وزارة التعليم العالي والبحث العلمي
جامعة الفرات الاوسط التقنية
المعهد التقني النجف

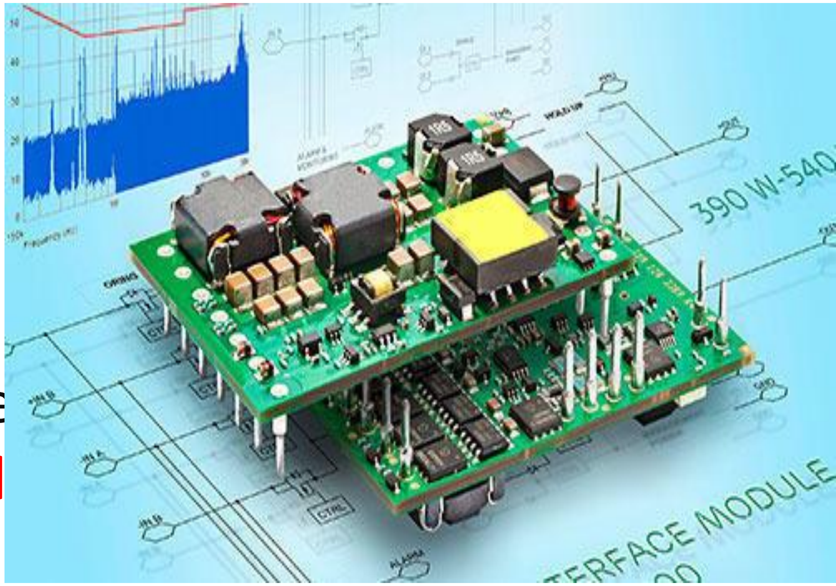
Power Electronic

م.م. صادق عبد الله شعبان محمد

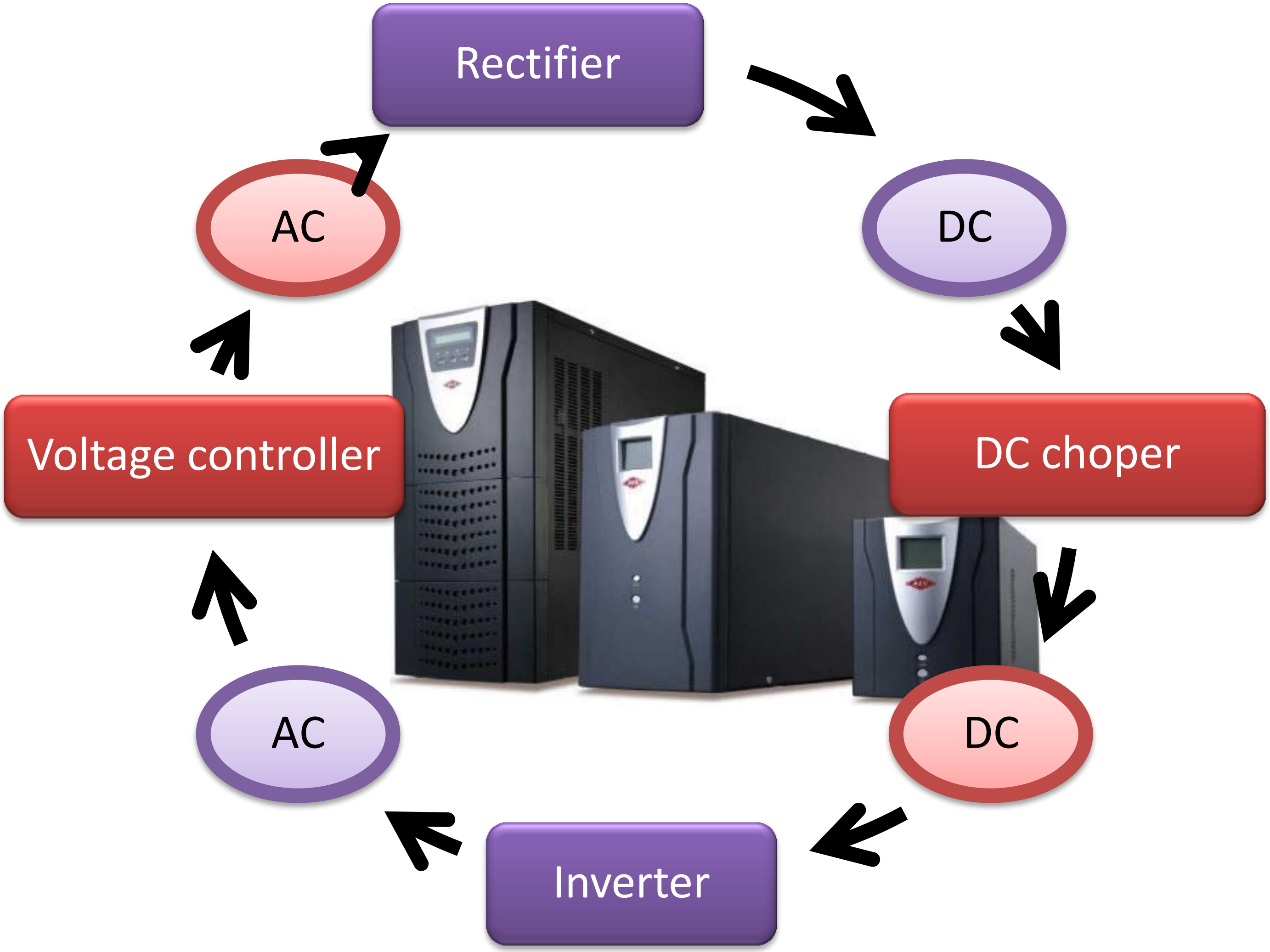
Power : deals with static or rotating **power equipments** for generation, transmision or distribution of electric power.

Electronic : it deals with solid state **semiconductors power devices** & circuit for **power conversion** to meet the desired control objectives.

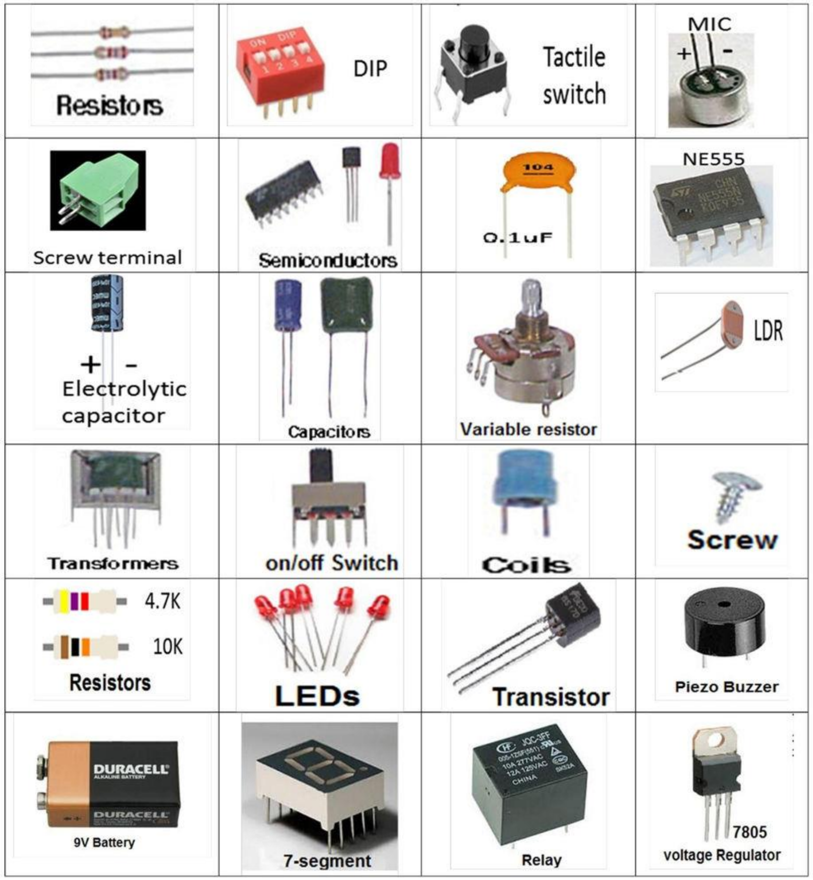
Power electronic : is the field of e combines between **power** and **el**

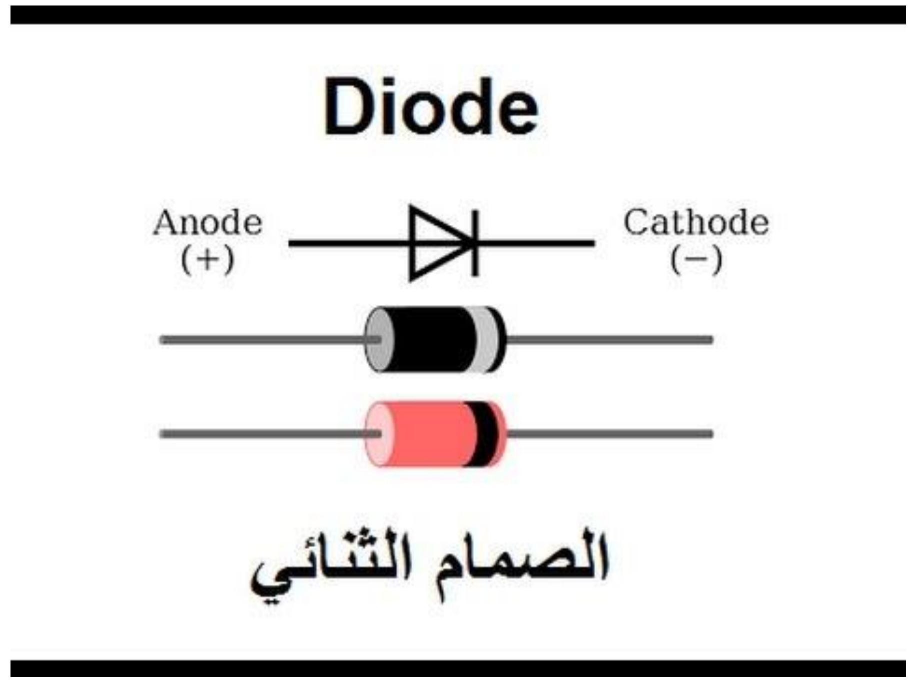


Power electronic functions



Powerdiode

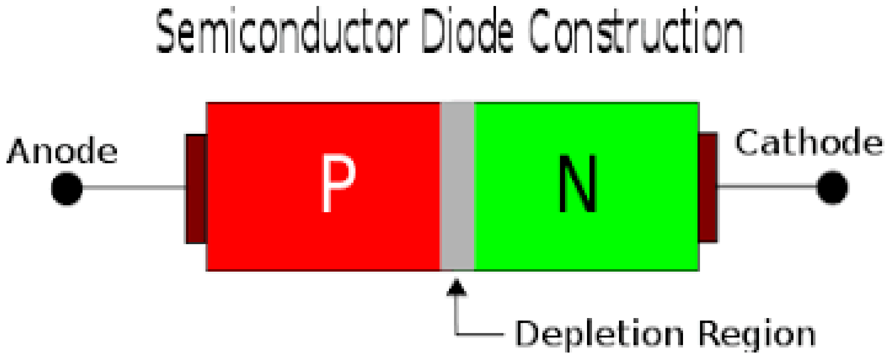


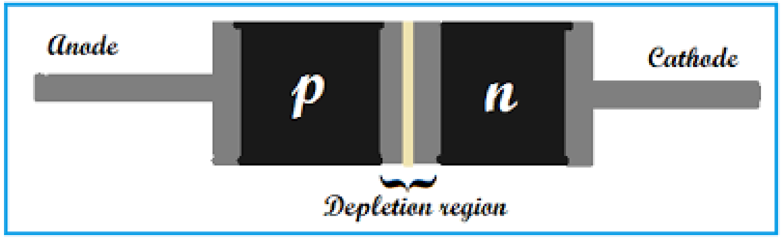


_ The current will pass through the circuit when diode will be forward bias.

_ Diode will work as opened switch when it will be reverse bias.

Diode’s construction

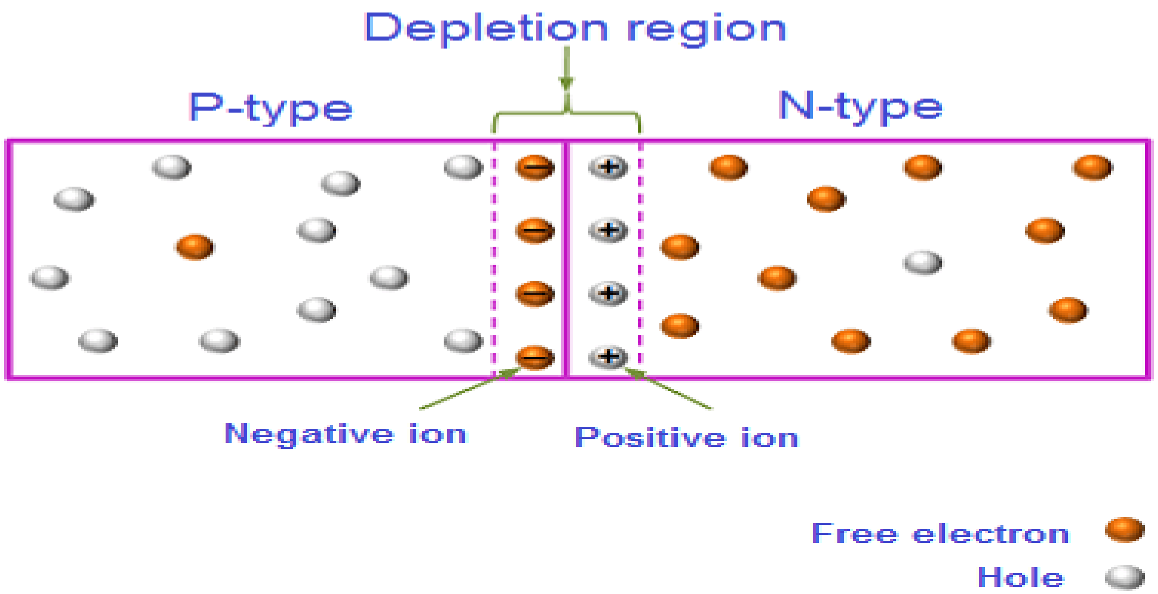




- Diode is an electronic device which contain two parts called **anode & cathode** are joined together.

- Depletion layer is the region where the **electrons** and **holes** are meeting.

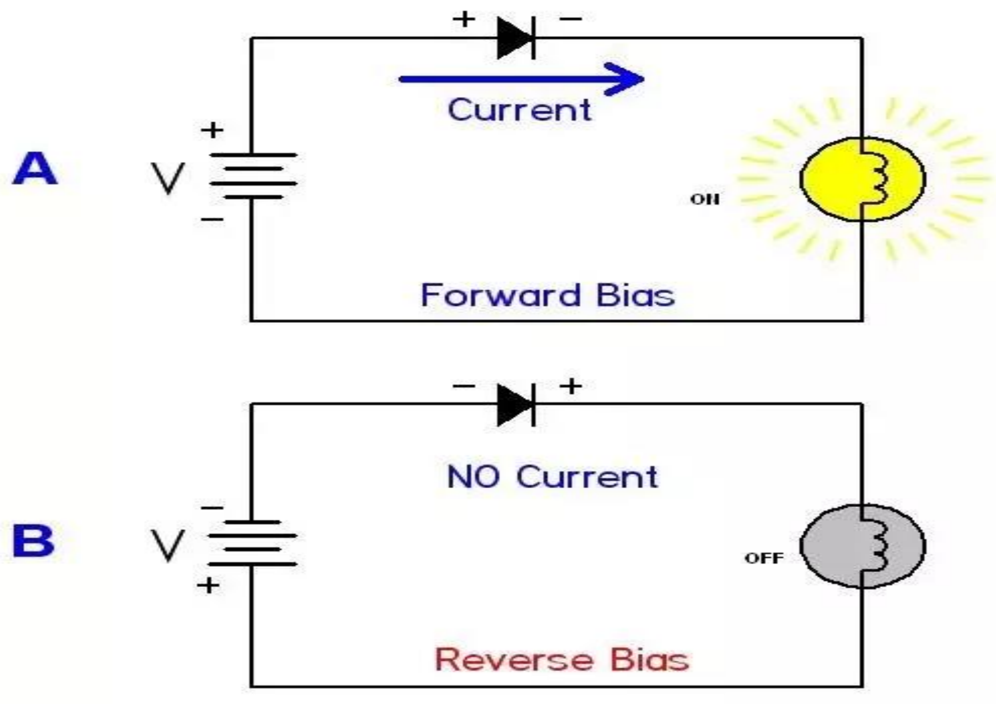
- The conduction principle is depending on the bias of the device which will move the electrons & holes together to the depletion region or move away from that region.



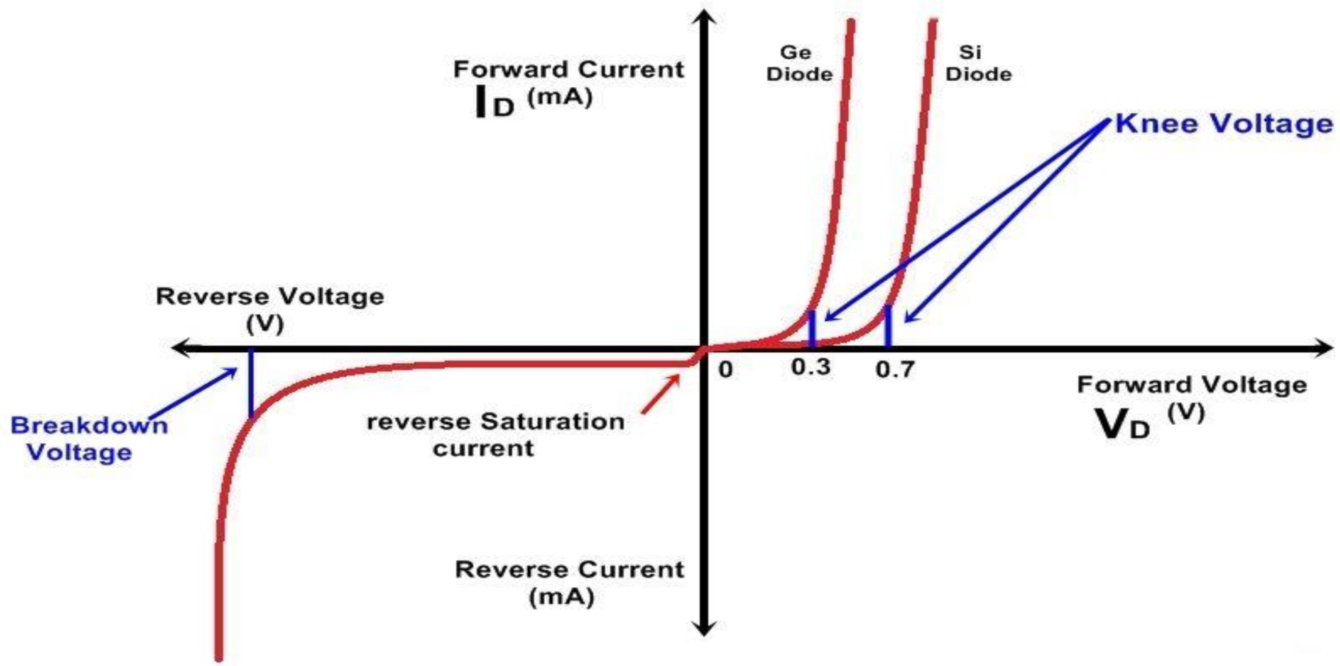
Forward & Reverse bias

- **(A)** The bulb will be **ON** when the device in forward state which means the current will pass through the switch.

- **(B)** Where the bulb will be **OFF** when the device in reverse bias which means the circuit will be open and there is no current wil pass through it.



V-I diode’s characterstic



P-N Junction Diode V-I Characteristics

The specifications of the diode

- Thermal reliability
- High peak inverse voltage
- Low reverse current
- Low forward voltage drop
- High efficiency
- compactness

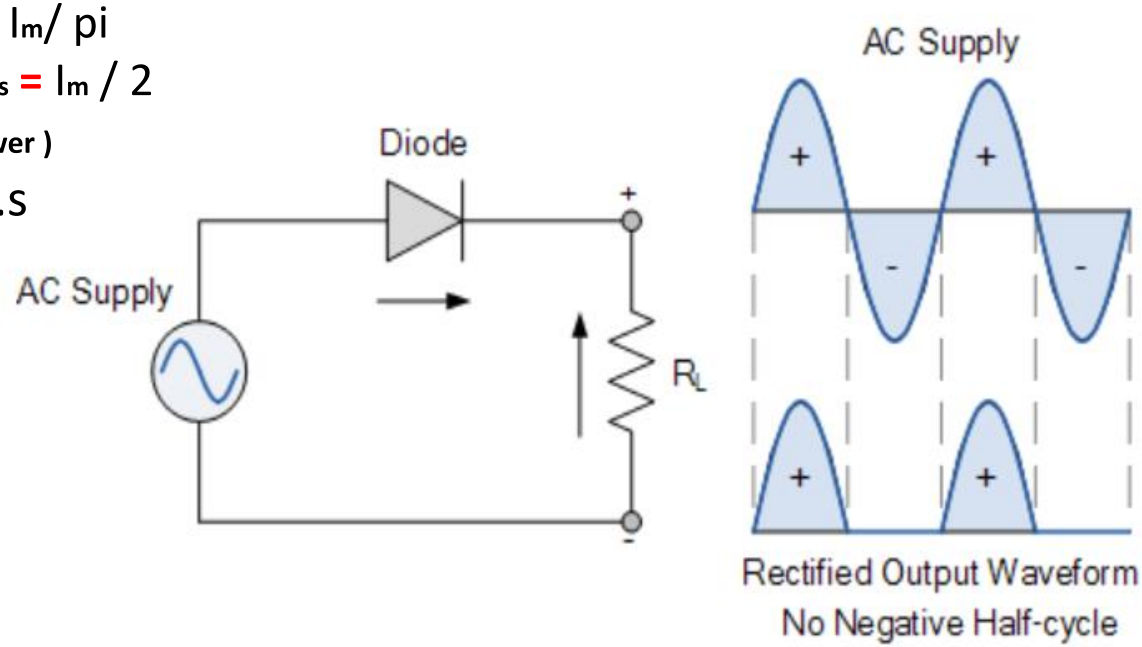
Half wave rectifier

V_{dc} = V_m/ pi , I_{dc} = I_m/ pi

$V_{r.m.s}$ = V_m/ 2 , $I_{r.m.s}$ = I_m / 2

P_{dc} = V_{dc} * I_{dc} (DC Power)

Ptotal = Vr.m.s * Ir.m.s



The main purpose of this circuit is to provide DC current from AC power source.

D.C, R.M.S values & efficiency

Ptotal = $V_{r.m.s} * I_{r.m.s}$

η = P_{dc} / P_{ac} **(Efficiency)**

η = $(Idc)^2 / (Ir.m.s)^2 = 4/(pi)^2 = 0.4$

FF = $V_{r.m.s} / V_{dc}$ **(Form factor)**

RF = V_{ac} / V_{dc} **(Ripple factor)**

H.W.R with capcitive filter

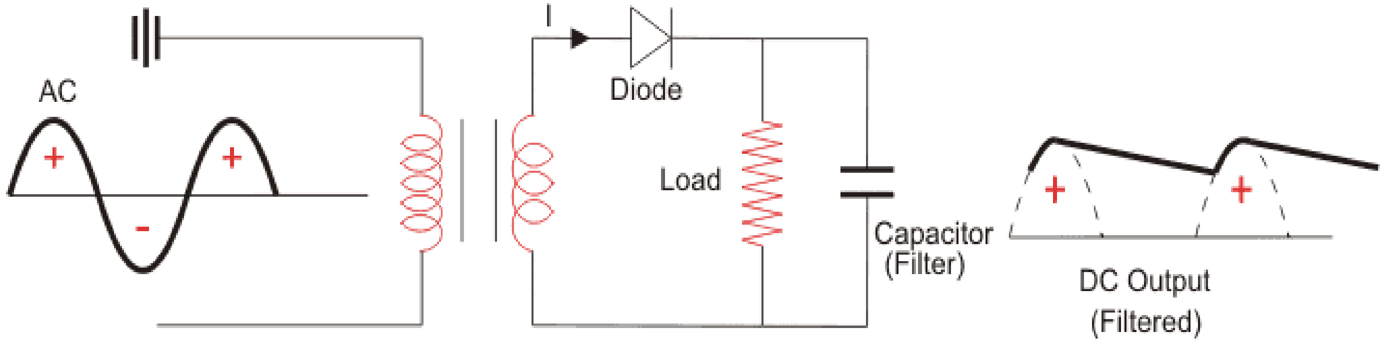


Figure - 6

The capacitor effect (chargin & discharging effect) will make the output of the circuit smother by decreasing the ripple of the output wave.

Advantages of half wave rectifier:

1. Simple construction
2. Low cost
3. Easy Mathmatical analysis

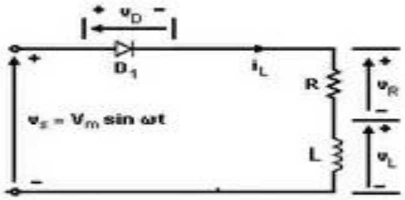
Disadvantages:

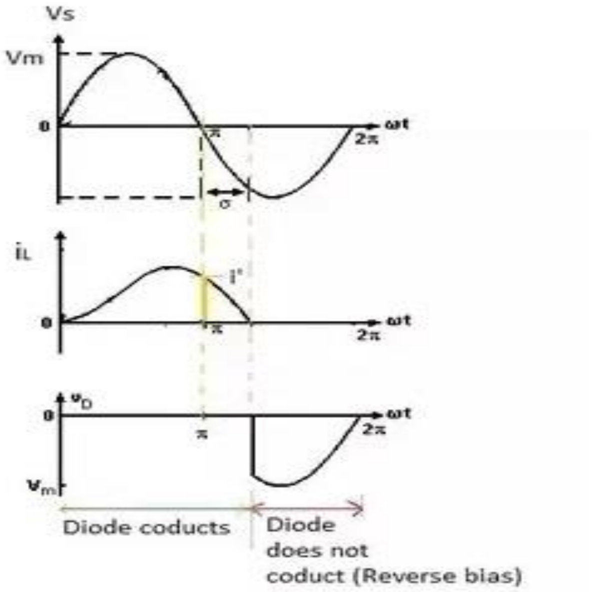
1. High ripple factor
2. Low rectification efficiency

Lecture no. 2

Ass. teacher Sadeq Abdullah

Single *phase (H.W.R) with inductive load*





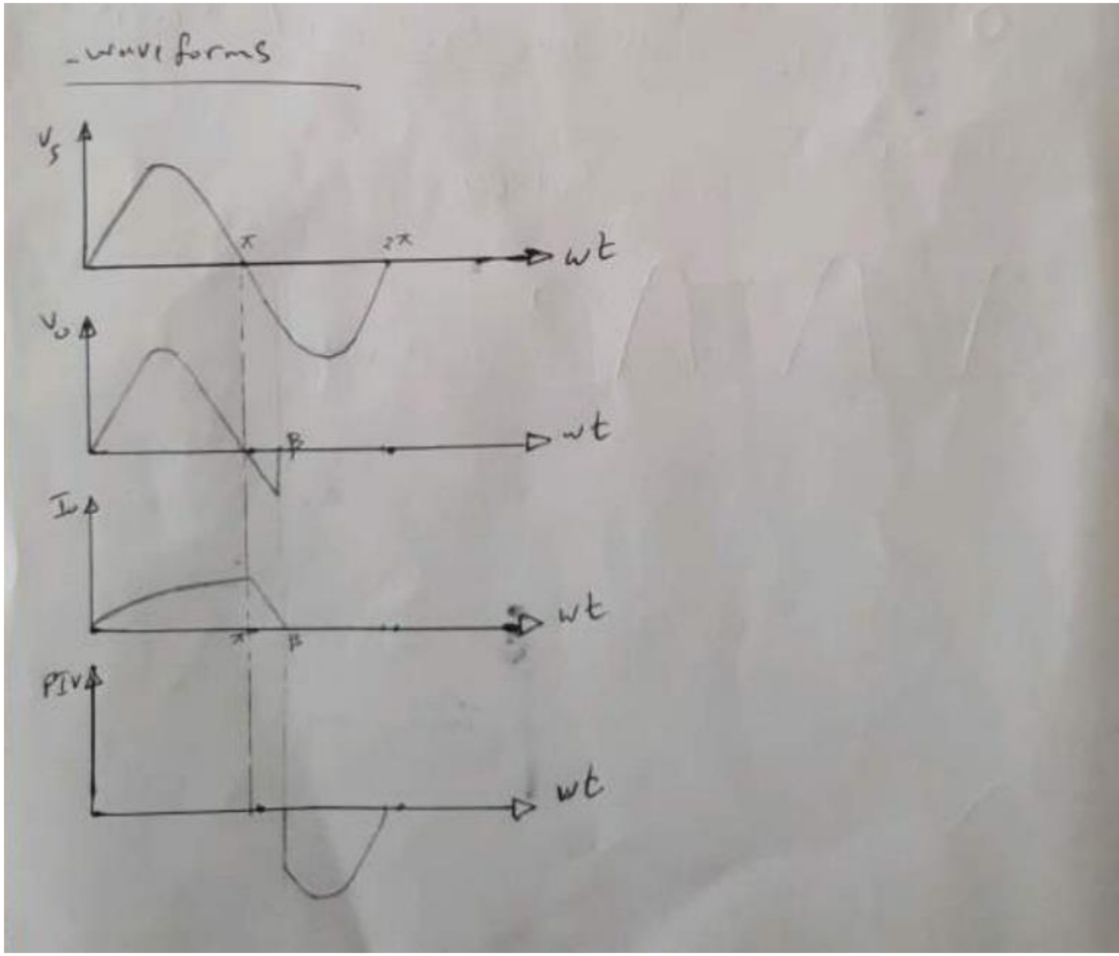
Because of the effect of the inductance the conduction period will continue up to complete discharge of the inductance .

Wave forms

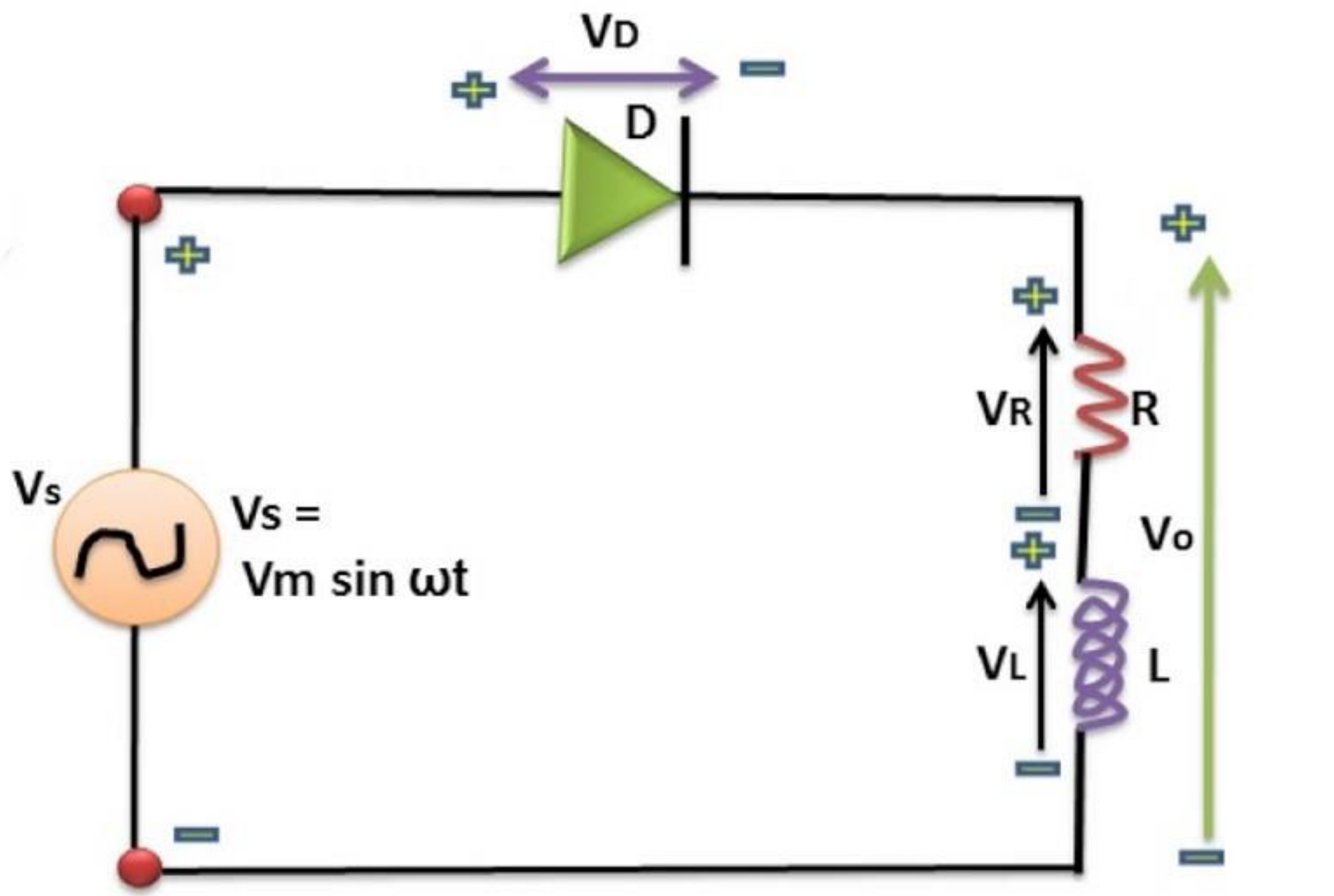
β : it is the angle where the iductance completely discharged .

It can be noticed that the current will Continue pass through the circuit up to this angle.

Peak inverse voltage (PIV) it is clearly Start from this angle up to 2π.



Voltage of the source and voltage on the resistance terminal



Voltage and current calculation

DC, RMS voltages & currents Can be calculated as shown below.

$$V_{dc} = \frac{V_m}{2\pi}\int_0^{\beta} \sin\omega t \; d\omega t$$

$$= \frac{V_m}{2\pi}(1-\cos\beta)$$

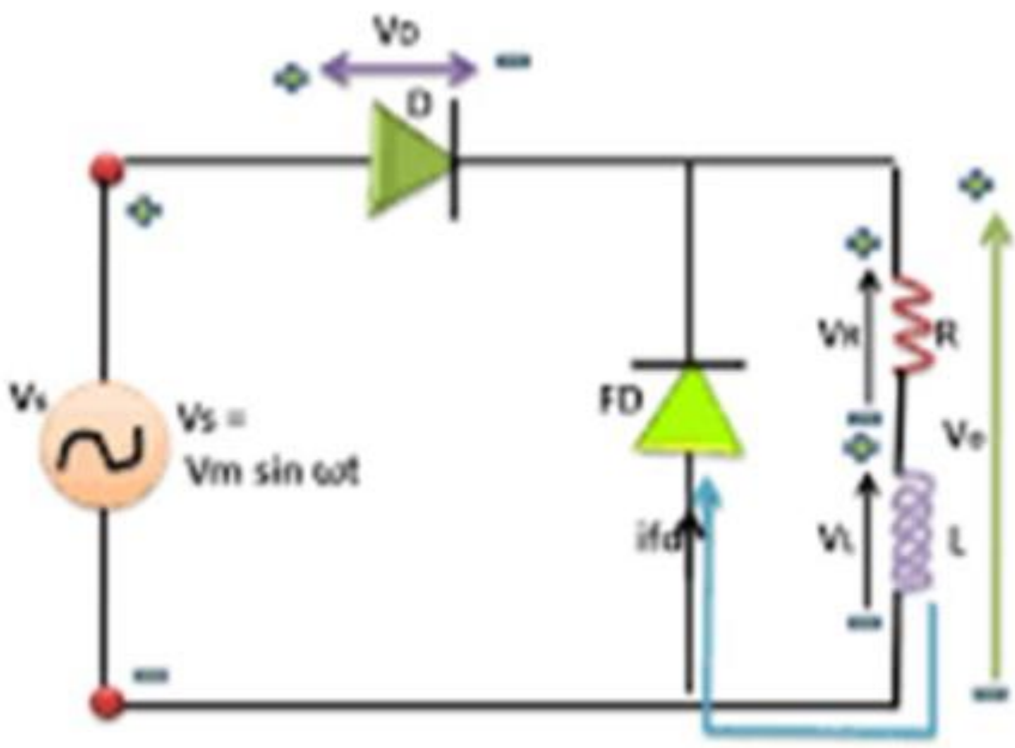
$$V_{r.m.s} = \sqrt{\frac{1}{2\pi}\int_0^{\beta} (V_m \sin\omega t)^2 \, d\omega t}$$

$$= \frac{V_m}{2\sqrt{\pi}}\sqrt{\beta + 0.5(1-\sin(2\beta)}$$

$$I_{dc} = \frac{V_{dc}}{R} = \frac{V_m}{2\pi R}(1-\cos\beta)$$

Single phase H.W.R inductive load with free wheeling diode

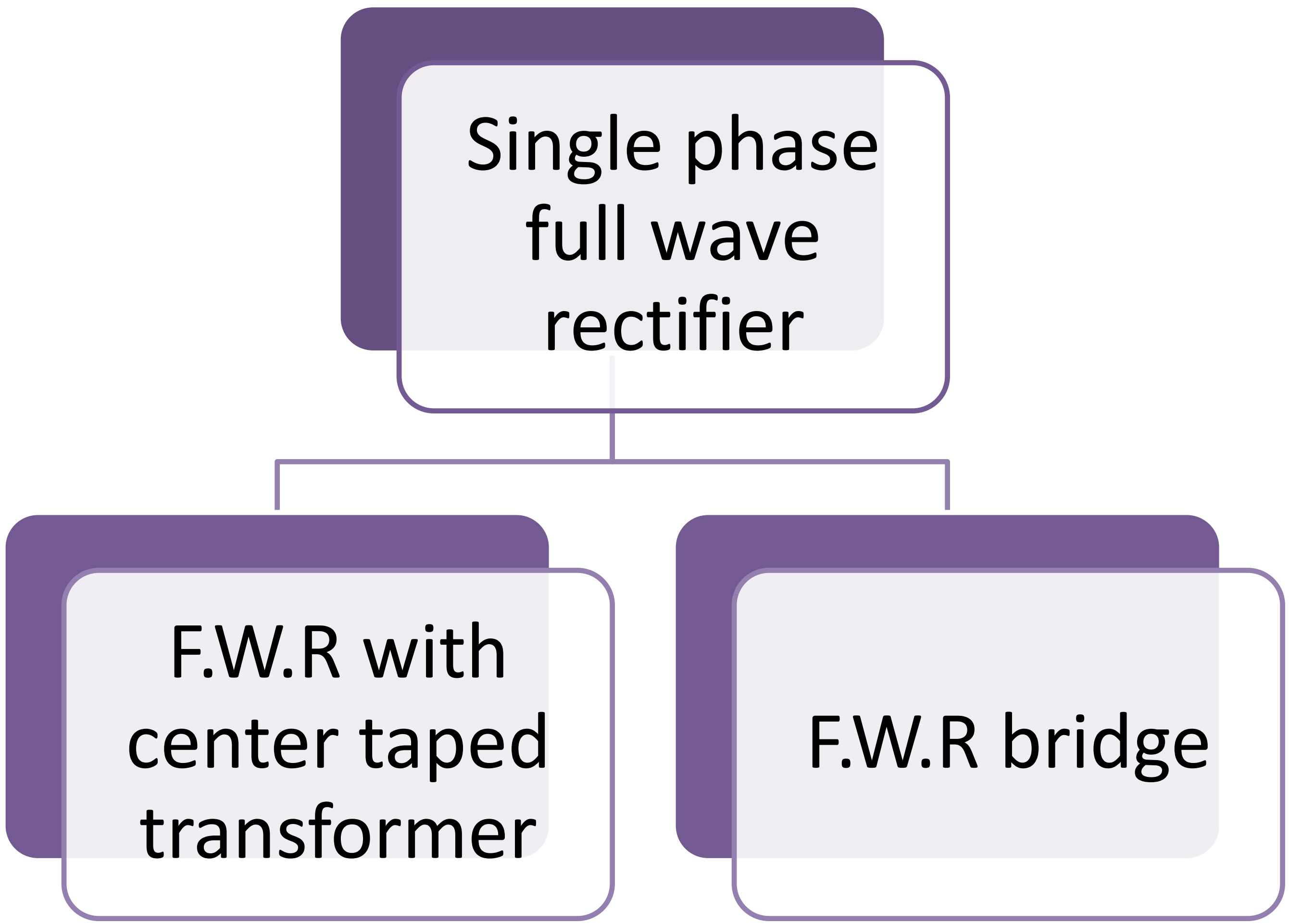
It is a diode connected across inductive load terminals to prevent the development of high voltage across the switch.



- When the inductive circuit is switched off, this diode gives short circuit path for the flow of inductor decay current and hence dissipation of stored energy in the inductor.

- The main purpose of free wheeling or “flyback” diode is to free wheel the stored energy in the inductor

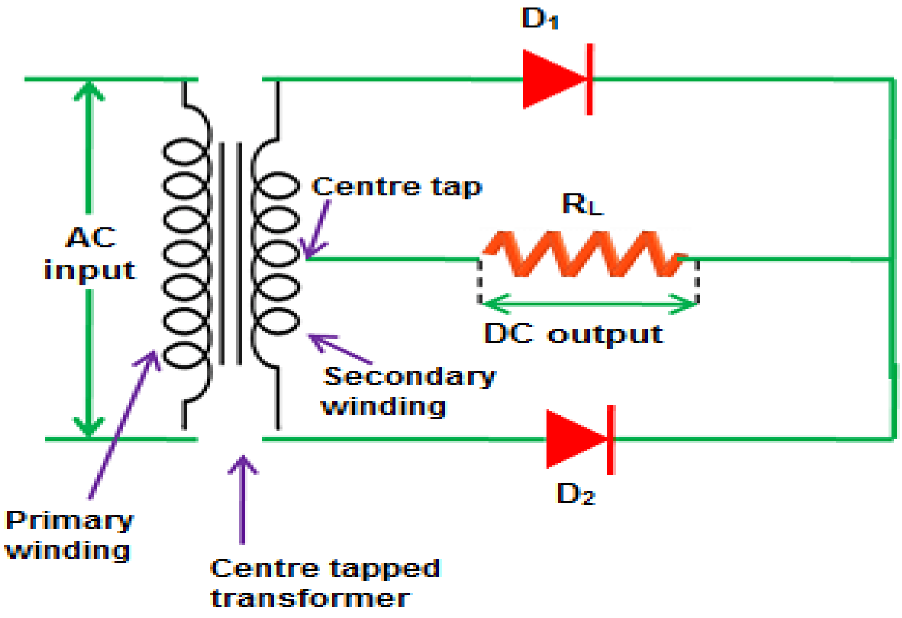
Full wave rectifier



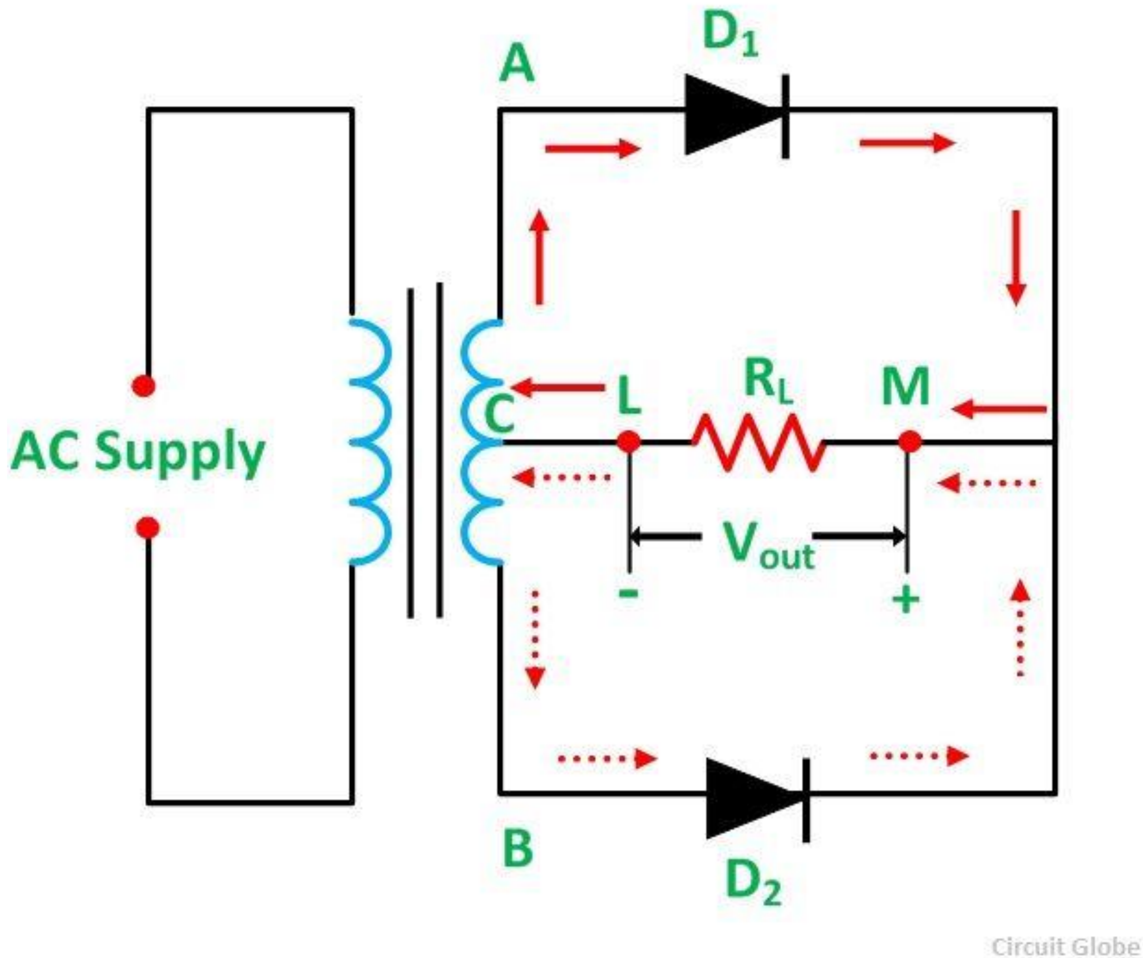
1 ph. (F.W.R) center tap

It is consist of two half wave rectifier circuits.

Each circuit will allow to part of the wave to pass through it.



The **positive** part of the wave will pass through **D1** to the load & the **negative** part will pass through **D2** as shown in the figure bellow .



D.C & R.M.S values calculation

- The output D.C voltage or current can be calculated as following:

$$V_{dc} = \frac{2}{\pi}\int_0^\pi V_m \sin\omega t \, d\omega t = \frac{2V_m}{\pi} = 0.636\, V_m$$

$$I_{dc} = \frac{2V_m}{\pi R}$$

$$V_{rms} = \sqrt{\frac{1}{\pi}\int_0^\pi (V_m \sin\omega t)^2 \, d\omega t} = \frac{V_m}{\sqrt{2}}$$

$$I_{r.m.s} = \frac{V_m}{\sqrt{2}\, R}$$, #

Wave forms

Peak inverse voltage (PIV) value will be twice of the input value.

