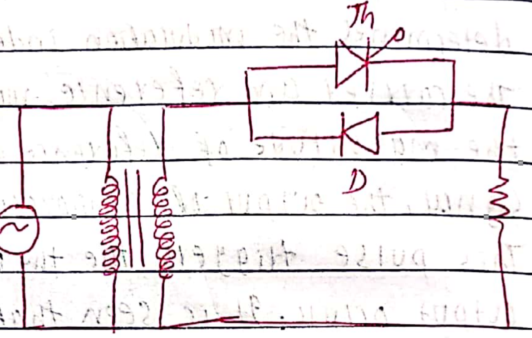
Ac voltage controller:-

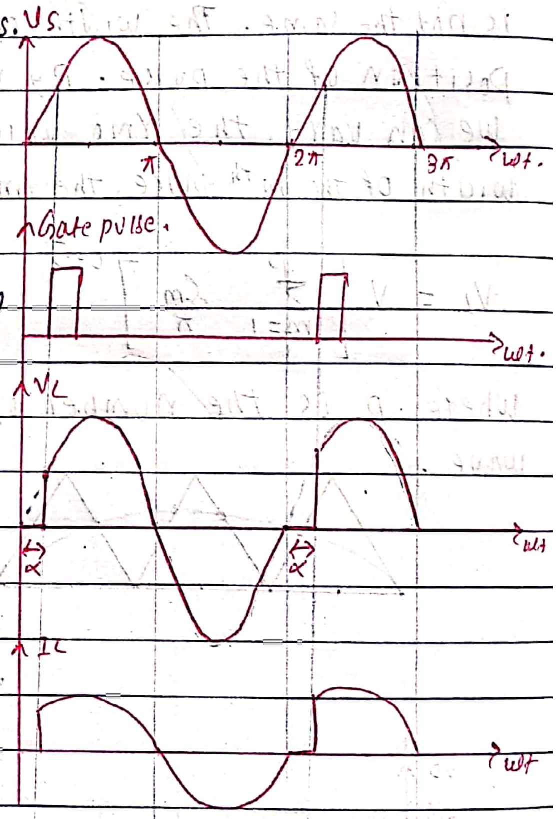
An Ac regulator converts a constant ac voltage into a variable ac voltage of the same frequency. Application of ac regulators include industrial heating, illumination level controller, on load transformer tap changing, speed control of induction motor, etc.

Single phase half wave Regulator.



The circuit uses one thyristor Th and one diode D. During positive half cycle the thyristor is turned on at α°. It conducts upto $\omega t = \pi$.

During negative half cycle diode conducts. Since no phase control is possible on a diode, the whole of negative half cycle appears in the output.



Since, the load is resistive, the waveform of load current is exactly similar to that of output voltage.

Then,

$$V_{av} = \frac{1}{2\pi}\int_{\alpha}^{2\pi} V_m \sin\omega t \cdot d\omega t$$

$$= \frac{V_m}{2\pi} \left. -\cos\omega t \right|_{\alpha}^{2\pi}$$

$$= \frac{V_m}{2\pi}(\cos\alpha - 1)$$

$$V_{rms} = \left[\frac{1}{2\pi}\int_{\alpha}^{2\pi} (V_m \sin\omega t)^2 \, d\omega t\right]^{1/2}$$

$$= \left[\frac{V_m^2}{2\pi}\int_{\alpha}^{2\pi} \frac{1-\cos 2\omega t}{2} \, d\omega t\right]^{1/2}$$

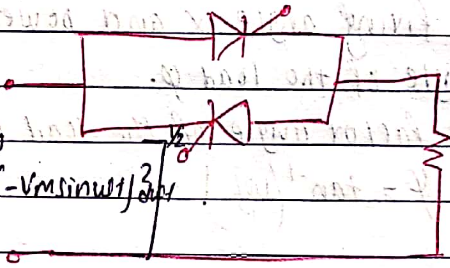
$$= \left[\frac{V_m^2}{4\pi} \left(\omega t - \frac{\sin 2\omega t}{2} \right) \Big|_{\alpha}^{2\pi} \right]^{1/2}.$$

$$= \left[\frac{V_m^2}{4\pi} \left\{ (2\pi - \alpha) - \frac{\sin 4\pi}{2} + \frac{\sin 2\alpha}{2} \right\} \right]^{1/2}.$$

$$= V_m \sqrt{\frac{1}{4\pi} (2\pi - \alpha) + \frac{\sin 2\alpha}{2}}$$

$$\therefore V_{rms} = V_m \sqrt{\frac{1}{4\pi} (2\pi - \alpha) + \frac{\sin 2\alpha}{2}}$$

