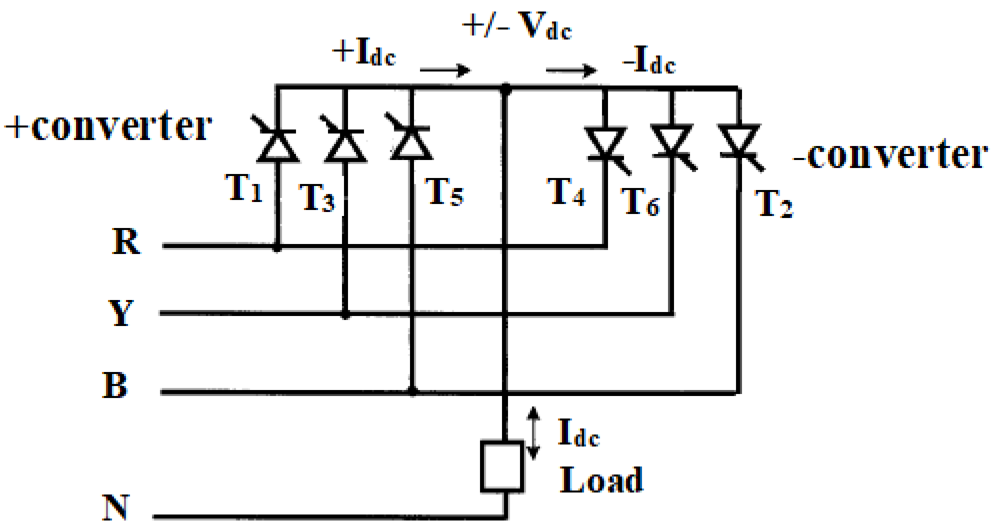
3 Pulse Dual Converter

- Circuit diagram
- Each device conducts for 1200
- Four quadrant operation
- DC O/P voltage

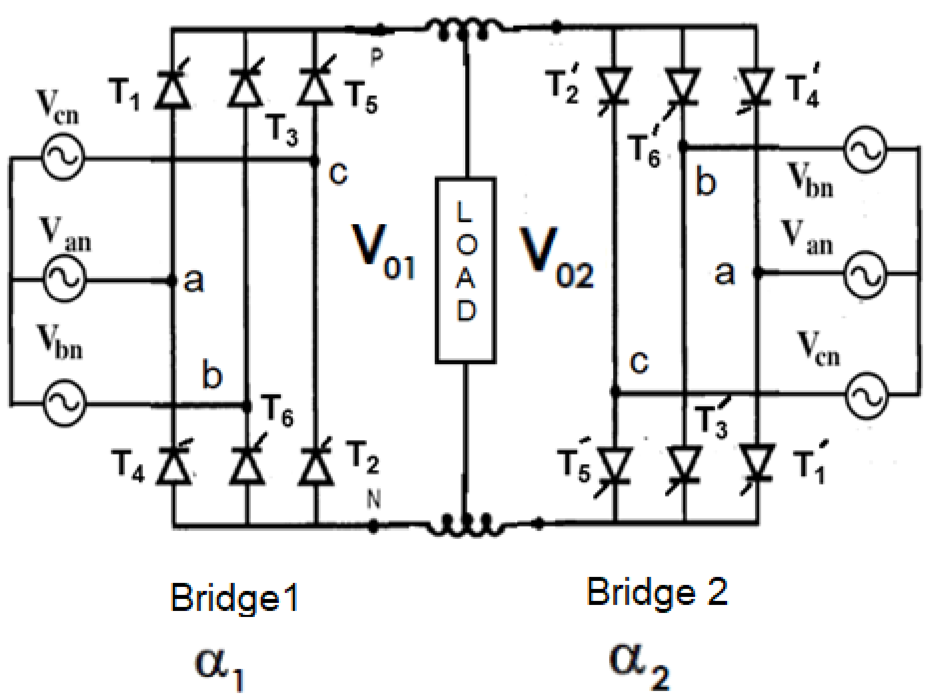


$V_{dc} = (3\sqrt{3}\,V_{mp}\,\text{Cos}\,\alpha)/2\pi$

where V_{mp} peak value of phase to neutral voltage

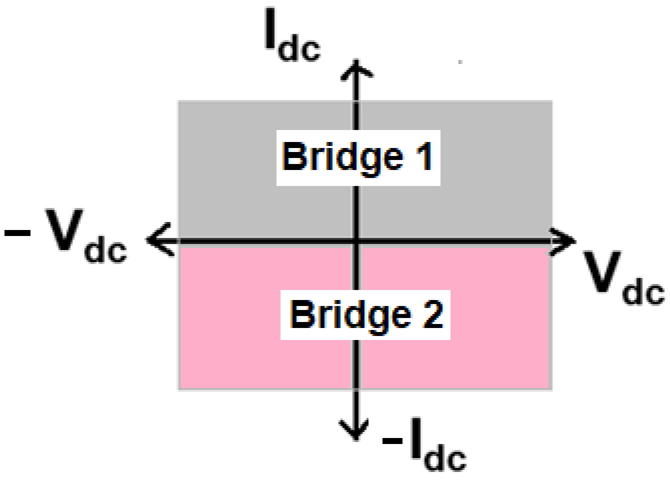
6 pulse dual converter

- 6 pulse dual converter => two six pulse converters connected in anti parallel



6 pulse 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

$$V_{01} = \frac{3V_{ml}}{\pi} \cos\alpha_1$$

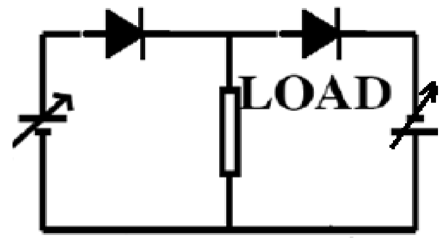
- Bridge 2 => α_2

$$V_{02} = \frac{3V_{ml}}{\pi} \cos\alpha_2$$

6 pulse Dual converter

- Average voltage provided by both converters are same

$$V_{01} = \frac{3V_{ml}}{\pi}\cos\alpha_1$$

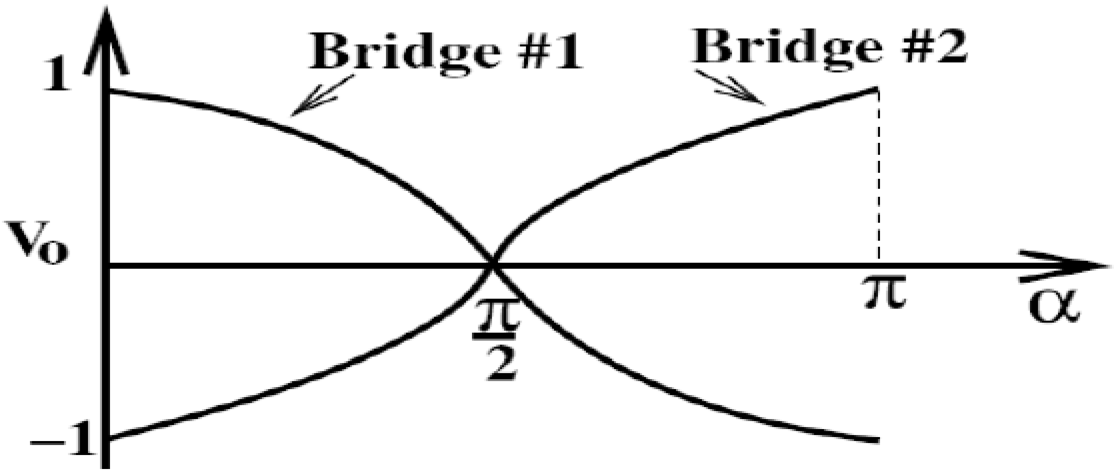


$$V_{02} = \frac{3V_{ml}}{\pi}\cos\alpha_2$$

- Applying KVL gives $V_{O1} + V_{O2} = 0$
- $\cos\alpha 1 + \cos\alpha 2 = 0$
- $\text{Cos } \alpha_1 = -\cos\alpha_2 \Rightarrow \text{Cos } \alpha_1 = \cos(\pi - \alpha_2)$
- $\alpha_1 + \alpha_2 = \pi$

6 pulse Dual converter

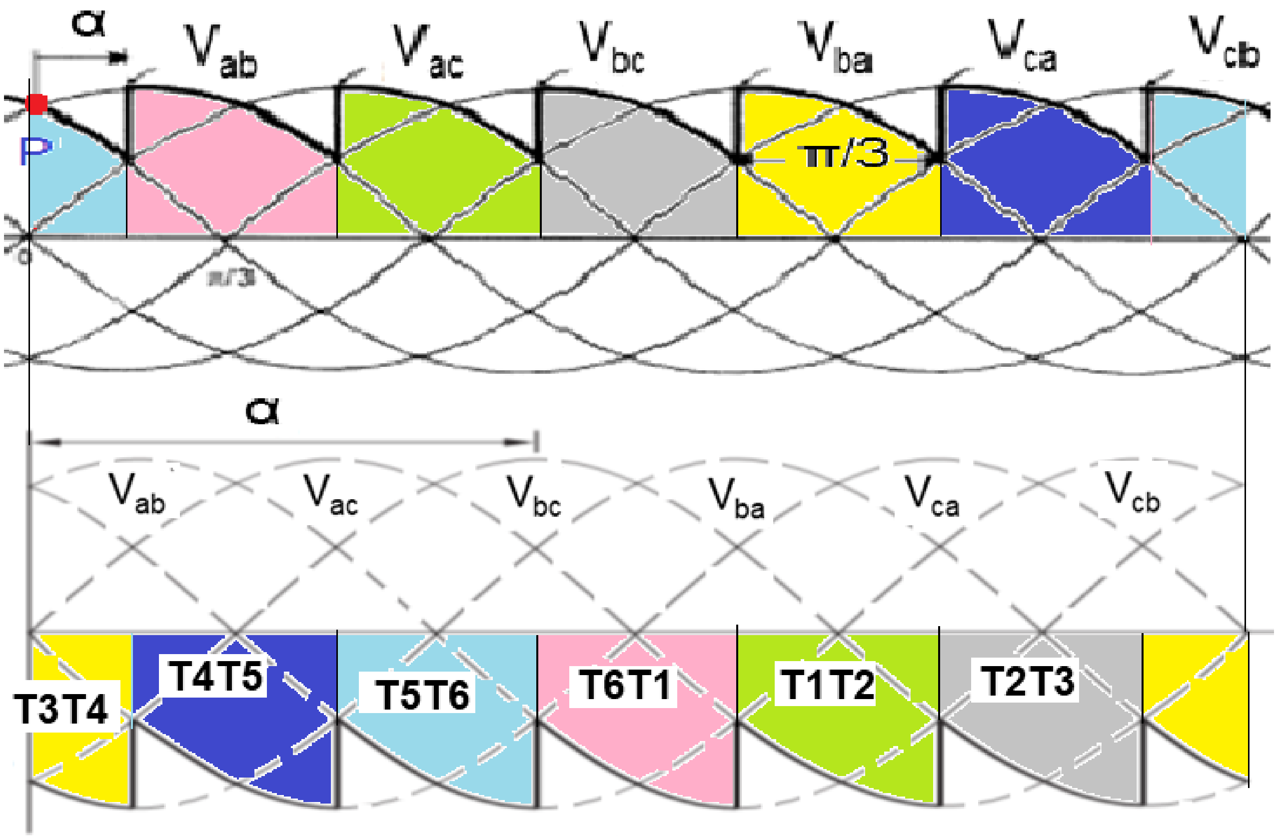
- Circulating mode and non circulating mode



