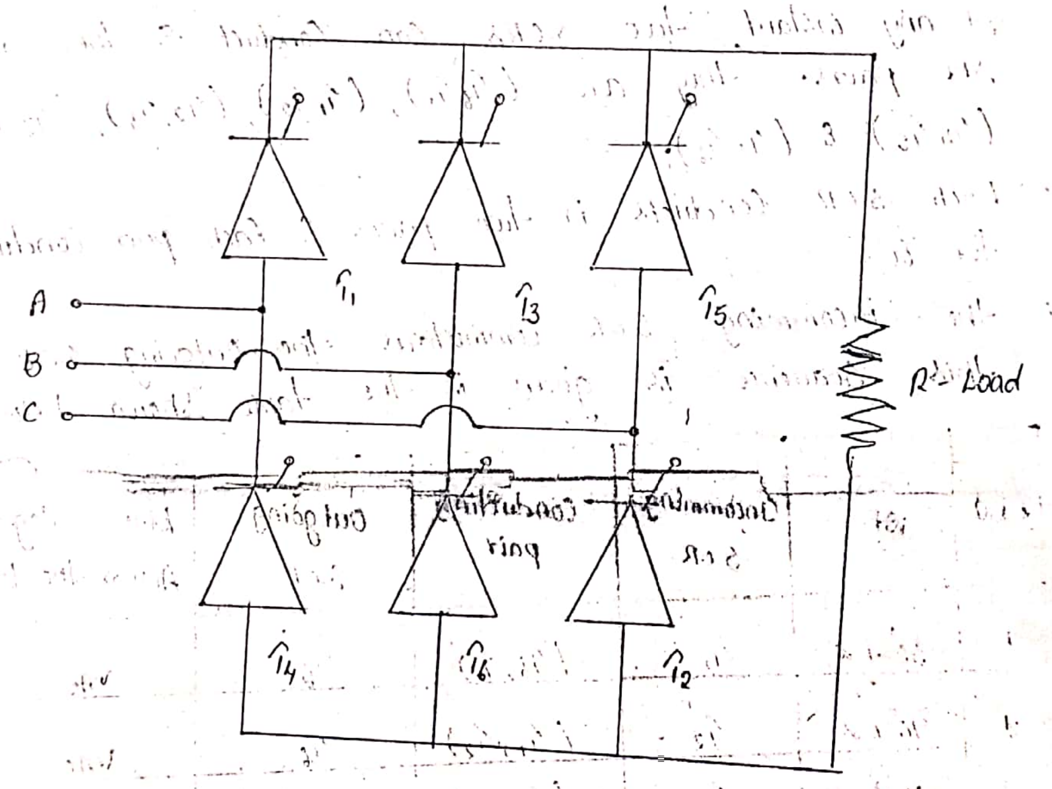
P.J DSK

3Φ Full wave Bridge type Converter with R- Load : [6-pulse Converter]

* Six pulse converter ckt is obtained by connecting a d.c. terminal of two 3-pulse converters in ||ᴸ, if we connect the d.c terminals of two 3-pulse converters in series, the converters so formed is called as 6-pulse bridge converter shown in the fig: this converter is most widely used in industrial applications upto the 120kW level, where two quadrant operation is required.



* This ckt consists of two groups of S.C.Rs, +ve group & -ve group
* Here, SCR's T_1, T_3, T_5 form a +ve group, where as S.C.Rs T_4, T_6, T_2 forms a -ve group.
* The +ve group S.C.R's are turned on when the supply voltages are +ve & -ve group S.C.R's are turned on when the supply voltages are -ve.

* for describing the operation of ckt we should remember the following points:

* Each device should be triggered at a desired firing angle "α".

* Each S.C.R can conduct for 120°

* S.C.R must be triggered in the sequence $T_1, T_2, T_3, T_4, T_5, T_6$.

* The phase shift between the triggering of the two adjacent S.C.R is 60°

* At any instant, two S.C.Rs can conduct & there are such six pairs. They are $(T_6 T_1)$, $(T_1 T_2)$, (T_2, T_3), $(T_3 T_4)$ (T_4, T_5) & $(T_5 T_6)$.

* Each S.C.R conducts in two pairs & each pair conducts for 60°.

* The incomming S.C.R commutates the outgoing S.C.R. This sequence is given in the table shown below.

S.No	ωt	Incomming S.C.R	Conducting pair	Out going S.C.R	Line Voltage Across the load
1	$30° + \alpha$	T_1	(T_6, T_1)	T_5	V_{AB}
2	$90° + \alpha$	T_2	(T_1, T_2)	T_6	V_{AC}
3	$150° + \alpha$	T_3	(T_2, T_3)	T_1	V_{BC}
4	$210° + \alpha$	T_4	(T_3, T_4)	T_2	V_{BA}
5	$270° + \alpha$	T_5	(T_4, T_5)	T_3	V_{CA}
6	$330° + \alpha$	T_6	(T_5, T_6)	T_4	V_{CB}

* When the two S.C.Rs are conducting, i.e., one from +ve (upper) group & one from −ve (lower) group, the corresponding line voltage is applied across the load.

* Phase A is connected to first ½ bridge (T_1/T_4) B-phase to 2nd ½ bridge (T_3/T_6) & C-phase to 3rd ½ bridge (T_5/T_2).

* Average o/p voltage Equ: for continious conduction Mode:-

General Equ: for Average o/p voltage is

$$E_{dc} = \frac{1}{2\pi}\int_0^{2\pi} E_{dc}(\omega t)\cdot d(\omega t)$$

for $\alpha < 60°$

$$E_{dc} = 6 \times \frac{1}{2\pi}\int_{\pi/6+\alpha}^{\pi/2+\alpha} E_{AB}(\omega t)\cdot d(\omega t)$$

Where the line to line voltage E_{AB} is given by

$$E_{AB} = \sqrt{3}\, E_m \sin(\omega t + \pi/6)$$

$$\therefore E_{dc} = 3/\pi \int_{\pi/6+\alpha}^{\pi/2+\alpha} \sqrt{3}\, E_M \sin(\omega t + \pi/6)\, d(\omega t)$$

$$= \frac{3\sqrt{3}\, E_m}{\pi}\int_{\pi/3+\alpha}^{2\pi/3+\alpha} \sin(\omega t)\cdot d(\omega t)$$

$$= \frac{3\sqrt{3}\, E_m}{\pi}(\cos\omega t)_{2\pi/3+\alpha}^{\pi/3+\alpha} = \frac{3\sqrt{3}\, E_m}{\pi}\left[\cos(\pi/3+\alpha) - \cos(2\pi/3+\alpha)\right]$$

$$= \frac{3\sqrt{3}\, E_m}{\pi}\left[\cos(\pi/3+\alpha) + \cos(\pi/3-\alpha)\right]$$

$$= \frac{3\sqrt{3}\, E_m}{\pi}\left[2\cdot\cos(\pi/3)\cdot\cos\alpha\right] = \frac{3\sqrt{3}\, E_m}{\pi}\cos\alpha$$

Average load Current :-

$$I_d = \frac{3\sqrt{3}\, E_m}{\pi\cdot R}\cos\alpha .$$

for discontinious conduction Mode :-

$$E_{dc} = 6 \times 1/2\pi \int_{\pi/6+\alpha}^{5\pi/6} \sqrt{3}\, E_m \sin\left[\omega t + \pi/6\right] = \frac{3\sqrt{3}\, E_m}{\pi}\int_{\pi/3+\alpha}^{\pi} \sin(\omega t)\, d\omega t$$

$$= \frac{3\sqrt{3}\, E_m}{\pi}\left[\cos\omega t\right]_{\pi}^{\pi/3+\alpha} = \frac{3\sqrt{3}\, E_m}{\pi}\left[1+\cos(\alpha+\pi/3)\right]$$

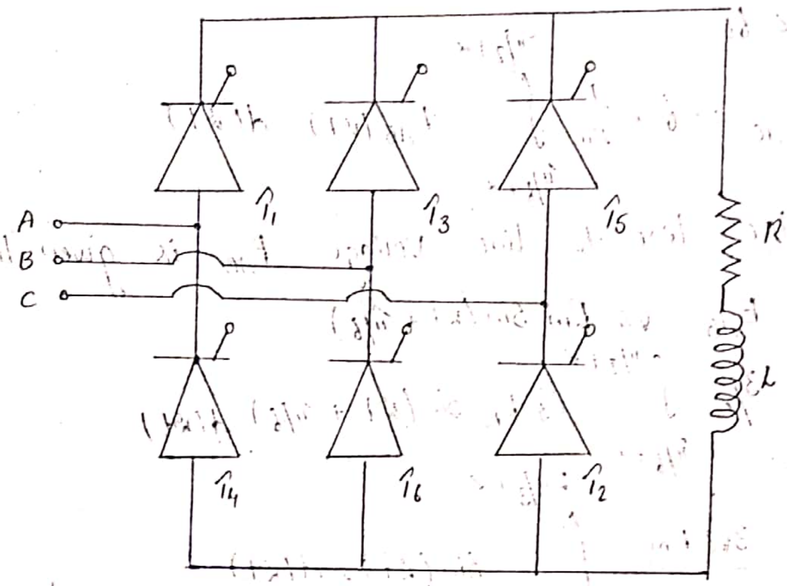
for α_{Max} $E_{dc} = 0$ $\Rightarrow \frac{3\sqrt{3}\, E_m}{\pi}\left[1+\cos(\alpha+\pi/3)\right] = 0$

Hence $\alpha_{Max} = 120°$

Average load Current $= \frac{3\sqrt{3}\, E_m}{\pi R}\left[1+\cos(\alpha+\pi/3)\right]$.

