POWER ELECTRONICS I

AC-DC Converters

Three-Phase Rectifiers

Dr. Islam Mohamed

Electrical Engineering Department
Shoubra Faculty of Engineering, Benha University
Islam.ahmed@fen.bu.edu.eg

Questions Lecture two

Q_1) what are the rating values of the Thyrsitors in the converter?

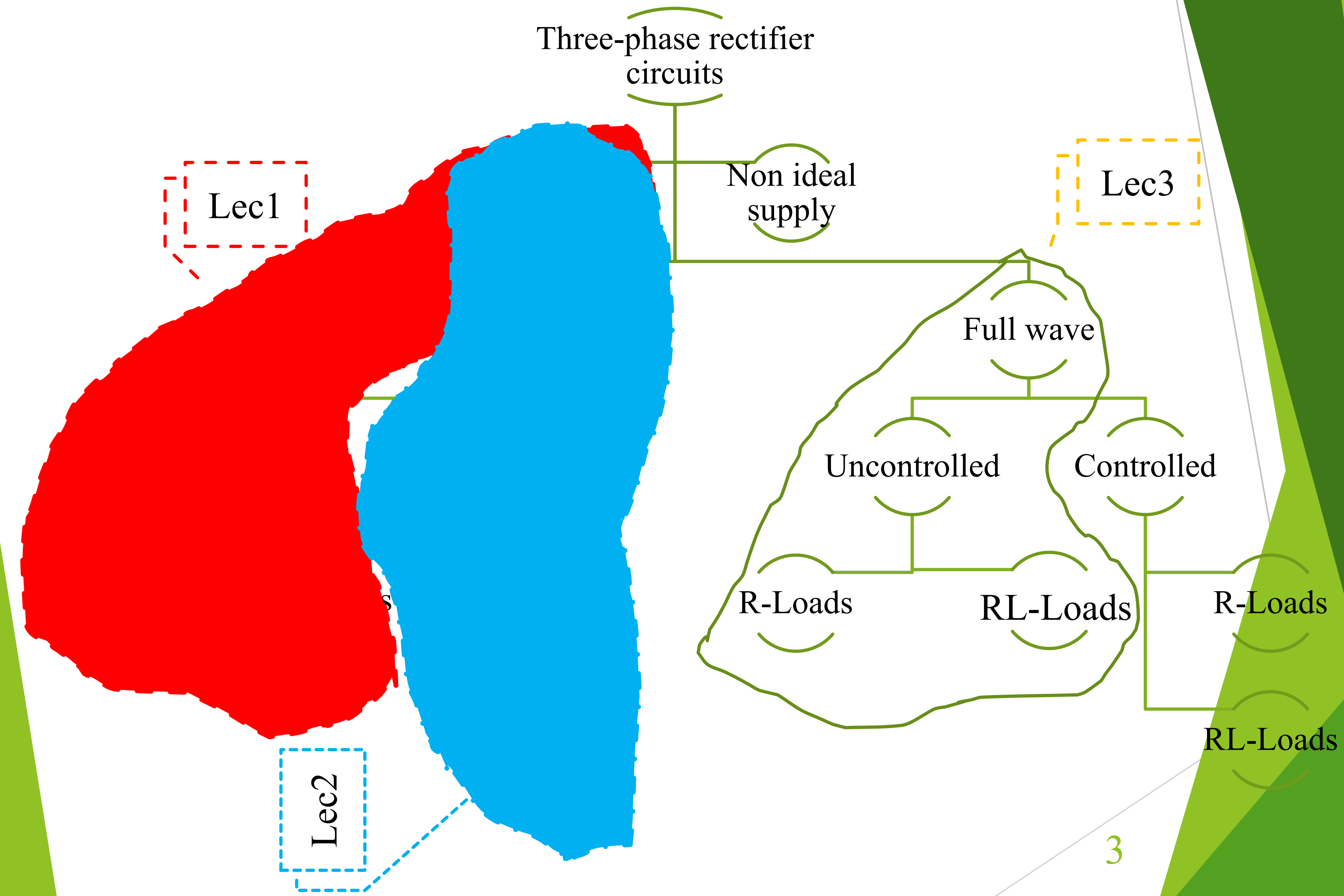
Q_2) Draw the waveforms of the Thyristor voltage and current

Q_3) What is the control range of α in the pervious case studies?

Q_4) Write an expression of the instantaneous load current for all pervious case studies

Q_5) what are the rating values of the freewheeling diode in the three-phase half-wave control rectifier with highly inductive loads?

