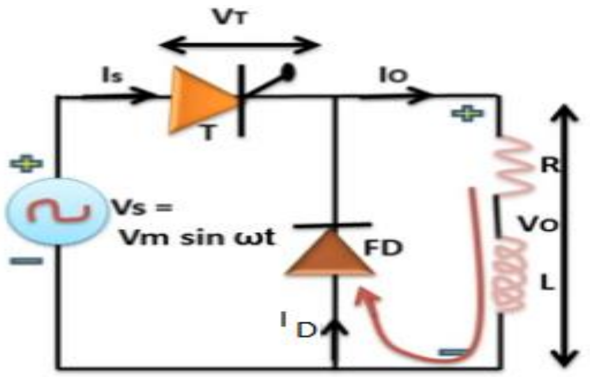
CMR INSTITUTE OF TECHNOLOGY	18EE53 - POWER ELECTRONICS Scheme & Solution	CMR

Internal Assesment Test - II

Answer Any FIVE FULL Questions

		Marks	OBE CO	OBE RBT
1	Explain single phase half wave controlled converter with RL load and freewheeling diode, derive the expression for average and RMS voltage.	[10]	CO4	L2



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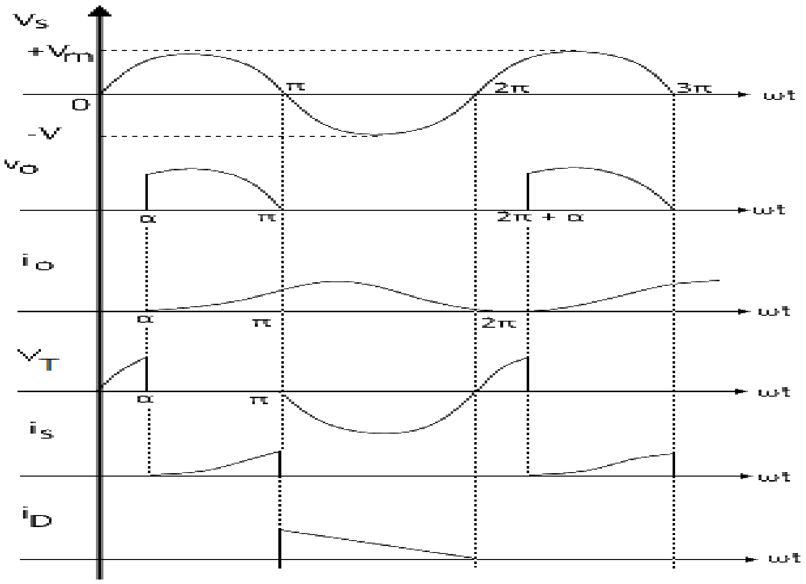


2

2

During the positive half cycle

- 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 ωt= α, 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

- During the negative half cycle, the thyristor T gets reverse biased.
- At this instant i.e at ωt = π, 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 freewheeling diode-R-L.
- So here the thyristor will not conduct in the negative half cycle and turns off at ωt=π.
- 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. 2

Average Output Voltage

Average Value of Load output Voltage

$$= (1/2\pi)\int_{\alpha}^{\pi} VmSin\omega t d(\omega t)$$

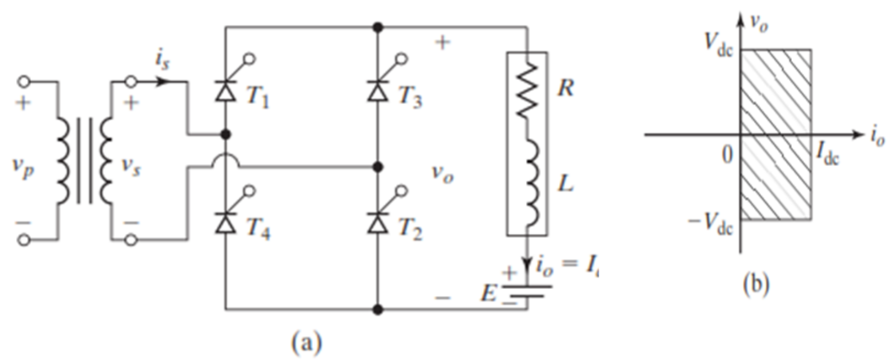
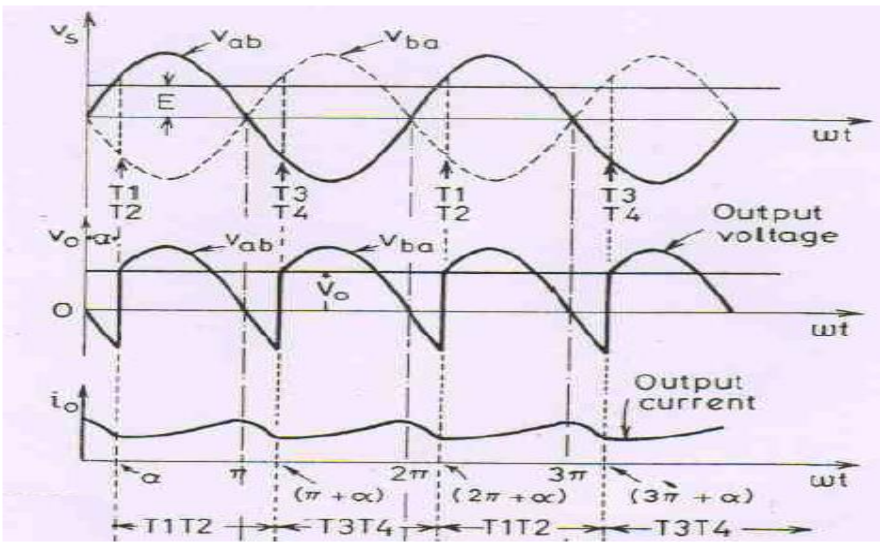
$$= (Vm/2\pi)\int_{\alpha}^{\pi} Sin\omega t d(\omega t) = \frac{V_m}{2\pi}[-Cos(\omega t)]_{\alpha}^{\pi}$$

