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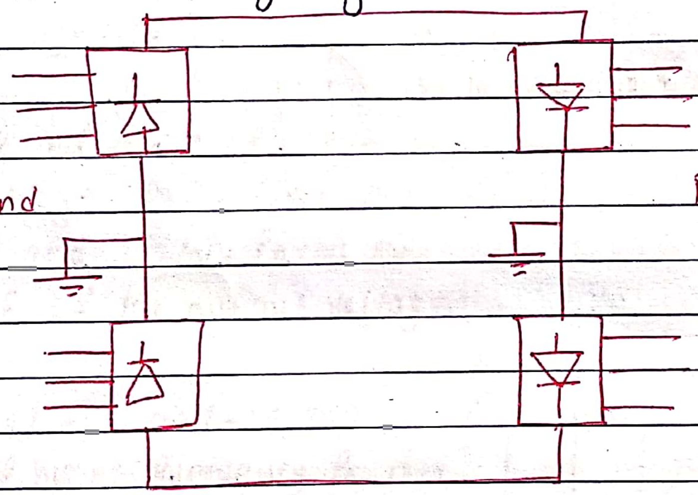
HVDC power transmission:

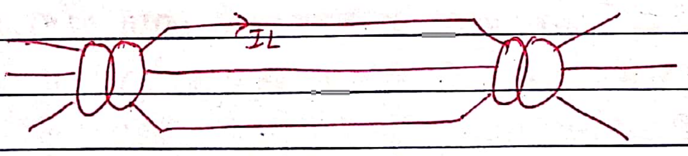
AC line commutated converters are natural commutated converters where turning OFF of the thyristors take place due to natural zero crossings of the current through the thyristors. Generally, full converters are used in HVDC line, where power flow in both directions are possible.

Comparison of HVDC and HVAC Transmission:

The power electronics devices such as rectifiers and inverters are the major components of a HVDC power transmission line. HVDC power transmission is more economical the AC transmission line for bulk power transmission through long line.



HVDC transmission line



HVAC transmission line.

Let us assume that both lines have the same length and are made of same conductor size and that the loading of both lines are thermally limited. So that current I_d equal the rms ac current I_L.

Let HVAC transmission line has three wire and power factor of 0.945 and HVDC transmission line has two

Conductors.

Power per conductor in HVDC transmission line $P_{dc} = V_d I_d$ watt/conduct.

power per conductor in HVAC transmission line $P_{ac} = V_p I_L \cos\phi$ watt/cond.

Now,

$$\frac{P_{dc}}{P_{ac}} = \frac{V_d I_d}{V_p I_L \cos\phi}$$

let us assume that ac and dc insulator can withstand the same creast voltage to ground.

$$\therefore V_d = \sqrt{2}\, V_p$$

Hence, $$\frac{P_{dc}}{P_{ac}} = \frac{\sqrt{2}\, V_p I_d}{V_p I_L \cos\phi} = \frac{\sqrt{2}}{0.945} = 1.5.$$

Now, total power transmitted by HVDC line $(P_{dc}) = 2 * P_{dc}$

total power transmitted by HVAC line $(P_{ac}) = 3 * P_{ac}$

$$\therefore \frac{P_{dc}}{P_{ac}} = \frac{2}{3}\frac{P_{dc}}{P_{ac}} \Rightarrow \frac{2}{3} \times \frac{1.5\, P_{ac}}{P_{ac}} \Rightarrow 1$$

$$\Rightarrow P_{dc} = P_{ac}.$$

Hence, both lines have the same transmission capacity. However, the dc line has only two conductors, where as ac line has three conductors. Therefore the required tower and Right of way are narrower in dc line than in the ac line.

Even though the power loss per conductor is same for both lines. The total power loss of dc line is only $2/3^{rd}$ of power loss in ac lines.

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Advantages of HVDC line.

* HVDC transmission line needs less conductor than HVAC transmission line. But due to the high cost of convertor station HVDC transmission line is only economical for long line.

* A HVDC transmission line is a synchronous that is, it has no stability problem ~~of~~ and synchronising problem. Therefore the two ac system connected at each end of HVDC line do not have to be operated in synchronism with respect to each other or even necessarily at the same frequency.

* The corona loss is less in HVDC line than that in HVAC line.

* The power factor of HVDC line is always unity and therefore no reactive compensation is needed.

