Power Electronics

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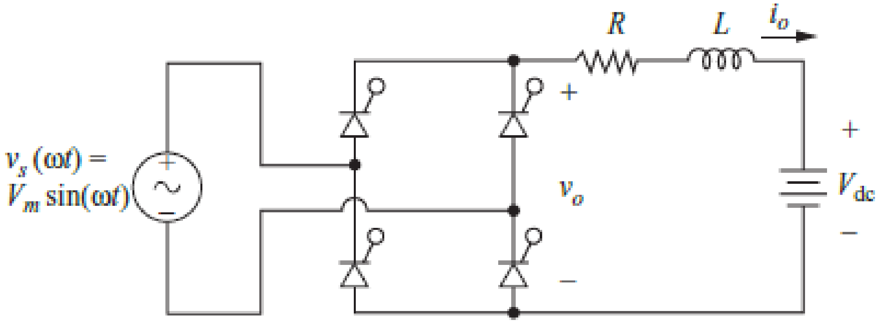
- The dc voltage in Fig represents the voltage generated by an array of solar cells and has a value of 110 V, connected such that *V*dc=-110 V. The solar cells are capable of producing 1000 W. The ac source is 120 V rms, *R* =0.5 ohm, and *L* is large enough to cause the load current to be essentially dc. Determine the delay angle such that 1000 W is supplied by the solar cell array. Determine the power transferred to the ac system and the losses in the resistance. Assume ideal SCRs.



For the solar cell array to supply 1000 W, the average current must be

$$I_o = \frac{P_{dc}}{V_{dc}} = \frac{1000}{110} = 9.09 \text{ A}$$

The average output voltage of the bridge

$$V_o = I_o R + V_{dc} = (9.09)(0.5) + (-110) = -105.5 \text{ V}$$

required delay angle $$\alpha = \cos^{-1}\left(\frac{V_o \pi}{2V_m}\right) = \cos^{-1}\left[\frac{-105.5\pi}{2\sqrt{2}(120)}\right] = 165.5°$$

Power absorbed by the bridge and transferred to the ac system

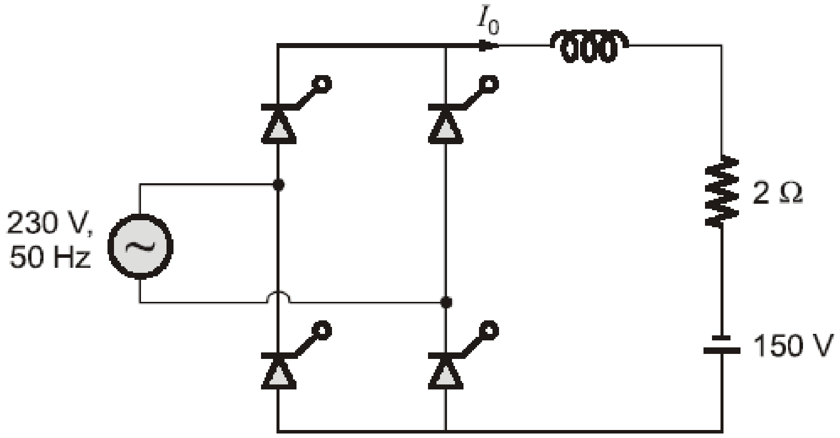
$$P_{ac} = -V_o I_o = (-9.09)(-105.5) = 959 \text{ W}$$

Power absorbed by the resistor is

$$P_R = I_{rms}^2 R \approx I_o^2 R = (9.09)^2(0.5) = 41 \text{ W}$$

- load current and power will be sensitive to the delay angle and the voltage drops across the SCRs because bridge output voltage is close to the dc source voltage.

A single phase fully controlled converter bridge is used for electrical braking of a separately excited dc motor. The dc motor load is represented by an equivalent circuit as shown in the figure. Assume continuous and ripple free load current. What is the firing angle for a load current of 10A.



(a) 44°
(b) 51°
(c) 129°
(d) 136°

Average output voltage of the converter,

$$V_0 = \frac{2V_m}{\pi}\cos\alpha$$

$$\text{Load current} = I_0 = 10\text{ A}$$

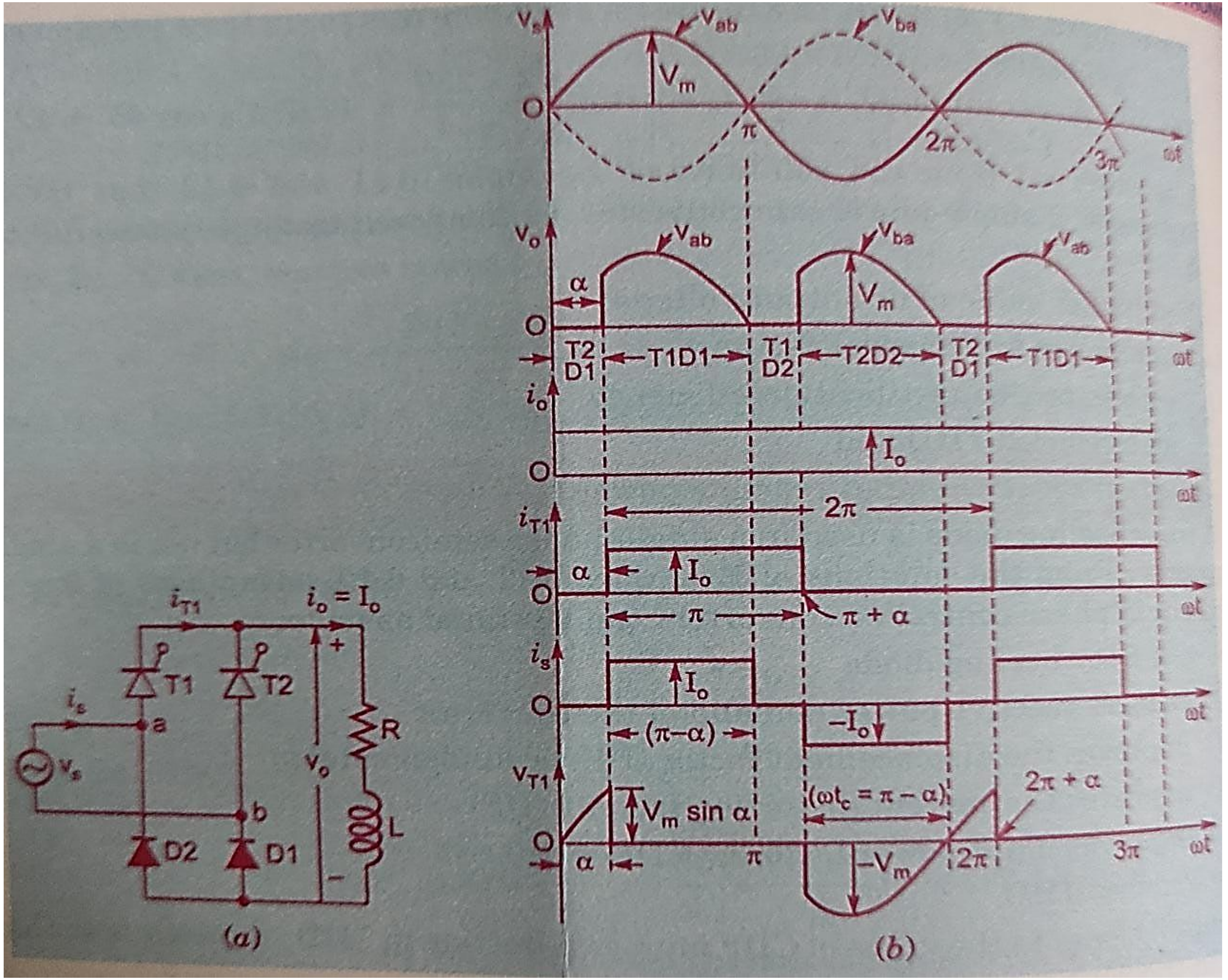
$$\text{Back emf} = E_b = 150\text{ V}$$

