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POWER ELECTRONICS

4th Sem

CONTROLLED RECTIFIERS

4th Sem

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CONTROLLED RECTIFIERS

- *In thyristor based control rectifiers ,Diodes of rectifier circuits are replaced by thyristors.*

- *Control Rectifiers converts I/p AC into Variable controlled output dc voltage . Magnitude of O/p DC can be controlled by varying firing angle of thyristor used. So they are termed as controlled rectifiers.*

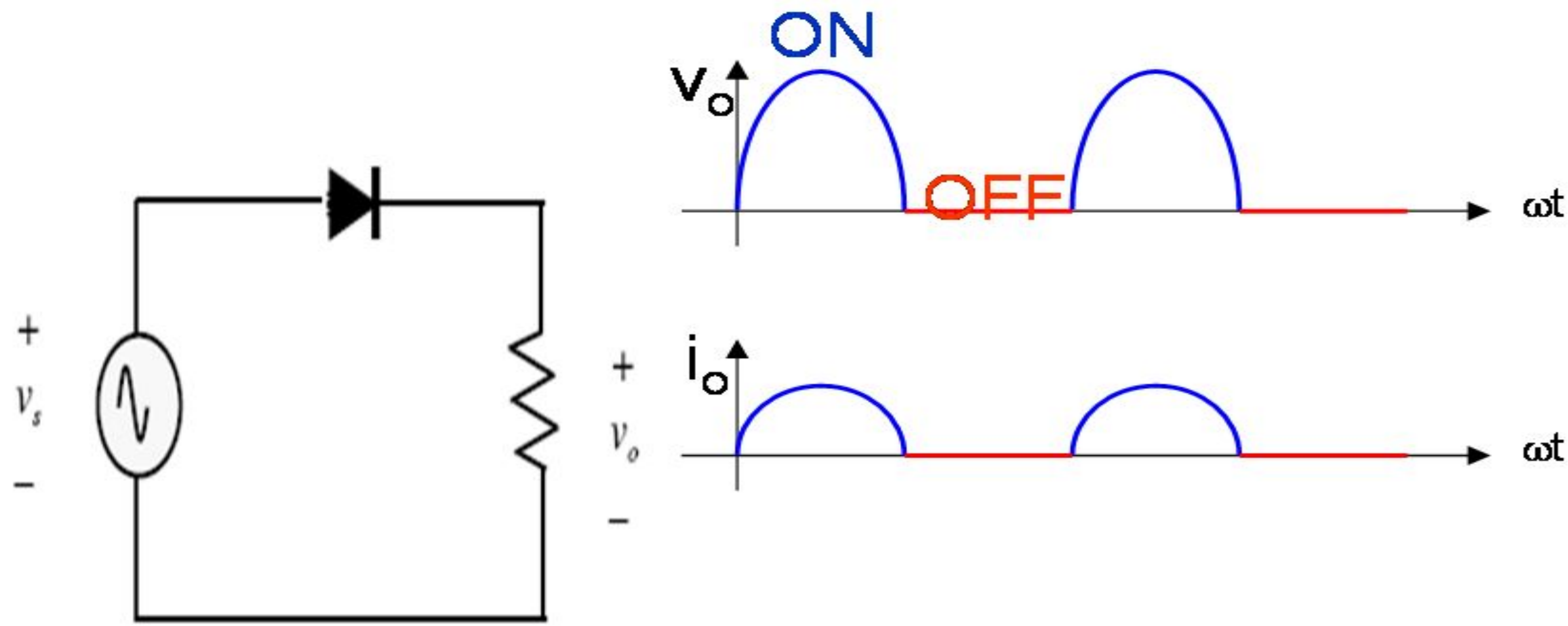
Phase Control

- *Controlled rectifiers produce variable controlled DC output, whose magnitude is varied by Phase control{ i.e.by varying firing angle of thyristors used) DC output from rectifier is controlled by controlling duration of the conduction period by varying the point at which gate signal is applied to SCR.*

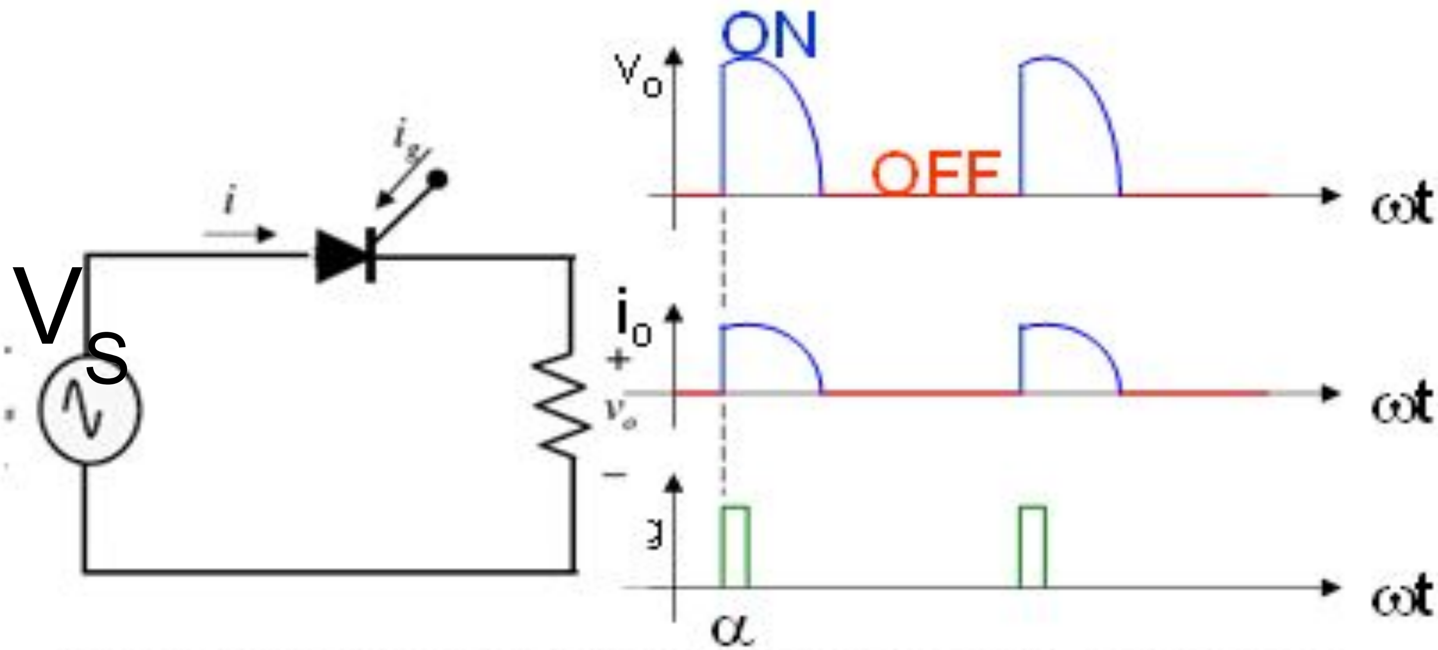
Comparison between controlled rectifier & Rectifier

Rectifier	Controlled Rectifier
• ***Rectifiers provide fixed output d.c for a fix magnitude of I/P A.C voltage. They can not by themselves control the output d.c voltage.*** • ***Rectifiers made up of diodes***	• ***The basic function of control rectifiers also known as phase control rectifiers is to convert A.C input voltage to a controllable d.c output voltage.*** • ***They consists of SCRs & combinations of SCRs & Diodes.***

Uncontrolled half-wave, R-load



Controlled half-wave, R-load



*The SCR turns OFF itself when i_o reduces to zero

Applications of controlled rectifiers

1. *Electroplating and other electrochemical process*

1. *Battery chargers*

3.Constant voltage supply.

4.Speed controllers such as used in paper mills,steel rolling mills etc.
5. High voltage d.c transmissions.

Controlled rectifiers are of two types,

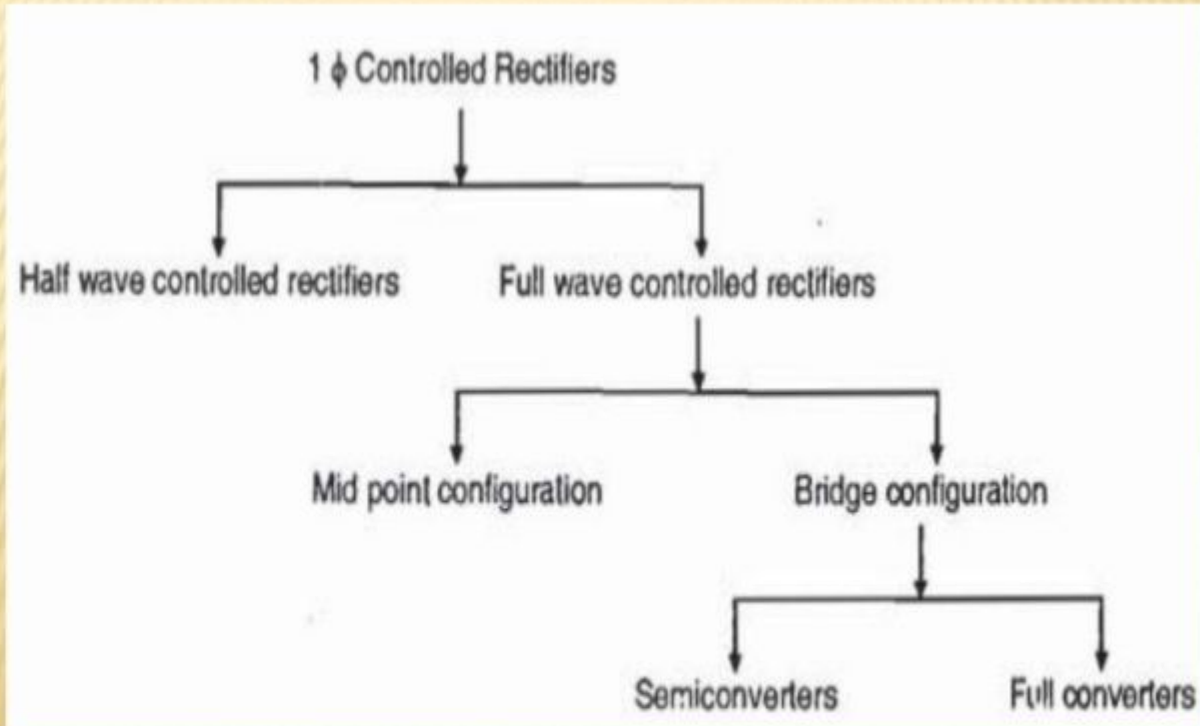
1- <u>Fully Controlled rectifiers</u>

- *All rectifying elements are SCRs.*
- *DC current is unidirectional, but DC voltage has either polarity. With one polarity, flow of power is from AC source to DC load---Rectification. With the reversal of DC voltage by the load, flow of power is from DC load to AC source---Inversion.*
- **This converter can convert a.c. to d.c. and d.c. to a.c. Power flow is possible in both directions and because of this feature, this circuit with inductive load is known as <u>Full Wave Fully Controlled Converter.</u>**
- *The conversion of A.C. to D.C. and D.C. to A.C. is also known as <u>Two—quadrant operation of converter circuit.</u>*

