POWER ELECTRONICS I

AC-DC Converters

Three-Phase Rectifiers

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Questions Lecture 3

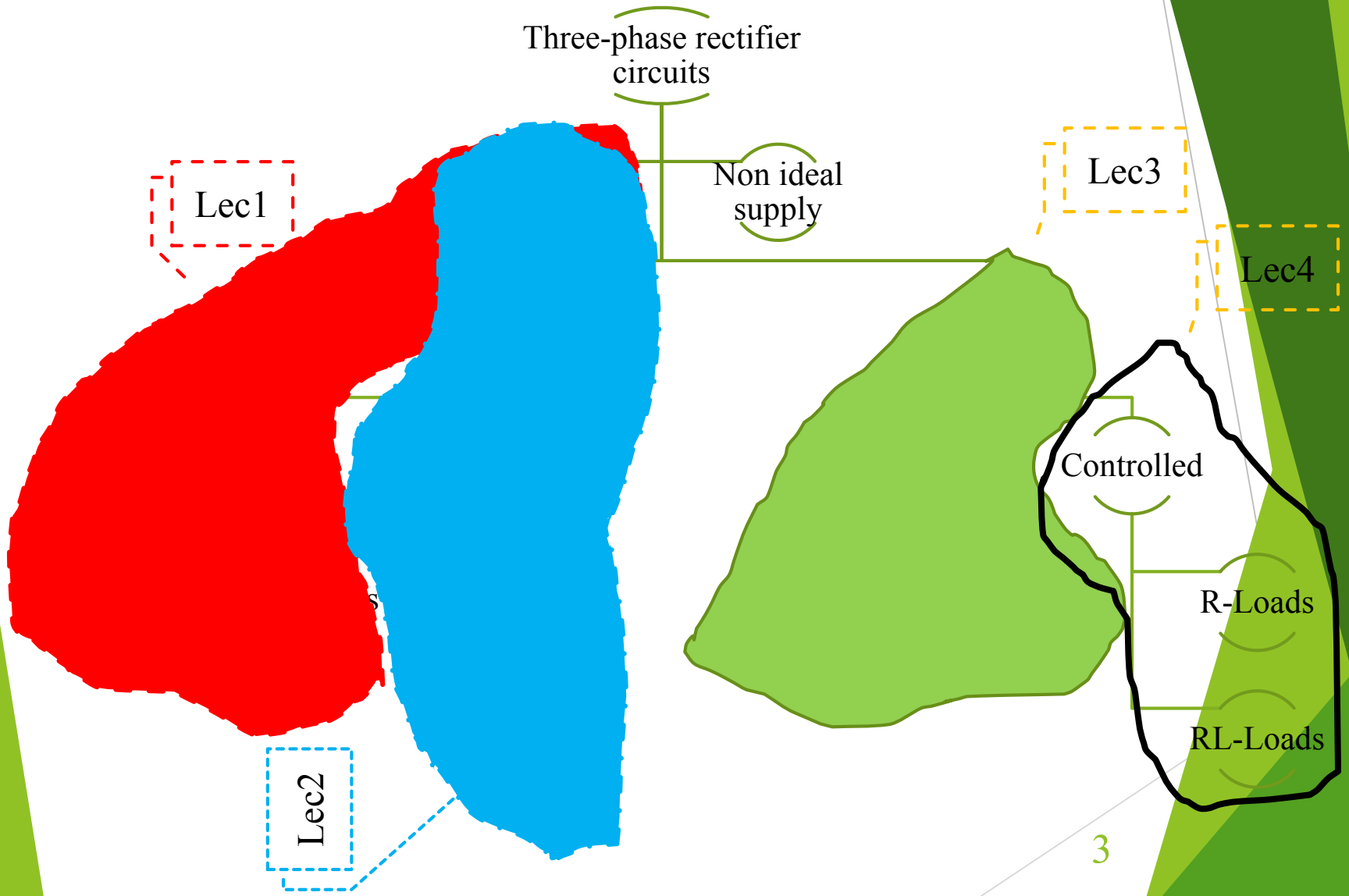
Q_1) what are the rating values of the Diodes in the converter?

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?

Three-phase rectifier Plan



Lecture Four: Three-phase Full wave Controlled rectifiers circuits

Construction
- Circuit diagram
- Components

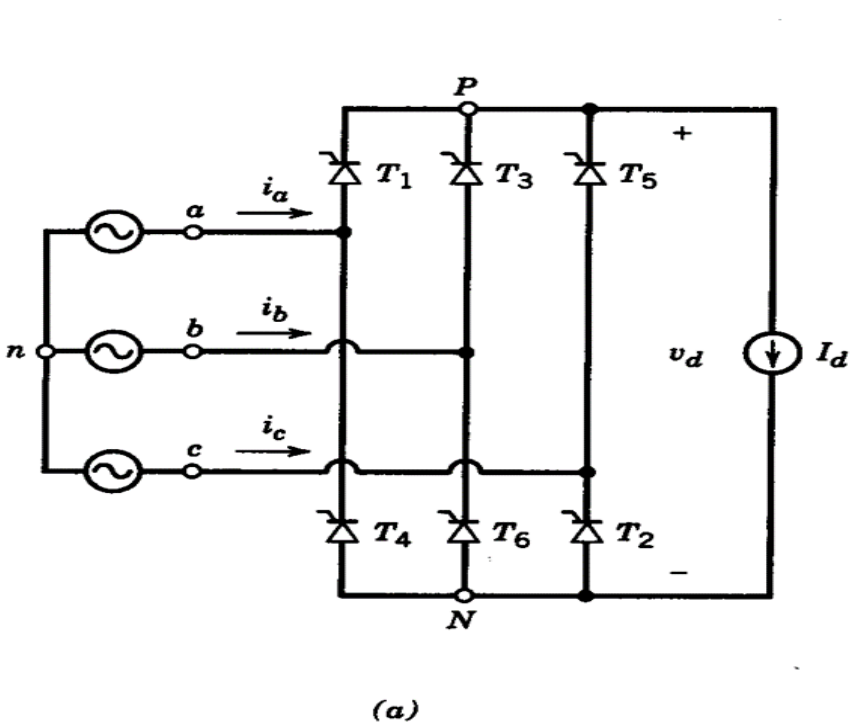
Operation
- Output waveforms
- R-load and Highly inductive load

