Lecture -5-

Ac-Cycloconverters

Traditionally, ac-ac conversion using semiconductor switches is done in two different ways:

1. in two stages (ac-dc and then dc-ac) as in dc link converters.
2. in one stage (ac-ac) cycloconverters.

Cycloconverter (CCV) is a device which converts input power at one frequency to output power at a different frequency with only one stage conversion. A Cycloconverter is basically a one-stage frequency changer. Here, one stage conversion means that input AC supply is directly converted to variable frequency output with the use of power electronic switches such as thyristors. It does not require any intermediate DC link, so it is very efficient.

The input power of this device is fixed AC voltage having a particular frequency. while the output of the device is variable voltage & variable frequency. The output voltage and frequency of this device are controllable.

A cycloconverter is a naturally commuted converter with inherent capability of bidirectional power flow, and there is no real limitation on its size unlike an SCR inverter with commutation elements. The main limitations of a naturally commutated cycloconverter are:
(1) limited frequency range for harmonic-free.
(2) poor power factor, particularly at low-output voltages.

Why do we need Cycloconverters?

The answer to this question is **(1)** Speed Control. Cycloconverters are extensively used for driving large motors like that used in Cement mills.

(**2)** The out frequency of cycloconverters can be reduced up to zero which helps us to start very large motors with full load at minimum speed and then gradually increase the speed of the motor by increasing the output Frequency.

Before the invention of cycloconverters, these large motors had to be unloaded completely and then after starting the motor, it had to be loaded gradually which led to time and effort consumption. **(3**) also, frequency can be increased to drive a light load.

❖ Classification of Cycloconverters:

→ <u>Based on the output frequency</u>:

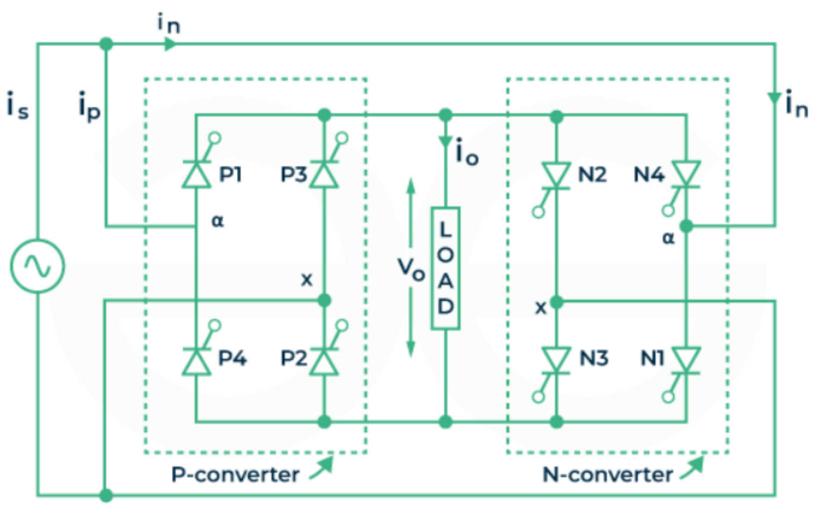
1) **Step-Up Cycloconverters**: this type of CCV provide an output frequency greater than that of input frequency ($f_o > f_s$). But it is not widely used since it does not have much practical application. Step-Up CCV requires *forced commutation* technique to turn OFF the conducting thyristor which increases the complexity of the circuit.

2) **Step-Down Cycloconverters**: this type of CCV provide an output frequency lower then the input frequency($f_o<f_s$). These are most commonly used and work with the help of *natural commutation* to switch off a thyristor, hence, easy to build and operate.