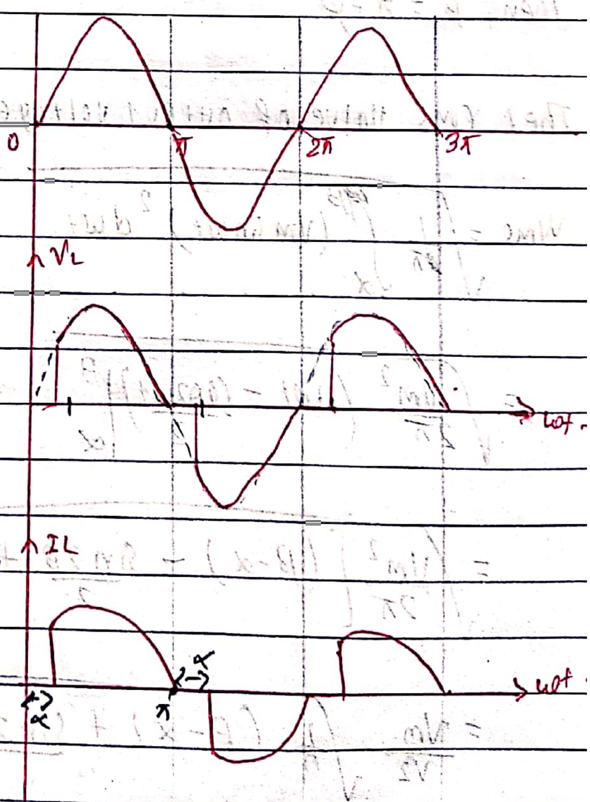
For circuit,



$$V_{rms} = \left[\frac{1}{2\pi} \int_{\alpha}^{\pi} (V_m \sin \omega t)^2 + \int_{\pi+\alpha}^{2\pi} (-V_m \sin \omega t)^2 d\omega t \right]$$

$$= \left[\frac{1}{\pi} \int_{\alpha}^{\pi} V_m \sin \omega t . \, d\omega t . \right]^{1/2}.$$

$$= V_m \sqrt{\frac{1}{2\pi} (\pi - \alpha) + \frac{\sin 2\alpha}{2}}$$



Fourier Analysis,

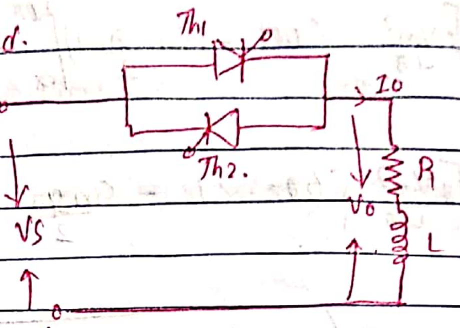
$A_0 = 0$

$$A_n = \frac{2}{2\pi} \left[\int_{\alpha}^{\pi} V_m \sin \omega t \cdot \cos n\omega t \cdot d\omega t + \int_{\pi+\alpha}^{2\pi} (-V_m \sin \omega t) \cdot \cos n\omega t \cdot d\omega t \right]$$

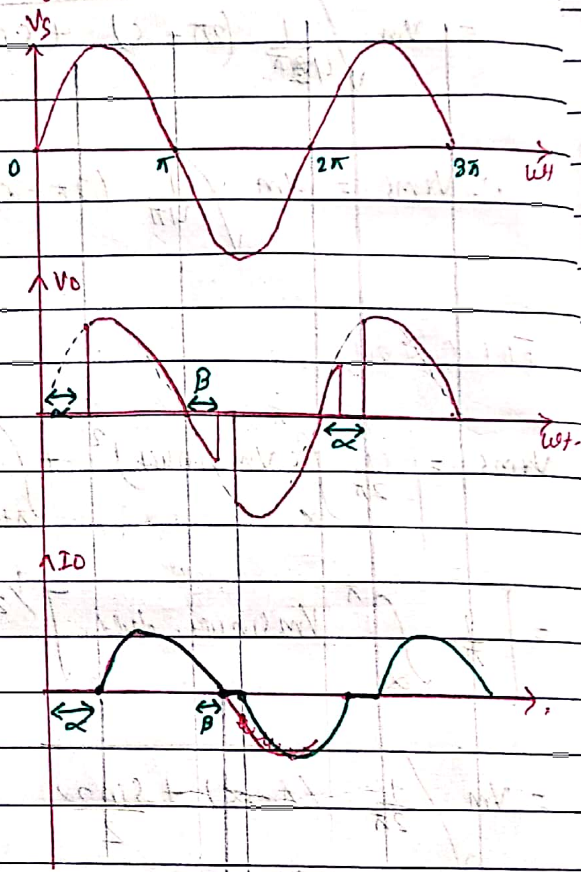
$$B_n = \frac{2}{2\pi} \left[\int_{\alpha}^{\pi} V_m \sin \omega t \cdot \sin n\omega t \, d\omega t + \int_{\pi+\alpha}^{2\pi} (-V_m \sin \omega t \cdot \sin n\omega t \cdot d\omega t \right]$$

Single phase ~~half~~ full wave with inductive load.

