

Power converters AC/DC and DC/AC - MM4

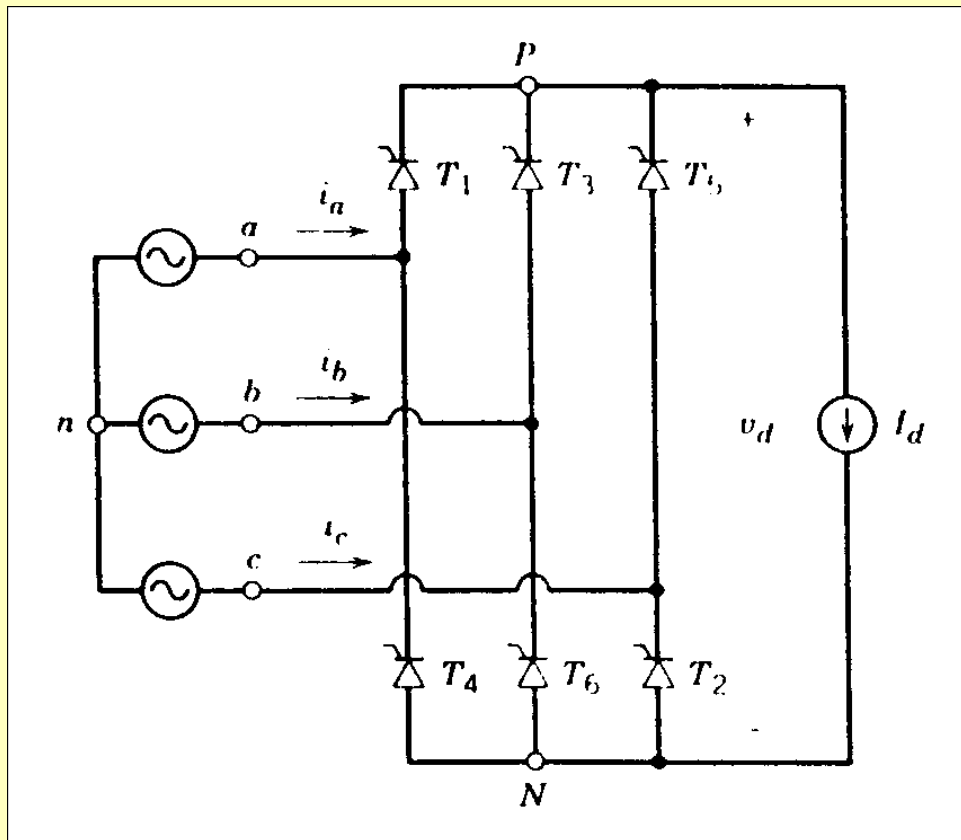
Three-phase Thyristor converters

Content MM4

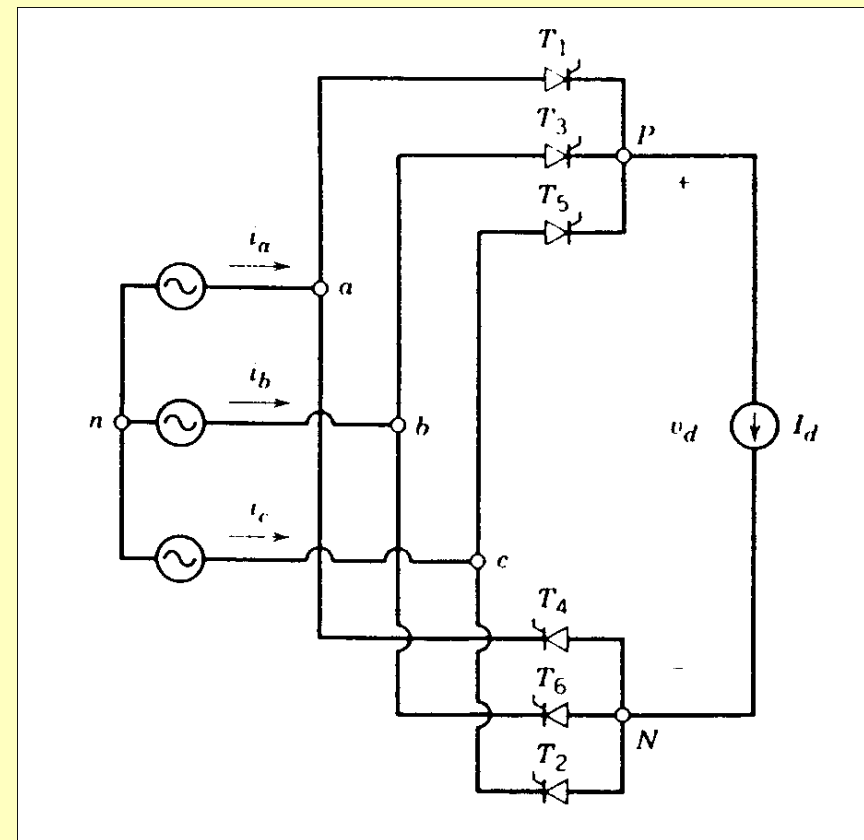
1. Summary from MM3
2. Three phase converter ($L_s = 0$)
3. Three phase converter ($L_s \neq 0$)
4. Characteristics
5. Inverter mode
6. Notching
7. Exercises