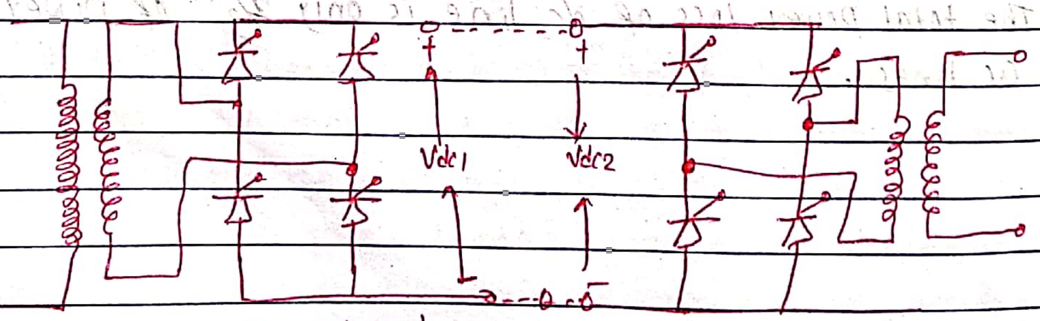
Disadvantages.

* The convertor generates harmonics on both ac and dc sides and therefore filters are required.

* The converter stations are expensive.

Reversible power flow and control in DC line.

Generally full converters are used in HVDC transmission line for reversible power flow. we have seen that a full converter can be operated as rectifier as well as inverter by controlling the firing angle 'α'.



Converter - 1

Converter - 2

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The firing angle of converter-1 and converter-2 shall be controlled in such a way that the average value of dc output of converter-1 is equal to the average value of dc input voltage of converter-2.

Let, α_1 and α_2 be firing angle of converter-1 and converter-2 respectively. Then,

$$V_{dc_1} = \frac{2V_m}{\pi}\cos\alpha_1 \quad \text{and} \quad V_{dc_2} = \frac{2V_m}{\pi}\cos\alpha_2.$$

$\therefore V_{dc_1} = -V_{dc_2}$

or, $\cos\alpha_1 = -\cos\alpha_2$

or, $\cos\alpha_2 = -\cos\alpha_1 = \cos(\pi-\alpha_1)$

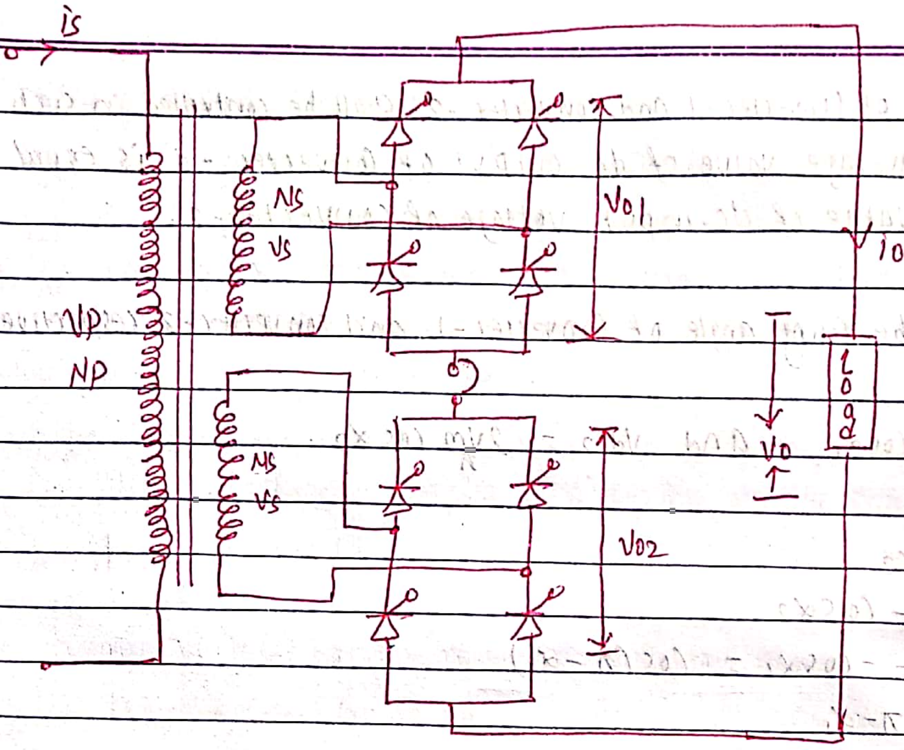
$\therefore \alpha_2 = \pi-\alpha_1$

Hence, if converter-1 is fired at α_1 than converter-2 shall be fired at $(\pi-\alpha_1)$ so that converter-1 acts as a rectifier and converter-2 acts as an inverter. In this case power flow from converter-1 to converter-2. If reversible power flow is required converter-2 shall be operated as rectifier and converter-1 as inverter.

