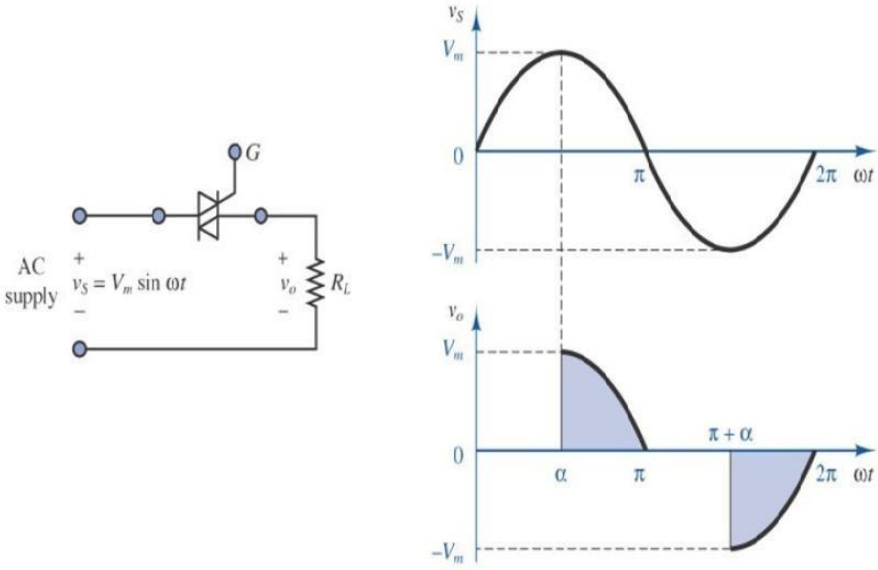
TRIAC characteristics

1. ***A TRIAC can conduct I both directions and is normally used in ac phase control (e.g., voltage controllers).***
2. ***It can be considered as two SCRs connected in antiparaller with a common gate connection.***
3. ***Since a TRIAC is a bidirectional device, its terminals cannot be designated as anode and cathode.***
4. ***If terminal MT_2 is positive with respect to terminal MT_1, the TRIAC can be turned on by applying a positive gate signal between gate G and terminal MT1.***
5. ***If terminal MT_2 is negative with respect to MT_1, it is turned on by applying negative gate signal between G and MT_1.***

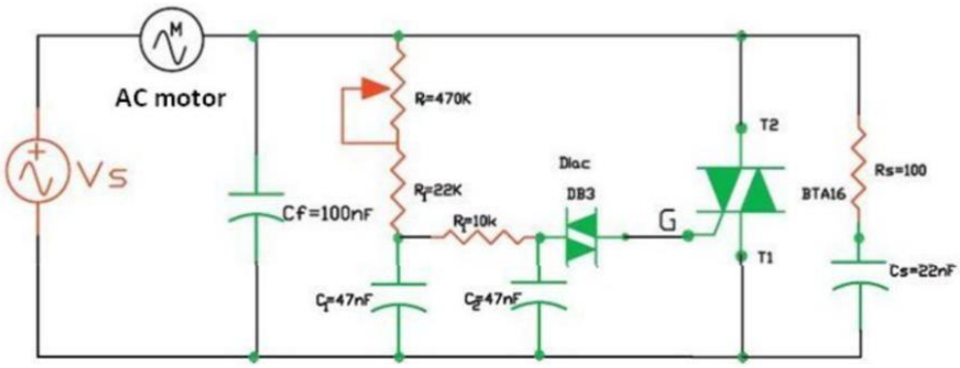
Triac applications:-

1) As a high power lamp switch.
2) Electronic changeover of transformer taps.
3) Light dimmer
4) Speed controls for electric fans and other electric motors
5) Modern computerized control circuits
6) For minimizing radio interference