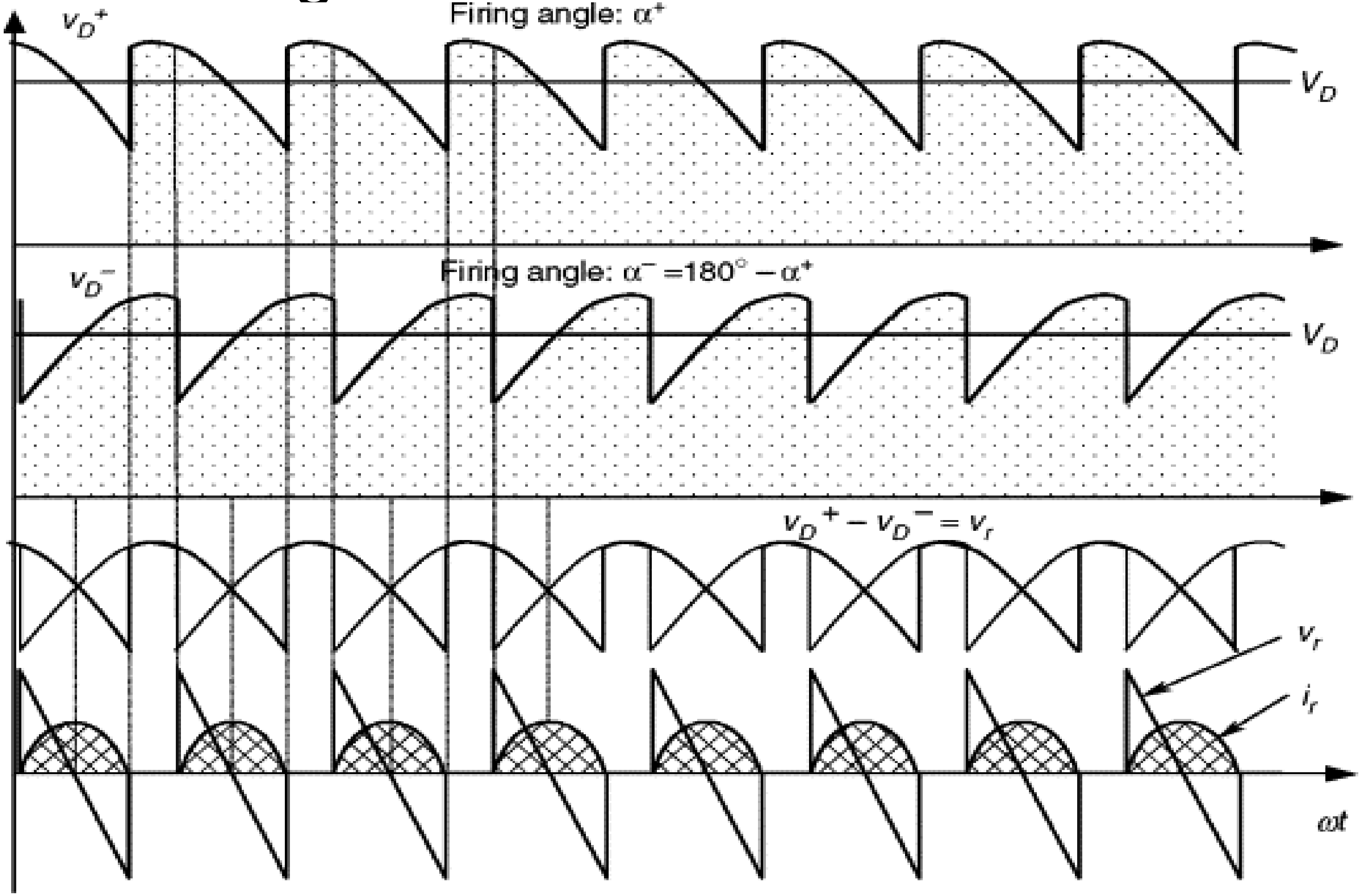
- Inductors L_1 and L_2 are required to limit the circulating current
- Dual converter for speed control of DC Motor

6 pulse dual converter

- 30^0 and 150^0 waveforms



6 pulse dual converter

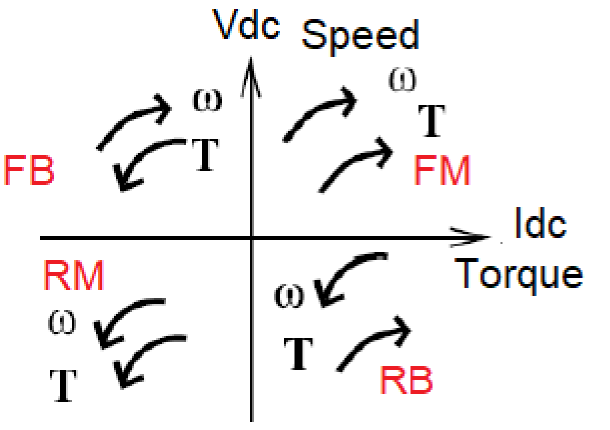
- Circulating current
- 

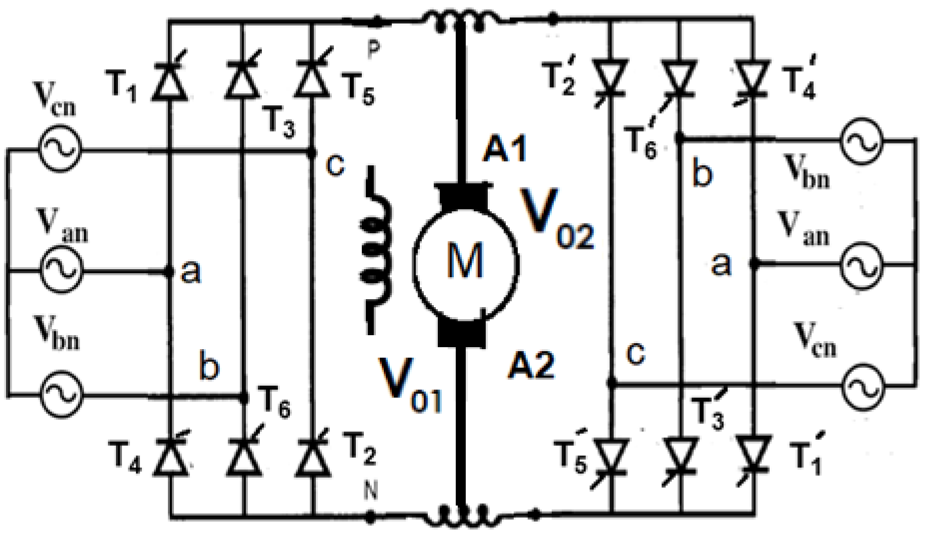
Operating Modes

- Circulating and Non circulating current Mode
- Advantages and disadvantages of circulating current mode
- Simple control
- Fast change over
- higher device rating
- Cost of Inductors

6 pulse dual converter : Application

- 4 quadrant DC Drive
- Armature voltge control





Bridge1 α_1

Bridge 2 α_2

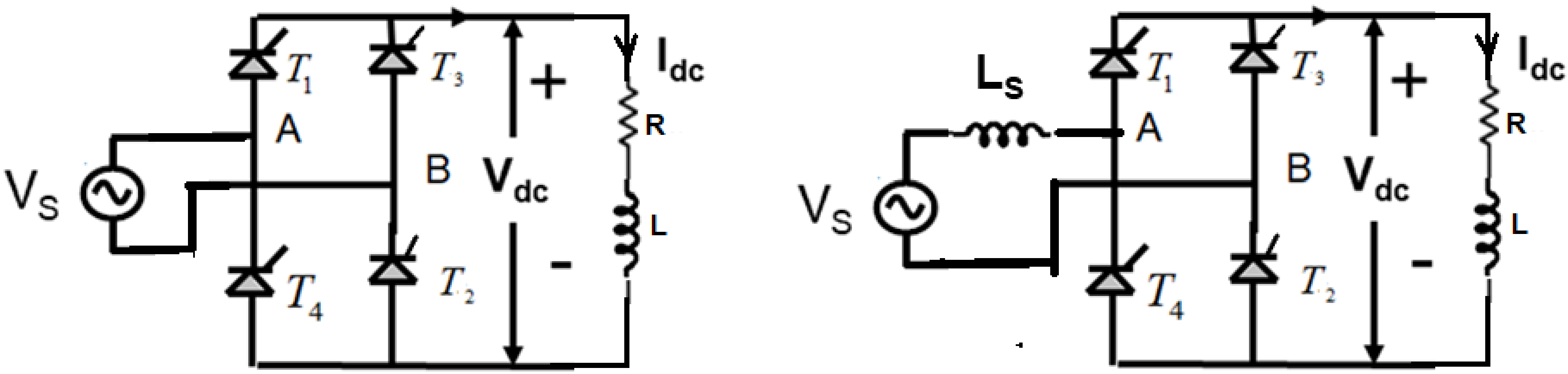
-

6 pulse dual converter : Application

- 4 quadrant DC drive
- Speed control method = armature voltage control
- Regenerative braking
- Speed control range = min to rated speed
- Flux remains constant
- Torque is proportional to Ia
- Applications: Electric traction, lift , cranes , hoists rolling mills

