



The Shirpur Education Society's
R. C. Patel College of Engineering and Polytechnic, Shirpur
Department of Electrical Engineering

NOTES

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Semester: 3rd

Course Title: Fundamentals of Power
Electronics

Course Abbr.: FPE

Course Code: 313335

Subject Teacher :- Ms. H.A.Badgujar

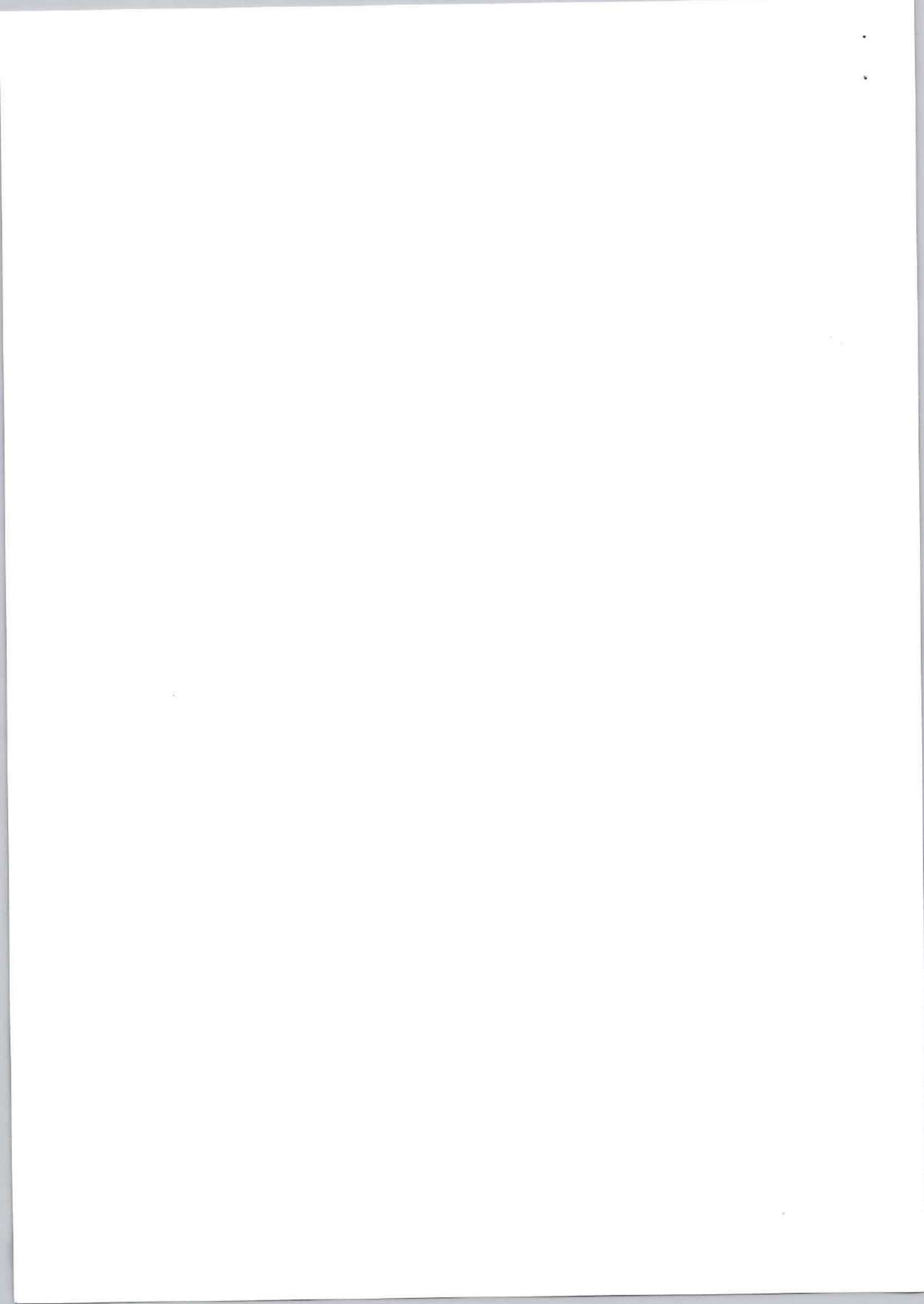
UNIT-03 – (18 MARKS)

CONTROLLED CONVERTERS

CO Coverage: - Test the performance of given controlled converter.

Unit -03 Content (Syllabus)

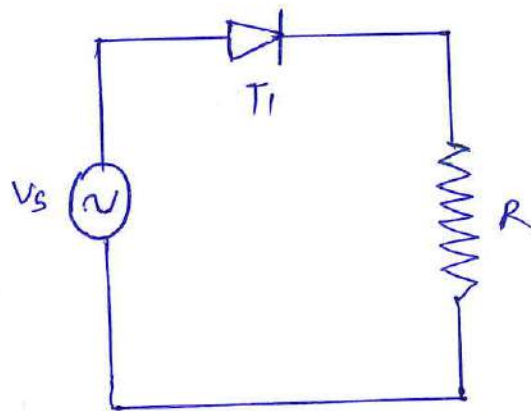
- 3.1 Basic terminologies: conduction angle, firing angle, output voltage, output current, voltage across switch, source current, source voltage
 - 3.2 Single phase half wave controlled rectifier with R, RL load: Circuit diagram, working, input-output waveforms, derivation for average output voltage, equations for output currents, voltages & power, and effect of freewheeling diode
 - 3.3 Single phase full wave controlled bridge rectifier with R, RL load: Circuit diagram, working, input- output waveforms, derivation for average output voltage, equations for output currents, voltages & power
 - 3.4 Three phase full wave controlled bridge rectifier: working principle with R load, input-output waveforms
 - 3.5 Inverters: concept of voltage source inverter and current source inverter
 - 3.6 Single phase half wave bridge inverter with R, RL load: Circuit diagram, working, input-output waveforms
 - 3.7 Single phase full wave bridge inverter with R, RL load: Circuit diagram, working, input-output waveforms
 - 3.8 Pulse width modulation: importance/need, types;
Sinusoidal pulse width modulation: concept, working principle and waveforms
-



3.1 Basic Terminologies: Conduction angle, firing angle, output voltage, output current, voltage across switch, source current, source voltage.

- 1) Conduction angle: In an AC input cycle, the period during which the SCR remains ON state after being triggered is called the conduction angle.
Conduction angle = $180^\circ - \alpha$
- 2) Firing Angle: The firing angle is the angle in the AC input cycle at which the SCR is turned ON by applying a gate current pulse.
- 3) Output Current: Output current of controlled rectifier is defined as the current flowing through the load. It is a controlled DC current measured in amperes.
- 4) Output Voltage: Output voltage of controlled rectifier is defined as the voltage measured across the load. It is a controlled DC voltage measured in volts.
- 5) Voltage across switch:
It is defined as the instantaneous voltage ~~across~~ measured at its anode with respect to its cathode.
- 6) Source Current: Source current of a controlled rectifier is defined as current supplied by the input AC supply to the controlled rectifier.
- 7) Source Voltage:
Source voltage of a controlled rectifier is defined as the voltage supplied by the input AC supply to the controlled rectifier.

3.2 Single phase half-wave controlled rectifier with R load:



- Fig. ① shows circuit diagram of 1 ϕ half wave controlled rectifier.
- It is called as half wave controlled rectifier, as only half cycle of AC input is converted to pulsating DC.
- It is called as controlled rectifier as the output can be controlled by controlling the SCR.
- To conduct SCR, it must be in forward conduction mode and a gate signal must be provided.
- The angle at which the gate signal is applied and SCR is turned ON is called as Firing angle denoted as α .

→ Working →

- During positive half cycle ($\omega t = 0$ to π), SCR is in forward blocking mode and acts open circuit as gate signal is not applied. No current flows through the circuit and the output voltage is 0.
- During positive half cycle ($\omega t = \alpha$ to π), SCR is forward biased and acts short circuit. Therefore the current I_o starts flowing from the source to the load. During this cycle, the output voltage is equal to the source voltage. ($V_o = V_s$)
- Therefore the output voltage waveform follows the input voltage ($\omega t = \alpha$ to π) as shown in waveform.
- For a resistive load, the output current would follow the output voltage waveform, however its magnitude is controlled by the Resistance 'R'.
- During negative half cycle ($\omega t = \pi$ to 2π), SCR is reverse

biased and acts as an open circuit.

→ Therefore, no current I_o flows from the source to the load. During this cycle, voltage (V_o) is equal to zero ($V_o = 0$).

→ Therefore, the output voltage & current waveform ($\omega t = \pi$ to 2π) is zero as shown in waveform.

→ However, the voltage across the SCR is $V_T = V_m \cdot \sin \omega t$ which is also called as Peak Inverse Voltage (PIV), which is maximum voltage that appears across the device during its blocking state.

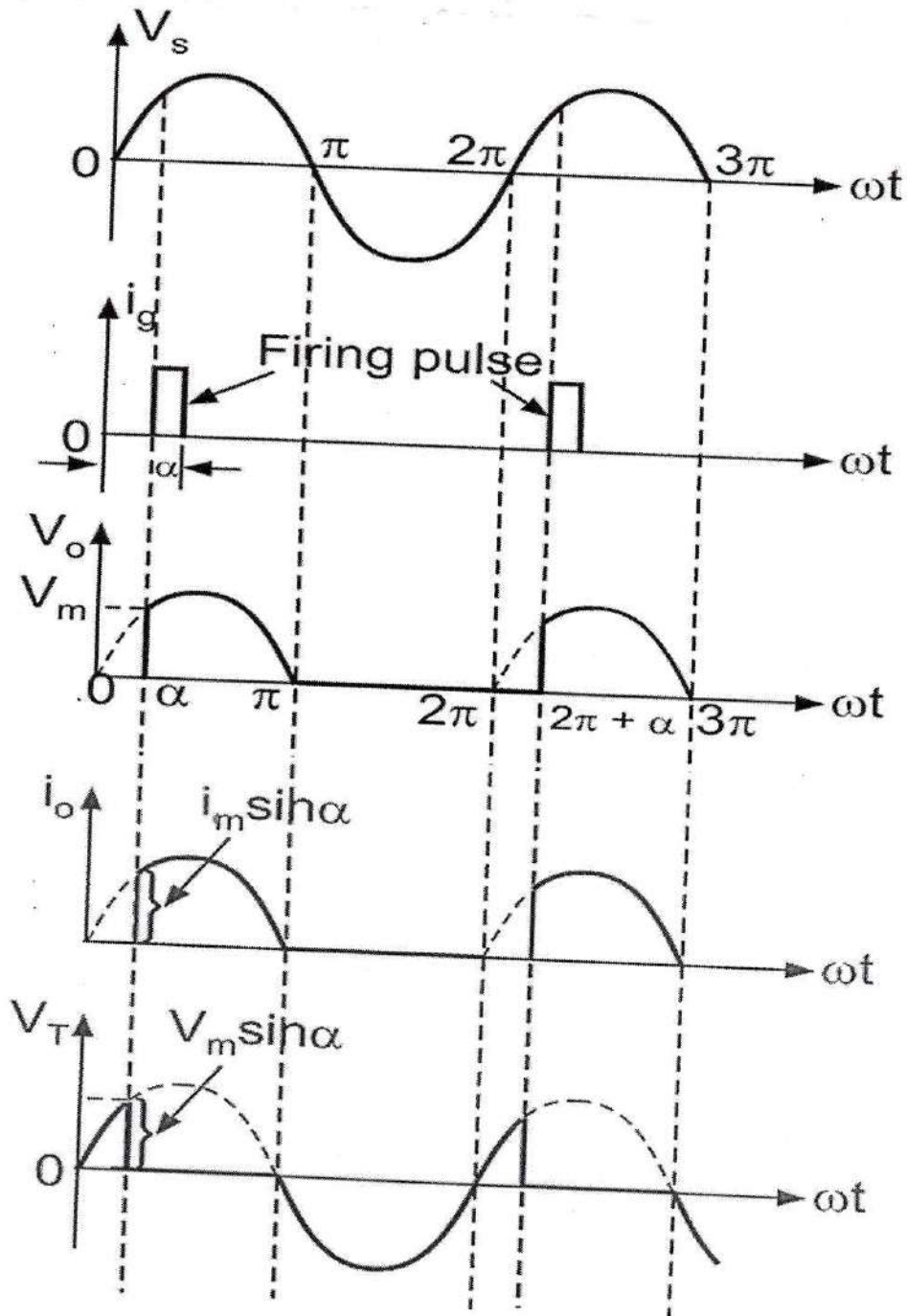


Fig 2 : Single Phase Half Wave Controlled Rectifier with R Load (Input/output waveform)