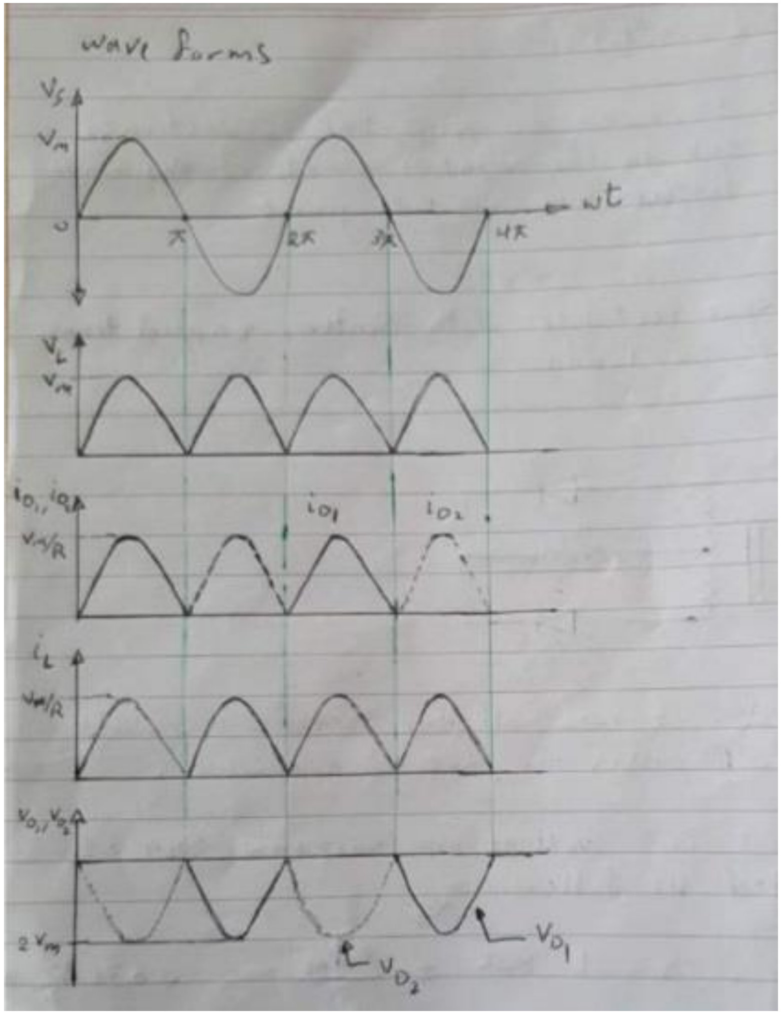
PIV = 2 Vm

FF = Vrms / Vdc =1.11

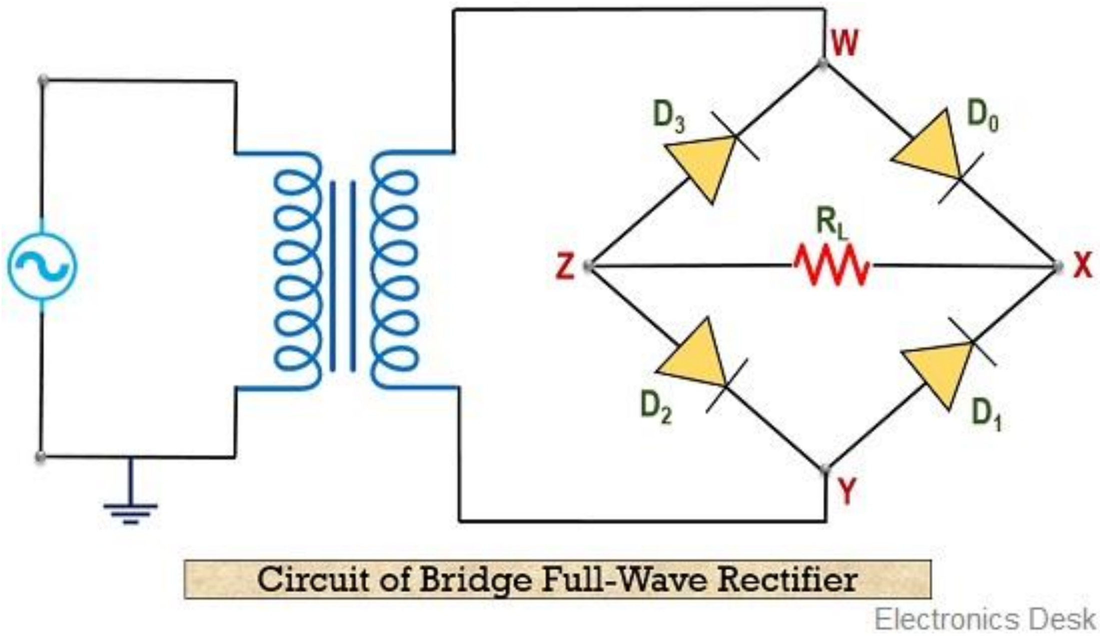
RF = Vac / Vdc = 0.48

TUF = Pdc / 2 VsIs = 0.5732

η = Pdc / Pac =81.05%



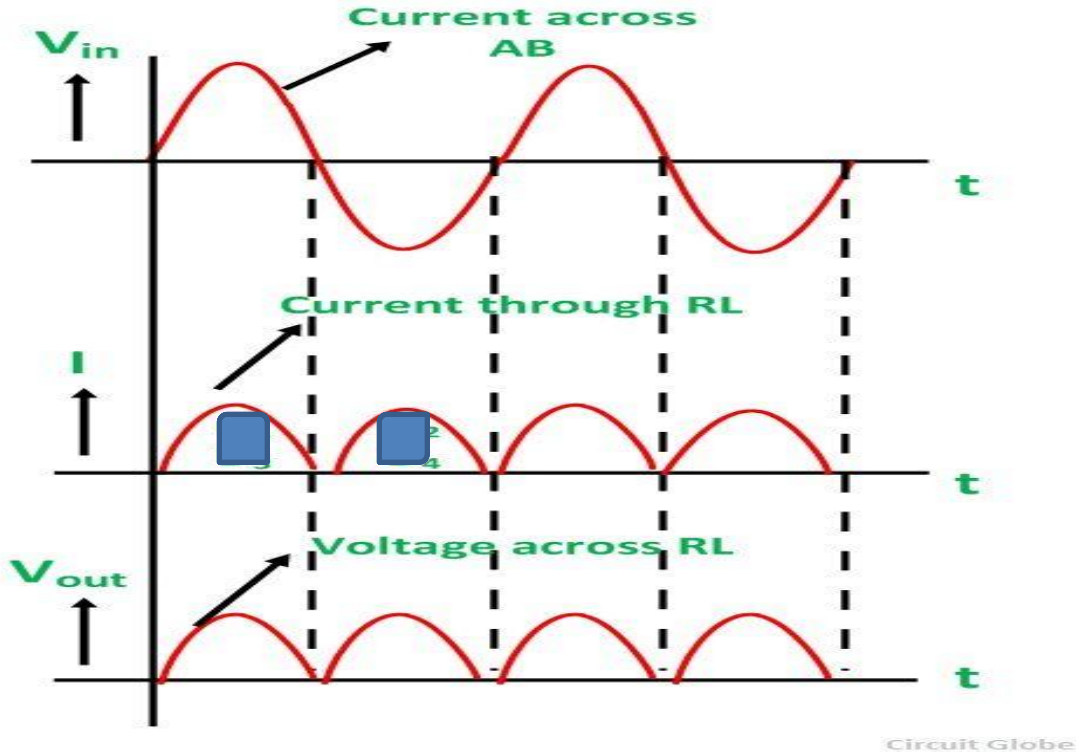
1 ph. (F.W.R) bridge type

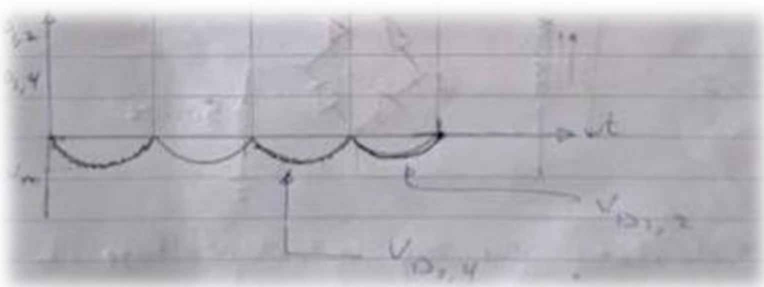


The **positive** part of the wave will pass through **D0&D1**, where the **negative** part will pass through **D1&D3.**

Wave forms

TUF = 81%





PIV is equal to the maximum value of the input wave

Comparison between (F.W.R) bridge & center tap forms

- Bridge rectifier better than center tap rectifier? **Because** it does not require bulky tapped transformer which make its cheaper and its weight lighter.

- The PIV ratings of the diodes in bridge rectifier is half than that of needed in a center tapped full wave rectifier, that **is why the diodes has capable to bearing high peak inverse voltage.**

- Transformer utilization factor (TUF) more in bridge rectifier compared to the center tap rectifier.

Compare between H.W.R & F.W.R

parameters	H.W.R	F.W.R (center tap)	F.W.R bridge
Rectified voltage Vdc	Vm/π = 0.318 Vm	$\frac{2Vm}{\pi}$ = 0.636 Vm	$\frac{2Vm}{\pi}$ = 0.636 Vm
Form factor FF	157%	111%	111%
Rectification ratio n	40.53%	81.05%	81.05%
Ripple factor RF	121%	48.2%	48.2%
Transformer utilization factor TUF	28.6%	57.32%	81%
Fundamental ripple freqency fr	Fs	2Fs	2Fs
PIV	Vm	2Vm	Vm

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Lecture 3

Ass. Teacher Sadeq Abdullah
Electrical department

3 phase half wave rectifier

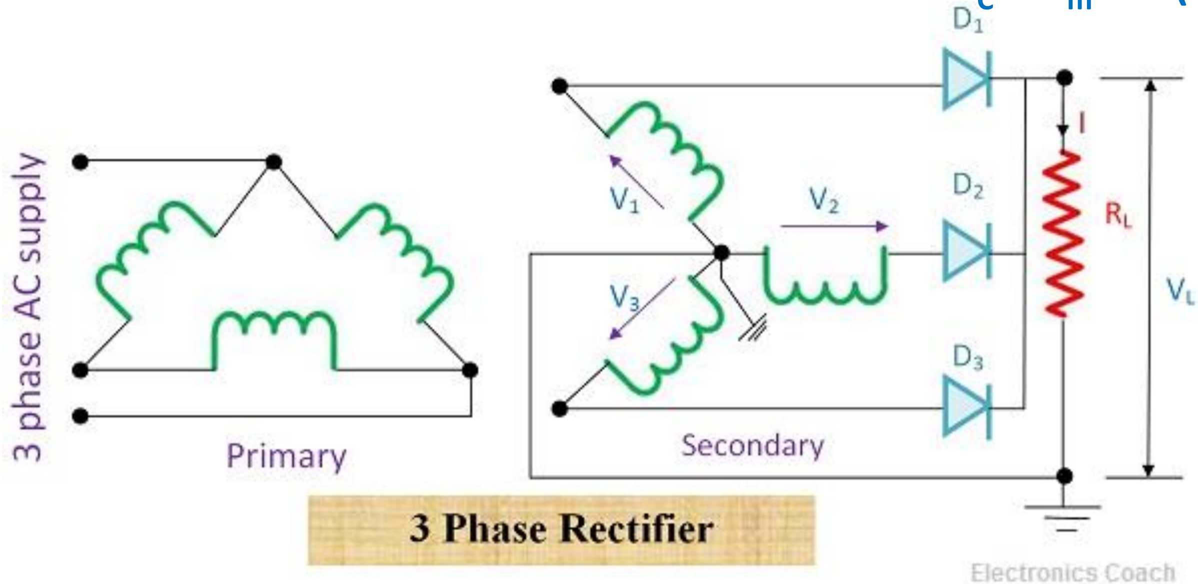
It consists of three half wave rectifier circuits each phase will be passed through specified diode.

The positive part of V1 will pass through D1 to the load , positive part of wave 2 & wave 3 will pass through D2 D3 respectively.

$V_A = V_m * \sin(\omega t - 0^o)$

$V_B = V_m * \sin(\omega t - 120^o)$

$V_C = V_m * \sin(\omega t - 240^o)$



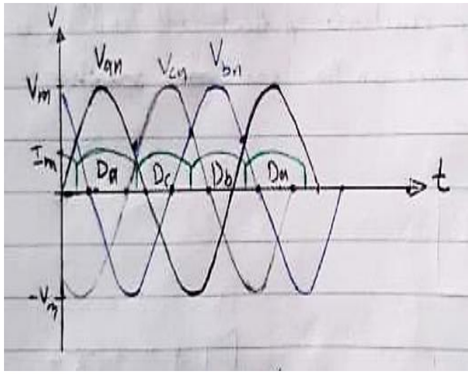
Principle of working

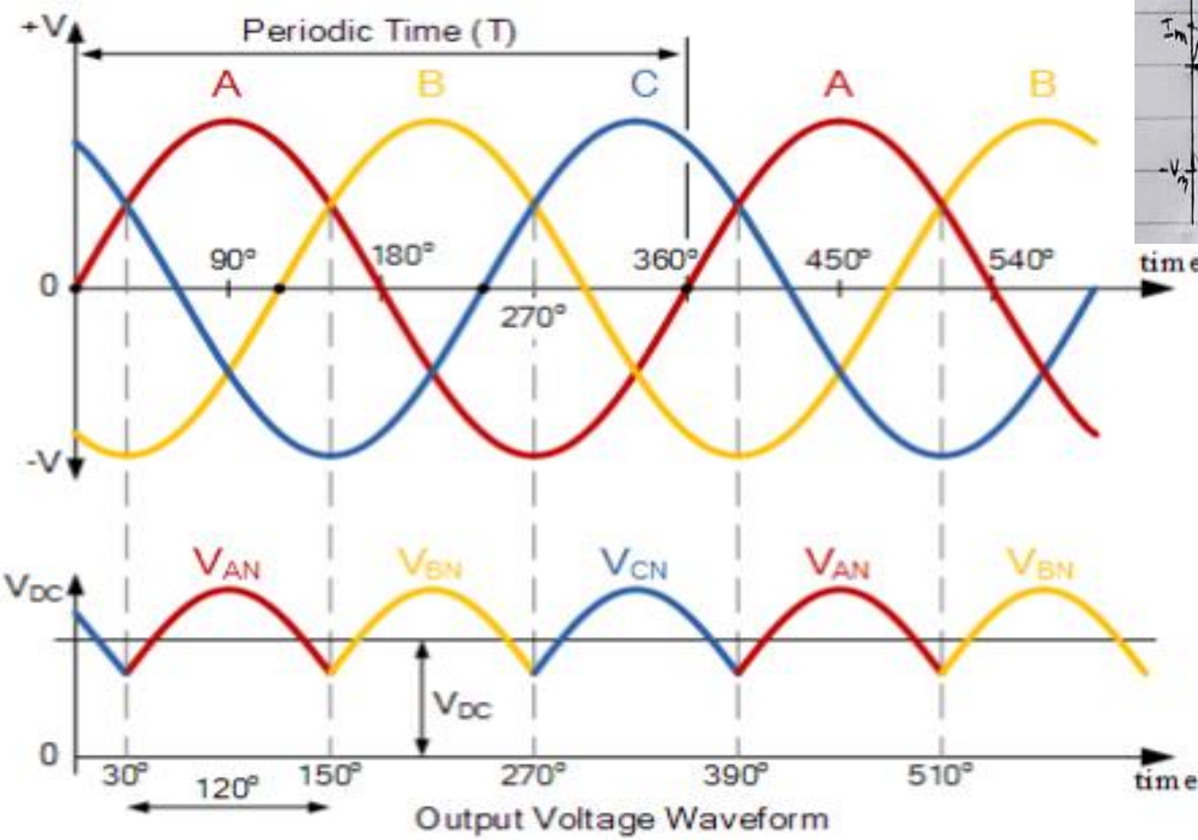
- The anode of each diode is connected to one phase of the voltage supply with the cathodes of all three diodes connected together to the same positive point, effectively creating a diode OR type arrangement. This common point becomes the positive (+) terminal for the load while the negative (-) terminal of the load is connected to the neutral (N) of the supply.

- The three-phase rectification, whichever diode has a more positive voltage at its anode compared to the other two diodes it will automatically start to conduct, thereby giving a conduction pattern of: D_1 D_2 D_3 as shown in the figure bellow.

Voltage and current wave forms

It can be noticed that the output wave consists of three parts each part represent one third of the total wave .





Output wave calculation

$$I_{dc} = \frac{1}{2\pi/3} \int_{\pi/6}^{5\pi/6} I_m \sin\omega t \, d(\omega t)$$

$$= \frac{3 I_m}{2\pi} \left| -\cos\omega t \right|_{\pi/6}^{5\pi/6}$$

$$= \frac{3 I_m}{2\pi} \left| -\left(\cos\frac{5\pi}{6} - \cos\frac{\pi}{6}\right) \right|$$

$$= \frac{3 I_m}{2\pi} \left| -\left(-\frac{\sqrt{3}}{2} - \frac{\sqrt{3}}{2}\right) \right|$$

6

$$I_{dc} = \frac{3\sqrt{3}}{2\pi} I_m$$

$$V_{r.m.s} = \sqrt{\frac{3}{2\pi} \int_{\pi/6}^{5\pi/6} (V_m \sin\omega t)^2 \, d\omega t}$$

$$= 0.8407 \, V_m$$

$$V_{dc} = I_{dc} R_L = \frac{3\sqrt{3}}{2\pi} I_m R_L$$

3 phase full wave rectifier

Each pair of the diodes will conduct one sixth of the total wave.

CIRCUIT DIAGRAM

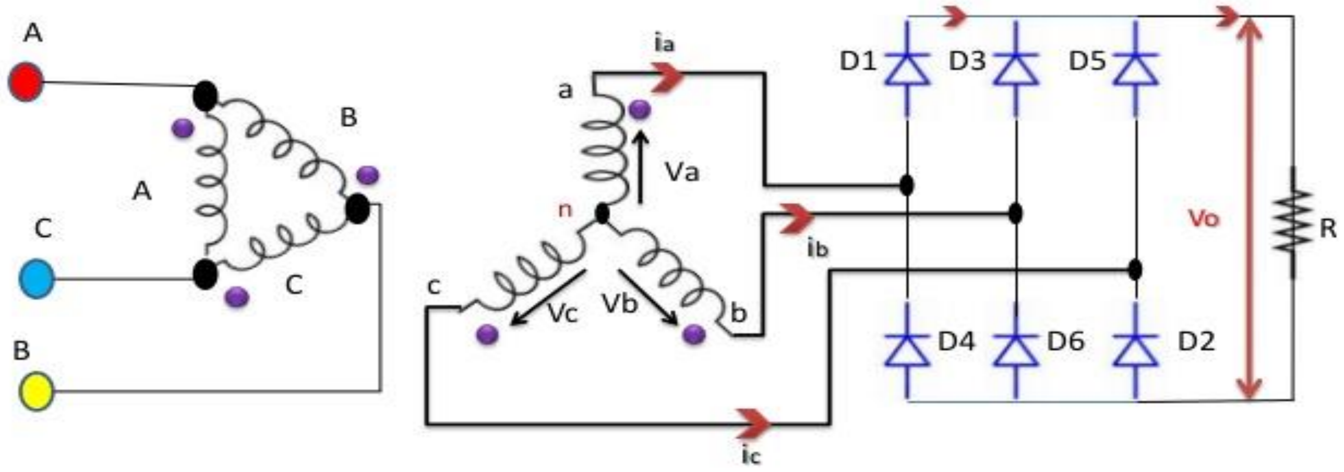
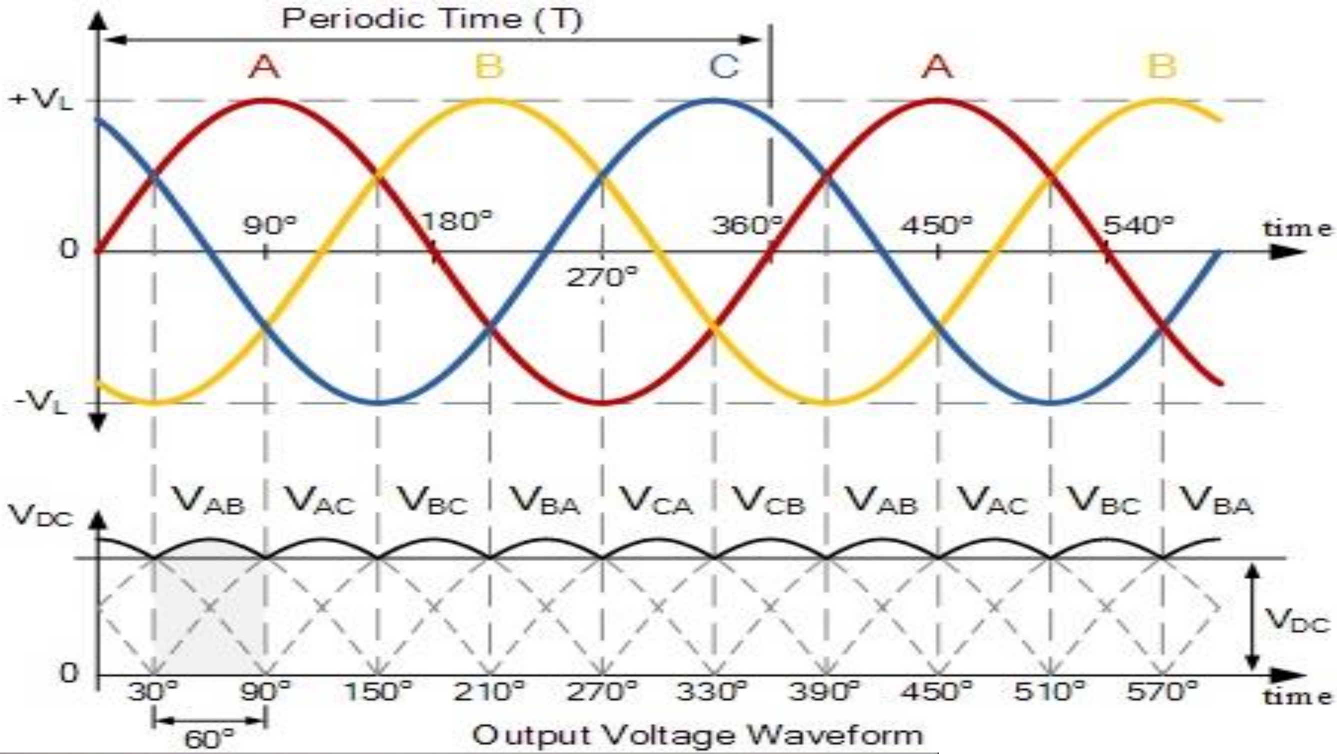


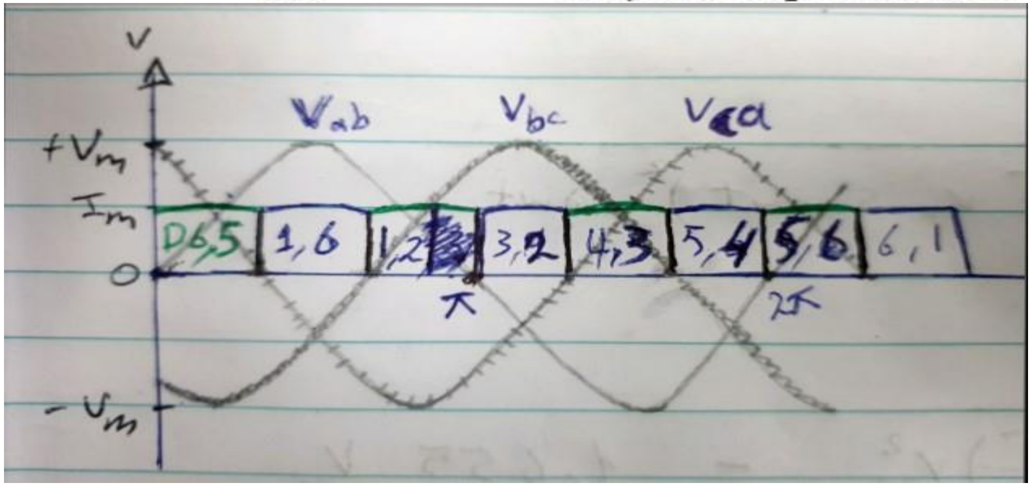
Fig. Three phase Bridge rectifier using Diodes

Principle of working

- Each phase connects between a pair of diodes as shown. One diode of the conducting pair powers the positive (+) side of load, while the other diode powers the negative (-) side of load.
- Diodes D_1 D_3 D_2 and D_4 form a bridge rectifier network between phases A and B, similarly diodes D_3 D_5 D_4 and D_6 between phases B and C and D_5 D_1 D_6 and D_2 between phases C and A.
- Thus diodes D_1 D_3 and D_5 feed the positive rail and depending on which one has a more positive voltage at its anode terminal conducts. Likewise, diodes D_2 D_4 and D_6 feed the negative rail and whichever diode has a more negative voltage at its cathode terminal conducts.
- Then we can see that for three-phase rectification, the diodes conduct in matching pairs giving a conduction pattern for the load current of: D_{1-6} D_{1-2} D_{1-2} D_{3-2} D_{3-4} D_{5-4} D_{5-6} and D_{1-6} as shown.

Output voltage & current wave forms





Which wave's part is positive with respect to the other will pass through the diodes.

Voltage & current calculation

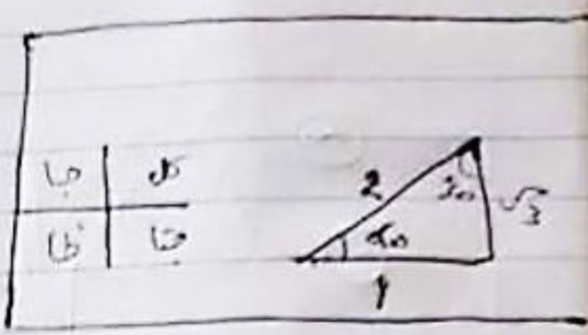
$$I_{dc} = \frac{1}{\pi/3} \int_{\pi/3}^{2\pi/3} I_m \sin \omega t \, d(\omega t)$$

$$I_{dc} = \frac{3 I_m}{\pi} \left[-\cos \omega t \right]_{\pi/3}^{2\pi/3}$$

$$I_{dc} = \frac{3 I_m}{\pi} \left[-\left(\cos \frac{2\pi}{3} - \cos \frac{\pi}{3} \right) \right]$$

$$= \frac{3 I_m}{\pi} \left[\frac{1}{2} + \frac{1}{2} \right]$$

$$I_{d.c} = \frac{3 I_m}{\pi}$$



$$V_{dc} = I_{d.c} * R_L$$

$$V_{dc} = \frac{3\, I_m}{\pi} R_L$$

$$V_{dc} = \frac{3}{\pi} V_m$$

$$V_{r.m.s} = \sqrt{\frac{3}{\pi} \int_{\pi/3}^{2\pi/3} (\sqrt{2}\, V_m \sin wt)^2 \, \partial wt}$$

$$= \sqrt{\left(\frac{3}{2} + \frac{9 * \sqrt{3}}{4\pi}\right) V_m^2} = 1.655\, V_m$$

$$I_{r.m.s} = \frac{1.655\, V_m}{R}$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{d.c}\, I_{dc}}{V_{r.m.s}\, I_{r.m.s}} = 99.83\%$$

$$FF = \frac{V_{r.m.s}}{V_{d.c}} = 100.08\%$$

$$RF = \frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{r.m.s}^2 - V_{dc}^2}}{V_{dc}}$$

$$= \sqrt{\frac{V_{r.m.s}^2}{V_{dc}^2} - 1} = \sqrt{FF^2 - 1} = 4\%$$

$$I_s = \sqrt{\frac{2}{3}}\, I_{r.m.s}$$

$$= 0.8 * \frac{1.655\, V_m}{R} = 1.352\, \frac{V_m}{R}$$

$$TUF = \frac{P_{dc}}{3 V_s I_s} = \frac{(1.65\, V_m)^2 / R}{3 \frac{V_m}{\sqrt{2}} * 1.352 \frac{V_m}{R}}$$

$$= 95.42\%$$

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LECTURE 4

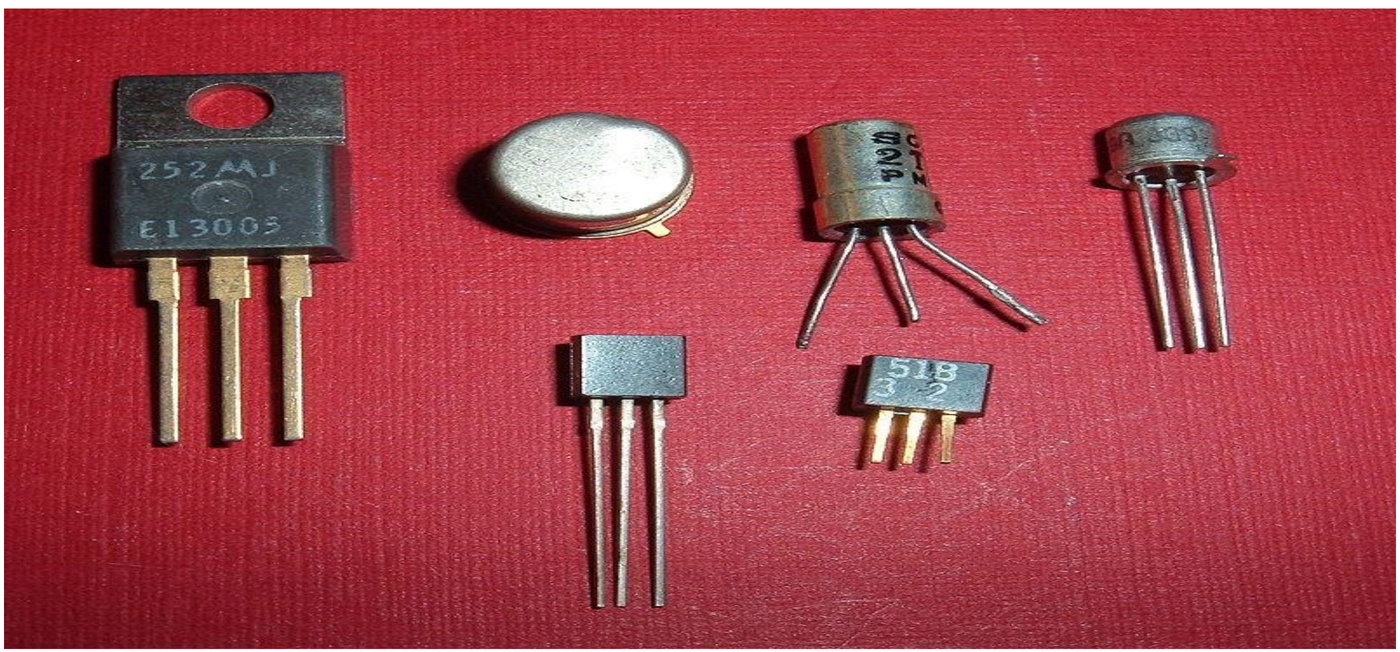
SECOND LEVEL

ASS. TEACHER SADEQ ABDULLAH

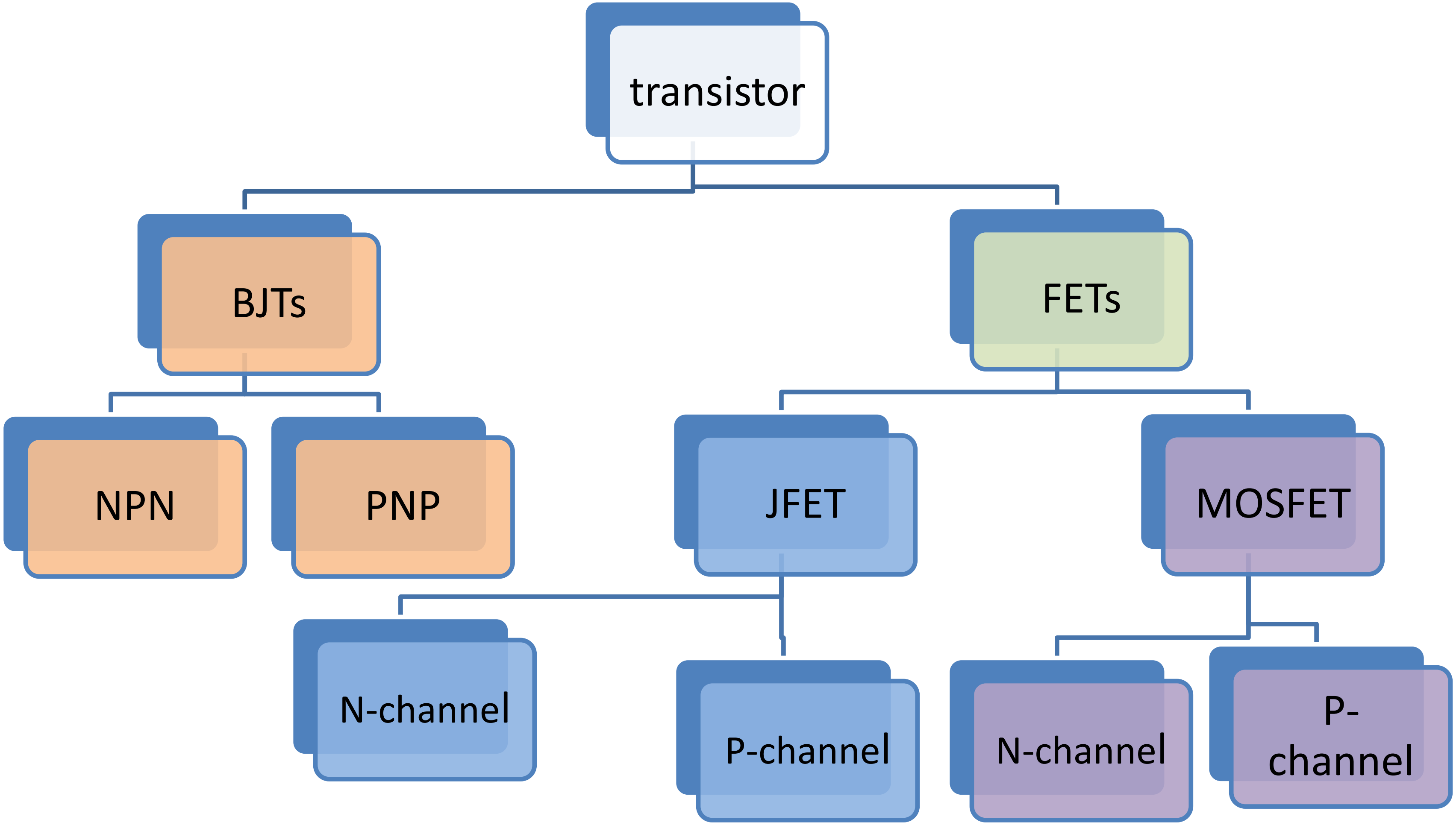
TRANSISTORS

A **transistor** is a semiconductor device used to amplify or switch electronic signals and electrical power. It is composed of **semiconductor** material usually with at least three terminals for connection to an external circuit.

Trans-resistance referred to as **mutual resistance.** It refers to the ratio between a change of the voltage at two output points and a related change of current through two input points.



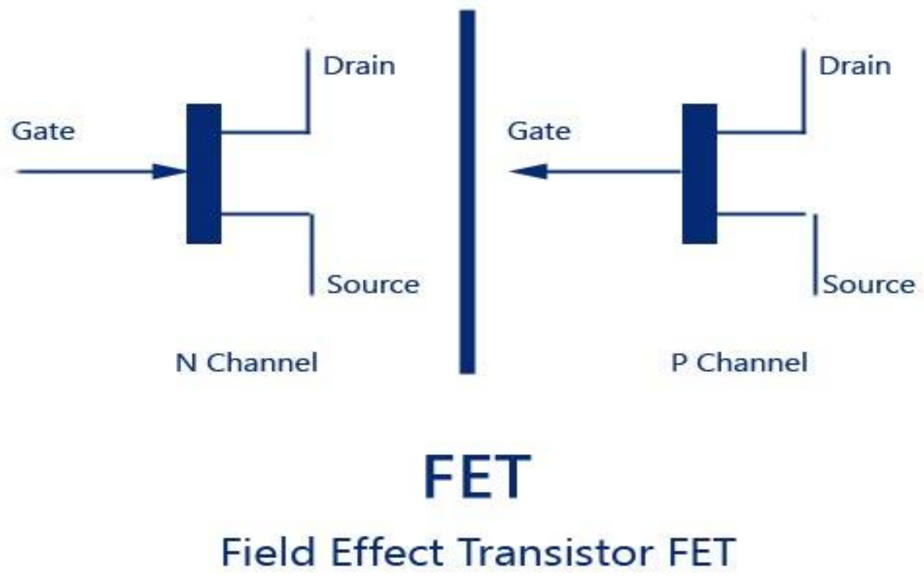
Transistor family



FET (Field effect transistor)

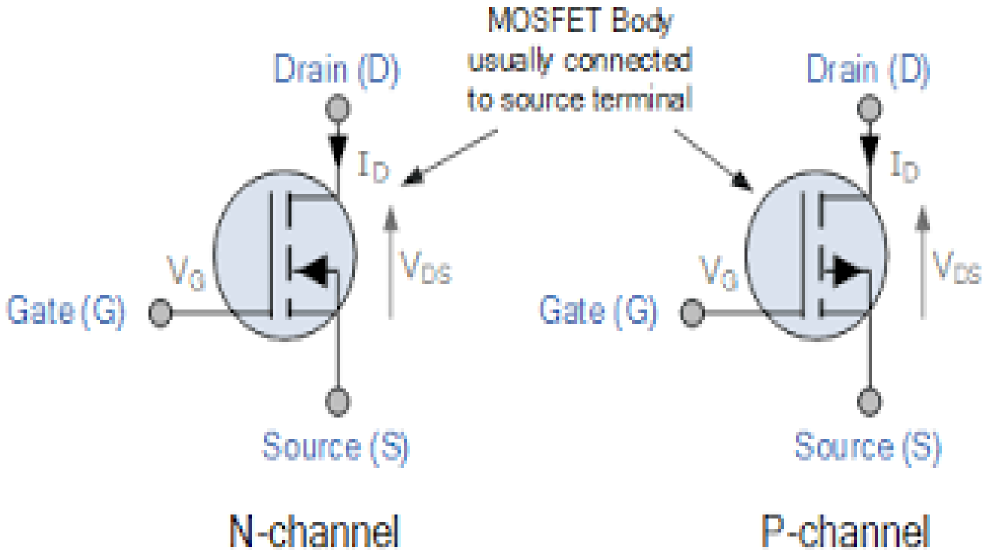
_ It is a transistor which made from three regions: **Gate, Source & drain**.

_ FETs are **voltage controlled devices** Which means that a voltage applied To the gate will control current Flowing from the source to the drain.



It is called **unipolar transistor** since it is using one type of charge carrier, holes or electrons not both as BJT.

The most wide used is **MOSFETs** (metal oxide semiconductor field effect transistor)



Bipolar junction transistor BJTs

Bipolar transistors are so named because they conduct by using both **majority** and **minority** carriers.

This construction produces two p–n junctions a **Base–Emitter** junction and a **Base–Collector** junction, separated by a thin region of semiconductor known as the **Base** region.

useful in **amplifiers** because the currents at the emitter and collector are controllable by a **relatively small base current.**

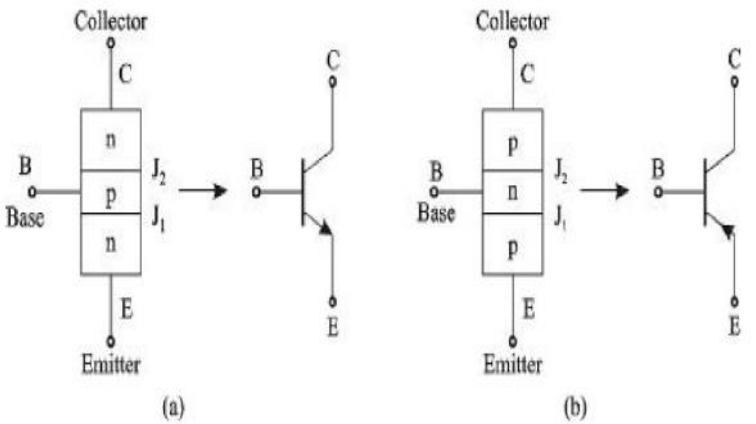
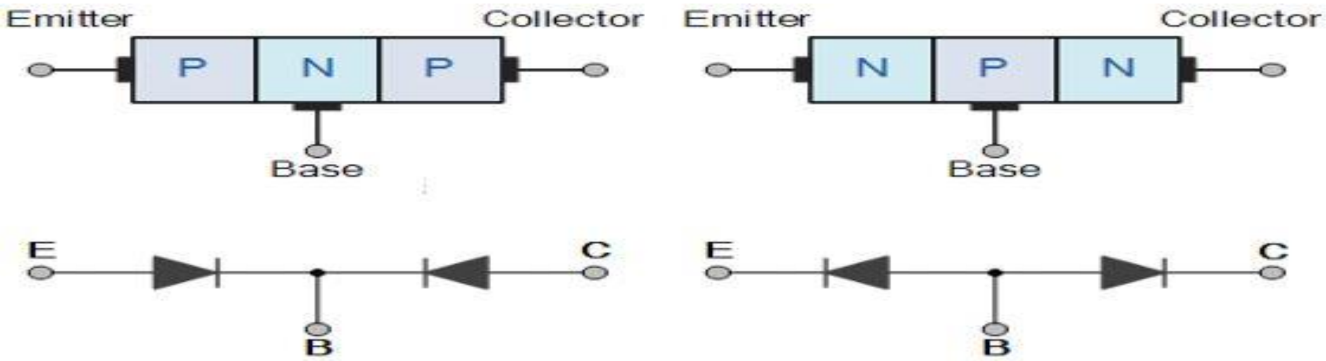


Fig.1 Bipolar power transistor and its symbol: (a) n-p-n; (b) p-n-p.



- the BJT has **low-input-impedance device.**

- If the **base–emitter voltage (V_{BE})** is increased the **base–emitter current** and hence the **collector–emitter current (I_{CE})** increase exponentially according to the Shockley diode model and the Ebers-Moll model.

- Because of this exponential relationship, the **BJT** has a higher t**rans-conductance** than **the FET**.

- the BJT remained the transistor of choice for many **analog circuits** such as **amplifiers** because of their **greater linearity**

Transistor current gain

$\alpha = \frac{Ic}{IE}$ $\beta = \frac{Ic}{IB}$

Ic = α .IE = β. IB

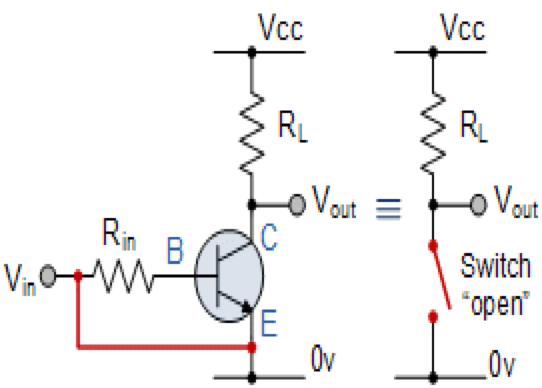
$\alpha = \frac{\beta}{\beta+1}$ $\beta = \frac{\alpha}{1-\alpha}$

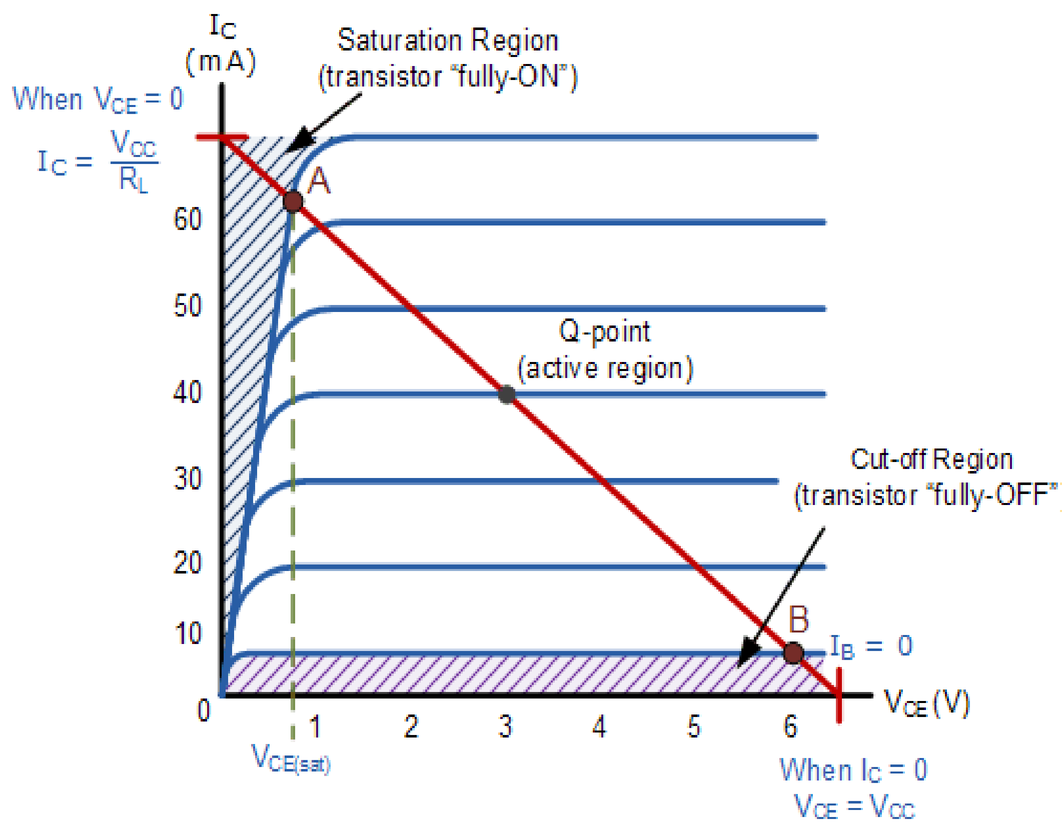
IE = Ic + IB

- β : **common-emitter** current gain
- α **: common-base** current gain
- α is changing in a **small rate** due to β changing which will **be huge compare to** alpha.
- It represents the **forward active** therefore it will be written as αf & βf
- α is **constant and it is around one** in the transistor e.g. if β = 100, α = 0.99

BJTs characterstics (cut- off & saturation regions)

Cut-off region: it is the region where the **depletion layer is too large** because that I_B is equal to zero and **Ic is zero** and **Vce is maximum**. (**FULLY OFF**)





I/P & base are grounded

$V_{BE} < 0.7$

B-E junction in reverse biase

B-C junction in reverse biase

Ic = 0 no collecter current

V out = V_{CE} = Vcc

Open switch

Saturation region

it will appear when a **maximum base current is applied** which will lead to **maximum collector current** will pass and **Vce** will be minimum **, depletion layer** will be as small as possible. **(FULLY- ON)**

I/P & Base are connected Vcc

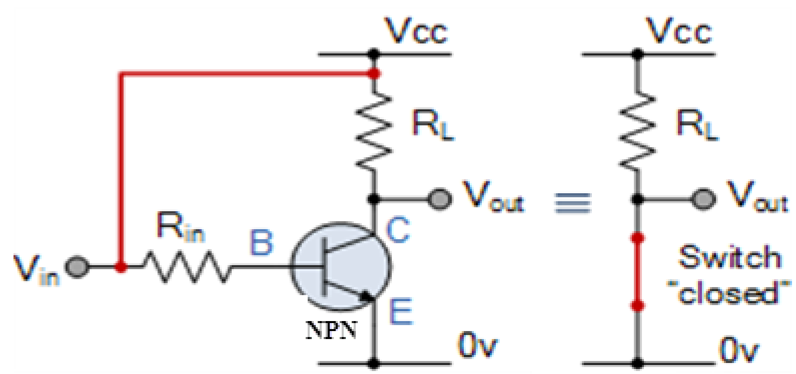
B-E voltage $V_{BE} > 0.7$

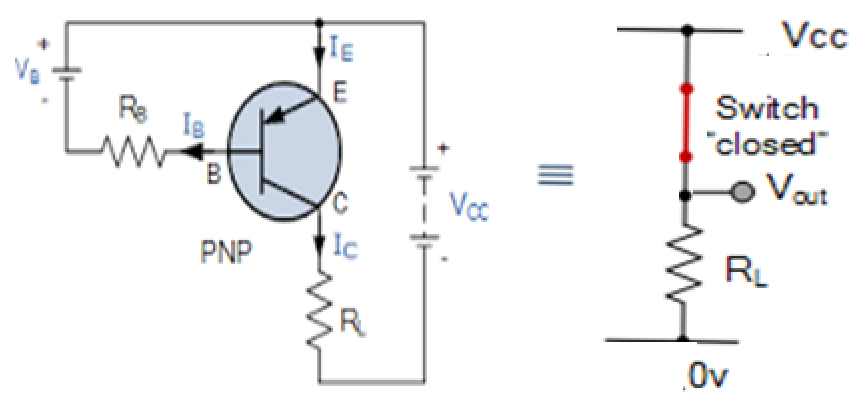
B-E junction is forward bias

B-C junction is forward bias

Ic = max = $\frac{Vcc}{RL}$

V_{CE} = Vout = 0 (ideal saturation)





Transistor as switch

The transistor will be used as a switch therefore the operation point will be between cut-off and saturation points.

