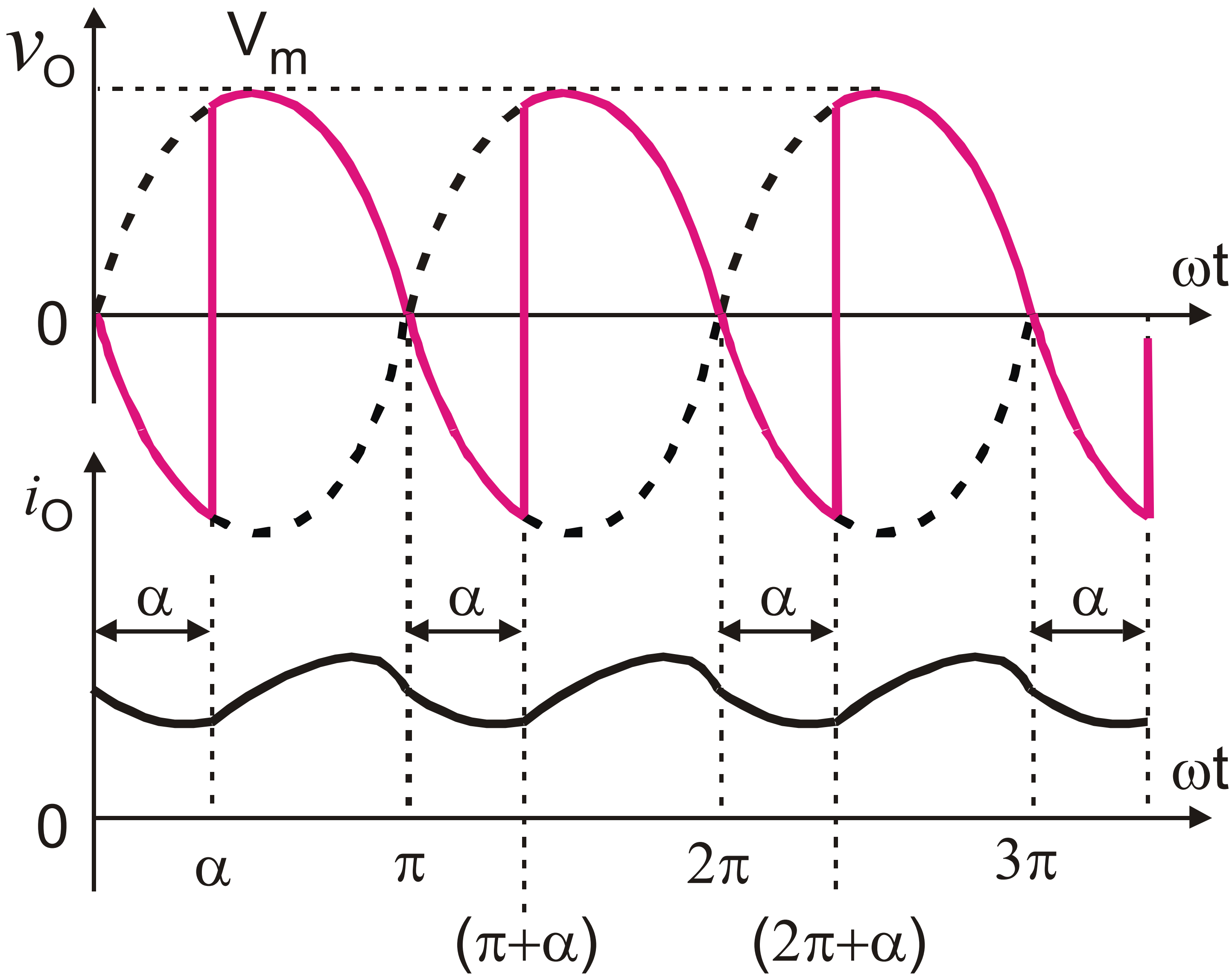
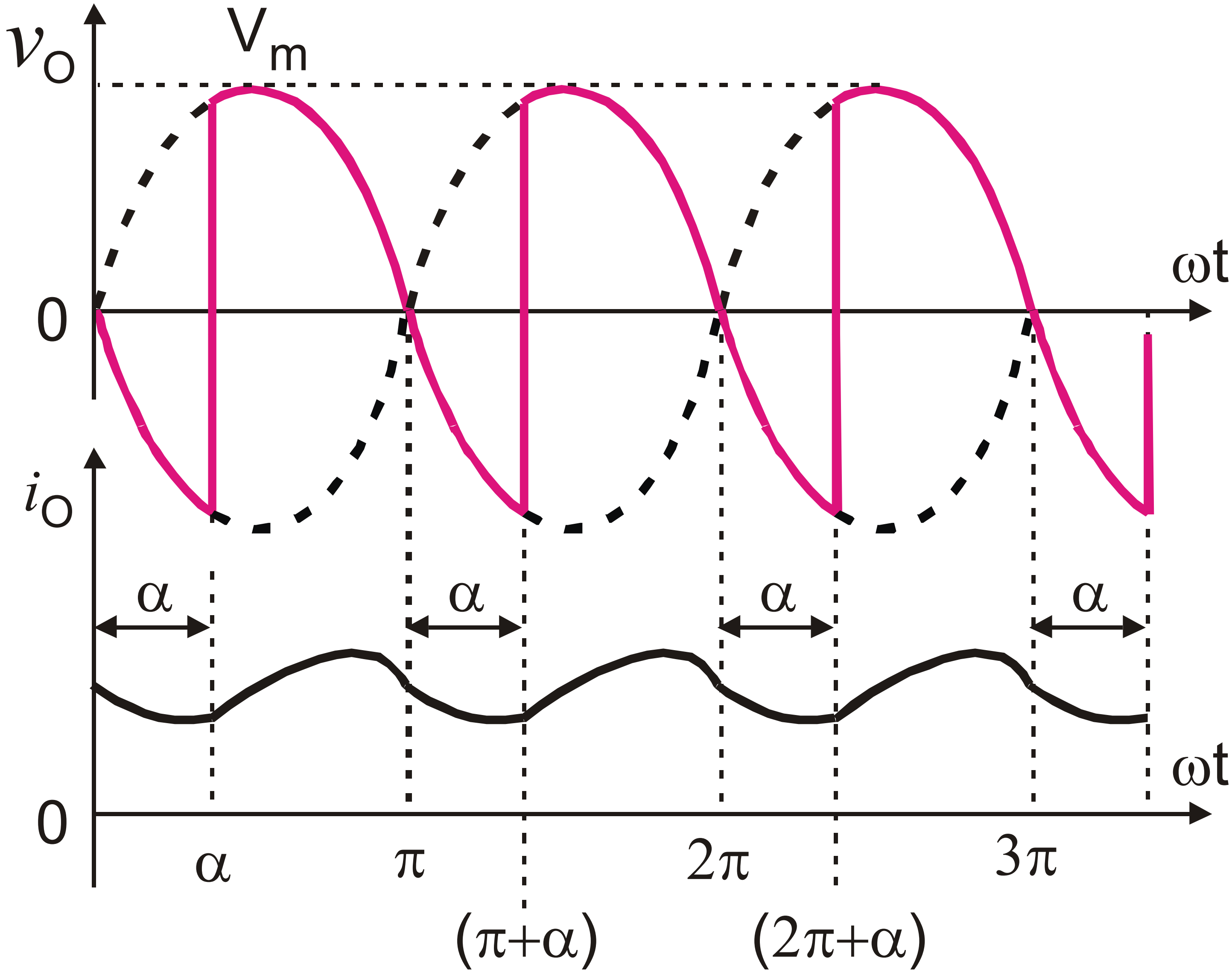
Continuous Load Current Operation (Without FWD)



v_O
V_m
ωt
0
i_O
α
α
α
α
ωt
0
α
π
2π
3π
(π+α)
(2π+α)