1) Average output voltage :-

As we know that average output voltage is given by,

$$V_o = \frac{1}{2\pi} \int_0^{2\pi} V_o \cdot d\omega t.$$

Considering only half cycle as the average value becomes zero, for full cycle,

$$V_o = \frac{1}{2\pi} \int_{\alpha}^{\pi} V_m \cdot \sin \omega t \cdot d\omega t.$$

$$V_o = \frac{V_m}{2\pi} (-\cos \omega t)_{\alpha}^{\pi}$$

$$\boxed{V_o = \frac{V_m}{2\pi} (1 + \cos \alpha)}$$

② Output Current ($I_{o(dc)}$) - Expression.

$$I_{o(dc)} = \frac{V_o}{R} = \frac{V_m}{2\pi R} (1 + \cos \alpha)$$

③ Output Power \rightarrow

$$P_{dc} = V_{dc} \times I_{dc}$$

$$= \frac{V_m}{2\pi} (1 + \cos \alpha) \times \frac{V_m}{2\pi R} (1 + \cos \alpha)$$

$$P_{dc} \text{ or } P_o = \frac{V_m^2}{4\pi^2 R} (1 + \cos \alpha)^2$$

④ Peak Inverse Voltage (PIV)

$$PIV = V_s = V_m \cdot \sin \omega t = \frac{V_m}{\sqrt{2}}$$

$$\boxed{V_m = \sqrt{2} \cdot V_s}$$

3.2.2 - 1 ϕ half wave controlled rectifier with RL load :-

\rightarrow fig. shows circuit diagram of 1 ϕ half wave controlled rectifier with RL load.

- During positive half cycle ($\omega t = 0$ to π), SCR is in forward blocking mode and acts open circuit as gate signal is not applied.
- No current flows through the circuit and the output voltage is 0.
- During positive half cycle ($\omega t = \alpha$ to π), SCR is forward biased and acts as short circuit.
- Therefore, the current I_o starts flowing from the source to load.
- During this cycle, the output voltage is equal to the source voltage ($V_o = V_s$). In addition, inductor starts storing energy and current keeps increasing.
- Therefore, the output voltage waveform follows input voltage ($\omega t = \alpha$ to π), as shown in waveform,

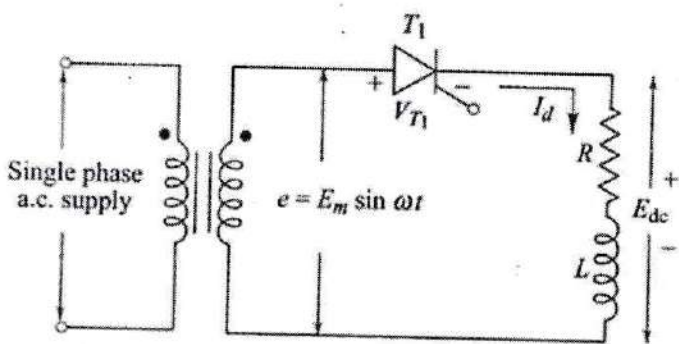


Fig.1(a) Half-wave controlled rectifier with R-L load

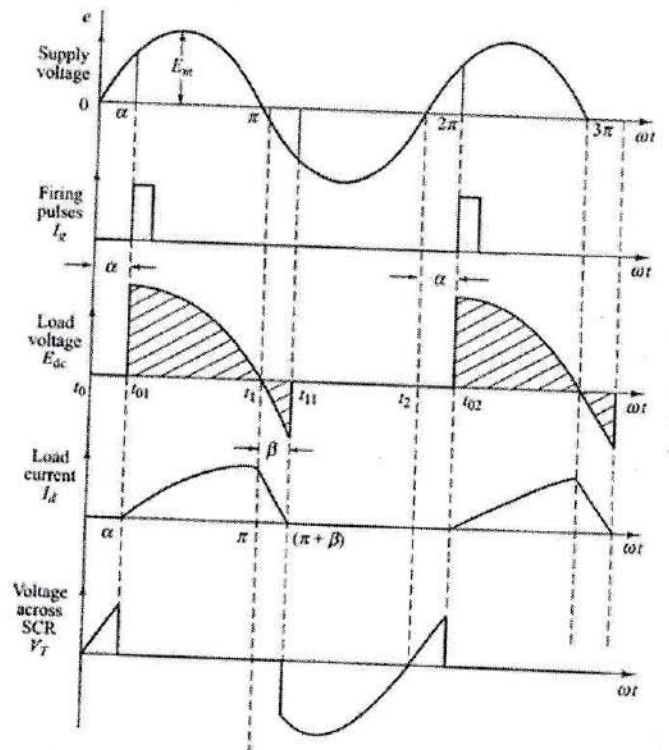


Fig.1(b) Waveforms for a half-wave controlled rectifier with RL load

- During negative half cycle ($\omega t = \pi$ to β), SCR still forward biased and acts short circuit due to the inductance at the load.
- Consequently, the output voltage is equal to the source voltage. ($V_o = -V_s$).
- However, the current flowing starts to decay as the inductor discharges through R and reaches 0 at $\omega t = \beta$.

- During negative half cycle ($\omega t = \beta$ to 2π), the SCR is reverse biased due to the source and also discharged, therefore the output voltage and current would be zero during this interval.
- Here β is called as the extinction angle, i.e. the angle at which the current decays to zero.

* 1) Average output voltage :-

The average output voltage is given by

$$V_o = \frac{1}{2\pi} \int_0^{2\pi} V_o \cdot d\omega t.$$

considering only half cycle as the average value becomes zero for full cycle,

$$V_o = \frac{1}{2\pi} \int_{\alpha}^{\beta} V_m \cdot \sin \omega t \cdot d\omega t.$$

$$V_o = \frac{V_m}{2\pi} \int_{\alpha}^{\beta} (-\cos \omega t) d\omega t$$

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

* 2) RMS output voltage :-

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

3) output current :-

$$I_{dc} = \frac{V_{dc}}{R} = \frac{V_m}{\pi R} (\cos \alpha)$$

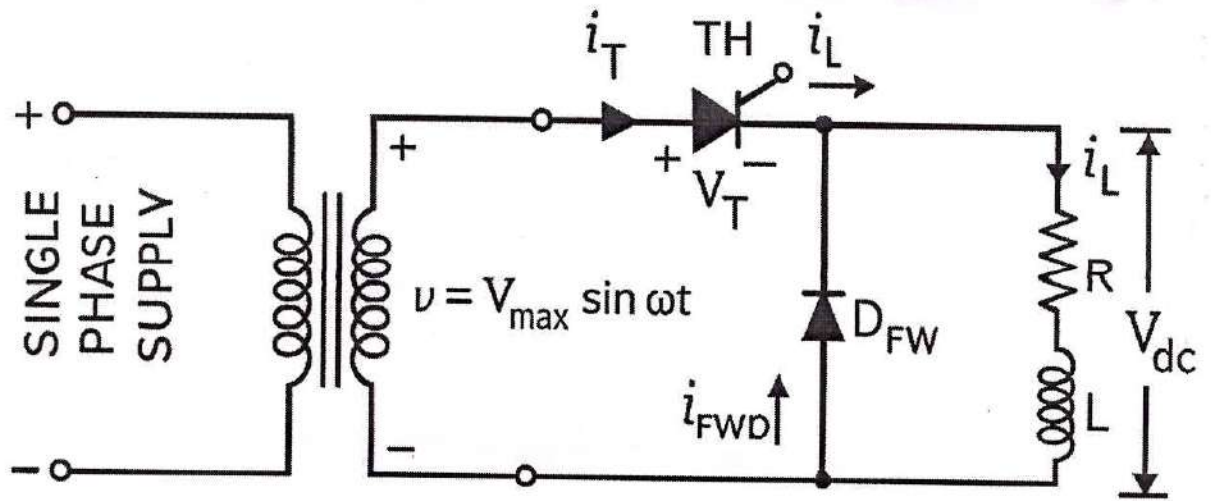
4) output Power :-

$$P_{o(dc)} = V_{dc} \times I_{dc}.$$

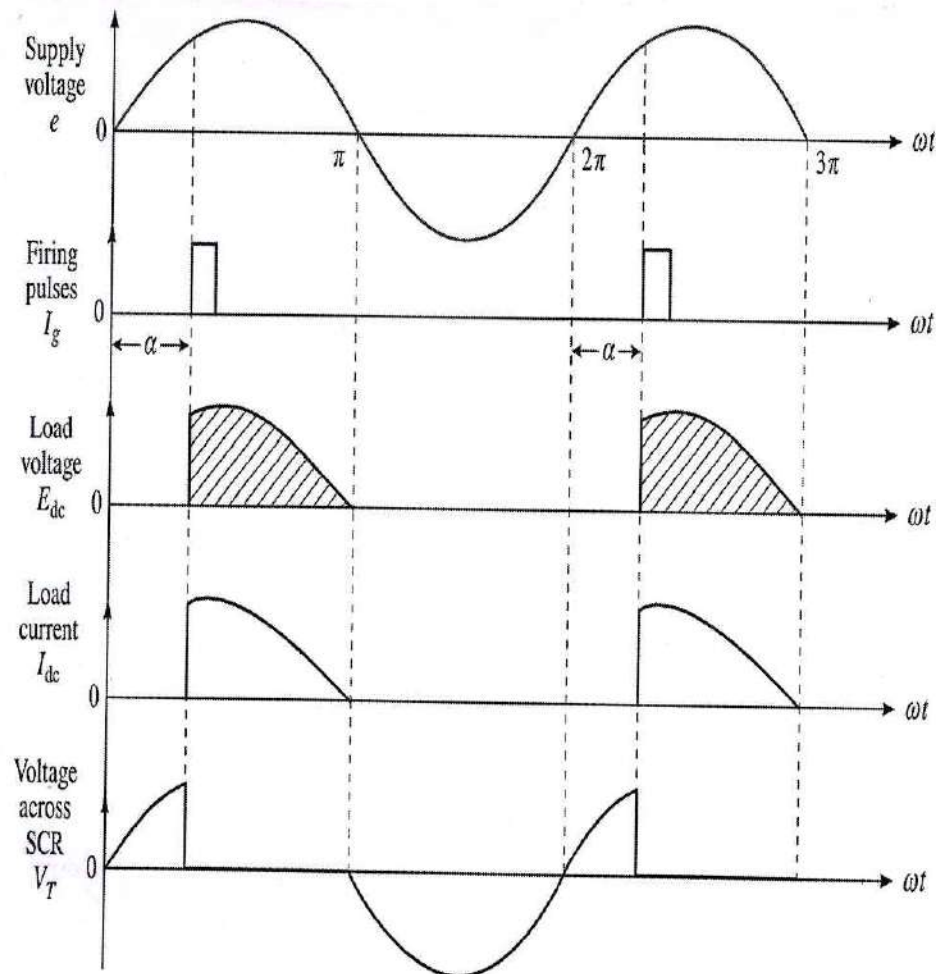
* Effect of Free wheeling diode :-

- Except for the diode voltage drop, this diode prevents the load voltage from becoming ~~voltage~~ negative.
- In half wave rectifiers with an Inductive load, the dc output voltage decreases. This is significant disadvantage. To avoid this,

a diode is connected in parallel with the load. This diode is called as Free wheeling Diode (DF)



