POWER ELECTRONICS

BY

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UNIT 1

On the completion of this period, You will be able to know

- Importance of Power Electronics Devices
- Types of Power Electronics Devices
- Constructional details of SCR

CONCEPT OF POWER ELECTRONIC DEVICES

Power Electronics deals with conversion/control of electric power by wave shaping of voltage, current or both using fast switching power semi conductor devices.

Power electronic system

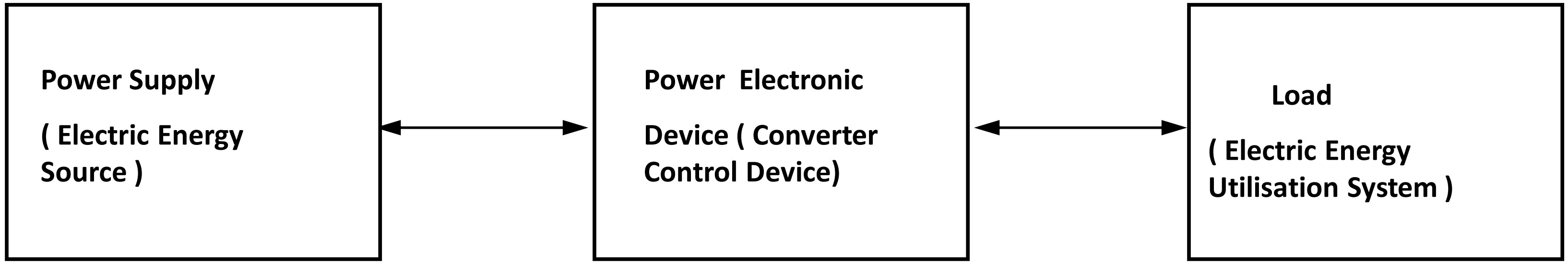


Figure : 1

ADVANTAGES OF POWER ELECTRONIC DEVICES

- High Efficiency due to low loss in Power semi conductor devices.

- Long life and less maintenance

- Small size and less weight.

- Low cost

Applications of Power Electronic Devices

- Residential (Cooking, Lighting, space Heating. Refrigerators, dryers etc.,)
- Transportation (Street Cars, Trolley Buses, Subways etc.,)
- Telecommunication (Battery Charges, Power supplies etc.,)
- Commercial (Advertising, Heating, Air- Conditioning, UPS etc.,)

Power BJT

Bipolar junction transistors are two types:

1.NPN 2. PNP

- For small signal processing any of the two can be used
- For handling large power, in power devices, NPN transistor used in the CE configuration

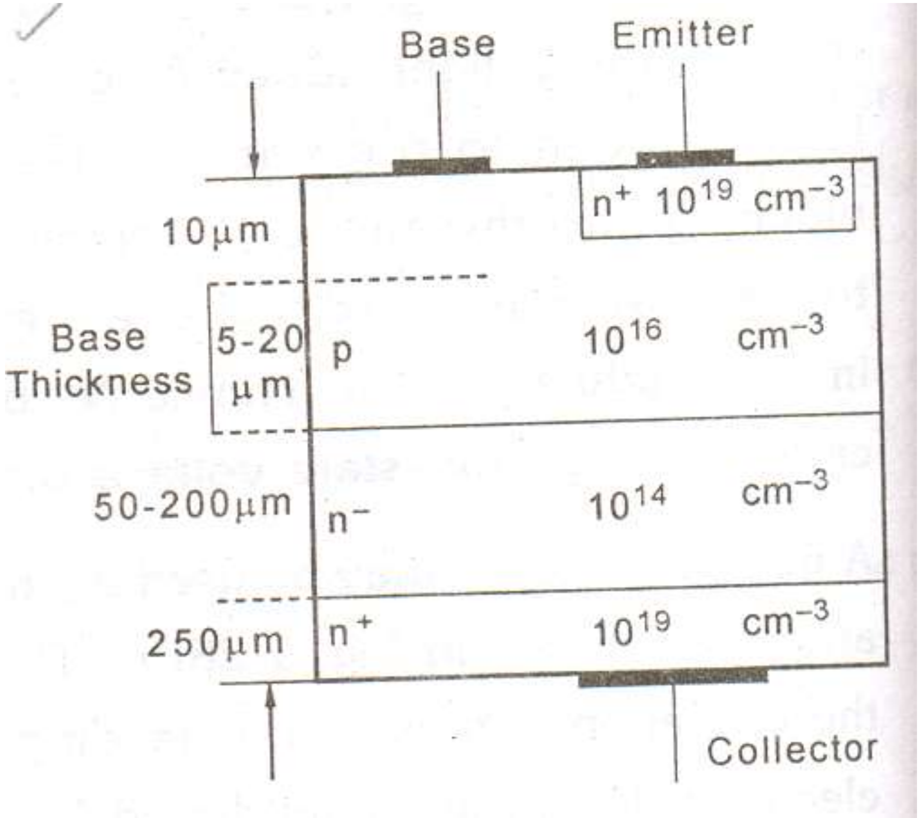
Power BJT:

- 3 terminals

  Base-B

  Emitter-E

  Collector-C



- 4 layers

  n+

  p

  n-

  n+

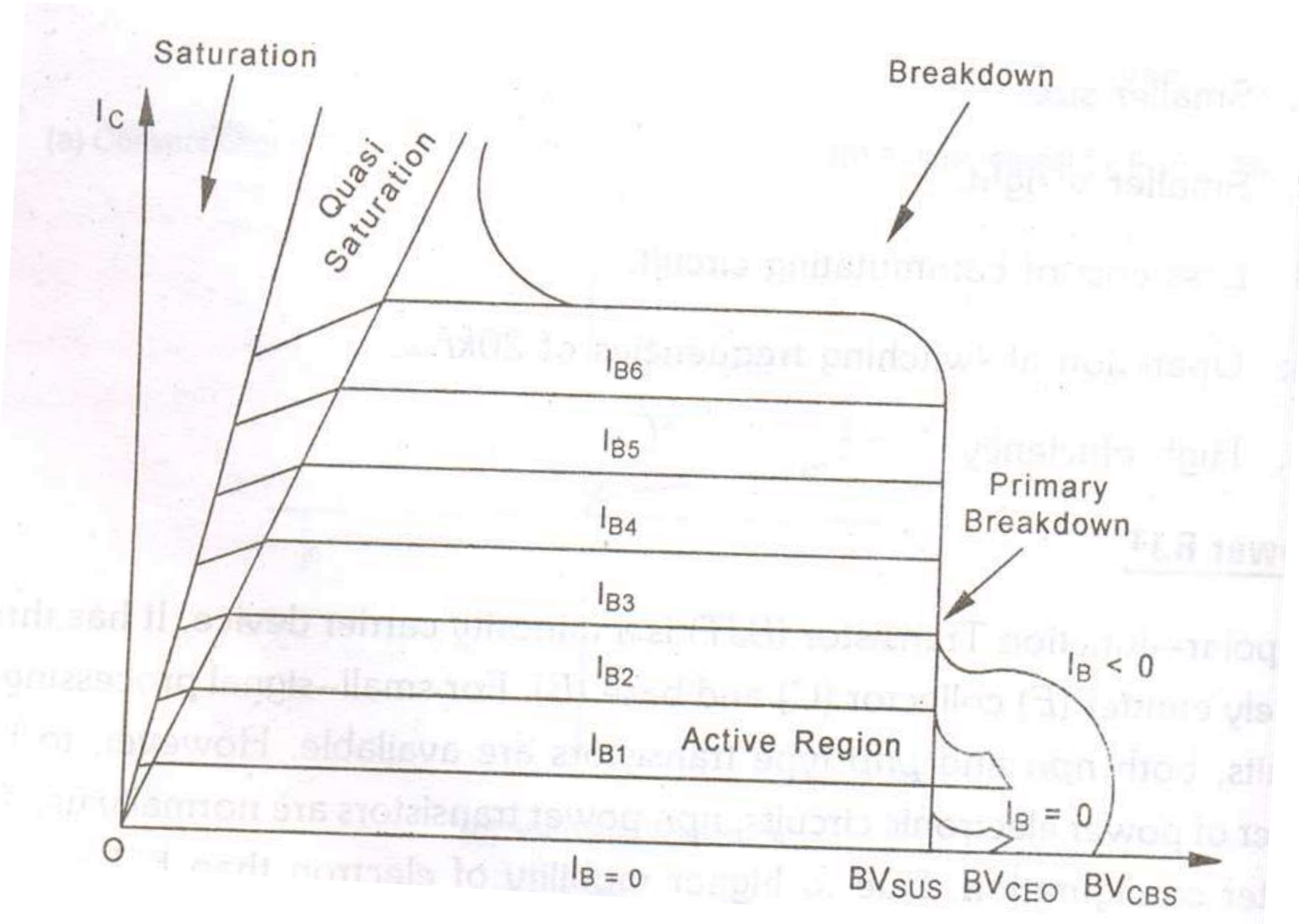
- n- region is called *Collector Drift region*

- The thickness of Collector drift region protects Breakdown voltage of transistor.

- If I_B is base current & I_C is collector current then current gain β is given by

$$\beta = I_C / I_B$$

V-I Characteristics of Power BJT



The four regions of the V-I Characteristics graph are:

- Primary Breakdown region:

  Both current & voltage dissipation is high. So this region should be avoided.

- Second Breakdown region:

  Power dissipation is not uniform, so chances of destruction of device is more.

- Quasi saturation:

The region between Saturation region & Active region is the quasi region

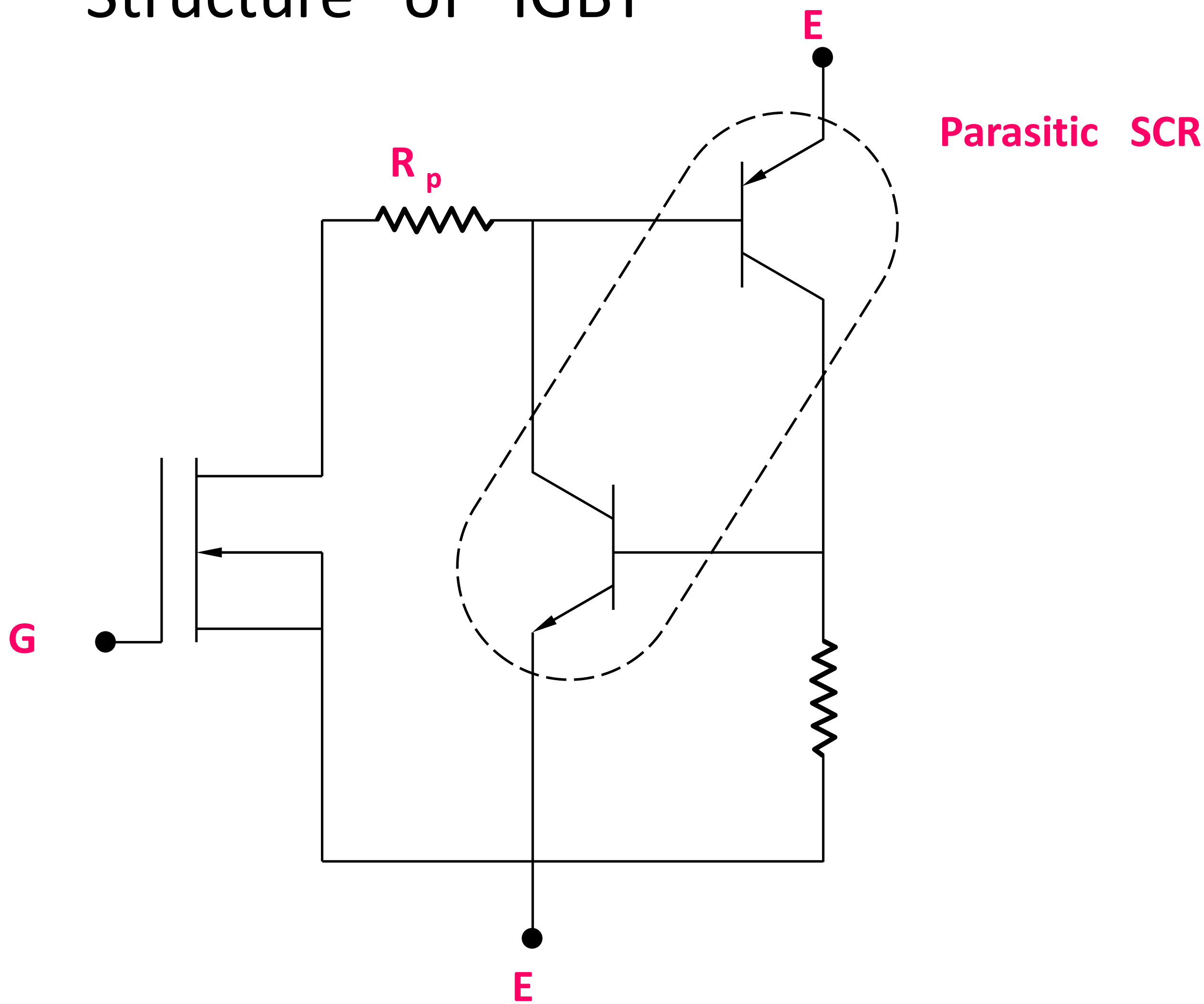
- Saturation region:

No variation of the current w.r.t to Voltage variations

Insulated Gate Bipolar Transistor (IGBT)

- BJT is a device with low power losses but long switching time
- MOSFET is a device with fast switching time but high power losses
- The draw backs of BJT & MOSFET can be overcome by IGBT

Structure of IGBT



Structure of IGBT

- IGBT is combination of MOSFET & BJT on a single chip.

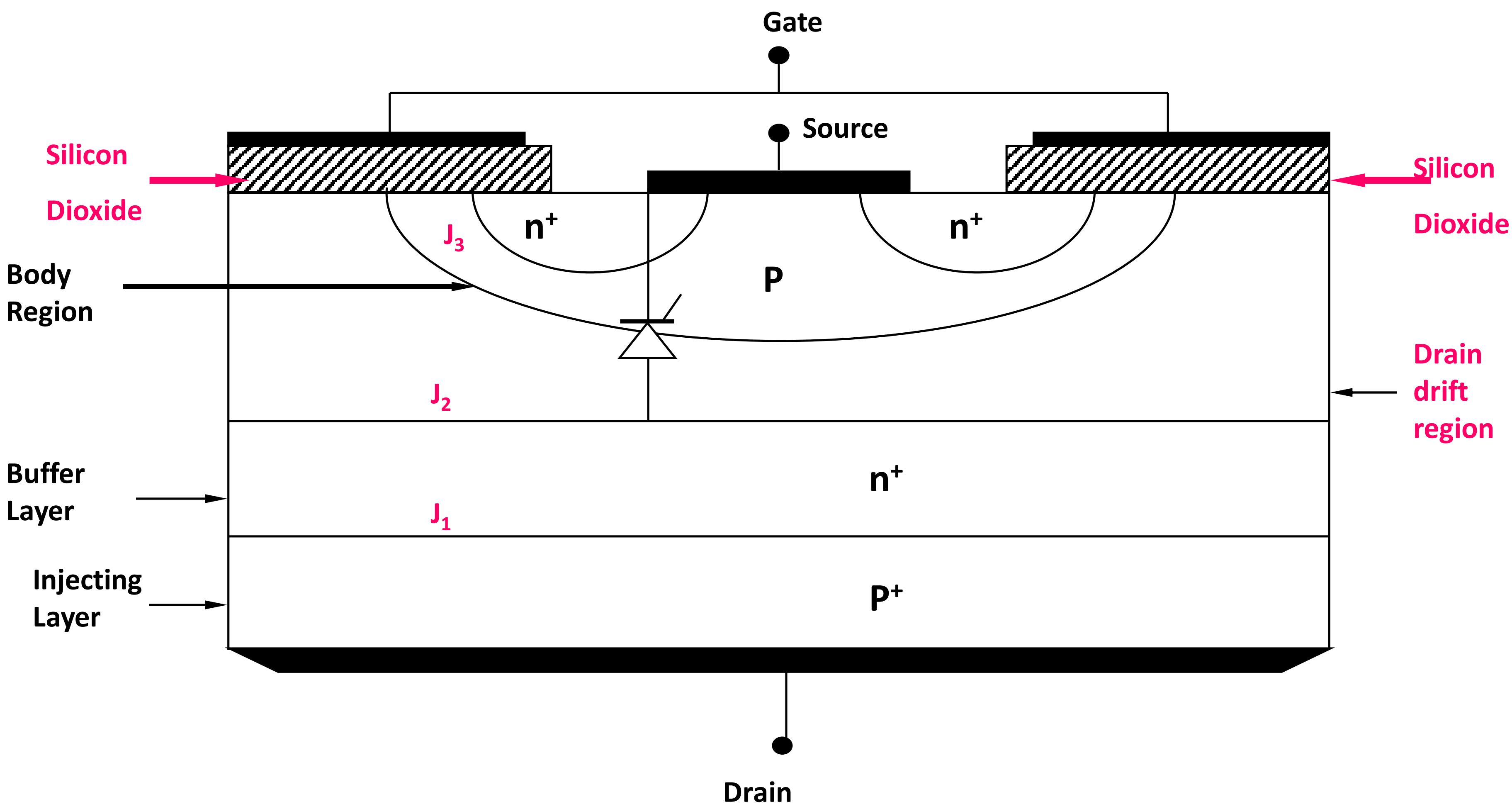
- Body of IGBT is designed to avoid the turn ON.

Construction of IGBT:

- If there is no n^+ layer it is Non punch through IGBT **(NPT-IGBT)**

- If there is n^+ layer it is punch through **IGBT (PT-IGBT)**

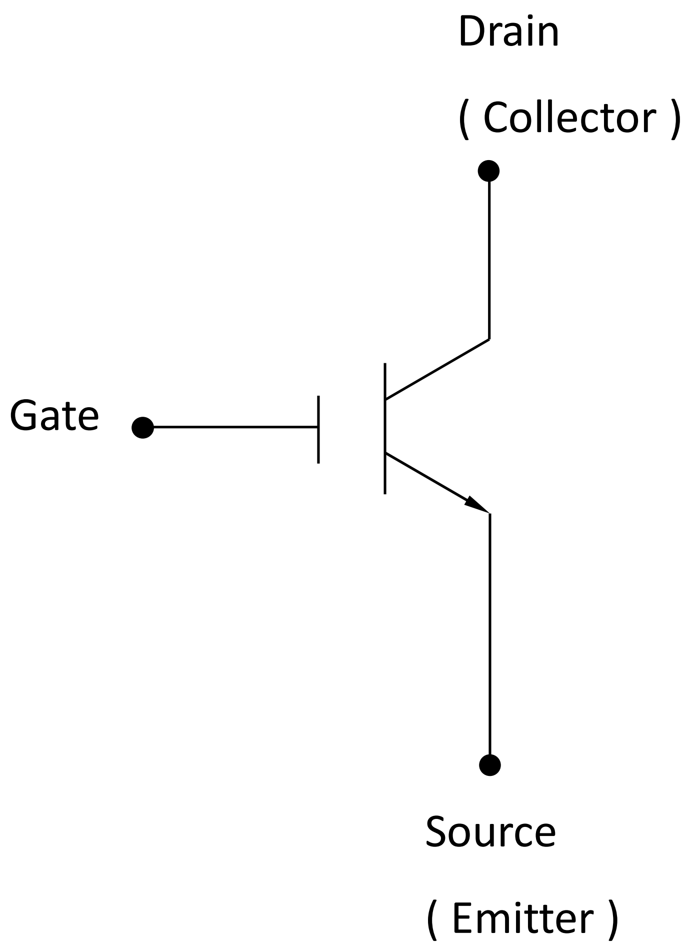
Construction of IGBT



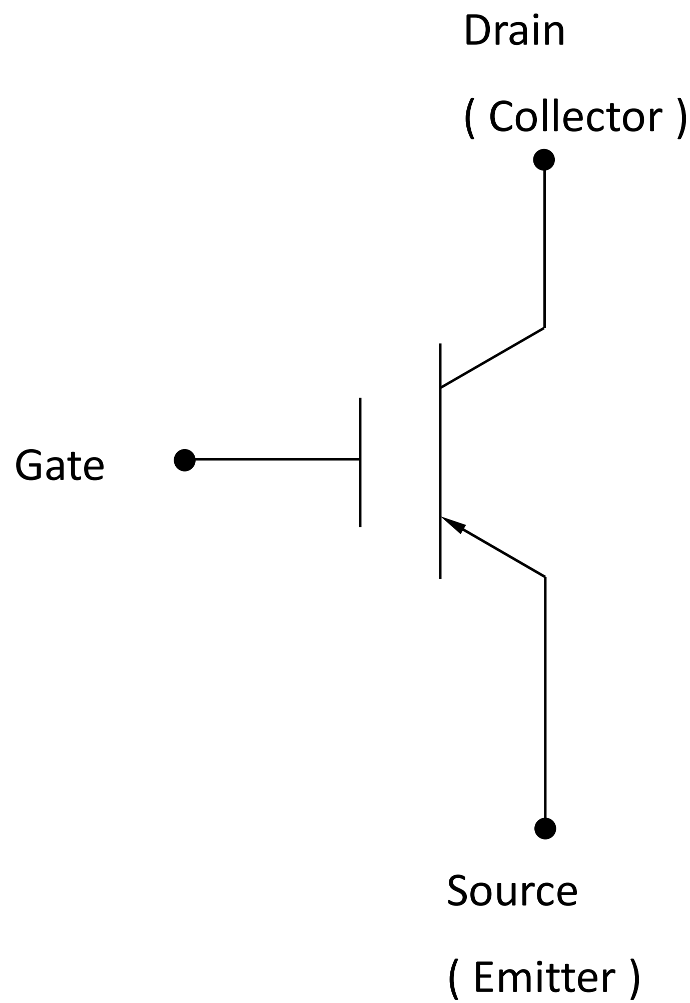
Types of IGBT

- N - Channel IGBT
- P - Channel IGBT

N-Channel IGBT

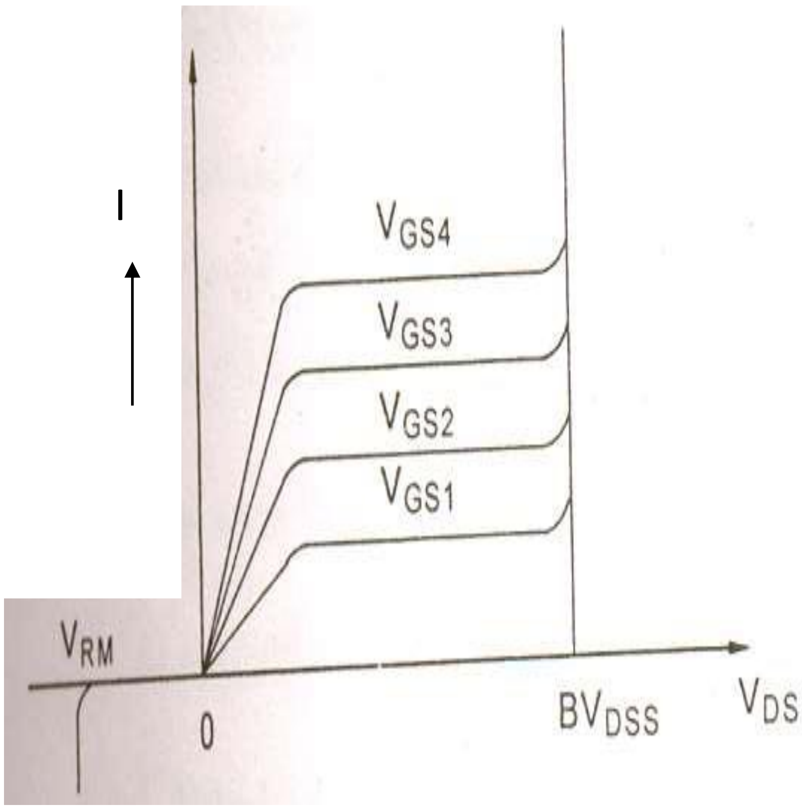


P- Channel IGBT

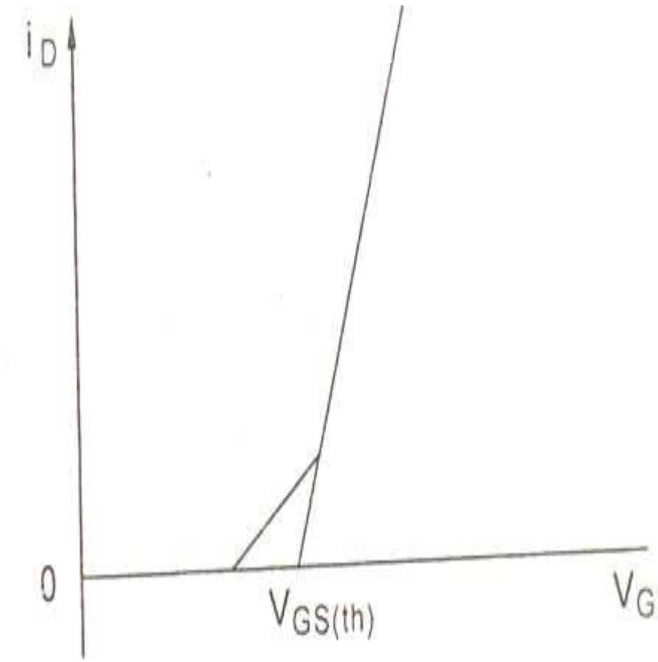


V - I Characteristics of IGBT

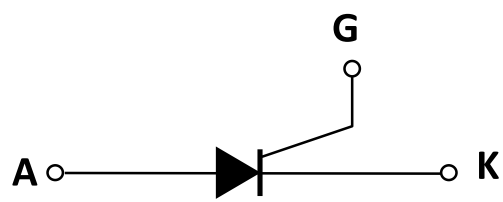
Drain Characteristics



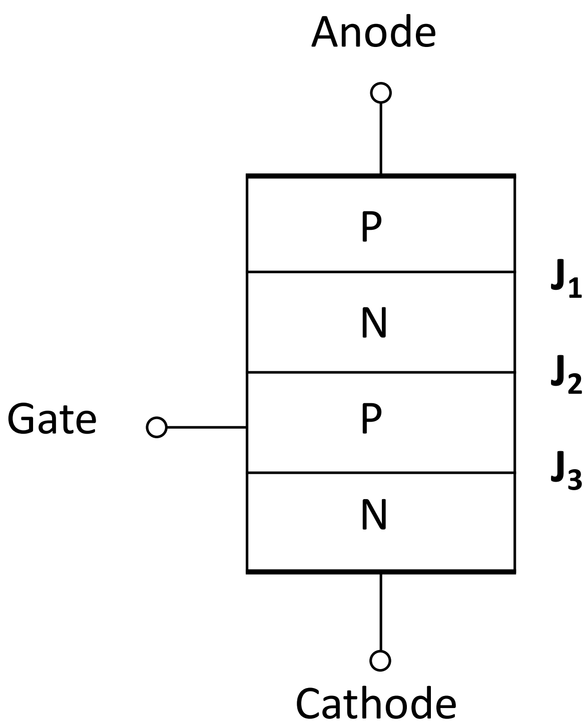
Transfer characteristics

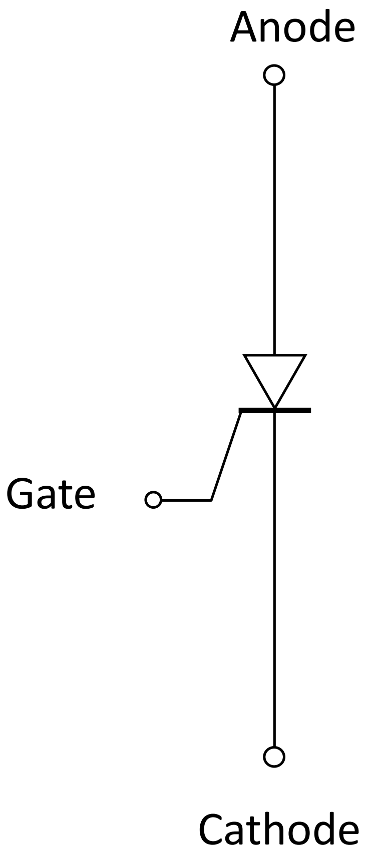


SCR (Silicon Controlled Rectifier)



CONSTRUCTION OF SCR





Constructional details of SCR

- SCR – is a four layer, three terminal, three P-N junction device.
- Outer P region is Called Anode
- Outer N region is called Cathode
- Inner P region is called Gate

Two Transistor Analogy of SCR

Two transistor model of SCR is obtained by splitting the two middle layers into two separate parts.

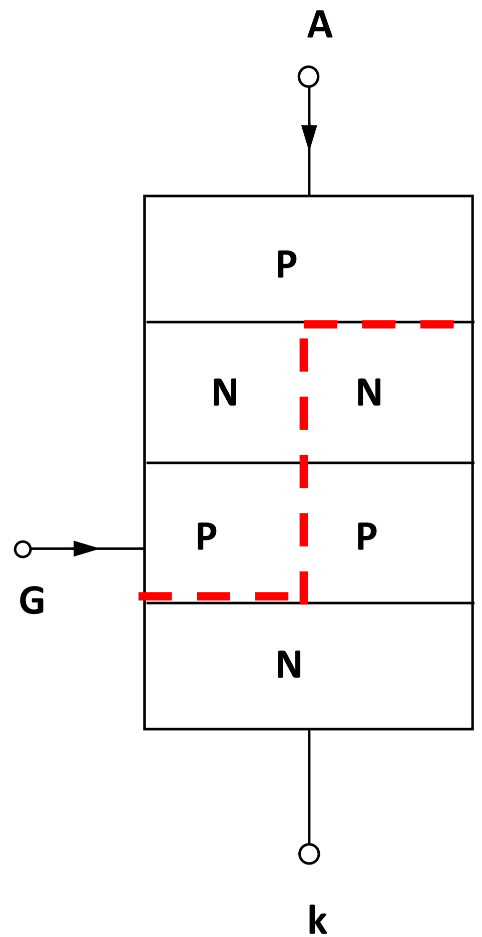


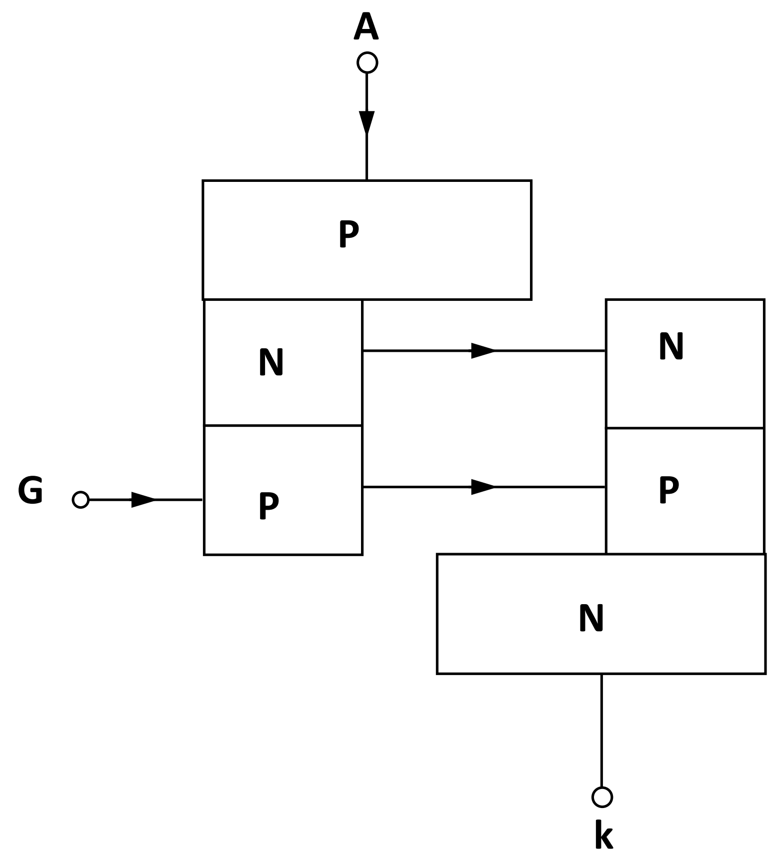
Fig 3 (a). Schematic Diagram

- Transistor T_1 - PNP and

  Transistor T_2 -NPN

- Emitter E of T_1 is Anode, Emitter E of T_2 is cathode

- Gate G is positive w.r.t cathode.



(b). Two transistor Model

Two Transistor Analogy of SCR

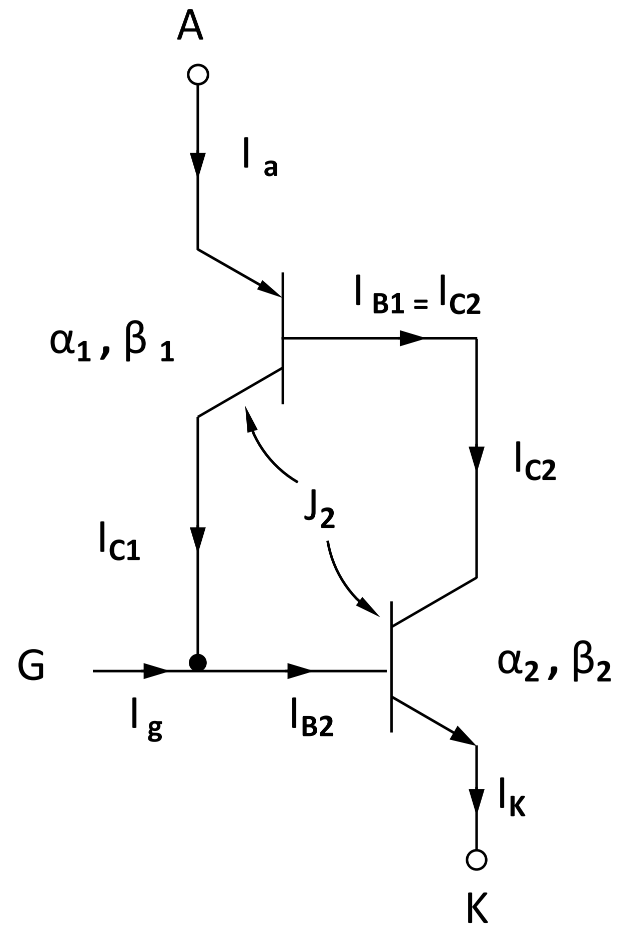


fig: 3 (c) Two transistor Model

During the OFF state of a transistor,

The collector Current, $I_C = \alpha\, I_E + I_{CBO}$

where

α – is the common base current gain

I_{CBO} - Common base leakage Current

For transistor – 1

$$I_{C1} = \alpha_1 I_E + I_{CBO1}$$

Similarly for transistor - 2

$$I_{C2} = \alpha_2 I_E + I_{CBO2}$$

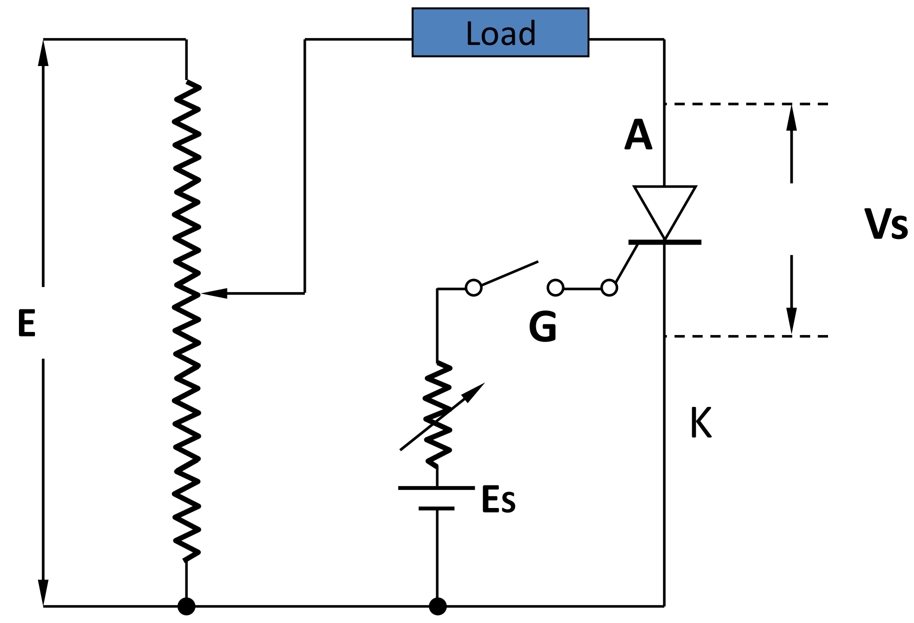
Total current I_a - is sum of collector currents of two transistors.

$$I_a = I_{c1} + I_{c2}$$

When gate is triggered , $I_K = I_a + I_g$

$$I_k = (\alpha_1 I_g + I_{CBO1} + I_{CBO2}) / (1 - (\alpha_1 + \alpha_2))$$

V-I Characteristics of SCR



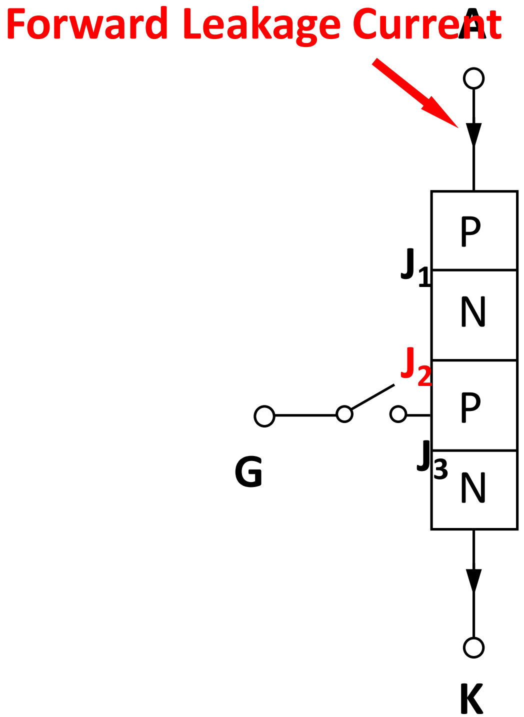
The thyristor is connected as shown

in circuit diagram.

Forward bias

When anode is made positive with respect to cathode and the switch is in open position the thyristor is said to be forward bias.

Junction J_1 , J_3 are forward bias and J_2 is in reverse bias.



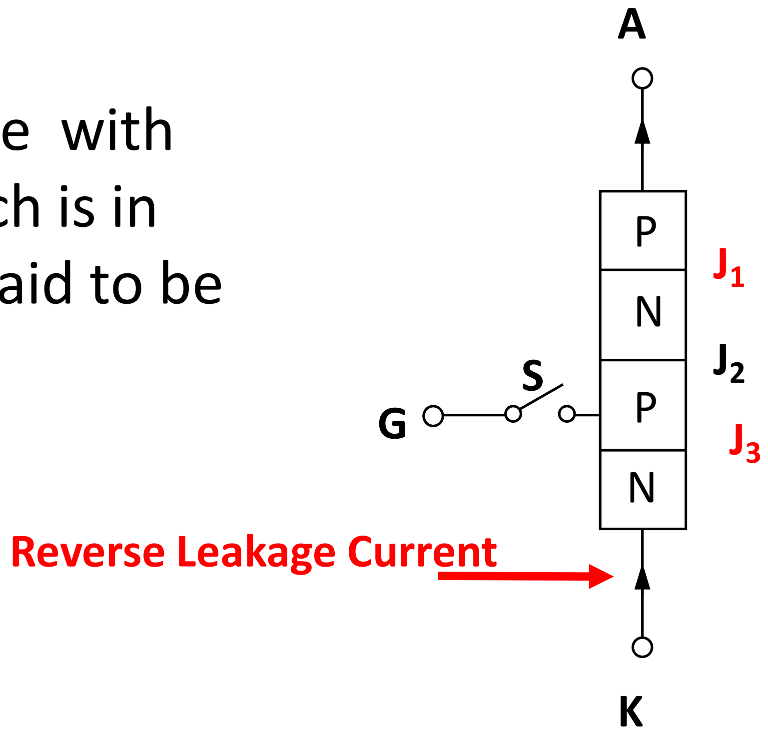
A small forward leakage current flows from anode to cathode. At this position the thyristor behaves like a "Forward Blocking or OFF- State Condition ".

If the anode to cathode voltage is increased to sufficiently large voltage , the J_2 will break down. This is known as “ Avalanche Breakdown ”.

The voltage at which the junction- J_2 gets break down. is called “ Forward Break Over Voltage ”.

Reverse bias

When Cathode is made positive with respect to anode and the switch is in open position the thyristor is said to be " Reverse Bias ".



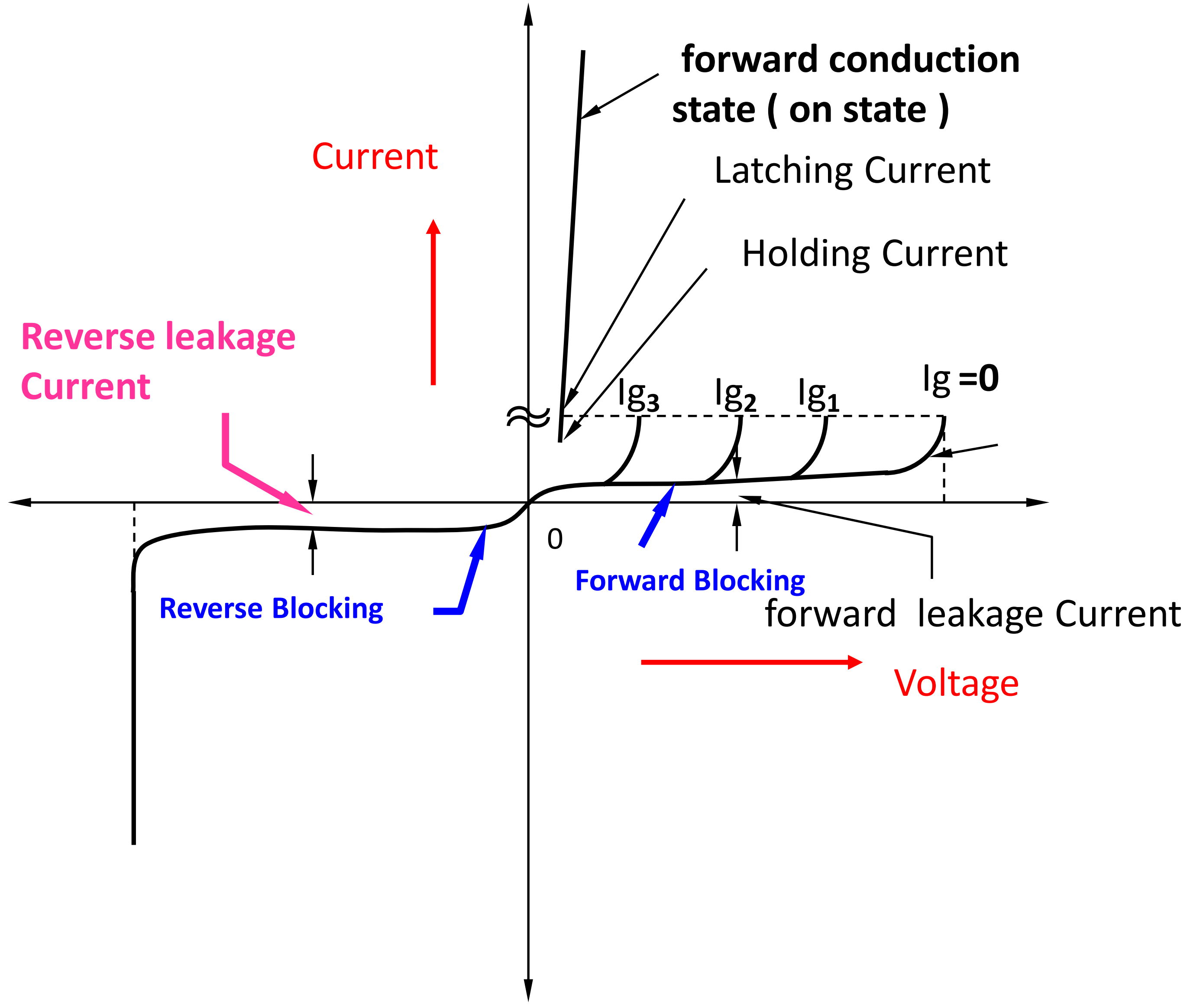
Junctions J_1 , J_3 are reverse bias and J_2 is in forward bias.

A small reverse leakage current flows from cathode to anode of the order of few milli amperes or microamperes will flow. This is known as " Reverse Blocking or OFF- State Condition " of thyristor.

If the reverse voltage is increased , then at a critical voltage the Junctions J_1 ,J_3 gets breakdown and the current increases rapidly.

Hence, a large magnitude of current flows through the thyristor causes thyristor gets damaged.