$$\text{Armature resistance} = R_a = 2\ \Omega$$

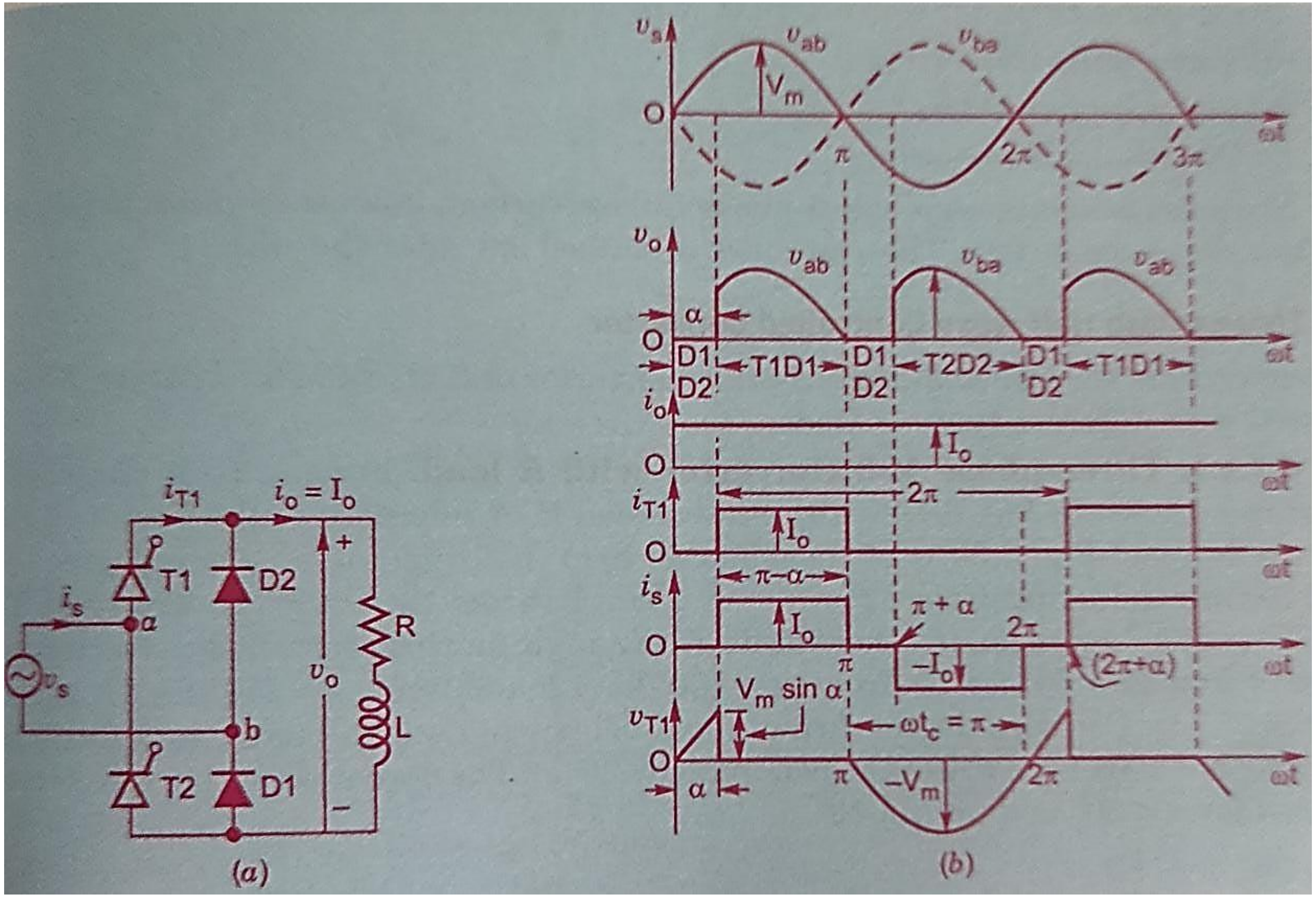
$$V_0 - 2I_0 + 150 = 0$$

$$V_0 = -150 + 2 \times 10 = -130\text{ V}$$

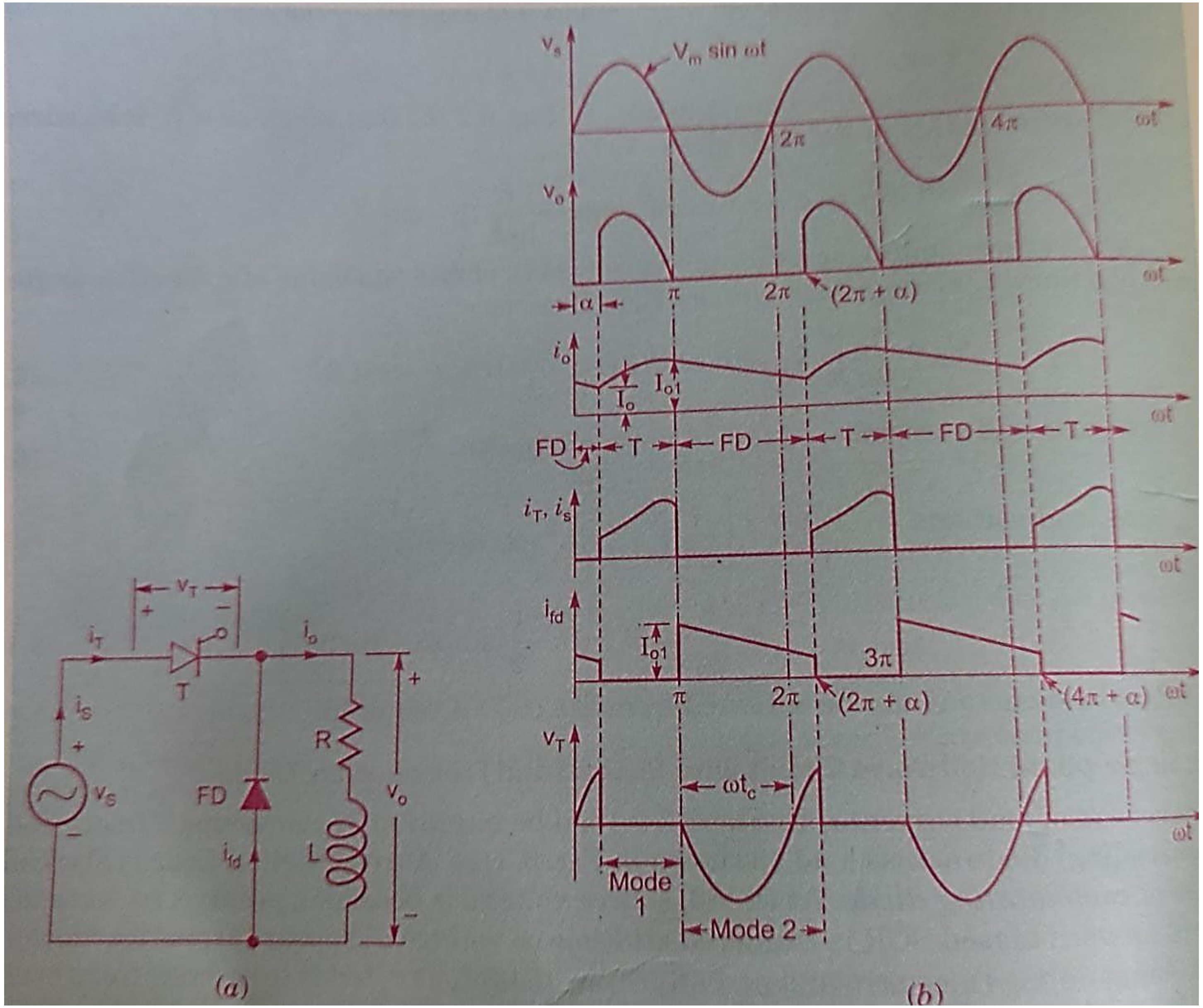
Symmertical Configuration
(w/o free wheeling diode)



Asymmetrical Configuration (w/o free wheeling diode)



Half wave phase controlled rectifier having a RL load with free wheeling diode across it (Assume continuous conduction)



Single-phase two-pulse converters(discontinuous)

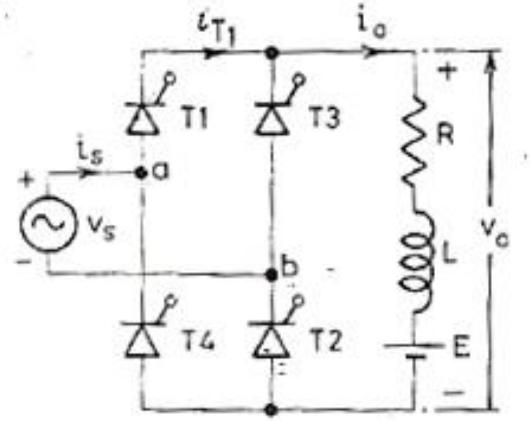
- So far, assumption -continuous load current
- Practically, the output current may become discontinuous at high values of firing angle or at low values of load current
- The term discontinuous is applied to the condition when load current reaches zero during each half cycle before the next SCR in sequence is fired.
- The term continuous means that load current never ceases but continues to flow through SCR/diode or their combination.
- The load performance deteriorates if load current becomes discontinuous
- Load performance improved by having freewheeling action and using an external inductor in series with the load.

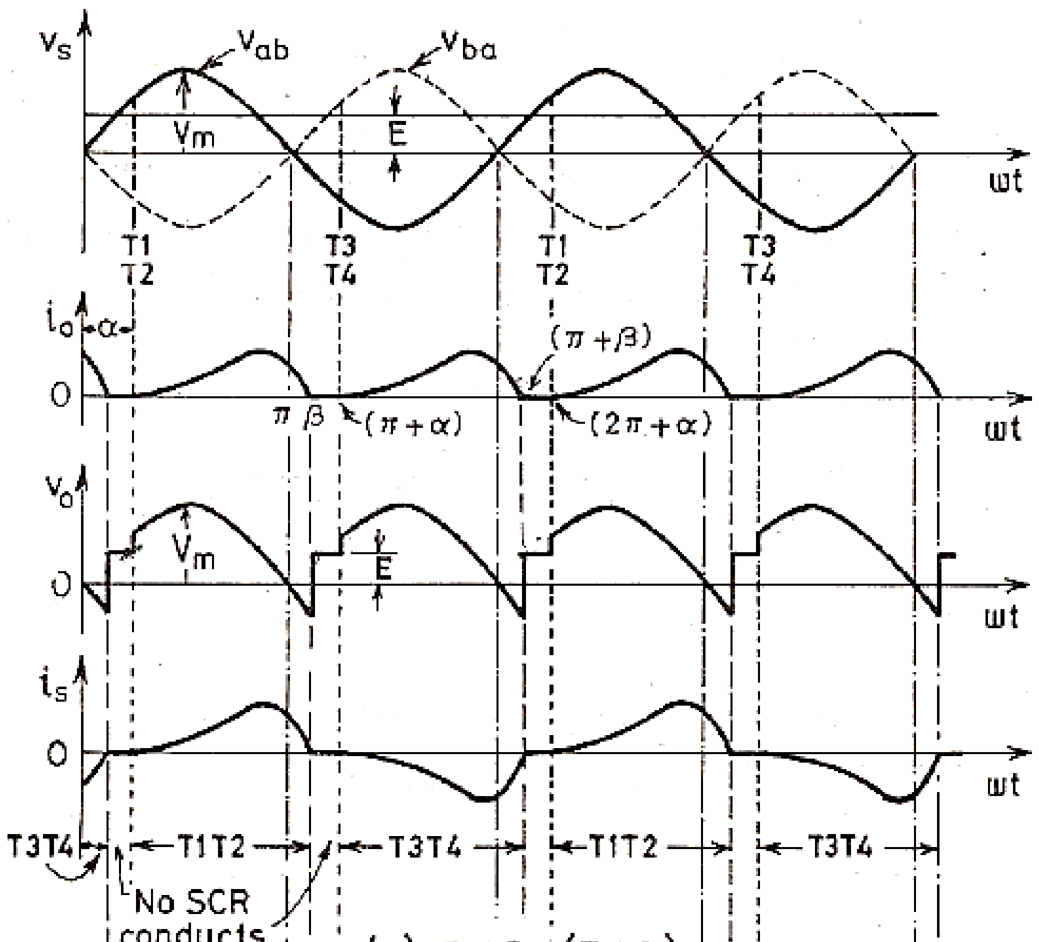
Single phase full converter

(*i*) Conduction period, $\alpha < \omega t < \beta$, T1, T2 conduct and $v_0 = v_s$. Also

$(\pi + \alpha) < \omega t < (\pi + \beta)$, T3 T4 conduct and $v_o = v_s$ and so on

(*ii*) Idle period , $\beta < \omega t < (\pi + \alpha)$, no circuit element conducts and $v_0 = E$.

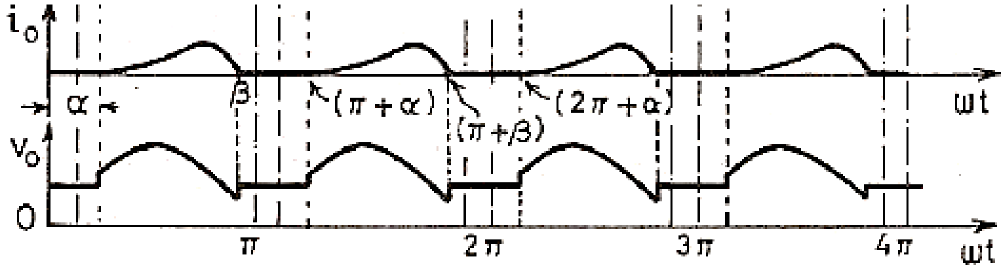




(a) $\pi < \beta < (\pi + \alpha)$

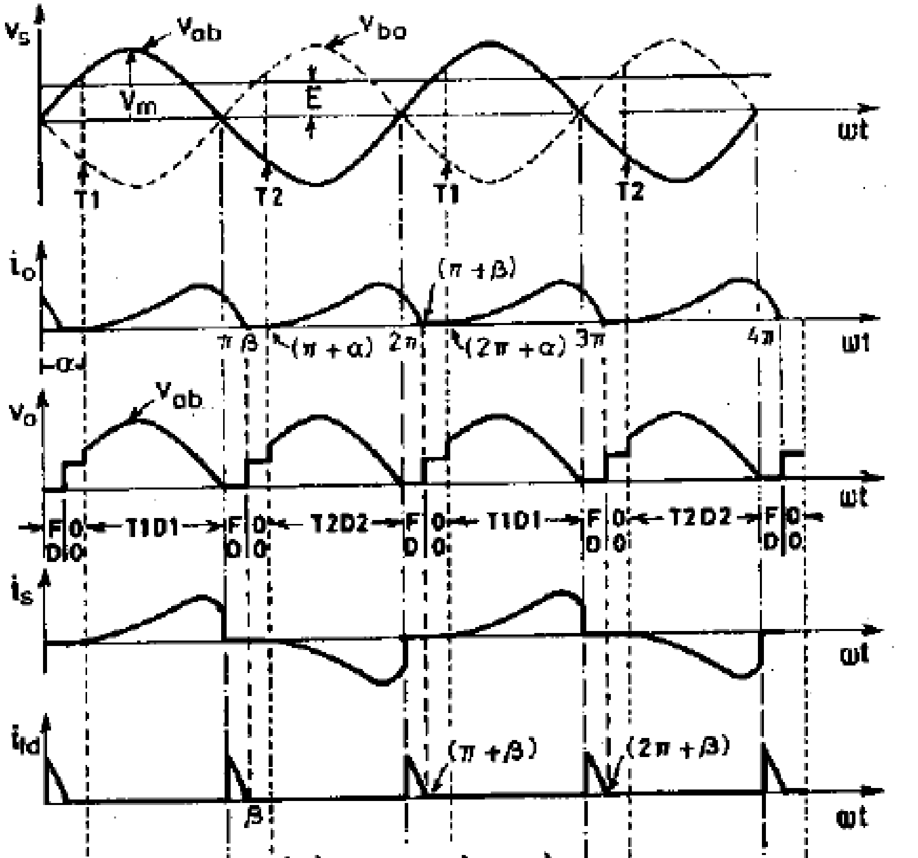
- when SCR pair TI T2 is triggered at $\omega t = \alpha$, load current begins to build up from zero.
- At some angle β (extinction angle) load current decays to zero.
- Here $\beta > \pi$, as TI and T2 commutates at $\omega t = \beta$ when $i_o = 0$.
- From α to β, output voltage v_o follows source voltage v_s
- From β to $(\pi + \alpha)$, no SCR conducts, the load voltage therefore jumps from $V_m \sin\beta$ to E
- At $\omega t =(\pi + \alpha)$, pair T3 T4 is triggered, load current starts to build up again as before and load voltage v_o follows v_s waveform as shown.
- At $\pi + \beta$, io fails to zero, v_o changes from $V_m \sin(\pi + \beta)$ to E as no SCR conducts.

- Under some conditions, load current may become zero at $\omega t = \beta$, where β is less than π
- It is assigned here that $v_m \sin\beta < E$.
- At β, v_o jumps from $v_m \sin\beta$ to E.
- No SCR conducts from β to $(\pi + \alpha)$ and during this interval, therefore v_o = E.



(b) $\beta<\pi$ and $V_m \sin\beta<E$

- Single phase semi converter (discontinuous)



(a) $\pi < \beta < (\pi + \alpha)$

(*a*) *When* $\pi < \beta < \pi + \alpha$:

(*i*) Conduction period, $\alpha < \omega t < \pi$, T1D1 conduct and $v_0 = v_s$. Also
for $\pi + \alpha < \omega t < 2\pi$, T2D2 conduct and $v_0 = v_s$ and so on.

(*ii*) Freewheeling period, $\pi < \omega t < \beta$, FD conducts, $i_{fd} = i_0$ and $v_0 = 0$. Also
for $2\pi < \omega t < \pi + \beta$, FD conducts, $i_{fd} = i_0$ and $v_0 = 0$ and so on.