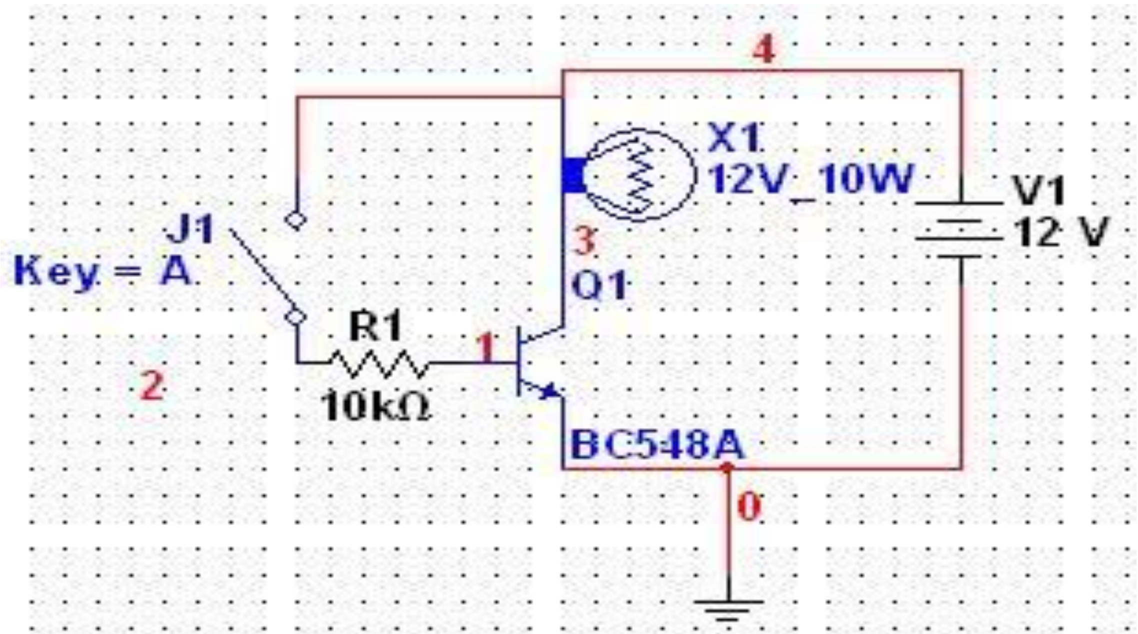
$I_B = \frac{VB - VBE}{RB}$

$V_C = V_{CE} = V_{CC} - I_C R_C$

$V_C = V_{CC} - \beta R_C \frac{VB - VBE}{RB}$

$V_{CE} = V_{CB} + V_{BE}$

$V_{CB} = V_{CE} - V_{BE}$ ………….. (1)



Max. Collector current can be obtained when VCB = 0

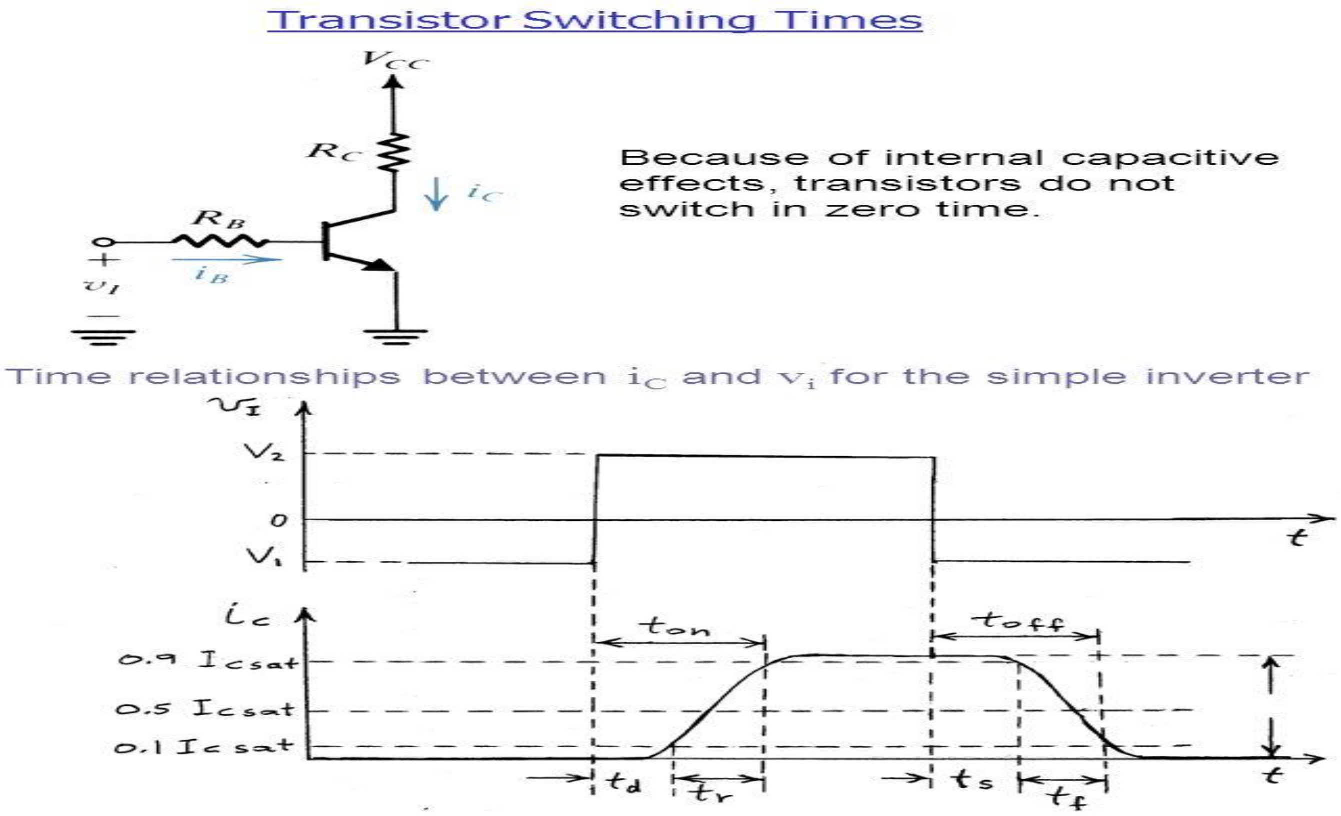
VCE = VBE

Ic = $\frac{Vcc - VcE}{Rc}$ **,** **IB =** $\frac{Ic}{\beta}$

Ic = $\frac{Vcc - VcE\ sat}{Rc}$ **,** **IB sat =** $\frac{Ics}{\beta}$ **at saturation**

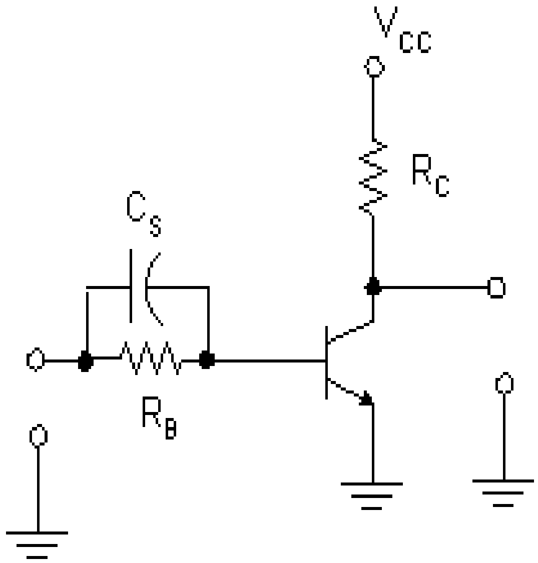
ODF (over drive factor) = $\frac{IB}{IBS}$

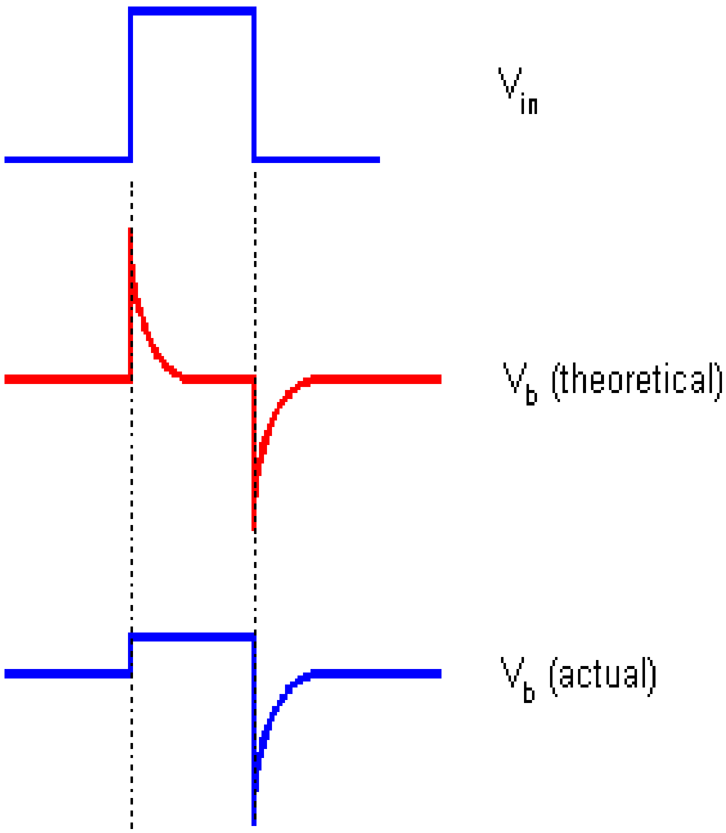
Switching time characterstics



td : delay time , **tr** : rise time , **ts**: storage time, **tf** : fall time

Transistor response characterstic


Vcc
Rc
Cs
RB


Vin
Vb (theoretical)
Vb (actual)

Comparison between NPN & PNP

NPN BJTS	PNP BJTs
In this the majority of n-types are present.	In this the majority of p-type materials are present
the carriers are electrons	the carriers in this type of transistors are holes
the terminal base is supplied with the increased amounts of current then the transistor gets switch to ON mode	for the low values of the currents the transistor is ON. Otherwise for high values of currents transistors it is OFF
the flow of current is evident from the collector to the emitter terminals.	the flow of current can be seen from the terminals of the emitter to the collector.
the arrow is pointing out	the indication of arrow is always pointing in
Sample as shown above	Sample as shown above

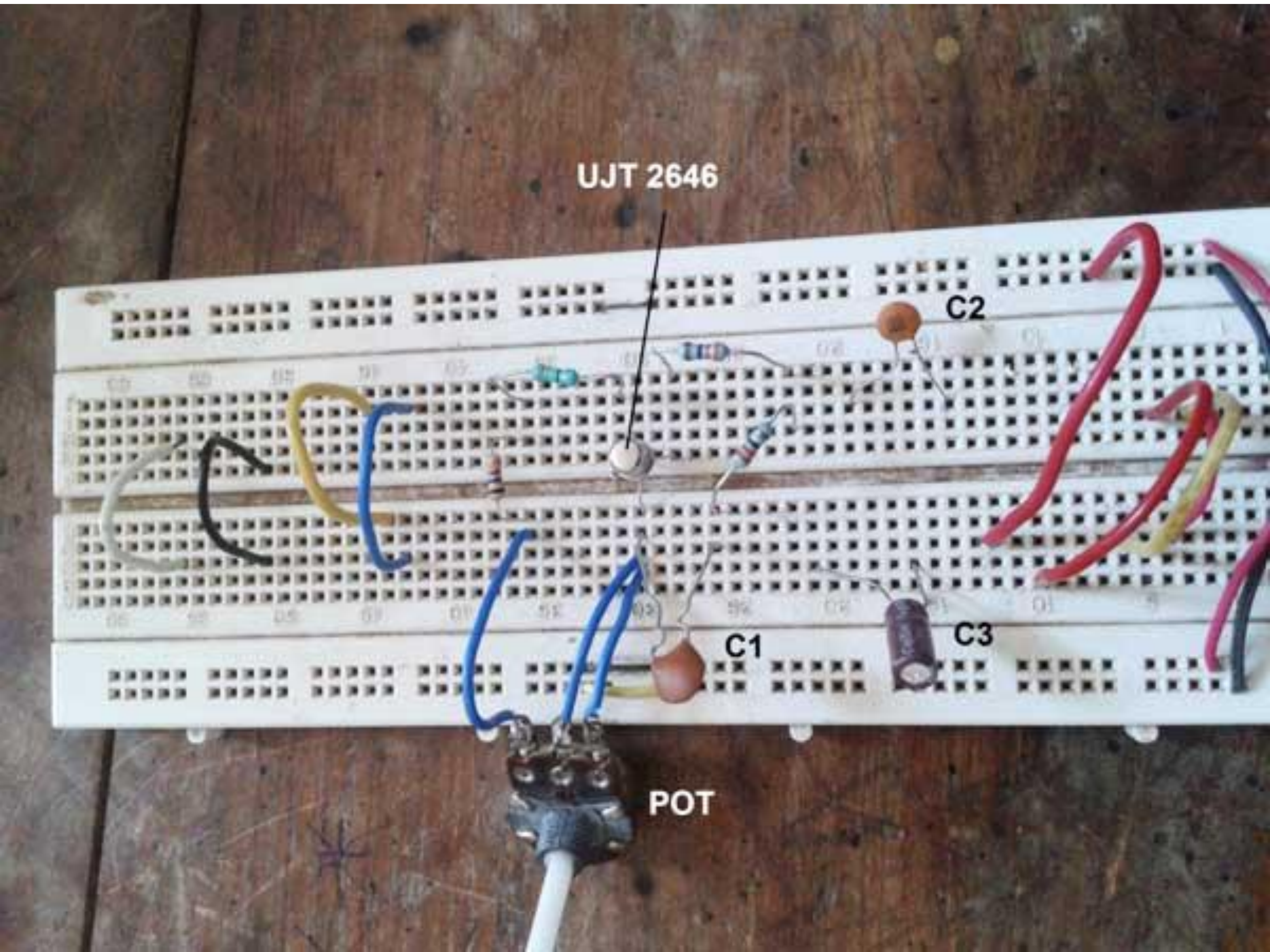
Table 2.1

وزارة التعليم العالي والبحث العلمي
جامعة الفرات الاوسط التقنية
معهد النجف التقني
قسم تقنيات الكهرباء

Power electronic

Lecture 5

Ass. Lecturer Sadeq abdullah

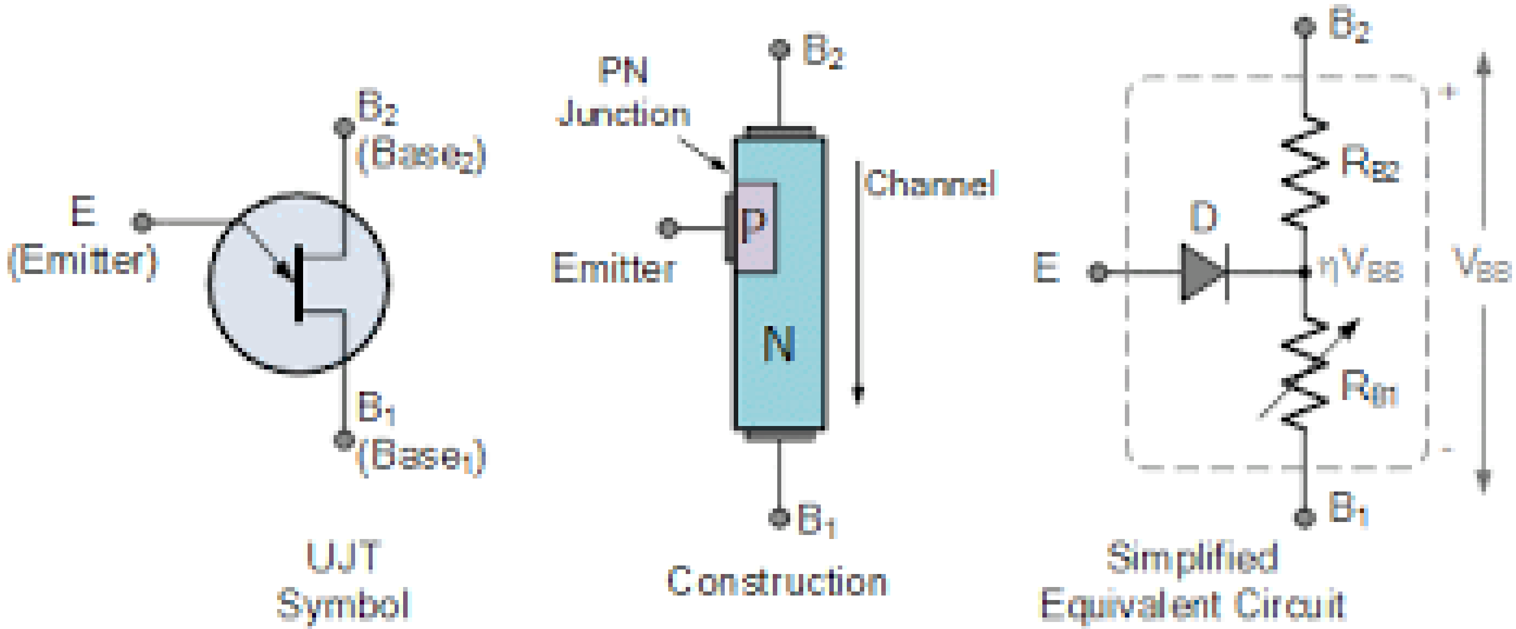

UJT 2646
C2
C1
C3
POT

Unijunction transistor UJT

It is a solid state **three terminal** device which can be used in:

Gate pulse, **timing circuit** & **trigger generator applications** to switch and control other electronic devices as thyristor and triac.

Symbol & construction



$V_{RB1} = \frac{RB1}{RB1+RB2} \; V_{BB}$,

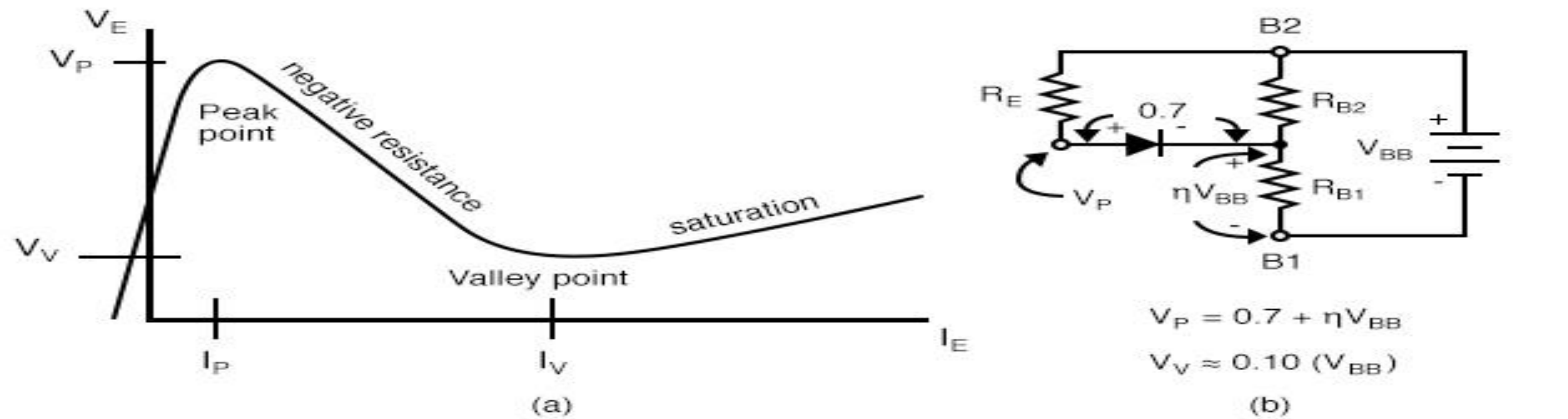
where the ratio $\frac{RB1}{RB1+RB2}$ is called ***intrinsic stand-off ratio*** **(η)** eta which its common value between 0.5 up to 0.8 for the most UJTs.

- If the **positive voltage** applied to the **emitter terminal** was **less than** the developed **voltage across R_{B1} (ηV_{BB})** the diode p-n junction will be **in reverse** biased and the current will not flow because of the **high impedance**.

- When the **emitter input voltage** is **increased** and become higher than the **voltage drop in R_{B1}** the p-n junction will be in **forward** biased and the transistor will **conduct** the current.

- The result is that the **emitter current (ηI_E)** will flows from the emitter to **the base region**, that will lead to reduce **the resistive portion** between the **emitter junction and B1** terminal and that will create **a negative resistance** at the **emitter** terminal and more current will flow through it.

I-V characteristics



Static emitter characteristic it is a curve that show the relationship between **emitter voltage VE** and **emitter current IE**.

Peak point emitter current (IP) it represent the **minimum current** required to trigger the UJTs and its **inversely proportional** to VBB.

Valley point voltage Vv : it is **the emitter voltage** at **valley point** and it **increases with increasing VBB**, it is estimated as 10% of the base voltage VBB.

Valley point current IV : it is the **emitter current** at **valley point** it is **proportional** to base voltage VBB.

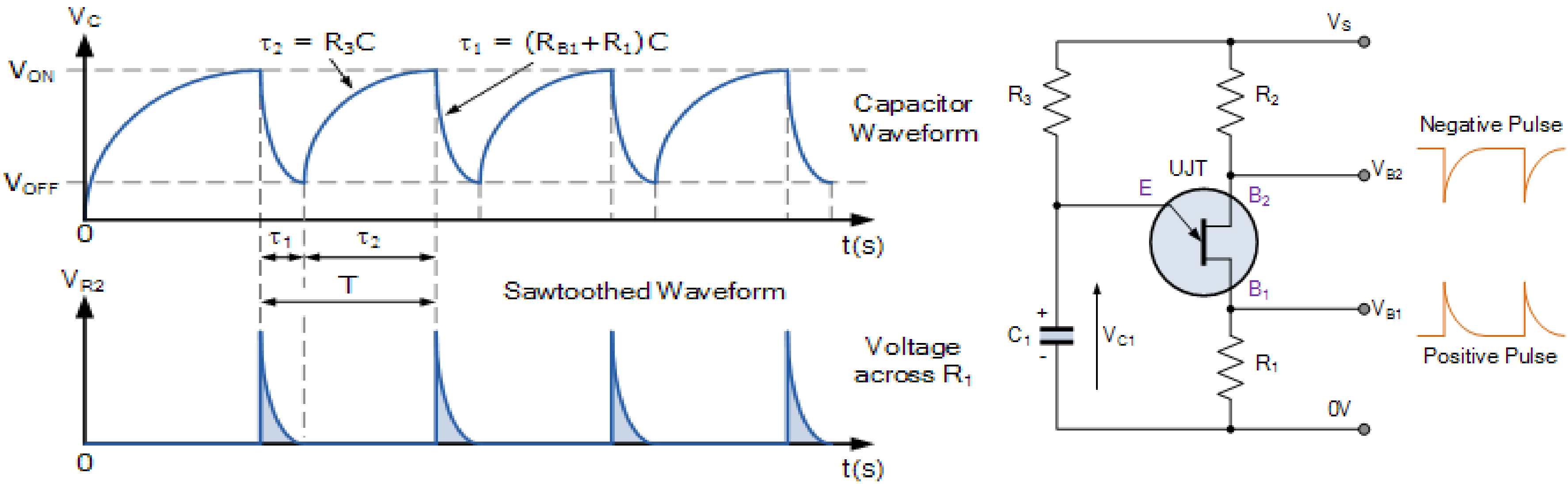
- **cut-off region:** To the left of peak point where IE never exceeds IEo.

- **Conduction region:** it is start when VE = VP and VE start to decrease with the increase IE.

- Decreasing of VE with increasing emitter current lead to decrease the RB resistance for increasing current, therefore **negative resistance** is stable to be used in many application with enough reliability.

- **Saturation region:** when IE = Iv (valley current)

Unijunction transistor applications



- **The most useful** application of this device is **triggering device** for SCRs & triacs but other applications includes **saw-toothed generator**, **simple oscillator** , etc.

- In a basic & typical UJT relaxation oscillator circuit , **the emitter terminal** is connected to the junction of series connected **resistance** & capacitance as shown above .

- When the voltage is **starting** apply to the transistor the capacitor is **fully discharged** and the transistor is **off**.

- The capacitor will begin to **charge up** exponentially through resistor 3.

- When the charging voltage **Vc across the capacitor** will be **greater** than the **diode volt drop value p-n junction** will be **forward biased** and triggering **the UJT to conduction** and the transistor is ON at this point.

- As the UJTs ohmic resistor is **very low** the capacitor will be **discharged rapidly through the UJT** and **fast rising pulse** will appear **through R1** and that will lead to **short discharging time** with respect to charging time.

- When the voltage across **the capacitor** will decrease below the holding **point of p-n junction (V_{OFF})** the UJT turn **OFF** and the current will not flow through emitter junction.

T = Ʈ1 + Ʈ2 , f = $\frac{1}{T}$ **,**

the **freq.** can be changed by changing **R3 & C** values

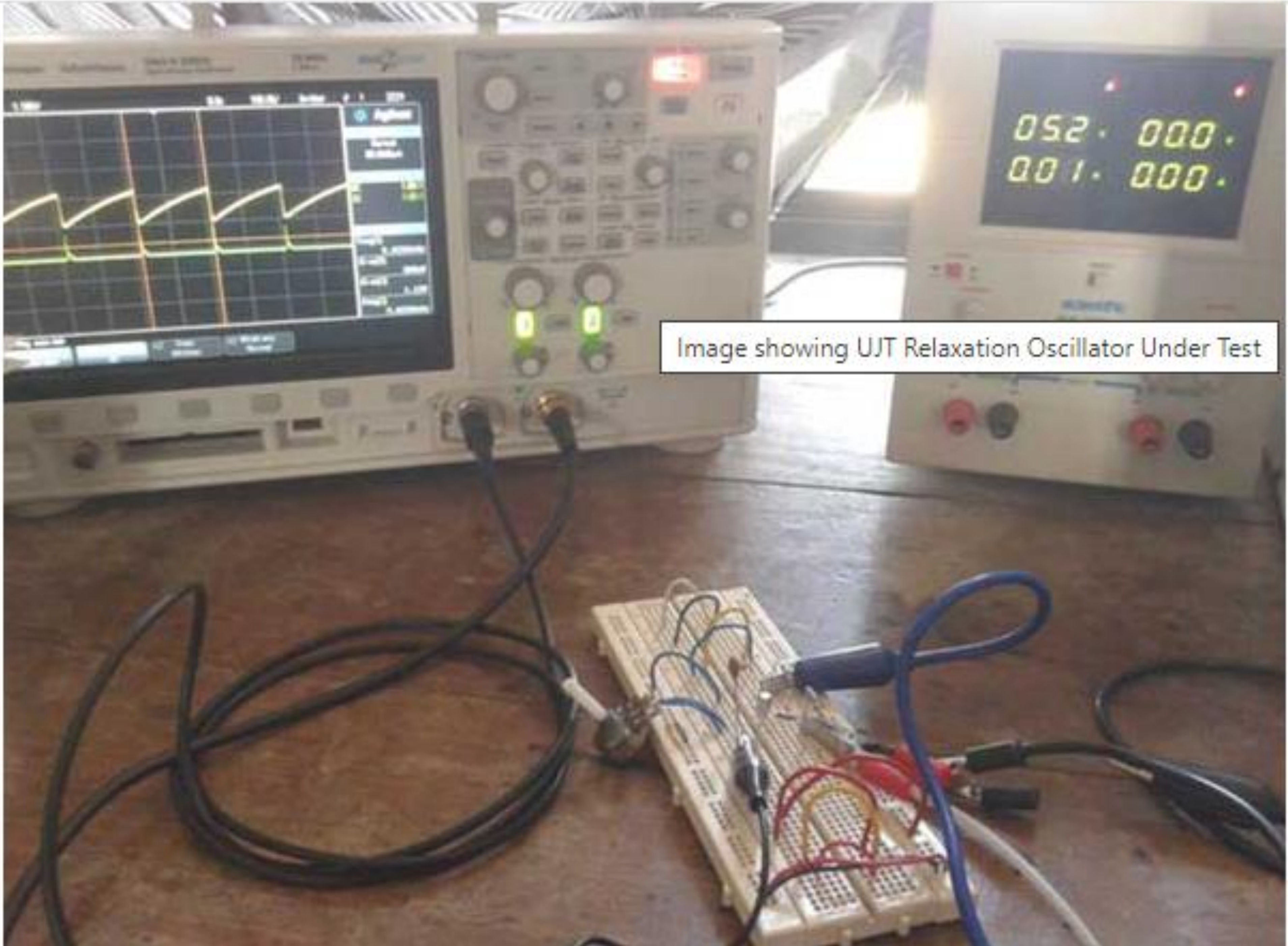


Image showing UJT Relaxation Oscillator Under Test

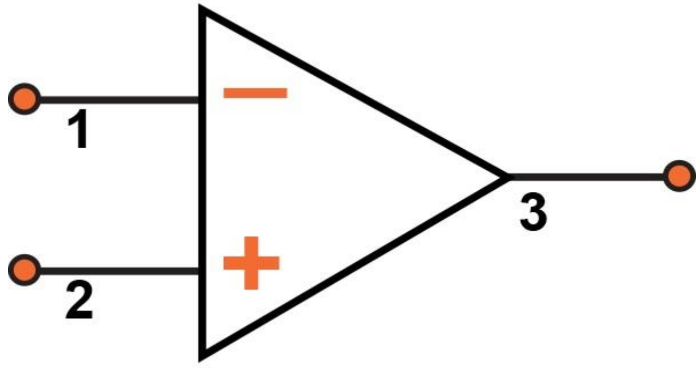
Operational amplifier op-amp

- It is the essential component of **linear** circuit design.

- Its traditional form is consisting of two inputs & one output terminals.

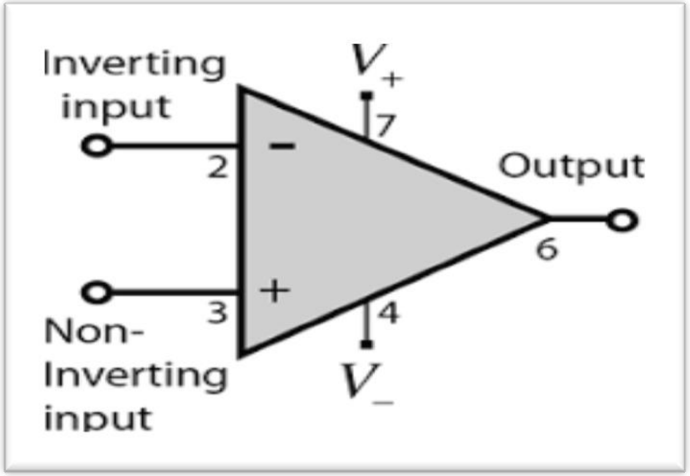
- One of the **inputs inverts** the phase of the signal and **the other input** will **preserves** the phase.

- It has two **power** supply ports .

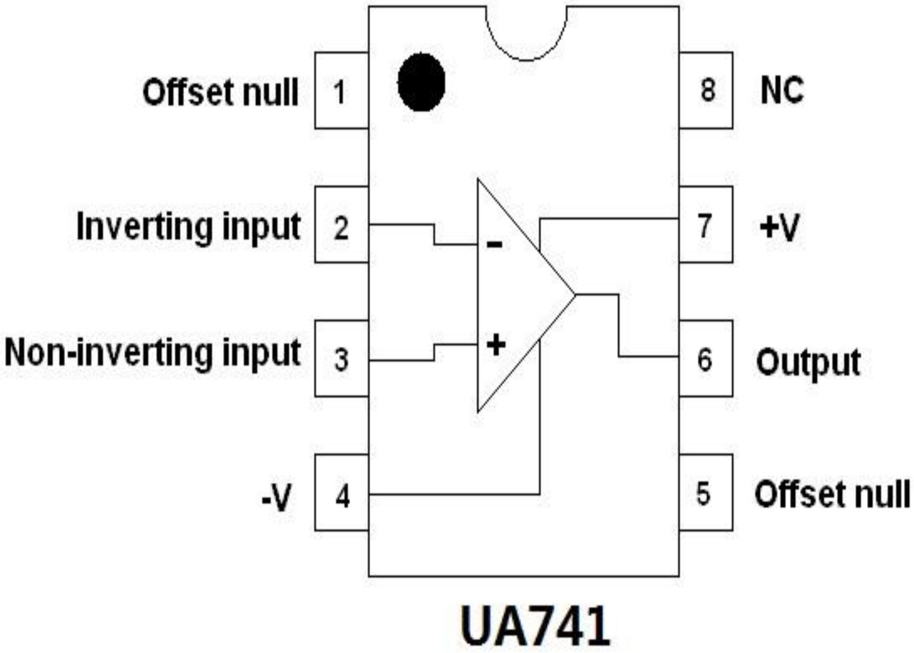


Op-amp configuration

Op-amp IC in the market has **8 of arms** as shown in the figure below.



1 : to set the output on Zero
2 : inverting terminal
3 : Non-inverting term.
4 : negative power supply
5 : similar to 1
6 : it the output terminal
7 : positive power supply
8 : it is not used



Terminals 1,5 are used to keep the output **Zero** if the input **Zero**

Equivalent circuit of op-amp

For ideal op-amp

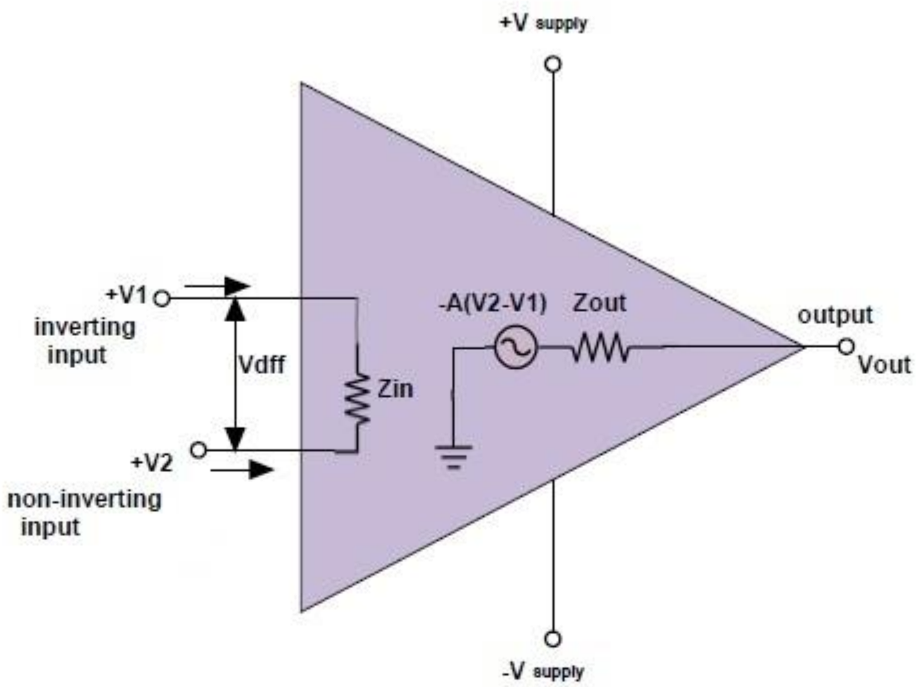
Zin: input impedance is **infinite** i.e current will **never flow** through the input.

Zout : output impedance is **zero** which it is mean that the device can **drive any load impedance** to any **voltage.**

The open-loop **gain A** or G is infinite.

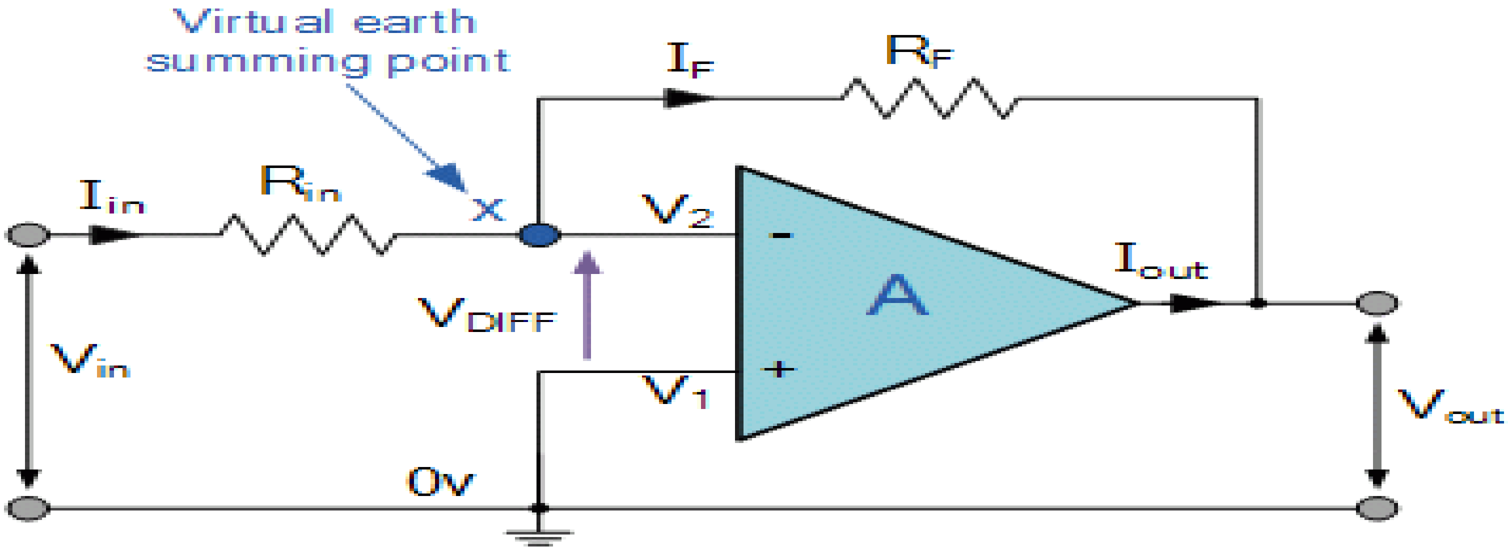
The **band width** is **infinite** .

Vo : output voltage is **zero** when the **input voltage** difference is zero.



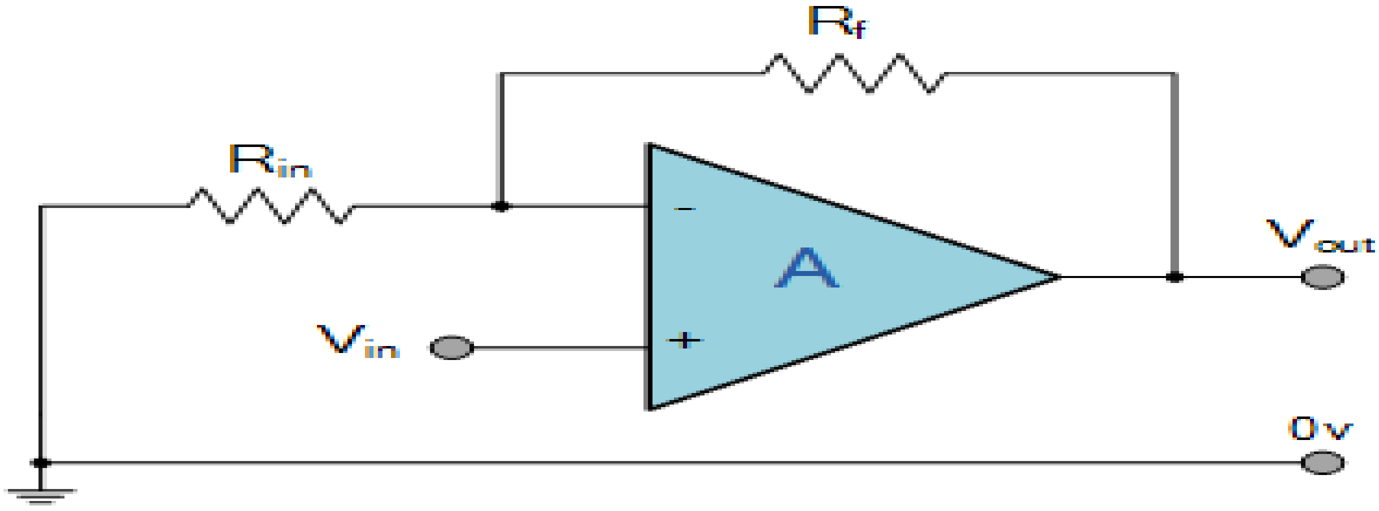
Applications of op-amp

Inverting op-amp



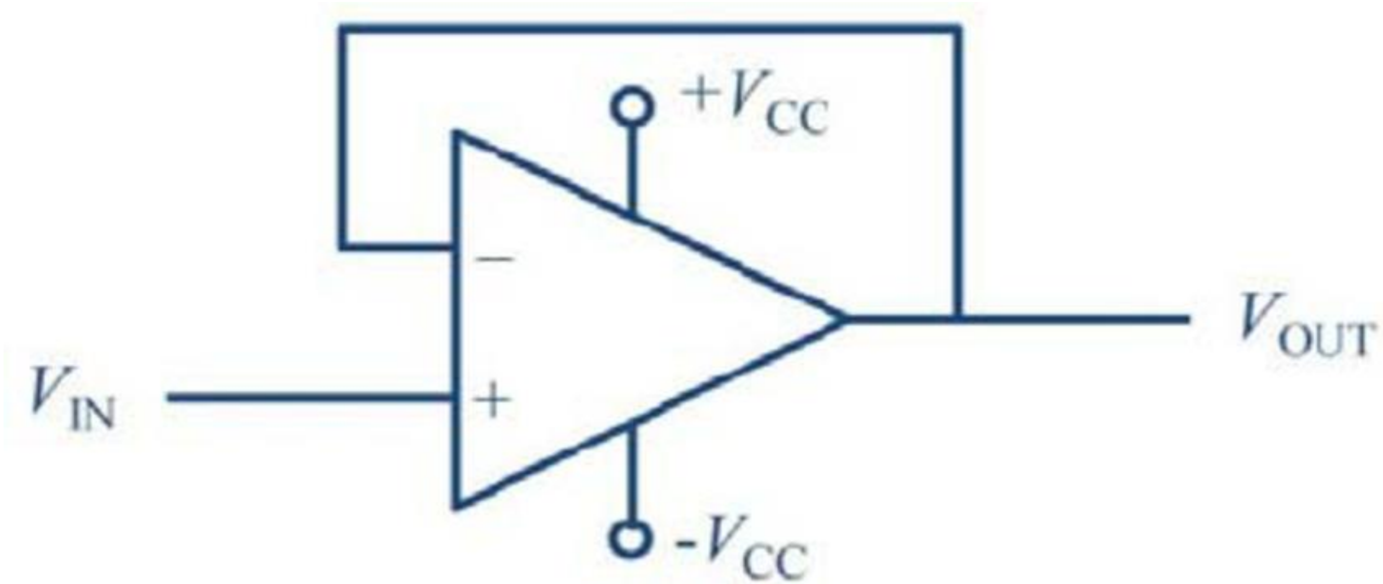
Gain = $\frac{Vout}{Vin} = -\frac{Rf}{R1}$

Non- inverting op-amp



$$A = \frac{Rin + Rf}{Rin}$$

Voltage follower op-amp

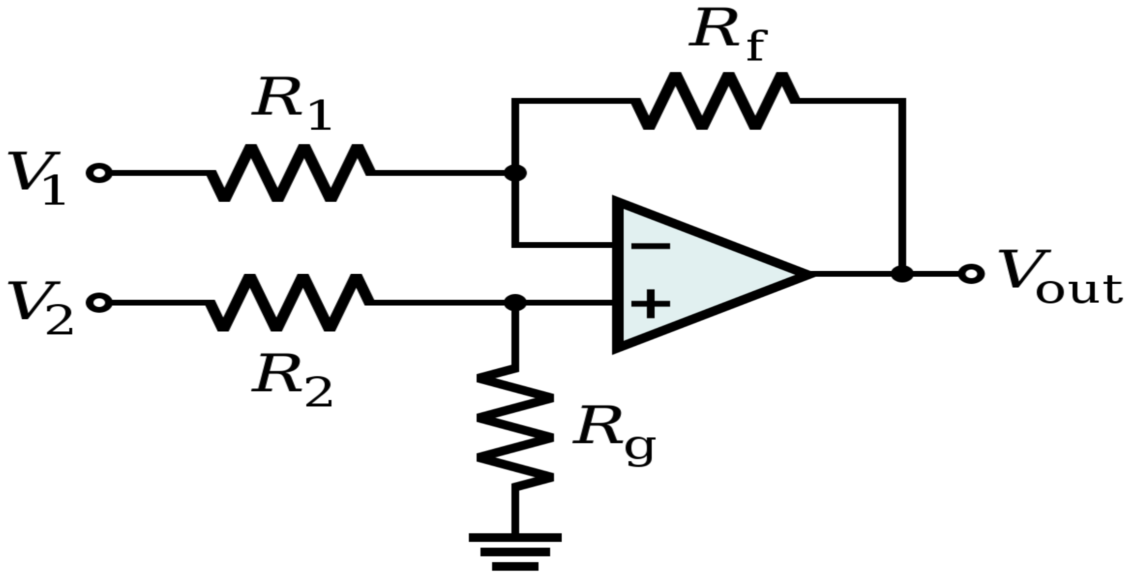


Vout = A (Vin-Vout)

Vin = V+ Vout

$$G = \frac{Vout}{Vin} = 1$$

Differential op-amp

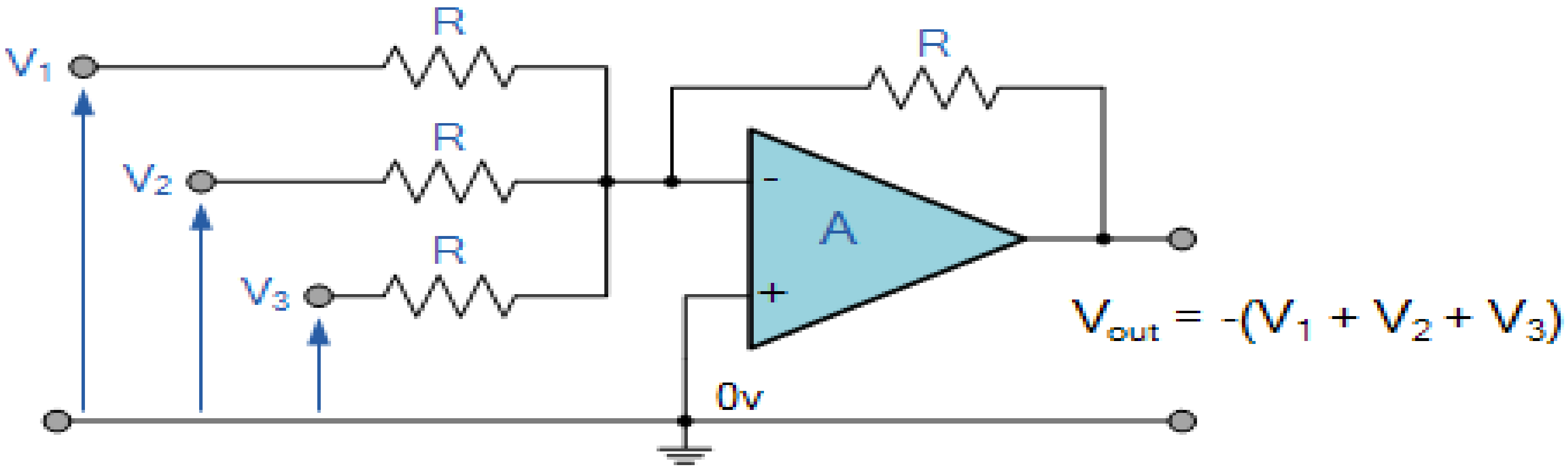


There are **two input signals** so the device will **find the difference** between them and **amplify** the result.

In **the ideal op-amp** if the inputs are equalls the output will be zero.

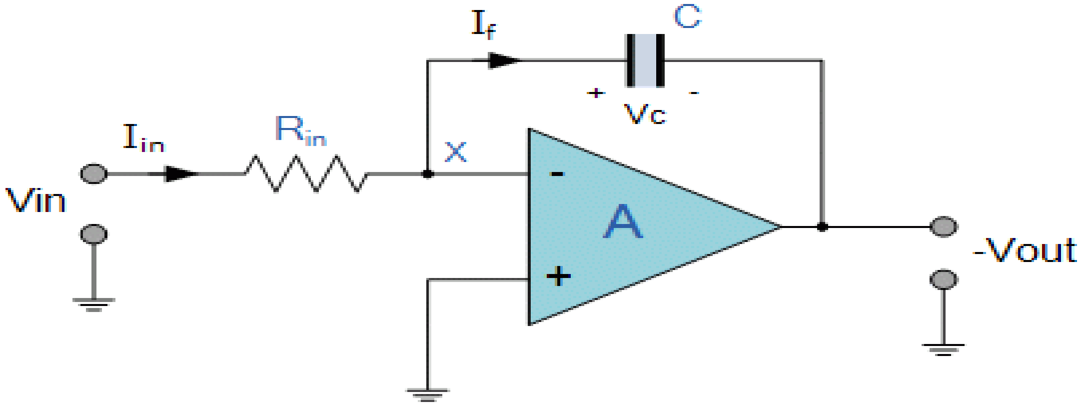
Vout = - $\frac{Rf}{R1}$ (V1-V2)

Summing op-amp



$$\text{Vout} = -\,\text{Rf}\left(\frac{V1}{R1} + \frac{V2}{R2} + \frac{V3}{R3}\right)$$

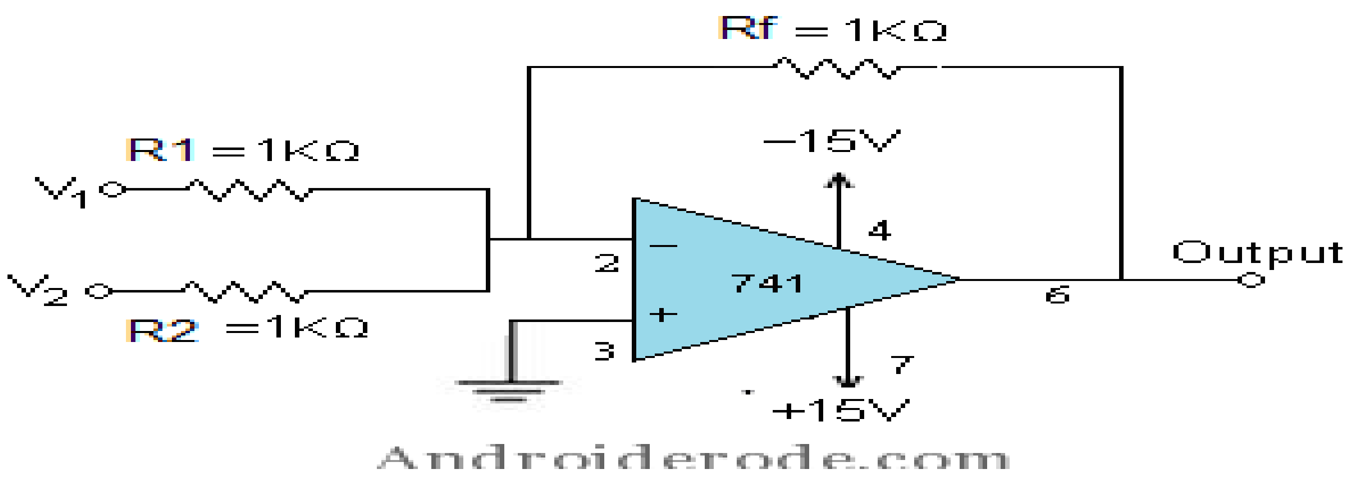
Integrator op-amp



It works to sum the values of input signal through specified time.