Three-phase rectifier Plan



Lecture Four: Three-phase Full wave uncontrolled rectifiers circuits

Construction	• Circuit diagram • Components
Operation	• Output waveforms • R-load and Highly inductive load
Analysis	• Analysis of the circuit with R-load • Analysis of the circuit with highly inductive load
End	• Summery • Questions

General

Why three-phase Full-wave rectifiers ?

- Three-phase full wave rectifiers provide higher average output voltage compared to the all pervious rectifier circuits.
- The harmonics frequency of output voltage ripples in a three-phase full wave rectifier circuits is higher compared to the pervious rectifier. Thus, the three-phase rectifier requires a smaller filter with a lower cost.
- Three-phase full wave rectifier circuits don't produce dc current component in the source. so the transformer is not saturated.
- The rectification efficiency is the highest

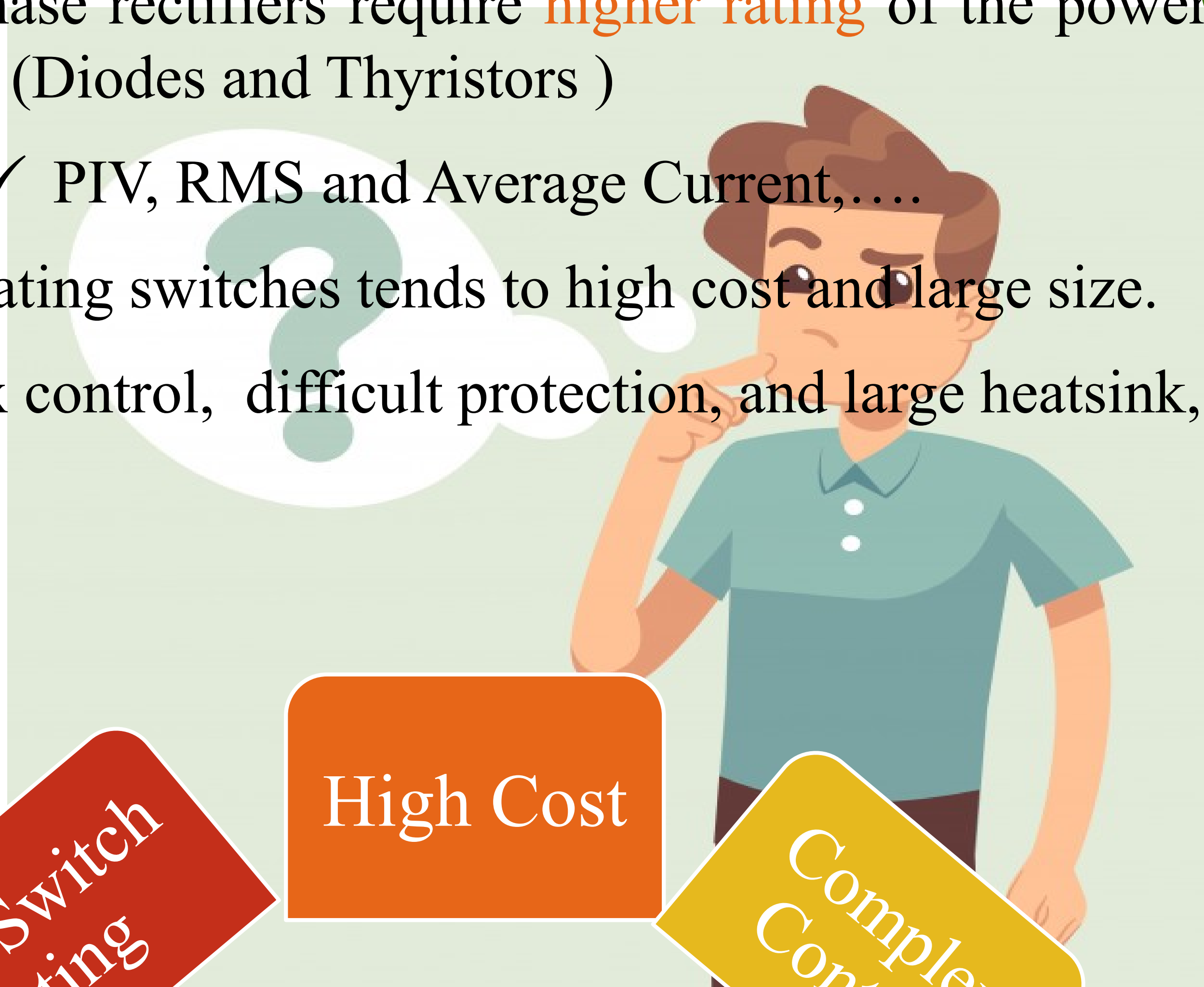
High efficiency

Large DC output

Less output ripples

Disadvantages:

- Three-phase rectifiers require higher rating of the power electronics switches (Diodes and Thyristors)
  - ✓ PIV, RMS and Average Current,….
- Higher rating switches tends to high cost and large size.
- Complex control, difficult protection, and large heatsink,



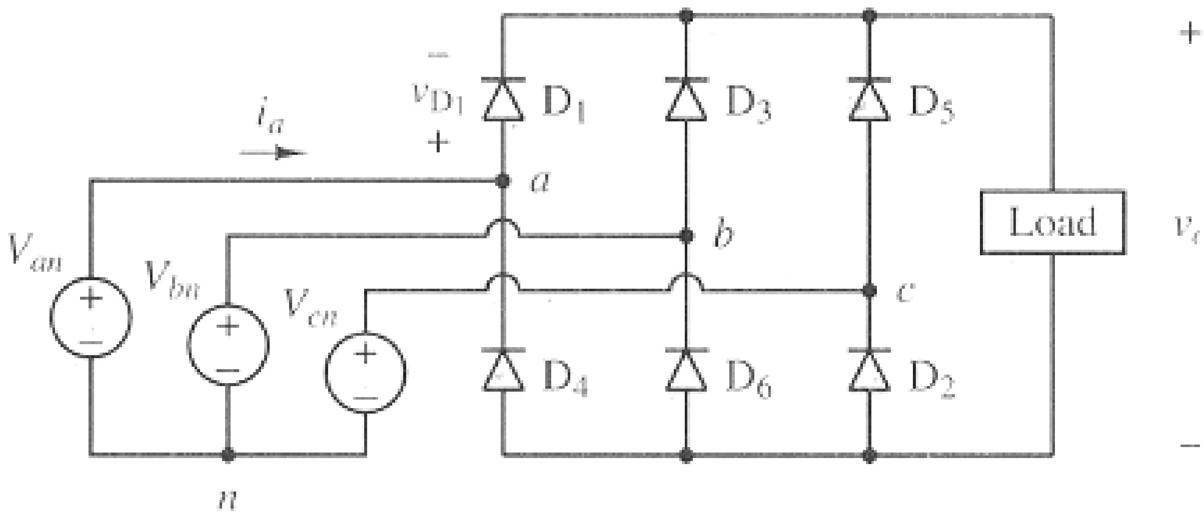
High Switch Rating

High Cost

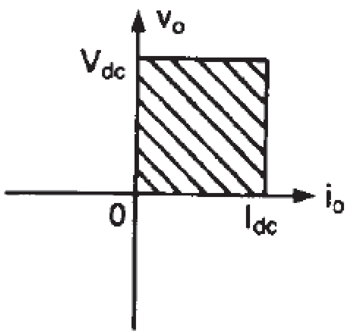
Complex Control

Construction

Power circuit and its components



(a)



(b) Quadrant

1- Two diodes must be forward at any instant (D_1,D_3,D_5) with (D_2,D_4,D_6).

