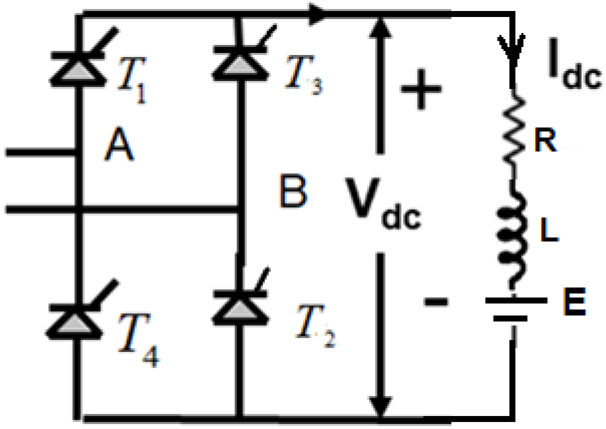
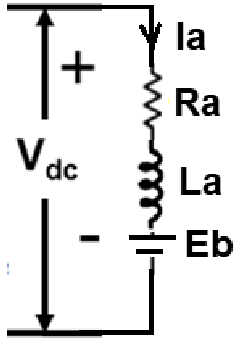
RLE load with continuous conduction

- Supply voltage =230 V , E =100 V
- α = 45^0 R= 5 Ω &L=large
- Power dissipated in R load
- Source current & supply pf
- % ripple in DC O/P voltage
- RLE load with continuous conduction avg V_L= 0
- Vdc (av) = Idc x R +E



$$Idc = \frac{Vdc\,(av) - E}{R}$$



RLE load with continuous conduction

$$V_{dc(avg)} = \frac{2V_m}{\pi}\cos\alpha = \frac{2\sqrt{2}\times 230}{\pi}\cos 45^\circ$$

$$\therefore V_{dc(avg)} = 146.42\,V$$

$$I_{dc} = \frac{V_{dc(avg)} - E}{R} = \frac{146.42 - 100}{5.0} = 9.284\,A$$

Power dissipated in R load $= I_{dc}^2 \times R$

$$= 9.284^2 \times 5 = 430.96\,W$$

Source current $I_{s(rms)} = 9.284\,A$

RLE load with continuous conduction

Powerfactor $= \frac{2\sqrt{2}}{\pi}\cos\alpha = \frac{2\sqrt{2}}{\pi}\cos 45 = 0.636$ lag.

$V_{dc(av)} = 146.42$

$V_{dc(rms)} = 230.0$

$$FF = \frac{V_{dc(rms)}}{V_{dc(av)}} = \frac{230}{146.42} = 1.5708$$

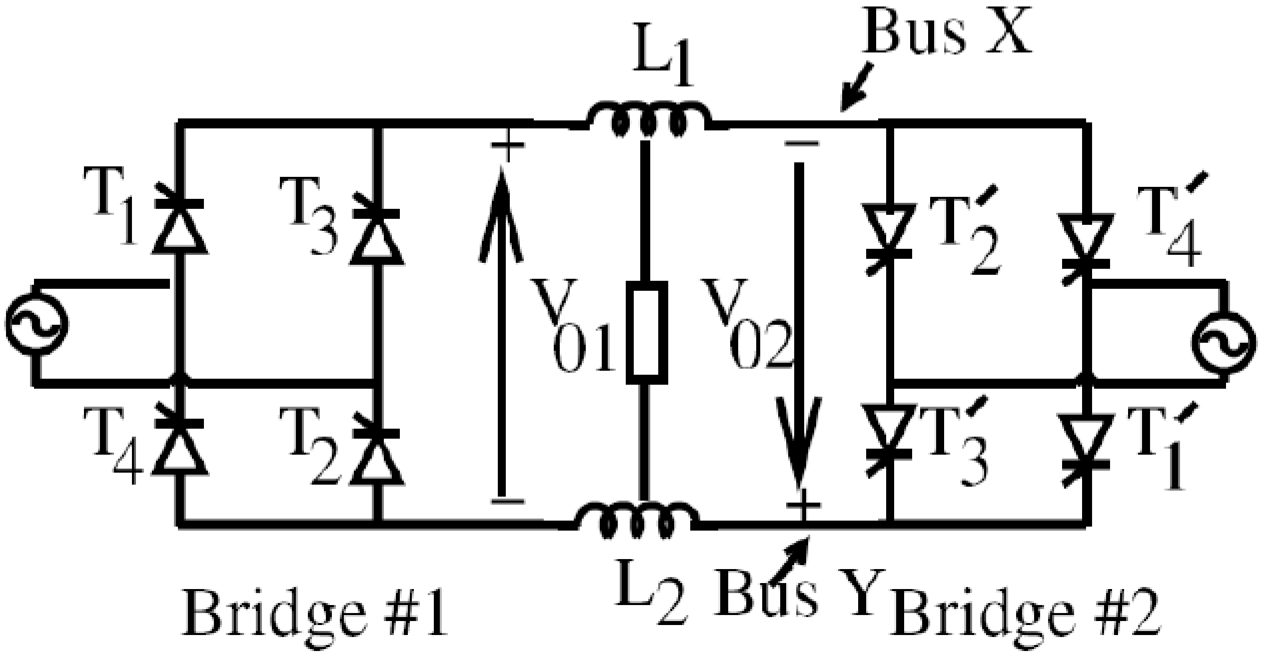
$\therefore$ Ripple factor $= \sqrt{FF^2 - 1}$

$= 1.211$

$\therefore$ % Ripple $= 121.1\%$

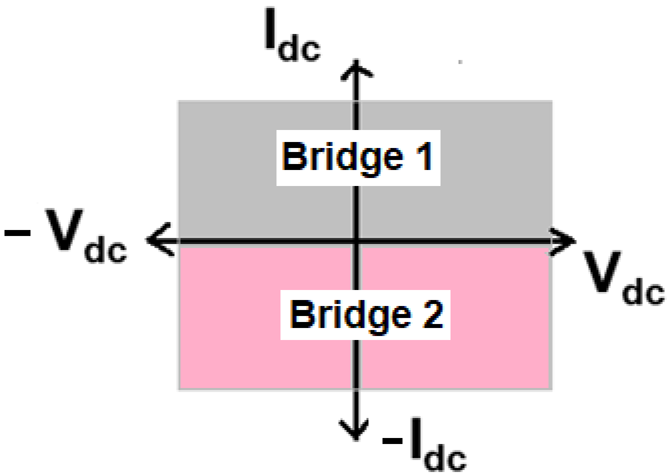
Dual converter

- Two full controlled converters connected anti-parallel



Dual converter

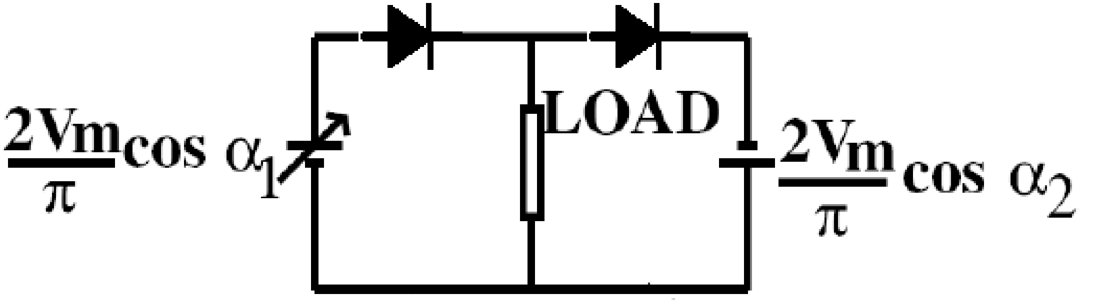
- Quadrant operation
- Bridge1 = I and II
- Bridge 2 = III and IV



- Bridge 1 provides +ve current to load and provides +ve and –ve voltage.
- Bridge 1 => α_1 $$V_{01} = \frac{2V_m}{\pi}\cos\alpha_1$$
- Bridge 2 => α_2 $$V_{02} = \frac{2V_m}{\pi}\cos\alpha_2$$

Dual converter

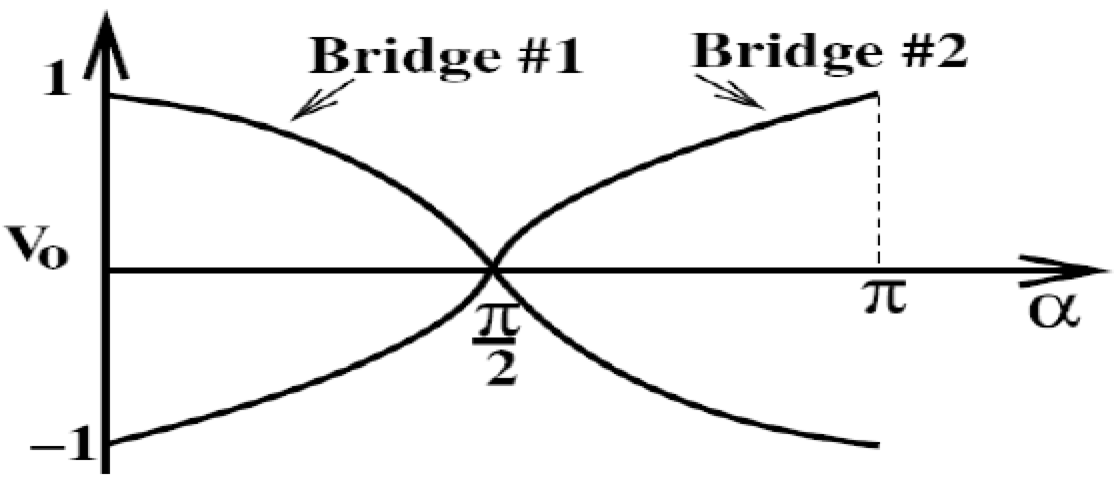
- Average voltage provided by both converters are same



- Applying KVL gives $V_{O1} + V_{O2} = 0$
- $\cos\alpha1 + \cos\alpha2 = 0$
- $\text{Cos } \alpha_1 = -\cos\alpha_2 \Rightarrow \text{Cos } \alpha_1 = \cos(\pi - \alpha_2)$
- $\alpha_1 + \alpha_2 = \pi$

Dual converter

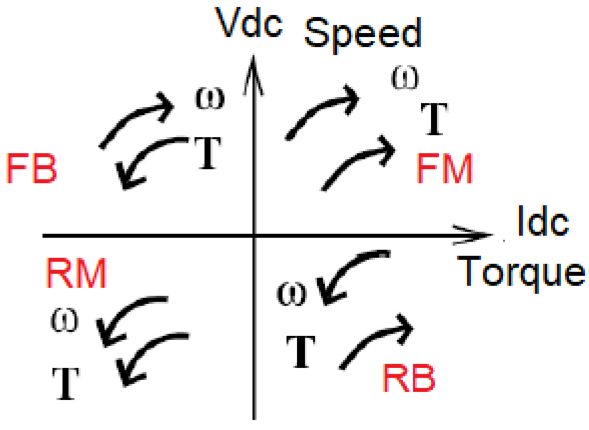
- Circulating mode and non circulating mode

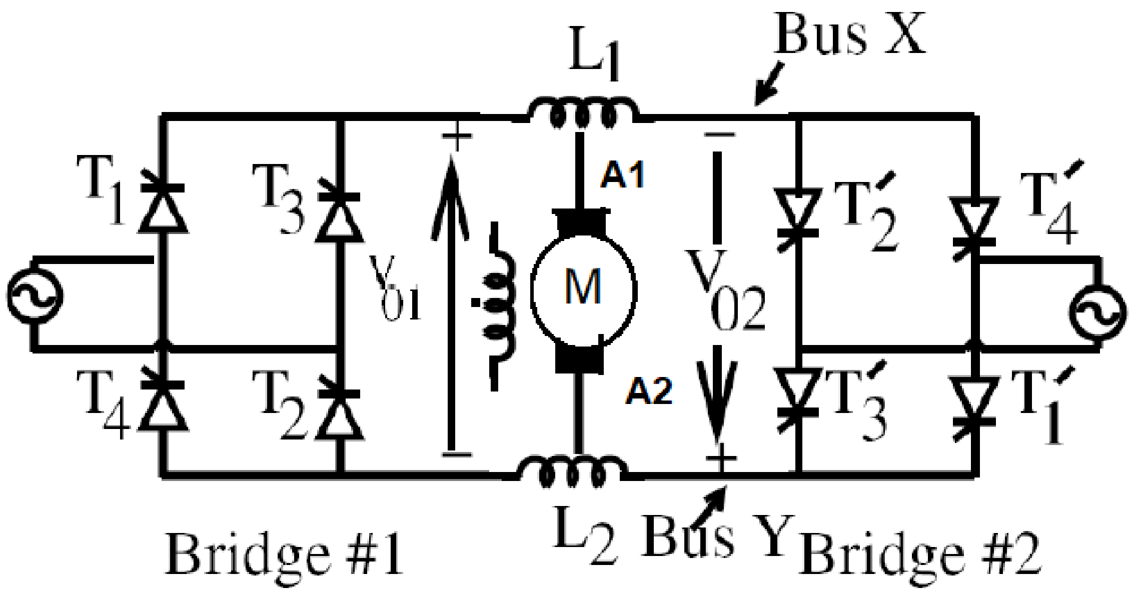


- Inductors L_1 and L_2 are required to limit the circulating current
- Dual converter for speed control of DC Motor

Speed control of sep. excited DC Motor

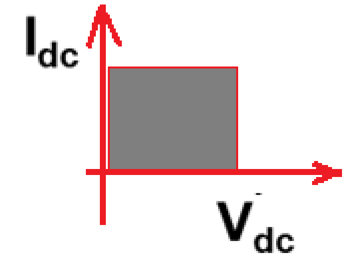
- 4 quadrant DC drive
- Armature voltage control

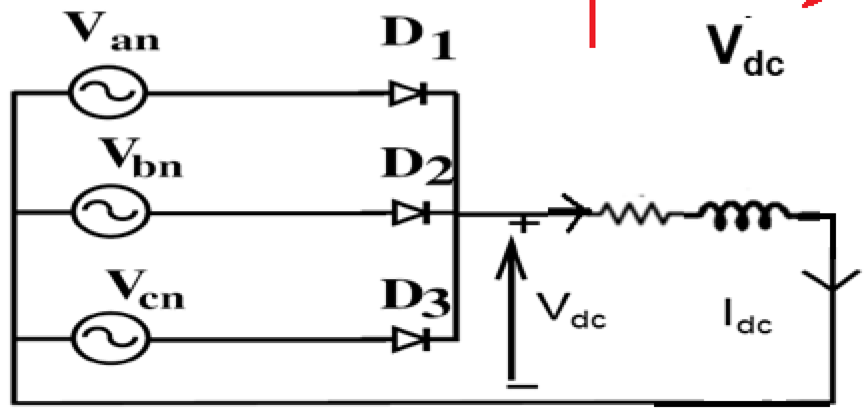


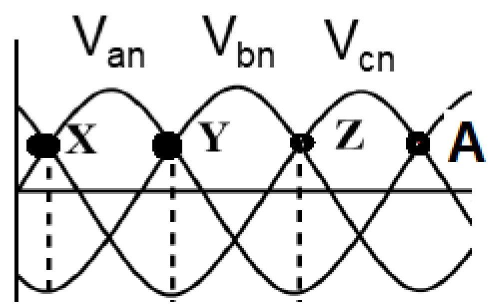


Three phase half wave rectifier

- Half wave rectification
- RL load =>Smooth and ripple free current
- Between X and Y, V_{an} is maximum positive so D_1 conducts
- Between YZ D_2 conducts
- During ZA period D_3
- conducts
- Diode conduction = 120^0
- Conduction is continuous

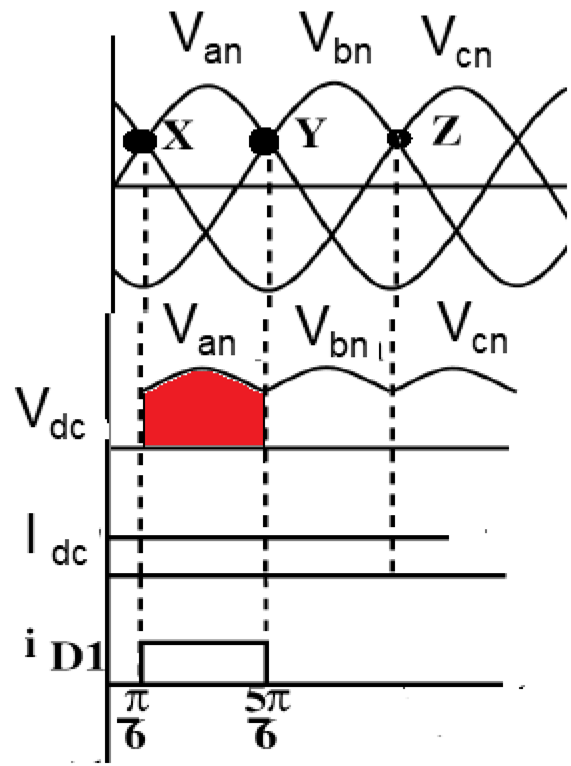






Three phase half wave rectifier

- V_{mp}= Peak value of phase voltage
- Vdc (av) = $\frac{3}{2\pi}\int_{\pi/6}^{5\pi/6} Vmp$ Sinθ dθ



- Diode avg current= Idc/3
- Diode RMS current = Idc/√3
- 3 pulse rectifier

Three phase half wave rectifier

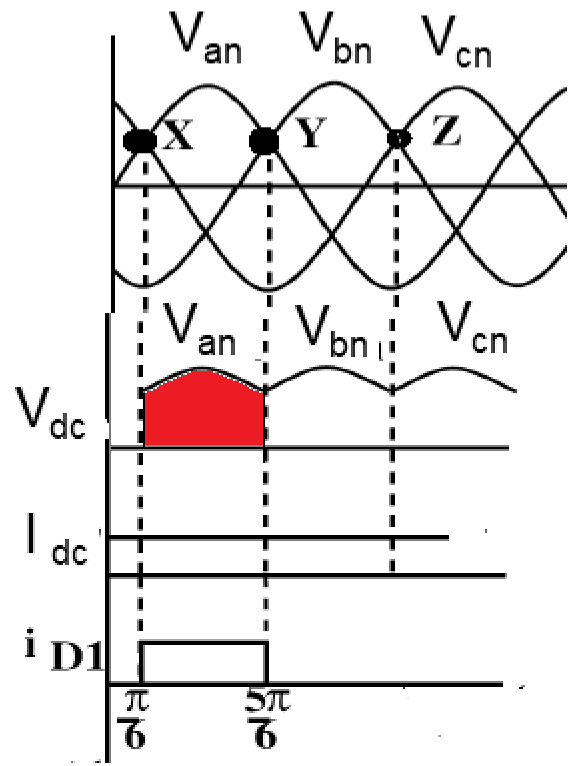
$$V_{dc(av)} = \frac{3}{2\pi}\int_{30}^{150^\circ} V_{mp} \sin\theta \cdot d\theta$$

$$= \frac{3V_{mp}}{2\pi}\left[-\cos\theta\right]_{30}^{150}$$

$$= \frac{3V_{mp}}{2\pi}\left[-\cos 150 + \cos 30\right]$$

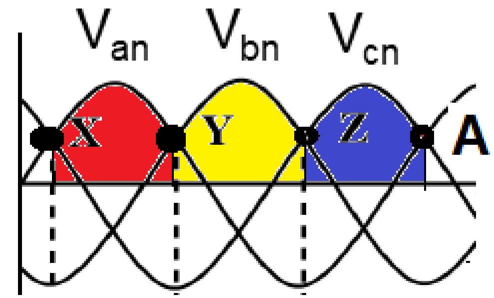
$$= \frac{3V_{mp}}{2\pi}\left[\frac{\sqrt{3}}{2} + \frac{\sqrt{3}}{2}\right]$$

$$= \frac{3\sqrt{3}\,V_{mp}}{2\pi}$$



Three phase half wave rectifier

- Vdc(rms)



$$V_{dc(rms)} = \left[\frac{3}{2\pi}\int_{30}^{150} V_{mp}^2 \sin^2\theta \cdot d\theta\right]^{1/2}$$

$$V_{dc(rms)} = \left[\frac{3V_{mp}^2}{2\pi}\int_{30}^{150}\left(\frac{1-\cos 2\theta}{2}\right) d\theta\right]^{1/2}$$

$$= \left[\frac{3V_{mp}^2}{4\pi}\left\{\int_{30}^{150} d\theta - \int_{30}^{150}\cos 2\theta \cdot d\theta\right\}\right]^{1/2}$$

$$= \left[\frac{3V_{mp}^2}{4\pi}\left\{\theta\Big|_{\pi/6}^{5\pi/6} - \frac{1}{2}(\sin 2\theta)\Big|_{30}^{150}\right\}\right]^{1/2}$$