2- <u>Half controlled rectifiers</u>

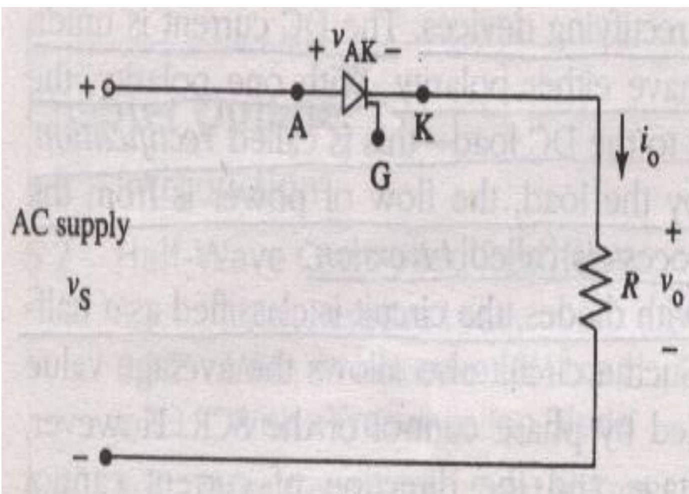
- *Half of SCRs are replaced by diodes.*
- *DC output current and voltage are unidirectional. i.e., flow of power is from AC source to DC load.*
- *These types of half controlled converters are cheaper as two SCRs are replaced by two diodes*

CLASSIFICATION OF RECTIFIERS

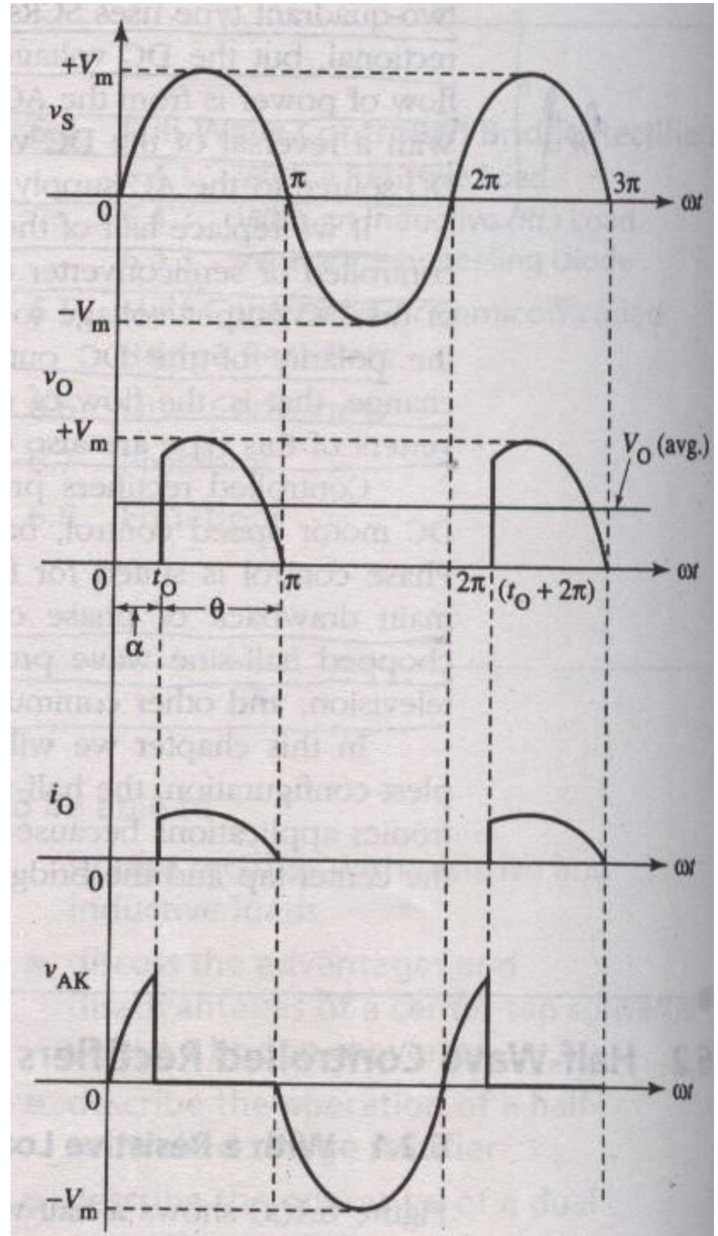


HALF-WAVE CONTROLLED RECTIFIERS

With Resistive Load

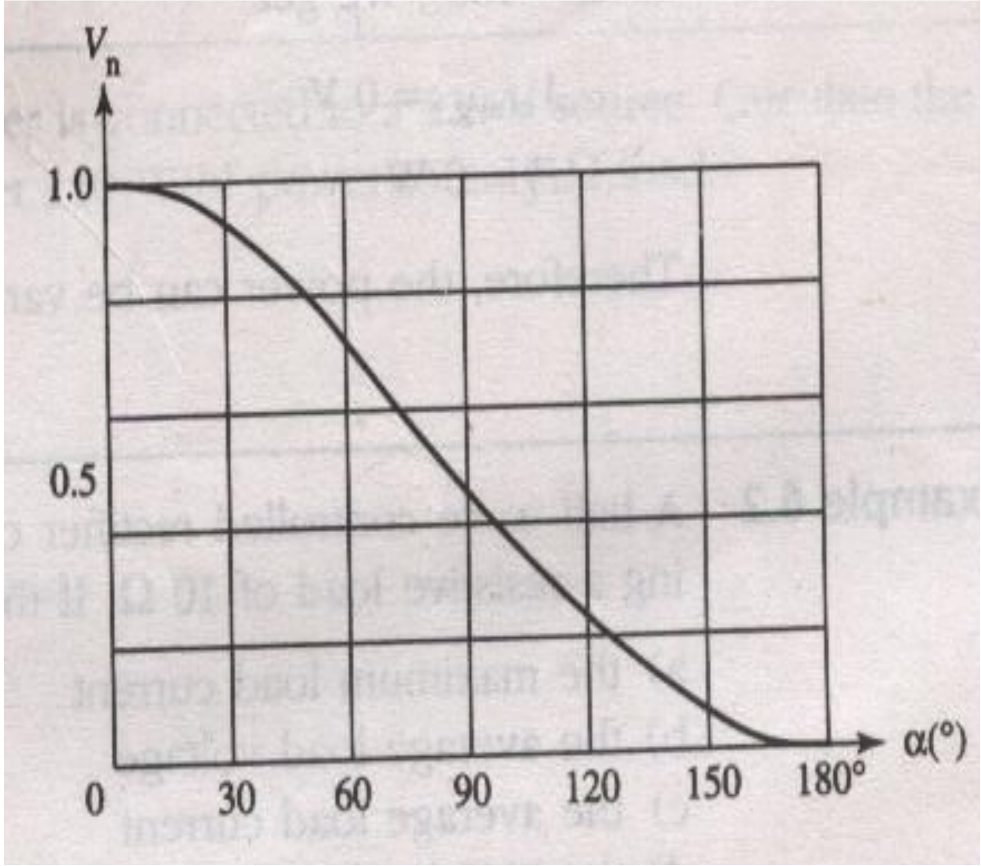


(a)



(b)

Control characteristics of half-wave rectifier



AVERAGE OUTPUT VOLTAGE

From the output voltage waveform time period of output (Vo) is given,

$$T = (2\pi + \alpha) - \alpha$$

$$T = 2\pi$$

As the input voltage, $V_i = V_m \sin wt$,

$V_{av} = 1/T \int_{\alpha}^{\pi} V_m \sin wt . d(wt)$ *Where, T is the time period of the output W/F.*

$$V_{av} = 1/2\pi \int_{\alpha}^{\pi} V_m \sin wt . d(wt)$$

$$= -V_m/2\pi \, |\cos wt|_{\alpha}^{\pi}$$

$=-V_m/2\pi (\cos \pi - \cos \alpha)$ *(as* $\cos \pi = -1$*)*

$$\mathbf{V_{av} = V_m/2\pi (1 + \cos \alpha) \ldots\ldots.(1)}$$

Thus,the average output voltage will be given by

$$\mathbf{V_{av} = V_m/2\pi (1 + \cos \alpha)}$$

PHASE CONTROL

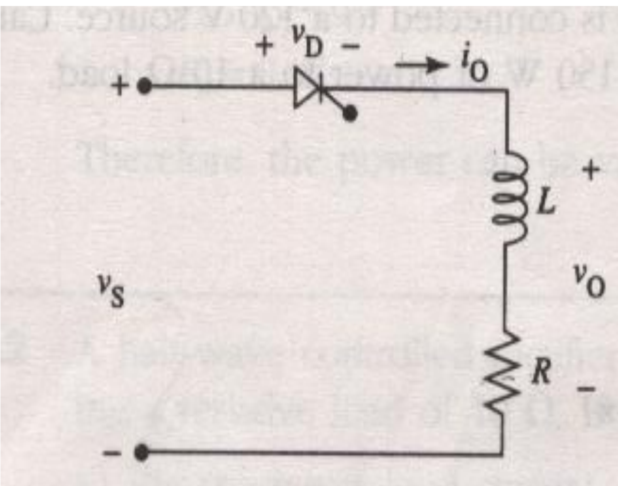
Average d.c voltage across the resistive load is given by

$$V_{av} = V_m/2л\ (1+ \cos α)$$

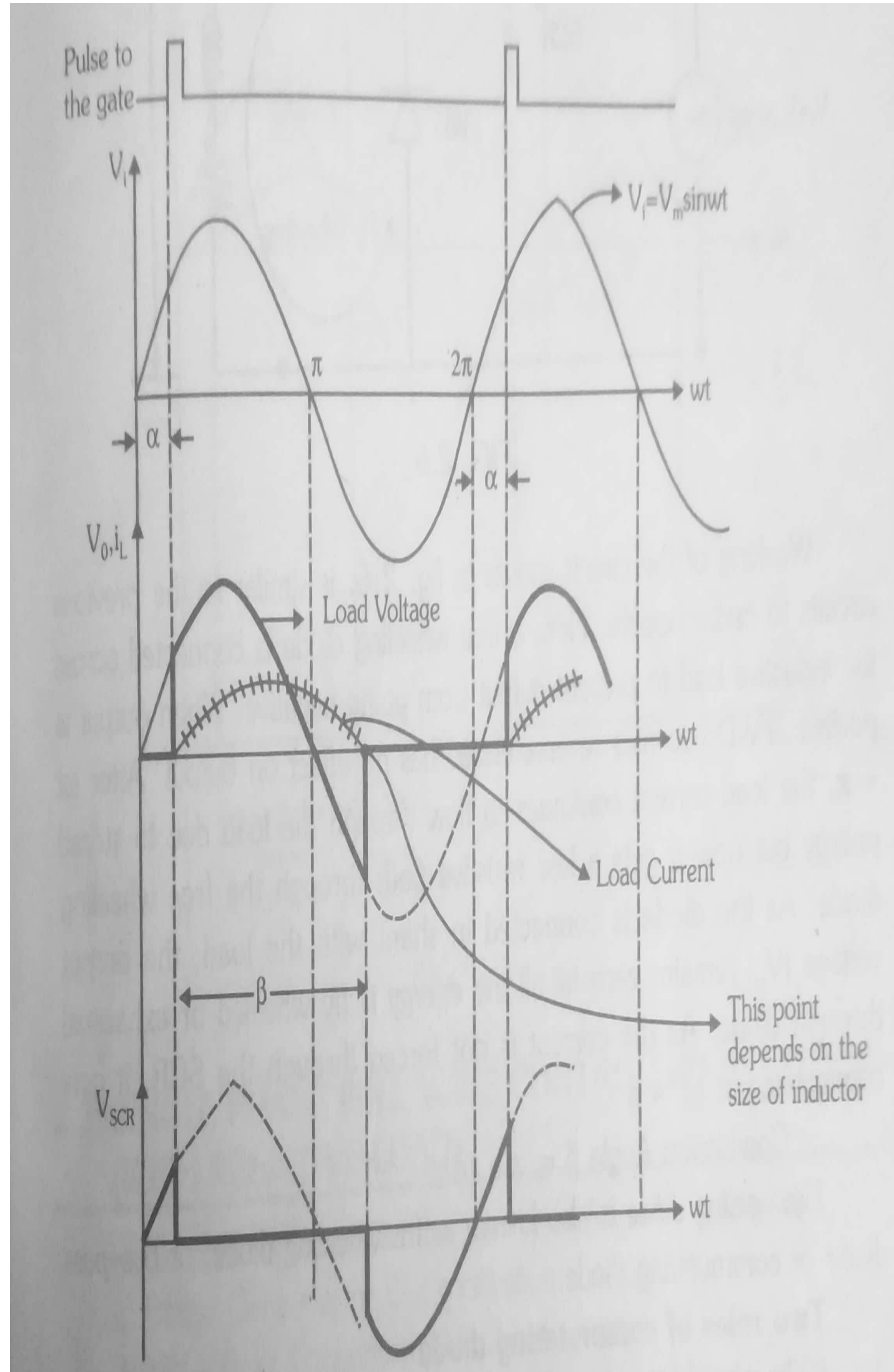
This equation shows that by decreasing the firing angle (α) output voltage can be increased and vice versa.