To Derive
An Expression For
Average / DC Output Voltage
Of
Single Phase Full Wave Controlled Rectifier For Continuous Current Operation without FWD



v_O
V_m
ωt
0
i_O
α
α
α
α
ωt
0
α
π
2π
3π
(π+α)
(2π+α)

$$V_{O(dc)} = V_{dc} = \frac{1}{\pi} \int_{\omega t=\alpha}^{(\pi+\alpha)} v_O . d(\omega t)$$

$$V_{O(dc)} = V_{dc} = \frac{1}{\pi} \left[\int_{\alpha}^{(\pi+\alpha)} V_m \sin \omega t . d(\omega t) \right]$$

$$V_{O(dc)} = V_{dc} = \frac{V_m}{\pi} \left[-\cos \omega t \Big/_{\alpha}^{(\pi+\alpha)} \right]$$

$$V_{O(dc)} = V_{dc}$$

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

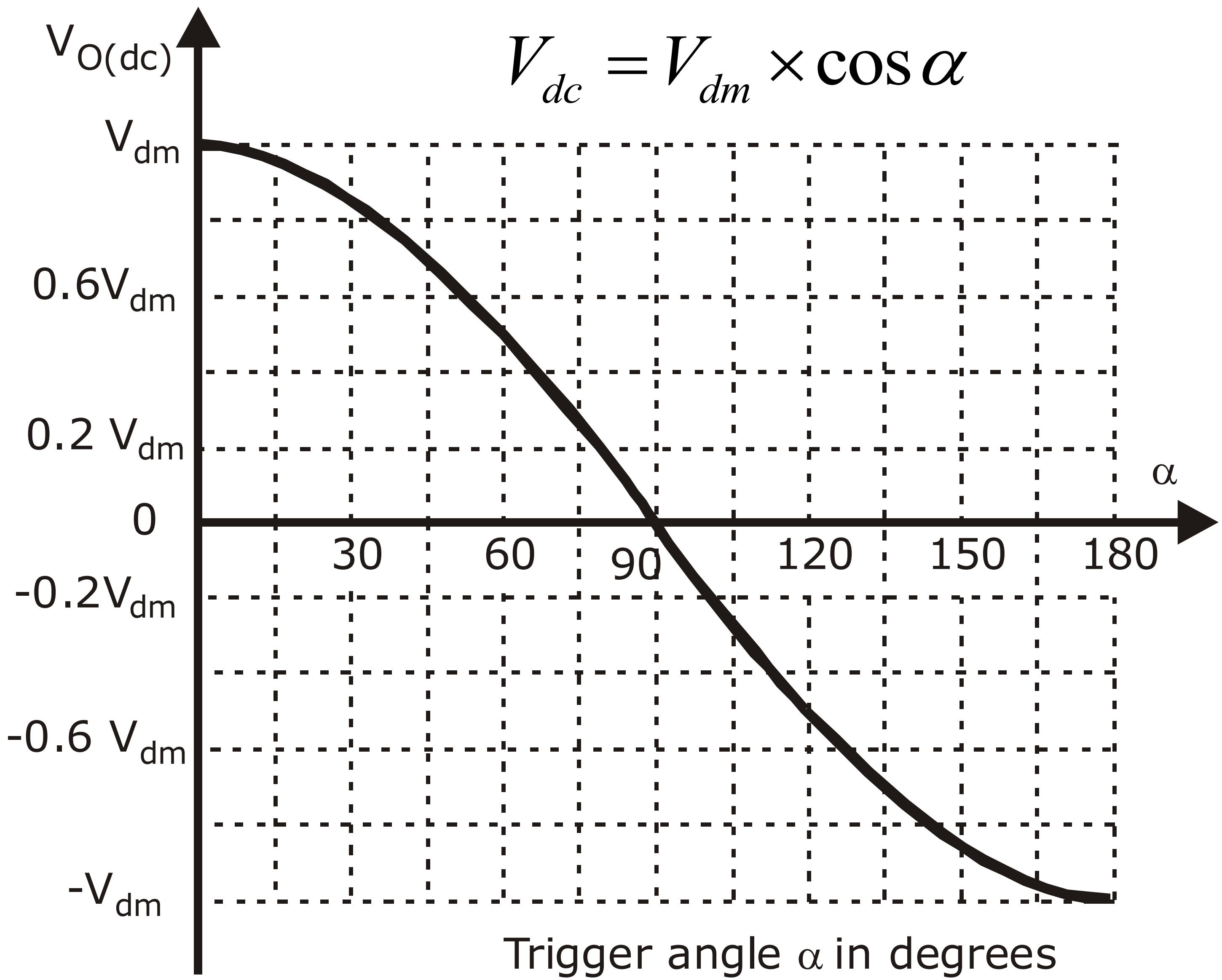
$$\cos\left(\pi + \alpha\right) = -\cos\alpha$$

$$V_{O(dc)} = V_{dc} = \frac{V_m}{\pi}\left[\cos\alpha + \cos\alpha\right]$$

$$\therefore \qquad V_{O(dc)} = V_{dc} = \frac{2V_m}{\pi}\cos\alpha$$

- By plotting $V_{O(dc)}$ *versus* α,
  we obtain the control characteristic of a single phase full wave controlled rectifier with RL load for continuous load current operation without FWD

Trigger angle α in degrees	$V_{O(dc)}$	**Remarks**
0	$V_{dm} = \left(\frac{2V_m}{\pi}\right)$	Maximum dc output voltage $V_{dc(\max)} = V_{dm} = \left(\frac{2V_m}{\pi}\right)$
30^0	$0.866\ V_{dm}$	$V_{dc} = V_{dm} \times \cos\alpha$
60^0	$0.5\ V_{dm}$	
90^0	$0\ V_{dm}$	
120^0	$-0.5\ V_{dm}$	
150^0	$-0.866\ V_{dm}$	
180^0	$-V_{dm} = -\left(\frac{2V_m}{\pi}\right)$	



$V_{O(dc)}$
$V_{dc} = V_{dm} \times \cos\alpha$
V_{dm}
$0.6V_{dm}$
$0.2\ V_{dm}$
0
$-0.2V_{dm}$
$-0.6\ V_{dm}$
$-V_{dm}$
α
30
60
90
120
150
180
Trigger angle α in degrees

By varying the trigger angle we can vary the output dc voltage across the load. Hence we can control the dc output power flow to the load.

For trigger angle α, 0 to 90^0 $\left(i.e.,\ 0 \le \alpha \le 90^0 \right)$;

$\cos\alpha$ is positive and hence V_{dc} is positive

V_{dc} & I_{dc} are positive ; $P_{dc} = \left(V_{dc} \times I_{dc} \right)$ is positive

Converter operates as a Controlled Rectifier.

Power flow is from the ac source to the load.

