MODULE 2

PHASE CONTROLLED RECTIFIER

2.1 Introduction

Unlike diode rectifiers, phase controlled rectifiers has and advantage of controlling the output voltage. The diode rectifiers are called uncontrolled rectifiers. When these diodes are replaced with thyristors, then in becomes phase controlled rectifiers. The output voltagecan be controlled by varying the firing angle of the thyristors. These phase controlled rectifiers has its main application in speed control of DC motors.

2.2 Application

- Steel rolling mills, paper mills, textile mills where speed control of DC motors are necessary.
- Electric traction.
- High voltage DC transmission
- Electromagnet power supplies

In this module, the following categories of phase controlled rectifiers will be studied in detail.

1. Single Phase Half Wave Controlled Rectifier with R Load.
2. Single Phase Half Wave Controlled Rectifier with RL Load.
3. Single Phase Half Wave Controlled Rectifier with RL Load and Freewheeling Diode.
4. Single Phase Full Wave Controlled Rectifier with R Load.
5. Single Phase Full Wave Controlled Rectifier with RL Load.
6. Single Phase Full Wave Controlled Rectifier with RL Load and Freewheeling Diode.
7. Single Phase Full Wave Half Controlled Rectifier (Semi Converter).
8. Three Phase Half Wave Controlled Rectifier.
9. Three Phase Full Wave Controlled Rectifier

important terms

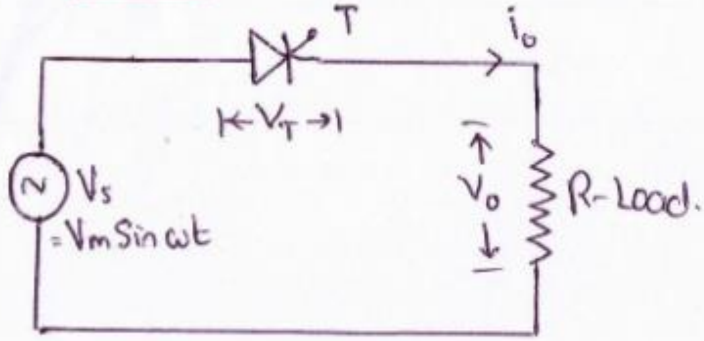
Firing angle : it is the angle at which scr triggers or
angle at which firing pulse (gate pulse) give to scr gate and cathode terminal.
Application of gate signal is also called Firing of SCR

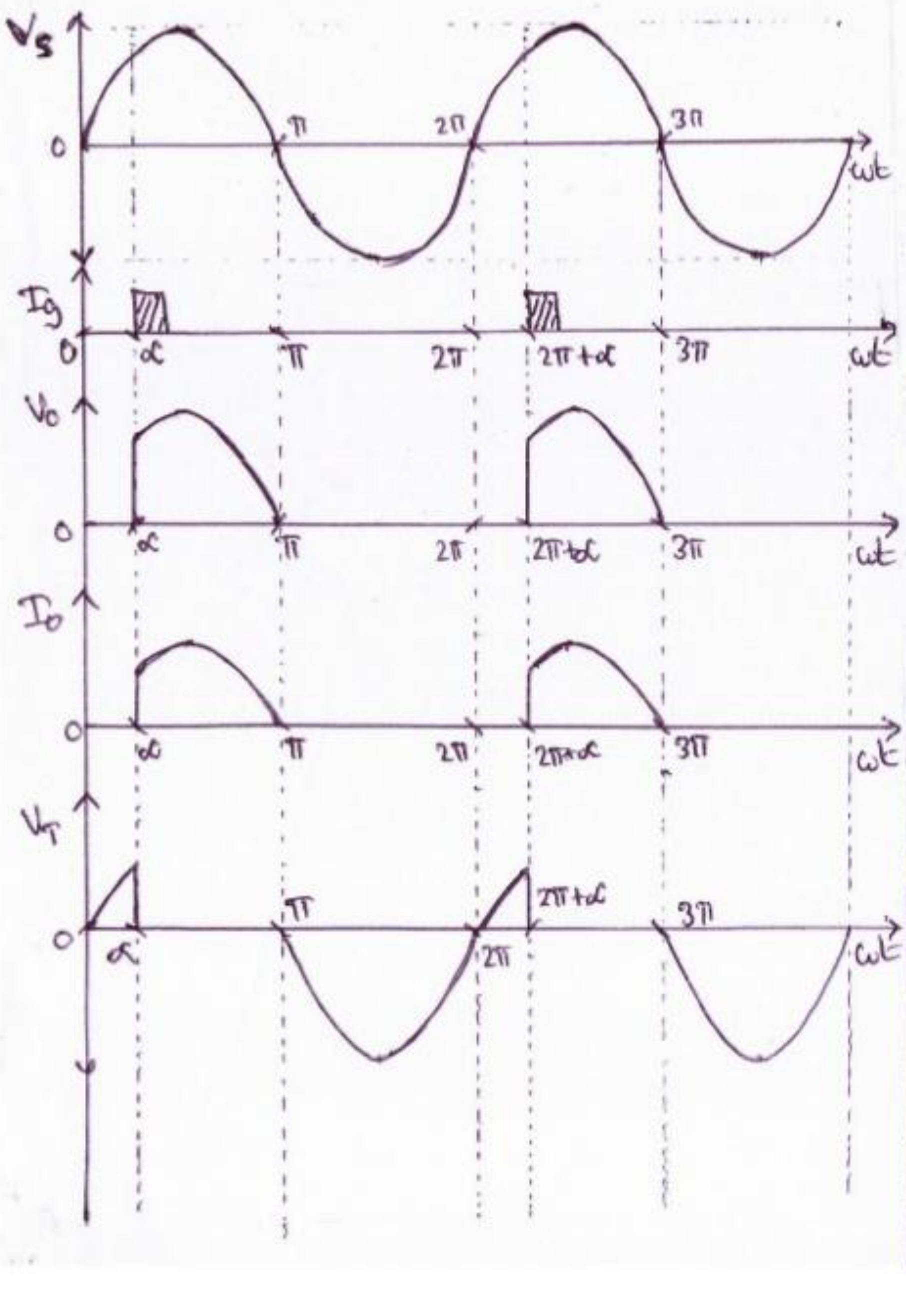
2) Extinction angle : for the rectifier with RL load, the SCR remains in conducting state even the reverse bias condition. this is because of energy stored in the inductor.The angle at which energy stored in the inductor will exhaust is known as extinction angle.
3) Conduction angle: The duration where the thyristors is in on state (conducting state) wherethe output load gets powered, is known as the conduction angle.