Three phase half wave rectifier

- Vdc(rms)

$$= \left[\frac{3V_{mp}^2}{4\pi} \left\{ \left(\frac{5\pi}{6} - \frac{\pi}{6} \right) - \frac{1}{2} \left\{ \sin 300 - \sin 60 \right) \right\} \right]^{1/2}$$

$$= \left[\frac{3V_{mp}^2}{4\pi} \left\{ \frac{2\pi}{3} - \frac{1}{2} \left(-0.866 - 0.866 \right) \right\} \right]^{1/2}$$

$$V_{dc(rms)} = \left[\frac{3V_{mp}^2}{4\pi} \left(\frac{2\pi}{3} + \frac{\sqrt{3}}{2} \right) \right]^{1/2}$$

$$V_{dc(rms)} = 0.8406\, V_{mp}$$

Three phase half wave rectifier

- % ripple in the O/P

$$V_{dc(rms)} = 0.8406\ V_{mp}$$

$$V_{dc(av)} = 0.82699\ V_{mp}$$

$$\therefore FF = \frac{V_{dc(rms)}}{V_{dc(av)}} = 1.01645$$

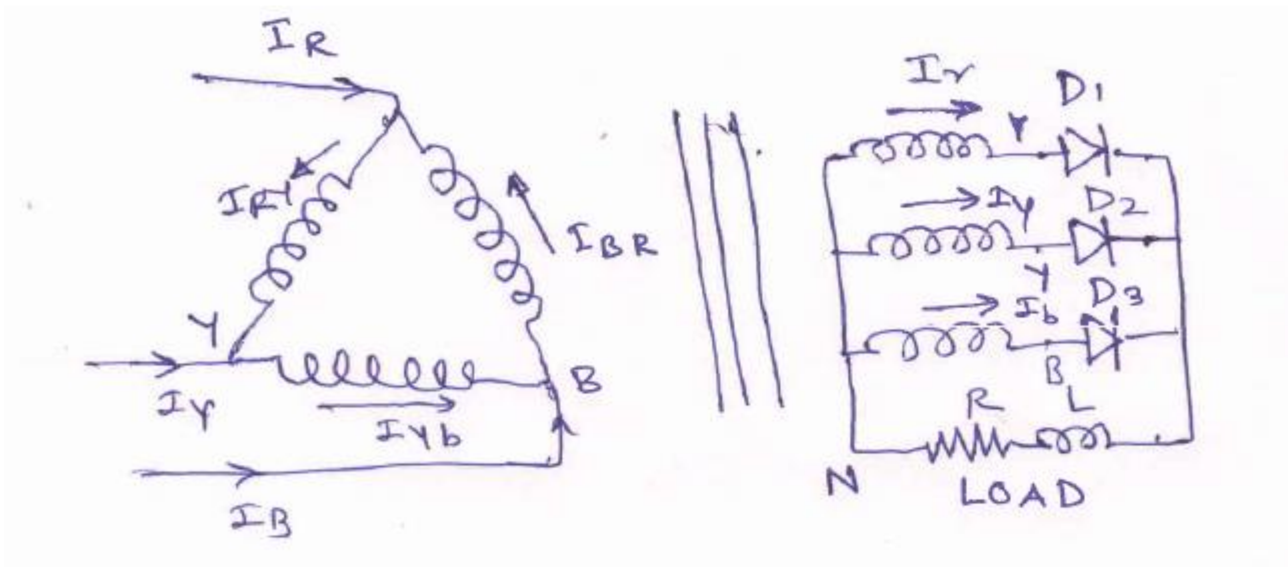
$$FF^2 = 1.03317$$

$$\therefore \%\ \text{Ripple} = \sqrt{1.03317-1} = \sqrt{0.3317} \times 100$$

$$\therefore \%\ \text{Ripple} = 18.21\%$$

Three phase half wave rectifier

- VA rating of the transformer



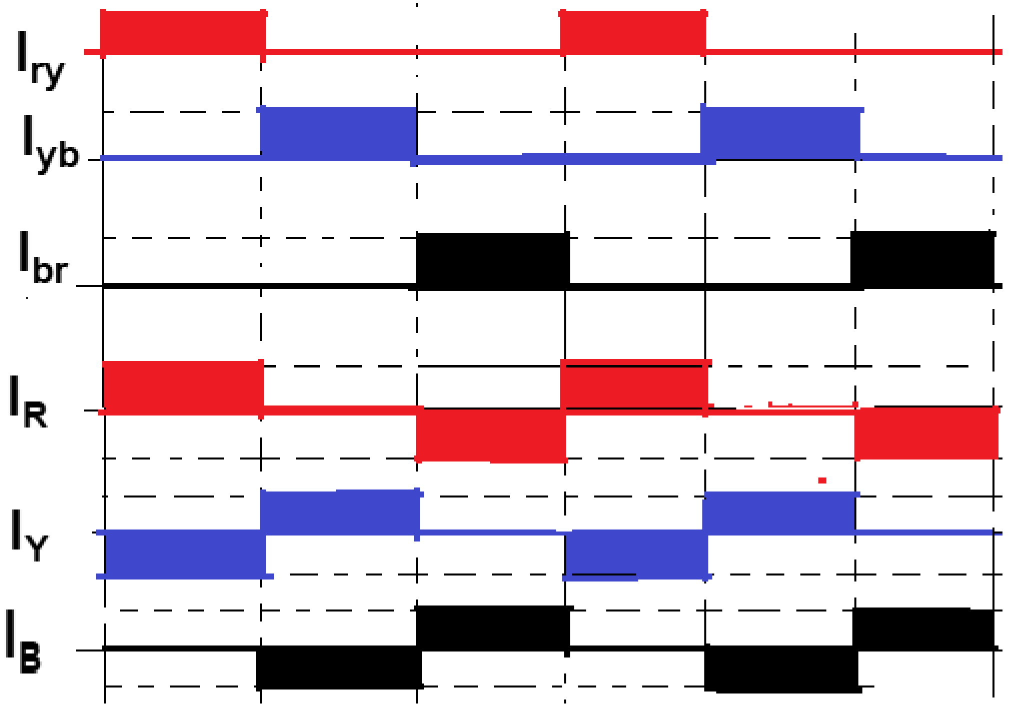
$$I_R = I_{RY} - I_{BR}$$

$$I_Y = I_{Yb} - I_{RY}$$

$$I_B = I_{BR} - I_{Yb}$$

Three phase half wave rectifier

- Transformer currents



Three phase half wave rectifier

- Assume turns ratio=1, V=phase voltage
- secondary VA Rating = $3 V_{ph} I_{ph}$

  Sec. VA Rating $= 3 \cdot V \times I_{ph} = 3 \times V \times I_{dc}/\sqrt{3}$

  But $V_{dc(av)} = \frac{3\sqrt{3}}{2\pi} \times \sqrt{2} V$

  $\therefore \quad V = \frac{V_{dc} \times 2\pi}{3\sqrt{6}}$

  $\therefore$ Sec. VA Rating $= 3 \times \frac{2\pi}{3\sqrt{6}} V_{dc} \cdot \frac{I_{dc}}{\sqrt{3}}$

  Sec. VA rating $= 1.48\, V_{dc} \cdot I_{dc}$

Three phase half wave rectifier

- Primary VA rating

Primary VA Rating $= \sqrt{3} \times V \times \sqrt{2/3} \cdot I_{dc}$

$\therefore$ Primary VA $= \sqrt{2} \times V \cdot I_{dc} = \frac{2\pi}{3\sqrt{6}} V_{dc} \times \sqrt{2} \times I_{dc}$

$\therefore$ Primary VA $= \frac{2\pi}{3\sqrt{6}} \times \sqrt{2} \cdot \frac{V_{dc}}{I_{dc}} = 1.209\, V_{dc} \cdot I_{dc}$

Three phase half wave rectifier

- Transformer utilization factor

$$\text{Average VA Rating} = \frac{\text{Primary VA} + \text{Sec VA}}{2}$$

$$\therefore \text{VA Rating of Tx} = 1.48\, V_{dc} \cdot I_{dc} + 1.209\, V_{dc} \cdot I_{dc}$$

$$= 1.34\, V_{dc} \cdot I_{dc}$$

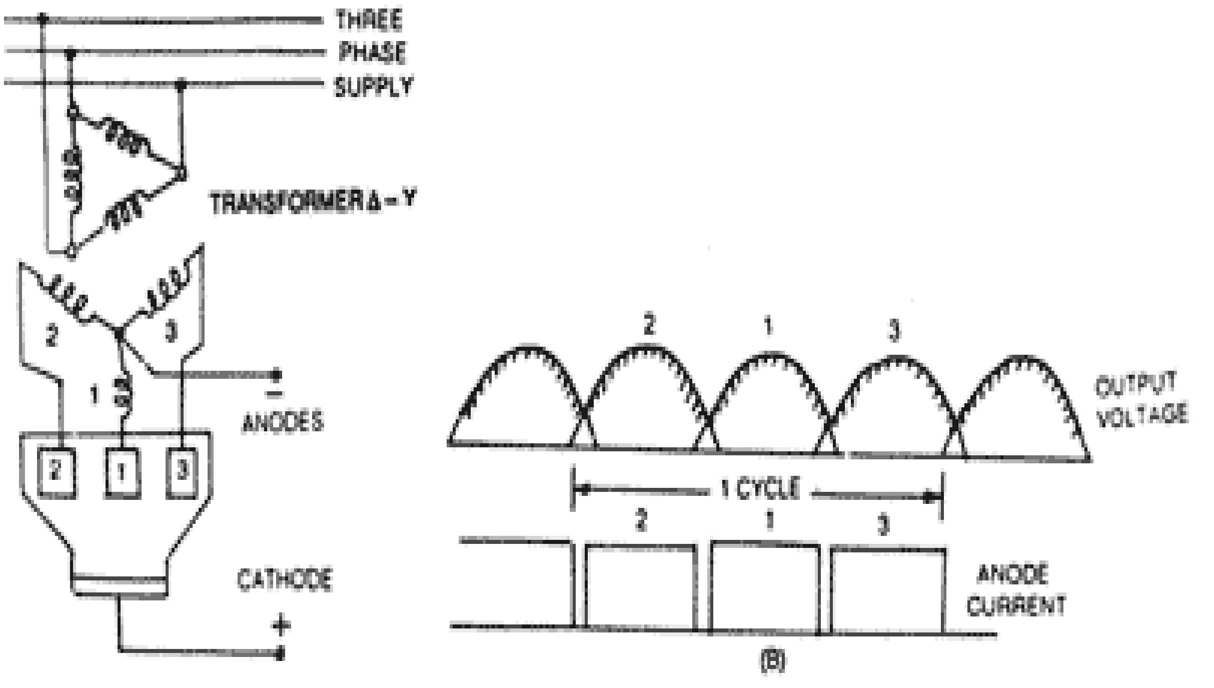
$$\text{Tx. Utilization Factor} = \frac{V_{dc} \cdot I_{dc}}{1.34\, V_{dc} \cdot I_{dc}} = 0.746$$

Three phase half wave rectifier

- Delta /star transformer is required.
- Transformer secondary current are unidirectional
- Transformer secondary VA rating =1.48Vdc Idc
- Transformer primary VA rating=1.209 Vdc Idc
- Transformer VA rating = 1.34 Vdc Idc
- Disadvantage : transformer VA rating is high
- VA rating of primary and secondary is different

Three phase half wave controlled converter

- Mercury Arc Rectifier
- 1960 steel plants are established

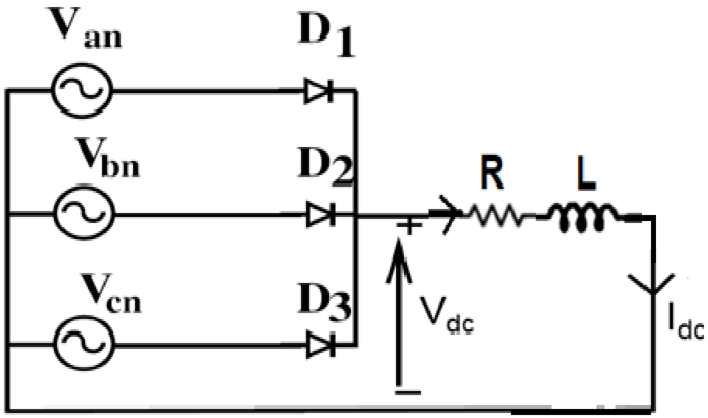


Mercury Arc Rectifier

- photo

Three phase half wave rectifier

- RL load – Power dissipation
- Phase voltage =230 V
- R=10 Ω , L large so Idc smooth
- and ripple free
- determine power dissipation in
- R load. Diode average and RMS
- Current
- Idc is determined from Vdc(av)
- Vdc(av)= $\frac{3\sqrt{3}\,Vmp}{2\pi}$
- Vmp= $\sqrt{2}$ 230 V

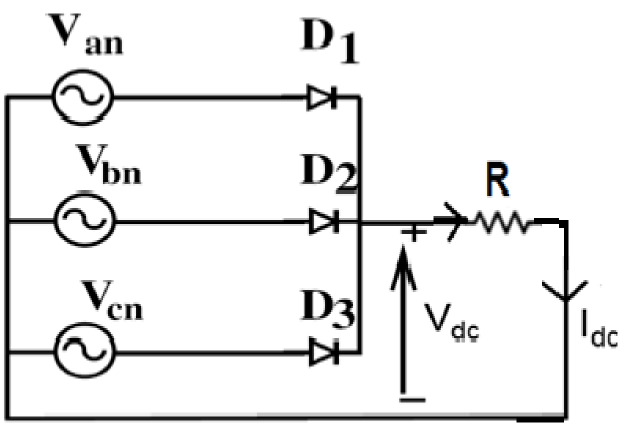


RL load power dissipation

- Vdc(av)= 269 V
- Idc= Vdc(av)/R = 269/10 = 26.9A
- Pdc= Vdc(av) X Idc = 7.236 kW
- Diode I (av) = Idc/3= 26.9/3= 8.96 A
- Diode I (rms) Idc/$\sqrt{3}$ = 26.9/ $\sqrt{3}$ = 15.53 A

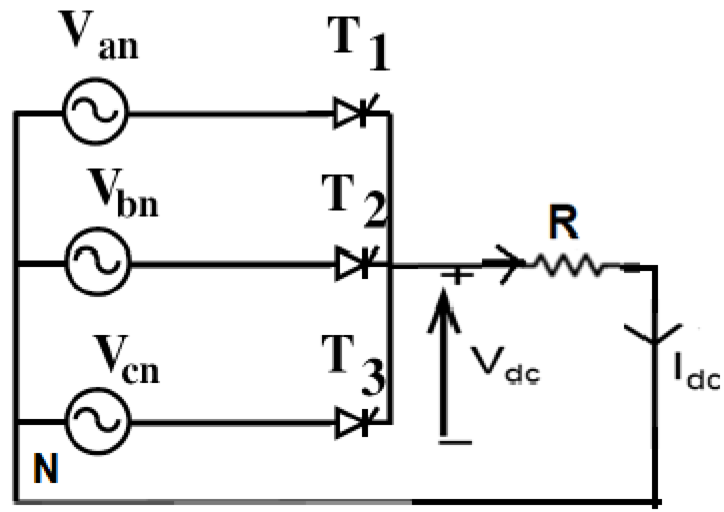
Three phase half wave rectifier

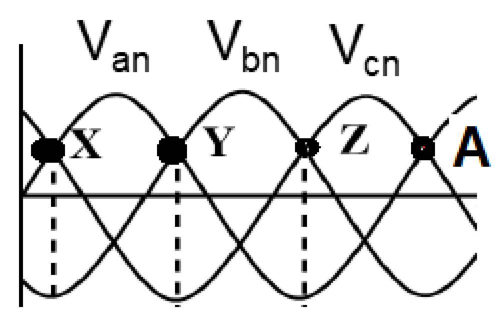
- Power dissipation in R load
- Phase voltage =230 V
- R=10 Ω ,
- For power dissipation
- Vdc(rms)
- Pdc = [Vdc(rms)]^2 /R
- Vdc(rms)= 0.8406 Vmp
- Vdc(rms)=0.8406X$\sqrt{2}$ X230= 273.42 V
- Pdc= 7.476 KW



Three phase half wave controlled converter with R load

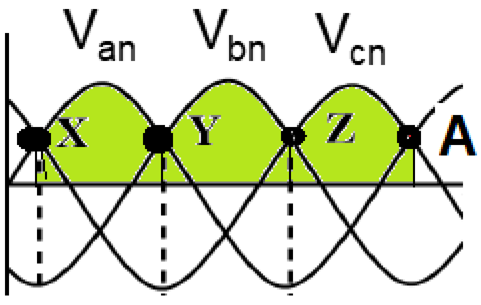
- Circuit configuration
- Three phase 4 wire
- Delta / star Tx
- X, Y and Z points
- Represents α =0
- R load => 0 to 150^0

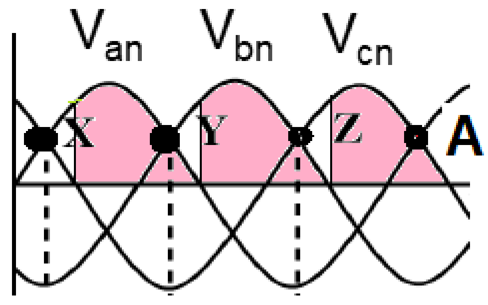


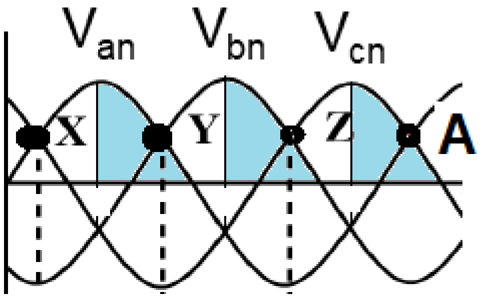


Waveforms with R load

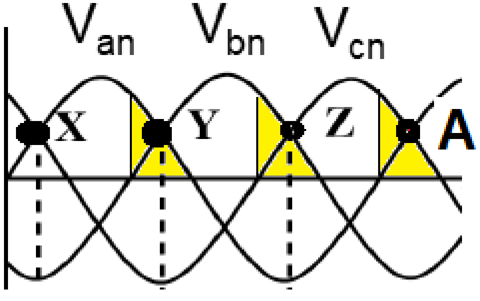
- Voltage waveforms at various α

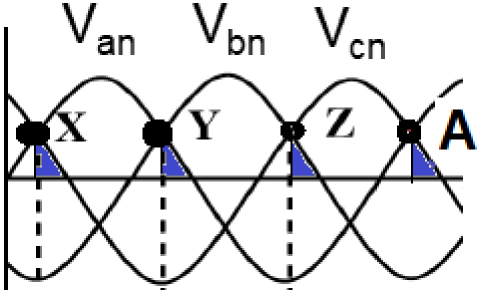


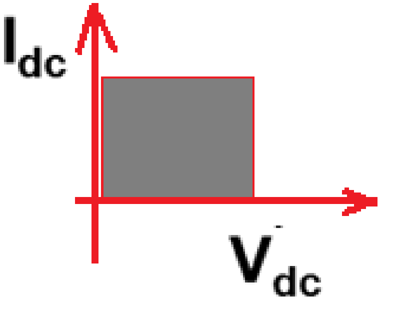




- $\alpha=0^0$ $\alpha=30^0$ $\alpha=60^0$



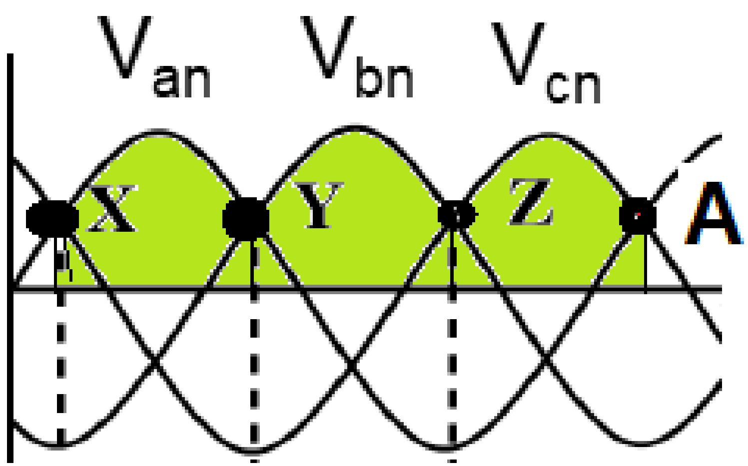


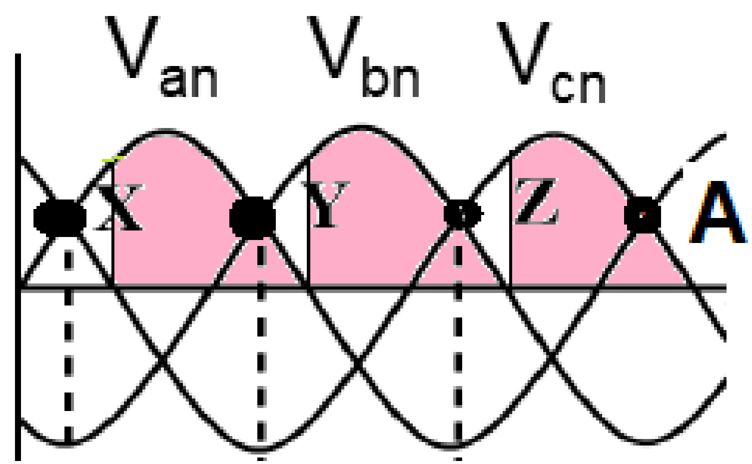


- $\alpha=90^0$ $\alpha = 120^0$

Three phase half wave controlled converter with R load

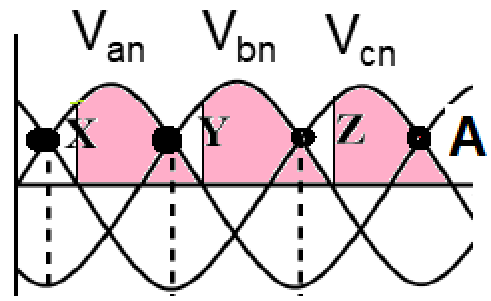
- Continuous conduction= $0<\alpha<30$
- Each device conducts for 120^0
- Vdc(av)= $\dfrac{3\sqrt{3}\,V_{mp}}{2\,\pi}\cos\alpha$