Analysis
- Analysis of the circuit with R-load
- Analysis of the circuit with highly inductive load

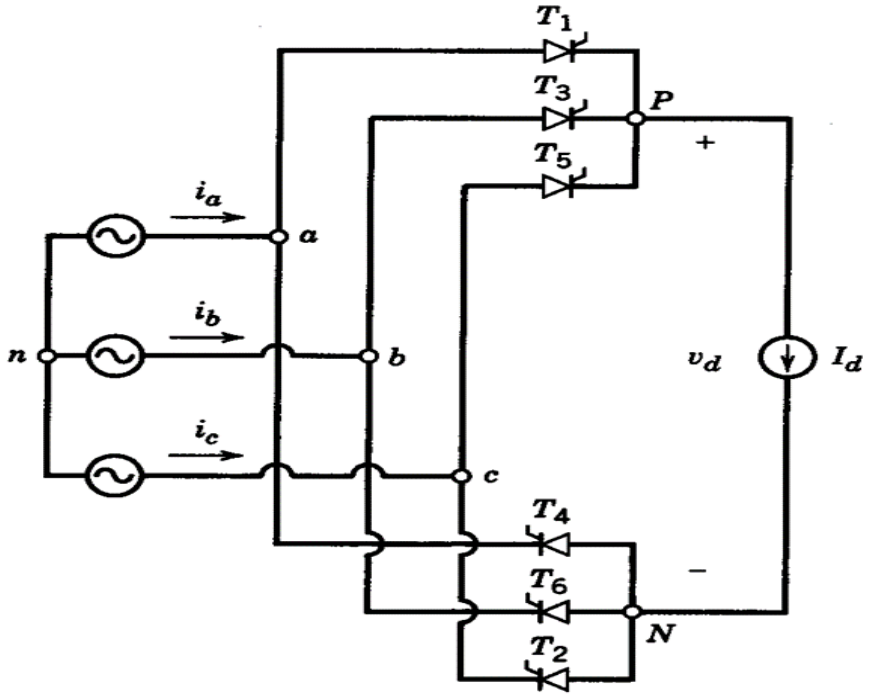
End
- Summery
- Questions

Construction

Power circuit and its components



(a)



(b)

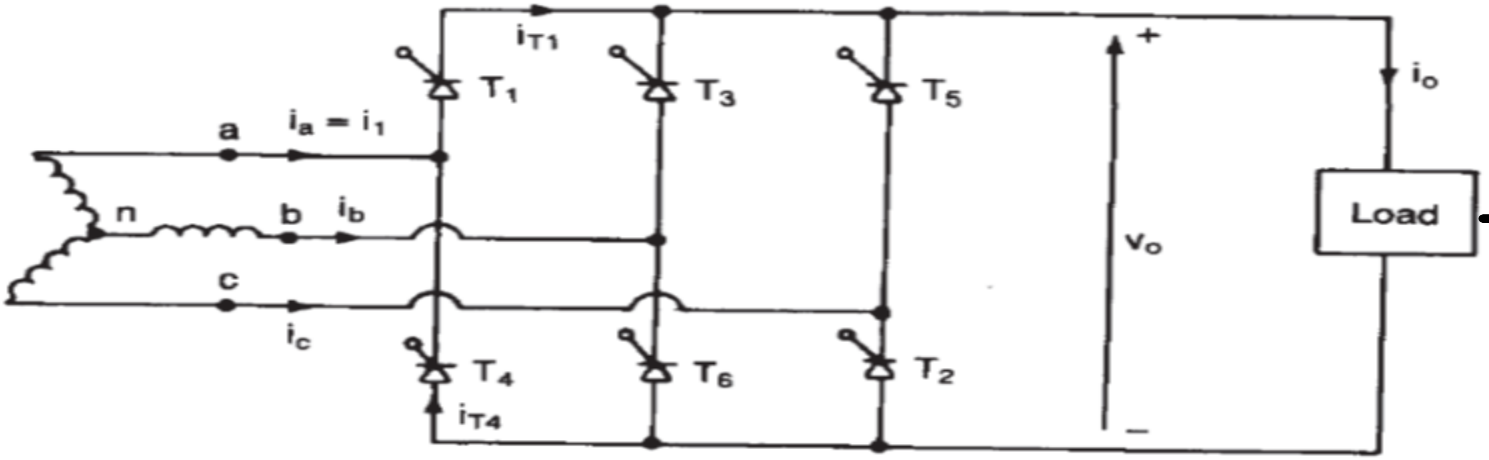
1- Two Thyristors must be forward at any instant (T_1,T_3,T_5) with (T_2,T_4,T_6