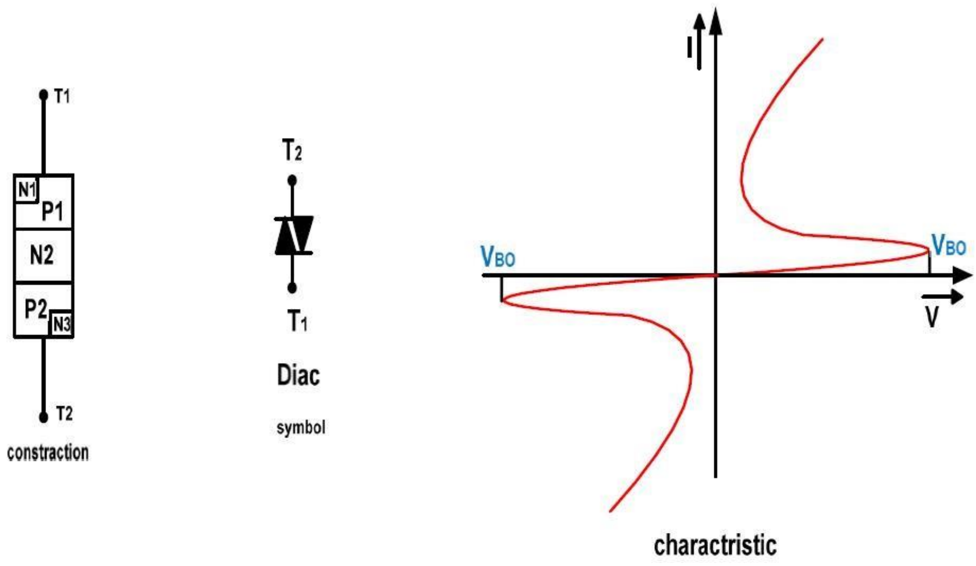
TRIAC phase control of power



Speed control of AC motor by triac



DIAC



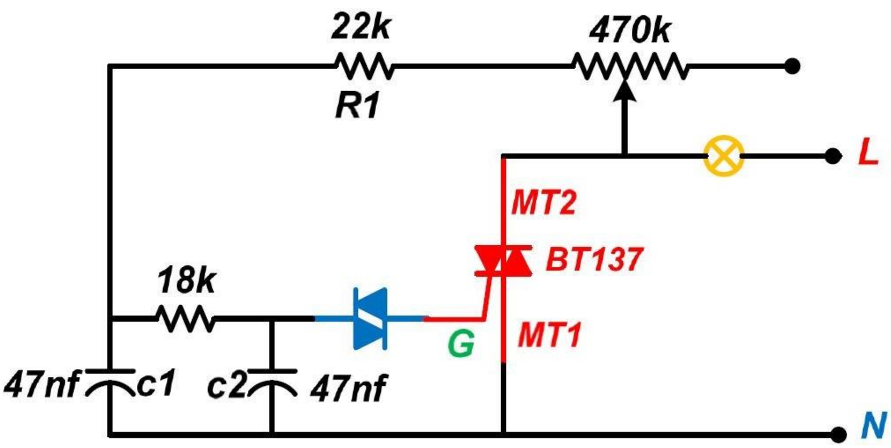
Characteristics Curve of Diac

It is a four layer device that can conduct in both directions. Conduction occurs in the diac when the break over voltage (V_{BR}) is reached with either polarity across the two terminals

DIAC applications:-

1) *Counters, register and timing circuits, computers,*
2) *Pulse generator,*
3) *Voltage sensors,*
4) *Oscillators*
5) *Proximity sensor circuit, etc.*

Light Dimer



Thyristor triggering circuits

It is very important to study the triggering circuits of the thyristor and study both DC and AC triggering circuits.

1- DC triggering circuits.
2- AC triggering circuits.
3- Pulse current triggering circuits.

DC triggering Circuits

a- Using resistance:-

1/Independent DC supply: as shown in fig 2A

2/Part of anode voltage: as shown in fig 2B

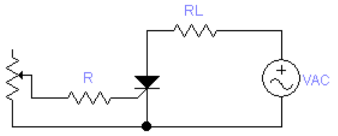


Fig2A

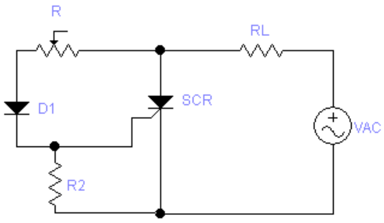


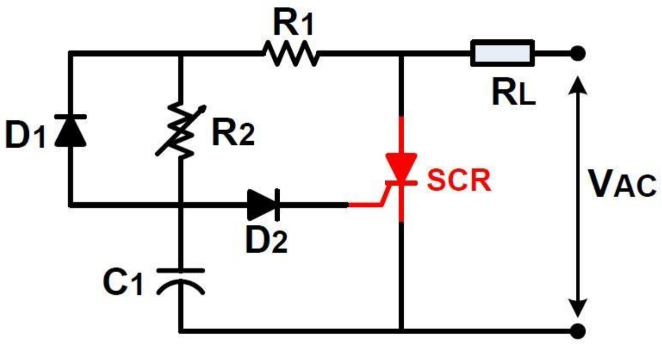
Fig 2B

A half-wave series static switch is shown in Fig.(a). A gate current will flow during the positive portion of the input signal, turning the SCR on.