Three phase half wave controlled converter with R load

- Continuous conduction



$$V_{dc(av)} = \frac{3}{2\pi}\int_{30+\alpha}^{150+\alpha} V_{mp}\sin\theta \cdot d\theta$$

$$= \frac{3V_{mp}}{2\pi}\int_{30+\alpha}^{150+\alpha} \sin\theta \cdot d\theta$$

$$= \frac{3V_{mp}}{2\pi}\Big[-\cos\theta\Big]_{30+\alpha}^{150+\alpha}$$

$$= \frac{3V_{mp}}{2\pi}\Big[-\cos(150+\alpha)+\cos(30+\alpha)\Big]$$

Three phase half wave controlled converter with R load

- Continuous conduction

$$= \frac{3V_{mp}}{2\pi}\left[-\cos 150 \cos\alpha + \sin 150 \sin\alpha + \cos 30 \cos\alpha - \sin 30 \sin\alpha\right]$$

$$= \frac{3V_{mp}}{2\pi}\left[-\cos 150 \cos\alpha + \cos 30 \cos\alpha\right]$$

$$= \frac{3V_{mp}}{2\pi}\left[\frac{\sqrt{3}}{2}\cos\alpha + \frac{\sqrt{3}}{2}\cos\alpha\right]$$

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

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

Three phase half wave controlled converter with R load

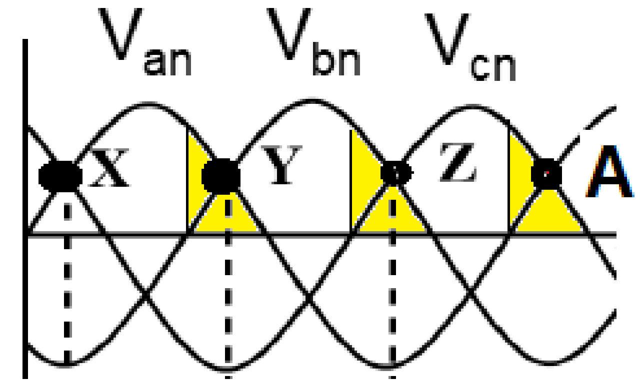
- Discontinuous conduction= 30<α <150
- Each device conducts for $150^0-\alpha^0$

$$V_{dc(av)} = \frac{3}{2\pi}\int_{30+\alpha}^{\pi} V_{mp}\sin\theta \cdot d\theta$$

$$= \frac{3V_{mp}}{2\pi}\left[-\cos\theta\right]_{30+\alpha}^{\pi}$$

$$= \frac{3V_{mp}}{2\pi}\left[-\cos\pi + \cos(30+\alpha)\right]$$

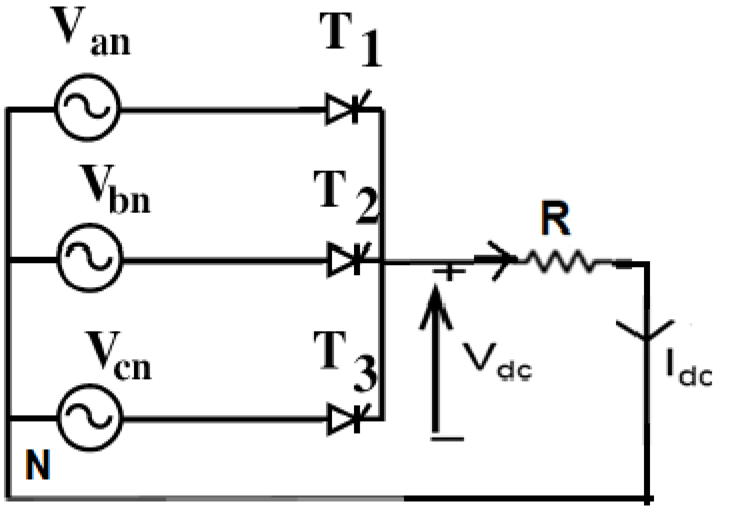
$$= \frac{3V_{mp}}{2\pi}\left(1+\cos(30+\alpha)\right)$$

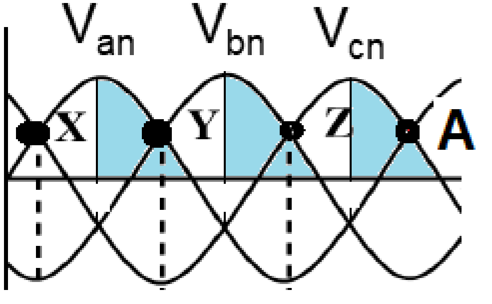


R load Power Dissipation

- V/ph = 230 V , α=60
- R = 10 Ω determine
- Power dissipated in R
- Vdc^2(rms) /R= Pdc

- Vdc(rms)= 228.7
- Pdc = 5230.69 W





R load Power Dissipation

$$V_{dc(rms)} = \left[\frac{3}{2\pi}\int_{90}^{180} V_{mp}^2 \sin^2\theta \cdot d\theta\right]^{1/2}$$

$$= \left[\frac{3V_{mp}^2}{2\pi}\int_{90}^{180}\left(\frac{1-\cos 2\theta}{2}\right)\cdot d\theta\right]^{1/2}$$

$$= \left[\frac{3V_{mp}^2}{4\pi}\left\{\int_{90}^{180} d\theta - \int_{90}^{180}\cos 2\theta \cdot d\theta\right\}\right]^{1/2}$$

$$V_{dc(rms)} = \left[\frac{3V_{mp}^2}{4\pi}\left\{\theta\Big|_{\pi/2}^{\pi} - \frac{1}{2}\sin 2\theta\Big|_{\pi/2}^{\pi}\right\}\right]^{1/2}$$

R load Power Dissipation

$$V_{dc(rms)} = \left[\frac{3 V_{mp}^2}{4\pi} \left\{ \theta \Big|_{\pi/2}^{\pi} - \frac{1}{2} \sin 2\theta \Big|_{\pi/2}^{\pi} \right\} \right]^{1/2}$$

$$= \left[\frac{3 V_{mp}^2}{4\pi} \left\{ (\pi - \pi/2) - \frac{1}{2} (\sin\pi - \sin\pi/2) \right\} \right]^{1/2}$$

$$= \left[\frac{3 V_{mp}^2}{4\pi} \left\{ \pi/2 + 1/2 \right\} \right]^{1/2}$$

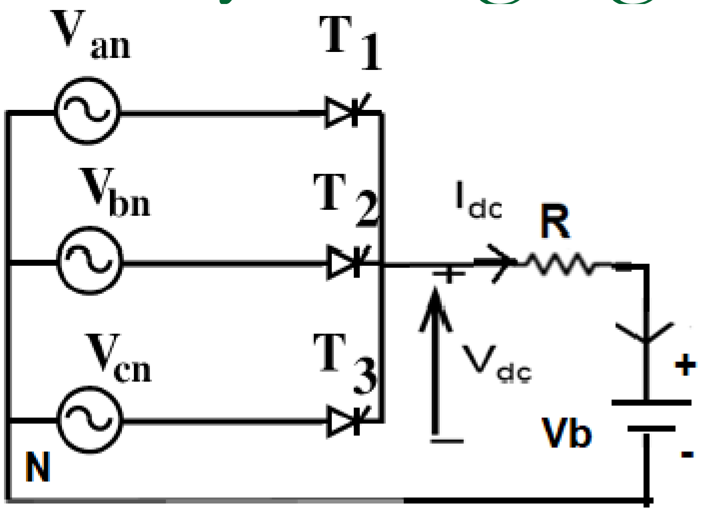
putting values.

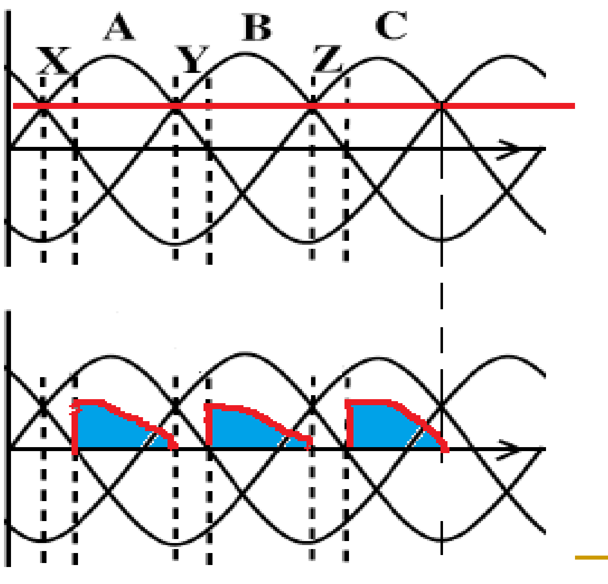
$$= \left[\frac{3 \times (\sqrt{2} \times 230)^2}{4\pi} \left(\pi/2 + 1/2 \right) \right]^{1/2}$$

$$V_{dc(rms)} = 228.7 \text{ V}$$

Numerical Problem Battery charging

- V/ph = 230 V R=5 Ω
- Vb= 150 V , α= 30^0
- Determine the average
- Charging current





Numerical Problem Battery charging

$V_{mp} \sin\theta_1 = V_b \quad \therefore \sin\theta_1 = \frac{V_b}{V_{mp}}$

$\sin\theta_1 = \frac{150}{\sqrt{2}\times 230} \qquad \theta_1 = \sin^{-1}(0.4611) = 27.45^\circ$

$\therefore \theta_2 = 180 - 27.45 = 152.55^\circ$

$$i = \frac{V_{mp}\sin\theta - V_b}{R}$$

Average charging current

$$I_{dc} = \frac{3}{2\pi}\int_{30+\alpha}^{\theta_2} \frac{V_{mp}\sin\theta - V_b}{R}\cdot d\theta$$

$$I_{dc} = \frac{3}{2\pi R}\left[\int_{60}^{152.55} V_{mp}\sin\theta \cdot d\theta - \int_{60}^{152.55} V_b \cdot d\theta\right]$$

Numerical Problem Battery charging

$$I_{dc} = \frac{3}{2\pi R}\left[V_{mp}(-\cos\theta)\Big|_{60}^{152.55} - V_b\left(\frac{152.55}{180}\pi - \frac{\pi}{3}\right)\right]$$

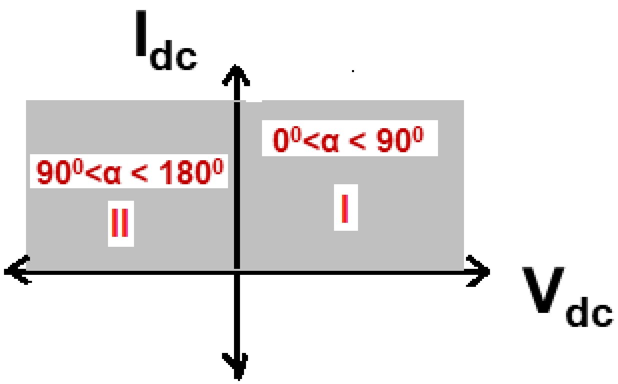
$$I_{dc} = \frac{3}{2\pi R}\left[\sqrt{2}\times 230(-\cos 152.55 + \cos 60) - 150(1.61)\right]$$

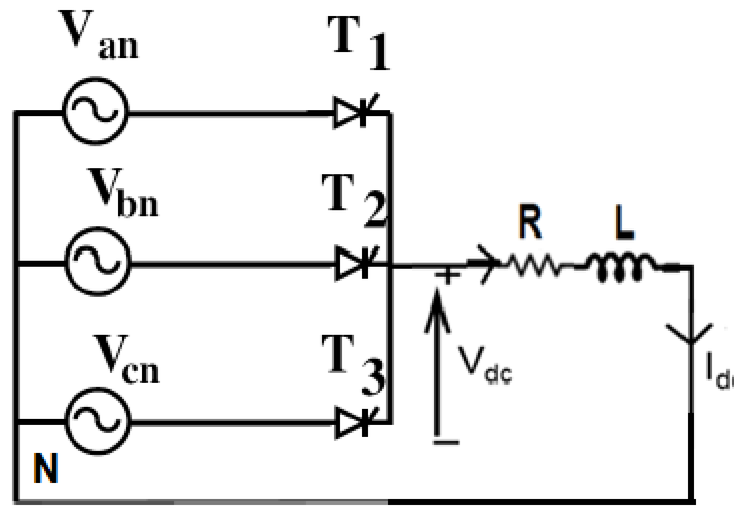
$$I_{dc} = \frac{3}{2\pi \times 5}\left[\sqrt{2}\times 230 \times 1.3874 - 150\times(1.61)\right]$$

$$\therefore I_{dc} = 20.031\,A$$

Three phase half wave controlled converter with R L load

- 3 pulse full controlled converter
- 2 quadrant converter



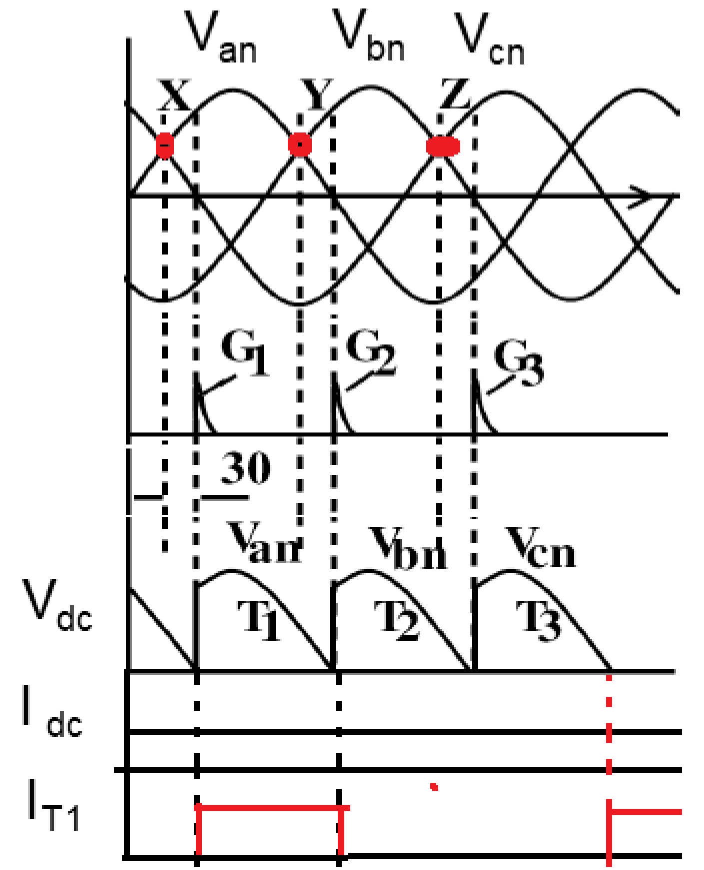


- Quadrant 1=> Rectifier operation
- Quadrant 2=> Inverter operation

Three phase half wave controlled converter with R L load

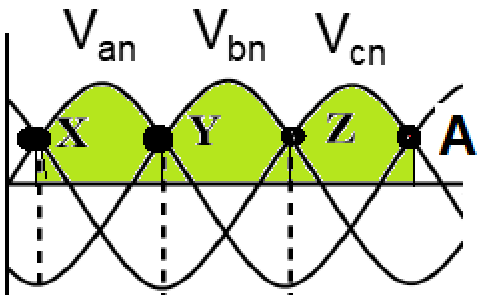
- Rectifier operation
- $0^0<\alpha<90^0$
- Vd(av) = $\frac{3\sqrt{3}\,V_{mp}}{2\,\pi}\cos\alpha$
- Power flow from AC to DC
- Side
- Device conduction =120^0
- DC current is smooth

