

# Module

# 4

# AC to AC Voltage Converters

# Lesson

# 31

## Three-phase to Three-phase Cyclo-converters

## Instructional Objectives

Study of the following:

- The three-phase to three-phase cyclo-converter circuit, using six three-phase half-wave thyristorised converters
- The operation of the above cyclo-converter circuit
- The analysis of the cyclo-converter output waveform

## Introduction

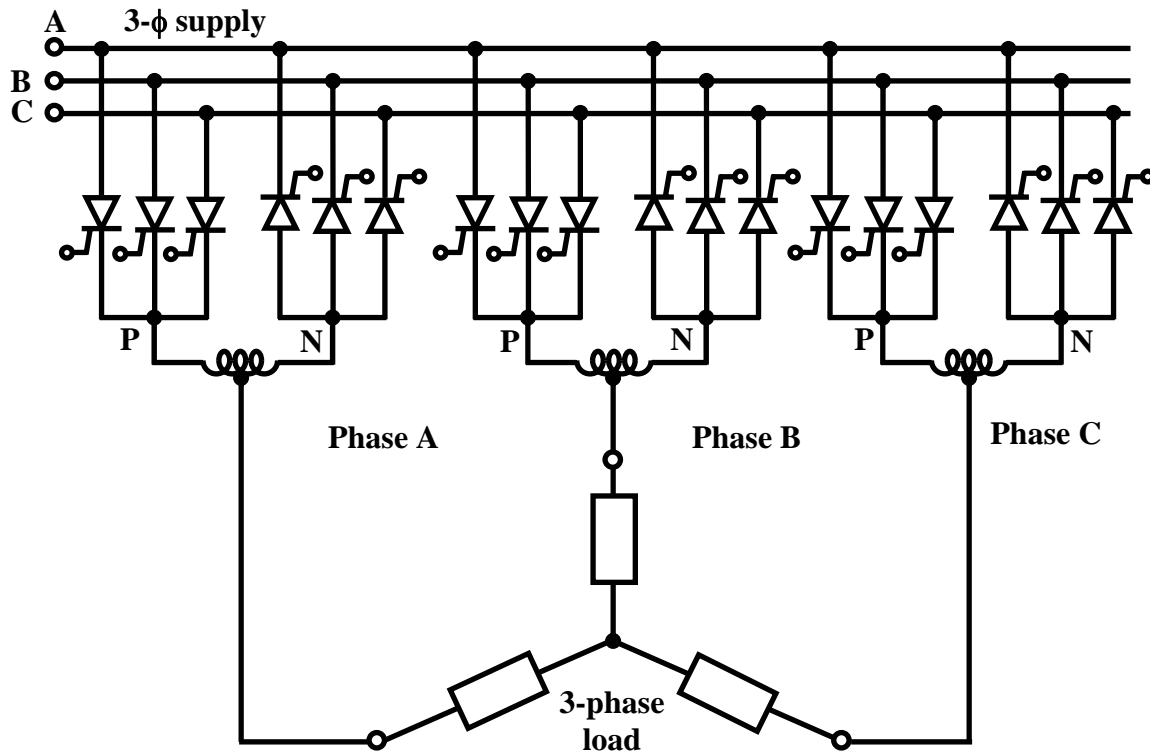
In the last lesson – second one in the second half of this module, firstly, the circuit and the operation of the three-phase to single-phase cyclo-converter, with both resistive and inductive loads, are described in detail. Two three-phase full-wave bridge converters (rectifiers) connected back to back, with six thyristors as power switching devices in each bridge, are used. The mode of operation is non-circulating current one, in which only one converter is conducting at a time. The following are briefly presented – the circulating current mode of operation with both converters conducting at a time, and the same type of cyclo-converter, using two three-phase half-wave converters, stating mainly the merits.

In this lesson – the third one in the second half, firstly, the three-phase to three-phase cyclo-converter circuit, using six three-phase half-wave thyristorised converters (two per each phase), is described. The operation of the above cyclo-converter circuit is briefly discussed. The mode of operation is the non-circulating current one. Lastly, the analysis of the cyclo-converter output waveform is presented. The procedure for obtaining the expression for the output voltage (rms) per phase for cyclo-converter is described.