- During the negative half-cycle, the induced voltage across the load inductor forward-biases the free wheeling diode (DF), causing it to turn ON.
- The energy stored in the load inductor is dissipated through the diode. As a result, the SCR turns off and the output voltage becomes zero.



* Functions of freewheeling Diode :-

- 1) It prevents the load voltage from becoming negative, except for the small voltage drop across the diode.
- 2) It transfers the load current away from the SCR, allowing the SCR to turn off when the supply voltage becomes negative.

* 3.3 single phase Full wave Controlled bridge rectifier With R Load

Fig. shows circuit diagram for 1 ϕ full wave controlled bridge rectifier with R load.

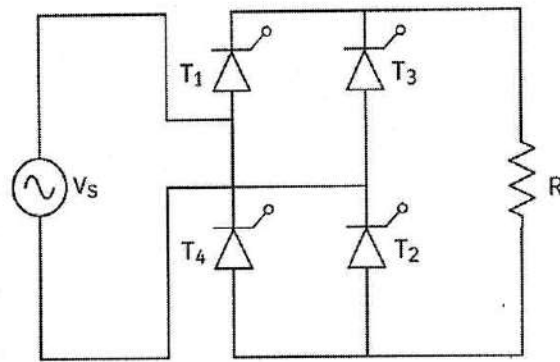


Fig. 1 ϕ full wave controlled bridge rectifier with R load.

- A 1 ϕ full wave controlled bridge rectifier converts a 1 ϕ AC supply into a controlled DC output using four SCR's (thyristors).
- The output voltage can be varied by changing the firing angle (α) of the SCR's.
- In this circuit, the load is purely resistive (R load), therefore: load current and voltage are in phase.
- Current becomes zero whenever voltage becomes zero.
- SCR's turn off naturally at the end of each conduction period.
- It consists of four SCR's, AC source and resistive load.
- SCR's are connected in bridge configuration.
- SCR Triggering pairs
 - 1) Positive half cycle - T_1 and T_2 are triggered
 - 2) For negative half cycle - T_3 and T_4 triggered.
- The firing angle is measured from zero crossing of the supply voltage.

* Working :- During +ve half cycle T_1 and T_2 are forward

biased. Initially gate pulse is not applied so SCR is turn off.

→ At firing angle ($\omega t = \alpha$) a gate pulse is applied simultaneously to T_1 and T_2 . Both SCRs start conducting.

→ At $\omega t = \pi$, supply voltage becomes zero. Therefore $I_o = 0$. SCR current falls below holding current, hence T_1 & T_2 turn off naturally.

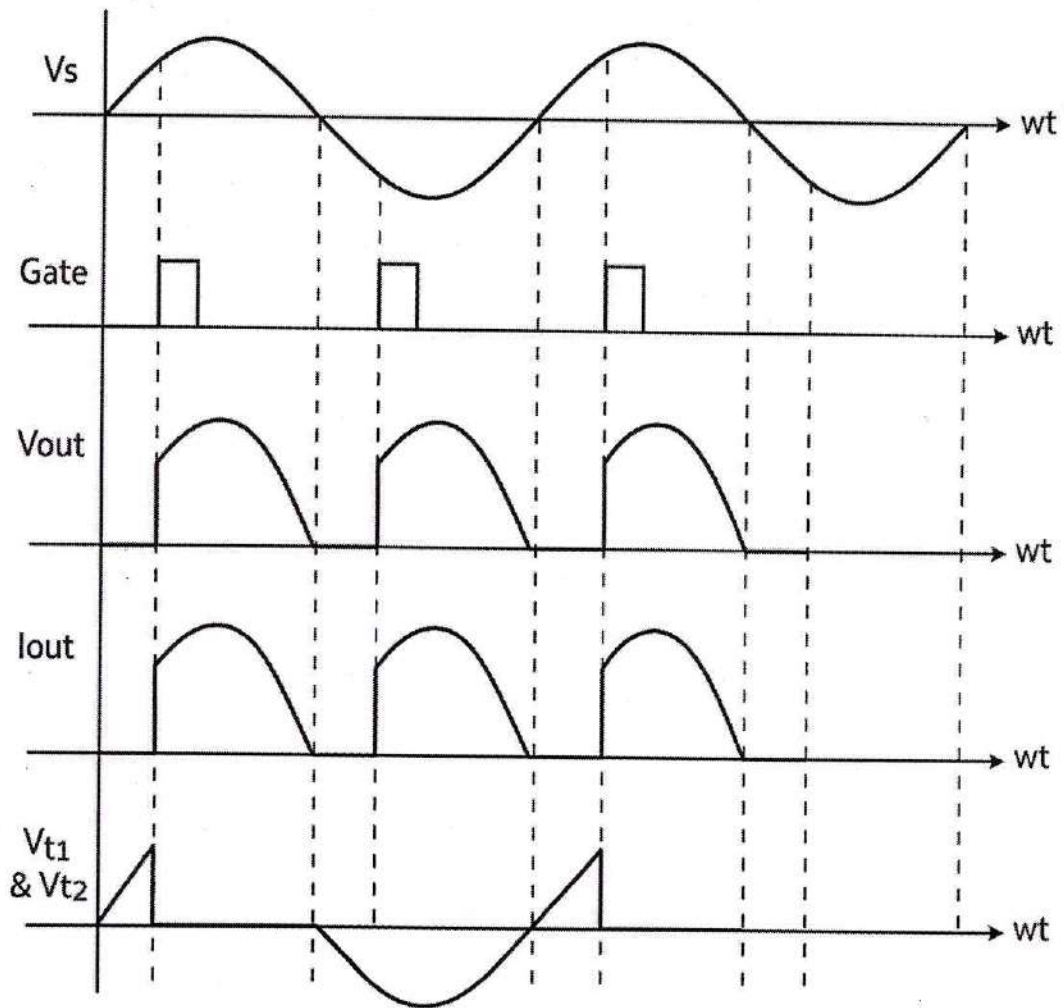


Fig. 2 - Single phase full wave controlled bridge rectifier with R load (Input/output waveform)

→ During negative half cycle SCR pairs T_3 and T_4 becomes forward biased

→ At $\omega t = \pi + \alpha$ gate pulses are applied to T_3 and T_4 .

→ Although source polarity is reversed, the bridge arrangement ensures that load current flows in the same direction.

→ At $\omega t = 2\pi$ current becomes zero. T_3 and T_4 turn off naturally the same cycle repeats continuously.

* Average output voltage :-

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

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

$$V_o = \frac{V_m}{\pi} [1 + \cos \alpha]$$

* RMS output voltage :-

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

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

$$V_{or} = \frac{V_m}{\sqrt{2}\pi} [(\pi - \alpha) + \sin 2\alpha]$$

* Equations for output current :-

$$I_{o,dc} = \frac{2}{\pi R} \int_{\alpha}^{\pi} V_m \cdot \sin \omega t \cdot d(\omega t)$$

$$I_{o,dc} = \frac{V_m}{\pi R} [1 + \cos \alpha]$$

* Equation for power output :-

$$P_{dc} = V_{dc} \times I_{dc}$$

$$P_{dc} = \frac{V_m^2}{\pi^2 R} [1 + \cos \alpha]^2$$

* 3.3.2 - 1 ϕ full wave controlled Bridge Rectifier with RL load :-

→ Fig. shows circuit diagram of 1 ϕ Full wave controlled bridge rectifier.

→ The circuit consists of four SCR's T₁, T₂, T₃ and T₄.

→ Single phase AC supply is connected in series with RL load.

→ SCR's are connected in bridge configuration.

→ Unlike the R-load case, the inductor stores energy and opposes sudden changes in current. Therefore the load

current becomes continuous and does not become zero immediately when supply voltage crosses zero.

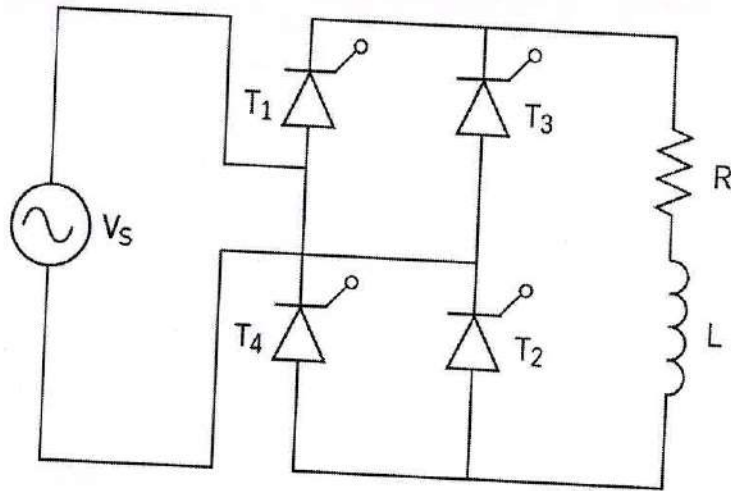


Fig. 1 - Circuit Diagram of Single phase full wave controlled bridge rectifier with RL load

* Working \Rightarrow mode - ①

- \rightarrow During positive half cycle, SCRs T_1 & T_2 are forward biased. At firing angle α , gate pulses are applied to T_1 and T_2 .
- \rightarrow Current path $V_s \rightarrow T_1 \rightarrow R-L \rightarrow T_2 \rightarrow V_s$. The output voltage becomes $V_o = V_m \cdot \sin \omega t$.