V - I Characteristics of SCR



TURN ON TIME

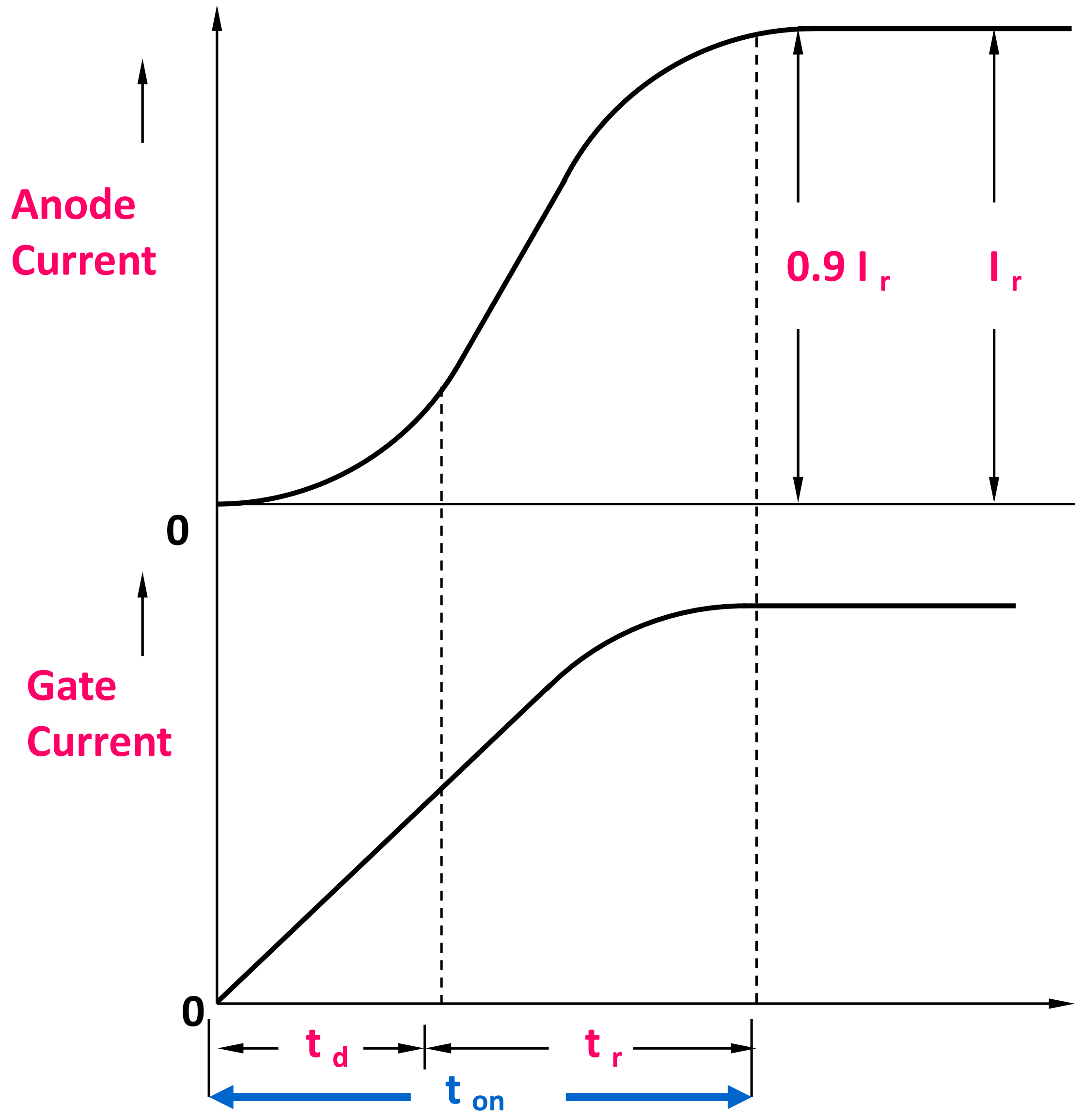
The time taken by the thyristor to reach full conduction state is turn on time

Turn on time consists of two parts, namely

Delay time (t_d)

Rise time (t_r)

TURN ON CHARACTERITICS



$t_{on} = t_d + t_r$

$t_{on} = t_d + t_r$

$= \text{Delay time } (t_d) + \text{Rise time } (t_r)$

Turn on time of SCR lies between 2 to 4 μsec

TURN OFF TIME

- When reverse voltage is applied to thyristor the time taken from zero current point to time when thyristor regains its full blocking voltage is called turn-off time.

Turn off time consists of:

Reverse recovery current time ,t_{rr}

Recombination time, t_r

Turn off time = Reverse Recovery time + combination time

- Circuit turn off time must be greaten than device turn off time for safe turnoff

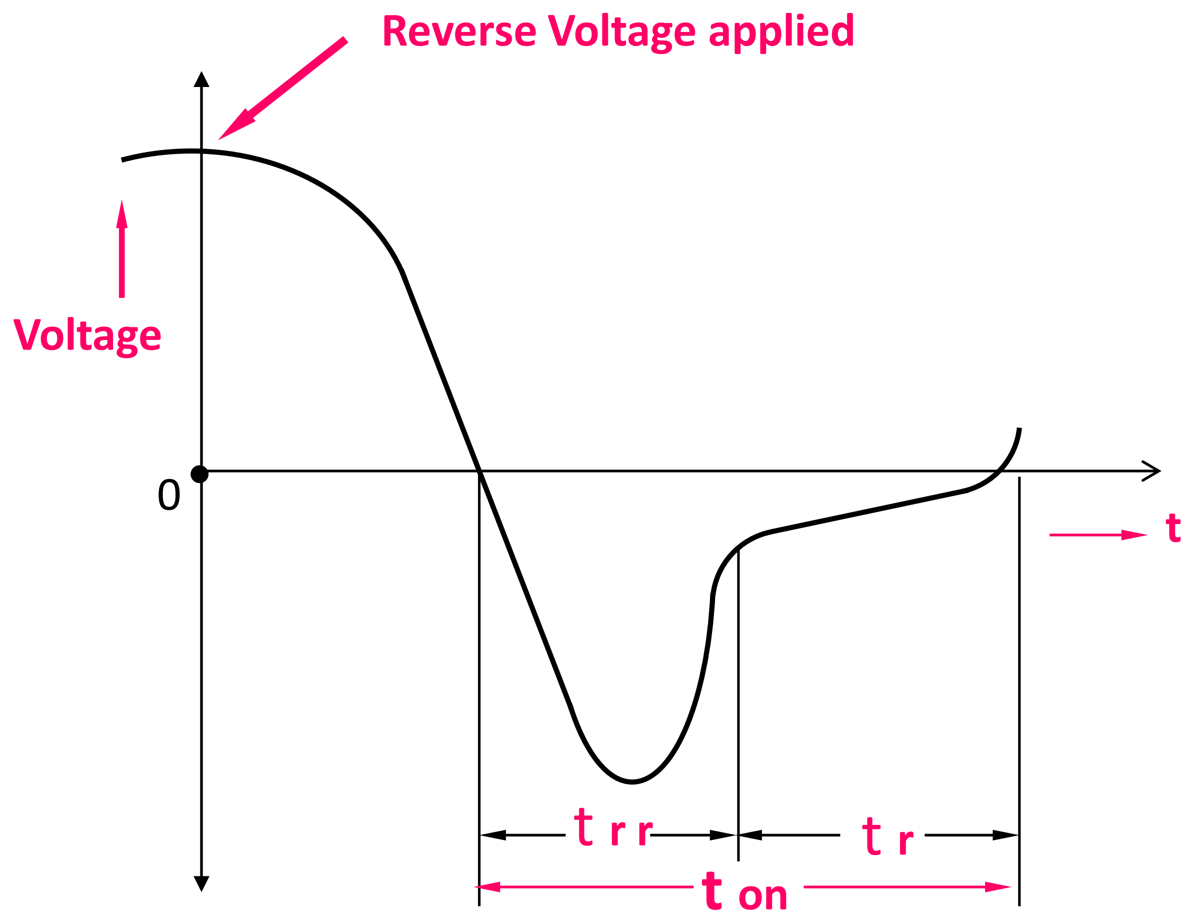
Turn off time consists of two parts, namely

Reverse recovery current time ,t_{rr}
Recombination time, t_r

Turn off time = Reverse Recovery time + Combination time

$$t_{off} = t_{rr} + t_r$$

TURN OFF CHARACTERITICS



$t_{off} = t_{rr} + t_r$

Turn off time of SCR is lies between 10-20 μsec.

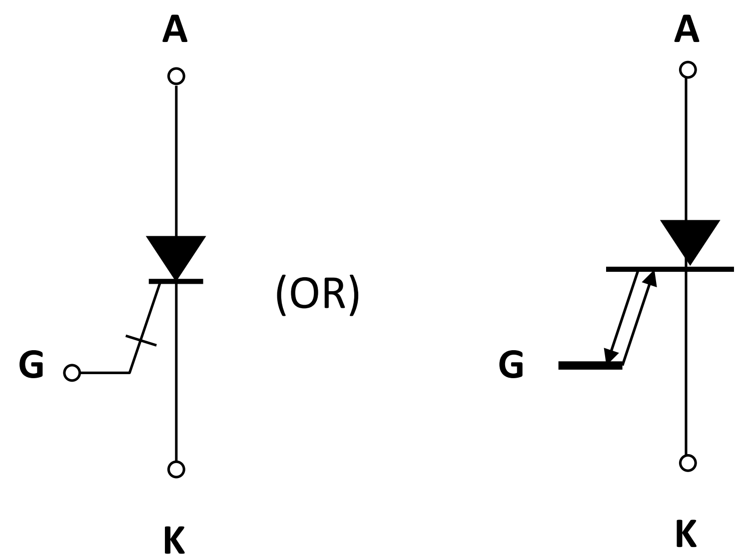
Construction of GTOSCR

It has Three terminals

Anode (A)

Cathode (K)

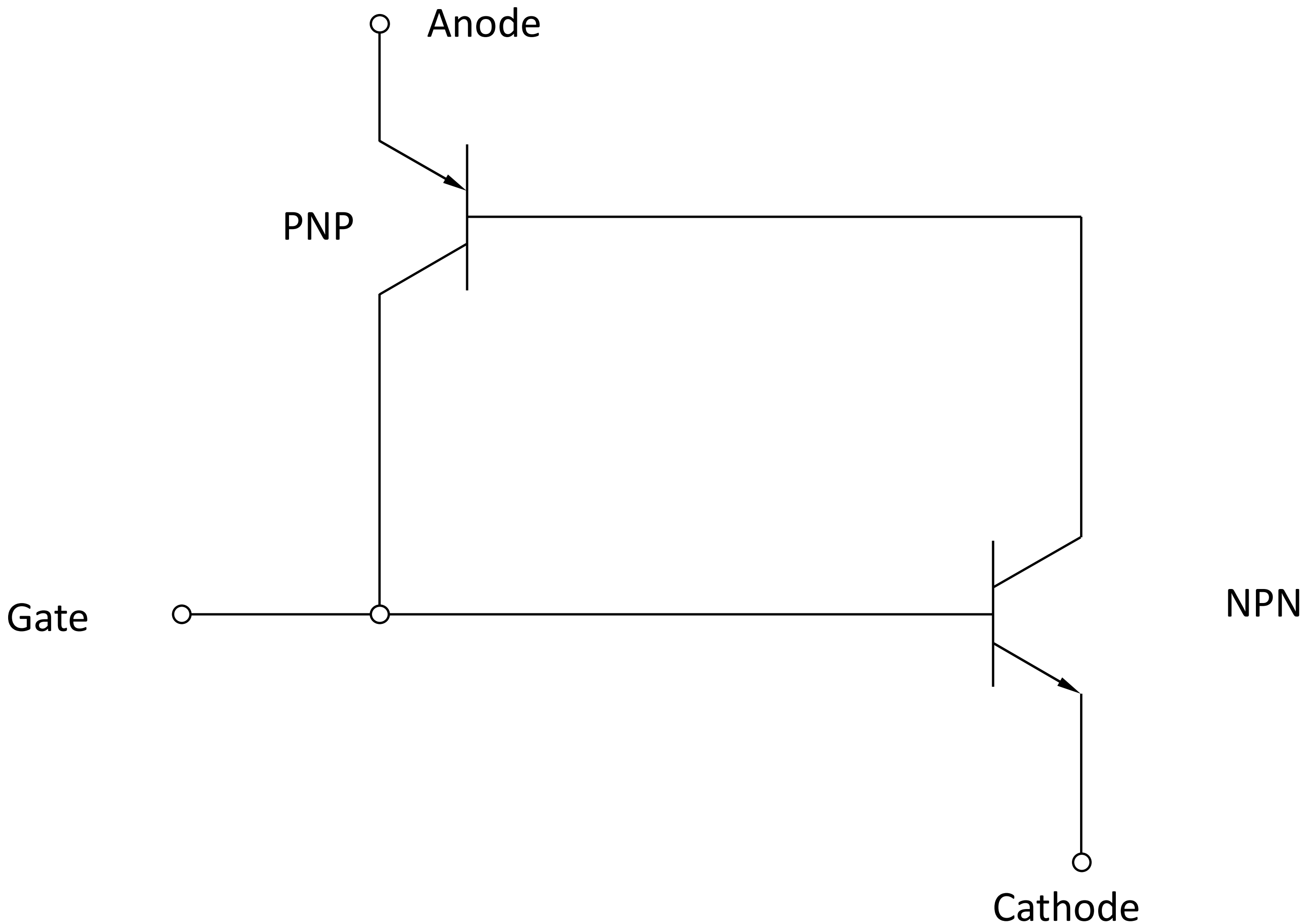
Gate (G)



CONSTRUCTION DETAILS OF GTO SCR

- It is 4-layer , 3-terminal device.
- It is a P-N-P-N device with three terminal namely anode, cathode and gate.
- It can be Turned-OFF by applying Negative gate pulse.
- It can be Turned-On by positive gate pulse.
- No forced commutation is required for GTO.

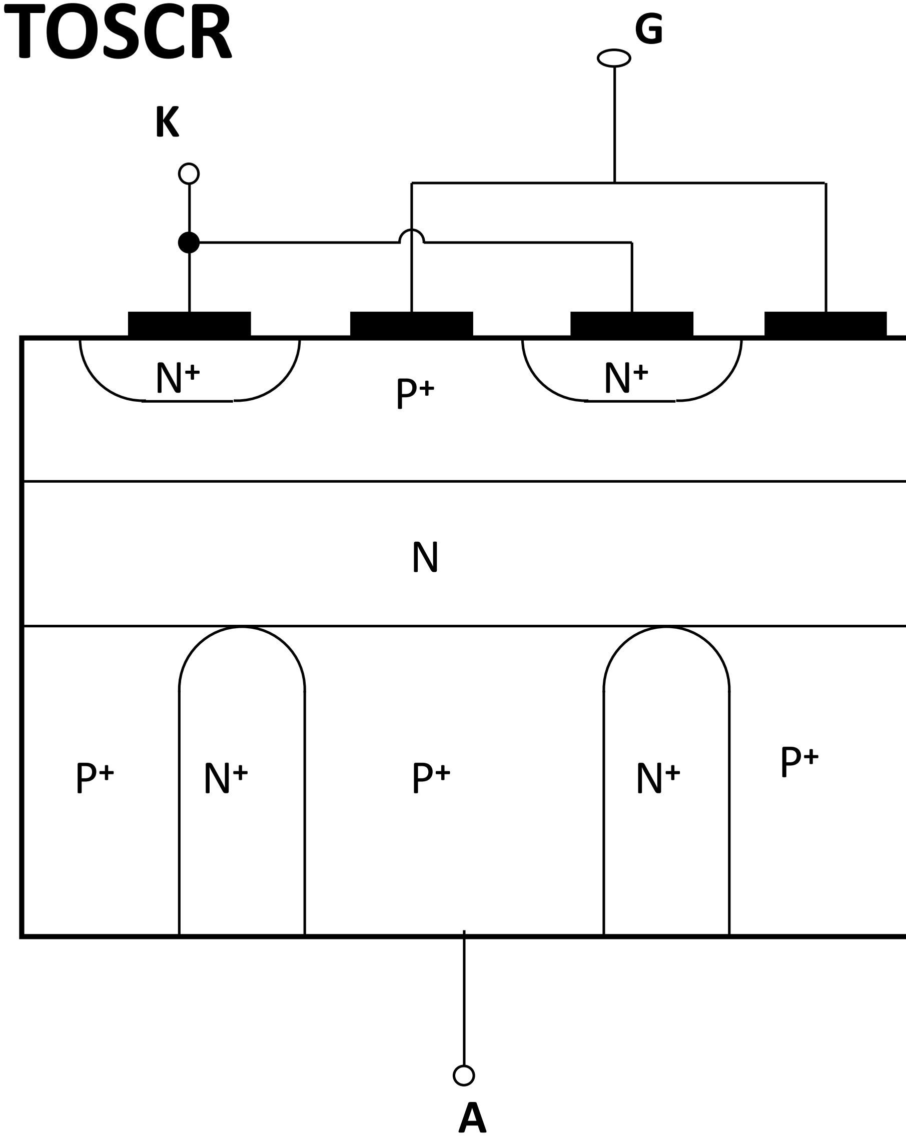
TURN-OFF ACTION OF GTOSCR



TURN – OFF ACTION

- The current gain of PNP Transistor is low
- If Gate signal is Negative excess carrier are drawn from the base region of the NPN transistor and collector current of PNP transistor is diverted to the gate.
- Base drive of NPN transistor is removed which inturn removes the base drive of PNP Transistor.
- Turn – OFF is Achieved.

STRUCTURE OF GTOSCR



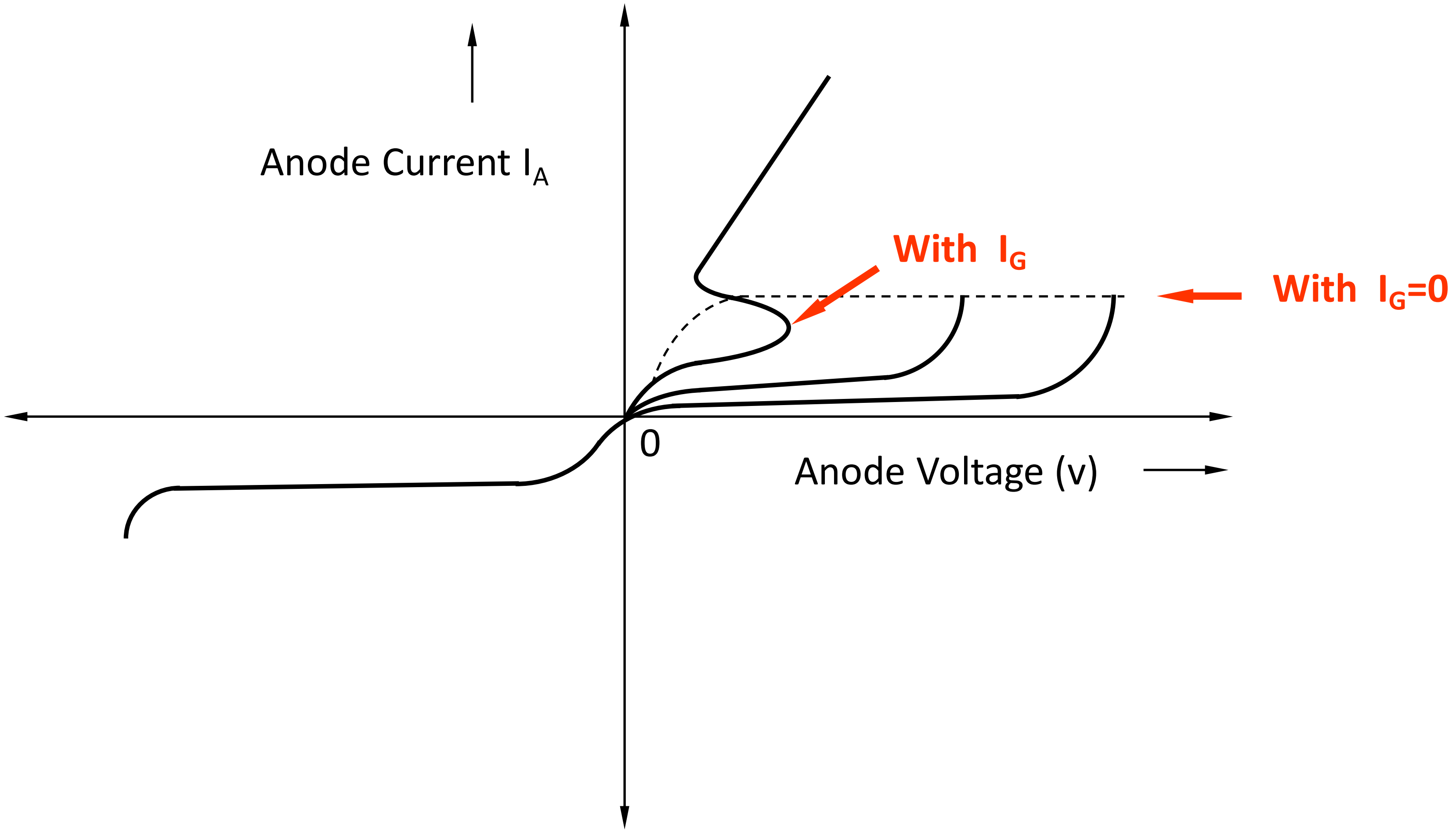
- This type of structure has simultaneous Turn-ON and turn-off operations.

- Reduction of Gain of the PNP transistor is obtained by introduction of Anode to N-base Short circuiting spots.

- This structure has Low ON-state Voltage and ability to block the reverse voltage is poor.

- Large GTOs have interdigited Gate- cathode structure in which the cathode emitter Consists of many parallel Connected N- type fingers diffused in to P-type gate region.

V - I Characteristics of GTOSCR



- It has large value of latching Current (2 amp)

- If gate current is not able to turn-on the GTOSCR, then it behaves like a high Voltage, Low Gain transistor.

- It has low power loss.

ADVANTAGES OF GTO SCR OVER SCR

- Small size and less weight.
- High efficiency.
- No need for commutation circuit.
- Fast switching speed.
- Lesser noise due to elimination of Commutation Circuit.
- High withstanding capability for surge Currents.

DISADVANTAGES OF GTOSCR OVER SCR

- High Gate current is required.
- High magnitude of latching and holding current.
- High gate circuit losses.
- High on state voltage drop.
- Lower reverse voltage blocking capability.

APPLICATIONS OF GTOSCR

- Used in Electric Traction.
- Used in adjustable frequency inverter drives.
- Used rolling mills & machine tools.

COMPARISON BETWEEN GTOSCR & SCR

GTOSCR	SCR
1. High efficiency	1. Low Efficiency
2. Less Noise	2. High Noise
3. Higher gate current	3. Lesser gate current
4. Small size & less weight	4. Larger size & weight

THEORETICAL CONCEPT ABOUT TRIAC

- It is a combination of two SCR'S in anti parallel.
- It can work on Alternating current.
- It is a Bidirectional Device (that is it can conduct in both the directions) .

TRIAC

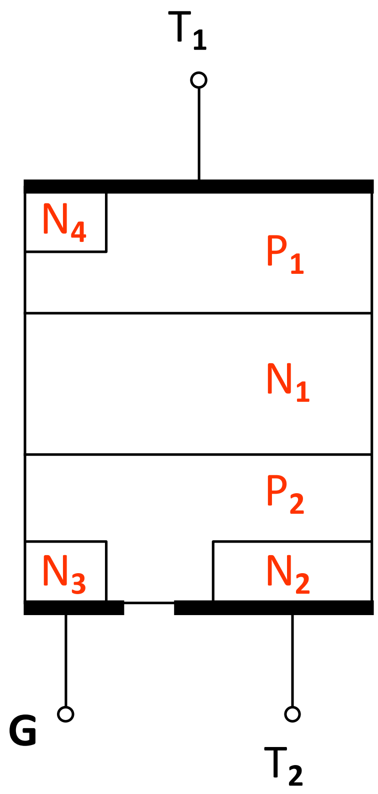


Fig : (a) Constructional View of Triac

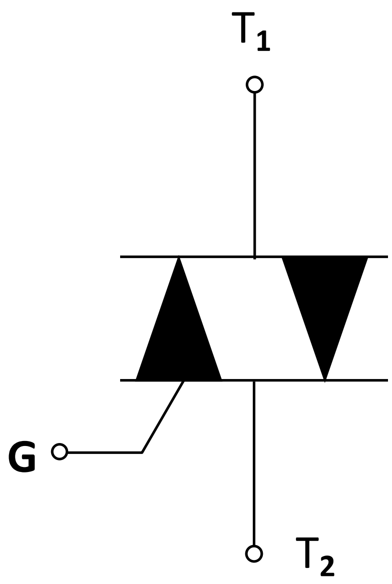


Fig : (b) Symbol of Triac

CONSTRUCTIONAL DETAILS OF TRIAC

- It is a four layer, three terminal Device.
- The three terminals are T_1, T_2 and G
- The terminal T_1 makes contact with layer N_2 and P_2
- The terminal T_2 makes contact with layers P_1 and N_4
- The gate terminal makes contact with layer N_3 and P_2

V - I Characteristics of TRIAC

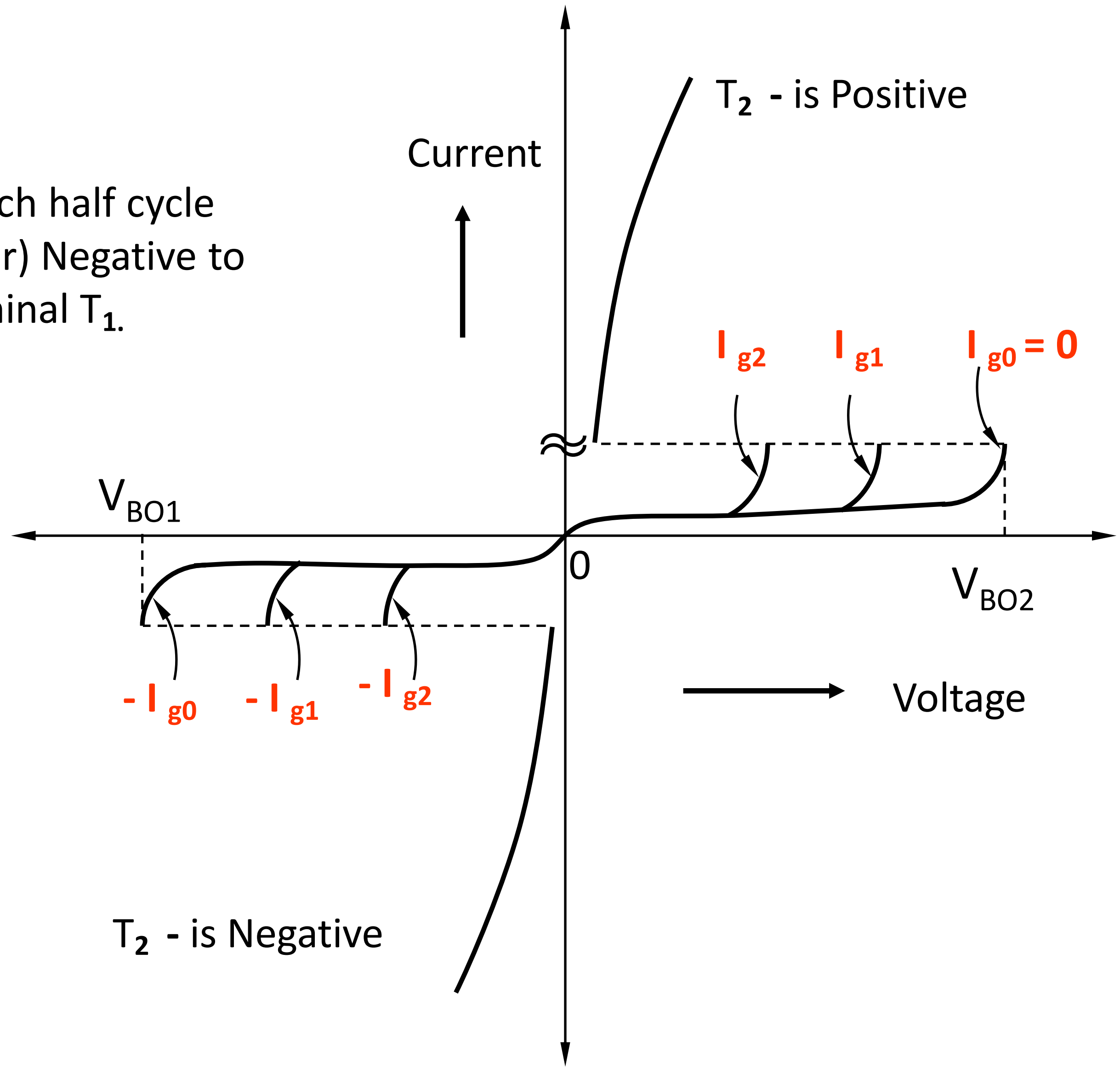
The TRIAC can operate either Positive (or) Negative control Voltage but in normal operation, the gate voltage is positive in first quadrant and negative in third quadrant.

The Supply voltage at which the TRIAC is turned ON depends on the gate current.

The TRIAC turn ON Voltage decreases as the gate current increases.

V- I Characteristics of TRIAC

TRIAC is turned on in each half cycle by applying a positive (or) Negative to the with respect to terminal T_1.



APPLICATION OF TRIAC

- Speed control of Single phase Induction motors
- Temperature control
- Liquid level control
- Phase control circuits

ADVANTAGES OF TRIAC

- It is triggered by positive & negative polarity voltages.
- It needs only one heat sink.
- Needs single fuse for protection.
- Safe Breakdown is possible so no need of any diode in parallel.

DISADVANTAGES OF TRIAC

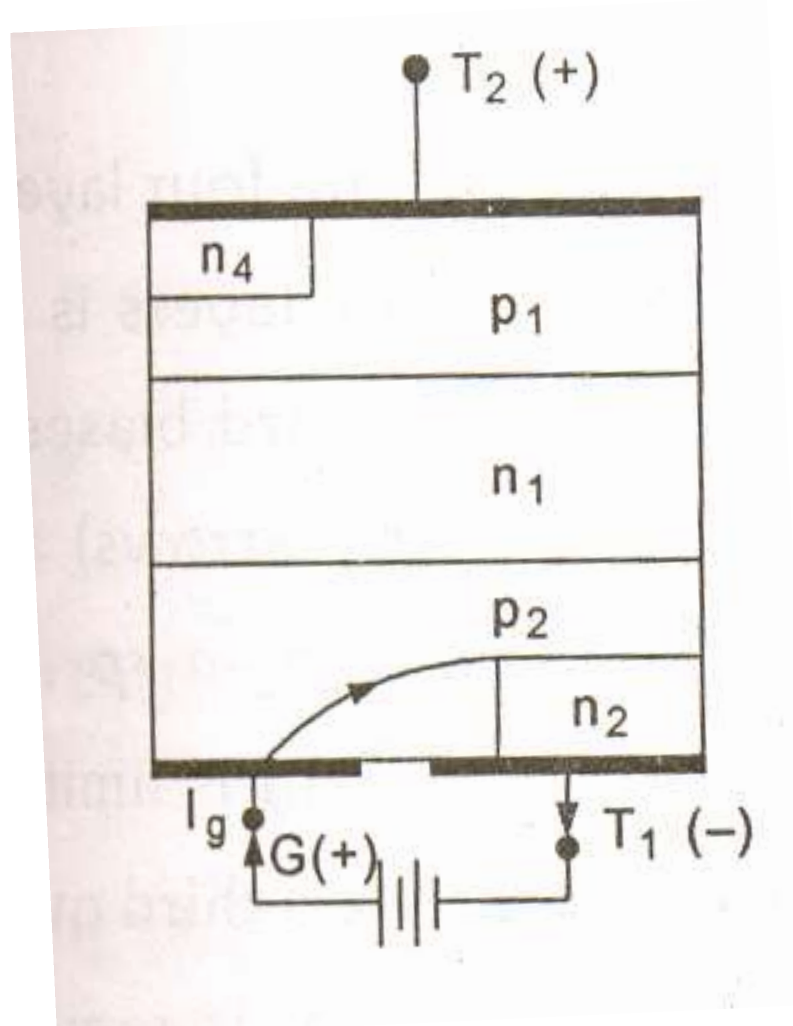
- Low (dv/dt) ratings .
- Smaller reliability .
- Requires careful consideration as it can be triggered in either direction.

COMPARISON BETWEEN SCR & TRIAC

SCR	TRIAC
1. It is a four layer three terminal device	1. It is a combination of two SCR's in anti parallel
2. It is Unidirectional device	2. It is Bidirectional device
3. High Power handling capacity	3. Low Power handling capacity

T_2 IS POSITIVE AND GATE (G) IS POSITIVE

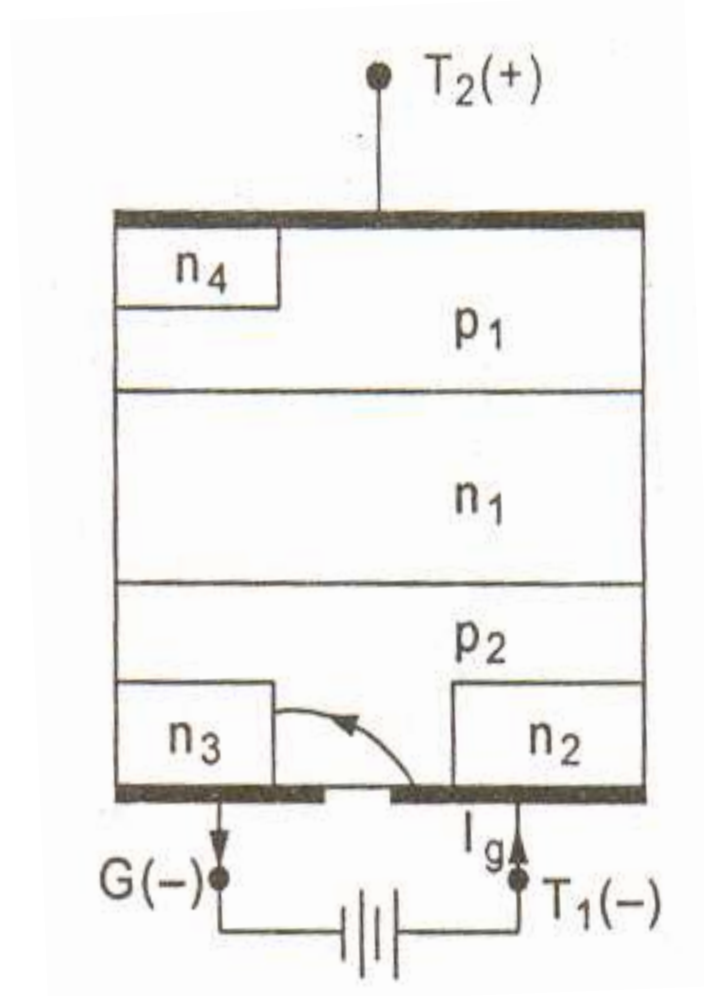
- The Junctions p1-n1 and p2-n2 are forward biased.
- n1-p2 is reverse biased.
- Gate current injects sufficient charge carriers in p2 layer.
- n1-p2 breaks down
- Triac conducts in 1st quadrant.



T_2 IS POSITIVE BUT GATE G IS NEGATIVE

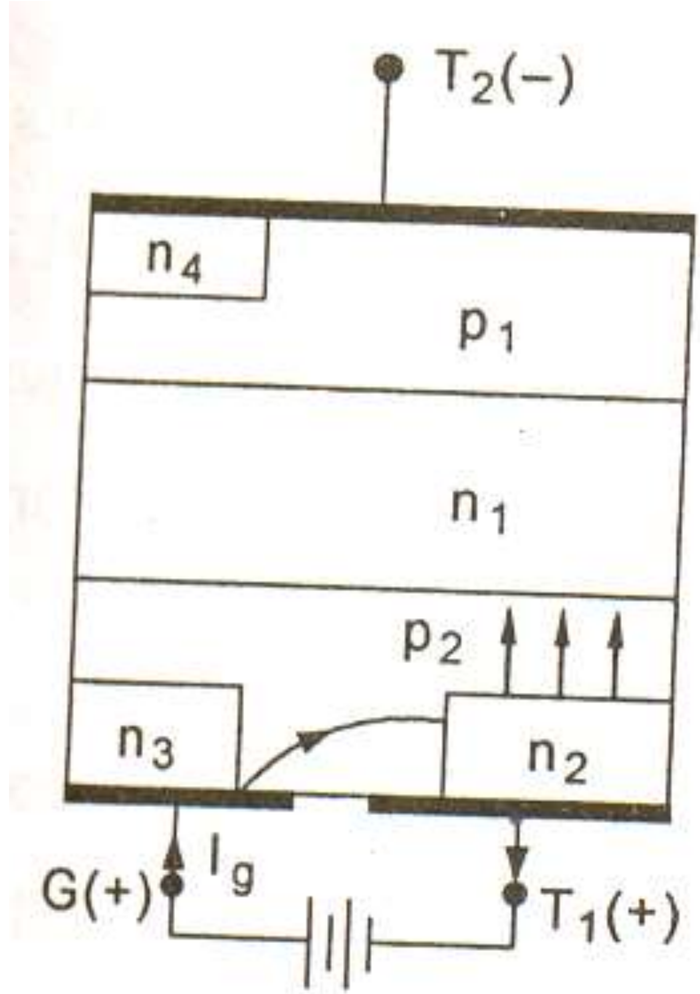
- Junctions p_1-n_1 and p_2-n_2 are forward biased
- n_1-p_2 is reverse biased
- Triac conduction current flows through the layers

  p_1-n_1-p_2-n_3
- p_1-n_1-p_2-n_2 start conducting.
- The device operates in the 1^{st} quadrant.



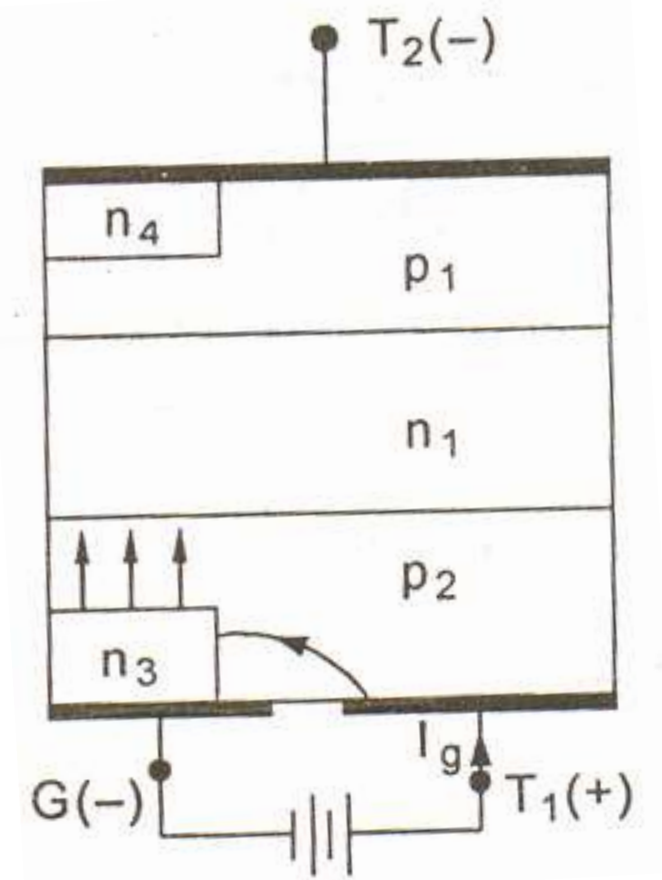
T_2 IS NEGATIVE AND GATE G IS POSITIVE

- **N_1-p_1 is reverse biased**
- **Layer n_2 injects electrons into p_2 layer**
- **N1-p1 breaks down**
- **p_2-n_1-p_1-n_4 start conducting**
- **The device operate in 3rd quadrant**



T_2 IS NEGATIVE AND GATE G IS NEGATIVE

- **Gate current flows from p_2 to n_3**
- **Reverse biased junction n_1-p_1 breaks down**
- **The current flows through the layer p_2-n_1-p_1-n_4**
- **In this mode required gate current is less**
- **It operate in the 3rd quadrant**



UNIT 2
Converters

Definition:

- A converter or rectifier converts ac power to dc power.
- The converter circuit comprises diodes or thyristors.

Converters

Introduction:

- Earlier, DC power was obtained from MG sets or ac power was converted to dc power by means of mercury-arc rectifiers or thyratrons.

- Presently, phase-controlled ac to dc converters employing thyristors are used.

- In industrial applications, the converter circuits make use of more than one SCR.

- In such circuits, When an incoming SCR is turned on by triggering, it is immediately reverse biases the outgoing SCR and turns it off.

ADVANTAGES OF PHASE CONTROLLED RECTIFIERS

- Simple.
- Less expensive.
- Fast in operation.
- Consumes less Power.
- Ease of control.

CLASSIFICATION OF CONVERTERS

Phase controlled converter

Single phase type

Three phase type

Uncontrolled converters
(contains only Diodes)

Controlled converters
(Contains both SCR & diodes)

Half –wave(1-pulse)

Full –wave(2-pulse)

With out FWD

With FWD

Center tap T/F

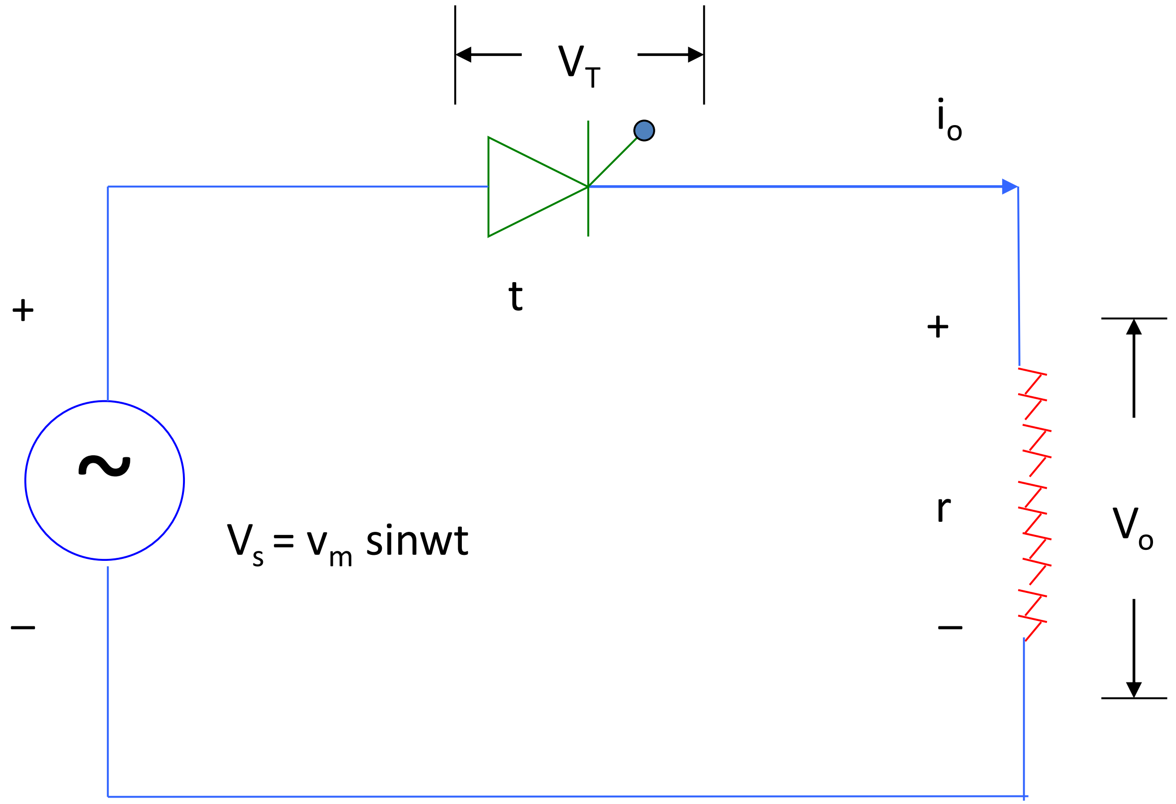
Bridge type

- Controlled converters (contains both SCRs & Diodes)
  - Half wave(1-pulse)
    - Half wave Full converters
    - Half wave Semi converters
  - Full wave (2-pulse)
    - Full wave Full converters
    - Full wave Semi converters

APPLICATIONS OF CONVERTERS

- Steel rolling mills, paper mills, Printing presses and textile mills employing dc motor drives.
- Traction systems working on dc.
- Magnet power supplies.
- Portable hand tool drives.
- High-voltage dc transmission.

1- Ø half wave fully controlled converter (with resistive load)



1-ø hw fully controlled converter circuit (with r load)
Fig1.