Let us assumed that thyristor Th_1 is fired during +ve half cycle and carries the load current.



Due to inductive load, current I_o will not fall to zero at $\omega t = \pi$. It will continue to conduct until I_o falls to zero at $\omega t = \beta$.



The conduction angle $\delta = \beta - \alpha$. depends upon the firing angle α and power factor angle of the load φ.

The power factor angle of the load is given by $\varphi = \tan^{-1}\left(\frac{\omega L}{R}\right)$

Then, $\beta = \pi + \varphi$.

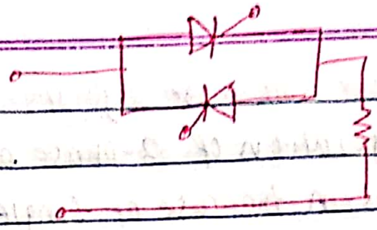
Ther rms value of output voltage is

$$V_{rms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\beta}(V_m \sin\omega t)^2 \, d\omega t}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\left(\omega t - \frac{\sin 2\omega t}{2}\right)\Big|_{\alpha}^{\beta}}$$

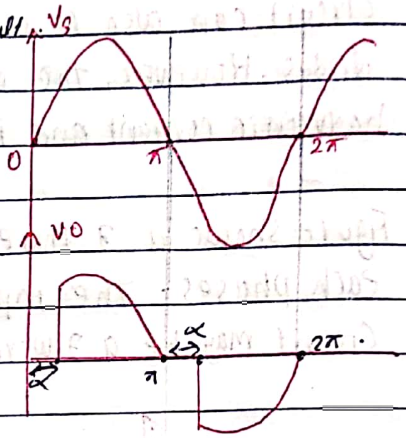
$$= \sqrt{\frac{V_m^2}{2\pi}\left[(\beta-\alpha) - \frac{\sin 2\beta}{2} + \frac{\sin 2\alpha}{2}\right]}$$

$$= \frac{V_m}{\sqrt{2}}\sqrt{\frac{1}{\pi}\left((\beta-\alpha) + \frac{\sin 2\alpha - \sin 2\beta}{2}\right)}$$



Fourier Analysis of

$$V_0(t) = \frac{A_0}{2} + \sum_{n=1}^{\infty} A_n \cos n\omega t + B_n \sin n\omega t.$$



$$A_0 = \frac{2}{2\pi}\left[\int_{\alpha}^{\pi} (V_m \sin\omega t)\, d\omega t + \int_{\pi+\alpha}^{2\pi} (-V_m \sin\omega t)\, d\omega t\right]$$

$$= \frac{V_m}{\pi}\left[-\cos\omega t\Big|_{\alpha}^{\pi} + \cos\omega t\Big|_{\pi+\alpha}^{2\pi}\right].$$

$$= \frac{V_m}{\pi}\left[1 - \cos\alpha + 1 - \cos(\pi+\alpha)\right]$$

$$= 0$$

$$A_n = \frac{2}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \cdot \cos n\omega t \cdot d\omega t.$$

$$= \frac{V_m}{\pi}\int_{\alpha}^{\pi} 2\sin\omega t \cdot \cos n\omega t \cdot d\omega t$$

$$= \frac{V_m}{\pi}\int_{\alpha}^{\pi}\left[\sin(1+n)\omega t - \sin(1-n)\omega t\right] d\omega t$$

$$= \frac{V_m}{\pi}\left(\frac{-\cos(1+n)\omega t}{(1+n)} + \frac{\cos(1-n)\omega t}{1-n}\right)\Bigg|_{\alpha}^{\pi}$$

$$= \frac{V_m}{\pi}\left[\frac{\cos(1+n)\alpha - 1}{1+n} - \frac{\cos(1-n)\alpha - 1}{n-1}\right]$$

$$B_n = \frac{2V_m}{\pi}\int_{\alpha}^{\pi} \sin\omega t \cdot \sin n\omega t \cdot d\omega t.$$

$$= \frac{V_m}{\pi}\left[\frac{\sin(1+n)\alpha}{n+1} - \frac{\sin(n-1)\alpha}{n-1}\right]$$