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 $360^0 / 6 = 60^0$

Construction

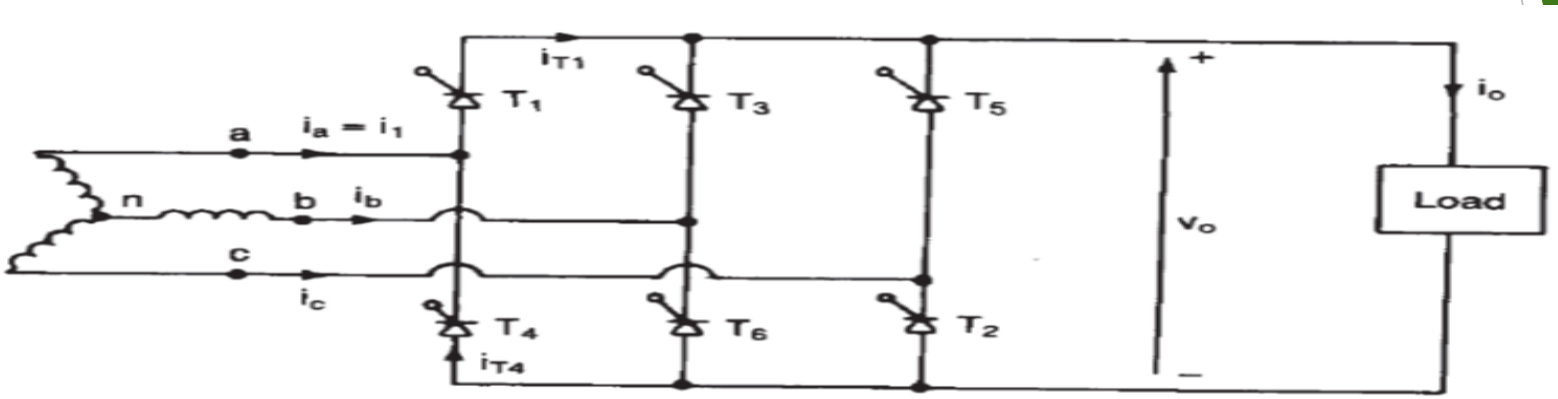
Power circuit and its components



- The three thyristors (T_1,T_3 andT_5) will not work together at the same time or two of them also will not work together at the same time.
- The three thyristors (T_2,T_4 andT_6) will not work together at the same time or two of them also will not work together at the same time.
- (T_1 and T_4), (T_3 and T_6) or (T_5 and T_2) will not work together at the same time.
- Each thyristor is triggered at an interval of $2\pi/3$.
- Each thyristors pair ((T_6&T_1), (T_1&T_2), (T_2&T_3), (T_3&T_4), (T_4&T_5), (T_5&T_6)) is triggered at an interval of $\pi/3$.
- The frequency of output ripple voltage is $6f_S$.

Construction

Firing schemes



Firing Angle	T_1	T_2	T_3	T_4	T_5	T_6
0°	30°	90	150°	210	270°	330
30°	60°	120°	180°	240°	300°	360°
60°	90°	150°	210°	270°	330°	390°
90°	120°	180°	240°	300°	360°	420°

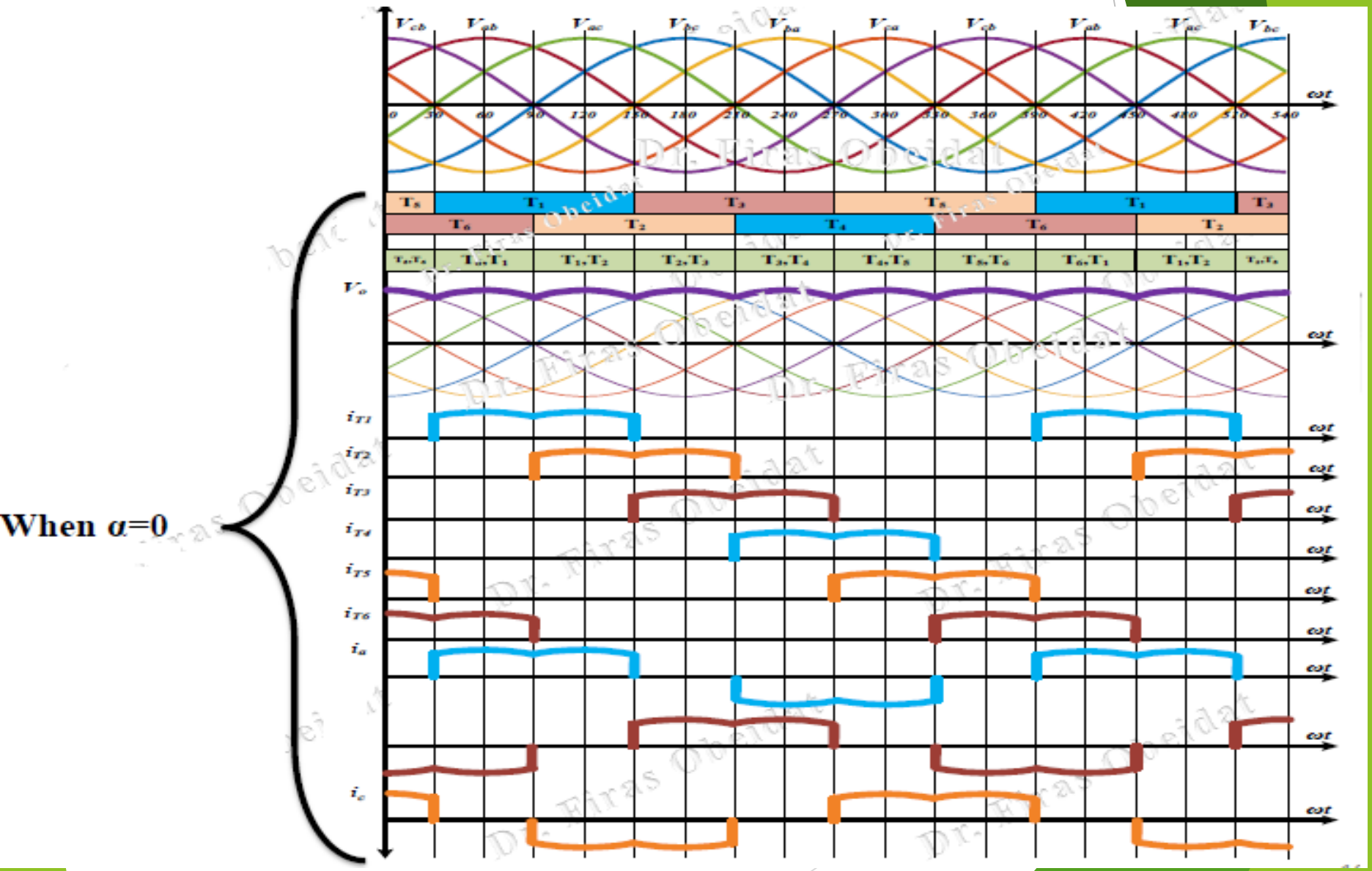
- Thyristors are numbered in the order in which they are triggered.
- The thyristor triggering sequence is 12, 23, 34, 45, 56, 61, 12, 23, 34, ……