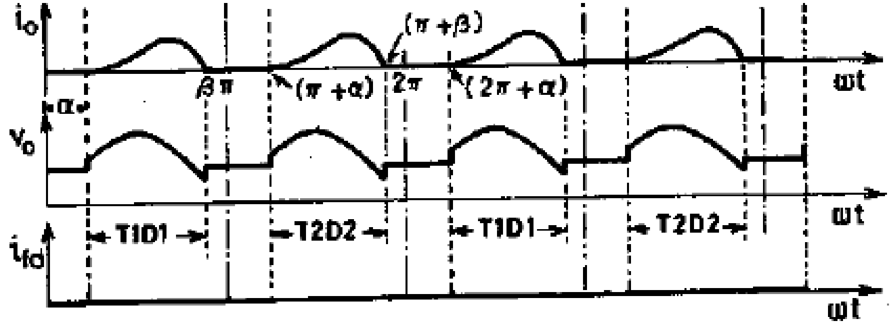
(*iii*) Idle period, $\beta < \omega t < \pi + \alpha$, no circuit component conducts, $i_0 = 0$ and $v_0 = E$

(b) When $\beta < \pi$ and $V_m \sin \beta < E$:

(*i*) Conduction period, $\alpha < \omega t < \beta$, $T_1 D_1$ conduct and $v_0 = v_s$. Also for $\pi + \alpha < \omega t < \pi + \beta$, T2 D2 conduct and $v_0 = v_s$ and so on

(*ii*) Freewheeling period, absent and $i_{fd} = 0$.

(*iii*) Idle period, $\beta < \omega t < \pi + \alpha$ and $\pi + \beta < \omega t < 2\pi + \alpha$, no circuit element conducts, $i_0 = 0$ and $v_0 = E$.



(b) $\beta < \pi$ and $V_m \sin \beta < E$

- For this controlled 2-pulse converter, when SCR T1 is triggered at $\omega t = \alpha$, load current builds up from zero , rises to a maximum and then decays to zero $\beta > \pi$
- From α to π, T1 D1 conduct and $v_o = v_s$.
- At $\omega t = \pi$, as vs tends to become negative, FD is forward biased and starts conducting the load current
- When FD conducts from π to β, $v_0=0$,
- From β to $\pi+ \alpha$, no circuit component conducts therefore v_o = E
- During β to $\pi+ \alpha$, as load current is zero, this makes the load current discontinuous.
- When T2 is triggered at $\pi+ \alpha$, i_o builds

- For single-phase full converter for $\beta > \pi$ or $< \pi$ and also for single-phase semi converter for $\beta < \pi$, the average load current is given by

$$I_0 = \frac{1}{\pi R}\int_{\alpha}^{\beta} (V_m \sin \omega t - E)\, d(\omega t) = \frac{V_m}{\pi R}(\cos \alpha - \cos \beta) - \frac{E}{\pi R}(\beta - \alpha)$$

Average output voltage

$$V_0 = E + I_0 R = \frac{V_m}{\pi}(\cos \alpha - \cos \beta) + E\left(1 - \frac{\gamma}{\pi}\right)$$

where $\gamma =$ conduction angle $= \beta - \alpha.$

For single-phase semiconverter with $\beta > \pi$,

$$I_0 = \frac{V_m}{\pi R}(\cos \alpha - \cos \beta) - \frac{E}{\pi R}(\beta - \alpha)$$

and average output voltage V_0 is

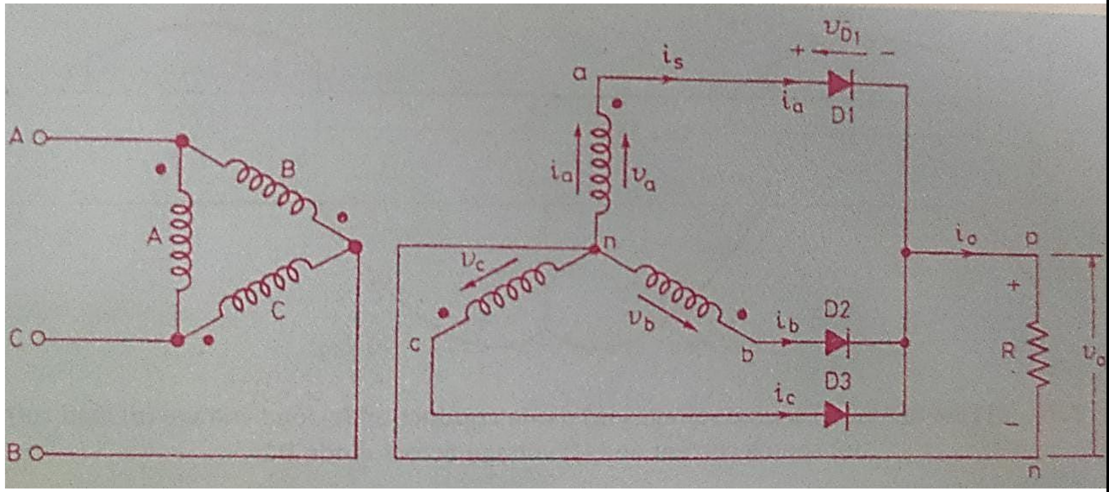
$$V_0 = \frac{1}{\pi}\left[\int_{\alpha}^{\pi} V_m \sin \omega t \cdot d(\omega t) + E\,(\pi + \alpha - \beta)\right]$$

$$= \frac{V_m}{\pi}(1 + \cos \alpha) + E\left(1 - \frac{\gamma}{\pi}\right)$$

- A single-phase full converter feeding RLE load has the following data source voltage = 230V, 50 Hz, R = 2.5 ohm, E = 100V and firing angle = 30°. If load inductance is large enough to make the load current virtually constant. Compute the average value of load voltage and load current.

- A single phase full bridge converter with a free wheeling diode feeds an inductive load. The load resistance is 15.53 ohm and it has a large inductance providing constant and ripple free d.c. current. Input to converter is fed from an ideal 230v, 50Hz single phase source. For a firing angle delay of 60°, the average value of diode current is

Three phase converter system



Advantages of three phase rectifiers

- High dc voltage
- Better TUF (transformer utilization factor)
- Better input p.f.
- Less ripple content in output current – better load performance
- Lower size of filter circuit parameters because of high ripple frequency

Three phase converter system

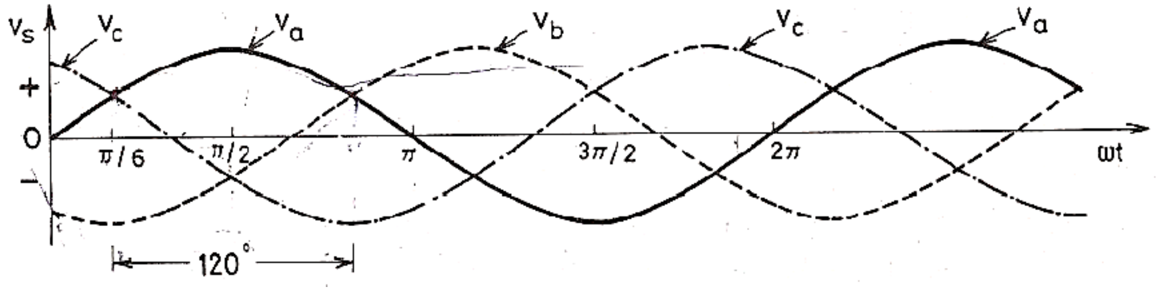
Using diodes

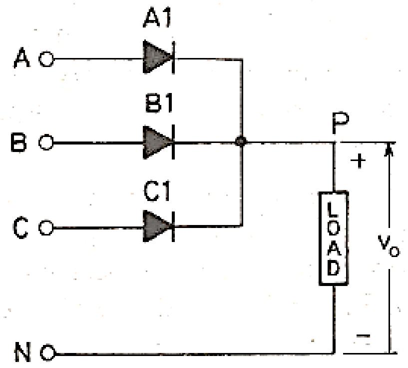
- The power circuit consists of three diodes A1, B1, C1 connected to a common load

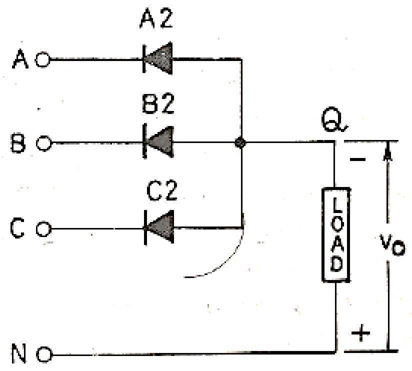
- The other load terminal must be connected to neutral N of the supply

- As the cathodes of three diodes are connected together, circuit is called common cathode circuit

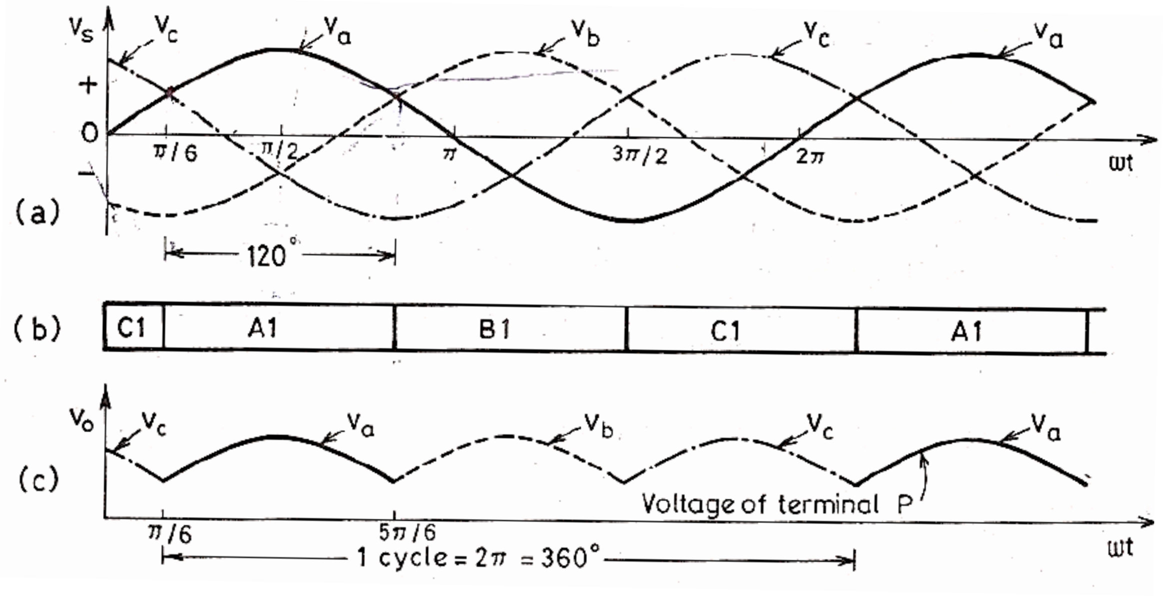
- The three- phase supply voltage is shown as V_a (= v_{an}, voltage between A and N), V_b, V_c