2.3 Single Phase Half Wave Controlled Rectifier with R Load

- The circuit consist of a thyristor T, a voltage source Vs and a resistive load R.
- During the positive half cycle of the input voltage, the thyristor T is forward biased but it does not conduct until a gate signal is applied to it.
- When a gate pulse is given to the thyristor T at $\omega t = \alpha$, it gets turned ON and begins to conduct.
- When the thyristor is ON, the input voltage is applied to the load.
- During the negative half cycle, the thyristor T gets reverse biased and gets tuned OFF.
- So the load receives voltage only during the positive half cycle only.
- The average value of output voltage can be varied by varying the firing angle α.
- The waveform shows the plot of input voltage, gate current, output voltage, output current and voltage across thyristor.

R-LOAD

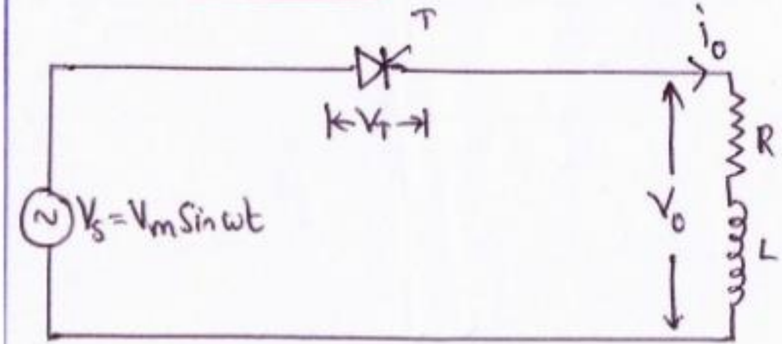

T
i_o
V_T
V_s
$= V_m \sin \omega t$
V_o
R-Load.