- V_S is source voltage
- V_O is average voltage across load(R)
- I_O is average load current
- V_T is voltage across thrystor

- Output voltage is controlled by varying the firing angle (α) at which the Thyristor starts conducting

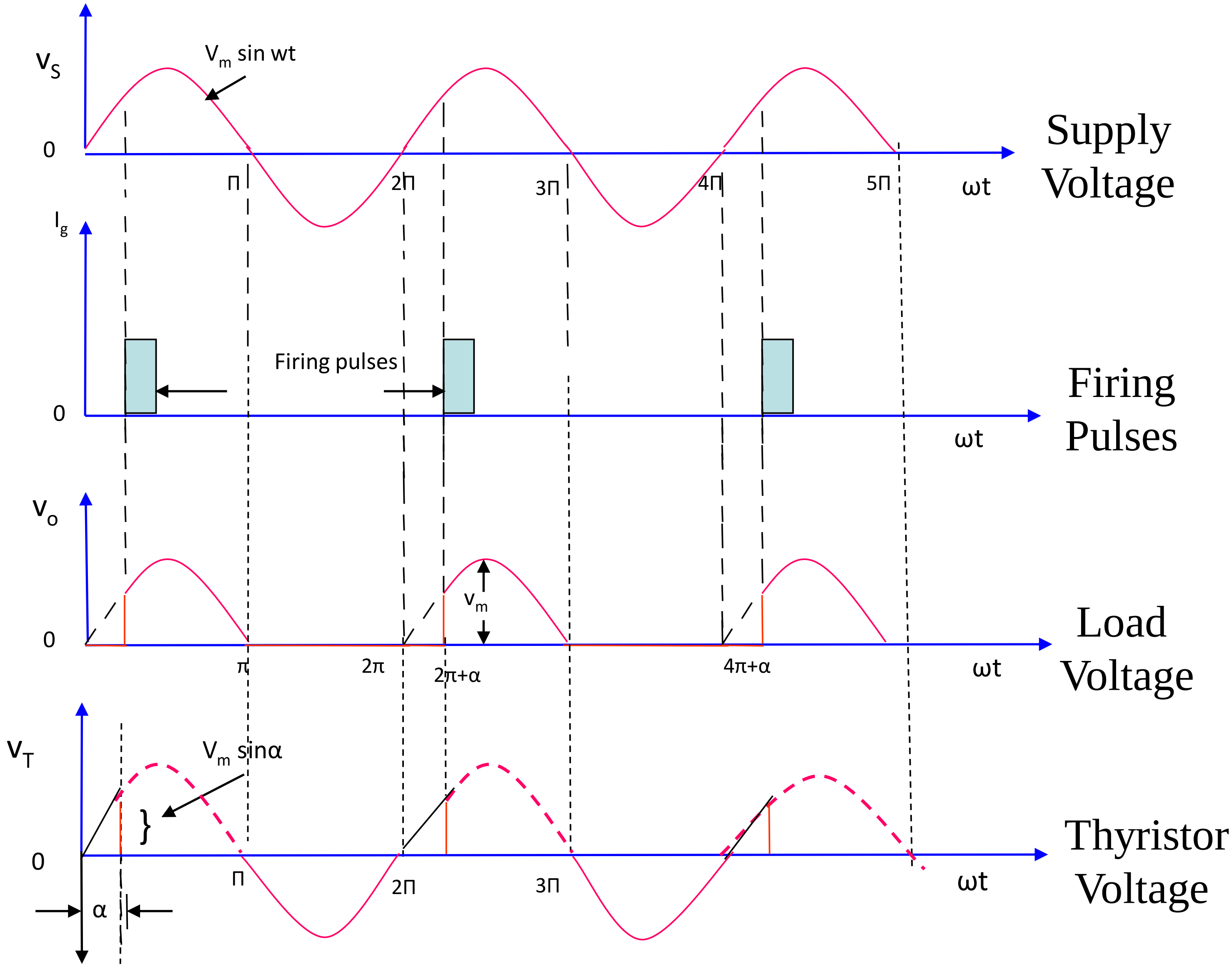
- During positive half cycle of supply voltage the Thyristor is forward biased and when fired at α, full supply voltage is applied to load (R) and current flows through it

Note:

Firing angle is the angle between the instant thyristor would conduct if it were a diode and the instant when it is triggered

- During negative half cycle of supply voltage the Thyristor is reverse biased and blocks the supply voltage and no current flows through the load

- Once SCR is on, load current flows until it is turned off by reversal of voltage at $\omega t=\Pi$, 3Π etc.



Waveforms of 1-Φ HW fully controlled converter (with R load)

- Thyristor conducts from α to Π, (2Π +α) to 3Π etc.

- Full supply voltage is applied across the load from α to Π, (2Π +α) to 3Π etc.

- Load voltage and load current is zero from 0 to α,

  α to (2Π +α), etc

- 1- Ø half wave converter circuit produces only

  one pulse of load current during one cycle of source voltage

V_0 in terms of firing angle α is

$$V_0 = (1/2\Pi)\int_{\alpha}^{\Pi} V_m \sin \omega t \, d(\omega t)$$

$$= (V_m/2\Pi)(-\cos \omega t)_{\underline{\alpha}}^{\Pi}$$

$$V_0 = (V_m/2\Pi)(1+\cos \alpha) \quad \ldots\ldots\ldots\ldots(1)$$

Inspection of the waveforms shows clearly that the greater the firing delay angle α, the lower is the V_0, Eqn. (1) conforming that it falls to zero when α = 180^0

Average load current

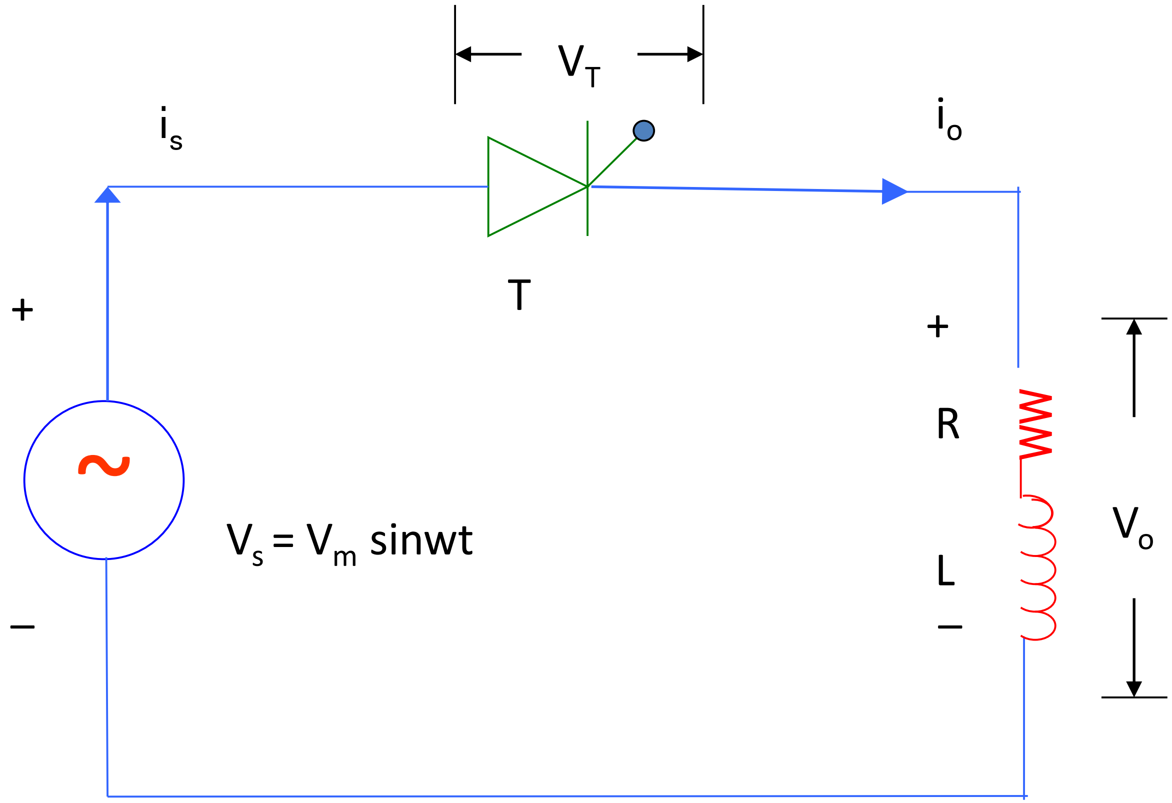
- $I_0 = V_0/R$
- $= Vm/2\Pi R\ (1+\cos\alpha)$ …………(2)
- I_0 is in-phase with V_0 for resistive load

- During the conduction period of Thyristor, $V_T=0$
- During non-conduction period, V_T has the wave shape of supply voltage of Vs

- $Vs = Vo + V_T$

- The Thyristor voltage V_T waveform shows a +ve voltage during the delay period, and also that both the peak forward and peak reverse voltages are equal to V_m of the supply

1- Ø, HALF WAVE FULLY CONTROLLED CONVERTER (WITH R-L LOAD)



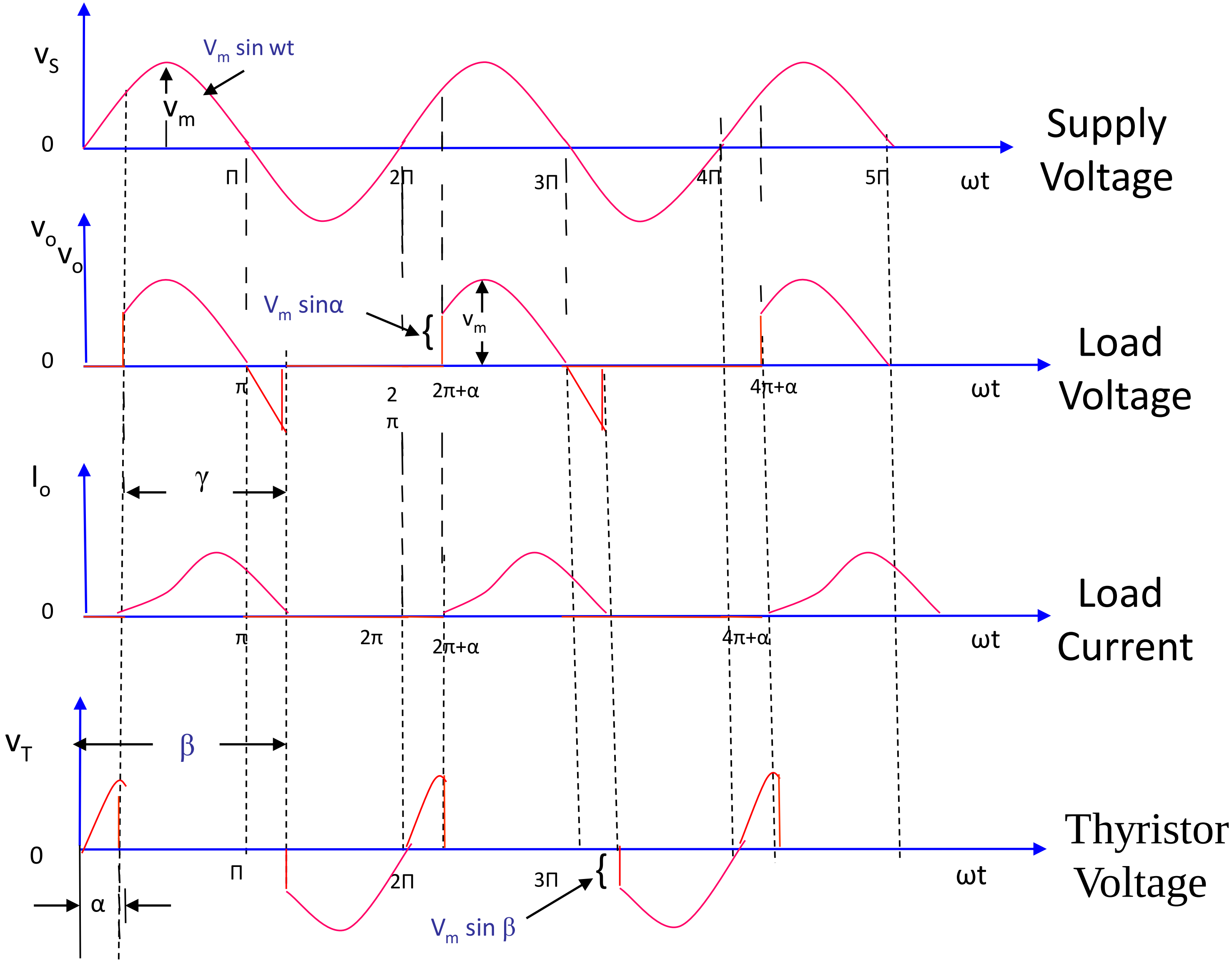
1-Φ HW fully controlled converter circuit (with R-L load)

- V_S is source voltage
- V_O is average voltage across R-L load
- I_S is supply current
- I_O is average load current
- V_T is voltage across thrystor

Thyristor will only conduct when its voltage $\mathbf{V_T}$ is positive and it has received a gate firing pulse.

We know that the load current (I_O) is in phase with load voltage (V_O) for pure resistive load

But when load is R-L, the situation becomes different and load current does not assumes the wave form of the load voltage.

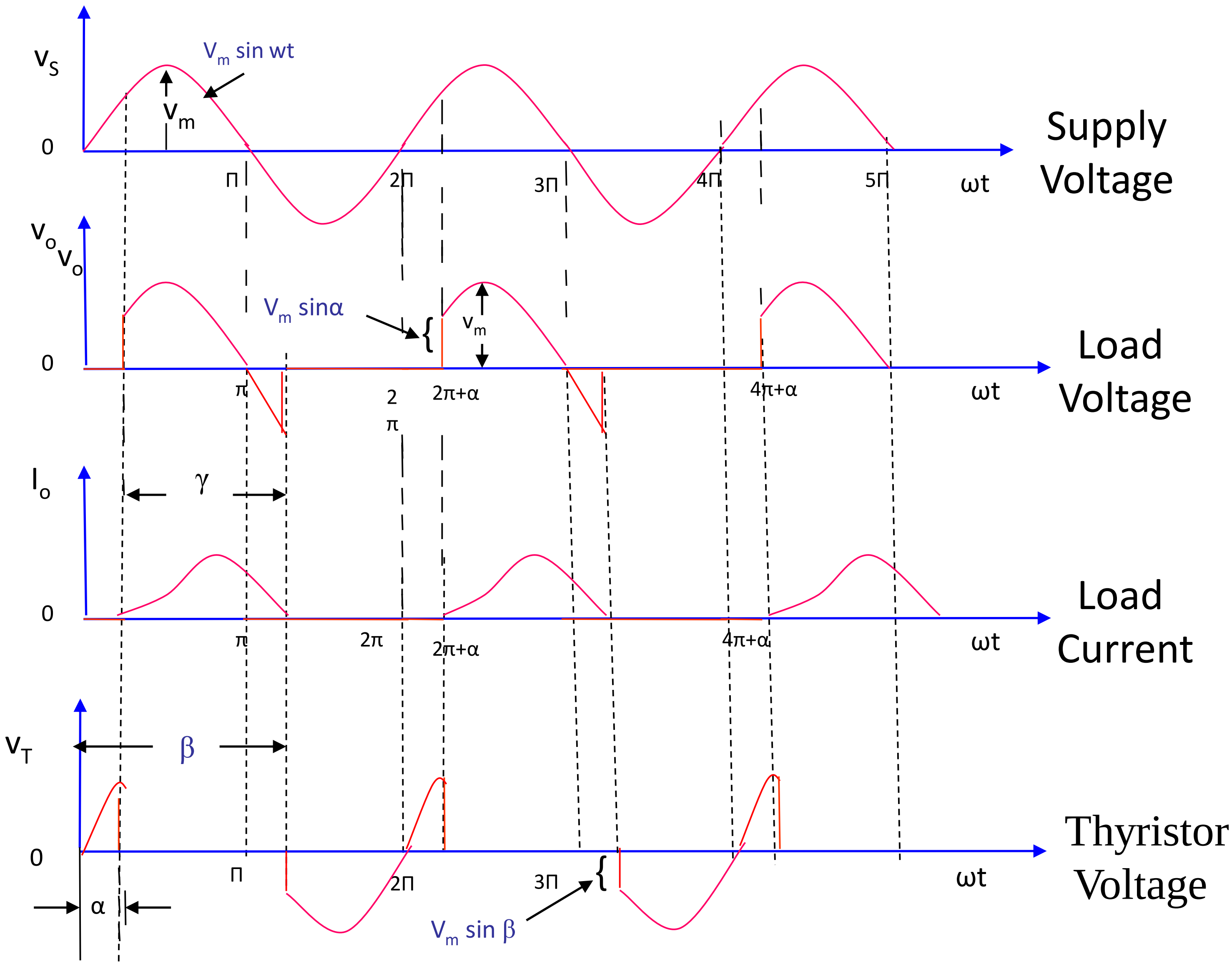


Waveforms of 1-Φ HW fully controlled converter (with R-L load)

At wt = α, thyristor is turned on by gating signal.

Thyristor conducts so that the load voltage is equal to supply voltage.

Load current will commence directly the supply voltage goes positive, but the presence of the ***inductance*** will **delay** the current change.

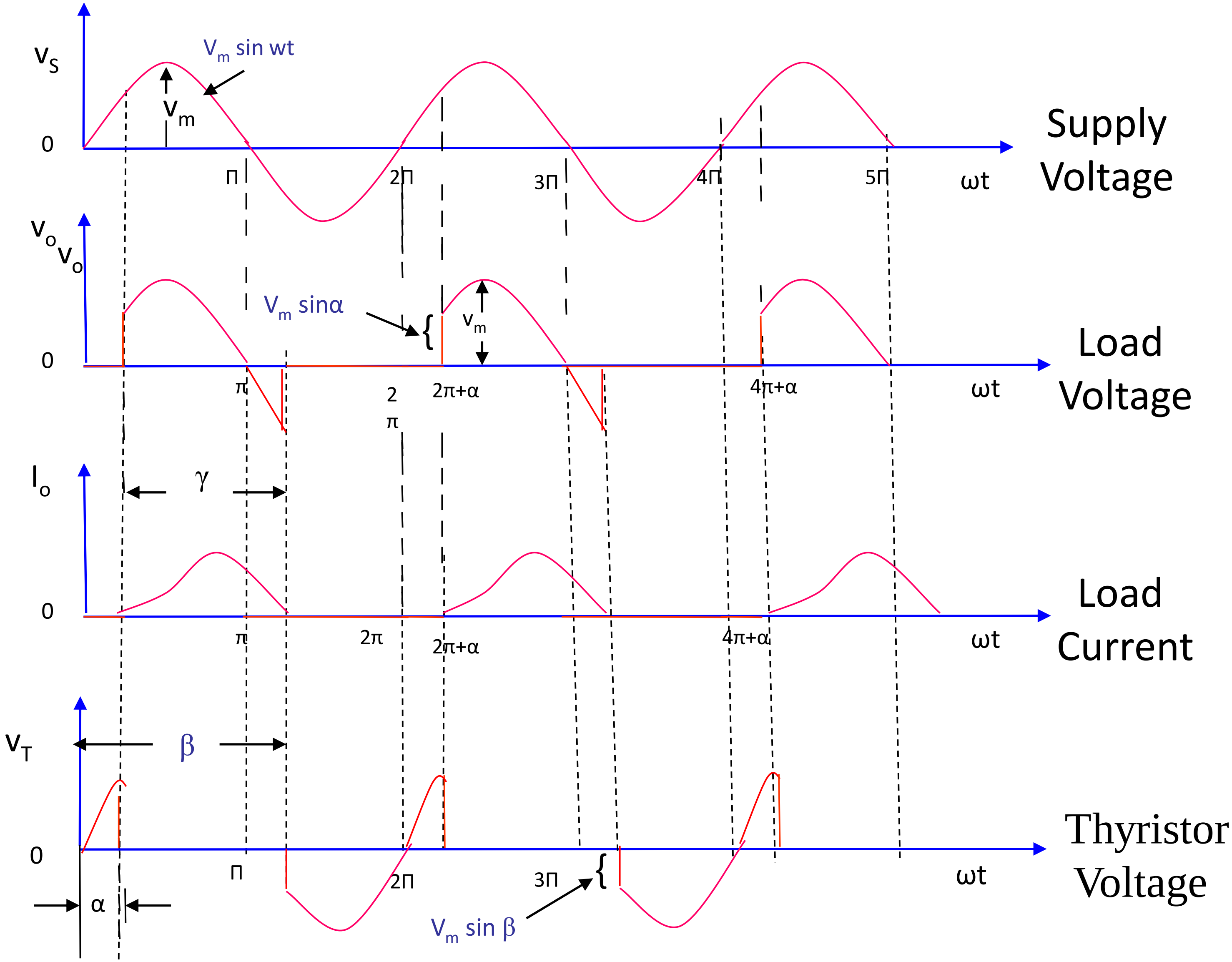


Waveforms of 1-Φ HW fully controlled converter (with R-L load)

At $wt = \Pi$, V_O is zero but I_O is not zero because of load inductance.

After $wt = \pi$, thyristor is subjected to reverse anode voltage but it will not be turned off as I_O is not less than the holding current.

At some angle $\beta > \pi$, I_O reduces to zero and thyristor is turned off as it is already reversed biased.



Waveforms of 1-Φ HW fully controlled converter (with R-L load)

From waveforms, it is clear that

Load current is driven by load voltage from α to Π

From π to β , the load voltage is negative and load current is maintained by inductance ‘**L**’

After $wt = \beta$, $V_O = 0$ and $I_O = 0$

At $wt = 2\pi + \alpha$, thyristor is triggered again, V_O is applied to the load and load current develops as before.

β is called extinction angle

$\beta - \alpha = \gamma$ is called conduction angle

- Waveform of V_T reveals that

  - when $wt = \alpha$, $V_T = V_M \sin \alpha$
  - From α to β, $V_T = 0$ and
    at $wt = \beta$, $V_T = V_M \sin \beta$

- As $\beta > \Pi$, V_T is negative and therefore thyristor is reverse biased from β to 2Π

As the thyristor is reverse biased for $(2\Pi - \beta)$ radians, the circuit turn-off time

$$t_c = (2\pi - \beta)/ \omega \ \text{sec}$$

where $\omega = 2 \pi f$ and f is supply frequency in Hz.

Average load voltage,

$V_0 \quad = (1/2\Pi)\int_{\alpha}^{\beta} V_m \sin \omega t \, d(\omega t)$

$\quad = (V_m / 2\Pi)(\mathrm{Cos}\,\alpha - \mathrm{Cos}\,\beta)$

Average load current,

$I_0 = (V_m/2\Pi R)(\mathrm{Cos}\,\alpha - \mathrm{Cos}\,\beta)$

Need for free wheeling diode

- In the case of 1-Φ HW fully controlled converter with R-L load, the waveform of load current is not continuous.

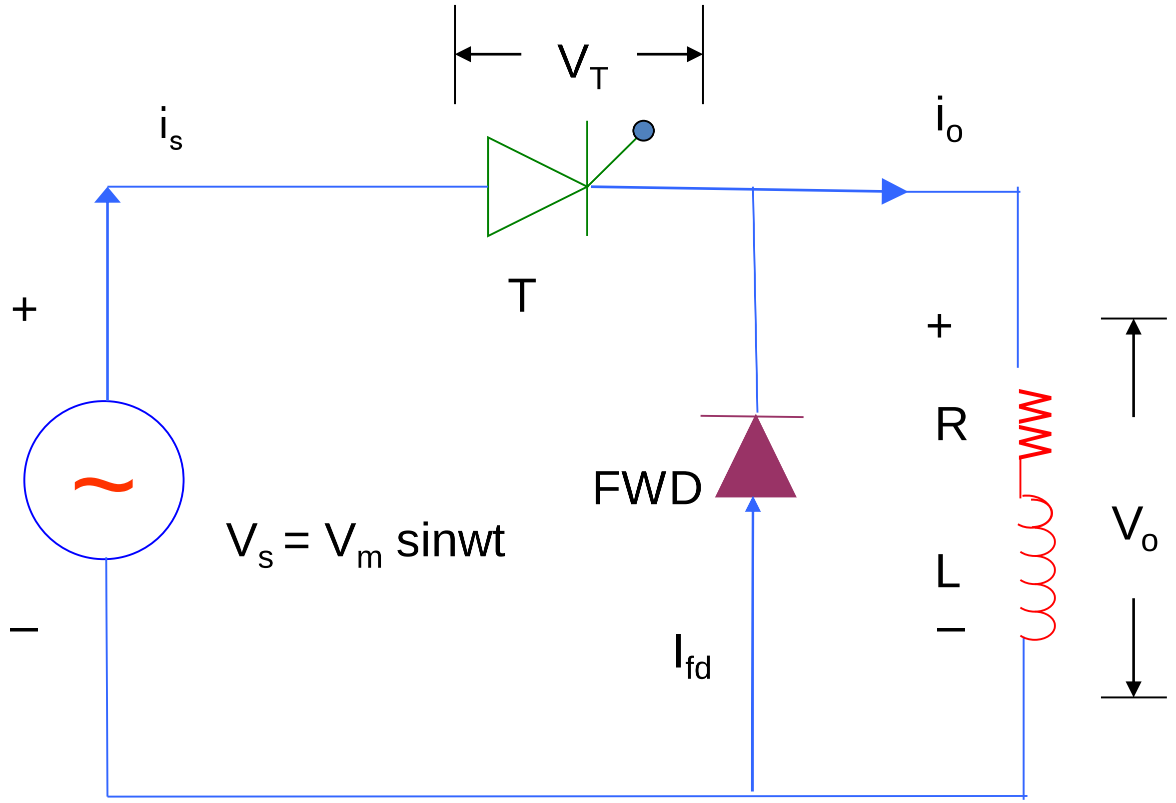
- For improving the waveform of load current, a free wheeling diode (FWD) is connected across the load.

- Free wheeling diode serves two functions

  - One is to prevent the reversal of load voltage V_o .

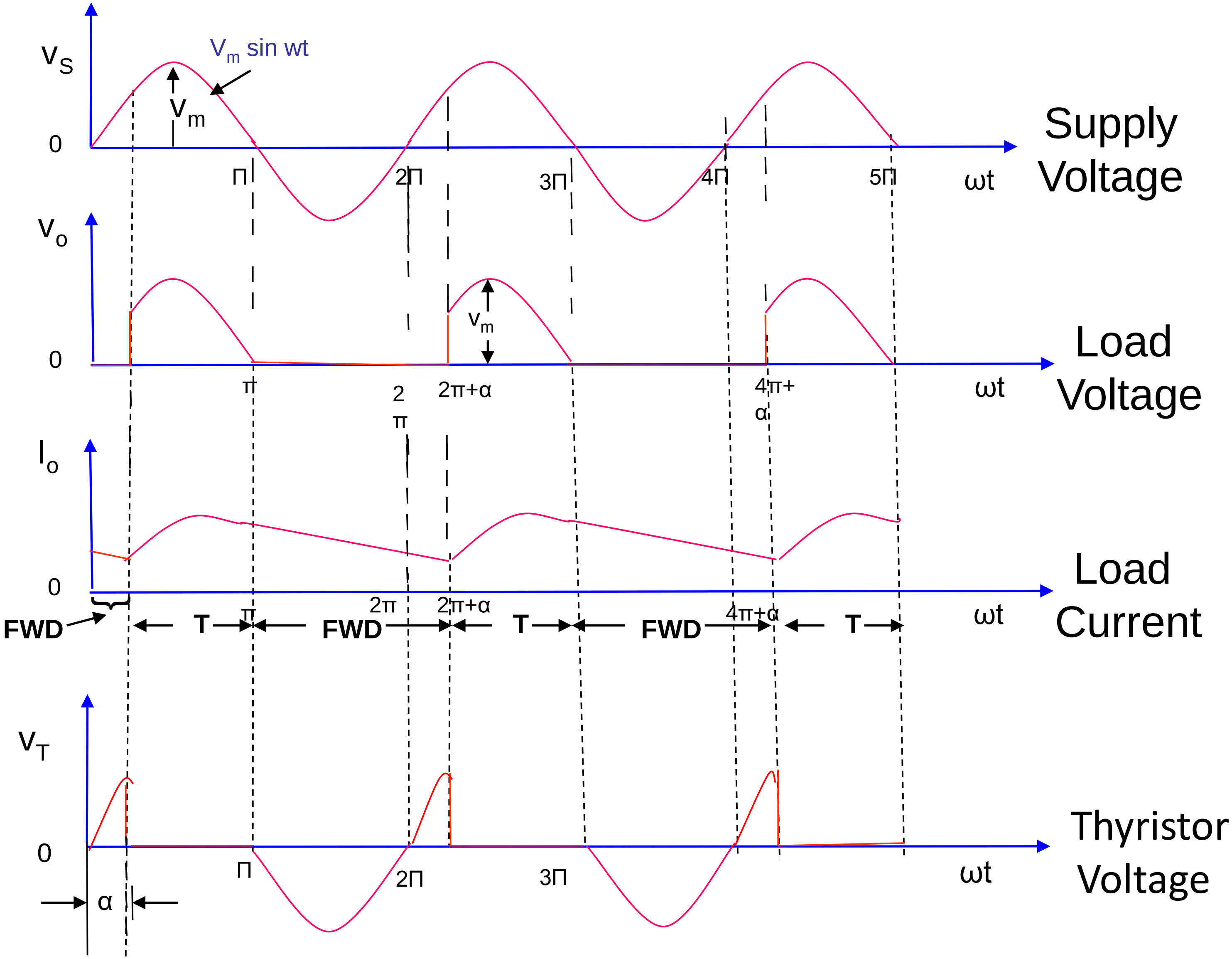
  - The other to allow the thyristor to regain its blocking state at the voltage zero by transferring the load current (I_o) away from the thyristor

1- ø HW fully controlled converter with R-L load and FWD



1-Φ HW fully controlled converter circuit with R-L load and Free Wheeling Diode (FWD)

- V_S is source voltage
- V_O is average voltage across R-L load
- I_S is supply current
- I_O is average load current
- I_{fd} is current through FWD
- V_T is voltage across thrystor



Waveforms of 1-Φ HW fully controlled converter (with R-L load and Free Wheeling Diode)

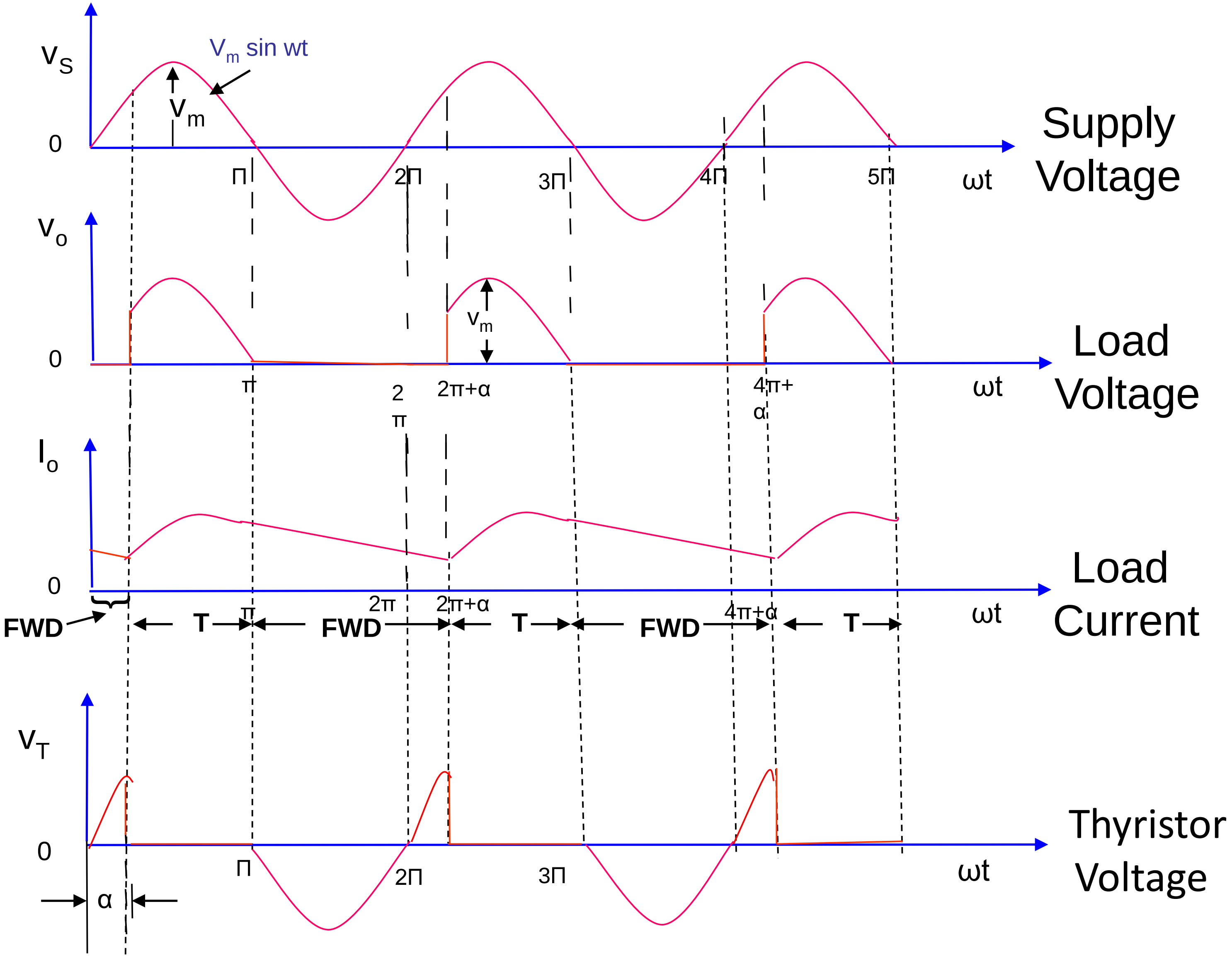
- At $\omega t = \alpha$, thyristor is turned on by triggering and source voltage (V_S**)** appears across load as V_0 .

- At $\omega t = \pi$,source voltage is zero and just after this instant, as V_S tends to reverse, FWD is forward biased through the conducting thyristor.

- As a result, I_0 is immediately transferred from thyristor to FWD as V_S tends to reverse.

- At the same time, thyristor is turned-off at wt = π (as it is subjected to reverse voltage and zero current).

- Until the thyristor is again triggered at $\omega t = (2\pi + \alpha)$, the I_0 flows through FWD.



Waveforms of 1-Φ HW fully controlled converter
(with R-L load and Free Wheeling Diode)

- Thyristor conducts from α to π, (2 π + α) to 3 π and so on. FWD is reverse biased.

- Thyristor is reverse biased from π to 2 π, 3 π to 4 π and so on. FWD conducts from π to (2 π + α), 3 π to (4 π + α) and so on.

- As thyristor is reverse biased from $\omega t = \pi$ to $\omega t = 2\pi$, the circuit turn-off time.

$$t_c = \pi / \omega \text{ sec.}$$

- ## Average load voltage

- $V_0 = (1/2\pi) \int_{\alpha}^{\Pi} V_m \sin \omega t \, d(\omega t)$

- $V_0 = (V_m / 2\pi)(1 + \cos \alpha)$ …………(1)

- Average load current
- $I_0 = V_0/R$
- $= V_m/2\pi R\,(1+\cos\alpha)$ …………(2)

- I_0 is contributed by thyristor from α to π, $(2\pi + \alpha)$ to 3π, and so on, and by FWD from 0 to α, π to $(2\pi + \alpha)$ and so on.

Advantages of Free Wheeling Diode

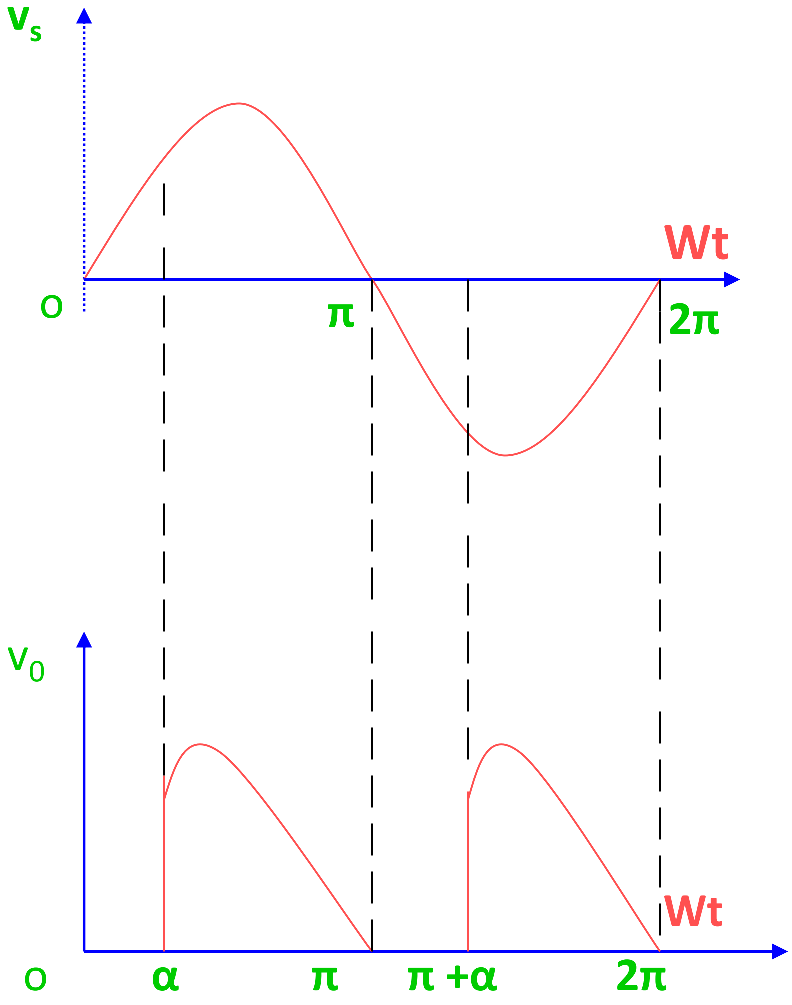
- Load current waveform is improved.
- Power factor of the circuit is improved.
- Load performance is better.

What is a 1-ø full converter

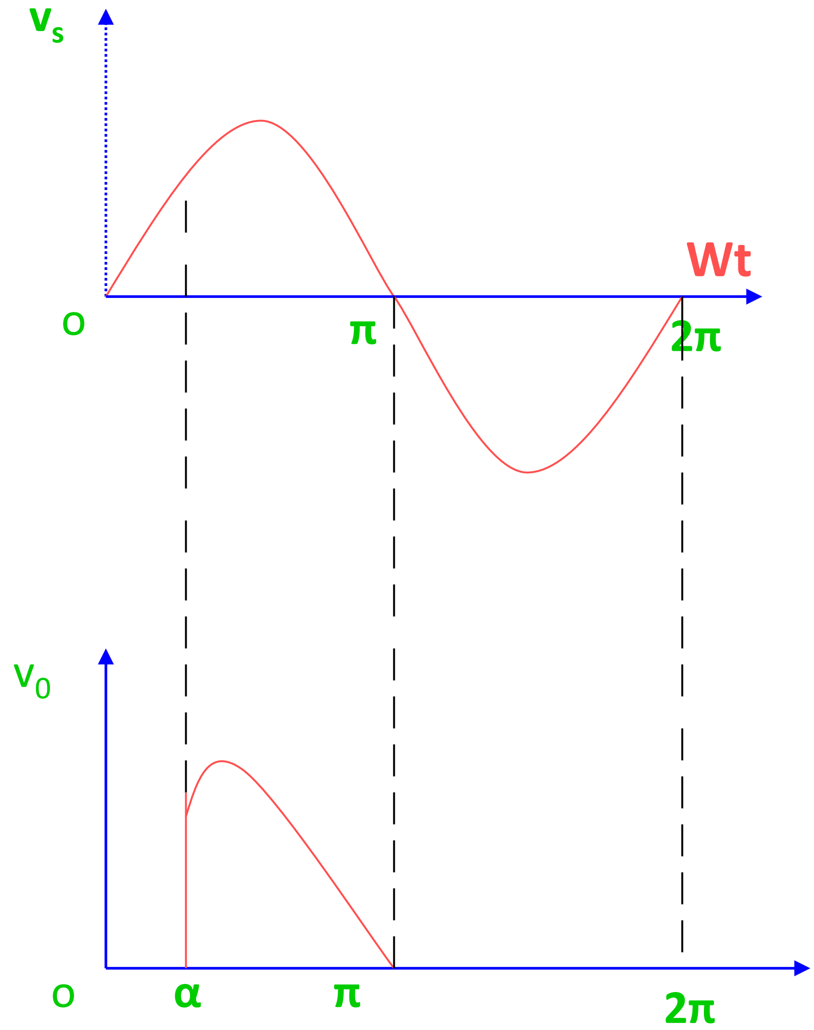
- A full converter produces two load current pulses during one cycle of supply voltage.

- A half wave converter produces only one current pulse during one cycle of supply voltage.

- Hence the average output voltage of full converter is more than the half wave converter.



Full wave conversion



Half wave conversion

Fig.1 shows difference between full wave conversion and half wave conversion.

Uncontrolled full wave converter

- It converts constant a.c. supply into constant d.c. output voltage.
- The level of d.c. output voltage cannot be controlled.
- It uses diodes only and no need of thyristors.

Types of a 1-ø full converter

- Uncontrolled converter.
- Half controlled converter.
- Fully controlled converter.

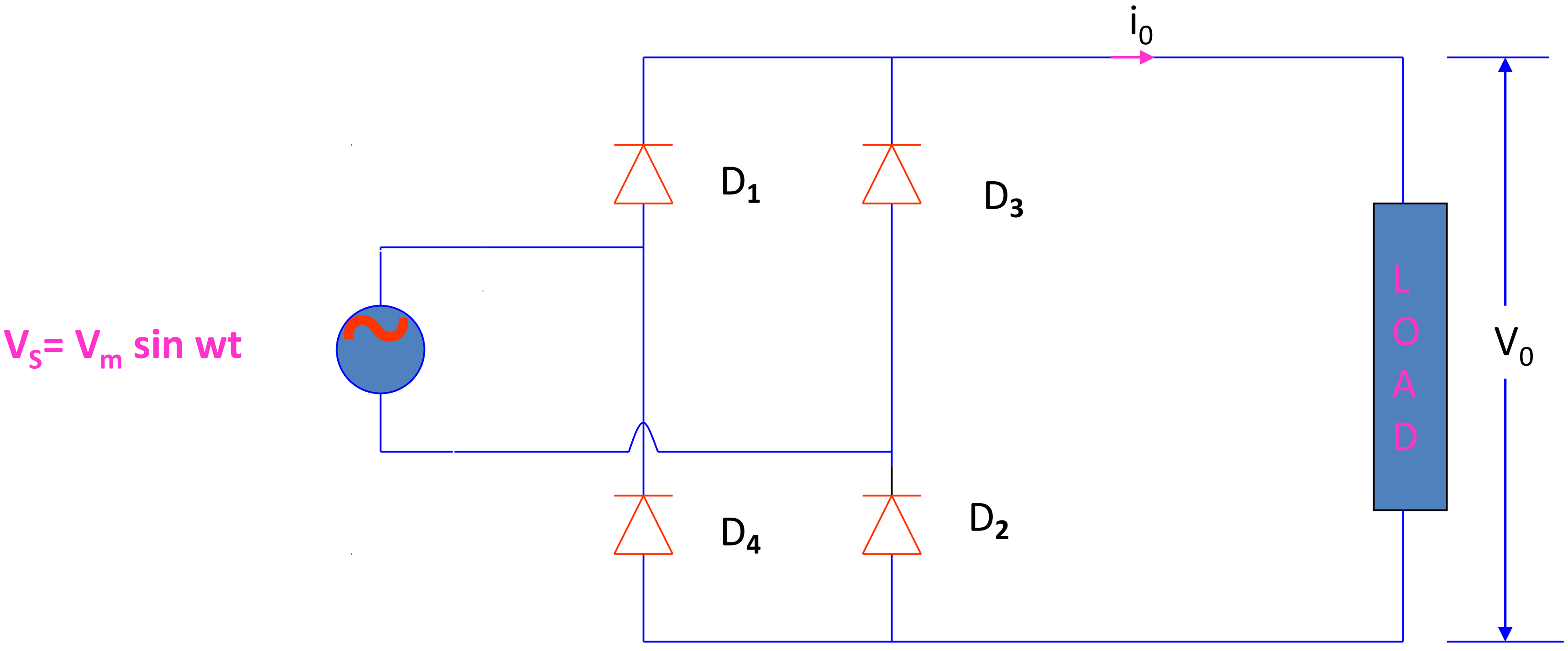


Fig.2 shows Single phase uncontrolled converter

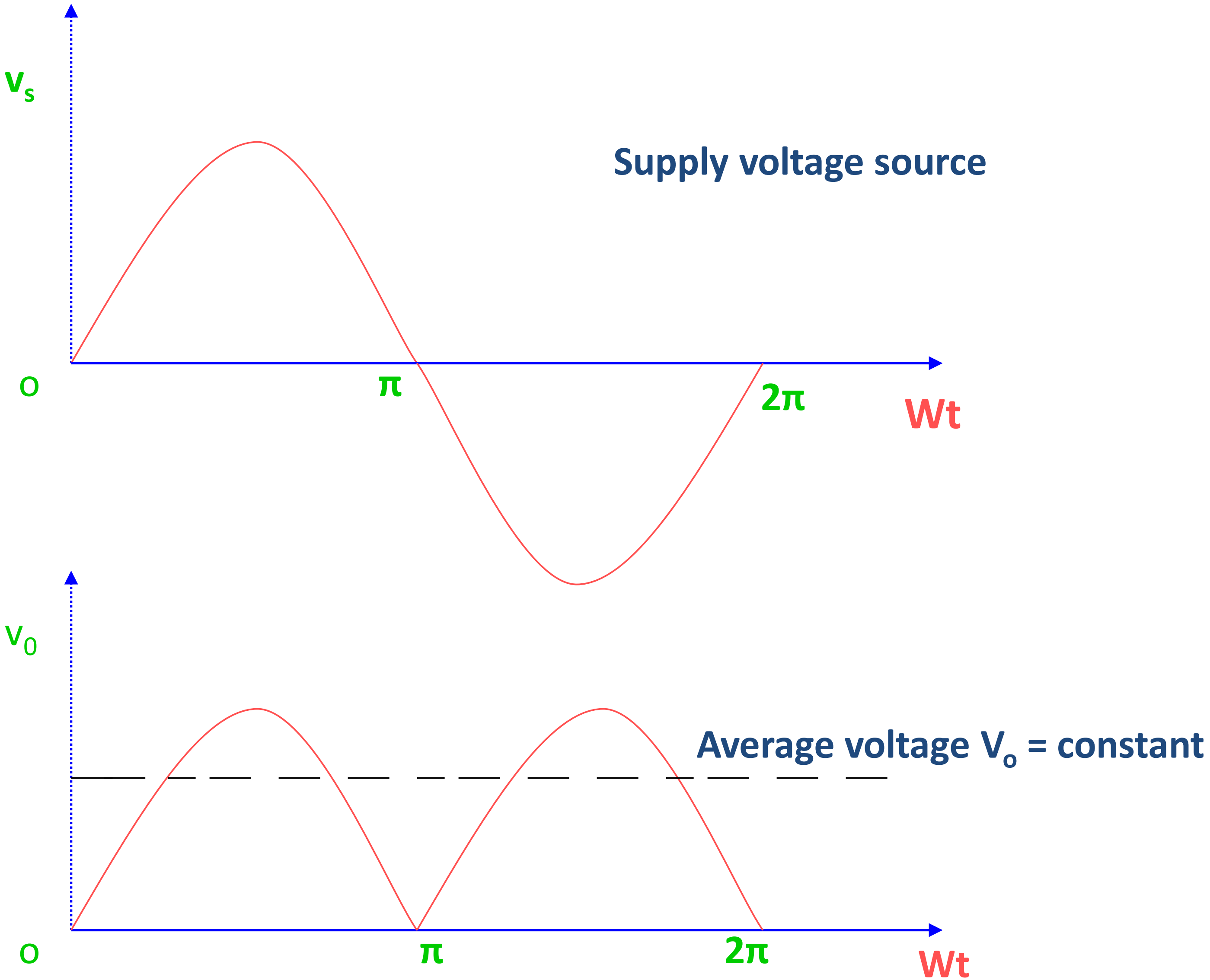


Fig.3 shows waveform of Uncontrolled full wave converter

Half controlled full wave converter

- It converts constant a.c. input supply voltage into limited range of controlled d.c. output voltage.
- The range of d.c. output voltage control is from 0 to $2\,V_m/\pi$.
- It uses diodes and thyristors.
- It is also called as semiconveter.