$$= \left(\frac{Vm}{2\pi}\right)[1 + Cos\alpha]$$

For Single Phase Half Wave Controlled Rectifier:

Average Value of Load output Voltage

$$Vdc = \left(\frac{Vm}{2\pi}\right)[1 + Cos\alpha]$$

	RMS Value of Output voltage ***RMS Value of Load output Voltage*** $= \sqrt{(1/2\pi)\int_{0}^{2\pi}[VmSin\omega t]^2 d(\omega t)}$ $= \sqrt{(Vm^2/4\pi)\int_{\alpha}^{\pi}[1 - Cos2\omega t]d(\omega t)}$ $= \left(\frac{Vm}{2\sqrt{\pi}}\right)\sqrt{(\pi - \alpha) + (1/2)Sin2\alpha} \quad = \left(\frac{Vm}{2}\right)\sqrt{\frac{1}{\pi}\{(\pi - \alpha) + (1/2)Sin2\alpha\}}$ ***RMS Value of Load output Voltage*** Vrms $= \left(\frac{Vm}{2\sqrt{\pi}}\right)\sqrt{(\pi - \alpha) + (1/2)Sin2\alpha}$	2		
2	Explain single phase fully controlled converter with RLE load with neat diagram and waveform and derive the expression for average and RMS voltage.   	[10] 2 2	CO4	L2

During the positive half-cycle

2

- The fully controlled bridge converter consists of four thyristors *T1, T2, T3 and T4* connected in the form of full wave bridge configuration.
- Each thyristor is controlled and turned on by its gating signal and naturally turns off when a reverse voltage appears across it (Line commutation or Natural commutation).
- Thyristors $T1$ and $T2$ are forward biased (0 to π);
- when these two thyristors are turned on simultaneously at $\omega t = \alpha$, the load is connected to the input supply through $T1$ and $T2$.
- Due to the inductive load, thyristors $T1$ and $T2$ continue to conduct beyond $\omega t = \pi$, even though the input voltage is already negative.
- $T1$ and $T2$ conduct from $\omega t = \alpha$ to $\pi + \alpha$
- The output voltage across the load follows the input voltage vo = vm sin ωt

During the negative half-cycle of the input voltage

- Thyristors $T3$ and $T4$ are forward biased (π to 2π);
- Turning on of thyristors $T3$ and $T4$ applies the supply voltage across thyristors $T1$ and $T2$ as reverse blocking voltage.
- *T3 & T4 are triggered at* $\omega t = \pi + \alpha$
- $T1$ and $T2$ are turned off due to *line* or *natural commutation.*
- The output voltage across the load follows the input voltage vo = - vm sin ωt
- Load current is transferred from *T1 and T2* to *T3* and *T4*.
- $T3$ and $T4$ conduct from $\omega t = \pi + \alpha$ to $2\pi + \alpha$
- During next half cycle T3 and T4 are turned off

During Period from α to π - *Rectification* mode

- The input voltage vs and input current *is* are positive,
- Power flows from the supply to the load.
- The converter is said to be operated in ***rectification* mode.**

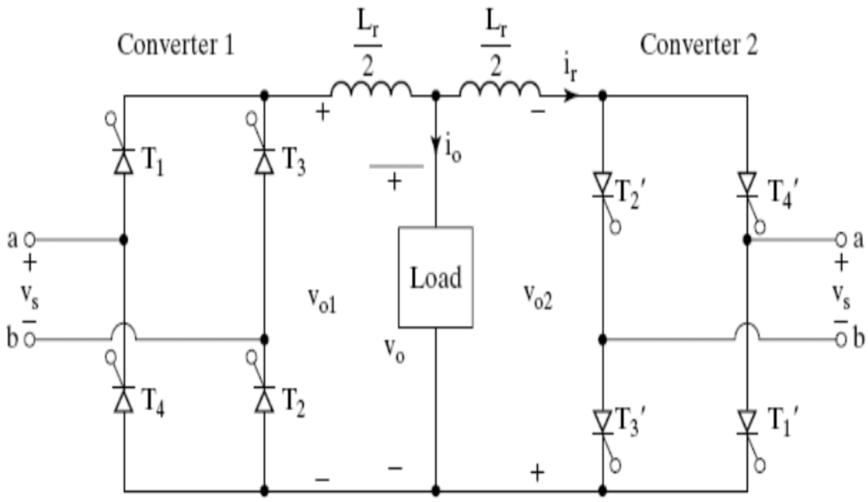
During Period from π to π + α - *Inversion* mode

- The input voltage vs is negative and the input current is is positive,
- Reverse power flows from the load to the supply.