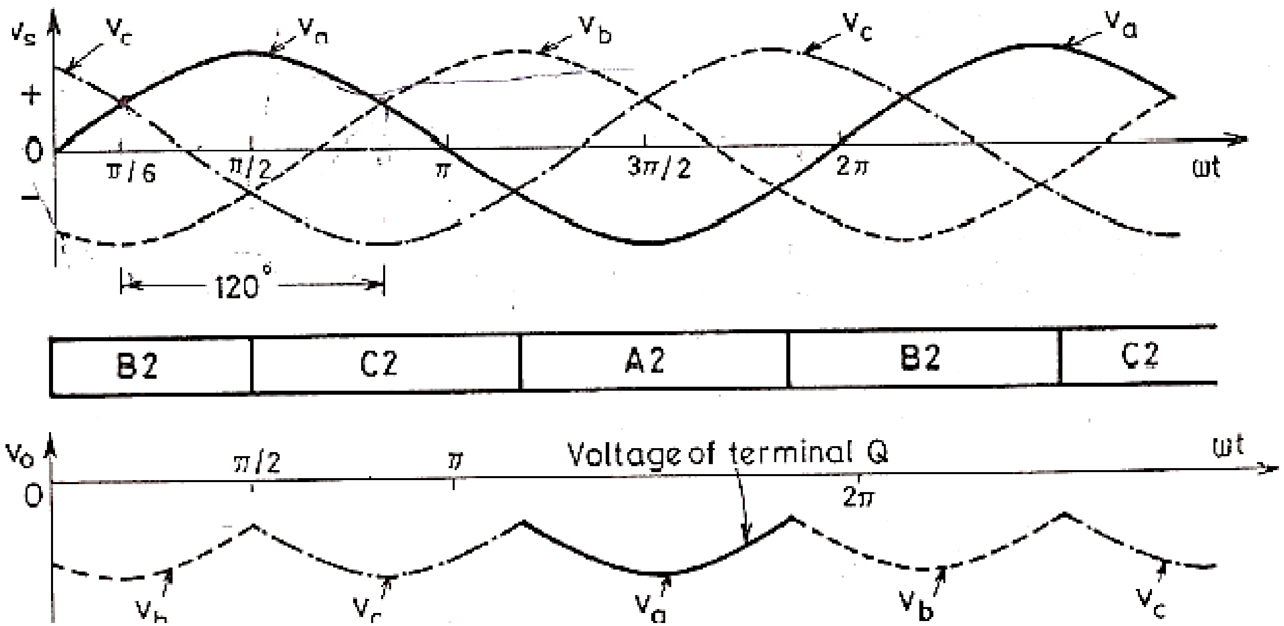






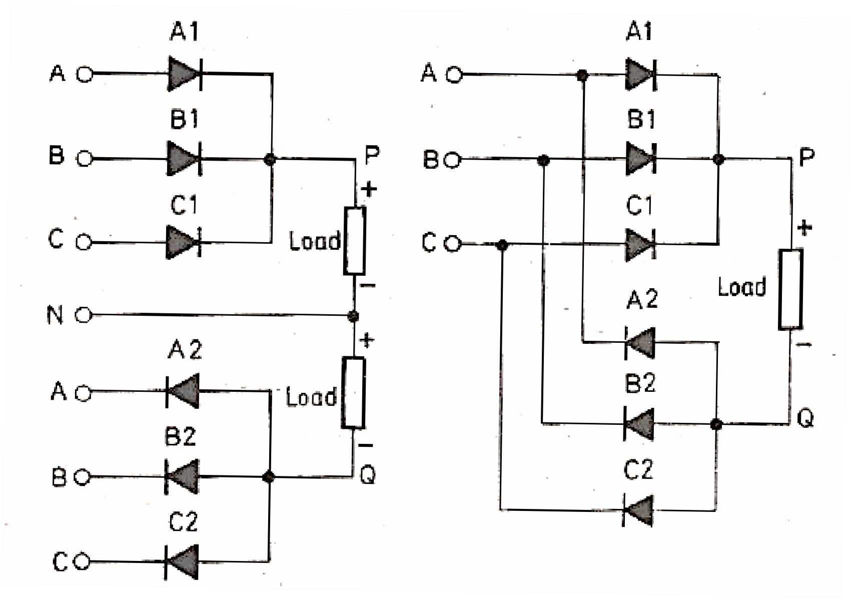
- The rectifier element connected to the line at the highest instantaneous voltage can only conduct
- A diode with the highest positive voltage will begin to conduct at the cross-over points of the three-phase supply.
- Diode A1 will conduct from $\omega t = 30^0$ to $\omega t = 150^0$ as this diode is the most positive as compared to the other two diodes during this interval
- Diode B1 will conduct from 150^0 to 270^0 and diode C1 from 270^0 to 390^0
- When a diode is conducting, the common cathode terminal P rises to the highest positive voltage of that phase and the other two blocking diodes are reverse biased.
- The voltage across the load V_o follows the positive supply voltage envelope.
- Voltage of the neutral point N is taken as zero
- For one cycle of supply voltage, output voltage has three pulses, the circuit is called a 3-phase 3-pulse diode rectifier or 3-phase half-wave diode rectifier.





- For the 3-phase half-wave rectifier circuit of common anode type, a diode will conduct only during the most negative part of the supply voltage cycle.
- This means that a diode will conduct when the neutral is positive with respect to A, B or C
- Diode C2 conducts from $\omega t = 90^0$ to 210^0 as this is the most negative as compared to other two diodes during this interval.
- Diode A2 conducts from $\omega t = 210^0$ to 330^0 and diode B2 from 330^0 to 450^0

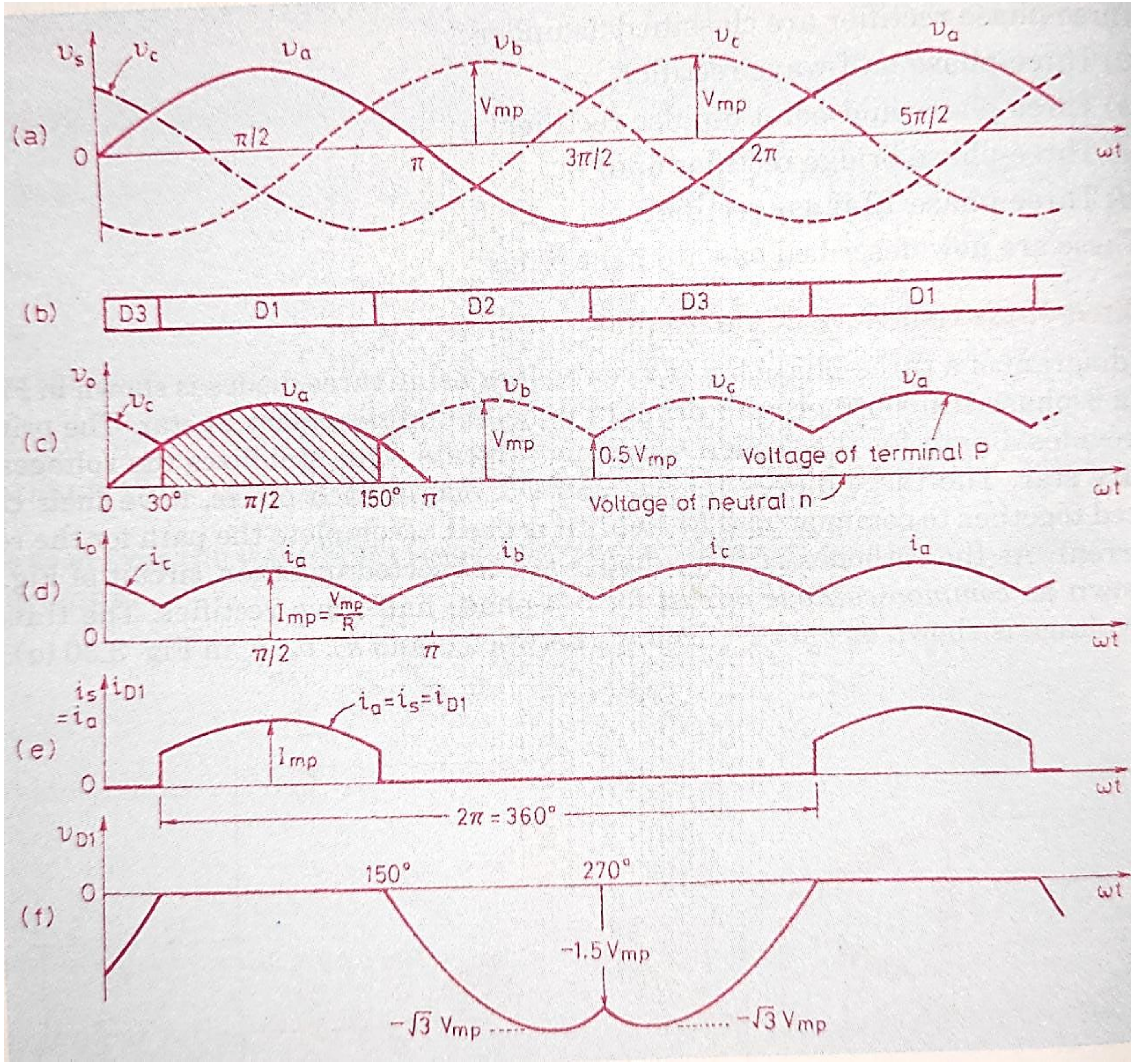
- Each diode conducts for 120^0 in both the circuits.
- The load voltage V_o follows the negative supply voltage envelope
- The voltage of point Q is shown by V_b, V_c, V_a etc. below the reference line
- Three-phase half-wave rectifier circuits can be connected in series.
- In this series connected circuit, load current can exist even without neutral N.



(a) (b)

- PIV of diode= $\sqrt{3}\, V_{mp}$
- Periodicity of output voltage $=120^0$
- Output voltage consists of phase voltages v_a , v_b , v_c
- $V_{o\ avg}$= Area over one periodicity/ Periodicity

$$=\frac{1}{periodicity}\int_{\alpha_1}^{\alpha_2} v_a \, \mathrm{d}(\omega t)$$



Common cathode half wave configuration

a) Line to neutral source voltages b) diode conduction c) load voltage d) load current e) source current f) voltage across diode 1

$$\therefore \quad V_o = \frac{3}{2\pi}\int_{\pi/6}^{5\pi/6} V_{mp} \sin \omega t \, . \, d(\omega t) = \frac{3\sqrt{3}}{2\pi} V_{mp} = \frac{3\sqrt{6}}{2\pi} V_{ph} = \frac{3}{2\pi} . V_{ml}$$

V_{mp} = maximum value of phase voltage, $V_{ph} = \sqrt{2}\, V_{ph}$

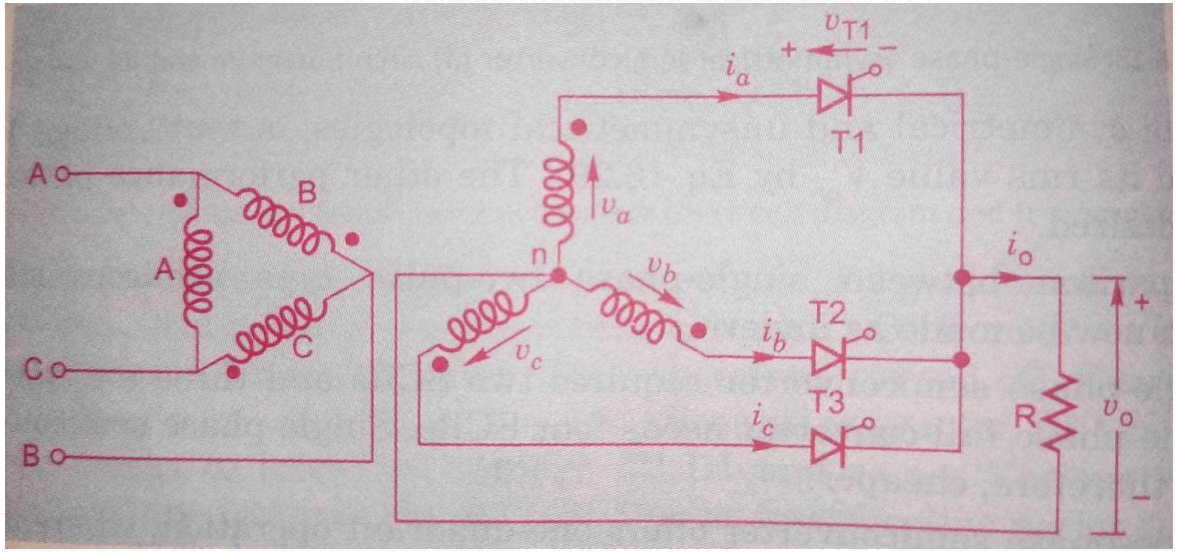
V_{ml} = maximum value of line voltage, $V_l = \sqrt{3}\ . V_{mp} = \sqrt{6}\ . V_{ph}$

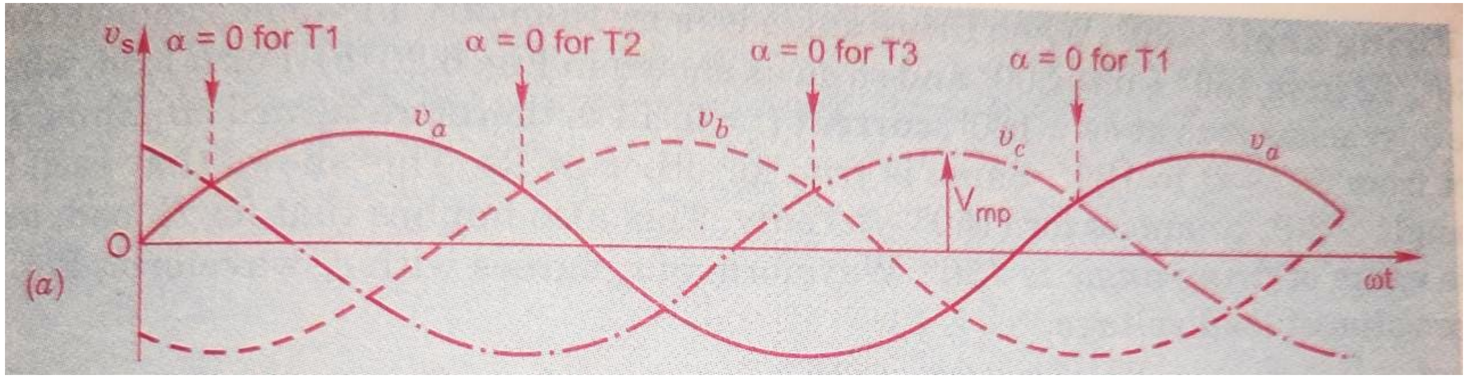
Rms value of output voltage, $V_{or} = \left[\frac{1}{2\pi/3}\int_{\pi/6}^{5\pi/6} (V_{mp} \sin \omega t)^2 \, . \, d(\omega t)\right]^{1/2}$

$$= \left[\frac{3V_{mp}^2}{2\pi \times 2} . \left| \omega t - \frac{\sin 2\omega t}{2} \right|_{\pi/6}^{5\pi/6}\right]^{1/2} = 0.84068\ V_{mp}$$

Disadvantage: Current in the secondary of transformer is unidirectional - DC component present in 2^0 current - can lead to core saturation - more losses and reduced efficiency