Vout = - $\frac{1}{RC}\int Vin\,dt$

Subtractor op-amp

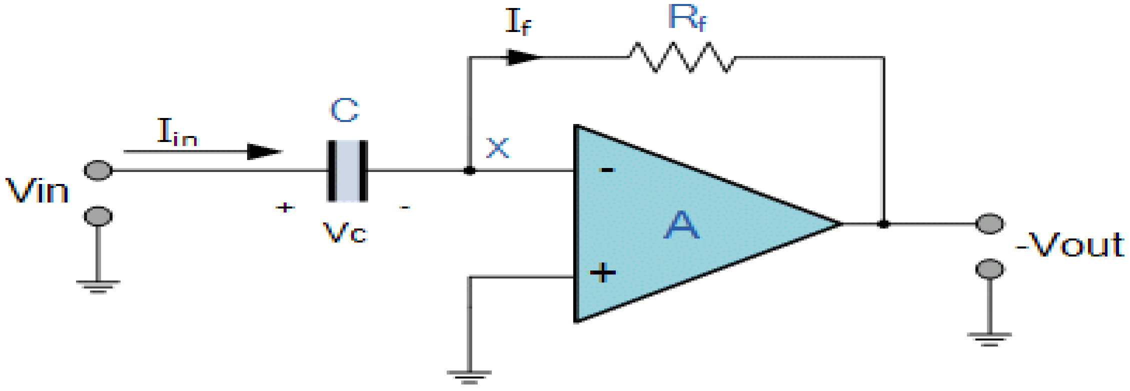


Subtractor is called **difference** operational amplifier which use both the **inverting and non inverting** to produce an output signal which is **proportional to the difference** between **the two input voltages**.

If the input resistances is unequal the circuit becomes a differential amplifier.

Vout = - $\frac{Rf}{R1}$ **(V2-V1)**

Differentiator op-amp



$$\text{Vout} = -\,R_f\,C\,\frac{dVin}{dt}$$

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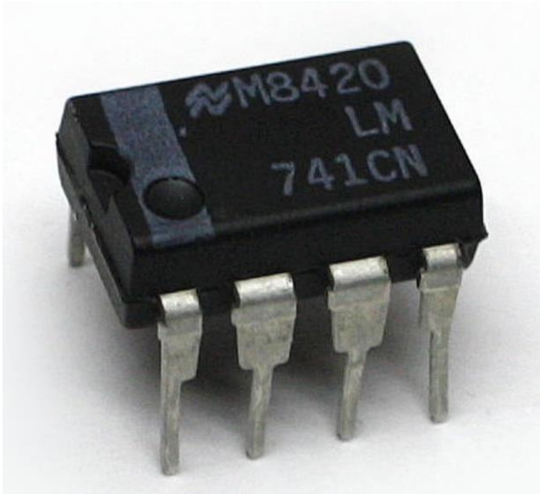
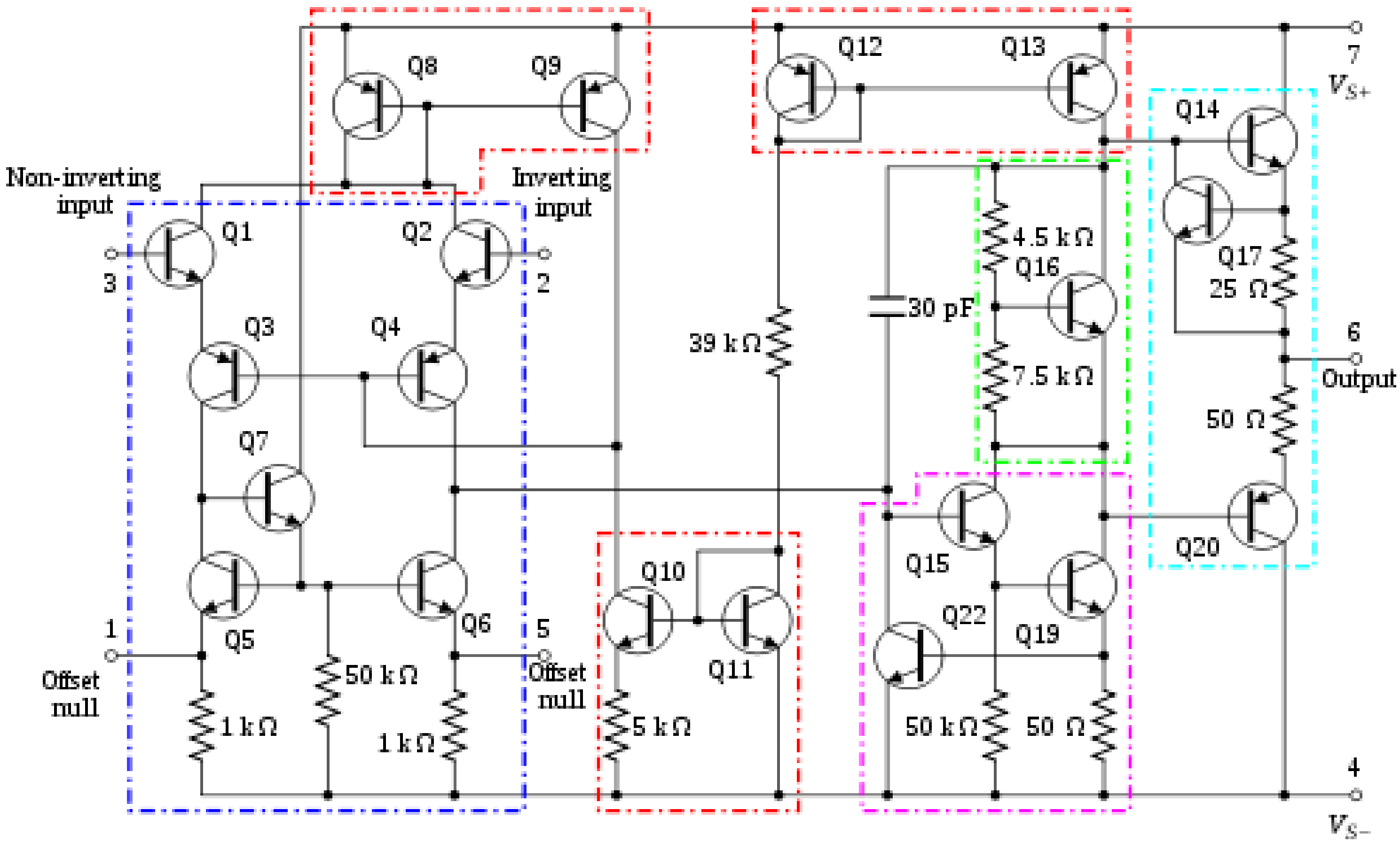
Power Electronic 6

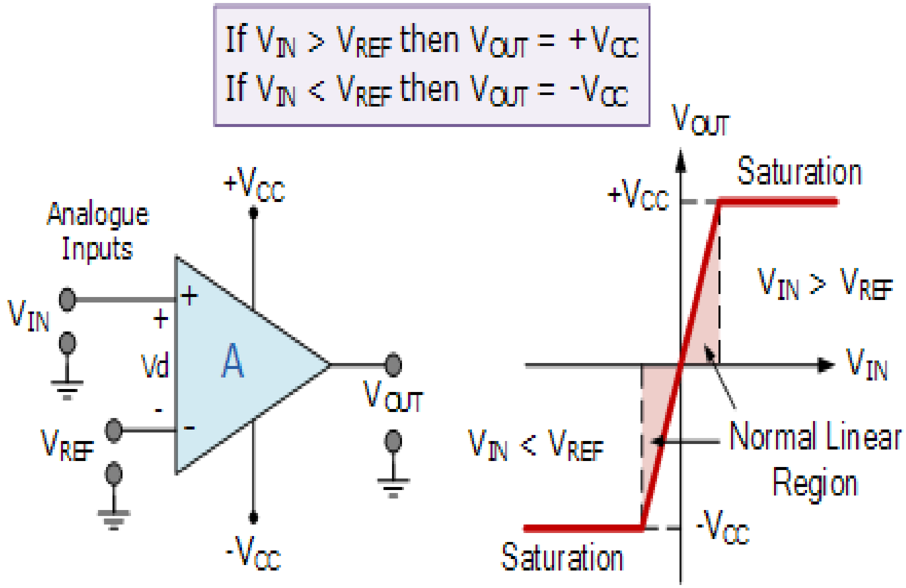
Ass. Teacher Sadeq abdullah



Operational amplifier



Op-amp comparator

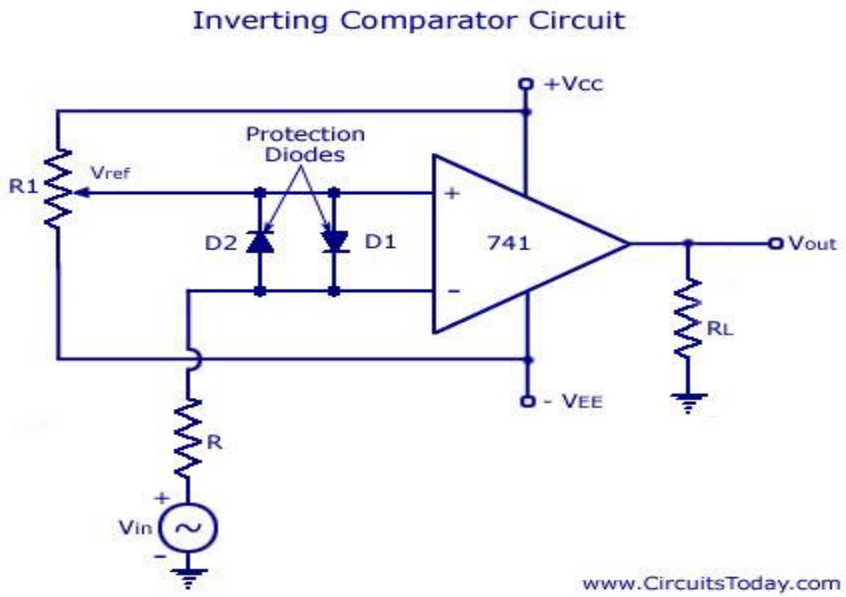


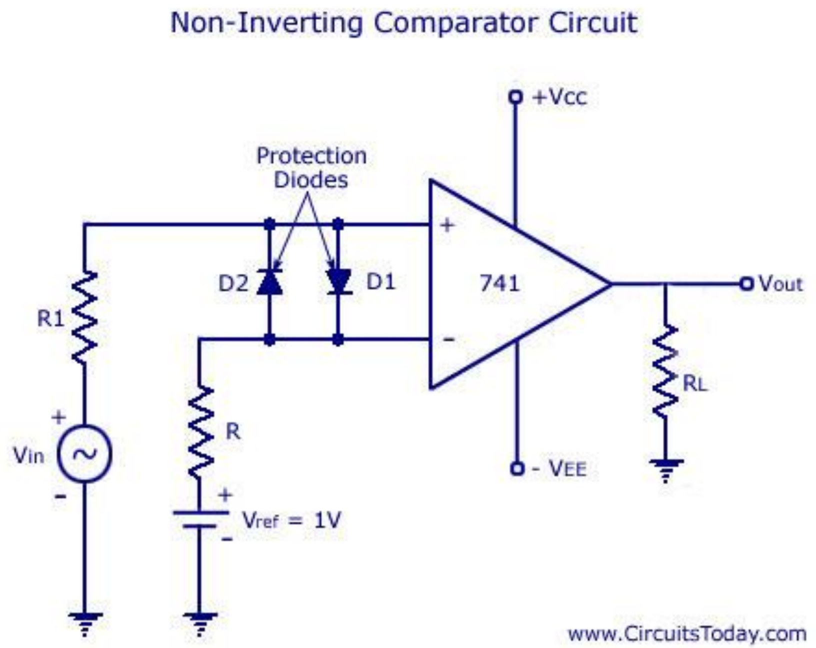
It is important where **two voltages signals are to be compared**, like the design of non sinusoidal waveform generators.

Vin > Vref, the output will change its state.

Vin < Vref, the output will switches back.

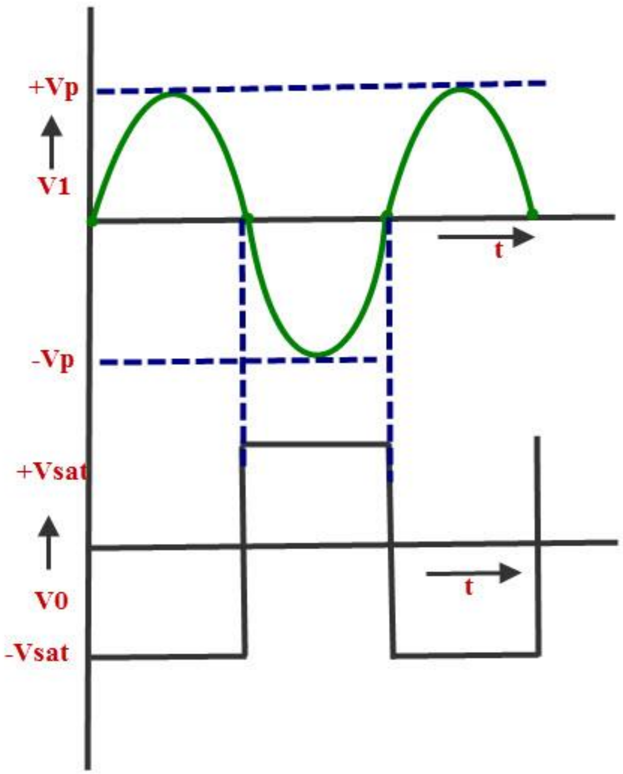
Inverting & Non-inverting Comparator

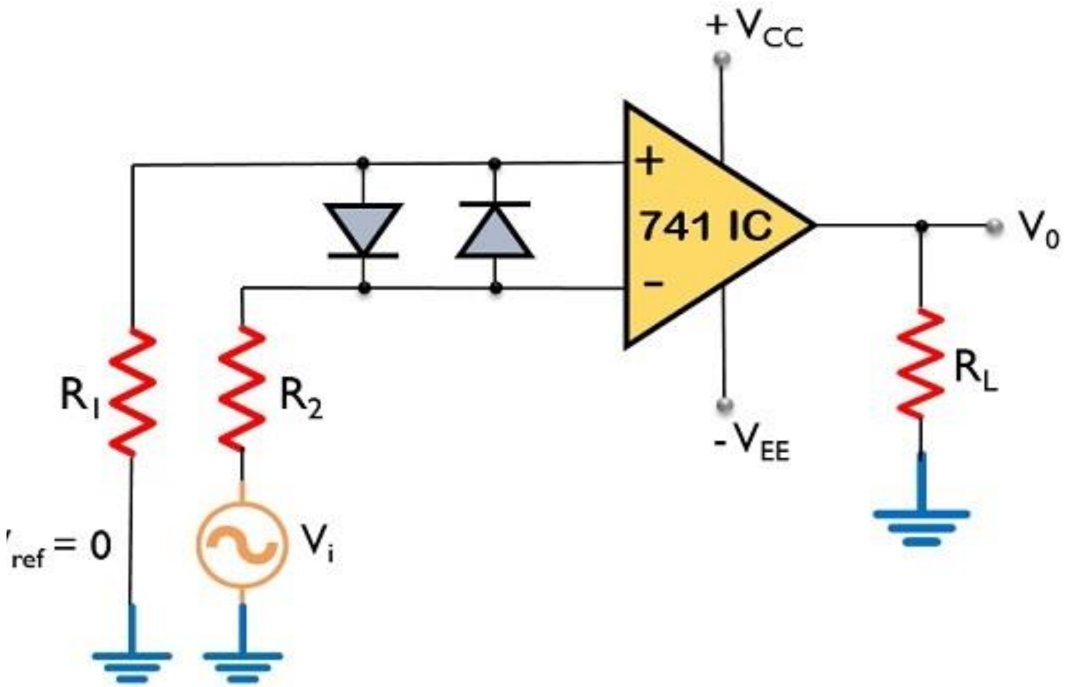




It will **be inverting** when **Vref** at the **positivre input terminal** of the op-amp.
The **non-inverting** when **Vref** at the **negative terminal input** of the op-amp .

Zero crossing detectors
741 IC





Circuit Diagram of Zero-Crossing Detector

It is the op-amp basic comparator with voltage reference Vref = 0

multivibrator

- It is an electronic circuit which be used to implement a variety of simple two states system such (oscillators, timers, flip-flops).

- It characterized by two amplifying devices (transistors) cross coupled by resistors and capacitors.

There are three types of multivibrator circuits:

1- **Astable:** it continuosly **oscillates** from one state to other, that is why **it is not stable** and does not require an **input** (clock pulse).

2- **Monostable:** it has one ***of the states is stable and the other is not*** and the circuit will flip into the unstable state for determined period & eventually will return back to the stable state.

3- **Bistable:** the circuit will remain in either state indefinitely, the circuit can changed just when **external trigger** is applying e.g (register or memory device)

Astable Multivibrator Using Transistors

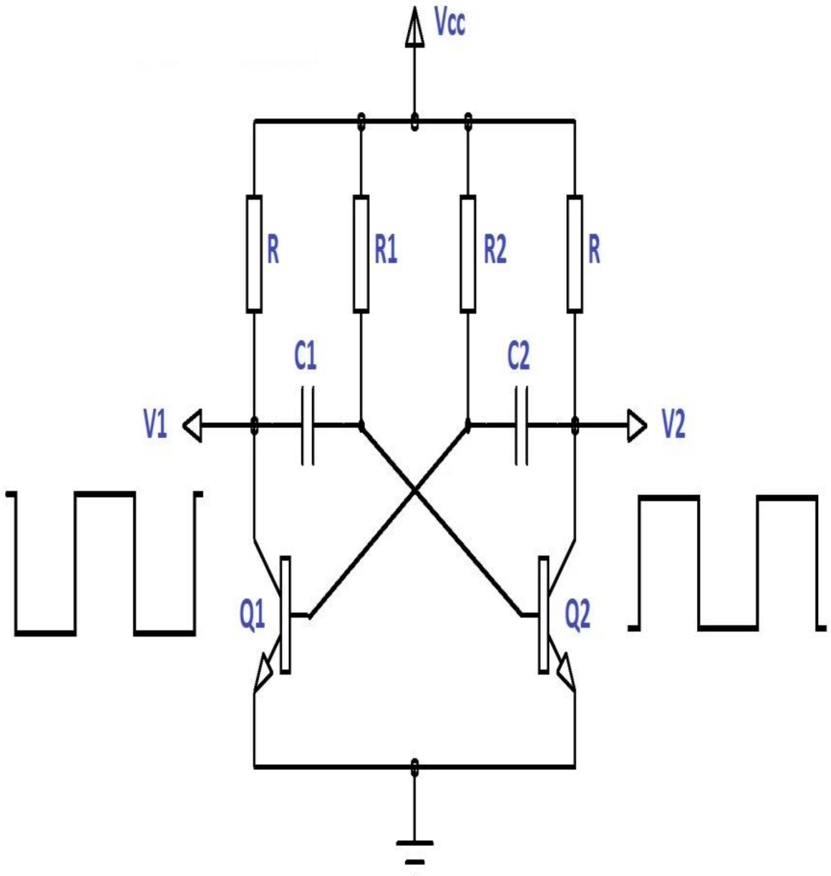
When the transistor is on the collector and the emitter will be short and Vce will be zero, and when it will work as off they will act as open and Vcc will appear on the collector terminal.

When one of the transistors is (ON), the other will be (OFF).

The (OFF) time of the transistor will be determined by time constant RC.

At the beginning time one of the transistors will be more conducting than the other because of the imbalance in the circuit or differences of the parameters of the transistors.

Gradually the more conducting transistor will be driven to saturation and the less conducting to cut-off.



Principle of working

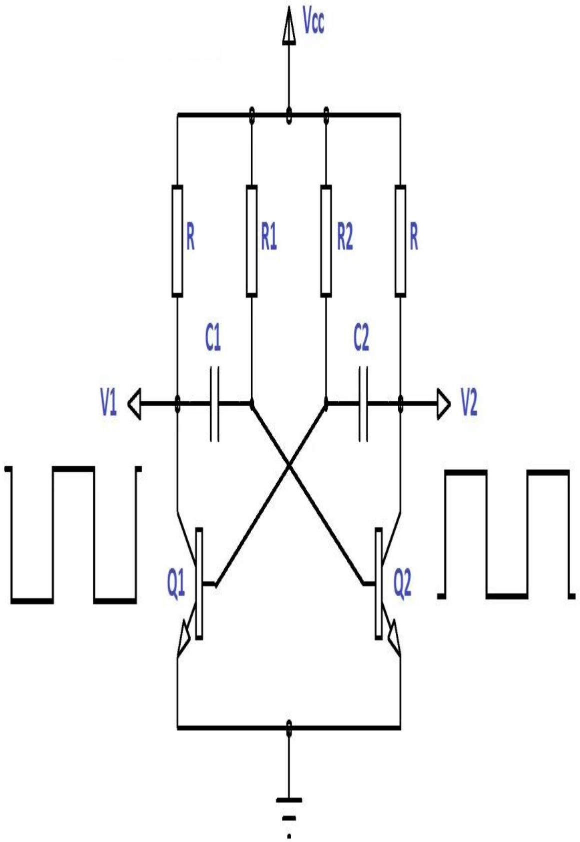
1- when the switch ON, one of the transistor will driven to saturation(ON) and the the other to cut-off (OFF). Suppose Q1 is (ON) & Q2 is (OFF)

2- during this time capacitor **C2** will be charged to Vcc through **resistor R.**

3- **Q2 is OFF** due to the **- ive** voltage from the discharged capacitor **C1** so the off **time duration of** Q2 will be determined by **R_1C_1** time constant.

4- after a time period determined by **R_1C_1** time constant the capacitor **C1** discharges completely & starts charging through **R_1** in reverse direction.

5- when the capacitor **C_1** charges to a voltage sufficient provide base emitter voltage of **0.7** to the transistor **Q2 & capacitor C2** start discharging.

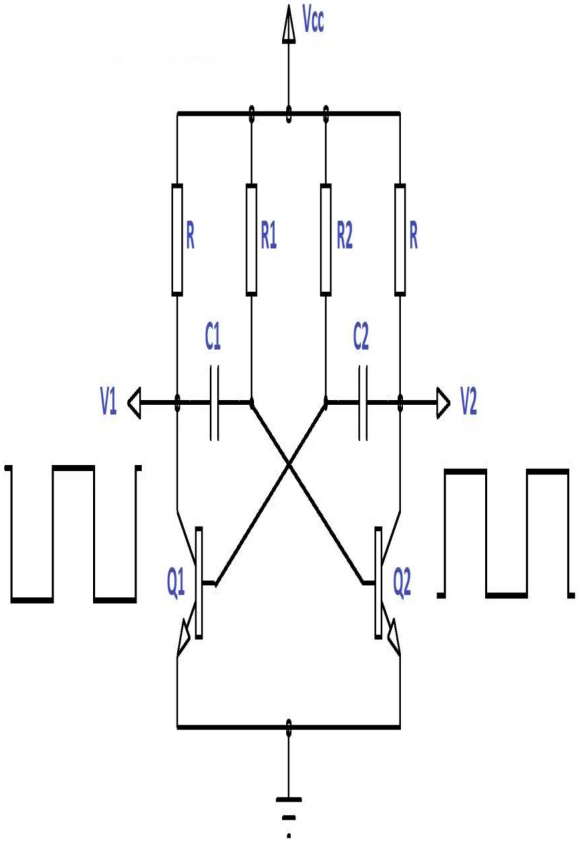


6- **the negative voltage** from the **capacitor C2** turn off the transistor **Q1** and the capacitor **C1** start charging from the **Vcc** through **R**.

7- when **C2** completely **discharged** it starts charging towards opposite direction through **R2**.

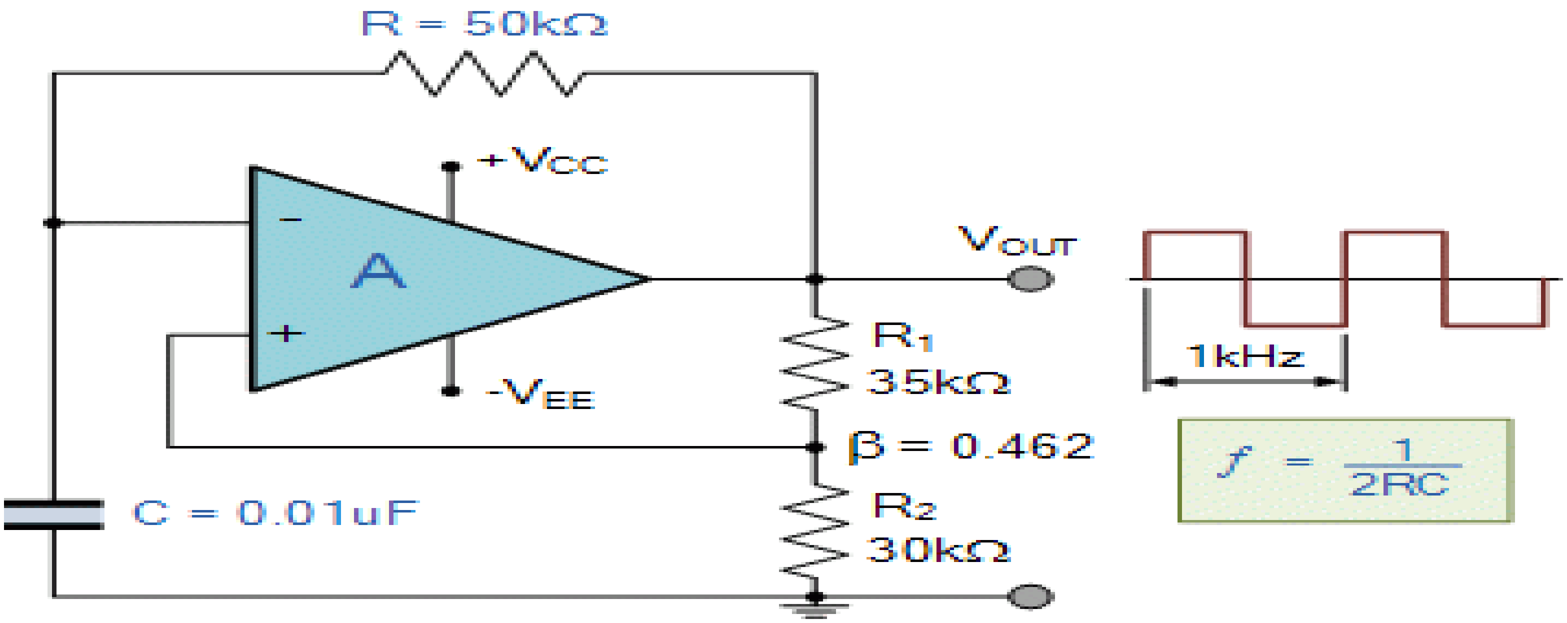
8- when the voltage across **C2** is sufficient to turn on transistor **Q1, Q1** will turn on & **C1** start discharging.

9- this process continuous and produce rectangular waves at the collector of each transistor.



$$F = \frac{1}{1.4\, RC}$$

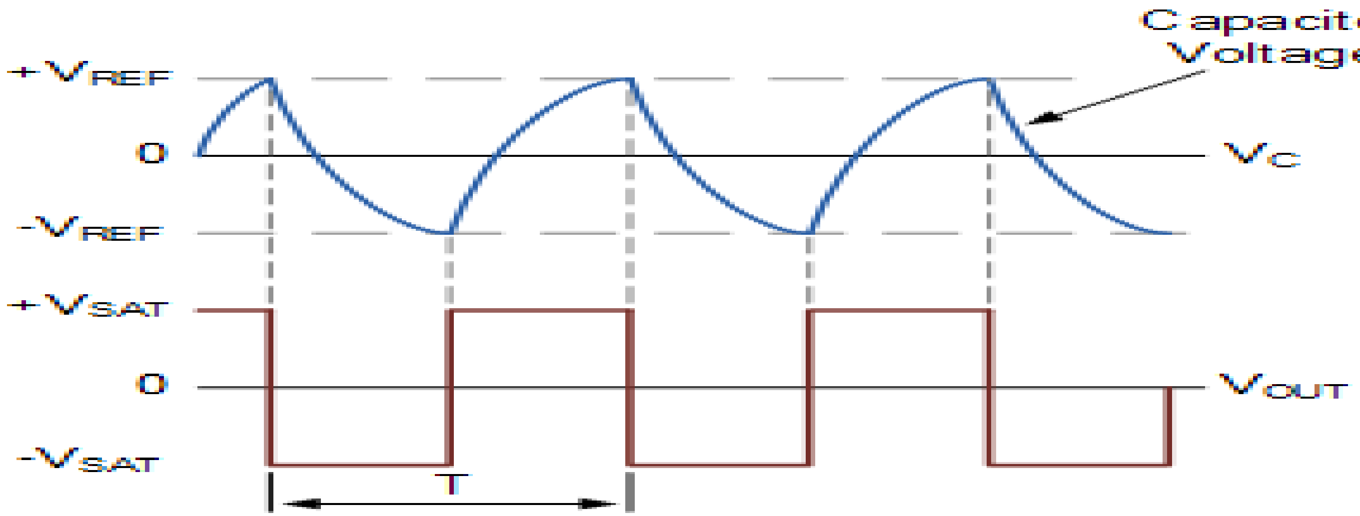
Astable multivibrator using op-amp



The **astable multivibrator** can be made by using transistors or IC such **op-amps.**

The op-amp's will drive to the positive or negative rail.

Principle of working



1- when the capacitor is **fully discharged** op-amp's output is **saturated** at the **positive supply rail**.

2- **the capacitor will start charge up** from the output voltage through resistor R at a rate determined by **RC** time constant.

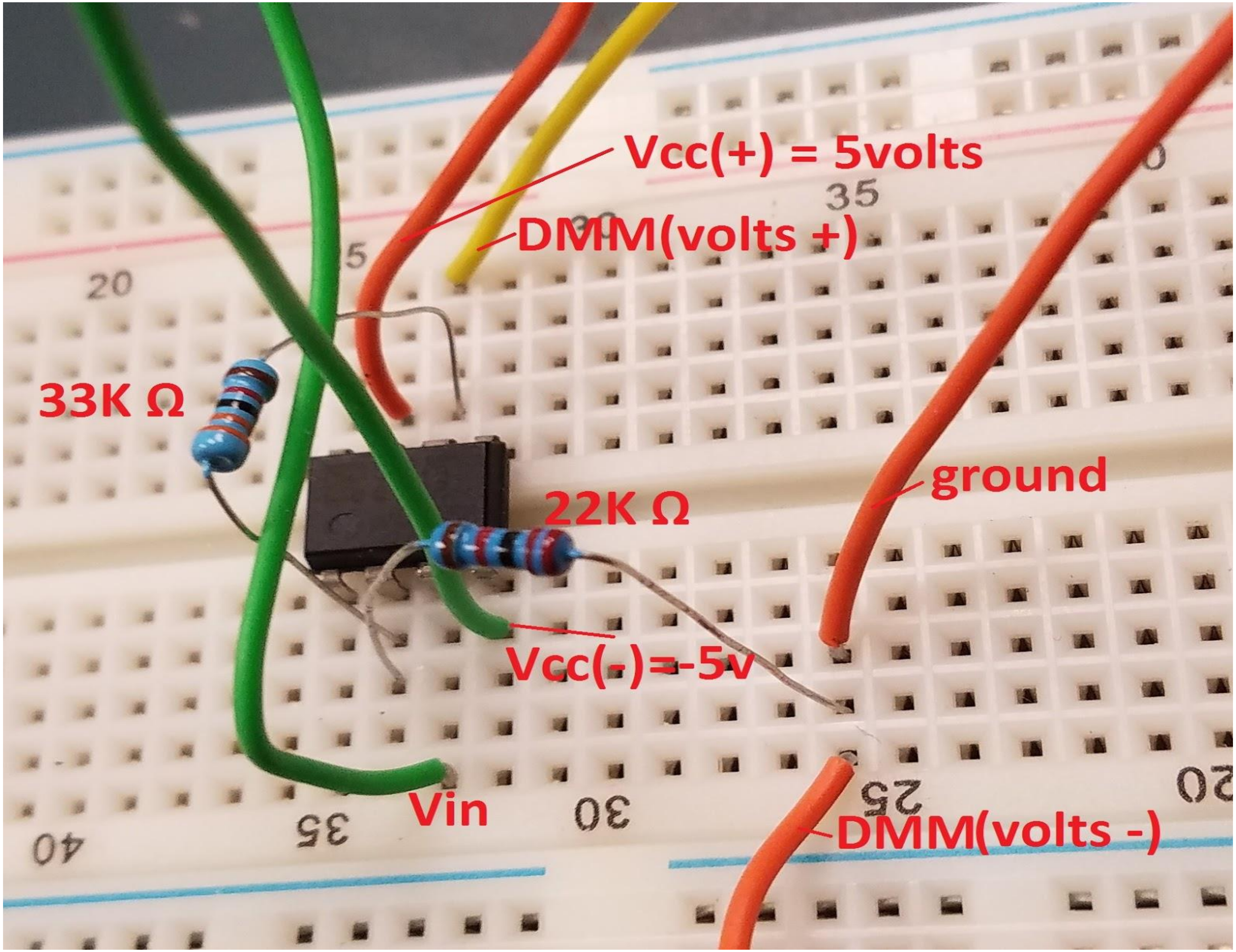
3- as soon as **the charging voltage** at the **inverting op-amp** terminal is **equal** or greater than the **voltage** at **the non-inverting terminal**, the output will change the state and be driven to **opposite negative supply rail.**

4- **The period of the output** is determined by **RC time** constant & **feed back ratio established by R1,R2** voltage divider network which sets **reference voltage level.**

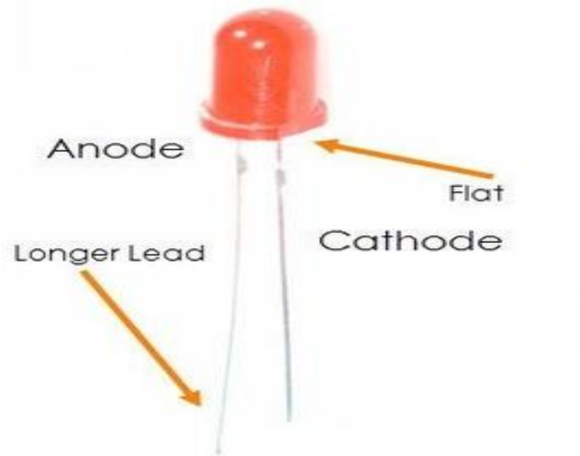
5- if the positive and negative values of the **amplifier saturation voltage** have the same magnitude, **then t1 = t2**, the expression of oscillation period.

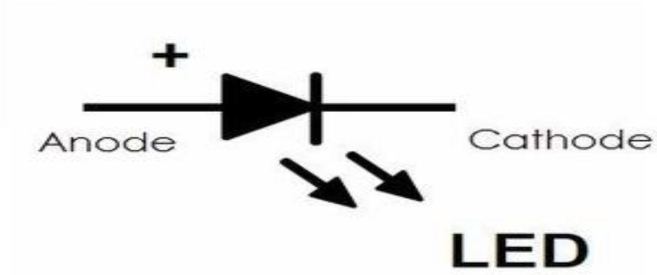
$$\beta = \frac{R2}{R1+R2}$$

$$T = 2RC \ln\frac{1+\beta}{1-\beta}, \quad \therefore f = \frac{1}{T}$$


Vcc(+) = 5volts
DMM(volts +)
33K Ω
ground
22K Ω
Vcc(-)=-5v
Vin
DMM(volts -)

Optoelectronic devices (LEDs)



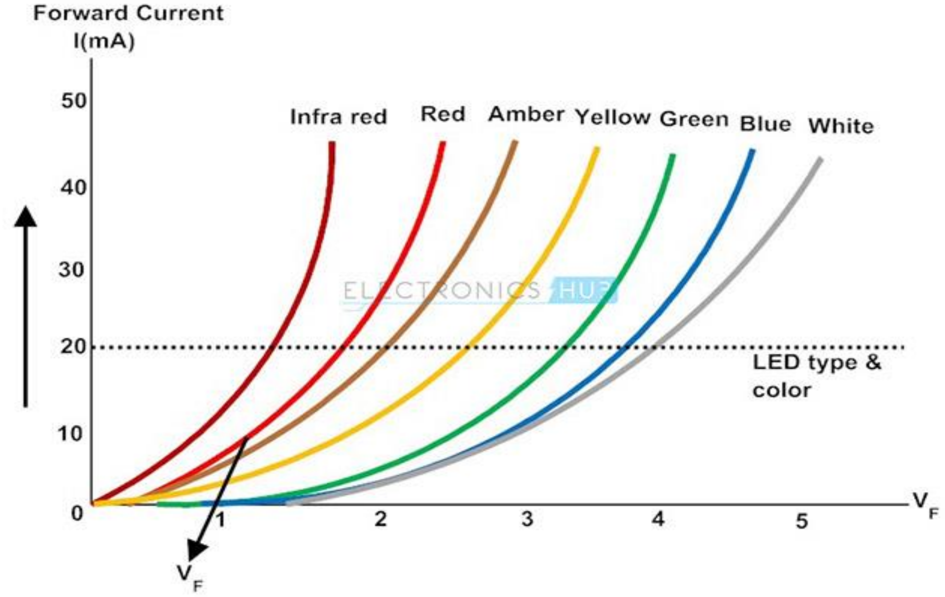


- **A light emitting diode**: it is an semiconductor device that **emits** visible light when electric current passes through it.

- It consist of **two elements** of a processed materials called **p-type** semiconductor and **n-type** semiconductor.

- These two elements are placed in direct contact forming a region called a **p-n junction.**

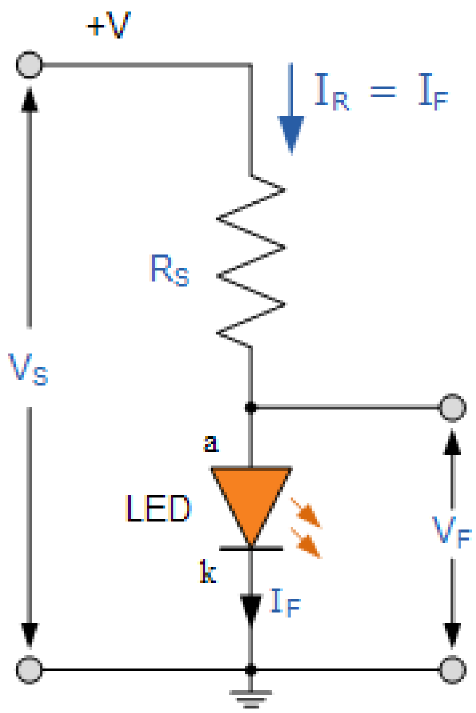
V-I characterstics



The **output** from an **LED** can locate in a **range** from **red** (700 nM wave length) to **blue violet** (400 nM wave length).

Light emitting diode schematic symbol & I-V characteristics curves showing the different colors available.

LED series resistance

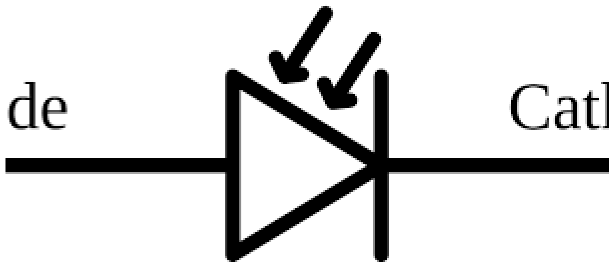


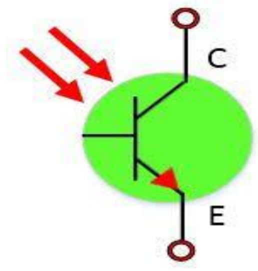
Rs can be calculated using ohm's law when:

- the forward current will be known IF for the LED.
- The supply voltage across the combination Vs.
- The expected forward voltage drop of the LED.
- And the required current level.

$$\mathbf{Rs} = \frac{Vs+VF}{IF}$$

Photo diode & photo transistor





- Optoelectronic device which able to **conduct** a current when exposed to light.

- It is phototransistor but the **phototransistor** is more sensitive to the light & **produce** more current for the same amount of light intensity.

- Phototransistor is made by placing a **photo diode** into the base of NPN transistor, when the light falling on the diode it will lead to change the transistor's state to be **ON** & **cause collector current** to be amplified.

- Phototransistor can be PNP and photodiode at **base- collector circuit.**

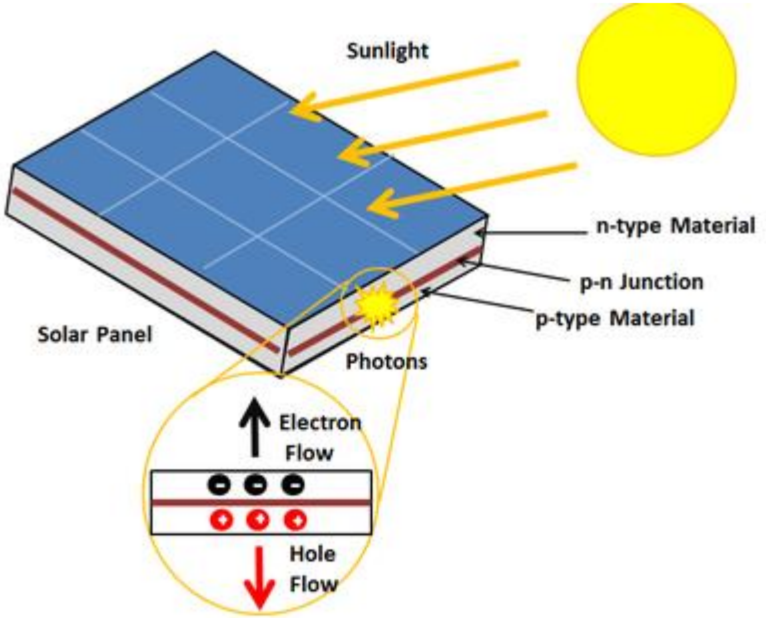
Photovoltaic cell or solar cell

-It is an **electronic device** which converts **light energy** into electrical energy.

- **The symbol** is similar to that of **battery** when exposed to the light and **produce a voltage** across its terminal.

- It can be connected in **series** or **parallel** to increase **voltage** or **current**.

- The device is widely used as a **power device** at solar powered homes and satellites applications.



Lecture no. 7

Ass. lecturer Sadeq Abdullah

Solar panel types

- **SOLAR PANELS** are used to collect solar energy from the sun and convert it into electricity.

- The typical **SOLAR PANEL** is composed of individual solar cells, each of which is made from layers of silicon, boron and phosphorus.

- When the sun's photons strike the surface of the panel, it knocks out electrons from the silicon "sandwich" and into the electric field generated by the solar cells.

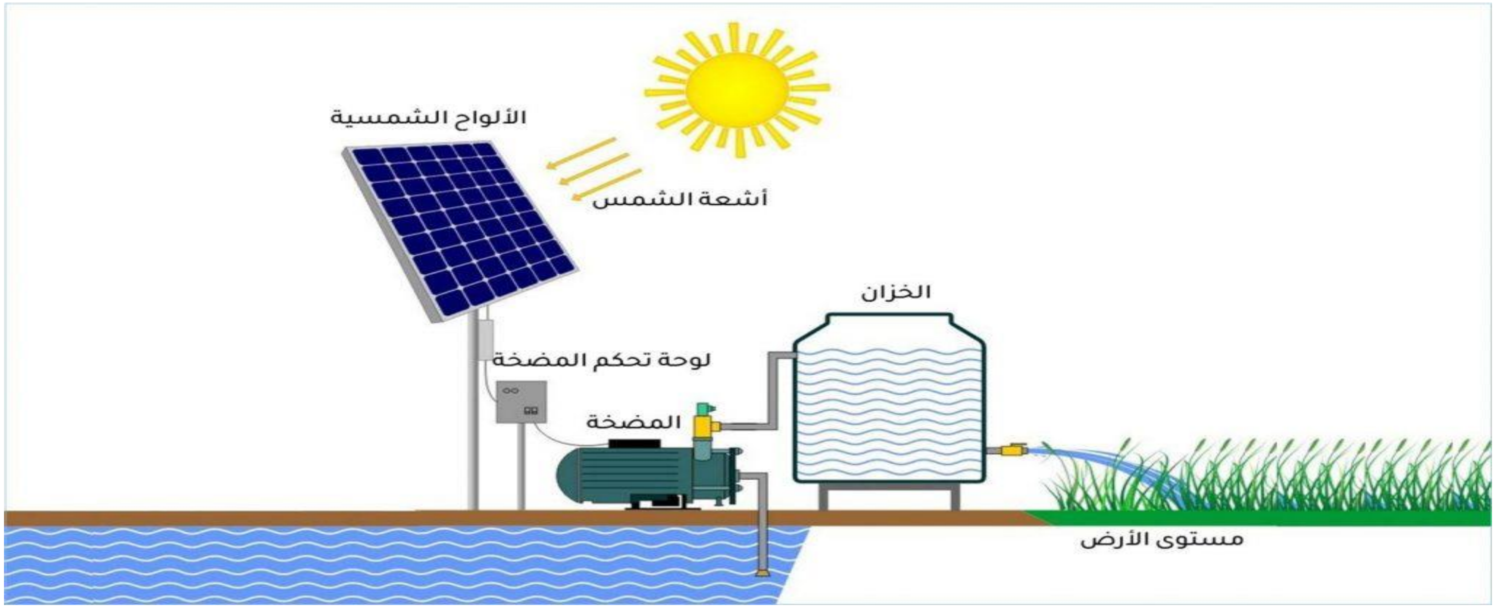
Monocrystalline solar panels

- Also known as single-crystal panels, these are made from a single pure silicon crystal that is cut into several wafers.
- Since they are made from pure silicon, they can be readily identified by their dark **BLACK COLOR.**

Polycrystalline solar panels

- As the name implies, these come from different silicon crystals instead of one. The silicon fragments are melted and poured into a square mold.

Types of solar grids



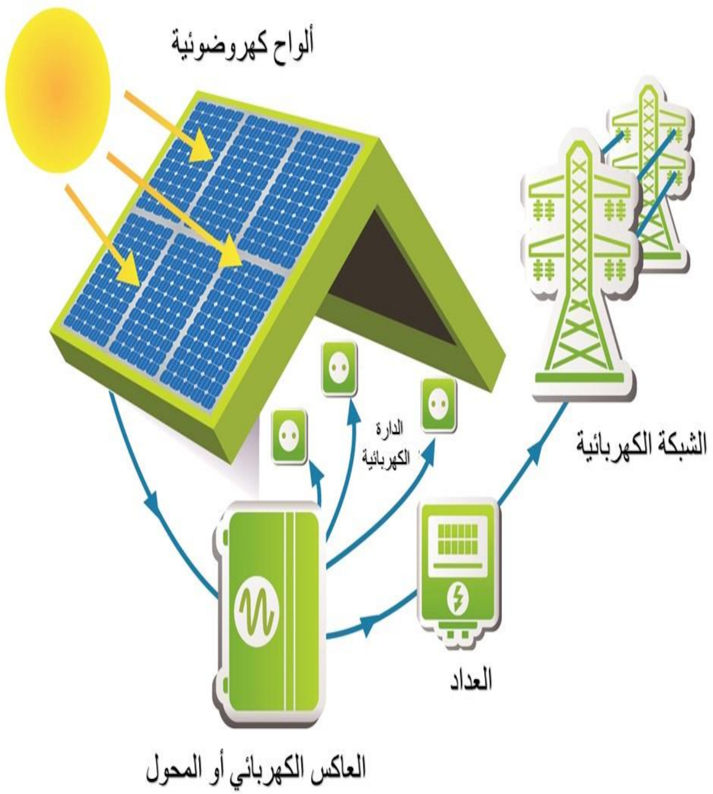
A- off-grid

complete packages for large scale projects. Homes that want to generate the majority of their energy through solar power to minimize running costs.

B- on-grid

- An on-grid or grid-tied solar system is a system that works along with the grid.

- This means that any excess or deficiency of power can be fed to the grid through net metering.



Solar system design (the components)

1- solar panel
2- battery charger
3- inverter
4- battery

Solar panel connection methods

A- **SERIES**: the current will be the same to all panels
B- **PARALLEL**: the voltage will be the same of all panels

Solar PV system sizing

Example: A house has the following electrical appliance usage:

- One 18 Watt fluorescent lamp with electronic ballast used 4 hours per day.
- One 60 Watt fan used for 2 hours per day.
- One 75 Watt refrigerator that runs 24 hours per day with compressor run 12 hours and off 12 hours.
- The system will be powered by 12V dc, 110 Wp PV module.

- **1.** The first step in designing a solar PV system is

Determining a power consumption demands

Total appliance use = (18 W x 4 hours) + (60 W x 2 hours) + (75 W x 24 x 0.5 hours)
= 1,092 Wh/day

Total PV panels energy needed = 1,092 x 1.3
= 1,419.6 Wh/day.

- **Note: 1.3 represent the power losing in the wiring and circuit breaker systems**

EX: to install a solar power system in our home for a total load of 800W where the required backup time of battery is 3 hours.

SOL:

Load = 800 Watts

Required Backup time for batteries = 3 Hours

1) Inverter / UPS Rating:

Inverter / UPS rating should be greater than 25% of the total load (for the future load as well as taking losses in consideration)

800 x (25/100) = **200W**

Our Load + 25% Extra Power = 800+200 = **1000 Watts**

- 2) Required No of Batteries

- **the required Back up Time of batteries in Hours = 3 Hours**

  to install **100Ah, 12 V batteries**,

  12V x 100Ah = 1200 Wh

  Now for one **Battery** (i.e. the Backup time of one battery)

  1200 Wh / 800 W = 1.5 Hours

  But our required Backup time is 3 Hours.Therefore, 3/1.5 = 2
- i.e. we will have to connect two (2) batteries each of 100Ah, 12V.

- Backup Hours of Batteries
- use this formula to calculate the backup hours of batteries.

1200 Wh x 2 Batteries = **2400 Wh**

2400 Wh / 800 W = **3 hours.**

- I) first scenario: we will use 12V inverter system, therefore, we will have to connect two (2) batteries (each of 12V, 100 Ah) in Parallel. But a question raised below:

Series or Parallel Connection for Batteries?

Why Batteries in Parallel, not in Series?