Operation

- T_1 is triggered at $\omega t = (30 + \alpha)$, T_6 is already conducting when T_1 is turned ON.
- During the interval $(30 + \alpha)$ to $(90 + \alpha)$, T_1 and T_6 conduct together & the output load voltage is equal to $v_o = v_{ab} = (v_{an} - v_{bn})$.
- T_2 is triggered at $\omega t = (90 + \alpha)$, T_6 turns off naturally as it is reverse biased as soon as T_2 is triggered. During the interval $(90 + \alpha)$ to $(150 + \alpha)$, T_1 and T_2 conduct together & the output load voltage $v_o = v_{ac} = (v_{an} - v_{cn})$.
- T_3 is triggered at $\omega t = (150 + \alpha)$, T_1 turns off naturally as it is reverse biased as soon as T_3 is triggered. During the interval $(150 + \alpha)$ to $(210 + \alpha)$, T_2 and T_3 conduct together & the output load voltage $v_o = v_{bc} = (v_{bn} - v_{cn})$.
- T_4 is triggered at $\omega t = (210 + \alpha)$, T_2 turns off naturally as it is reverse biased as soon as T_4 is triggered. During the interval $(210 + \alpha)$ to $(270 + \alpha)$, T_3 and T_4 conduct together & the output load voltage $v_o = v_{ba} = (v_{bn} - v_{an})$.
- T_5 is triggered at $\omega t = (270 + \alpha)$, T_3 turns off naturally as it is reverse biased as soon as T_5 is triggered. During the interval $(270 + \alpha)$ to $(230 + \alpha)$, T_4 and T_5 conduct together & the output load voltage $v_o = v_{ca} = (v_{cn} - v_{an})$.
- T_6 is triggered at $\omega t = (330 + \alpha)$, T_4 turns off naturally as it is reverse biased as soon as T_6 is triggered. During the interval $(330 + \alpha)$ to $(390 + \alpha)$, T_5 and T_6 conduct together & the output load voltage $v_o = v_{cb} = (v_{cn} - v_{bn})$.