For trigger angle α, 90^0 to 180^0

$$\left(i.e.,\ 90^0 \le \alpha \le 180^0\right),$$

$\cos\alpha$ is negative and hence

V_{dc} is negative; I_{dc} is positive ;

$$P_{dc} = \left(V_{dc} \times I_{dc}\right) \text{ is negative.}$$

In this case the converter operates

as a Line Commutated Inverter.

Power flows from the load ckt. to the i/p ac source.

The inductive load energy is fed back to the

i/p source.

Drawbacks Of Full Wave Controlled Rectifier With Centre Tapped Transformer

- We require a centre tapped transformer which is quite heavier and bulky.
- Cost of the transformer is higher for the required dc output voltage & output power.
- Hence full wave bridge converters are preferred.

Single Phase
Full Wave Bridge Controlled Rectifier

2 types of FW Bridge Controlled Rectifiers are

- Half Controlled Bridge Converter

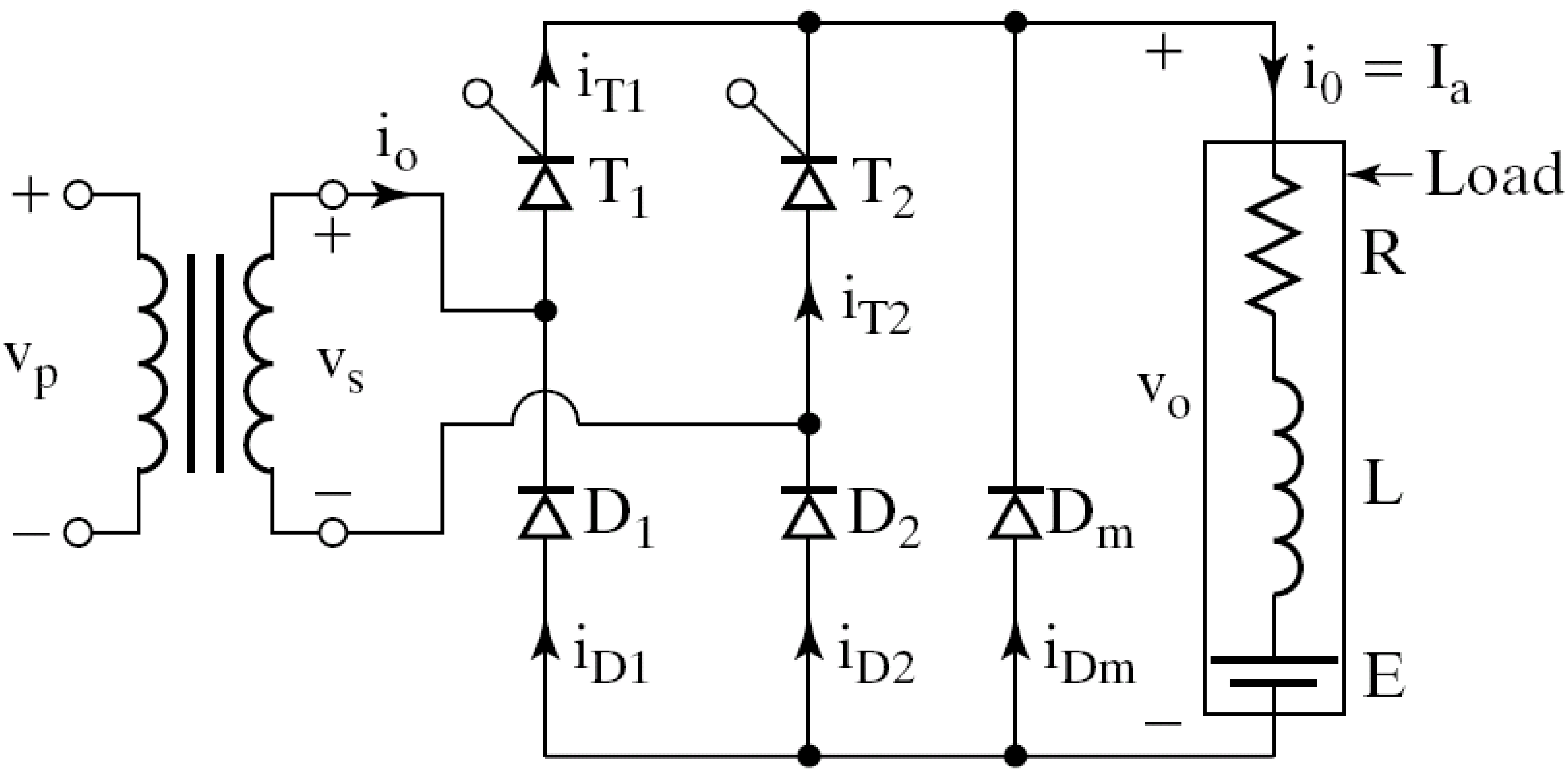
  (Semi-Converter)

- Fully Controlled Bridge Converter

  (Full Converter)

The bridge full wave controlled rectifier does not require a centre tapped transformer

Single Phase
Full Wave Half Controlled Bridge Converter
(Single Phase Semi Converter)



+
−
v_p
v_s
+
−
i_o
i_{T1}
T_1
T_2
i_{T2}
D_1
D_2
D_m
i_{D1}
i_{D2}
i_{Dm}
+
$i_0 = I_a$
Load
R
v_o
L
E
−