2. Three phase converter ($L_s = 0$)

Circuit

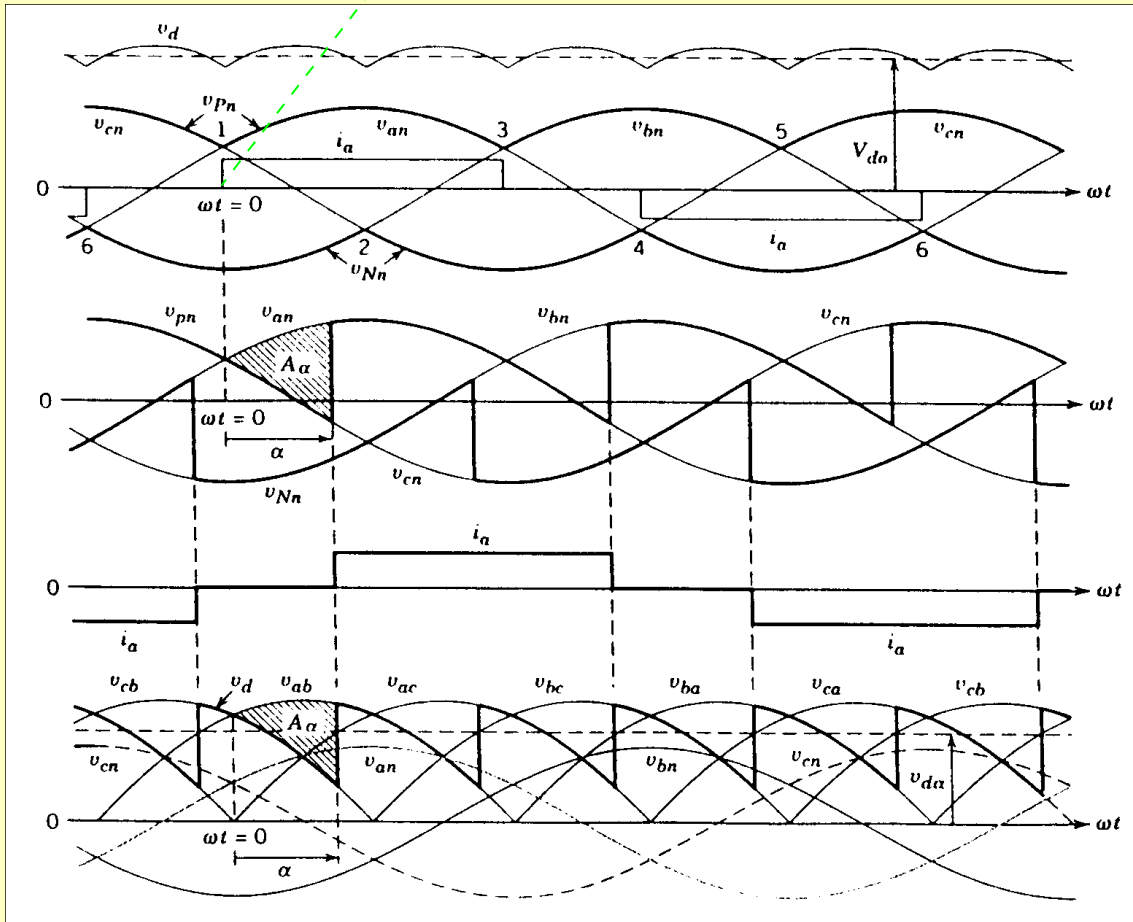


Simplified



2. Three phase converter ($L_s = 0$)

Curves



Average voltage

$$V_{d\alpha} = V_{do} - \frac{A_\alpha}{\pi/3}$$

$$v_{ac} = \sqrt{2}V_{LL}\sin \omega t$$

$$A_\alpha = \int_0^\alpha \sqrt{2}V_{LL}\sin \omega t d(\omega t) = \sqrt{2}V_{LL}(1 - \cos \alpha)$$

$$V_{d\alpha} = \frac{3\sqrt{2}}{\pi} V_{LL}\cos \alpha = 1.35V_{LL}\cos \alpha = V_{do}\cos \alpha$$