2 pulse Full controlled converter with source Inductance

- With and without source inductance



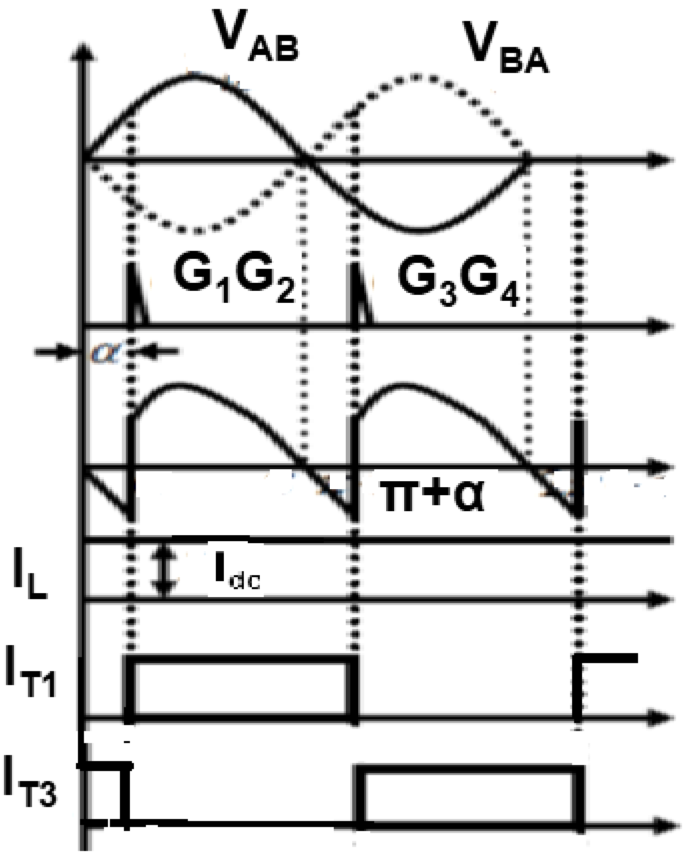
- Change of current from one
- Device to other is instantaneous

simultaneously incoming and outgoing devices are conducting

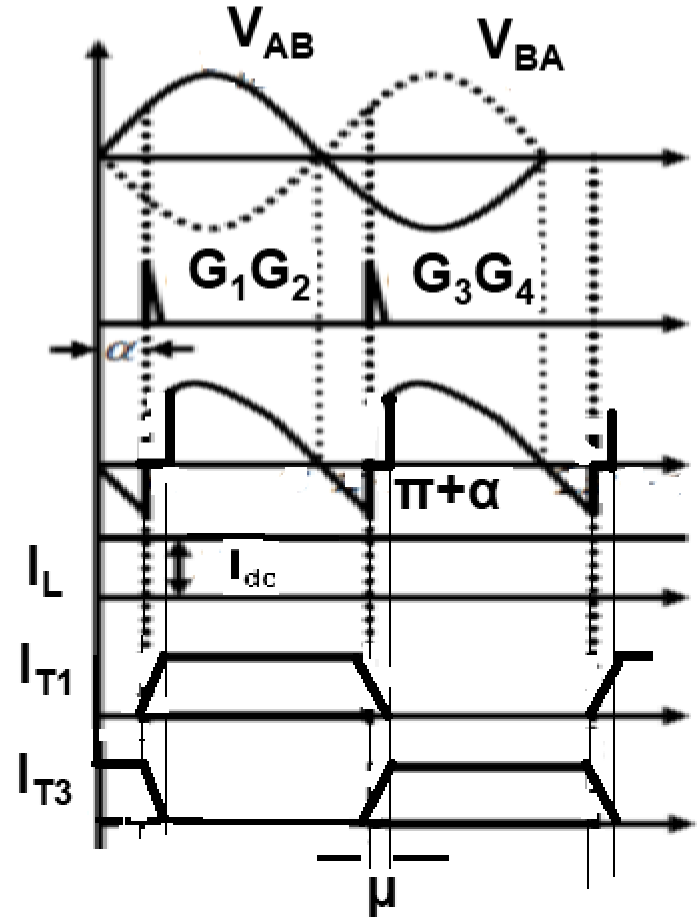
-

Effect of source Inductance -2 pulse converter

- Without Ls



With Ls



Effect of source Inductance

- O/P voltage without source inductance

$$V_{dc(av)} = \frac{2}{2\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\theta \, d\theta$$

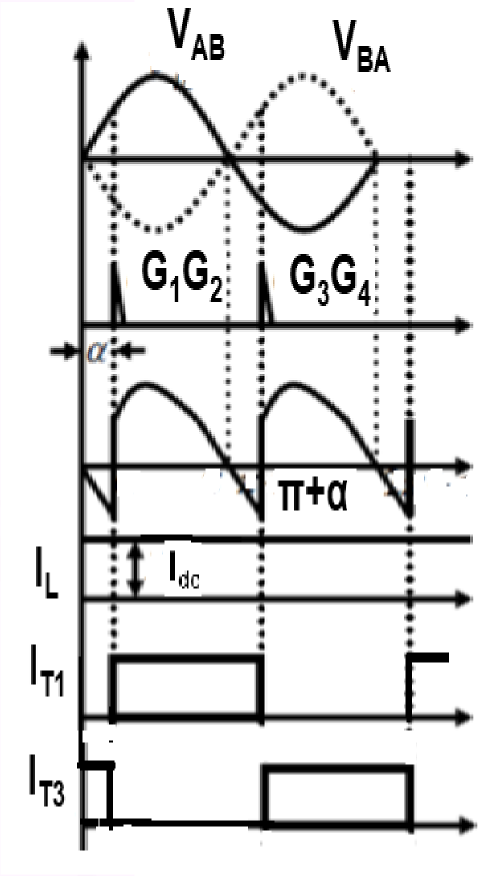
$$V_{dc(av)} = \frac{2V_m}{2\pi}\left[-\cos\theta\right]\Big|_{\alpha}^{\pi+\alpha}$$

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

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

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

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



Effect of source Inductance

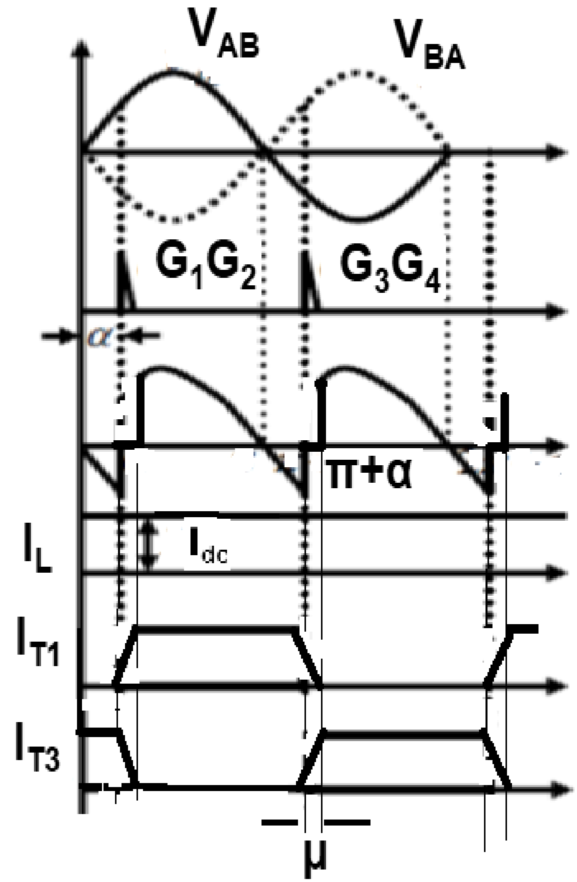
- O/P voltage with source inductance

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

$$V_{dc(av)} = \frac{2V_m}{2\pi}\Big[-\cos\theta\Big]_{\alpha+\mu}^{\pi+\alpha}$$

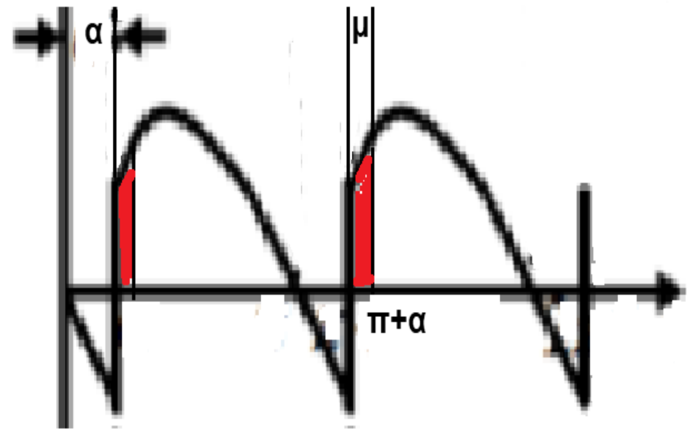
$$V_{dc(av)} = \frac{V_m}{\pi}\Big[-\cos(\pi+\alpha) + \cos(\alpha+\mu)\Big]$$

$$V_{dc(av)} = \frac{V_m}{\pi}\Big[\cos\alpha + \cos(\alpha+\mu)\Big]$$



Effect of source Inductance

- Reduction in O/P voltage



Drop in voltage due to overlap

= $V_{dc(av)}$ without overlap − $V_{dc(av)}$ with overlap

$$\Delta V = \frac{2V_m}{\pi}\cos\alpha - \frac{V_m}{\pi}\left[\cos\alpha + \cos(\alpha+\mu)\right]$$

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

Effect of source Inductance

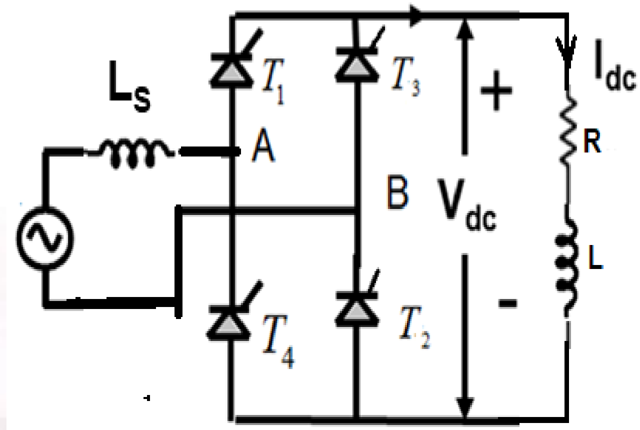
- Vdc

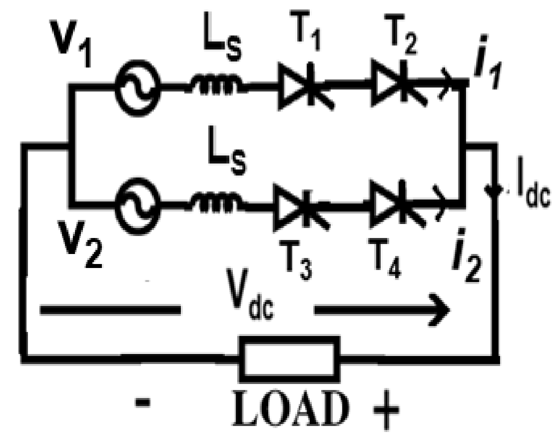
$$v_1 - L_s \frac{di_1}{dt} = v_2 - L_s \frac{di_2}{dt}$$

$$v_1 - v_2 = L_s\left(\frac{di_1}{dt} - \frac{di_2}{dt}\right)$$

$$v_1 = V_m \sin \omega t, \quad v_2 = -V_m \sin \omega t$$

$$L_s\left(\frac{di_1}{dt} - \frac{di_2}{dt}\right) = 2V_m \sin \omega t$$





Effect of source Inductance

- Drop in voltage

$$i_1 + i_2 = I_{dc} = \text{constant}$$

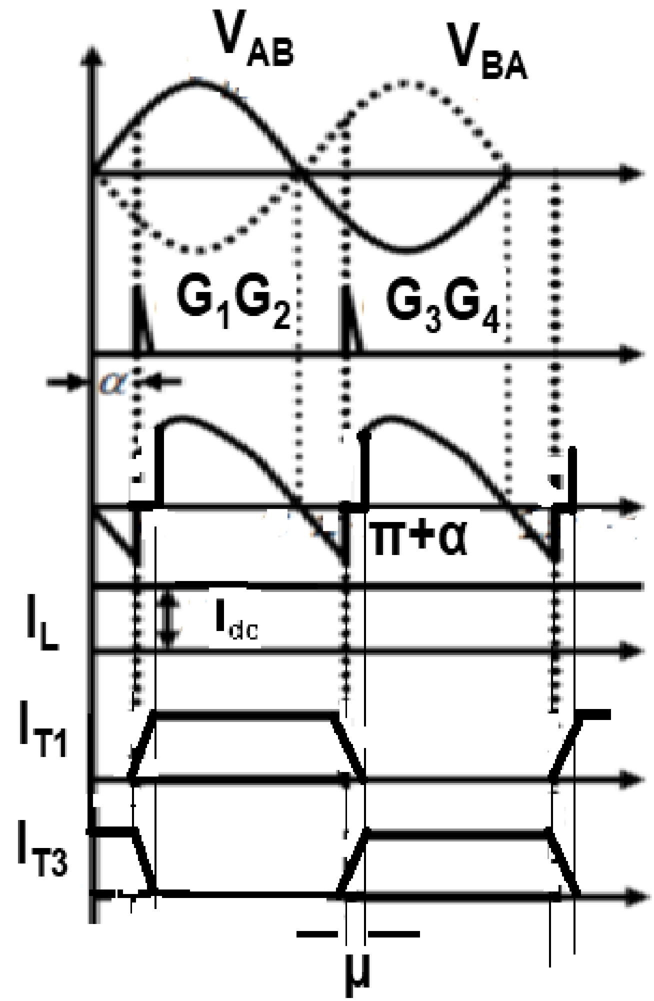
$$\therefore \frac{di_1}{dt} + \frac{di_2}{dt} = 0 \quad \ldots\ldots \text{I}$$

$$L_s\left(\frac{di_1}{dt} - \frac{di_2}{dt}\right) = 2V_m \sin\omega t \quad \ldots \text{II}$$