- Because this is a 12V inverter System, so if we connect these batteries in series instead of parallel, then the rating of batteries become $V_1 + V_2$ = 12V + 12V = 24V while the current rating would be same i.e.100Ah.
- That’s why we will connect the batteries in parallel, because the Voltage of batteries (12 V) remains same, while its Ah (Ampere Hour) rating will be increased. i.e. the system would become = 12V and 100Ah +100Ah = 200Ah.

- We will now connect 2 batteries in parallel (each of 100Ah, 12V)
- i.e. 2 12V, 100Ah batteries will be connected in Parallel
- = 12V, 100Ah + 100Ah = 12V, 200 Ah (Parallel)

3) Charging Current for Batteries

- Now the **Required Charging Current** for these two **batteries**.
  (Charging current should be 1/10 of batteries Ah)
  200Ah x (1/10) = **20A**

- Charging Time required for Battery
- Here is the formula of Charging Time of a Lead acid battery.
  Charging Time of battery = Battery Ah / Charging Current
  T = Ah / A
- For example, for a single 12V, 100Ah battery, The charging time would be:
  T = Ah / A = 100Ah / 10A = 10 Hrs (Ideal Case)

- due to some losses, (it has been noted that 40% of losses occurred during the battery charging), this way, we take 10-12 A charging current instead of 10 A, this way, the charging time required for a 12V, 100Ah battery would be:

100Ah x (40/100) = 40 (100Ah x 40% of losses)

- the battery rating would be 100Ah + 40 Ah = 140 Ah (100Ah + losses)

Now the **required charging current for the battery** would be:

140Ah / 12A = 11.6 Hours.

3) Required No of Solar Panels (Series or Parallel)

- **Scenario 1: DC Load is Not Connected = Only Battery Charging**

We know the famous power formula (DC)

P = VI ………… (Power = Voltage x Current)

- Putting the values of batteries and charging current.

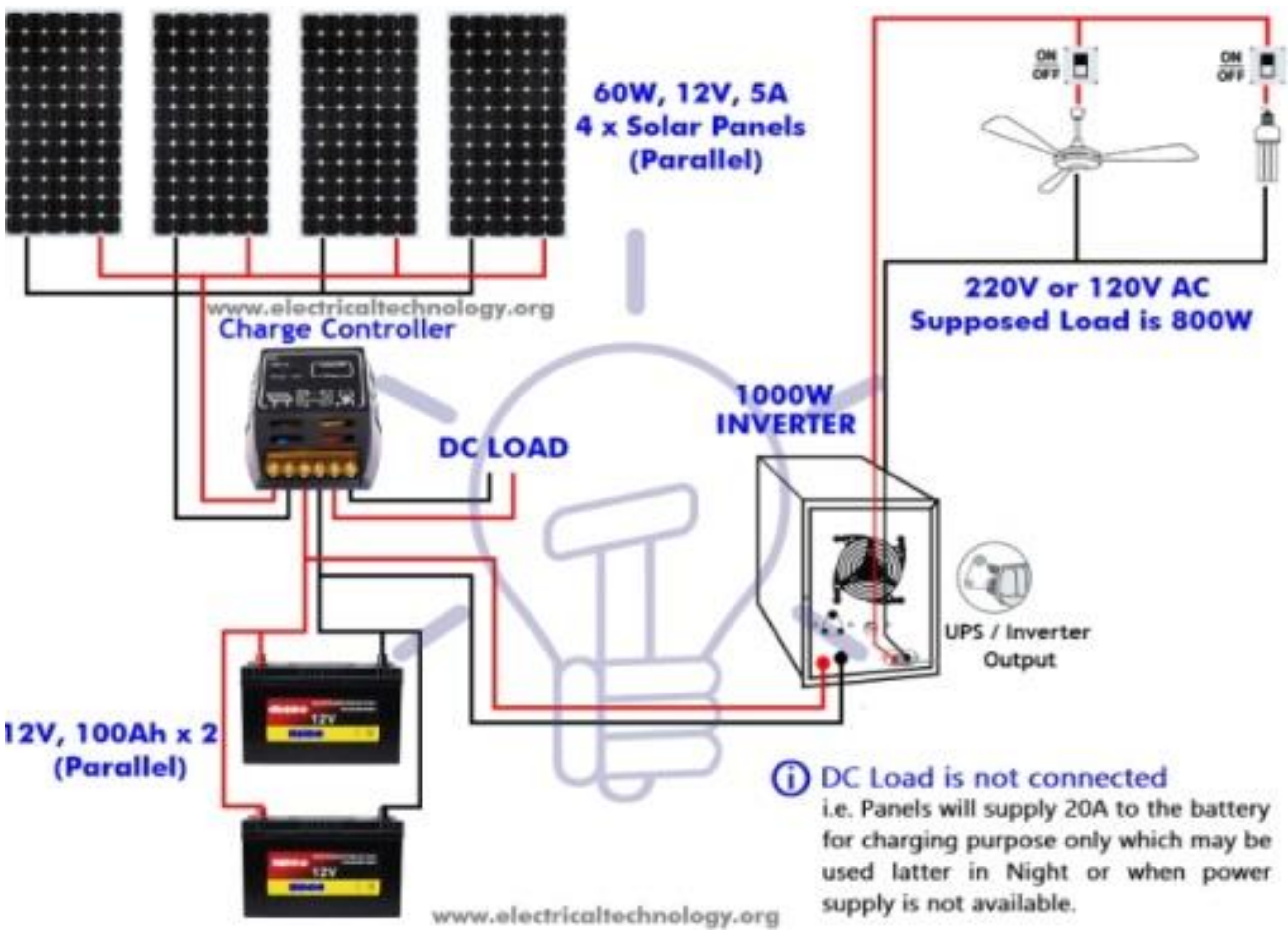
P = 12V x 20 A

P = **240 Watts**

these are the required wattage of solar panel (only for battery charging, and then battery will supply power to the load i.e. direct load is not connected to the solar panels)

240W/60W = 4 No. of Solar panels

Therefore, we will connect 4 Solar Panels (each of 60W,12V,5A) in parallel


60W, 12V, 5A
4 x Solar Panels
(Parallel)
www.electricaltechnology.org
Charge Controller
DC LOAD
1000W
INVERTER
ON
OFF
ON
OFF
220V or 120V AC
Supposed Load is 800W
UPS / Inverter
Output
12V, 100Ah x 2
(Parallel)
12V
12V
DC Load is not connected
i.e. Panels will supply 20A to the battery for charging purpose only which may be used latter in Night or when power supply is not available.
www.electricaltechnology.org

- **Scenario 2: DC Load is Connected as well as Battery Charging**

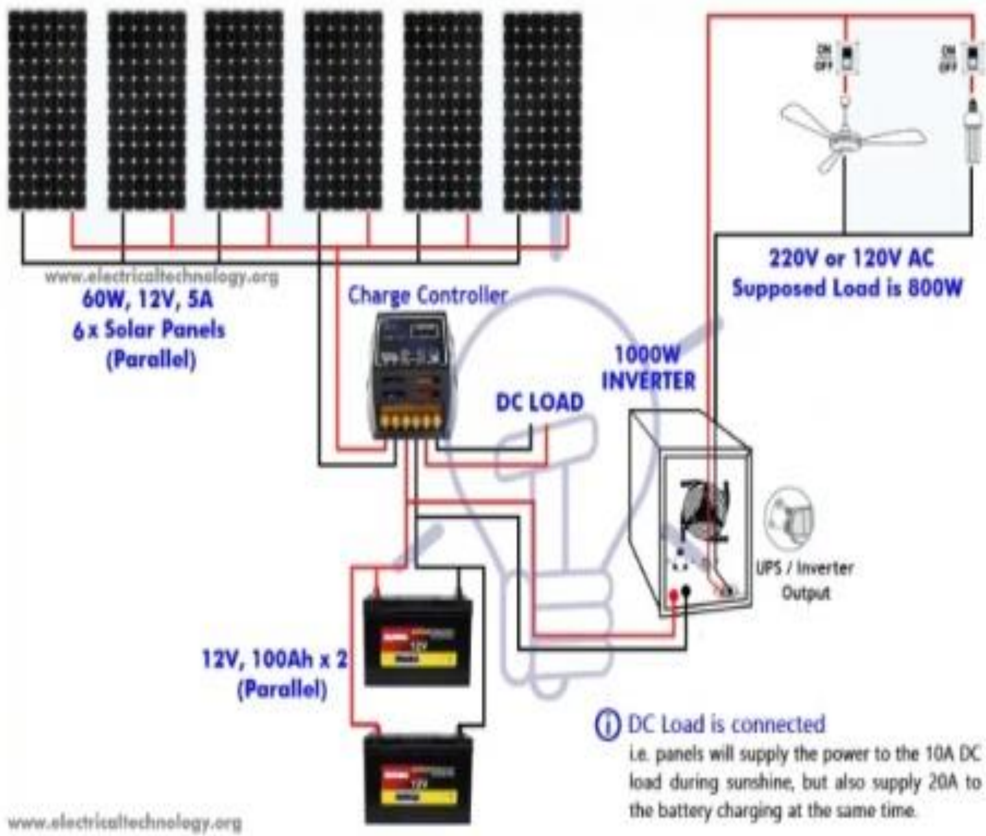
- Now suppose there is a 10A directly connected load to the panels through inverter (or may be DC load via Charge Controller). During the sunshine, the solar panel provide 10A to the directly connected load + 20A to the battery charging i.e. solar panels charge the battery as well as provide 10A to the the load as well.

- In this case, the total required current (20 A for Batteries Charging and 10 A for directly connected load)

- In this case above, total required current in Amperes,
- **20A + 10 A = 30A**
- Now, I = 30 A, then required Power

P = V x I = 12V x 30A = 360 Watts

- I.e. we need 360 W system for the above explained system (This is for both Direct Load and Batteries Charging)
- Now, the number of solar panels we need
- 360/60W = **6 Nos of Solar Panels**
- Therefore, we will Connect **6** Nos of **Solar panels in parallel (each of 60W, 12V,5A)**


www.electricaltechnology.org
60W, 12V, 5A
6 x Solar Panels
(Parallel)
Charge Controller
DC LOAD
1000W
INVERTER
220V or 120V AC
Supposed Load is 800W
UPS / Inverter
Output
12V, 100Ah x 2
(Parallel)
DC Load is connected
i.e. panels will supply the power to the 10A DC load during sunshine, but also supply 20A to the battery charging at the same time.
www.electricaltechnology.org

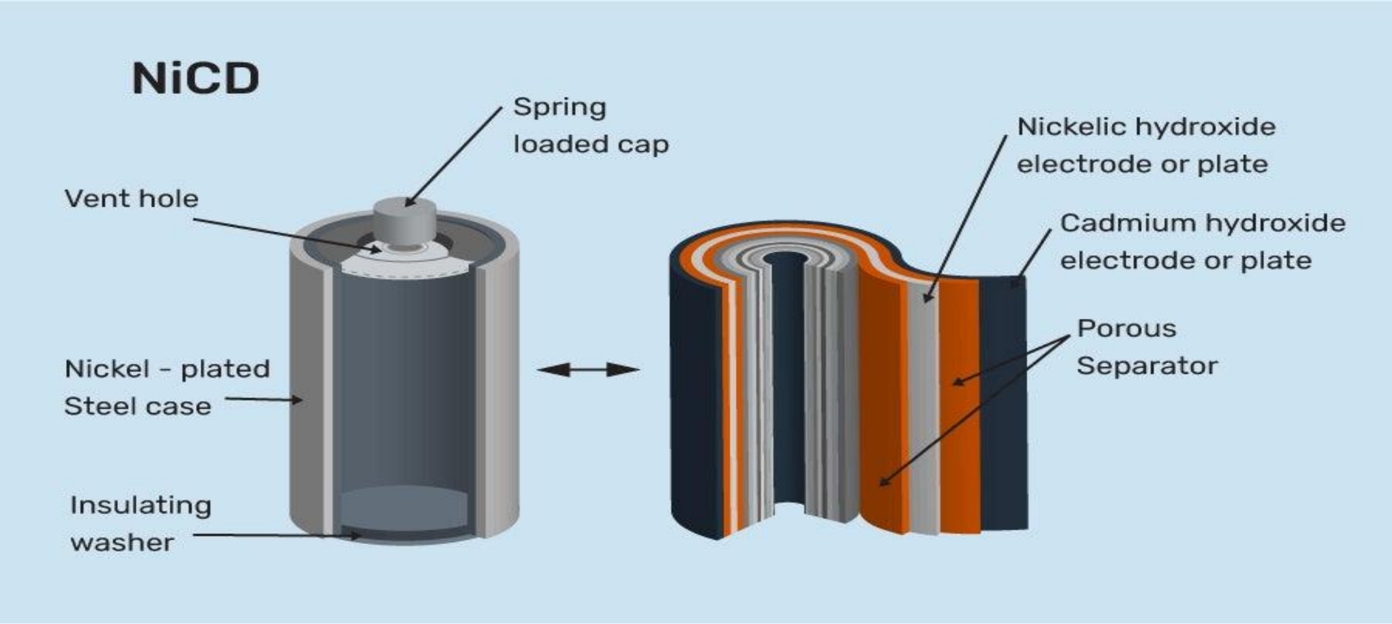
Battery types of solar system

1) LEAD ACID

- The common automobile batteries in which the electrodes are grids of metallic lead-containing lead oxides that change in composition during charging and discharging.

2) LITHIUM

- Lithium batteries have many advantages over traditional battery types. **They have an extremely long cycle life and high discharge and recharge rates.**



3) NICAD (NICKEL CADMIUM)

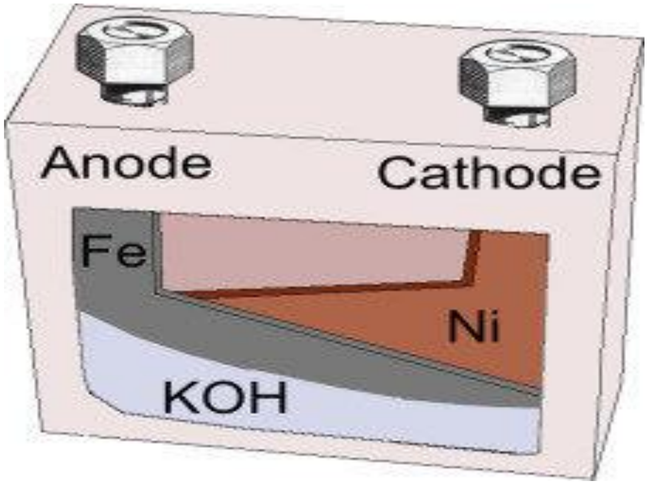
- Alkaline storage batteries in which the positive active **material is nickel** oxide and **the negative** contains **cadmium**.

Downsides:

- Very expensive
- Very expensive to dispose of - Cadmium is considered VERY hazardous.
- Low efficiency (65-80%)

4) NIFE (NICKEL IRON)

- Energy storage density = 55 watts per kilogram



Downsides:

- Low efficiency - may be as low as 50%, typically 60-65%. Very high rate of self-discharge
- high gassing/water consumption
- high internal resistance means you can get large voltage drops across series cells.
- high specific weight/volume

Classification of Inverter

(I) According to the Output Characteristic

- Square Wave Inverter
- Sine Wave Inverter
- Modified Sine Wave Inverter

(II) According to the Source of Inverter

- Current Source Inverter
- Voltage Source Inverter

- **(III) According to the Type of Load**
- Single Phase Inverter
  – Half Bridge Inverter
  – Full Bridge Inverter

- Three Phase Inverter
  – 180-degree mode
  – 120-degree mode

(IV) Classification According to Control Techniques

- Single Pulse Width modulation (single PWM)

- drawback of this technique is high harmonic content.

- Maximum power point tracking (MPPT)

- Harmonic is less compare to (pwm) so it is more usable.

Solar system connection

Refrences

1. https://www.leonics.com/support/article2_12j/articles2_12j_en.php

2. https://www.solar-electric.com/learning-center/battery-types-for-solar-electric-systems.html/

3. https://circuitdigest.com/tutorial/different-types-of-inverters

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قسم تقنيات الكهرباء

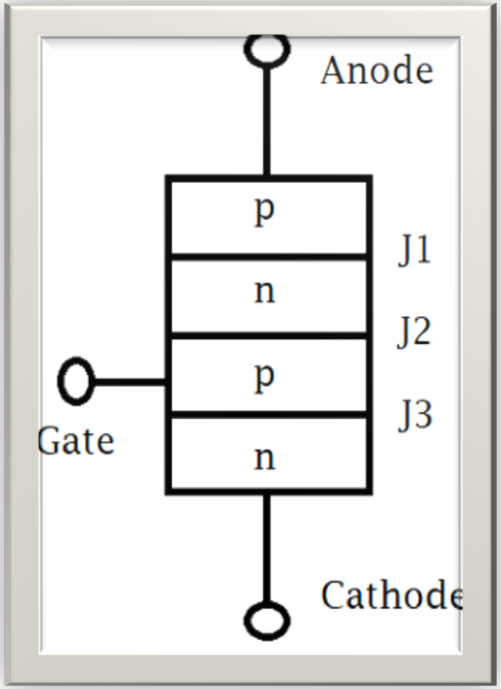
Lecture 8

Ass. Teacher sadeq abdullah

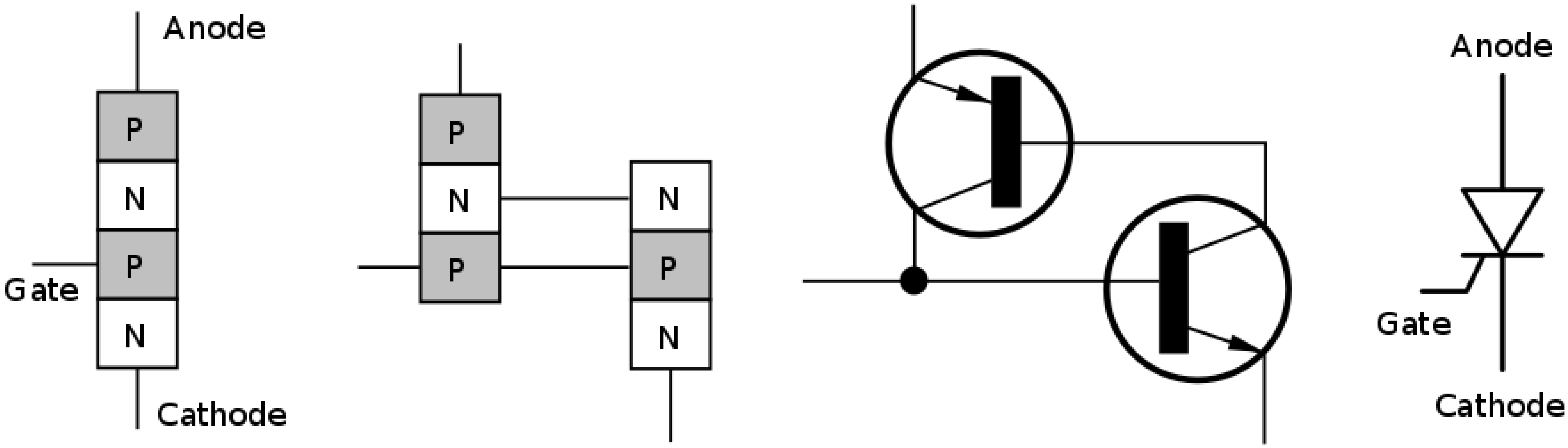
Thyristor

It is a **solid state semi conductor device** with **four layers** of alternating P-type and n-type materials.it **has three terminals**, anode **A**, cathode **K** and Gate **G**.

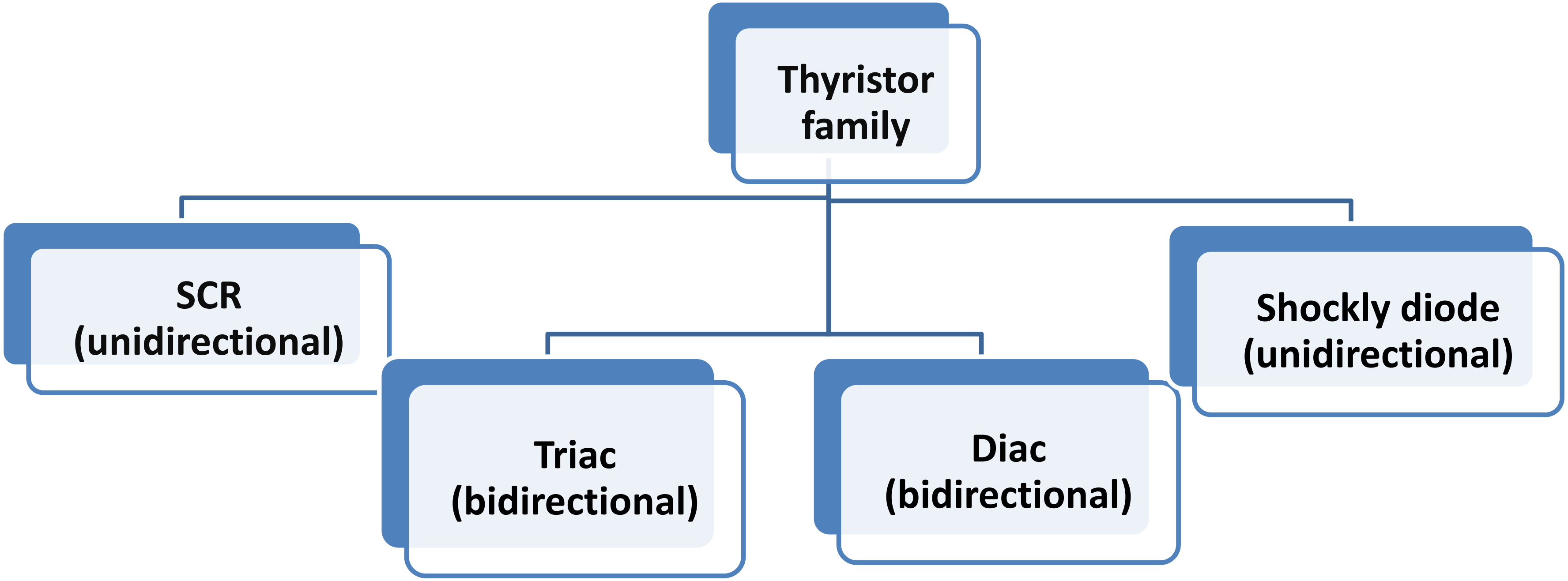
It acts exclusively as a bistable switch, conducting when the gate receives a current trigger, and continuing to conduct until the voltage across the device is reversed biased, or until the voltage is removed (by some other means).

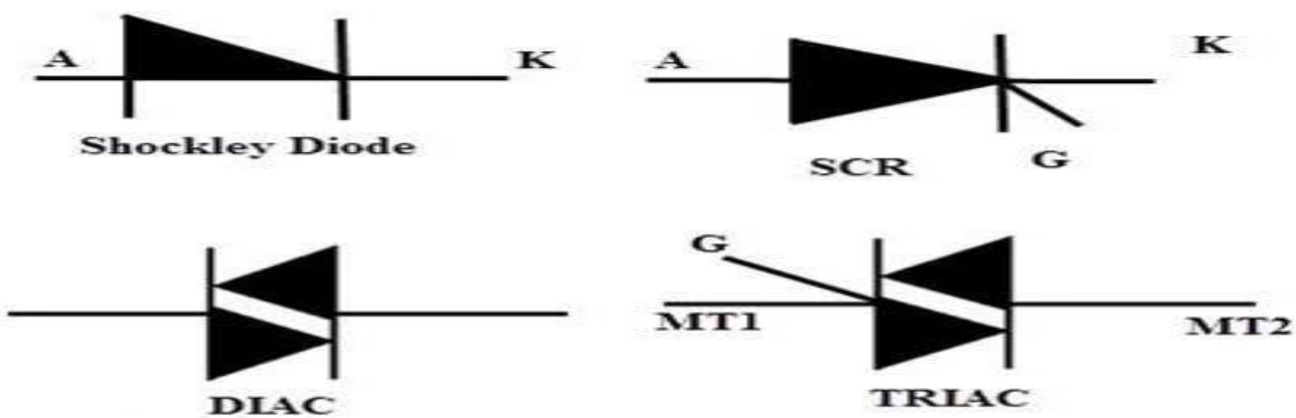


Two transistor model of SCR



There are two designs, differing in what triggers the conducting state. In a three-lead thyristor, a small current on its Gate lead controls the larger current of the Anode to Cathode path.


Thyristor family
SCR (unidirectional)
Triac (bidirectional)
Diac (bidirectional)
Shockly diode (unidirectional)


A
K
Shockley Diode
A
K
SCR
G
DIAC
G
MT1
MT2
TRIAC

Silicon controlled rectifier (SCR)

- SCR : it is a semiconductor device which it is a member of the thyristor's family and it represent **main segment in the industrial control.**

- SCR is a three terminals device: anode, cathode & gate. It is represent a **rectifier which can be controlled**.

- Once when the gate trigger (on) ,the device will start conducting even after removing trigger signal.

- The load to be controlled place in the anode circuit.

I-V characterstics

- Reverse & forward blocking

- Forward conducting

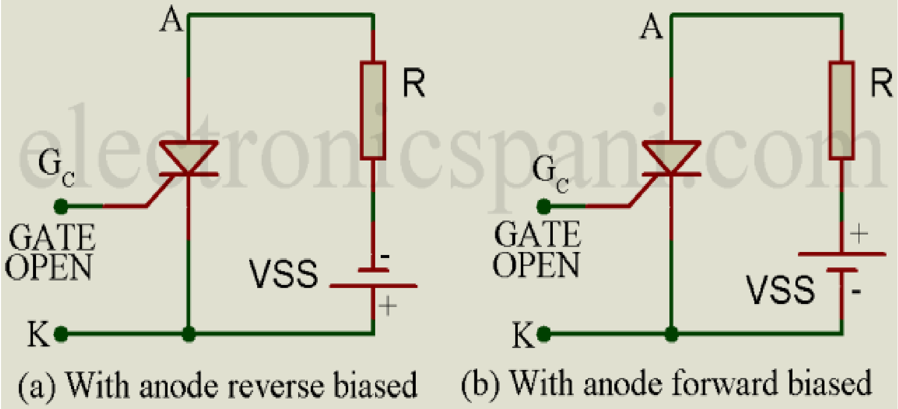
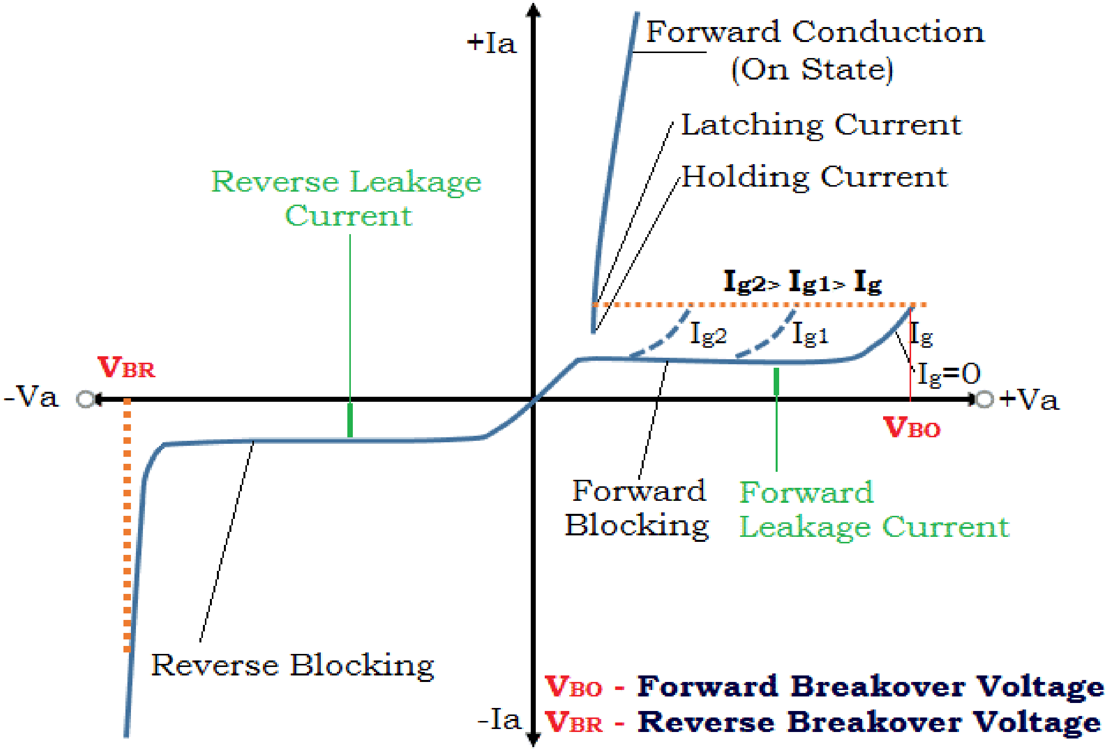


Figure 2: SCR with anode reverse and forward biased



Turning the SCR ON triggering

- The turning "ON" process of the SCR called triggering. It is mean turning SCR from forward-blocking state to forward conduction state.

Methods of thyristor turn ON:

1- Forward **voltage** triggering.

2- **Thermal** or **temperature** triggering.

3- **Radiation** or **light** triggering.

4- **dv/dt** triggering.

5- **Gate** triggering.

Forward voltage triggering

- Forward-voltage triggering **occurs** when the **anode–cathode forward voltage** is increased with the **gate** circuit **opened**.

- This is known as **avalanche breakdown**, during which junction **J2** will break down.

- At sufficient voltages, the thyristor changes to its **ON** state with low voltage drop and large forward current. In this case, **J1 and J3** are already **forward** biased.

- otherwise forward-voltage triggering may **occur**, a single small positive voltage pulse can then be applied between the **gate** and **the cathode**. This supplies **a single gate current** pulse that turns the thyristor to its on state. In practice, this is the most common method used to trigger a thyristor.

Thermal triggering

- The reverse leakage current depends on **the temperature**. If the temperature is **increased** to a certain value, the number of **hole-pairs** also increases. This causes to increase the **leakage current** and further it increases **the current gains** of the **SCR**. This starts the **regenerative action** inside the SCR since the (α1 + α2) value approaches to unity (as the current gains increases).

- By increasing the **temperature at junction J2** causes the **breakdown** of the junction and hence it **conducts**. This triggering occur in some circumstances particularly when it the **device temperature is more** (also called false triggering). This type of triggering is practically not employed because it causes the thermal runaway and hence the device or SCR may be **damaged.**

Light Triggering

- An SCR turned ON by light radiation is also called as Light Activated SCR (LASCR). This type of triggering is employed for phase controlled converters in HVDC transmission systems. In this method, light rays with appropriate wavelength and intensity are allowed to strike the junction J2.

- These types of SCRs are consisting of a niche in the inner p-layer. Therefore, when the light struck on this niche, electron-hole pairs are generated at the junction J2 which provides additional charge carriers at the junction leads to turn ON the SCR.

dv/dt Triggering

- In forward blocking state junctions **J1 and J3** are **forward biased** and **J2 is reverse biased**. So the junction **J2** behaves as a capacitor (of two conducting plates J1 and J3 with a dielectric (J2) due to the space charges in the depletion region. The charging current of the capacitor is given as

$$I = C\, dv/dt$$

- where **dv/dt** is the **rate of change** of applied voltage **and C** is the junction capacitance.

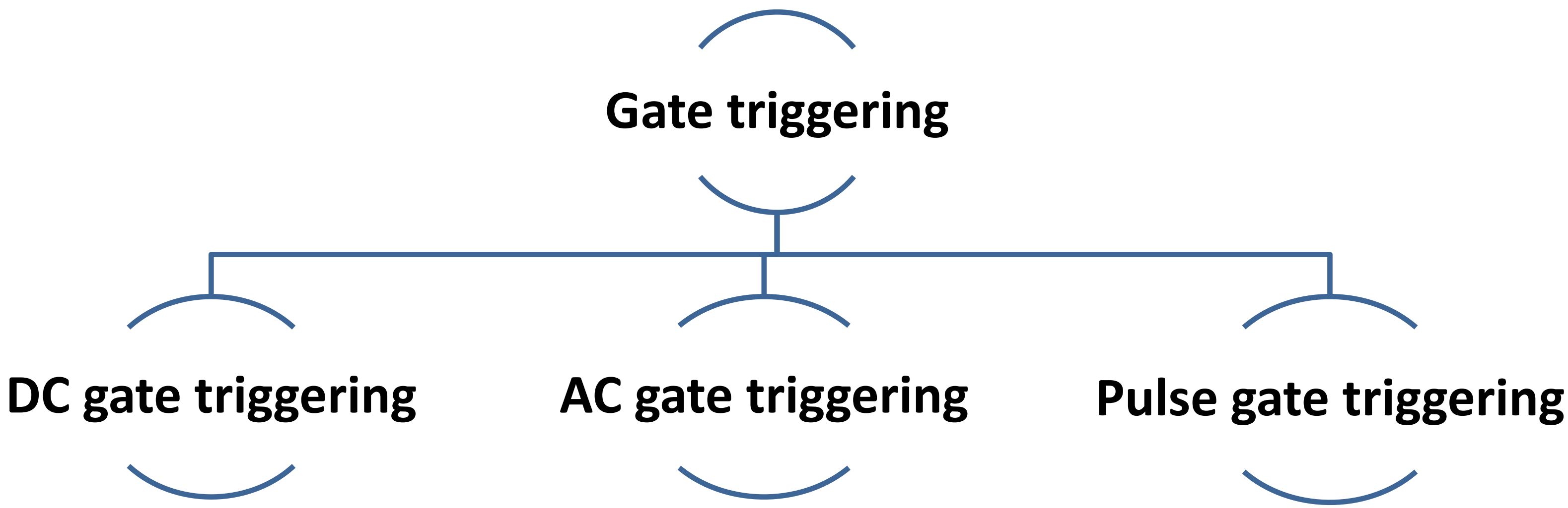
- From the above equation, if the rate of change of the applied voltage **is large** that leads to increase the charging current which is enough to increase the value of alpha. **So the SCR becomes turned ON without a gate signal.**

- However, this method is also practically **avoided** because it is **a false turn ON** process and also this can produce **very high** voltage spikes across the SCR so there will **be considerable damage to it**

Gate triggering

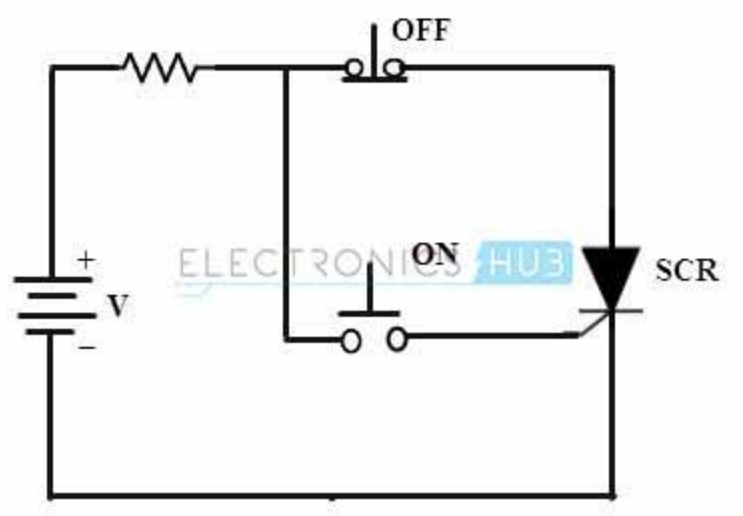
- The common method which widely used to trigger the SCR.
- Applying a positive voltage between the gate and the cathode which can turn **ON** the forward biased thyristor.
- When that voltage applied to the gate, charge carriers will be injected to p-layer & that will lead to decrease the depletion layer.

• Gate triggering methods:



DC gate triggering

By applying a **proper dc voltage** between the gate and cathode, where the gate will be **positive** with respect to cathode.



- When the applied voltage is enough to supply gate's current, the device will start conducting.

- The drawbacks:

1- both power & control circuit are DC and no insulation between them.

2- continues DC signal has to be applied, so Gate loss power is high.

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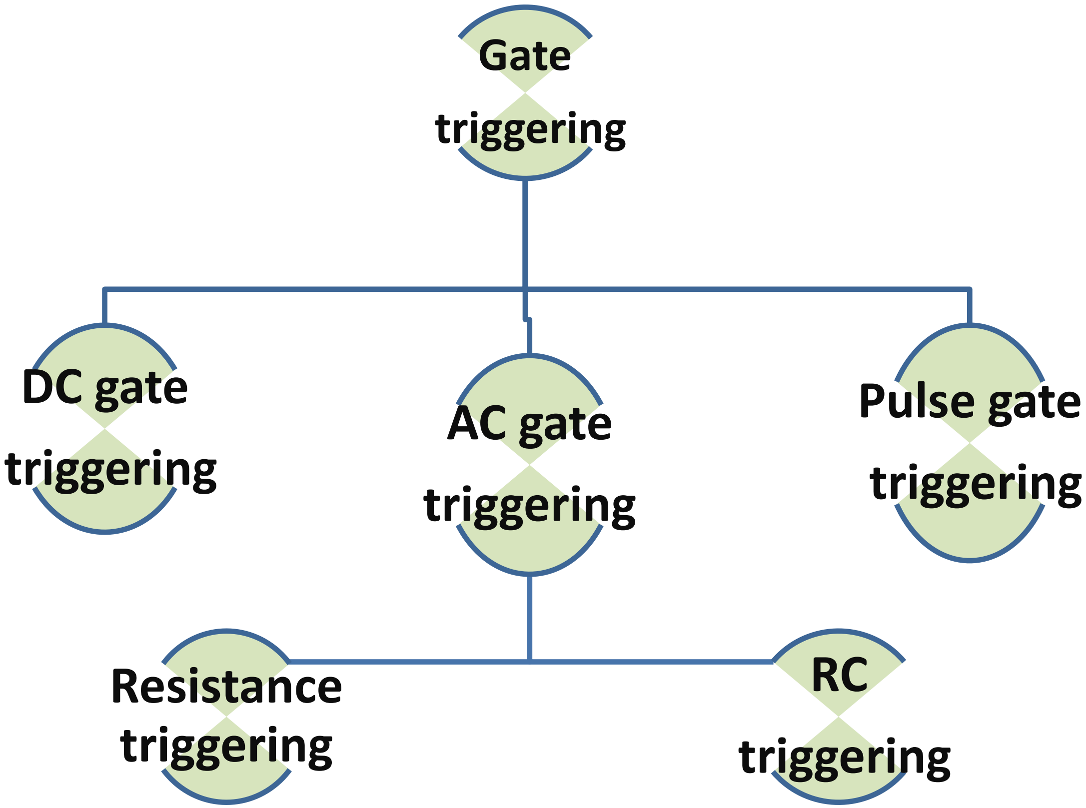
قسم تقنيات الكهرباء

Lecture 9

Ass. Teacher Sadeq Abdullah

Thyristor gate triggering method



AC gate triggering

- AC source will be used for **gate's signals**.
- This technique will provide a proper **insulation** between **the power** & **control circuit**.
- Here a **step-down** transformer is required to ac **supply** and that will represent a **draw back**.
- There are two triggering methods in this technique: **resistance & RC triggering**.

a) Resistance triggering

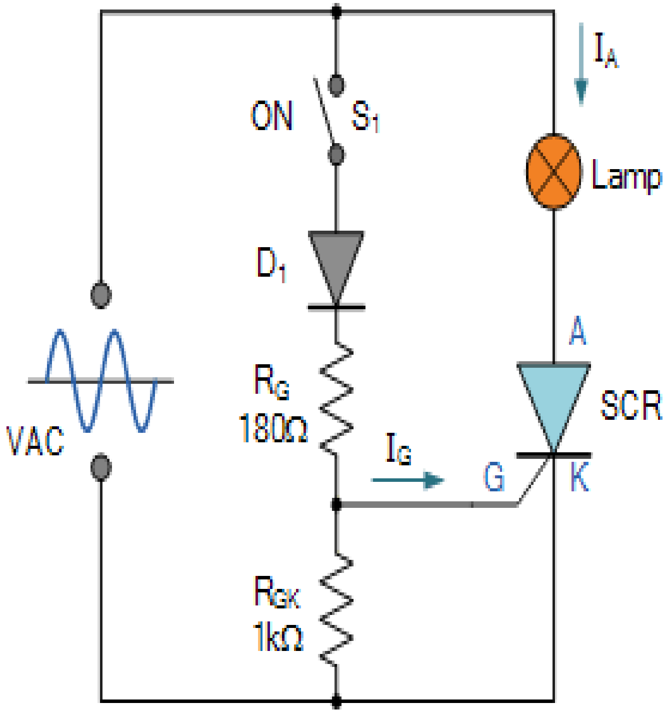
- in this method a **variable resistance** **R** is used to control the gate current.

- depending upon **R** value, when the value of gate current reaches to **a proper** value to **trigger** the device (latching current), the device will start to **conduct**.

- Diode **D** called blocking diode which will be used to prevent the **gate-cathode** junction damage of the device during the **negative cycle.**

- when **r** circuit is a pure resistive, the gate current in phase with the **applied voltage**.

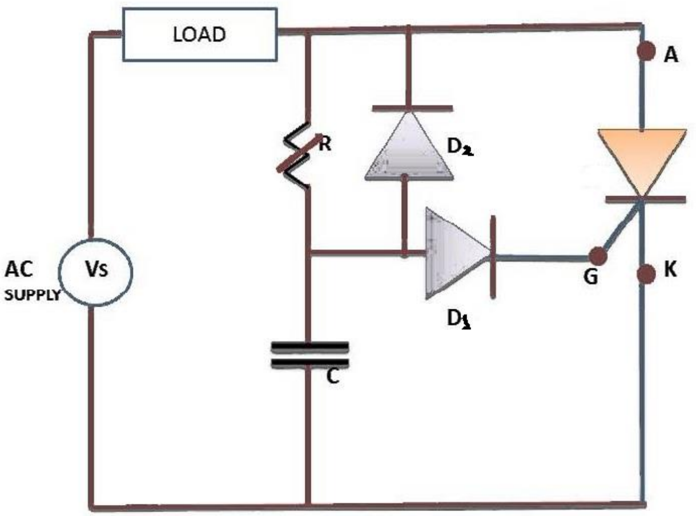
- maximum **firing angle** can be achieved up to **90** using this triggering method.



b) RC triggering

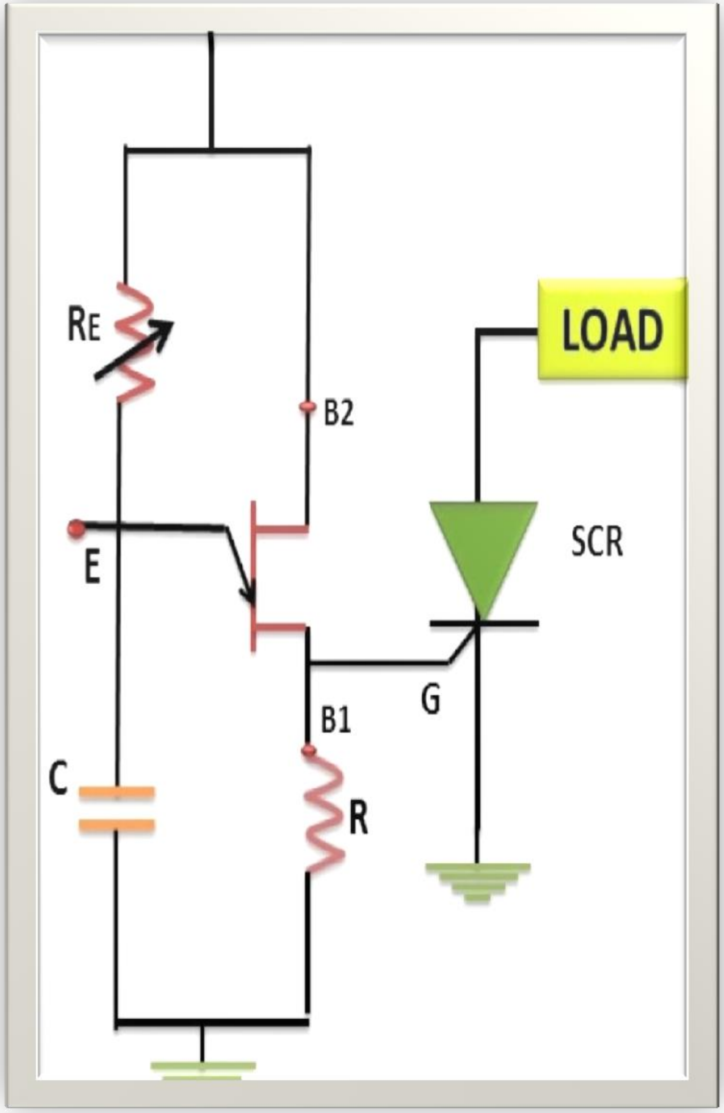
The following circuit shows the **resistance-capacitance** triggering.

- An firing angle more than **90** can be **achieved** using this **method**.
- The capacitor will **charge up** to its peak vaue through the resistance **R** during the **positive part** of the applied voltage.
- The charging time will be controlled by the **variable resistance R.**
- The gate of the transistor will be triggered depending **on the voltage** across the **capacitor** when it will be in proper value the **SCR will start to conduct**.
- The capacitor will charge up to **the negative peak** during **D2** through negative half cycle.
- to prevent the reverse breakdown of the gate cathode junction through negative cycle, additional diode can be used.

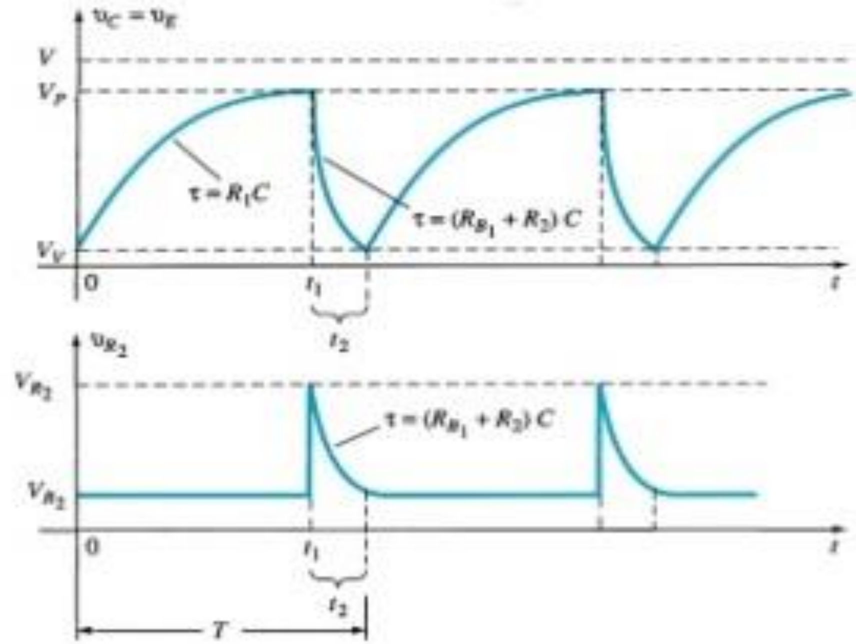


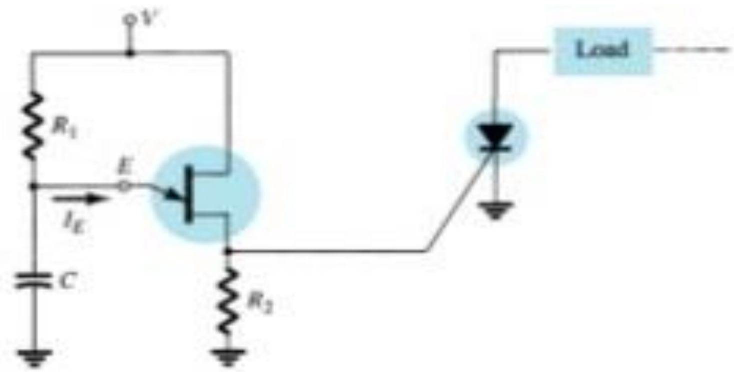
Pulse gate triggering

- In this method the gate will be driven by a **periodic single pulse** or **sequence** of high frequency **pulses.**
- This frequency called **carrier frequency.**
- Pulse transformer will be used for **insulation.**
- There is no need to **apply continues signals** and that will lead to reduce gate losses.
- **UJT** will be used to implement this circuit.



The V_E and V_{R2} waveforms for the SCR triggering circuit (below) are shown.