This is known as phase control.

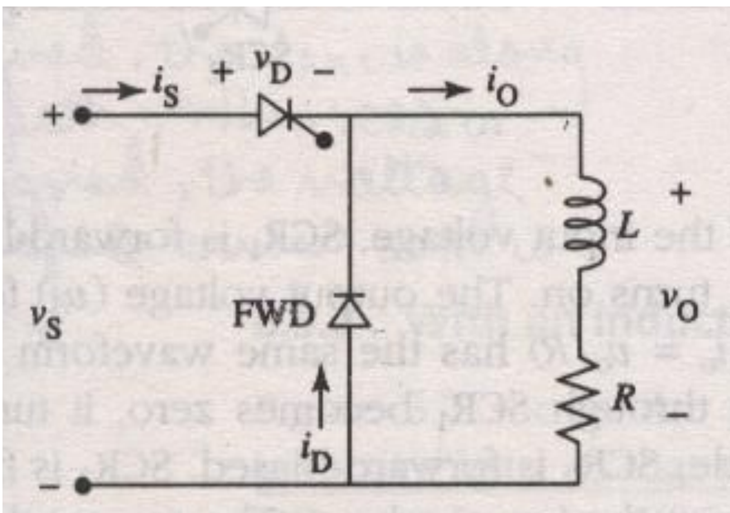
With an Inductive (RL) Load



(a)



With Inductive Load and Freewheeling Diode



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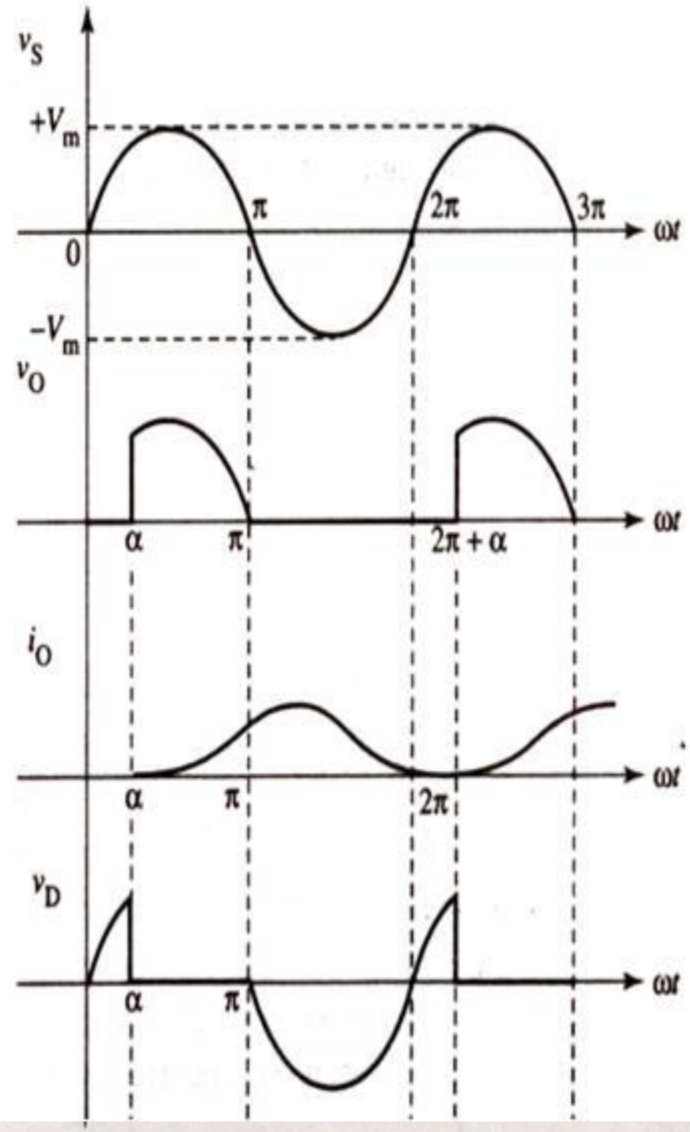


(b)

Working

- ***Free wheeling diode is connected across the inductive load to prevent output from going -VE.***
- ***When output is positive, FWD becomes reverse biased has no effect on output.***
- ***After wt=л, the load current continues to flow through the load due to stored energy but now it gets a less resistive path through the FWD.***
- ***As the diode is connected in shunt with the load, the output voltage (V_o) remains zero till the energy is fly wheeled or exhausted through diode. As the current is not forced through SCR, it gets commutated at wt= л***

  Conduction Angle $\underline{\beta = л-\alpha}$

-

Roles of commutating diode

(i)To prevent the negative load voltage.

(ii) To allow the SCR to regain its blocking state at the voltage zero by transferring the load current away from the thyristor.

SINGLE PHASE FULL WAVE CONTROLLED RECTIFIER

Single phase full wave rectifier can be of two types:

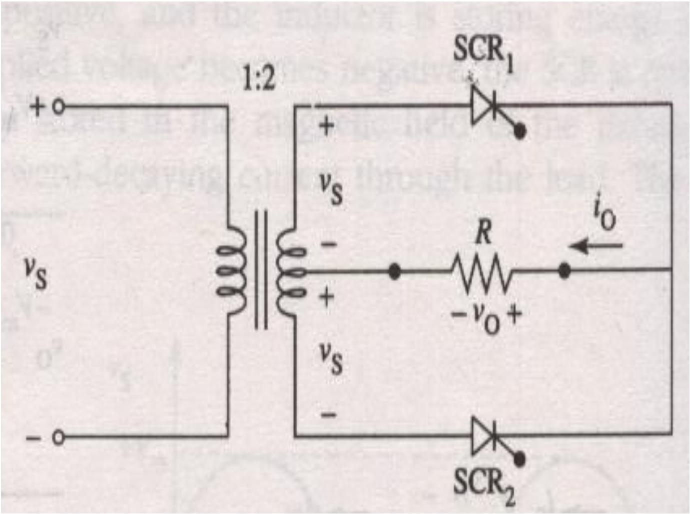
1. Bridge converter or B-2 connection

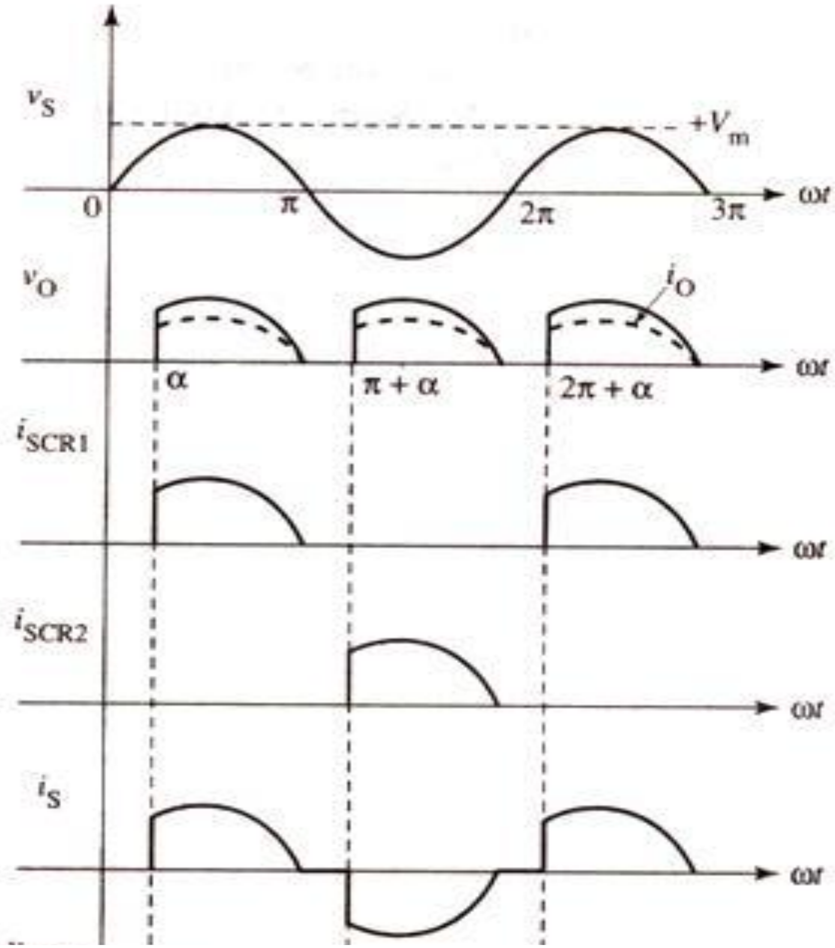
2. Mid-point converter or M-2 connection.