$$V_{do} = 1.35V_{LL}$$

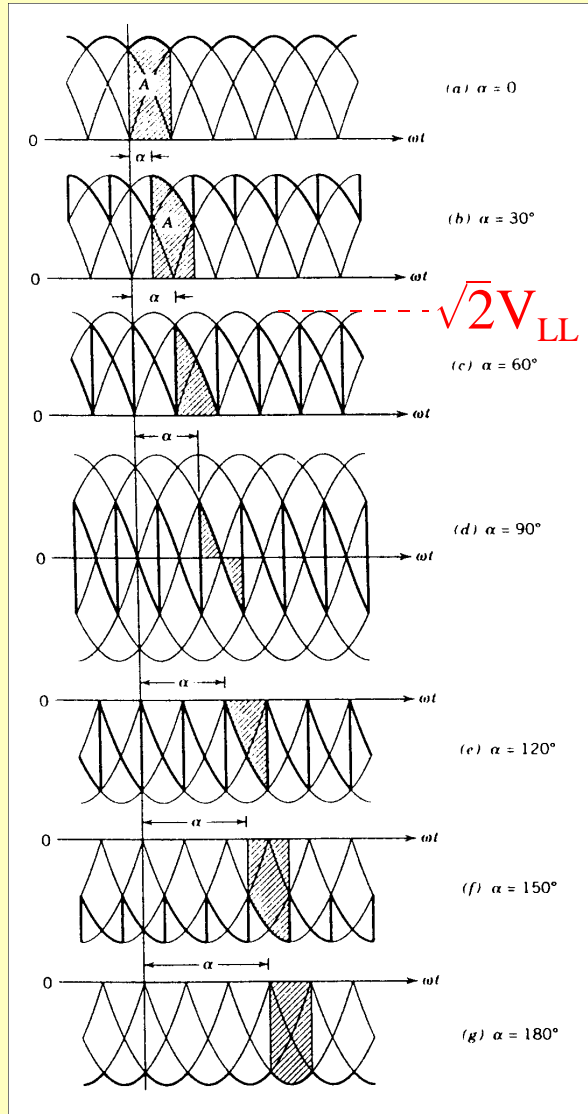
Power

$$P = V_d I_d = 1.35V_{LL} I_d \cos \alpha$$

$|V_{LL}|$

2. Three phase converter ($L_s = 0$)

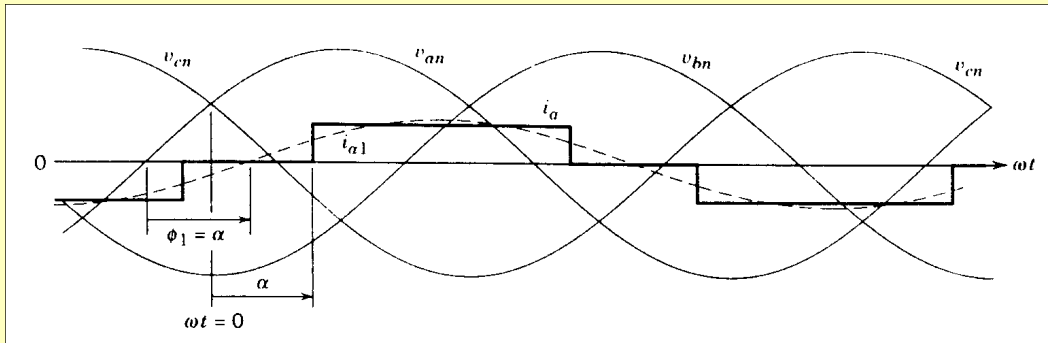
DC voltage as function of delay angle α



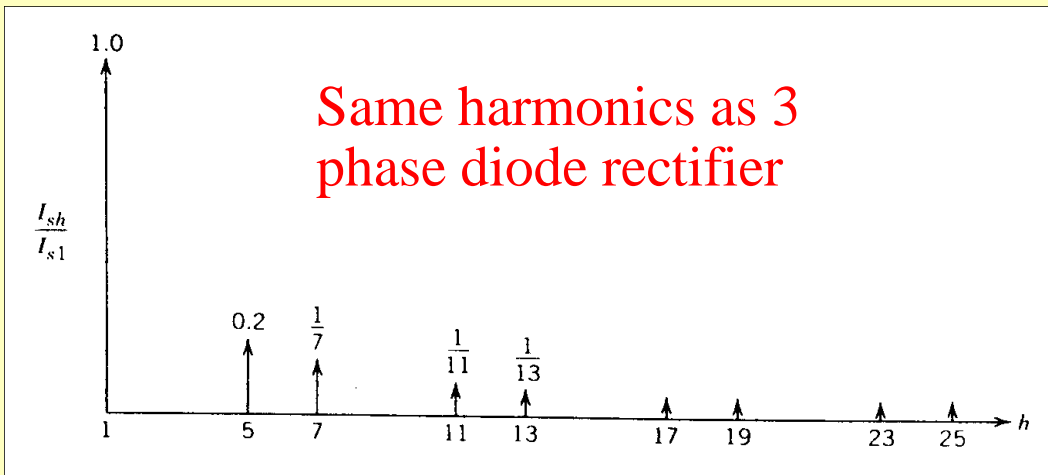
$$V_{d0} = 1.35V_{LL}\cos(\alpha)$$

2. Three phase converter ($L_s = 0$)

Line currents



Harmonics



Currents by Fourier coefficients

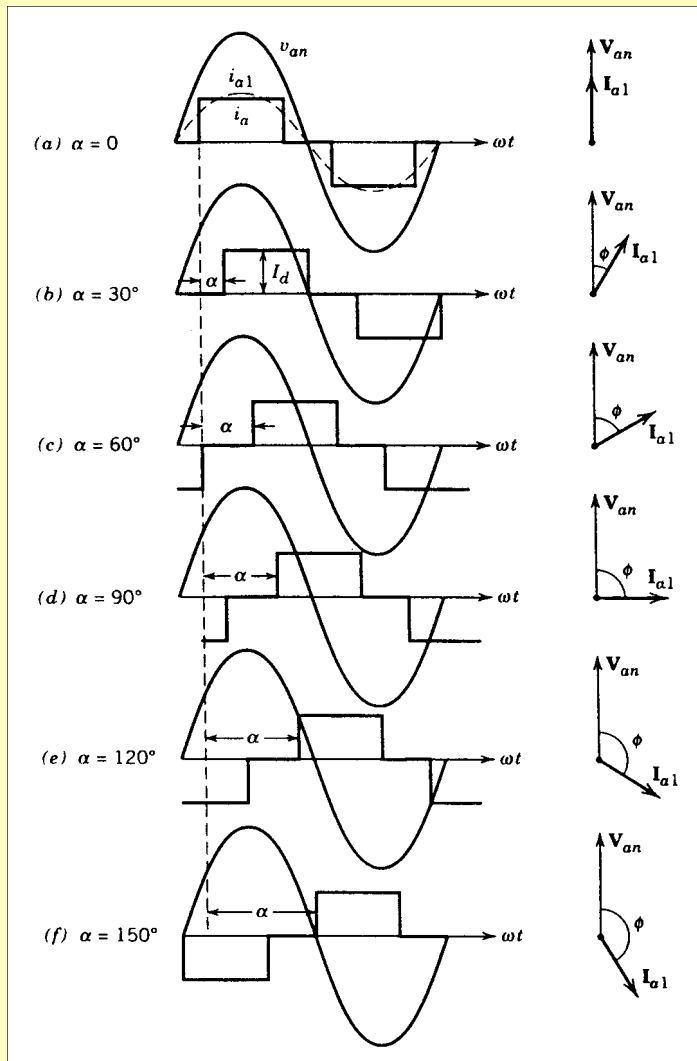
$$i_a(\omega t) = \sqrt{2}I_{s1}\sin(\omega t - \alpha) - \sqrt{2}I_{s5}\sin[5(\omega t - \alpha)] - \sqrt{2}I_{s7}\sin[7(\omega t - \alpha)] \\ + \sqrt{2}I_{s11}\sin[11(\omega t - \alpha)] + \sqrt{2}I_{s13}\sin[13(\omega t - \alpha)] \\ - \sqrt{2}I_{s17}\sin[17(\omega t - \alpha)] - \sqrt{2}I_{s19}\sin[19(\omega t - \alpha)] \dots$$