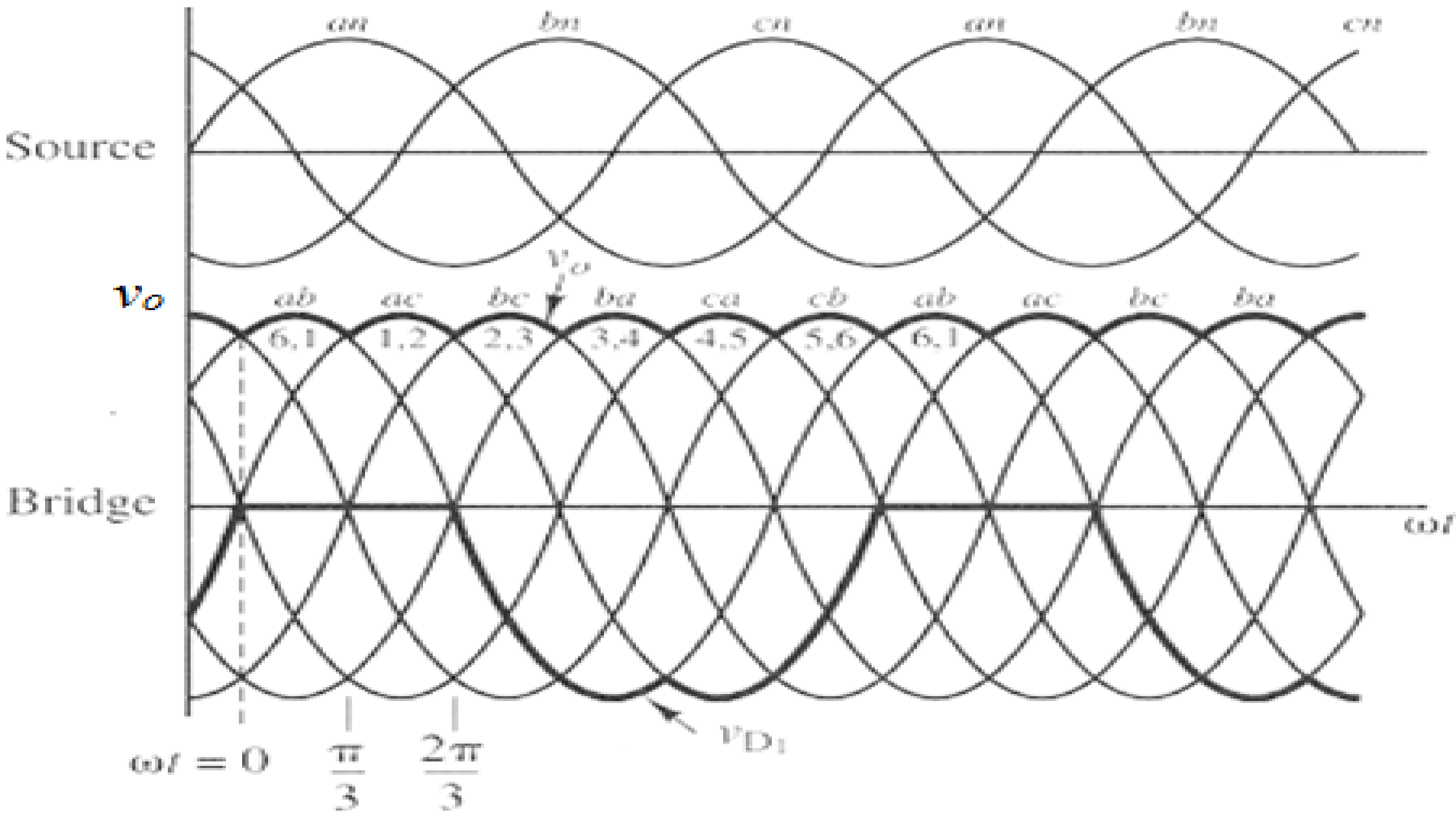
2- Line voltage will be applied to the load at any instant.

3- A transition of the highest line-to-line voltage must take place every $360^0 / 6 = 60^0$