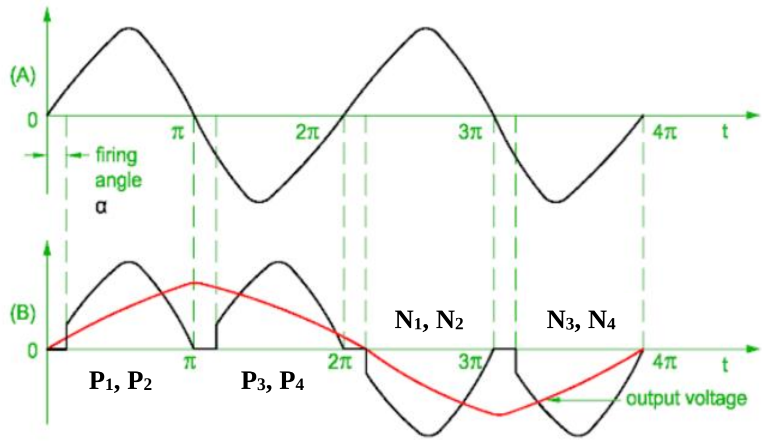
→ <u>Based on the phase input and phase output:</u>

1) single -phase to single -phase bridge Cycloconverter:

- Two single-phase fully-controlled bridges are connected in opposite directions.
- It consists of a total of eight thyristors, P1 to P4 and N1 to N4. four for positive group (P – converter) and the remaining four for the negative group (P – converter). Both groups never operate together as produce a short circuit at the input.
- By various sequences of SCRs, we can get various output frequencies.
- The output voltage becomes symmetrical if the firing angle of the both converter SCRs are kept same.
- during the positive half cycle of supply voltage from $\omega t = 0$ to π, load current i_P flows through path (P_1– LOAD– P_2), which result the first half cycle in positive side. pairs P_1, P_2 naturally turn off due to negative half cycle of the alternating supply. At negative supply voltage ($\omega t = \pi$ to 2π) the load current flows through other positive group path (P_3– LOAD– P_4), which produces another positive half cycle and so on according to the required frequency.



- After passing the controlled cycles in the positive group, in the same manner, the other group can be operated.
- pairs N_1, N_2 resulting load current i_n flows through path (N_1– LOAD– N_2) during the positive cycle of supply voltage and N_3, N_4 works at negative supply voltage which all produce negative half cycles.

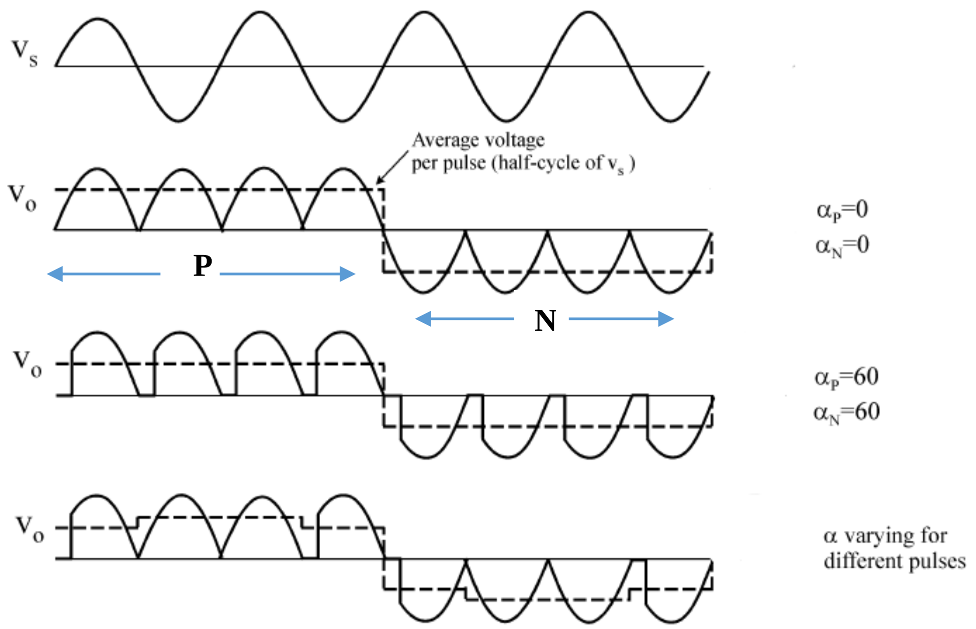


WAVEFORMS OF THE BRIDGE TYPE CYCLOCONVERTER

n =2
50/2=25

The input and output waveforms of the bridge configuration cycloconverter are shown in figure above. When there are two complete cycles at the input sides, there is only one complete cycle at the output side, so we can say that the output frequency is **one-half** that of input frequency. For example, if the input frequency is 50 Hz, the output frequency will be 25 Hz. The waveform of the output voltage is adjusted by adjusting the firing angle of the SCRs.