- Resistor R limits the magnitude of the gate current.
- When the SCR turns on, the anode-to cathode voltage (V_{AK}) will drop to the gate circuitry.
- For the negative region of the input signal, the SCR will turn off since the anode is negative with respect to the cathode.
- The diode D_1 is included to prevent a reversal in the gat current.

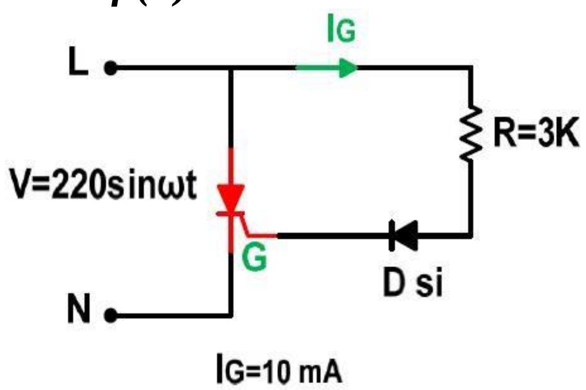
(Gate trigger between 0° and 90°)

b- Using Resistor and capacitor:-



Gate trigger between 0° and 180°

EX1:- For the cct. Shown determine the value of (α).



Solution:-

$V = I_G R + V_D + V_{GK}$

$Vm\ sin\ wt = I_G R + V_D + V_{GK} =$

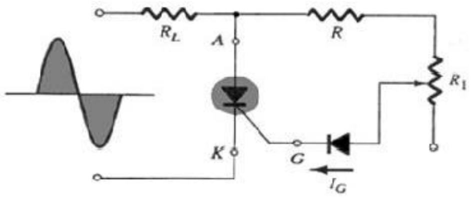
$220\sqrt[2]{2}\ sins\ wt = 10 * 10^{-3} * 3 * 10^{3} + 0.7 + 1$

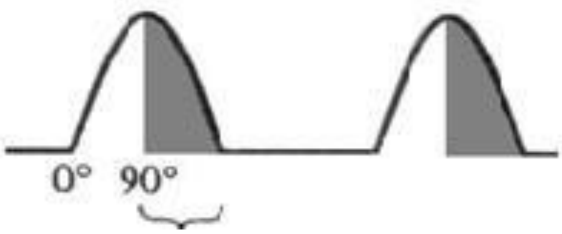
$Sin\ wt = 0.101887$

$\therefore \alpha = wt = \sin^{-1}(0.101887)$

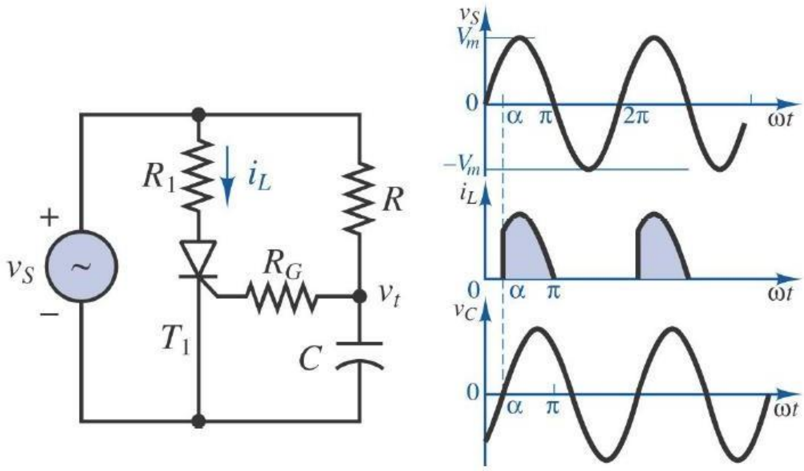
$= 5.8$

EX2 .Draw the waveform of the output voltage across RL as shown in fig. At 90 firing angle.