The amplitude of n^{th} harmonic is $V_{mn} = \sqrt{a_n^2 + b_n^2}$

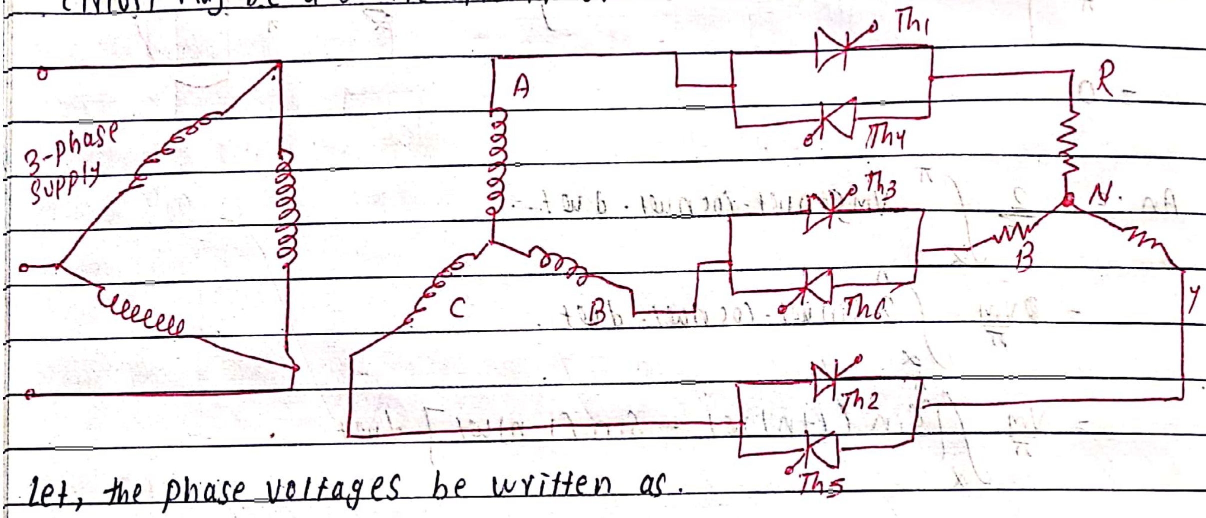
$$\varphi_n = \tan^{-1}\left(\frac{a_n}{b_n}\right)$$

n^{th} harmonic current $(I_{mn}) = \frac{V_{mn}}{R}$.

Three phase full wave Regulator:

For regulation of 3-phase ac voltage, a three phase regulator can be used. As in the case of single phase, a 3-phase half wave regulator circuit can also be used. This circuit uses three thyristors and three diodes. However, the output of such a circuit would contain high harmonic content and half wave circuit is not used in actual practice.

Figure shows a 3-phase full wave regulator. It uses 6 thyristors, 2 for each phases. The input transformer may not be used. Moreover, the circuit may be a 3 wire circuit or a 4 wire circuit:



Let, the phase voltages be written as.

$V_{AN} = V_m \sin\omega t$.

$V_{BN} = V_m \sin\left(\omega t - \frac{2\pi}{3}\right)$

$V_{CN} = V_m \sin\left(\omega t - \frac{4\pi}{3}\right)$

The line to line input voltages are

$V_{AB} = V_{AN} - V_{BN} = \sqrt{3}\, V_m \sin\left(\omega t + \frac{\pi}{6}\right)$

$V_{BC} = V_{BN} - V_{CN} = \sqrt{3}\, V_m \sin\left(\omega t - \frac{\pi}{2}\right)$

$V_{CA} = V_{CN} - V_{AN} = \sqrt{3}\, V_m \sin\left(\omega t + \frac{5\pi}{6}\right)$

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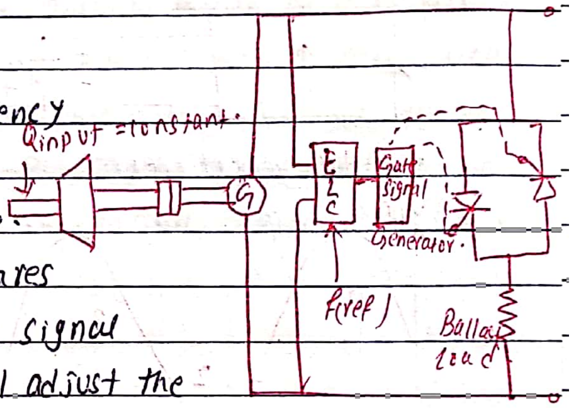
* For $\alpha < 60^\circ$, two thyristors conduct during some interval and three during another interval. The conditions alternate between two and three conducting thyristors.

* For $60^\circ \leq \alpha \leq 90^\circ$, two thyristors conduct at one time.
* For $90^\circ \leq \alpha \leq 150^\circ$, two thyristors conduct at one time, but there are some intervals when no thyristor conducts.
* For $\alpha \geq 150^\circ$, the output voltage is zero.

Hence, the range of control of α is $0 \leq \alpha \leq 150^\circ$

Single phase voltage controller in ELC.