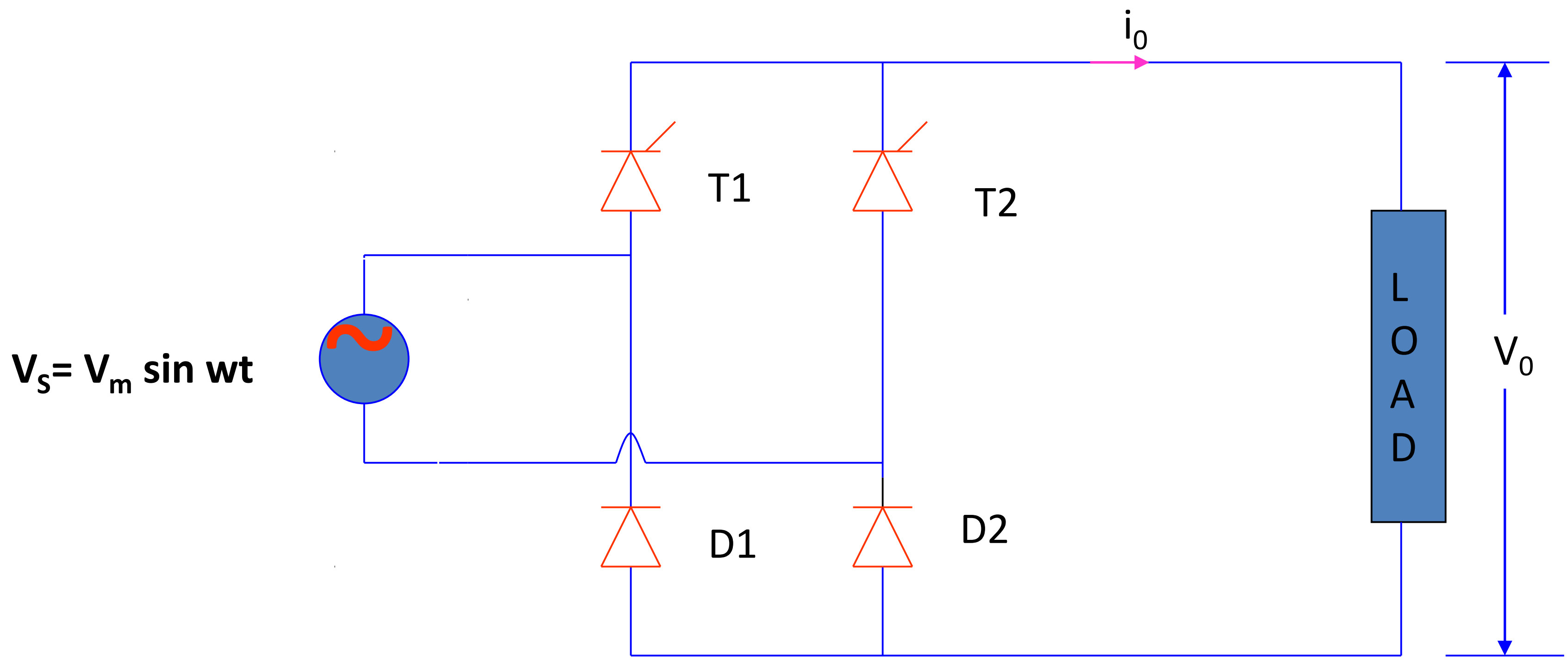
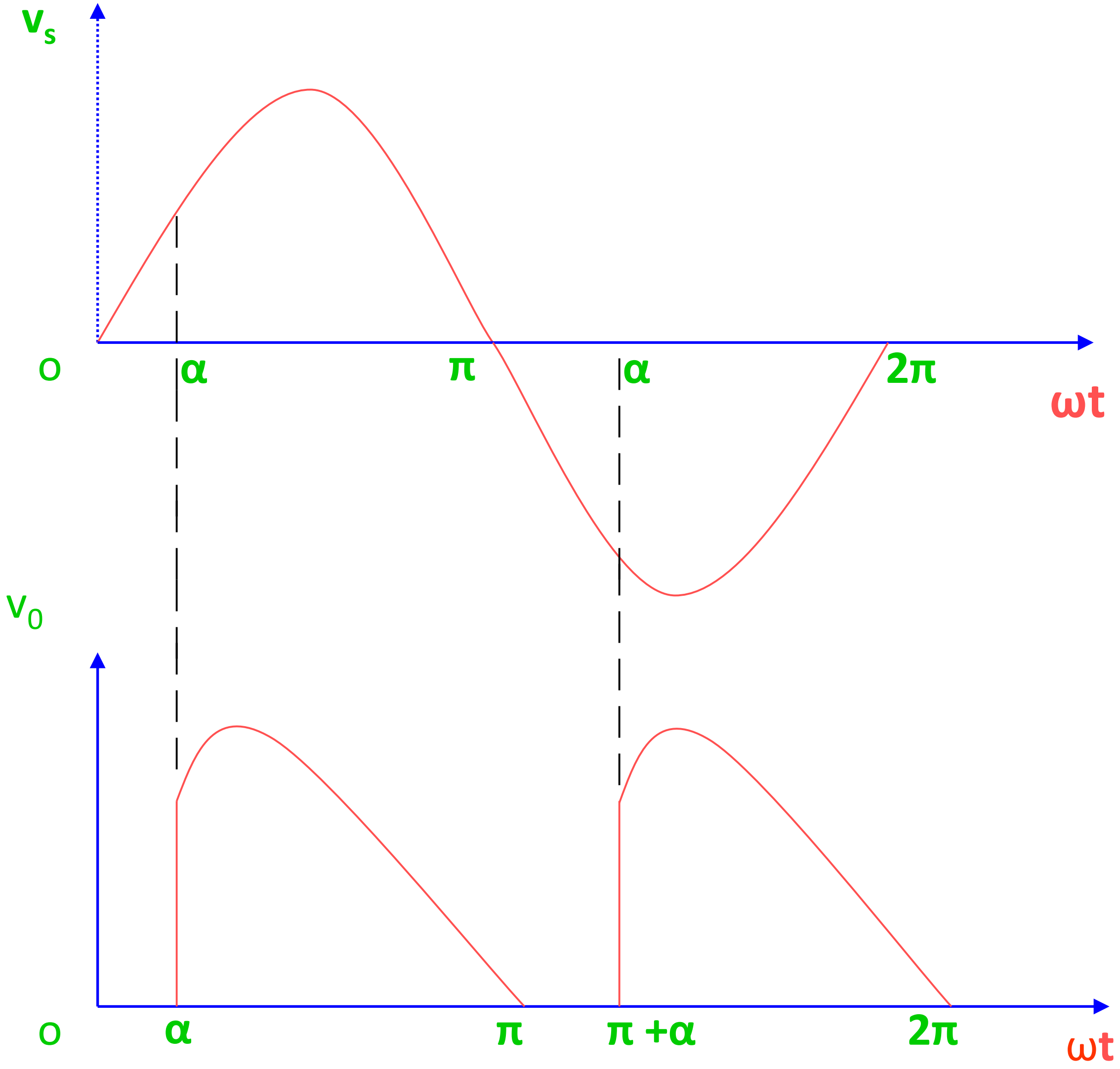


Fig.4 shows Single phase half controlled converter



ig.5 shows the waveform of Single phase half controlled converter

Fully controlled full wave converter

- It converts /inverts constant a.c. input supply voltage into wide range of controllable d.c. output voltage.
- The range of controllable average d.c. output voltage is from $-2V_m/\pi$ to $2V_m/\pi$.
- $-2V_m/\pi$ to 0 is the inversion operation.
- O to $2V_m/\pi$ is the conversion operation.

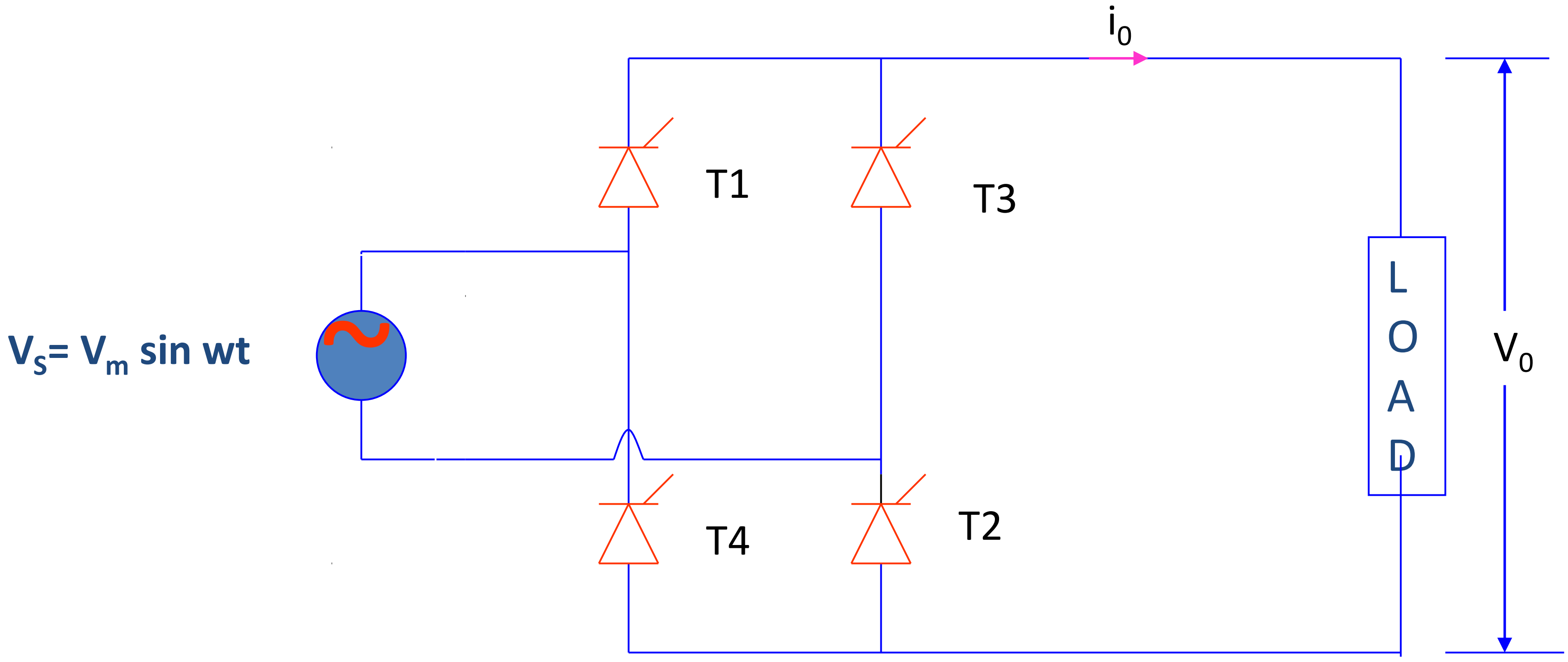


Fig.6 shows Single phase fullycontrolled converter

Connection diagram of 1-ø fully controlled converter

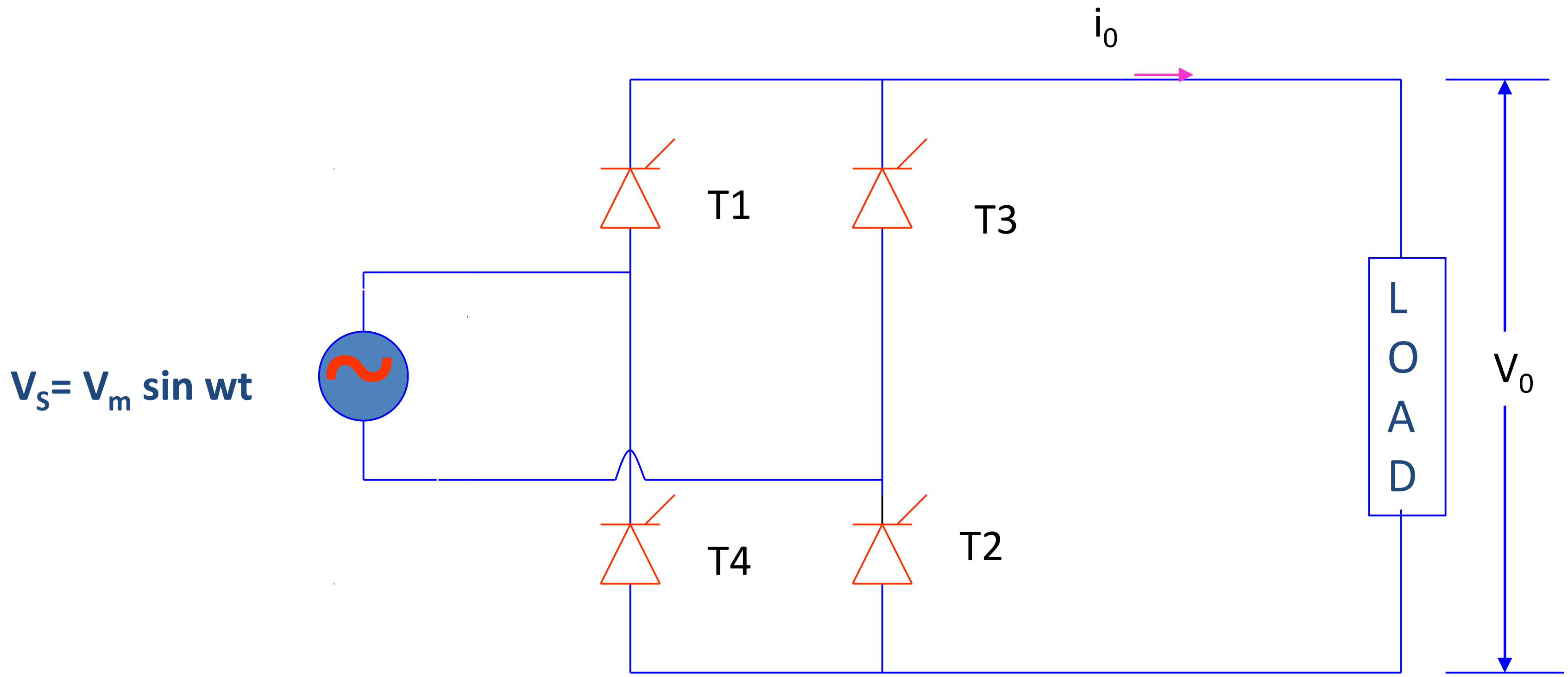


Fig.7 shows Single phase fully controlled converter

- It consists of four thyristors arranged in the form of bridge.

- The load across which the output voltage to be controlled is fed to the a.c. supply source through this bridge.

- The load may be resistive or resistive-inductive or any d.c. motor.

Operation of 1-ø fully controlled converter with resistive load

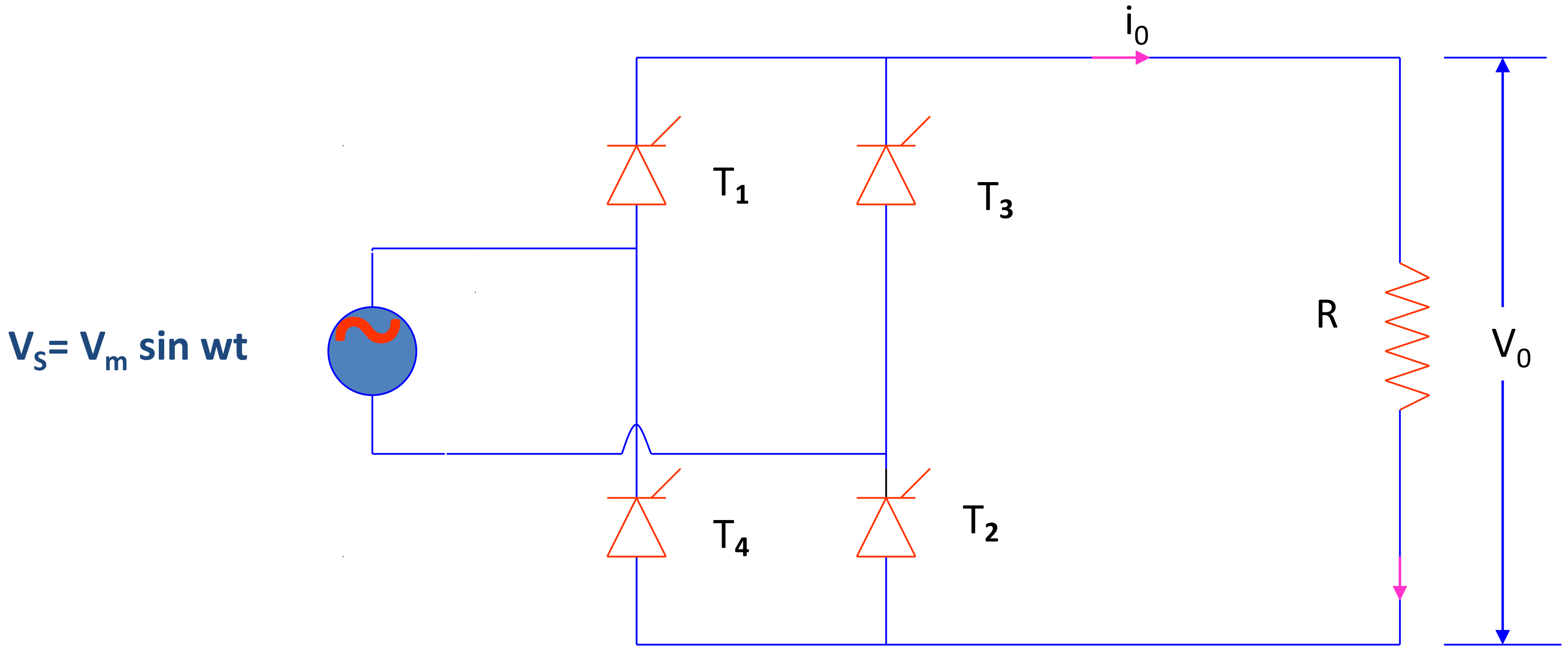


Fig.8 shows single phase fullycontrolled converter with resistive load

During positive half cycle of supply source

- T_1 and T_2 are forward biased

  T_3 and T_4 are reverse biased.

- T_1 and T_2 will be triggered when firing pulses applied at a given value of firing angle α.

- T_1 and T_2 acts as short circuit .

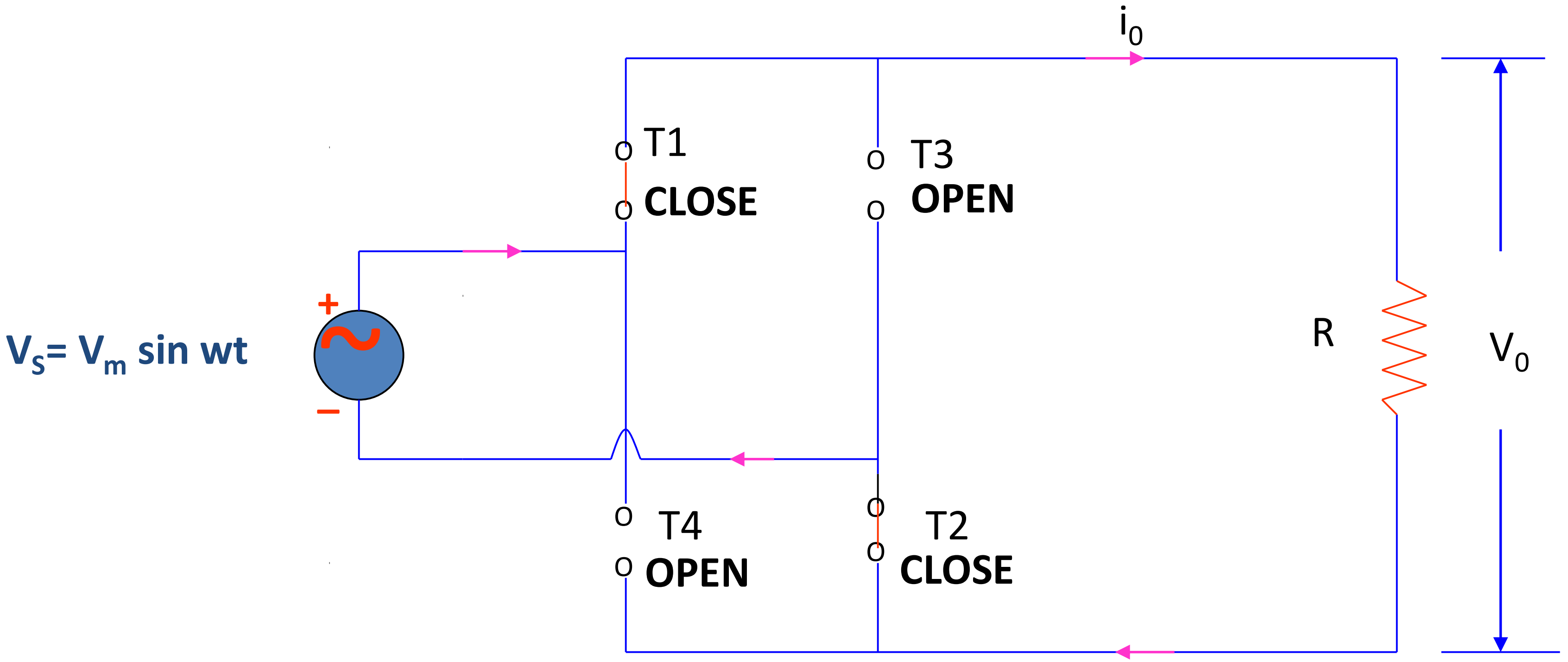
  T_3 and T_4 acts as open circuit .

- Hence the current flows through T_1 load and T_2 .

- The supply voltage appears across resistive load called output volta V_o.

- At $\omega t = \pi$, as source voltage is zero a becoming negative, T_1 and T_2 are reverse biased.

- T_1 and T_2 will be turned OFF by natural commutation.



g.9 shows Conversion during positive half cycle of supply

During negative half cycle of supply source

- T_3 and T_4 are forward biased,

  T_1 and T_2 are reverse biased.

- T_3 and T_4 will be triggered when firing pulses applied at $\omega t = \Pi + \alpha$.

- T_1 and T_2 acts as open circuit,

  T_3 and T_4 acts as short circuit .

- Hence the current flows through T_3 , load and T_4.

- The supply voltage appears across resistive load called output voltage V_o.

- At $\omega t = 2\Pi$, as source voltage is zero and becoming positive, T3 and T3 are reverse biased .

- T_3 and T_4 will b turned-OFF by natural commutation.

- The same operation will be repeated for subsequent cycles of supply source V_s .

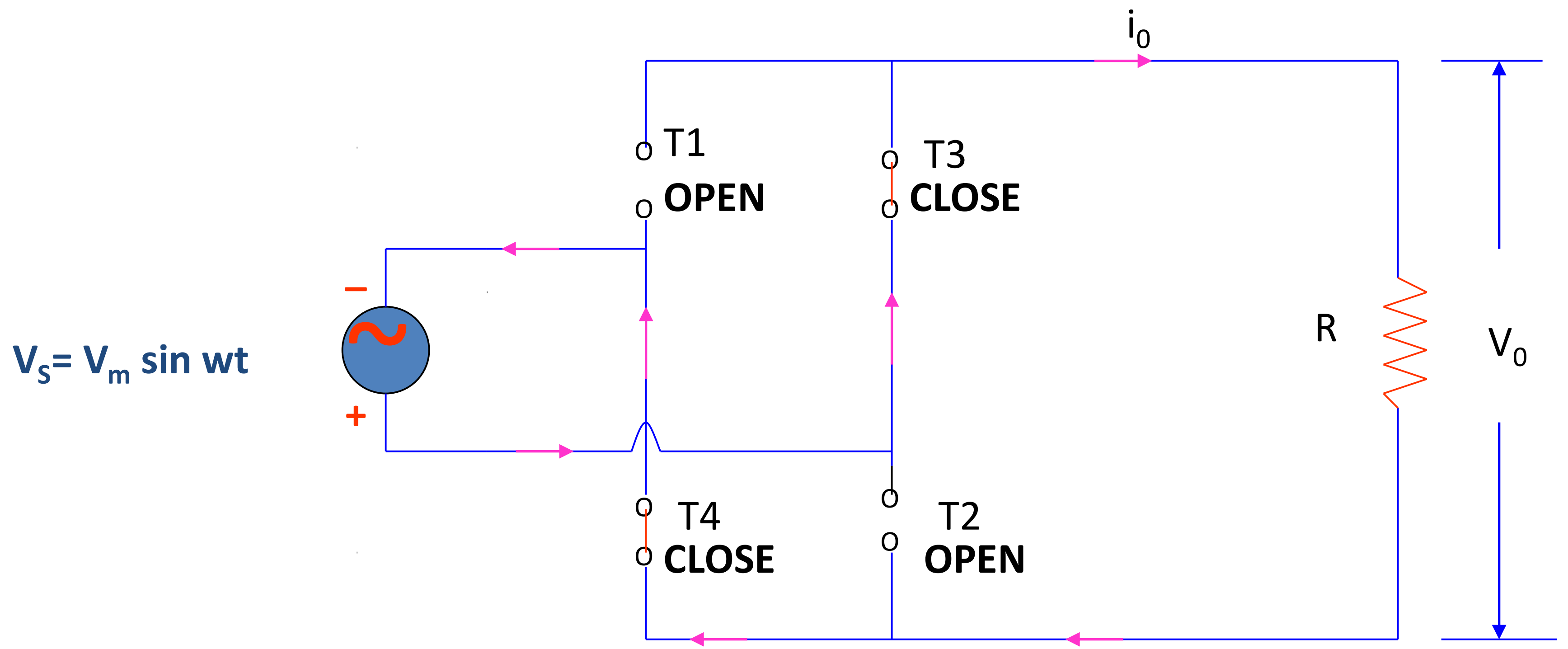


Fig.10 shows Conversion during negative half cycle of supply

It is observed that

- The load current i_0 is unidirectional for both half cycles of supply.
- The output voltage v_0 is also unidirectional (d.c.).

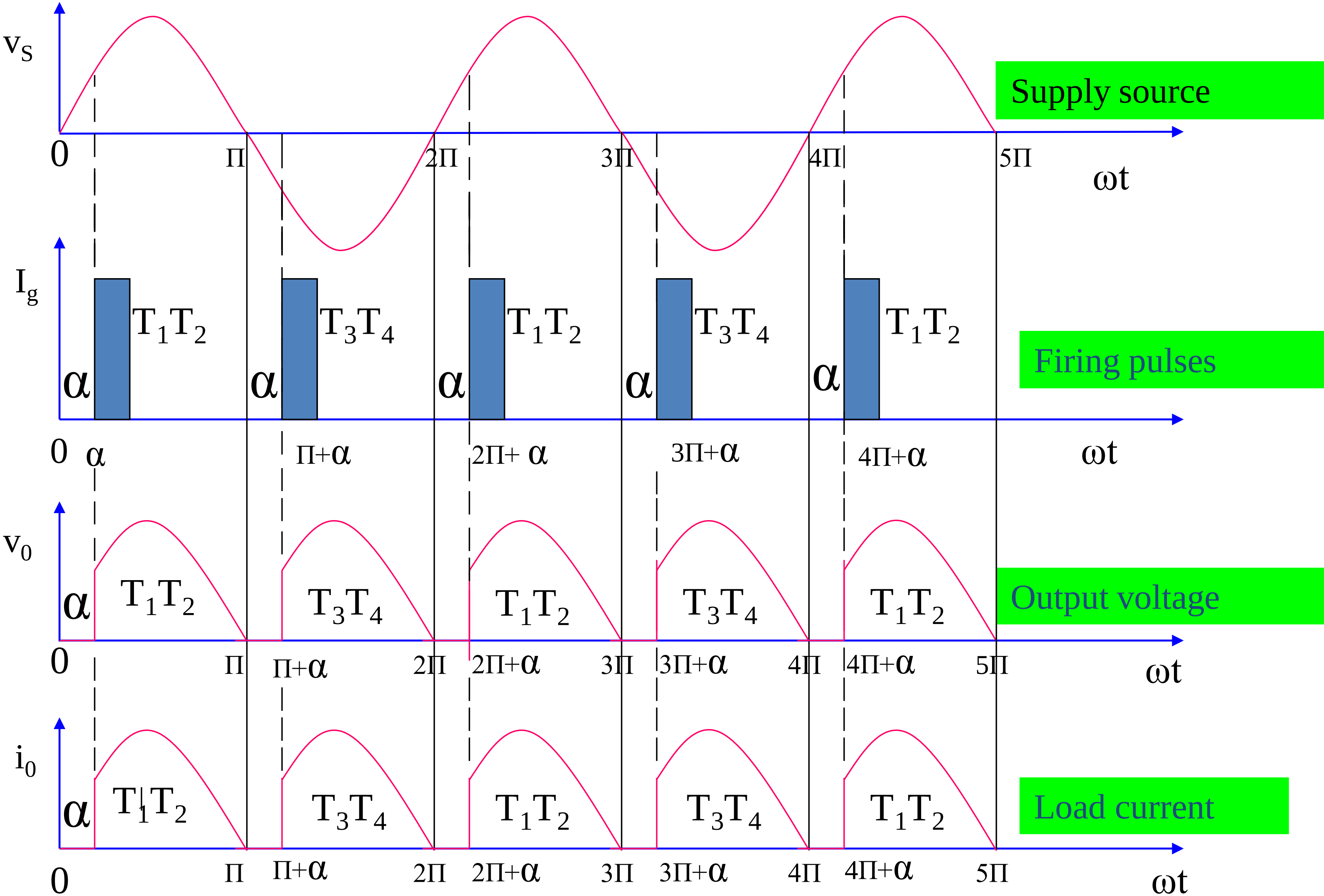


Fig.11 shows the input and output waveforms

Average output voltage

From the wave form of output voltage, the average value is given by ,

$$V_0 = \frac{\text{Area under the curve over one cycle}}{\text{Time period}}$$

$$V_0 = (1/2\pi)\ {}_{\alpha}\int^{2\pi} v_s\ d(\omega t)$$

OR $$V_0 = (1/\Pi)\ {}_{\alpha}\int^{\Pi} v_s\ d(\omega t)$$

$$V_0 = (1/\Pi)\ {}_{\alpha}\int^{\Pi} v_m \sin \omega t\ d(\omega t)$$

$$= (v_m/\Pi)\ [-\cos \omega t]_{\alpha}^{\Pi}$$

$V_0 = (v_m / \Pi) [1 + \cos \alpha]$

At $\alpha = 0$, $V_0 = 2v_m / \pi$

$\alpha = \pi/2$, $V_0 = V_m / \pi$

$\alpha = \pi$, $V_0 = 0$

It is observed that

- **As the firing angle α increases, the output voltage v_0 decreases.**

Average load current (i_0)

- $I_0 = V_0 / R$

- $I_0 = (V_m / \Pi R)[1+\cos\alpha]$

Circuit turn-off time (t_c)

- The pair of thyristors (T_1,T_2 and T_3,T_4) are reverse biased for Π radians alternatively .

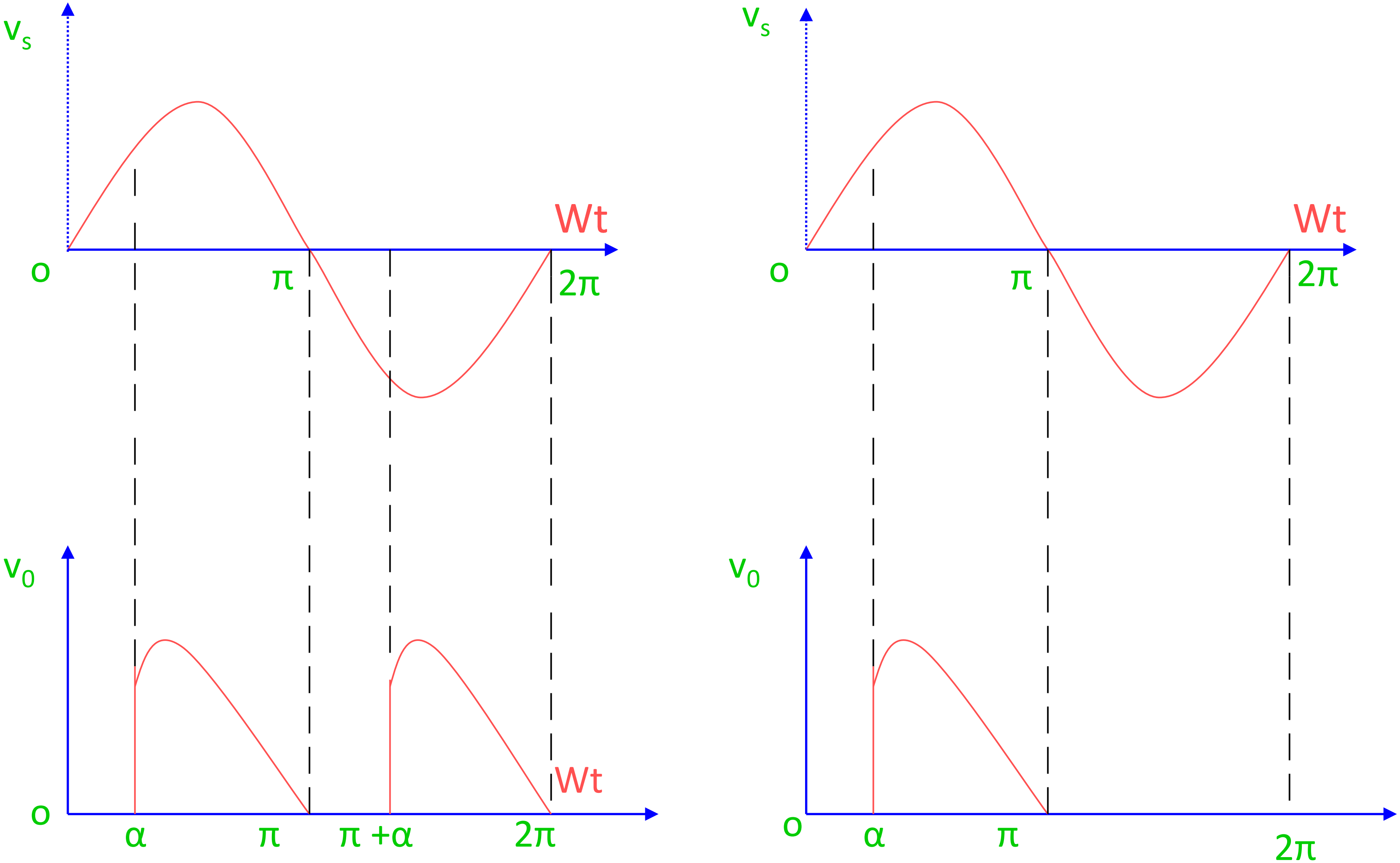
- Hence the circuit tu en by

$$t_c = \pi / \omega \ \ \mathrm{seC}$$

Recap

What is the difference between full wave converter and half wave converter?

- A full converter produces two load current pulses during one cycle of supply voltage
- A half wave converter produces only one current pulse during one cycle of supply voltage
- Hence the average output voltage of full converter is more than the half wave converter



Full wave conversion

Half wave conversion

Fig.1 shows difference between full wave conversion and half wave conversion.

- Give types of a 1-ø full converter .

- Uncontrolled converter. It gives constant d.c. output voltage

- Half controlled converter. It gives limitted range of control of d.c. output voltage

- Fully controlled converter. It gives wide range of control of d.c. output voltage

- What we have discussed during previous class.

- **1-ø fully controlled converter with resistive load**

Objectives

- On the completion of this topic, you would be able to :

- Connection diagram of single phase fully controlled converter with R-L load
- Operation of single phase fully controlled converter with R-L load.
- Input and output waveforms.
- Derivation for expression of V_0 .

Function of 1-ø fully controlled converter with R-L load

- It converts / inverts constant a.c. supply voltage into wide range of controllable d.c. output voltage

- The range of controllable average d.c. output voltage is $-2V_m/\pi$ to $2V_m/\pi$

- $-2V_m/\pi$ to 0 is the inversion operation

- 0 to $2V_m/\pi$ is the conversion operation

Connection diagram of 1-ø fully controlled converter with R-L load

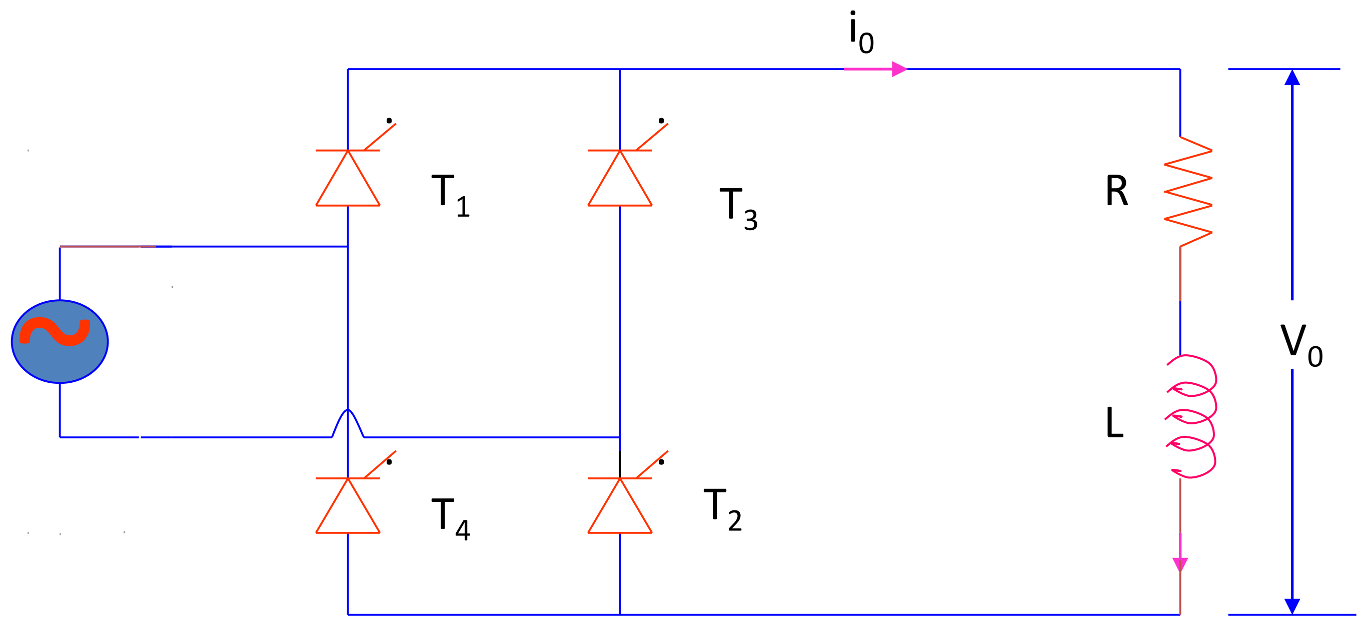


Fig.2 shows single phase fully controlled converter with resistive-inductive load

Operation of 1-ø fully controlled Converter with R-L load

During positive half cycle of supply source

- T_1 and T_2 are forward biased
  T_3 and T_4 are reverse biased

- T_1 and T_2 will be triggered simultaneously when firing pulses applied at $\omega t = \alpha$

- T_{1}, T_2 acts as short circuit
  T_3,T_4 acts as open circuit

- Supply voltage (v_{ab}) appears across the load, called output voltage v_0

- Current (i_0) flows through T_1 **, load &** T_2

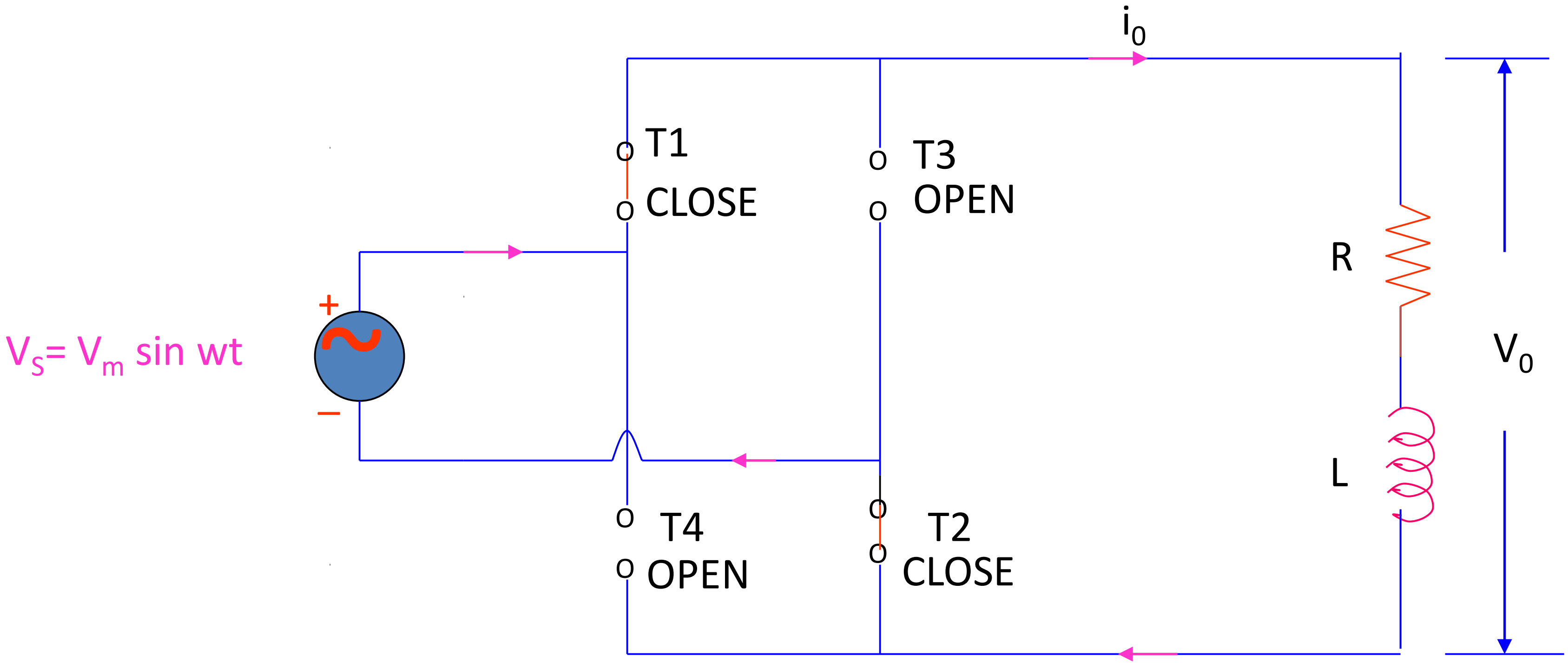


Fig.3 shows Conversion during positive half cycle of supply source

- As the load is inductive, the current rises slowly to its maximum value and falls slowly to zero value
- Hence the output voltage v_0 reaches zero value earlier than current i_0
- The output voltage follows input voltage (v_{ab}) through a small portion of negative half cycle (v_{ab}) untill T_1, T_2 will be turned OFF
- T_1,T_2 will be turned off by natural commutation when current (i_0) is less than holding current
- Assume that the current (i_0) falls to holding current at an angle $(\Pi + \alpha)$

During negative half cycle of supply source

- T_3 and T_4 are forward biased
  T_1 and T_2 are reverse biased
- T_3 and T_4 will be triggered simultaneously when firing pulses applied at $\omega t = \Pi + \alpha$
- T_3 ,T_4 acts as short circuit
  T_1,T_2 acts as open circuit
- Supply voltage (v_{ba}) appears across the load, called output voltage V_0

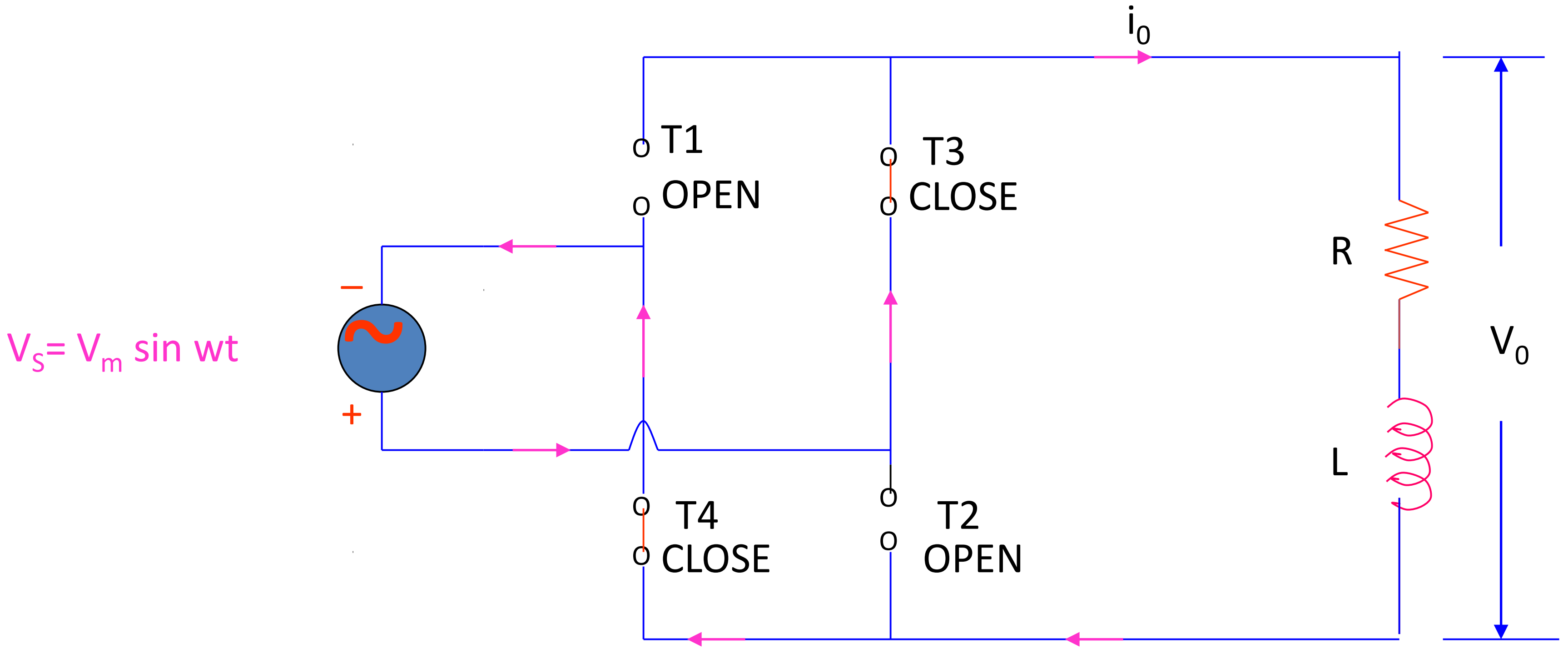


Fig.4 shows Conversion during negative half cycle of supply source

- current (i_0) flows through T_3, load and T_4
- As the load is inductive, the current rises slowly to its maximum value and falls slowly to zero value
- Hence the output voltage v_0 reaches zero value earlier than current i_0
- The output voltage follows input voltage (v_{ba}) through a small portion of negative half cycle (v_{ba}) until T_3, T_4 will be turned - OFF

- T_3,T_4 will be turned OFF by natural commutation when current (i_0) is less than holding current.
- Assume that the current (i_0) falls to holding current at an angle ($2\Pi+\alpha$) .
- The same operation will be repeated for subsequent cycles of supply.