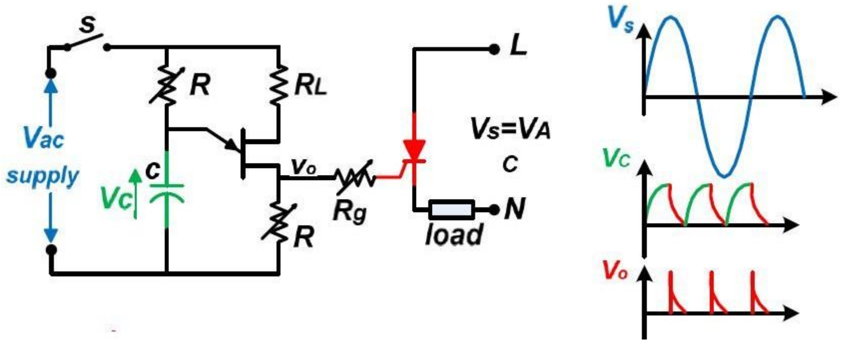
Triggering by A.C current



$\tan \theta = X_C/R$
$\theta = \tan^{-1} (X_C/R)$

Pulse current triggering circuit

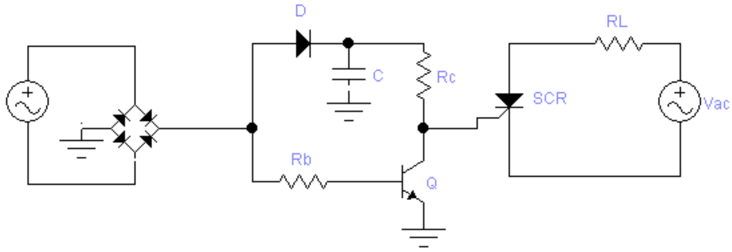
1- Relaxation oscillator



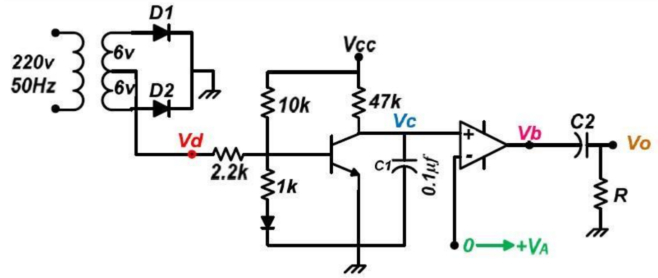
$Vo\ (firing) = \eta\ V_{BB} + V_D$

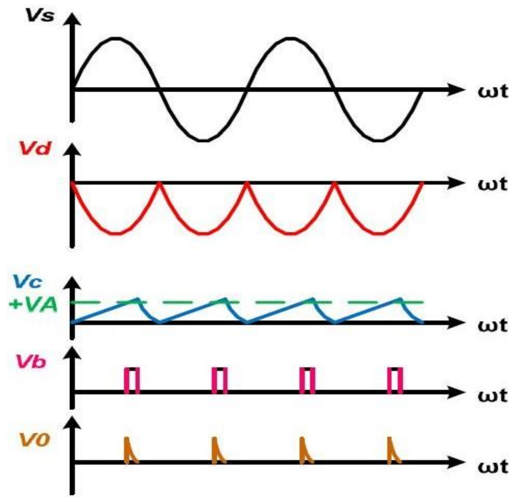
$$T = RC \ Ln \frac{1}{1 - \eta}$$

2- Zero - crossing detector

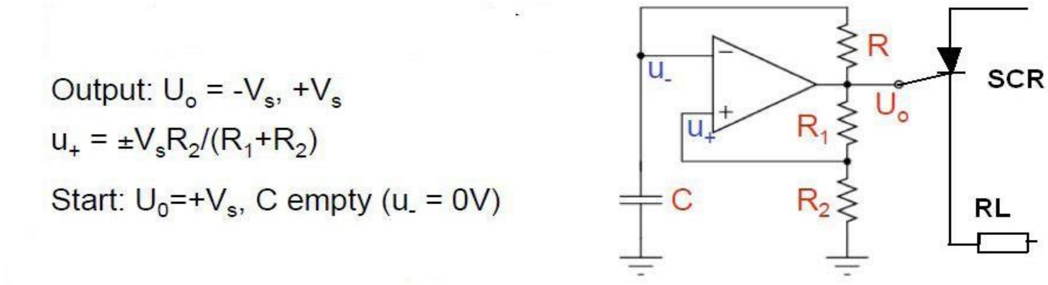


3- Comparator

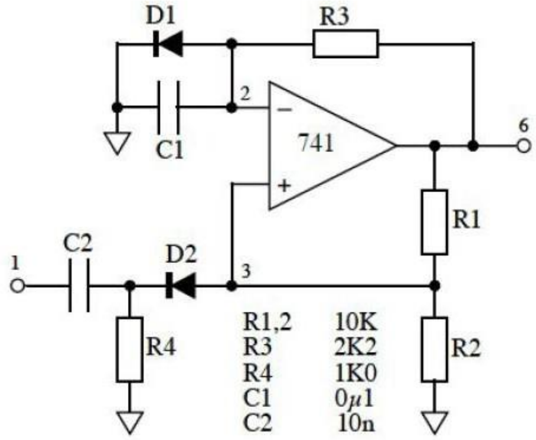




4- A stable multi vibrators with operational amplifier.

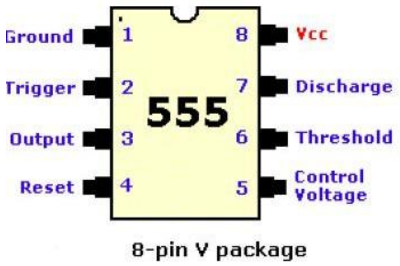