	• The converter is said to be operated in inversion mode. • This converter is extensively used in industrial applications up to 15 kW . • Depending on the value of **α**, the average output voltage could be either positive or negative and it provides two-quadrant operation. **Average Output Voltage Vdc** $V_{O(dc)} = V_{dc} = \frac{2}{2\pi}\left[\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t.d(\omega t)\right]$ $V_{O(dc)} = V_{dc} = \frac{1}{\pi}\left[\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t.d(\omega t)\right]$ $V_{O(dc)} = V_{dc} = \frac{V_m}{\pi}\left[\int_{\alpha}^{\pi+\alpha} \sin\omega t.d(\omega t)\right]$ $V_{O(dc)} = V_{dc} = \frac{V_m}{\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi+\alpha}$ $V_{O(dc)} = V_{dc} = \frac{V_m}{\pi}\left[-\cos(\pi+\alpha)+\cos\alpha\right]$ $\cos(\pi+\alpha) = -\cos\alpha$ Therefore $V_{O(dc)} = V_{dc} = \frac{2V_m}{\pi}\cos\alpha$ **RMS Output Voltage Vrms** The rms value of the output voltage is given by $V_{rms} = \left[\frac{2}{2\pi}\int_{\alpha}^{\pi+\alpha} V_m^2 \sin^2\omega t\, d(\omega t)\right]^{1/2}$ $= \left[\frac{V_m^2}{2\pi}\int_{\alpha}^{\pi+\alpha} (1 - \cos 2\omega t)\, d(\omega t)\right]^{1/2}$ $= \frac{V_m}{\sqrt{2}} = V_s$ With a purely resistive load, thyristors T_1 and T_2 can conduct from α to π, and thyristors T_3 and T_4 can conduct from α + π to 2π.	2 2		
3	Illustrate the single phase dual converter with neat diagram and waveform and also explain the significance of circulating current in dual converter. • Dual converter- the name itself indicates that it has two converters in it. • The dual converter system will provide four quadrant operation	[10]	CO4	L2

- Normally used in high power industrial variable speed drives.
- In the case of a single phase full converter with inductive loads, the converter can operate in two different quadrants in the *Vdc* versus *Idc* operating diagram.
- If two single phase full converters are connected in parallel and in opposite direction (connected in back to back) across a common load four quadrant operation is possible.

Such a converter is called as a dual converter.



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- Two single phase full converters are connected in parallel and in opposite direction (connected in back to back) across a common load

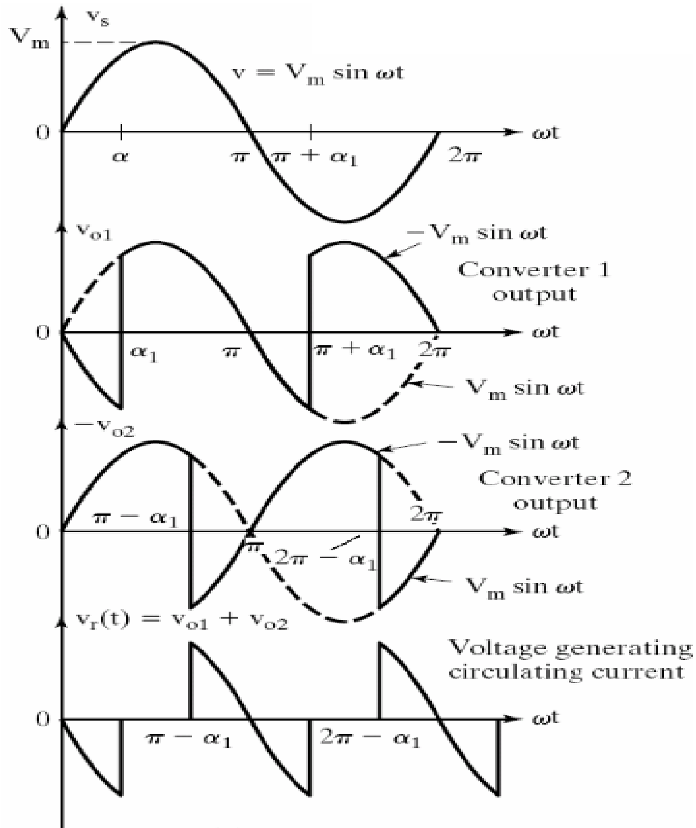
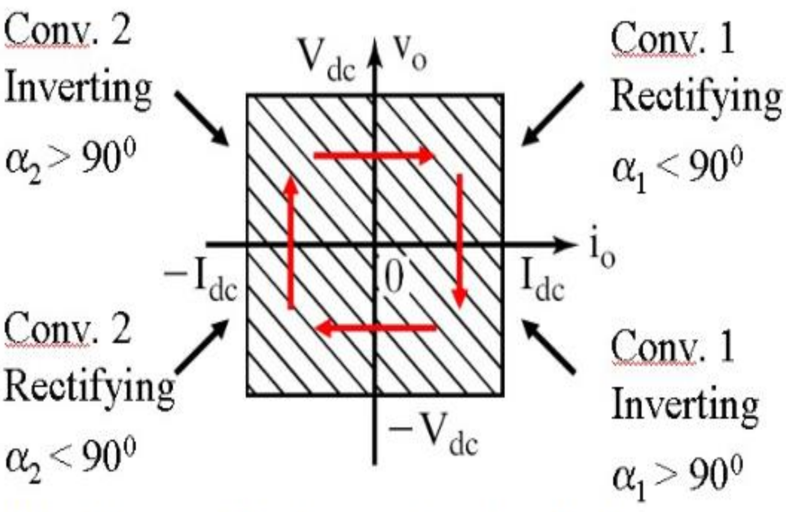
Converter 1