Three phase half wave controlled rectifier with R load

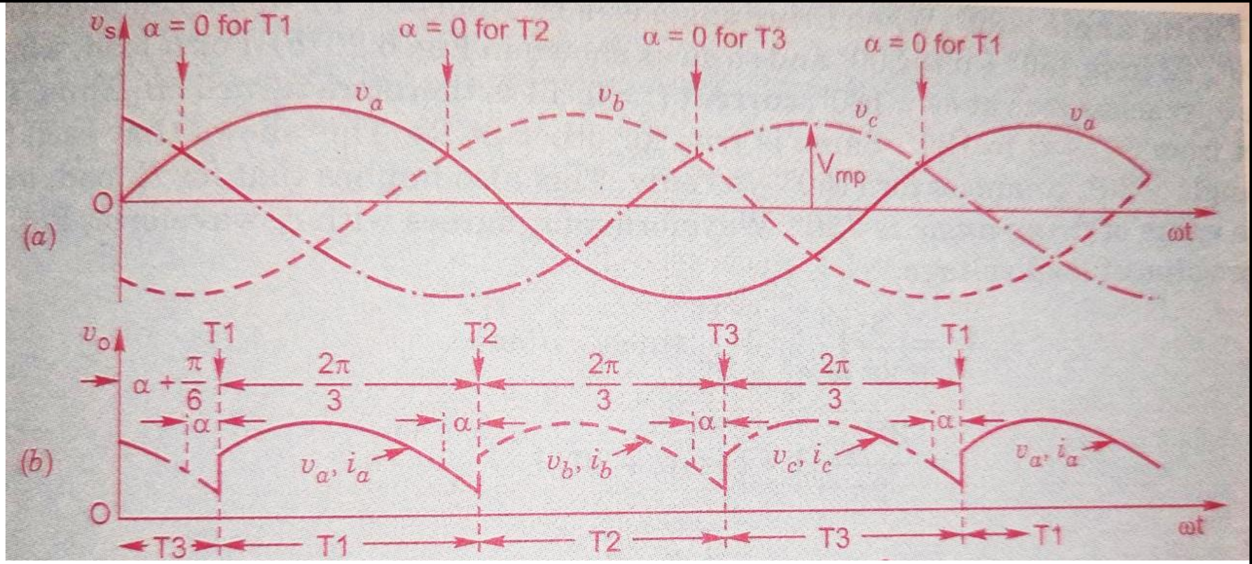




- Power circuit diagram of this converter is shown in Fig. with resistive load R
- If firing angle is zero degree, SCR T1 would begin conducting from $\omega t = 30°$ to $150°$, T2 from $\omega t = 150°$ to $270°$ and T3 from $\omega t = 270°$ to $390°$ and so on
- Firing angle for this controlled converter would be measured from $\omega t = 30°$ for T1, from $\omega t = 150°$ for T2 and from $\omega t = 270°$ for T3
- For zero degree firing angle delay, thyristor behaves as a diode
- The operation of this converter is described for $\alpha < 30°$ and for $\alpha > 30°$.

α < 30° (say 15^0)

- T1 conducts from ωt=30+α to ωt=150+α
- Each SCR conducts for 120^0
- Load current identical to load voltage



Average value of output voltage, $V_o = \frac{3}{2\pi} \int_{\alpha+\frac{\pi}{6}}^{\alpha+\frac{5\pi}{6}} V_{mp} \sin \omega t \, d(\omega t)$

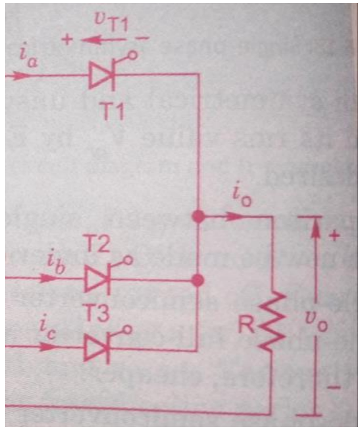
$$= \frac{3\sqrt{3}}{2\pi} V_{mp} . \cos \alpha = \frac{3V_{ml}}{2\pi} \cos \alpha$$

where V_{mp} = maximum value of phase (line to neutral) voltage

V_{ml} = maximum value of line voltage = $\sqrt{3} \, . \, V_{mp}$

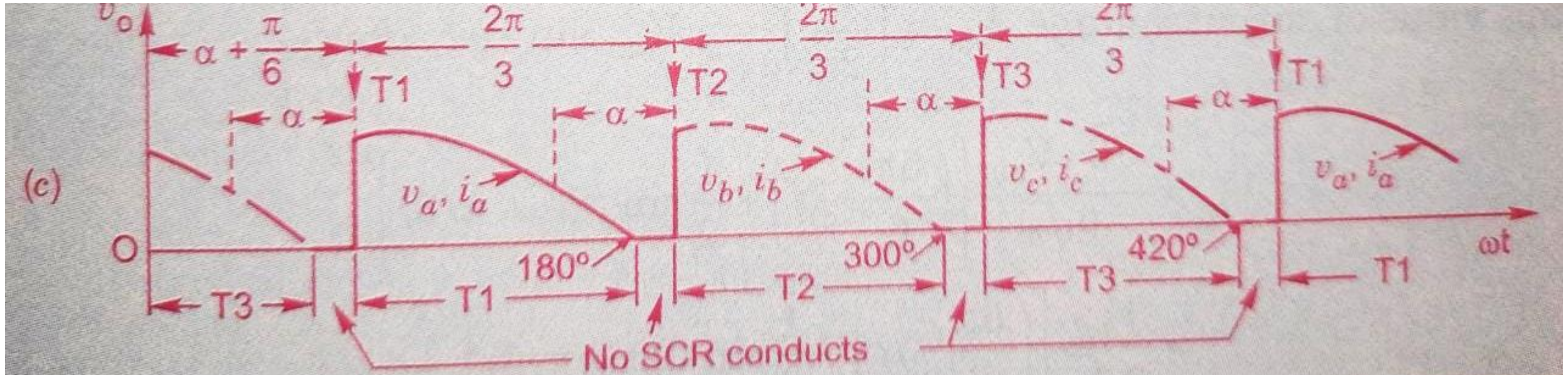
α = firing-angle delay

Average load current, $I_o = \frac{V_o}{R} = \frac{3V_{ml}}{2\pi . R} \cos \alpha$



$\alpha > 30°$

- When firing angle is more than 30°, T1 would conduct from 30°+α to 180°, T2 from 150°+α to 300°
- For R load, when phase voltage v reaches zero at ωt = 180°, current i = 0, T1 is therefore turned off.
- This shows that each SCR, for firing angle > 30°, conducts for (150 -α) only
- For R load maximum possible value of firing angle is 150°.
- Waveform of i_o is same as v_0



$$V_o = \frac{3}{2\pi}\int_{\alpha+\frac{\pi}{6}}^{\pi} V_{mp} \sin \omega t \,.\, d(\omega t)$$

$$= \frac{3V_{mp}}{2\pi}[1 + \cos(\alpha + 30°)]$$

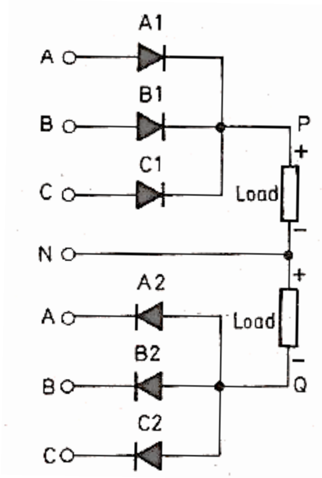
Rms value of output voltage, $V_{or} = \left[\frac{3}{2\pi}\int_{\alpha+\frac{\pi}{6}}^{\pi} V_{mp}^2 \sin^2 \omega t \,.\, d(\omega t)\right]^{1/2}$

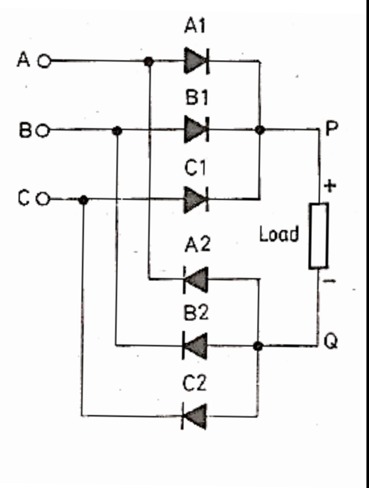
$\therefore$

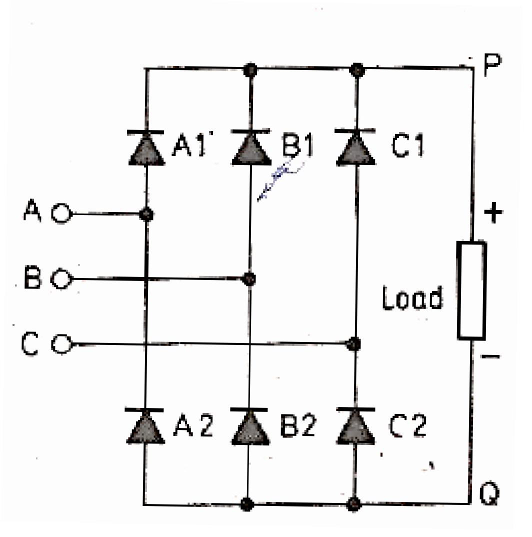
$$V_{or} = \frac{\sqrt{3}\,.\,V_{mp}}{2\sqrt{\pi}}\left[\left(\frac{5\pi}{6} - \alpha\right) + \frac{1}{2}\sin(2\alpha + \pi/3)\right]^{1/2}$$

$$= \frac{V_{ml}}{2\sqrt{\pi}}\left[\left(\frac{5\pi}{6} - \alpha\right) + \frac{1}{2}\sin(2\alpha + \pi/3)\right]^{1/2}$$

- Three-phase half-wave rectifier circuits can be connected in series
- In this series connected circuit, load current can exist even without neutral
- When diode A1 is conducting, the return path for the current is through diode B2 from $\omega t = 30^0$ to 90^0 and through diode C2 from $\omega t = 90^0$ to 150^0
- Supply point A connected to the anode of diode A1 is the same as connected to the cathode of diode A2
- The neutral wire can thus be eliminated
- The only difference between Fig. (a) and Figs. (b) and (c) is that load voltage is equal to line to neutral voltage in Fig.(a) and it is line to line voltage in Fig. (b) and (c)
- 3 phase full wave bridge rectifier and 3 phase six pulse bridge rectifier







(c)

Three phase uncontrolled full converter

- Note that diodes A1,B1,C1 of the bridge will conduct when supply voltage is the most positive whereas diodes A2, B2, C2 will conduct when supply voltage is the most negative.

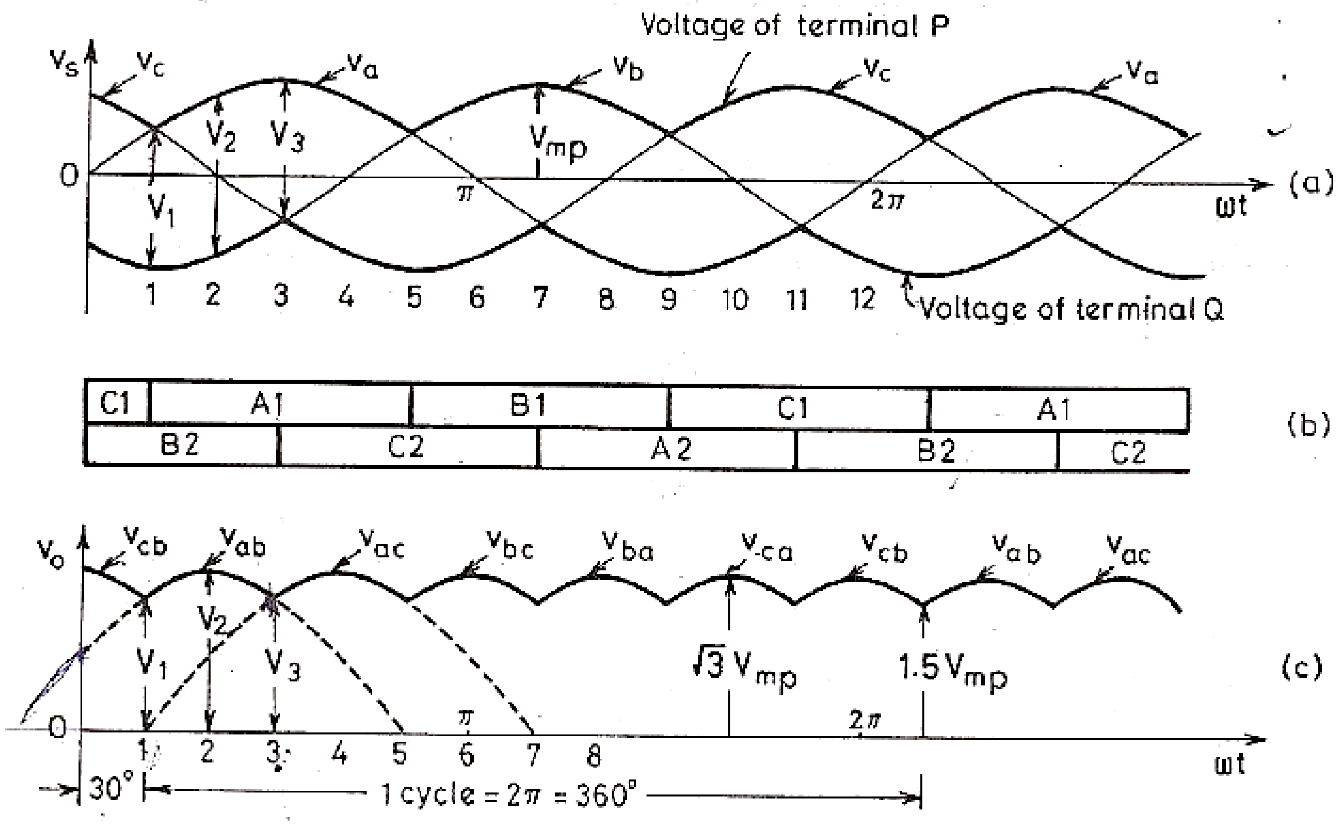
- Diodes A1, B1, C1 - positive diode group   A2, B2, C2 - negative diode group.