**Keywords:** Three-phase to three-phase cyclo-converter, Three-phase half-wave converters. Output waveform analysis

## Three-phase to Three-phase Cyclo-converter

The circuit of a three-phase to three-phase cyclo-converter is shown in Fig. 31.1. Two three-phase half-wave (three-pulse) converters connected back to back for each phase, with three thyristors for each bridge, are needed here. The total number of thyristors used is 18, thus reducing the cost of power components, and also of control circuits needed to generate the firing pulses for the thyristors, as described later. This may be compared to the case with 6 (six) three-phase full-wave (6-pulse) bridge converters, having six thyristors for each converter, with total devices used being 36. Though this will reduce the harmonic content in both output voltage and current waveforms, but is more costly. This may be used, where the total cost may be justified, along with the merit stated. This has also been discussed in the last section of the previous lesson (#30). The ripple frequency is 150 Hz, three times the input frequency of 50 Hz. In Fig. 31.1, the circulating current mode of operation is used, in which both (positive and negative) converters in each phase, conduct at the same time. Inter-group reactor in each phase as shown, is needed here. But, if non-circulating current mode of operation is used, where only one converter (positive or negative) in each phase, conducts at a time, the reactors are not needed.



**Fig. 31.1: Three-phase to three-phase cycloconverter**

It may be noted that the circuit in each of the three phases is similar to the cyclo-converter circuit shown in Fig. 30.5. The firing sequence of the thyristors for the phase groups, B & C are same as that for phase group A, but lag by the angle,  $120^\circ$  and  $240^\circ$ , respectively. Thus, a balanced three-phase voltage is obtained at the output terminals, to be fed to the three-phase load. The average value of the output voltage is changed by varying the firing angles ( $\alpha$ ) of the thyristors, whereas its frequency is varied by changing the time interval ( $T/3 = 1/(3 \cdot f_0)$ ), after which the next (incoming) thyristor is triggered. With a balanced load, the neutral connection is not necessary, and may be omitted, thereby suppressing all triplen harmonics.

Normally, the output frequency of the cyclo-converter is lower than the supply (input) frequency (step-down region), limited to about one-third of it ( $f_0 = f_i/3$ ). This is necessary for obtaining reasonable power output, efficiency and harmonic content. If the output frequency is to be increased, the harmonic distortion in the output voltage increases, because its waveform is composed of fewer segments of the supply voltage. Thus, the losses in cyclo-converter and also in ac motor become excessive. By using more complex converter circuits with higher pulse numbers, the output voltage waveform is improved, with the maximum useful ratio of output to input frequency is increased to about one-half.

## Analysis of the Cyclo-converter Output Waveform

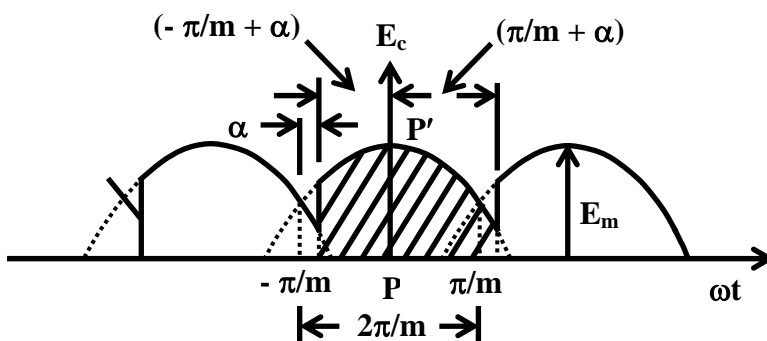
An expression for the fundamental component of the phase voltage (rms) delivered by the cyclo-converter is obtained by the procedure given here.

An  $m$ -phase converter circuit is assumed in which each phase conducts for  $((2 \cdot \pi)/m)$  electrical radians in one cycle of supply (input) voltage. For example, in a three-phase, half-wave (three-pulse) converter ( $m = 3$ ), each phase conducts for  $((2 \cdot \pi)/3 = 120^\circ)$  radians in a cycle of

$(2 \cdot \pi)$  radians. Similarly, in a three-phase, full-wave (six-pulse) converter ( $m = 6$ ), the conduction period of the periodic waveform is  $((2 \cdot \pi) / 6 = \pi / 3 = 60^\circ)$  radians in one cycle.

The output voltage waveform for an  $m$ -phase converter with firing delay angle  $\alpha$ , is shown in Fig. 31.2. With the time origin,  $PP'$  taken at the peak value of the supply voltage, the instantaneous phase voltage is given by  $e = E_m \cos \omega t = \sqrt{2} E_{ph} \cos \omega t$

where,  $E_{ph}$  = Supply voltage per phase (rms).