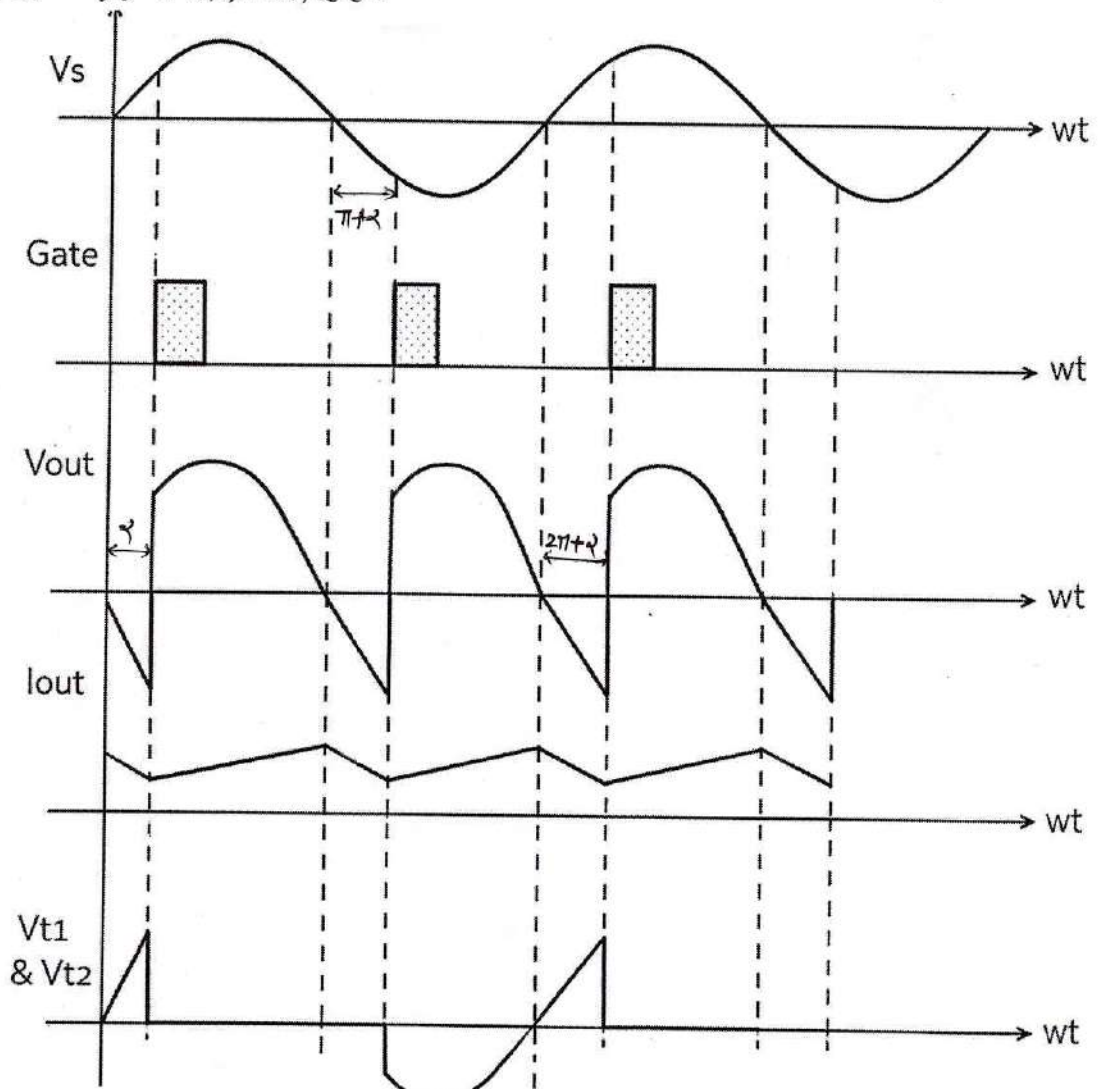


Fig. 10 Full wave controlled bridge Rectifier - RL load.

mode - (2)

- ~~From~~ At $\omega t = \pi$, supply voltage becomes negative. However load current is still positive due to stored magnetic energy in L.
- Therefore T_1 and T_2 continue conducting beyond π . Current continues through the same SCR pair.
- In this interval output voltage becomes negative and load current remains positive.

→ mode - (3)

- Negative half cycle ($\omega t = \pi + \alpha$) → Gate pulses are applied to SCR's T_3 and T_4 , then T_3 & T_4 will turn ON.
- Immediately T_1 and T_2 are reverse biased, they turn off naturally.

* mode - (4) - (from 2π to $(2\pi + \alpha)$)

- Again supply voltage changes polarity. However current continues to due to stored energy.
- T_3 and T_4 conduct beyond 2π . At the next firing pulses, T_1 and T_2 take over. The cycle repeats continuously.

* Average output voltage :-

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

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

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

$$V_o = \frac{2V_m}{\pi} \cdot \cos \alpha$$

* RMS output voltage

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

$$V_{or} = \sqrt{\frac{V_m^2}{\pi} \int_{\alpha}^{\pi + \alpha} \left[\frac{2 - \cos 2\omega t}{2} \right] d\omega t}$$

$$V_{or} = \sqrt{\frac{V_m^2}{\pi} \left[\frac{\omega t}{2} - \frac{\sin 2\omega t}{4} \right]_{\alpha}^{\pi + \alpha}}$$

$$V_{or} = \frac{V_m}{\sqrt{2}}$$

* output current;

$$I_{dc} = \frac{V_{dc}}{R} = \frac{2V_m}{\pi R} [\cos \alpha]$$

* output power =

$$P_{o(dc)} = V_{o(dc)} \times I_{dc}$$

* 3.4 Three phase full wave controlled bridge rectifier \Rightarrow

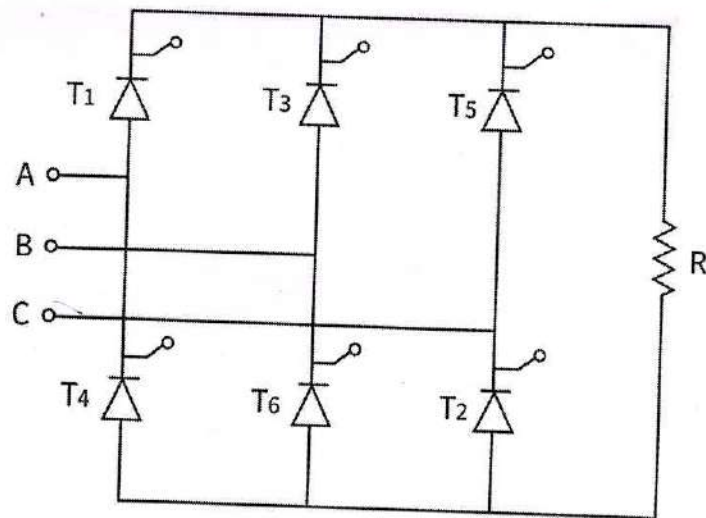


Fig. 1. - Circuit Diagram of Three phase full wave controlled bridge rectifier with R load

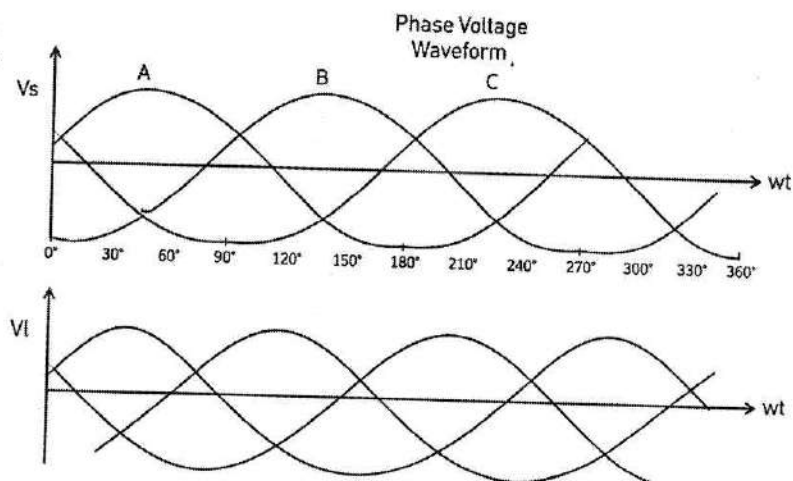


Fig. -2 Phase voltage and Line voltage waveform

\rightarrow Fig. ① shows a 3 ϕ full wave controlled bridge rectifier with a resistive load. It consist of 3 ϕ AC voltage: phase A, B, C each displaced by 120° .

- Six SCR's are used: T_1, T_3, T_5 (upper group) and T_4, T_6, T_2 (lower group)
- The circuit operates by triggering one SCR in the upper leg and one in the lower leg simultaneously to create conducting path for current.
- The conduction sequence follows a cyclic pattern involving pairs of SCR's: $6 \& 1 \rightarrow 1 \& 2 \rightarrow 2 \& 3 \rightarrow 3 \& 4 \rightarrow 4 \& 5 \rightarrow 5 \& 6 \rightarrow$ Repeat
- Fig-2 shows phase voltage and line voltage waveform.

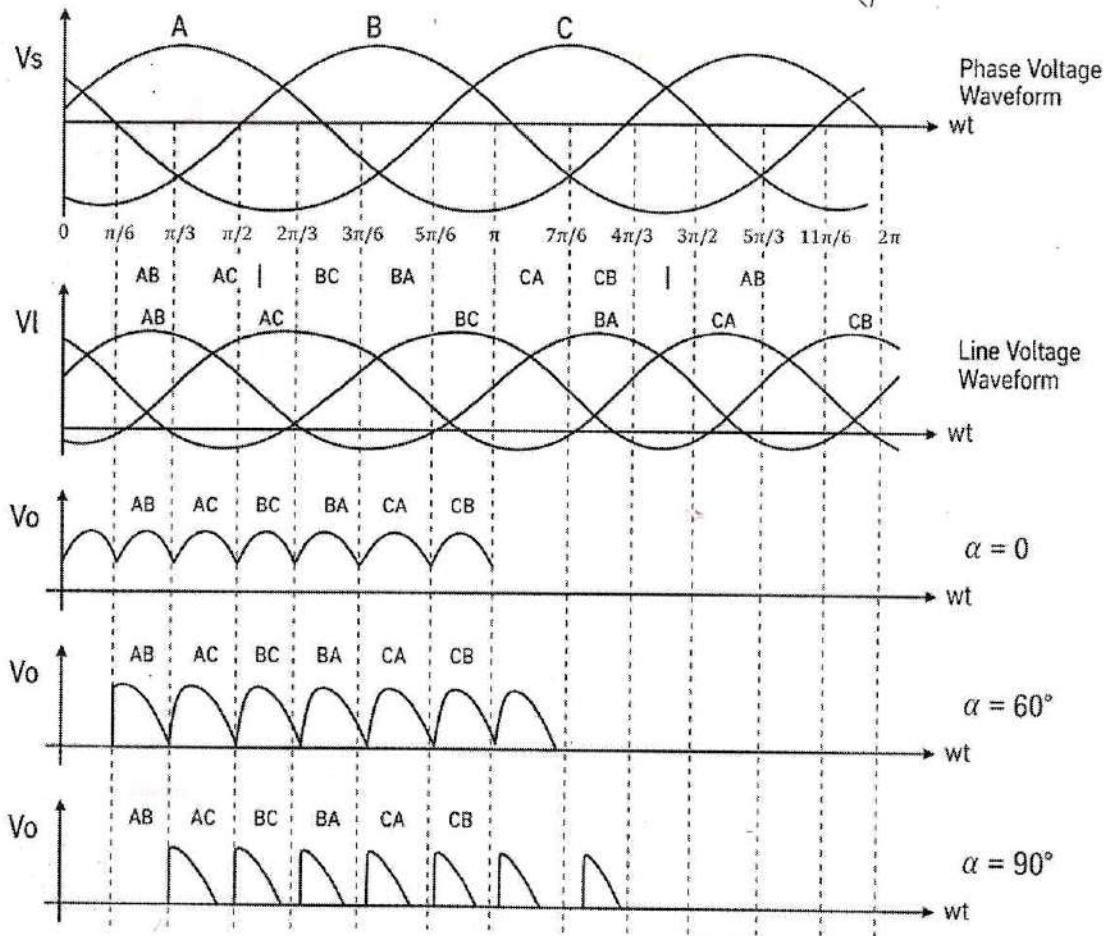


Fig. I/P- o/p waveform of 3φ Full wave Controlled bridge Rectifier with R Load.