3ϕ full wave Bridge converter with R-L load:

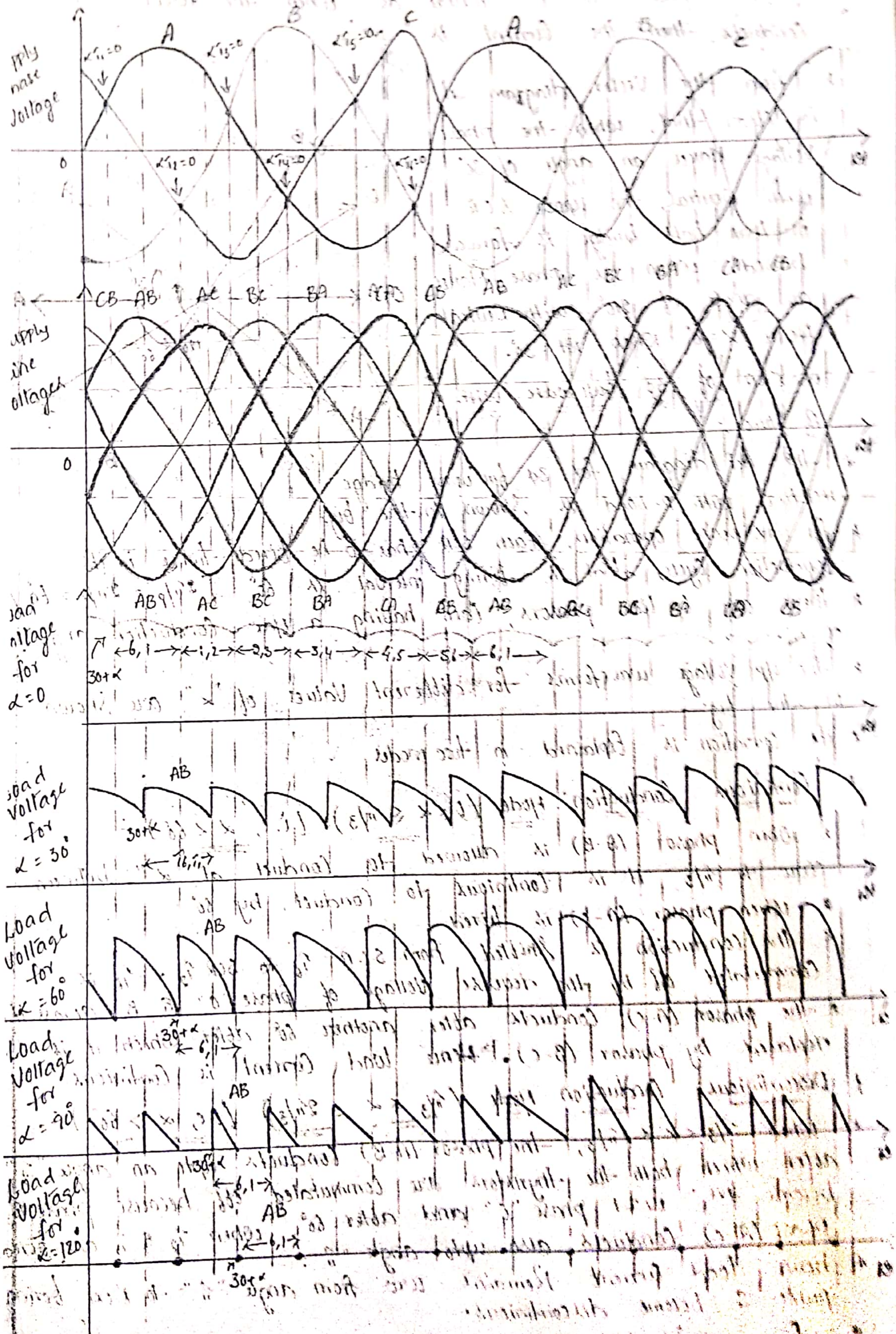
the power diagram of the three phase fully-controlled converter with R-L Load is shown in the fig:



* the o/p voltage & o/p current waveforms for different firing angles are shown in the fig. the load inductance is assumed to be very large so as to produce constant load current.

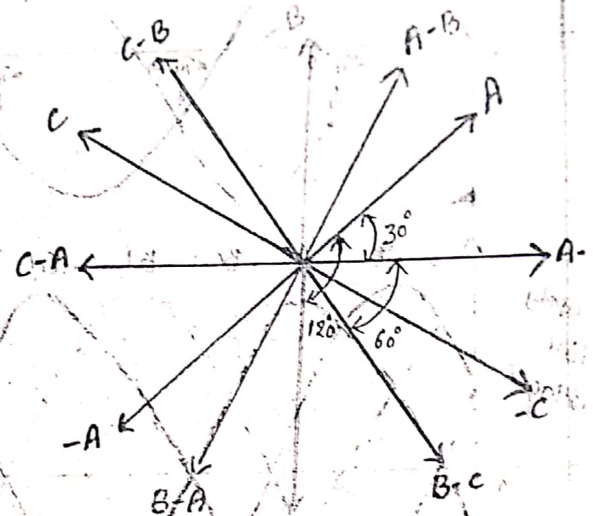
* from the o/p voltage & current waveforms we observe that
(1) the waveforms of R-L load is similar to that of R-Load for $\alpha = 0°, 30°, 60°$.
(2) for $\alpha > 60°$, the waveforms are different. the voltage goes -ve due to the inductive nature of the load.
(3) for $\alpha = 90°$, the Area under the +ve & -ve cycle are equal & the Average voltage is zero.
(4) for $\alpha < 90°$ the Average o/p voltage is +ve & for $\alpha > 90°$ the Average o/p voltage is -ve.
(5) the max value of $\alpha = 180°$

* O/P Voltage Waveforms for 3φ full bridge converter with R- Load



* when the upper S.C.R of a 1/2 bridge conducts, the current of that phase is "+ve" where as when the lower S.C.R conducts, then the current is "-ve".

* from the vector diagram it is clear that, when the phase voltage makes an angle of 30° with neutral, the upper S.C.R in that half bridge is forward biased. when its phase makes an angle of 210° with neutral. Hence $\alpha = 0°$ when $\omega t = 30°$.



Operation of 3φ full wave with R-Load :-

* the ckt diagram for 3φ full wave bridge rectifier with R-Load is shown in the fig.
* for six pulse operation, each SCR has to be fired twice in its conduction cycle, that is firing interval is 60° $[2\pi/P = 2\pi/6 = 60°]$
* there are 6 line phasors, each having a max. conduction angle of 60°.
* the o/p voltage waveforms for different values of "α" are shown in the fig:-
* its operation is explained in two modes
* Continious Conduction Mode $(0 \le \alpha \le \pi/3)$ (i.e, $\alpha < 60°$)
  * when phasor (A-B) is allowed to conduct at "α" between zero to $\pi/3$, it is continious to conduct by 60°
  * when phasor (A-C) is fired
  * the conduction is shifted from S.C.R T_6 to SCR T_2. T_6 is commutated off by the reverse voltage of phase "C" & "B" across it.
  * the phasor (A-C) conducts after another 60° after which it is replaced by phasor (B-C). Hence load current is continious.
* Discontinious Conduction Mode $(\pi/3 \le \alpha \le 2\pi/3)$ (i.e, $\alpha > 60°$)
  * when $\pi/3 \le \alpha \le 2\pi/3$, the phasor (A-B) conducts upto an angle "π" after which both the thyristors are commutated off because phase B become "+ve" w.r.t phase "C" and after 60°, when T_2 & T_1 are fired phase (A-C) conducts also upto angle "π".
  * hence load current remains zero from angle "π" to next firing pulse & become discontinious.
  * for $\alpha = 120°$, the o/p voltage is zero, & hence $\alpha_{Max} = 120°$ [?

$$= \frac{3\sqrt{3}\,E_m}{\pi}\left[\cos(\omega t)\right]_{120+\alpha}^{60+\alpha}$$

$$= \frac{3\sqrt{3}}{\pi}E_m\left[\cos(60+\alpha) - \cos(120+\alpha)\right]$$

$$\therefore E_{dc} = \frac{3\sqrt{3}\,E_m}{\pi}\cos\alpha \quad \text{for } 0<\alpha<120^\circ$$

Where "E_m" is the peak value of the line to neutral voltage

* As the firing angle changes from 0° to 90°, the voltage also changes from Max. to zero & the converter is said to be in rectification mode.