Consider the operation of the cycloconverter to get one-fourth of the input frequency at the output as seen in *Fig below*. For the first two cycles of vs, the positive SCRs operate supplying current to the load. It rectifies the input voltage; thus, the load sees 4 positive half cycles as seen in *Fig below*. In the next two cycles, the negative SCRs operate supplying current to the load in the reverse direction.



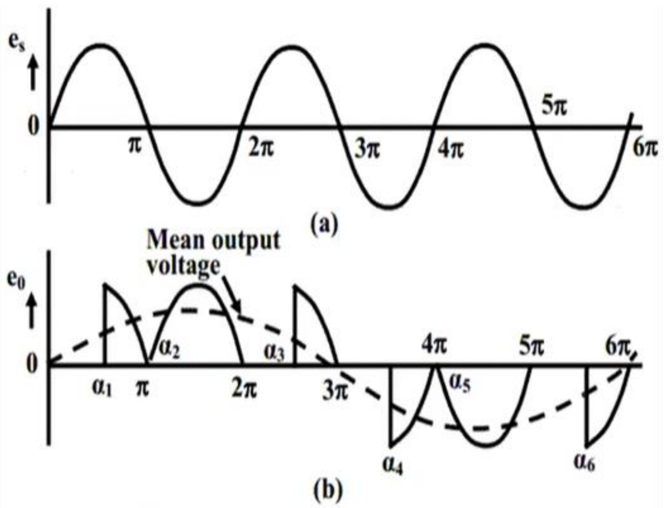
n =4

$$f_{out} = \frac{f_{in}}{4}$$

$$f_{out} = \frac{60}{4} = 15\ Hz$$

αP = Firing angle of positive converter
αN = Firing angle of negative converter

- The firing angle control scheme must be adjusted such that only one converter conducts at a time, and the change of firing pulses from one converter to another should be periodic between positive and negative half cycles according to the output frequency this is the **circulating-current** free mood of operation.
- α_1 in first half cycle that pulses P_1 and P_2 must be equal to α_4 that pulses N_1 and N_2 and so on for all firing angle, as shown in fig below. This mood is **non-circulating-current.**



Input (a) and output (b) voltage waveforms of a cyclo-converter with an output frequency

❖ Applications of Cycloconverters

1. Heavy Washing Machines
2. Power lines
3. Aircraft Power supply
4. SVG (Static VAR Generators)
5. Ship Propulsion system.

❖ Advantages of Cycloconverters

1. Efficiency is high compared to other converters that are available.
2. Capable of power transfer in bi-directions.
3. Frequency conversion can be achieved in one stage.
4. Ensures that voltage and frequencies are controllable.
5. The need to use commutation circuits is not necessary because it utilizes natural commutation.
6. Power transfer is possible from supply to load and vice versa at any power factor.
7. The dynamic response is very good.
8. Smooth low-speed operation is achieved.

❖ Disadvantages of Cycloconverters

1. Complex circuit thus it is difficult to design.
2. The power factor is very poor at large values of Alpha (α).
3. There is more distortion at low frequencies.
4. Smooth output frequency is difficult to maintain.

Example:

The input voltage to the cycloconverter is 120 V (rms), 60 Hz. The load resistance is 5 Ω and the load inductance is $L = 40$ mH. The frequency of the output voltage is 20 Hz. If the converters are operated as semiconverters such that $0 \le \alpha \le \pi$ and the delay angle is $\alpha_p = 2\pi/3$, determine (a) the rms value of output voltage V_o, (b) the rms current of each thyristor I_R, and (c) the input PF.