Operation

Output Voltage waveforms

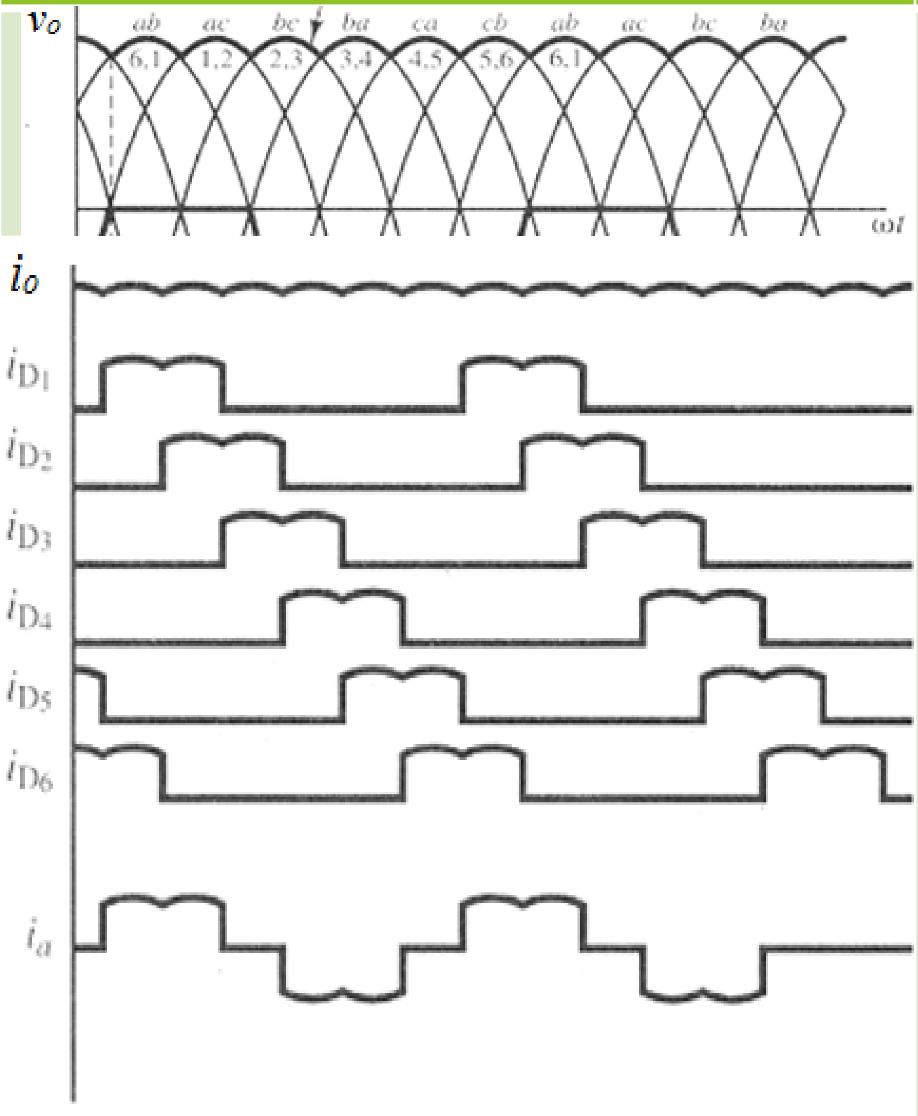
R-Loads	Highly inductive Loads

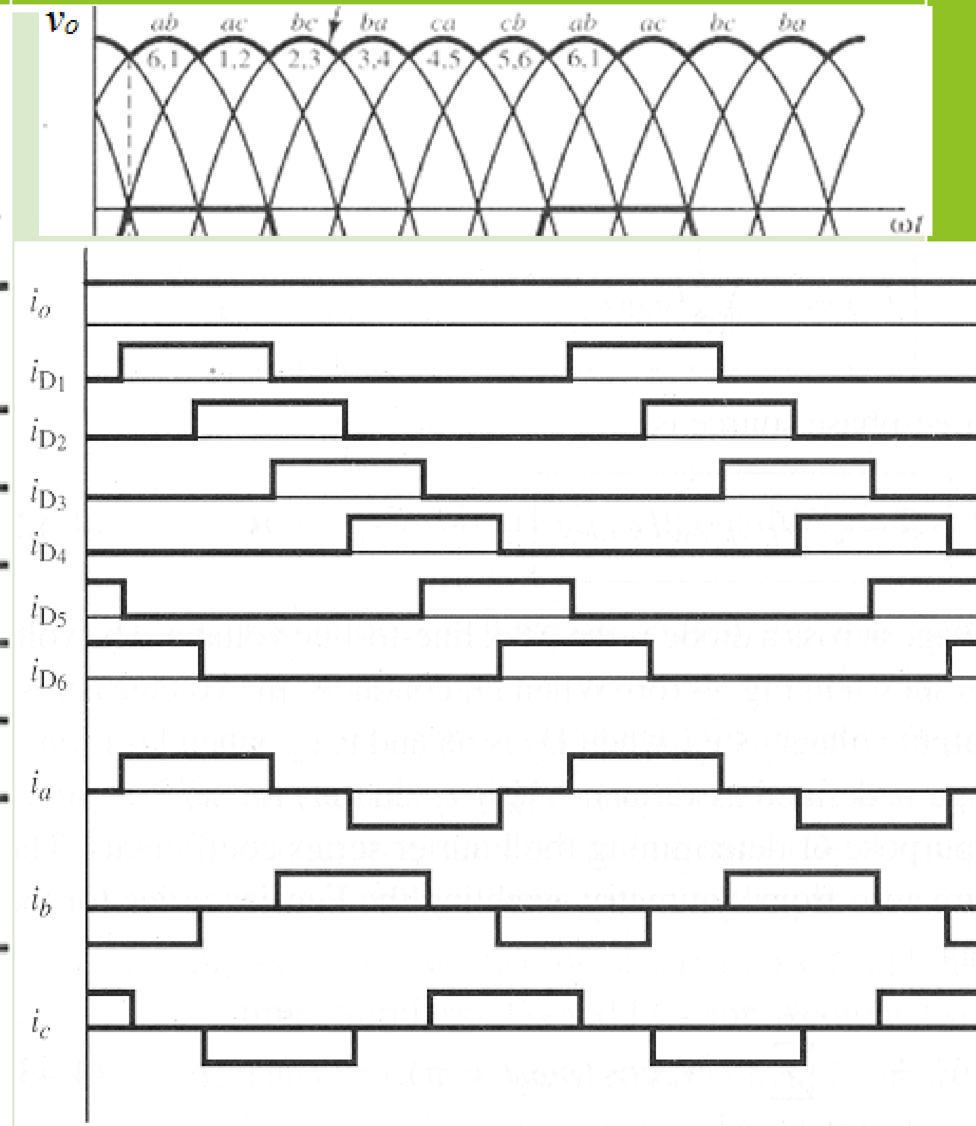


Operation

Currents waveforms

R-Loads	Highly inductive Loads



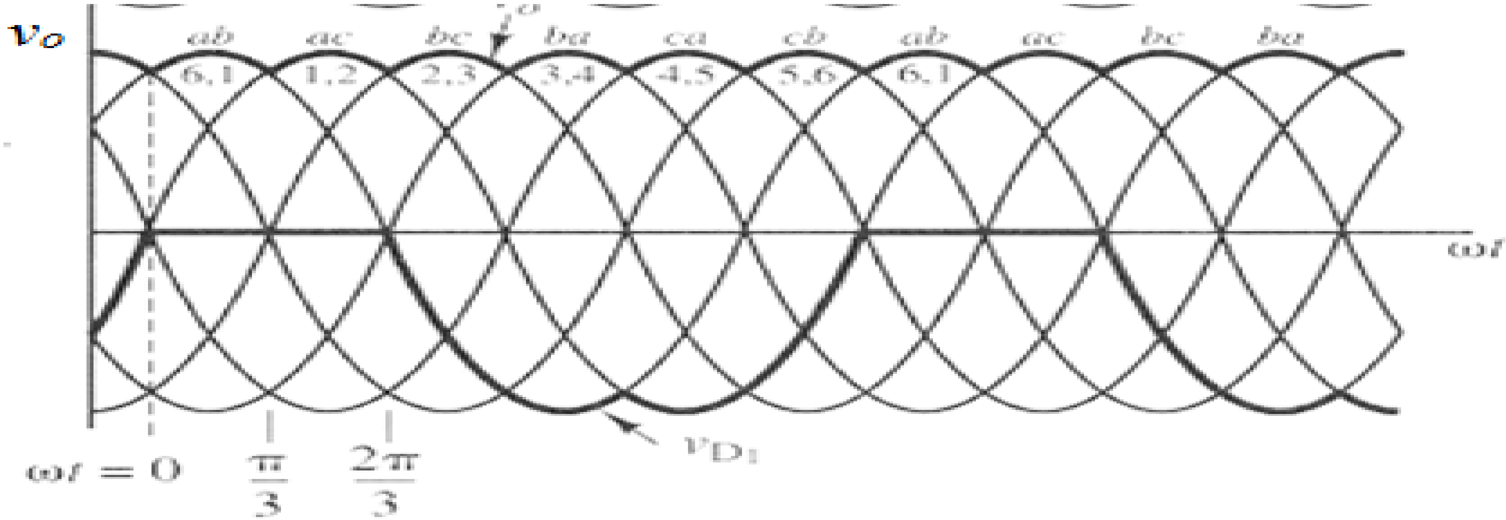


Analysis:

1- Supply voltages:

$V_{ab}(\omega t) = V_{ml}\sin(\omega t + \pi/6)$, $V_{bc}(\omega t) = V_{ml}\sin(\omega t - \pi/2)$, $V_{ca}(\omega t) = V_{ml}\sin(\omega t - 7\pi/6)$

2- Output average voltage:



$$V_{o.avg} = \frac{1}{\pi/3}\int_{\pi/6}^{\pi/2} v_{ab}\, d\omega t = \frac{1}{\pi/3}\int_{\pi/3}^{2\pi/3} V_{m,L-L}\sin wt\, d(wt) = \frac{3V_{m,L-L}}{\pi}$$

$$= 0.95V_{m,L-L}$$

Analysis:

3- RMS Load voltage

- Since the output voltage is periodic with period 1/6 of the ac supply voltage, the harmonics in the output are of order 6kω, k=1,2,3,…

- Advantage：output is inherently like a dc voltage, and the high-frequency low-amplitude harmonics enable filters to be effective.

$$v_0(t) = V_{o,avg} + \sum_{n=6,12,18..}^{\infty} V_n \cos(nw_0 t + \pi)$$

$$V_n = \frac{6\ V_{m,L-L}}{\pi(n^2-1)} \qquad , \qquad n = 6, 12, 18, \ldots$$

$$V_{o,rms} = \sqrt{V_{o,avg}^2 + \left(V_6 \middle/ \sqrt{2} \right)^2 + \left(V_{12} \middle/ \sqrt{2} \right)^2}$$

Analysis:

4- Average load current For R & RL-Loads

For both cases:

$$I_{o\_avg} = \frac{Vo,avg}{R}$$

5- RMS Load current

For Resistive load:

$$I_{o,rms} = V_{o,rms}/R$$

For Highly in[illegible]tive load:

$I_{o,rms} = V_{o,rm}$ [illegible] $/Z$

For Highly inductive load:

$$I_{o,rms} = I_{o,avg}$$

,

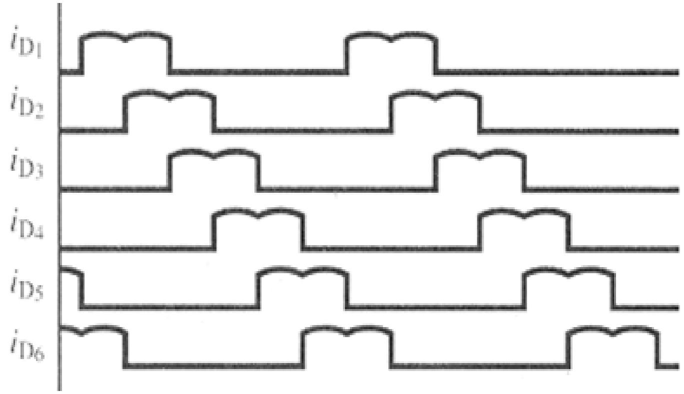
Analysis:

6- Diode currents

- Each diode conducts one-third of the time, resulting in

$$I_{D,avg} = \frac{1}{3} I_{o,avg}$$

$$I_{D,rms} = \frac{1}{\sqrt{3}} I_{o,rms}$$

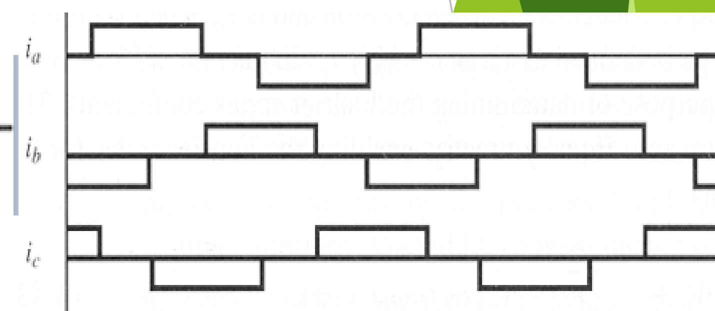


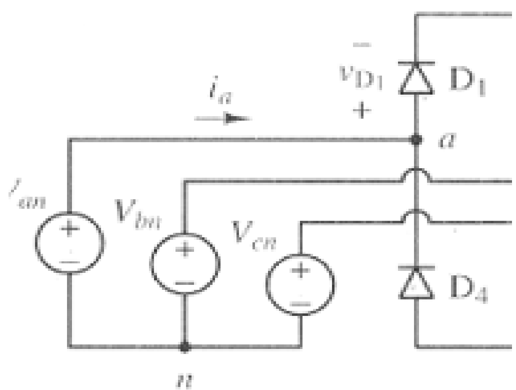
7- RMS supply current

$$i_a = i_{D1} - i_{D4}$$

$$i_b = i_{D3} - i_{D6}$$

$$i_c = i_{D5} - i_{D2}$$





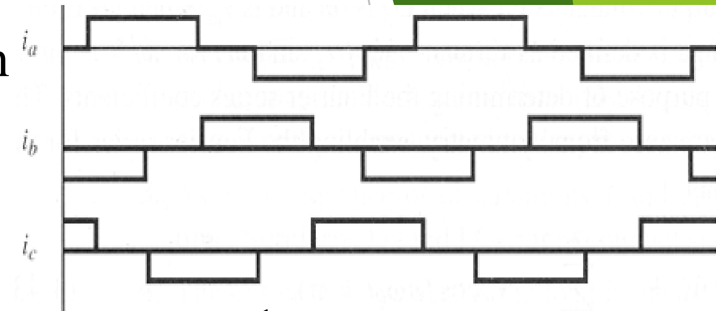
$$I_{S,rms} = \sqrt{\frac{2}{3}} I_{o,rms}$$