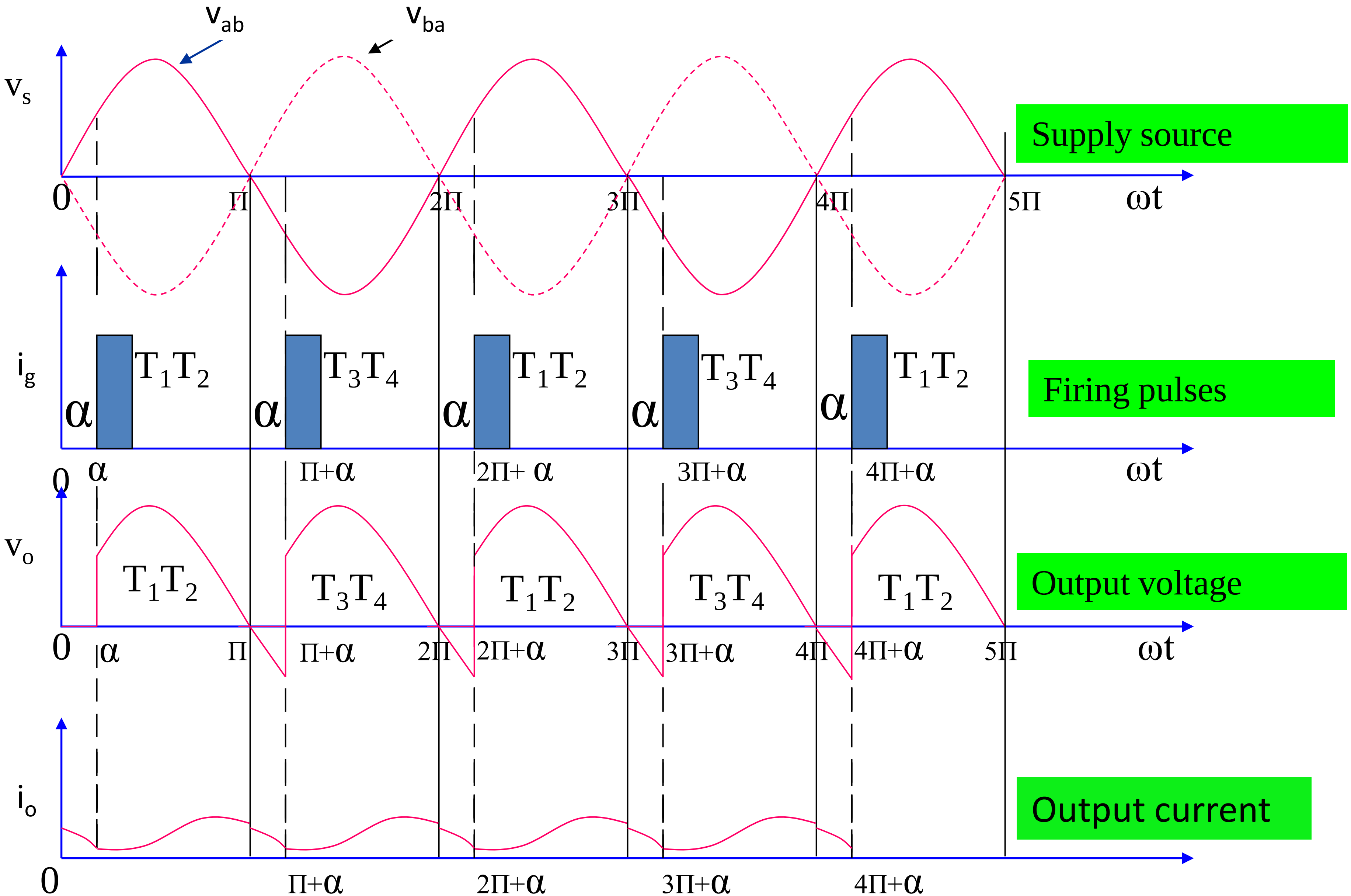


Fig.5 shows the input and output waveforms

- Note that the current (i_0) is unidirectional (d.c) for both half cycles of supply.

- The output voltage(v_0) is negative until the incoming thyristors turned – ON.

- Hence the average output voltage v_0 may be positive, zero or negative depending upon the value of firing angle α.

Average output voltage (v_0)

- From the wave form, the average value of output voltage V_0 is given by

$$V_0 = \frac{\text{Area under the curve over one cycle}}{\text{Time period for the same cycle}}$$

$$V_0 = (1/2\Pi)\int_{\alpha}^{2\Pi+\alpha} v_m \sin \omega t \, d(\omega t)$$

OR $$V_0 = (1/\Pi)\int_{\alpha}^{\Pi+\alpha} v_m \sin \omega t \, d(\omega t)$$

$$V_0 = (v_m/\Pi)\int_{\alpha}^{\Pi+\alpha} \sin \omega t \, d(\omega t)$$

$$= (v_m/\Pi)\,[-\cos \omega t\,]_{\alpha}^{\Pi+\alpha}$$

$$V_0 = (2\,v_m/\Pi)\cos \alpha$$

Variation of V_0 w.r.t. α :

$$V_0 = (2 v_m / \Pi) \cos \alpha$$

α	0^0	30^0	60^0	90^0	120^0	150^0	180^0
V_0	$2V_m/\pi$	$\sqrt{3}v_m/\Pi$	v_m/Π	0	$- v_m/\Pi$	$-\sqrt{3}v_m/\Pi$	$-2v_m/\Pi$

conversion ⟷ inversion

It is observed that

- As the firing angle α increases, the output voltage V_0 decreases.

Circuit turn-off time (t_c)

- The pair of thyristors (T_1,T_2 and T_3,T_4) are reverse biased for $(\Pi - \alpha)$ radians alternatively.

- Hence the circuit turn-off time is given by

$$\boxed{t_c = (\pi - \alpha)/\omega \ \text{sec}}$$

Three phase Half wave controlled converter

Advantages of 3- ø converters over 1- ø converters

- Higher ripple frequency
- Less filtering requirements for smoothing out load current
- Load performance is superior as load current is mostly continuous in 3-Ø converters

Three phase Half wave controlled converter

Connection diagram

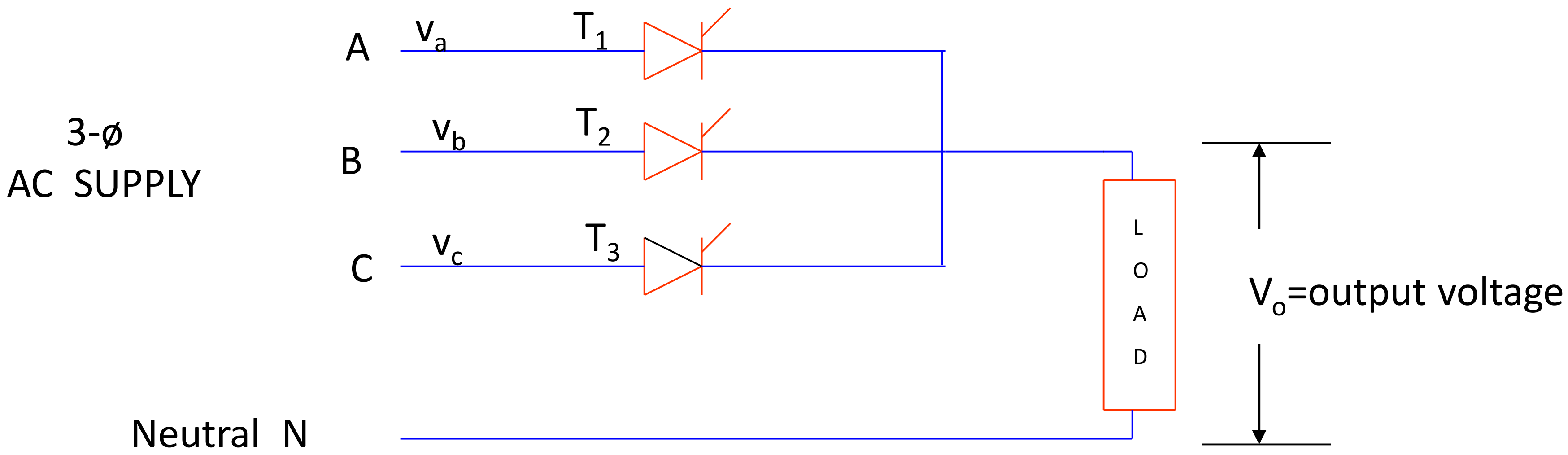


Fig.1 shows the connection diagram of 3-Ø HWCC

Three phase Half wave controlled converter

- A 3-ø half wave controlled converter produces three load current pulses during one cycle of input a.c 3-ø supply

- $\mathbf{V}_a$,v_b and v_c are the instantaneous input voltages applied to T_1,T_2, and T_3 respectively

- v_o is an instantaneous output voltage

- The load may be resistive or resistive - inductive or any d.c.motor

Conducting sequence of thyristors

- A thyristor is said to be forward biased when its anode connected to highest positive instantaneous voltage
- The other thyristors are said to be in reverse blocking mode
- The thyristors T1, T2 and T3 will become forward biased at $\omega t = \pi / 6$, $5\pi / 6$ and $9\pi / 6$ respectively
- Let us suppose firing pulses applied at an angle α
- The thyristors T1, T2 and T3 will be triggered at $\omega t = (\pi / 6) + \alpha$, $(5\pi / 6) + \alpha$ and $(9\pi / 6) + \alpha$ respectively
- Each thyristor will conduct for 120^0

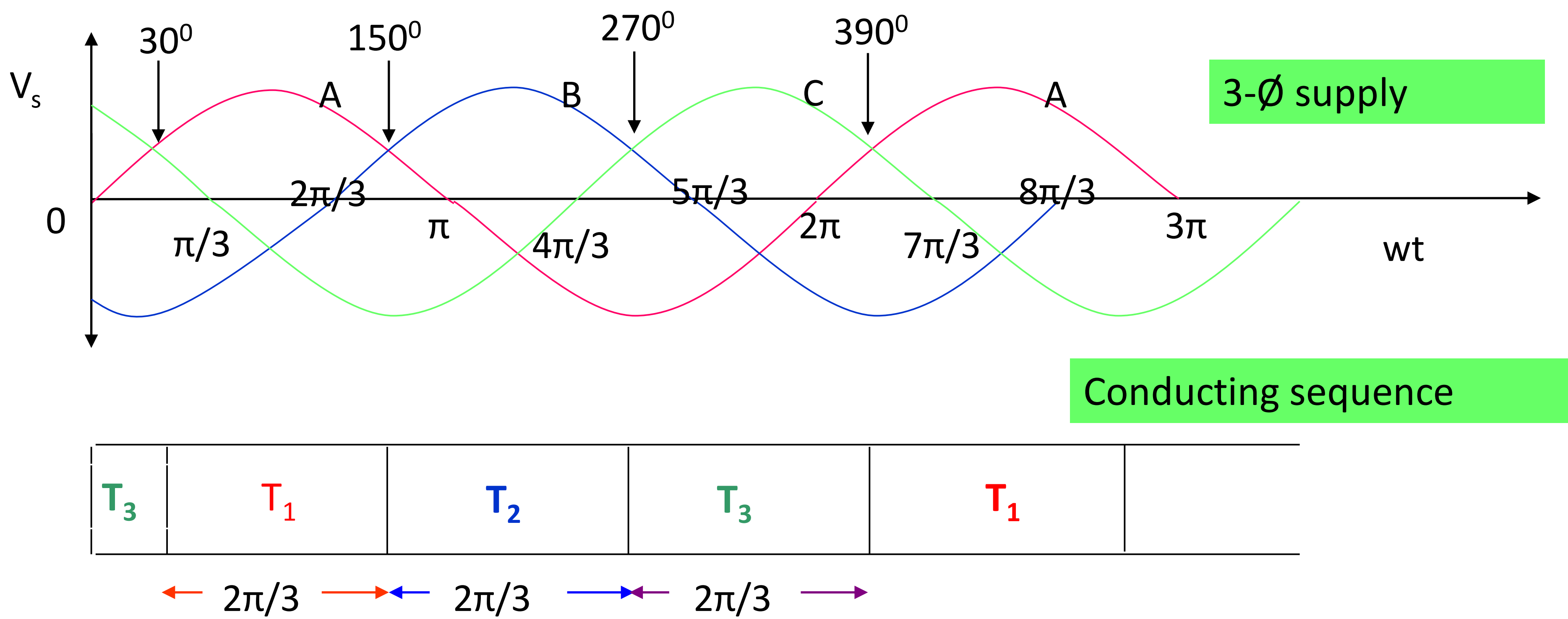


Fig.2 shows the conducting sequence of thyristors in a 3-Ø HWCC

3-ø Half-Wave Controlled Converter with R- load Operation

at $\omega t = (\pi / 6) + \alpha$

- T_1 acts as short circuit

  T_2,T_3 acts as open circuit

- The instaneous voltage v_a will be connected across R - load

  from $\omega t = (\pi / 6) + \alpha$ to $(\pi / 6) + \alpha + 120^0$

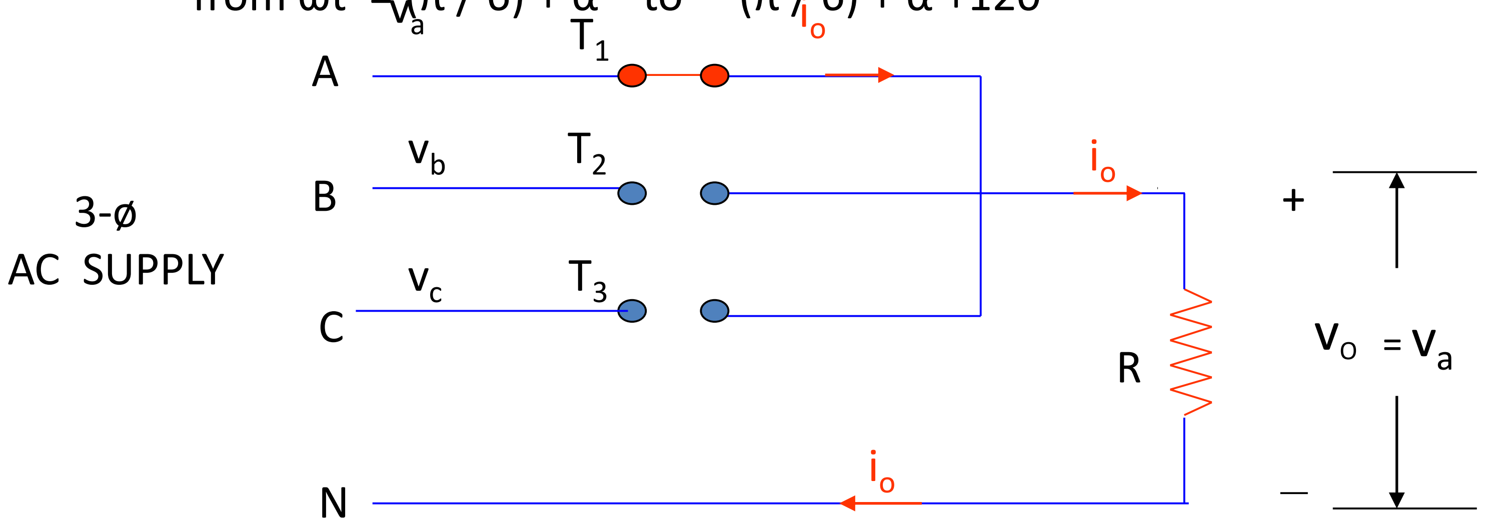


Fig.3 shows the conversion when T_1 will conduct

at $\omega t = (5\pi / 6) + \alpha$

- T_2 acts as short circuit.

T_1,T_3 acts as open circuit

- The instaneous voltage v_b will be connected across R–load

from $\omega t = (5\pi / 6) + \alpha$ to $(5\pi / 6) + \alpha + 120^0$

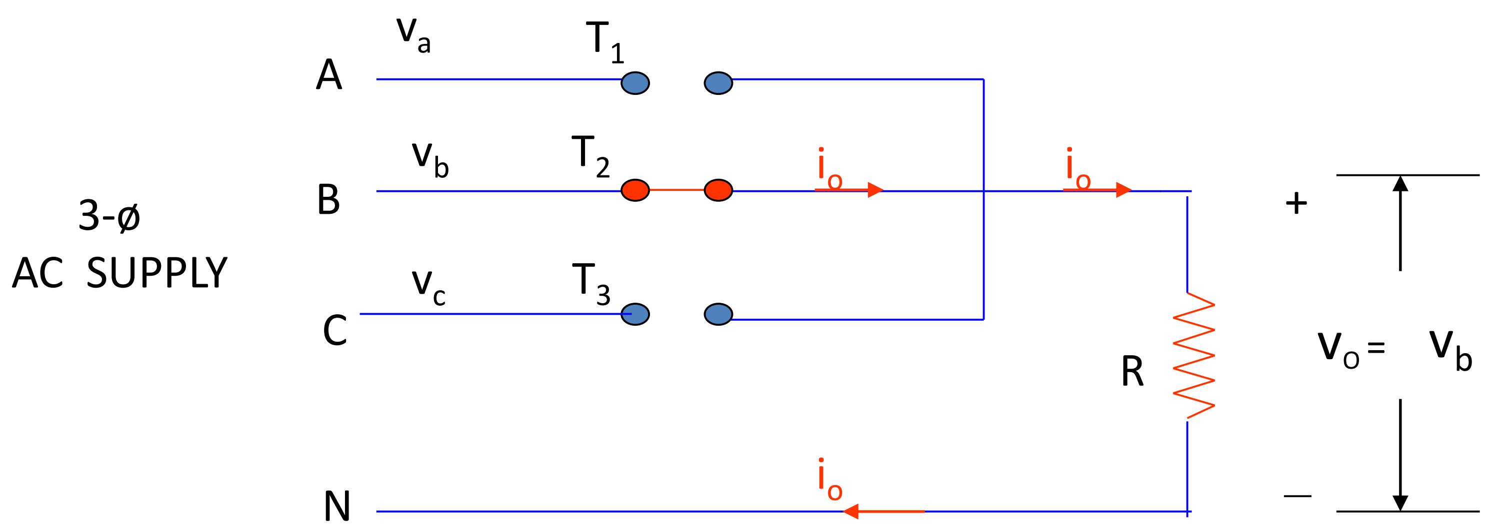


Fig4. shows the conversion when T_2 will conduct

at $\omega t = (9\pi / 6) + \alpha$

- T_3 acts as short circuit

  T_1, T_2 acts as open circuit

- The instaneous voltage v_c will be connected across

  R-load from $\omega t = (\mathbf{9}\pi / \mathbf{6}) + \alpha$ to $(\mathbf{9}\pi / \mathbf{6}) + \alpha + 120^0$

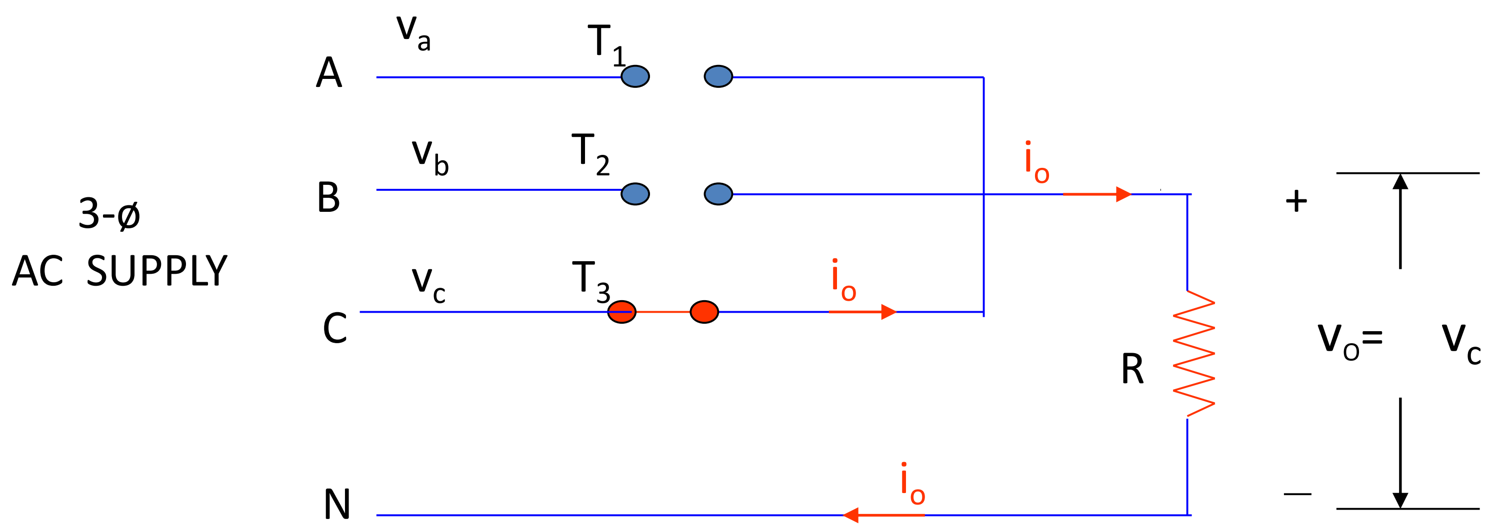


Fig.5 shows the conversion when T_3 will conduct

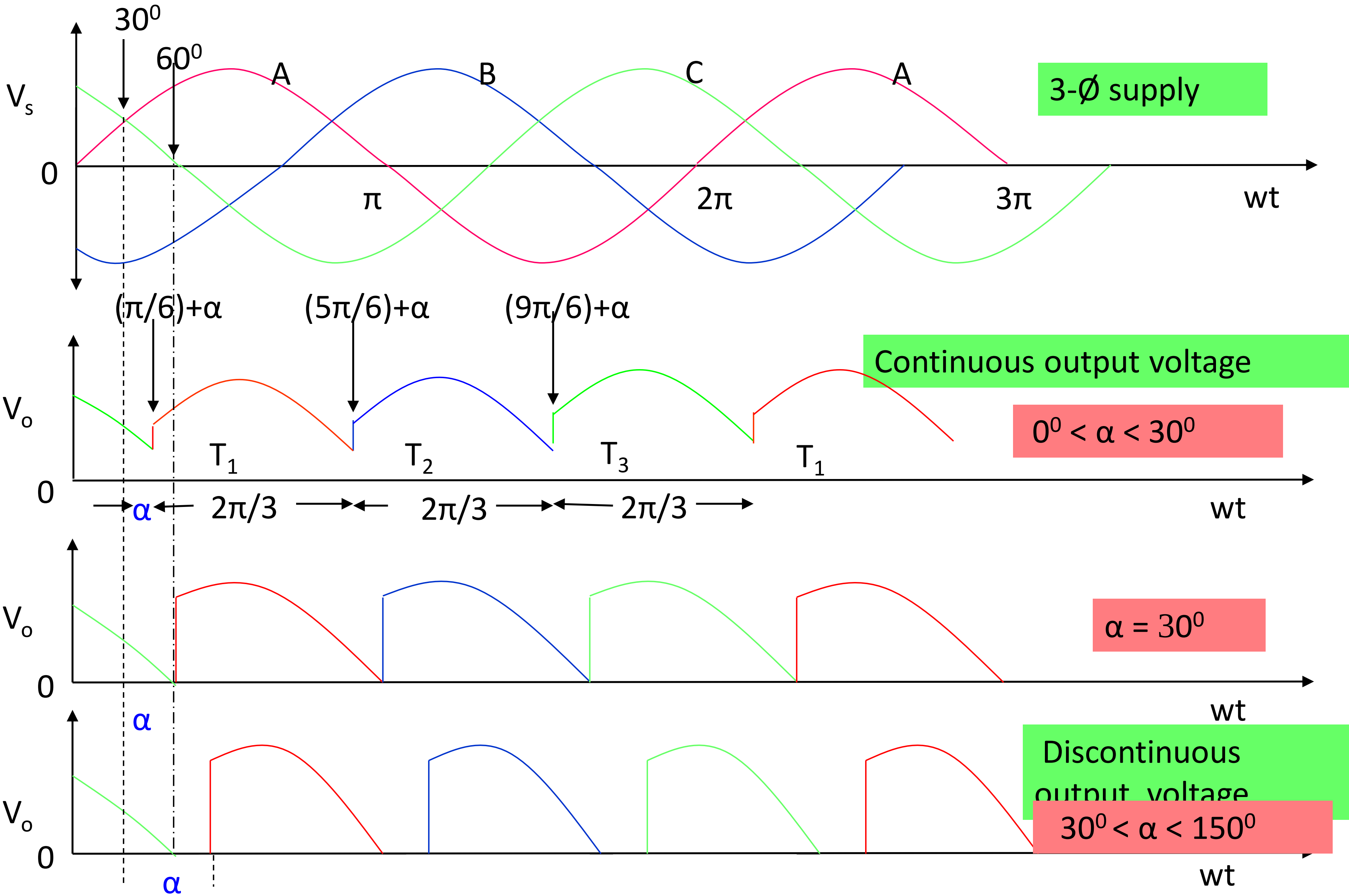


Fig.6 Shows the Input and output waveforms of 3-Ø HWCC with R-load

Average output voltage (V_0)

$$V_0 = \frac{\text{Area under the curve over considered cycle}}{\text{Time period for the same cycle}}$$

$V_0 = (1 / \text{periodic time}) \int v_a \, d(\omega t)$

Case (a) : If v_0 is continuous ($0^0 < \alpha < 30^0$)

$$V_0 = (1 / (2\Pi / 3))\int_{(\pi / 6) + \alpha}^{(5\Pi/6)+ \alpha} v_a \, d(\omega t)$$

$$V_0 = (3/2\Pi)\int_{(\pi / 6) + \alpha}^{(5\Pi/6)+ \alpha} v_{mp} \sin \omega t \, d(\omega t)$$

$$V_0 = (3v_{mp}/ 2\Pi)\,[-\cos \omega t]_{(\pi / 6) + \alpha}^{(5\Pi/6)+ \alpha}$$

$$V_0 = (3\sqrt{3}v_{mp} / 2\Pi) \cos \alpha$$

- where v_{mp} is the maximum value of phase voltage V_{ph}.

Case (b) : If v_0 is discontinuous $(30^0 < \alpha < 150^0)$
from the wave form

$$V_0 = (1 / (2\Pi / 3)) \int_{(\pi / 6) + \alpha}^{\Pi} v_a \, d(\omega t)$$

$$V_0 = (3/2\Pi) \int_{(\pi / 6) + \alpha}^{\Pi/6} v_{mp} \sin \omega t \, d(\omega t)$$

$$V_0 = (3v_{mp} / 2\Pi) [- \cos \omega t]_{(\pi / 6) + \alpha}^{\Pi}$$

$$V_0 = (3v_{mp} / 2\Pi) [1 + \cos (\pi / 6 + \alpha)]$$

3 - ø Half - Wave Controlled Converter with R–L load

Operation

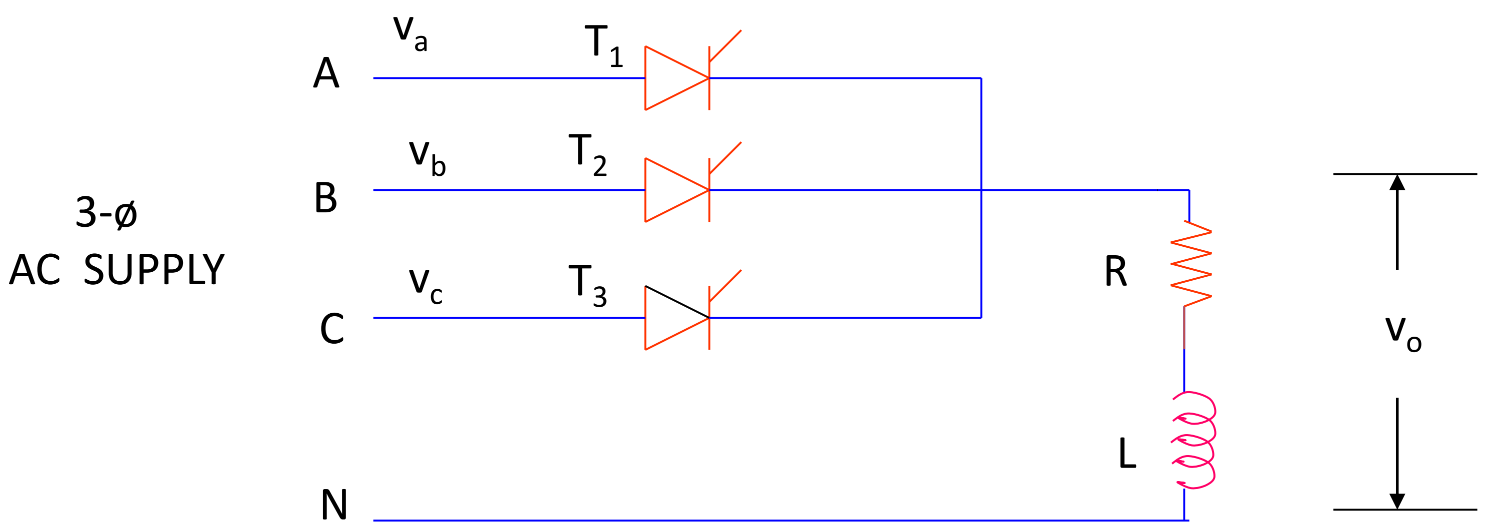


Fig.7 shows the connection diagram of 3-Ø HWCC

- Let us suppose firing pulses applied at angle α.
- The thyristors T_1, T_2 and T_3 will be triggered at $\omega t = (\pi / 6) + \alpha$, $(5\pi / 6) + \alpha$ and $(9\pi / 6) + \alpha$ respectively.

At $\omega t = (\pi / 6) + \alpha$

- T_1 acts as short circuit

  T_2, T_3 acts as open circuit

- As the load is inductive, the current rises slowly to its maximum value and falls slowly to zero value

- The output voltage follows input voltage v_a through a small portion of negative half cycle until T_1 will be turned-off

- The next incoming thyristor T2 will be fired at an angle $\omega t = (5\pi / 6) + \alpha$

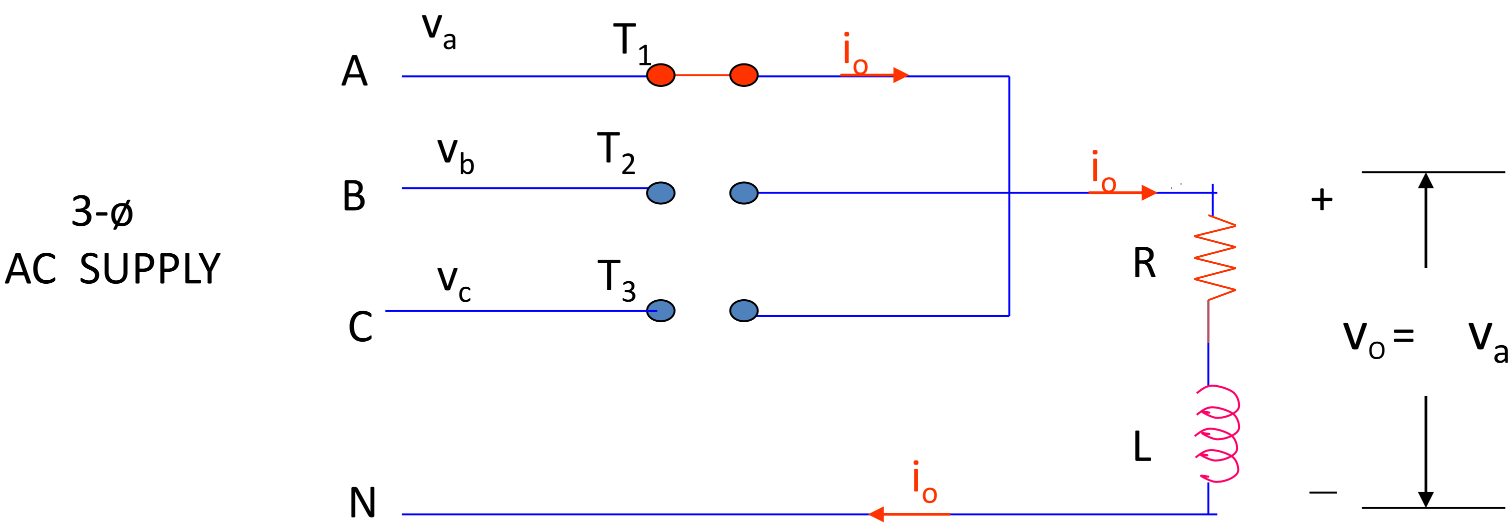


Fig.8 shows the conversion when T_1 will conduct

$$\omega t = (5\pi / 6) + \alpha$$

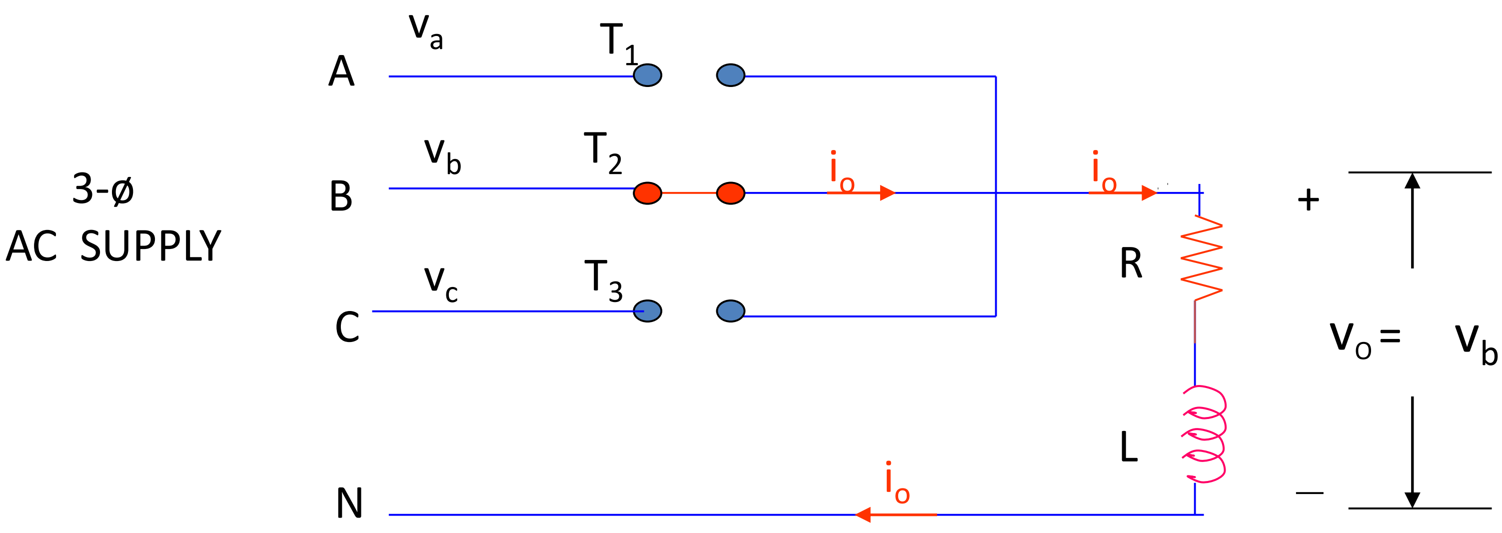


Fig.9 shows the conversion when T_2 will conduct

At $\omega t = (9\pi / 6) + \alpha$

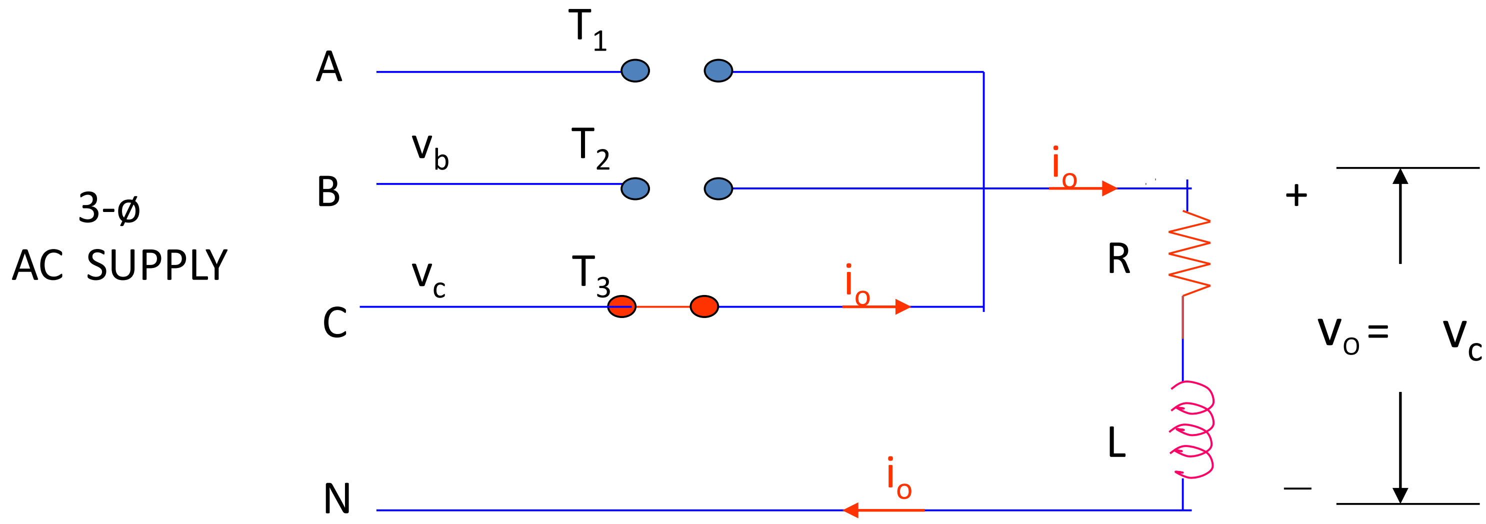


Fig.10 shows the conversion when T_3 will conduct

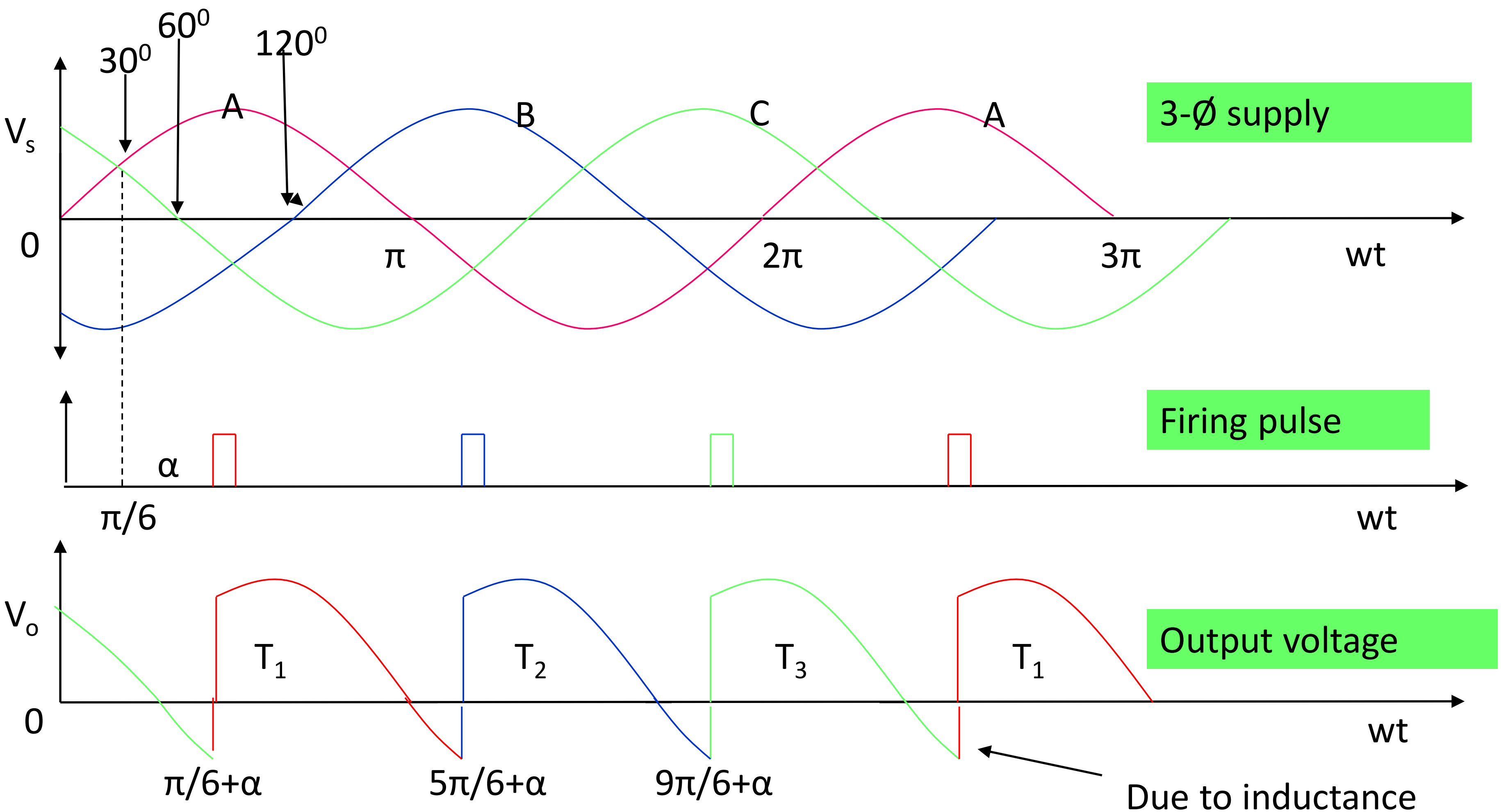


Fig.10 shows the input and output waveforms of 3-Ø HWCC with R-L load

Average output voltage (V_0)