RMS Value of line current

$$I_s = \sqrt{\frac{2}{3}}I_d = 0.816I_d$$

Power

2. Three phase converter ($L_s = 0$)



DPF

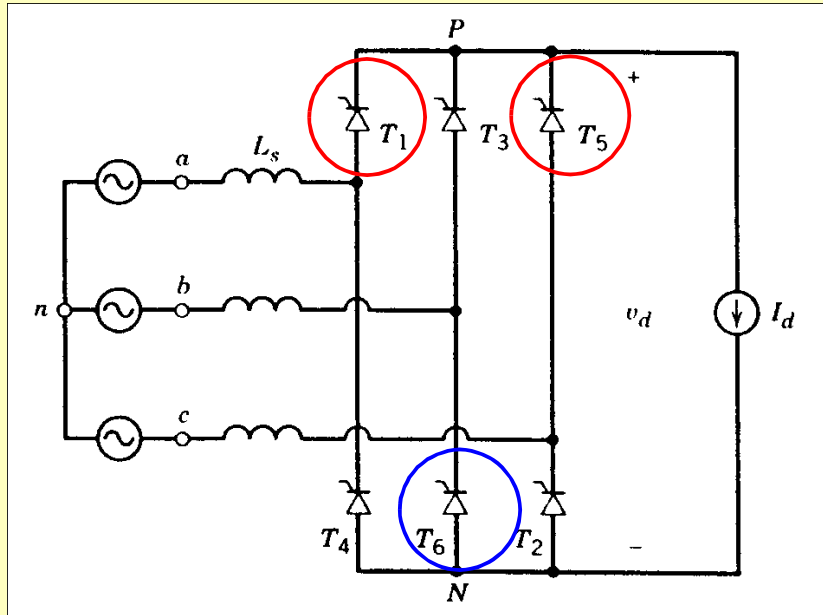
$$\text{DPF} = \cos \phi_1 = \cos \alpha$$

PF

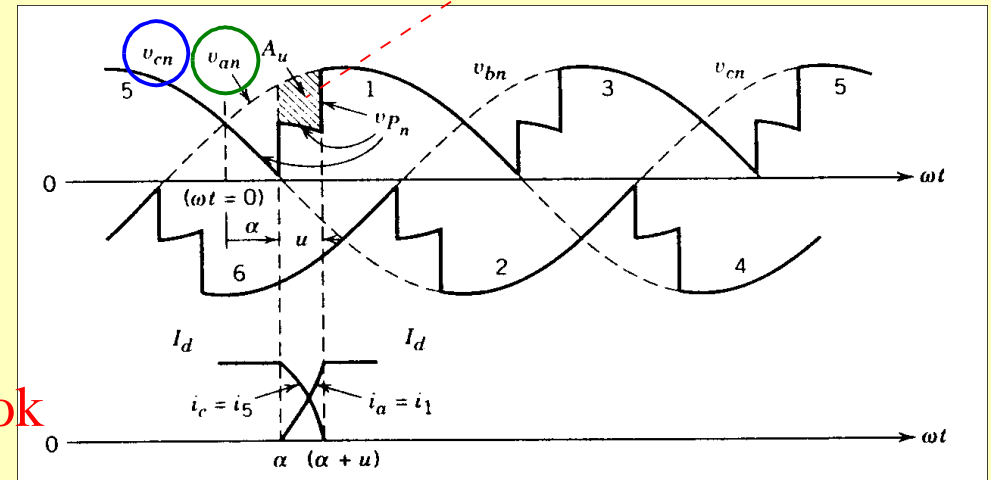
$$\text{PF} = \frac{3}{\pi} \cos \alpha$$

Commutation

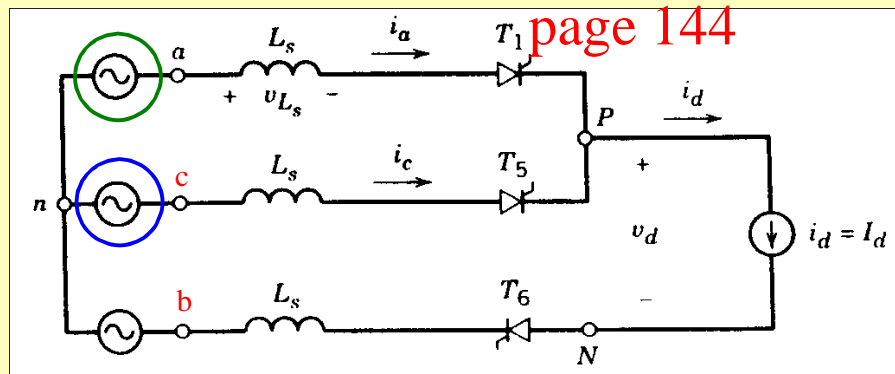
3. Three phase converter ($L_s \neq 0$)