→ Three phase voltages are described as -

$$V_a = V_m \cdot \sin(\omega t)$$

$$V_b = V_m \cdot \sin(\omega t - 120^\circ)$$

$$V_c = V_m \cdot \sin(\omega t - 240^\circ)$$

$$V_o = V_{ab} = V_a - V_b = V_m \cdot \sin(\omega t) - V_m \cdot \sin(\omega t - 120^\circ)$$

$$V_{ab} = \sqrt{3} \cdot V_m \cdot \sin(\omega t + 30^\circ)$$

→ Line voltages themselves are 120° apart, each leading their corresponding phase voltages by 30° ,

- Minimum firing angle is 30° , meaning SCR's can not be triggered before 30° because other phases would have higher voltages.
- In this topic three cases of firing angle :-
 - $\alpha = 0$ (effective start at 30°)
 - $\alpha = 60^\circ$ (effective start at 90°)
 - $\alpha = 90^\circ$ (effective start at 120°)

* At $\alpha = 0$, The output voltage follows the line voltage waveform continuously, resulting in a continuous output voltage waveform.

* At $\alpha = 60$

→ The output voltage waveform is delayed and starts at 90° . The output voltage waveform shows periods of zero voltage as the SCR do not conduct when the line voltage is negative or below the threshold.

→ This result in discontinuous output voltage with intervals where voltage drops to zero.

* At $\alpha = 90$:-

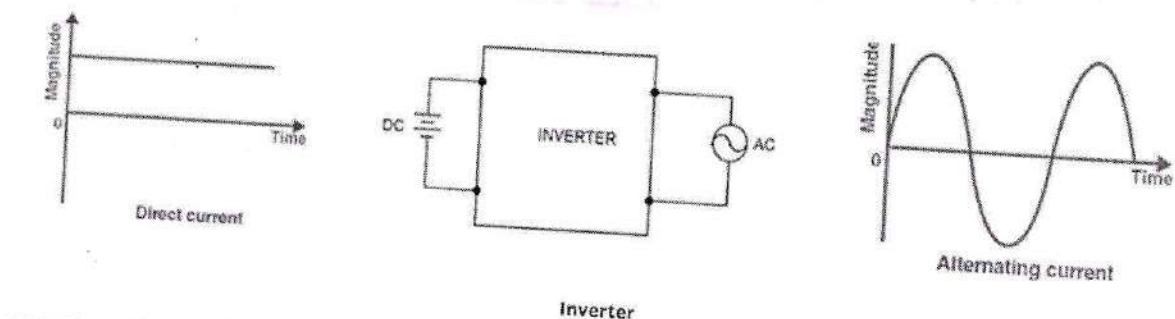
→ The output voltage starts even later, at 120° .

→ The conduction interval become shorter, and the output voltage waveform contains larger zero voltage intervals.

→ The SCR do not conduct during negative lines voltages, causing the output voltage to be zero in these intervals.

3.5 - Inverters

An Inverter is a power electronics device, used to convert fixed DC (Direct Current) into controlled AC (Alternating Current)



* Detailed classification of Inverters :-

- 1) According to output characteristics
 - a) Square wave inverter.
 - b) Sine wave inverter.
 - c) modified sinewave inverter.
- 2) According to the source of inverter
 - a) current source inverter.
 - b) voltage source inverter.
- 3) According to type of load
 - a) Single phase Inverter.
 - i) Half bridge inverter
 - ii) full bridge inverter.
 - b) Three phase Inverter
 - i) 180 degree mode inverter.
 - ii) 120 degree mode inverter.
- 4) According to PWM techniques
 - a) Single Pulse width modulation (SPWM)
 - b) multiple Pulse width modulation (MPWM)
 - c) Sinusoidal Pulse width modulation (SPWM)
 - d) modified sinusoidal Pulse width modulation (MSPWM)
- 5) According to the connection
 - i) series Inverters.
 - ii) Parallel inverters.

* Concept of voltage source Inverters \Rightarrow (VSI)

- \rightarrow voltage source inverter is an Inverter where the input DC voltage is considered as a constant voltage source.
- \rightarrow In VSI input voltage is kept constant. VSI is fed from a DC voltage source having negligible or zero impedance.
- \rightarrow so, to make a VSI we connect a DC source in parallel with large capacitors that maintained input voltage constant.
- \rightarrow In case of VSI an output voltage is independent of load.
- \rightarrow Here, the waveform of the load current as well as its magnitude depends upon the nature of load impedance.

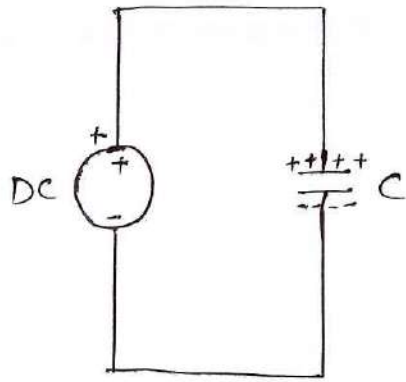


Fig. Voltage Source Inverter.

- In Voltage Source Inverter (VSI) we use power semiconductor switching devices in the circuit like power BJT, Power MOSFET, IGBT having self commutation properties.
- VSI drives are more efficient than CSI design. This is because in VSI drives we use IGBT switching devices that is more efficient than the GTO or SGT devices used in CSI versions.

* Concept of Current Source Inverter (CSI)

- They are also called Current fed inverter. An ideal current source has infinite internal resistance, so current supplied remains constant.
- In a CSI, the DC source has very high internal resistance. Therefore, the DC source behaves as a current source.
- To obtain a constant current source in a CSI, a large series inductor is connected with the DC source.
- In a current source inverter, the DC source, the DC source has very high internal resistance, which provide a constant current.
- In a CSI, the ~~at~~ output current does not depend on the load impedance.
- Thyristors are generally used as switching devices in a CSI.
- The inverter output voltage varies according to the load impedance.
- Even if a short circuit occurs in the circuit, the current does not increase significantly, therefore, short circuit protection is generally not required.
- CSI is not suitable for multimotor drive.

* Difference between VSI and CSI →

VSI (Voltage Source Inverter)	CSI (Current Source Inverter)
1. In voltage source inverter input voltage is kept constant.	1. In current source inverter input current is kept constant.
2. VSI is fed from a DC voltage source having small or negligible impedance.	2. CSI is fed with adjustable current source from a DC voltage source of high impedance.
3. DC source in parallel with large capacitor.	3. VSI can be converted into CSI, By connecting large series inductance.
4. Input voltage is maintained constant.	4. The input current is constant but adjustable.
5. An output voltage is independent of load.	5. An output current is independent of load
6. The waveform of the load current as well as its magnitude depends upon the nature of load impedance.	6. The magnitude of output voltage and its waveform depends upon the nature of the load impedance.
7. VSI has slow response than CSI.	7. CSI has fast response than VSI.
8. VSI requires feedback diodes	8. The CSI does not require any feedback diodes.
9. The commutation circuit is complicated. It uses current commutation.	9. Commutation circuit is simple as it contains only capacitors. It uses voltage commutation.
10. Power BJT, Power MOSFET, IGBT with self-commutation can be used in the circuit.	10. Thyristors are Used.
11. In VSI diodes are connected in parallel.	11. In CSI diodes are connected in series.
12. PWM technique is used.	12. PWM technique is not used.

* 3.6.1 → 1 ϕ half waver bridge inverter with R Load :->

* Circuit working :- Half wave bridge inverter with R load as shown in fig. The circuit consist of SCR T_1 and T_2 , two feedback diodes D_1 and D_2 , two equal DC sources $V_s/2$ and Load Resistance R .

→ The load is connected between the midpoint of the DC supply and the midpoint of the inverter switches.

→ circuit configuration is shown below :-

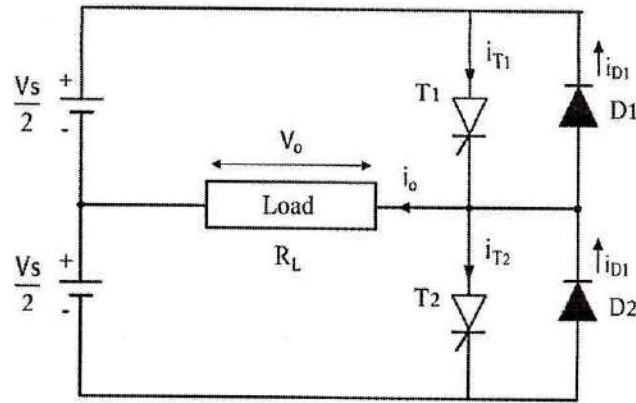


Fig. -1 Single phase half wave bridge inverter with R

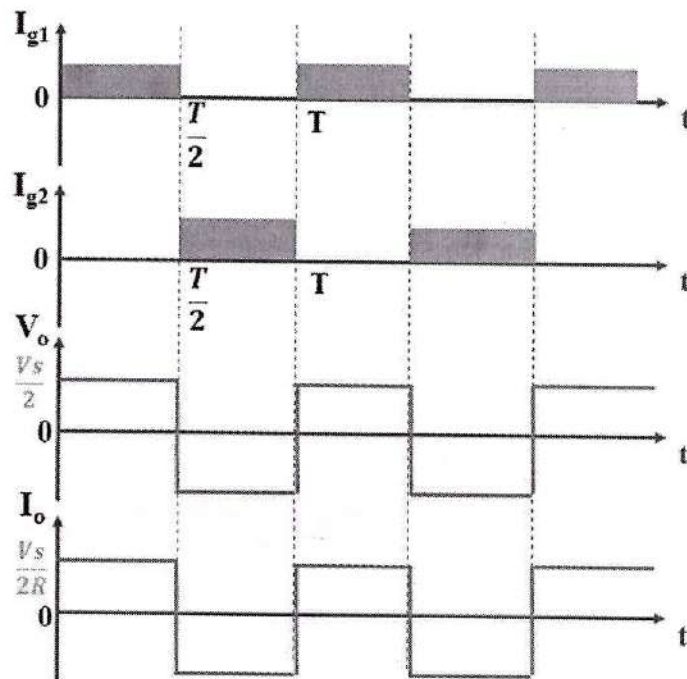


Fig. 2 waveform – Single phase half wave bridge inverter waveform (R Load)