- ***Bridge connection is generally preferred as they do not need transformer. If one end of the load is to be grounded mid-point configuration is used. As centre-tapped secondary is used, the rating of the transformer has to be double the load rating in the mid-point configuration. The circuit diagrams are shown in the next figure.***

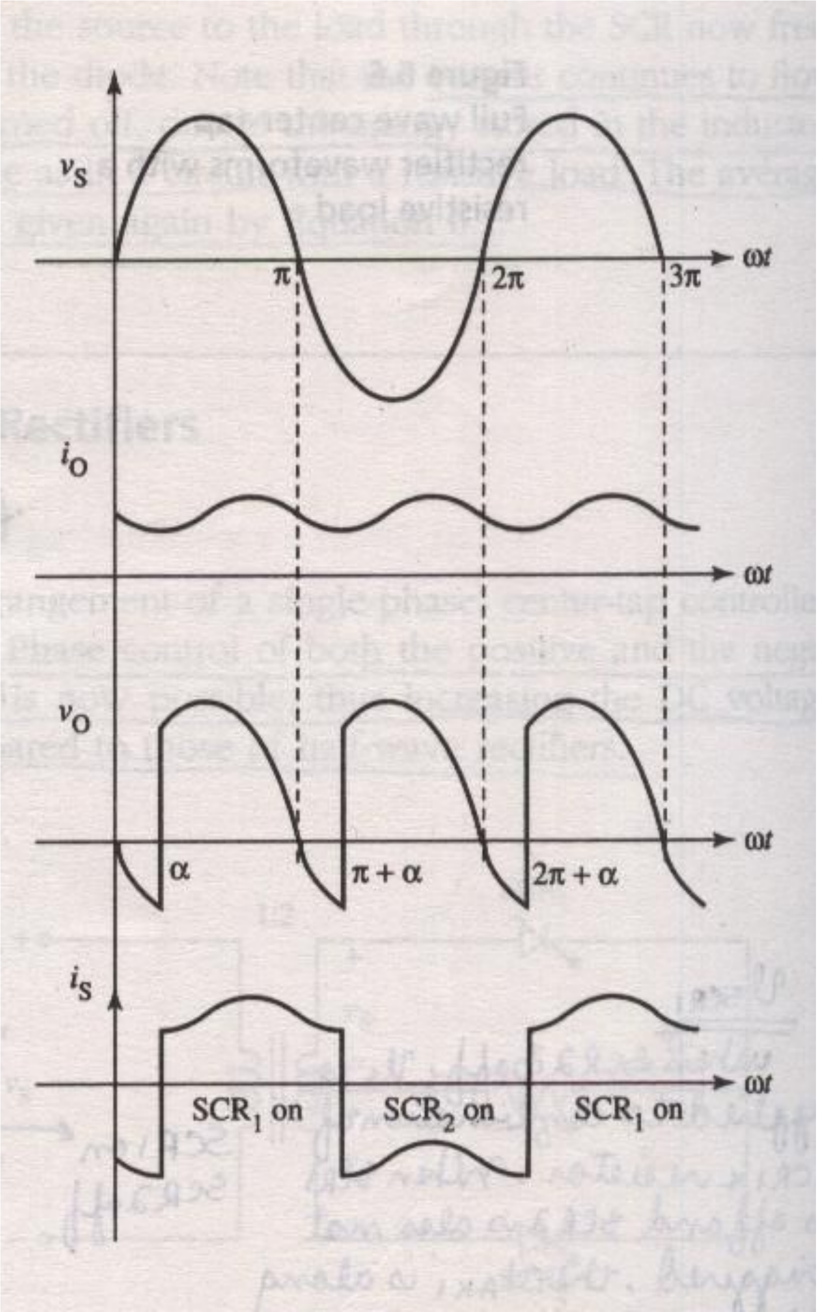
FULL-WAVE CONTROLLED CENTER-TAP RECTIFIERS

With Resistive Load



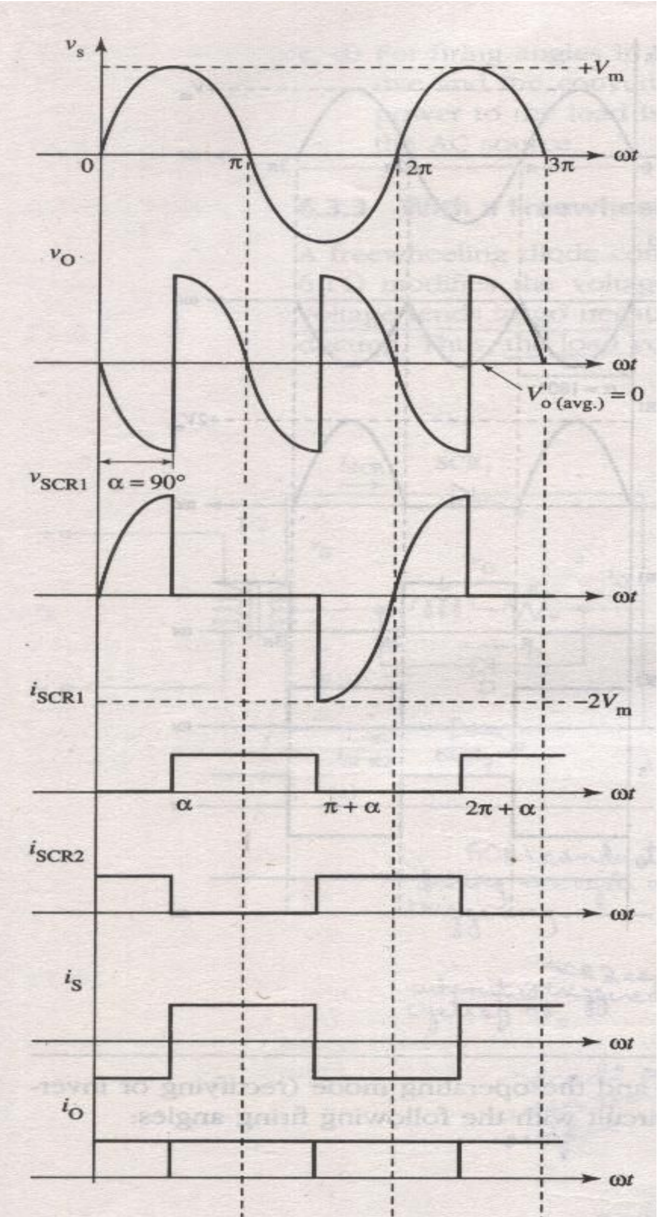


With an Inductive (RL) Load

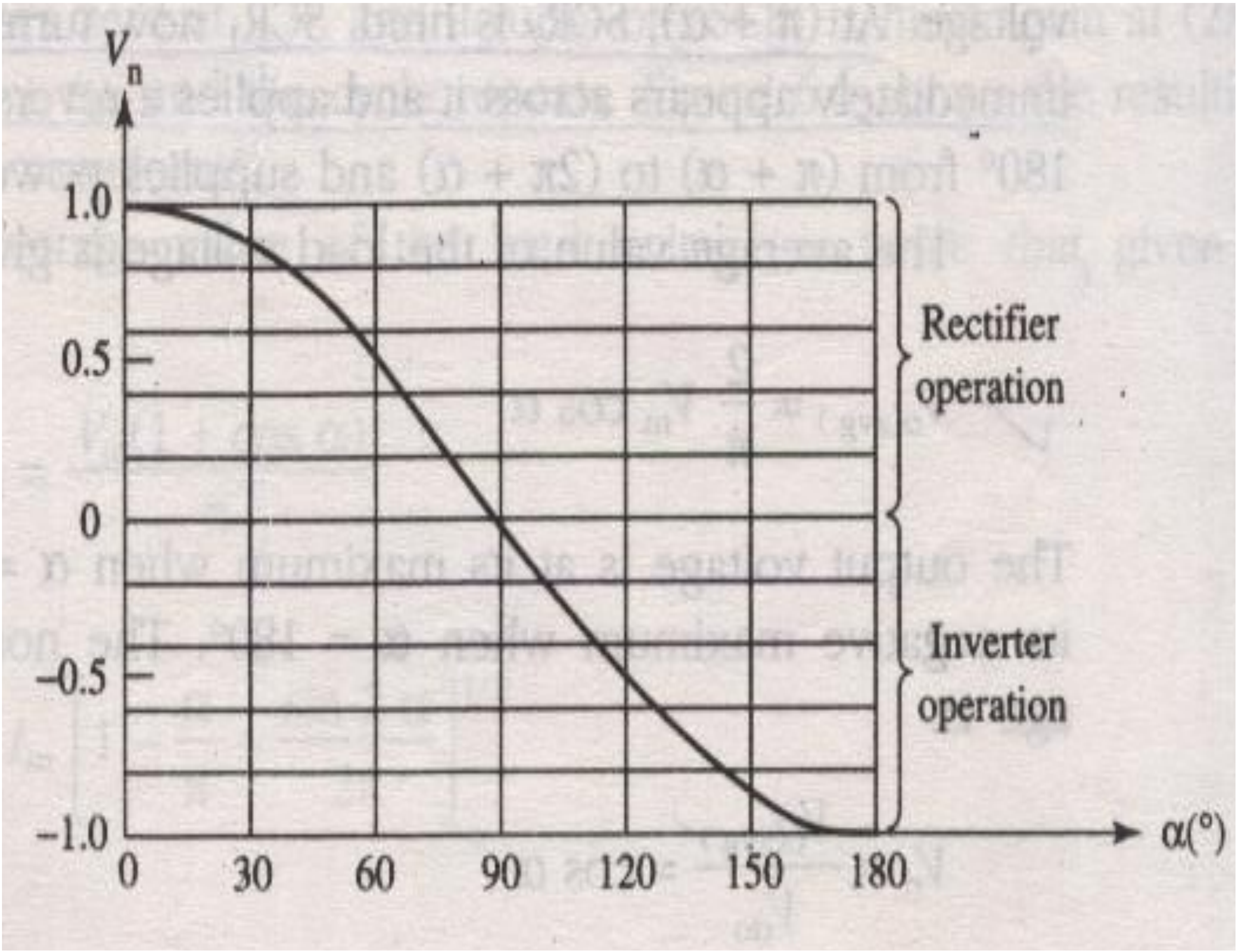


Voltage and current waveforms for α=90°

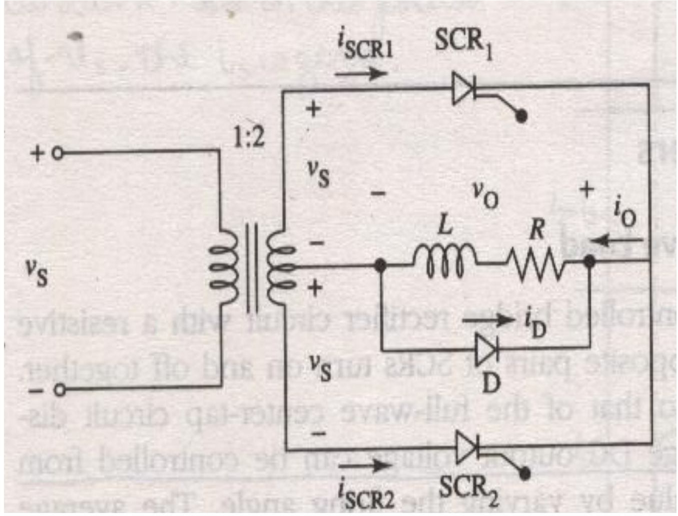
- Average DC voltage is zero, so there is no transfer of power from AC source to DC load.
- Each SCR remains in conduction for 180°
- As firing angle is increased from 0 to 90°, the power supplied to the DC load decreases, becoming zero at α=90°