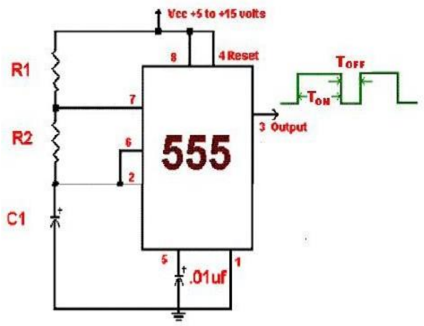
5- Monostable multi vibrators with operational amplifier.



Circuit Monostable Multivibrator

6- Timer (555)





$T_{on} = 0.693(R_1 + R_2)C_1$

$T_{off} = 0.693(R_2)C_1$

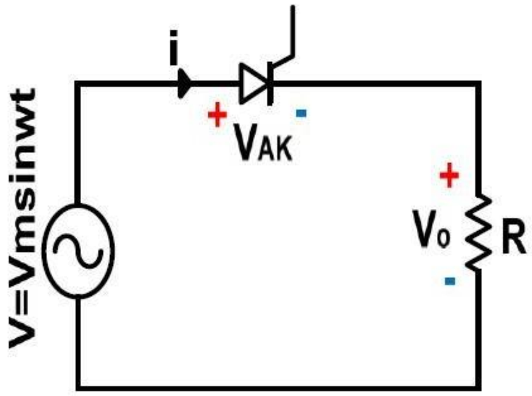
These equations determine the characteristics of your output pulses based on the values you choose for R_1, R_2 and C_1.

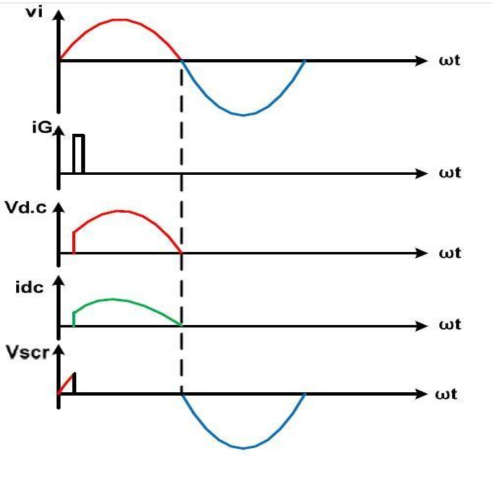
Thyristor general application

1- AC to DC (rectifier or convertor).
2- DC to AC (inverter).
3- DC to DC (chopper).
4- AC to AC (voltage controller or regulator).