- The converter number 1 provides a positive dc output voltage and a positive dc load current, when operated in the rectification mode.
- The converter number 1 provides a negative dc output voltage and a positive dc load current, when operated in the inverter mode.

2

Converter 2

- The converter number 2 provides a negative dc output voltage and a negative dc load current when operated in the rectification mode.
- The converter number 2 provides a positive dc output voltage and a negative dc load current when operated in the inverter mode.
- We can have **bi- directional load current and bi-directional dc output voltage.**

	• The magnitude of output dc load voltage and the dc load current can be controlled by varying the trigger angles **α** 1 & **α** 2 of the converters 1 and 2 respectively. • **α 1 - Firing angle for converter 1** • **α 2 - Firing angle for converter 2**	2		
	 (b) Waveforms	1		
	 **Fig.: Four quadrant operation of a dual converter**	1		

	CIRCULATING CURRENT • In this mode of operation both the converters 1 and 2 are switched on and operated simultaneously and both the converters are in a state of conduction. • If converter 1 is operated as a controlled rectifier by adjusting the trigger angle α_1 **between 0 to 90º (0<α_1< 90º**) • The second converter 2 is operated as a line commutated inverter by increasing its trigger angle α_2 **above 90 (90º<α_2<180º**). • The trigger angles α_1 and α_2 are adjusted such that they produce the same average dc output voltage across the load terminals. • Instantaneous output voltages of two converters are out of phase , this voltage difference causes circulating current between two converters. • This cannot flow through the load, and it is limited by limiting reactor. • In the circulating current mode a current builds up between the two converters even when the load current falls to zero. • In order to limit the circulating current flowing between the two converters, we have to include current limiting reactors in series between the output terminals of the two converters. **Significance of circulating current** • We can have faster reversal of load current as the two converters are in a state of conduction simultaneously. • This greatly improves the dynamic response of the output giving a faster dynamic response. • The output voltage and the load current can be linearly varied by adjusting the trigger angles α_1 **and** α_2 to obtain a smooth and linear output control. • The control circuit becomes relatively simple. • Output response is very fast. • The load current is free to flow in either direction at any time. The reversal of the load current can be done in a faster and smoother way.	2		
4 a	A single phase fully controlled bridge converter is connected with RLE load where R = 4Ω, L= 4mH and E = 60V.The converter is fed from 220V,50Hz	[5]	CO4	L3

	ac supply. Calculate the average value of load current when the firing angle is 60°. $V_{0\,avg} = \frac{2V_m}{\pi} \cos\alpha$ $= \frac{2\times\sqrt{2}\times 220}{\pi} \cdot \cos 60 \Rightarrow 99.03V$ $I_0(avg.) = \frac{V_{0avg} - E}{R} = \frac{99.03 - 50}{5} \Rightarrow 9.806\ A$			
4 b	A single phase circulating current Dual converter is fed by a single phase 120V, 50Hz supply. The load is resistive. The peak current of converter 1 is 35 A. The firing angles are 30° and 150° respectively. If peak circulating current is 13A, Find (i) Inductance of current limiting reactor (ii) Load Resistance. 4) Circulating Current mode dual converter: $V_s = 120V$, $V_m = \sqrt{2}\ V_s = \sqrt{2}\times 120 = 169.7\ V$ $f = 50Hz$; R load. $\omega = 2\pi f = 2\times 3.14\times 50 = 314.16$ rad/sec. Peak Current of converter 1 = 35A. $\alpha_1 = 30°$; $\alpha_2 = 150°$ Peak Circulating Current $I_{rmax} = 13A$	[5] 5	CO4	L3