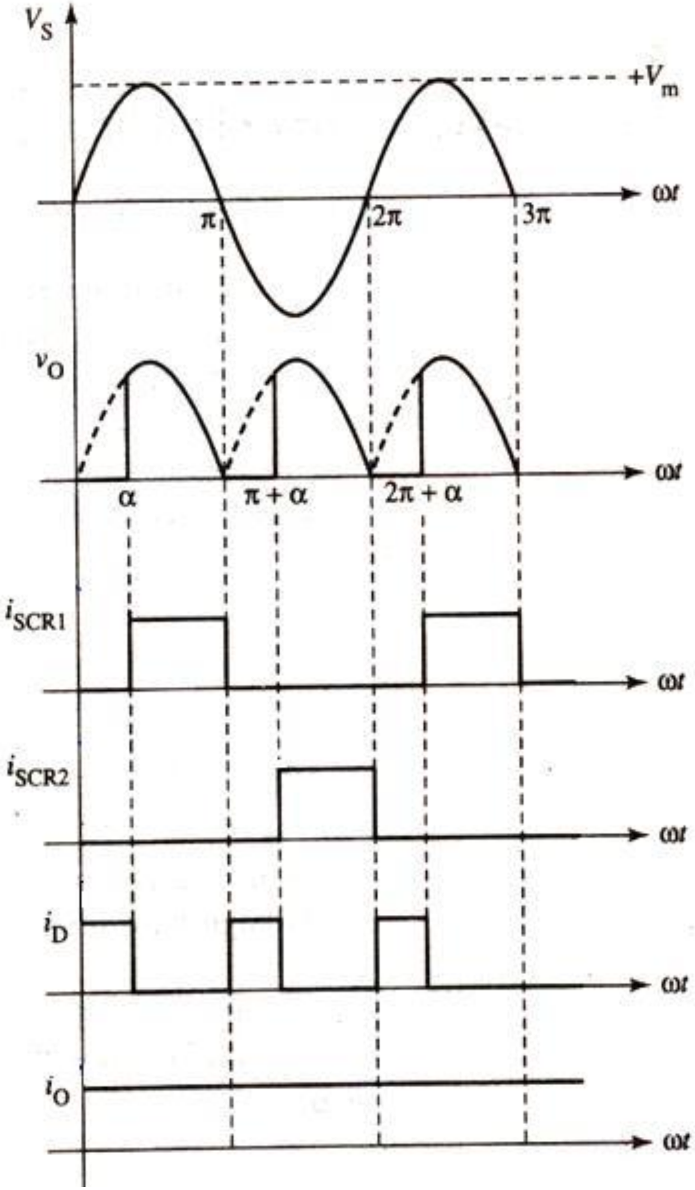


Control Characteristics for center-tap rectifier



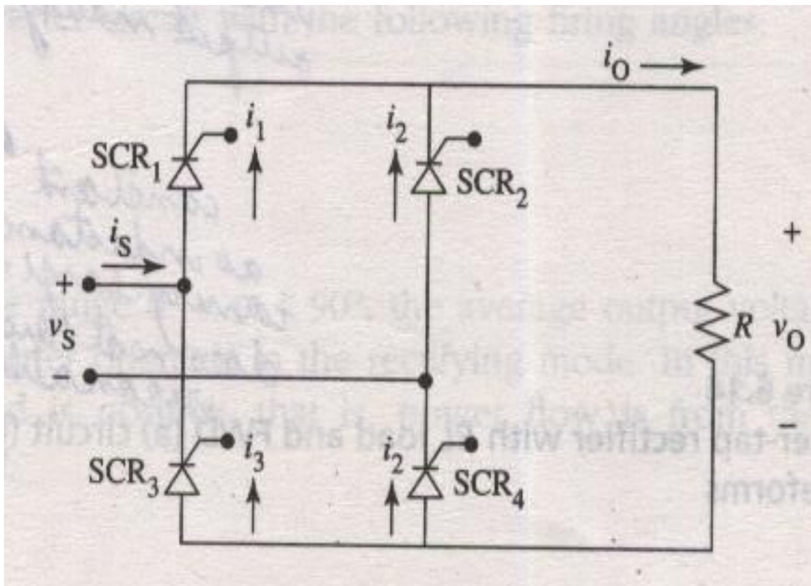
With Freewheeling Diode

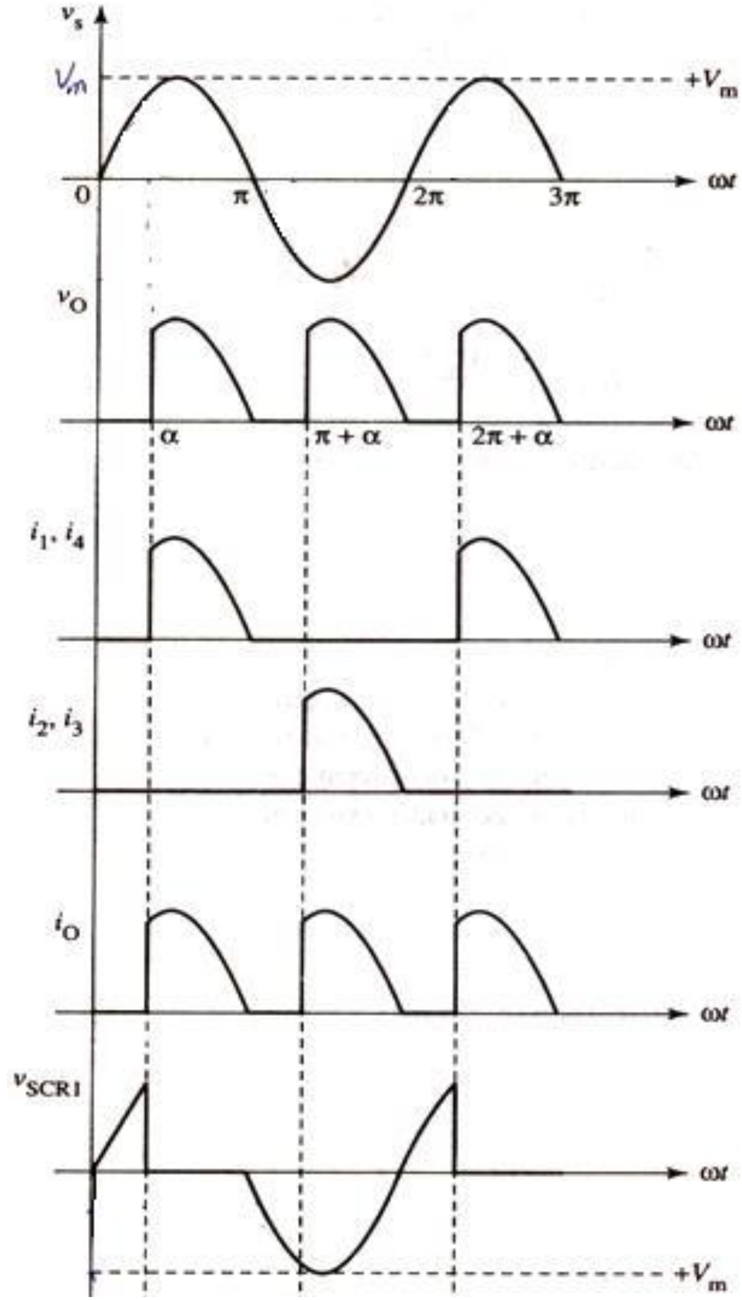




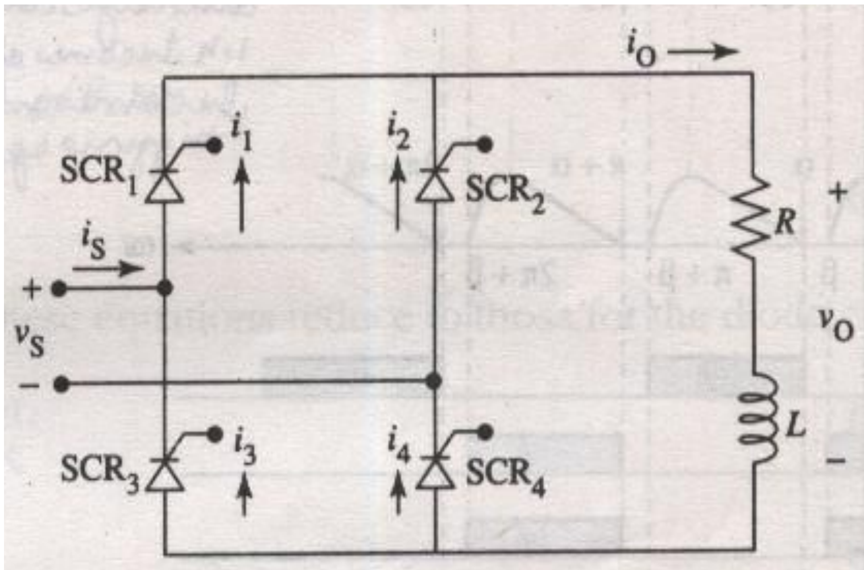
FULL-WAVE CONTROLLED BRIDGE RECTIFIER

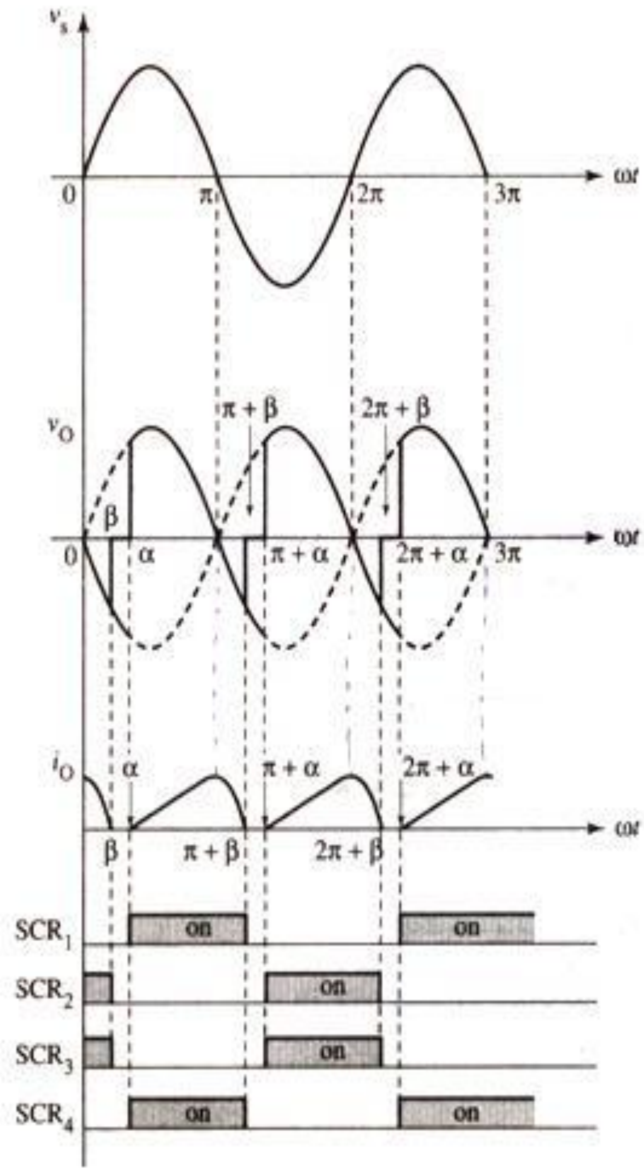
With Resistive Load



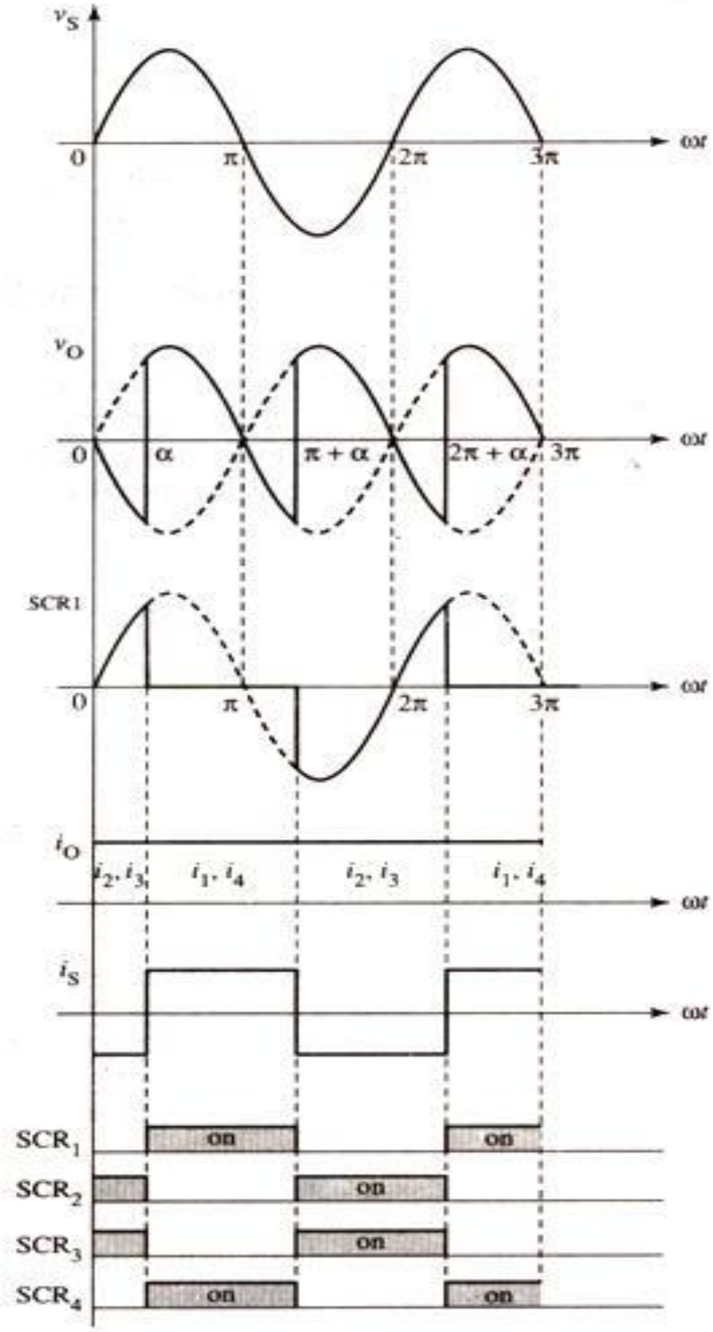


With an Inductive (RL) Load



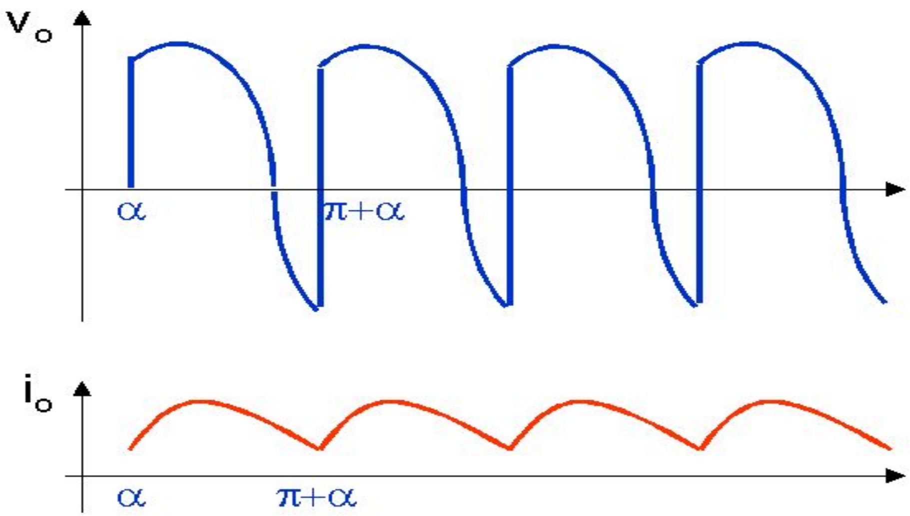


For L >>> R

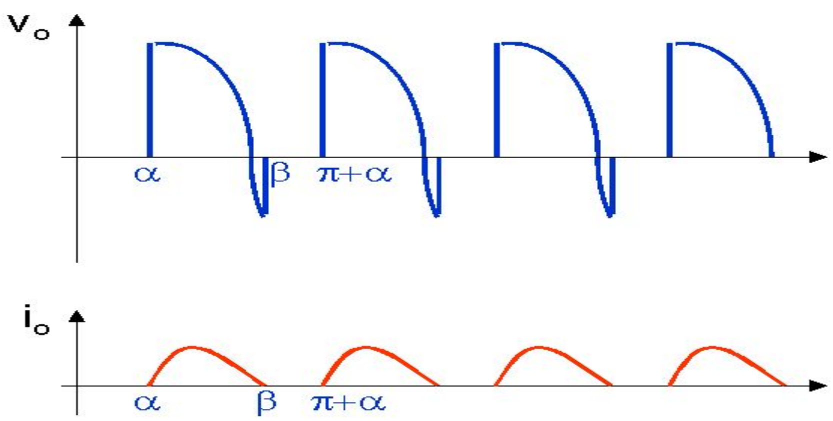


v_S
ωt
0
π
2π
3π
v_O
α
π + α
2π + α
SCR1
i_O
i_2, i_3
i_1, i_4
i_S
SCR_1
SCR_2
SCR_3
SCR_4
on

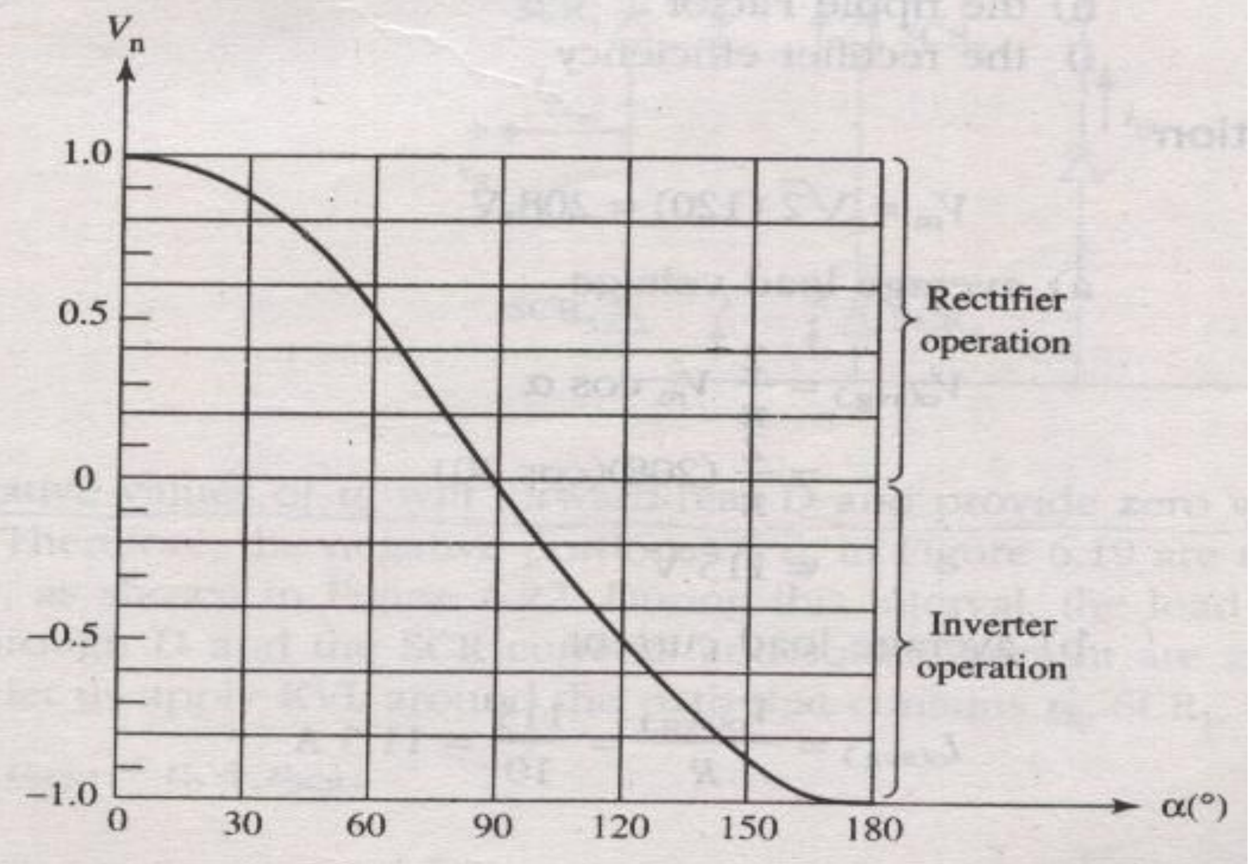