* Working: Mode-① $0 < t < T/2$ (Thyristor T_1 is ON and T_2 is off)

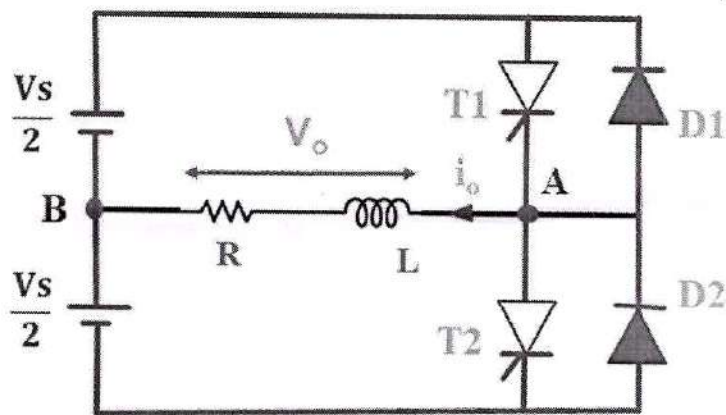
- At this interval, gate pulse is applied to T_1 , so T_1 turns ON and T_2 remains OFF.
 - Current path: $+V_s/2 \rightarrow T_1 \rightarrow \text{Load} \rightarrow \text{Neutral Point} \rightarrow \text{Source}$.
The current flow in upper half circuit and flow the path.
 - direction of output current is +ve and output voltage is also positive.
 - The magnitude of output voltage $V_o = \frac{V_s}{2}$
 - The magnitude of output current $I_o = \frac{V_o}{R} = \frac{V_s}{2R}$
- Load is resistive so, current and voltage are in phase.

* Mode ② $T_1 < t < T$ ($T_1 = \text{off}$ and $T_2 = \text{ON}$) \rightarrow

- \rightarrow At instant $t = \frac{T}{2}$ gate signal is removed from T_1 and it turns off and T_2 will turn ON.
- \rightarrow Current path - Neutral \rightarrow Load $\rightarrow T_2 \rightarrow -V_s/2$, polarity across the load reverses.
- \rightarrow magnitude of output voltage = $V_o = -\frac{V_s}{2}$
- \rightarrow magnitude of output current = $\frac{V_o}{R} = -\frac{V_s}{2R}$
- \rightarrow By alternately turning ON T_1 and T_2 for equal intervals (180° each), the inverter converts the DC input into a square wave AC output.
- \rightarrow For a pure R load, the output current follows the output voltage exactly and remains in phase with it.

* 3.6.2 single phase half wave bridge inverter with RL Load:

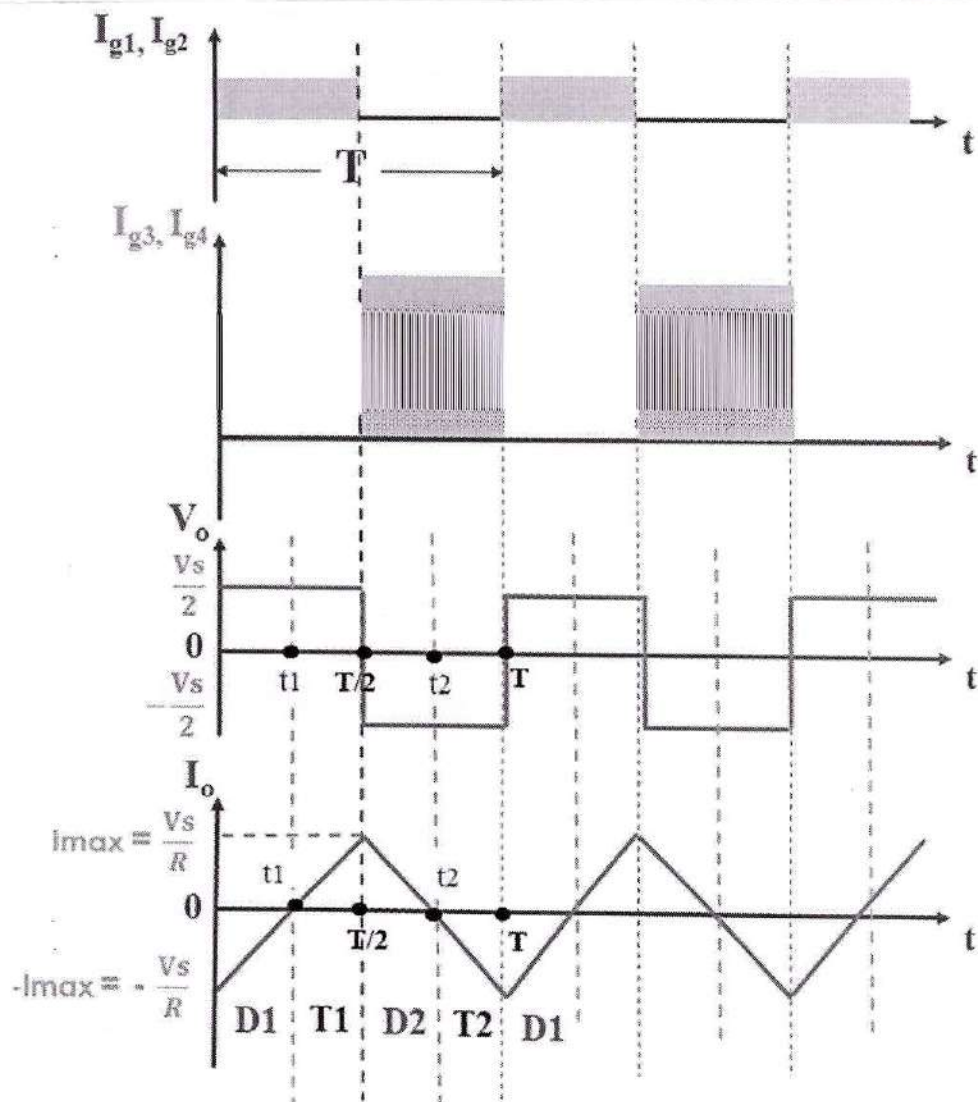
- \rightarrow The circuit shown is 1 ϕ half wave bridge inverter with RL load.
- \rightarrow It converts DC supply (V_s) into an AC square wave output voltage (V_o) using two controlled switches (T_1, T_2) and two feedback diodes (D_1, D_2) for inductive load current continuity.



Circuit Diagram Of Single Phase half Bridge With RL Load

- \rightarrow Circuit description: From the diagram DC source is split into $+V_s/2$ and $-V_s/2$.
- \rightarrow T_1 is upper switch and T_2 is lower switch connected to load $+V_s/2$ and $-V_s/2$ respectively.
- \rightarrow D_1 and D_2 are antiparallel diodes for freewheeling.
- \rightarrow Load is RL series combination

* Working: The inverter works by turning T_1 & T_2 alternately on and off, producing an AC output.



Wave Form Single Phase Full Bridge VSI (RL Load)

→ The operation of Half wave bridge inverter - RL Load is divided into four modes -

* Mode - ① - $t_1 < t < T/2$ - T_1 ON

→ In this mode T_1 is ON and T_2 is off.

→ Current flows: $+V_s/2 \rightarrow T_1 \rightarrow$ Load (R-L) \rightarrow Midpoint B

→ Current I_o lags behind voltage. Even after T_1 turns OFF, current continues due to stored energy in L.

→ This current flows through diode D_2 (free-wheeling path)

* Mode - ② $T/2 < t < t_2$ Freewheeling Interval :

→ T_1 off, but current in L cannot change instantly,

→ Current continuous in same direction through: Load $\rightarrow D_2 \rightarrow$ lower supply rail.

→ This prevents sudden interruption of current.

* Mode - ③ T_2 is ON (negative half cycle)

→ T_2 is turned ON, T_1 is off.

→ Load terminal A is connected to $-V_s/2$.

→ Current flows in reverse direction: $-V_s/2 \rightarrow T_2 \rightarrow$ Load $\rightarrow B$

→ current lags voltage due to inductance.

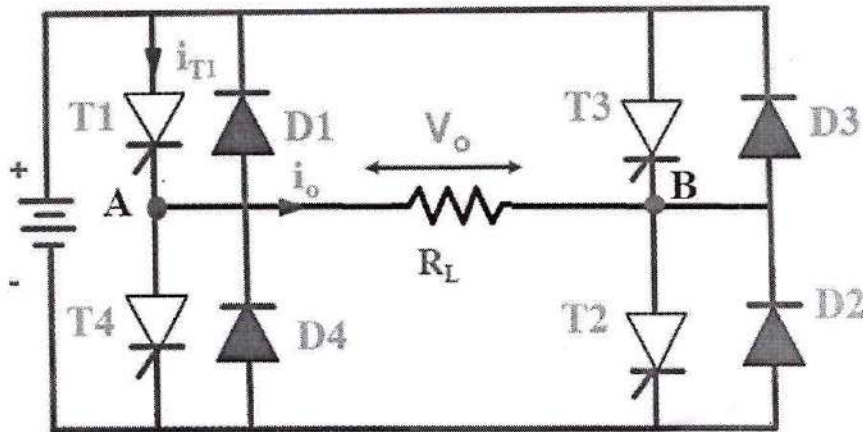
* mode - 4) Free-wheeling after T_2 off

→ when T_2 turns off, inductive current continues. It flows through D_1 (upper diode)

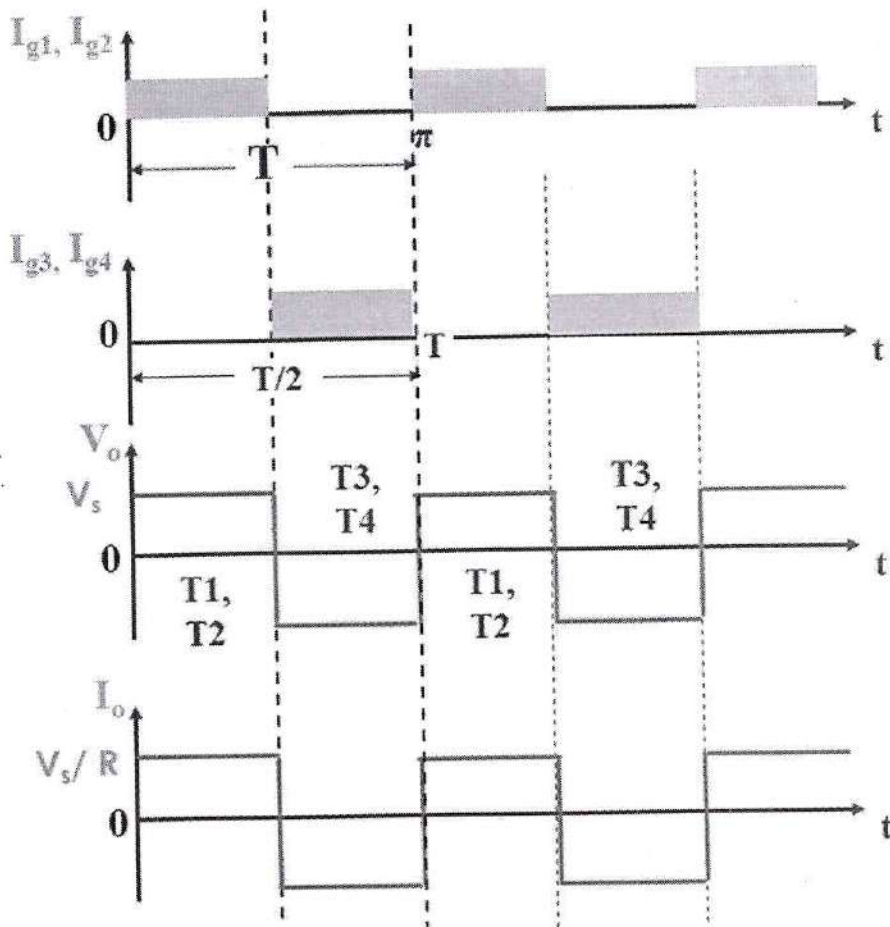
→ Ensures smooth current continuity.