Addition of I & II equation

$$2\frac{di_1}{dt} = \frac{2V_m}{L_s}\sin\omega t$$

$$\frac{di_1}{dt} = \frac{V_m \sin\omega t}{L_s}$$



Effect of source Inductance

$i_1 = 0$ at $\omega t = \alpha$

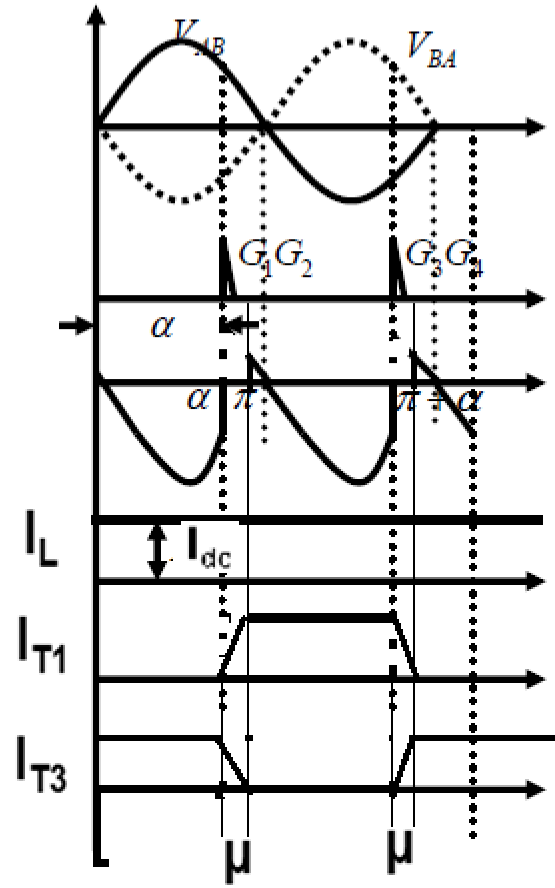
$i_1 = I_{dc}$ at $\omega t = \alpha + \mu$.

$$\int_0^{I_{dc}} di_1 = \frac{V_m}{L_s} \int_{\alpha/\omega}^{\alpha+\mu/\omega} \sin \omega t \cdot dt$$

$$I_{dc} = \frac{V_m}{L_s} \left[-\frac{\cos \omega t}{\omega} \right] \Bigg|_{\alpha/\omega}^{(\alpha+\mu)/\omega}$$

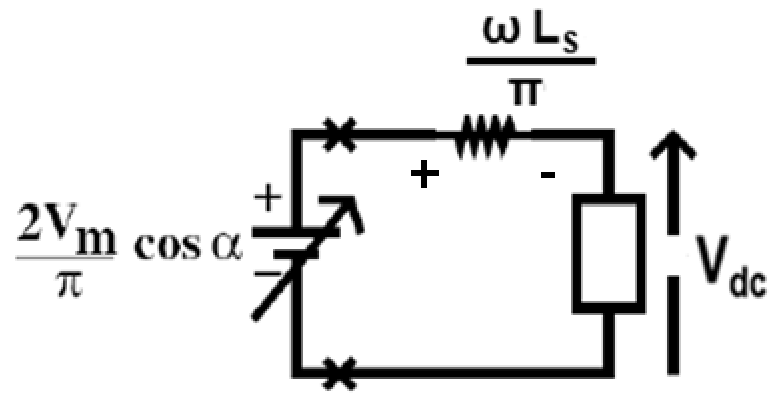
$$I_{dc} = \frac{V_m}{\omega L_s} \left(\cos \alpha - \cos(\alpha + \mu) \right)$$

$$I_{dc} \cdot \omega L_s = V_m \left(\cos \alpha - \cos(\alpha + \mu) \right) \text{ --- } \cdots \text{ (III)}$$



Effect of source Inductance

- Equivalent circuit

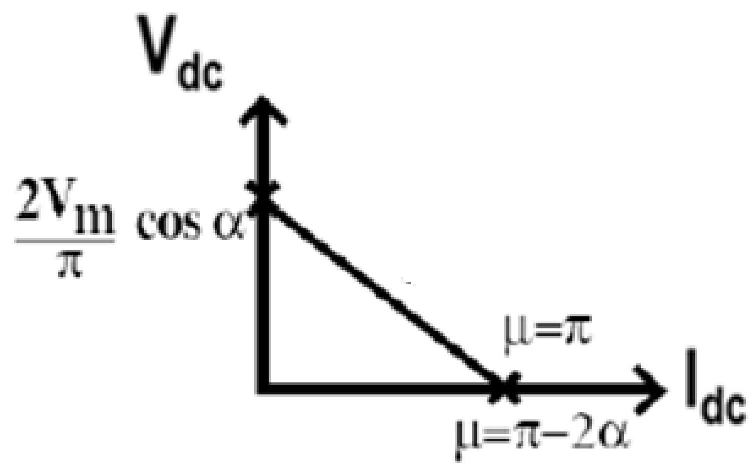


devide equation III by π

$$\frac{I_{dc}\cdot \omega L_s}{\pi} = \frac{V_m}{\pi}\left[\cos\alpha - \cos(\alpha+\mu)\right]$$

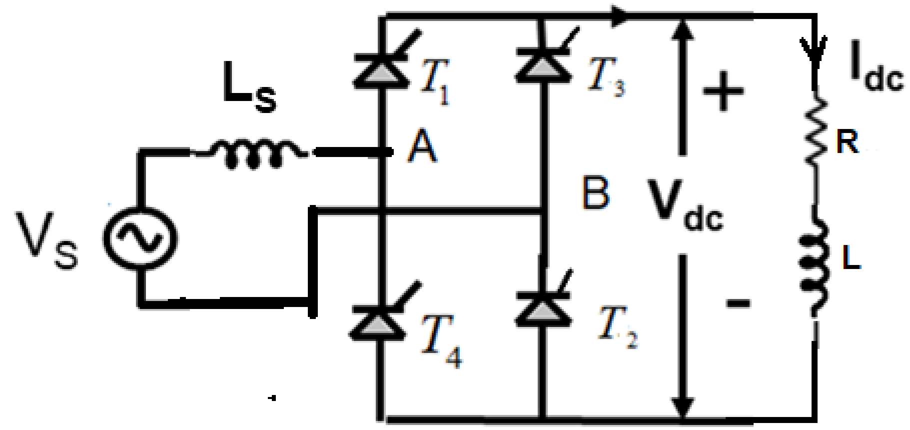
Drop in voltage $= \dfrac{I_{dc}\cdot \omega L_s}{\pi}$

Drop in Voltage $= \dfrac{\omega L_s}{\pi}\cdot I_{dc}$



Source inductance Numerical Problem

- Vph (rms) = 230 V
- α= 450 , Idc= 5 A
- Vdc =135 V
- Determine Ls , angle μ,
- And load resistance



O/p voltage without over lap for $\alpha = 45^0$

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

$$\therefore V_{dc(av)} = 146.42$$

Source inductance Numerical Problem

Voltage with overlap = 135 V

Drop in voltage due to overlap = 146.42 − 135

= 11.42 V

Drop in voltage = $\frac{\omega L_s}{\pi} \cdot I_{dc}$

$11.42 = \frac{2\pi f \times L_s}{\pi} \times 5A$

$L_s = \frac{11.42}{2 \times 50 \times 5} = 22.84\ mH$

Drop in voltage = $\frac{V_m}{\pi}\left(\cos\alpha - \cos(\alpha+\mu)\right)$

Source inductance Numerical Problem

Putting the values

$$11.42 = \frac{\sqrt{2} \times 230}{\pi} \left(\cos 45 - \cos(\alpha + \mu) \right)$$

$$\cos 45 - \cos(\alpha + \mu) = \frac{11.42 \times \pi}{\sqrt{2} \times 230} = 0.1102$$