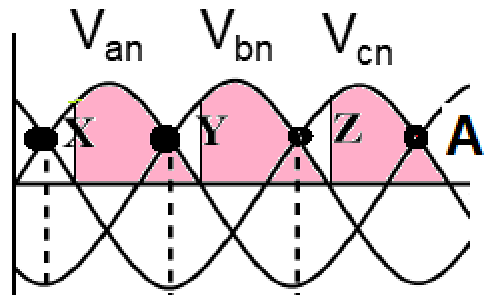
  &ripple free

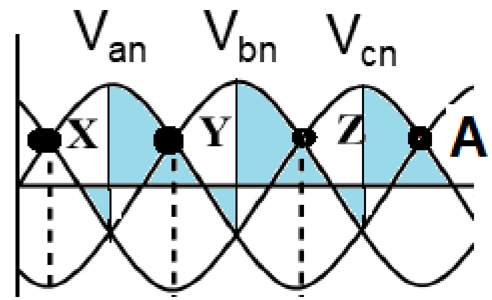


Waveforms with R L load

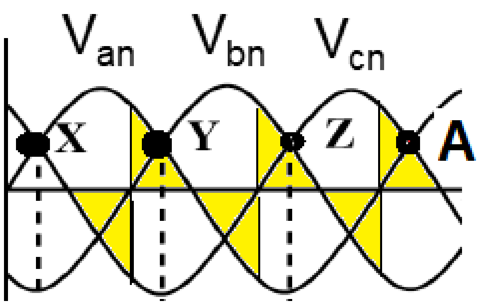
- Voltage waveforms at various α

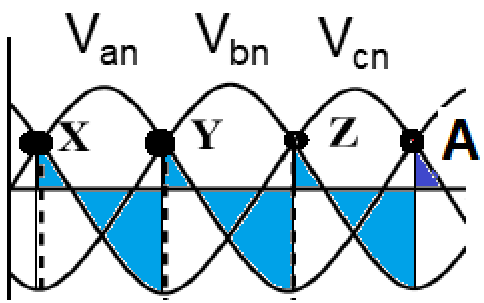


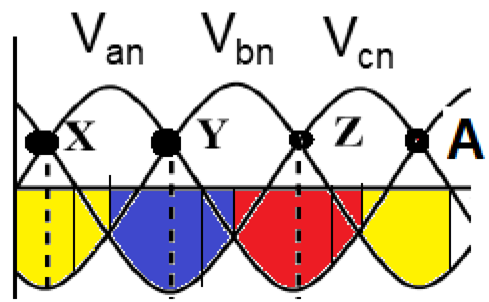




- $\alpha=0^0$ $\alpha=30^0$ $\alpha=60^0$



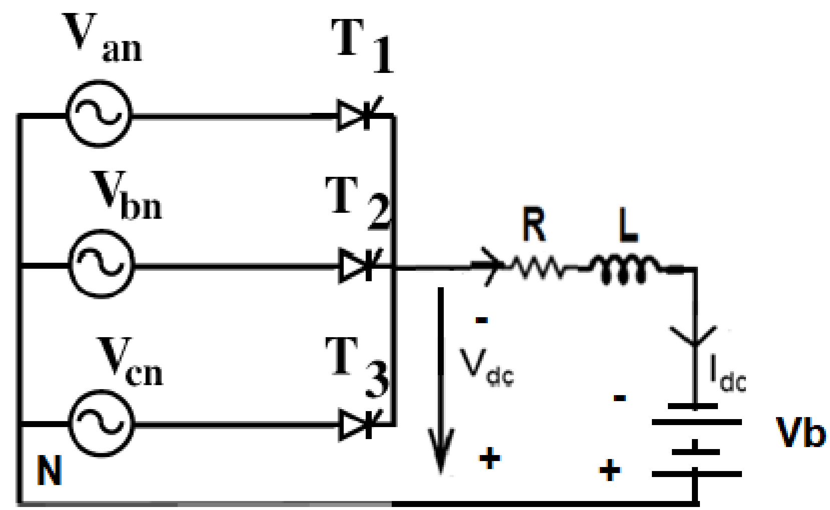




- $\alpha=90^0$ $\alpha = 120^0$ $\alpha = 180^0$

Three phase half wave controlled converter with R L load

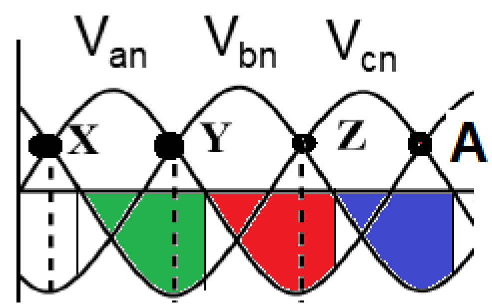
- Inverter operation
- $90^0 < \alpha < 180^0$
- Vd(av) = $\frac{3\sqrt{3}\, V_{mp}}{2\pi} \cos\alpha$
- Power flow from dC to AC
- Side
- Device conduction $=120^0$



- DC current is smooth

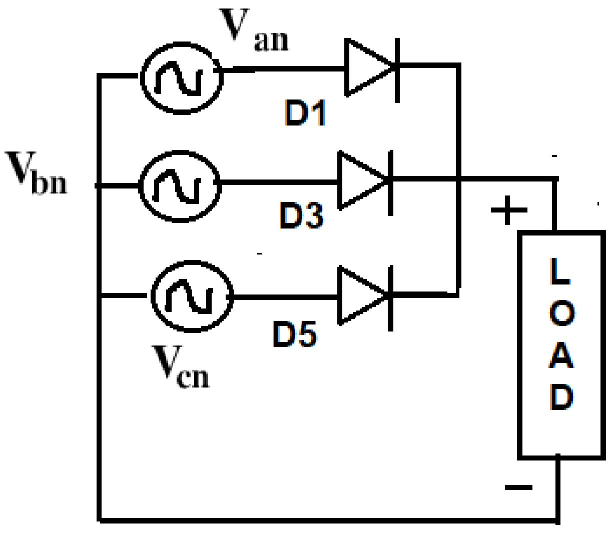
  &ripple free

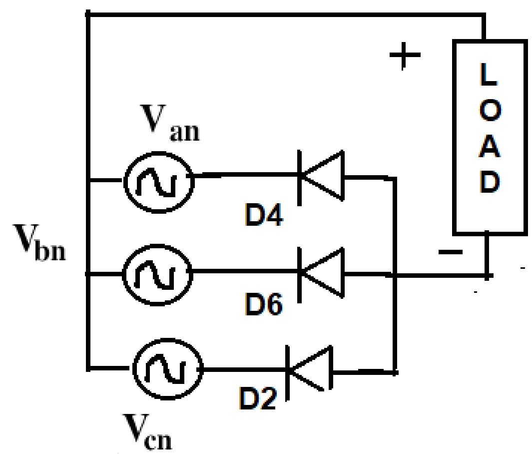
Idc =[Vb – Vdc(av)]/R



3 phase full wave diode bridge

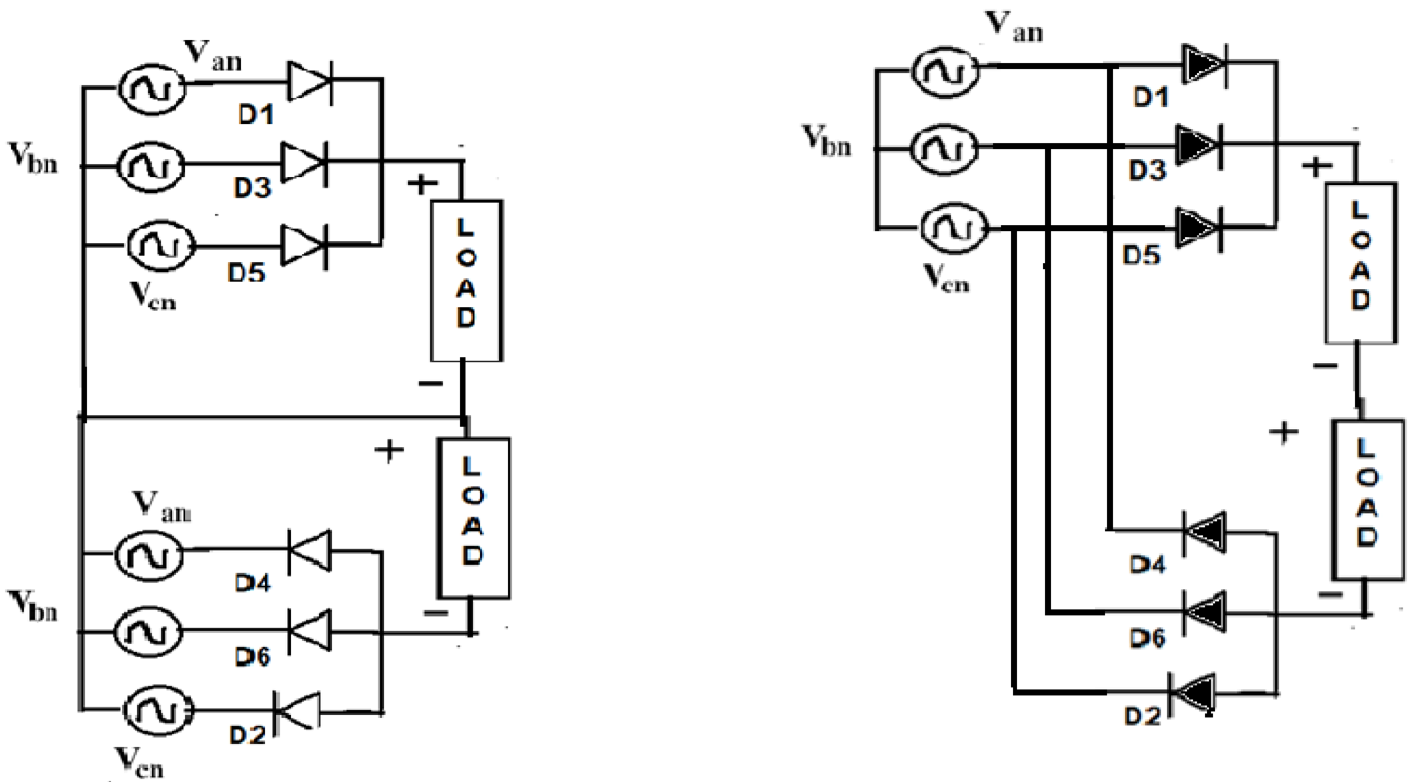
- 3 pulse rectifier





3 phase full wave diode bridge

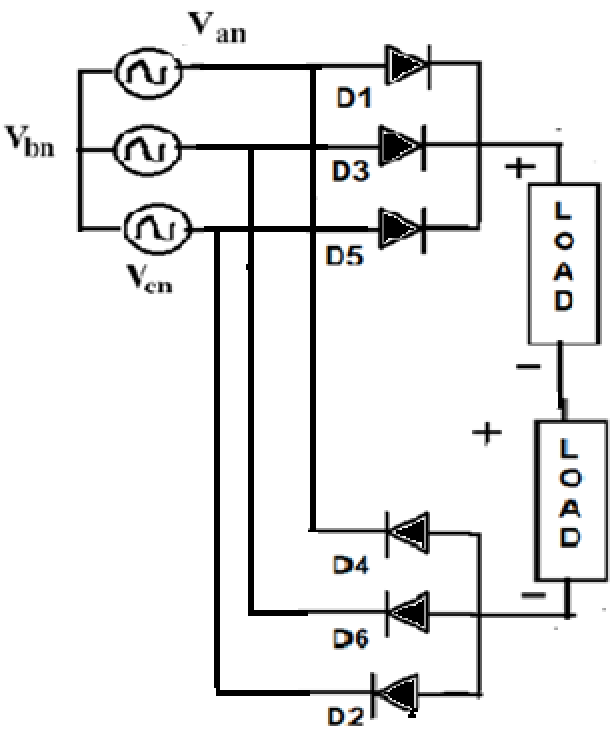
- 6 pulse Rectifier

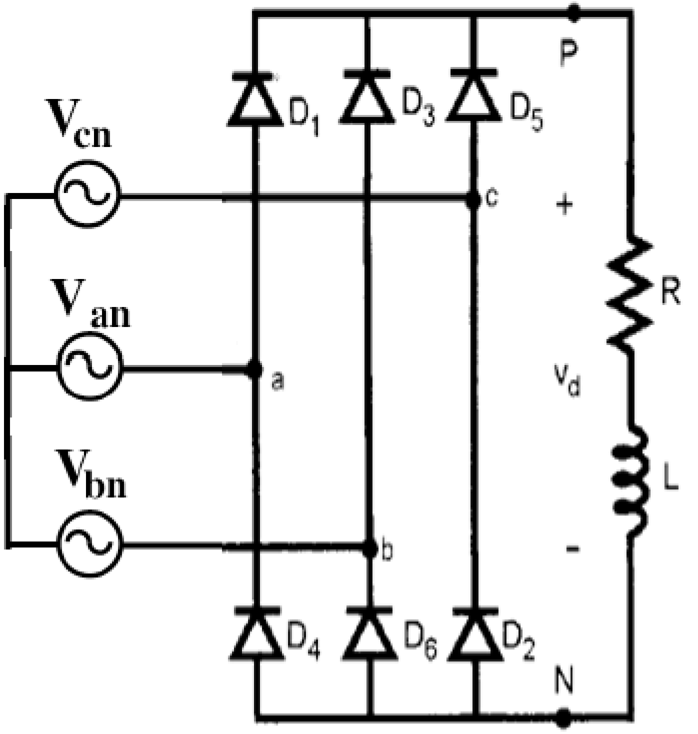


- Outputs is connected in series where as input are connected in parallel

3 phase full wave diode bridge

- 6 pulse Rectifier

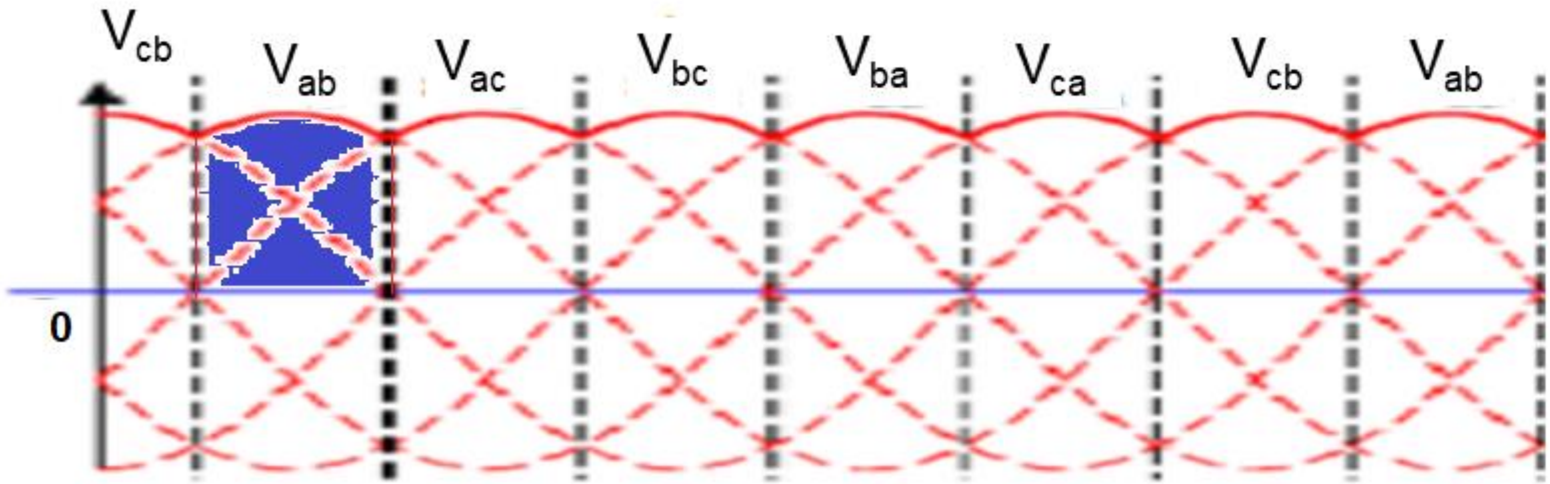




- Outputs is connected in series where as input are connected in parallel

3 phase full wave diode bridge

- 6 pulse rectifier

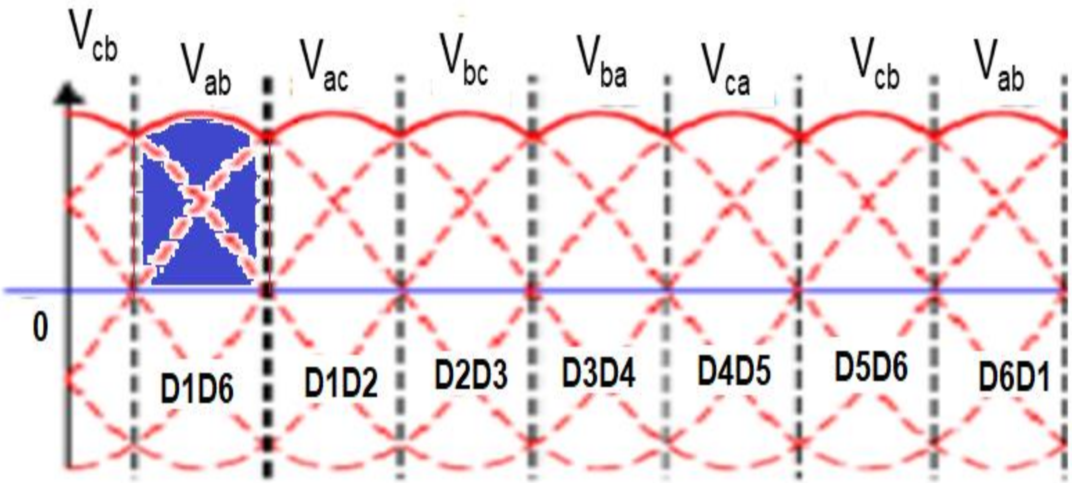


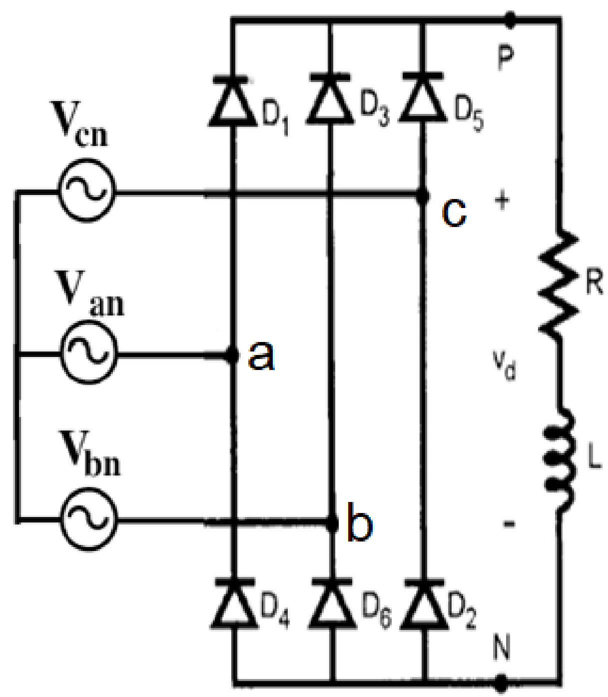
- Draw the three line voltage waveform Vab Vbc and Vca

- Invert Vab Vbc and Vca to obtain Vba Vcb and Vac

3 phase full wave diode bridge

- Devices are named as per conducting sequence

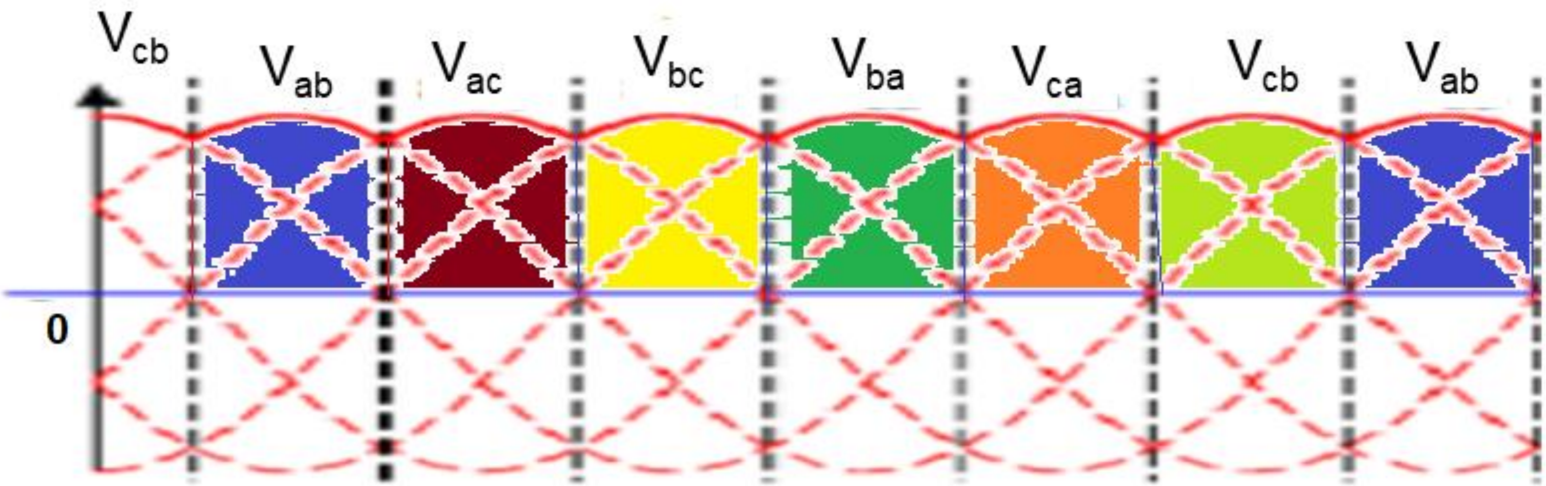




- One device from upper group &
- one device from lower group is on
- Each device conducts for 120^0
-

3 phase full wave diode bridge

- Vdc (av)