Continuous current mode:



Discontinuous current mode:



Control characteristics for bridge rectifier



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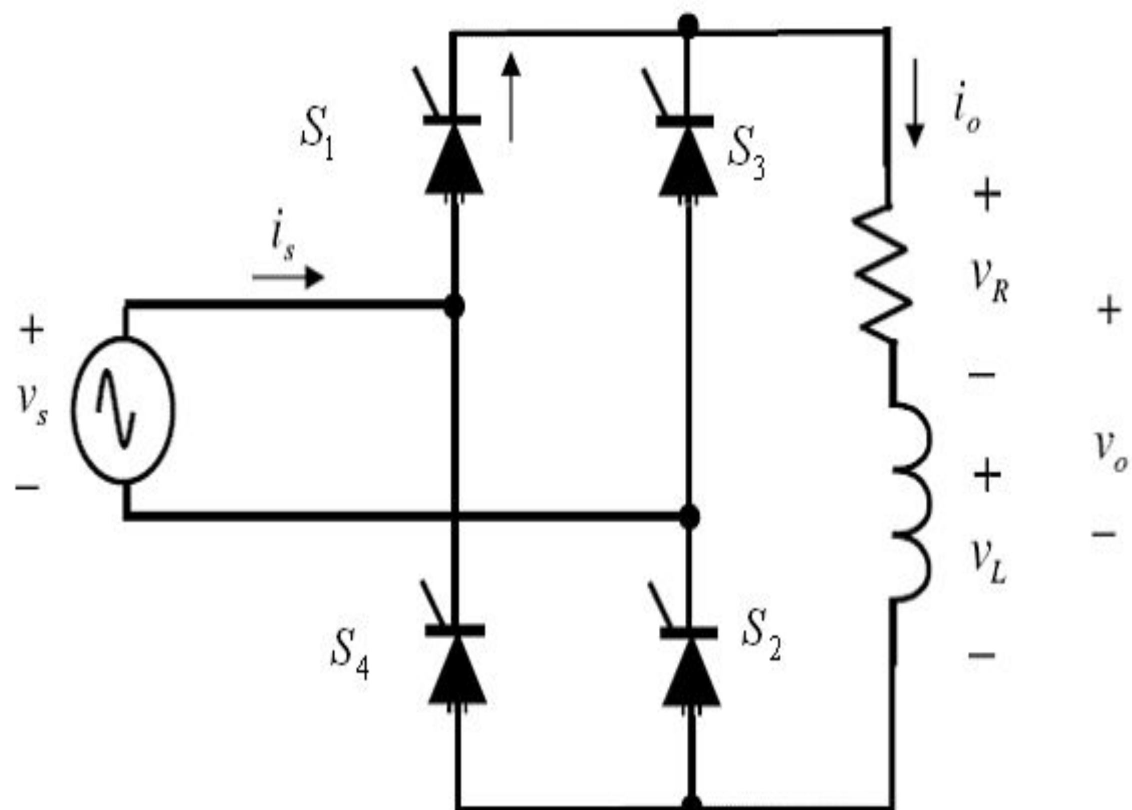
Controlled full-wave, RL-load



Single Phase Full Wave Controlled Bridge Rectifier with inductive load :

Assumption :

1. *On-state voltage drop of SCRs to be zero.*
2. *Source inductance assumed to be zero.*
3. *Load inductance ($L_d \to \infty$) assumed very very high.*

Operation:

In +ve cycle of a.c. i/p at firing angle ’α ’ the SCRs 1 and 2 are fired, positive voltage at input becomes available at the output and the current flows in the direction.