* For the angles in the range of 90° to 180°, the voltage varies from 0 to $-$ve Max. & the converter is in the inversion mode.

* **RMS o/p voltage:-**

$$E_{rms} = \left[\frac{1}{2\pi}\int_0^{2\pi} E_{dc}^2(\omega t)\, d\omega t\right]^{1/2}$$

$$= \left[\frac{1}{2\pi}\times 6\int_{30+\alpha}^{90+\alpha} E_{AB}^2(\omega t)\, d\omega t\right]^{1/2}$$

$$= \left[\frac{9E_m^2}{2\pi}\int_{60+\alpha}^{120+\alpha} 1-\cos(2\omega t)\, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{9E_m^2}{2\pi}\left\{60^\circ + \frac{1}{2}\left(\sin(2\omega t)\right)_{120+\alpha}^{60+\alpha}\right\}\right]^{1/2}$$

$$= \left[\frac{9E_m^2}{2\pi}\left\{60^\circ + \frac{1}{2}\left(\sin(120+2\alpha) - \sin(240+2\alpha)\right)\right\}\right]^{1/2}$$

$$= \left[\frac{9E_m^2}{2\pi}\left\{60^\circ + \frac{1}{2}\left[\sqrt{3}\cos 2\alpha\right]\right\}\right]^{1/2}$$

$$= \frac{3E_m}{2\pi}\left[\frac{2}{3} + \frac{\sqrt{3}}{\pi}\cos 2\alpha\right]^{1/2}$$

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Operation of 3ϕ full wave bridge rectifier with R-L Load:

Operation of three phase full wave rectifier with R-L load can be explained in two modes.

* Rectifier operation ($\alpha < 90°$):

* The o/p voltage wave forms for rectification mode is shown in the fig:
* Supply waveforms are Quasi - Square wave for α upto $90°$
* The peak inverse voltage rating of thyristor is $\sqrt{3}\,E_m$
* The ckt works in the first quadrant since E_{dc} & I_{dc} are both +ve & hence $P_{dc\,(av)}$ is +ve & power flows from source to load.

* Inverter operation ($\alpha > 90°$):

* The o/p voltage waveforms for inverter mode of operation is shown in the fig:
* Average o/p voltage is -ve for inverting operation
* The Average power flow is from load to source

∴ Average o/p power P_{dc} (av) is -ve.

* Hence ckt works in fourth quadrant.

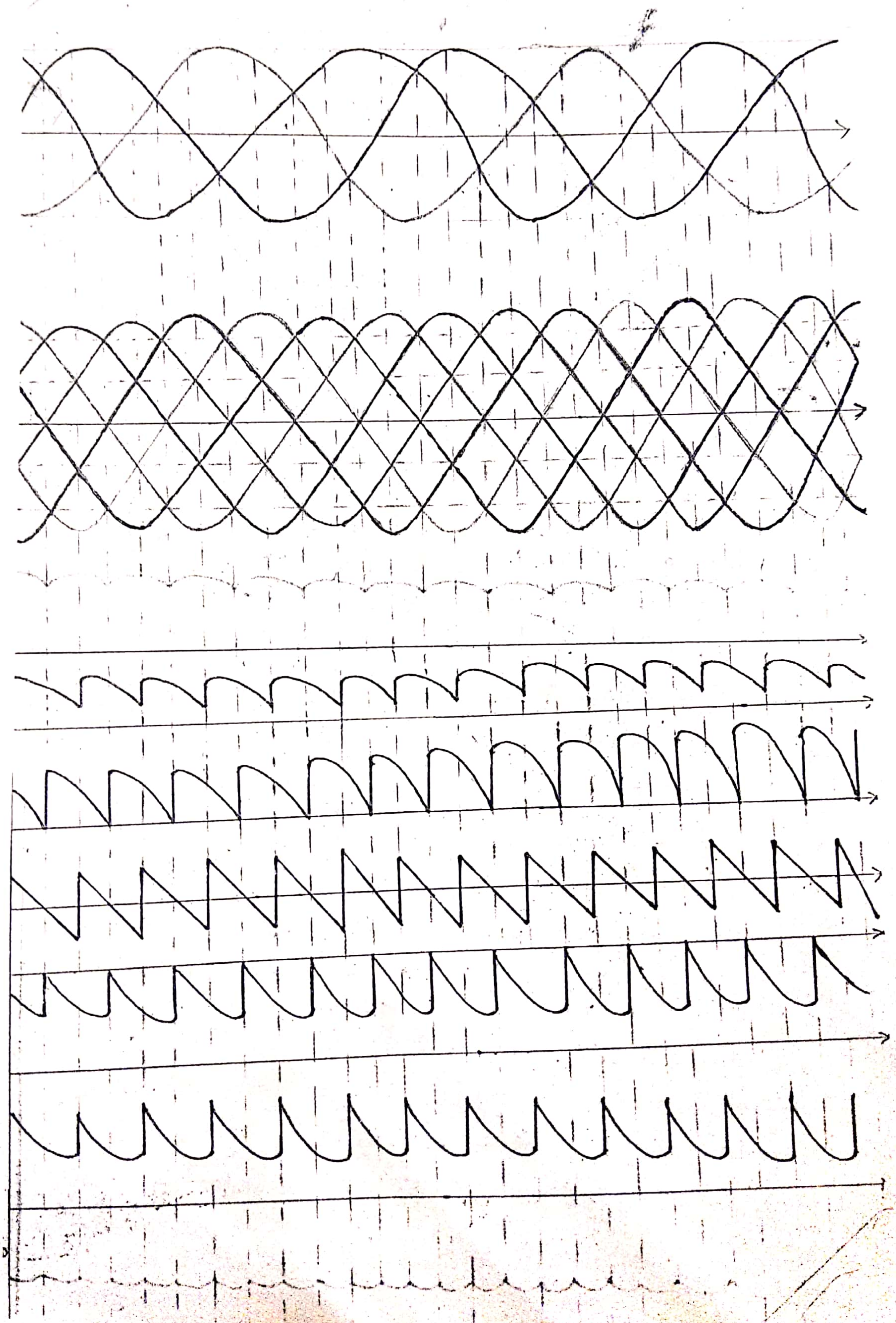
Average o/p Voltage:

$$\text{Average o/p voltage} = E_{dc} = 6 \times \frac{1}{2\pi}\int_{30+\alpha}^{90+\alpha} E_{dc}(\omega t)\, d(\omega t)$$

$$= \frac{3}{\pi}\int_{30+\alpha}^{90+\alpha} \sqrt{3}\,E_m \sin(\omega t + 30°)\, d\omega t$$

$$= \frac{3}{\pi}\int_{60+\alpha}^{120+\alpha} \sqrt{3}\,E_m \sin(\omega t)\, d(\omega t)$$

i) Voltage waveforms for 3φ full bridge converter for R-L load:



* At $\omega t = 30° + \mu$, $I_5 = 0$ while $I_1 = I_0$ ∴ from $\omega t = 30°$ to 36, three S.C.R's T_5, T_6, T_1 Conducts.
* After $\omega t = 30° + \mu$, T_6, T_1 conducts.
* At $\omega t = 90°$, "T_2" is triggered, "I_6" began to decrease & "I_2" Starts to build up. ∴ from $\omega t = 90° + \mu - 90°$, three S.C.R's T_6, T_1, T_2 Conducts.
* At $\omega t = 90° + \mu$, $I_6 = 0$ & $I_2 = I_0$.
* After $\omega t = 90° + \mu$, only two S.C.R's T_1, T_2 Conducts.
* This Sequence of operation repeats for other S.C.R's
* It May be observed from this that when +ve group of S.C.R's are undergoing Commutation, two S.C.R's from +ve group & one SCR from -ve group Conducts.
* After the Commutation of +ve group Completes only two S.C.R's Conduct one from +ve group & other from -ve group.
* Similarly when the -ve group of S.C.R's are undergoing Commutation, three S.C.R's Conduct, two from the -ve group & one from the +ve group.
* After the Commutation of -ve group Completes only two SCR's Conduct one from +ve group & other from -ve group.
* Conduction of Various thyristors are shown below.
  5-6, 5-6-1, 6-1, 6-1-2, 1-2, 1-2-3, 2-3, 2-3-4, 3-4, 3-4-5, 4-5, 4-5-6, 5-6, & so on.
* it is Seen that three & two S.C.R's Conducts alternately. & also for 6-pulse Converter, there are Six shaded Areas indicating Six Commutations / cycle of Source Voltage.