Trigger Pattern of Thyristors

$$Thyristor\ T_1\ is\ triggered\ at$$

$$\omega t = \alpha,\ at\ \omega t = \left(2\pi + \alpha\right), \ldots$$

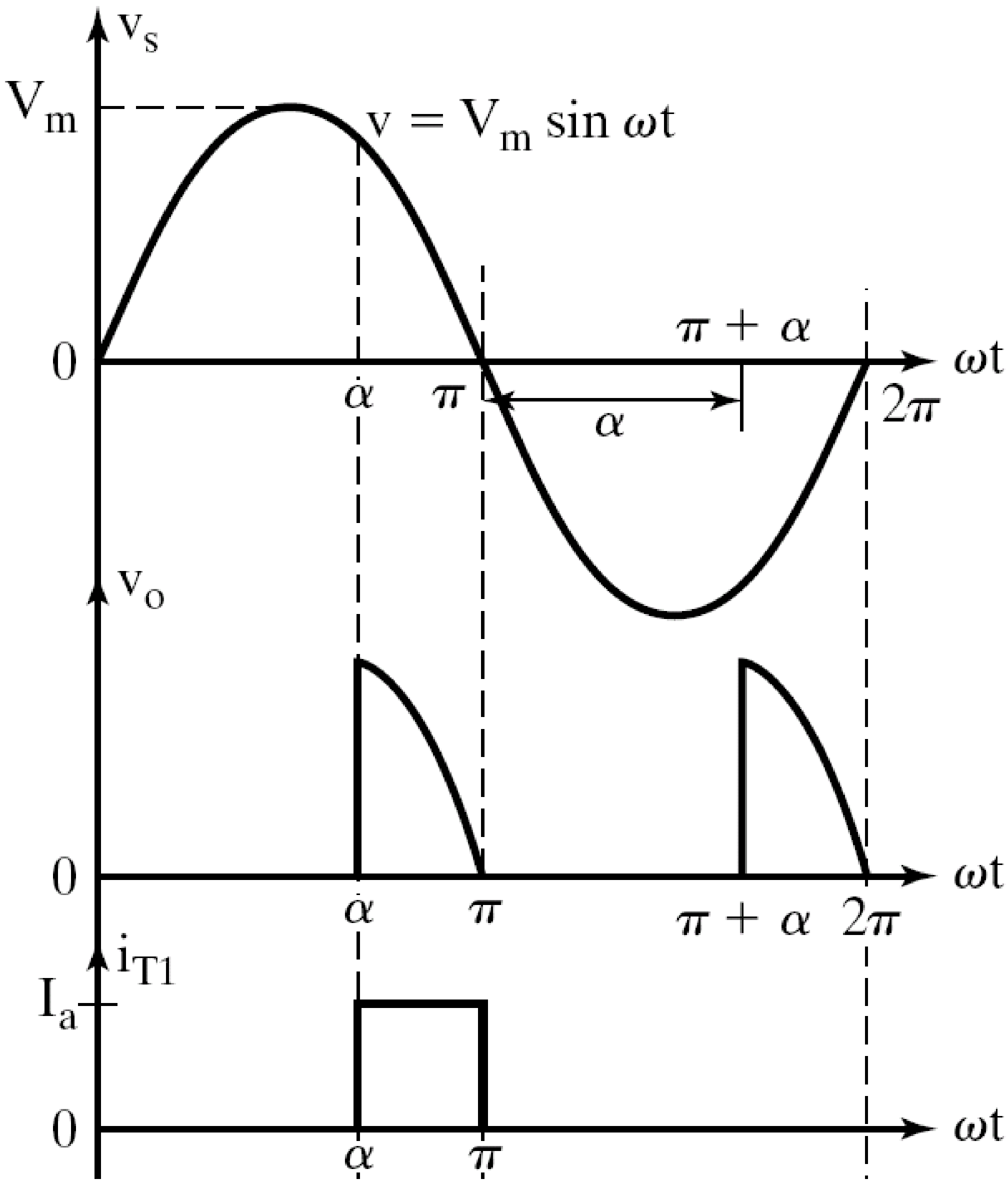
$$Thyristor\ T_2\ is\ triggered\ at$$

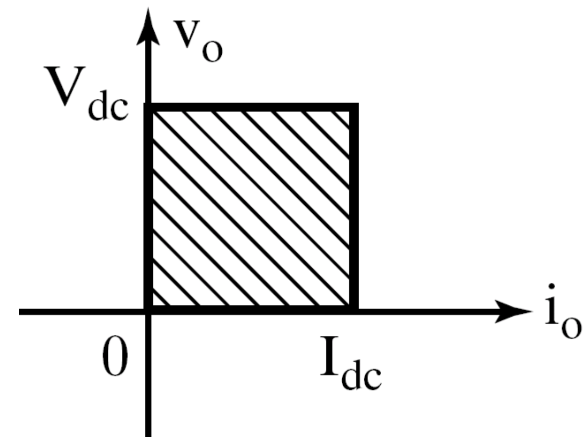
$$\omega t = \left(\pi + \alpha\right),\ at\ \omega t = \left(3\pi + \alpha\right), \ldots$$

$$The\ time\ delay\ between\ the\ gating$$

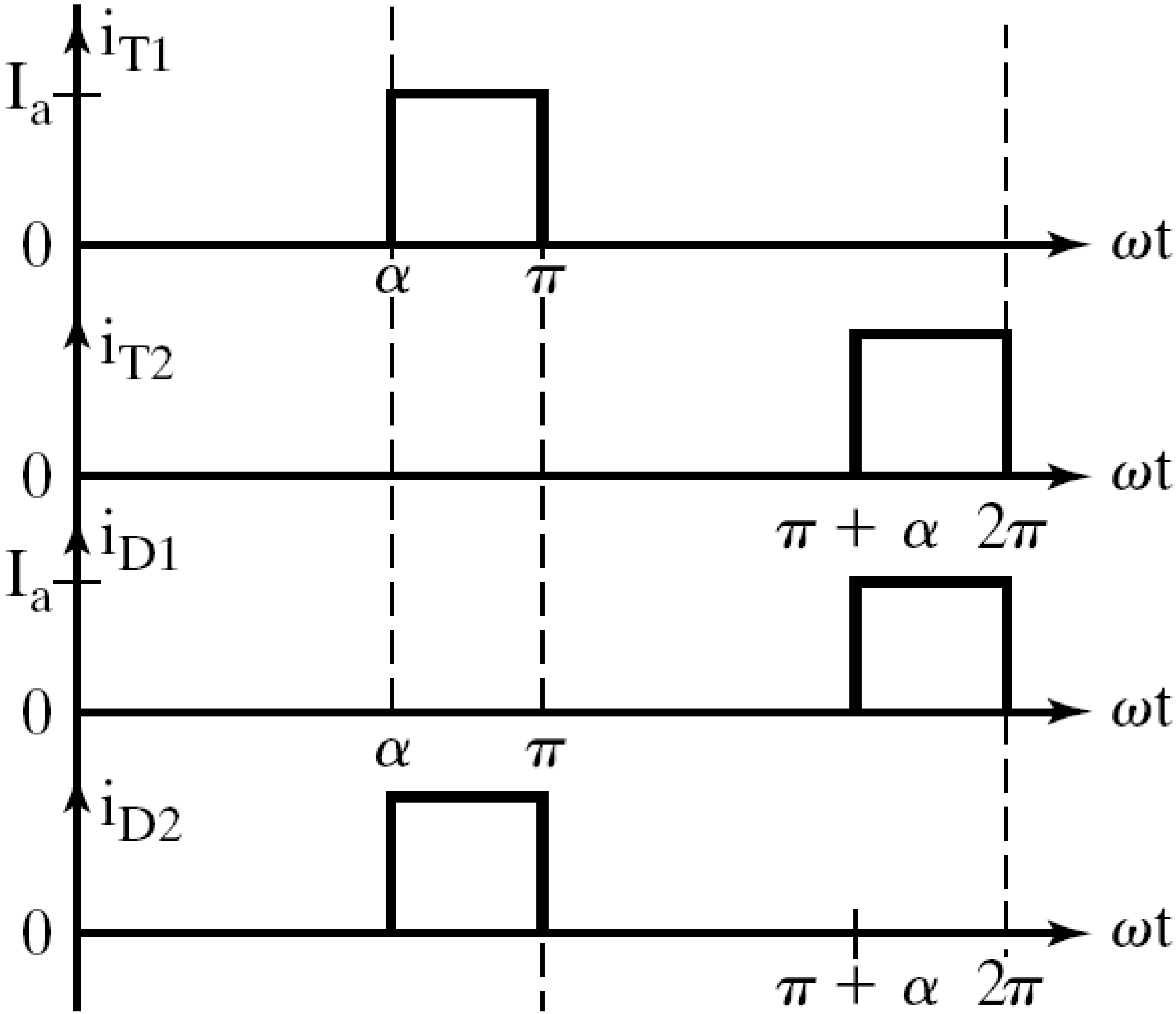
$$signals\ of\ T_1\ \&\ T_2 = \pi\ radians\ or\ 180^0$$

Waveforms of single phase semi-converter with general load & FWD for $\alpha > 90^0$