- The voltage across load will always be direct emf with the polarity of P positive and that of Q negative

- For ωt = 0^0 to 30^0, diodes C1, B2 conduct together

- For ωt = 30^0 to 90^0, diodes A1, B2 conduct together

- Each diode conducts for 120^0.



- At the instant marked 1, diode B2 is already, conduction of diode C1 stops and that of A1 begins.
- The magnitude of load voltage V1 at instant 1 is therefore given by

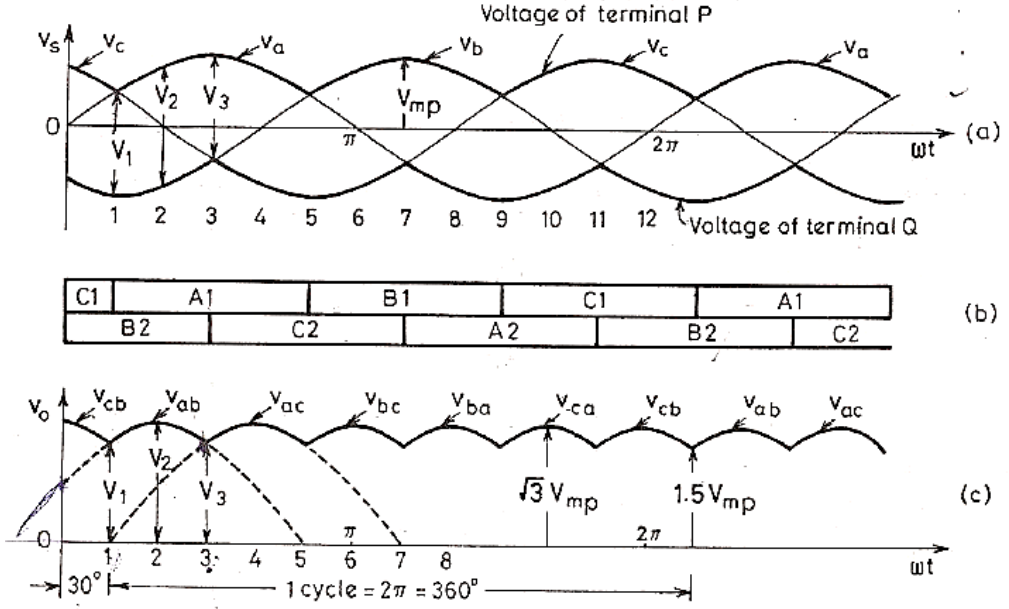
$$V_1 = V_{mp} \sin 30 + V_{mp} \sin 90° = 1.5\, V_{mp}$$

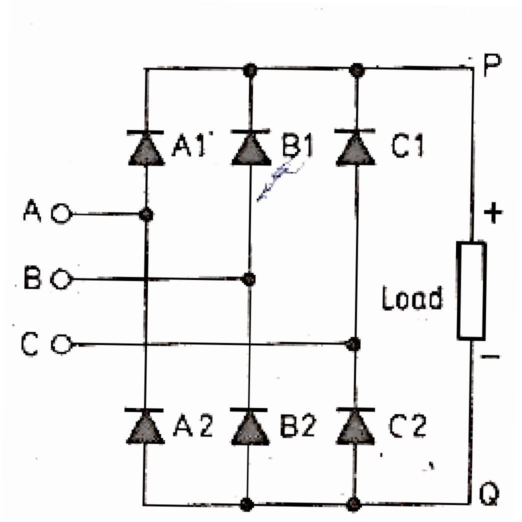
At the instant marked 2, the load voltage has a magnitude of

$$V_2 = V_{mp} \sin 60 + V_{mp} \sin 60° = \sqrt{3}\, V_{mp}$$

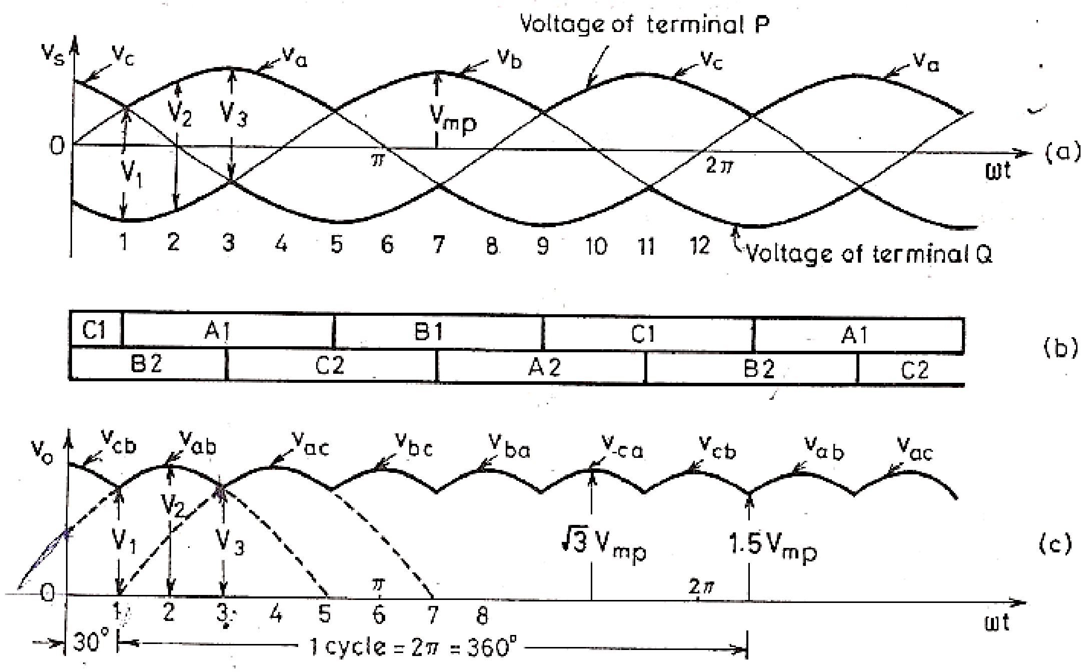
At the instant marked 3 , $V_3 = 1.5\, V_{mp}$.

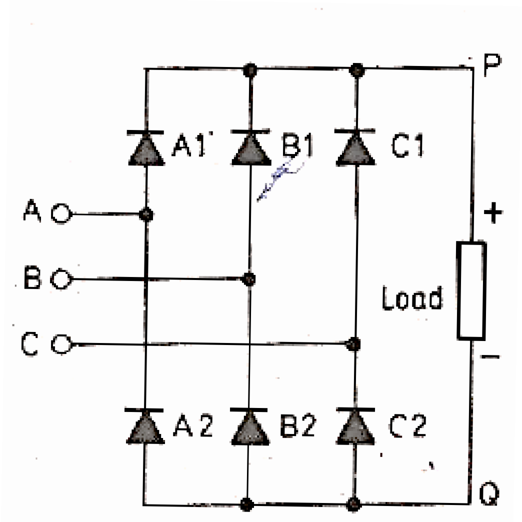
- v_{mp} is the maximum value of phase (or line to neutral) voltage
- At instants marked 2, 4, 6, 8, 10 etc, the load voltage has a magnitude of $\sqrt{3}\,V_{mp}$ and at instants the marked 1, 3, 5, 7, 9, 11 etc., the magnitude of load voltage is 1.5 V_{mp} .
- The load voltage, or the rectified output voltage, v_o can be plotted as shown in Fig.
- Each diode conducts for 120^0.
- V_{ab}, V_{ac}, V_{ba} etc., are line voltages whereas V_a , V_b , V_c are phase voltages
- For example, for voltage v_{cb}, diode C1 from positive group and diode B2 from negative group conduct.





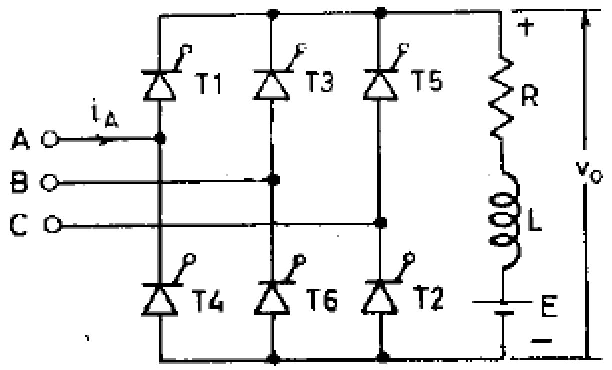
- Voltage of terminal Q is shown at zero potential by straight reference line ωt
- The voltage of terminal P is shown by line values v_{cb}, v_{ab}, v_{ac} ,etc
- There are 6 pulses for one cycle of supply voltage.
- This bridge can be called a 3-phase six-pulse diode rectifier.
- As in single-phase converters, the average output voltage in a 3-phase diode rectifier can be obtained by considering the output voltage wave over one periodic cycle.



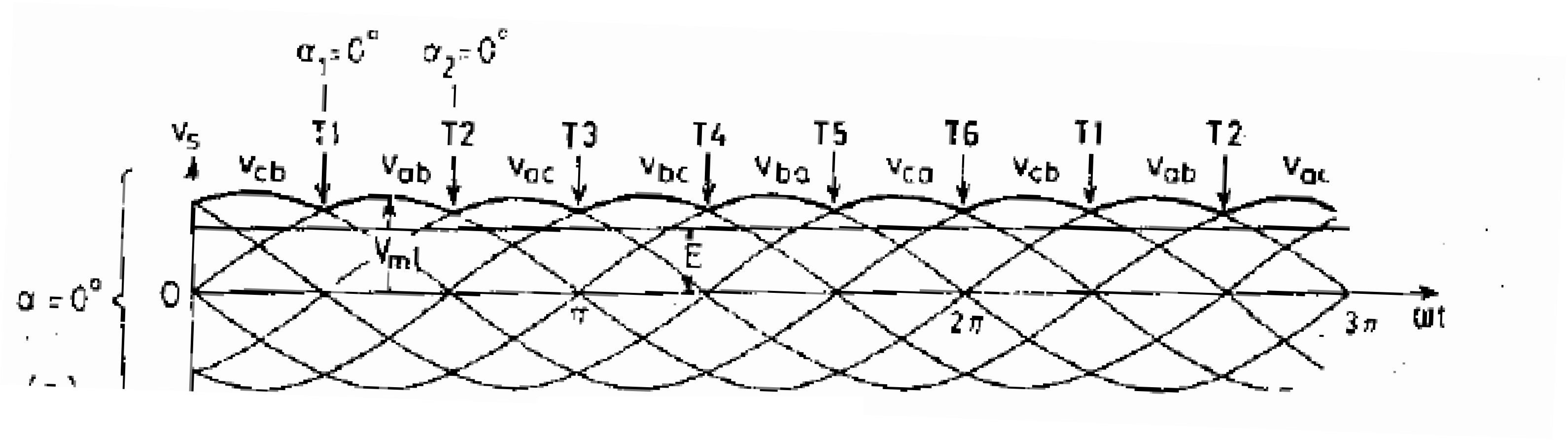


Three phase full converter (controlled)

- All the diodes are replaced by thyristors, a three-phase full-converter bridge is made
- The three-phase input supply is connected to terminals A, B, C and the load RLE is connected across the output terminals of converter.
- As in a single-phase full-converter, it works as a three-phase ac to dc converter for firing angle delay $0^0 < \alpha < 90^0$ and as three-phase line-commutated inverter for $90^0 < \alpha < 180^0$.
- A three-phase full converter is preferred where regeneration of power is required
- Positive group= 1,3,5 Negative group=4,6,2



- For $\alpha = 0^0$; T1, T2, T3…..T6 behave like diodes. This is shown in Fig. 6.25 (a).
- The sequence of conduction of SCRs T1 to T6
- The load voltage has, therefore, the waveform as shown in Fig.



- For $\alpha = 60^0$, the conduction sequence of thyristors T1 to T6

- Here T1 is triggered at $\omega t=30+60=90^0$, T2 is triggered at 90 + 60 = 150^0 and so on.