$T_5 + T_6 \rightarrow T_1 + T_6$ Voltage divider
Waveforms



Commutation circuit Note : Error in book page 144



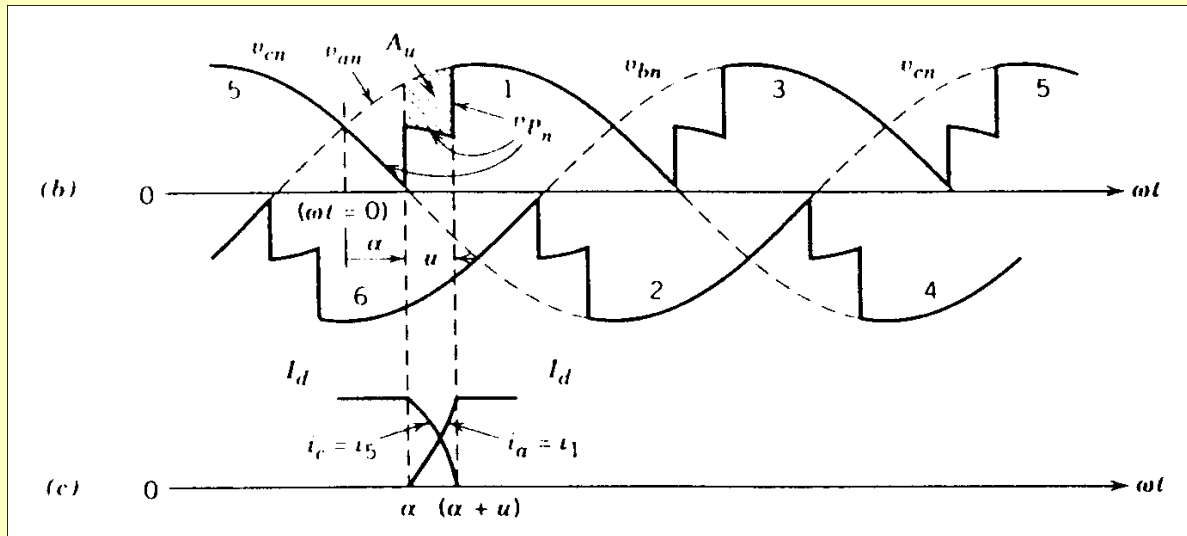
Requirements (VDE-German)

$$\omega L_s \geq 0.05 \frac{V_{LL}/\sqrt{3}}{I_{s1}}$$

Short circuit impedance

3. Three phase converter ($L_s \neq 0$)

Waveforms



Commutation interval

$$v_{Pn} = v_{an} - v_{L_s}$$

$$A_u = \int_{\alpha}^{\alpha+u} v_{L_s} d(\omega t) \Rightarrow$$

$$v_{L_s} = L_s \frac{di_a}{dt}$$

$$A_u = \omega L_s \int_0^{I_d} di_a = \omega L_s I_d$$

$$v_d = \frac{3\sqrt{2}}{\pi} V_{LL} \cos \alpha - \frac{3\omega L_s}{\pi} I_d$$

$$v_{Pn} = v_{an} - L_s \frac{di_a}{dt}$$

$$v_{Pn} = v_{cn} - L_s \frac{di_c}{dt}$$

$\frac{A_u}{3/\pi}$

Commutation interval

$$v_{Pn} \text{ (during commutation)} = \frac{v_{an} + v_{cn}}{2} - \frac{L_s}{2} \left(\frac{di_a}{dt} + \frac{di_c}{dt} \right)$$

$$\int_0^{I_d} di_a = \sqrt{2} \frac{V_{LL}}{2\omega L_s} \int_{\alpha}^{\alpha+u} \sin \omega t d(\omega t)$$

or

$$\cos(\alpha + u) = \cos \alpha - \frac{2\omega L_s}{\sqrt{2} V_{LL}} I_d$$

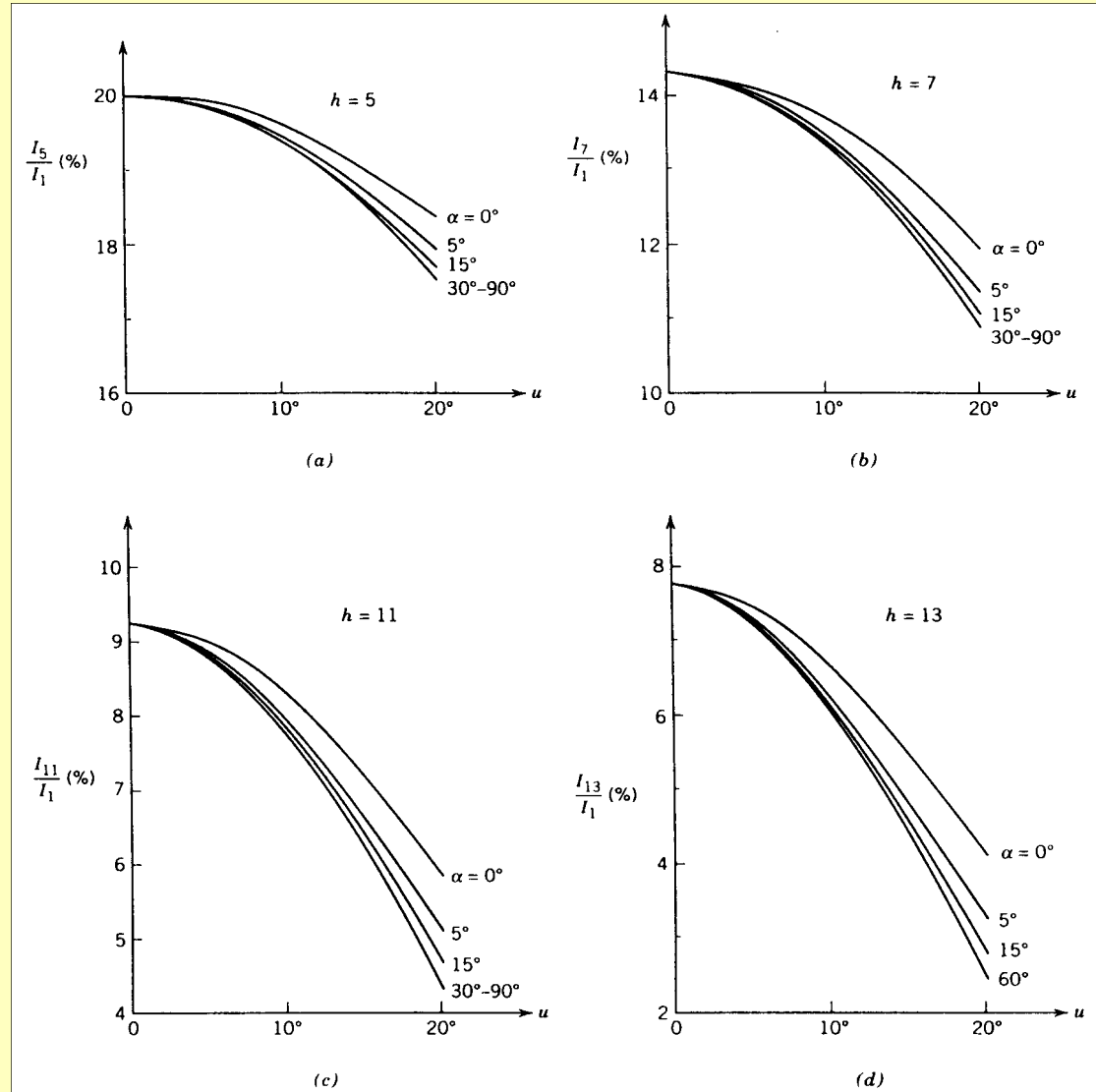
$$\frac{di_a}{dt} = -\frac{di_c}{dt} \Rightarrow$$