When consumer load decreases, the tendency would be over speeding of turbine thus producing voltage at higher frequency. The ELC senses the frequency and compares it with f(ref) [50 HZ) and gives signal to gate signal generator which will adjust the firing angle of AC voltage controller to increase the ballast power so that total power of generator is equal to power of consumer + power of ballast load again remains constant.

Cycloconverter:

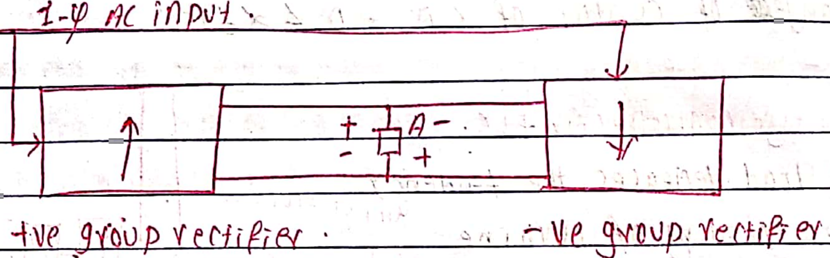
A cycloconverter is a direct frequency changer that converts ac power of one frequency to ac power of another frequency by ac-ac conversion without any intermediate link. It is a single stage frequency converter.

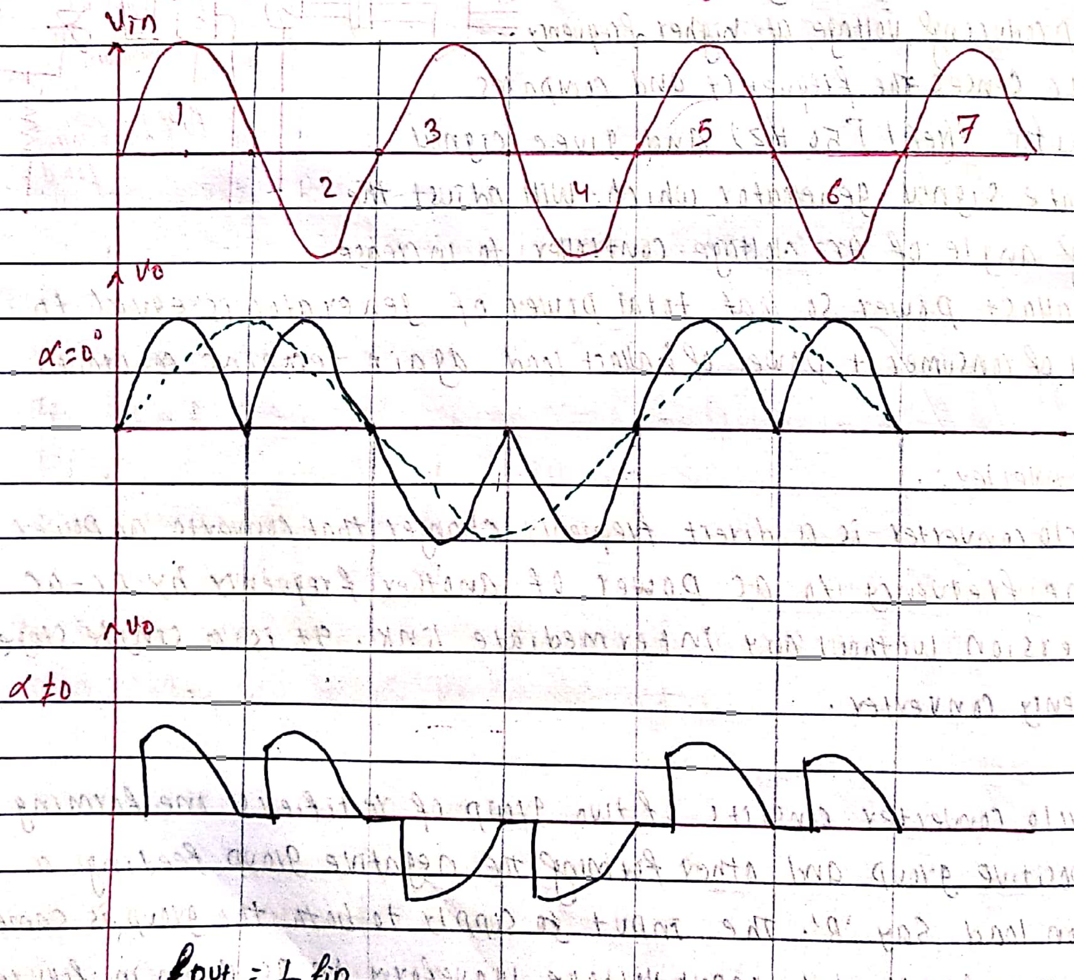
A cycloconverter consists of two group of rectifiers one forming the positive group and other forming the negative group feeding a common load say 'R'. The input ~~to~~ supply to both the group is same. Let the sinusoidal input voltage waveform be as shown in figure with frequency f and numbers as 1 to 6. The p-group rectifier

Converts all the +ve and -ve half waves into positive half waves and a negative group rectifier converts all +ve and -ve half waves into negative half waves.