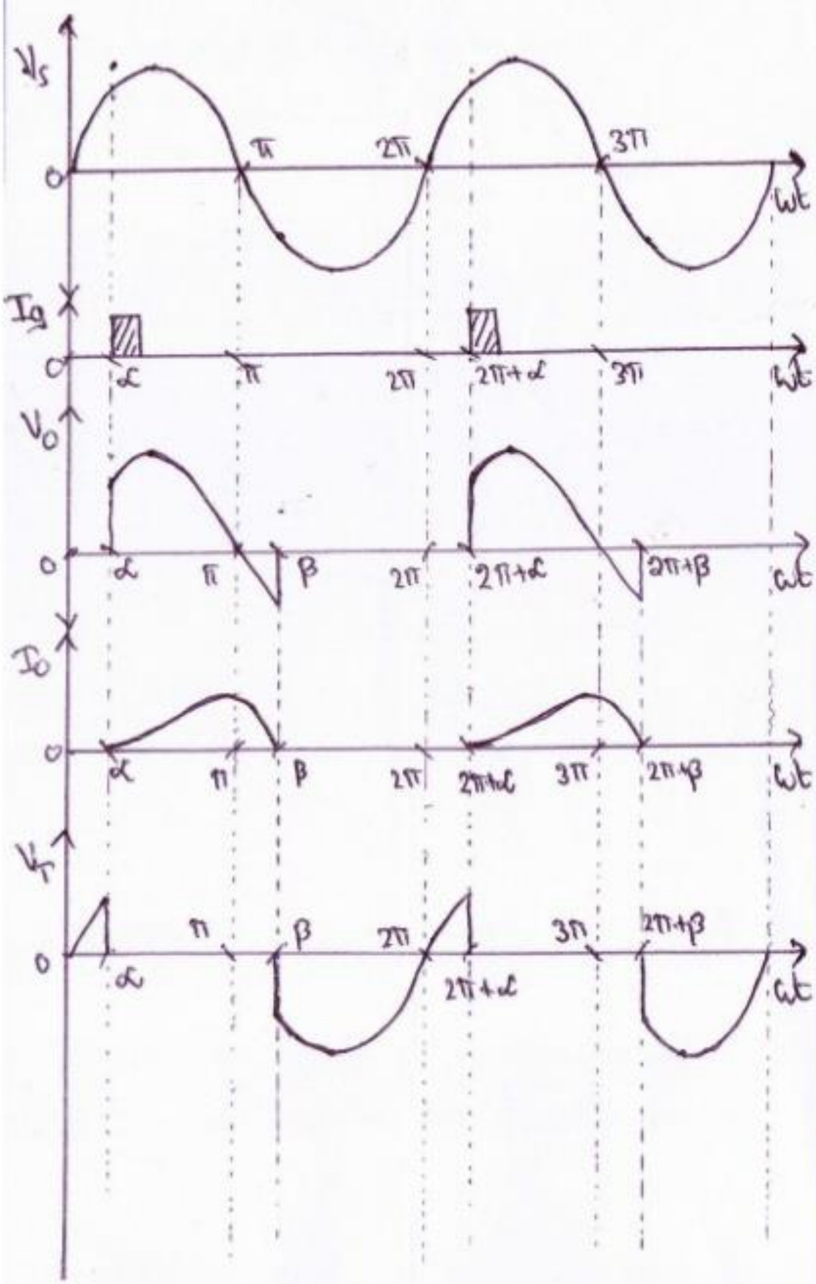

V_s
0
π
2π
3π
ωt
I_g
α
$2\pi+\alpha$
V_o
I_o
V_T

2.4 Single Phase Half Wave Controlled Rectifier with RL Load

- The circuit consist of a thyristor T, a voltage source Vs, an inductive load L and a resistive load R.
- During the positive half cycle of the input voltage, the thyristor T is forward biased but it does not conduct until a gate signal is applied to it.
- When a gate pulse is given to the thyristor T at $\omega t = \alpha$, it gets turned ON and begins to conduct.
- When the thyristor is ON, the input voltage is applied to the load but due to the inductor present in the load, the current through the load builds up slowly.
- During the negative half cycle, the thyristor T gets reverse biased but the current through the thyristors is not zero due to the inductor.
- The current through the inductor slowly decays to zero and when the load current (i.e the current through the thyristor) falls below holding current, it gets turned off.
- So here the thyristor will conduct for a few duration in the negative half cycle and turns off at $\omega t = \beta$. The angle β is called extinction angle.
- The duration from α to β is called conduction angle.
- So the load receives voltage only during the positive half cycle and for a small duration in negative half cycle.
- The average value of output voltage can be varied by varying the firing angle α.
- The waveform shows the plot of input voltage, gate current, output voltage, output current and voltage across thyristor.