Series operation of converters.

For high voltage applications two or more converters can be connected in series to share the voltage. Manufacturing of a thyristor, which can be operated in high voltage would be complicated and expensive with compare to connecting converters of low voltage rated in series.

Figure shows the two single phase full converters connected in series. The turn ratio between the primary and secondary is $N_P/N_S = 2$. The total output voltage across the load is the sum of the output voltage of two converters.



In rectification mode, the first converter is fully conducted with $\alpha_1 = 0$ and the delay angle of second-converter (α_2) is varied from 0 to π to control the dc output voltage.

In the inversion mode, the second converter is fully retarted ($\alpha_2 = \pi$) and delay angle of the first converter (α_1) is varied from 0 to π to control the average output voltage.

$V_{dc_1} = \frac{2V_m}{\pi} \cos\alpha_1$ and $V_{dc_2} = \frac{2V_m}{\pi} \cos\alpha_2$

The resultant average output voltage is $V_{dc} = V_{dc_1} + V_{dc_2}$

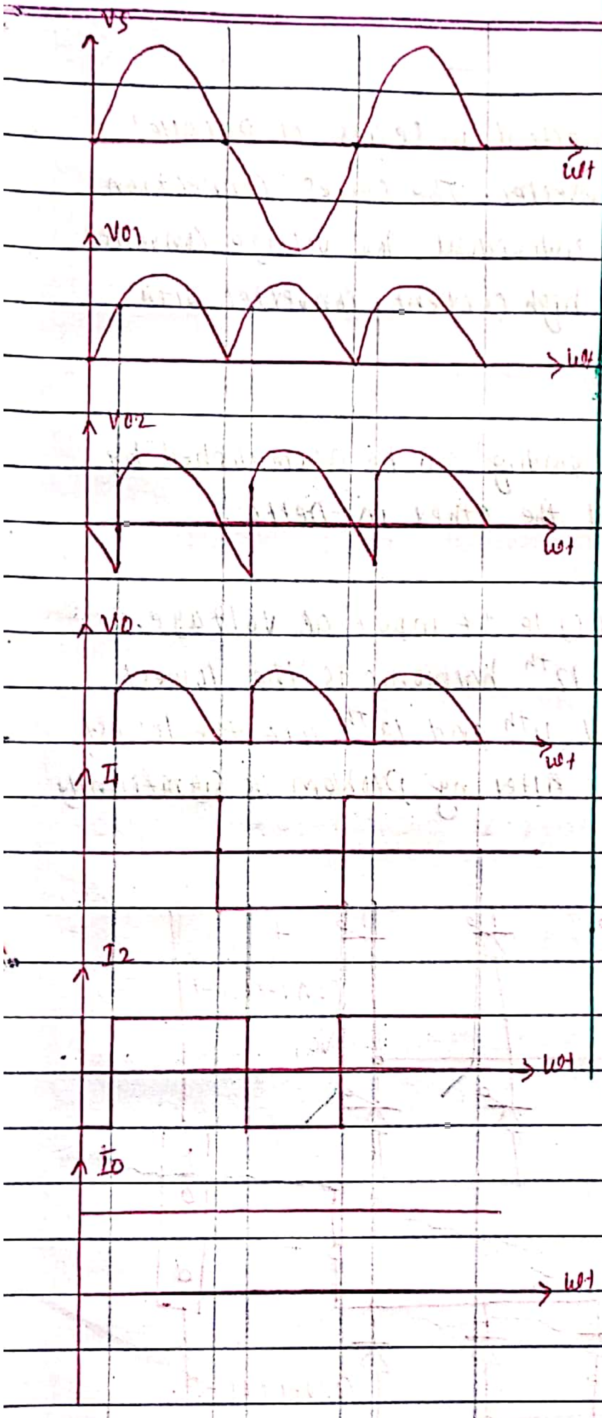
$$= \frac{2V_m}{\pi}\left[\cos\alpha_1 + \cos\alpha_2\right]$$

In rectification mode:

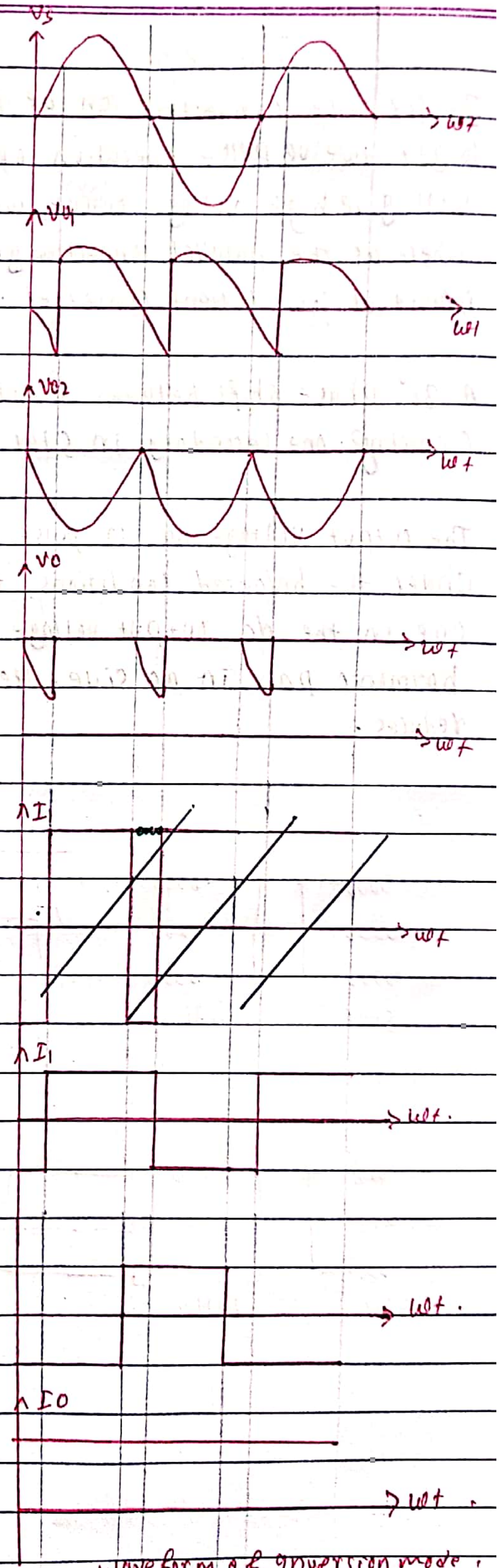
$\alpha_1 = 0$ and $0 \le \alpha_2 \le \pi$ Then, $V_{dc} = \frac{2V_m}{\pi}(1 + \cos\alpha_2)$

In inversion mode.

$\alpha_2 = \pi$ and $0 \le \alpha_1 \le \pi$ Then, $V_{dc} = \frac{2V_m}{\pi}(\cos\alpha_1 - 1)$



Waveform of Rectification mode



waveform of inversion mode.