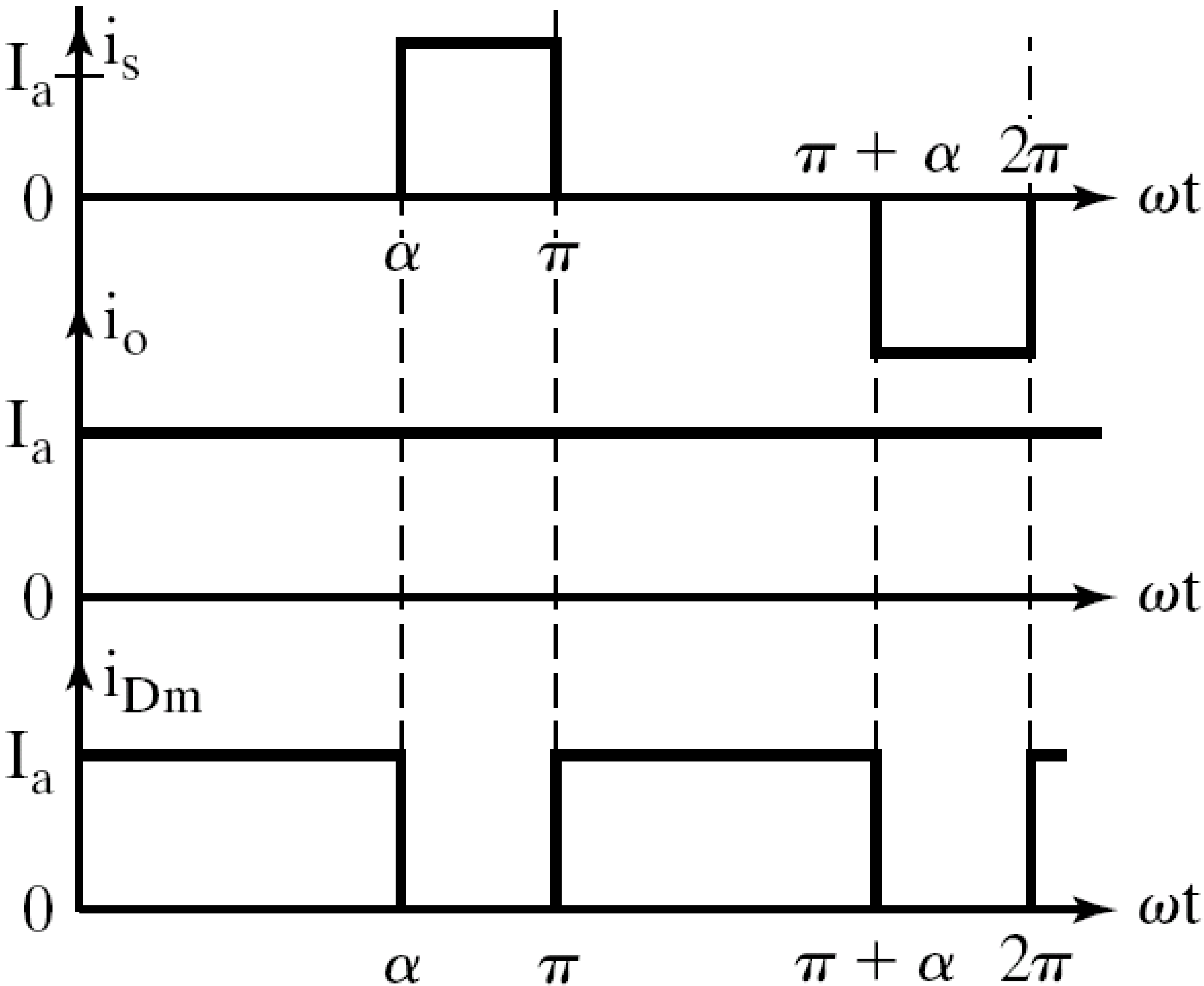




Single Quadrant Operation



i_{T1}
I_a
0
ωt
α
π
i_{T2}
0
ωt
π + α
2π
i_{D1}
I_a
0
ωt
α
π
i_{D2}
0
ωt
π + α
2π



i_s
I_a
0
$\pi + \alpha$
2π
ωt
α
π
i_o
I_a
0
ωt
i_{Dm}
I_a
0
ωt
α
π
$\pi + \alpha$
2π

Thyristor T_1 & D_1 conduct

$$\text{from } \omega t = \alpha \ to \ \pi$$

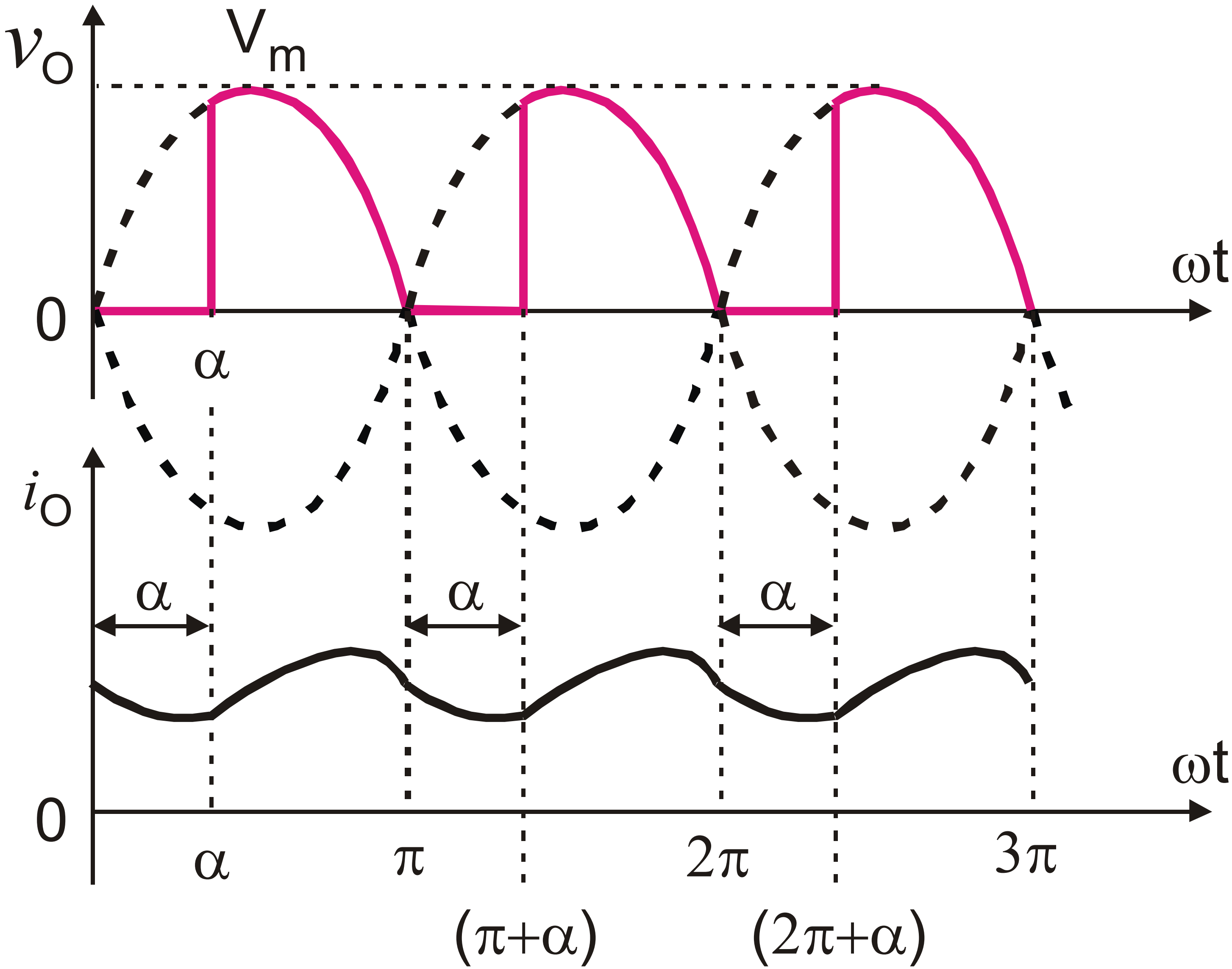
Thyristor T_2 & D_2 conduct

$$\text{from } \omega t = (\pi + \alpha) \ to \ 2\pi$$

FWD conducts during

$$\omega t = 0 \text{ to } \alpha, \ \pi \ to \ (\pi + \alpha), \ldots$$

Load Voltage & Load Current Waveform of Single Phase Semi Converter for $\alpha < 90^0$ & Continuous load current operation