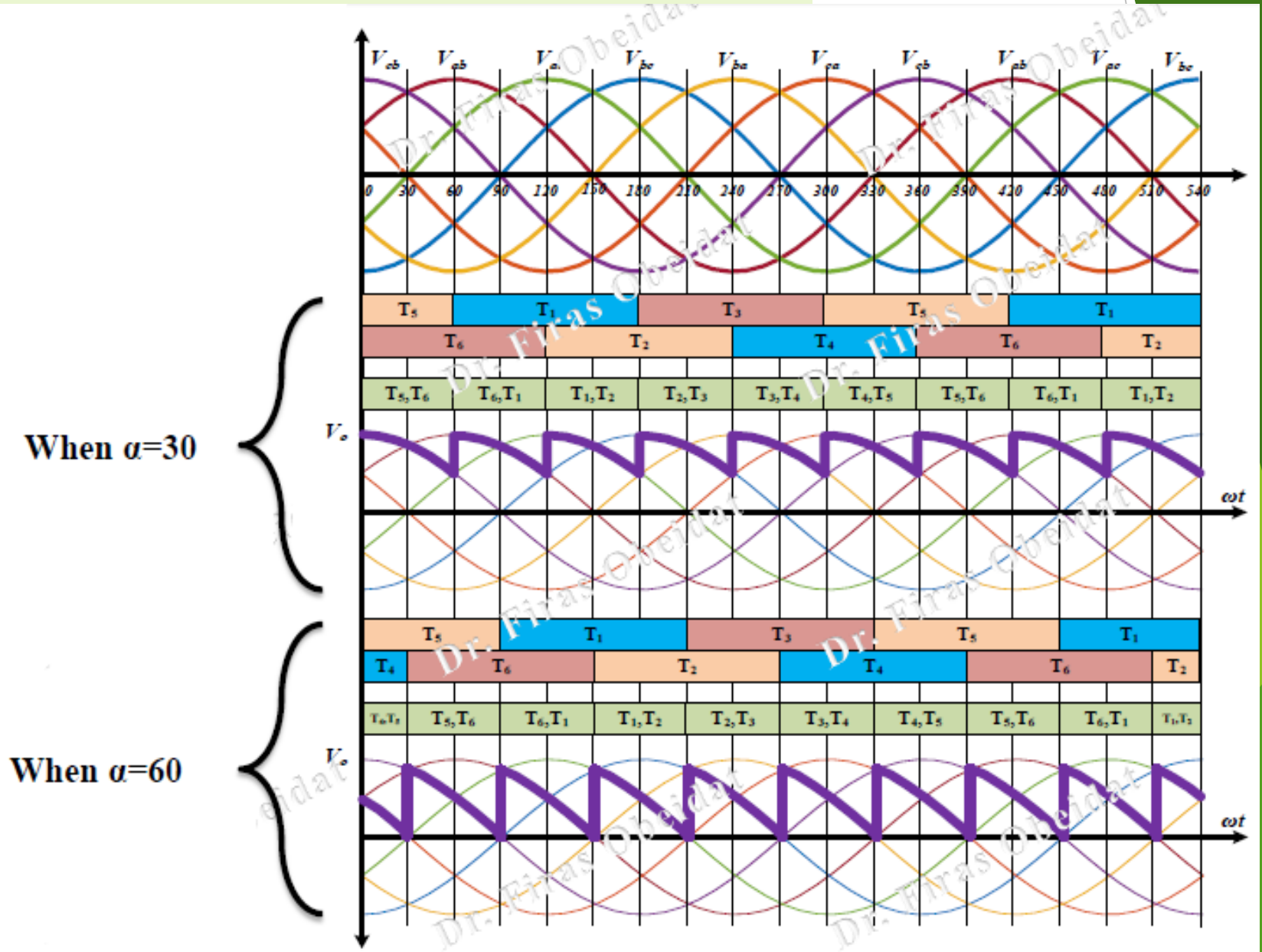
Operation

Output Voltage waveforms for R& RL loads



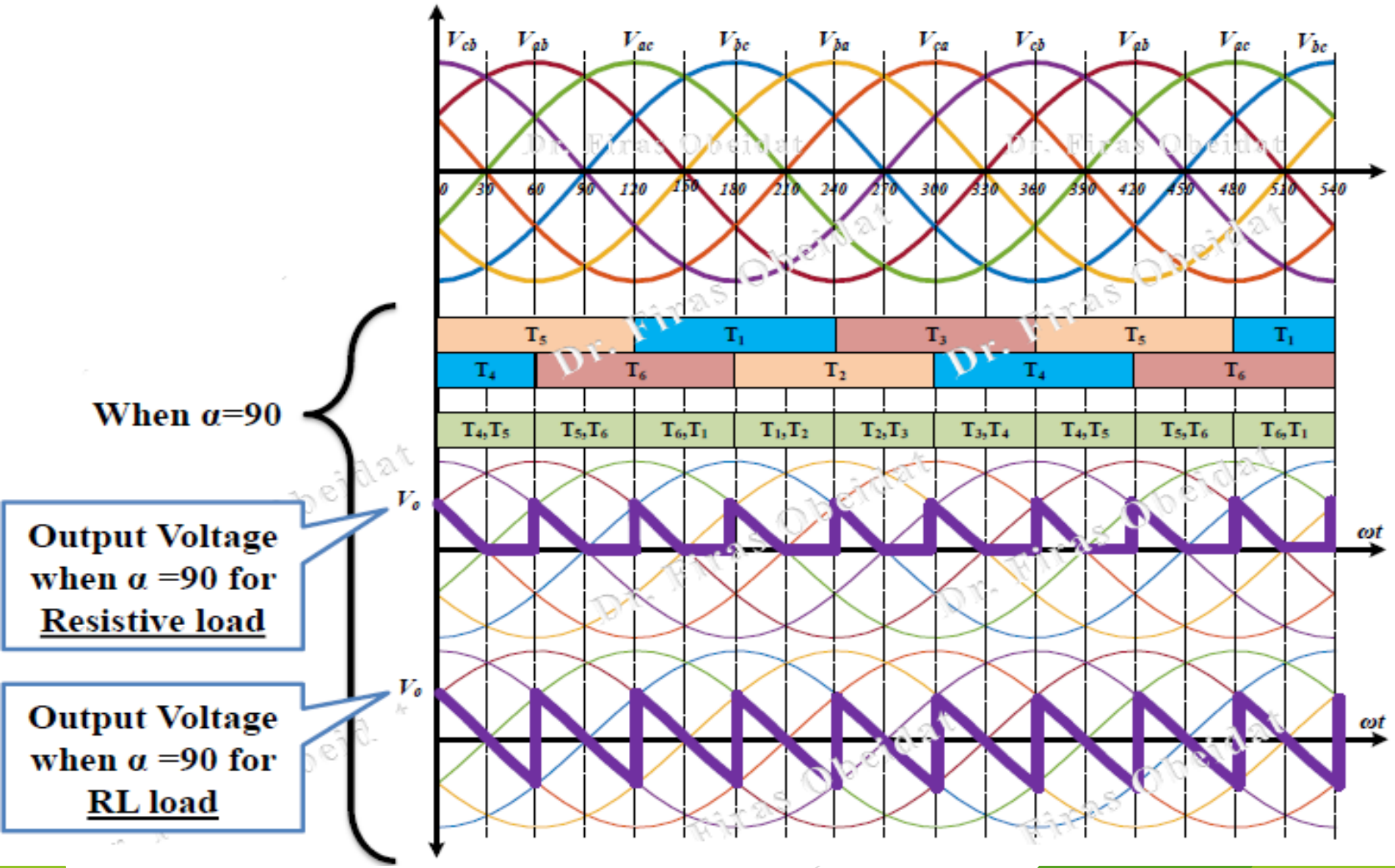
Operation

Output Voltage waveforms for R& RL loads



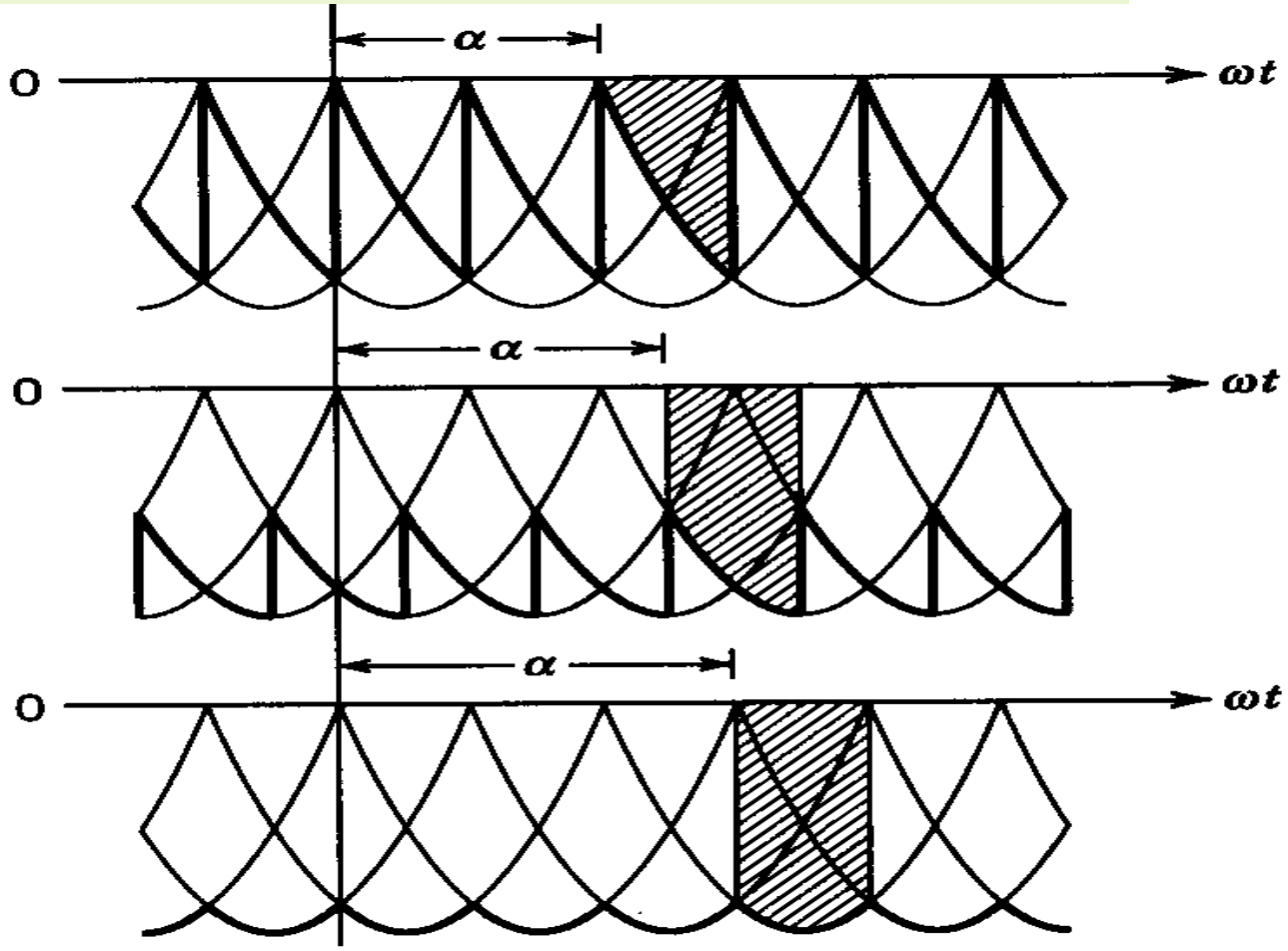
Operation

Output Voltage waveforms



Operation