	(i) Inductance of Current limiting Reactor L_r. $I_{rmax} = \frac{2V_m}{\omega L_r}(1-\cos\alpha_1) = \frac{2\times 169.7}{314.16\times L_r}(1-\cos 30)$ $13 = \frac{339.4}{314.16\times L_r}\times 0.134$ (5 marks) $L_r = \frac{339.4\times 0.134}{314.16\times 13} = 0.01113 H$. $L_r = 11.13\ mH$ (ii) Load Resistance R. (5 marks) Peak current of converter 1 $= I_{rmax} + I_p$ $35 = 13 + I_p$ $I_p = 35 - 13 = 22\ A$. $I_p = \frac{V_m}{R} \Rightarrow R = \frac{V_m}{I_p} = \frac{169.7}{22} = 7.71\ \Omega$. $R = 7.71\Omega$ R = 7.71 W	5		
5	a. Explain the working of single phase full wave AC voltage controller with RL load. Derive the expression for rms value of output voltage. b. List the applications of AC voltage controller.	[10] 1	CO4	L2

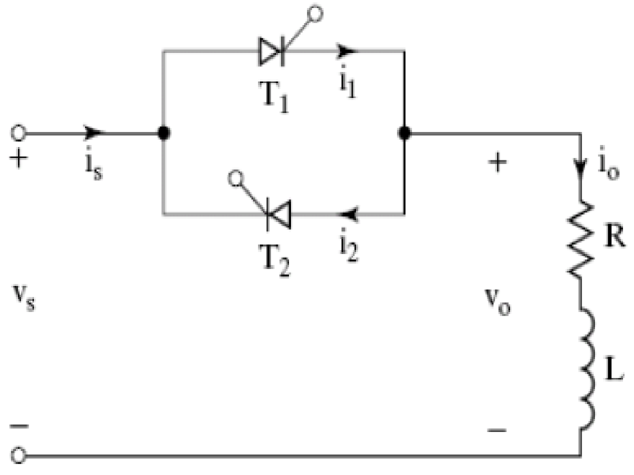
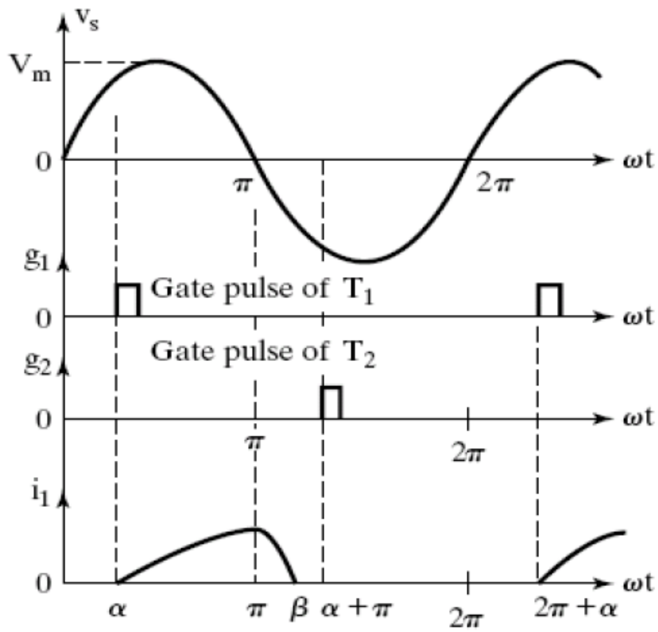