Let us suppose that we want an o/p voltage with frequency f_0, half the frequency of input voltage (f_s).

For $\alpha = 0$, the firing of thyristor is such that half waves 1 & 2, 5 & 6 passes through +ve group. For negative group rectifier the firing is such that half wave 3 & 4 passes through it.





$f_{out} = \frac{1}{2} f_{in}$

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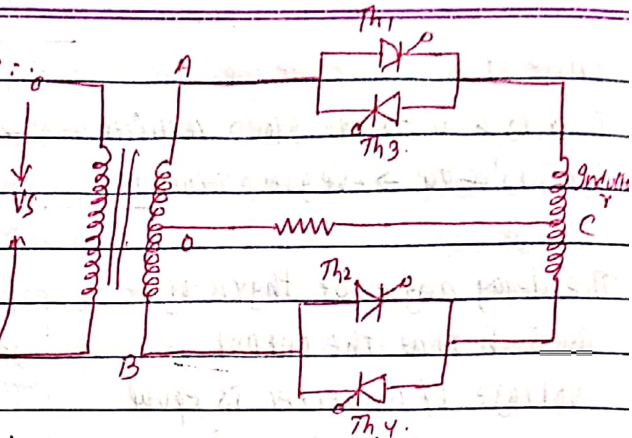
Single phase step-down cycloconverter:

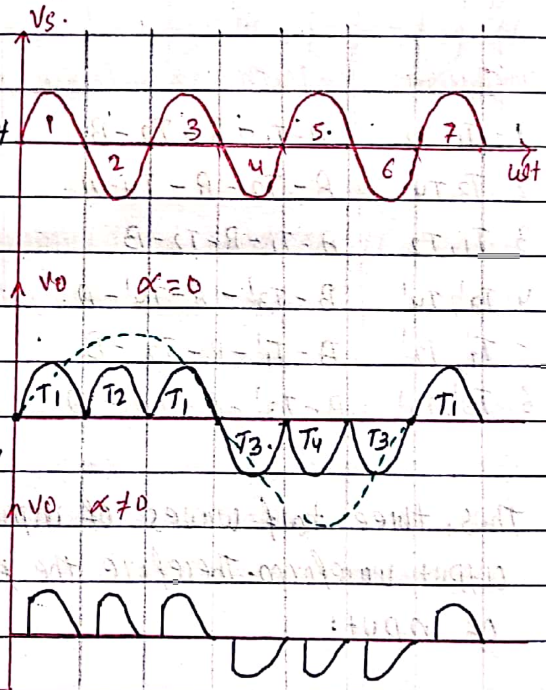
It consists of 1-φ transformer with mid-point tap on the secondary winding and four thyristor.

$T_1, T_2 \Rightarrow$ +ve group thyristor

$T_3, T_4 \Rightarrow$ -ve group thyristor.



The inductor is used to limit the short circuit current during the positive half cycle of the supply voltage, terminal A is +ve w.r.t O. Thyristor T_1 & T_2 are fired at $\omega t = \alpha$. Initially while T_3 & T_4 are kept off. T_1 will conductor from the $\omega t = \alpha$ to $\omega t = \pi$ and output positive voltage will appear across the load. During the negative half cycle of input voltage, terminal B is positive w.r.t O, so thyristor T_2 will conduct from $\pi+\alpha$ to 2π and the load voltage is again positive.



In next half positive cycle, T_1 will conduct from $2\pi+\alpha$ to 3π. These 3 half wave will constitutes the positive half of the output voltage waveforms.

Thyristors T_1 & T_2 are then turned off due to natural commutation and thyristor T_3 & T_4 are fired. During ④, 5 & ⑥ half cycle of supply voltage, thyristor T_3, T_4, T_3 will conduct, causing current flow through and from o to c.