- Note that each SCR conducts for 120^0

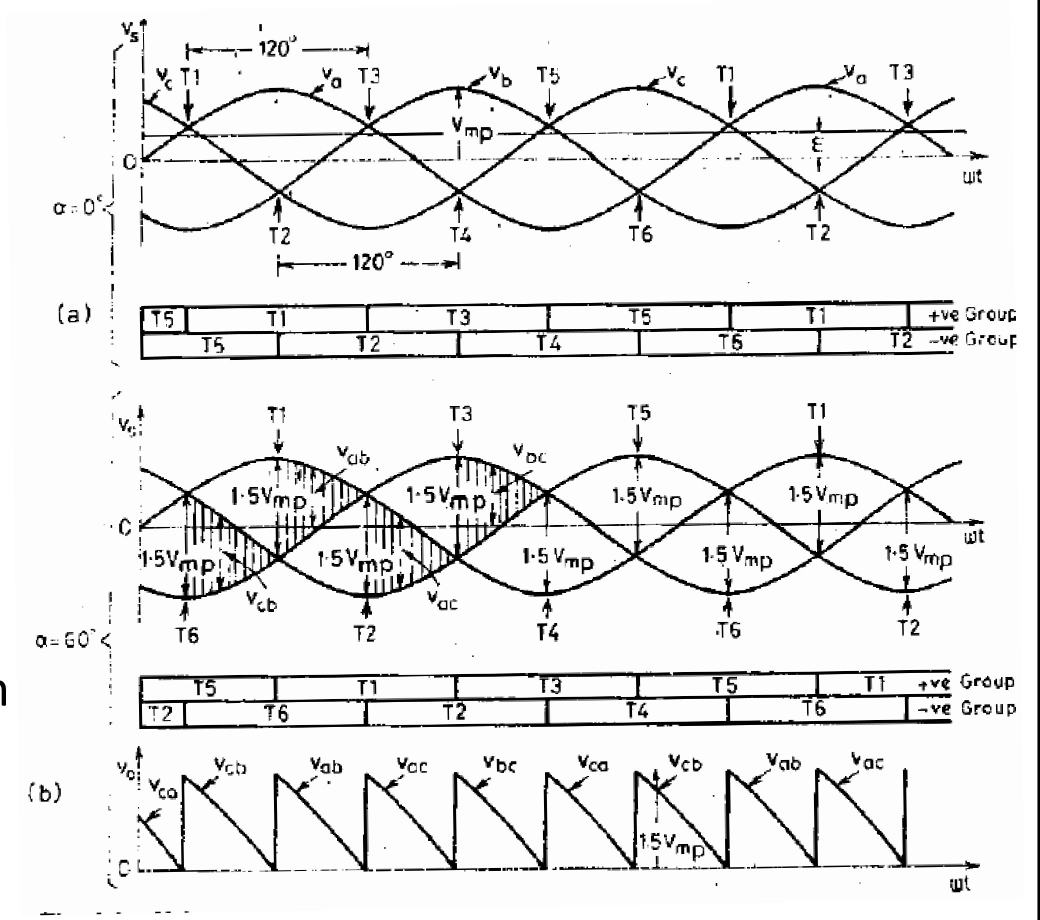
- When T1 is triggered, reverse biased thyristor T5 is turned off and T1 is turned on.

- T6 is already conducting. As T1 is connected to A and T6 to B, voltage v_{ab} appears across load.

- It varies from 1.5 V_{mp} to zero as shown. Here V_{mp} is the maximum value of phase voltage.

- When T2 is on, T6 is commutated from the negative group.

- T1 is already conducting. As T1 and T2 are connected to A and C respectively, voltage v_{ac} appears across load.



- Positive and negative group of SCRs are fired at an interval of 120^0 .But SCRs from both the groups are fired at an interval of 60^0.

- Commutation occurs every 60^0, alternatively in upper and lower group of SCRs.

- At any instant, two SCRs, one from the positive group and the other from negative group, must conduct together for the source to energize the load.

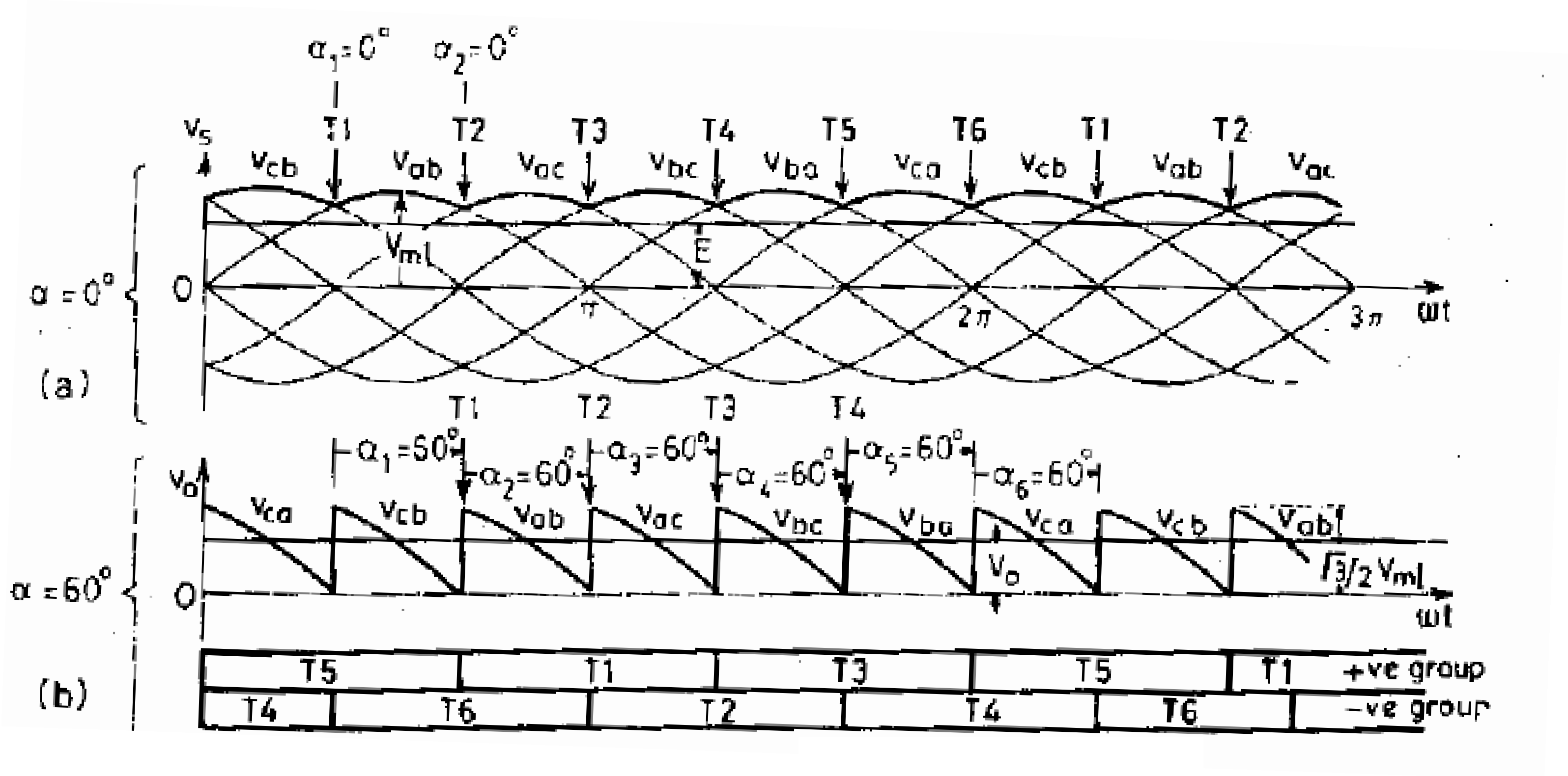
- For ABC phase sequence of the three-phase supply, thyristors conduct in pairs ; T1 and T2, T2 and T3, T3 and T4 and so on

- The sequence of events can be shown more conveniently if line voltages, instead of phase voltages, are considered.

- The subscripts in sequence appear twice. When first subscript appears twice, the SCR in the positive group pertaining to that line conducts for 120^0

- when second subscript comes twice, the SCR in the negative group pertaining to that line conducts for 120^0.

- For α= 60^0, T1 is turned on at ωt= 60 + 60 = 120^0, T2 at ωt = 180^0, T3 at ωt = 240^0
- When T1 is turned on at 120^0, T5 is turned off. T6 is already conducting.
- As TI and T6 are connected to A and B respectively, load voltage must be v_{ab}
- When T2 is turned on, T6 is commutated.



- For $\alpha = 90^0$, the load voltage is symmetrical about the reference line ωt , therefore its average value is zero.

- For $\alpha = 150^0$, T1 is triggered at $\omega t = 210^0$, T2 at 270^0 and so on.

- Average voltage is reversed in polarity.

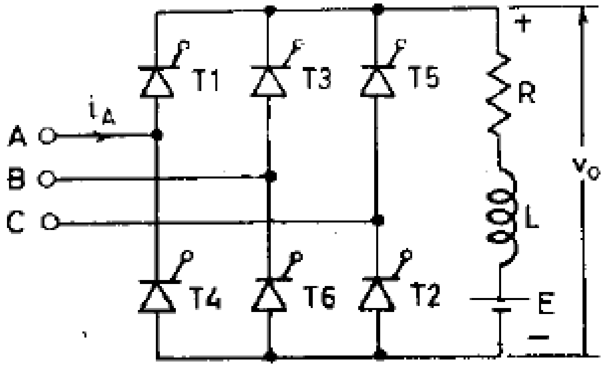
- This means that dc source is delivering power to ac source, this is called line-commutated inverter operation of the 3-phase full converter bridge.

- For $\alpha = 0^0$ to 90^0, power circuit works as a 3-phase full converter delivering power from ac source to dc load

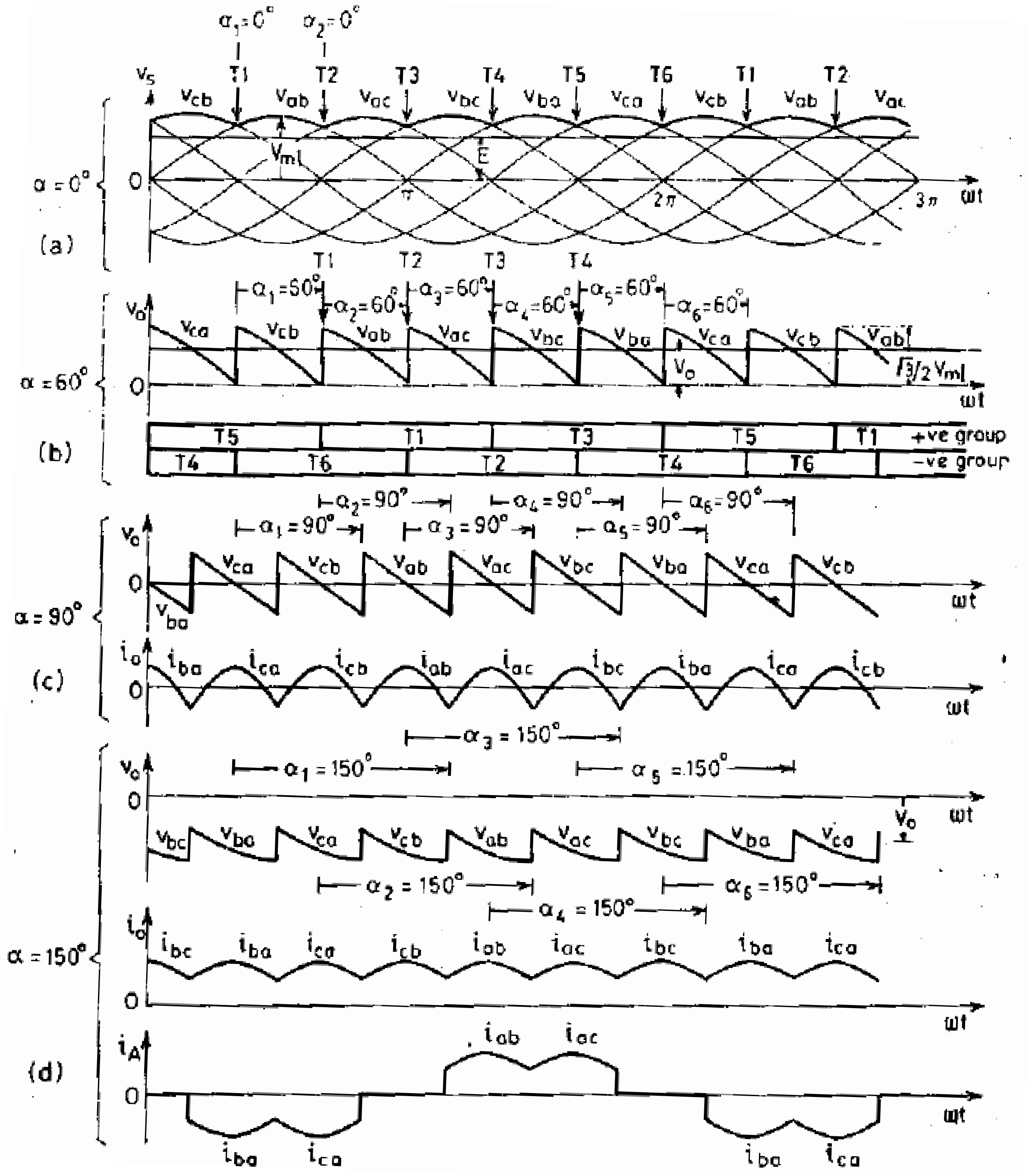
- For $\alpha = 90^0$ to 180^0, it works as a line-commutated inverter delivering power from dc source ac load.