Solution

$V_s = 120$ V, $f_s = 60$ Hz, $f_o = 20$ Hz, $R = 5\ \Omega$, $L = 40$ mH, $\alpha_p = 2\pi/3$, $\omega_0 = 2\pi \times 20 = 125.66$ rad/s, and $X_L = \omega_0 L = 5.027\ \Omega$.

a. For $0 \le \alpha \le \pi$,

$$\boxed{V_{o,\text{rms}} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi}[V_m \sin(\omega t)]^2 d(\omega t)} = \frac{V_m}{\sqrt{2}}\sqrt{1 - \frac{\alpha}{\pi} + \frac{\sin(2\alpha)}{2\pi}}}$$

$$V_{o,rms} = \frac{120\sqrt{2}}{\sqrt{2}}\sqrt{1 - \frac{2\pi/3}{\pi} + \frac{\sin(2 * 2\pi/3)}{2\pi}} = 120 * \sqrt{0.45} = 52.6\ v$$

b.

$$Z = \sqrt{R^2 + (\omega L)^2}$$

$$Z = \sqrt{5^2 + (2\pi * 20 * 0.04)^2} = 7.09\ \Omega$$

$$I_{o,rms} = \frac{V_{o,rms}}{Z} = \frac{52.6}{7.09} = 7.41\ \ A$$

$$I_P = I_N = \frac{I_{o,rms}}{\sqrt{2}} = \frac{7.41}{\sqrt{2}} = 5.24\ \ A$$

The rms current in each SCR is

$$I_{SCR,rms} = \frac{I_P}{\sqrt{2}} = \frac{5.24}{\sqrt{2}} = 3.7\ A$$

$$PF = \frac{P}{S} = \frac{I_{o,rms}^2 * R}{V_{s,rms} * I_{s,rms}} = \frac{I_{o,rms} * R}{V_{s,rms}} = \frac{7.41 * 5}{120} = 0.31$$

The previous equations are used for the resistive load also.

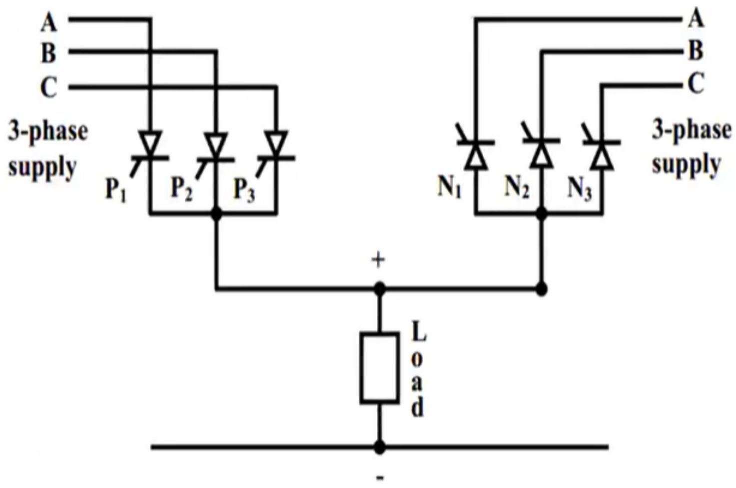
2) Three -phase to single -phase Cycloconverter:

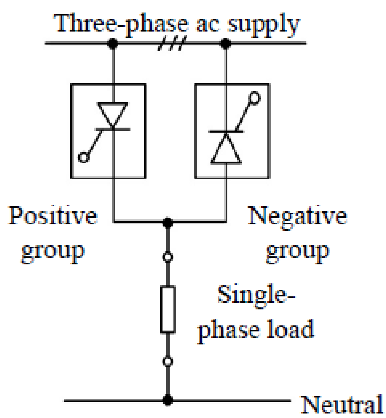
A three-phase to single-phase cycloconverter is used to convert a three-phase supply at one frequency to a single-phase load at a lower frequency. A three-phase to single phase cycloconverter consists of positive and negative group thyristors. Positive converters will provide positive current and negative converters will provide negative current to the load.