V_0 = Area under the curve over considered cycle / Time period for the same cycle

$$V_0 = \frac{\text{Area under the curve over considered cycle}}{\text{Time period for the same cycle}}$$

V_0 = (1 / periodic time) $\int v_a \, d(\omega t)$

$$= (1/(2\Pi / 3)) \int_{(\pi / 6) + \alpha}^{(5\Pi/6)+ \alpha} v_{mp} \sin \omega t \, d(\omega t)$$

$$= (3\sqrt{3} v_{mp} / 2\Pi) \cos \alpha$$

Three Phase fully controlled converter with R-load

Circuit Diagram

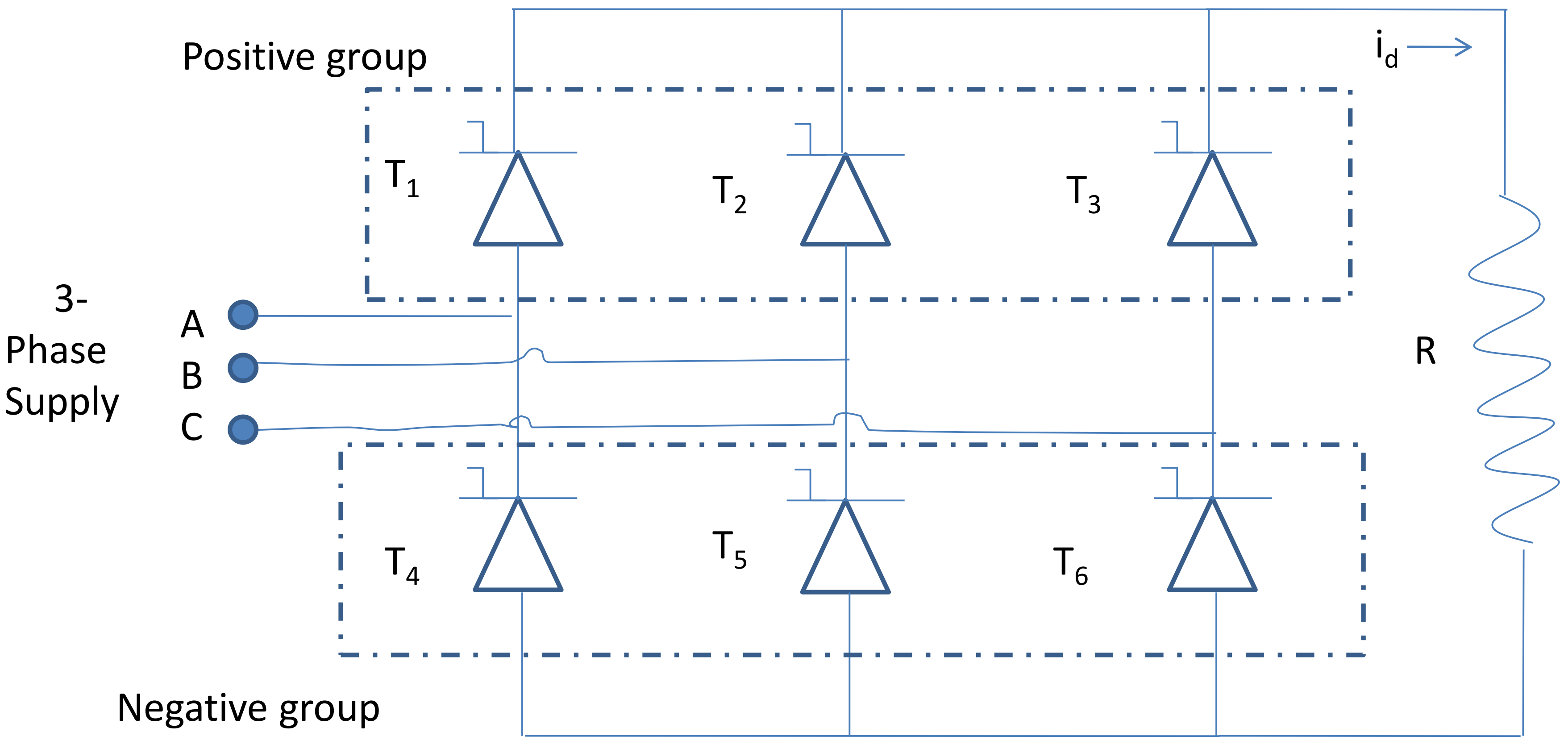
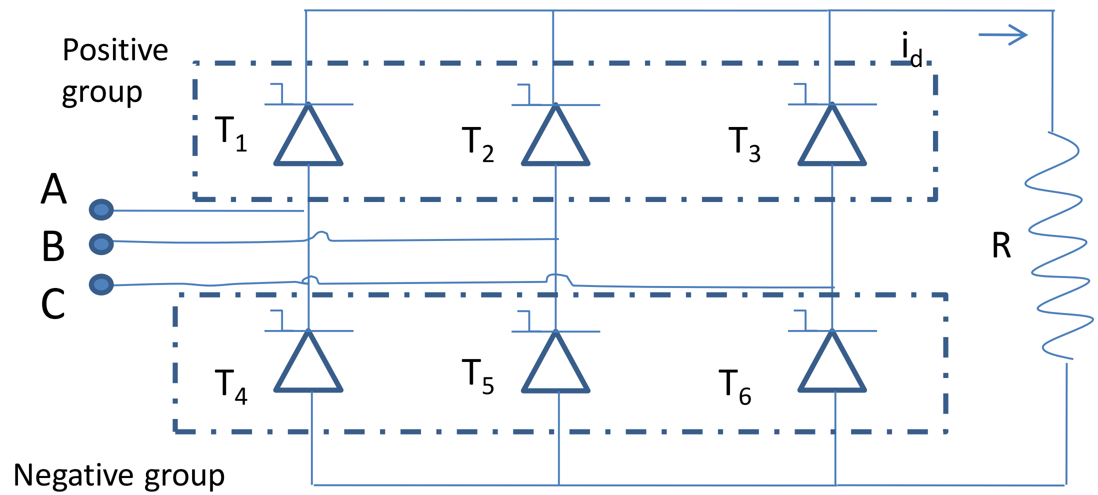


Fig. 1

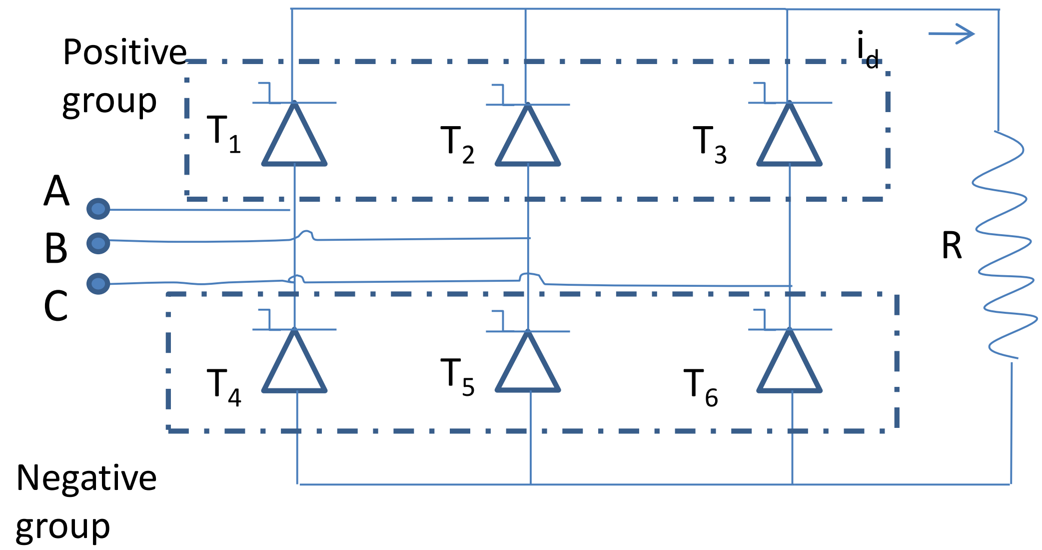


- Circuit consists of two groups of SCR

- Positive group – SCRs T1, T2, T3

- Negative group – SCRs T4, T5, T6

- The positive group SCRs are turned on when the supply voltages are positive



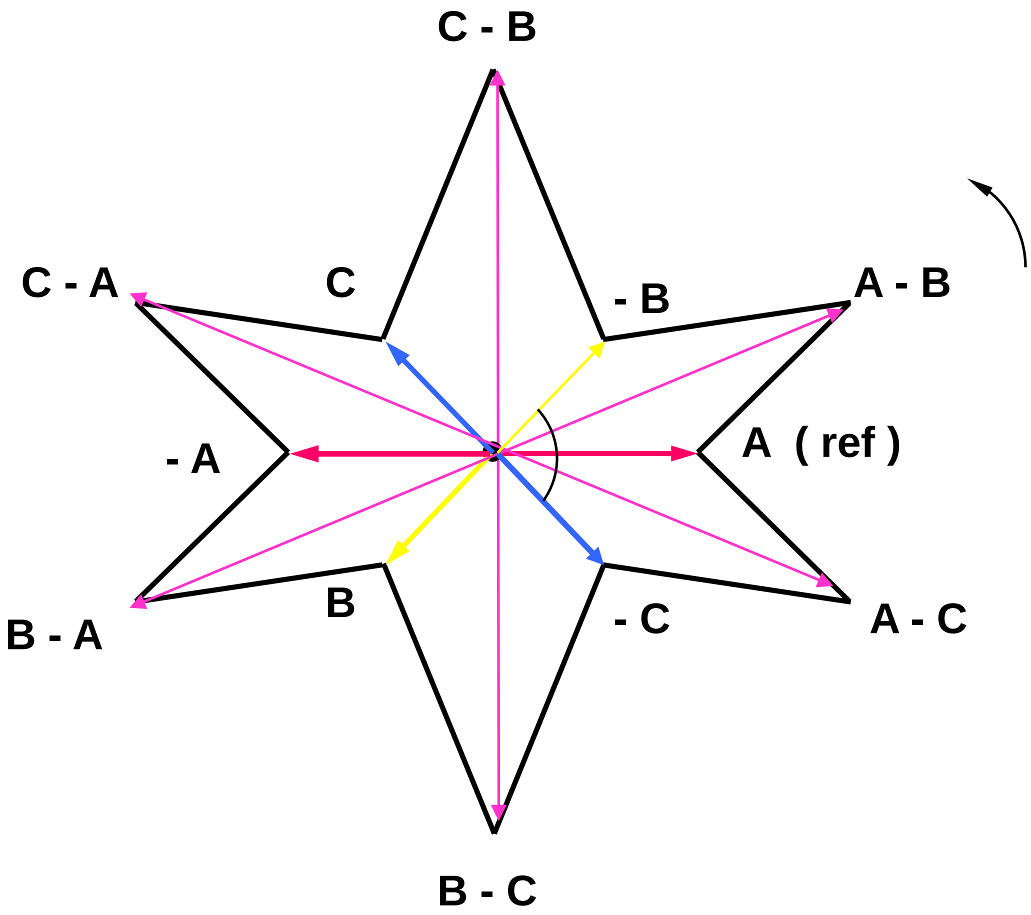
- Negative group SCRs are turned on when the supply voltages are negative

- Two SCRs must be fired simultaneously to commence current flow

- One SCR in the upper – arm

- Second in the lower arm (to provide return path)

Vector Diagram :



from the vector diagram

Assuming the phasor A as the reference phasor

If it is triggered, then the load current flows from phase A and returns through the Phase B or phase C.

Similarly if the thyristor of Phase – B is triggered then the load current flows from Phase B and returns through Phase C or Phase A.

From vector diagram

- When phase-A has highest value, it is triggered

- Thyristor T5 triggered simultaneously with T1

- When Phase-B has highest value T3 & T4 are triggered simultaneously

From vector diagram

- When Phase-C has highest valueT2 & T5 are triggered simultaneously.
- For six pulse operation, each thyristor is fired twice in its conduction cycles.
- firing Intervals should be 60 deg

The sequence of conduction as follows

- A-B: From T1 to load and returns through T5
- A-C: From T1 to load and returns through T6
- B-C: From T2 to load and returns through T6

The sequence of conduction as follows

- B-A: From T2 to load and returns through T4
- C-A: From T3 to load and returns through T4
- C-B: From T3 to load and returns through T5

Wave forms

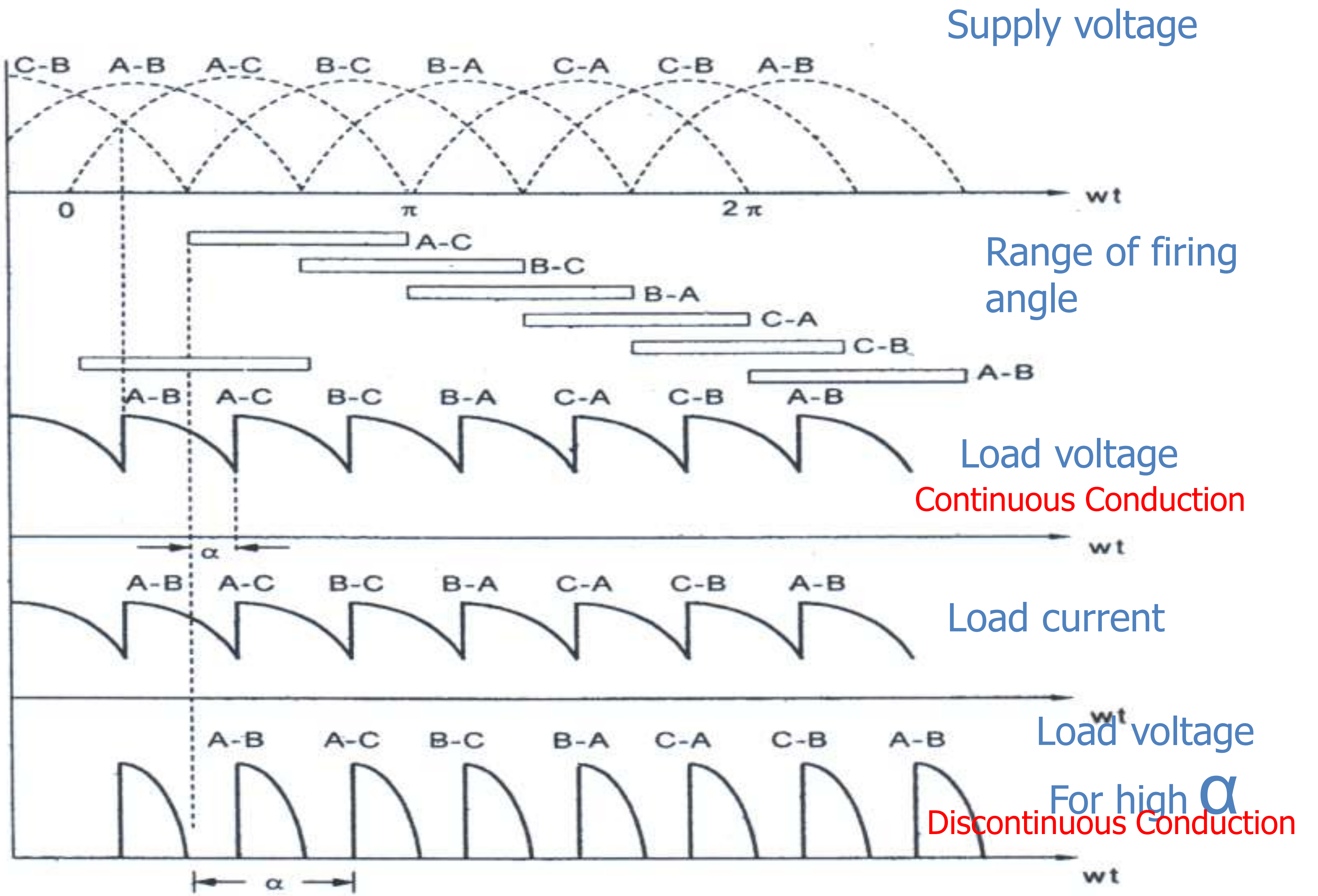


Fig. 3 Shows wave forms for output voltage and current of 3-phase FWCC with R-load

Continuous Conduction mode (0º ≤ ά ≤ 60º

- Wave forms of output load voltage and current is same
  - Average load voltage

$$v_o = \frac{6}{2\pi}\sqrt{2}E\int_{\alpha}^{\frac{\pi}{3}+\alpha} \sin(\omega t + \frac{\pi}{3})\, d(\omega t)$$

$$\boxed{v_o = \frac{3\sqrt{2}}{\pi} E \, Cos\alpha} \quad \text{for } 0 \leq \alpha \leq \frac{\pi}{3} \quad (or) \quad V_o = \frac{3\sqrt{3}}{\pi} V_m \cos\alpha$$

Where E- is the R.M.S value

- Average load current

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

$$\boxed{I_o = \frac{3\sqrt{2}}{\pi R} E \, Cos\alpha \;\; Amp \;\; (or)\; I_o = \frac{3\sqrt{3}}{\pi R} V_m \cos\alpha \;\; Amp}$$

UNIT-3

A.C. Regulator

"A.C. regulator is a thyristor device, which converters fixed A.C. voltage into variable A.C. voltage without change in the frequency".

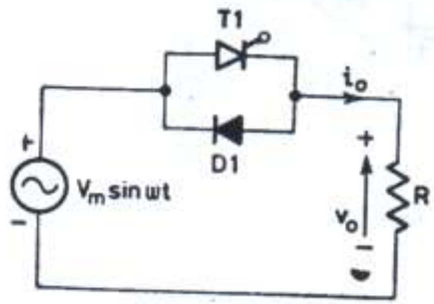
Applications

- Domestic and industrial heating.
- Transformer tap changing.
- Speed control 1-Ø and 3-Ø A.C drives.
- Lighting control.
- Starting of induction motor.

Types

- Single – phase A.C. Regulators
  - Half - wave
  - Full - wave
- Three – phase A.C. Regulators

1-Ø half - wave a.c. regulator



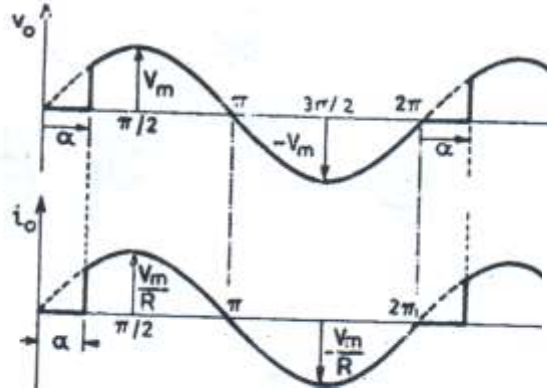


Fig.1 Circuit diagram

Fig.2 Out put waveforms

It is observed that

- One thyristor and diode connected in antiparallel
- positive cycle and negative cycle are not identical
- Output wave forms of voltage and current are same
- DC component is introduced in the supply and load

1-Ø full - wave a.c. regulator

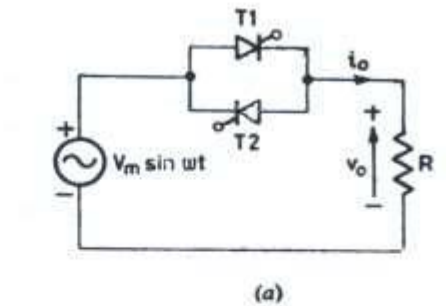


Fig.3 Circuit diagram

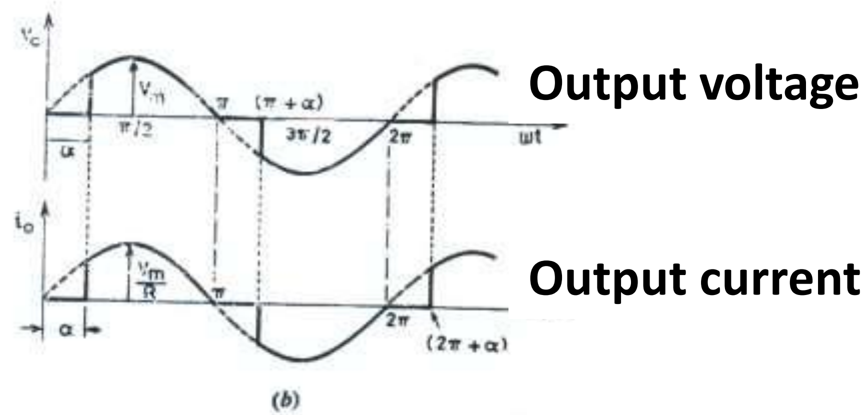


Fig.4 Out put waveforms

It is observed that

- Two thyristors connected in antiparallel
- positive cycle and negative cycle are identical
- Output wave forms of voltage and current are different
- DC component is not introduced in the supply and load
- More suitable for practical circuits

Operation of Single-phase full wave A.C. Regulator with resistive load

Single-phase full wave A.C. Regulator with resistive load

It consists of two thyristors connected in antiparellel.

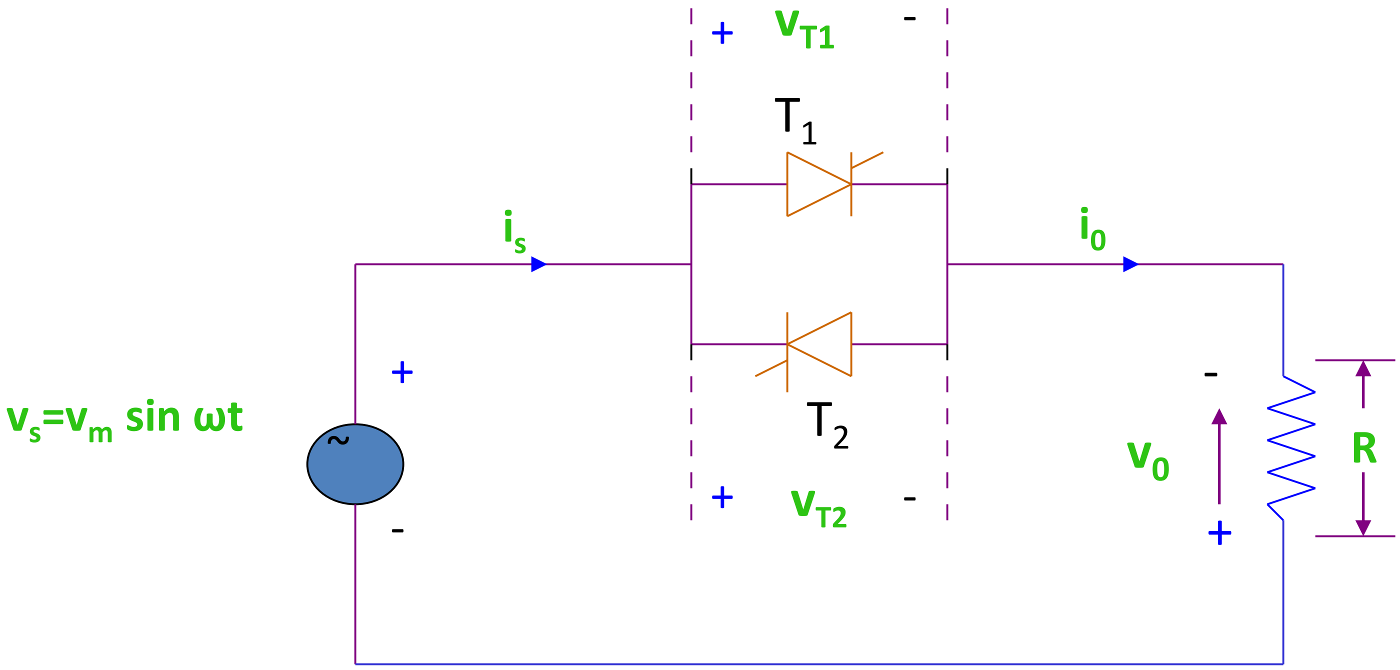


Fig.5 Single phase full wave A.C regulator with resistive load

Working principle

During positive half cycle:

- T_1 is triggered at a firing angle α
- T_1 starts conducting from α to Π
- Source voltage is applied to the load

  from α to Π
- At $\omega t=\Pi$, both v_0 and i_0 falls to zero

During the negative half cycle:

- T_2 is triggered at $\omega t = \Pi+\alpha$
- T_2 starts conducting from $\Pi + \alpha$ to 2Π
- After $\omega t=2\Pi$, T_2 is reverse bias (i.e., turned-off)

Wave forms

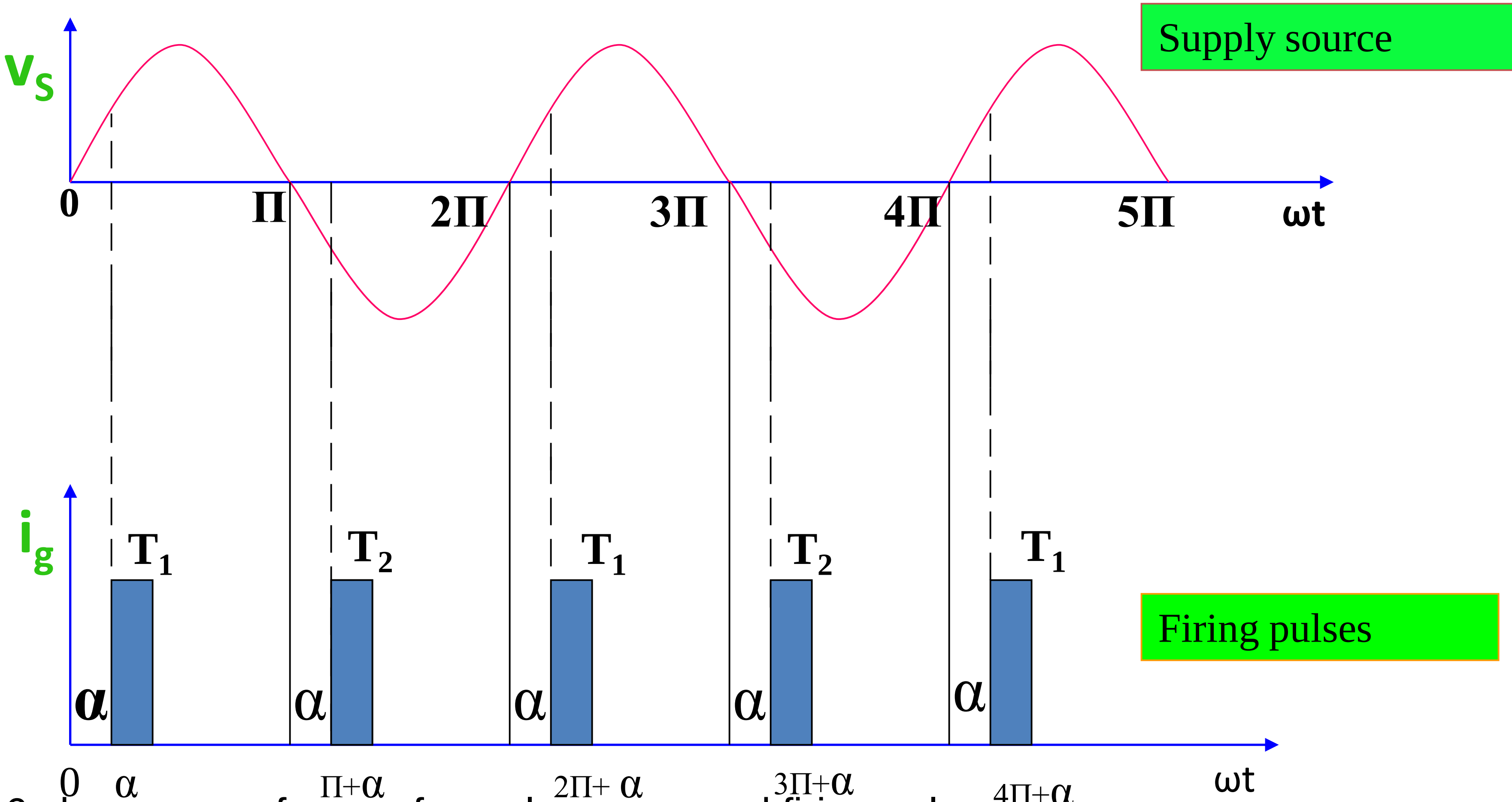


Fig.6 shows wave forms of supply source and firing pulses.

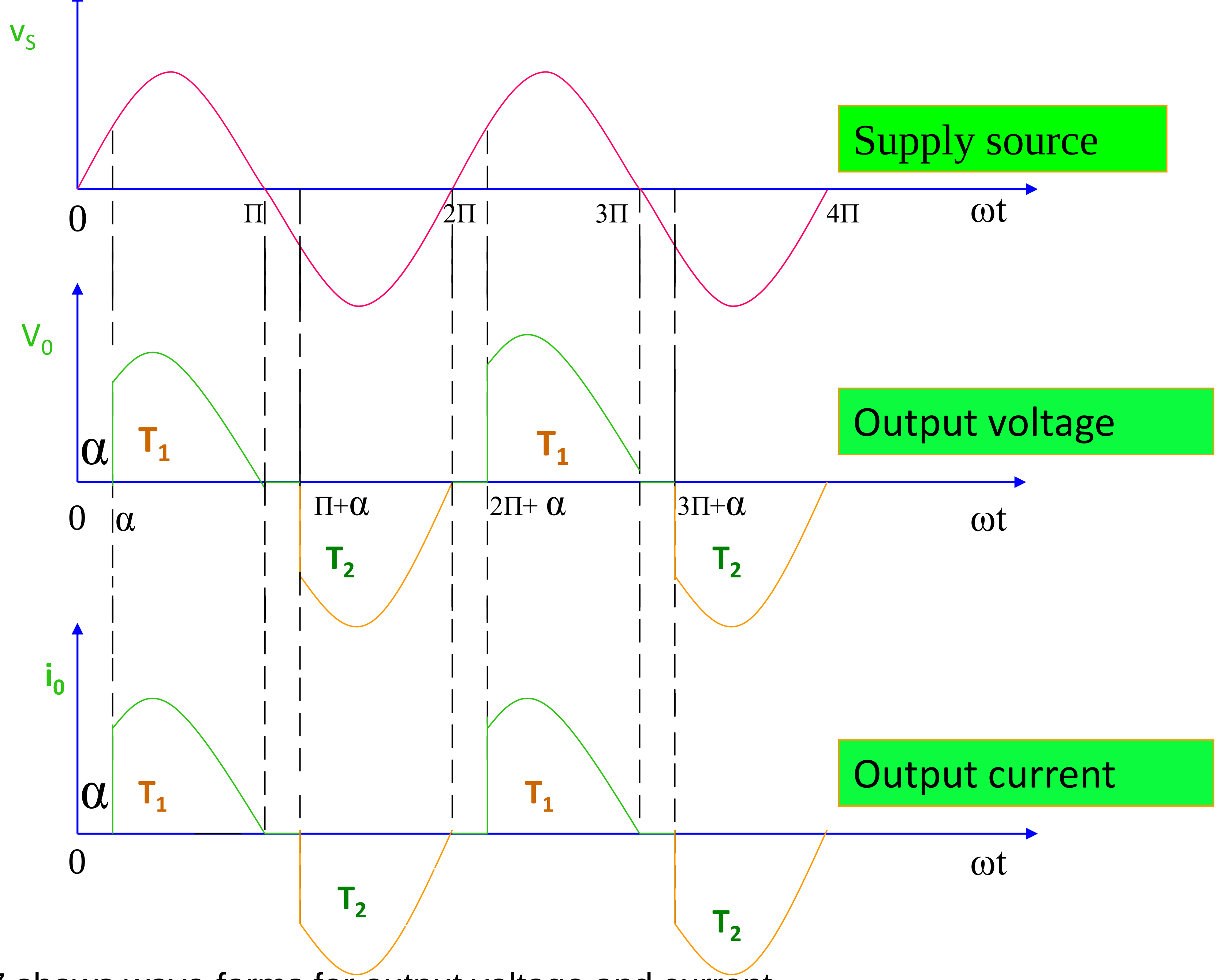


Fig.7 shows wave forms for output voltage and current

Features :

- The circuit turn-off time

$$t_c = \Pi/\omega \text{ sec}$$

- Average voltage

$$Vo= (Vm /\Pi)*(1+\cos \alpha) \text{ Volts}$$

- Average load current

$$Io = Vo/R$$

$$= (Vm/ \Pi R)*(1+\cos \alpha) \text{ Amp}$$

CYCLO CONVERTER

- A cyclo converter is a device which converts input power at one frequency to output power at a different frequency.

- That is it will converts the constant input frequency into output frequency.

Types of Cyclo Converters

(1). **<u>STEP-UP</u>**

In which the Output frequency is greater than supply frequency.

(2). **<u>STEP-DOWN</u>**

In which the Output frequency is less than supply frequency.

Classification of Cyclo Converts

Cyclo Converts:

(1). 1-phase Cyclo Converter

a) Transformer with centre tapped configuration.

b) Bridge configuration

(2). 3-phase Cyclo Converter

a) 3-pulse Cyclo Converter

b) 6-pulse Cyclo Converter

Application of Cyclo Converters

a) Special control of AC drivers
b) Induction heating
c) Static VAR generation
d) Traction

Principle of Operation

- It mainly consists two group of rectifiers
- One is positive group and other one is negative group
- The positive group allows all positive half waves and also converts the negative half wave into positive half wave.
- The circuit diagram is shown in fig (1)

Principle of Operation

- The negative group allows all negative half waves and also converts positive half waves into negative half waves.
- The output voltage can be varied by the firing angle of thyristors in both groups.
- The input & out put wave forms are shown in fig (2)

Block Diagram

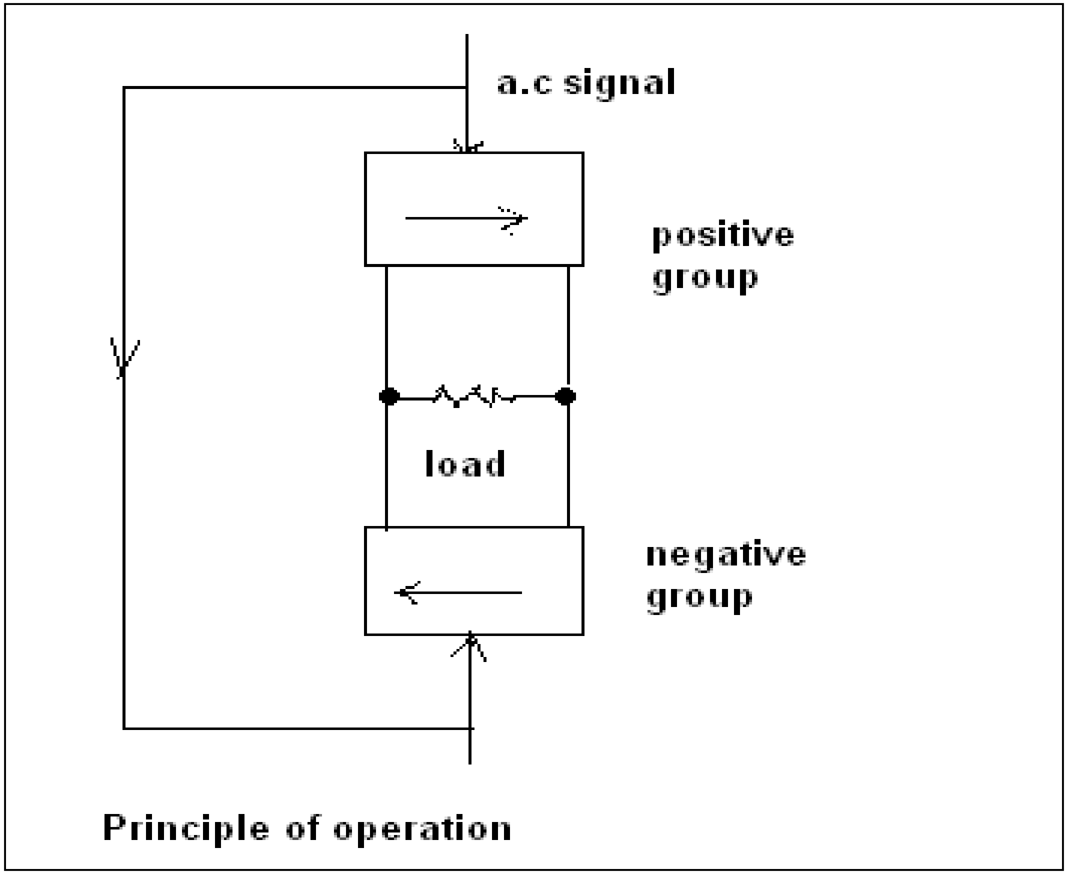
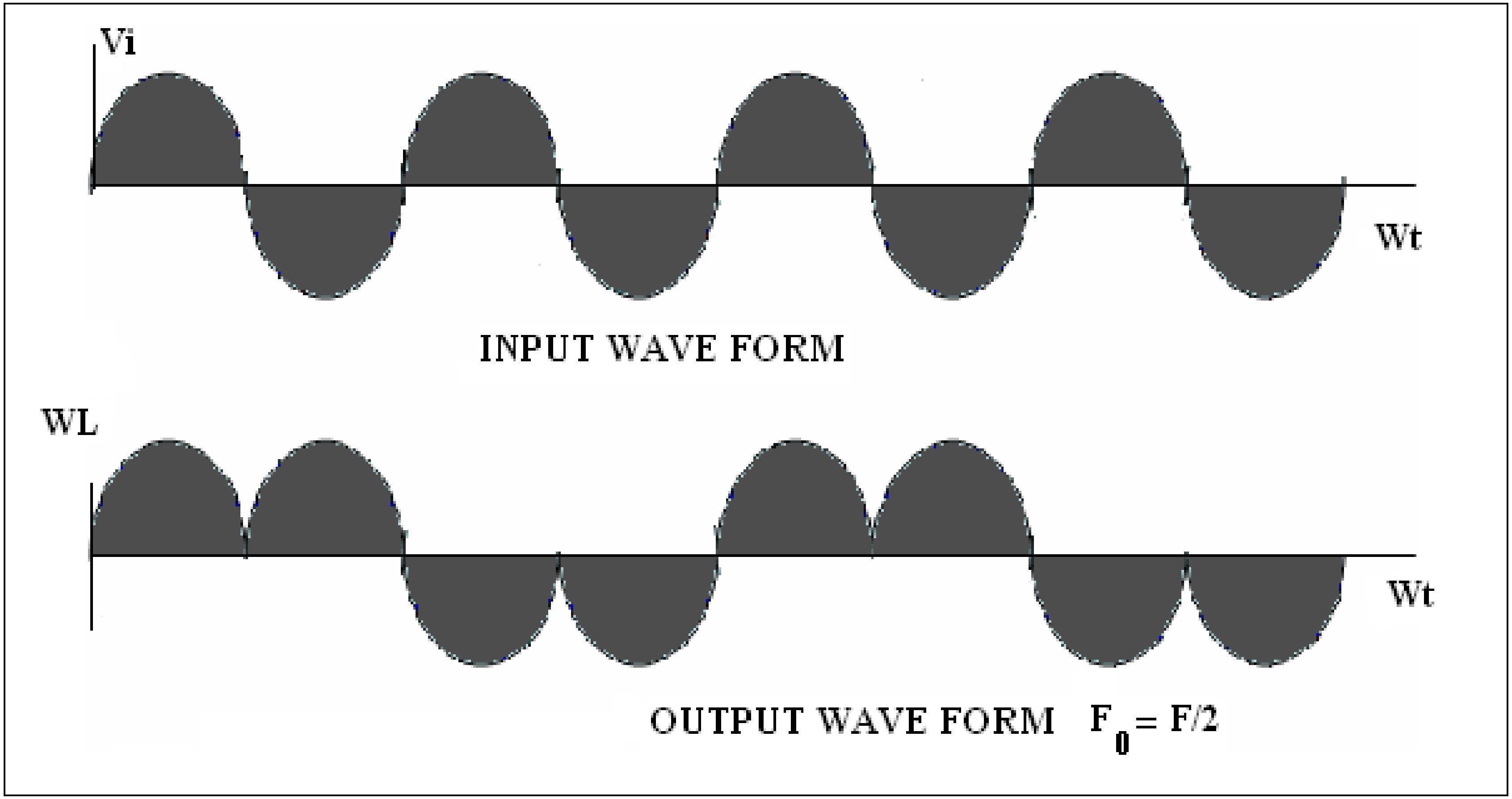


Fig 1

Step Down Cyclo Converter:



Wave forms Fig 2

Step Down Cyclo Converter:

- SCR based step-down cyclo converter does not require forced commutation where as step-up cyclo converter requires forced commutation.

- The main drawbacks of SCR cyclo converters are limited frequency of operation and poor power factor at low output voltages.

- Transistorised switches are preferred in step-up cyclo converter.

Single Phase Center Tapped Cyclo Converters

- The secondary winding of the transformer is provided with center tappings.

- It consists of four thyristors, two of these thyristors p_1,p_2 are formed as positive group and the other two n_1,n_2 are formed as negative group is shown in the fig (1).

- The load is connected between secondary winding mid point ‘0’ and terminal ‘a’.