Fig: Single phase full wave ac voltage controller with RL load

Input Supply Voltage and Thyristor Current Waveform



Output Voltage and Current Waveform

2

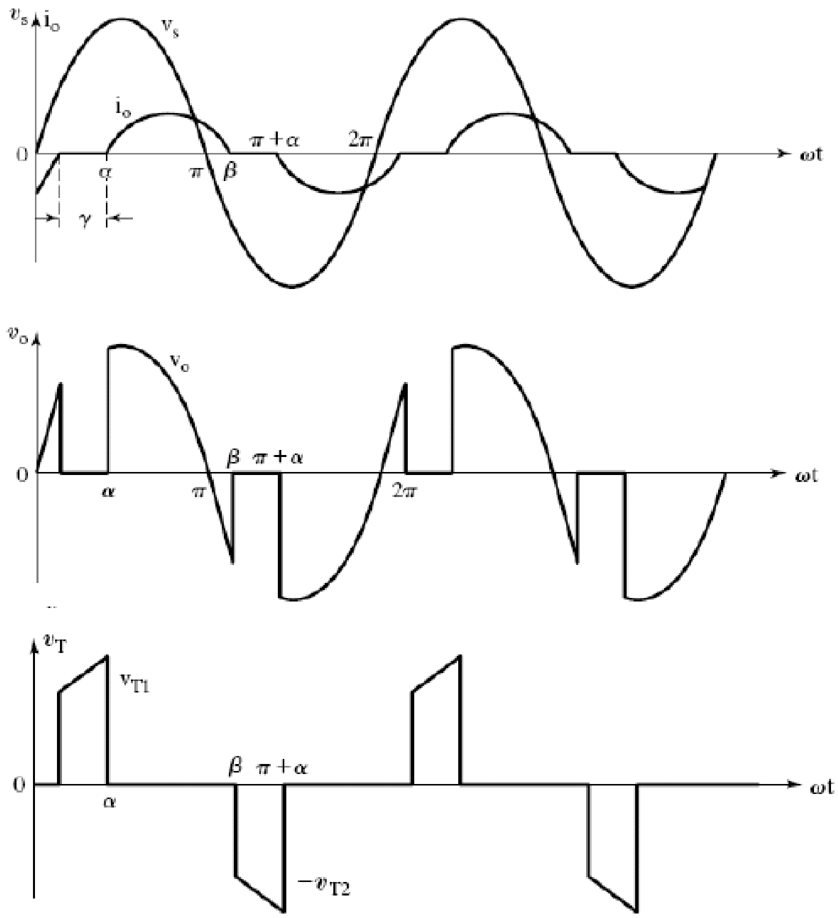


Fig.: Waveforms of Input supply voltage, Load Current, Load Voltage and Thyristor Voltage across T_1

During Positive Half Cycle ωt = 0 to π

- The thyristor $T1$ is forward biased during the positive half cycle of input ac supply.
- It can be triggered and made to conduct by applying a suitable gate trigger pulse '**α**'. only during the positive half cycle of input supply.
- When $T1$ is triggered it conducts and the load current flows through the thyristor $T1$, the load and through the transformer secondary winding.
- By assuming $T1$ as an ideal thyristor switch it can be considered as a closed switch when it is ON during the period ωt = **α** to π radians. Output Voltage Vo = Vs
- Due to the inductance in the load, the load current *i0* flowing through $T1$ would not fall to zero at ωt = π, when the input supply voltage starts to become negative.

2

	• The thyristor $T1$ will continue to conduct the load current until all the inductive energy stored in the load inductor L is completely utilized and the load current through $T1$ falls to zero at ωt = β. • β is referred to as the Extinction angle, (the value of ωt) at which the load current falls to zero. **Conduction Period of T1 ωt = α to** β • β is referred to as the Extinction angle, (the value of ωt) at which the load current falls to zero. • The thyristor $T1$ conducts from **ωt = α to** β. • The conduction angle of $T1$ is δ = (β - **α**) , which depends on the delay angle **α** and the load impedance angle ϕ. • Thyristor $T1$ turns off naturally at ωt = β. • Hence load current flows from at ωt = **α to** β. • β is the extinction angle which depends upon the load inductance value. **During Negative Half Cycle** ωt = π to 2π • Between the time period to ωt = π to 2π, • The thyristor $T2$ is forward biased during the negative cycle of input supply • Thyristor $T2$ is triggered at a delay angle (π+**α**) • The output voltage follows the negative half cycle of input from ωt = π+**α** to 2π. • When $T2$ is ON, the load current flows in the reverse direction (upward direction) through $T2$ during ωt = π+**α** to 2π+ β, because of inductive load • The time interval (spacing) between the gate trigger pulses of $T1$ and $T2$ is kept at π radians or 180 degrees. • Thyristor $T2$ turns off naturally at ωt = 2π+ β. • Hence load current flows from ωt = π+**α** to 2π+ β, due to conduction of T2 **EXPRESSION FOR RMS OUTPUT VOLTAGE** $V_{O(RMS)}$	3		

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

Output $v_o = V_m \sin\omega t$, for $\omega t = \alpha$ to β, when T_1 is ON.

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

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

$$V_{O(RMS)} = \left[\frac{V_m^{\,2}}{2\pi}\left\{(\omega t)\Big/_{\alpha}^{\beta} - \left(\frac{\sin 2\omega t}{2}\right)\Big/_{\alpha}^{\beta}\right\}\right]^{1/2}$$

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

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

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

b. Applications of AC voltage controller.

- Lighting / Illumination control in ac power circuits.
- Induction heating.
- Industrial heating & Domestic heating.
- Transformer tap changing (on load transformer tap changing).
- Speed control of induction motors (single phase and poly phase ac induction motor control).

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<tr><td>6</td><td>A single phase full wave AC voltage controller has a resistive load of R=10Ω and the input voltage is Vs= 200 V (rms), 50 Hz. The delay angle of thyristor T1 and T2 are equal $\alpha_1 = \alpha_2 = \pi/2$. Determine (i) RMS output voltage V_o (ii) The input Power Factor P.F. (iii) The average thyristor current I_A (iv) The rms value of thyristor current (v) Output power</td><td>[10]</td><td>CO4</td><td>L3</td></tr>
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Given Data