v_O
V_m
ωt
0
α
i_O
α
α
α
ωt
0
α
π
2π
3π
(π+α)
(2π+α)

To Derive an Expression For The DC Output Voltage of A Single Phase Semi-Converter With R,L, & E Load & FWD For Continuous, Ripple Free Load Current Operation

$$V_{O(dc)} = V_{dc} = \frac{1}{\pi} \int_{\omega t=0}^{\pi} v_O . d(\omega t)$$

$$\therefore \quad V_{O(dc)} = V_{dc} = \frac{1}{\pi} \int_{\alpha}^{\pi} V_m \sin \omega t . d(\omega t)$$

$$V_{O(dc)} = V_{dc} = \frac{V_m}{\pi} \left[-\cos \omega t \Big/_{\alpha}^{\pi} \right]$$

$$V_{O(dc)} = V_{dc} = \frac{V_m}{\pi} \left[-\cos \pi + \cos \alpha \right] \;\; ; \;\; \cos \pi = -1$$

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

V_{dc} can be varied from a max.

value of $\frac{2V_m}{\pi}$ *to* 0 by varying α from 0 to π.

For $\alpha = 0$, The max. dc o/p voltage obtained is

$$V_{dc(\max)} = V_{dm} = \frac{2V_m}{\pi}$$

Normalized dc o/p voltage is

$$V_{dcn} = V_n = \frac{V_{dc}}{V_{dn}} = \frac{\frac{V_m}{\pi}\left(1+\cos\alpha\right)}{\left(\frac{2V_m}{\pi}\right)} = \frac{1}{2}\left(1+\cos\alpha\right)$$

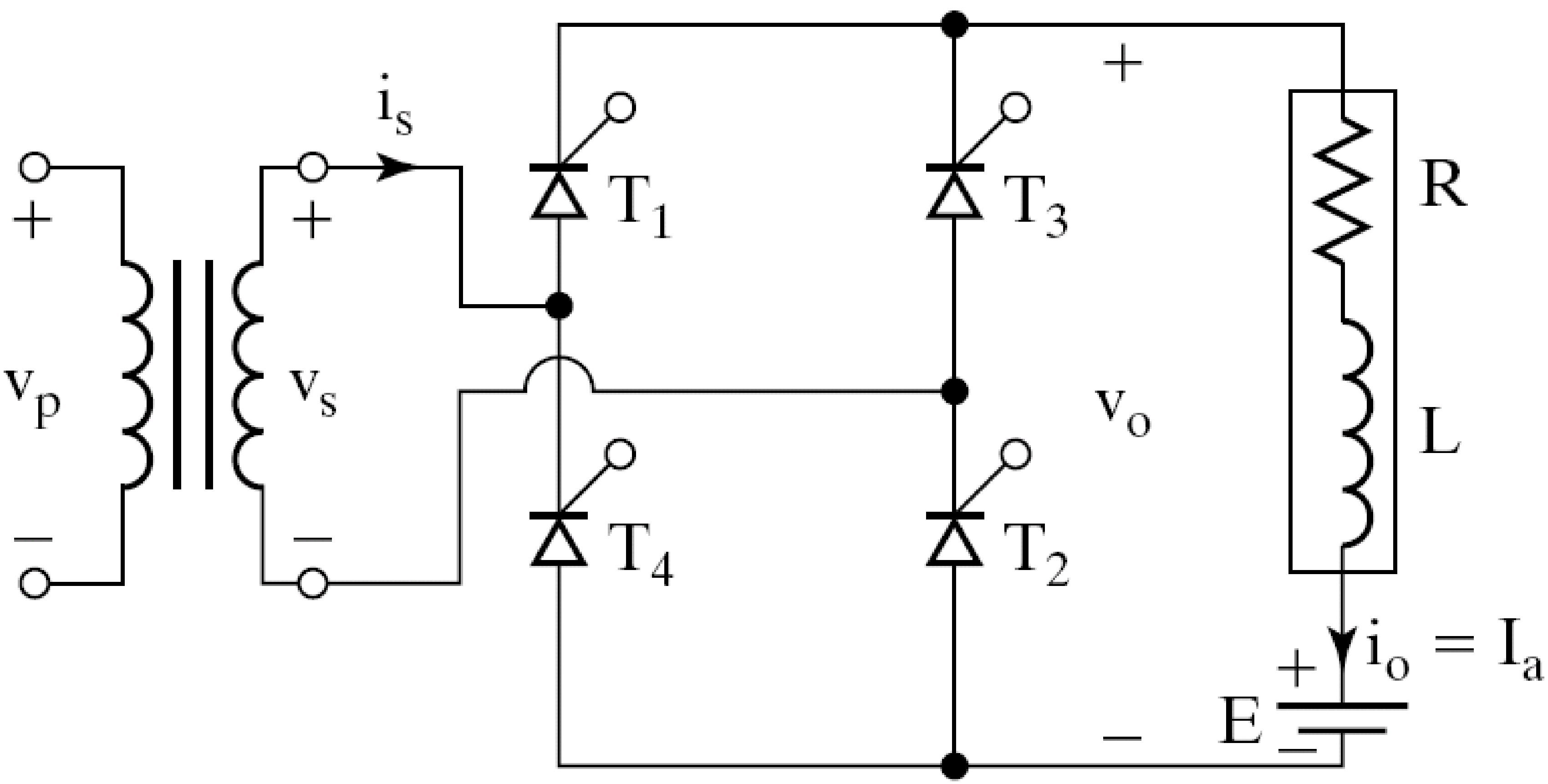
RMS O/P Voltage $V_{O(RMS)}$

$$V_{O(RMS)} = \left[\frac{2}{2\pi} \int_{\alpha}^{\pi} V_m^2 \sin^2 \omega t.d\left(\omega t\right) \right]^{\frac{1}{2}}$$