RL- LOAD

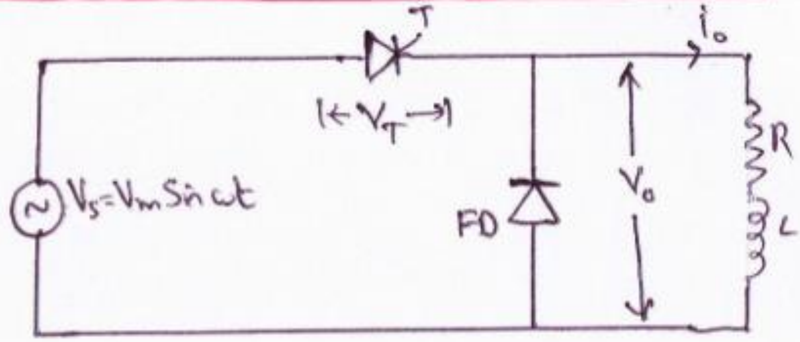


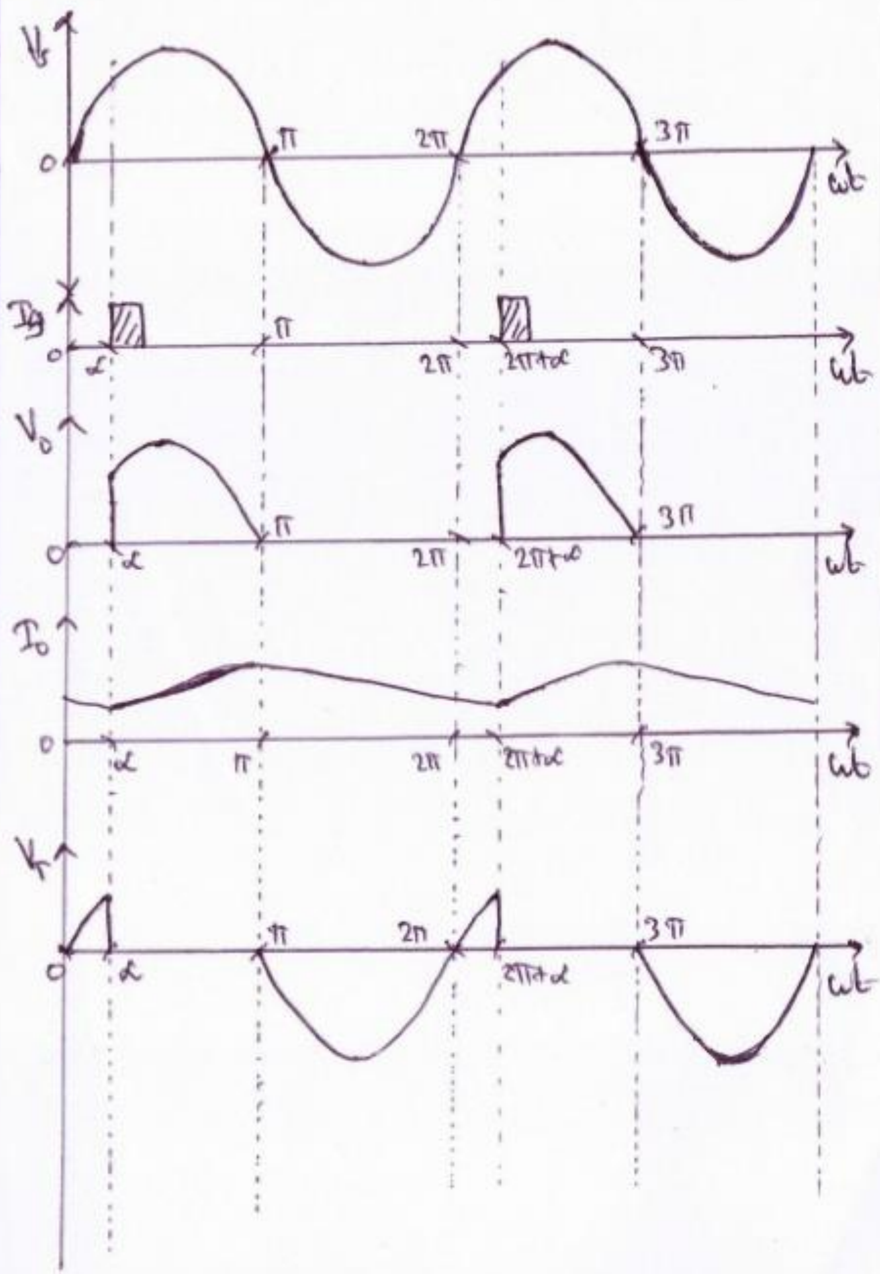


2.5 Single Phase Half Wave Controlled Rectifier with RL Load and Freewheeling Diode

- The circuit consist of a thyristor T, a voltage source Vs, a diode FD across the RL load, an inductive load L and a resistive load R.
- During the positive half cycle of the input voltage, the thyristor T is forward biased but it does not conduct until a gate signal is applied to it.
- When a gate pulse is given to the thyristor T at $\omega t = \alpha$, it gets turned ON and begins to conduct.
- When the thyristor is ON, the input voltage is applied to the load but due to the inductor present in the load, the current through the load builds up slowly.
- During the negative half cycle, the thyristor T gets reverse biased. At this instant i.e at $\omega t = \pi$, the load current shift its path from the thyristor to the freewheeling diode.
- When the current is shifted from thyristor to freewheeling diode, the thyristor turns OFF.
- The current through the inductor slowly decays to zero through the loop R-freewheeling diode-L.
- So here the thyristor will not conduct in the negative half cycle and turns off at $\omega t = \pi$.
- So the load receives voltage only during the positive half cycle.
- The average value of output voltage can be varied by varying the firing angle α.