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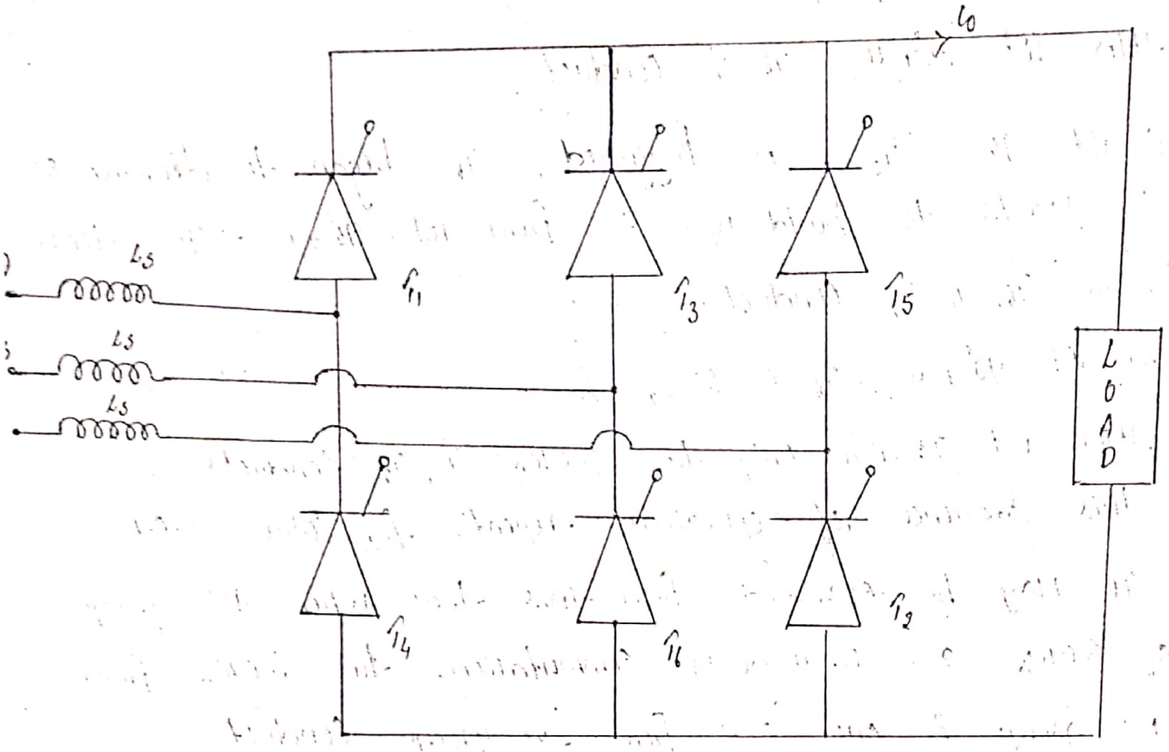
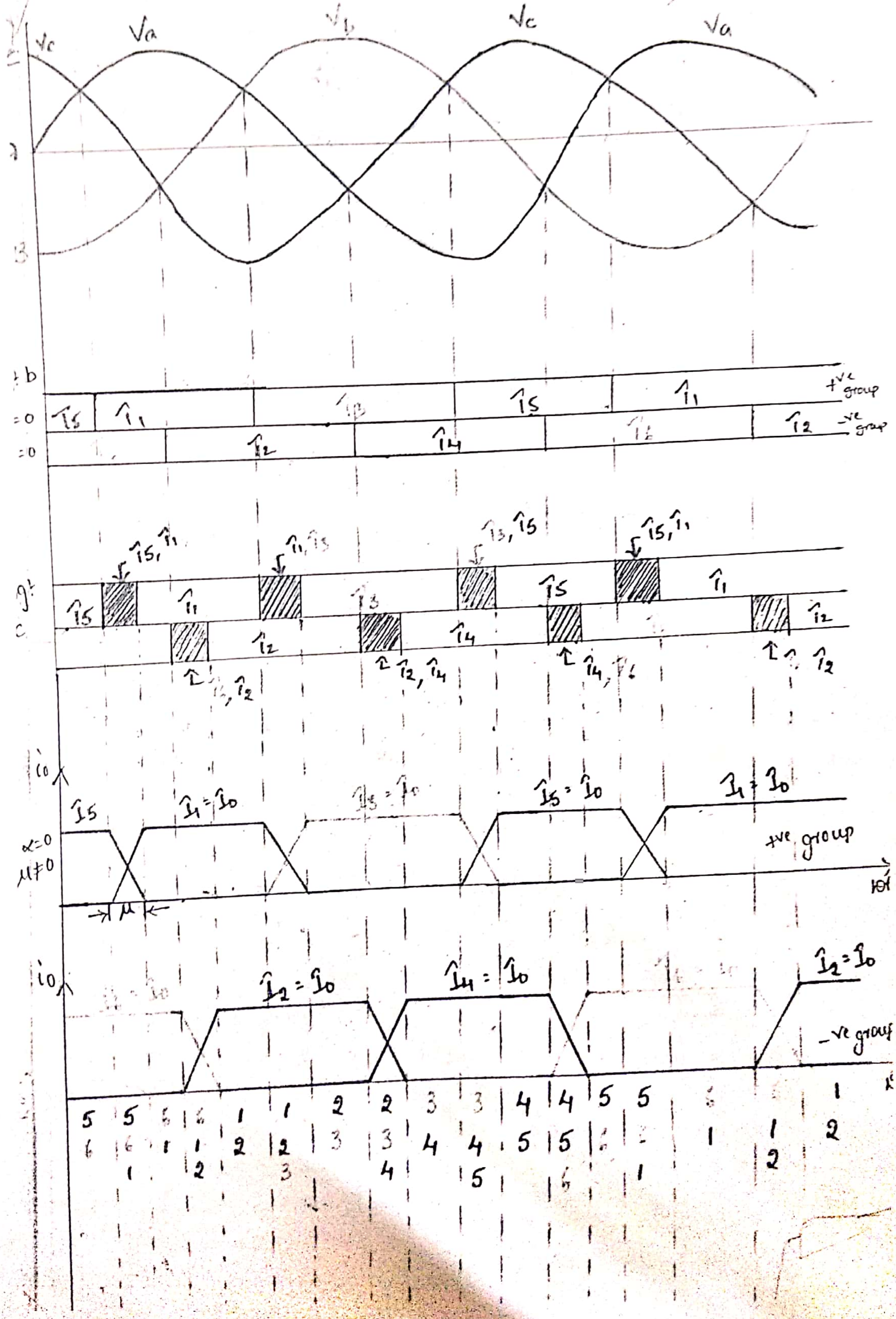
Effect of source inductance for 3ϕ full bridge converter:



* fig: shows a 3ϕ full converter bridge with a source inductance "L_s" in each line. the load current is assumed constant as the analysis with pulsating current is complicated.
* from the waveforms shown in the fig:b, the conduction of various S.C.R's with firing angle $\alpha = 0$, & overlap angle $\mu = 0$.
* we observe that T_5, T_6 conduct upto $\omega t = 30°$
* from $\omega t = 90°$ to $150°$ T_1, T_2 conducts.
* from $\omega t = 30°$ to $60°$ T_1, T_6 conducts. & so on.
* it is seen that only two S.C.R.s conduct at a time, one from the +ve group & the other from -ve group.
* fig: c shows the effect of the overlap from $\omega t = 0°$ to $30°$ T_5, T_6 conduct. At $\omega t = 30°$, "T_5" is outgoing S.C.R & "T_1" is incomming S.C.R
* As "T_1" is triggered current through "T_5" starts decaying while through "T_1" current began to build up.