$$v_{pn} = \frac{v_{an} + v_{cn}}{2}$$

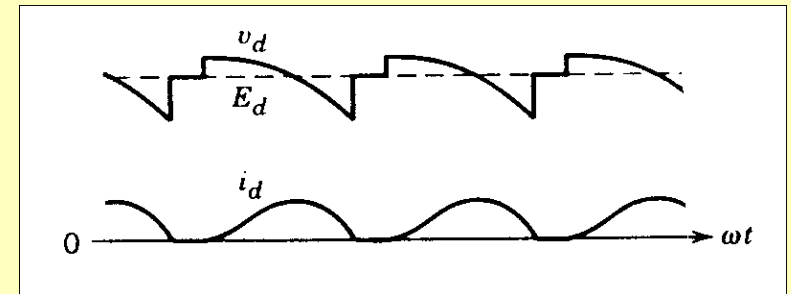
u depends of α , L_s , I_d

DC-motor

4. Characteristics



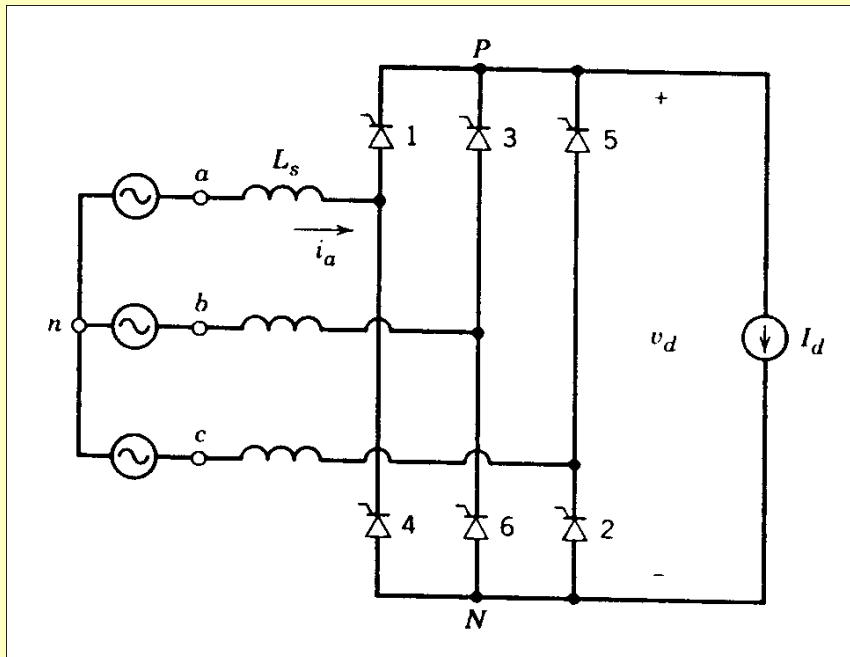
Discontinuous operation (emf)