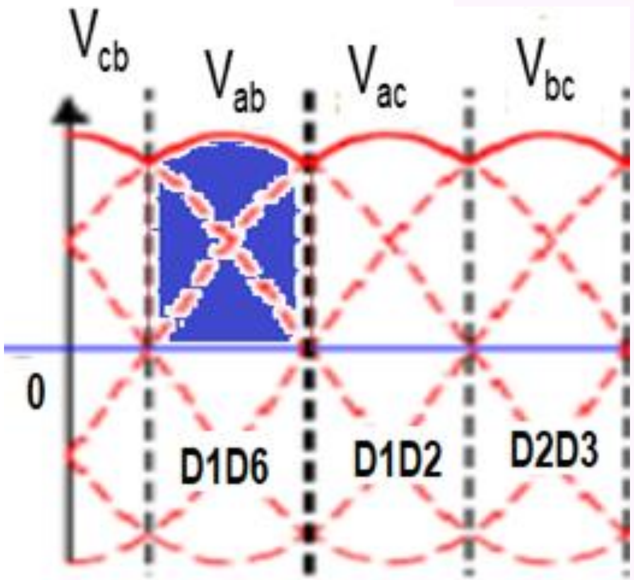


- Vdc(av)= $6/2\pi\int_{60}^{120} V_{ml}\, sin\theta\, d\theta \;=\; \dfrac{3V_{ml}}{\pi}$

- V_{ml} => peak amplitude of line voltage

3 phase full wave diode bridge

- Vdc(rms)



$$V_{dc(rms)} = \left[\frac{6}{2\pi} \int_{60}^{120} V_{ml}^2 \sin^2\theta \cdot d\theta \right]^{1/2}$$

$$= \left[\frac{3V_{ml}^2}{2\pi} \int_{60}^{120} \left(\frac{1-\cos 2\theta}{2} \right) \cdot d\theta \right]^{1/2}$$

$$= \left[\frac{3V_{ml}^2}{2\pi} \left\{ \int_{60}^{120} d\theta - \int_{60}^{120} \cos 2\theta \cdot d\theta \right\} \right]^{1/2}$$

$$= \left[\frac{3V_{ml}^2}{2\pi} \left\{ \theta \Big|_{\pi/3}^{2\pi/3} - \frac{1}{2} \sin 2\theta \Big|_{60}^{120} \right\} \right]^{1/2}$$

3 phase full wave diode bridge

- Vdc (rms)

$$V_{dc(rms)} = \left[\frac{3V_{ml}^2}{2\pi}\left\{\left(\frac{2\pi}{3} - \frac{\pi}{3}\right) - \frac{1}{2}\left(\sin 240 - \sin 120\right)\right\}\right]^{1/2}$$

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

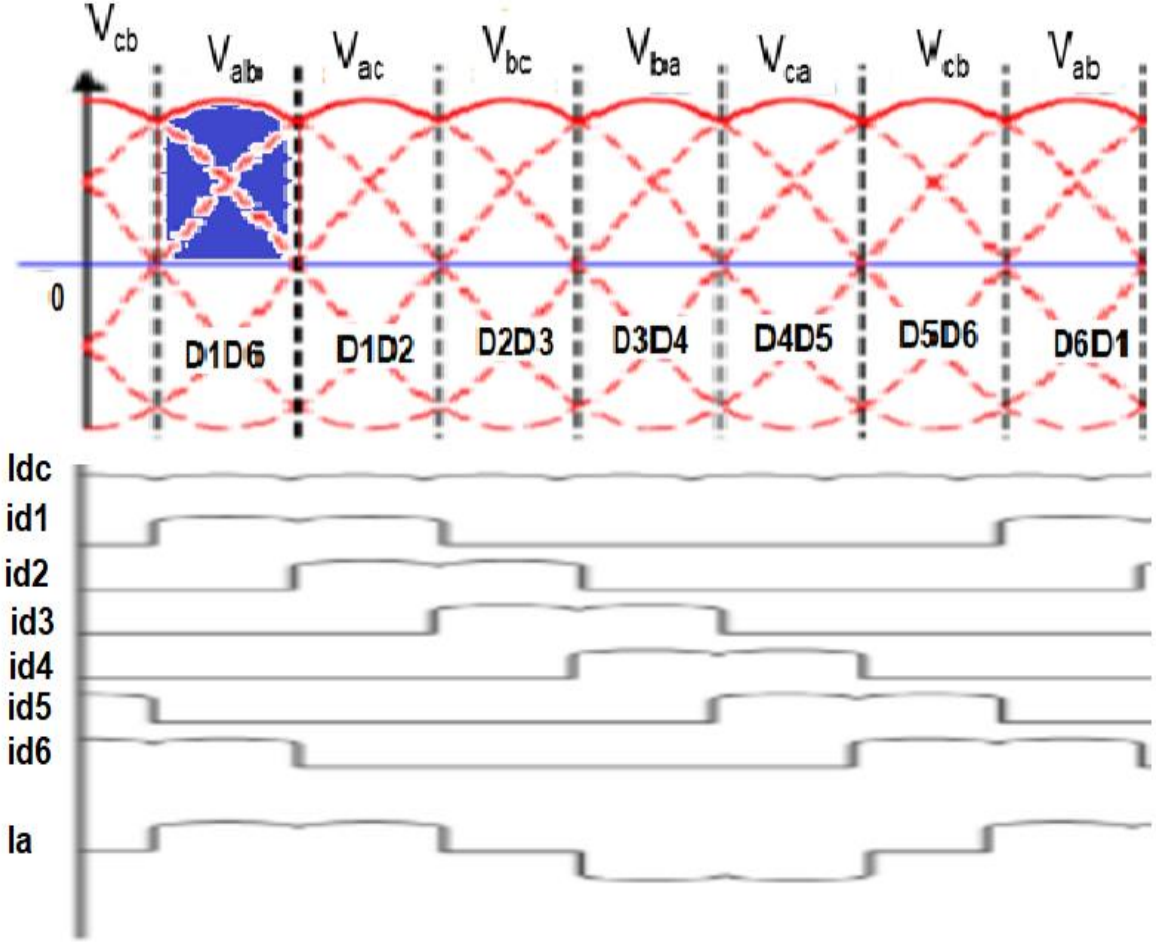
$$= \left[\frac{3V_{ml}^2}{2\pi}\left\{\left(\frac{\pi}{3} + \frac{\sqrt{3}}{2}\right)\right\}\right]^{1/2}$$

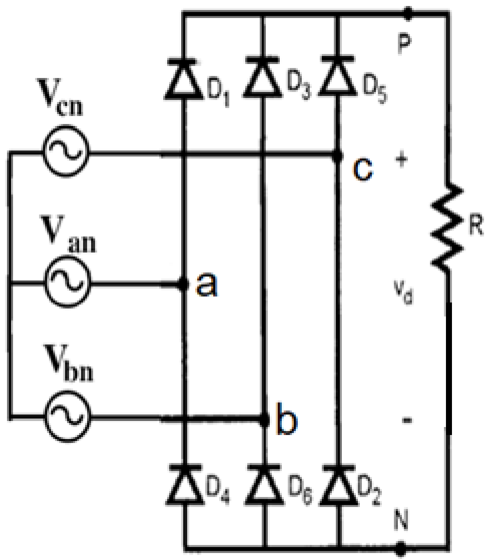
$$V_{dc(rms)} = 0.95577\, V_{ml}$$

3 phase full wave diode bridge

- O/P voltage ripple
- Vdc(av)= 0.95492 Vml
- Vdc(rms)= 0.95577 Vml
- FF=Vdc(rms)/ Vdc(av)= 1.00089
- %ripple =$\sqrt{(FF^2} - 1)$ X100
- % ripple = 4.21%

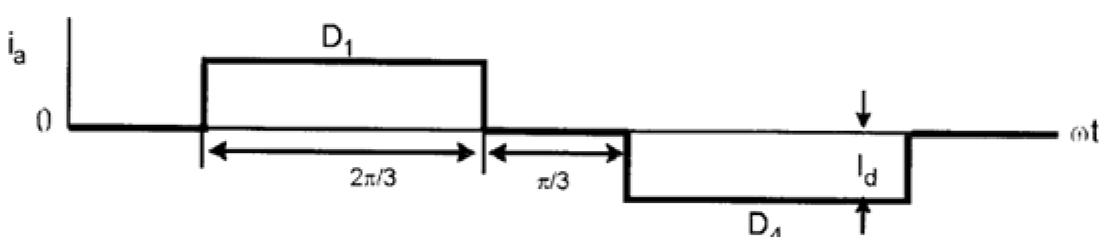
3 phase full wave diode bridge with R load



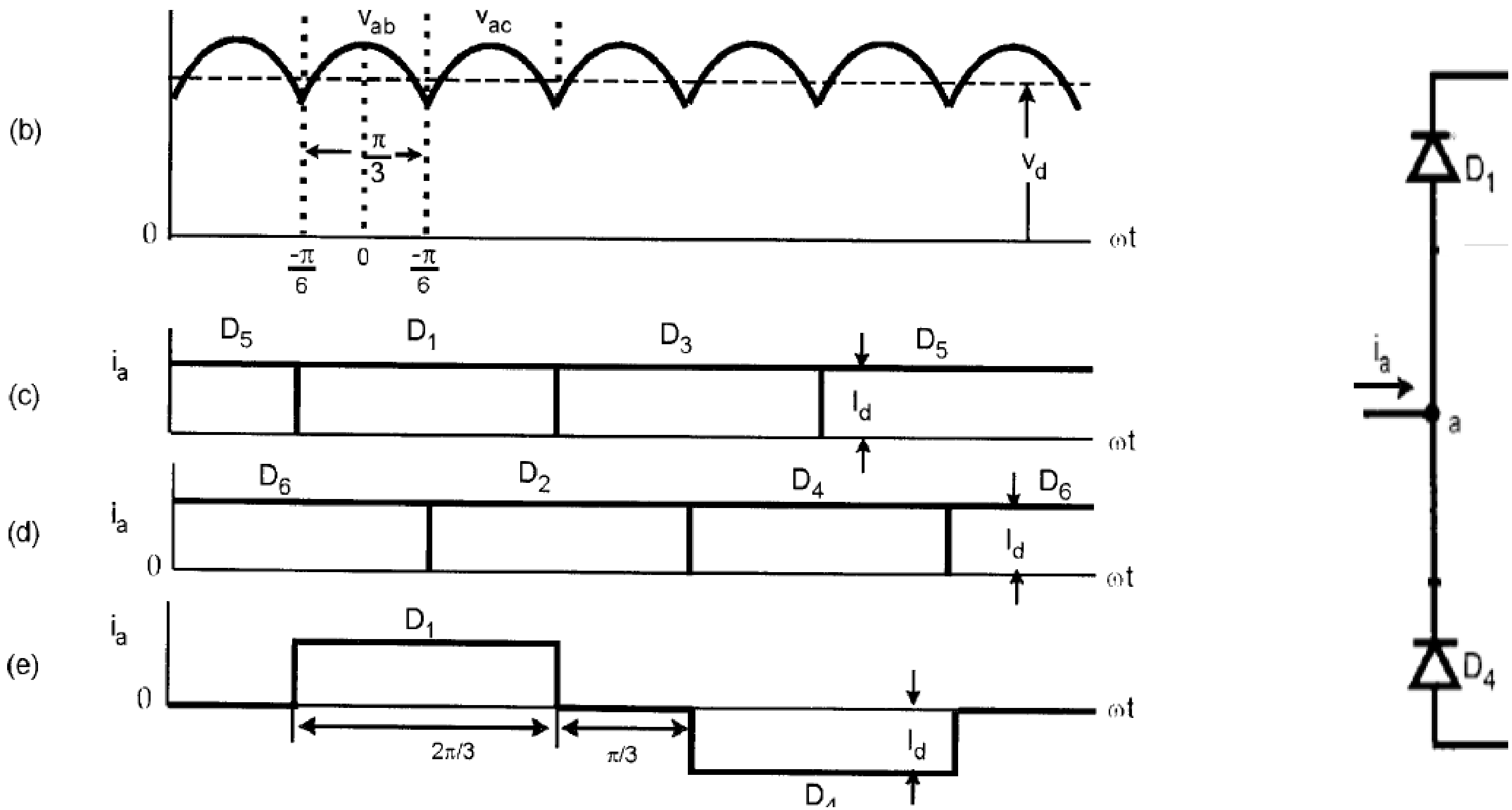


3 phase full wave diode bridge

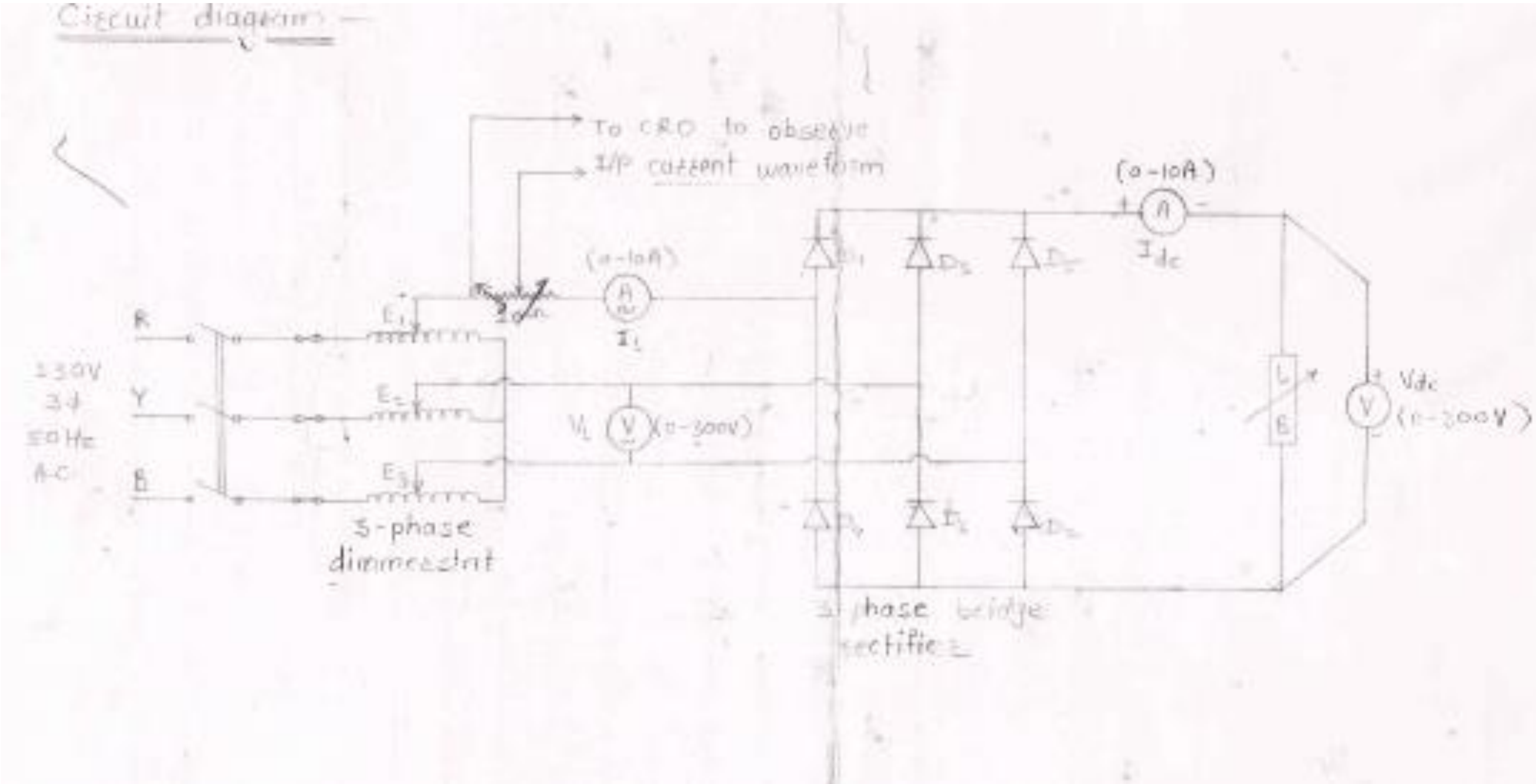
- Salient features for R and RL load
- Load current is continues
- Each device conducts for 120^0
- Names are given as per conducting sequence.
- DC voltage ripple is 4.2%
- Conducting sequence of devices:D1D2D3 D4 D5 D6
- Every pair (D1D2,D2D3,D3D4, D4D5,D5D6, D6D1) conducts for 60^0
- Source current is quasi square wave



Diode bridge with RL load



Voltage and current relationship



3 phase diode bridge

A) Voltage Relationship

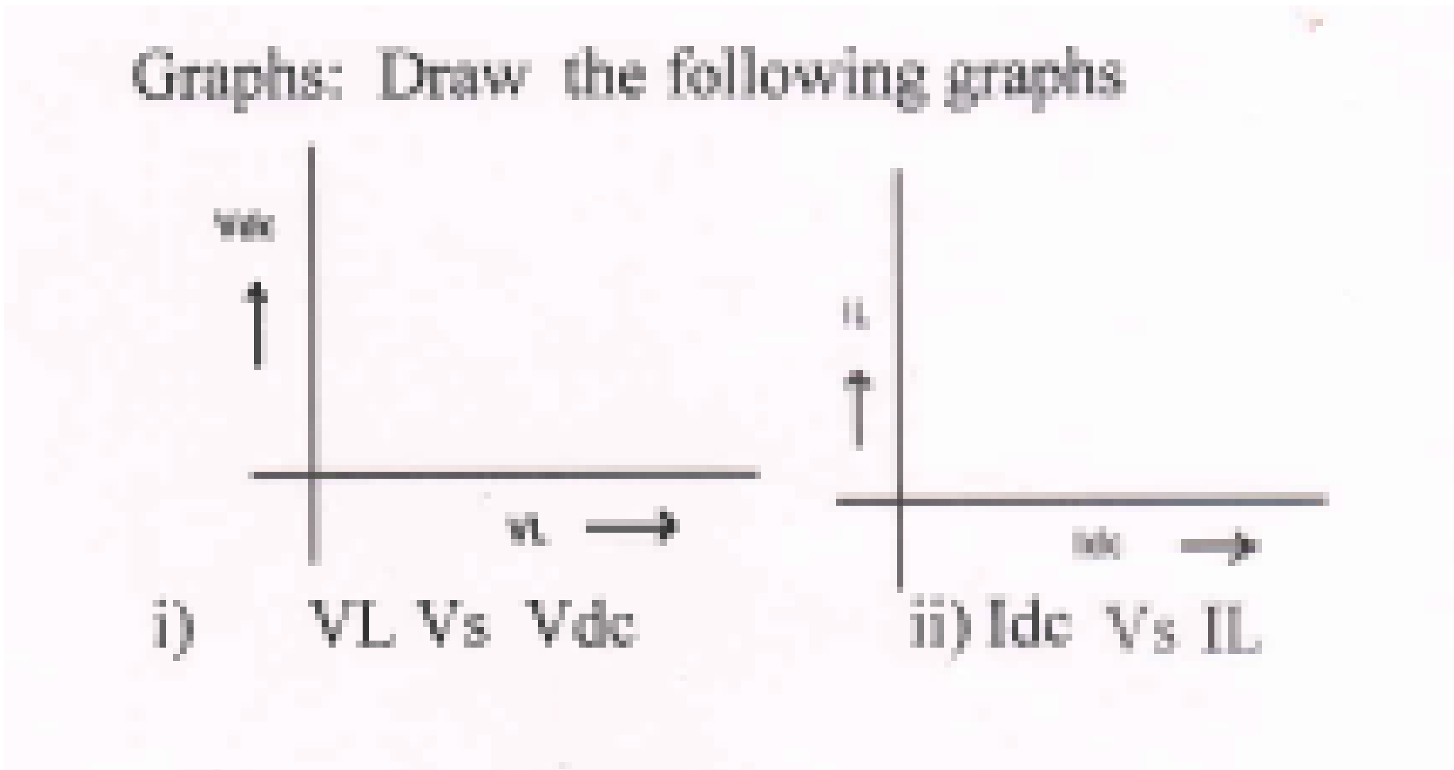
Sr. No	Supply voltage VL	DC Output Voltage Vdc	Supply current IL	DC current Idc	Vdc/ VL	Theritical Vdc/ VL
1						
2						
3						
10						

3 phase diode bridge

B) Current Relationship

Sr. No	Supply voltage VL	DC output Voltage Vdc	Supply current IL	DC current Idc	Idc/ IL	Theritical Idc/ IL
1						
2						
3						
10						