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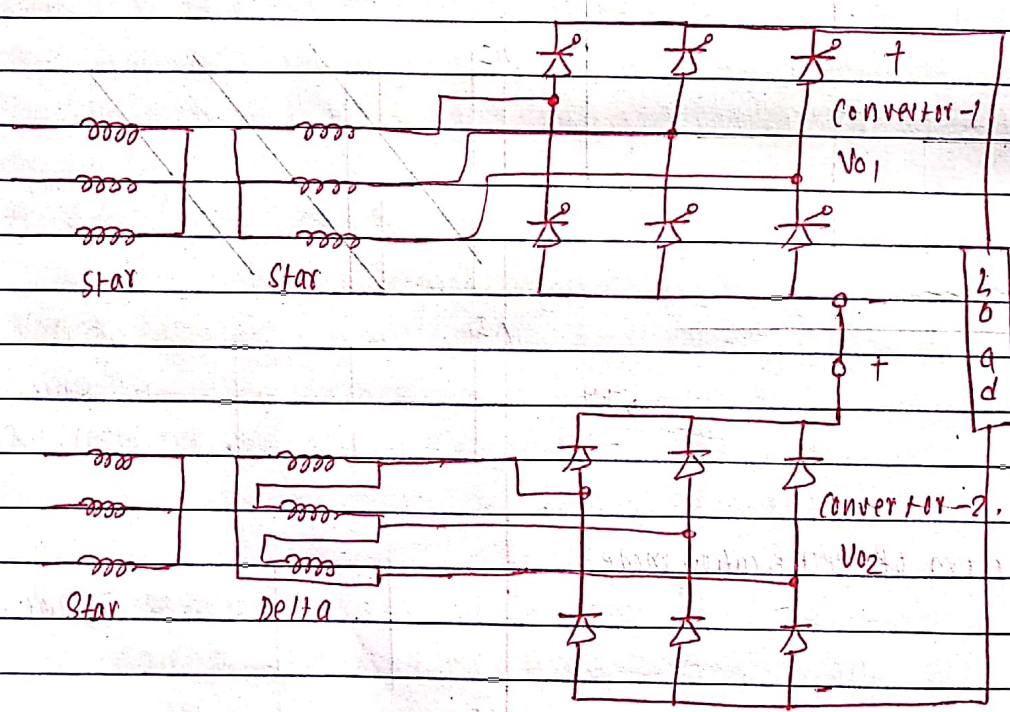
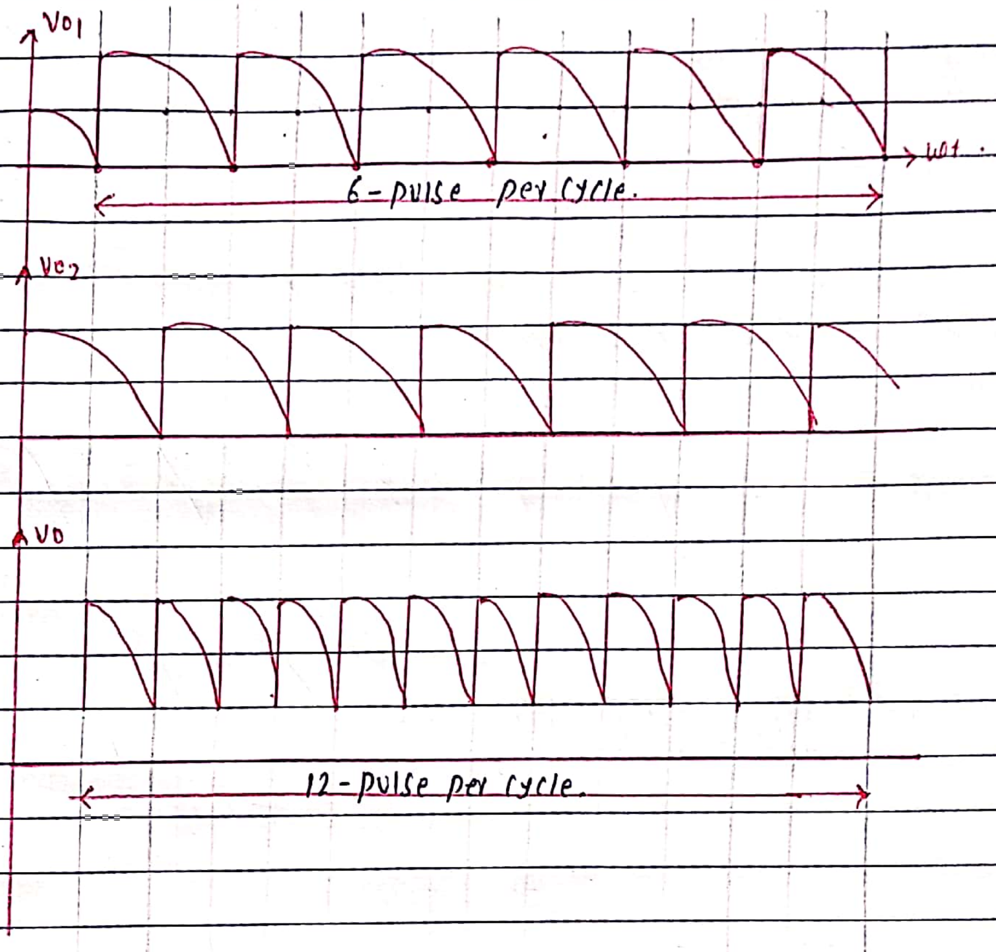
12-pulse operation of converter:

The six pulse converters can be connected in series or parallel to get twelve pulse operation of converter. The series connection will give high voltage output with individual low voltage converter where as the parallel connection gives high current converter with individual low current converter.

A 30° phase shift between secondary winding can be accomplished by connecting one secondary in star and the other in delta.

The output voltage has 12 pulse per cycle of input ac voltage. Under the balanced conditions, the 12^{th} harmonic is the lowest one in the dc output voltage and 11^{th} and 13^{th} are the lowest harmonic pair in ac side. Hence, filtering problem is significantly reduces.




Vo1
wt
6-pulse per cycle.
Vo2
Vo
12-pulse per cycle.