L(+ve) ⟶ SCR1 ⟶ A ⟶ Load ⟶ B ⟶ SCR2 ⟶ N(-ve)

The magnitude of line current i_d is same as that of load current.

As -ve half cycle starts,the load current continues to flow in the same direction with the same magnitude (load current assumed constant) due to the stored energy in the inductor. As a result SCR1 and SCR2 remain in on state. So the negative voltage appears at the output terminals. Then, at (л + α), SCR3 and SCR4 are fired, as a result reverse voltage is applied across SCRs 1 and 2 and they get commutated.

- *As –ve half of the input appears across the output terminals A and B as positive through SCRs 3 and 4 and the output current flows in the path Which is in the direction*

N (+ve) → SCR3 → A → Load → B → SCR4 → L (-ve)

Same so far as the load current is concerned, While Opposite so far as the line current is concerned. load current is unidirectional but the line current is reverses its polarity periodically.

MATHEMATICALLY ANALYSIS

Assume input $V_i = V_m \sin wt$

$V_{av} = V_{dc} = 1/T\ V_m \sin wt\ .\ (d.wt)$

Here, $T = (л + α) - α = л$

So, $V_{av} = V_{dc} = 1/л \int_{α}^{(л+α)} \sin wt\ d(dt)$

$= -V_m/л\ |\cos wt|_{α}^{л+α}$

$-V_m/л\ (\cos(л+α) - \cos α)$

$-V_m/л\ (-\cos α - \cos α)$

$\mathbf{V_{av} = V_{dc} = 2V_m/л \cos α}$

.

$V_{av} = V_{dc} = 2V_m/л \cos α$

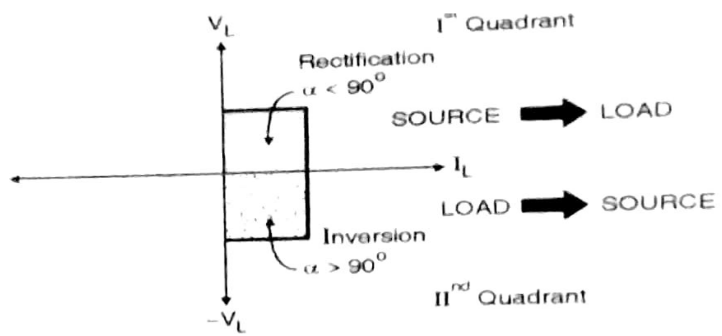
When $α = 0$, $V_{dc} = 2V_m/л \cos 0 = 2V_m/л$

When $α = л/2$, $V_{dc} = 2V_m/л \cos л/2 = 0$

When $α = л$, $V_{dc} = 2V_m/л \cos л = -2V_m/л$

This shows the variation of V_{dc} with α

Load Power = Output voltage X load current= $V_{dc}.I_L$



(a) Two quadrant operation of full converter

Why a fully controlled converter is called so?

Here,Load current I_L is unidirectional and always positive.

For α < л/2, V_{dc} is +ve i.e.Load Power ($V_{dc}.I_L$) is also +ve. This means that power flows is from a.c. side to d.c. side. This is known as conversion operation or rectification mode.

But, for α > л/2, V_{dc} is -ve,and I_L is always +ve. So the load power comes out to be -ve. This means that load will supply power back to a.c. This is known as inversion I.e. converter is said to be operating in Inverting mode

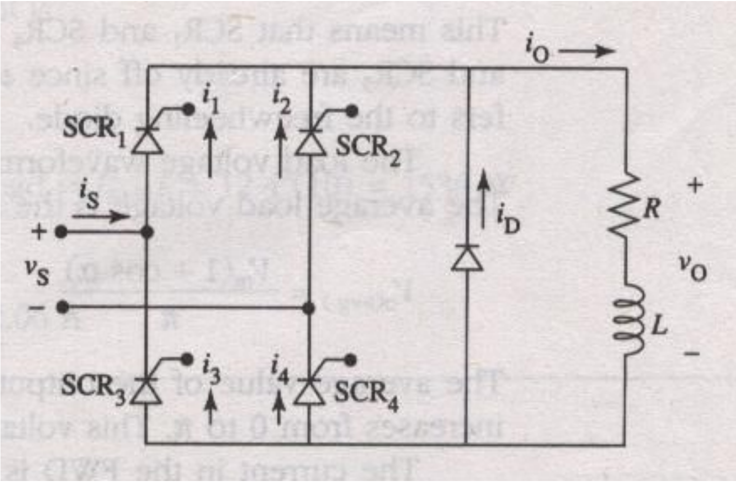
This converter can convert a.c. to d.c. and d.c. to a.c. Power flow is possible in both directions and because of this feature, this circuit with inductive load is known as Full Wave Fully Controlled Converter. The conversion of A.C. to D.C. and D.C. to A.C. is also known as Two—quadrant operation of converter circuit.

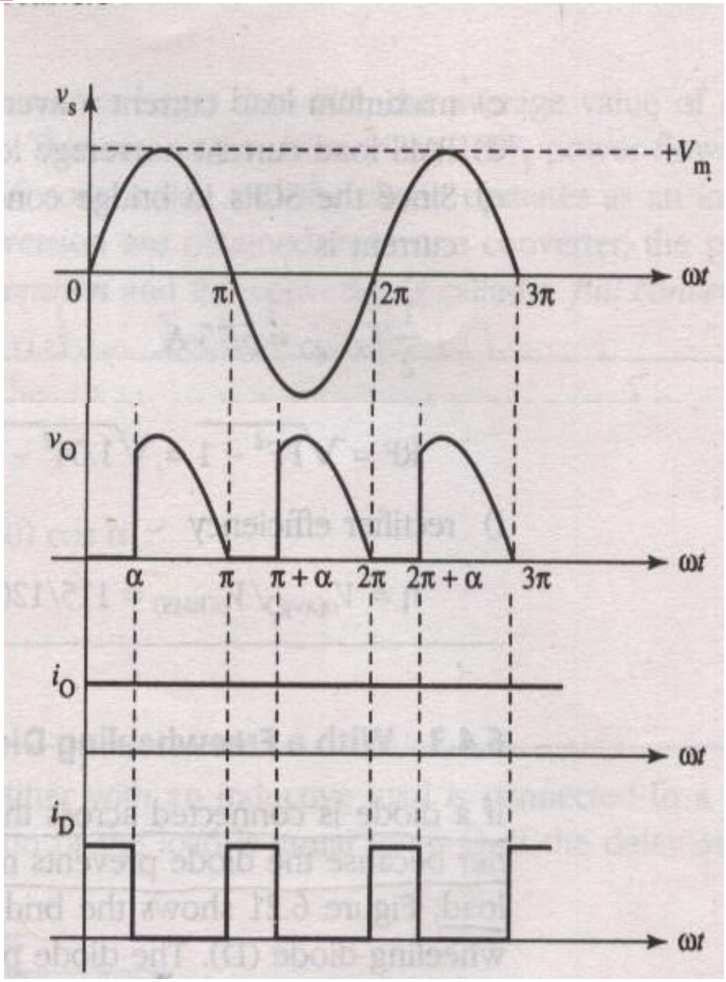
HALF-CONTROLLED
OR
SEMICONTROLLED BRIDGE RECTIFIERS

- *In fully-controlled rectifier, only rectification can be obtained by connecting a freewheeling diode across the output terminals of the rectifier.*

- *Another method of obtaining rectification in bridge rectifiers is replacing half of the SCRs with diodes. These circuits are called semicontrolled bridge rectifiers.*

With RL load and freewheeling diode





Working

In the +ve half SCR 1 and 4 are fired and positive output voltage is obtained. The FWD remains R.B and has no effect on the output.

But when -ve half of the a.c. cycle starts, stored energy in the load forward biased the FWD and gets fly wheeled through the FWD. Thus, output becomes zero. Also the SCR 1 and 4 get commutated due to -ve potential of the a.c. input. Though the output voltage becomes zero, the load current continuous to flow through the load and FWD.

Working

Next at wt = л + α, SCRs 2 and 3 are fired So, the -ve alternation of a.c. input appears as +ve across the load and FWD becomes R.B & the current follows the path:

N (+ve) → SCR2 → A → Load → B → SCR3 → L (-ve)

In this ckt, the line current becomes zero during the period FWD is conducting. Similarly, in the next +ve half FWD is used to fly wheel the stored energy and SCR1 &SCR2 are fired symmetrically at firing angle to get the positive output.

AVERAGE OUTPUT VOLTAGE

Input voltage is $V_i = V_m$ Sin wt.

The average output voltage V_{av} will be given by

$$V_{av} = V_{dc} = 1/T \int_{\alpha}^{\pi} V_m \sin wt.\, d(wt)$$

Here, $T = \pi - 0 = \pi$

$$\text{So, } V_{av} = V_{dc} = 1/\pi \int_{\alpha}^{\pi} V_m \sin wt\, d(wt)$$

$$-V_m/\pi\, |\cos wt|_{\alpha}^{\pi}$$

$$-V_m/\pi\, (\cos \pi - \cos \alpha)$$

$$V_{av} = V_{dc} = V_m/\pi\, (1+ \cos \alpha)$$

Why a half controlled converter is called so?

The average output voltage V_{av} is given by

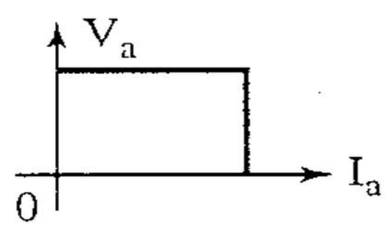
$$V_{av} = V_{dc} = V_m / л (1+ \cos α)$$

When $α = 0$, $V_{dc} = V_m/л (1+\cos 0) = 2V_m / л$ When $α = л/2$, $V_{dc} = V_m/л(1+\cos л/2) = V_m/л$

When $α = л$, $V_{dc} = V_m / л (1+\cos л) = 0$

V_{dc} is always +ve & also the load current is always +ve. So, the load power which is equal to v_{dc}* IL is also +ve for this circuit.In this circuit power flow is only in one direction. Thus control has become half therefore, it can be said single phase full wave half controlled converter.It is one quadrant converter.