3 phase diode bridge

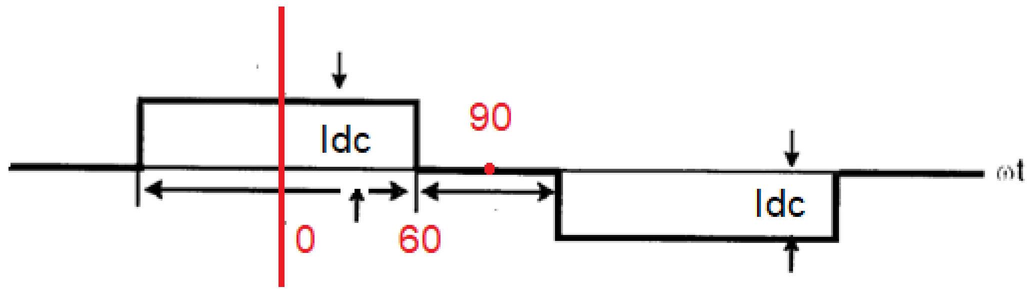


Harmonic spectrum of a waveform

- Procedure
- Determine the RMS value of the waveform.= I
- Determine the peak amplitude of nth harmonic
- Considering quarter wave symmetry
- An=$\frac{8}{2\pi}\int_0^{\pi/2} F(\theta)\cos(n\theta)\,d\theta$
- Where An= peak amplitude of nth Harmonic.
- Determine peak amplitude of fundamental and the RMS value of fundamental = I_1
- $I^2 = I_1^2 + I_h^2$
- %THD =(I_h/I_1) x100

Harmonic spectrum of a waveform

- An=$\frac{8}{2\pi}\int_0^{\pi/2} F(\theta)\cos(n\theta)\,d\theta$



- An=$\frac{8}{2\pi}\int_0^{\pi/3} Idc\cos(n\theta)\,d\theta$
- $A_n = (4/n\pi)\, I_{dc}\sin(n\pi/3)$
- $I^2 = I_1^2 + I_h^2$
- $A_1 = \frac{2\sqrt{3}}{\pi}\ I_{dc}$ $\qquad I_1 = \frac{\sqrt{6}}{\pi} I_{dc}$

Harmonic spectrum of a waveform

- I = RMS value of source current
- $I = \sqrt{(2/3)}\, I_{dc}$ $\qquad I^2h = I^2 - I_1^2$

$$I_h = \sqrt{I^2 - I_1^2}$$

$$I_h = \sqrt{\tfrac{2}{3} I_{dc}^2 - \frac{6}{\pi^2} I_{dc}^2}$$

$$I_h = I_{dc}\sqrt{\tfrac{2}{3} - \frac{6}{\pi^2}}$$

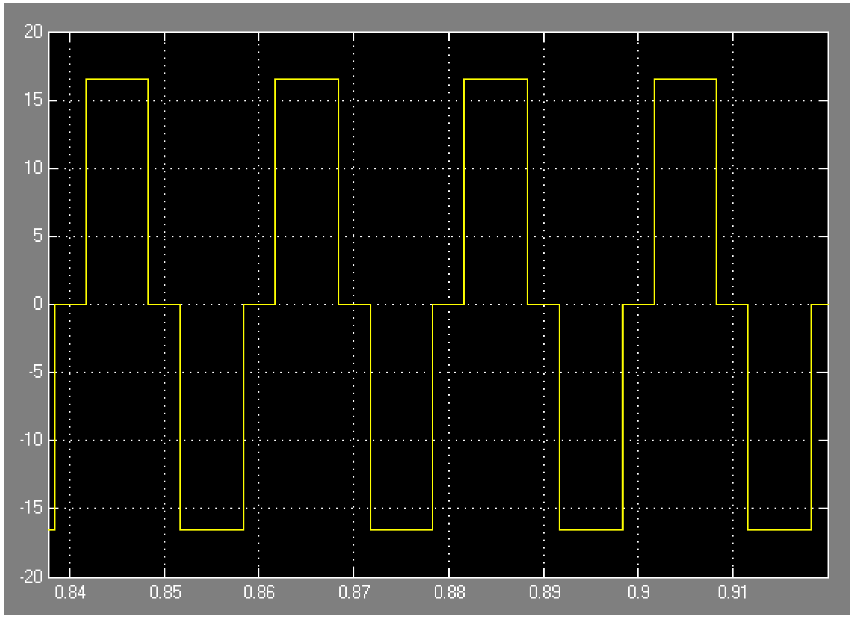
$$I_h = 0.24236\, I_{dc}$$

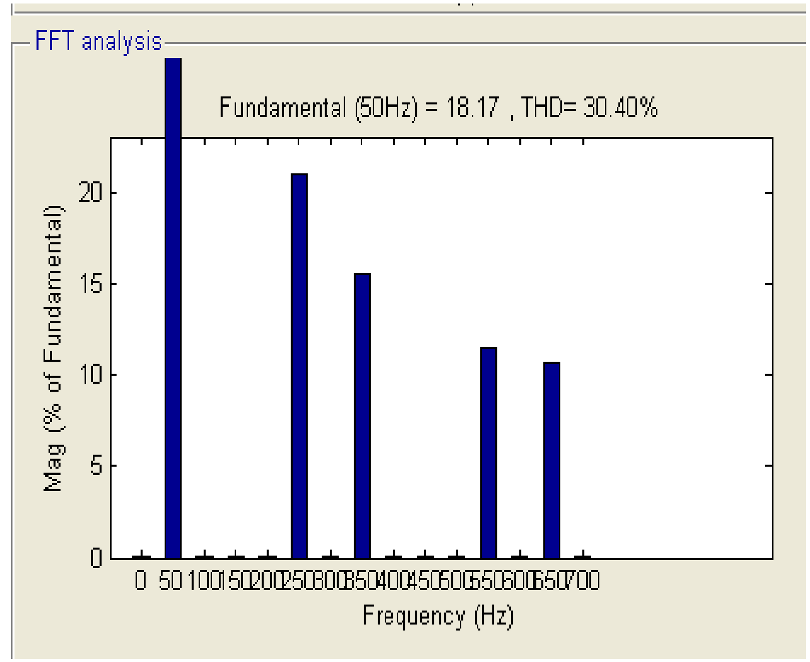
$$\%\ THD = \frac{I_h}{I_1} \times 100$$

$$= \frac{0.24236\, I_{dc}}{\frac{\sqrt{6}}{\pi} \cdot I_{dc}} \times 100$$

$$\%\ THD = 31.08\%$$

Three phase diode Bridge- RL Load



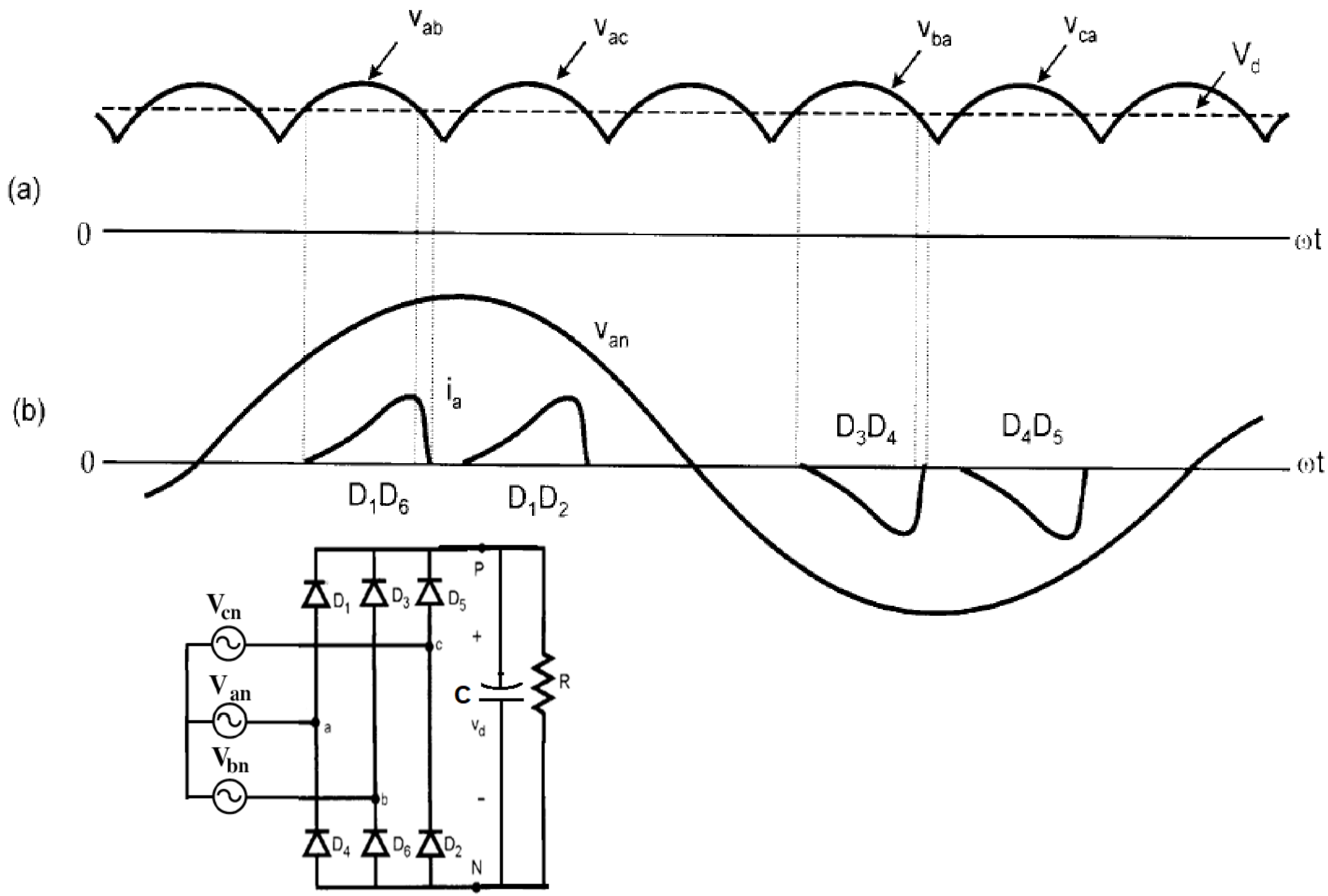


- Peak value of harmonic component
- $A_n = (4/n\pi)\ I_{dc}\ \sin(n\pi/3)$
- All odd harmonics except tripplen harmonics, (6m+1 & 6m-1)

$\%THD = (I_h / I_1) X\ 100$

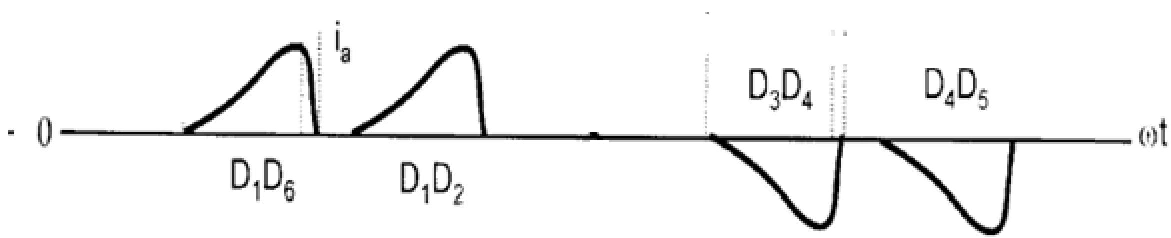
THD in current = 30.40%

Three phase diode bridge -RC load



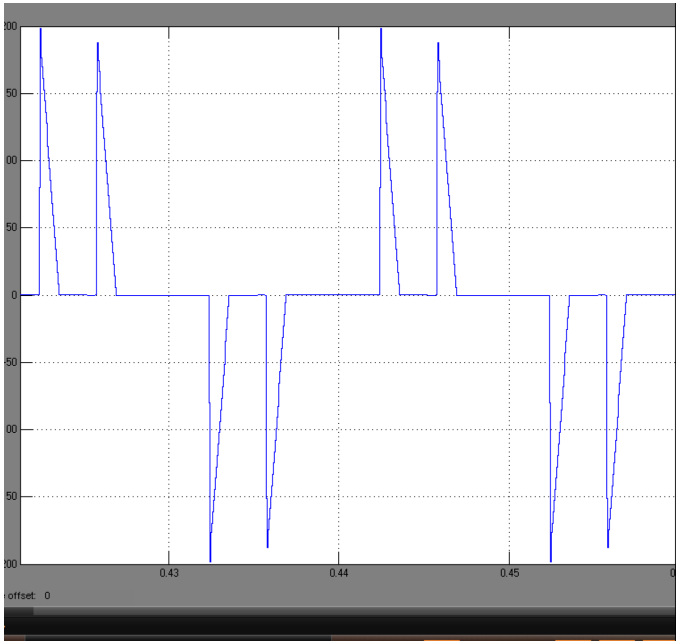
Three phase diode bridge -RC load

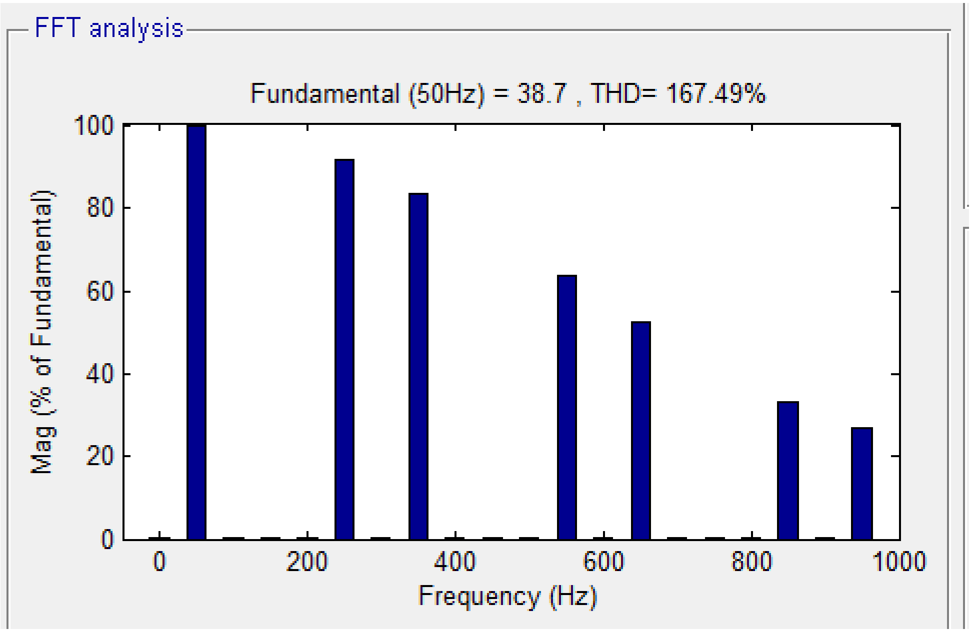
- Salient features for RC load
- Capacitor is used to remove voltage ripple
- Due to capacitor voltage, conduction period of each device is less than 120^0
- Every pair (D1D2,D2D3,D3D4, D4D5,D5D6, D6D1) conducts for less than 60^0
- Source current : Harmonic spectrum is same as



Diode bridge with RC parallel load

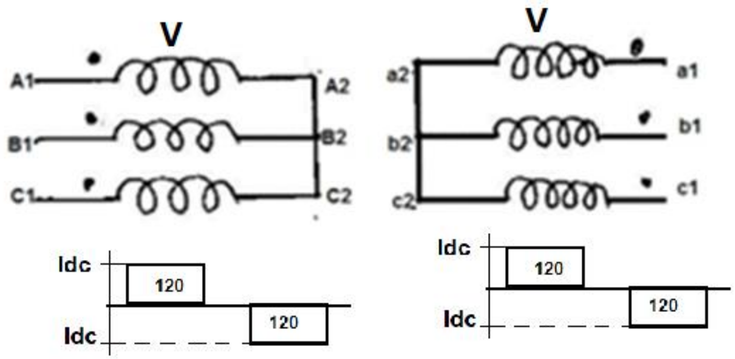
- Source current





3 phase diode bridge

- Transformer utilization factor



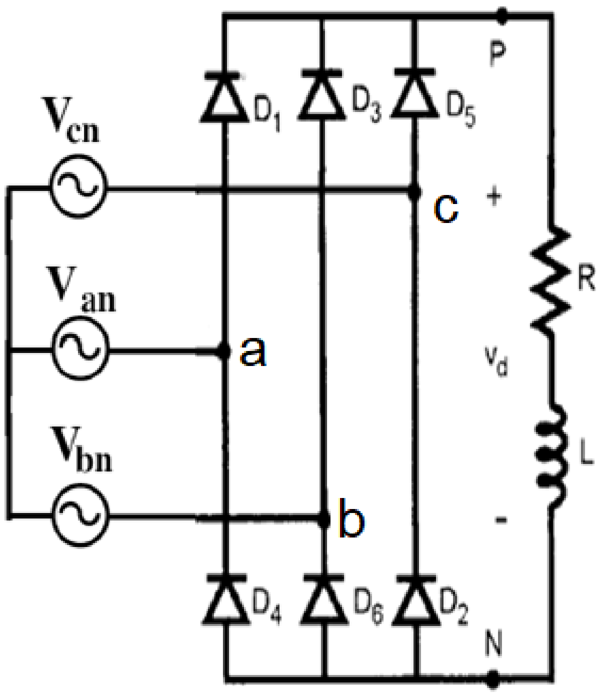
- Transformer primary and secondary currents are quasi square wave
- Idc = $\sqrt{\frac{2}{3}}\, Idc$
- Vdc= (3/π)vml = (3/π) $\sqrt{6}\;\; V \;\Rightarrow\;\; V = \;\; (Vdc\;\; \pi)/3\sqrt{6}$

3 phase diode bridge

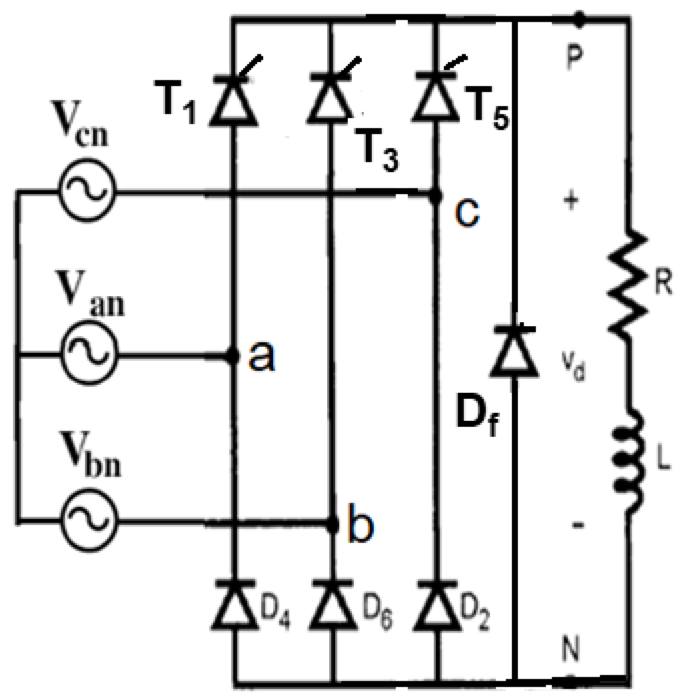
- VA rating of the transformer
- 3 V I =[3 $(Vdc\ \ \pi)/3\sqrt{6}$]$\sqrt{\frac{2}{3}}\ Idc$
- VA rating = (π/3) Vdc Idc = 1.047 Vdc Idc
- TUF = (Vdc Idc)/ VA rating of transformer
- TUF = 3/π = 0.954 Vdc Idc