**Fig. 31.2: Output voltage waveform for  $m$ -phase converter with firing angle  $\alpha$**

From Fig. 31.2, it can be observed that the conduction period is from  $(-\pi/m)$  to  $(\pi/m)$ , if the firing delay angle is  $\alpha = 0^\circ$ . For the firing delay angle  $\alpha$ , the conduction period is from  $(-\pi/m + \alpha)$  to  $(\pi/m + \alpha)$ . From the above cases, the total conduction period is  $((2 \cdot \pi) / m)$ . The average value of the output voltage is,

$$E_{dc} = \left( \frac{m}{2 \cdot \pi} \right) \cdot \int_{(-\pi/m + \alpha)}^{(\pi/m + \alpha)} \sqrt{2} E_{ph} \cos \omega t d(\omega t) = \sqrt{2} E_{ph} \cdot \left( \frac{m}{\pi} \right) \cdot \sin \left( \frac{\pi}{m} \right) \cdot \cos \alpha$$

This expression is obtained for dc to ac converter in module 2, and also available in text book. When the firing delay angle is  $\alpha = 0^\circ$ ,  $E_{dc}$  has the maximum value of

$$E_{d0} = \sqrt{2} \cdot E_{ph} \cdot \left( \frac{m}{\pi} \right) \cdot \sin \left( \frac{\pi}{m} \right)$$

If the delay angle in the cyclo-converter is slowly varied as given earlier, the output phase voltage at any point of the low frequency cycle may be calculated as the average voltage for the appropriate delay angle. This ignores the rapid fluctuations superimposed on the average low frequency waveform. Assuming continuous conduction, the average voltage is  $E_{dc} = E_{d0} \cdot \cos \alpha$ .

If  $E_{0r}$  is the fundamental component of the output voltage (rms) per phase for the cyclo-converter, then the peak output voltage for firing angle of  $0^\circ$  is,

$$\sqrt{2} \cdot E_{0r} = E_{d0} = \sqrt{2} \cdot E_{ph} \cdot \left( \frac{m}{\pi} \right) \cdot \sin \left( \frac{\pi}{m} \right)$$

$$\text{or, } E_{0r} = E_{ph} \cdot \left( \frac{m}{\pi} \right) \cdot \sin \left( \frac{\pi}{m} \right)$$

However, the firing angle of the positive group,  $\alpha_p$  cannot be reduced to zero ( $0^\circ$ ), for this value corresponds to a firing angle of ( $\alpha_n = 180^\circ$ ) in the negative group. It may be noted that the firing delay angles of the two (positive and negative) converters are related by ( $\alpha_p + \alpha_n = 180^\circ$ ), or  $\alpha_p = 180^\circ - \alpha_n$ . In practice, inverter firing cannot be delayed by  $180^\circ$ , because sufficient margin

must be allowed for commutation overlap and thyristor turn-off time, as given in module 2. Consequently, the delay angle of the positive group cannot be reduced below a certain finite value,  $\alpha_{\min}$ . Therefore, the maximum output voltage per phase is,

$$E_{dc(\max)} = E_{d0} \cdot \cos \alpha_{\min} = r \cdot E_{d0}$$

where,  $r = \cos \alpha_{\min}$ , and is called the 'voltage reduction factor'.

Thus, the expression for the fundamental component of the phase voltage (rms) delivered by the cyclo-converter is,  $E_{0r} = r \cdot \left[ E_{ph} \cdot \left( \frac{m}{\pi} \right) \cdot \sin \left( \frac{\pi}{m} \right) \right]$

Since  $\alpha_{\min}$  is necessarily greater than zero, the voltage reduction factor is always lower than unity. By deliberately increasing  $\alpha_{\min}$ , and thereby reducing the range of variation of  $\alpha$  about the value of  $90^\circ$ , the output voltage,  $E_{0r}$  can be reduced, and a static method of voltage control is obtained. In practice, the output voltage is lower than the theoretical value obtained earlier, due to the influence of the commutation overlap and the circulating current between the positive and negative groups. Thus, the expression for the output voltage (rms) per phase for a three-phase to three-phase or a three-phase to single-phase cyclo-converter given earlier is obtained.

In this lesson, firstly, the circuit, and the operation, in brief, of the three-phase to three-phase cyclo-converter, is described. Six three-phase half-wave converters are used in this case, with two converters, connected back to back, per phase. A total of 18 thyristors are needed as power switching devices, having three thyristors for each converter. Lastly, the analysis of the output waveform for the cyclo-converter is presented. The procedure for obtaining the expression for the output voltage (rms) per phase for cyclo-converter is described. In the next, i.e. last lesson of this module on ac to ac voltage converters, the complete control circuit for the three-phase to three-phase cyclo-converter, will be presented. The functional blocks, with circuits and waveforms, will be described.

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