$R = 10\Omega$, $V_s = 200\,V\,(rms)$, $f = 50Hz$, $\alpha_1 = \alpha_2 = \pi/2$

(i) Rms Output Voltage V_o (2 marks)

$$V_{orms} = V_s \sqrt{\frac{1}{\pi}(\pi - \alpha) + \frac{\sin 2\alpha}{2}}$$

$$= V_s \sqrt{\frac{1}{\pi}(\pi - \pi/2) + \frac{\sin 2\pi/2}{2}}$$

$$= V_s \sqrt{\frac{1}{\pi} \times \pi/2 + 0} = \frac{V_s}{\sqrt{2}} = \frac{200}{\sqrt{2}}$$

$$V_{orms} = \frac{200}{\sqrt{2}} = 141.42\,V$$

(ii) Input Power factor (2 marks)

$$= \frac{V_{orms}}{V_s} = \frac{141.42}{200} = 0.707 \text{ lag}$$

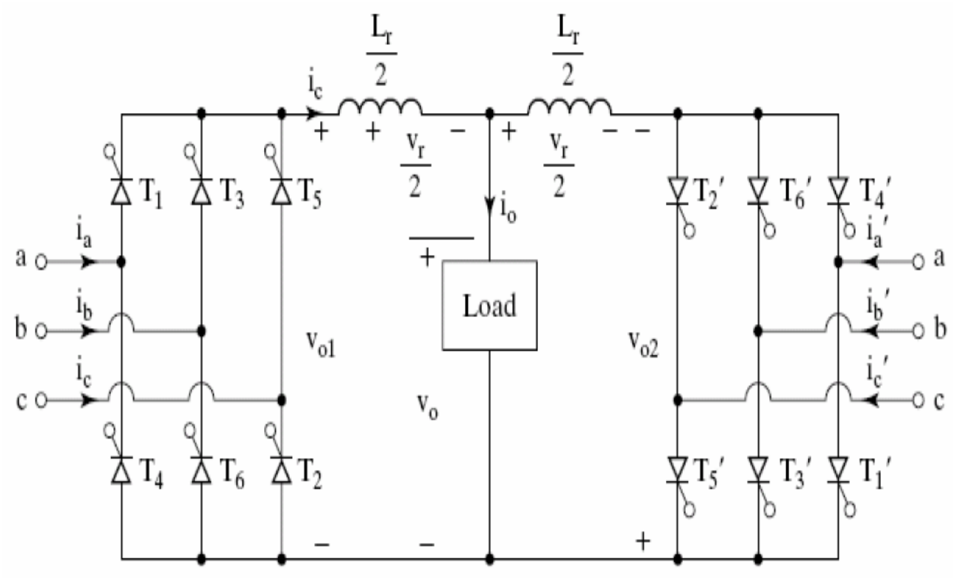
$$I/p \; PF = 0.707 \text{ lag}$$

(iii) Average Thyristor Current. (2 marks)

$$I_{T\,avg} = \frac{V_m}{2\pi R}(1 + \cos\alpha) \qquad V_m = \sqrt{2}\,V_s$$

$$= \frac{\sqrt{2} \times 200}{2 \times \pi \times 10}(1 + \cos 90) \quad (\cos 90 \to 0)$$

$$I_{T\,avg} = 4.5\,A$$

	(iv) RMS Thyristor current. (2 marks) $$I_{T\,RMS} = \frac{V_s}{\sqrt{2}R}\sqrt{\frac{1}{\pi}(\pi-\alpha)+\frac{\sin 2\alpha}{2}}$$ $$= \frac{V_s}{\sqrt{2}R}\sqrt{\frac{1}{\pi}(\pi-\pi/2)+0}$$ $$= \frac{V_s}{\sqrt{2}R}\times\frac{1}{\sqrt{2}} = \frac{V_s}{2\times R} = \frac{200}{2\times 10}$$ $I_{TRMS} = 10\,A$ (v) Output Power (2 marks) $$P_o = I_{o\,RMS}^2 \times R = \left(\frac{V_{orms}}{R}\right)^2 \times R = \left(\frac{141.42}{10}\right)^2 \times 10$$ $P_o = 1.99\,kW$			
7	Explain the three phase dual converter with neat diagram and waveform.  • Three phase dual converter gives much higher dc output voltage and higher dc output power than a single phase dual converter system. • But the drawback is that the three phase dual converter is more expensive and the design of control circuit is more complex.	[10] 2	CO4	L2