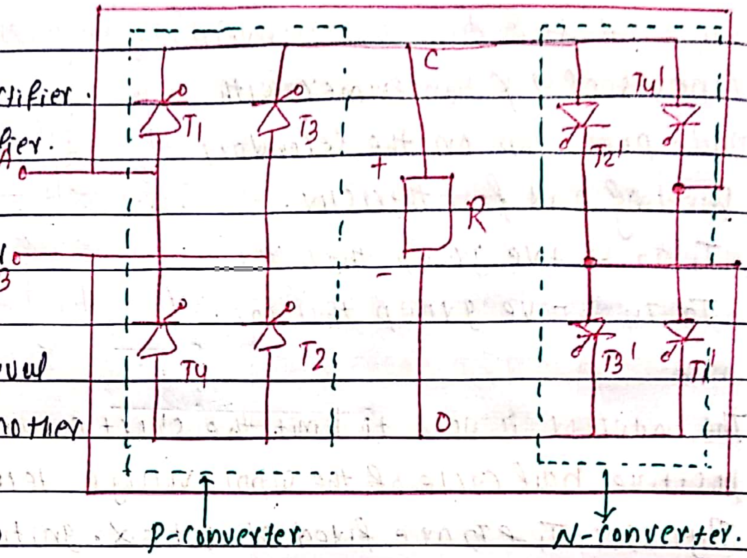
Half cycle.	Thyristor.	Path	Direction
1	Th_1	$A-Th_1-C-O$	$C-O$
2	Th_2	$B-Th_2-C-O$	$C-O$
3	Th_1	$A-Th_1-C-O$	$C-O$
4	Th_3	$O-C-Th_3-A$	$O-C$
5	Th_4	$O-C-Th_4-B$	$O-C$
6	Th_3.	$O-C-Th_4-A$	$O-C$.

Since, 3-half cycles of input wave-forms in one half cycle of o/p waves. The o/p frequency is $\frac{1}{3}^{rd}$ of input frequency.

Bridge type Cycloconverter.

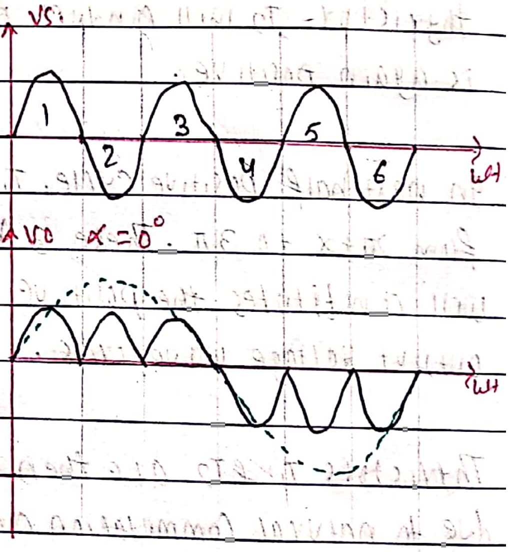
T_1, T_2, T_3 & T_4 → +ve group rectifier.

T_1', T_2', T_3' & T_4' → -ve group rectifier.



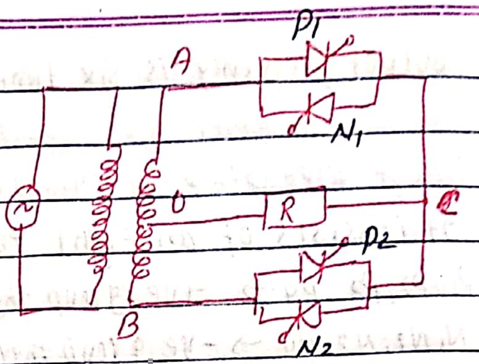
The delay angle of thyristor are such that the output voltage of converter is equal and opposite to that of another converter. Only thyristors belonging to one group (either P or N) are fired at one time. If P-converter is fired alone, average o/p voltage is positive while if N-converter is operating alone, average output voltage is negative. By combining the two, we get ac output voltage.

Cycle	Thyristor.	Path.	Direction.
1	T_1, T_2	$A - T_1 - R - T_2 - B$	C - O
2	T_3, T_4	$B - T_3 - R - T_4 - A$.	C - O
3	T_1, T_2	$A - T_1 - R - T_2 - B$	C - O
4	T_3', T_4'	$B - T_3' - R - T_4' - A$.	O - C
5	T_1', T_2'	$A - T_1' - R - T_2' - B$	O - C
6	T_3', T_4'	$B - T_3' - R - T_4' - A$	O - C.



Thus, three half waves of input waveform in one half wave of output waveform. Therefore the frequency of o/p is 1/3 of the frequency of input.

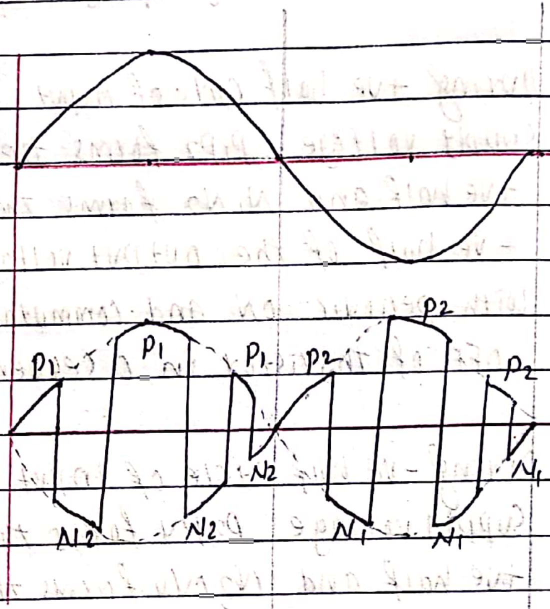
Single-phase Step-up cycloconverter:



A step up cycloconverter requires forced commutation. It consists of a 1-φ transformer with mid-tap on the secondary winding and 4 thyristors.