F = $\dfrac{1}{RC\ln\left(\frac{1}{1-\eta}\right)}$, freq. can be more than 1Khz

T = t1+t2,   t1: charging time , t2: discharging time

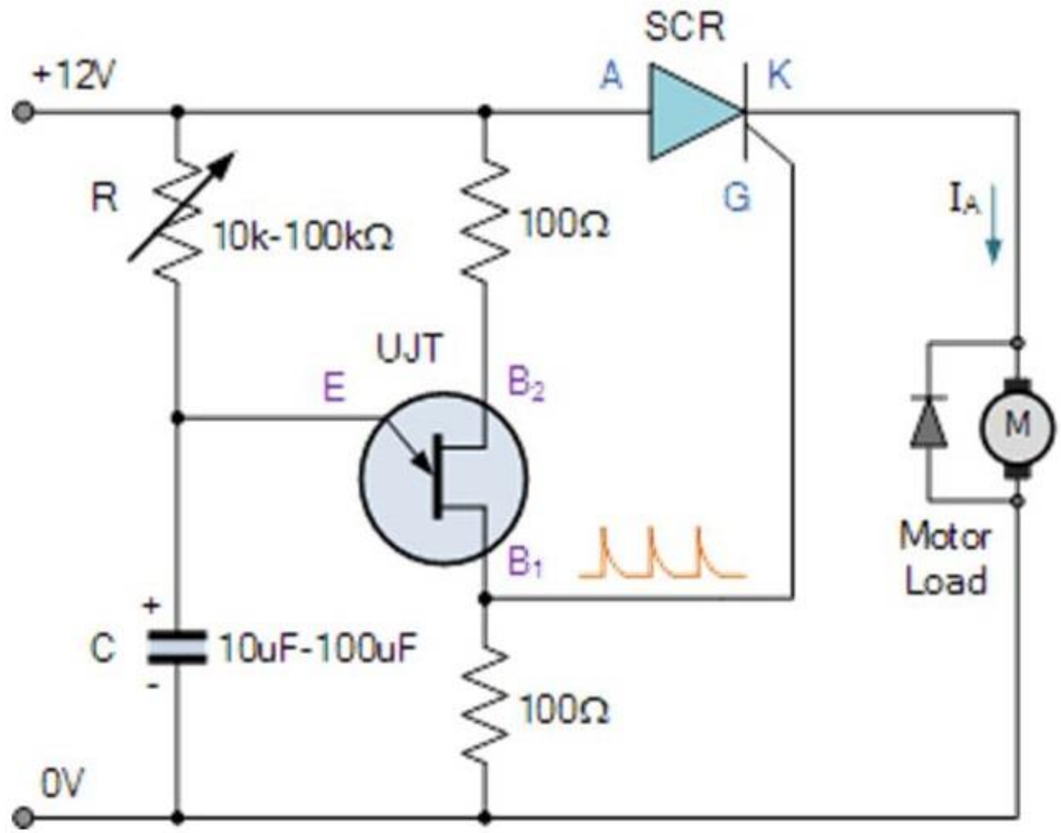
Speed control of DC motor

❑ SCR are used here to control the motor’s speed.

❑ UJT are used to control SCR.

Advantages of pulse train triggering:

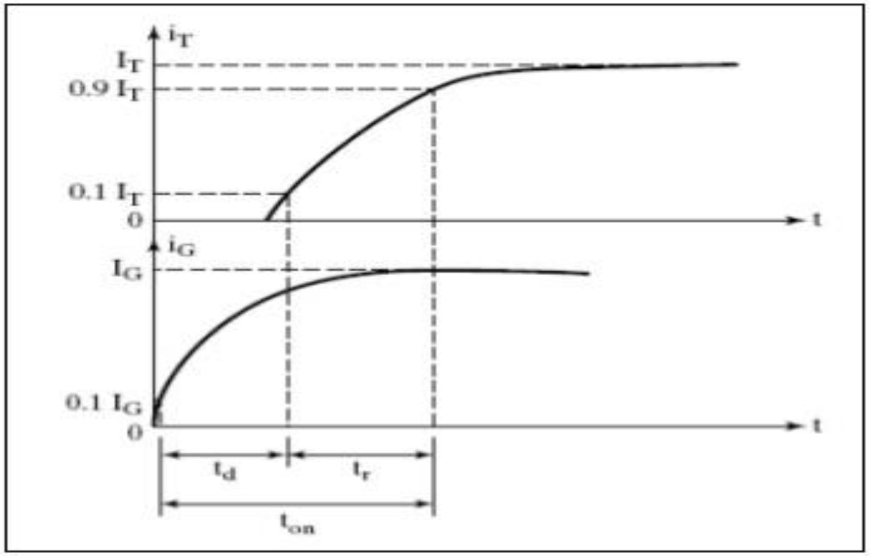
➢ **Low gate dissipation.**
➢ **Insulating gate transformer is small.**
➢ **Dissipation is low in reverse biased condition.**



Conditions of turning (thyristor) ON

SWITCHING CHARACTERISTICS (DYNAMIC CHARACTERISTICS)

THYRISTOR TURN-ON CHARACTERISTICS



$t_{on} = t_d + t_r$

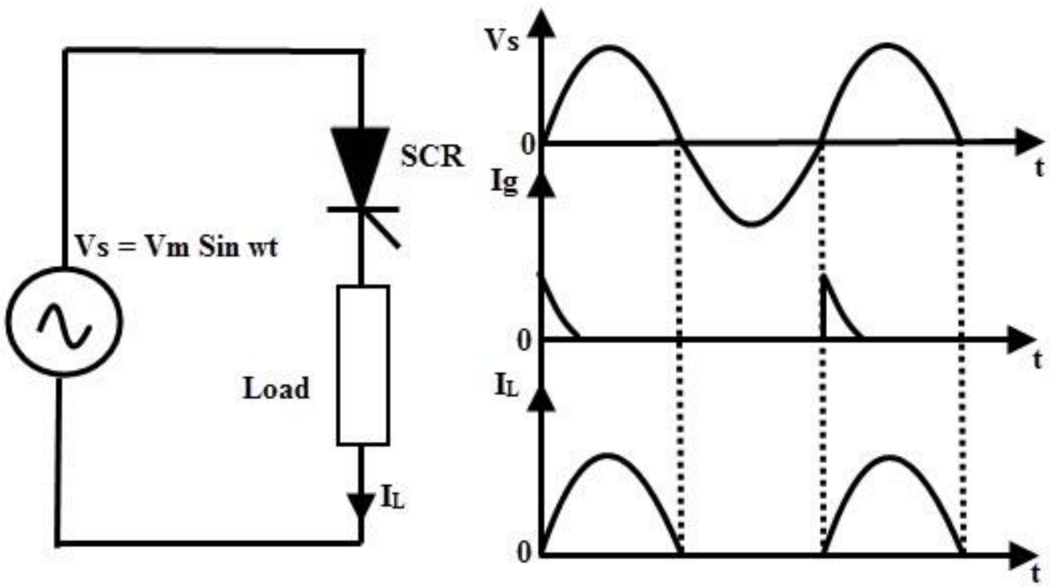
- gate current must be applied till all the load current to pass.
- Load current must be met the lowest expected operating temperature.
- To urn off the thyristor, the load current must be < I_H for sufficient time to allow returning to blocking state.
- The current which required to fire the device is usually specified by the manufacturer as a maximum at specified temperature.

Using of SCR

- Power control.
- Speed control of DC & AC motors.
- Over light detector.
- Battery charging regulator.
- Emergency light system.
- Inverters.
- Heat control.

Methods of turn off of SCR

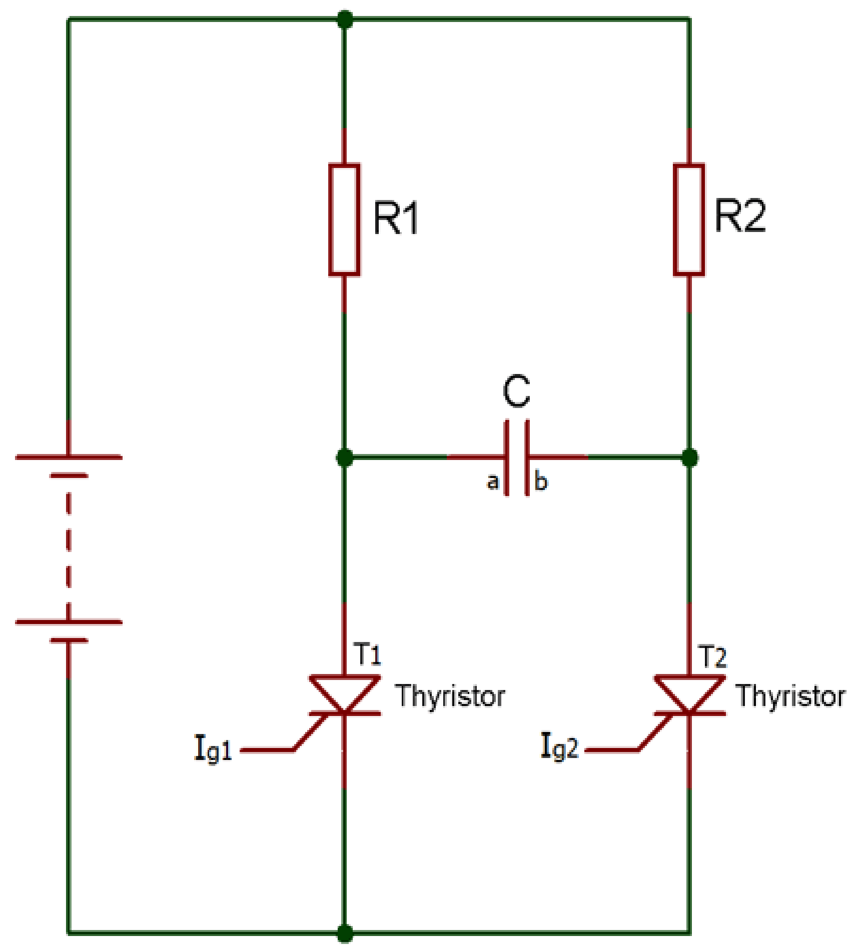
I. Natural commutation: which occurs in AC circuit



II. Forced commutation: which wil be applied to choppers and inverters.

- Two thyristor will work periodically **each one** will turn off the other .

- T1 **is fired**, the load current will flow through **R1**.
- **C** will charge up to **V** of **R2** and plate **b** is positive.
- To turn off **T1**, **T2** is fired in capacitor voltage reverse biasing **T1** and turning it **off**.
- When **T2** is fired current through load shoots up as voltage across load is V+Vc.

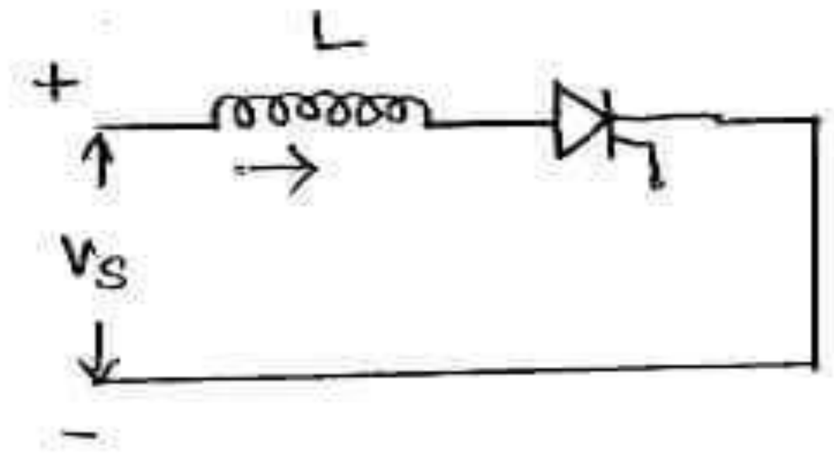


Thyristor protection

- protection against the voltage and current changing.
- protection against transient effect of the voltage source.
- protection against all possibilities of voltage and current changes.

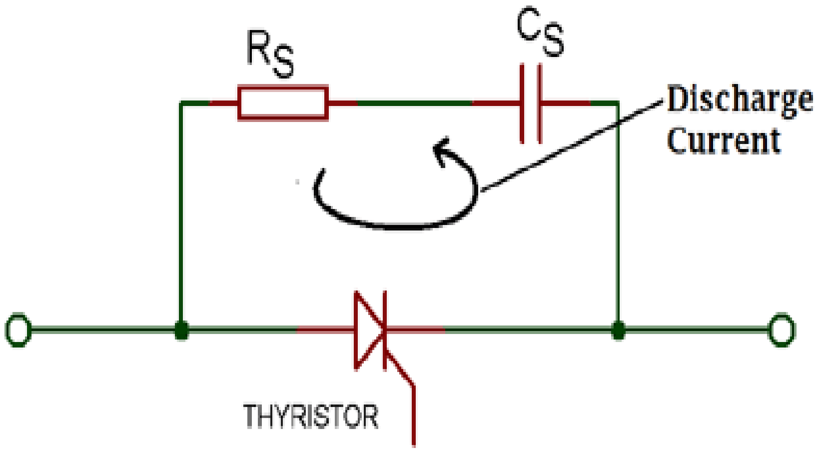
Protection against di/dt

Inductor can be used to avoid the state where di/dt is increasing.

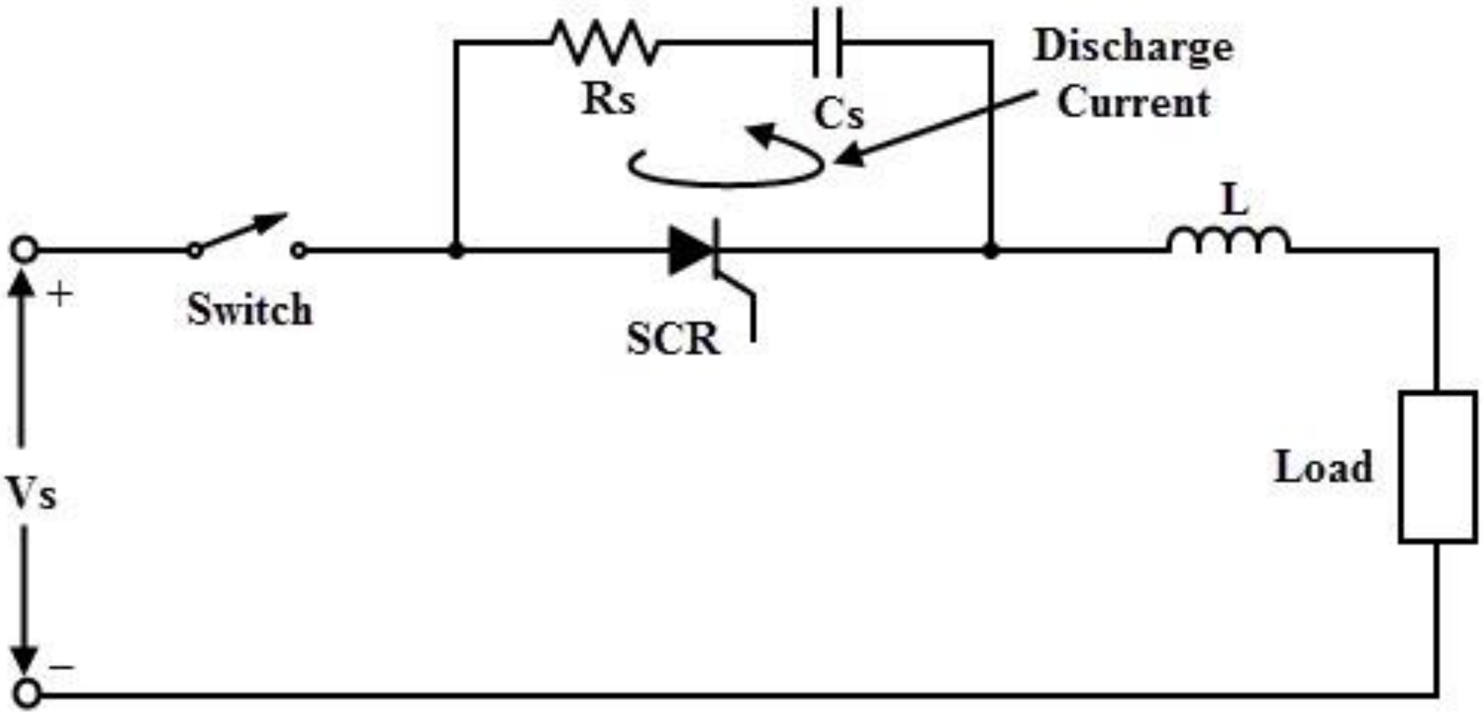


Protection against dv/dt (snubber- circuit)

The additional charge can be removed using combination of resistance and capacitance.



SCR protection



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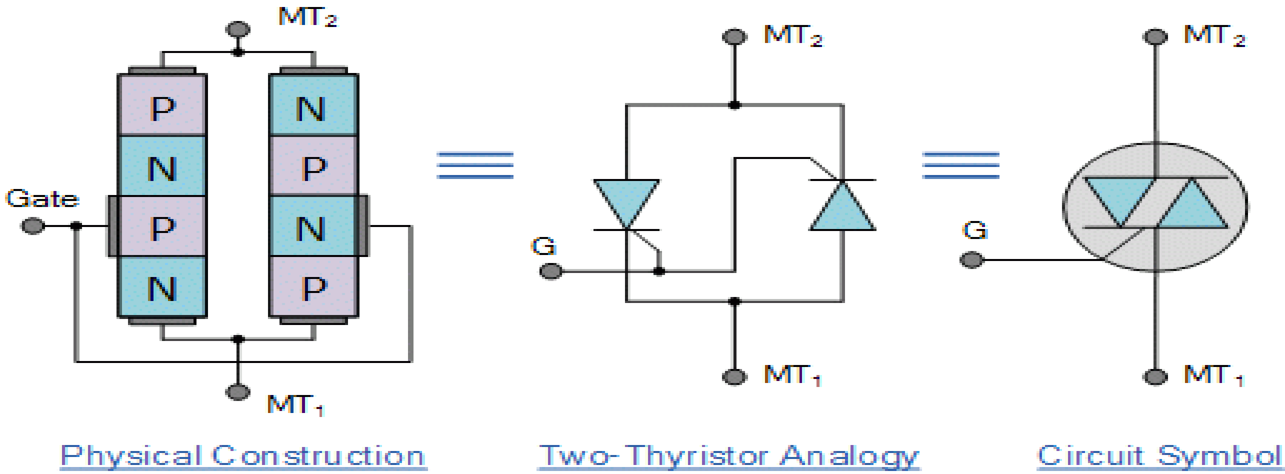
Lecture 10

Ass. Teacher Sadeq abdullah

TRIAC

three terminal electronic component that conducts current in either direction when triggered. Its formal name is **bidirectional triode** thyristor or **bilateral triode** thyristor.

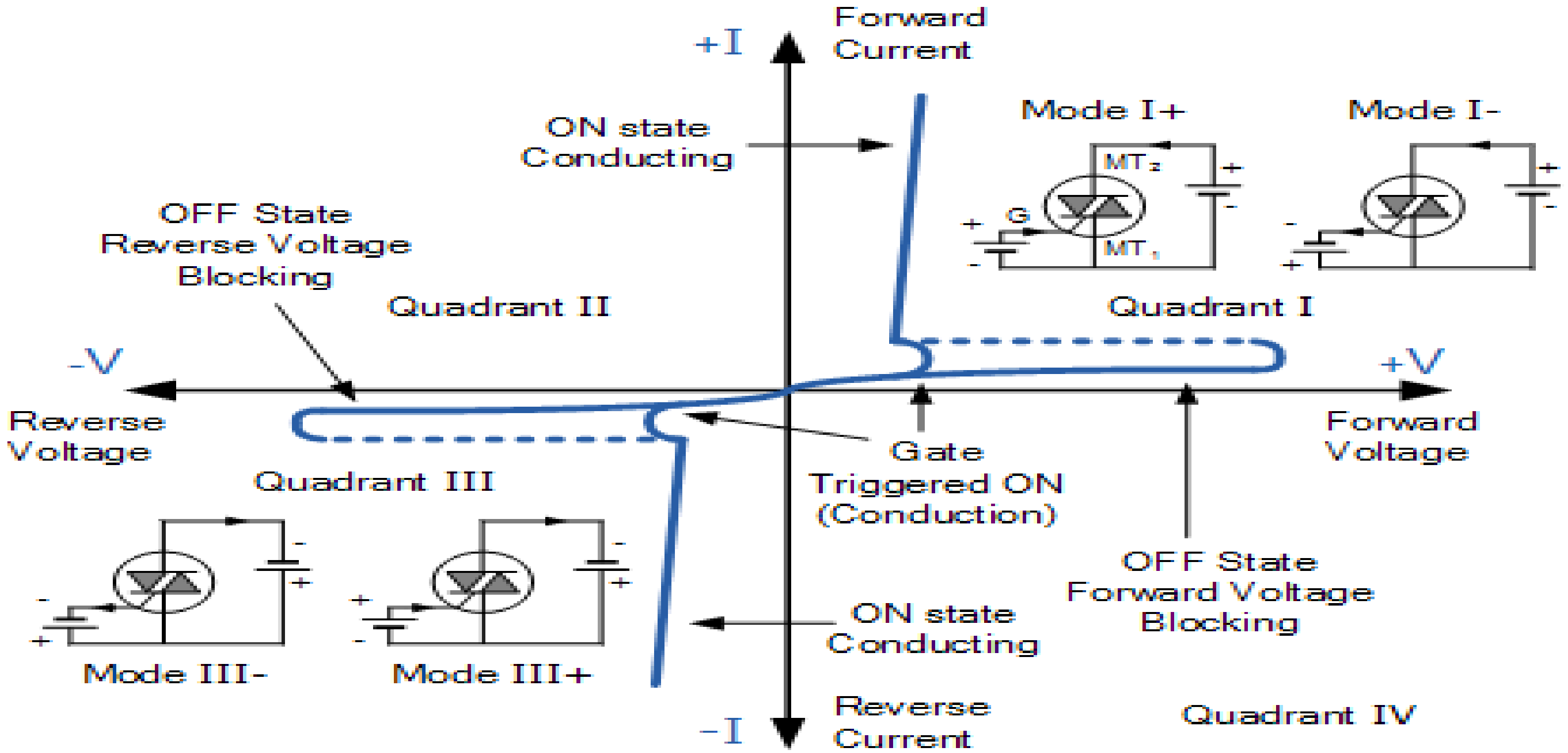
symbol for a **TRIAC** where **"A1"** is Anode 1, **"A2"** is Anode 2, and **"G"** is Gate. Anode 1 and Anode 2 are normally termed **Main Terminal 1 (MT1)** and Main Terminal 2 **(MT2)** respectively.



TRIACs differ from **SCRs** in that **they allow current flow in both directions**, whereas an **SCR can only conduct current in a single direction.**

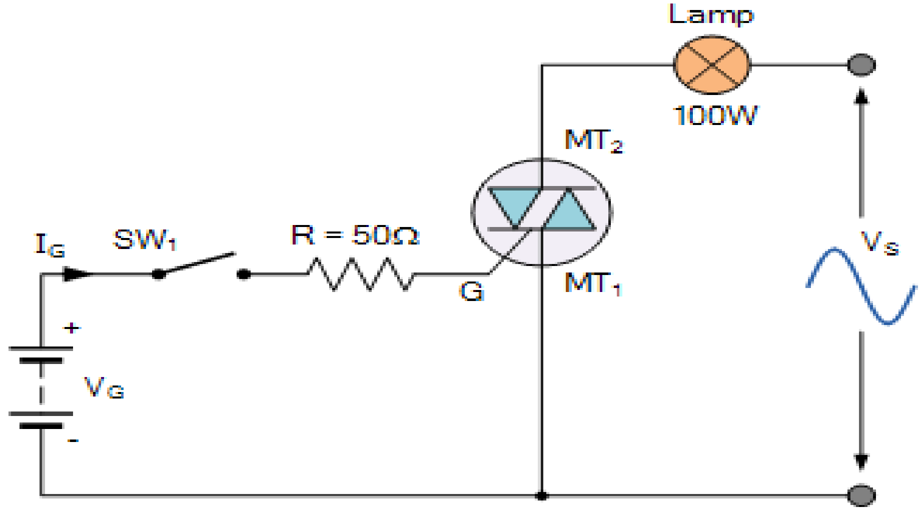
TRIACs can be triggered by **applying either a positive or negative voltage to the gate** (an SCR requires a positive voltage). Once triggered, **SCRs and TRIACs** continue to conduct, even if the gate current **ceases**, until the main **current drops below a certain level** called the **holding current.**

TRIAC CURRENT-VOLTAGE CHARACTERSTICS



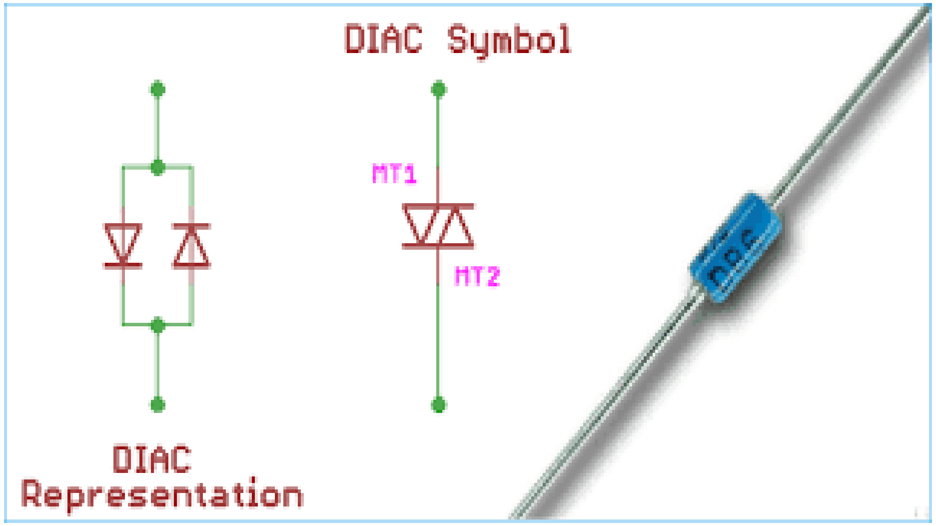
TRIAC APPLICATIONS

- It is the most commonly used semiconductor device for **swtching** and **power control** **because of** the **property which allow to be work on either positive and negative Gate pulse.**
- It is convenient to control **AC motors** and **lamp control.**



DIAC

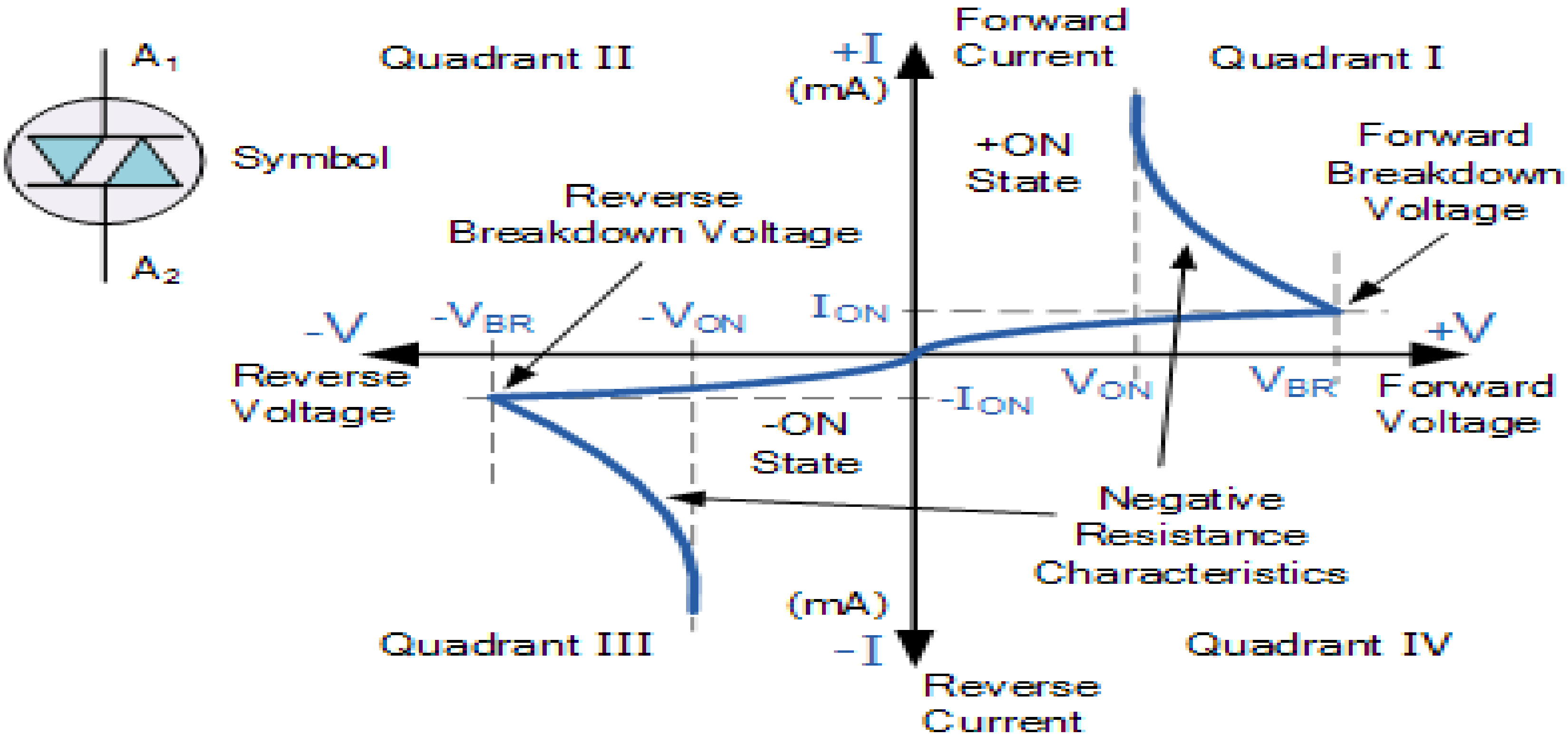
It is a **diode** that **conducts electrical current** only after its **breakover voltage**, V_{BO} has been reached momentarily.



DIACs have **no gate electrode**, **unlike some other thyristors,** So that they are commonly used to **trigger** TRIACs.

DIAC I-V CHARACTERSTICS

When breakdown occurs, the diode enters a region of negative dynamic resistance, leading to decrease in the voltage drop across the diode and, usually, a sharp increase in current through the diode. The diode remains in conduction until the current through it drops below a value characteristic for the device, called the *holding current*, I_H. Below this value, the diode switches back to its high-resistance, non-conducting state. This behavior is bidirectional, meaning typically the same for both directions of current.



A1
Symbol
A2
Quadrant II
Quadrant I
Quadrant III
Quadrant IV
+I
(mA)
Forward Current
+ON State
Forward Breakdown Voltage
Reverse Breakdown Voltage
-V
-VBR
-VON
ION
+V
Reverse Voltage
-ION
VON
VBR
Forward Voltage
-ON State
Negative Resistance Characteristics
(mA)
-I
Reverse Current

Use of DIAC

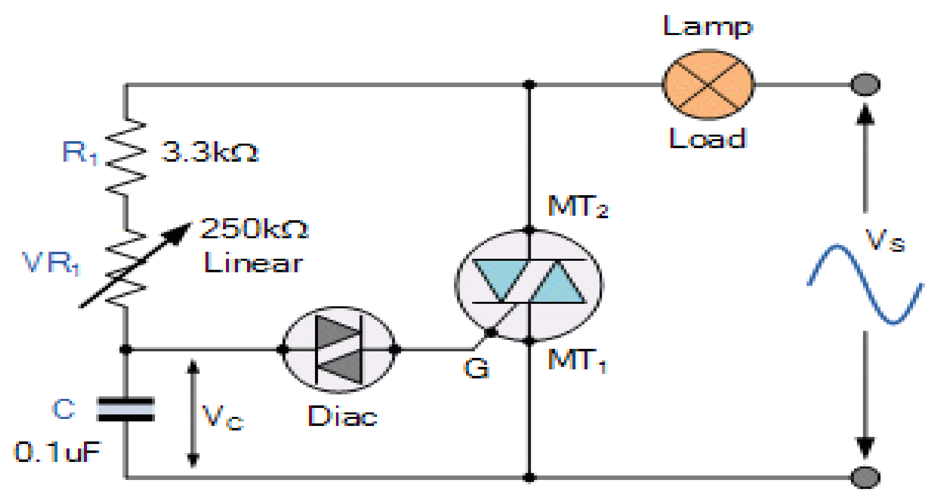
It is used to **triggering the triac** because of the triggering characterstic of **triac** is nonsymmetrical. There are **others application** of that electronic device:

1) **Register & counter and timing circuit for computer uses.**

2) **Oscillator.**

3) **Pulse generator.**

4) **Voltage sensors.**



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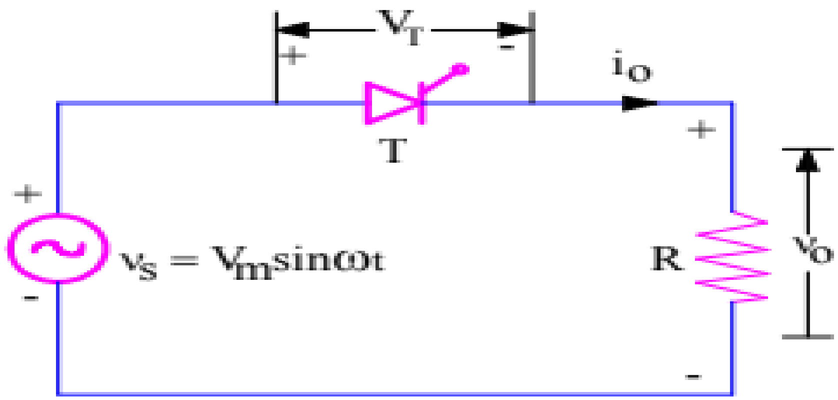
Lecture 11

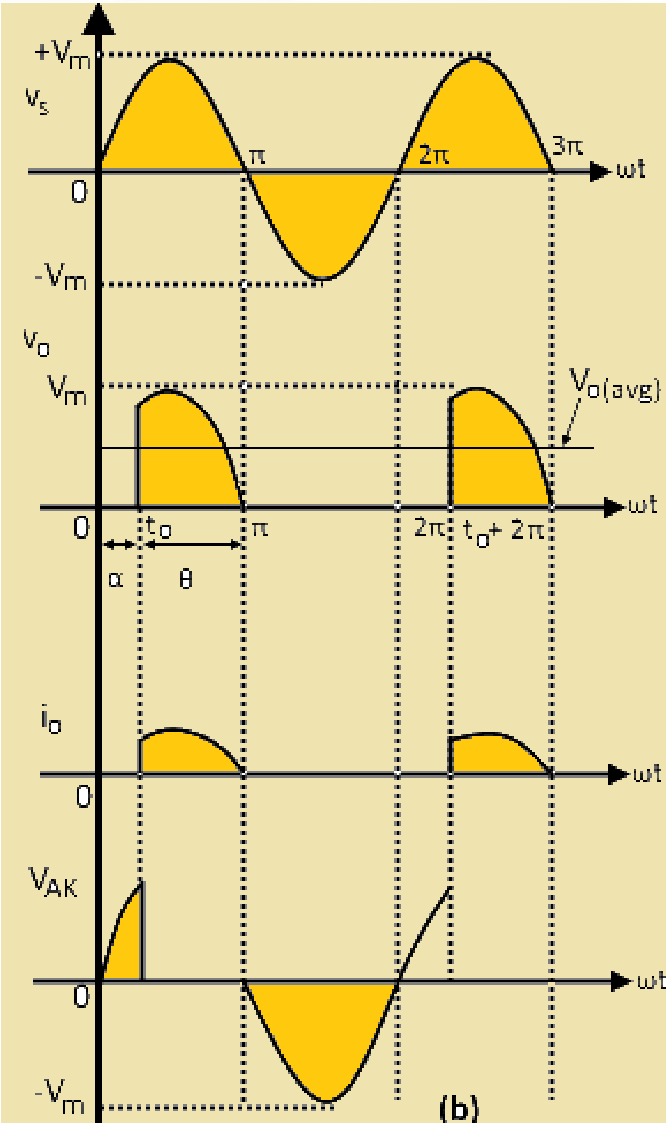
Ass. Teacher Sadeq Abdullah

Single-Phase Controlled rectifiers

- Half wave controlled rectifiers.
- Full wave controlled rectifiers.
  - using center tapped transformer.
  - full wave bridge circuit.
    - semi converter.
    - full converter.

Single-Phase Half wave controlled rectifier





load in the Fig. above is resistive and therefore current id has the same waveform as the load voltage.

The thyristor goes to the non-conducting condition, OFF state, when the load voltage and, consequently, the current try to reach a negative value. The load average voltage is given by:

$$V_{d\alpha} = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_{max} \sin \omega t d(\omega t) = \frac{V_{max}}{2\pi}(1 + \cos \alpha)$$

From the expression of average output voltage, it can be seen that, by changing firing angle α, we can change the average output voltage. The average output voltage is maximum when firing angle is zero and it is minimum when firing angle α = π. This is the reason, it is called phase controlled rectifier.

the root mean square (rms) value of load voltage

$$RMS\ Value = \sqrt{(1/T)\int_0^T [f(x)]^2 dx}$$

RMS Value of Load output Voltage

$$= \left(\frac{Vm}{2\sqrt{\pi}}\right)\sqrt{(\pi - \alpha) + (1/2)Sin2\alpha}$$

- RMS value of load current can be calculated by dividing the rms load voltage by resistance R. This means,
  RMS Load Current I_{0rms}= RMS Load Voltage / R
- Input volt ampere can be calculated as

Input Volt Ampere = RMS Supply Voltage x RMS Load Current

= $V_s x I_{0rms}$

EX: single phase half Wave controlled rectifier with resistive load is supplied from 120V, R = 10Ω. Calculate the average load voltage at firing angle: 0, 45, 90 & 180.

$$V_{av} = \frac{V_{max}}{2\pi}(1 + \cos\alpha)$$

at $\alpha = 0$

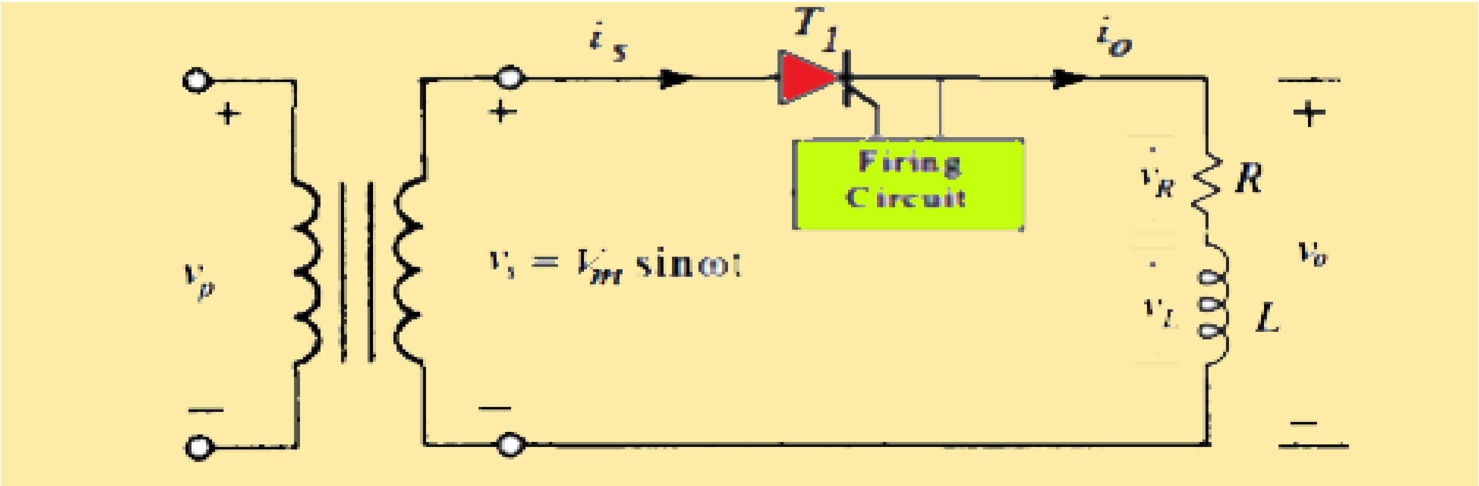
$$V_{av} = \frac{120}{2\pi}(1 + \cos 0) = 38.19\ V$$

at $\alpha = 45$

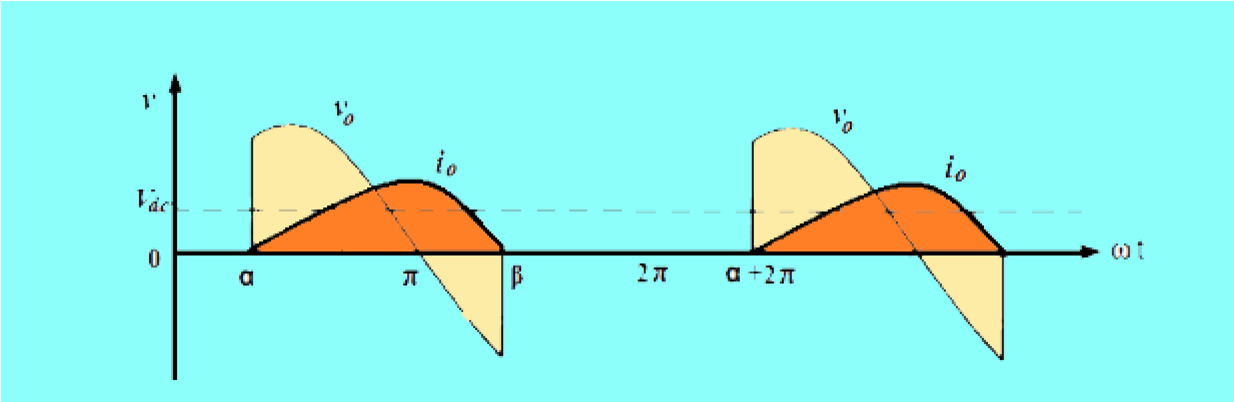
$$V_{av} = \frac{120}{2\pi}(1 + \cos 45) = 32.6\ V$$

Single-Phase, Half-Wave, Controlled Rectifier Loaded with Series Resistive – Inductive Load

- This circuit is the same as previous circuit except that the load consists of a resistor and inductor connected in series.
- At ωt = α, the voltage across the load will be the instantaneous value of the supply voltage at this firing angle.
- At this instant, because of the existence of the inductor, the current will increase slowly .



The wave forms and equations



The average value of the load voltage V_{dc} can be calculated as follows:

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

$$= \frac{V_m}{2\pi}\,(-\,cos\beta + cos\alpha)$$

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

Output power & r.m.s output

The output d.c. power is given by:

$$P_{dc} = V_{dc} I_{dc} = \frac{V_{dc}^2}{R}$$

The *rms* value of the load voltage V_{orms} can be calculated as follows:

$$V_{orms} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\beta} v_s^2(\omega t)d\omega t}$$

$$= \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\beta} (V_m sin\omega t)^2 \, d\omega t} = \sqrt{\frac{(V_m)^2}{2\pi}\int_{\alpha}^{\beta} \frac{1}{2}(1 - cos2\omega t)d\omega t}$$

$$= \frac{V_m}{2}\sqrt{\frac{1}{\pi}[(\beta - \alpha) - \frac{1}{2}(sin2\beta - sin2\alpha)]}$$

The output a.c. power is given by:

$$P_{ac} = V_{orms} I_{orms}$$

The *PRV* of the thyristor for this configuration is V_m . To find the power factor of the circuit, the current drawn from the source i_s is the same as the load current. Hence,

$$S = V_s \, I_{orms}$$

But $$PF = \frac{P_{ac}}{S}$$

Hence $$PF = \frac{V_{orms} I_{orms}}{V_s \, I_{orms}} = \frac{V_{orms}}{V_s}$$

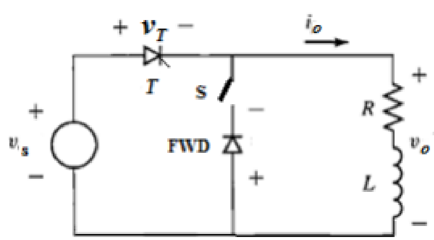
$$= \frac{V_m}{2V_s}\sqrt{\frac{1}{\pi}[(\beta - \alpha) - \frac{1}{2}(sin2\beta - sin2\alpha)]}$$

Since $$V_m/2V_s = \sqrt{2}V_s/2V_s$$

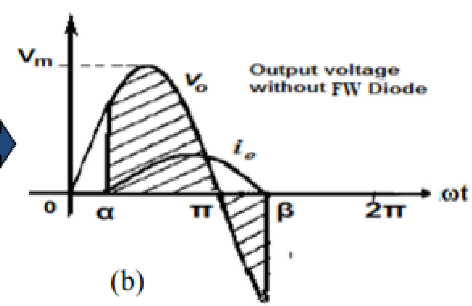
$$\therefore \quad PF = \sqrt{\frac{1}{\sqrt{2}\pi}[(\beta - \alpha) - \frac{1}{2}(sin2\beta - sin2\alpha)]}$$

The Freewheeling Diode in Single-Phase Controlled Rectification

The freewheeling diode (FWD) is connected in the circuit across an R-L load in such a way as to provide an alternative path for the decaying load current so that the thyristor current is allowed to become zero and the thyristor is allowed to turn off.



(a)



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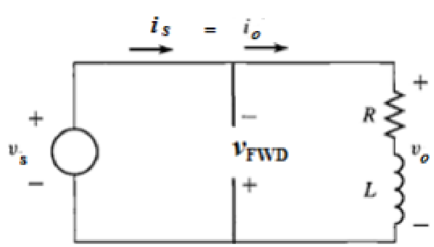
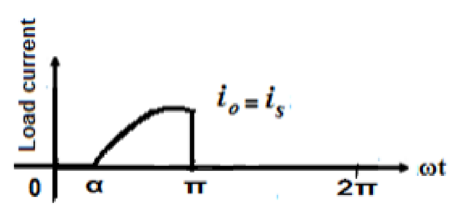
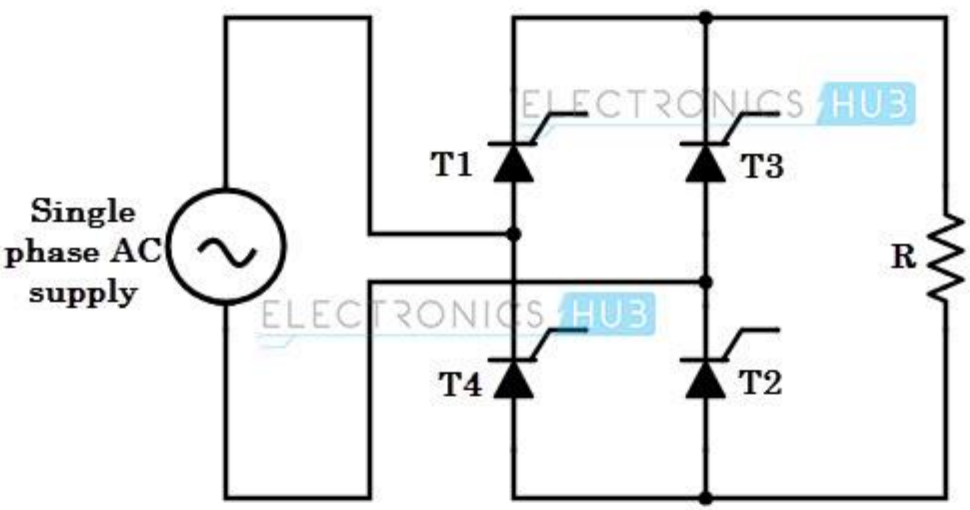




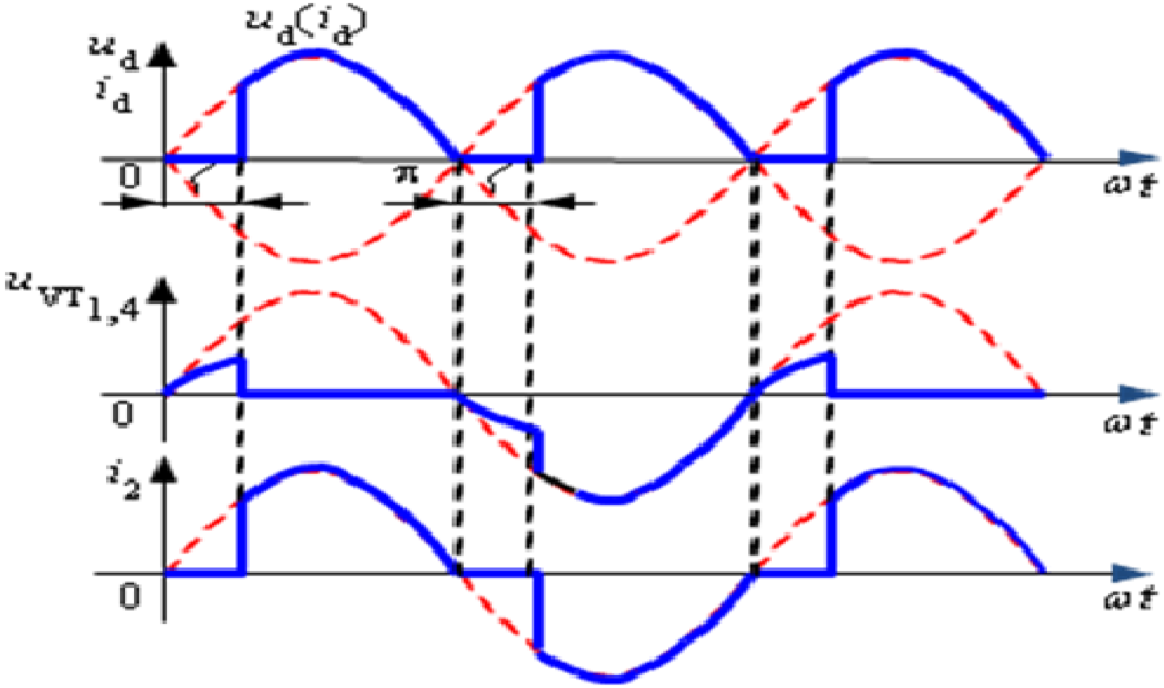
Single-Phase full wave bridge controlled rectifier

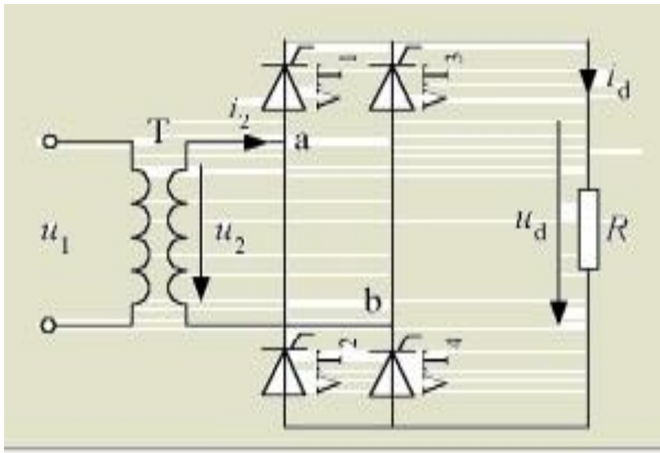
Phase controlled AC-DC converters employing thyristor are extensively used for changing constant ac input voltage to controlled dc output voltage. In phasecontrolled rectifiers, a thyristor is tuned off as AC supply voltage reverse biases it, provided anode current has fallen to level below the holding current.