There are two kinds of three-phase to single-phase cycloconverters:

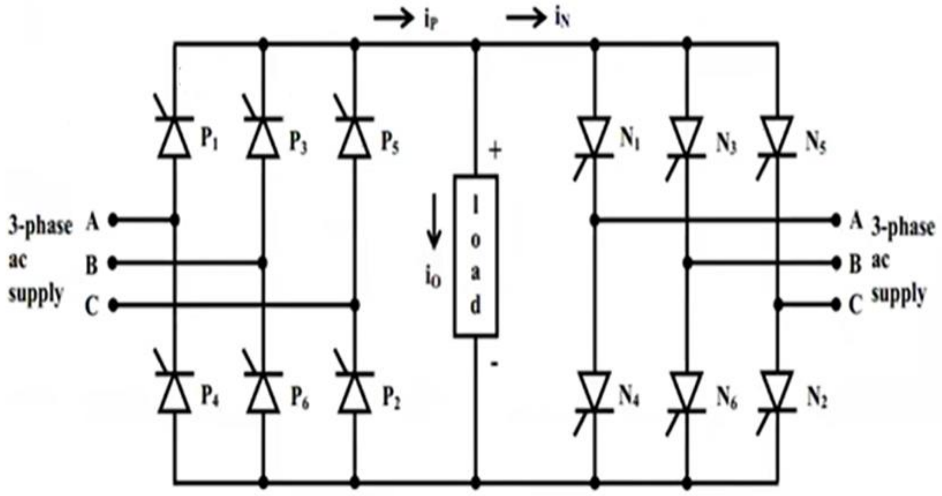
a) 3φ-1φ half-wave cycloconverter

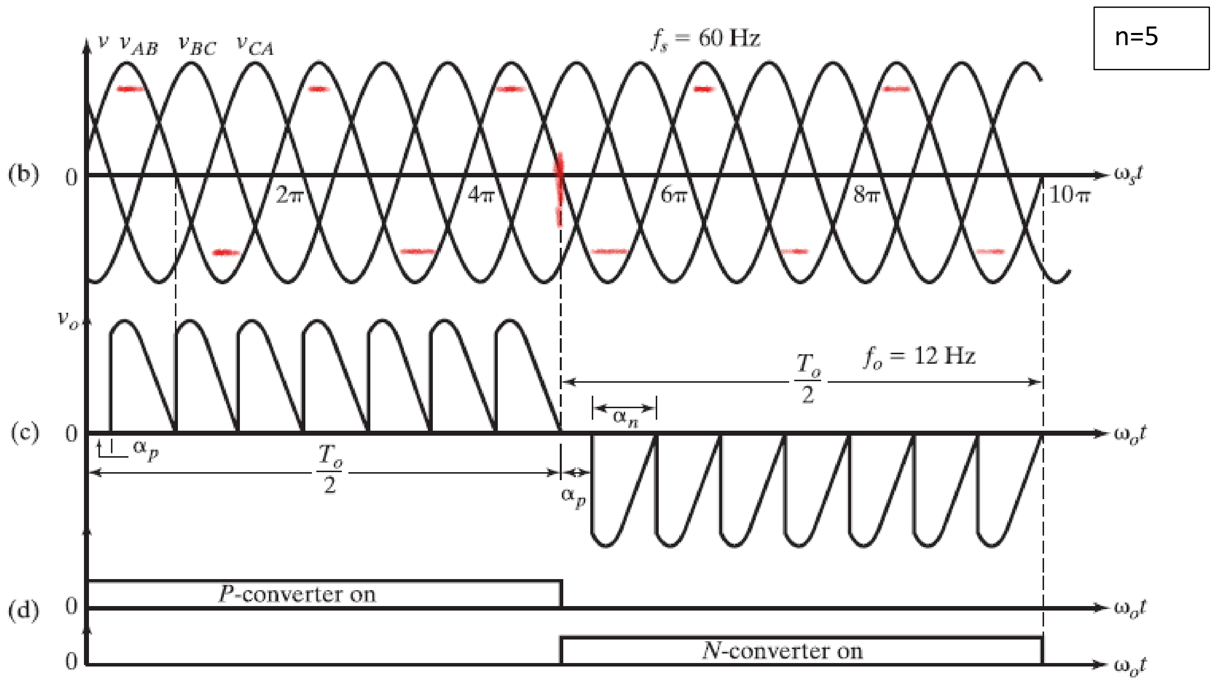
A three-phase to single-phase cycloconverter is shown in Fig. 4.17. The positive group converter P is a three-phase half wave controlled rectifier that can conduct load current that flows downward towards the neutral. Similarly, negative group converter N is also a three-phase half wave controlled rectifier which conducts the load current in the reverse.