Three phase controlled converter

- Single quadrant converter
- Uncontrolled

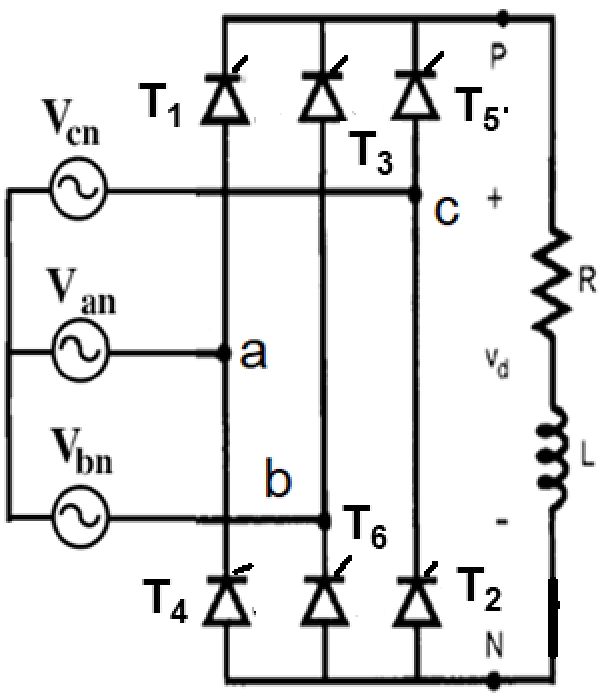


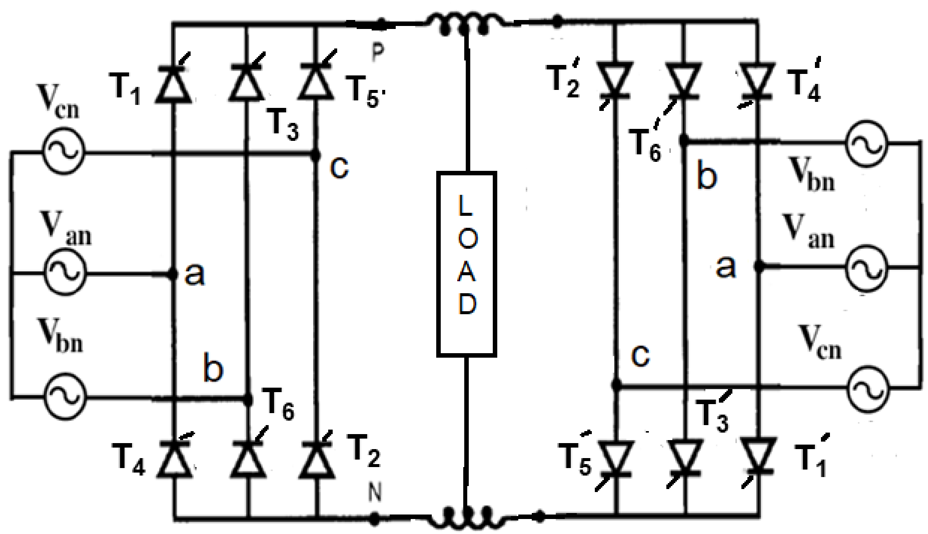
Controlled



Three phase controlled converter

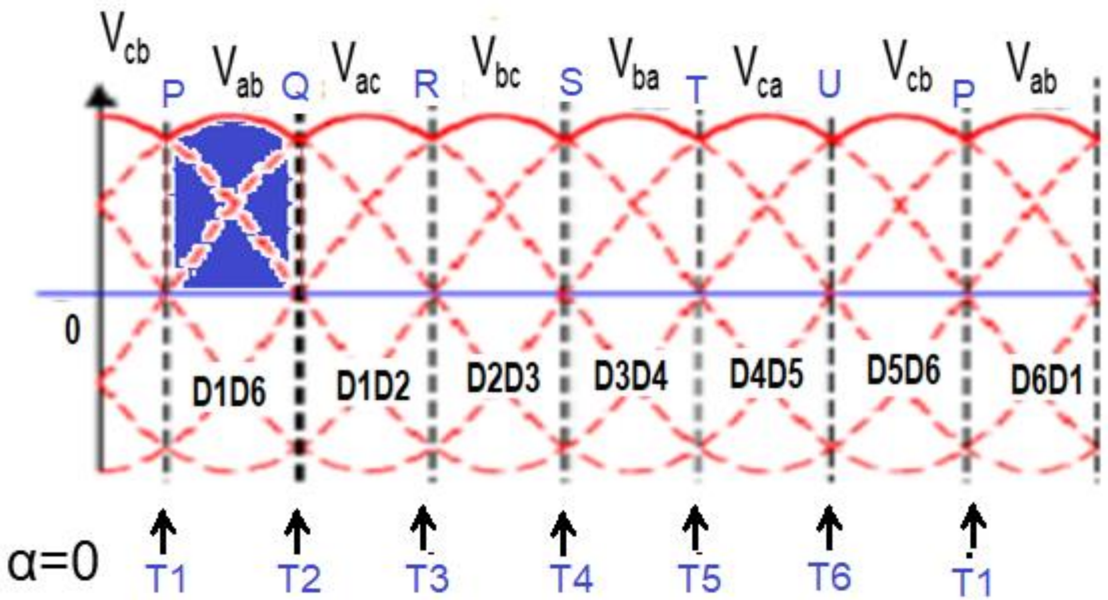
- Full controlled converter
- Two quadrant — Four quadrant
- 6 pulse full controlled converter — 6 pulse dual converter

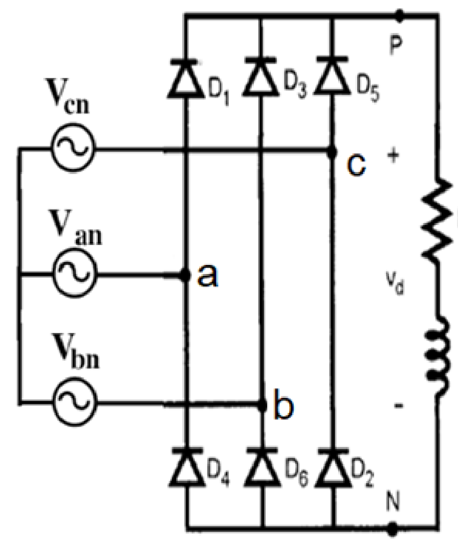


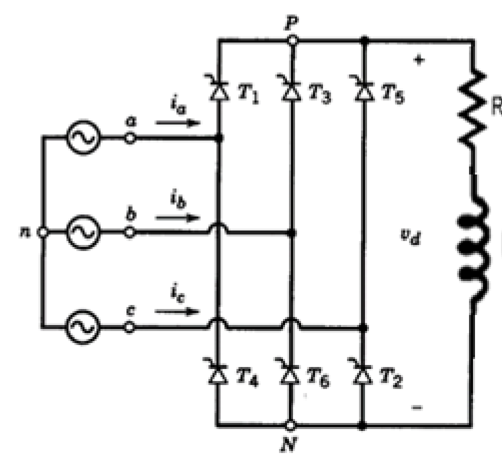


6 pulse full controlled converter

- From where to measure α



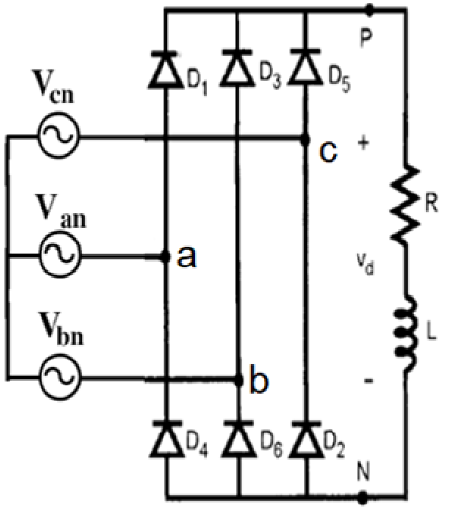


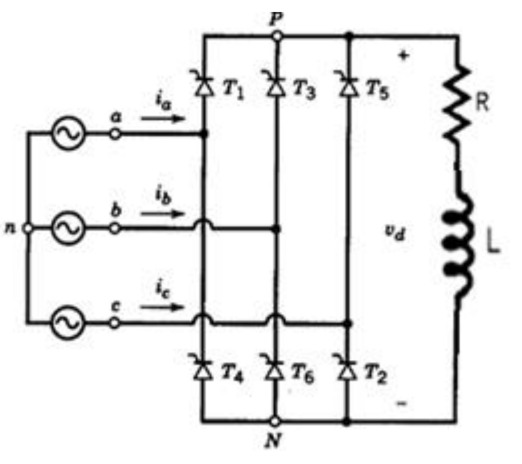


- What is voltage waveform of 6 pulse full controlled converter when α=0

6 pulse full controlled converter RL load

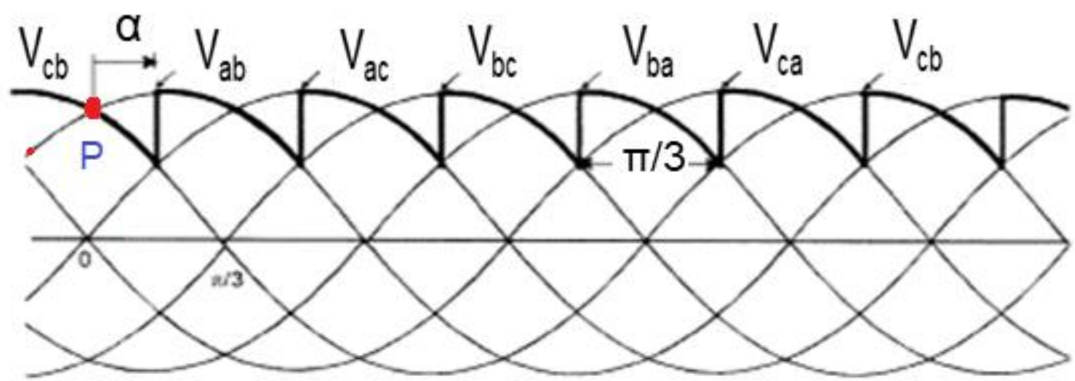
- Firing angle =0 => Three phase diode bridge
- Range of Firing angle => 0 to 180^0
- Each device conducts for 120
- Converter and Inverter operation
- Positive source current for 120 degree and negative current for 120 degree π/3





6 pulse converter O/P voltage waveform

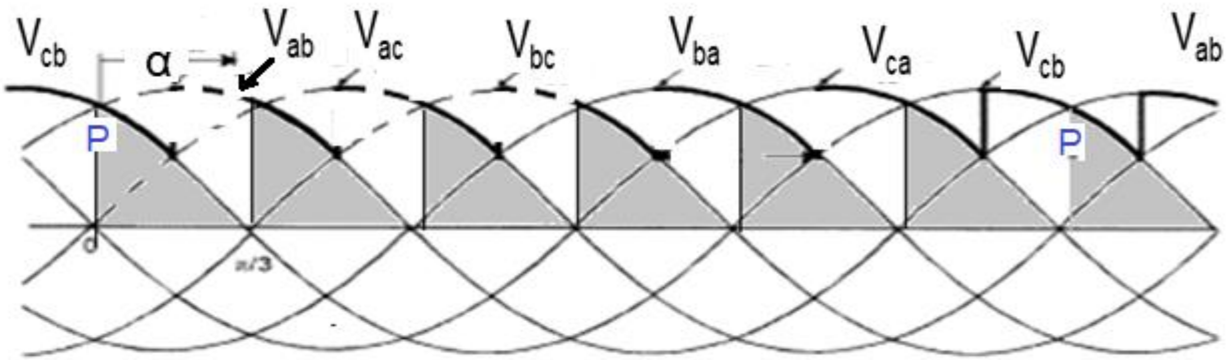
- $\alpha = 30^0$

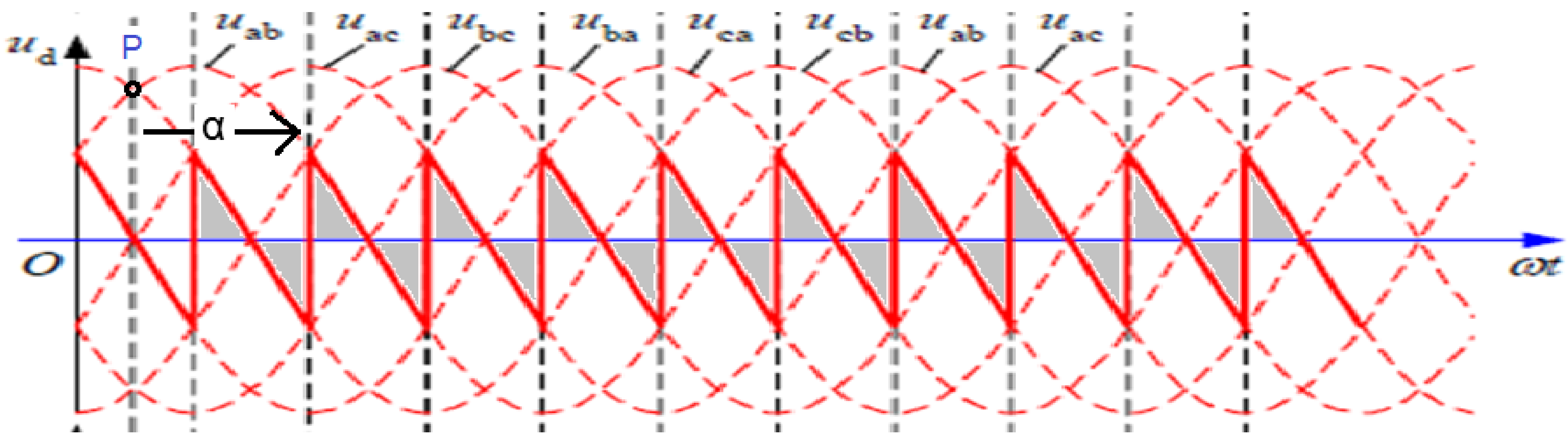


- Draw three line voltages and inverted line voltages
- Determine position of α=0
- Mark the α on the line voltage
- Trace the same waveform for next 60^0