$P_1, P_2 \rightarrow$ positive group thyristor.

$N_1, N_2 \rightarrow$ Negative group thyristor.



load is connected between secondary winding mid-value terminal C. During positive half cycle of the supply voltage, the terminal A is +ve w.r.t b. So SCR's P_1 and N_2 are forward biased from $\omega t = 0$ to $\omega t = \pi$. SCR P_1 is turned on at $\omega t = 0$. So that load voltage is +ve.

At the instant, ωt_1, P_1 is forced commutated and N_2 is turned ON and the load voltage is again negative.

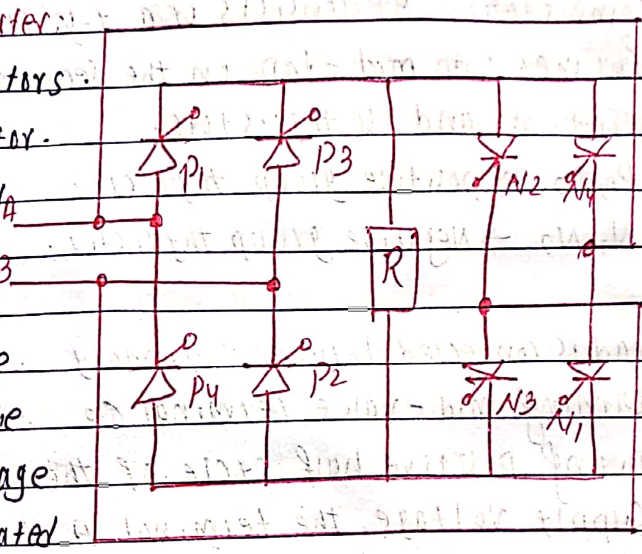
Similarly at ωt_2, N_2 is forced commutated and P_1 is turned ON and the load voltage is again positive.

At $\omega t = \pi$, terminal B is positive w.r.t A. Both SCRs P_2 and N_1 are thus forward biased from $\omega t = \pi$ to $\omega t = 2\pi$.

At $\omega t = \pi$, N_2 is forced commuted and forward biased SCR P_2 is turned ON. At ωt_7, P_2 is forced commutated and SCR N_1 is turned ON.

In this way, +ve and -ve o/p voltages of higher frequency f_o then that of supply frequency f_s is obtained. In this case output frequency is six times of input frequency (i.e $f_0 = 6f_s$).

Bridge type step up cycloconverter:

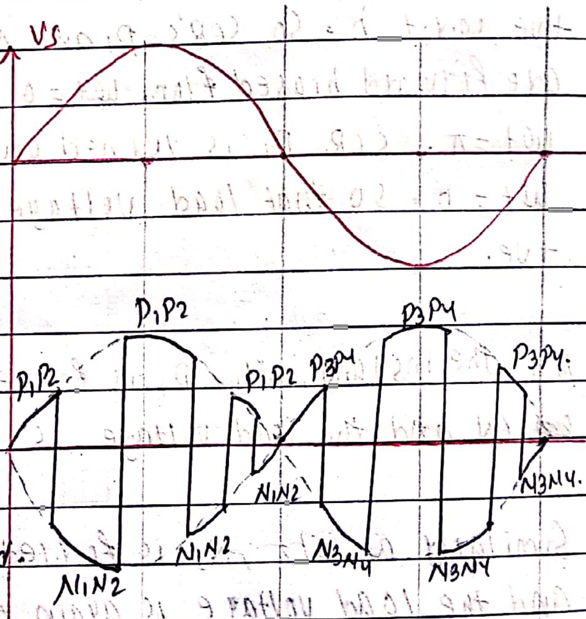


It consists of an eight thyristors.

P_1, P_2, P_3, P_4 → +ve group thyristor.

N_1, N_2, N_3, N_4 → -ve group thyristor.

During +ve half cycle of input supply voltage P_1P_2 forms the +ve half and N_1N_2 forms the -ve half of the output voltage with periodic ON and commutated OFF of thyristor in a sequence.



During -ve half cycle of input supply voltage P_3P_4 forms the +ve half and N_3N_4 forms the -ve half of the output voltage.

In this way +ve and -ve o/p voltage of higher frequency f_0, then that of supply frequency f_s is obtained. In this case o/p frequency is six times that of i/p frequency (i.e $f_0 = 6f_s$)

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