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

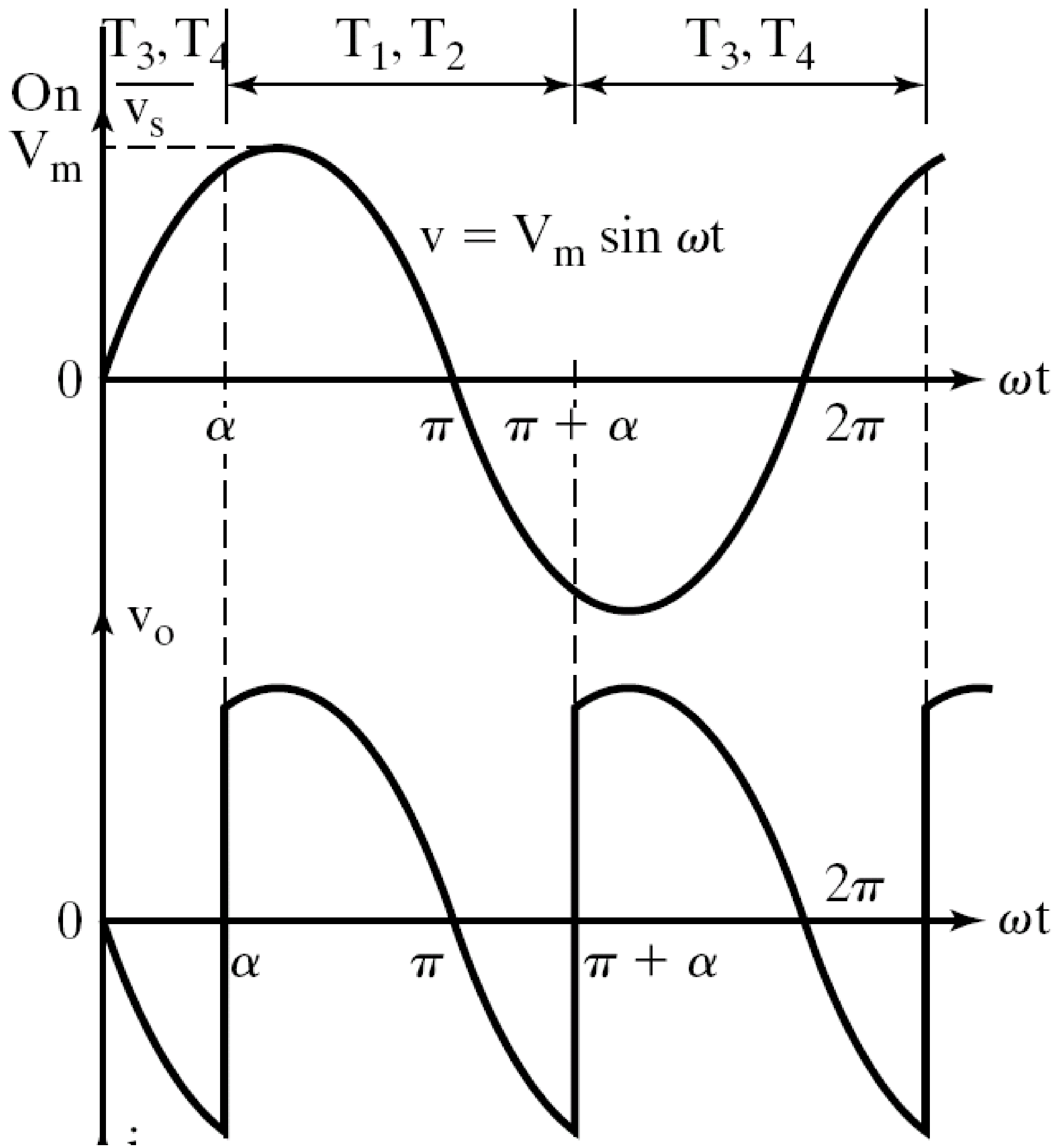
$$V_{O(RMS)} = \frac{V_m}{\sqrt{2}} \left[\frac{1}{\pi} \left(\pi - \alpha + \frac{\sin 2\alpha}{2} \right) \right]^{\frac{1}{2}}$$

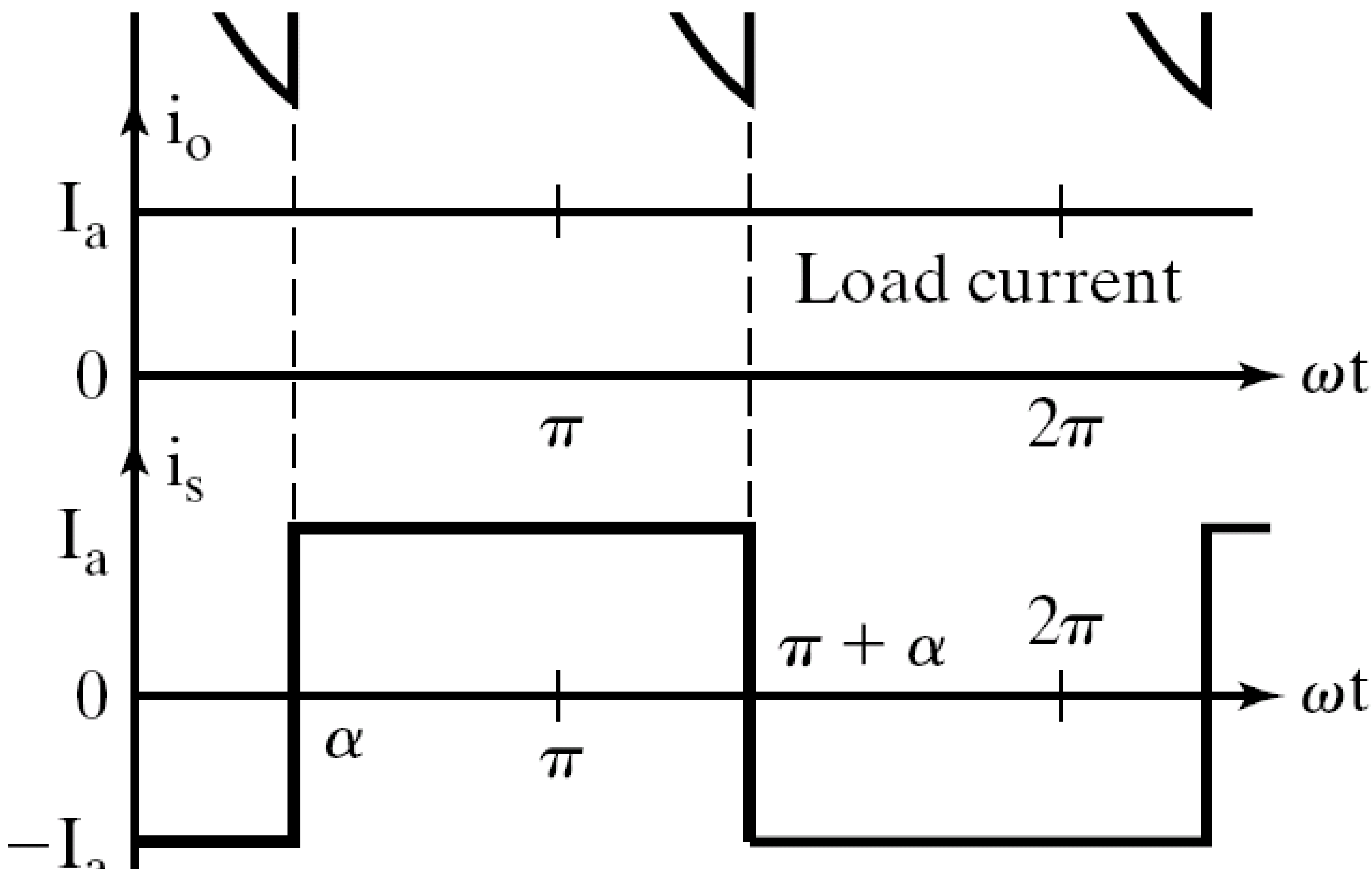
Single Phase Full Wave
Full Converter
(Fully Controlled Bridge Converter)
With R,L, & E Load