- The waveform shows the plot of input voltage, gate current, output voltage, output current and voltage across thyristor.

RL-LOAD WITH FREEWHEELING DIODE





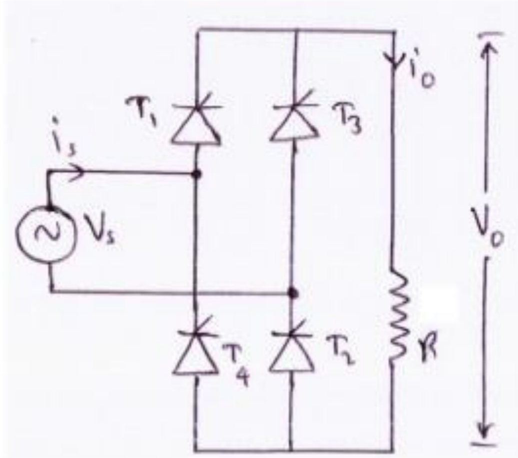
2.6 Single Phase Full Wave Controlled Rectifier with R Load

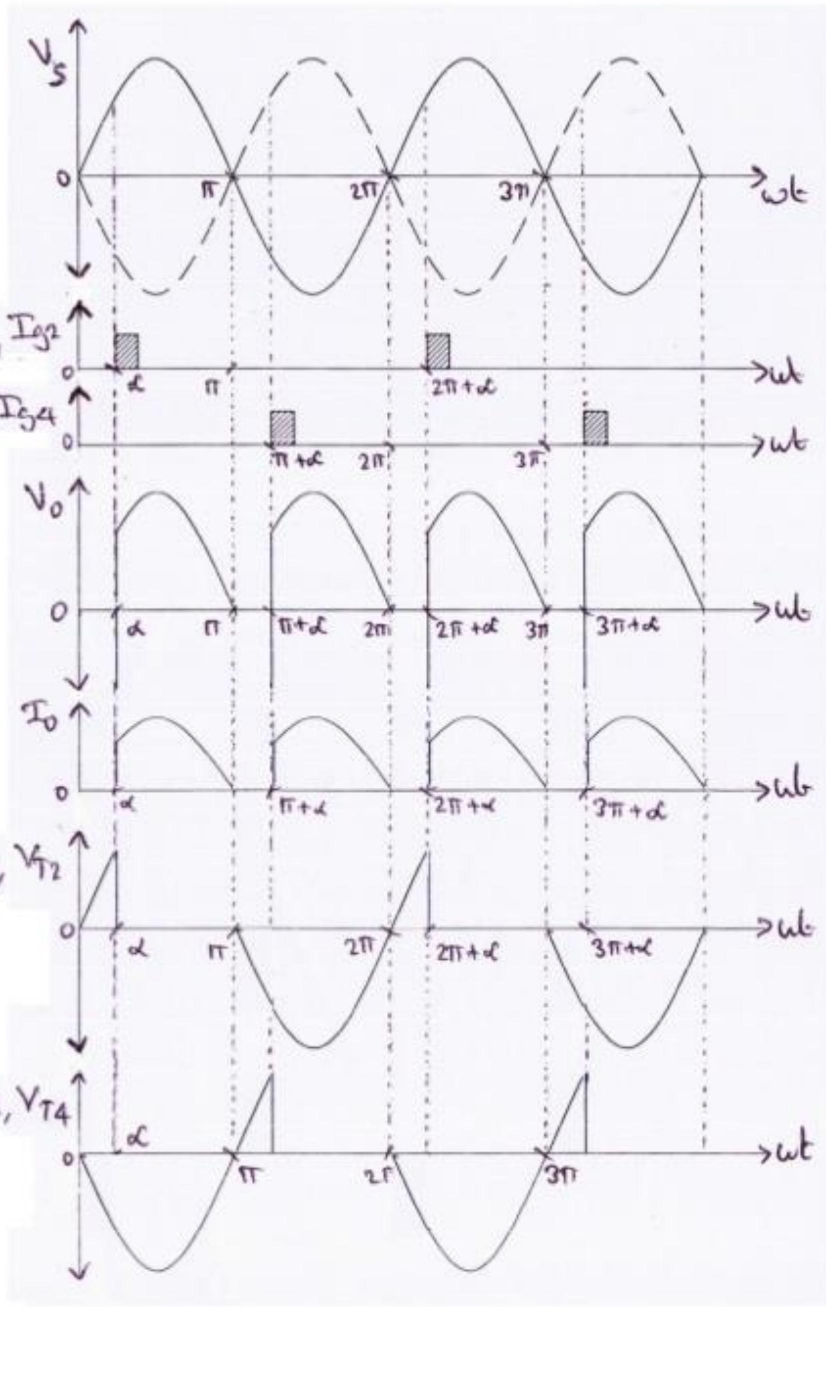
- The circuit consist of four thyristors T1, T2, T3 and T4, a voltage source Vs and a R Load.
- During the positive half cycle of the input voltage, the thyristors T1 & T2 is forward biased but it does not conduct until a gate signal is applied to it.
- When a gate pulse is given to the thyristors T1 & T2 at $\omega t = \alpha$, it gets turned ON and begins to conduct.
- When the T1 & T2 is ON, the input voltage is applied to the load through the path Vs-T1-Load-T2-Vs.
- During the negative half cycle, T3 & T4 is forward biased, the thyristor T1 & T2 gets reverse biased and turns OFF
- When a gate pulse is given to the thyristor T3 & T4 at $\omega t = \pi+\alpha$, it gets turned ON and begins to conduct.
- When T3 & T4 is ON, the input voltage is applied to the load Vs-T3-Load-T4-Vs.
- Here the load receives voltage during both the half cycles.
- The average value of output voltage can be varied by varying the firing angle α.
- The waveform shows the plot of input voltage, gate current, output voltage, output current and voltage across thyristor.