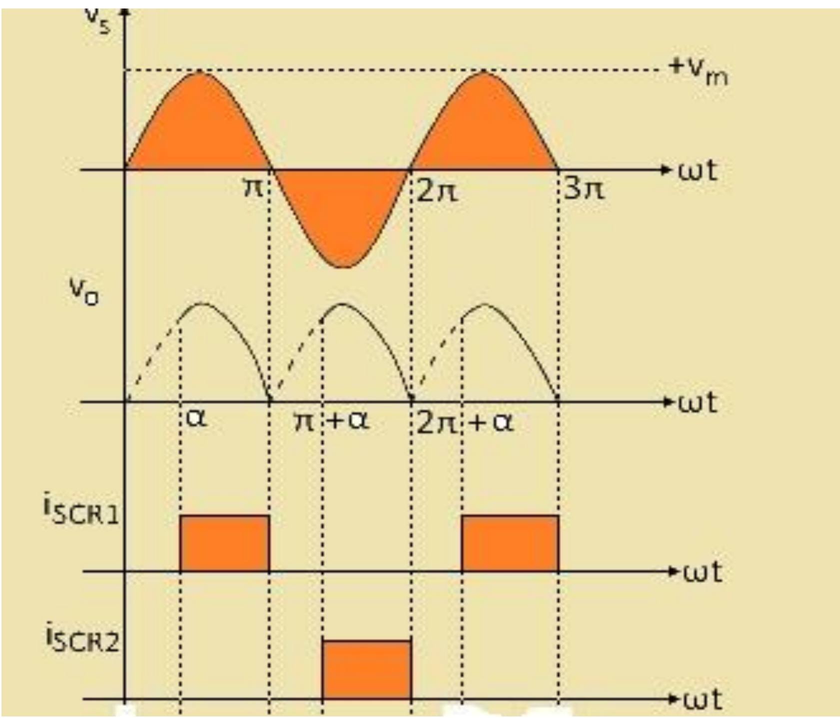
Controlled rectifiers have a wide range of applications, from small rectifiers to large high voltage direct current (HVDC) transmission systems. They are used for electrochemical processes, many kinds of motor drives, traction equipment, controlled power supplies, and many other applications.

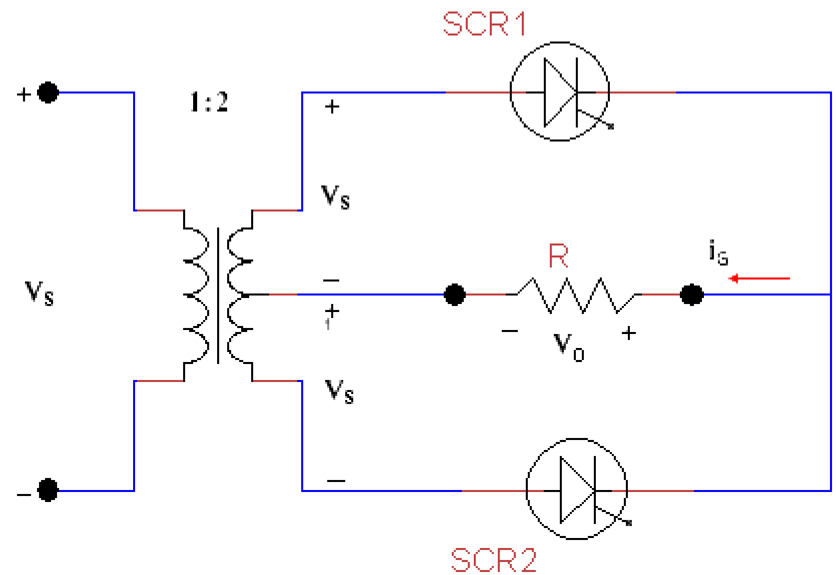
The fig. above shows the voltage and current waveforms of the fully controlled bridge rectifier for a resistive load. Thyristors T1 and T2 must be fired simultaneously during the positive half-wave of the source voltage Vs to allow conduction of current. Alternatively, thyristors T3 and T4 must be fired simultaneously during the negative half wave of the source voltage. To ensure simultaneous firing, thyristors T1 and T2 use the same firing signal.





Single-Phase full wave center tap transformer with resistive load controlled rectifier

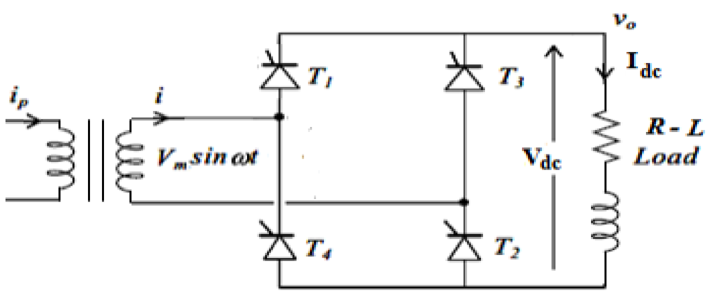




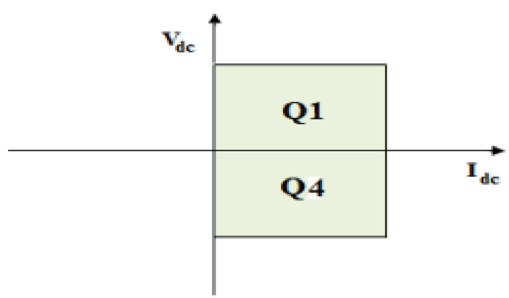
$$V_{d\alpha} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_{max} \sin \omega t d(\omega t) = \frac{2V_{max}}{\pi}\cos \alpha$$

Case of highly inductive load (L > > R)

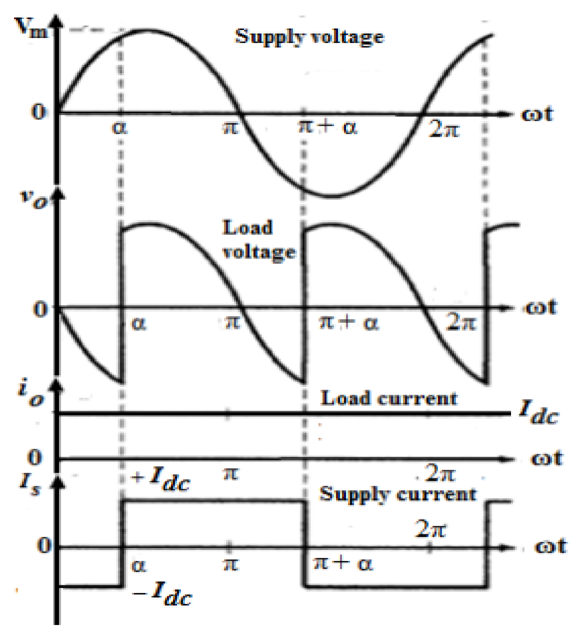
Fig. bellow shows the circuit connection for a single-phase, fullwave, controlled rectifier loaded with a highly inductive load. For one total period of operation of this circuit, the corresponding waveforms are shown bellow.



(a) Circuit



(c) Operating quarters



(b) Waveforms.

Average & r.m.s output calculations

The average value of the load voltage V_{dc} can be calculated as follows,

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

The *rms* value of the load voltage V_{orms} can be calculated as follows,

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

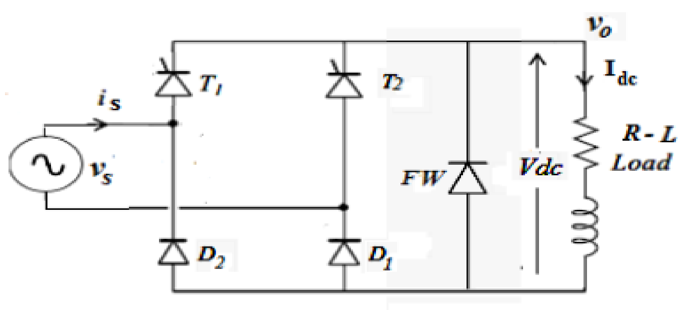
$$= \sqrt{\frac{V_m^2}{\pi}\int_{\alpha}^{\pi+\alpha} \frac{1}{2}(1 - \cos 2\omega t) d\omega t} = \frac{V_m}{\sqrt{2}}$$

SINGLE-PHASE HALF-CONTROLLED (SEMICONVERTER) with F.W.D RECTIFIER

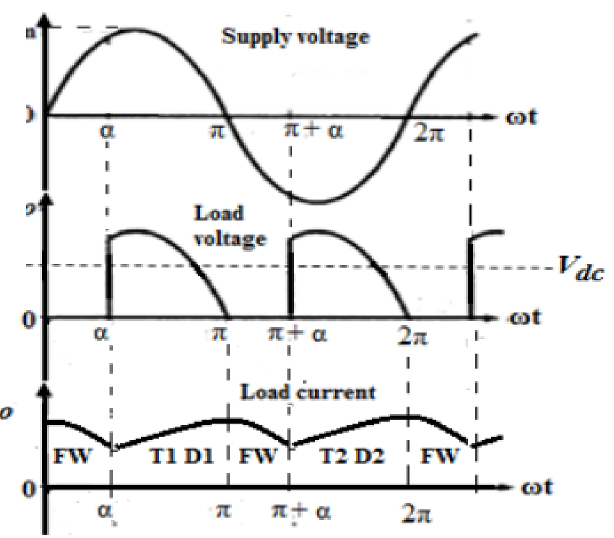
A single-phase half-controlled (semiconverter) rectifier.

This configuration consists of a combination of thyristors and diodes to reduce the cost of the full-wave fully-controlled rectifier.

With resistive load, the converter operates in the same manner as fully controlled one. The load current and voltage have the same form as presented in Subsection 3.3.1 also apply to this circuit.



(a) Circuit



(b) Waveforms

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Lecture 12

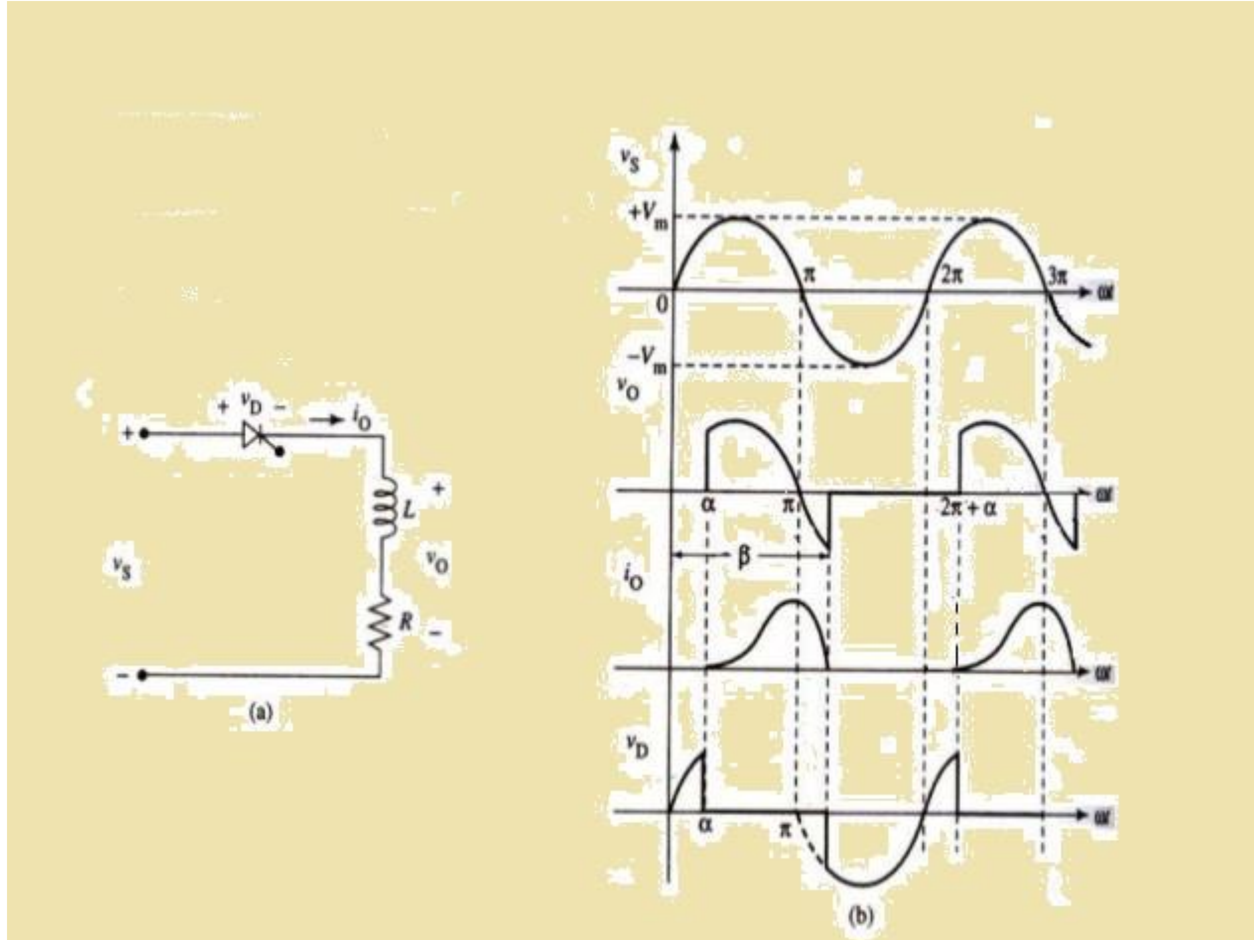
Ass. Teacher Sadeq Abdullah

Lecture aims to

The lecture aim to that the student should be able to **draw** the circuits and **draw the wave** forms and do the **math calculation** of that cicuits.

- Single phase half wave controlled rectifier with inductive load.
- Single-phase full-wave controlled rectifier with inductive load.

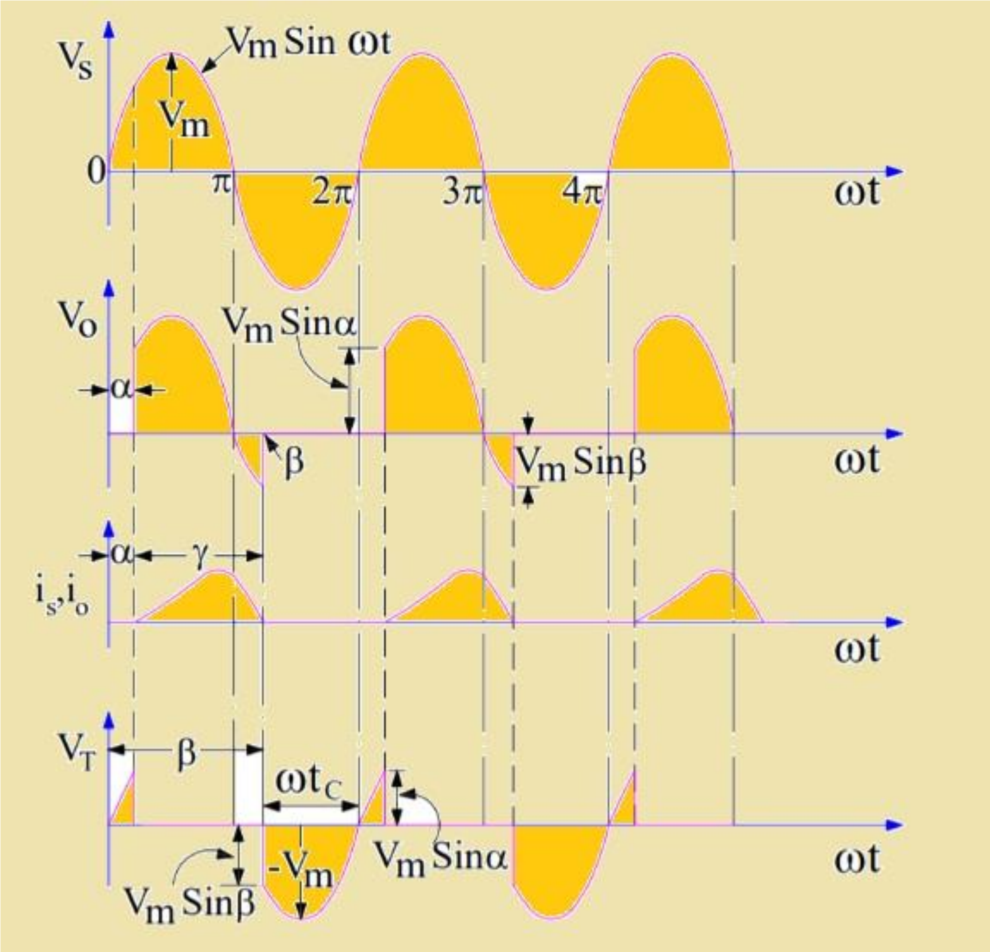
The circuit diagram of a single phase half wave controlled rectifier with RL load is shown below. This circuit consists of a thyristor T, source Vs and RL load. The output voltage is the voltage across the load and shown as V_o. Output current is the current through the load and shown as i_o



Single phase half wave controlled rectifier with inductive load

- It is assumed that the thyristor T is fired at an angle ωt = α. As soon as the thyristor T is fired at ωt = α, load voltage equal to the source voltage instantaneously appears across the load terminal.

- At ωt = π, the load voltage V_o reduces to zero. However, the load current will not be zero at this instant because of inductance L. Due to this, thyristor will not turn off, even though it is reversed biased. Rather it will continue to conduct till ωt = β. At ωt = β, the load current becomes zero and thyristor is reversed biased, hence it will turn off. This is a case of natural commutation



Calculation of average & RMS Load

output voltage of single phase half wave controlled rectifier is given as below

$$Avg.Voltage, Vo = \frac{1}{2\pi}\int_{\alpha}^{\beta} Vm\sin(\omega t)d(\omega t)$$

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

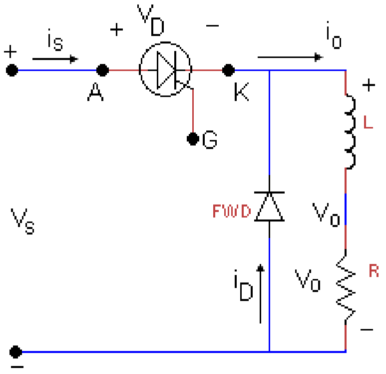
RMS load voltage of single phase half wave controlled rectifier is given as below

$$RMS\ Voltage, Vo = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\beta}(Vm\sin\omega t)^2\,d(\omega t)}$$

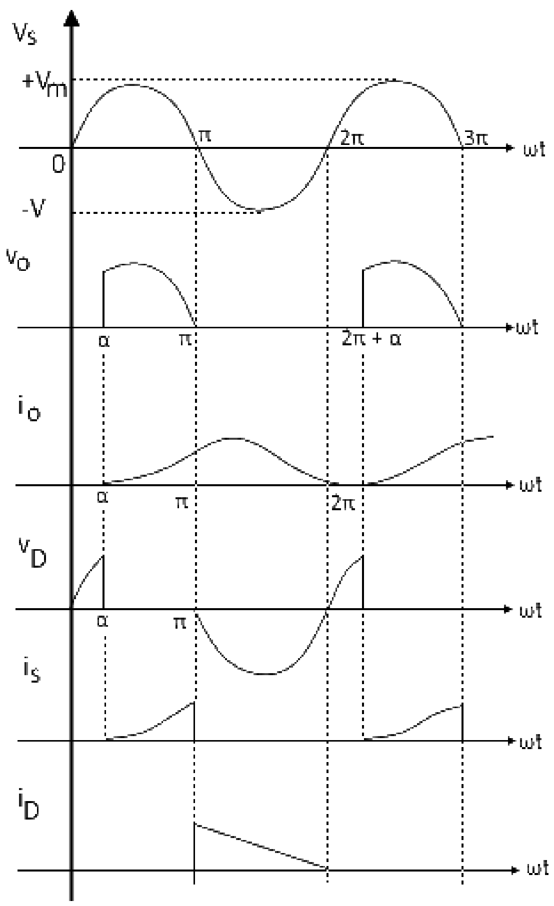
$$= \frac{Vm}{2\sqrt{\pi}}\sqrt{[(\beta - \alpha) - 1/2\{\sin 2\beta - \sin 2\alpha\}]}$$

Single phase half wave controlled rectifier with inductive load with freewheeling diode

During the negative half-cycle of the supply, the load current io flows through the low resistance path provided by FWD rather than against the negative supply voltage, so that I = io, and is = 0. Hence the thyristor T is allowed to switch off. In this part of the half-cycle, the current is driven by the energy stored in L; it decays according to the time constant of the circuit (R, L, and FWD)



(a)



(b)

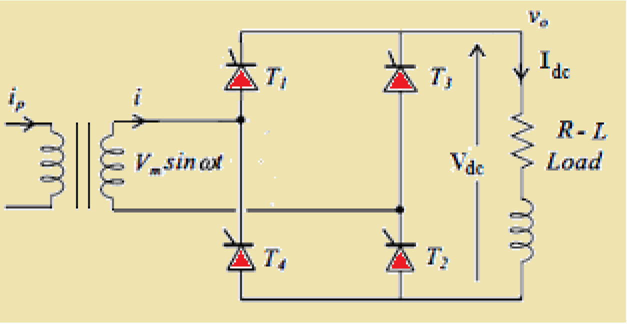
Calculation of the average output

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

$$= \frac{V_m}{2\pi}\,(-cos\pi + cos\alpha) \;\; = \frac{V_m}{2\pi}\,(1 + cos\alpha)$$

Single-phase full-wave controlled rectifier with inductive load

- In the Full Wave fully-controlled rectifier configuration, the average DC load voltage is controlled using two thyristors / SCRs per half-cycle. Thyristors Q1 and Q4 are fired together as a pair during the positive half-cycle, While thyristors Q2 and Q3 are also fired together as a pair during the negative half-cycle (i.e. 180o after Q1 and Q4).
- When the load is inductive, the output voltage can be negative for part of the cycle. This is because an inductor stores energy in its magnetic field which is later released.



The average value & The rms value calculation

The average value of the load voltage Vdc can be calculated as follows

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

The rms value of the load voltage Vorms can be calculated as follows

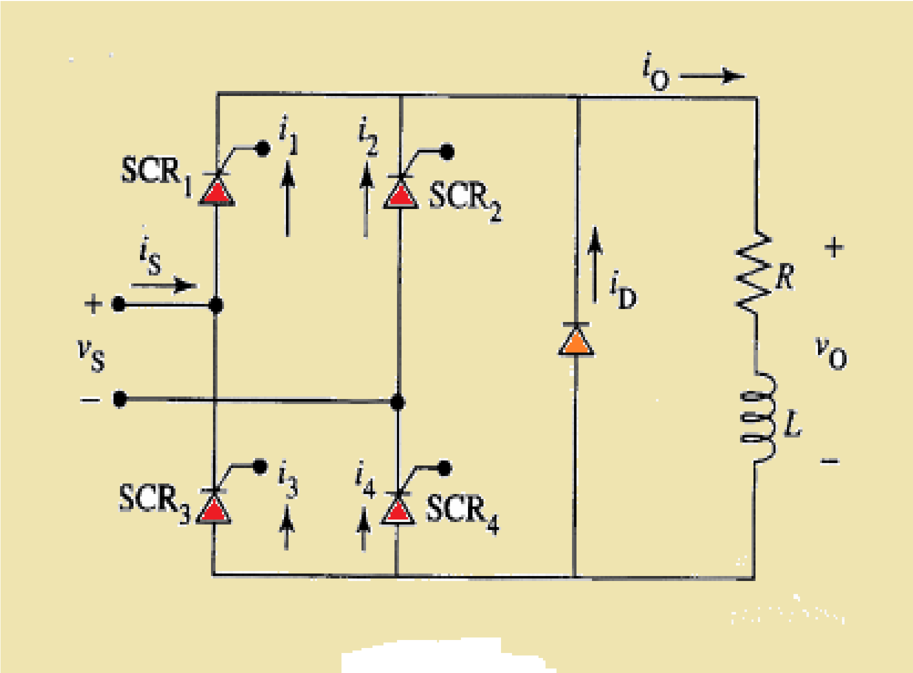
$$V_{orms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} v_s^2\,(\omega t) d\omega t} \quad = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} (V_m \sin\omega t)^2 \, d\omega t}$$

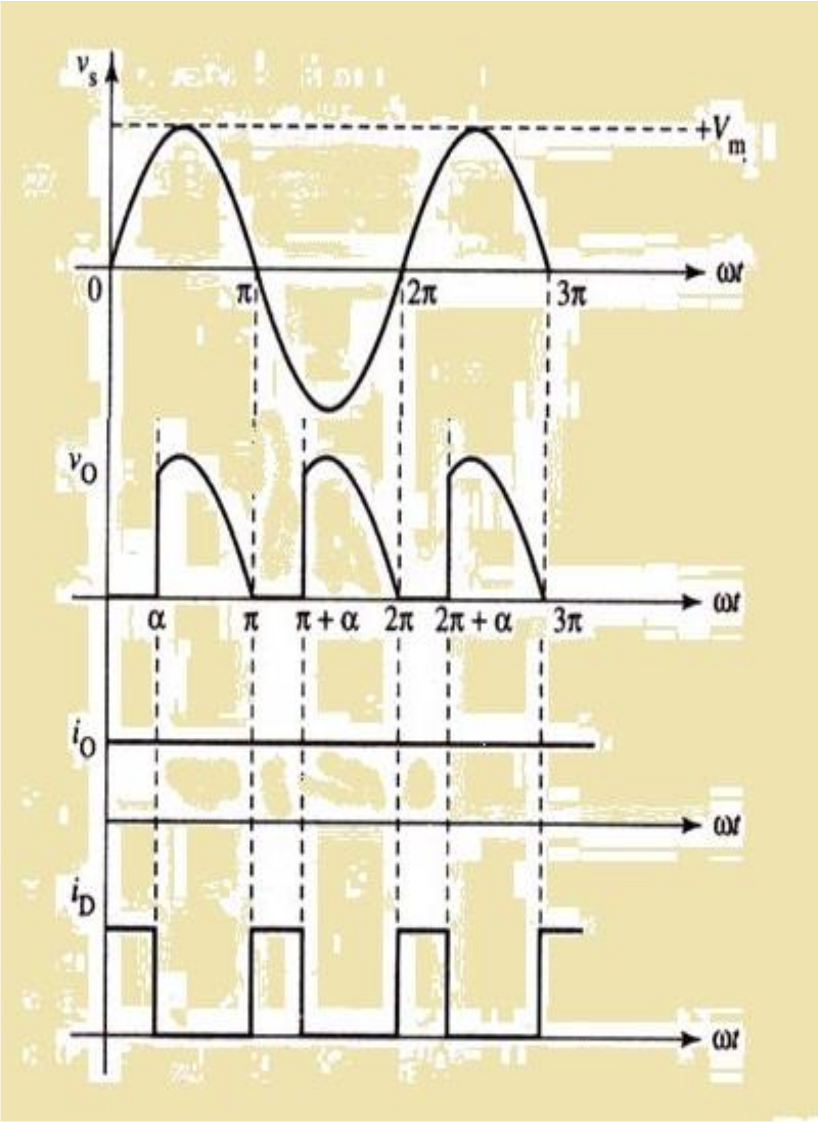
$$= \sqrt{\frac{V_m^2}{\pi}\int_{\alpha}^{\pi+\alpha} \frac{1}{2}(1 - \cos 2\omega t) d\omega t} \quad = \frac{V_m}{\sqrt{2}}$$

Single-phase full-wave controlled rectifier with inductive load and free wheeling diode

- A free-wheeling diode can be placed in the circuit to prevent the output voltage from going negative.

- The Circuit Diagram Full Wave Full controlled rectifier with R-L Load & Free Wheeling Diode is as shown below:





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Lecture 13

Ass. Teacher Sadeq Abdullah

EX1: The single-phase half-wave controlled rectifier shown in Fig.3.2(a) supplies a resistive load draws an average current of 1.62 A. If the converter is operated from a 240 V, 50 Hz supply and if the average value of the output voltage is 81V, calculate the following:

(a) The firing angle α.

(b) Load resistance .

(c)The rms load voltage.

(d) The rms load current.

(e) DC power.

(f) The ripple factor .

Solution

(a) For single-phase half-wave controlled rectifier with resistive load; the average value of the output voltage is calculated from Eq.(3.1) as

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

$$81 = \frac{240 \times \sqrt{2}}{2\pi}(1 + cos\alpha) \quad \rightarrow \quad \text{Hence } \alpha = 60^\circ.$$

(b) $$R = \frac{V_{dc}}{I_{dc}} = \frac{81}{1.62} = 50\ \Omega$$

(c) The rms load voltage is calculated using Eq.(3.4) as

$$V_{orms} = \frac{V_m}{2}\sqrt{\frac{1}{\pi}(\pi - \alpha + \frac{1}{2}sin2\alpha)}$$

$$= \frac{240 \times \sqrt{2}}{2}\sqrt{\frac{1}{\pi}(\pi - \frac{\pi}{3} + \frac{1}{2}sin120°)} = 152.14 \text{ V}$$

(d) The *rms* load current

$$I_{orms} = \frac{V_{orms}}{R} = \frac{152.14}{50} = 3.04 \text{ A}$$

(e) The output d.c. power is given by:

$$P_{dc} = V_{dc}I_{dc} = \frac{V_{dc}^2}{R} = \frac{81^2}{50} = 131.22 \text{ W}$$

(f) Ripple factor $= \frac{\sqrt{V_{orms}^2 - V_{dc}^2}}{V_{dc}} = \frac{\sqrt{152.14^2 - 81^2}}{81} = 1.57$

EX2: A single-phase half-wave controlled rectifier shown in Fig.3.2 supplied from 230V a.c. supply is operating at α = 60º. If the load resistor is 10 , determine:
(a) The power absorbed by the load (Pdc).
(b) The power drawn from the supply (Pac).
(c) The power factor at the a.c. source.
Solution:

(a) The d.c. power absorbed by the load (P_{dc}) :

$$P_{dc} = V_{dc} I_{dc} = \frac{V_{dc}^2}{R}$$

$$V_{dc} = \frac{V_m}{2\pi}(1 + cos\alpha) = \frac{\sqrt{2} \times 230}{2\pi}(1 + cos60^\circ) = 77.68 \text{ V}$$

$$P_{dc} = \frac{77.68^{\ 2}}{10} = 603.4 \text{ W}$$

(b) The power drawn from the supply P_{ac} :

$$P_{ac} = V_{orms} I_{orms} = \frac{V_{orms}^2}{R} = \frac{(0.5V_m)^2}{R} = \frac{1}{4} \times \frac{(\sqrt{2} \times 230)^2}{10}$$
$$= 2644.2 \text{ W}$$

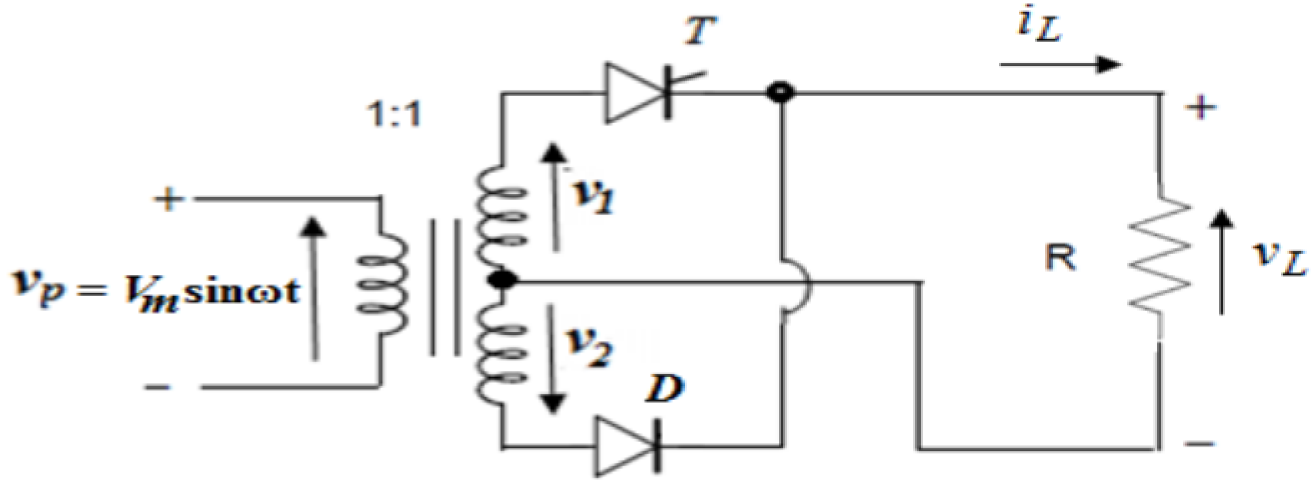
(c) The power factor at the a.c. source.

The power factor can be calculated from Eq.(3.7) as

$$PF = \sqrt{\frac{1}{2\pi}(\pi - \alpha + \frac{1}{2}sin2\alpha)} = \sqrt{\frac{1}{2\pi}(\pi - \frac{\pi}{3} + \frac{1}{2}sin120°)}$$

$$= 0.633 \text{ lagging}$$

EX: The single-phase half-controlled rectifier shown in Fig.3.11 operating at a triggering angle of 60º from a.c. source vs= 300 sinωt. Assuming the load is resistive, express Vdc of the load as a function of α, and calculate its value.



Solution

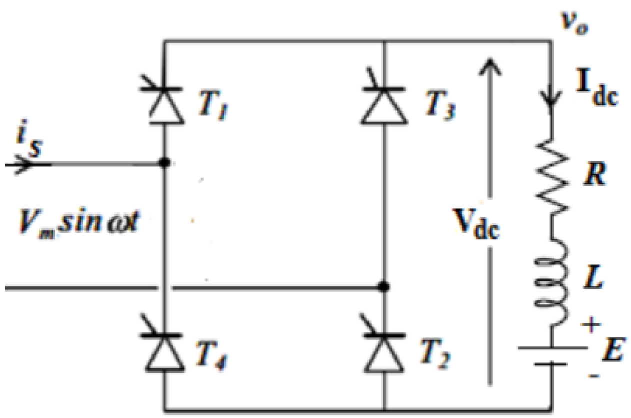
$$V_{dc} = \frac{1}{2\pi}\{\int_{\alpha}^{\pi} V_m sin\omega t \ d\omega t + \int_{\pi}^{2\pi} -V_m sin\omega t \ d\omega t \}$$

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

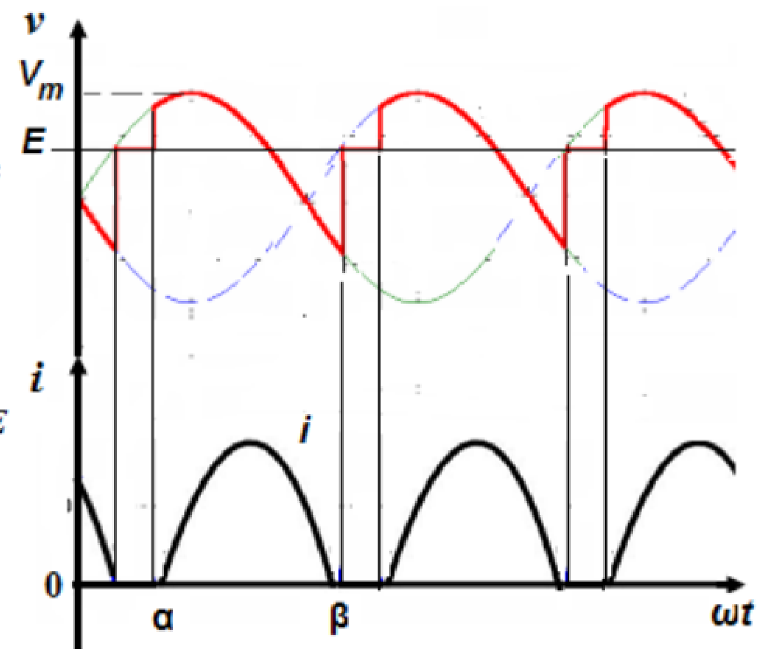
$$= \frac{V_m}{2\pi}\{1 + cos\alpha + 1 + 1\} \quad = \frac{V_m}{2\pi}\{3 + cos\alpha\}$$

$$\text{For } \alpha = 60^\circ \quad : \quad V_{dc} = \frac{V_m}{2\pi}\{3 + cos60^o\} = 167.2 \text{ V}$$

Single-phase full-wave rectifier operating with RLE load.



(a) Circuit



(b) Waveforms

Single-phase full-wave rectifier operating with *RLE* load.

EX: A fully-controlled single-phase bridge rectifier is supplied from a 50Hz, 230/100V transformer .The rectifier supplying a highly inductive load of 10 resistor. For a firing angle of 45º, determine the rectified voltage, the rectified current and the power factor.

Solution:
For highly inductive load, referring to Fig. 3.16(b), the average output voltage Vdc is calculated as follows,

$$V_{dc} = \frac{1}{\pi}\int_{\alpha}^{\alpha+\pi} V_m sin\omega t \, d\omega t = \frac{V_m}{\pi}\left\{-cos\omega t]\begin{matrix}\alpha+\pi \\ \alpha\end{matrix}\right\} = \frac{2V_m}{\pi} cos\alpha$$

$$V_m = 100 \times \sqrt{2} = 141.42 \text{ V} \qquad \text{since } V_m = \sqrt{2}\, V_{rms}$$

$$\therefore V_{dc} = \frac{2 \times 141.24}{\pi} cos45^o = 63.64 \text{ V}$$

$$I_{dc} = \frac{V_{dc}}{R} = \frac{63.64}{10} = 6.364 \text{ A}$$

$$PF = \frac{\text{Average Power}}{V_{orms} \times I_{orms}} = \frac{(\frac{2V_m}{\pi} cos\alpha) \times I_{orms}}{V_{orms} \times I_{orms}}$$

$$= \frac{2\sqrt{2}}{\pi} cos\alpha = \frac{2\sqrt{2}}{\pi} cos45° = 0.636$$

EX: A single-phase fully controlled, full-wave, bridge rectifier has a source of 230 V rms at 50 Hz, and is feeding a load R = 25 and L = 10 mH. The firing angle $\alpha = 45^\circ$ and the current extinction angle $\beta = 230^\circ$. It is required to:

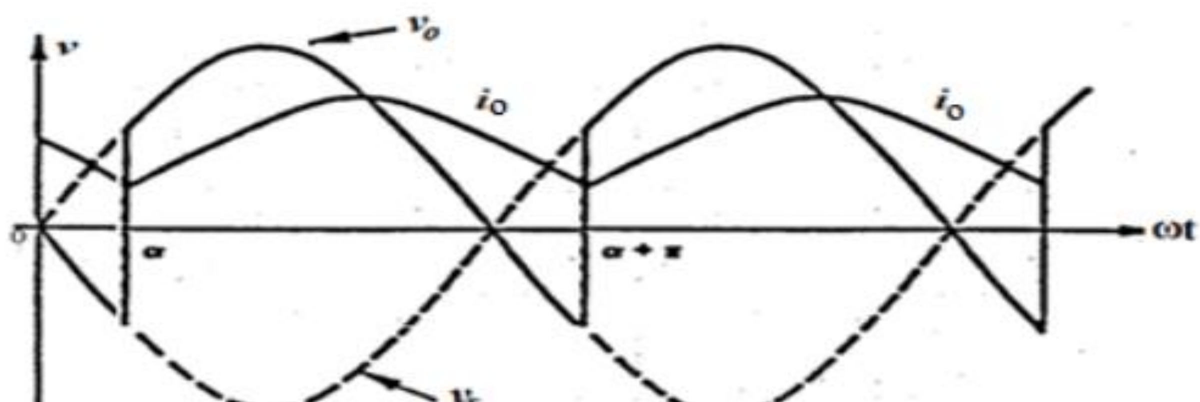
(a) Sketch the appropriate load voltage and load current waveforms.
(b) Determine whether the current is continuous or discontinuous.
(d) Determine the average load voltage and current.
(e) Determine the rms load voltage and current.
(f) Determine the a.c. and d.c powers absorbed by the load.
(g) Determine the efficiency of the converter.

Solution:

(a) Since $\pi + \alpha = 180^\circ + 45^\circ = 225^\circ < \beta$, then the current is continuous.

(b) The waveforms for v_o, and i_o are as shown in Fig.3.22,

Fig.3.22.



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

$$= \frac{2 \times 230 \times \sqrt{2}}{\pi} \cos 45 = 146.45 \text{ V}$$

$$I_{dc} = \frac{V_{dc}}{R} = \frac{146.45}{25} = 5.85 \text{ A}$$

(d) The *rms* values of the output voltage and current: Using Eq.(3.24),

$$V_{orms} = \frac{V_m}{\sqrt{2}} = \frac{230 \times \sqrt{2}}{\sqrt{2}} = 230 \text{ V}$$

$$I_{orms} = \frac{V_{rms}}{Z_L} = \frac{V_{rms}}{\sqrt{R^2 + (\omega L)^2}} = \frac{230}{\sqrt{25^2 + (2\pi \times 50 \times 10 \times 10^{-3})^2}}$$

$$\therefore \quad I_{orms} = 9.12 \text{ A}$$

(f) The d.c. and a.c. powers are,

$$P_{dc} = V_{dc}\, I_{dc} = 146.45 \times 5.85 = 856.73 \text{ W}$$

$$P_{ac} = V_{rms}\, I_{rms} = 230 \times 9.12 = 2097.6 \text{ W}$$

(g) The efficiency of the converter,

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{856.73}{2097.6} = 0.408 = 40.8\%$$

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Lecture 14

Ass. Teacher Sadeq Abdullah

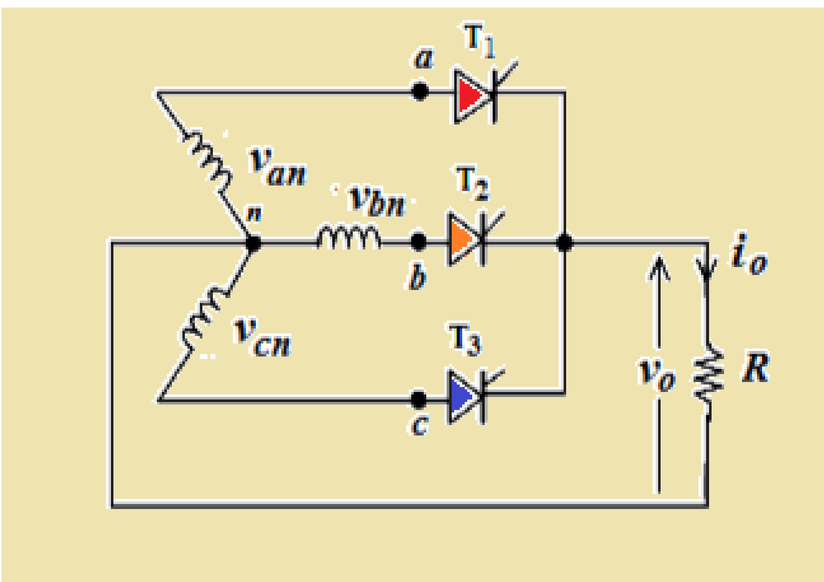
3-ph controlled rectifiers

Lectur’s objectives

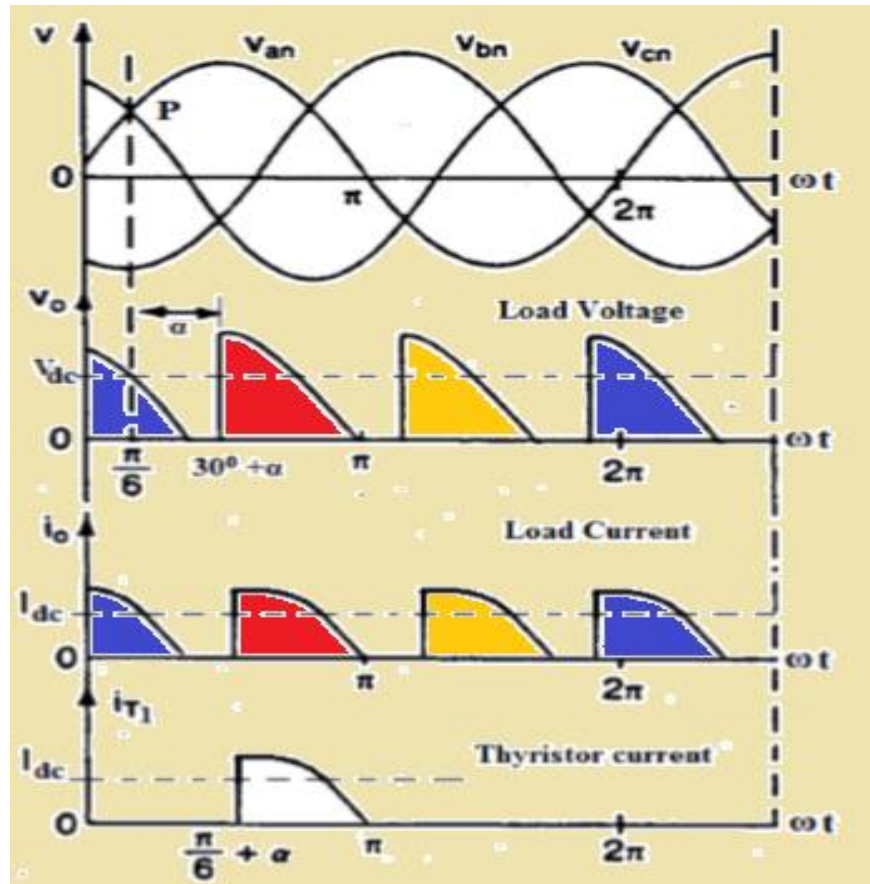
The student after the end of the lecture should be able to draw the circuits and wave forms and do the mathmatic analysis and determinations of the three-ph controlled rectifiers.

Three-Phase Half-wave Controlled Rectifier with resistive load

The Three-phase half-wave controlled rectifier is shown in Fig. below. The waveforms for the supply voltage, output voltage, and load current are shown in Fig. below for case of resistive load.



Circuit.



Waveforms.

- As for the half-wave 3-phase uncontrolled diode rectifier, the load is connected between the converter positive terminal (cathodes of all thyristors) and the supply neutral. The thyristor with the highest voltage with respect to the neutral, when triggered, **conducts**.
- When the thyristor T1 is triggered at **wt = (30+α)** the phase voltage **V**an appears across the load when T1 conducts. The load current flows through the supply phase winding 'a − n ' and through thyristor T1 as long as T1 conducts.
- When thyristor T2 is triggered at **wt = (150+α)** T1 becomes reverse biased and turns-off. The load current flows through the thyristor T2 and through the supply phase winding 'b − n '. When T2 conducts the phase voltage **V**bn appears across the load until the thyristor T3 is triggered .
- When the thyristor T3 is triggered at **wt = (270+α)** T2 is reversed biased and hence T2 turns-off. The phase voltage vcn appears across the load when T3 conducts.
- When T1 is triggered again at the beginning of the next input cycle the Thyristor T3 turns off as it is reverse biased naturally as soon as T1 is triggered . The output voltage which appears across the load, and the load current assuming a constant and ripple free load current for a highly inductive load and the current through the thyristor T1 .

Analytical properties of the output voltage waveform of the three phase half-wave controlled rectifier with resistive load

$$v_{an} = V_m \sin \omega t$$
$$v_{bn} = V_m \sin(\omega t - 2\pi/3)$$
$$v_{cn} = V_m \sin(\omega t - 4\pi/3)$$

The average value of the load voltage wave is

$$V_{dc} = \frac{1}{\frac{2\pi}{3}} \int_{30^\circ+\alpha}^{180^\circ} V_m \sin\omega t \, d\omega t = \frac{3V_m}{2\pi} [-\cos\omega t]_{30^\circ+\alpha}^{180^\circ}$$

$$= \frac{3V_m}{2\pi} [-(\cos(180^\circ) + \cos(30^\circ + \alpha)]$$

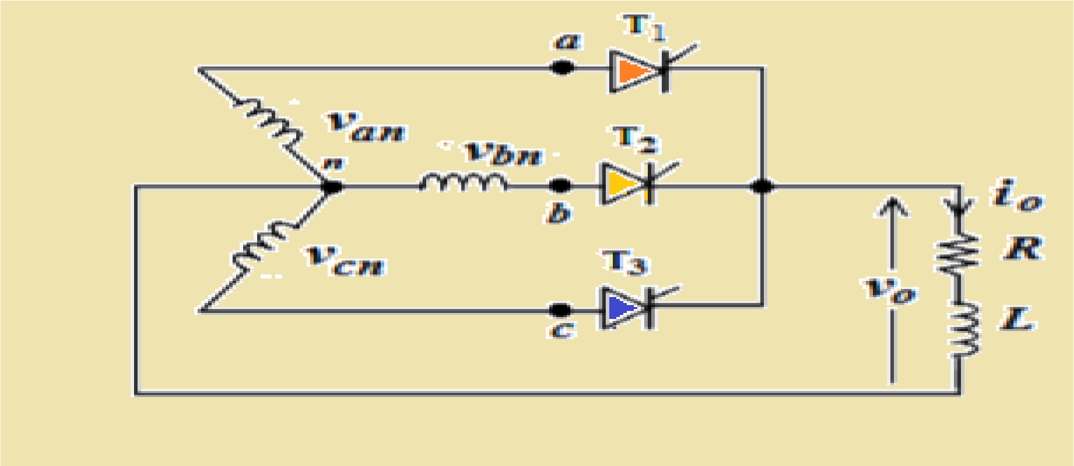
$$= \frac{3V_m}{2\pi} [1 + \cos(\alpha + 30^\circ)]$$

The load current I_{dc} is:

$$I_{dc} = \frac{3V_m}{2\pi R} [1 + \cos(\alpha + 30^\circ)]$$

Three-Phase Half-wave Controlled Rectifier with inductive load

- When the load is highly inductive it tends to maintain constant output current even with large delay angles, and the thyristor current remains rectangular as shown in Fig. below.Consequently, the induced emf in the load inductor maintains current flow even when the anode polarity has reversed.
- This means that energy is being returned from the magnetic field of the inductor through the transformer to the supply, and the circuit is temporarily acting as an inverter.The average value of the load voltage wave is



Circuit.