Output Voltage waveforms for RL-loads



(e) $\alpha = 120°$

(f) $\alpha = 150°$

(g) $\alpha = 180°$

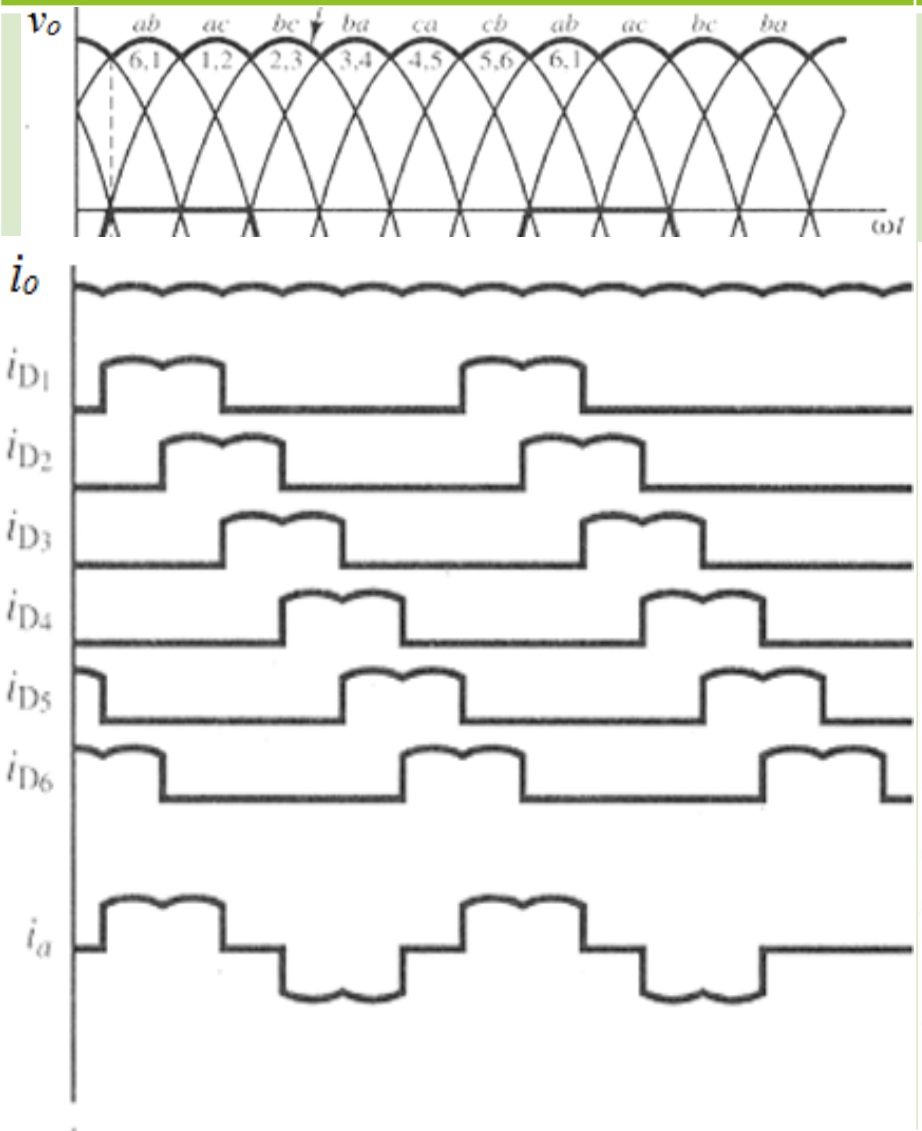
What about output Voltage waveforms for R-loads after $\alpha > 120$

What about output currents waveforms for R-loads and RL-loads?