→ This circuit produces AC square-wave voltage by alternately switching T_1 and T_2 .

* 3.7.1 Single phase full wave bridge inverter with R load :



Circuit Diagram of Single-Phase Full Bridge Inverter with R Load



Waveform of Single-Phase Full Bridge Inverter with R Load

- 1 ϕ Full ~~wave~~ bridge inverter basically consists of of SCR's (T_1-T_4) and four diode (D_1 to D_4) these diodes are called feedback diode.
- These diodes functions only when load is other than resistive load. Each diode connected in antiparallel with each SCR.
- Fig. ① shows circuit configuration of full wave bridge inverter with R-load.

→ The voltage and current waveforms for a resistive load are as shown in fig. ②. The bridge inverter operates in two modes within one cycle of the output.

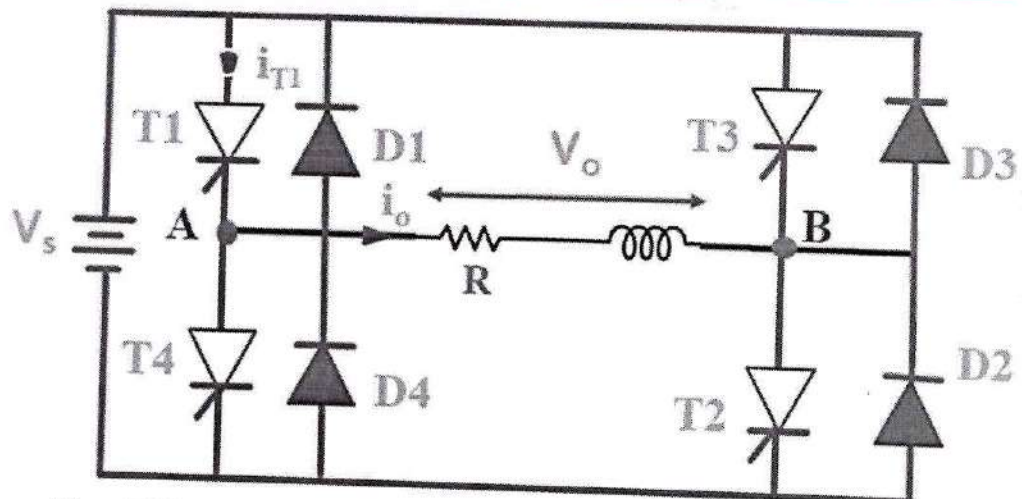
* Mode-I ($0 < t < T/2$)

- In this mode, switches T_1 and T_2 conduct simultaneously. The load voltage is $+V_s$.
- At $t = T/2$, switches T_1 and T_2 are turned off and T_3, T_4 are turned on.

* mode-II ($T/2 < t < T$) :-

- When $t = T/2$, switches T_3 and T_4 are turned on, and T_1 and T_2 are turned off.
- The load voltage becomes $-V_s$. When $t = T$, switches T_3 and T_4 are turned off, and T_1 and T_2 are again turned on.
- Since the load is resistive, it does not store any energy. Therefore feedback diodes do not play any significant role.
- The output is a square wave AC voltage, and for an R load, current is in phase with voltage.

* 3.7.2 Single phase full wave bridge inverter with RL load :-



Circuit Diagram of Single Phase Full Bridge Inverter with RL Load

→ The circuit for full bridge inverter with RL load connected between points A and B.

→ It converts DC input voltage (V_s) into AC output voltage (V_o) by controlled switching of four devices.

1) T_1, T_2, T_3, T_4 (Power switches)

2) D_1, D_2, D_3, D_4 (Feedback diodes) connected in antiparallel combination.

* Circuit operation is explained in four modes :->

1) mode-1 ($t_1 < t < t_2$) :->

→ At instant t , T_1 and T_2 are turned ON, and output voltage is $+V_{dc}$.

→ Due to the inductive nature of load, current gradually increases. The instantaneous load current through T_1 and T_2 is equal to the load current.

→ During this interval, energy is stored in the load inductance.

2) mode-2 ($t_2 < t < t_3$) :-

→ Both switches T_1 and T_2 are suddenly turned off at t_2 . Due to inductive nature of load, the load current does not become immediately zero.

→ The output voltage becomes $V_o = -V_{dc}$. The load current continues to flow through diode D_3 and D_4 , in the same direction.

→ Thus, in this mode, the energy stored in the load inductance is fed back to the source. The diode D_3 and D_4 turned off.

3) mode-3 ($t_3 < t < t_4$) :->

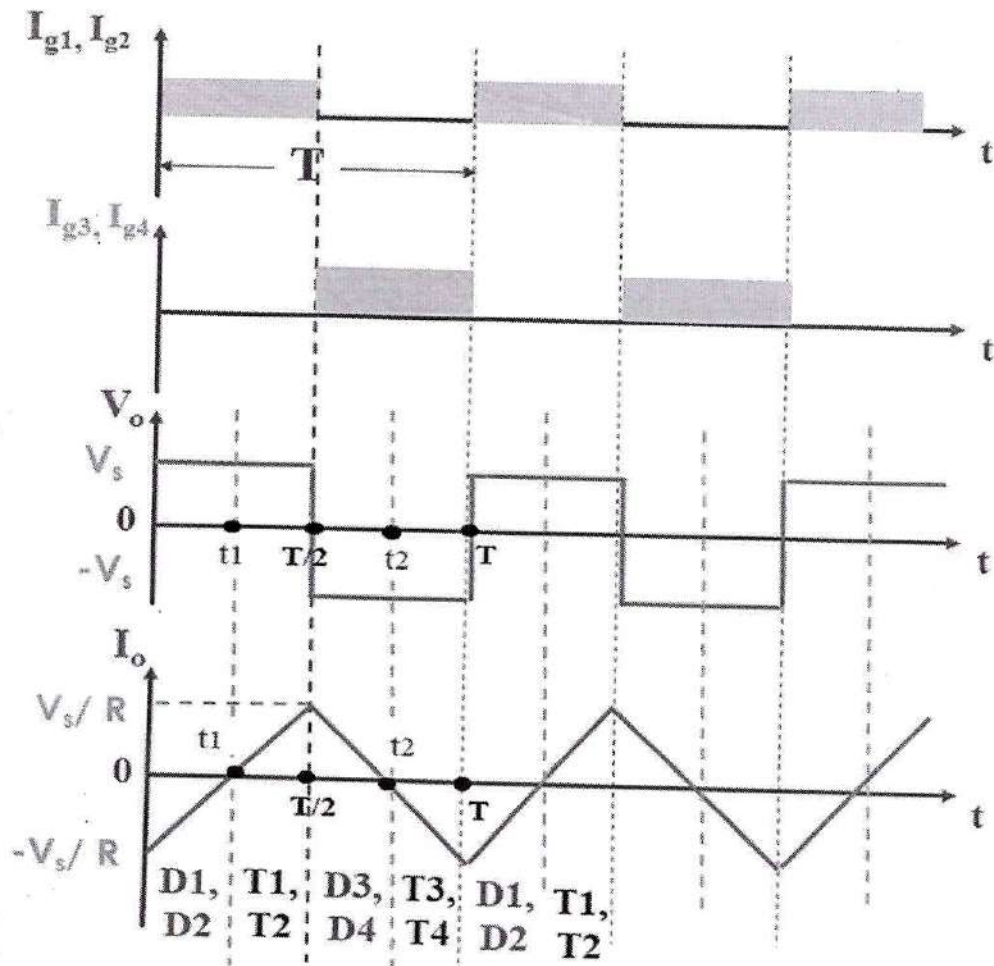
→ When switches T_3 and T_4 are turned off simultaneously, the load voltage remains negative, but the direction of load current starts to reverse.

→ At the same time, current in the opposite direction gradually increases, and the load again stores energy.

4) mode-4 ($t_4 < t < t_1$) :->

→ switches T_3 and T_4 are turned off at t_4 . The load inductance.

- tries to maintain current by inducing a positive voltage.
- Diode D_1 and D_2 become forward biased and the energy stored in the load is returned to the DC source.
 - During this mode, $V_o = +V_s$, but load current is still -ve and gradually decreases to zero, and switches T_1 and T_2 can be turned ON again.



Wave Form of Single Phase Full Bridge Inverter with RL Load

* 3.8 Pulse width modulation :->

Pulse width modulation is a technique used to regulate the amount of power delivered to an electrical load by controlling the duration for which a signal stays on and off.

* Importance/Need of PWM :->

- 1) Efficiency :- PWM allows switching between fully ON and fully OFF states at high speed, enabling efficient power transfer and

reducing power losses.

- 2) Precise Control :- PWM accurately controls the average voltage or current supplied to the load by adjusting the duty cycle of the signal.
- 3) Voltage Regulation :- PWM can regulate voltage or current levels without dissipating excess energy as heat, unlike resistive control methods.
- 4) PWM is used in Digital to Analog Converters to generate analog voltage levels from digital signals.

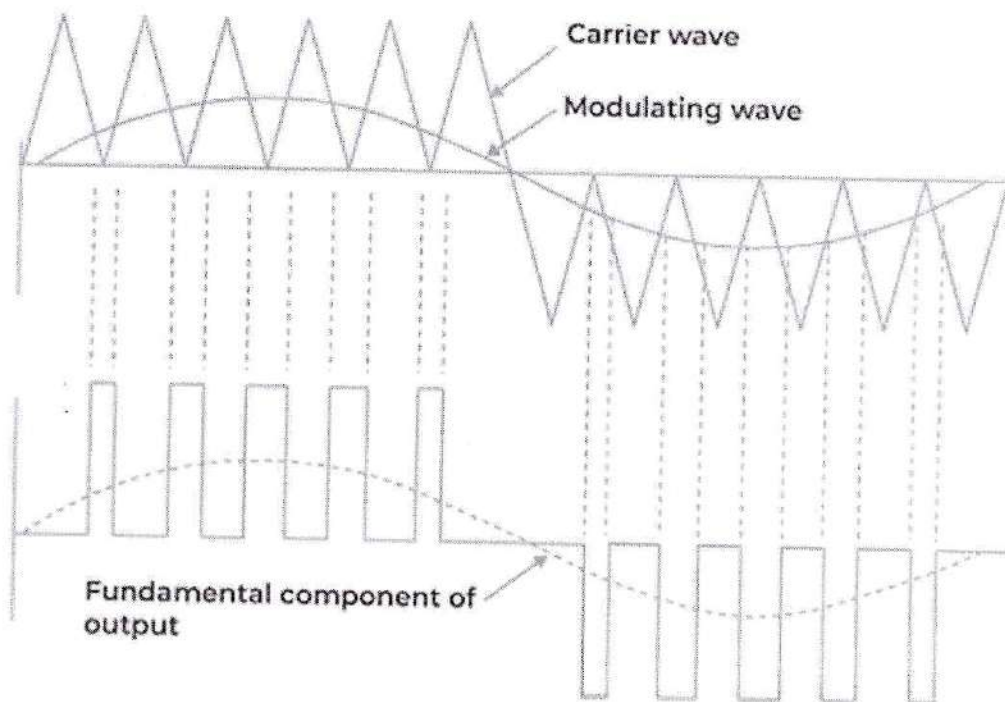
* Types of PWM :->

- 1) Single Pulse width modulation.
- 2) Multiple Pulse width modulation.
- 3) Sinusoidal pulse width modulation.