1φ full wave bridge converter

(fully controlled)

R - LOAD



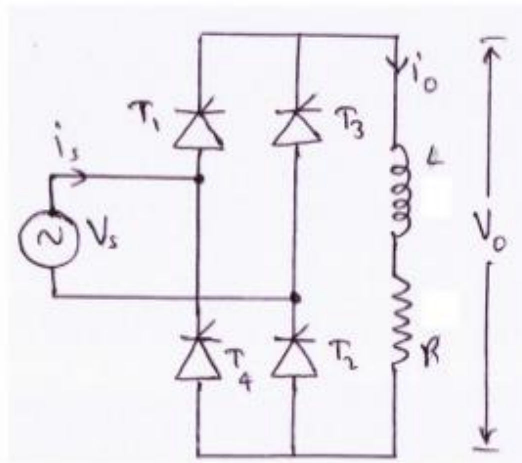


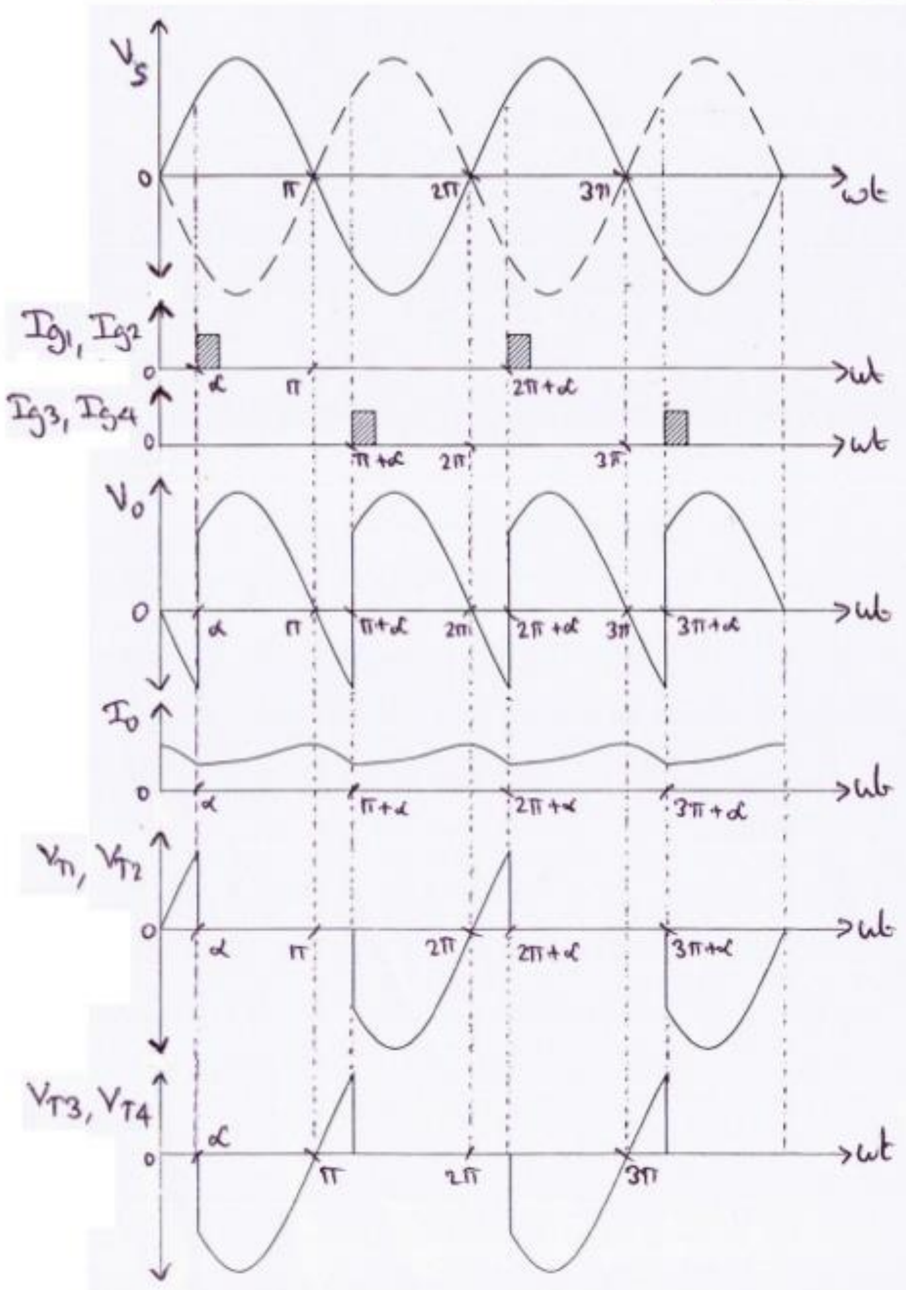
B. BRIDGE CONVERTER

- The circuit consist of four thyristors T1, T2, T3 and T4, a voltage source Vs and a RL Load.
- During the positive half cycle of the input voltage, the thyristors T1 & T2 is forward biased but it does not conduct until a gate signal is applied to it.
- When a gate pulse is given to the thyristors T1 & T2 at $\omega t = \alpha$, it gets turned ON and begins to conduct.
- When the T1 & T2 is ON, the input voltage is applied to the load but due to the inductor present in the load, the current through the load builds up slowly through the path Vs-T1-Load-T2-Vs.
- During the negative half cycle, T3 & T4 is forward biased, the thyristor T1 & T2 gets reverse biased but the current through them is not zero due to the inductor and does not turns OFF
- The current through the inductor begins to decay to zero and T1 & T2 conducts for a small duration in negative half cycle..
- When a gate pulse is given to the thyristor T3 & T4 at $\omega t = \pi+\alpha$, it gets turned ON and begins to conduct.
- When the thyristor T3 & T4 is ON, the load current shifts its path to T3 & T4 and turns OFF T1 & T2 at $\omega t = \pi+\alpha$.
- When T3 & T4 is ON, the current through the load builds up slowly through the path Vs-T3-Load-T4-Vs.
- So here all the thyristor will conduct for a few duration in the negative half cycle.
- The load receives voltage during both the half cycles.
- The average value of output voltage can be varied by varying the firing angle α.
- The waveform shows the plot of input voltage, gate current, output voltage, output current and voltage across thyristor.

1ϕ full wave bridge converter

(fully controlled)