Analysis:

8- The harmonics in the supply currents

- Supply current waveform is: odd, f(x)=-f(x+180), so using Fourier

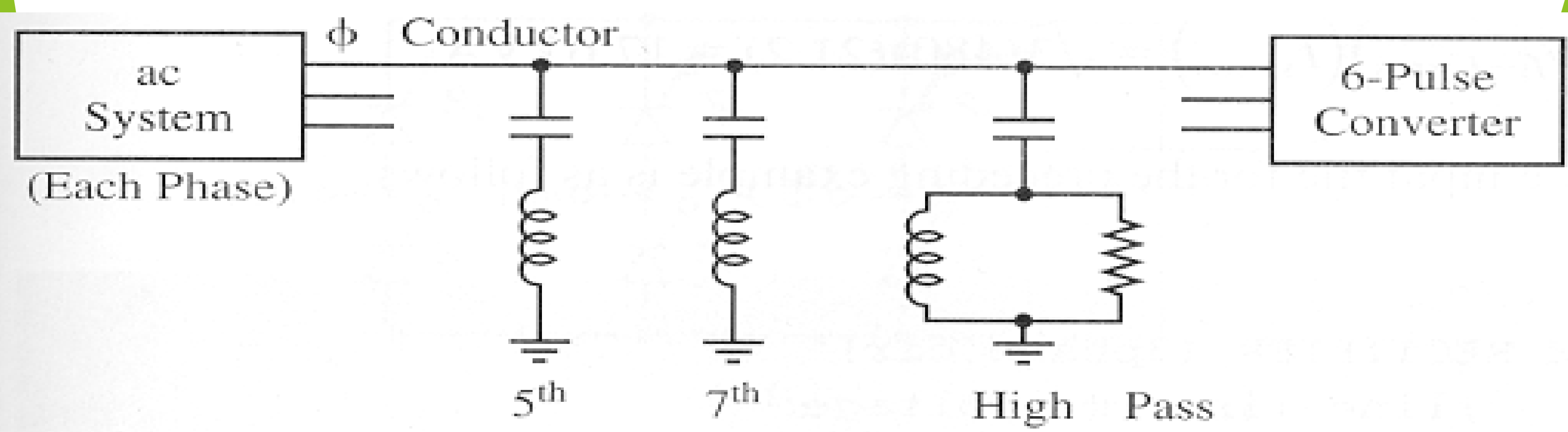
The fundamental frequency of the ac system and harmonics of order:



$$6k \pm 1 \quad \text{where } k=1,2,3,....$$

$$i_a = \frac{2\sqrt{3}}{\pi} I_o(\cos\omega_o t - \frac{1}{5}\cos 5\omega_o t + \frac{1}{7}\cos 7\omega_o t - \frac{1}{11}\cos 11\omega_o t + \frac{1}{13}\cos 13\omega_o t + ...)$$

- To prevent harmonic currents to enter the ac system.
  - ✓ Resonant filters for 5th and 7th harmonics.
  - ✓ High-pass filters for higher order harmonics.



Analysis:

9- Output power

For R & RL Loads??

$$P_s = P_o = I_{o,rms}^2 R$$

10- Input power factor

$$pf = \frac{P_o}{S} = \frac{I_{o,rms}^2 R}{3 V_s I_{s,rms}}$$

Remember $I_{s,rms} = \sqrt{2/3}\, I_{o,rms}$

11- Converter efficiency

$$\eta = \frac{P_{dc}}{P_{o,rms}} = \frac{V_{o,avg}\, I_{o,avg}}{V_{o,rms} I_{o,rms}}$$

Questions

Q_1) what are the rating values of the Diodes in the converter?

Q_2) Calculate the rectification efficiency for R and highly inductive loads.

Q_3) what happen to the load voltage and current waveforms if a freewheeling diode is connected incase RL-loads?

Q_4) what happen to the load voltage and current waveforms if a freewheeling diode is connected incase RL-loads?