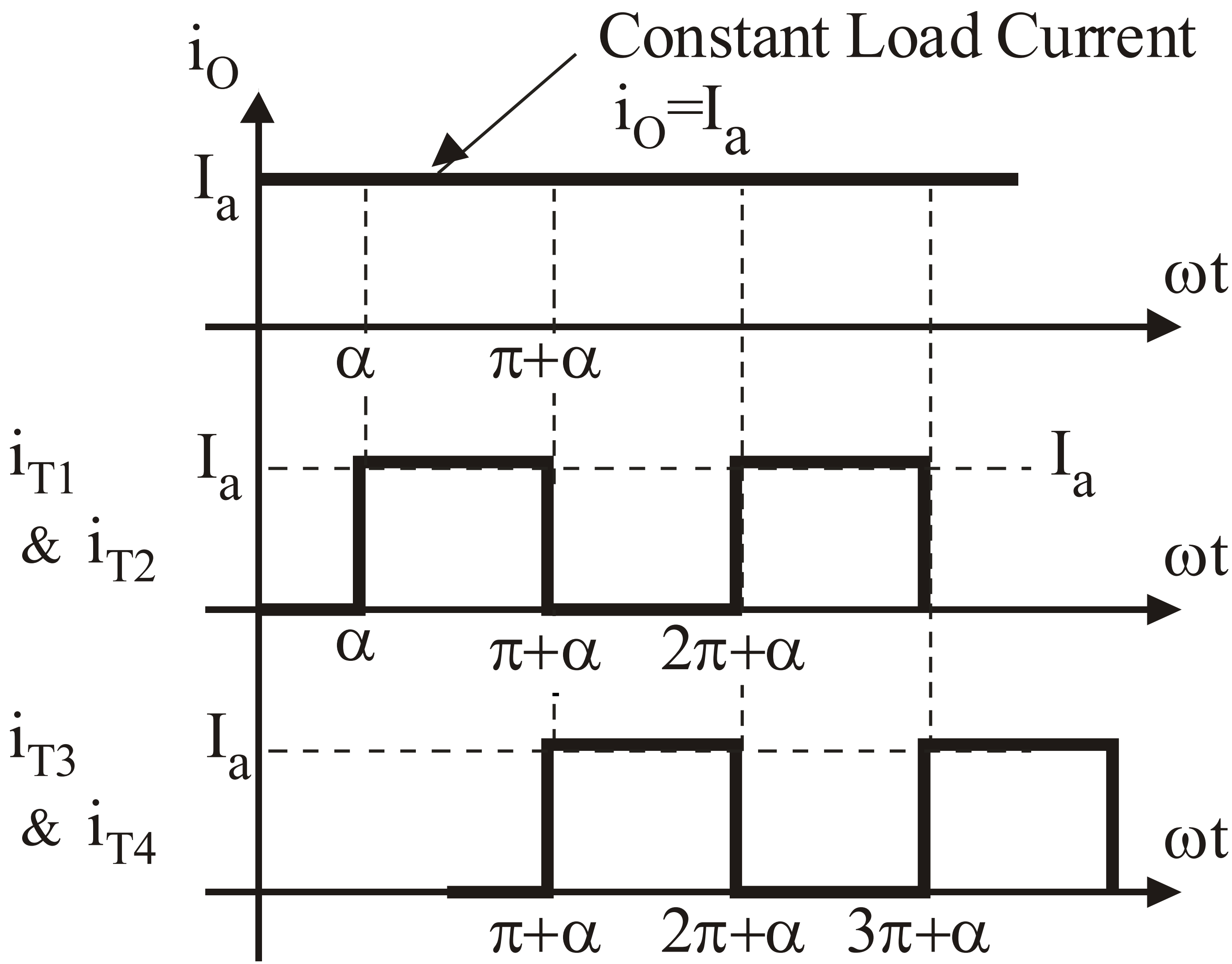
i_s
+
+
+
v_p
v_s
T_1
T_3
T_4
T_2
R
L
v_o
−
−
−
$i_o = I_a$
+
E
−

Waveforms of
Single Phase Full Converter
Assuming Continuous (Constant Load Current)
&
Ripple Free Load Current


T3, T4
T1, T2
T3, T4
On
vs
Vm
v = Vm sin ωt
0
ωt
α
π
π + α
2π
vo
0
2π
ωt
α
π
π + α



i_o
I_a
Load current
0
ωt
π
2π
i_s
I_a
π + α
2π
0
ωt
α
π
−I_a



Constant Load Current
$i_O = I_a$
i_O
I_a
ωt
α
$\pi+\alpha$
i_{T1} & i_{T2}
I_a
I_a
ωt
α
$\pi+\alpha$
$2\pi+\alpha$
i_{T3} & i_{T4}
I_a
ωt
$\pi+\alpha$
$2\pi+\alpha$
$3\pi+\alpha$

To Derive
An Expression For
The Average DC Output Voltage of a Single Phase Full Converter
assuming
Continuous & Constant Load Current

The average dc output voltage can be determined by using the expression

$$V_{O(dc)} = V_{dc} = \frac{1}{2\pi}\left[\int_{0}^{2\pi} v_O . d\left(\omega t\right)\right];$$

The o/p voltage waveform consists of two o/p pulses during the input supply time period of 0 to 2π radians. Hence the Average or dc o/p voltage can be calculated as

$$V_{O(dc)} = V_{dc} = \frac{2}{2\pi}\left[\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t . d\left(\omega t\right)\right]$$

$$V_{O(dc)} = V_{dc} = \frac{2V_m}{2\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi+\alpha}$$

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

Maximum average dc output voltage is calculated for a trigger angle $\alpha = 0^0$ and is obtained as

$$V_{dc(\max)} = V_{dm} = \frac{2V_m}{\pi} \times \cos(0) = \frac{2V_m}{\pi}$$

$$\therefore V_{dc(\max)} = V_{dm} = \frac{2V_m}{\pi}$$

The normalized average output voltage is given by

$$V_{dcn} = V_n = \frac{V_{O(dc)}}{V_{dc(\max)}} = \frac{V_{dc}}{V_{dm}}$$

$$\therefore V_{dcn} = V_n = \frac{\frac{2V_m}{\pi}\cos\alpha}{\frac{2V_m}{\pi}} = \cos\alpha$$

By plotting $V_{O(dc)}$ *versus* α,

we obtain the control characteristic of a single phase full wave fully controlled bridge converter

(single phase full converter)

for constant & continuous

load current operation.

To plot the control characteristic of a Single Phase Full Converter for constant & continuous load current operation.

We use the equation for the average/ dc output voltage

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

Trigger angle α in degrees	$V_{O(dc)}$	Remarks
0	$V_{dm} = \left(\frac{2V_m}{\pi}\right)$	Maximum dc output voltage $V_{dc(\max)} = V_{dm} = \left(\frac{2V_m}{\pi}\right)$
30^0	$0.866\ V_{dm}$	
60^0	$0.5\ V_{dm}$	
90^0	$0\ V_{dm}$	
120^0	$-0.5\ V_{dm}$	
150^0	$-0.866\ V_{dm}$	
180^0	$-V_{dm} = -\left(\frac{2V_m}{\pi}\right)$	