6 pulse converter with RL Load

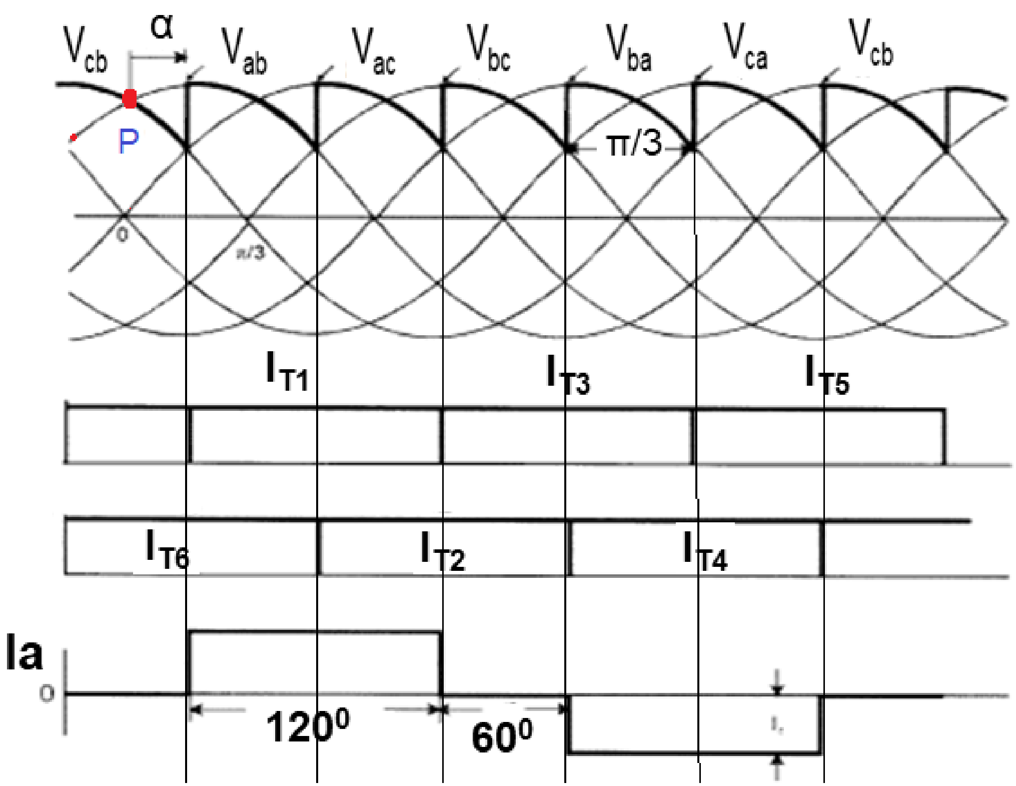
- I) α = 60⁰ and α =90⁰

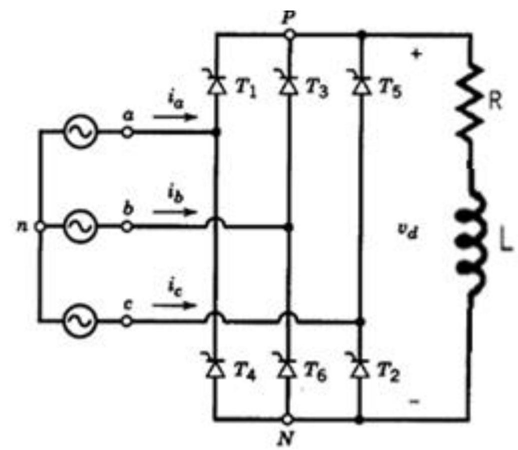




6 pulse converter with RL Load

Output voltage and source current waveforms at α=30 degree

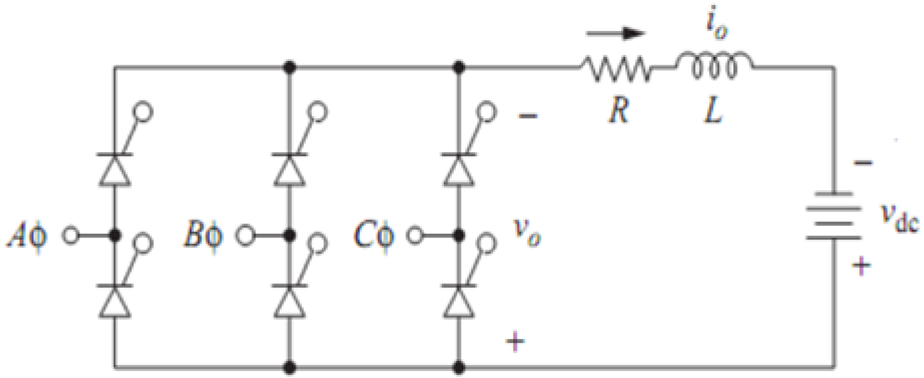


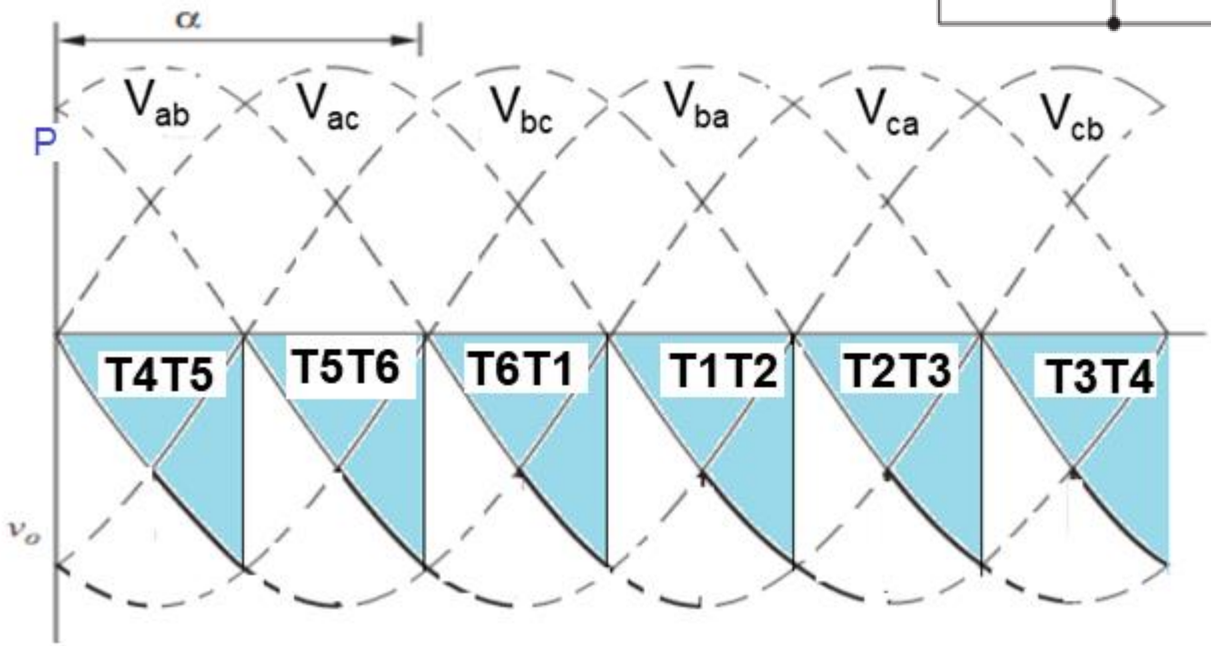


Current THD is same as diode bridge THD= 30.40%

6 pulse converter with RL Load

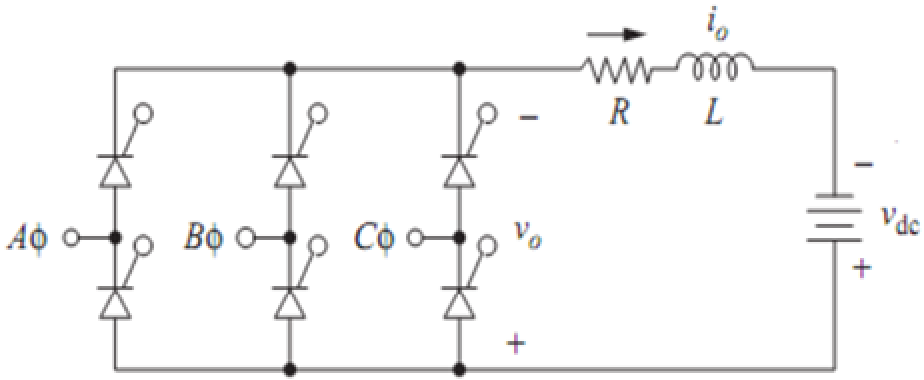
- firing angle α=120



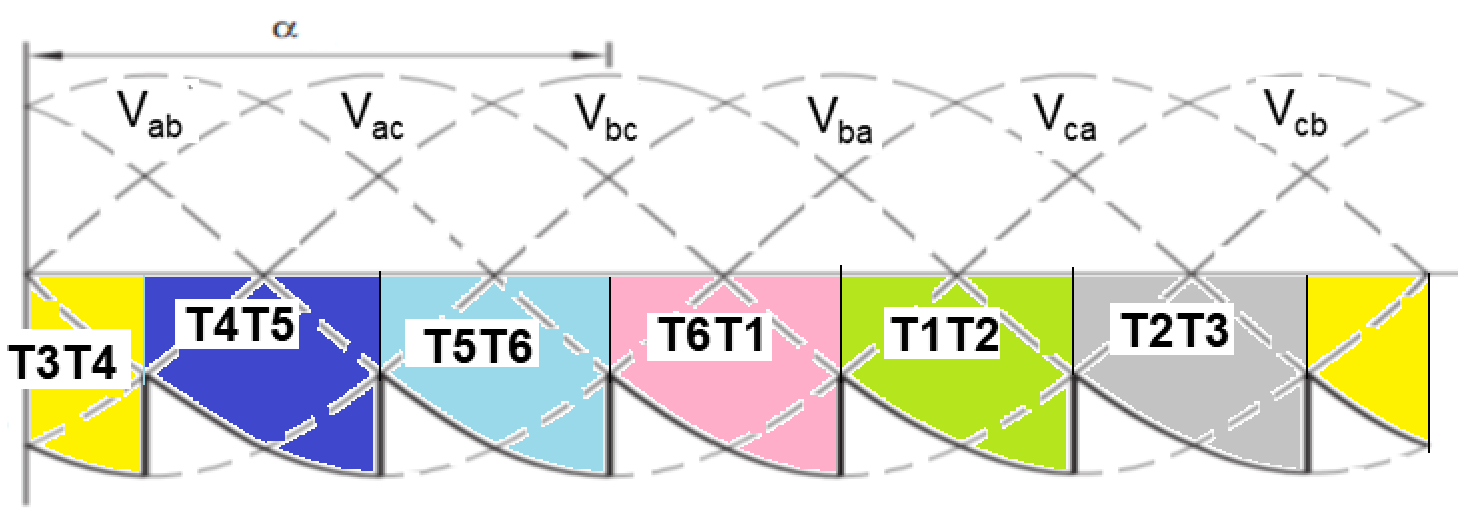


6 pulse converter with RL Load

- Inverter operation :$\alpha = 150^0$

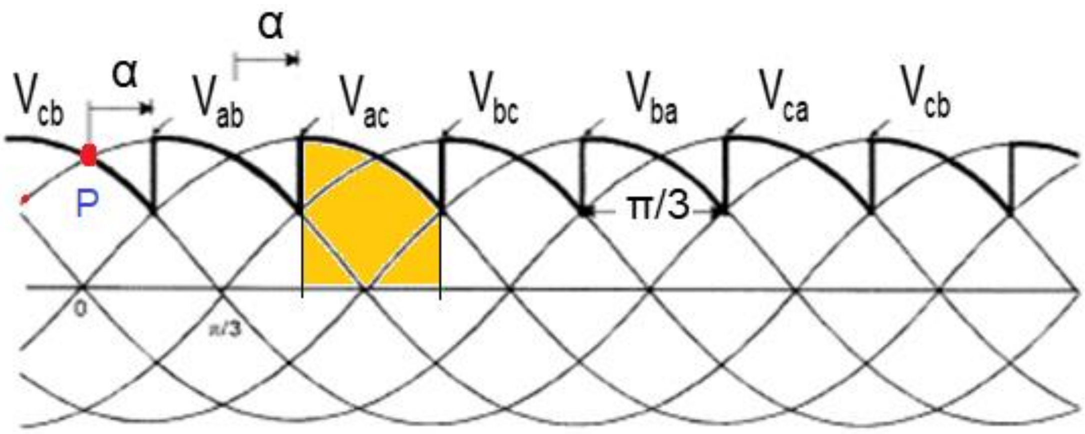


Wave shape of source current remains same for rectifier and inverter operation



6 pulse converter with RL Load

- DC O/P voltage



- Vdc(av) $=\frac{6}{2\pi}\int_{60+\alpha}^{120+\alpha} Vml\ sin\theta\ d\theta$
- V_{ml} is peak value of line voltage

6 pulse converter with RL Load

$$V_{dc(av)} = \frac{6}{2\pi} \int_{60+\alpha}^{120+\alpha} V_{mL} \sin\theta \cdot d\theta$$

$$V_{dc(av)} = \frac{3V_{mL}}{\pi} \int_{60+\alpha}^{120+\alpha} \sin\theta \cdot d\theta$$

$$V_{dc(av)} = \frac{3V_{mL}}{\pi} \Big[-\cos\theta\Big]_{60+\alpha}^{120+\alpha}$$

$$V_{dc(av)} = \frac{3V_{mL}}{\pi} \Big[-\cos(120+\alpha) + \cos(60+\alpha)\Big]$$

$$V_{dc(av)} = \frac{3V_{mL}}{\pi} \Big[(-\cos 120 \cdot \cos\alpha + \sin 120 \cdot \sin\alpha)$$

$$+ (\cos 60 \cdot \cos\alpha - \sin 60 \sin\alpha)$$

6 pulse converter with RL Load

$$V_{dc(av)} = \frac{3V_{mL}}{\pi}\left[(-\cos 120 \cdot \cos\alpha + \sin 120 \cdot \sin\alpha) + (\cos 60 \cdot \cos\alpha - \sin 60 \sin\alpha)\right]$$

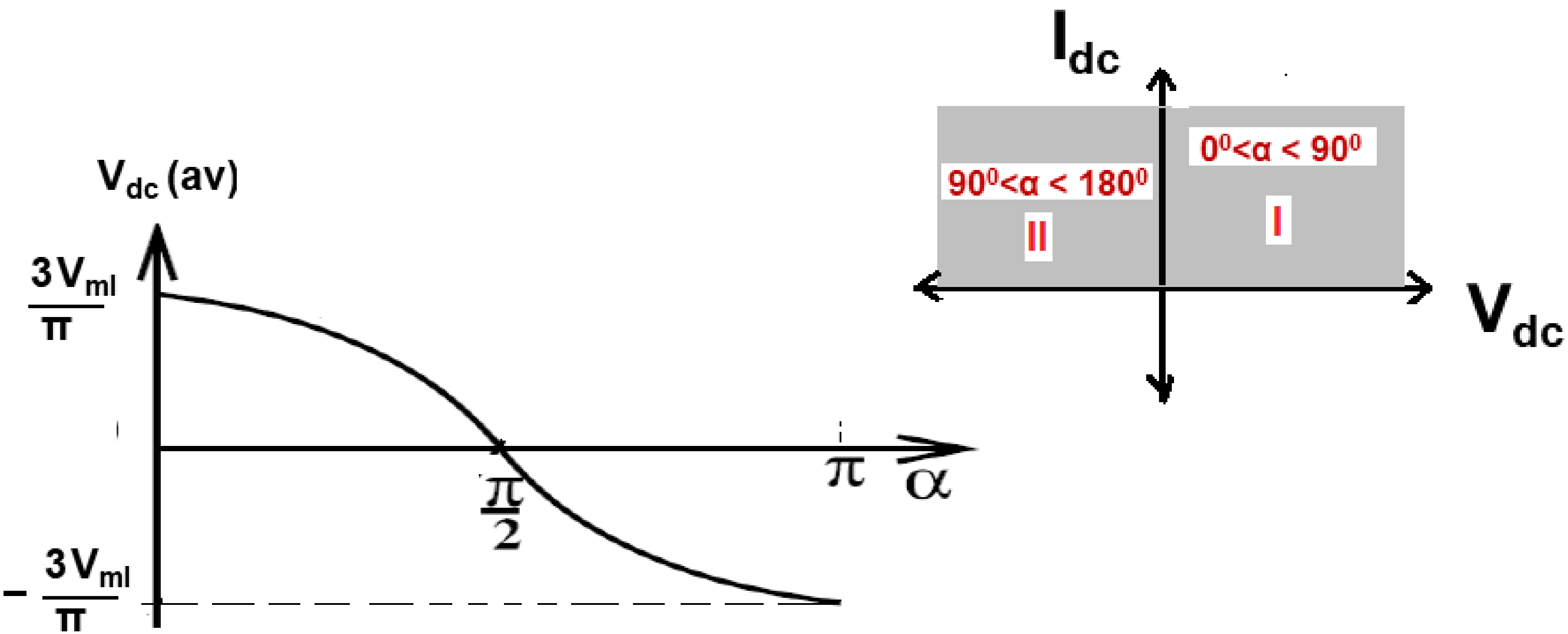
$$V_{dc(av)} = \frac{3V_{mL}}{\pi}\left[-\cos 120 \cos\alpha + \cos 60 \cos\alpha\right]$$

$$V_{dc(av)} = \frac{3V_{mL}}{\pi}\left[0.5\cos\alpha + 0.5\cos\alpha\right]$$

$$V_{dc(av)} = \frac{3V_{mL}}{\pi}\cos\alpha$$

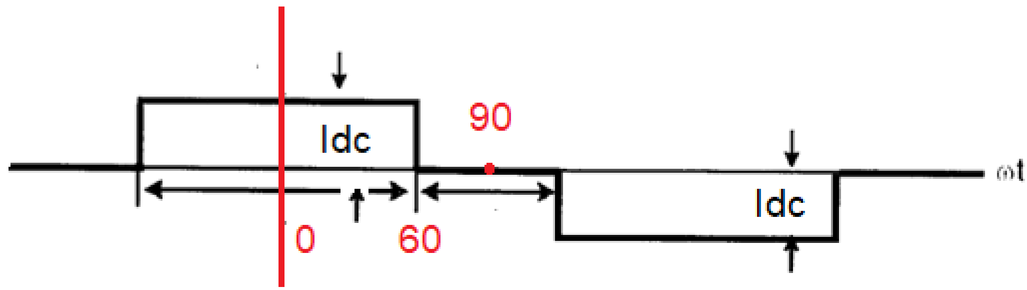
6 pulse converter with RL Load

- Rectifier and Inverter operation



Harmonic spectrum of a waveform

- An=$\frac{8}{2\pi}\int_0^{\pi/2} F(\theta)\cos(n\theta)\, d\theta$



- An=$\frac{8}{2\pi}\int_0^{\pi/3} \ Idc\cos(n\theta)\, d\theta$
- A_n= (4/nπ) I_{dc} sin(nπ/3)
- $I^2=I_1^{\ 2}+I_h^{\ 2}$
- $A_1 = \frac{2\sqrt{3}}{\pi}\ I_{dc}$ $\qquad I_1 = \frac{\sqrt{6}}{\pi} I_{dc}$

Harmonic spectrum of a waveform

- I = RMS value of source current
- $I = \sqrt{(2/3)}\, I_{dc}$ $\qquad I^2h = I^2 - I_1^2$

$$I_h = \sqrt{I^2 - I_1^2}$$

$$I_h = \sqrt{\tfrac{2}{3} I_{dc}^2 - \tfrac{6}{\pi^2} I_{dc}^2}$$

$$I_h = I_{dc}\sqrt{\tfrac{2}{3} - \tfrac{6}{\pi^2}}$$

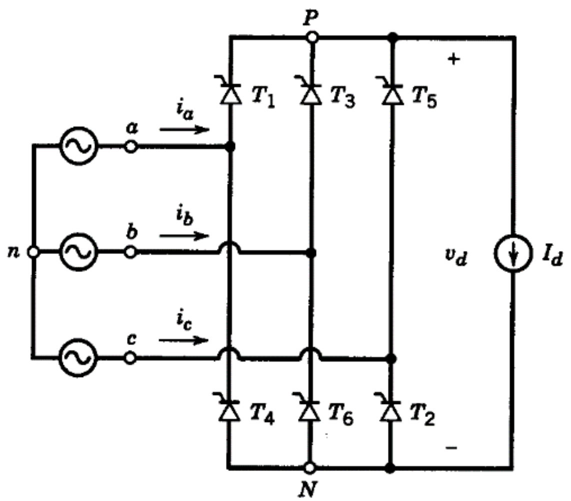
$$I_h = 0.24236\, I_{dc}$$

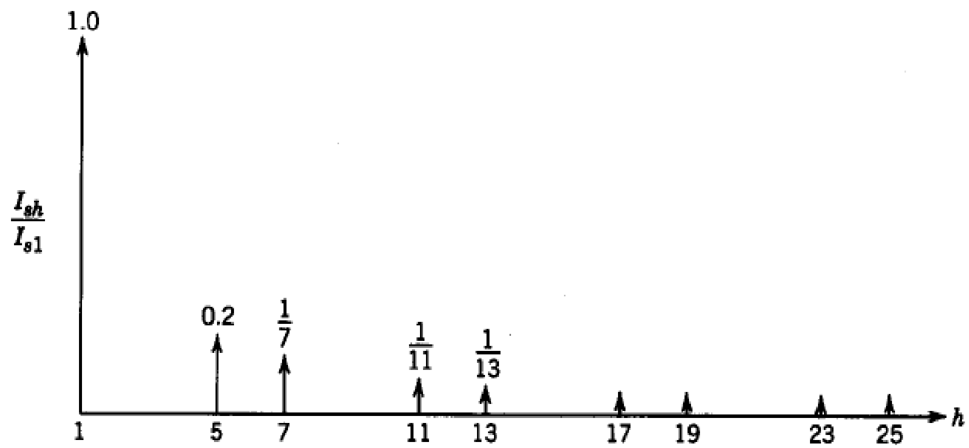
$$\%\ THD = \frac{I_h}{I_1} \times 100$$

$$= \frac{0.24236\, I_{dc}}{\frac{\sqrt{6}}{\pi} I_{dc}} \times 100$$

$$\%\ THD = 31.08\%$$

6 pulse converter with RL Load

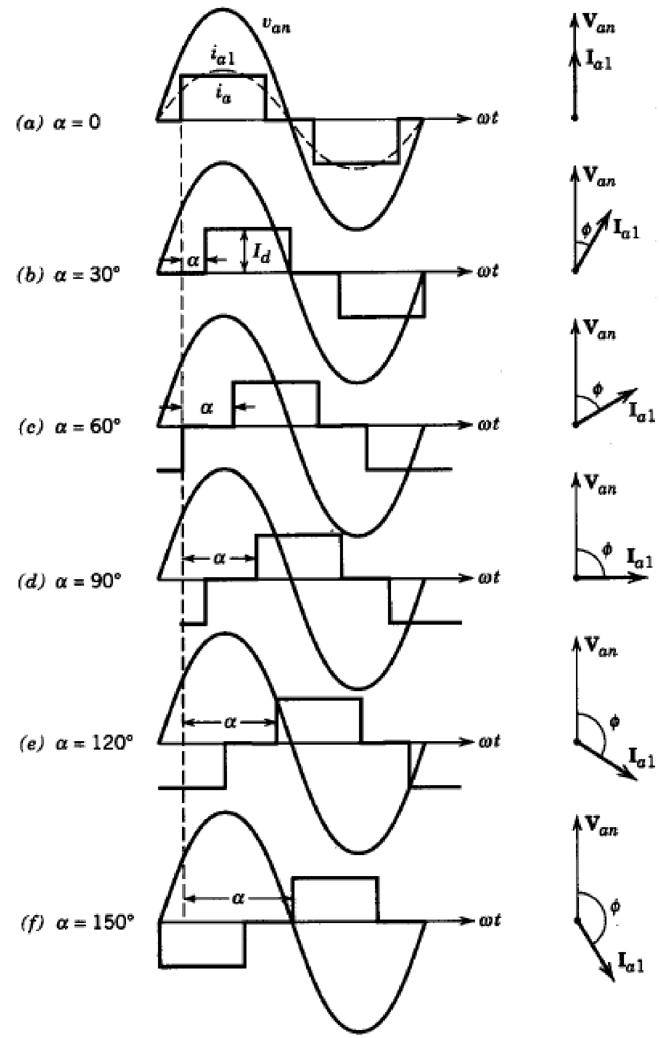
- Each device conducts for 120 degree.
- Positive source current for 120 degree and negative current for 120 degree
- harmonic spectrum 6m+1 and 6m-1 harmonics
- 



6 pulse converter with RL Load

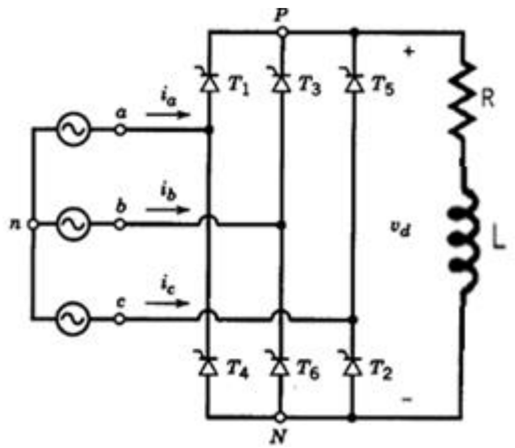
Important Features

- Harmonic spectrum remains Same
- Fundamental component of source current lags the voltage by an angle α
- Requires lagging reactive power
- PF = (3/π) cosα



6 pulse converter with RL Load

- Numerical problem => Rectifier operation
- 6 pulse converter supplied from 400 V 3ϕ 50 Hz
- RL load => R=50 Ω and L is very large
- $\alpha = 30^0$ determine
- i) dc O/P voltage & DC current
- ii) Power dissipated in R load
- iii) Source current and supply pf
- iv) rms value of fundamental component of source current
- V) Active and reactive power supplied from the source



Numerical problem: RL load

$$V_{dc(av)} = \frac{3V_{ml}}{\pi}\cos\alpha = \frac{3\times\sqrt{2}\times 400}{\pi}\cos 30$$

$$V_{dc(av)} = 467.818\ V$$

$$I_{dc} = V_{dc(av)}/R = \frac{467.818}{50} = 9.356\ A$$

Power dissipated in R $= V_{d(av)} \cdot I_{dc(av)}$

$= 4377.07\ W.$

Source current $I_s = \sqrt{2/3} \cdot I_{dc} = 7.639\ A$

Supply pf $= \frac{3}{\pi}\cos\alpha = 0.826$ lag.

Numerical Problem: RL load

Peak value of fund. comp $= \frac{2\sqrt{3}}{\pi} I_{dc}$

RMS value of funda. component $= \frac{\sqrt{6}}{\pi} \cdot I_{dc}$

$I_1 = 7.2948$ A

Active Power $= \sqrt{3}\, V_L I_L \cos\phi$

$= \sqrt{3} \times 400 \times 7.639 \times 0.826$

$= 4371$ W

Reactive Power $= \sqrt{3}\, V_L I_L \sin\phi$

$= \sqrt{3} \times 400 \times 7.639 \times \sin(34.309)$

$= 2983.12$ VAR