b) 3φ-1φ full-wave bridge cycloconverter.





FIGURE

Three-phase/single-phase cycloconverter. (a) Circuit, (b) Line voltages, (c) Output voltage, and (d) Conduction periods for P and N converters.

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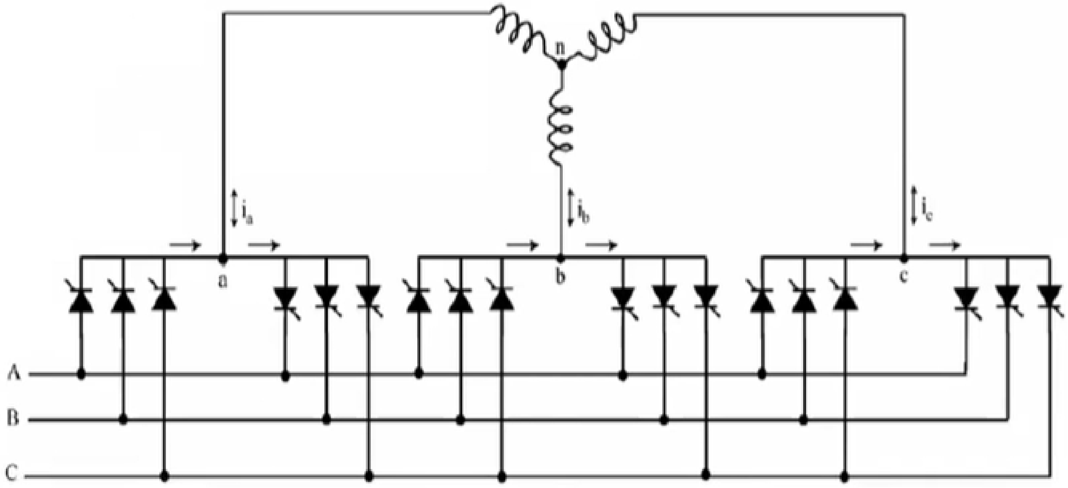
Calculate number of sine wave for one line like V_{AB} = 5 (10 half cycle)
That mean 2.5 positive and 2.5 negative.
So, output frequency is 60 /5 = 12 hz.

3) Three -phase to Three -phase Cycloconverter:

a) 3φ-3φ half-wave cycloconverter

When a three-phase low frequency output is required, three sets of phase controlled three-phase to single-phase cycloconverters with a phase displacement of 120° between their outputs are connected, as shown in Fig below. This circuit requires 18 thyristors.



b) 3φ-3φ full-wave bridge cycloconverter

The three-phase bridge circuit gives a smooth output voltage variation and is suitable for controlling large industrial drives though the control and the firing circuits are complex and expensive. This circuit requires 36 thyristors s shown in Fig.

In this arrangement, as individual phase groups are isolated from each other on the input side, the interconnection of load phases in star and delta is possible. The magnitude of the output voltage in a three-phase bridge circuit is double of that in the three-phase half wave arrangement. The VA rating of a bridge circuit is also double of three-phase half wave circuit provided the voltage and current ratings of the thyristors of these two circuits are identical.