$$0.1102 = \cos 45 - \cos(\alpha + \mu)$$

$$\therefore \cos(\alpha + \mu) = \cos 45 - 0.1102$$

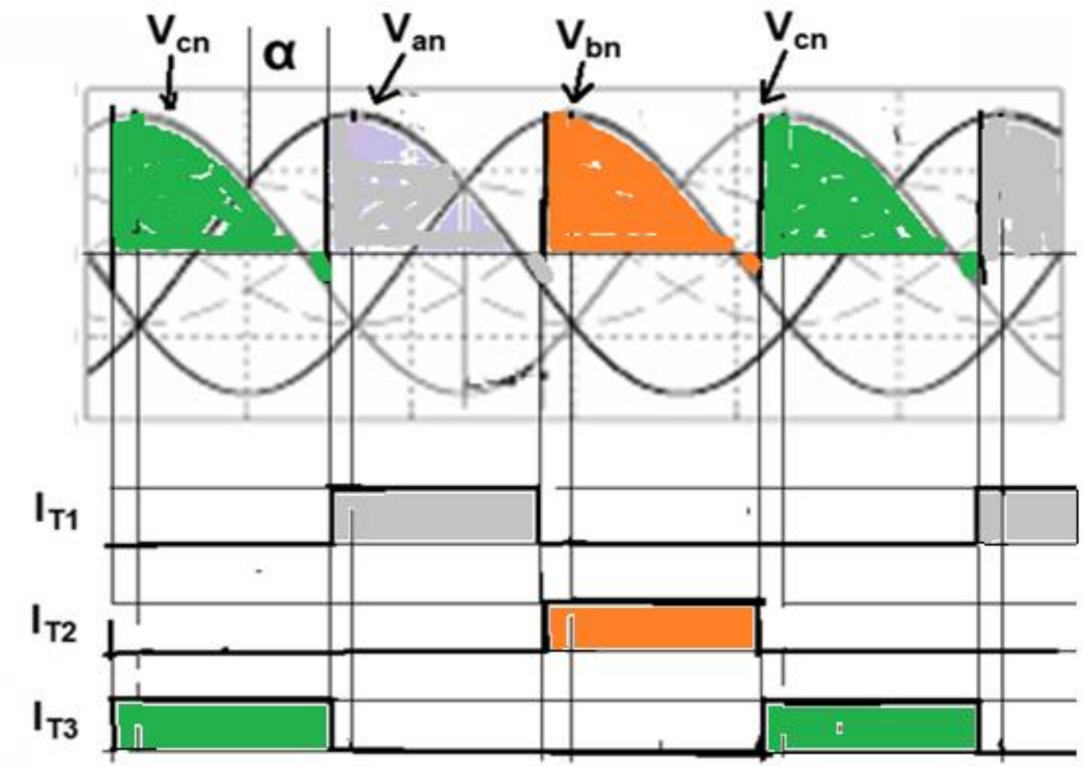
$$= 0.566906$$

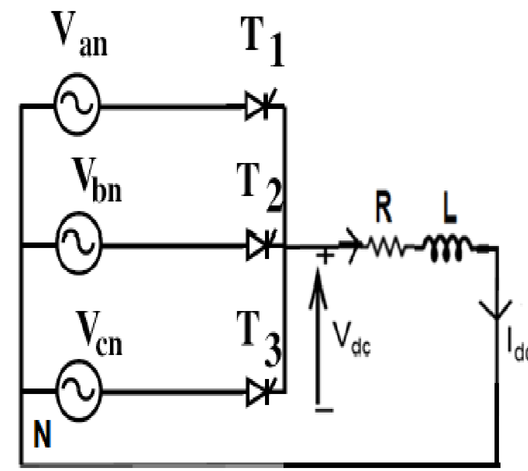
$$\therefore \cos(\alpha + \mu) = 55.46 \quad \therefore \mu = 10.46^\circ$$

$$\text{Load } R = \frac{V_{dc}}{I_{dc}} = \frac{135}{5} = 27\,\Omega$$

Source Inductance- 3 pulse converter

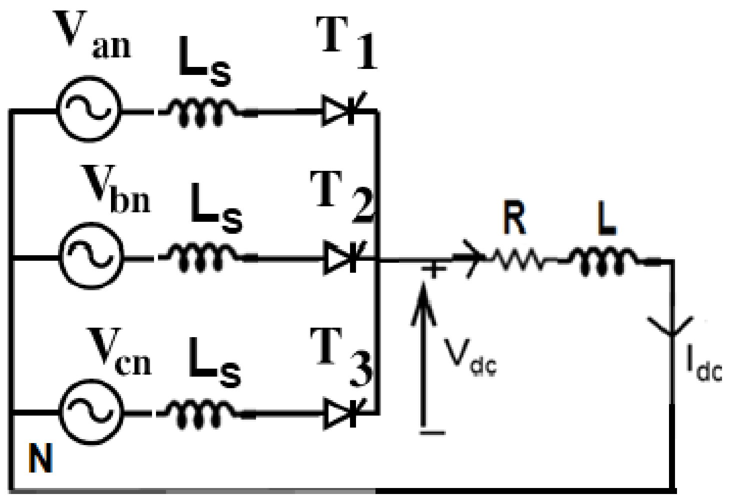
- o/p voltage without source inductance $\alpha = 45^0$





Source Inductance- 3 pulse converter

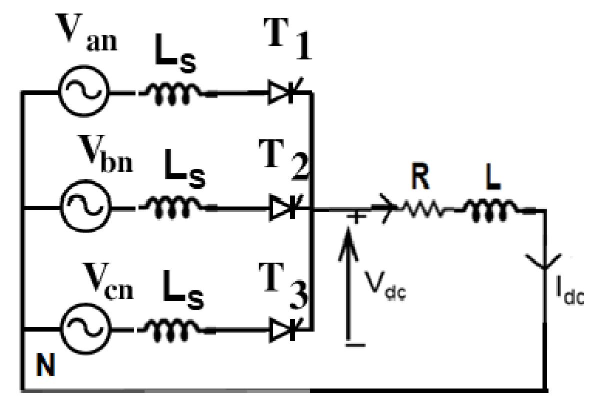
- Commutation from T3 to T1
- Transfer of current is gradual from T3 to T1
- Line to line voltage is shorted
- Voltage is absorbed across source inductance



- O/P voltage during commutation is the average of outgoing and incoming voltages

Source Inductance- 3 pulse converter

Considering commutation from T_3 to T_1



$$V_{an} = L_s \frac{di_{T_1}}{dt} + V_d' \quad \ldots\ldots \text{(I)}$$

$$V_{cn} = L_s \frac{di_{T_3}}{dt} + V_d' \quad \ldots\ldots \text{(II)}$$

During commutation I_{dc} = constant

$$i_{T_1} + i_{T_3} = I_{dc} \quad \ldots\ldots \text{III}$$

$$\frac{di_{T_1}}{dt} + \frac{di_{T_3}}{dt} = 0 \quad \ldots\ldots \text{IV}$$

Source Inductance- 3 pulse converter

Adding equations I and II

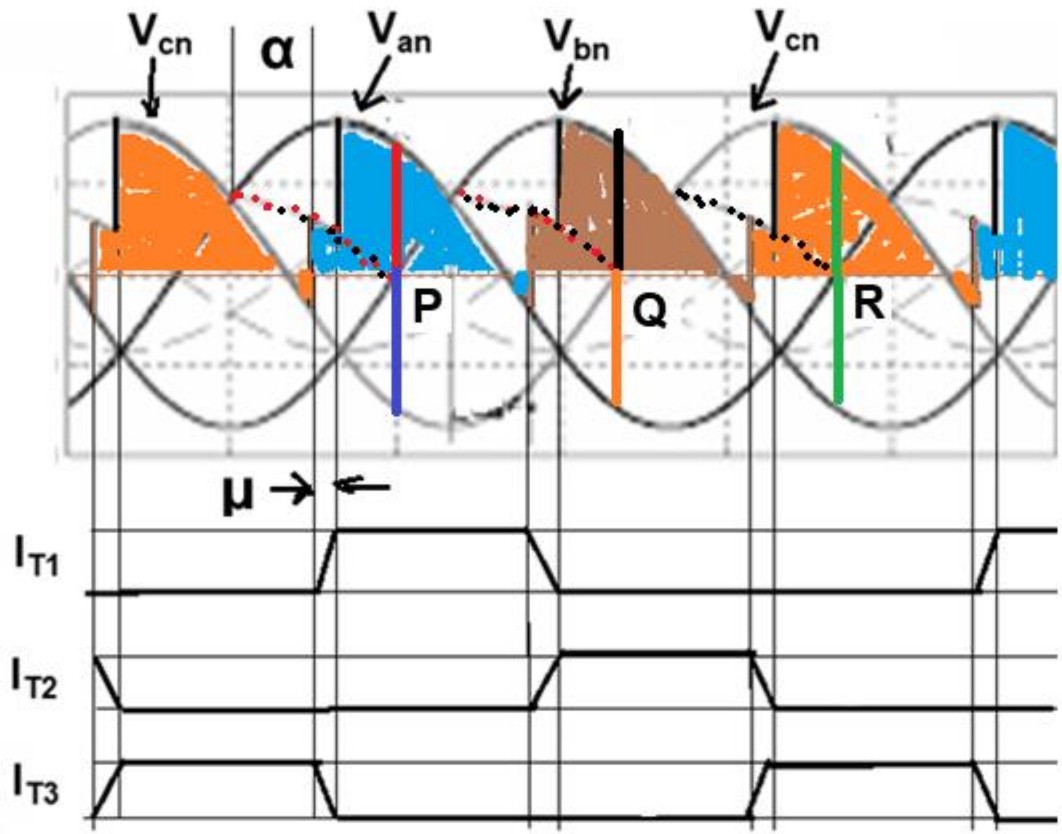
$$V_{an} + V_{cn} = L_s\left(\frac{di_{T_1}}{dt} + \frac{di_{T_3}}{dt}\right) + 2V_d'$$

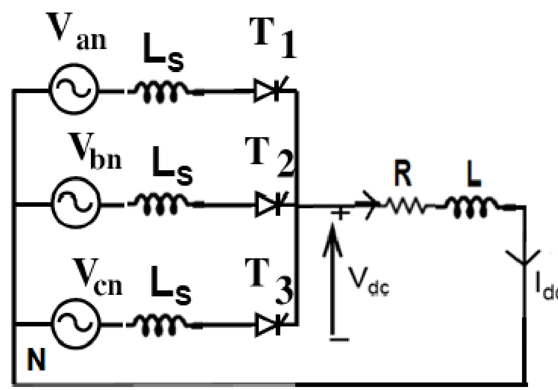
$$\therefore \quad V_d' = \frac{1}{2}\left(V_{an} + V_{cn}\right)$$

- During commutation period (overlap period) output voltage is average of incoming and outgoing voltages

Source Inductance- 3 pulse converter

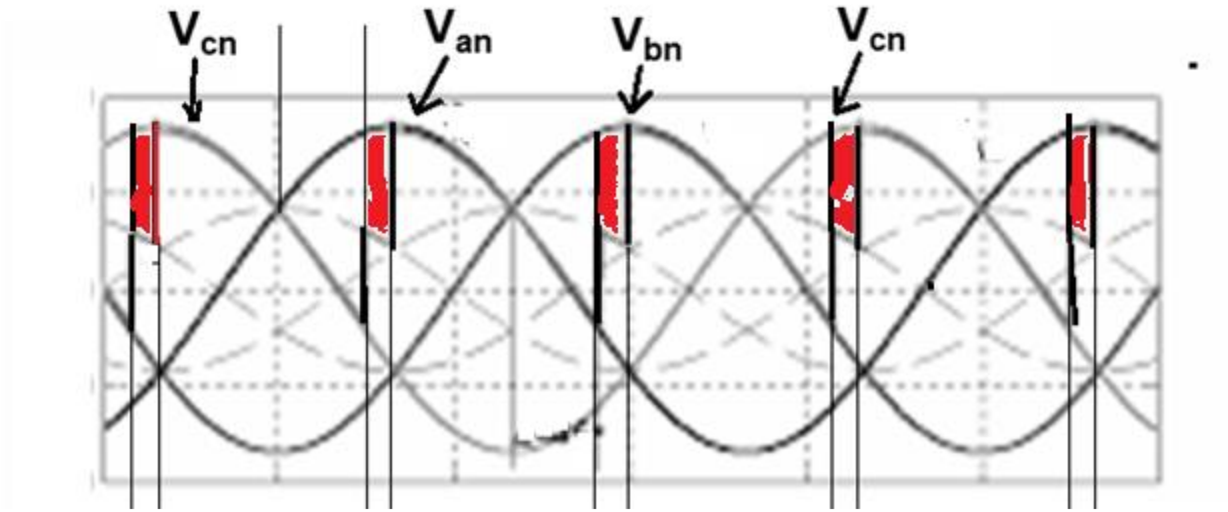
- Output voltage with source inductance $\alpha = 45^0$