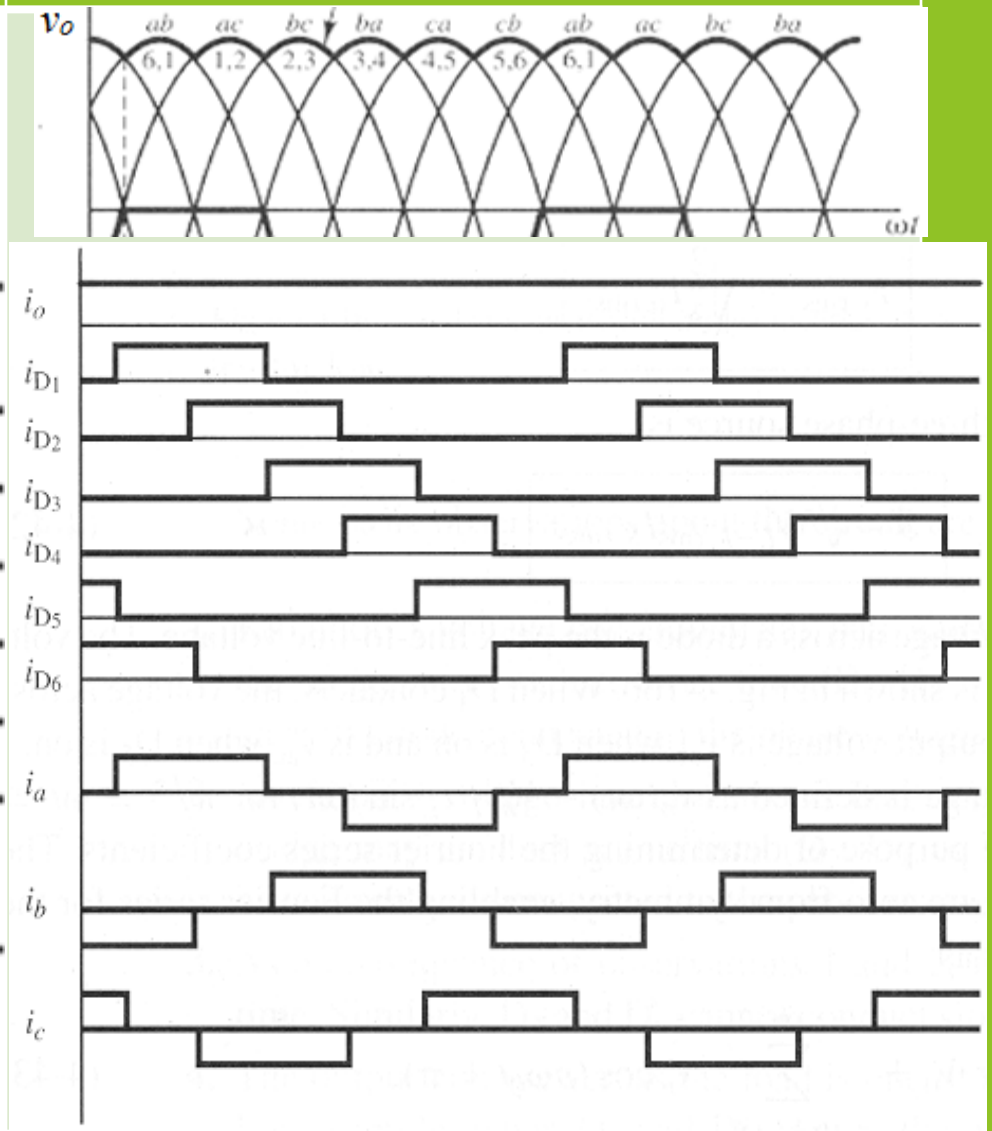
Operation

Currents waveforms

R-Loads



Highly inductive Loads



Analysis:

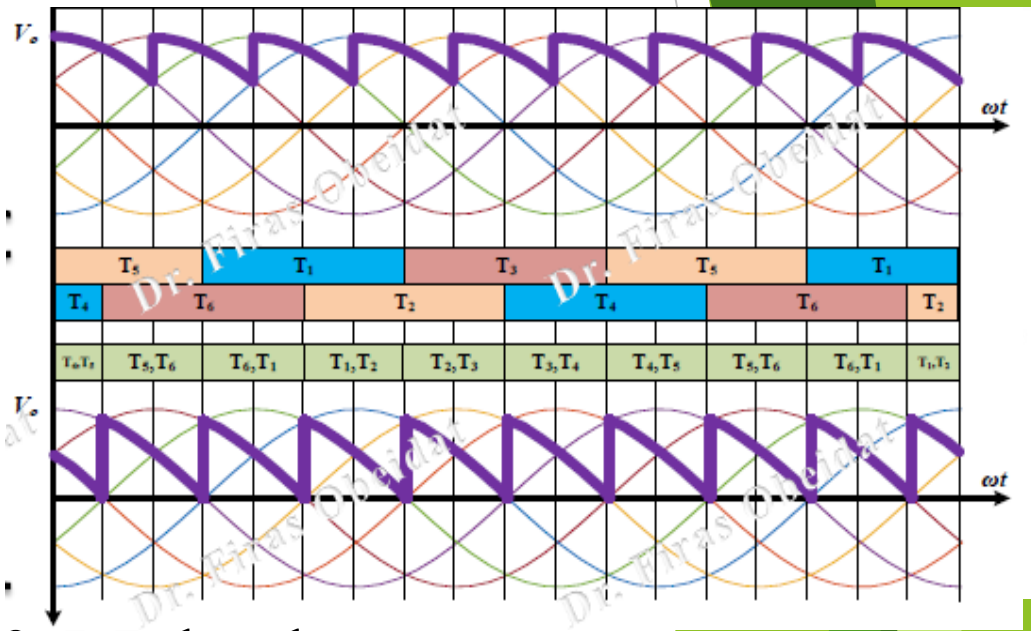
1- Supply voltages:

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

$\alpha \leq 60$ for R & RL loads:

2- Output average voltage

$$V_{o,avg}=\frac{3}{\pi}\int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{2}+\alpha}\sqrt{3}V_m\sin\left(\omega t+\frac{\pi}{6}\right)d\omega t=\frac{3\sqrt{3}V_m}{\pi}\cos\alpha$$



3- Output rms voltage for R & RL loads:

$$V_{o,rms}=\sqrt{\frac{3}{\pi}\int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{2}+\alpha}\left(\sqrt{3}V_m\sin\left(\omega t+\frac{\pi}{6}\right)\right)^2 d\omega t}=\sqrt{3}V_m\sqrt{\frac{1}{2}+\frac{3\sqrt{3}}{4\pi}\cos 2\alpha}$$

Analysis:

4- Average load current For R & RL-Loads

For both cases:

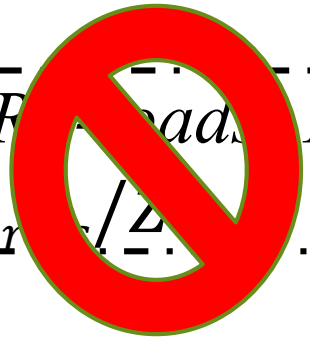
$$I_{o\ avg} = \frac{Vo,avg}{R}$$

5- RMS Load current

For Resistive load:

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

For R load: $I_{o,rms} = V_{o,rms}/Z$



For Highly inductive load:

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

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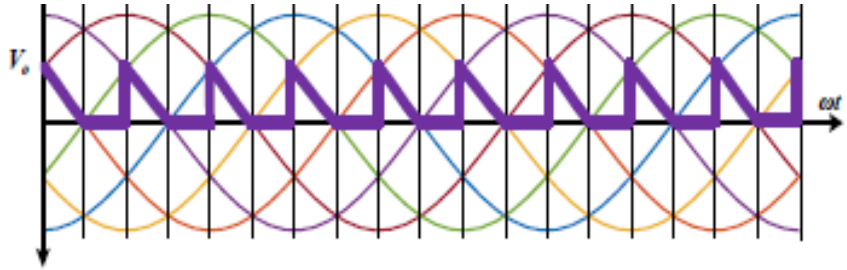
Analysis:

$$60 < \alpha$$

for R-loads:

$$60 < \alpha < 120$$

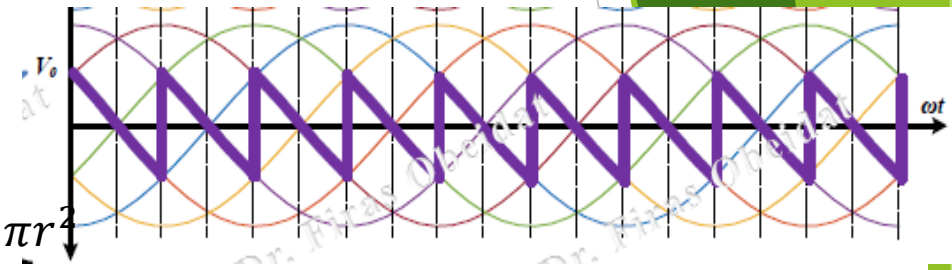


$$V_{o,avg} = \frac{3}{\pi}\int_{\frac{\pi}{6}+\alpha}^{5\pi/6} \sqrt{3}V_m \sin(\omega t + \frac{\pi}{6})d\omega t = \frac{3\sqrt{3}V_m}{\pi}\cos(\frac{\pi}{3}+\alpha)$$

$$V_{o,rms} = \sqrt{\frac{3}{\pi}\int_{\frac{\pi}{6}+\alpha}^{5\pi/6} \left(\sqrt{3}V_m \sin(\omega t + \frac{\pi}{6})\right)^2 d\omega t}$$

for RL-loads:

$$60 < \alpha < 180$$



$$A = \pi r^2$$

$$V_{o,avg} = \frac{3}{\pi}\int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{2}+\alpha} \sqrt{3}V_m \sin(\omega t + \frac{\pi}{6})d\omega t = \frac{3\sqrt{3}V_m}{\pi}\cos\alpha$$

$$V_{o,rms} = \sqrt{\frac{3}{\pi}\int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{2}+\alpha} \left(\sqrt{3}V_m \sin(\omega t + \frac{\pi}{6})\right)^2 d\omega t} = \sqrt{3}V_m\sqrt{\frac{1}{2}+\frac{3\sqrt{3}}{4\pi}\cos 2\alpha}$$

Analysis:

$60 < \alpha$

For both cases:

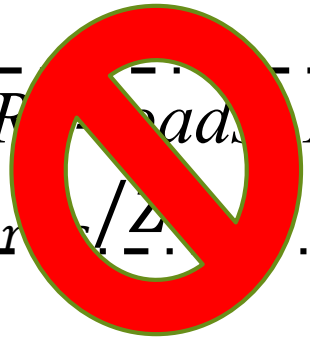
$$I_{o\ avg} = \frac{Vo,avg}{R}$$

5- RMS Load current

For Resistive load:

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

For R load: $I_{o,rms} = V_{o,rms}/Z$



For Highly inductive load:

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

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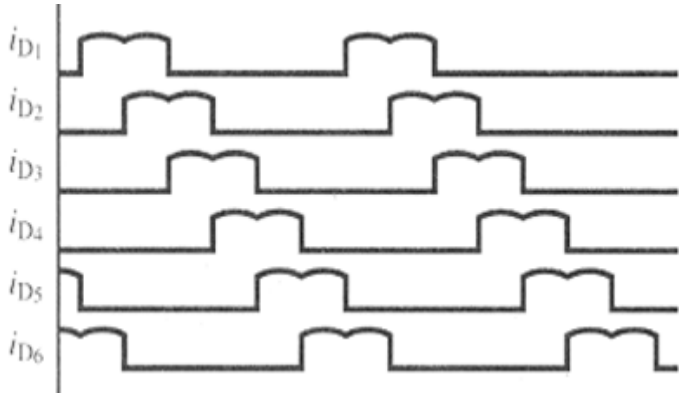
Analysis:

6- Thyristor currents

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

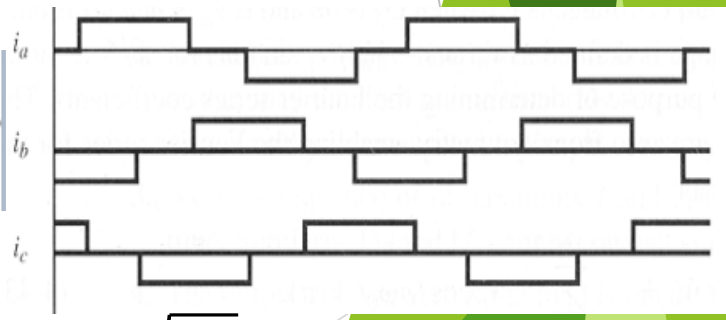
$$I_{T,avg} = \frac{1}{3} I_{o,avg}$$

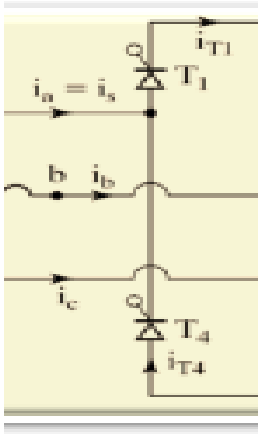
$$I_{T,rms} = \frac{1}{\sqrt{3}} I_{o,rms}$$



7- RMS supply current

$$\begin{cases} i_a = i_{T1} - i_{T4} \\ i_b = i_{T3} - i_{T6} \\ i_c = i_{T5} - i_{T2} \end{cases}$$





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

Analysis:

8- Output power

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

For R & RL Loads??

9- Input power factor

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

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

10- 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 Thyrisors in the converter?

Q_2) Draw a relation between the rectification efficiency and firing angles for R-load and highly inductive loads.

Q_3) Draw a relation between the average output voltage and firing angles for R-load and highly inductive loads.

Q_4) Draw the load voltage and current waveforms if a freewheeling diode is connected incase RL-loads.

Q_5) Draw the load voltage and current waveforms at for RL-loads if T2, T4, T6 are replaced with diodes At $\alpha = 30, 60, 90$