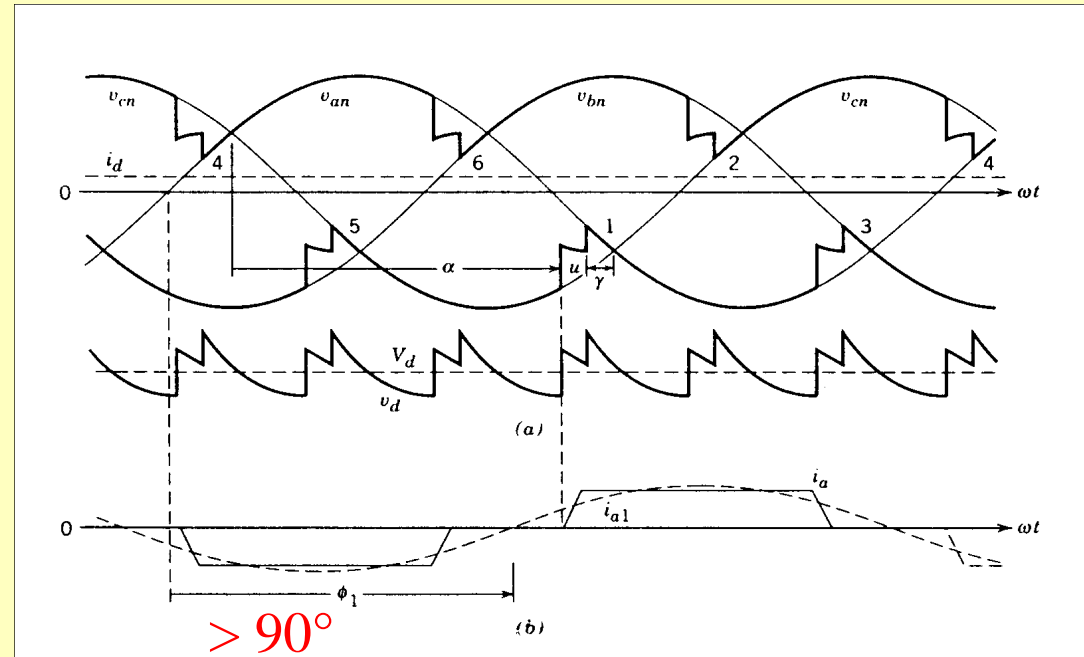
5. Inverter mode

$$\alpha > 90^\circ \text{ \& \ } \alpha < 180^\circ$$

Circuit

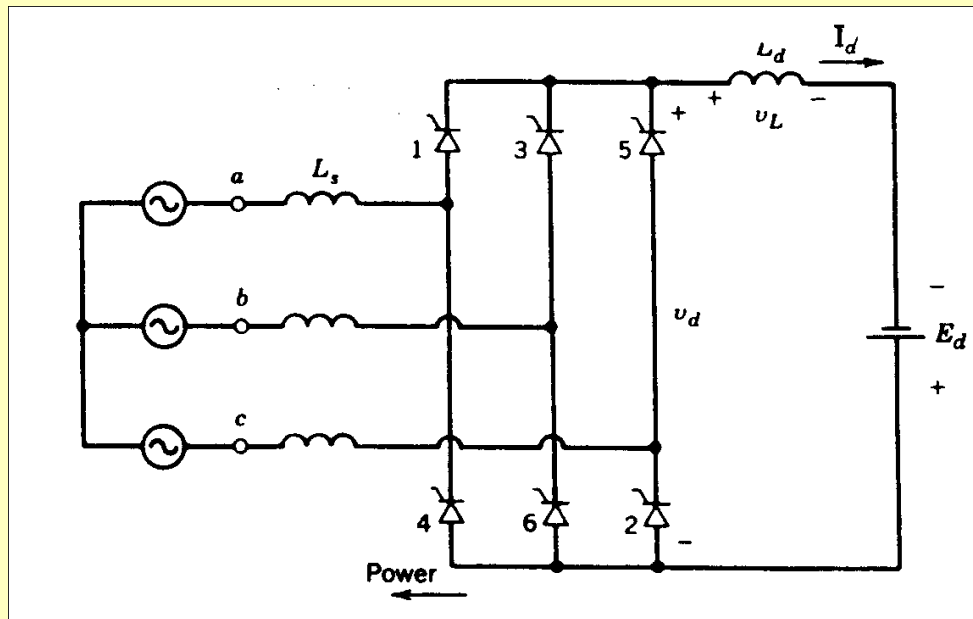


Waveforms

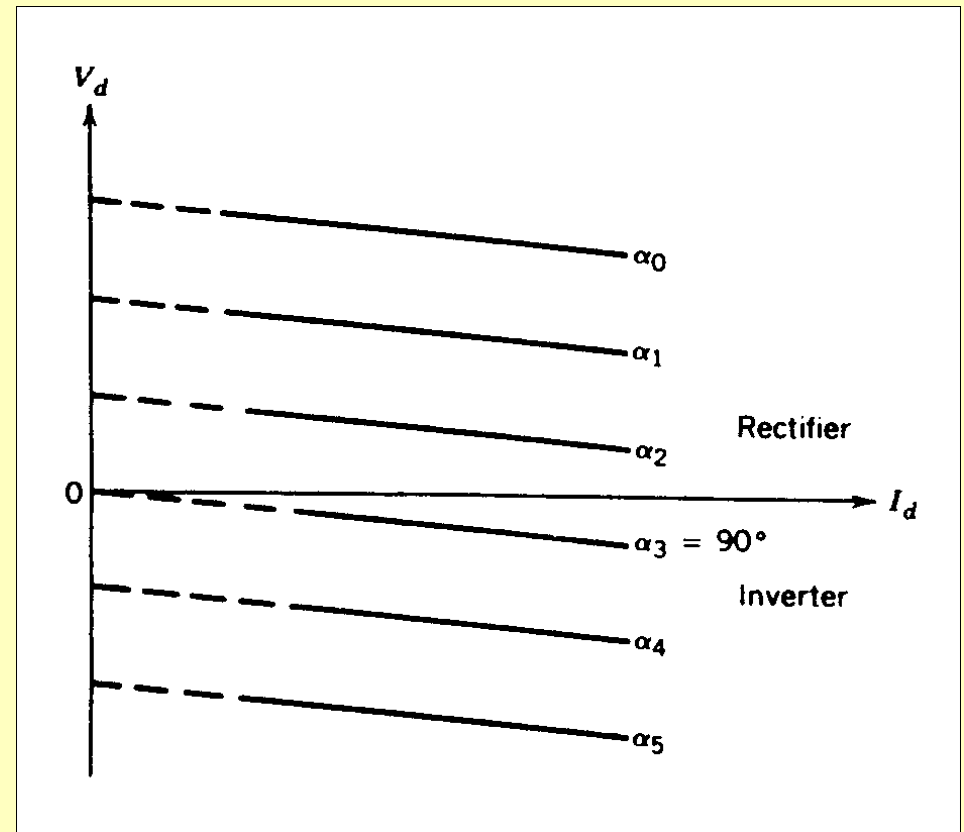


5. Inverter mode

Circuit



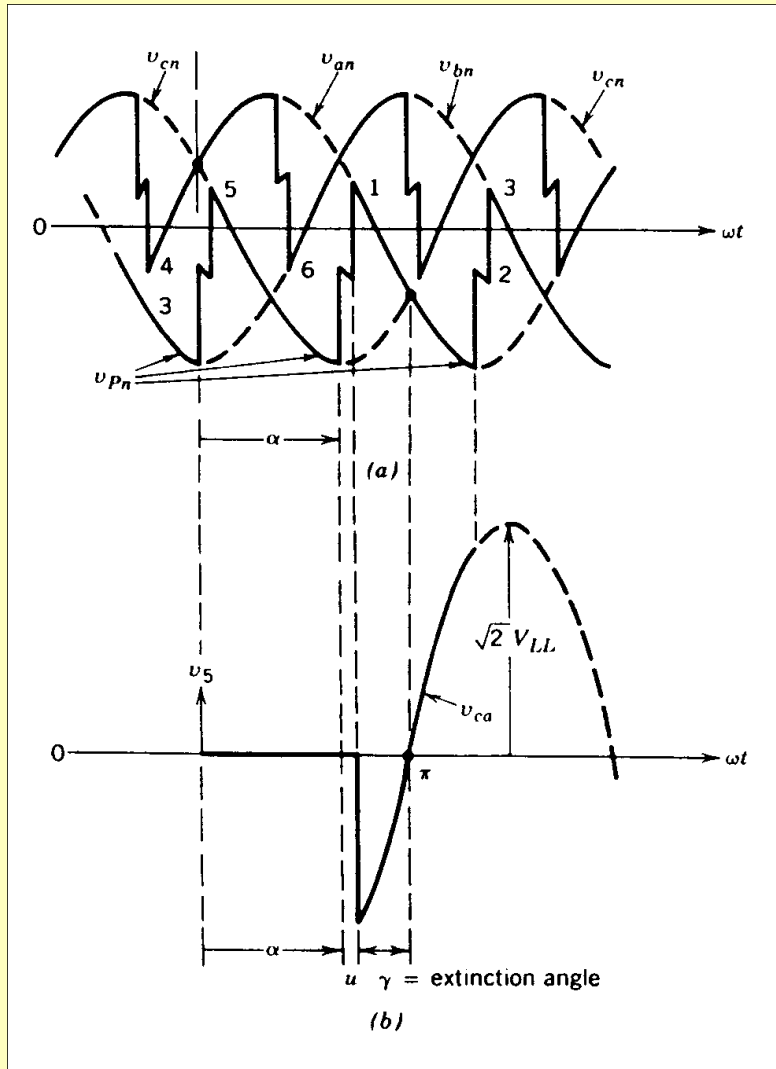
Characteristic



Load depend due to L_s

Thyristor voltage

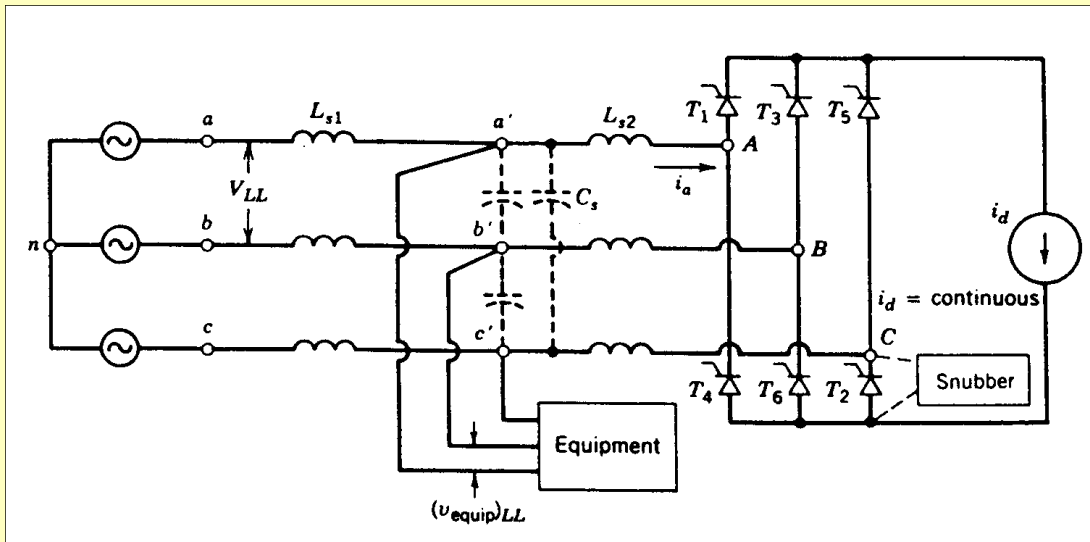
5. Inverter mode



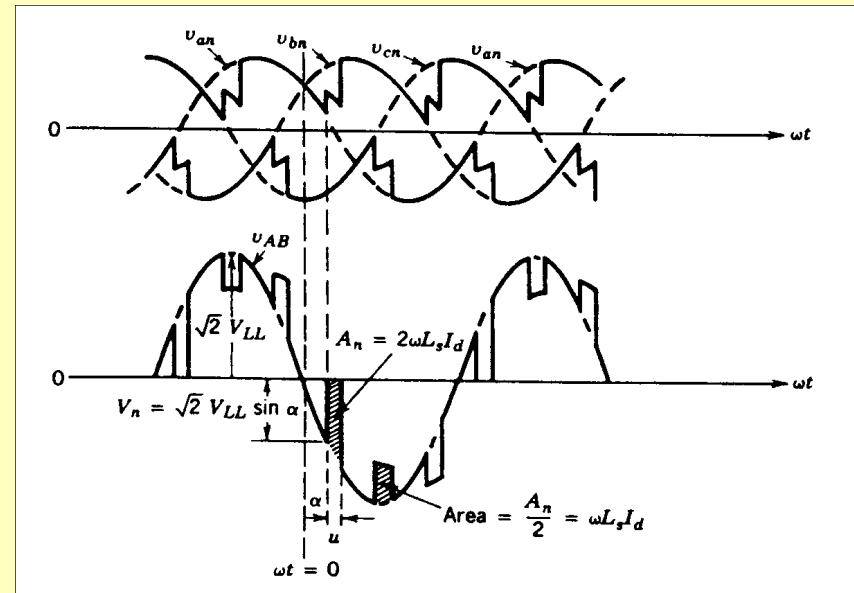
Extinction angle γ (time) has to be larger than the Thyristor turn-off time t_q

6. Notching

Circuit and practical connection



“Equipment” waveforms



Guidelines (IEEE 519-1981)

Class	Line Notch Depth $\rho(\%)$	Line Notch Area ($V \cdot \mu s$)	Voltage Total Harmonic Distortion (%)
Special applications	10	16,400	3
General system	20	22,800	5
Dedicated system	50	36,500	10

7. Exercises

Exercise 6.12

Exercise 6.21

Exercise 6.22

Exercise 6.24