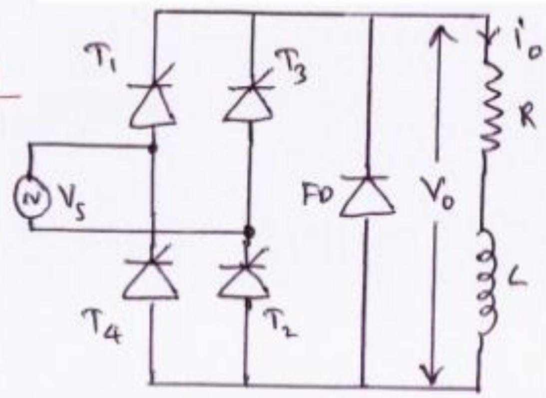


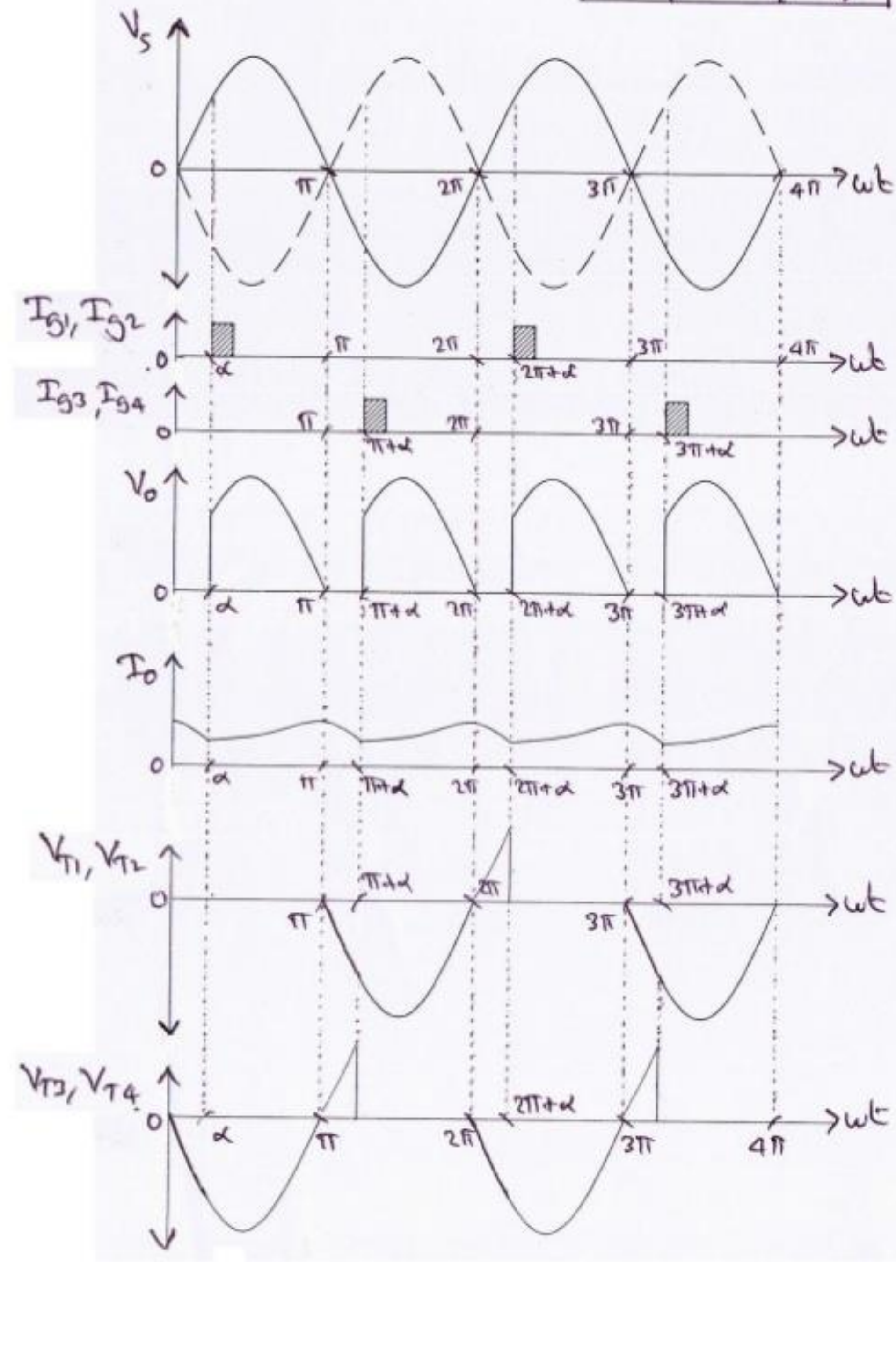


2.8 Single Phase Full Wave Controlled Rectifier with RL Load and Freewheeling Diode.

- The circuit consist of four thyristors T1, T2, T3 and T4, a voltage source Vs, a RL Load and a freewheeling diode across the load.
- During the positive half cycle of the input voltage, the thyristors T1 & T2 is forward biased but it does not conduct until a gate signal is applied to it.
- When a gate pulse is given to the thyristors T1 & T2 at $\omega t = \alpha$, it gets turned ON and begins to conduct.
- When the T1 & T2 is ON, the input voltage is applied to the load but due to the inductor present in the load, the current through the load builds up slowly through the path Vs-T1-Load-T2-Vs.
- During the negative half cycle (at $\omega t = \pi$), T3 & T4 is forward biased, the thyristor T1 & T2 gets reverse biased.
- The current shifts its path to the freewheeling diode and circulates through the loop FD-R-L-FD.
- Thus T1 & T2 turns off at $\omega t = \pi$
- When a gate pulse is given to the thyristor T3 & T4 at $\omega t = \pi+\alpha$, it gets turned ON and begins to conduct.
- When T3 & T4 is ON, the current through the load builds up slowly through the path Vs-T3-Load-T4-Vs.
- During the next positive half cycle (at $\omega t = 2\pi$), T1 & T2 is forward biased, the thyristor T3 & T4 gets reverse biased.
- The current shifts its path to the freewheeling diode and circulates through the loop FD-R-L-FD.
- Thus T3 & T4 turns off at $\omega t = 2\pi$
- So here all the thyristor will conduct only in the positive half cycle.
- The load receives voltage during both the half cycles.
- The average value of output voltage can be varied by varying the firing angle α.
- The waveform shows the plot of input voltage, gate current, output voltage, output current and voltage across thyristor

1Φ full wave bridge rectifier with freewheeling diode (fully controlled)





Single phase full wave mid point Converter

- In this converter Two thyristor (T1 T2) connected as diode in centre tapped rectifier.
- **During Positive half cycle** T1 – Forward mode and turned when gate trigger applied, and T2 Rev. Mode.
- **During negative half cycle** T2 – Forward mode and T1 reverse mode. T2 conducts when gate trigger applied.
- Output voltage is a Controlled DC. it can be done by changing the firing angle α of both T1 and T2
- The average output voltage can be obtained as Vo =(2Vm/π)*cosα

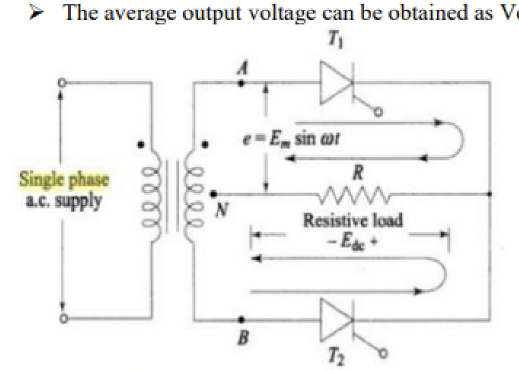
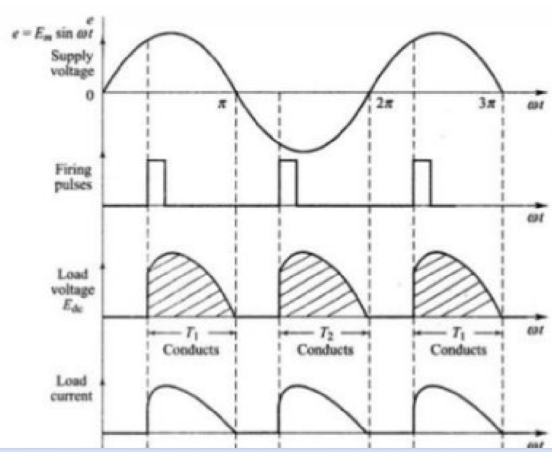
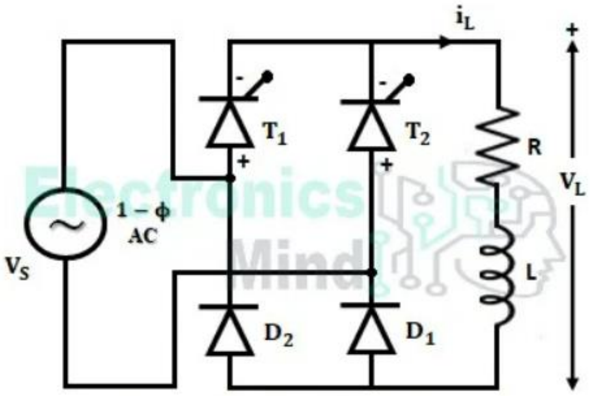


Fig. 6.12 *Full-wave mid-point circuit with resistive load*



Single-Phase Semi Converter With RL-Load :

The below shows the circuit diagram of a single-phase semi or half-controlled converter supplying power to an RL load. When a converter delivers power to the RL load, the load current can be of two types. Either the load current can be continuous or it can be discontinuous depending upon the inductance of inductive load.



Single-Phase Half-Controlled Converter with RL Load

It is also known as half controlled bridge converter.

The continuous current mode (load current never becomes zero) of operation is obtained when the inductance of the load (shown in the above circuit) is large enough to supply the load current until the next thyristor is triggered.

So, in this mode of operation, extinction angle, $\beta \geq (\pi + \alpha)$ and therefore the load current never remains at zero.

During the positive half cycle of the supply, thyristor T_1 and diode D_1 get forward biased, while thyristor T_2 and diode D_2 get reverse biased. Now, if T_1 is triggered at a firing angle α it starts conducting. As a result, the load current i_L starts flowing through the path $V_s \rightarrow T_1 \rightarrow R \rightarrow L \rightarrow D_1 \rightarrow V_s$. As soon as V_s reaches zero, V_L also becomes zero.