Circuit Diagram Of Single Phase Center Tapped Cyclo Converters

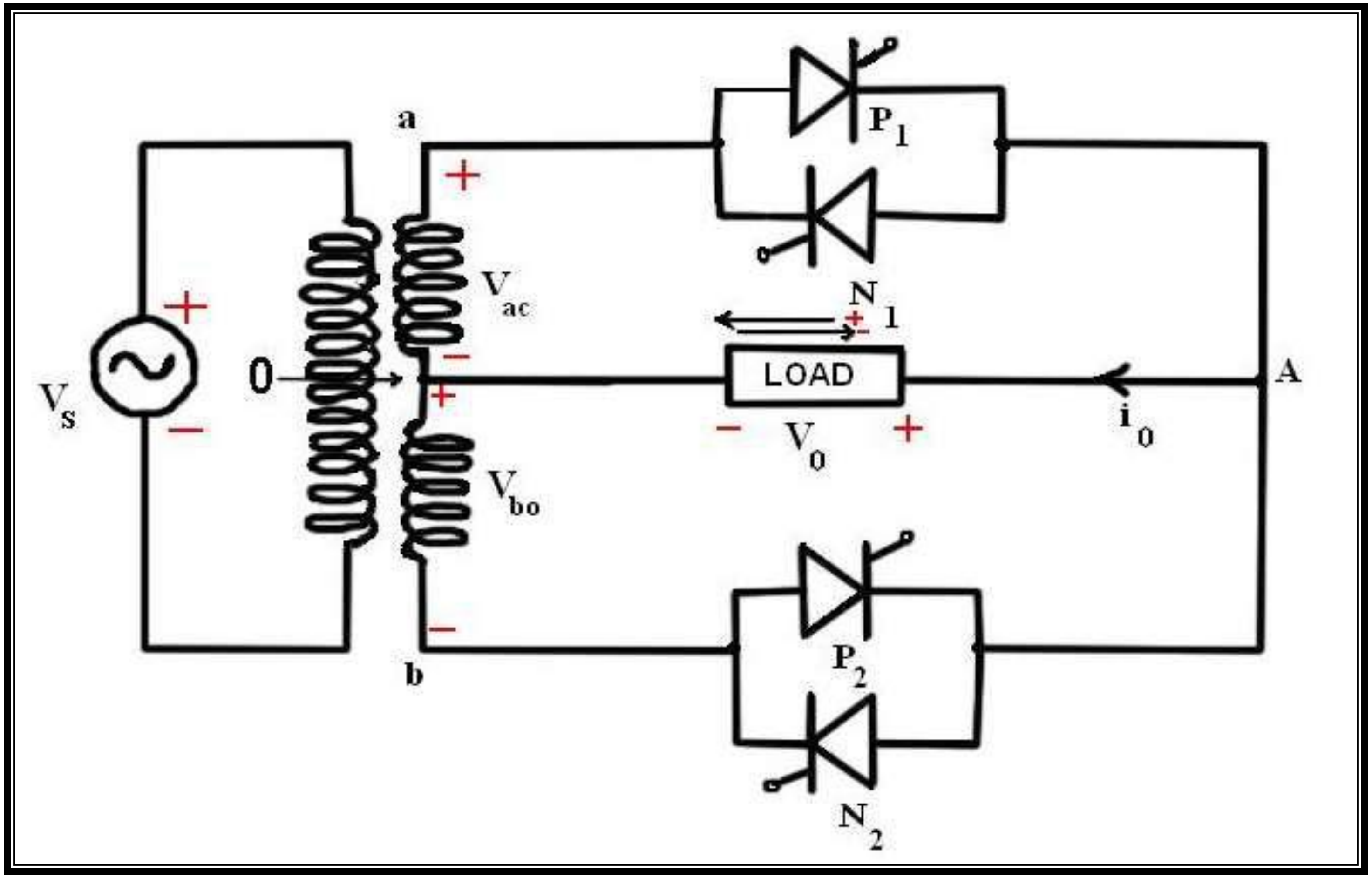


Fig 1

Waveforms Of Step-up Cyclo Converters

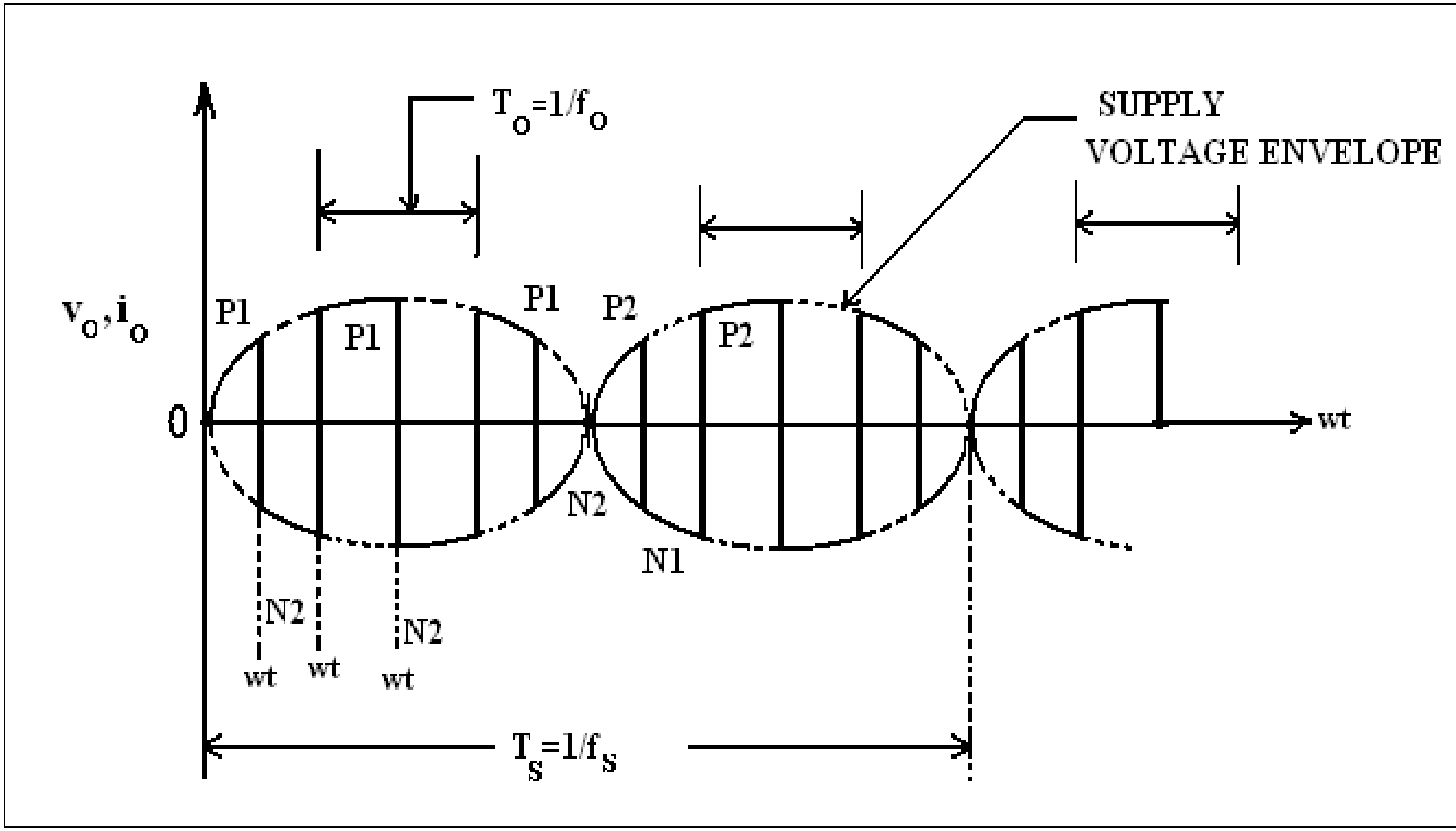


Fig 2

Operation Of Step-up Cyclo Converters

- During the negative half cycle of supply voltage , terminal ‘a’ is positive with respect to terminal ‘b’. The thyristor p_1& n_1 are forward bias from ‘wt=0’ to ‘wt=Π ’.If the thyristor ‘p_1 is turned on at ‘wt=0^0’so that the voltage is positive with terminal ‘0’.The load voltage now follows the positive envelope of the supply voltage.

Operation Of Step-up Cyclo Converters

- At instant wt_1, p_1 is forced commutated and the other forward biased thyristor n_2 is turned on so that load voltage is negative terminal ‘0’ positive & ‘a’ negative. Hence the output voltage waveform now traces the negative envelope of the supply voltage.

- At instant wt_2,thyristor n_2 is forced   commutated and p1 is turned on, causes the load voltage is now traces the positive envelope.

Operation Of Step-up Cyclo Converters

- After ‘wt=p ’ terminal ‘b’ is positive with respect to terminal al both thyristors p_2 & n_1 are forward biased from ‘wt=p to 2p ’.

- At wt=p, the thyristor n_2 is forced commutated and forward biased thyristor n_1 is turned on.

Operation Of Step-up Cyclo Converters

- At $wt=1|2f_s+1|2f_0$, p_2 is forced commutated and forward biased thyristor n_1 is turned on.

- The above thyristor p_1,n_2 are switched on alternatively during negative half cycle .

- The output frequency (f_0) is higher than supply frequency (f_s) .

$$\boxed{f_0=6\,f_s}$$

UNIT-4
What is a Chopper

- A Chopper is a static switch used to convert fixed input DC voltage into Variable output DC voltage.

TYPES OF CHOPPERS

- 1. Types of Choppers according to process of conversion:

  They are two types:

  i) AC Linked Chopper

  ii) DC Chopper

TYPES OF CHOPPERS

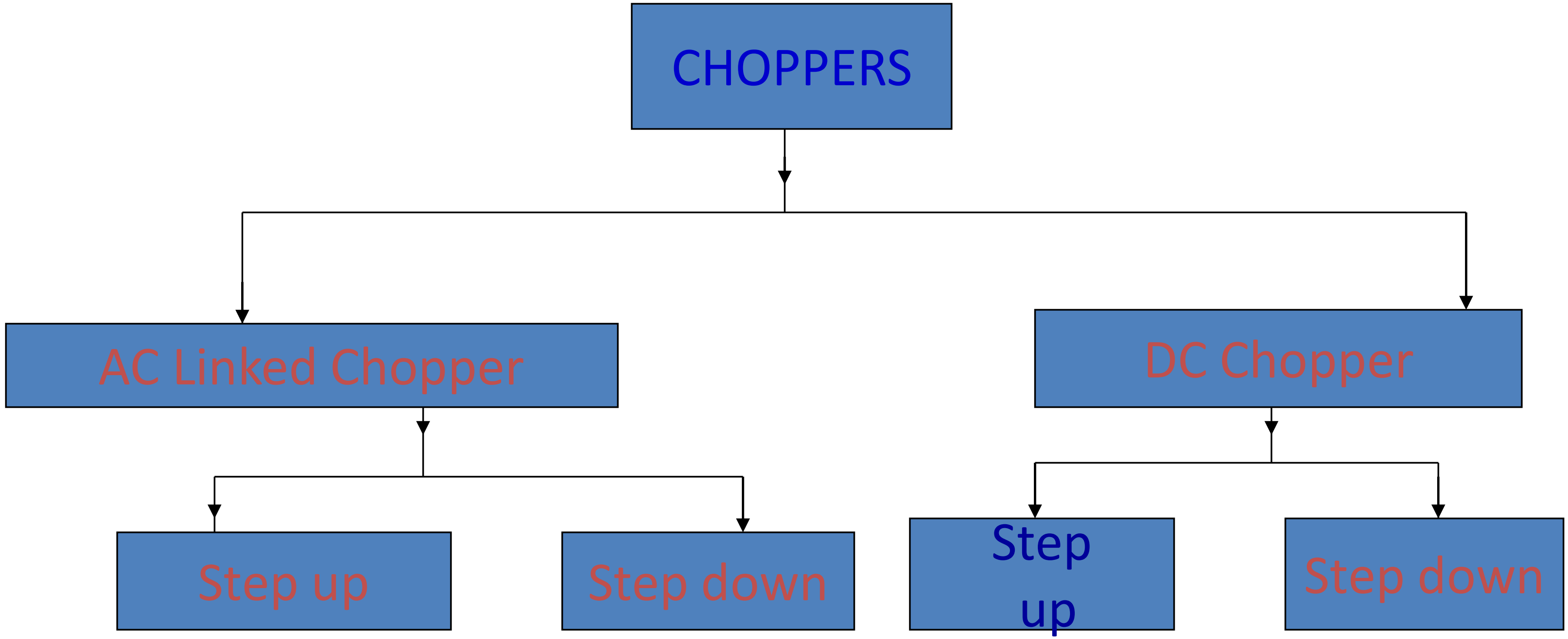
- 2. Types of Choppers according to magnitude of output voltage:

They are two types:

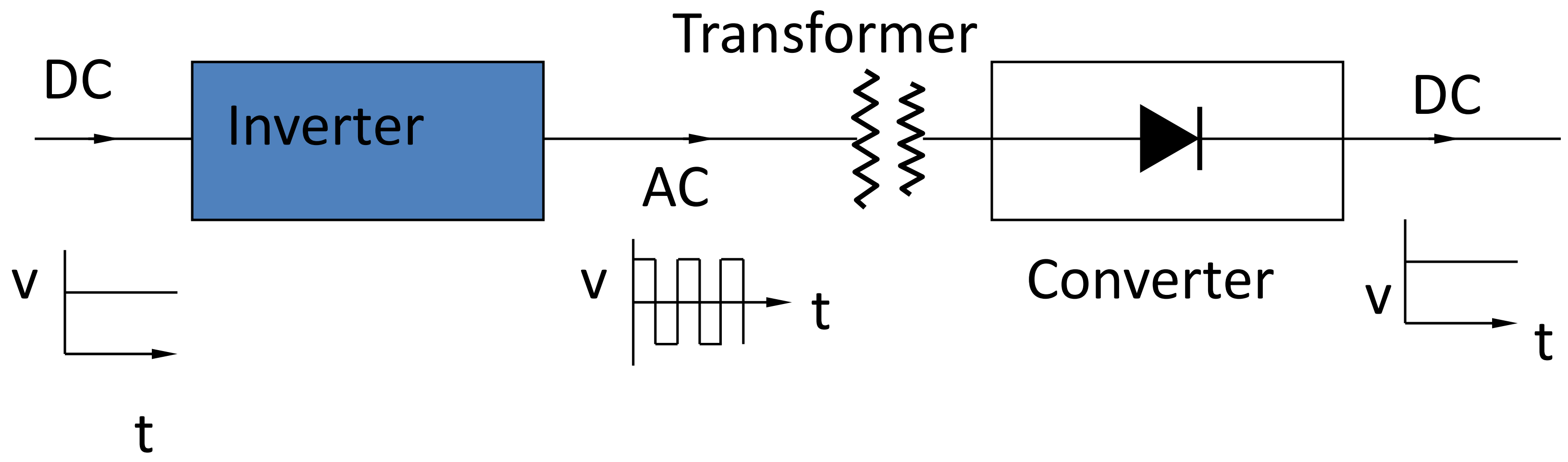
i) Step up Chopper

ii) Step down Chopper

TYPES OF CHOPPERS IN FLOW CHART FORM



A.C. LINKED CHOPPER



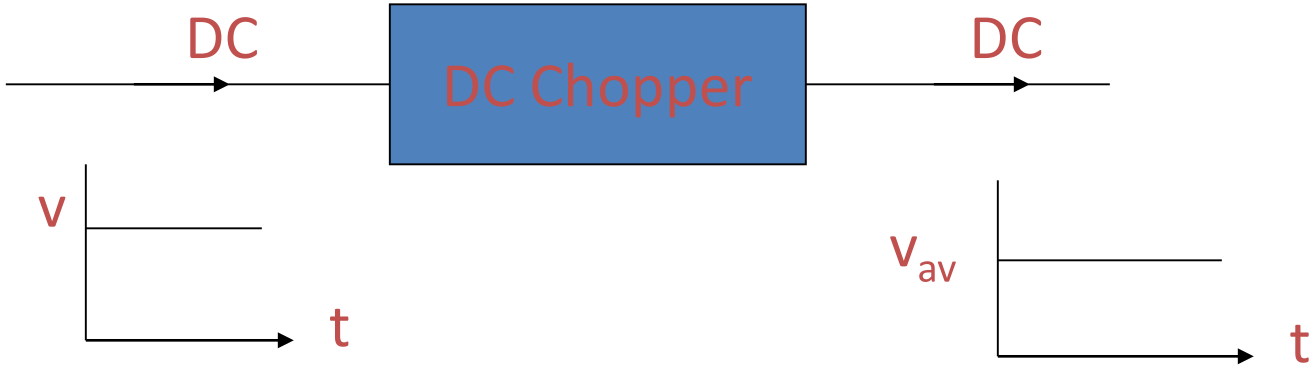
A.C. LINKED CHOPPER

- In A.C. Linked Chopper the fixed D.C. is first converted to A.C. by an inverter
- The converted A.C. is then step up OR step down using transformer
- Again this A.C. voltage inverted to D.C. voltage using a Rectifier

DIS-ADVANGES OF AC LINKED CHOPPER

- The AC linked chopper requires two stages of conversion.
- They are bulky in size.
- They are Costly.
- They are less efficient.

DC CHOPPER



WHAT IS DC A CHOPPER.

- This chopper is a static device which converts fixed DC voltage to a variable DC output voltage.

APPLICATIONS OF CHOPPERS

Choppers find many applications, namely :

- Trolley cars
- Marine hoists
- Speed control of motors

Contd.,

APPLICATIONS OF CHOPPERS

- Traction motor control
- Battery operated vehicles
- Forklift lights

ELEMENTARY CHOPPER CIRCUIT

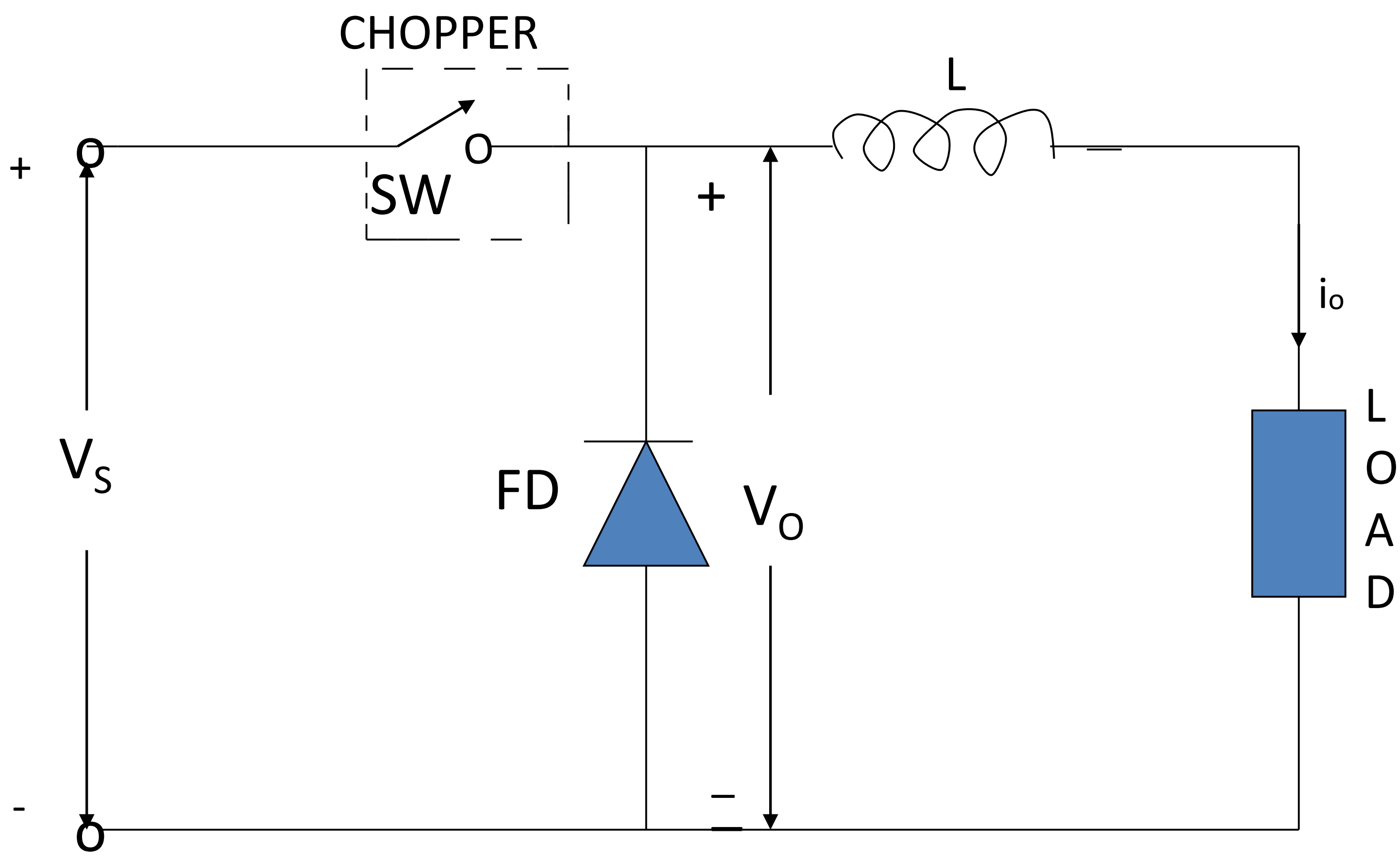


Fig. 1

- Fig. a   shows the basic Chopper circuit
- Chopper is also a high speed ON/OFF switch
- Chopper is a Semiconductor switch.

- It connects source to load and disconnects the load from source at a fast speed.
- A Chopped (variable) voltage is obtained from a constant DC input supply.
- For low and medium power ratings, transistors are used as a switch.
- while for high power applications Thyristors are used.

OUTPUT VOLTAGE & CURRENT WAVE FORMS

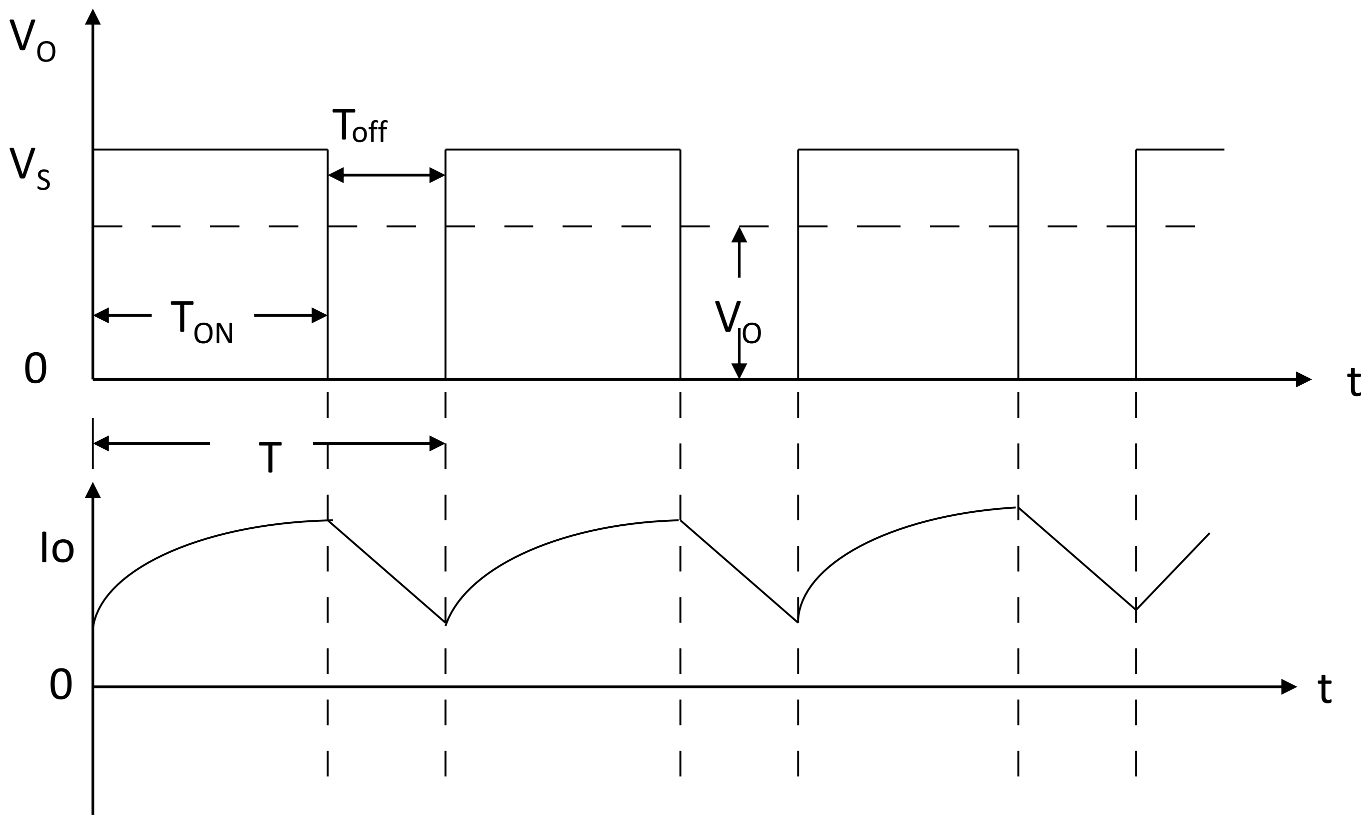


Fig. 2

- The Chopper is represented by a switch
- It may be turned ON or OFF as desired.
- During the period T_{on}, the Chopper is ON and load voltage is equal to source voltage.
- During the period T_{off}, the Chopper is OFF and the load current flows through the free wheeling diode FD.

- Therefore, load terminals are short circuited by FD and load voltage becomes zero.
- Hence a chopped voltage is produced at the load terminals.
- The output voltage and currents are shown in fig.b.

$$\text{Average load voltage } V_o = \frac{T_{on}}{T_{on}+T_{off}} \times V_s$$

$$V_o = \frac{T_{on}}{T} \times V_s$$

$$= \alpha \times V_s$$

FORMULAS

- Where, $T = T_{on} + T_{off}$ = Chopping period
- $\alpha = \dfrac{T_{on}}{T}$ = Duty cycle
- T_{on} = ON-Time
- T_{off} = OFF-Time

FORMULAS

- Therefore $V_o = f.T_{on}.V_s$
- Where f = 1/ T = Chopping frequency
- Conclusion: The load voltage V_o can be changed by varying the duty cycle α or by varying the chopping frequency f.

OBJECTIVES

On completion of this period the student would be able to know:

Control methods of Chopper:

- Variable frequency Control method.
- Constant frequency Control method.

CONTROL METHODS OF CHOPPER

Control methods of Chopper

Variable frequency Control method

Constant frequency Control method

VARIABLE FREQUENCY CONTROL METHOD

- The chopping frequency f can be varied:
- By varying T_{ON}, keeping T_{OFF} constant
- By varying T_{OFF}, keeping T_{ON} constant.
- The duty cycle α changed when T changed.
- Hence the average output voltage and current changed.

BY VARYING T_{ON}, KEEPING T_{OFF} CONSTANT METHOD

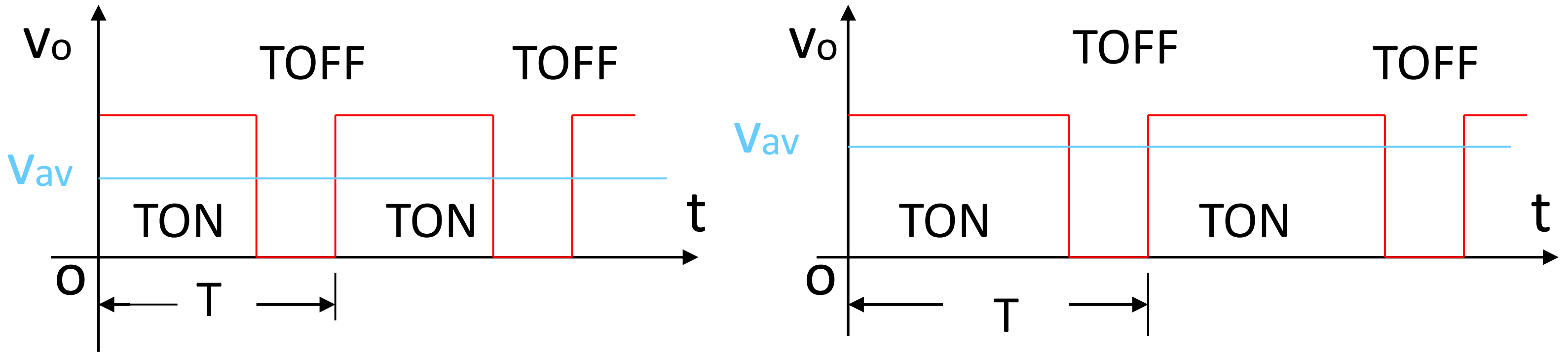


Fig.2a   Fig.2b

Fig.2: Shows varying TON , TOFF constant method graphs.

- Fig.2a: shows output voltage for duty cycle
  $\alpha = 0.6$ [i.e., $T_{ON} = 0.6T$]

- Fig.2b: shows output voltage for duty cycle
  $\alpha = 0.7$ [i.e., $T_{ON} = 0.7T$]

BY VARING T_{OFF}, KEEPING T_{ON} CONSTANT METHOD

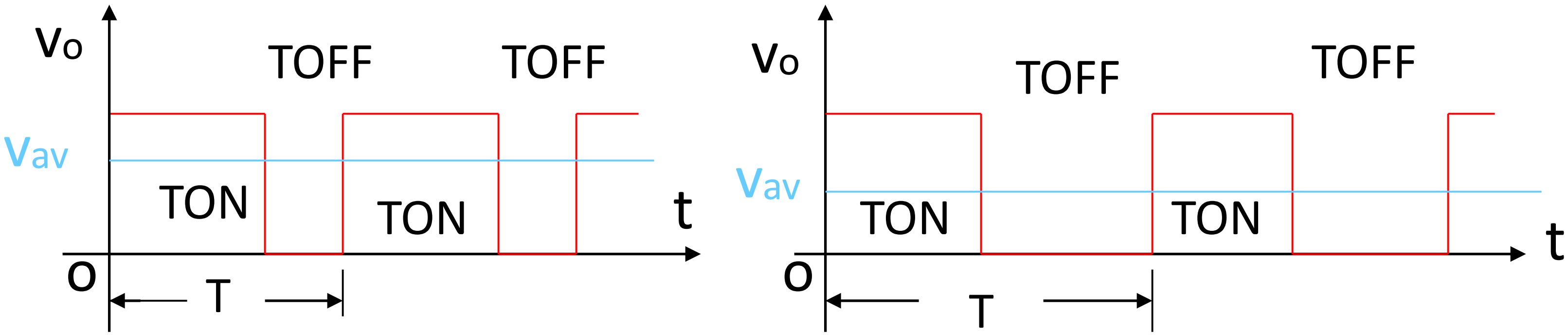


Fig.3a

Fig. 3b

Shows varying TOFF, constant TON method graphs

- Fig.3a: shows output voltage for duty cycle
  $\alpha = 0.6$ [i.e., $T_{ON} = 0.6T$]

- Fig.3b: shows output voltage for duty cycle
  $\alpha = 0.45$ [i.e., $T_{ON} = 0.45T$]

CONSTANT FREQUENCY CONTROL METHOD

- The chopping frequency f can be constant:

- By varying turn on time T_{ON}.
- The duty cycle α is changed when T_{ON} is changed.
- Hence the average output voltage and current are changed.

CONSTANT FREQUENCY CONTROL METHOD

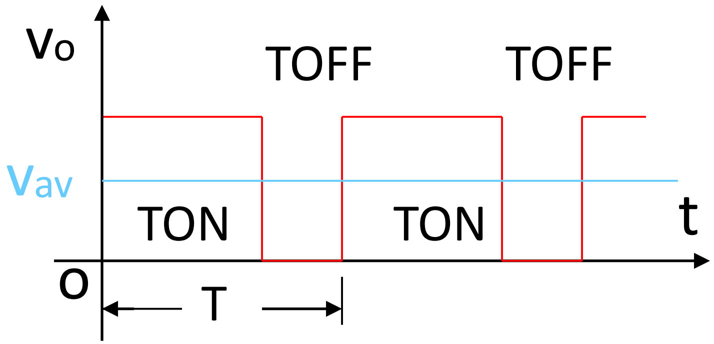


Fig.4a

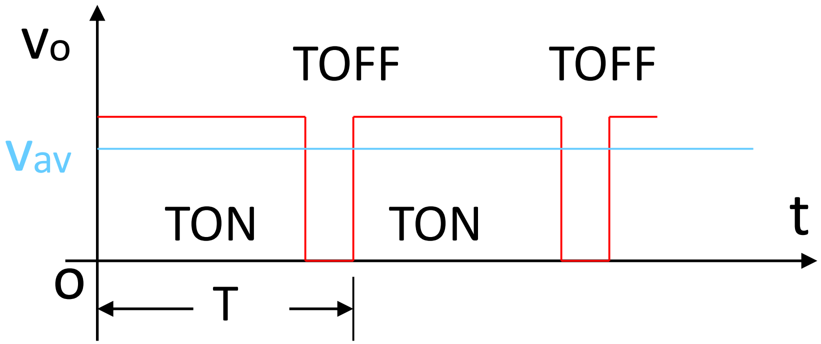


Fig.4b

Fig.3: Shows varying TON, T constant method graphs

- Fig. 4a: shows output voltage for duty cycle

  $\alpha = 0.6$ [i.e., TON = 0.6T]

- Fig. 4b: shows output voltage for duty cycle

  $\alpha = 0.8$ [i.e., TON = 0.8T]

Objectives

- On completion of this period, you would be able to know:
- Classification of Choppers.
- Operation of Chopper in all four quadrants.

Classification of choppers

- Choppers are mainly classified into <u>five</u> types depending on the direction of output (load) voltage v_o and current i_o.
- **They are,**

- Class-A Chopper
- Class-B Chopper
- Class-C Chopper
- Class-D Chopper
- Class-E Chopper

Class-A chopper

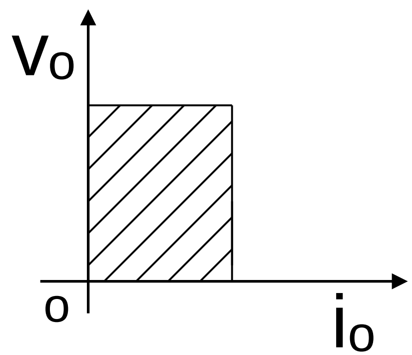


Fig1: class-A chopper

The output voltage is positive and current also flows in positive direction. Hence it is also called FIRST quadrant (or Class-A) chopper

Class-B chopper

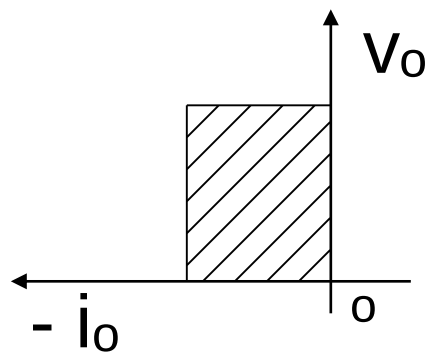


Fig2: class-B chopper

The output voltage is positive and current flows in negative direction. Hence it is also called SECOND quadrant (or Class-B) chopper

Class-C chopper

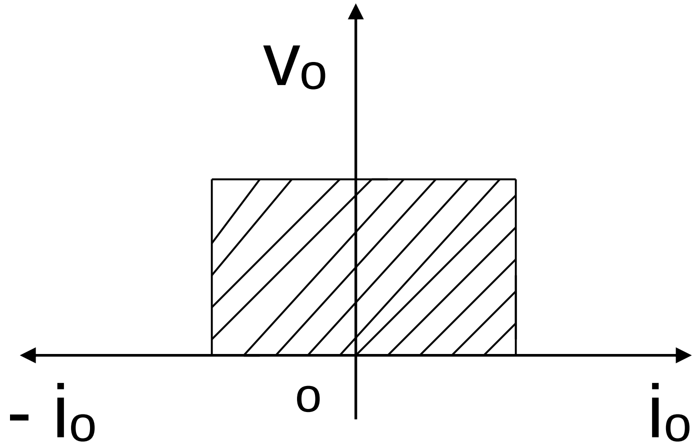


Fig3: class-C chopper

The output Voltage is positive, where as current flows in both positive and negative directions. Hence this type of chopper operates in First and Second quadrants and called Class-C chopper.

Class-D chopper

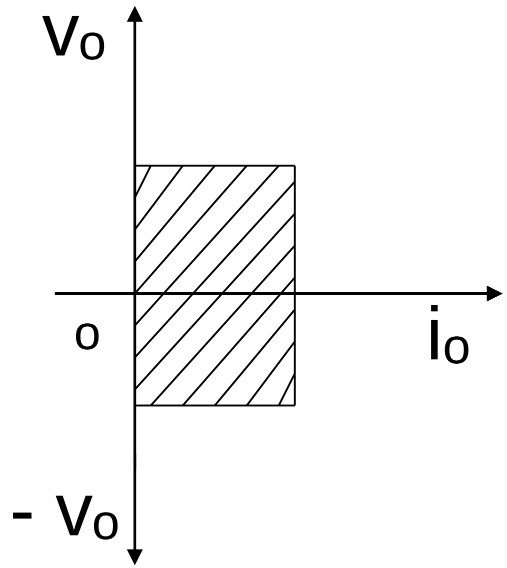


Fig4: class-D chopper

The output Voltage is operated in both positive and negative directions but the current flows in positive direction. Hence it is operated in first and fourth quadrants.

Class-E chopper

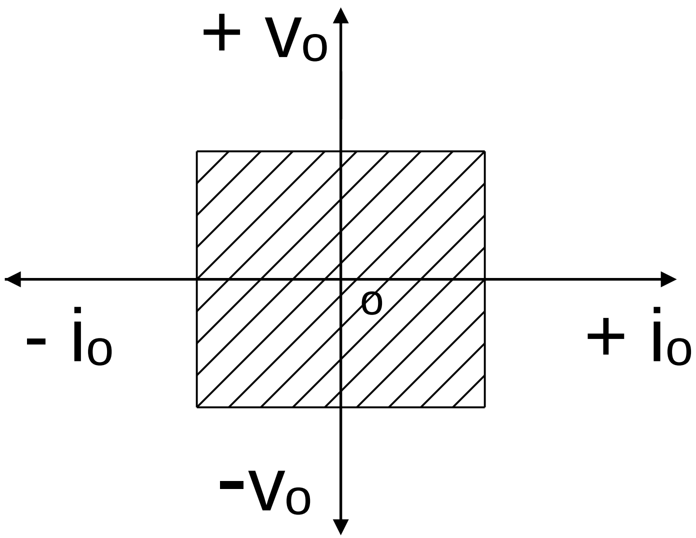


Fig5: class-E chopper

- Load voltage and currents flows in both positive and negative directions. Hence it is operated in all four quadrants and called class–E chopper.

OPERATION OF CHOPPER IN ALL FOUR QUADRANTS

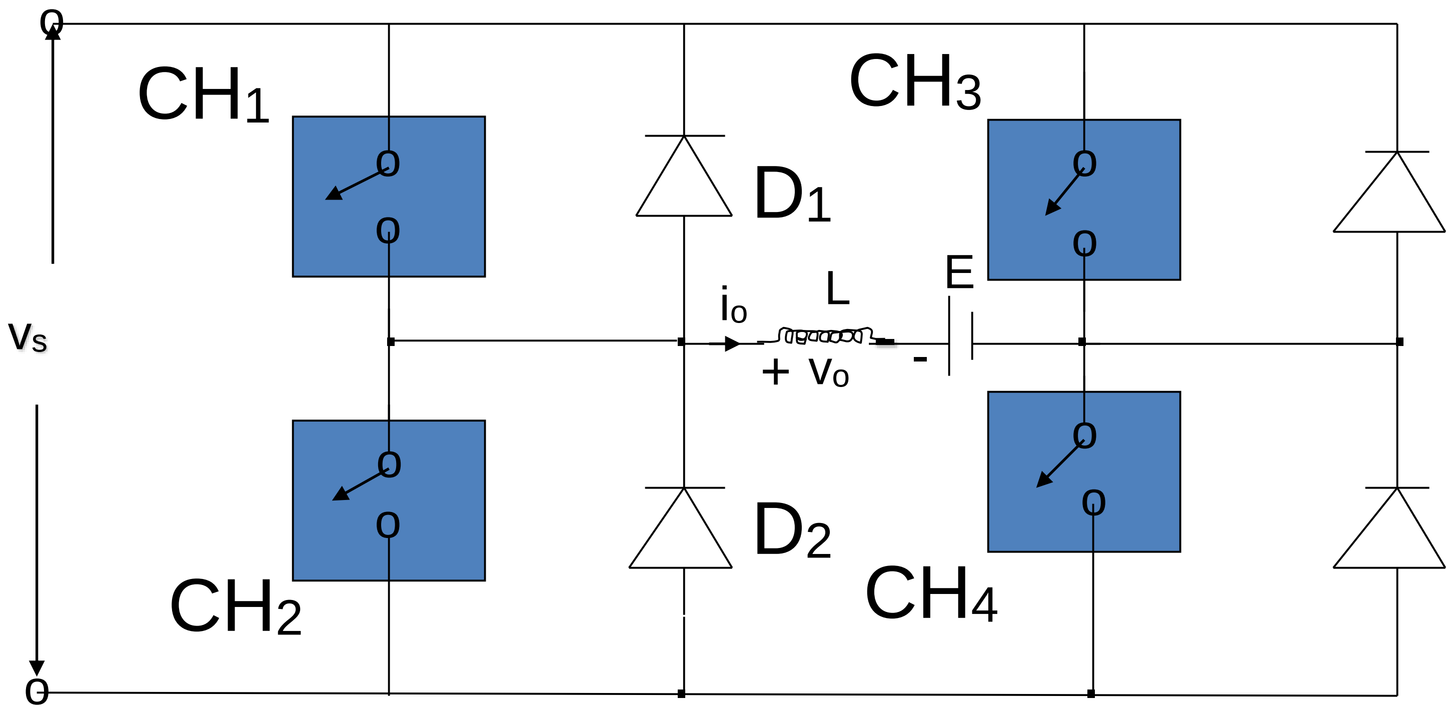


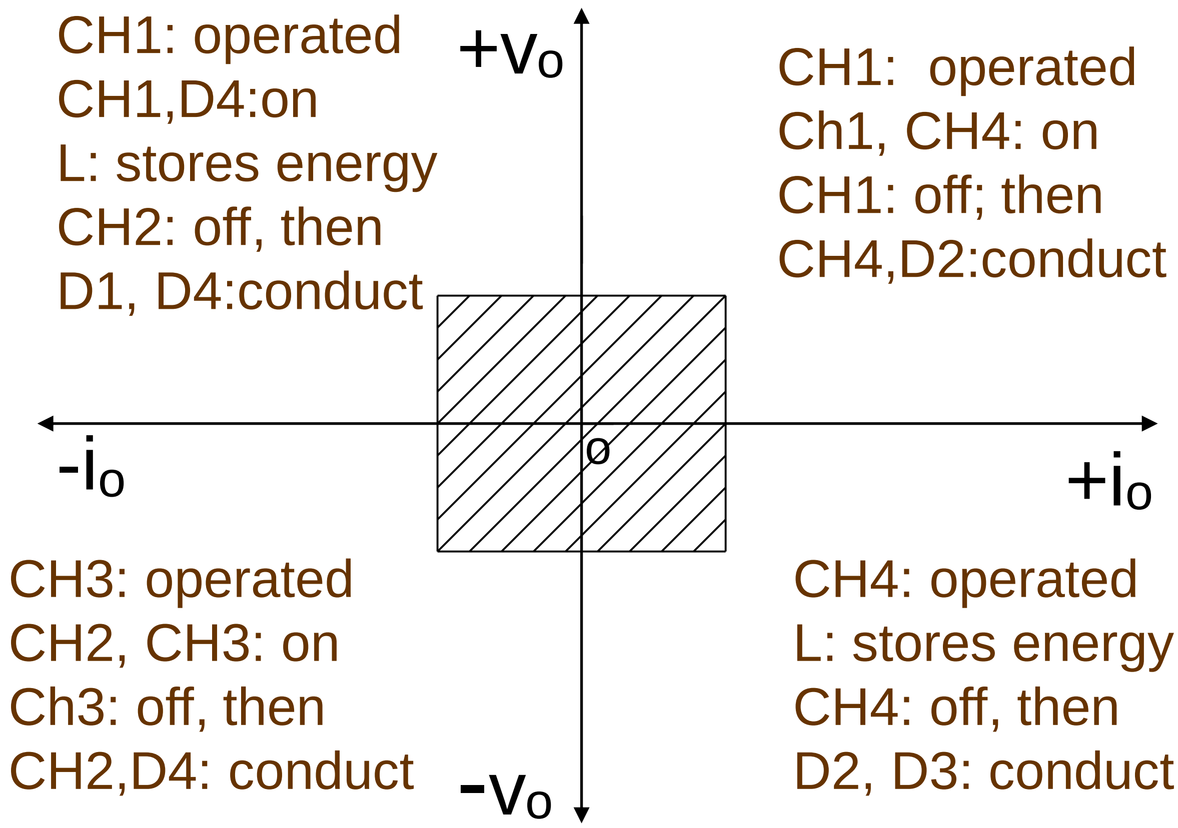
Fig6: Shows Circuit diagram

- Fig(a) shows the power circuit diagram for a FOUR quadrant Chopper.

- It consists of four semiconductor switches CH_1 to CH_4 and four diodes D_1 to D_4.

- The input voltage, current are vs, is and the output voltage, current are vo, io respectively.

Operation of conducting devices



- Fig.7: Operation of chopper in all four quadrants.

Operation of chopper in first quadrant

- For this operation CH_4 is on, CH_2 and CH_3 are off and CH_1 is operated.
- When CH_1 and CH_4 conducts, i_0 flows from source to load and $v_O=v_S$.
- When CH_1 is off, i_0 free wheels through CH_4 and D_2.
- Thus both load voltage v_o and current i_0 are positive, it is first quadrant operation.

Operation of chopper in second quadrant

- For this operation CH_2 is operated while CH_1, CH_3 and CH_4 are off.
- When CH_2 is on the negative current flows through L, CH_2, D_4 and E.

Contd.,

- The inductance L stores energy during the time CH_2 is on.

- When CH_2 is off, current is fed back to source through diodes D_1 ,D_4 as the feed back energy [E+di /dt] is more than the source voltage v_s.

- Thus load voltage v_o is positive and current i_0 is negative, it is second quadrant operation.

Operation of chopper in third quadrant

- For this operation CH_1, CH_4 and are off, CH_2 is on and CH_3 is operated.
- When CH_3 is on the load is connected to the source through CH_2, CH_3 and both v_o and i_0 are negative.
- When CH_3 is turned off, the negative current free wheels through CH_2 and D_4.
- Thus load voltage v_o and current i_0 are negative, it is third quadrant operation

Operation of chopper in fourth quadrant

- The polarity of EMF E is reversed for this operation
- For this operation CH_4 is operated and the CH_1, CH_2 and CH_3 are off.

Contd.,

- When CH_4 is on, positive current flows through E, CH_4, D_2 and L.

- Energy is stored in inductance L.

- When CH_4 is off, current is fed back to source through D_3 and D_2.

- Thus the load voltage v_o is negative and current i_0 is positive, it is fourth quadrant operation.