- It can work in the inverter mode only if the load has a direct emf E due to a battery
or a dc motor.

- i_A (Source current in phase A) is positive when T1 is conducting, negative when T4 is conducting, (ie. when the second subscript for voltages or currents is 'a')

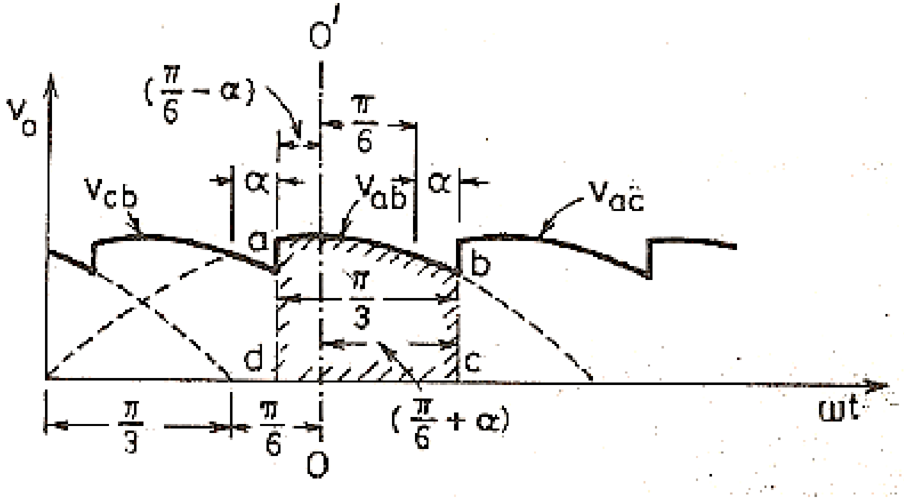


A
B
C
i_A
T1
T3
T5
T4
T6
T2
R
L
E
+
−
v_o



(a)
α = 0°
$\alpha_1 = 0°$
$\alpha_2 = 0°$
v_s
v_{cb} v_{ab} v_{ac} v_{bc} v_{ba} v_{ca} v_{cb} v_{ab} v_{ac}
T1 T2 T3 T4 T5 T6 T1 T2
V_{ml}
E
π
2π
3π
ωt
(b)
α = 60°
$\alpha_1 = 60°$ $\alpha_2 = 60°$ $\alpha_3 = 60°$ $\alpha_4 = 60°$ $\alpha_5 = 60°$ $\alpha_6 = 60°$
v_o
V_o
$\sqrt{3}/2\, V_{ml}$
+ve group
−ve group
(c)
α = 90°
$\alpha_1 = 90°$ $\alpha_2 = 90°$ $\alpha_3 = 90°$ $\alpha_4 = 90°$ $\alpha_5 = 90°$ $\alpha_6 = 90°$
i_o
i_{ba} i_{ca} i_{cb} i_{ab} i_{ac} i_{bc} i_{ba} i_{ca} i_{cb}
α = 150°
$\alpha_1 = 150°$ $\alpha_2 = 150°$ $\alpha_3 = 150°$ $\alpha_4 = 150°$ $\alpha_5 = 150°$ $\alpha_6 = 150°$
(d)
i_A
i_{ab} i_{ac}
i_{ba} i_{ca}

firing angle delay $\alpha < 30°$



$$V_0 = \frac{3}{\pi} \int_{-\left(\frac{\pi}{6}-\alpha\right)}^{\left(\frac{\pi}{6}+\alpha\right)} V_{ml} \cos \omega t \cdot d(\omega t)$$

$$= \frac{3V_{ml}}{\pi}\left[\sin\left(\alpha + \frac{\pi}{6}\right) - \sin\left(\alpha + \frac{\pi}{6}\right)\right] = \frac{3V_{ml}}{\pi} \cos \alpha$$

Here V_{ml} is the maximum value of line voltage.

- Source current or phase A, i.e. i_A (or for any other phase) flows for 120^0 for every 180^0
- Therefore, in case output current is assumed constant at I_0 the rms value of source current is

$$I_s = \sqrt{I_0^2 \frac{2\pi}{3} \times \frac{1}{\pi}} = I_0 \sqrt{\frac{2}{3}}$$

- Each thyristor conducts for 120^0 for every 360^0. RMS value of thyristor current is

$$I_{Th} = \sqrt{I_0^2 \frac{2\pi}{3} \times \frac{1}{2\pi}} = I_0 \sqrt{\frac{1}{3}}$$

Q. (a) A 3-phase full converter charges a battery from a three-phase supply of 230 V, 50 Hz, The battery emf is 200 V and its internal resistance is 0.5 ohms. On account of inductance connected in series with the battery, charging current is constant at 20 A. Compute the firing angle delay and the supply power factor

(b) In case it is desired that power flows from dc source to ac toad in part (a), find the firing angle delay for the same current.

The battery terminal voltage V_0 is

$$V_0 = 200 + 20 \times 0.5 = 210 \text{ V}$$

$$V_0 = \frac{3V_{ml}}{\pi} \cos \alpha = 210 \text{ V}$$

$$\alpha = \cos^{-1} \frac{210 \times \pi}{3\sqrt{2} \times 230} = 47.453°.$$

∴ Rms value of the supply current I_s over π radians is

$$I_s = \left[\frac{1}{\pi} (20)^2 \frac{2\pi}{3} \right]^{1/2} = 20 \sqrt{\frac{2}{3}} = 16.33 \text{ A}$$

Rms value of output current, $I_{or} = 20$ A

Power delivered to load $= EI_0 + I_{or}^2 \cdot r = 200 \times 20 + (20)^2 \times 0.5 = 4200$ W

Now $$\sqrt{3}\, V_s I_s \cos\phi = 4200 \text{ W}$$

$\therefore$ Input supply $$pf = \frac{4200}{\sqrt{3} \times 230 \times 16.33} = 0.646 \text{ lag.}$$

(*b*) When battery is delivering power, then

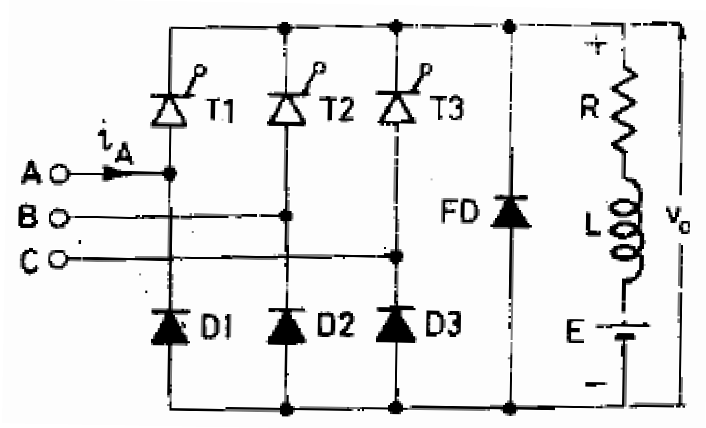
$$V_0 = 200 - 120 \times 0.5 = 190 \text{ V}$$

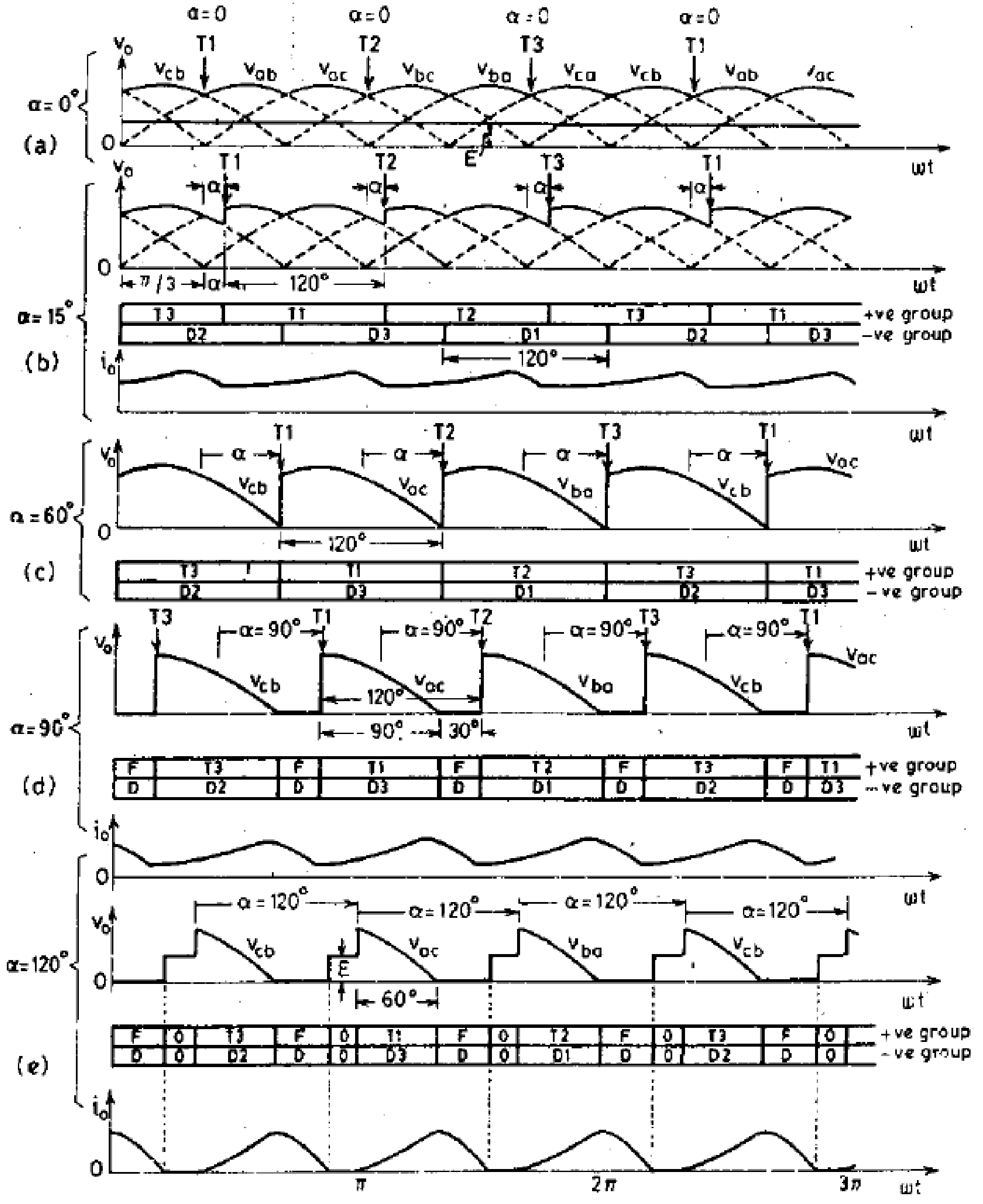
When power flows from dc source to ac load, the 3-phase full converter then works as a 3-phase line commutated inverter.

$\therefore$ $$\frac{3\, V_{ml}}{\pi} \cos\alpha = -190 \text{ V}$$

or $$\alpha = \cos^{-1}\left[\frac{-190 \times \pi}{3\sqrt{2} \times 230}\right] = 127.72°.$$

Three phase semi-converter





- Refer the remaining portion of semi converter from the text book

Wide Band Gap (WBG) Semi-Conductor Devices

- Silicon semiconductor devices restrict many features of PE devices: switching speeds, power density and operation at high ambient temperatures
- Conventional Silicon FET technology has reached its saturation point puts a limit on performance of devices
- Demands: lower switching losses, higher switching speeds, higher power densities
- Wide Band Gap (WBG) materials include Silicon Carbide (SiC), Gallium Nitride (GaN) and Diamond
- They have higher break down voltage, higher thermal conductivity, greater energy band gap and have better carrier mobility
- WBG semiconductor materials can be defined as materials with band gap of more than 2.2 eV
- Band gap of SiC and GaN have same level but larger than that of Si

Silicon carbide (SiC) Devices:

- High dielectric strength, low ON resistance, high power density

- More than 100 polymorphs depending upon the stacking of layers of Si and carbon (C) layers

- 3C, 6H and 4H because of their better performance

- first introduced in market in 2001

- main advantages that 4H-SiC diode have over Si diodes include:

a. 2 times lesser ON state resistance of SiC based Schottky Diodes, (less ON state voltage drop).

b. Thinner epitaxial layers result in 30 times (more switching speeds)

- Higher band gap of silicon carbide helps to develop MOSFET substrate several times thinner and with higher doping than silicon MOSFET

GaN Power Devices:

- Five major characteristics of GaN devices includes: high Dielectric strength, High operating temperature, high current density, high switching speed and low-on resistance.
- 10 times more break down strength than that of Silicon devices
- Exceptional Electron Mobility makes GaN perfect choice for unipolar devices
- Thermal coefficient of expansion (CTE) of GaN is very well suited for the ceramic material that is being used a packaging material for semiconductor devices
- Low charge storing capability of GaN -- possible to develop devices capable of being switched in RF range with very high efficiencies
- it becomes possible to achieve devices with zero recovery characteristics

- SiC devices -high gate threshold voltage and higher turn ON and OFF times
- GaN devices are ideal devices for high voltage & medium range frequency applications
- SiC power devices are way more mature than GaN power devices