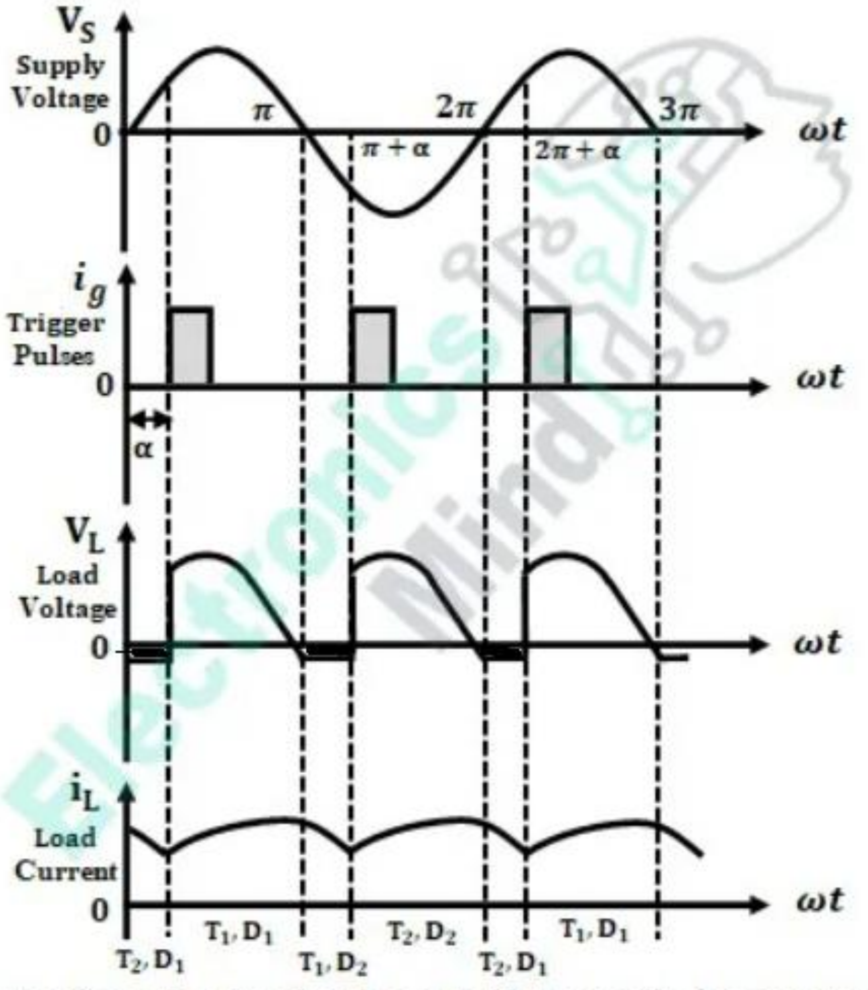
Once V_s enters into the negative cycle, T_2 and D_2 get forward biased and T_1 and D_1 get reverse biased. But, the load inductance L opposes a sudden change in current and hence releases the energy which is stored in the positive cycle. So, an EMF, e_1 is induced in the inductor with opposite polarity. This EMF is responsible for maintaining the load current in the negative cycle before T_2 is triggered.

Since T_1 cannot be turned OFF until i_L falls below its holding current value, i_L continues to flow through the path $L \rightarrow D_2 \rightarrow T_1 \rightarrow R \rightarrow L$.

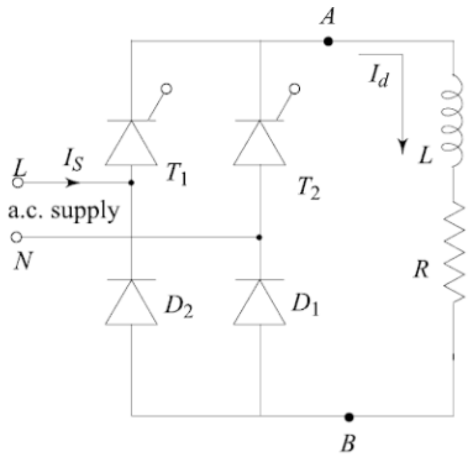
Therefore, V_L follows the negative cycle of supply voltage till β (extinction angle). Here we assume β = π+α.

During negative cycle : Once T_2 is triggered i.e., at (π + α), the load current rushes through the path $V_S \rightarrow T_2 \rightarrow R \rightarrow L - D_2 \rightarrow V_S$. At the instant 2π, the load voltage falls to zero and once again the inductor releases the energy which has been stored in the negative cycle. This freewheel current flows through the path $L \rightarrow D_1 \rightarrow T_2 \rightarrow R \rightarrow L$.

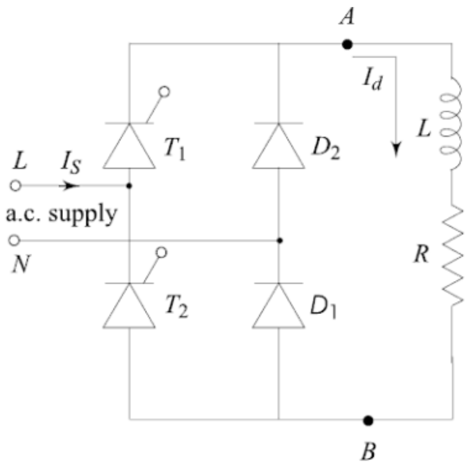
The waveform for this mode is shown below.



Waveform for Single-Phase Half-Controlled Converter with RL Load in Continuous Current Mode



(a) Symmetrical configuration



(b) Asymmetrical configuration

Advantages of Freewheeling Diode

- It does not allow the output voltage to become negative.
- The rectifier efficiency improves because the energy stored in inductor L is transferred to load and is utilized.
- The load performance enhances because the load current is continuous.

- Improve input power factor.