Source Inductance- 3 pulse converter

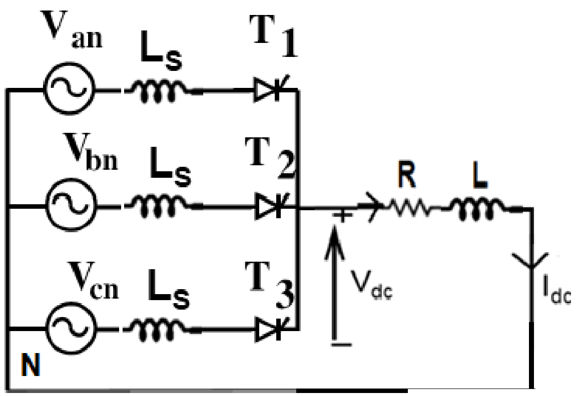
- Loss of voltage due to overlap

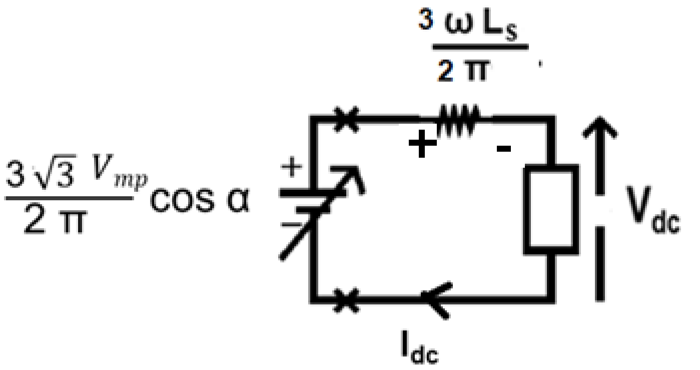


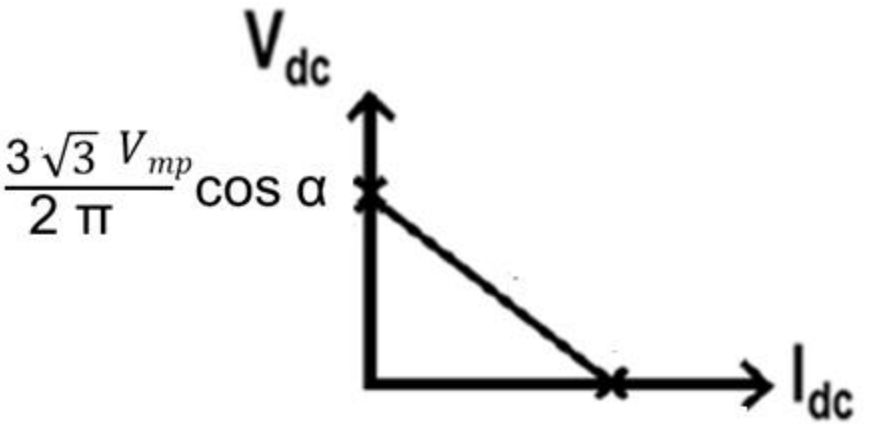
- Hatched area will represent reduction in O/P voltage
- Reduction of o/p voltage = $(3\omega L_s I_{dc}) / 2\pi$

Source Inductance- 3 pulse converter

- Equivalent circuit







Converter with source induction

- 2 pulse => Drop in voltage = $\frac{\omega L_s I_{dc}}{\pi}$
- 3 pulse => Drop in voltage = $\frac{3 \omega L_s I_{dc}}{2 \pi}$
- 6 pulse => Drop in voltage = $\frac{3 \omega L_s I_{dc}}{\pi}$

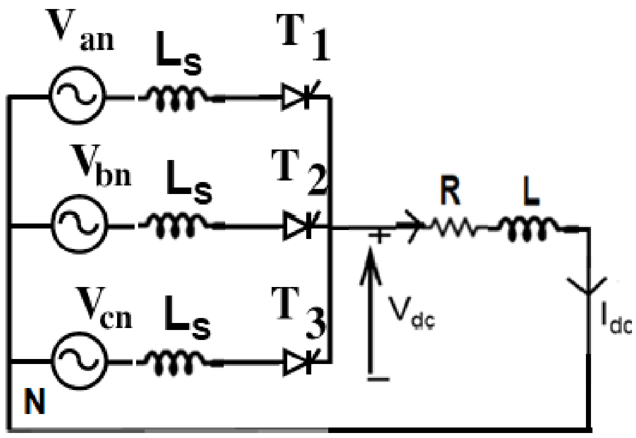
Converter with source induction

- O/P voltage without source inductance
- $V_{dc(av)} = V_{dc(max)} \cos\alpha$
- O/P voltage with overlap
- $V_0 = (V_{dc(max)}/2)(\cos\alpha + \cos(\alpha+\mu))$
- Drop in voltage = $(V_{dc(max)}/2)(\cos\alpha - \cos(\alpha+\mu))$

- $V_{dc(max)} = \dfrac{2V_m}{\pi}$ => For 2 pulse converter
- $V_{dc(max)} = \dfrac{3\sqrt{3}\,V_{mp}}{2\pi}$ => For 3 pulse converter
- $V_{dc(max)} = \dfrac{3V_{ml}}{\pi}$ => For 6 pulse converter

Source Inductance- 3 pulse converter

- Numerical problem
- Vph (rms) = 230 V
- $\alpha = 30^0$, Idc= 15 A
- Vdc =220 V
- Determine Ls , angle μ, and load resistance
-



Source Inductance- 3 pulse converter

$$V_{dc(av)} = \frac{3\sqrt{3}\, V_{mp}}{2\pi} \cos\alpha = \frac{3\sqrt{3} \times \sqrt{2} \times 230}{2\pi} \cos 30^\circ$$

$$V_{dc(av)} = 232.9568\,V$$

Voltage without overlap $= 232.9568\,V$

Voltage with overlap $= 220\,V$

Drop in voltage due to overlap $= 232.95 - 220$

$$= 12.9568\,V$$

Drop in voltage $= \dfrac{3\omega L_s}{2\pi} . I_{dc}$

Putting values

$$12.9568 = \frac{3 \times 2\pi \times 50 \times L_s \times 15}{2\pi}$$

$$\therefore L_s = 5.758\,mH$$

Source Inductance- 3 pulse converter

Drop in voltage $= \frac{3\sqrt{3}\, V_{mp}}{2\pi} \times \left(\frac{\cos\alpha - \cos(\alpha + \mu)}{2} \right)$

Putting values.

$$12.9568 = \frac{3\sqrt{3} \times \sqrt{2} \times 230}{4\pi} \left(\cos\alpha - \cos(\alpha + \mu) \right)$$

$$\cos(\alpha) - \cos(\alpha + \mu) = \frac{12.9568 \times 4\pi}{3\sqrt{3} \times \sqrt{2} \times 230}$$

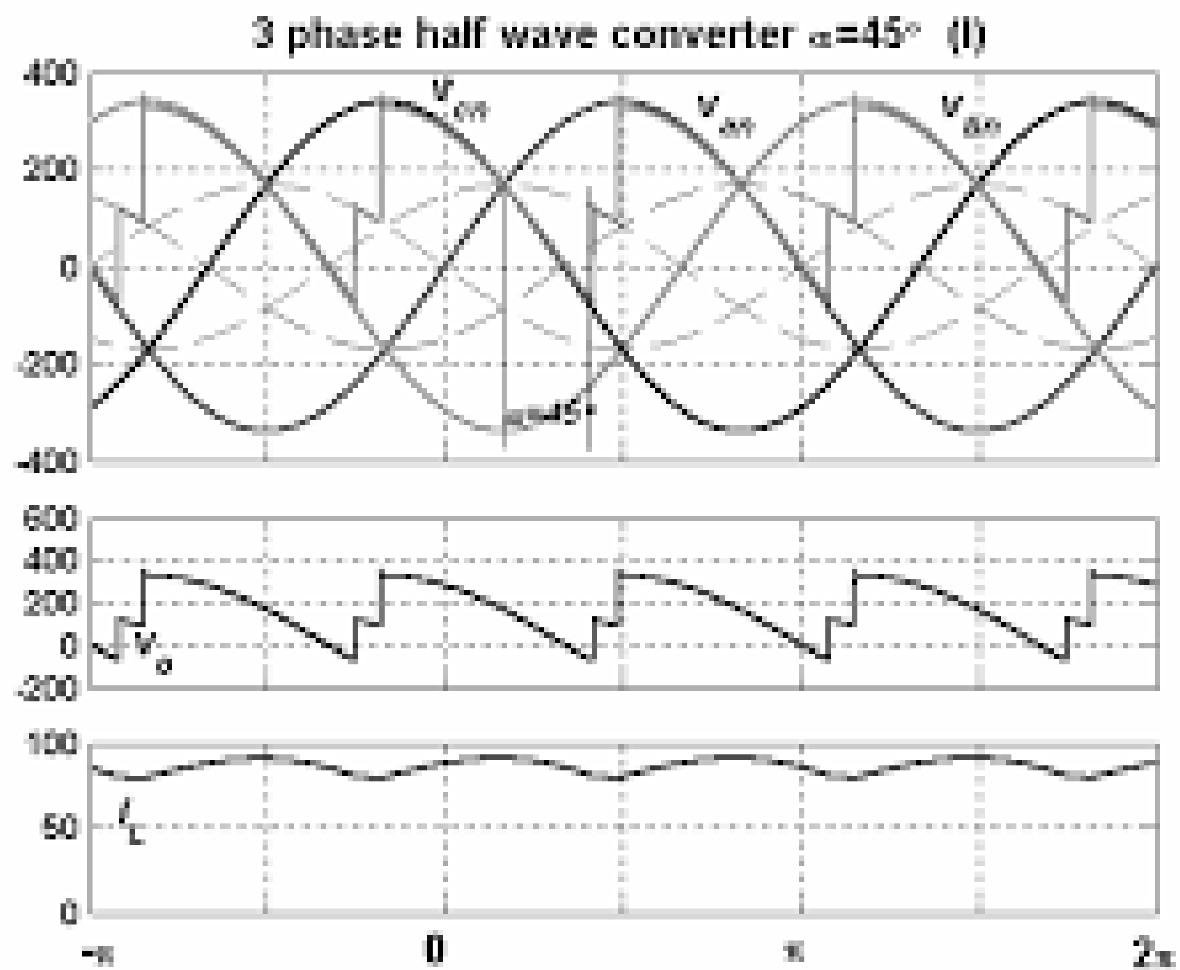
$$= 0.09633$$

$$\cos(\alpha + \mu) = \cos 30 - 0.09633$$

$$= 0.7696$$

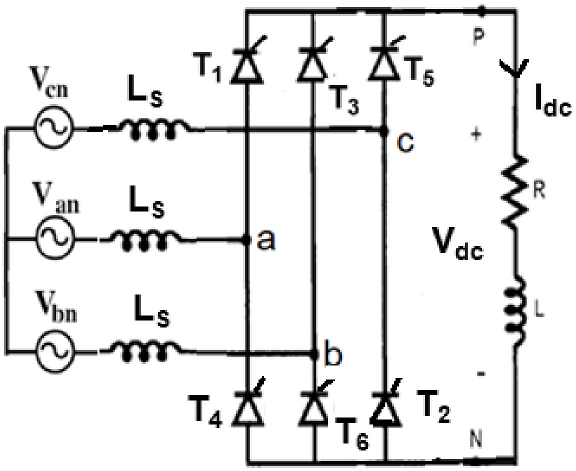
$$(\alpha + \mu) = 39.68^{0} \quad \therefore \mu = 9.68^{0}$$