O/P voltage wave forms for above ckt:



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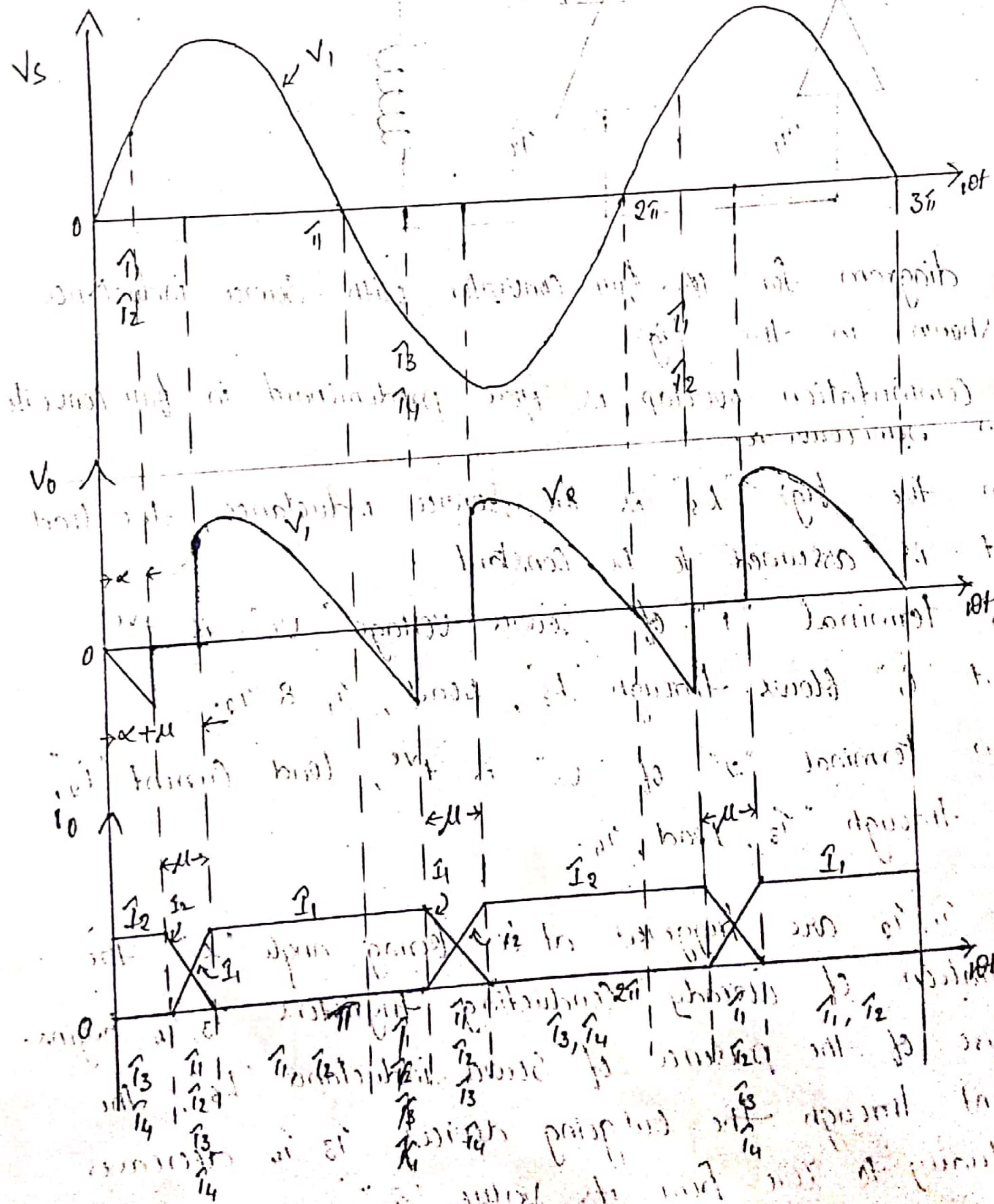
* Where as incomming thyristors T_1, T_2, the current gradually build up from zero to full value of load current "I_0".

* At that time all the four S.C.R's will be in a conduction for a small time period. angle at that particular period is called overlap angle.

* Current and Voltage wave-forms with L_s



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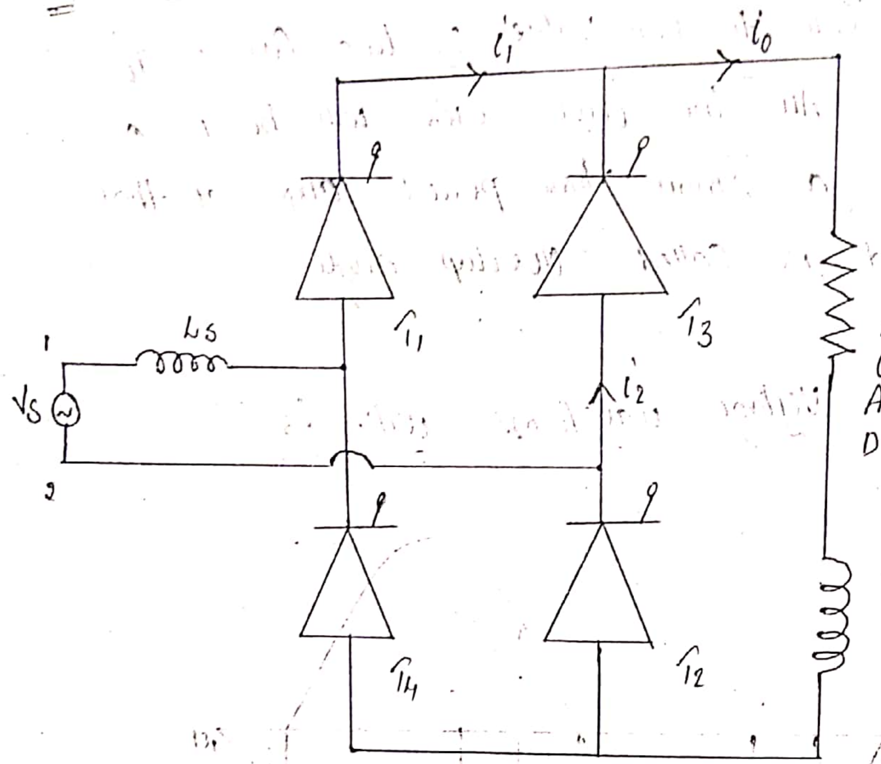
* 1ϕ full converter with Effect of Source inductance :-



* ckt diagram for 1ϕ full converter with Source inductance is shown in the fig:
* the Commutation overlap is more predominant in full converters
* from the fig: "L_s" is the Source inductance, the load Current is assumed to be Constant
* when terminal "1" of Source voltage "V_s" is +ve Current "i_1" flows through "L_s", Load, T_1 & T_2.
* when terminal "2" of "V_s" is +ve, load Current "i_2" flows through "T_3, Load, T_4.
* when T_1, T_2 are triggered at a firing angle "α", the Commutation of already Conducting thyristors T_3, T_4 begins.
* Because of the presence of Source inductance "L_s", the Current through the Outgoing devices T_3, T_4 decreases gradually to zero from its Value "I_0".