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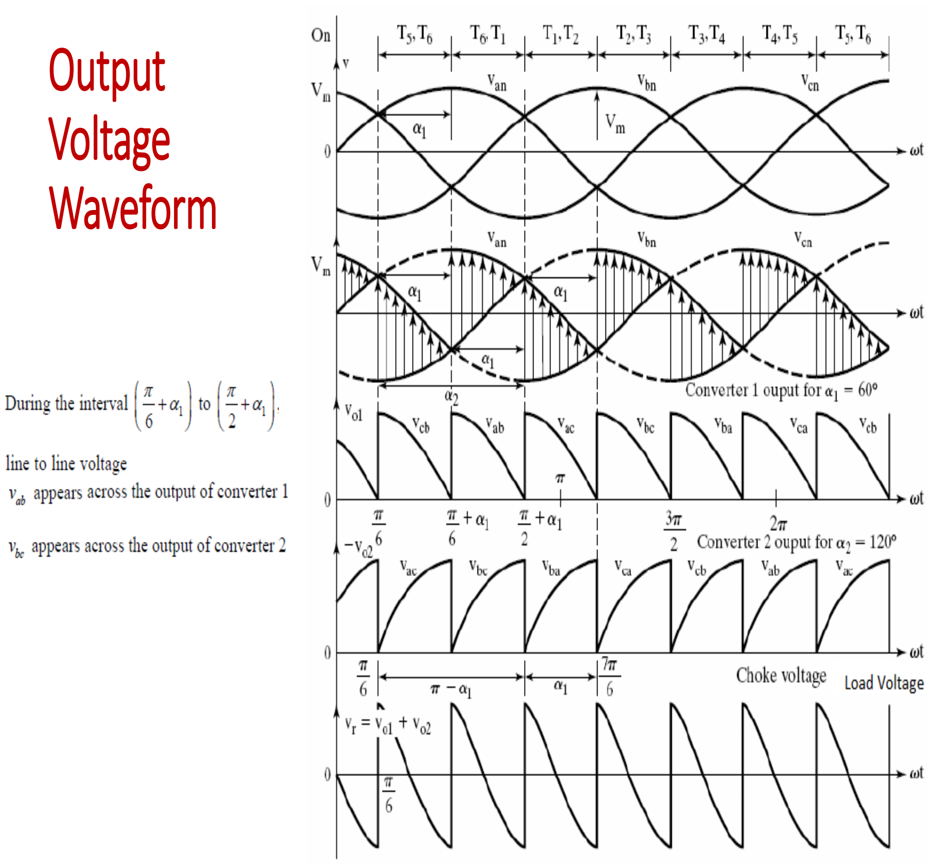
Average



Four Quadrant Operation

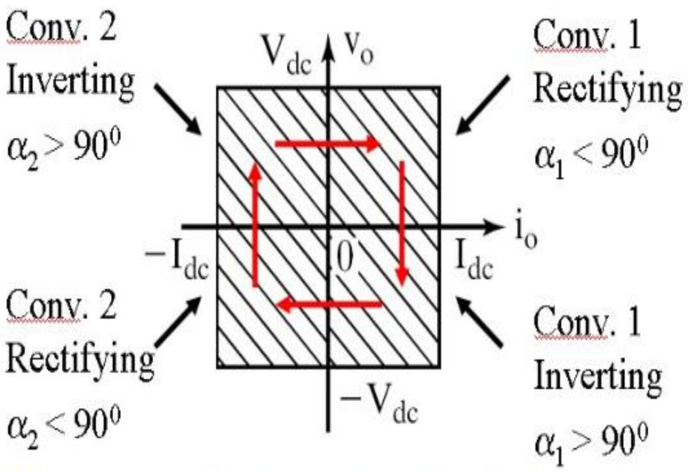


Fig.: Four quadrant operation of a dual converter

Average Output Voltage

$$V_{dc} = \frac{3\sqrt{3}V_m}{\pi}\cos\alpha = \frac{3V_{mL}}{\pi}\cos\alpha$$

Condition for α_1 and α_2

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	$\alpha_1 + \alpha_2 = \pi$ There are two modes of operations possible for a dual converter system. 1. Circulating current mode of operation. 2. Non circulating current mode of operation (circulating current free mode of operation). **Converter 1** • When the converter 1 is switched on and the gate trigger signals are released to the gates of thyristors in converter 1, we get an average output voltage across the load, which can be varied by adjusting the trigger angle α_1 of the converter 1. • **If $0<\alpha_1< 90^o$,** the converter 1 operates as a controlled rectifier and converts the input ac power into dc output power to feed the load. • *Vdc* and *Idc* are both positive and the operation occurs in the first quadrant. • The average output power $Pdc = Vdc \times Idc$ is positive. • The power flows from the input ac supply to the load. • **When $90^o<\alpha_1<180^o$** converter 1 operates as a line commutated inverter and *Vdc* becomes negative, while *Idc* is positive and the output power *Pdc* becomes negative. This operation occurs in the fourth quadrant • The power is fed back from the load circuit to the input ac source through the converter 1. Converter 1 operates as a Inverter. • The load current falls to zero when the load energy is utilized completely. **Converter 2** • When the converter 2 is switched on and the gate trigger signals are released to the gates of thyristors in converter 2, we get an average output voltage across the load, which can be varied by adjusting the trigger angle α_2 of the converter 2. • **If $0<\alpha_2< 90^o$,** the converter 2 operates as a controlled rectifier and converts the input ac power into dc output power to feed the load. • *Vdc* and *Idc* are both negative and the operation occurs in the third quadrant. load current flows in the reverse direction.			

	• The average output power $P_{dc} = -V_{dc} \times -I_{dc}$ is positive. • The power flows from the input ac supply to the load. • **When $90^o<\alpha_2<180^o$** converter 2 operates as a line commutated inverter and V_{dc} becomes positive, while I_{dc} is negative and the output power P_{dc} becomes negative. This operation occurs in the second quadrant • The power is fed back from the load circuit to the input ac source through the converter 2. Converter 2 operates as a line commutated Inverter. • The load current falls to zero when the load energy is utilized completely. **Applications of Dual converter** • Direction and speed control of DC motors. • Applicable wherever the reversible DC is required. • Industrial variable speed DC drives upto 2000KW.			