Source Inductance- 3 pulse converter



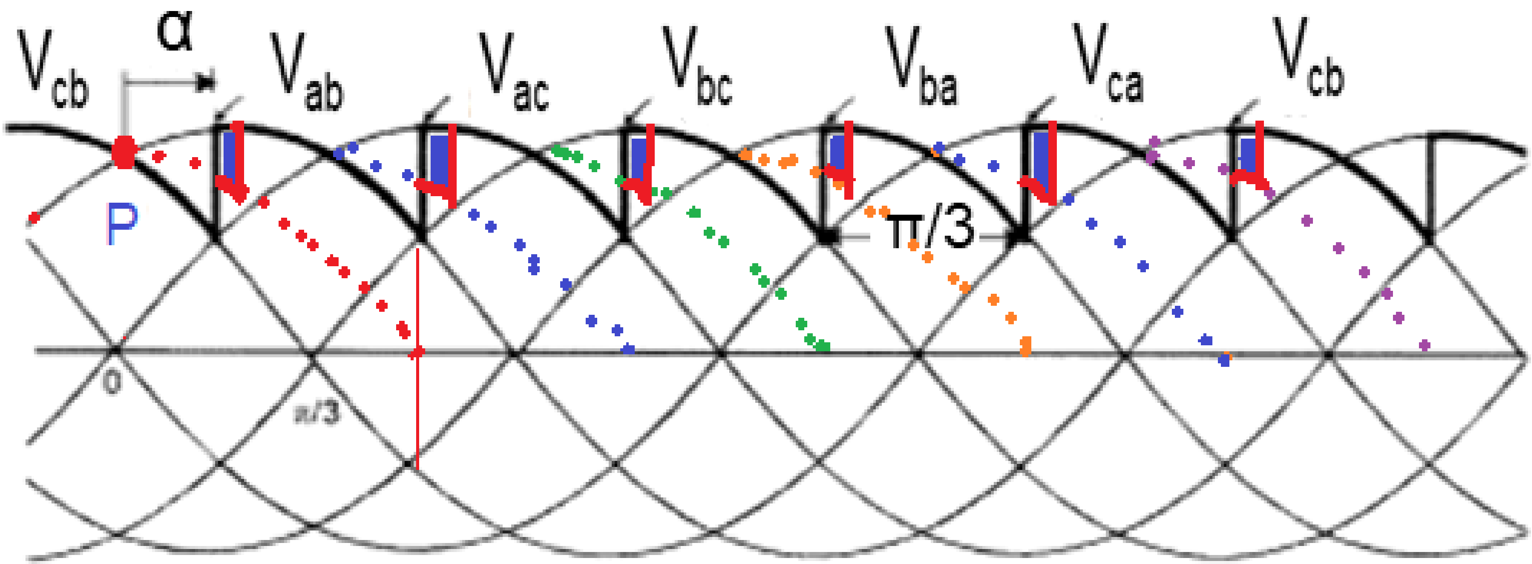
Source inductance 6 pulse converter

- Commutation between T_1, T_3 and T_5
- Commutation between T_2, T_4 and T_6
- During commutation three deices are conducting
- a)T1 T2 T3 b) T2 T3 T4
- c) T3 T4 T5 d) T4 T5 T6
- e) T5 T6 T1 f) T6 T1 T2
- six commutations per cycle



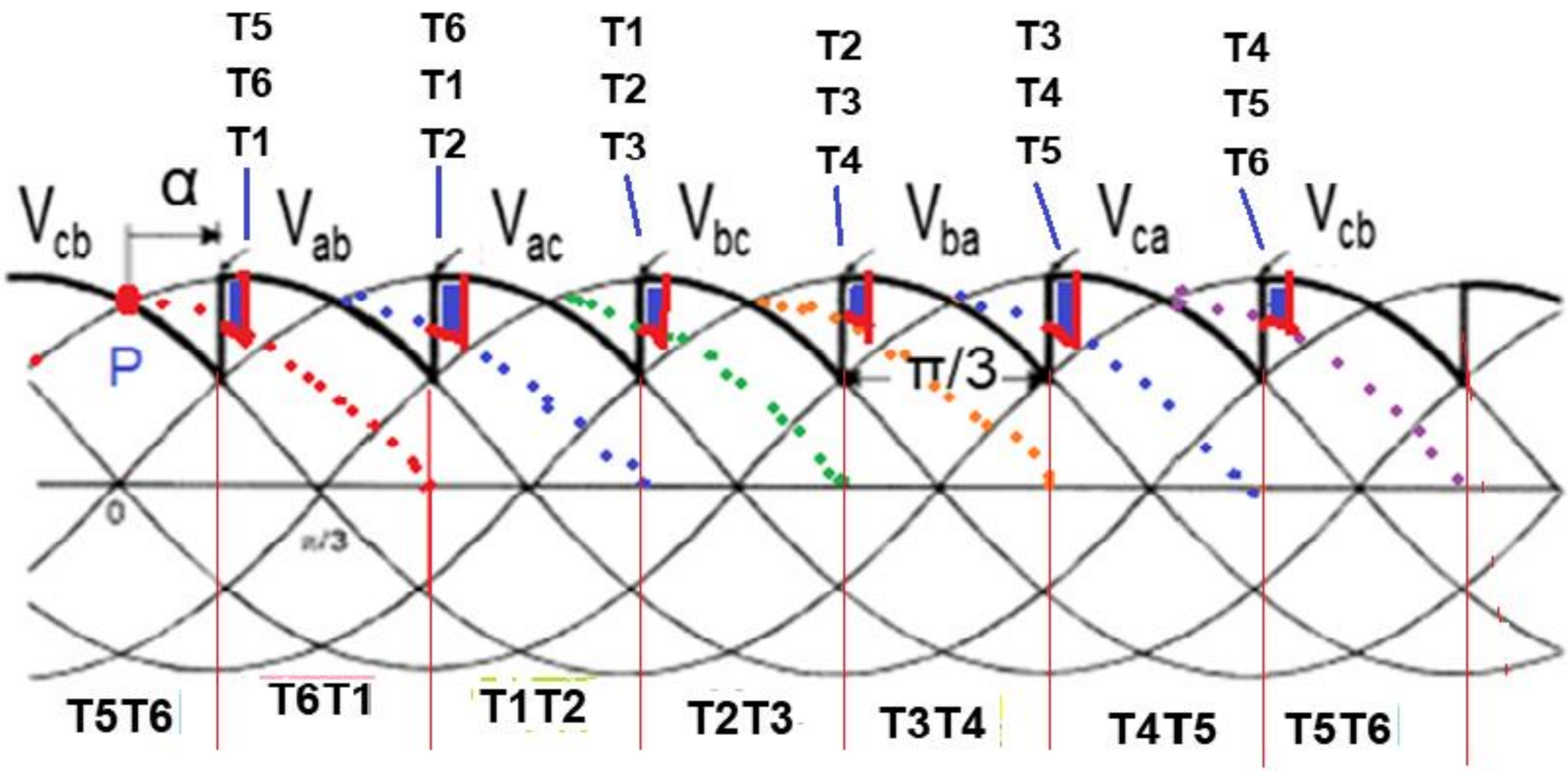
Source inductance 6 pulse converter

- Waveform for $\alpha = 30^0$
- Output voltage during commutation is average of incoming and outgoing voltages



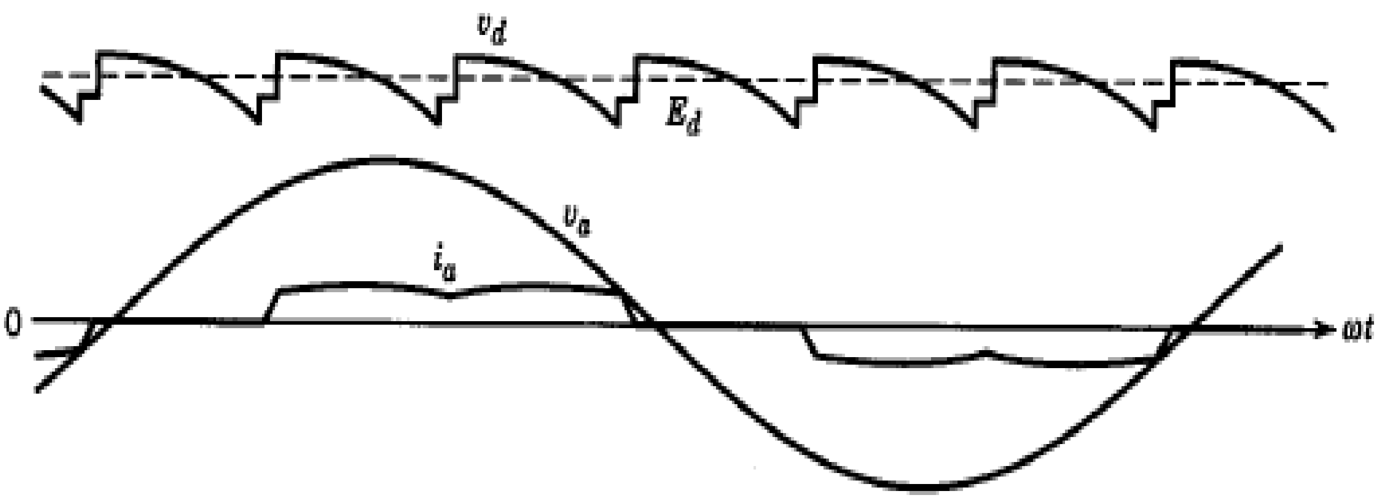
6 pulse converter : source inductance

- Commutation process



Source inductance 6 pulse converter

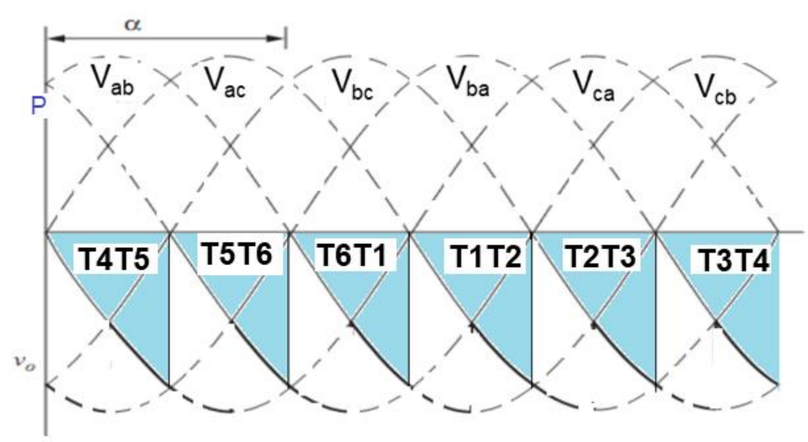
- Output voltage and source current
- Firing angle $\alpha = 30^0$