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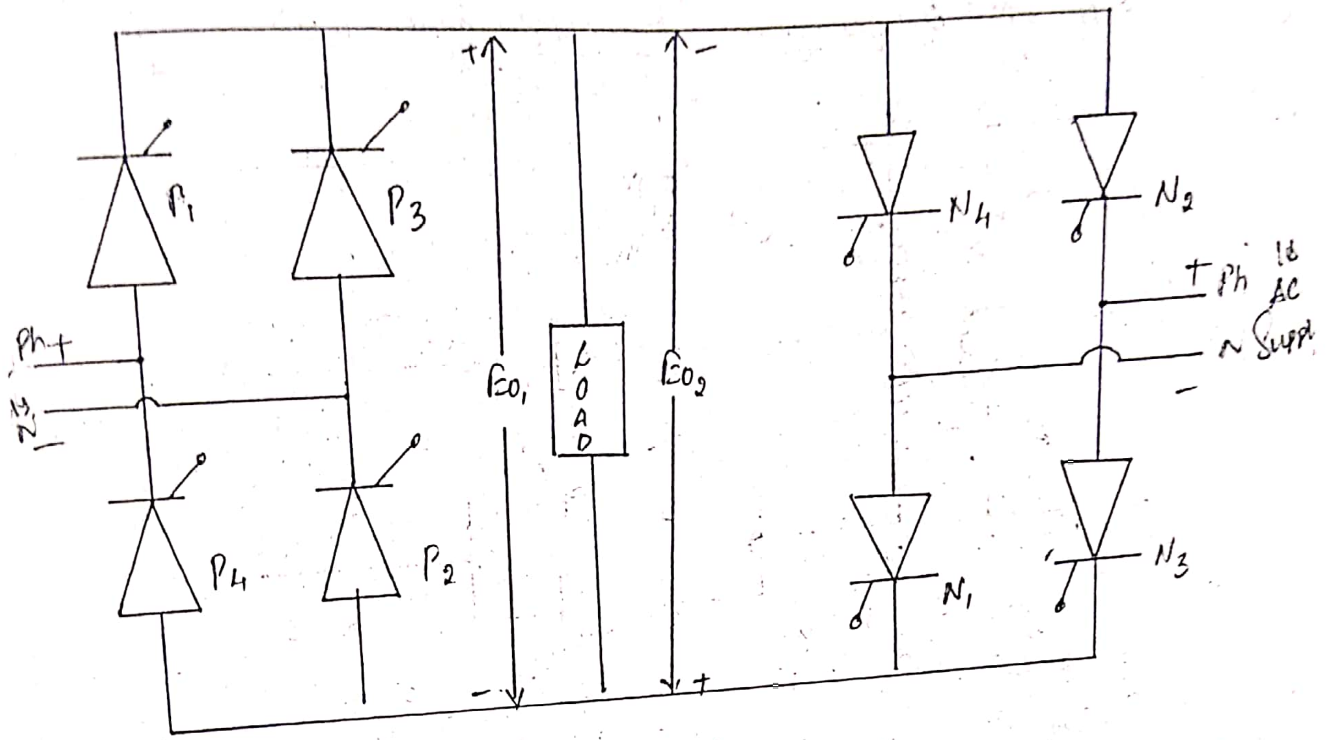
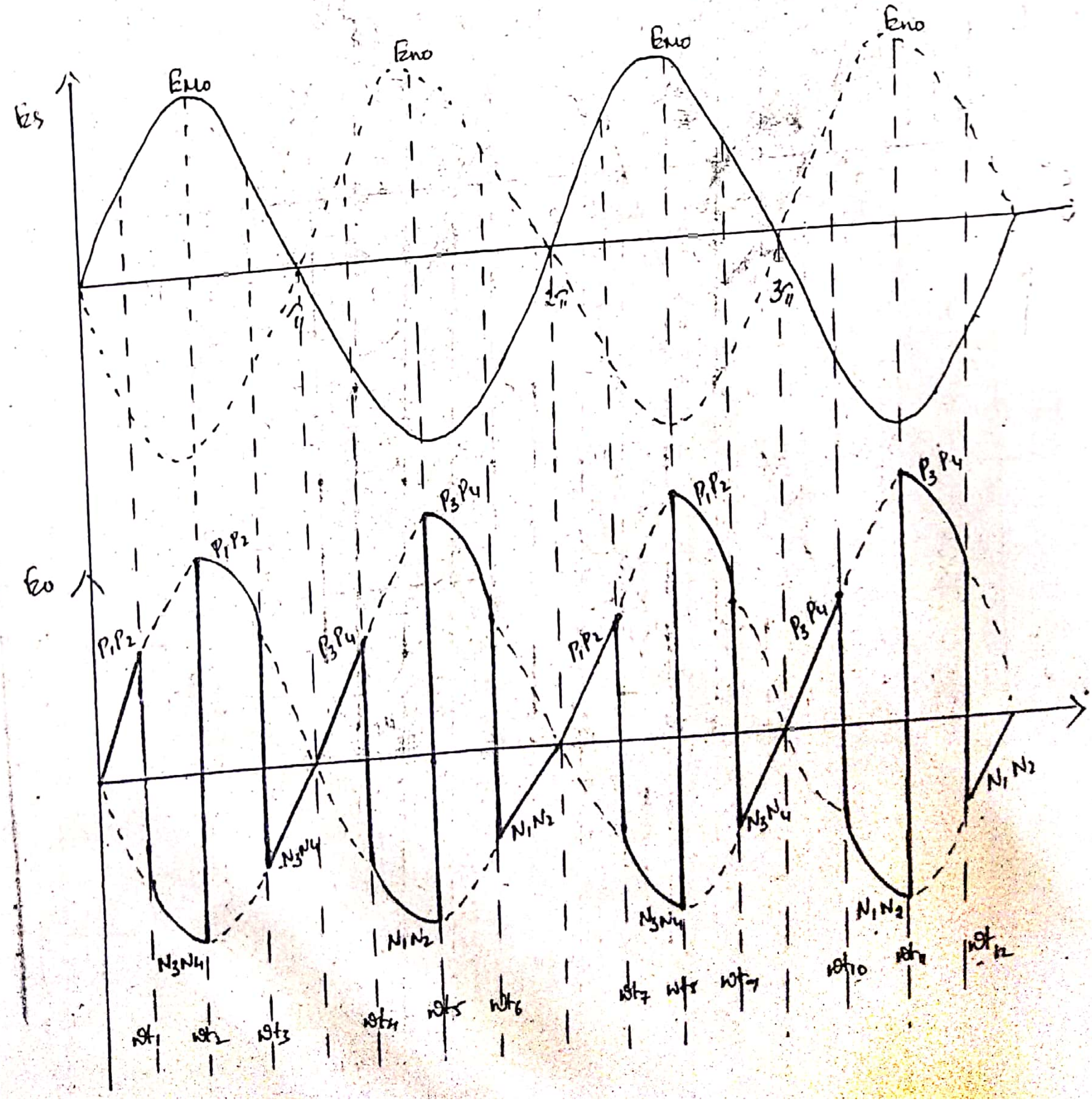
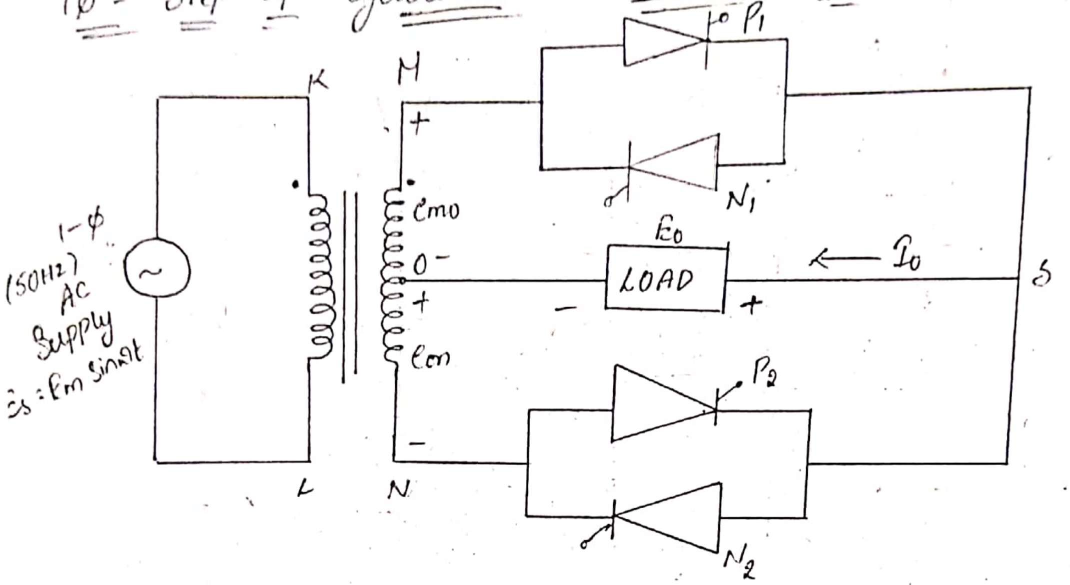
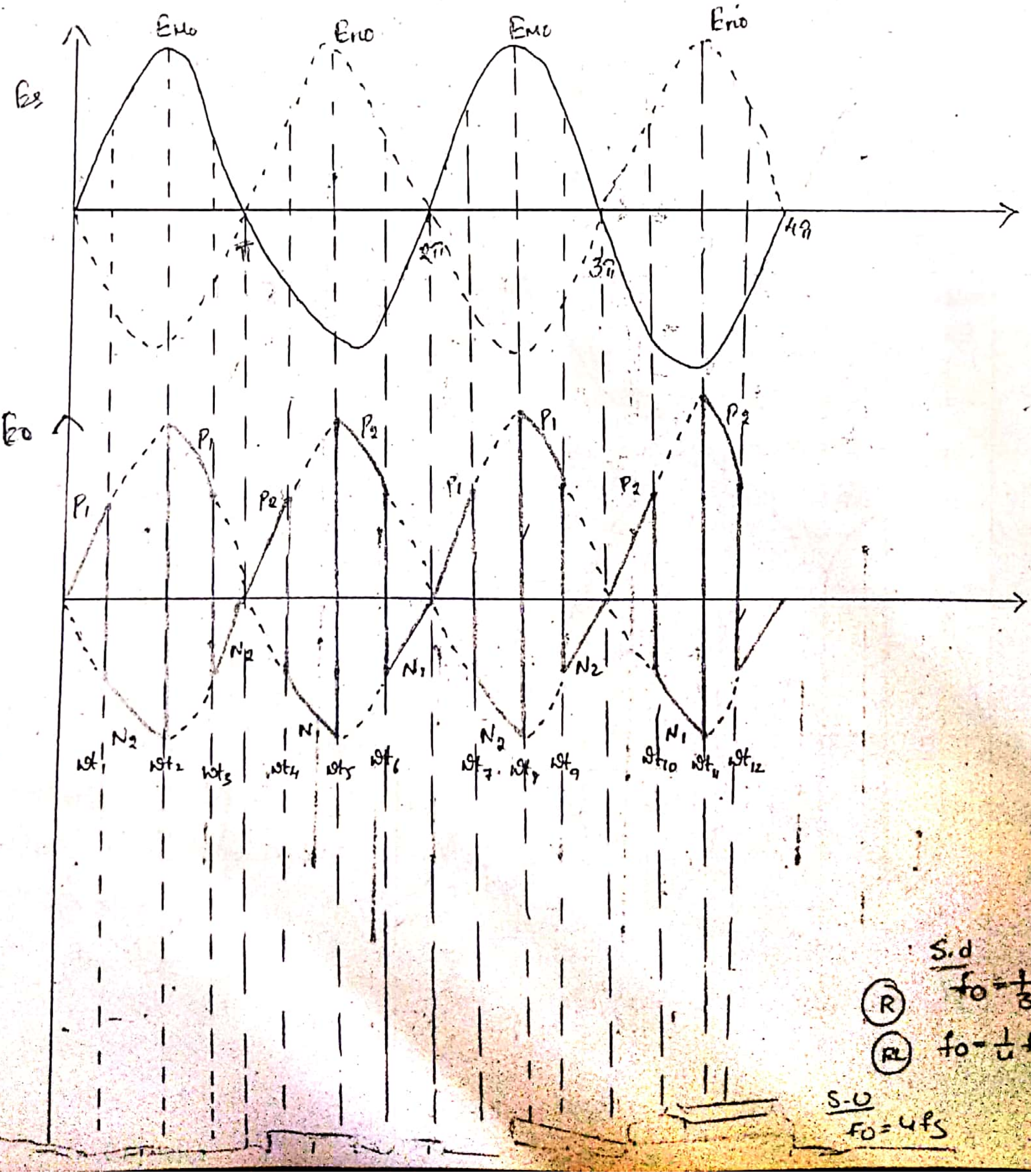
* Bridge type Step up Cycloconverter :-





1ϕ - Step up cycloconverter Midpoint type with R - load.