Wave forms and Analytical properties

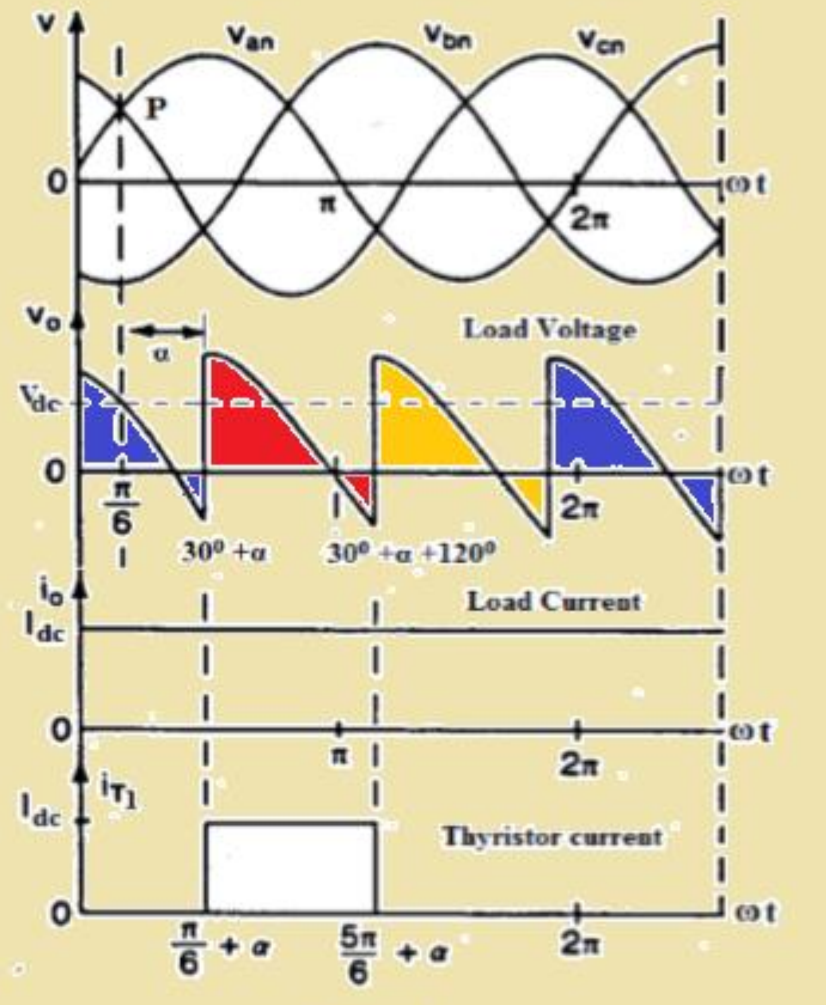
$$V_{dc} = \frac{1}{\frac{2\pi}{3}} \int_{30^\circ+\alpha}^{30^\circ+\alpha+120^\circ} V_m \; sin\omega t \; d\omega t = \frac{3V_m}{2\pi} \left[-cos\omega t\right]_{30^\circ+\alpha}^{150^\circ+\alpha}$$

$$V_{dc} = \frac{3V_m}{2\pi}\left[-(\cos(150^\circ+\alpha) - \cos(30^\circ+\alpha))\right]$$

$$= \frac{3\sqrt{3}V_m}{2\pi} cos\alpha$$

The load current I_{dc} is:

$$I_{dc} = \frac{3\sqrt{3}V_m}{2\pi R} cos\alpha$$



Waveforms

Example: The load in Fig.3.31 consists of a resistance and a very large inductance. The inductance is so large that the output current Io can be assumed to be continuous and ripple-free. For α = 60°, (a) Draw the wave forms of Vo and Io. (b) Determine the average value of the output voltage, if phase voltage Van = 120 V. (c) Find the average output voltage if a free wheel diode is connected across the load.

Solution:

(a) The waveforms of Vo and Io are as shown in Fig. above

(b) The average value of the output voltage is given in Eq. above

$$V_{av} = \frac{3\sqrt{3}\, V_m}{2\pi} \cos\alpha$$

$$\text{For } \alpha = 60^\circ: \qquad V_m = \sqrt{2}\, V_{an} = \sqrt{2} \times 120\ \text{V} = 169.7\ \text{V}$$

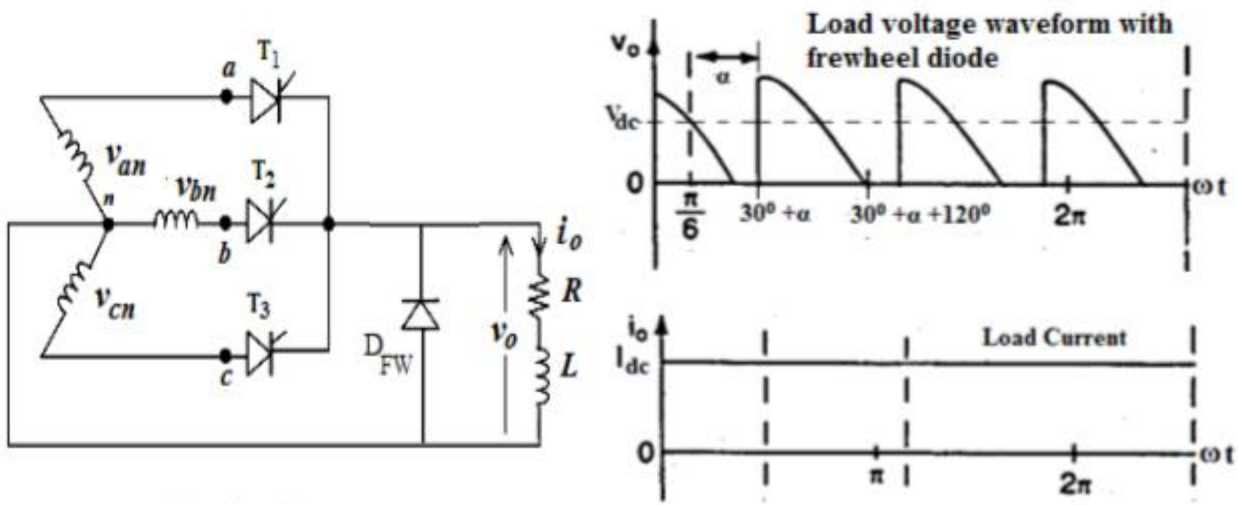
$$\therefore V_{dc} = \frac{3\sqrt{3}}{2\pi} \times 169.7 \cos 60^\circ = 70.2\ \text{V}$$

(c) If a freewheel diode is connected across the load, the circuit and output voltage waveform will be as shown in Fig. below The average voltage of the waveform can be determined as

$$V_{dc} = \frac{1}{\frac{2\pi}{3}} \int_{30^\circ+\alpha}^{\pi} V_m \; sin\omega t \; d\omega t = \frac{3V_m}{2\pi} \left[-cos\omega t\right]_{30^\circ + \alpha}^{\pi}$$

$$V_{dc} = \frac{3V_m}{2\pi}(1 + \cos(30^\circ + \alpha))$$

$$\therefore V_{dc} = \frac{3\sqrt{3}}{2\pi} \times 169.7\,(1 + \cos(30^\circ + 60^\circ)) = 81\ \text{V}$$



(a) Circuit

(b) Waveform

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مسائل الكترونيك القدرة

المحاضر : صادق عبد الله

Q1. The applied input a.c. power to a half-wave rectifier is 100 watts. The d.c. output power obtained is 40 watts.
(i) What is the rectification efficiency ?
(ii) What happens to remaining 60 watts ?

Solution :

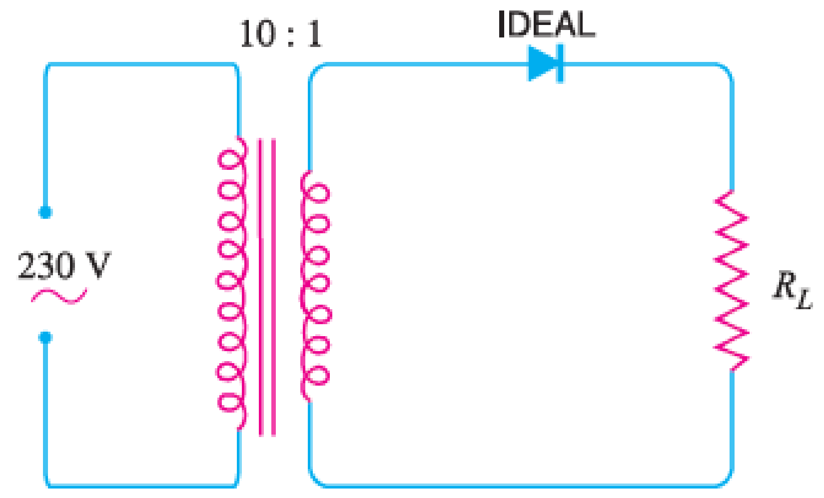
(i) $$\text{Rectification efficiency} = \frac{\text{d.c. output power}}{\text{a.c. input power}} = \frac{40}{100} = 0.4 = 40\%$$

(ii) 40% efficiency of rectification does not mean that 60% of power is lost in the rectifier circuit. In fact, a crystal diode consumes little power due to its small internal resistance. The 100 W a.c. power is contained as 50 watts in positive half-cycles and 50 watts in negative half-cycles. The 50 watts in the negative half-cycles are not supplied at all. Only 50 watts in the positive half-cycles are converted into 40 watts.

$$\therefore \quad \text{Power efficiency} = \frac{40}{50} \times 100 = 80\%$$

Although 100 watts of a.c. power was supplied, the half-wave rectifier accepted only 50 watts and converted it into 40 watts d.c. power. Therefore, it is appropriate to say that efficiency of rectification is 40% and not 80% which is power efficiency.

Q2. An a.c. supply of 230 V r.m.s is applied to a half-wave rectifier circuit through a transformer of turn ratio 10 : 1. Find (i) the output d.c. voltage and (ii) the peak inverse voltage. Assume the diode to be ideal.



Solution :

Primary to secondary turns is

$$\frac{N_1}{N_2} = 10$$

R.M.S. primary voltage

$$= 230 \text{ V}$$

$\therefore$ Max. primary voltage is

$$V_{pm} = (\sqrt{2}) \times \text{r.m.s. primary voltage}$$

$$= (\sqrt{2}) \times 230 = 325.3 \text{ V}$$

Max. secondary voltage is

$$V_{sm} = V_{pm} \times \frac{N_2}{N_1} = 325.3 \times \frac{1}{10} = 32.53 \text{ V}$$

(i)

$$I_{d.c.} = \frac{I_m}{\pi}$$

$$V_{dc} = \frac{I_m}{\pi} \times R_L = \frac{V_{sm}}{\pi} = \frac{32.53}{\pi} = \mathbf{10.36\ V}$$

(ii) During the negative half-cycle of a.c. supply, the diode is reverse biased and hence conducts no current. Therefore, the maximum secondary voltage appears across the diode.

$$\therefore \quad \text{Peak inverse voltage} = \mathbf{32.53\ V}$$

Q3. A half-wave rectifier is used to supply 50V d.c. to a resistive load of 800 Ω. The diode has a resistance of 25 Ω. Calculate a.c. voltage required.

Solution :

Output d.c. voltage, $V_{dc} = 50\text{ V}$

Diode resistance, $r_f = 25\ \Omega$

Load resistance, $R_L = 800\ \Omega$

Let V_m be the maximum value of a.c. voltage required.

$$\therefore \quad V_{dc} = I_{dc} \times R_L$$

$$= \frac{I_m}{\pi} \times R_L = \frac{V_m}{\pi (r_f + R_L)} \times R_L \qquad \left[\because I_m = \frac{V_m}{r_f + R_L}\right]$$

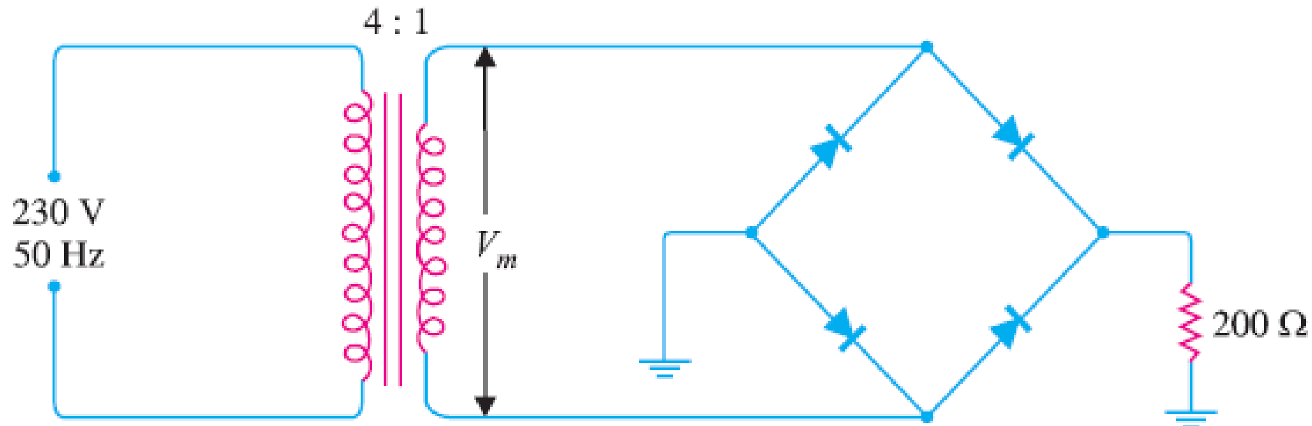
or

$$50 = \frac{V_m}{\pi (25 + 800)} \times 800$$

$$\therefore \quad V_m = \frac{\pi \times 825 \times 50}{800} = \mathbf{162\ V}$$

Hence a.c. voltage of maximum value 162 V is required.

Q4. In the bridge type circuit shown in Fig. 3, the diodes are assumed to be ideal. Find : (i) d.c. output voltage (ii) peak inverse voltage (iii) output frequency. Assume primary to secondary turns to be 4.



Solution :

Primary/secondary turns, $N_1/N_2 = 4$

R.M.S. primary voltage $= 230$ V

$\therefore$ R.M.S. secondary voltage $= 230\,(N_2/N_1) = 230 \times (1/4) = 57.5$ V

Maximum voltage across secondary is

$$V_m = 57.5 \times \sqrt{2} = 81.3 \text{ V}$$

(*i*) Average current, $I_{dc} = \dfrac{2V_m}{\pi R_L} = \dfrac{2 \times 81.3}{\pi \times 200} = 0.26$ A

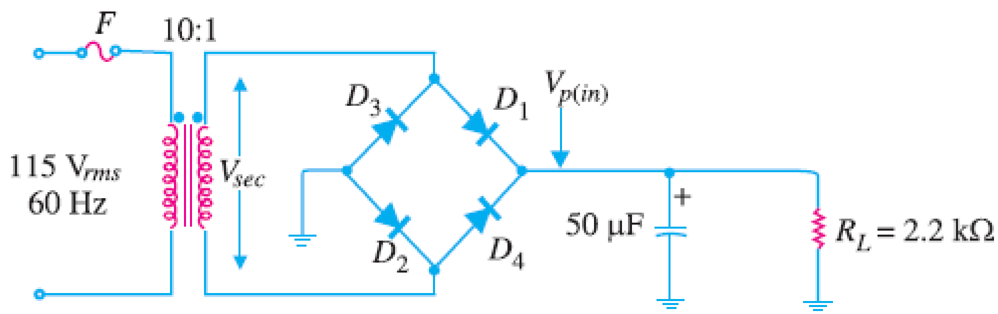
$\therefore$ d.c. output voltage, $V_{dc} = I_{dc} \times R_L = 0.26 \times 200 =$ **52 V** (*ii*) The peak inverse voltage is equal to the maximum secondary voltage *i.e.*

$$PIV = \mathbf{81.3\ V}$$

(*iii*) In full-wave rectification, there are two output pulses for each complete cycle of the input a.c. voltage. Therefore, the output frequency is twice that of the a.c. supply frequency *i.e.*

$$f_{out} = 2 \times f_{in} = 2 \times 50 = \mathbf{100\ Hz}$$

Q5. For the circuit shown in Fig.7, find the output d.c. voltage.



Solution :

It can be proved that output d.c. voltage is given by :

$$V_{dc} = V_{p(in)}\left(1 - \frac{1}{2f\ R_L C}\right)$$

Here $V_{p(in)}$ = Peak rectified full-wave voltage applied to the filter

f = Output frequency

Peak primary voltage, $V_{p(prim)} = \sqrt{2} \times 115 = 163\text{V}$

Peak secondary voltage, $V_{p(sec)} = \left(\frac{1}{10}\right) \times 163 = 16.3\text{V}$

Peak full-wave rectified voltage at the filter input is

$$V_{p\ (in)} = V_{p\ (sec)} - 2\times0.7 = 16.3 - 1.4 = 14.9\text{V}$$

For full-wave rectification, $f = 2\ f_{in} = 2\times60 = 120$ Hz

Now $$\frac{1}{2f\ R_L C} = \frac{1}{2\times120\times(2.2\times10^3)\times(50\times10^{-6})} = 0.038$$

Q6. A power supply A delivers 10 V dc with a ripple of 0.5 V r.m.s. while the power supply B delivers 25 V dc with a ripple of 1 mV r.m.s. Which is better power supply ?

Solution :

The lower the ripple factor of a power supply, the better it is.
For power supply A

$$\text{Ripple factor} = \frac{V_{ac(r.m.s.)}}{V_{dc}} = \frac{0.5}{10} \times 100 = 5\%$$

For power supply B

$$\text{Ripple factor} = \frac{V_{ac(r.m.s.)}}{V_{dc}} = \frac{0.001}{25} \times 100 = 0.004\%$$

Clearly, power supply *B* is better.

Transistors

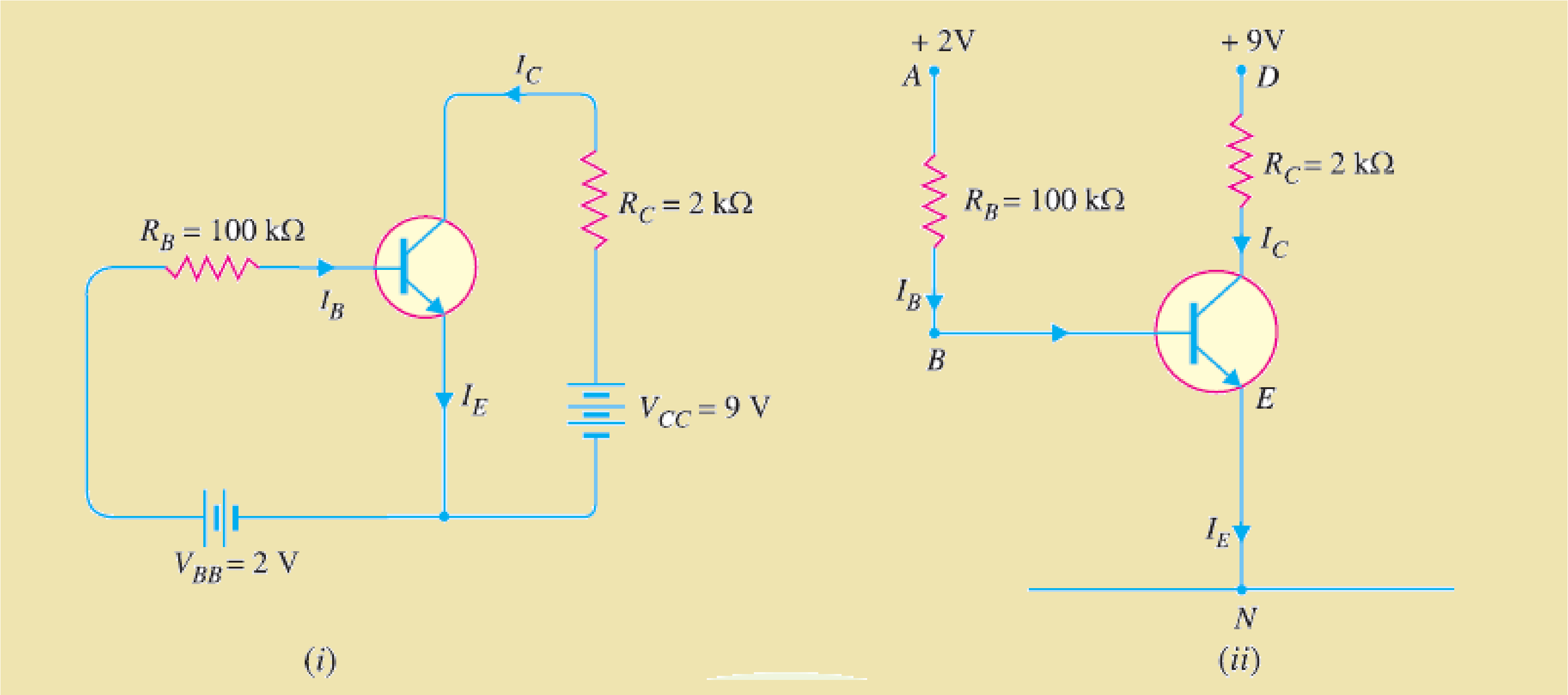
Q: A transistor employs a 4 kΩ load and V_{CC} = 13V. What is the maximum input signal if β = 100 ? Given V_{knee} = 1V and a change of 1V in V_B causes a change of 5mA in collector current.

- **Solution :**
- **Collector supply voltage, V_{CC} = 13 V**
  Knee voltage, V_{knee} = 1 V
  Collector load, R_C = 4 kΩ

∴ Max. allowed voltage across R_C = 13 − 1 = 12 V
∴ Max. allowed collector current, i_C =12 V /R_C = 12 V/ 4 KΩ = 3 mA

- Maximum base current, $i_B = i_C / \beta$ = 3 mA / 100 = 30 µA
- Now Collector current / Base voltage (signal voltage) = 5 mA/V
- ∴ Base voltage (signal voltage) = Collector current / (5 mA/V)= 3 mA /(5 mA/V) = 600 mV

Q: in the Fig. bellow (i) shows biasing with base resistor method. (i) Determine the collector current I_C and collector-emitter voltage V_{CE}. Neglect small base-emitter voltage. Given that β = 50. (ii) If R_B in this circuit is changed to 50 kΩ, find the new operating point.



Solution :

- In the circuit shown in Fig. 2 (i), biasing is provided by a battery V_{BB} (= 2V) in the base circuit which is separate from the battery V_{CC} (= 9V) used in the output circuit.
- The same circuit is shown in a simplified way in Fig. 2 (ii). Here, we need show only the supply voltages, + 2V and +9V. It may be noted that negative terminals of the power supplies are grounded to get a complete path of current.
- (i) Referring to Fig.2 (ii) and applying Kirchhoff 's voltage law to the circuit ABEN, we get,

$$I_B R_B + V_{BE} = 2\,\text{V}$$

As V_{BE} is negligible,

$$\therefore \quad I_B = \frac{2\text{V}}{R_B} = \frac{2\text{V}}{100\ \text{k}\Omega} = 20\ \mu\text{A}$$

$$\text{Collector current, } I_C = \beta I_B = 50 \times 20\ \mu\ \text{A} = 1000\ \mu\,\text{A} = \mathbf{1\ mA}$$

Applying Kirchhoff's voltage law to the circuit *DEN*, we get,

$$I_C R_C + V_{CE} = 9$$

or $$1\ \text{mA} \times 2\ \text{k}\Omega + V_{CE} = 9$$

or $$V_{CE} = 9 - 2 = \mathbf{7\ V}$$

(ii) When R_B is made equal to 50 kΩ, then it is easy to see that base current is doubled i.e. I_B = 40 μA.

∴ Collector current, $I_C = \beta I_B = 50 \times 40 = 2000 \mu A = 2 mA$

Collector-emitter voltage, $V_{CE} = V_{CC} - I_C R_C = 9 - 2 mA \times 2 k\Omega = 5 V$

∴ New operating point is **5 V, 2 mA.**

- **Q5. (i) A germanium transistor is to be operated at zero signal I_C = 1mA. If the**
  collector supply V_{CC} = 12V, what is the value of R_B in the base resistor method ? Take β = 100.
  (ii) If another transistor of the same batch with β = 50 is used, what will be the new value of zero signal I_C for the same R_B ?
- **Solution :**
- Given, V_{CC} = 12 V, β = 100
- As it is a Ge transistor, therefore, V_{BE} = 0.3 V
- **(i)** Zero signal I_C = 1 mA

$$\therefore \quad \text{Zero signal } I_B = I_C/\beta = 1 \text{ mA}/100 = 0.01 \text{ mA}$$

$$\text{Using the relation, } V_{CC} = I_B R_B + V_{BE}$$

$$\therefore \quad R_B = \frac{V_{CC} - V_{BE}}{I_B} = \frac{12 - 0.3}{0.01 \text{ mA}}$$

$$= 11.7 \text{ V}/0.01 \text{ mA} = \mathbf{1170\ k\Omega}$$

(ii) Now β = 50

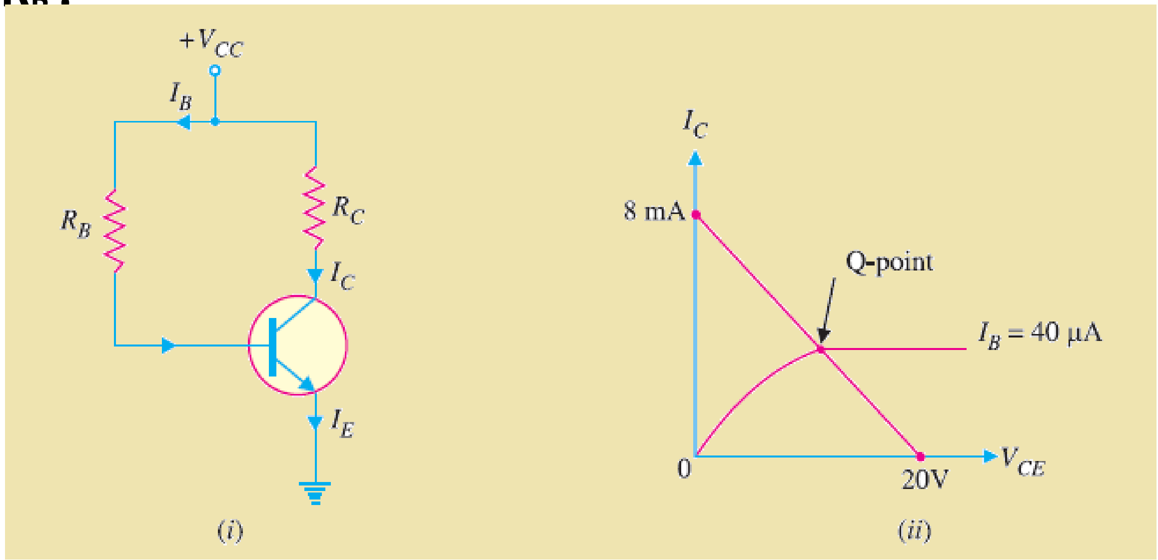
Again using the relation, $V_{CC} = I_B R_B + V_{BE}$

$$\therefore \quad I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12 - 0.3}{1170\ \text{k}\Omega}$$

$$= 11.7\ \text{V}/1170\ \text{k}\Omega = 0.01\ \text{mA}$$

$$\therefore \quad \text{Zero signal } I_C = \beta\, I_B = 50 \times 0.01 = \mathbf{0.5\ mA}$$

Q10. Fig. 8 (i) shows the base resistor silicon transistor circuit. The device (i.e. transistor) has the characteristics shown in Fig. 8 (ii). Determine V_{CC}, R_C and R_B .



Solution :

From the d.c load line, $V_{CE} = V_{CC} - I_C R_C$, When $I_C = 0$, $V_{CE} = V_{CC}$ $V_{CC} = 20V$.

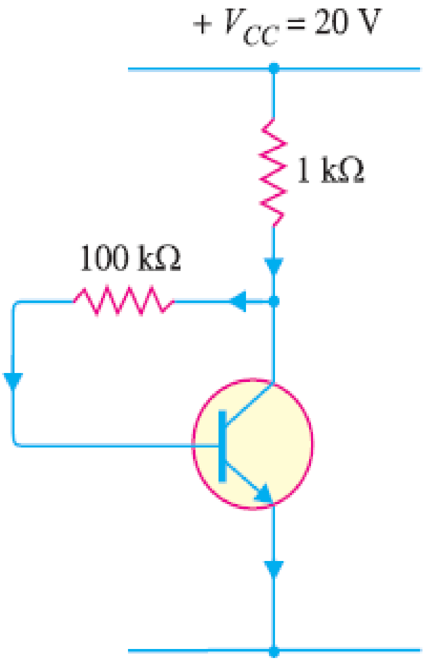
$$\text{Max. } I_C = \frac{V_{CC}}{R_C} \text{ (when } V_{CE} = 0\text{V)}$$

$$\therefore \quad R_C = \frac{V_{CC}}{\text{Max. } I_C} = \frac{20\text{V}}{8\text{mA}} = \mathbf{2.5\ k\Omega}$$

Now $$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

$$\therefore \quad R_B = \frac{V_{CC} - V_{BE}}{I_B} = \frac{20\text{V} - 0.7\text{V}}{40\ \mu\text{A}} = \frac{19.3\text{V}}{40\ \mu\text{A}} = \mathbf{482.5\ k\Omega}$$

- **Q14. Fig. 12 shows a silicon transistor biased by collector feedback resistor method. Determine the operating point. Given that β = 100.**



Solution :

V_{CC} = 20V, R_B = 100 kΩ, R_C = 1kΩ

Since it is a silicon transistor, V_{BE} = 0.7 V.

Assuming I_B to be in mA and using the relation

$$R_B = \frac{V_{CC} - V_{BE} - \beta\, I_B R_C}{I_B}$$

or $$100 \times I_B = 20 - 0.7 - 100 \times I_B \times 1$$

or $$200\, I_B = 19.3$$

or $$I_B = \frac{19.3}{200} = 0.096 \text{ mA}$$

∴ Collector current, $I_C = \beta\, I_B = 100 \times 0.096 = 9.6$ mA

Collector-emitter voltage is

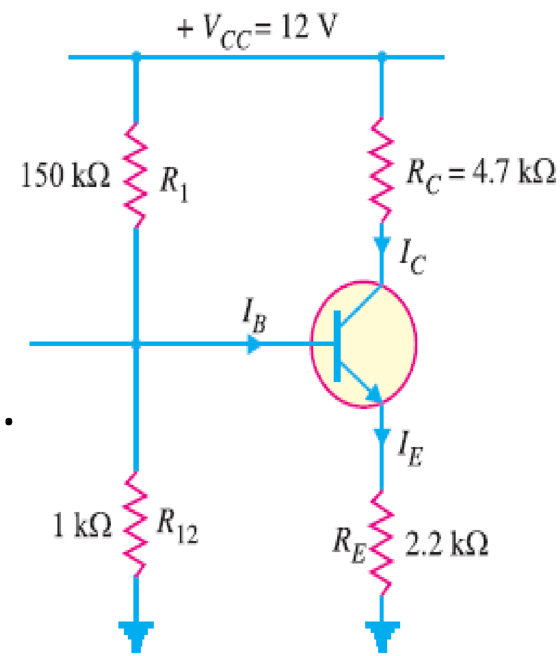
$$V_{CE} = V_{CC} - I_C R_C$$
$$= 20 - 9.6 \text{ mA} \times 1 \text{ k}\Omega$$
$$= 10.4 \text{ V}$$

∴ Operating point is **10.4 V, 9.6 mA.**

Q21. For the circuit shown in Fig. 19, find the operating point. What is the stability factor of the circuit ? Given that β = 50 and V_{BE} = 0.7V.

Solution :

Fig. 19 shows the circuit of potential divider bias and Fig. 20 shows it with potential divider circuit replaced by Thevenin's equivalent circuit.

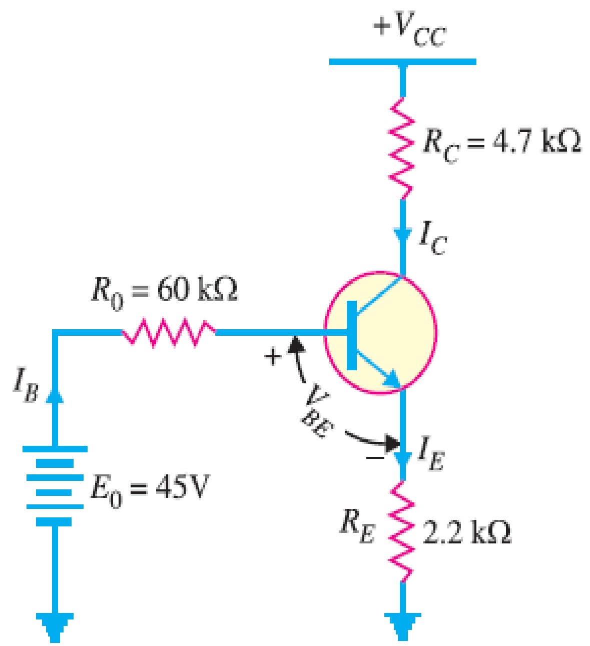


$$E_0 = \frac{V_{CC}}{R_1 + R_2} \times R_2 = \frac{12\text{V}}{150\text{ k}\Omega + 100\text{ k}\Omega} \times 100\text{ k}\Omega = 4.8\text{V}$$

$$R_0 = \frac{R_1 R_2}{R_1 + R_2} = \frac{150\text{ k}\Omega \times 100\text{ k}\Omega}{150\text{ k}\Omega + 100\text{ k}\Omega} = 60\text{ k}\Omega$$

$\therefore$
$$I_B = \frac{E_0 - V_{BE}}{R_0 + \beta R_E} \quad \ldots$$

$$= \frac{4.8\text{V} - 0.7\text{V}}{60\text{ k}\Omega + 50 \times 2.2\text{ k}\Omega} = \frac{4.1\text{V}}{170\text{ k}\Omega} = 0.024\text{ mA}$$



Now $I_C = \beta I_B = 50 \times 0.024 = 1.2$ mA

$\therefore$ $V_{CE} = V_{CC} - I_C (R_C + R_E)$

$= 12\text{V} - 1.2\text{mA} (4.7\text{ k}\Omega + 2.2\text{ k}\Omega) = 3.72\text{V}$

$\therefore$ Operating point is **3.72V, 1.2 mA.**

Now
$$\frac{R_0}{R_E} = \frac{60\text{ k}\Omega}{2.2\text{ k}\Omega} = 27.3$$

$\therefore$ Stability factor,
$$S = (\beta + 1) \times \frac{1 + R_0 / R_E}{\beta + 1 + R_0 / R_E}$$

$$= (50 + 1) \times \frac{1 + 27.3}{50 + 1 + 27.3} = \mathbf{18.4}$$

Thyristors

EX: The single-phase half-wave controlled rectifier shown in fig. bellow supplies a resistive load draws an average current of 1.62 A. If the converter is operated from a 240 V, 50 Hz supply and if the average value of the output voltage is 81V, calculate the following:

(a) The firing angle α.

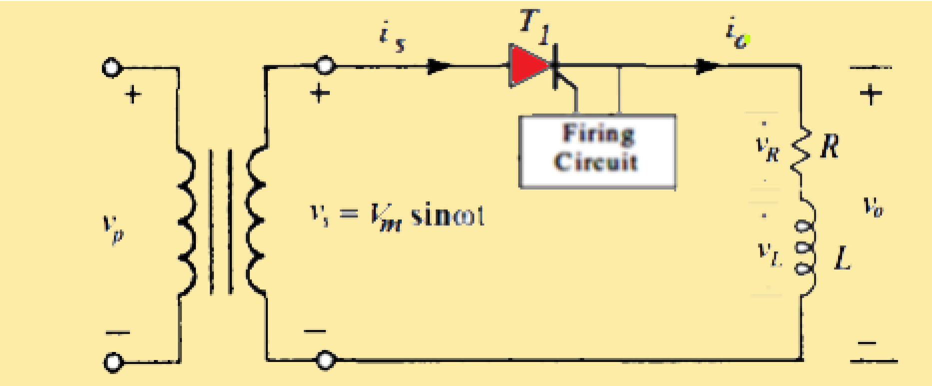
(b) Load resistance .

(c)The rms load voltage.

(d) The rms load current.

(e) DC power.

(f) The ripple factor .



Solution

(a) For single-phase half-wave controlled rectifier with resistive load; the average value of the output voltage is calculated

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

$$81 = \frac{240 \times \sqrt{2}}{2\pi}(1 + cos\alpha) \quad \rightarrow \quad \text{Hence } \alpha = 60°.$$

(b) $$R = \frac{V_{dc}}{I_{dc}} = \frac{81}{1.62} = 50\ \Omega$$

(c) The *rms* load voltage is calculated using Eq.(3.4) as

$$V_{orms} = \frac{V_m}{2}\sqrt{\frac{1}{\pi}(\pi - \alpha + \frac{1}{2}sin2\alpha)}$$

$$= \frac{240 \times \sqrt{2}}{2}\sqrt{\frac{1}{\pi}(\pi - \frac{\pi}{3} + \frac{1}{2}sin120°)} = 152.14 \text{ V}$$

(d) The *rms* load current

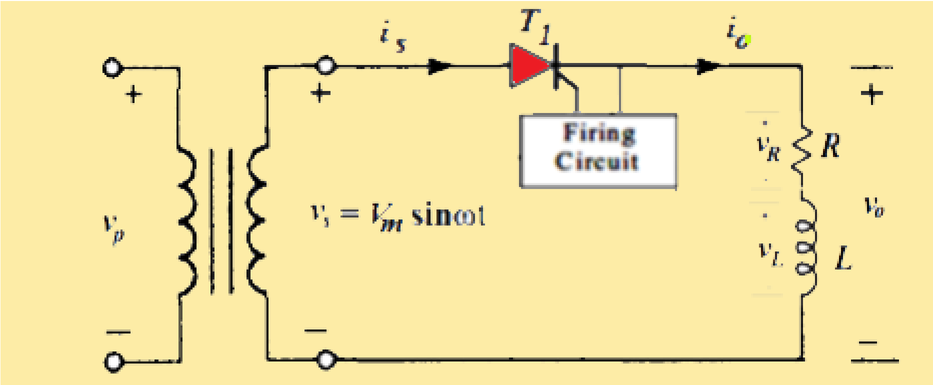
$$I_{orms} = \frac{V_{orms}}{R} = \frac{152.14}{50} = 3.04 \text{ A}$$

(e) The output d.c. power is given by:

$$P_{dc} = V_{dc}I_{dc} = \frac{V_{dc}^2}{R} = \frac{81^2}{50} = 131.22 \text{ W}$$

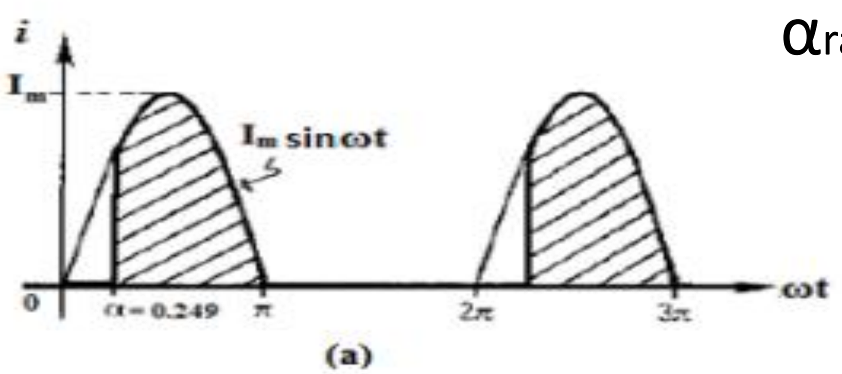
(f) Ripple factor $= \frac{\sqrt{V_{orms}^2 - V_{dc}^2}}{V_{dc}} = \frac{\sqrt{152.14^2 - 81^2}}{81} = 1.57$

EX: The circuit shown bellow is used as a half-wave controlled rectifier supplying resistive load from 230v a.c with RL = 1 k . For the firing angle α = 14.3˚draw the load current waveforms for the angle .



Solution :

The load current waveform is shown in Fig. bellow (a) when α = 14.3˚ = 0.249 rad.



$\alpha_{rad} = \alpha * (\pi/180)$

EX: A single-phase half-wave controlled rectifier shown in previous example supplied from 230V a.c. supply is operating at α = 60º. If the load resistor is 10 , determine:

(a) The power absorbed by the load (Pdc).

(b) The power drawn from the supply (Pac).

(c) The power factor at the a.c. source.

Solution:

(a) The d.c. power absorbed by the load (P_{dc}) :

$$P_{dc} = V_{dc} I_{dc} = \frac{V_{dc}^2}{R}$$

$$V_{dc} = \frac{V_m}{2\pi}(1 + cos\alpha) = \frac{\sqrt{2} \times 230}{2\pi}(1 + cos60°) = 77.68 \text{ V}$$

$$P_{dc} = \frac{77.68^2}{10} = 603.4 \text{ W}$$

(b) The power drawn from the supply P_{ac} :

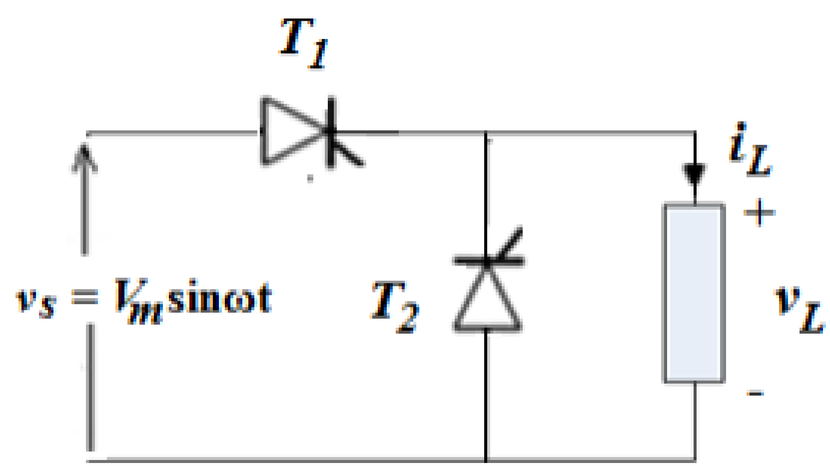
$$P_{ac} = V_{orms} I_{orms} = \frac{V_{orms}^2}{R} = \frac{(0.5V_m)^2}{R} = \frac{1}{4} \times \frac{(\sqrt{2} \times 230)^2}{10}$$
$$= 2644.2 \text{ W}$$

(c) The power factor at the a.c. source.

The power factor can be calculated from Eq.(3.7) as

$$PF = \sqrt{\frac{1}{2\pi}(\pi - \alpha + \frac{1}{2}sin2\alpha)} = \sqrt{\frac{1}{2\pi}(\pi - \frac{\pi}{3} + \frac{1}{2}sin120^\circ)}$$
$$= 0.633 \text{ lagging}$$

EX: For the single-phase half-wave controlled rectifier shown bellow, thyristor T1 is operating at α1 = 80º. Thyristor T2 is connected across the load and operating with a delay angle α2 of 40º. Assume the load is highly inductive such that IL is continuous. Plot waveforms for the instantaneous values of vL, iT1 , iT2 ,iL , vT1 and vT2. Derive an expression for the average load voltage Vdc as a function of α1 and α2 (with α1 < α2).



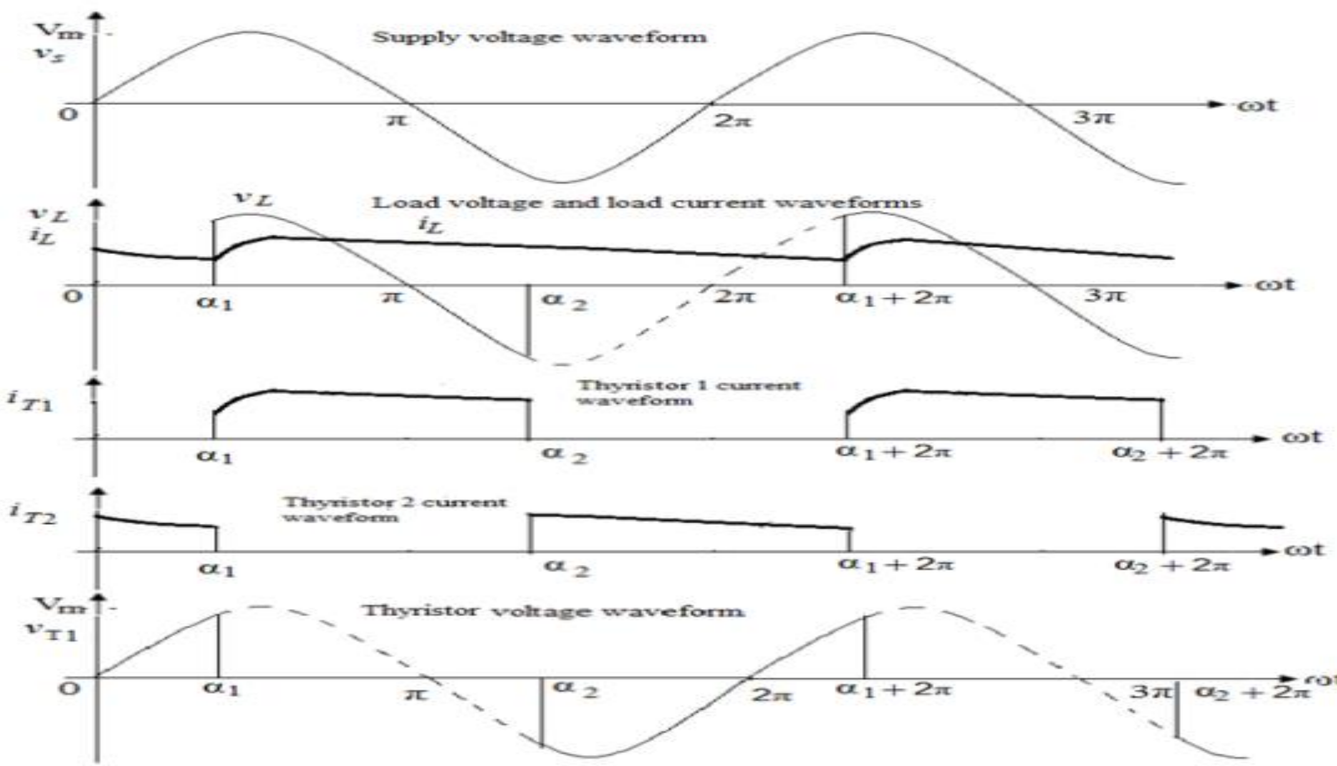
Solution

The voltage and current waveforms are shown

The average d.c. voltage may be obtained as

$$V_{dc} = \frac{1}{2\pi}\int_{\alpha_1}^{\alpha_2} V_m sin\omega t \, d\omega t = \frac{V_m}{2\pi}\int_{\alpha_1}^{\alpha_2} sin\omega t \, d\omega t$$

$$= \frac{V_m}{2\pi}\left\{-cos\omega t \Big| \begin{matrix}\alpha_2\\ \alpha_1\end{matrix}\right\} = \frac{V_m}{2\pi}\{cos\alpha_1 - cos\alpha_2\}$$



Ex: A fully-controlled single-phase bridge rectifier is supplied from a 50Hz, 230/100V transformer .The rectifier supplying a highly inductive load of 10 resistor. For a firing angle of 45º, determine the rectified voltage, the rectified current and the power factor.

Solution

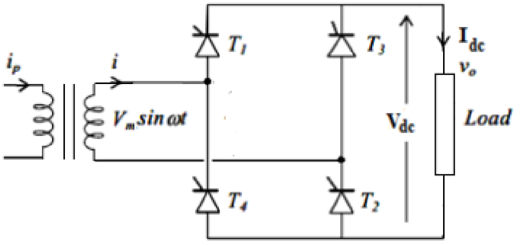
For highly inductive load, referring to Fig. 3.16(b), the average output voltage V_{dc} is calculated as follows,

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

$$V_m = 100 \times \sqrt{2} = 141.42\text{ V} \qquad \text{since } V_m = \sqrt{2}\, V_{rms}$$

$$\therefore V_{dc} = \frac{2 \times 141.24}{\pi} cos45^o = 63.64\text{ V}$$

$$I_{dc} = \frac{V_{dc}}{R} = \frac{63.64}{10} = 6.364\text{ A}$$



(a)

$$PF = \frac{\text{Average Power}}{V_{orms} \times I_{orms}} = \frac{(\frac{2V_m}{\pi} cos\alpha) \times I_{orms}}{V_{orms} \times I_{orms}}$$

$$= \frac{2\sqrt{2}}{\pi} cos\alpha = \frac{2\sqrt{2}}{\pi} cos45^\circ = 0.636$$

EX: The single-phase half-controlled rectifier shown in Fig.3.11 operating at a triggering angle of 60º from a.c. source vs = 300 sinωt. Assuming the load is resistive, express Vdc of the load as a function of α, and calculate its value.

Solution

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

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

$$= \frac{V_m}{2\pi}\{1 + cos\alpha + 1 + 1\} = \frac{V_m}{2\pi}\{3 + cos\alpha\}$$

For $\alpha = 60°$: $V_{dc} = \frac{V_m}{2\pi}\{3 + cos60^o\} = 167.2$ V