Rectifier Circuits AC → DC

1-Half wave rectifier resistive load:-





Waveforms

The currents and voltages of the cct. Can be calculated:-

Let V = Vm sin wt

$$Vd.c = \frac{1}{2\pi}\int_{\alpha}^{\pi} V\, d(wt)$$

$$= \frac{1}{2\pi}\int_{\alpha}^{\pi} Vm\, sinwt\, d(wt)$$

$$= \frac{V_m}{2\pi}\left[-coswt\right]_{\alpha}^{\pi}$$

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

$$Vd.c = \frac{V_m}{2\pi}(1 + cos\alpha)$$

The voltage on the thyristor is:-

Let V = Vm sin wt

$$Vscr = \frac{1}{2\pi} \int_0^{\alpha} Vm \sin wt \, dwt$$

$$Vscr = \frac{Vm}{2\pi} \int_0^{\alpha} \sin wt \, dwt$$

$$Vscr = \frac{Vm}{2\pi} \{-\cos wt\}_0^{\alpha} = \frac{Vm}{2\pi} (-\cos\alpha + \cos o)$$

$$= \frac{Vm}{2\pi} (1 - \cos\alpha)$$

$$V\,rms = \sqrt{\frac{1}{2\pi} \int_{\alpha}^{\pi} Vm^2 \sin^2 wt \, dwt}$$

$$V\,rms = \sqrt{\frac{Vm^2}{2\pi} \int_{\alpha}^{\pi} \sin^2 wt \, dwt}$$

$$= \sqrt{\frac{Vm^2}{4\pi} \int_{\alpha}^{\pi} (1 - \cos 2wt) \, dwt}$$

$$= \frac{Vm}{2} \sqrt{\frac{1}{\pi} (\pi - \alpha + \frac{\sin 2\alpha}{2} - \frac{\sin 2\pi}{2})}$$

$$V\,rms = Vo(rms) = \frac{Vm}{2} \sqrt{\frac{1}{\pi} (\pi - \alpha + \frac{\sin 2\alpha}{2})}$$

$$I(rms) = \frac{Vo(rms)}{RL} \text{ Amp}$$

$$Po(rms) = \frac{[Vo(rms)]^2}{RL} \; watt$$

$$Pin = \frac{VmIo(rms)}{\sqrt{2}} \; watt$$

$$P.F = \frac{Po(rms)}{Pin}$$

EX :- *A heater of 10 Ω resistance (constant with temperature if it is used with a half wave rectifier, the input voltage source is (V = 240v) calculate at (α = π/3).*

1- *Vd.c of the heater.*
2- *The power of the load.*
3- *The power factor.*
4- *The voltage across the thyristor (SCR).*
5- *Draw the wave forms.*

Solution: -

$$Vd.c = \frac{V_m}{2\pi}(1 + \cos\alpha)$$

$$Vdc = \frac{\sqrt{2}\times 240}{2\pi}(1 + \cos 60) = 81\ volt$$

$$Vo(rms) = \frac{Vm}{2}\sqrt{\frac{1}{\pi}(\pi - \alpha + \frac{\sin 2\alpha}{2})}$$

$$Vo(rms) = \frac{\sqrt{2}\times 240}{2}\sqrt{\frac{1}{3.14}\left(3.14 - \frac{3.14}{3} + \frac{\sin 2\times 60}{2}\right)} = 152\ volt$$

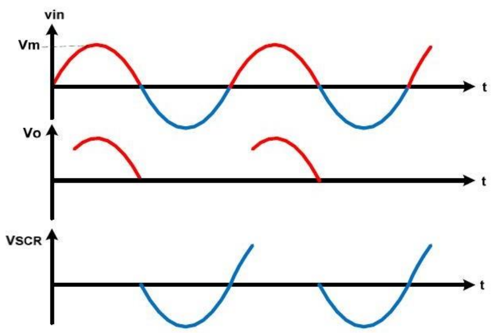
$$Io(rms) = \frac{152}{10} = 15.2\ A$$

$$Po(rms) = \frac{152^2}{10} = 2.31\ Kwatt$$

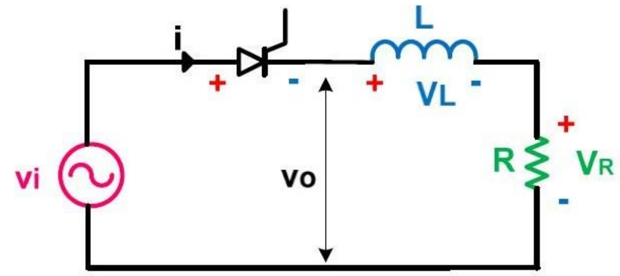
$$Pin = vin \times Io(rms) = \frac{Vm}{\sqrt{2}} \times 15.2 = \frac{240}{\sqrt{2}} \times 15.2 = 3.648\ Kwatt$$

$$Power\ factor(P.F) = \frac{Po(rms)}{Pin} = \frac{2.31}{3.648} = 0.633$$

$$Vscr = \frac{Vm}{2\pi}(1 - \cos\alpha) = \frac{240\times\sqrt{2}}{2\pi}(1 - \cos 60) = 27\ volt$$