* Sinusoidal Pulse Width Modulation :- Concept

Sinusoidal Pulse width modulation (SPWM) is a technique used to generate a waveform similar to sinusoidal waveform.

In this method, the pulse width of a triangular carrier wave is varied according to a sinusoidal reference signal.



Working :->

1) Carrier signal Generation :- A triangular carrier waveform is

generated, which serves as the basis for PWM signal.

2) Reference signal generation :-

Sinusoidal reference signal is generated, which represents the desired output waveform to be produced.

3) Comparison :-

The amplitude of the sinusoidal reference signal is compared with the triangular carrier waveform.

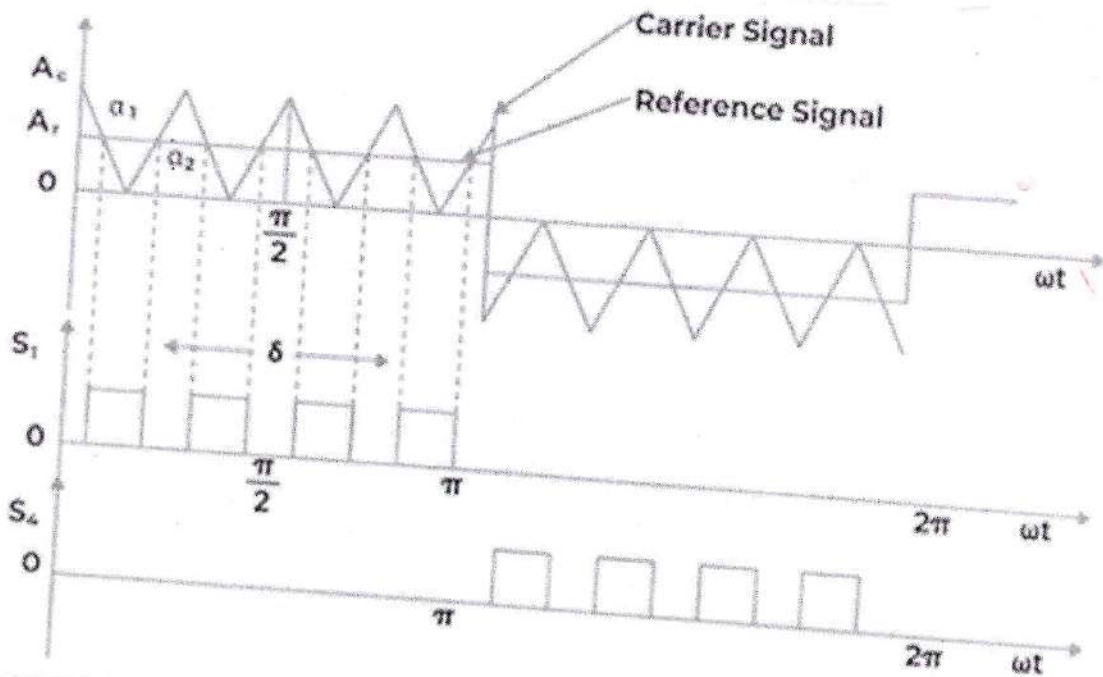
4) Pulse width modulation :-

- i) when sinewave amplitude higher - pulse width increases.
- ii) when sinewave amplitude lower - pulse width decreases.

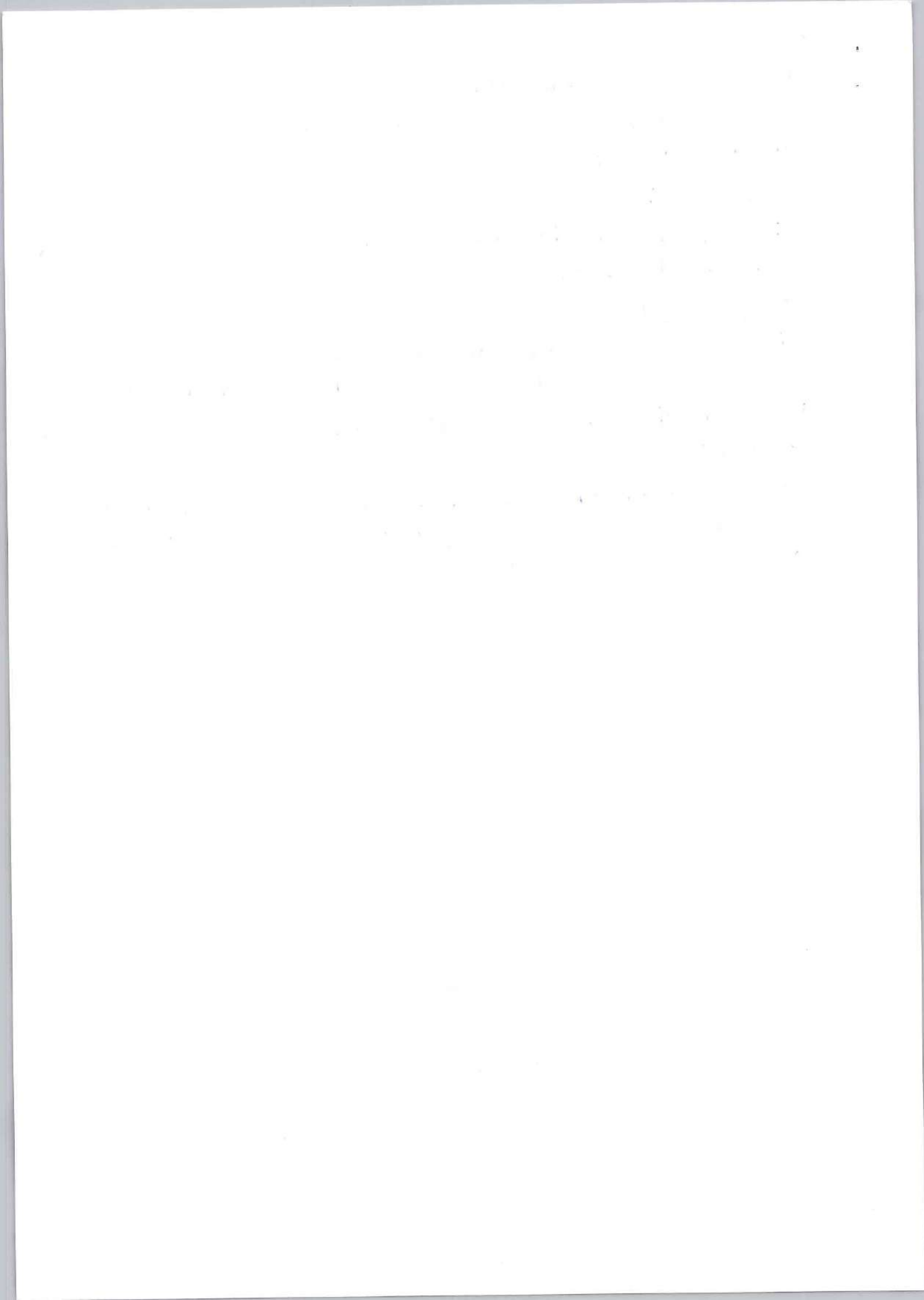
Based on this comparison, the width of pulses is modulated.

5) output :-

The modulated PWM signal, when passed through a low pass filter, produces an output waveform that closely matches the desired sinusoidal waveform.



* * * * *





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QUESTION BANK/ASSIGNMENT -03

Course & Code: EE-3K

Semester: Third

Name of Subject: Fundamentals of Power Electronics

Subject Code: 313325

Que. No.	Unit 3 Controlled Converters (22 Marks)	Exam	Marks
1	Compare Symmetrical and Asymmetrical Halfly Controlled Rectifier.	W-22	4
2	Draw and explain 1ϕ midpoint-controlled rectifier with Resistive load. Also draw input, output waveform of it.	S-24 W-22	4/6
3	Explain with circuit diagram the operation of single phase fully controlled bridge rectifier with R-load.	W-24 W-23 S-24	4
4	Compare Half and Full converter (any 4 points).	W-24	4
5	Draw a neat circuit diagram of 1ϕ half-controlled rectifier with R-L load. Write its operation.	W-24 S-24	4
6	Explain with neat circuit operation of 1ϕ full bridge inverter with R-L load.	W-24	4
7	Draw the circuit diagram of pulse width modulator. Explain the working principle and draw the output waveforms.	W-24	4
8	Draw a neat circuit diagram and waveforms for half converter with R-L load and free-wheeling diode. Explain its working.	W-24	6
9	Describe with neat circuit and waveforms of $1-\phi$ Half bridge inverter with R-load.	W-24	6
10	Draw full bridge and half bridge configuration with common cathode.	S-24	4
12	Explain the operation of single phase fully controlled midpoint configuration rectifier with RL load.	W-23 S-22	4
13	Draw and explain the working of $1-\phi$ half wave-controlled rectifier with RL load. Explain the effect of freewheeling diode.	W-23	6
14	State classification of phase-controlled rectifier. Also differentiate between controlled and uncontrolled rectifiers (4 points).	W-23 W-22	6/4
15	Give importance of free-wheeling diode in controlled Rectifier.	W-22	4
16	Draw and describe 1ϕ Bridge Controlled Rectifier in common anode connection.	W-22	4
17	Draw and describe 1ϕ fully controlled bridge with inductive load. Draw input and output waveform.	W-22	6
18	Explain with circuit diagram the operation of single-phase full bridge-controlled rectifier with R load.	S-23	4



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19	<p>Draw waveform of the following power electronic circuit. Also identify the name of the circuit. Refer Fig. No. 01</p> <div style="text-align: center;"> <p style="text-align: center;">Fig. No. 01</p> </div>	S-23	4
20	Draw a neat diagram of 1 ϕ half wave-controlled converter with RL load. Give its operation.	S-23	4
21	State the effect of source inductance in controlled rectifier with waveform.	S-23	4
22	Explain the operation of single-phase half-controlled rectifier with RL load.	S-22	4
23	State the effect of source inductance in controlled rectifies with waveforms.	S-22	6
24	Justify with sketches the effect of freewheeling diode in a fully controlled rectifier with RL load.	S-22	6