S.d

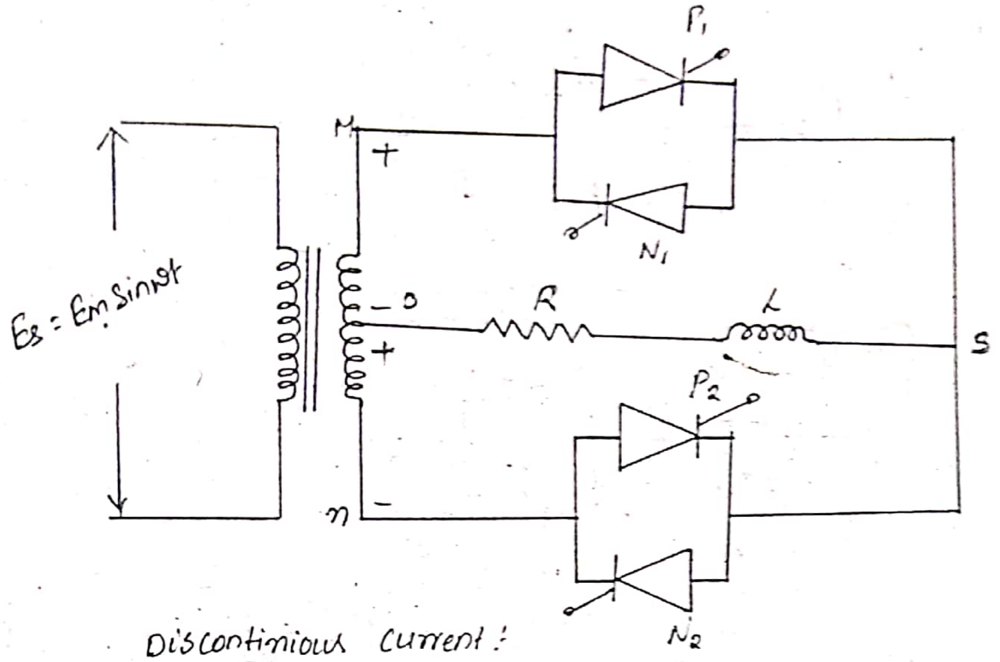
R $f_0 = \frac{1}{3} f_s$

RL $f_0 = \frac{1}{4} f_s$

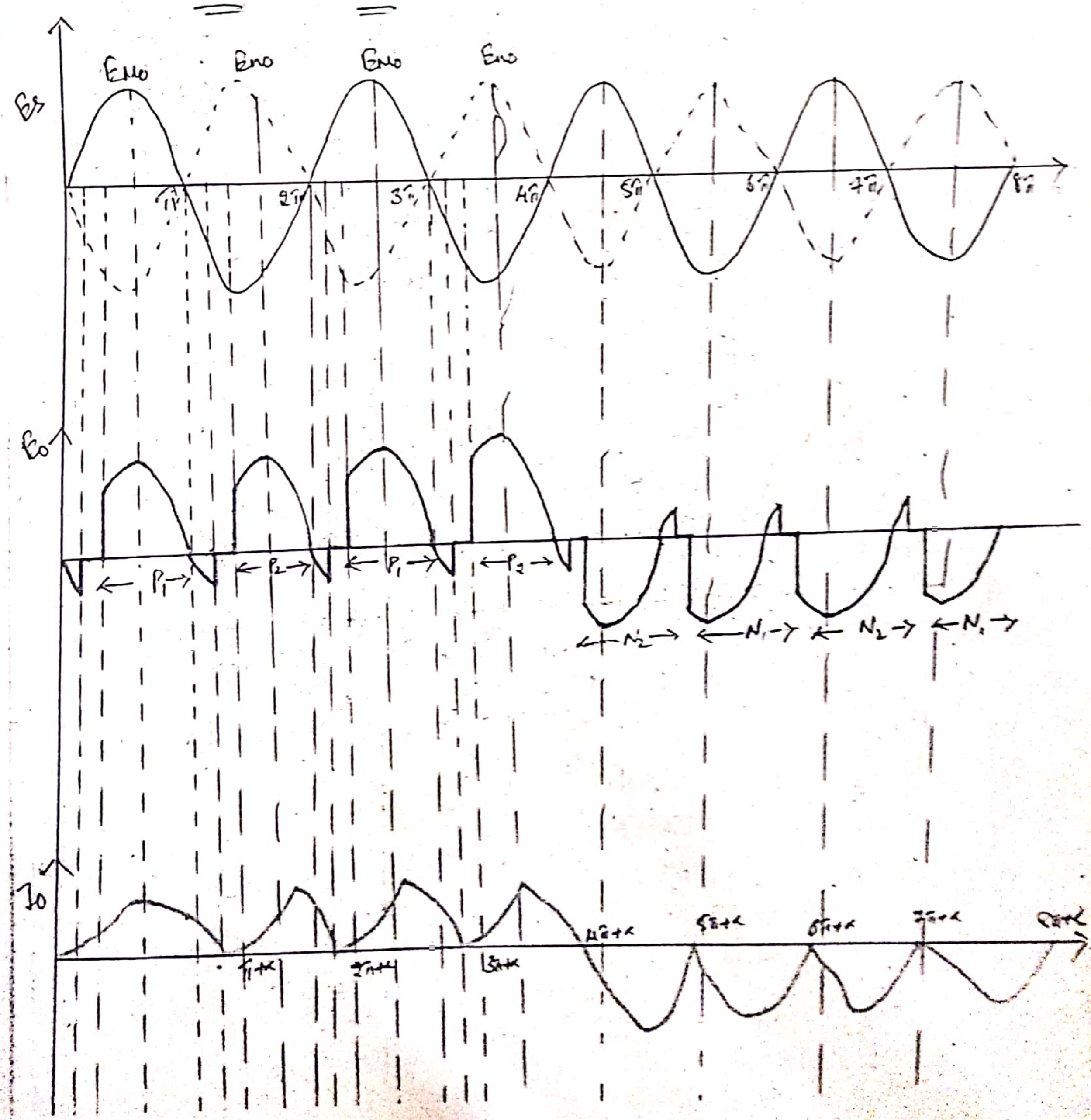
S.U

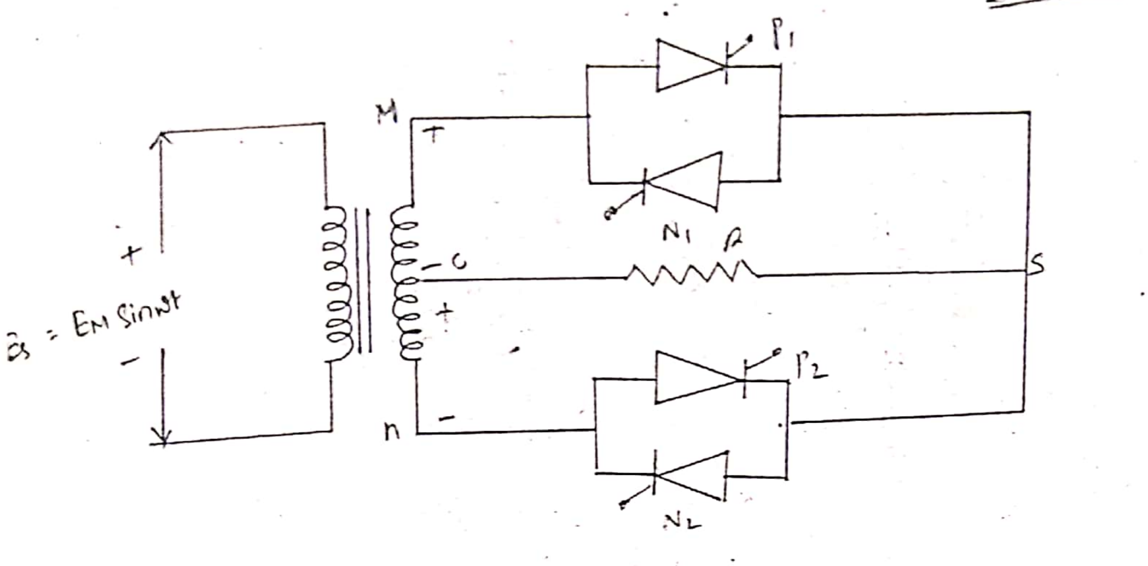
$f_0 = 4 f_s$

* Step down Cycloconverter Midpoint type with R-L load