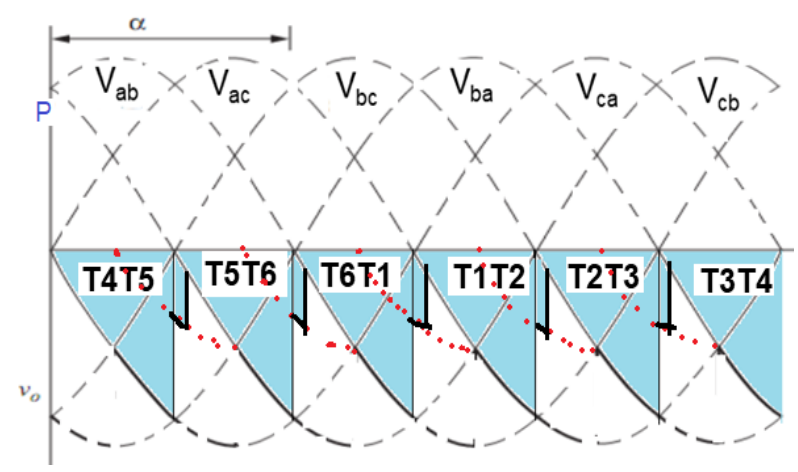
Source inductance 6 pulse converter

- Firing angle α =120^0

- Without overlap

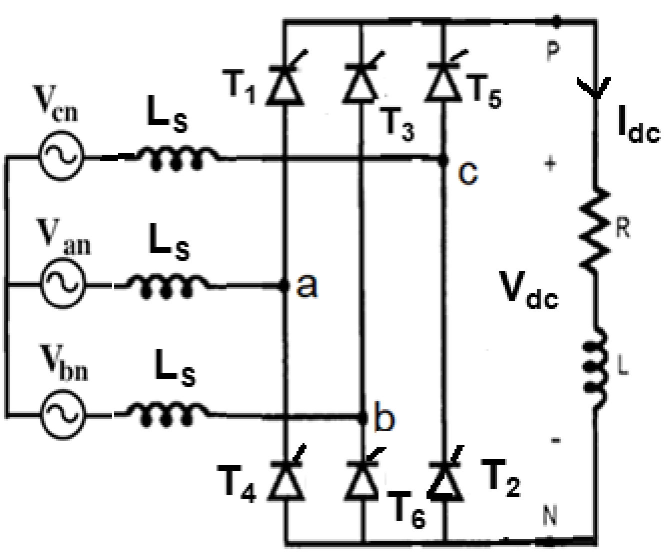


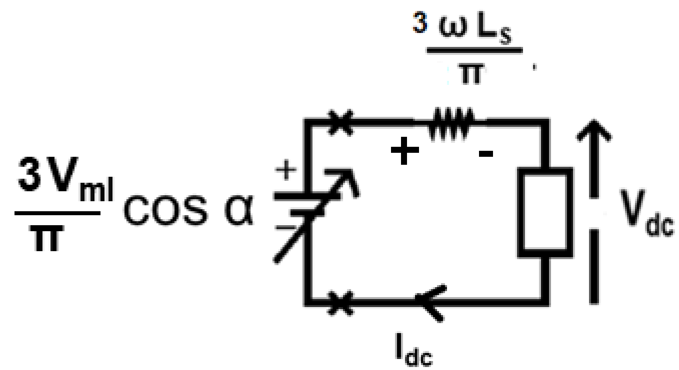
With overlap

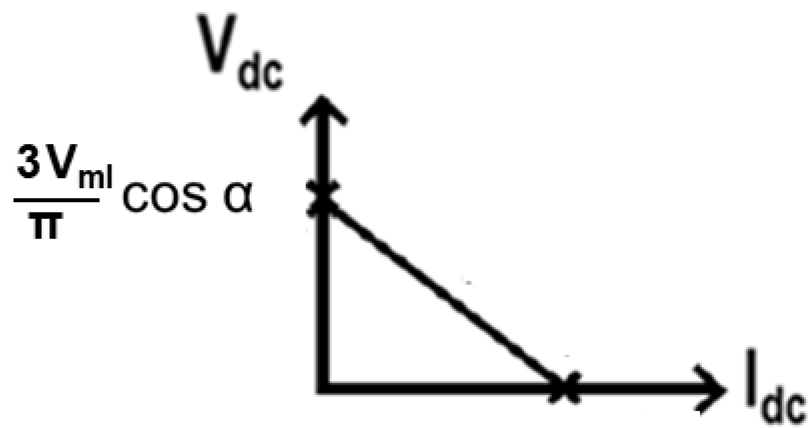


Source inductance 6 pulse converter

- Circuit diagram

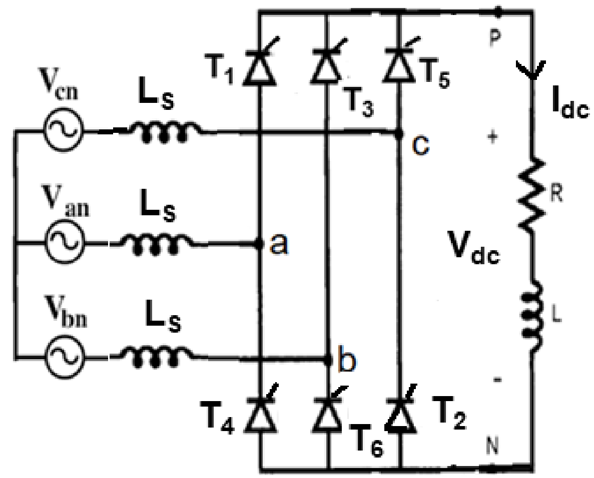






Source inductance 6 pulse converter

- Numerical problem
- VL (rms) = 400 V
- $\alpha = 60^0$, Idc= 25 A
- Vdc =255 V
- Determine Ls , angle μ, and load resistance



Source inductance 6 pulse converter

Voltage without overlap $= \frac{3 V_{mL}}{\pi} \cos\alpha$

$$= \frac{3 \times \sqrt{2} \times 400}{\pi} \cos 60 = 270.09\,V$$

Voltage with overlap $= 255\,V$

Drop due to overlap $= 270.09 - 255 = 15.09\,V$

Drop in voltage $= \frac{3\,\omega\, L_s}{\pi} I_{dc}$

$$15.09 = \frac{3 \times 2\pi \times 50\, L_s}{\pi} \times 25$$

$$\therefore L_s = \frac{15.09\,\pi}{3 \times 2\pi \times 50 \times 25} = 2.01\,mH$$

Source inductance 6 pulse converter

$$\text{Drop in voltage} = \frac{3V_{mL}}{\pi}\left(\frac{\cos\alpha - \cos(\alpha+\mu)}{2}\right)$$

$$15.09 = \frac{3\times\sqrt{2}\times 400}{2\pi}\left(\cos\alpha - \cos(\alpha+\mu)\right)$$

$$\cos\alpha - \cos(\alpha+\mu) = \frac{15.09\times 2\pi}{3\times\sqrt{2}\times 400} = 0.05586$$

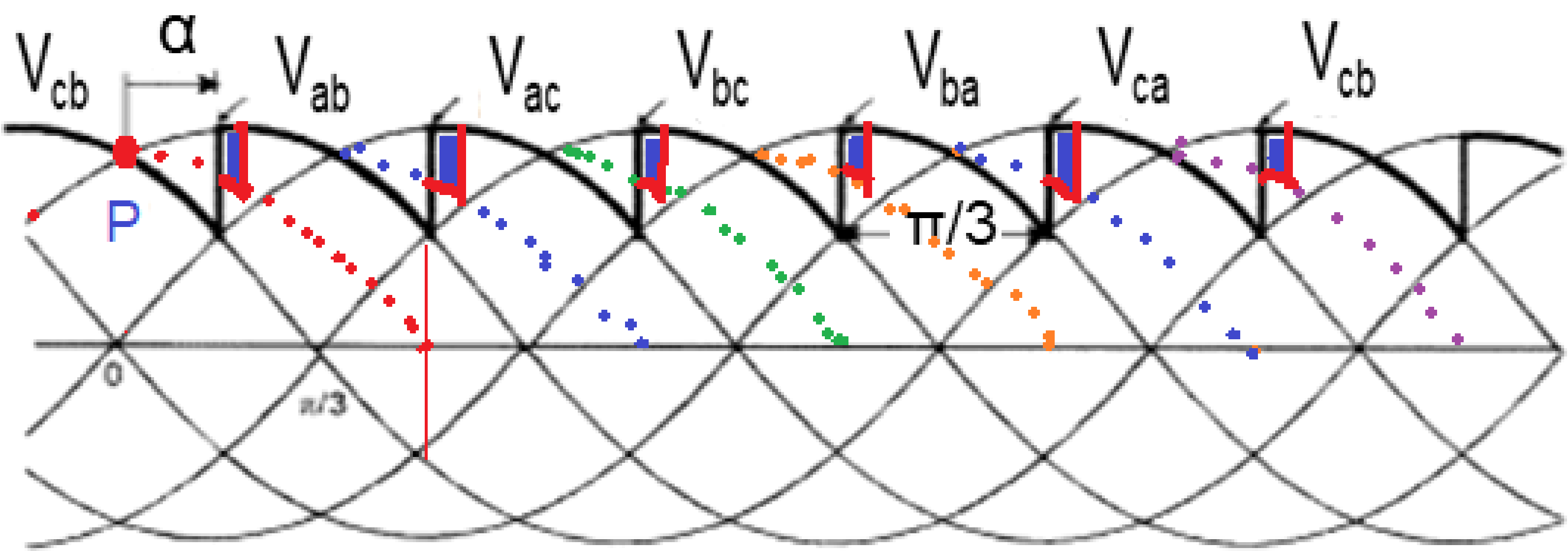
$$\therefore \cos(\alpha+\mu) = \cos 60 - 0.05586$$

$$= 0.4441$$

$$\alpha+\mu = 63.634^\circ$$

$$\mu = 3.634^\circ$$

Source inductance 6 pulse converter



Converter with source induction

- 2 pulse => Drop in voltage = $\dfrac{\omega L_s I_{dc}}{\pi}$

- 3 pulse => Drop in voltage = $\dfrac{3\,\omega L_s I_{dc}}{2\,\pi}$

- 6 pulse => Drop in voltage = $\dfrac{3\,\omega L_s I_{dc}}{\pi}$

Converter with source induction

- O/P voltage without source inductance
- $V_{dc(av)} = V_{dc(max)} \cos\alpha$
- O/P voltage with overlap
- $V_0 = (V_{dc(max)}/2)(\cos\alpha + \cos(\alpha+\mu))$
- Drop in voltage $= (V_{dc(max)}/2)(\cos\alpha - \cos(\alpha+\mu))$

- $V_{dc(max)} = \dfrac{2V_m}{\pi}$ => For 2 pulse converter
- $V_{dc(max)} = \dfrac{3\sqrt{3}\, V_{mp}}{2\pi}$ => For 3 pulse converter
- $V_{dc(max)} = \dfrac{3V_{ml}}{\pi}$ => For 6 pulse converter

THANKS !

Any Questions?