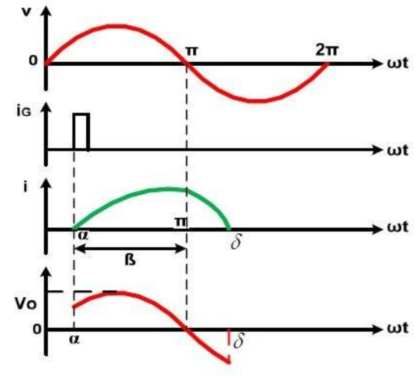


2- Half wave Rectifier with inductive load:-



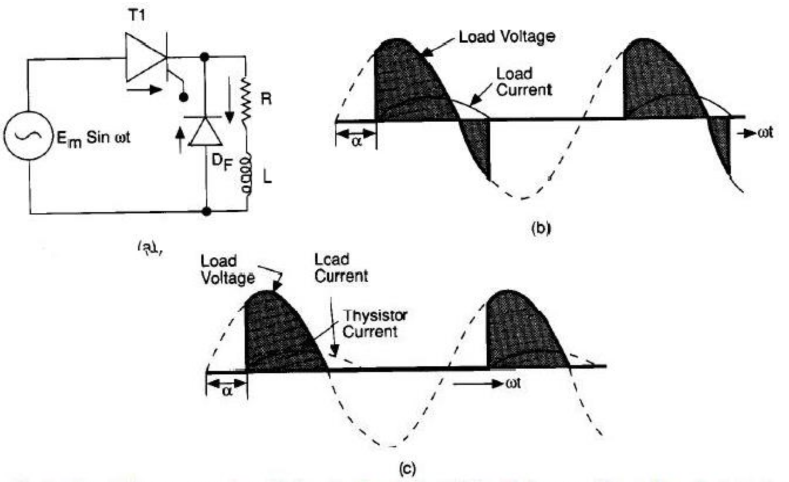
$$V = V_R + V_L$$

The wave forms of a half wave rectifier with inductive load



The waveforms of ahalf wave
rectifier with inductive load

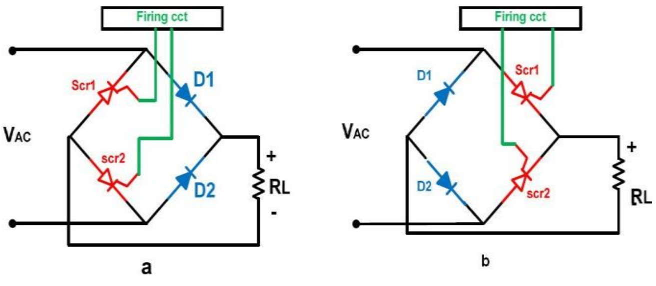
***Free-Wheeling diode:-** It is used to release the energy stored in the inductive (L) after turning off the(SCR) . Its connected in parallel with the load. inverse with the power supply and forward with the stored energy in (L).*

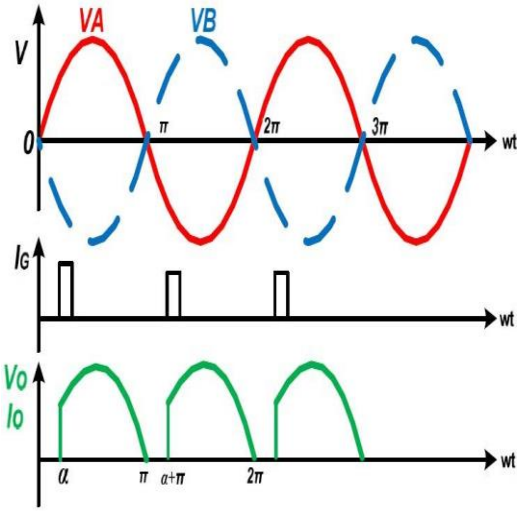


Single-phase half-wave converter with freewheeling diode. (a) Circuit diagram; (b) waveform for inductive load with no freewheeling diode; (c) waveform with freewheeling diode.