UNIT 5
Introduction to inverter

- A device which converts D.C. power into A.C. power at desired output voltage and frequency is called INVERTER.

- Inverters are mainly available from few watts to thousands of kilowatts and operate at a frequency from 50 Hz to hundreds of kilo Hz.

Requirements of inverters

- Able to operate for inductive loads such as motors, fans etc.,
- Ability to work under no-load conditions (or) load is disconnected.
- The output wave form must be close to sinusoidal.
- Provision for over current protection.
- It should not operate beyond it's rating.

Classification of inverters:

- **Based on number of phases**

  a) Single phase inverters

  b) Three phase inverters

- **Based on the nature on driving D.C source**

  a) Voltage source inverter (VSI)

  b) Current source inverter (CSI)

Main classification of Inverters

- **Voltage Source Inverter (VSI):**

  It is one in which DC source has small or negligible impedance or it has stiff DC voltage source at its input terminals.

- **Current Source Inverter (CSI):**

  It is fed with adjustable current from a DC source of high impedance is at from DC current source.

Applications of Inverters

- Variable Speed A.C. Motor drives
- High Voltage D.C. Transmission systems
- Un-interruptible Power Supplies (U.P.S)
- Emergency power supplies in domestic lighting appliances
- Timing devices
- A.C. power supplies for LASERS

Voltage source inverter

- A Voltage Source Inverter (VSI) is one in which the DC source has small (or) negligible impedance.

- If VSI are made up of using GTOs, power transistors, MOSFETs, IGBTs, then self (or) line commutation is used and where as for thyristors type, forced commutation is used.

Voltage source inverter

- The working principle of Voltage Source Inverters can be explained by using Single Phase Bridge Inverter.

- Single Phase Bridge Inverters are of two types, namely

i) Single – Phase Half Bridge Inverter

ii) Single – Phase Full Bridge Inverter

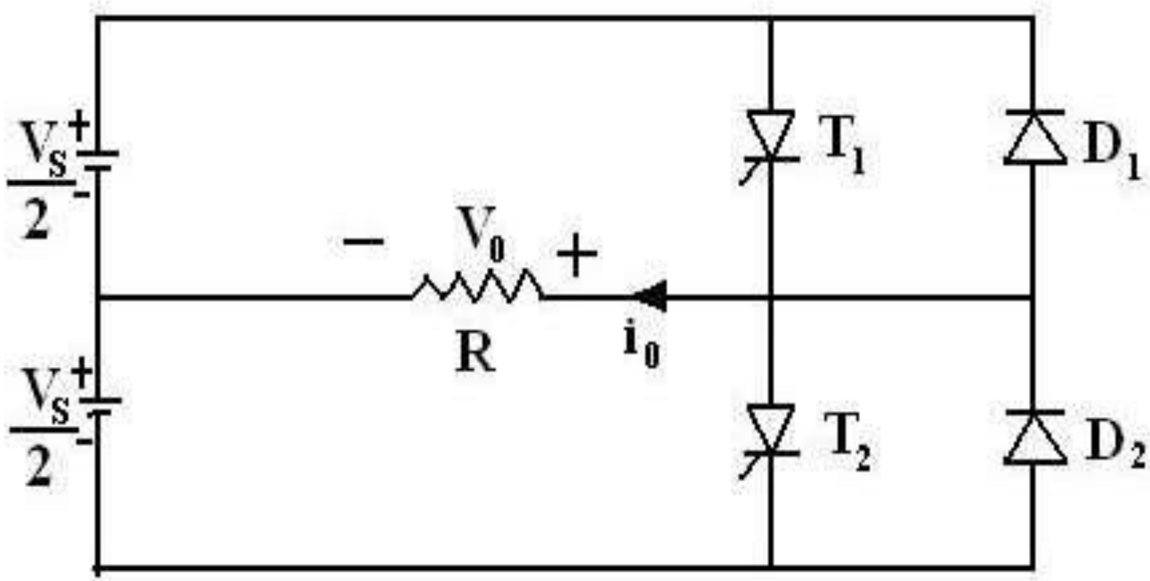
Voltage Source Inverter

- The working principle of Voltage Source Inverter (VSI) can be explained by using single phase bridge inverters
- Single Phase bridge inverters are classified into two types

    i) Single-Phase Half Bridge Inverter

    ii) Single-Phase Full Bridge Inverter

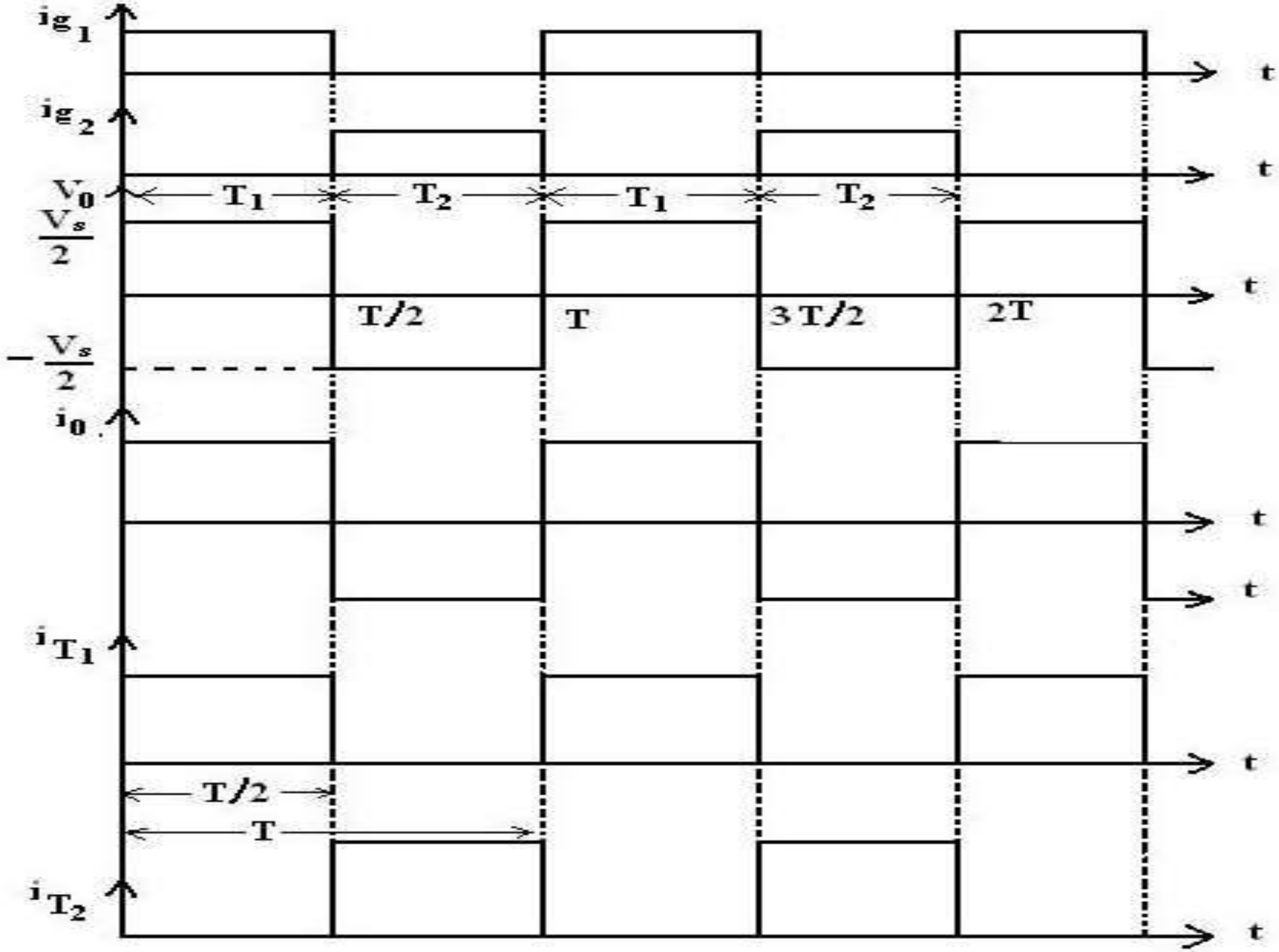
Single-Phase Half Bridge Inverter



Fig(1)

It consists of

- Two thyristors (T1 & T2)
- Two diodes (D1 & D2)
- Three terminal DC supply



Firing pulse and output voltage wave form

Fig(2)

Operation

During the period $0 < t \leq T/2$, the thyristor T1 is triggered and conducts

i) The current flows through the load from positive to negative terminal

ii) Then result is positive half cycle of output wave i.e., $V_s/2$ is shown in fig(1)

Operation

During the period $T/2 < t \leq T$, the thyristor T1 is turn off and T2 is triggered and conducts

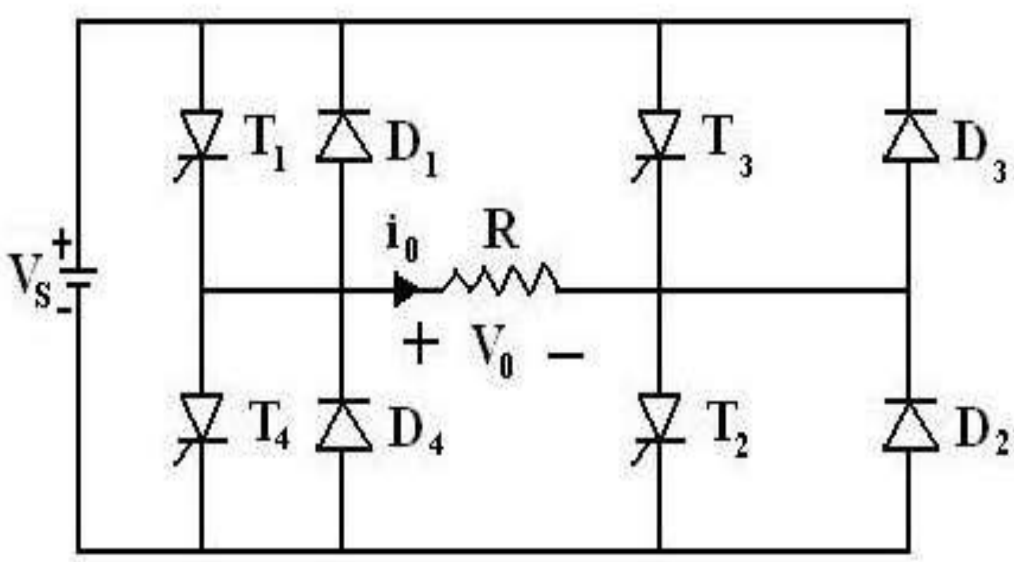
i) T2 conducts causes the current flows through the load from negative to positive terminal

ii) Then result is negative half cycle of output wave i.e., $-V_s/2$ is shown in fig(2)

Conclusion

- It is observed that the load voltage is alternating, and voltage wave form of amplitude ‘Vs/2’ i.e., half of the source voltage with a frequency of 1/T hertz.

Single-phase Full Bridge Inverter

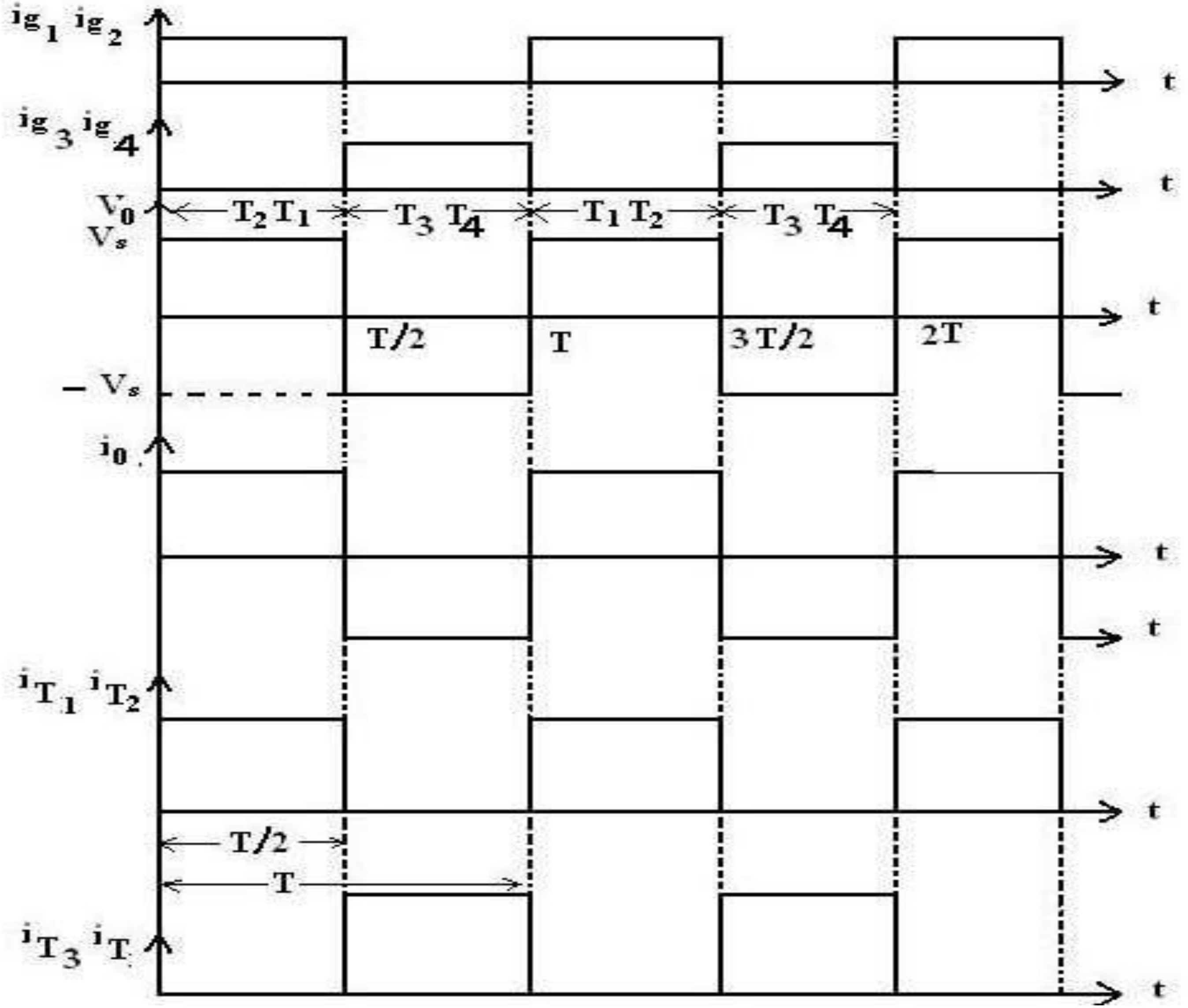


Fig(3)

Fig(3)

It consists of

- Four thyristors (T1 to T4)
- Four diodes (D1 to D4)
- Two wire DC supply



output voltage waveform of single phase full bridge inverter

Fig(4)

Operation

During the period $0 < t \leq T/2$, the thyristors T1 & T2 are triggered and conducts.

i) The current flows through load from positive to negative terminal.

ii) Then result is positive half cycle of the output wave i.e., Vs

Operation

During the period $T/2 < t \leq T$, the thyristors T1 & T2 are Turn – OFF, T3 & T4 are Turn – ON, starts conducting

i) The current flows through the load from negative to positive terminal

ii) The result is negative half cycle of the output wave i.e., $-V_s$

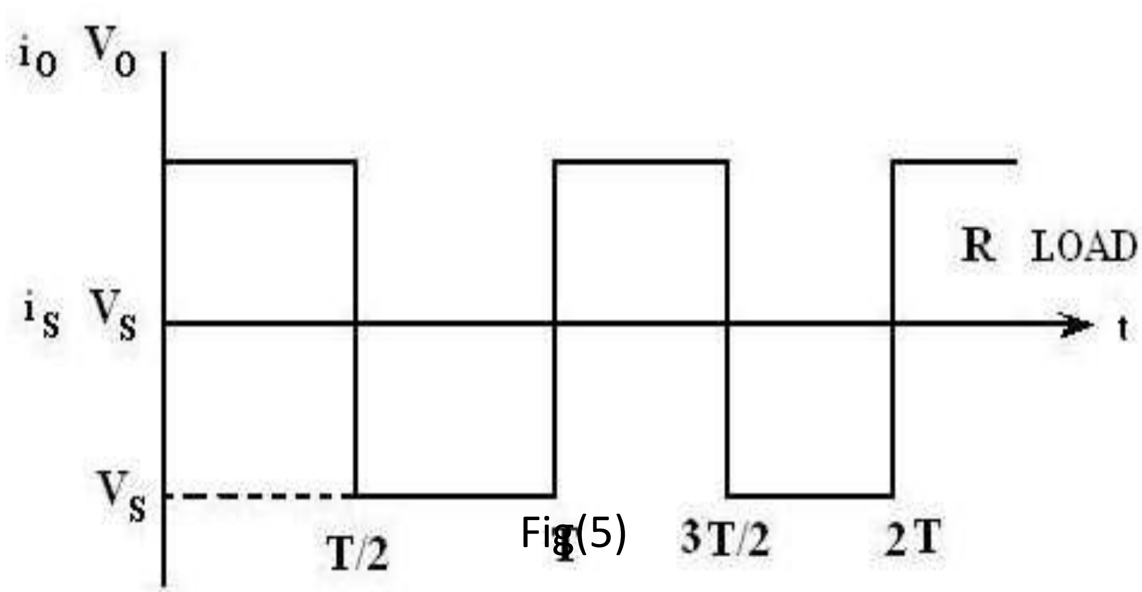
Conclusion

- It is observed that the load voltage is alternating, and voltage wave form of amplitude ‘Vs’ i.e., source voltage with a frequency of 1/T Hertz.

Voltage and Current wave forms for different loads

<u>Case (i)</u>: For Resistive Load

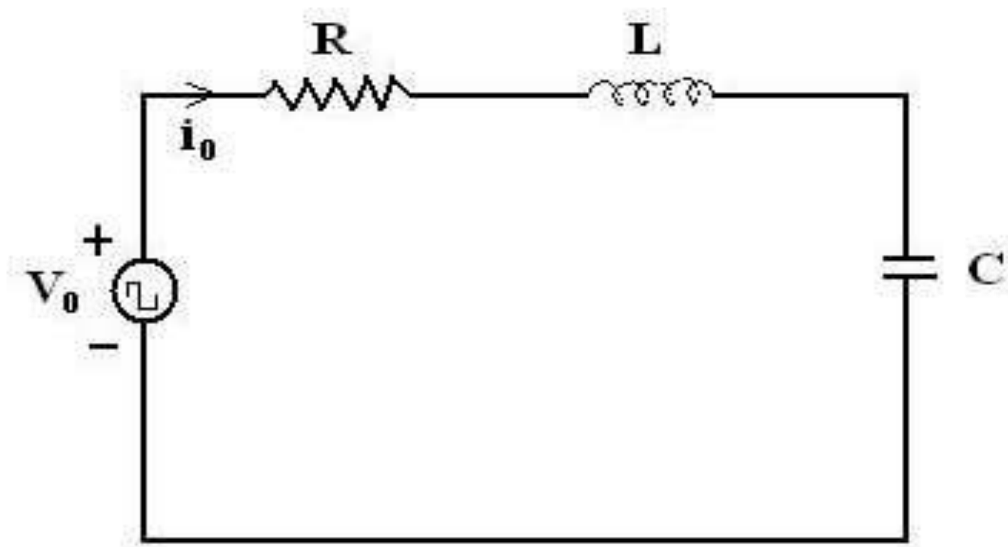
- The load voltage (vo) and load current (io) always in phase with each other.
- Wave form shown below:



Fig(5)

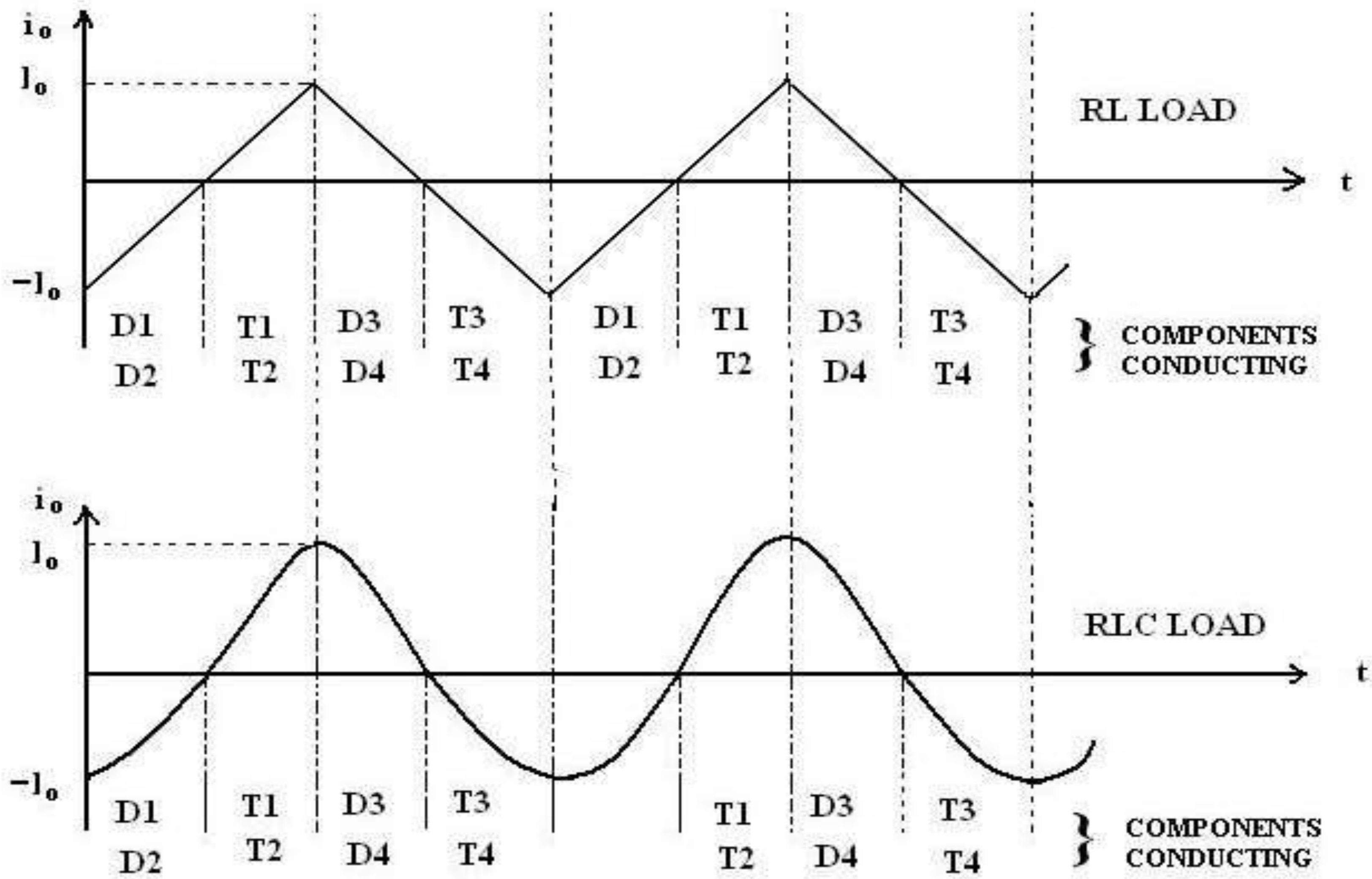
Case (ii): For Non-Resistive Load

- The load current (io) and voltage (vo) are not in phase.
- Diodes were connected in antiparallel with thyristors allows current .
- Current flows through main thyristors are turned OFF. These diodes are called feed back diodes.



Fig(6)

Wave forms for Non-Resistive loads (R-L, R-L-C)



Fig(7)

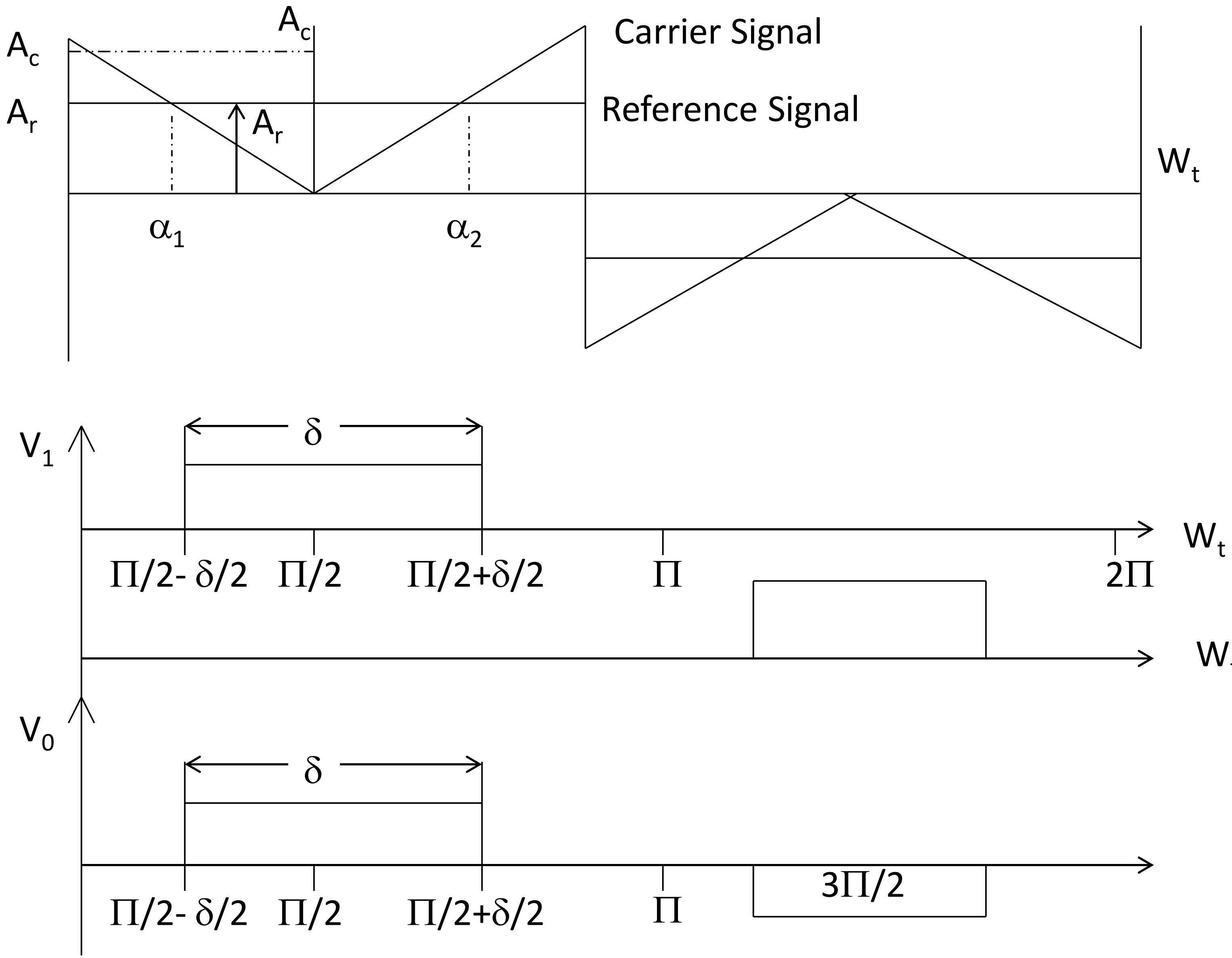
PWM Inverter

- The most efficient method to vary the gain of the inverter is pulse width modulation control in the inverter circuit

- The following techniques are used
    - Single Pulse width modulation
    - Multiple Pulse width modulation
    - Sinusoidal Pulse width modulation

Single Pulse Width Modulation

- Here only one pulse per half cycle is used
- The width of the pulse will be varied to control the output of the inverter



A_c
A_c
Carrier Signal
A_r
Reference Signal
A_r
W_t
α_1
α_2
V_1
δ
W_t
$\Pi/2- \delta/2$
$\Pi/2$
$\Pi/2+\delta/2$
Π
2Π
W_t
V_0
δ
$3\Pi/2$
$\Pi/2- \delta/2$
$\Pi/2$
$\Pi/2+\delta/2$
Π

- A rectangular reference signal amplitude A_r is compared with a triangular carrier wave of amplitude A_c

- Amplitude modulation index $M = A_r / A_c$

- RMS output voltage $V_0 = V_s \sqrt{(\delta / \Pi)}$

- Pulse width δ can be varied from 0^0 to 180^0 by varying A_r from 0 to A_c. This variation produces an rms output voltage variation from 0 to V_s.

- From Fourier analysis of output voltage, it is found that even harmonics are not present in the output

- Third harmonic content is more at low output voltage

- Timing angles

$t_1 = \alpha_1/w = (1-M)\ T_s / 2$

$t_2 = \alpha_2/w = (1+M)\ T_s / 2$

- Pulsed width d

$d = \delta/w = t_2 - t_1 = M\ T_s$ where $T_s = T/2$

Gating Sequence

- Gating signal g_1 is produced by multiplying the resultant square wave by a unity signal which should be a unity pulse of 50% duty cycle at a period T

- g_2 is to be produced by multiplying the square wave by a logic invert signal of V_2

Multiple Pulse width Modulation

- The harmonic content in the output can be reduced, using many pulses in each half cycle of output voltage

- This is known as uniform pulse width modulation

- The generation of gating signals to turn on and off the transition is done by comparing a reference signal with a triangular carrier wave

- Frequency of the reference signal determines the output frequency f_0

- Carrier frequency determines the number of pulses per half cycle p

- The output voltage is controlled by the modulation index

- No. of pulses required per half cycle

  $P = f_c / 2f_0 = M_f/2$

  where $M_f = f_c / f_0$ = frequency modulation ratio.

- Instantaneous output voltage $V_0 = V_s (g_1 - g_4)$

- $V_0 = V_s (g_1 - g_4)$
- $V_0 = V_s \sqrt{(P\delta / \Pi)}$

- The m^{th} time t_m and angle α_m of intersections can be determined from

  - $t_m = \alpha_m / w = (m\text{-}M)\, T_s / 2$ for m= 1,3,…….2p

  - $t_m = \alpha_m / w = (m-1+M)\, T_s / 2$ for m= 2,4,…….2p

  - Pulse width d

    $$D = \delta / w = t_{m+1} - t_m = MT, \text{ where } T_s = T/2p$$

Sinusoidal Pulse width Modulation

- In this, dominant harmonic frequency DF and the lower order harmonics can be reduced
- The width of all pulses will be the same
- The width of each pulse is varied in proportion to the amplitude of a sine wave evaluated at the centre of the pulse

- A sinusoidal reference signal will be compared with a triangular carrier wave of frequency f_c to generate the gating signals

- Output voltage $V_0 = V_s (g_1 - g_4)$

- Carrier frequency determines the number of pulses per half cycle

- Reference signal is V_r Sinwt

- Variation of modulation index produces variation in the rms output

- If the mth pulse has a width of δ_m, the rms output voltage is

$$V0 = Vs \sqrt{\sum_{m=1}^{2p} (\delta m/\Pi)}$$

3-Ø INVERTER

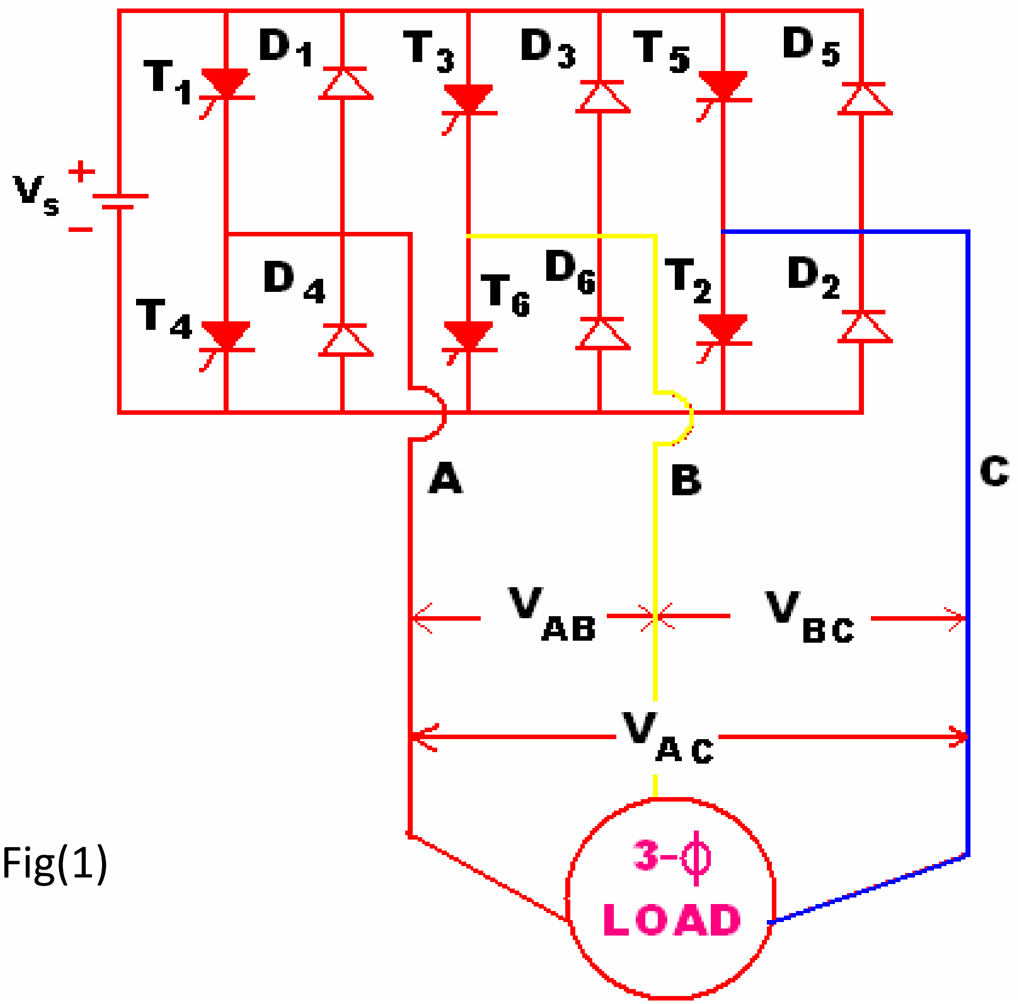
Three 1-ø inverters in parallel & gating pulses for three inverters has a phase difference of 120°.

Three phase bridge inverter:

3-Ø bridge inverter consists of three half-bridge inverters arranged side by side. There are two possible patterns of gating the thyristors.

- 3-Ø 180° conduction mode
- 3-Ø120° conduction mode

3-Ø INVERTER CIRCUIT

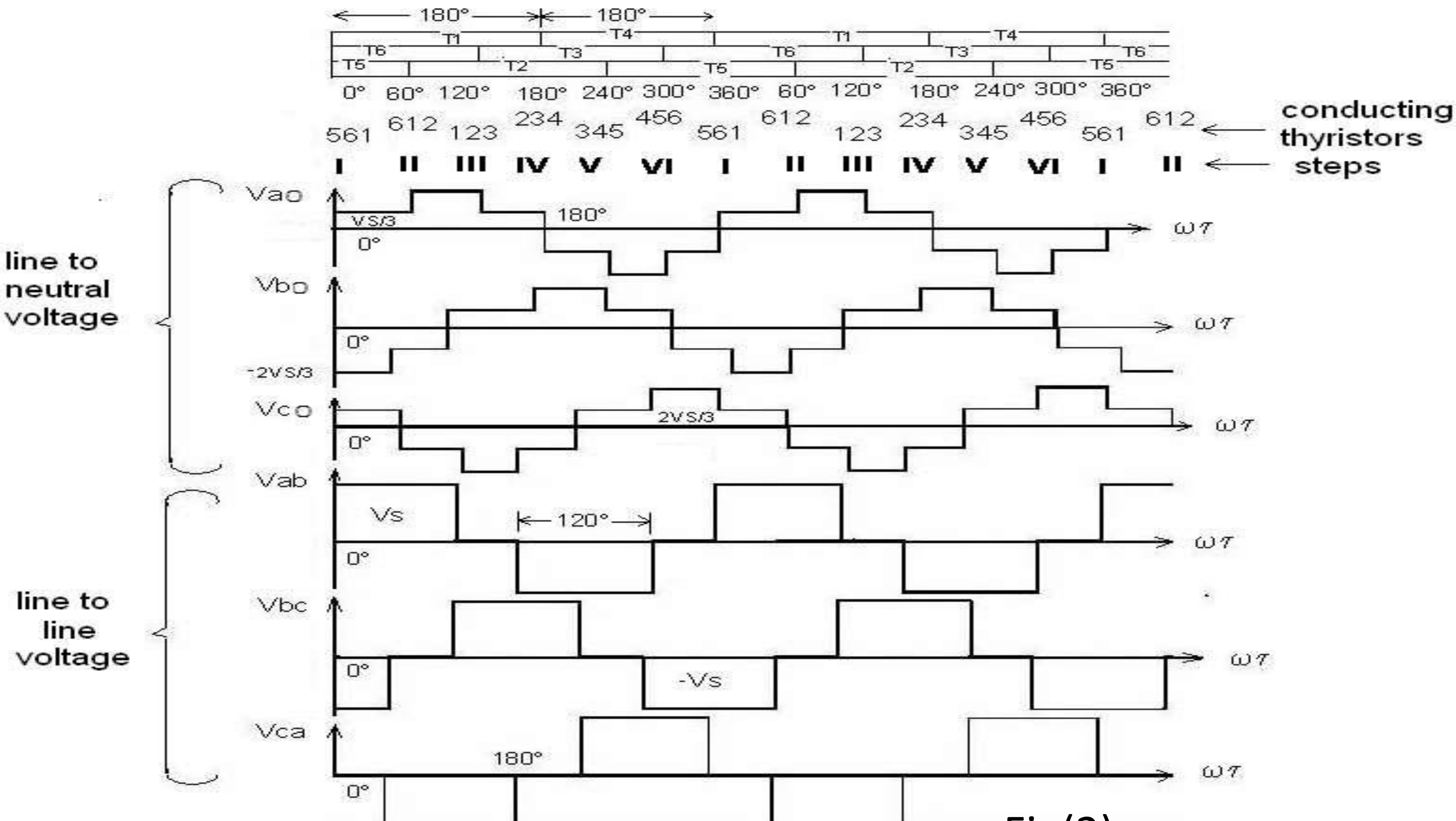


Fig(1)

VOLTAGE WAVE FORMS FOR

180^0 3-Φ CONDUCTION

Wave form



Fig(2)

Three phase 180° conduction mode

As shown in the fig(1)

- Thyristor pair in each arm, i.e., T1,T4; T3,T6 and T5,T2 are turned on with a time interval of 180°
- In the 3-Ø Inverter,each SCR conducts for 180° of a cycle
- Thyristors in upper group, i.e., T1,T3,T5 conduct at an interval of 120°

Three phase 180° conduction mode

- It implies that if T1 is fired at $\omega t=0^\circ$, then T3 must be fired at $\omega t=120^\circ$ and T5 at $\omega t=240^\circ$
- Same is turned for lower group of SCRs
- First row shows that T1 from upper group conducts for 180°, T4 for next 180°

Three phase 180° conduction mode

- In the second row T3 from the upper group is start conducting 120° after T1 starts conducting. After T3 conduction for 180°; T6 conducts for the next 180° again T3

- Third row, T5 from the upper group starts conducting 120° after T3 (or) 240° after T1. After T5 conduction for 180°, T2 conducts for the next 180°, T5 for the next 180°

- The sequence of firing the thyristors is T1,T2,T3,T4,T5,T6,T1,T2……..

Three phase 180° conduction mode

- In every step of 60° duration, only three SCRs are conducting one from upper group and two from lower group.
- The pattern of firing the six SCRs are

Step-I : T5,T6,T1

Step-II : T6,T1,T2

Step-III : T1,T2,T3

Step-IV: T2,T3,T4

Step-V : T3,T4,T5

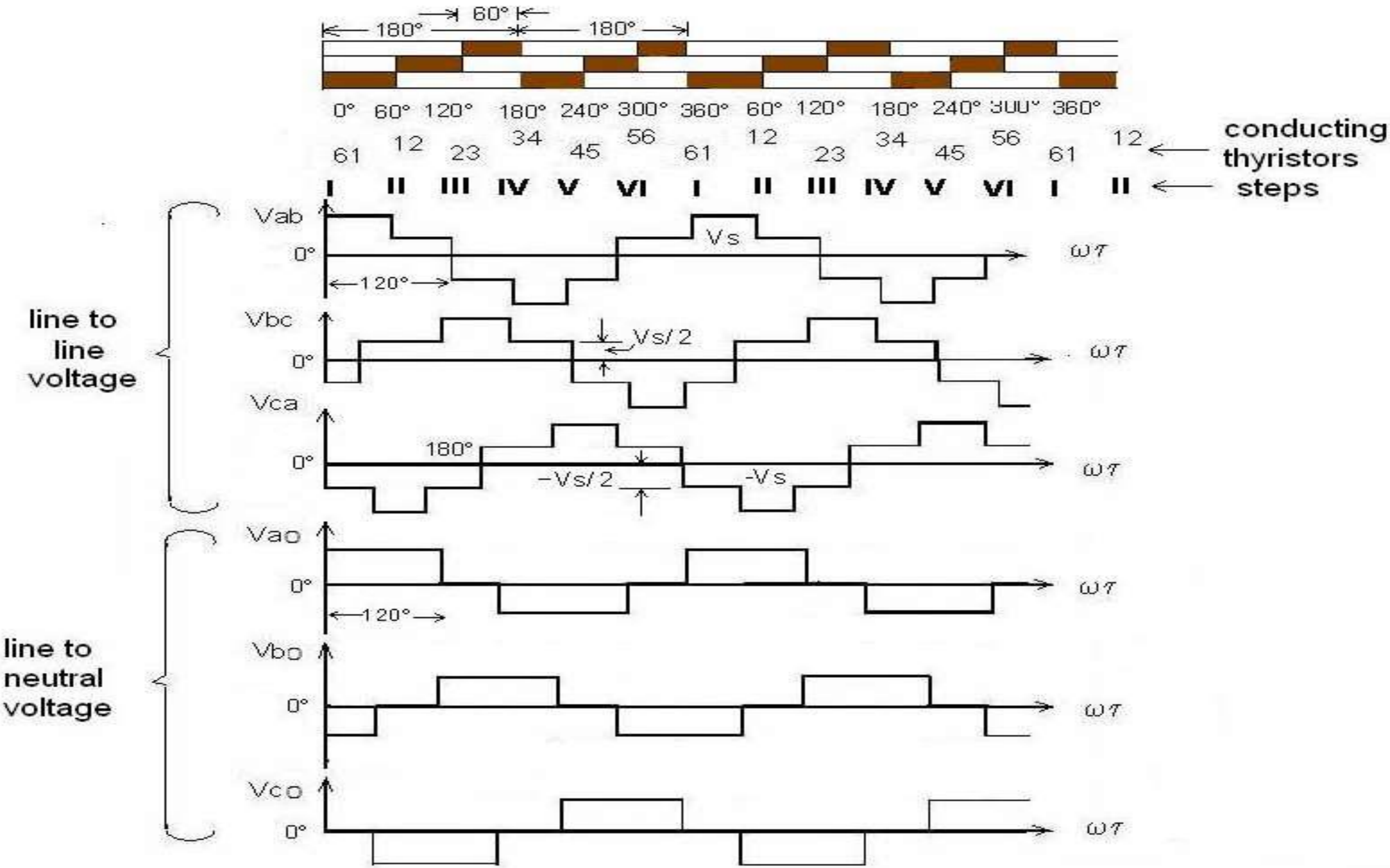
Step-VI: T4,T5,T6

Step-I : T5,T6,T1

………………… so on, is shown in fig(2)

VOLTAGE WAVE FORMS FOR 120^0

3-PHASE CONDUCTION



60°
180°
180°
0° 60° 120° 180° 240° 300° 360° 60° 120° 180° 240° 300° 360°
61 12 23 34 45 56 61 12 23 34 45 56 61 12
conducting thyristors
I II III IV V VI I II III IV V VI I II
steps
line to line voltage
Vab
Vs
120°
Vbc
Vs/2
Vca
180°
-Vs/2
-Vs
line to neutral voltage
Vao
120°
Vbo
Vco
0°
ωτ

Fig(1)

three phase 120° conduction mode

- Each thyristor conducts for 120° of a Cycle.
- First row shows that T_1 conducts for 120° and for the next 60°, neither T_1 nor T_4 conducts.
- In second row, T_3 is turned ON at $\omega t=120°$ (or) in 180° mode inverter. Now T_3 conducts for 120°, then 60° interval elapses during which neither T_3 nor T_6 conducts

- In the third row T_2 conducts for 120° and for the next 60°, neither T_2 nor T5 conducts

- The pattern of firing the six SCRs are

  Step-I : T_6,T_1

  Step-II : T_1,T_2

  Step-III : T_2,T_3

  Step-IV: T_3,T_4

  Step-V : T_4,T_5

  Step-VI: T_5,T_6

………………. so on. It is clearly shown in fig(1)