Quadrant(s) of Operation



Semiconverter – one quadrant converter

One polarity of output voltage and current

Single phase full wave half controlled converters

(using SCRs and diodes)

These types of half controlled converters are cheaper as two SCRs are replaced by two diodes and are used for applications where converter is not required to work as an inverter.

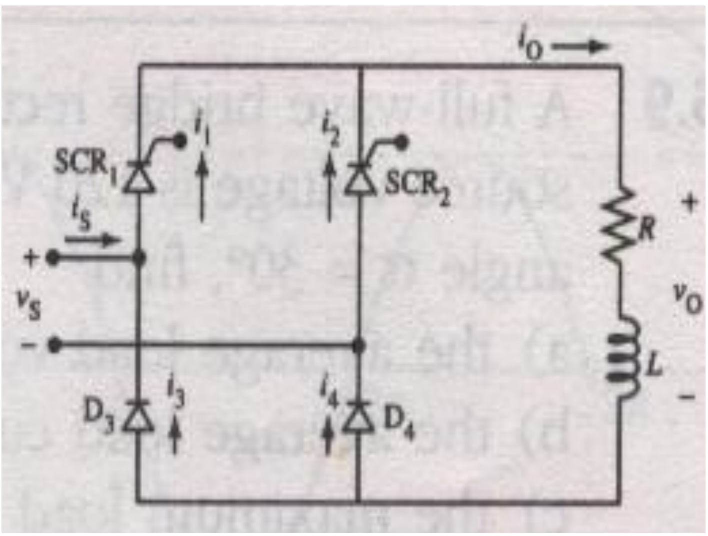
- *Half controlled converters can be fabricated in two connections: Symmetrical Configuration & Asymmetrical Configuration*

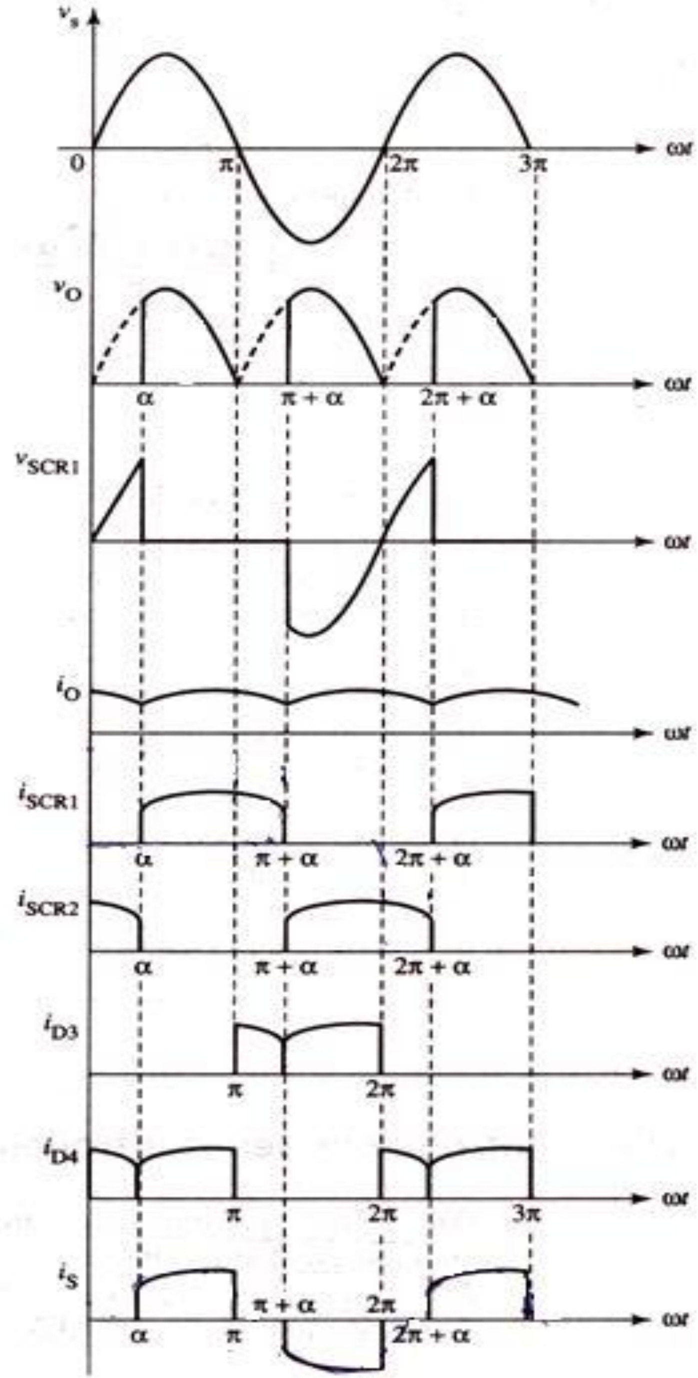
Symmetrical Configuration*-In Symmetrical Configuration, the cathodes of two SCRs are at the same potential so their gates can be connected & a single gate pulse can be used for triggering either SCR.*

In Asymmetrical Configuration, separate-triggering circuits are to be used

Full-wave semicontrolled bridge rectifier circuit

(Symmetrical Configuration)





Symmetrical Configuration:

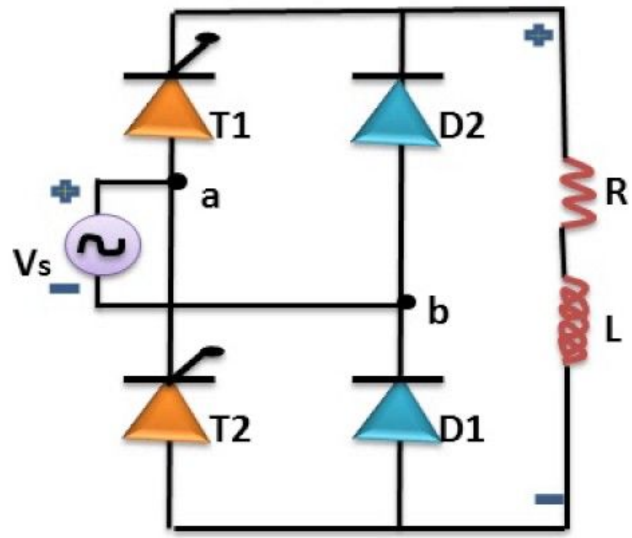
-In Positive half SCR1 is fired SCR_1 and diode D_4 conduct.

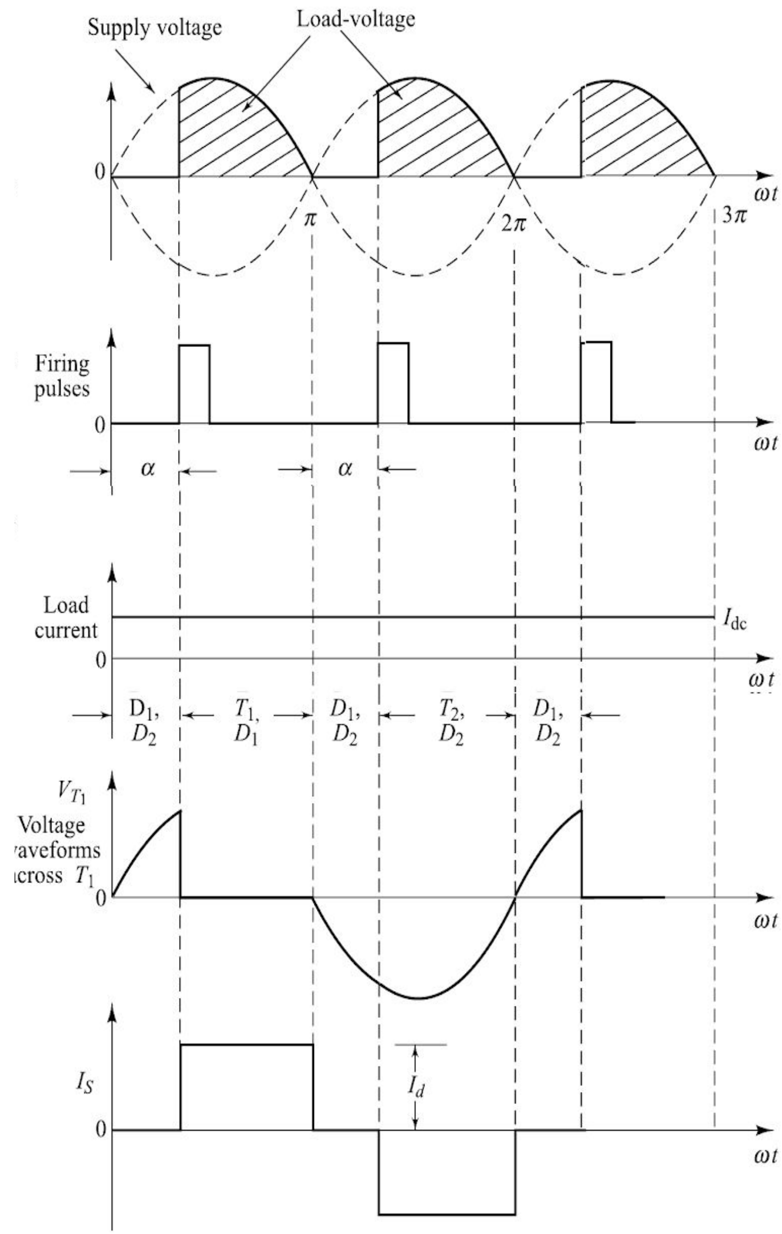
-In negative half SCR_2 is fired and SCR_2 & D_3 conduct.

- *After positive half fly wheeling takes place through SCR_1 and D_3. After negative half flywheeling takes place through SCR_2 and D_4.*
- *Free wheeling diode is not required as inherent flywheeling action is there.*

(ii) Asymmetrical Configuration

- *During [positive half SCR1 and D1 conduct and then energy is flywheeled through diodes D1 and D2.*
- *During negative half D2 and SCR2 conduct & flywheeling is through diodes D1 and D2.*


T1
D2
a
Vs
R
b
L
T2
D1


Supply voltage
Load-voltage
0
ωt
π
2π
3π
Firing pulses
α
α
Load current
I_{dc}
D_1, D_2
T_1, D_1
D_1, D_2
T_2, D_2
D_1, D_2
V_{T_1}
Voltage waveforms across T_1
I_S
I_d

Comparison between Half Controlled & Fully Controlled Rectifier

Half Controlled Rectifier

1. Contains a mixture of diodes and SCR.
2. Mean d.c load voltage can be controlled but reversal of load voltage is not possible.
3. One Quadrant converter.
4. It is also a unidirectional converter ,one polarity of dc output voltage

Fully Controlled Rectifier

1. All rectifying elements are SCRs.
2. By suitable control of phase angle (firing angle) at which the SCRs are turned ON, it is possible to control mean d.c voltage and to reverse d.c load voltage as well.
3. Two quadrant converter, voltage polarity can reverse.
4. It is a bidirectional converter, as it allows the power flow in either direction between the a.c supply and d.c load.

THANK YOU