Full Wave Rectifier

1- Half controlled full wave rectifier with –R





$$Vd.c = Vo = \frac{1}{\pi}\int_{\alpha}^{\pi} V\, d\,(wt)$$

$$\because V = Vm\, sinwt \quad \therefore Vd.c = \frac{1}{\pi}\int_{\alpha}^{\pi} Vm\, sinwt\, d\,(wt)$$

$$Vd.c = \frac{Vm}{\pi}\,(1 + \cos\alpha)$$

$$Id.c = IO = \frac{V_{d.c}}{R_L}$$

$$Vo\,(r.m.s) = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} V^2\, d\,(wt)} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} Vm^2\, sinwt^2\, d\,(wt)}$$

$$\because sin2wt = \frac{1}{2}\,(1 - cos2wt)$$

$$\therefore Vo\,(r.m.s) = \frac{Vm}{\sqrt{2}}\sqrt{\frac{\pi - \alpha + \frac{1}{2}\sin 2\alpha}{\pi}}$$

$$Io\,(r.m.s) = \frac{Vo\,(r.m.s)}{R_L} \quad \& \quad Po\,(r.m.s) = \frac{V^2\,(r.m.s)}{R_L}$$

$$P.F = \frac{Po\,(r.m.s)}{Pin\,(VA)}$$

EX :- A resistive load of (R =30 Ω) feeding from a half controlled full wave rectifier , calculate Vo(r.m.s) , Io (r.m.s) , at α = 30 if Vin = 230 volt , Pin , Po , P.F

Solution :-

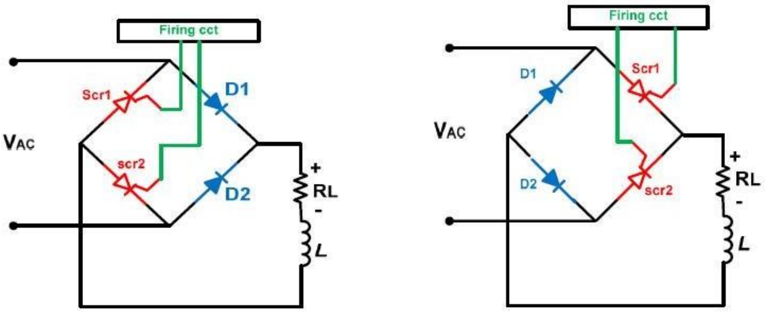
$$Vo\,(r.m.s) = \frac{Vm}{\sqrt{2}}\sqrt{\frac{\pi-\alpha+\frac{1}{2}\sin 2\alpha}{\pi}} = \frac{\sqrt{2}*230}{\sqrt{2}}\sqrt{\frac{\pi-\frac{\pi}{6}+\frac{1}{2}\sin(\frac{\pi}{3})}{\pi}}$$

$$= 226.6\ v$$

$$Io\ (r.m.s) = \frac{Vo\,(r.m.s)}{R_L} = \frac{226.66}{30}$$

$$= 7.55\ Amp$$

2- Half controlled full wave rectifier with(R+ l):-



a b

$$Vd.c = Vo = \frac{1}{\pi}\int_{\alpha}^{\partial} V\, d(wt) \quad ,V = Vm\, sinwt \quad ,\partial = \pi + \alpha$$

$$\therefore Vd.c = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} Vm\, sinwt\, d(wt)$$

$$= \frac{Vm}{\pi}\left[-\cos\alpha\right]_{\alpha}^{\pi+\alpha}$$

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

$V_{d.c}$ = Vm/π [cos α - cosπ cosα + sinα sin π]
= Vm/π [cos α + cos α]

Vd.c = 2Vm/π cos α

EX **:If the** ***winding of a DC motor is supplied from a half wave full controlled rectifier .the inductance of the winding is (L=0.14 H) and (R=100Ω) if the current of the winding is (I=1.8 A) calculate the firing angle (α) if Vin = 230 v and draw the waveforms.***

Solution : -

Vf = If Rf , ***Vd.c =*** $\frac{2Vm}{g}$ cos ∝ , ***Cosα = =*** $\frac{565.5}{622.25}$ ***= 0.9087*** , ***α = cos-1 0.9087***

α = 24.6 ***the time constant*** , ***τ =*** $\frac{L}{R} = \frac{0.14}{100}$ ***= = 14msec 1***