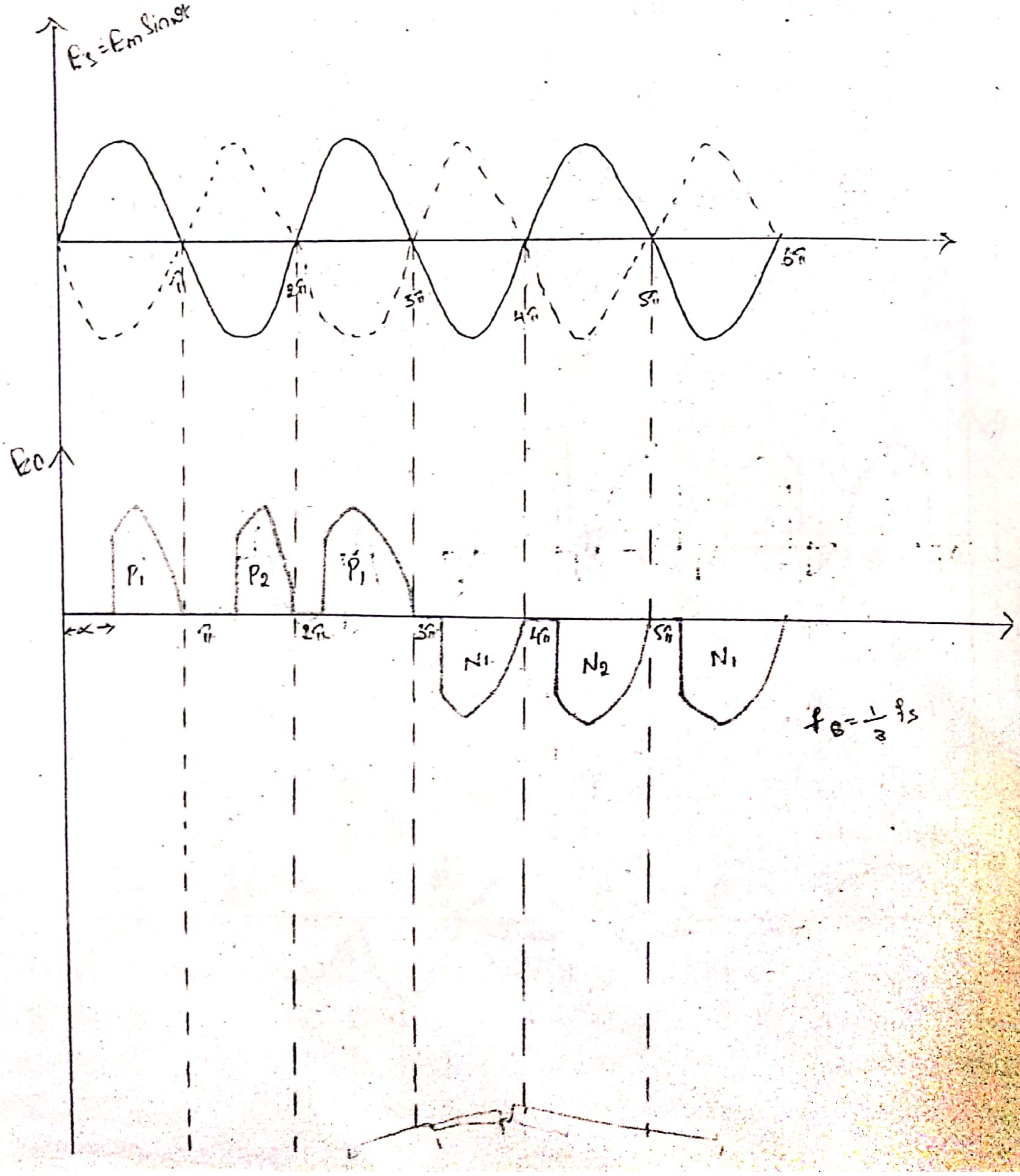


Discontinious current:



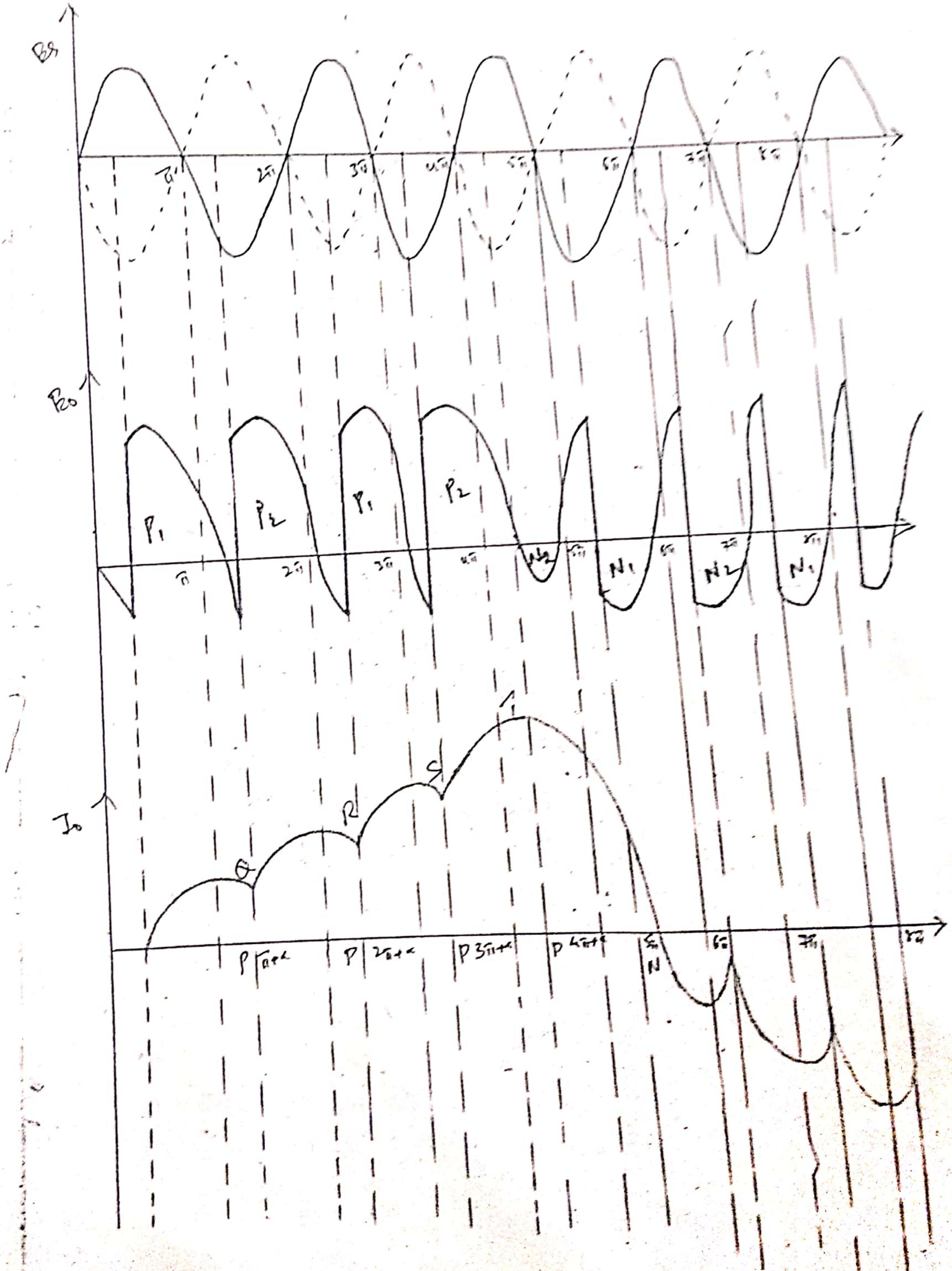


P1
M
+
N1
R
-c
+
S
P2
n
-
N2
Es = Em Sinωt



Es=Em Sinωt
π
2π
3π
4π
5π
Ec
P1
P2
P1
α
N1
N2
N1
fo = 1/3 fs

Continuous Load current:



$$\boxed{f_0 = \frac{1}{4} f_s}$$