Module
4
AC to AC Voltage Converters

Lesson 30

Three-phase to Single-phase Cyclo-converters

Instructional Objectives

Study of the following:

- The three-phase to single-phase cyclo-converter circuit, using two three-phase full-wave thyristorised bridge converters
- The operation of the above cyclo-converter circuit, along with the voltage waveforms

Introduction

In the last lesson − first one in the second half of this module, firstly, the basic principle of operation of the cyclo-converter circuits has been presented. This followed by the discussion of the circuit, and the operation of the single-phase to single-phase cyclo-converter circuit with both resistive and inductive loads, in detail. Two full-wave bridge converters (rectifiers) connected back to back, with four thyristors as power switching device in each bridge, are used. Also described are the advantages and disadvantages of the cyclo-converter. The dc link converter is introduced briefly, along with its advantages and disadvantages.

In this lesson − the second one in the second half, firstly, the three-phase to single-phase cyclo-converter circuit, using two three-phase full-wave thyristorised bridge converters, is presented. Then, the operation of the above cyclo-converter circuit, with both resistive and inductive loads, is described in detail, along with voltage waveforms. The mode of operation used is the non-circulating current one. The following are discussed in brief −.the circulating current mode of operation for the above, and also the cyclo-converter circuit, using two three-phase half-wave converters.

Keywords: Three-phase to single-phase cyclo-converter, Voltage waveforms, Non-circulating current, and Circulating current modes of operation, Three-phase full-wave bridge, and half-wave converters.

Three-phase to Single-phase Cyclo-converter

The circuit of a three-phase to single-phase cyclo-converter is shown in Fig. 30.1. Two three-phase full-wave (six-pulse) bridge converters (rectifier) connected back to back, with six thyristors for each bridge, are used. The ripple frequency here is 300 Hz, six times the input frequency of 50 Hz. So, low value of load inductance is needed to make the current continuous, as compared to one using single-phase bridge converters described in the previous lesson (#4.4) with ripple frequency of 100 Hz. Also, the non-circulating current mode of operation is used, where only one converter − bridge 1 (positive) or bridge 2 (negative), conducts at a time, but both converters do not conduct at the same time. It may be noted that each thyristor conducts for about $120°(\pi/3)$, i.e., one-third of one complete cycle, whereas a particular thyristor pair, say 1& 2 conduct for about $60°(\pi/6)$, i.e., one-sixth of a cycle. The thyristors conduct in pairs as stated, one (odd-numbered) thyristor in the top half and the other (even-numbered) one in the bottom half in two different legs. Two thyristors in one leg are not allowed to conduct at a time, which will result in short circuit at the output terminals. The sequence of conduction of the thyristors is 1 & 6, 1 & 2, 3 & 2, and so on. When thyristor 1 is triggered, the conducting thyristor (#5) in top half, being reverse biased at that time, turns off. Similarly, when thyristor 2 is triggered, the conducting thyristor (#6) in bottom half, being reverse biased at that time turns off. This sequence is repeated in cyclic order. So, natural or line commutation takes place in this case. Otherwise, the procedure is similar to the one as discussed in the previous lesson.

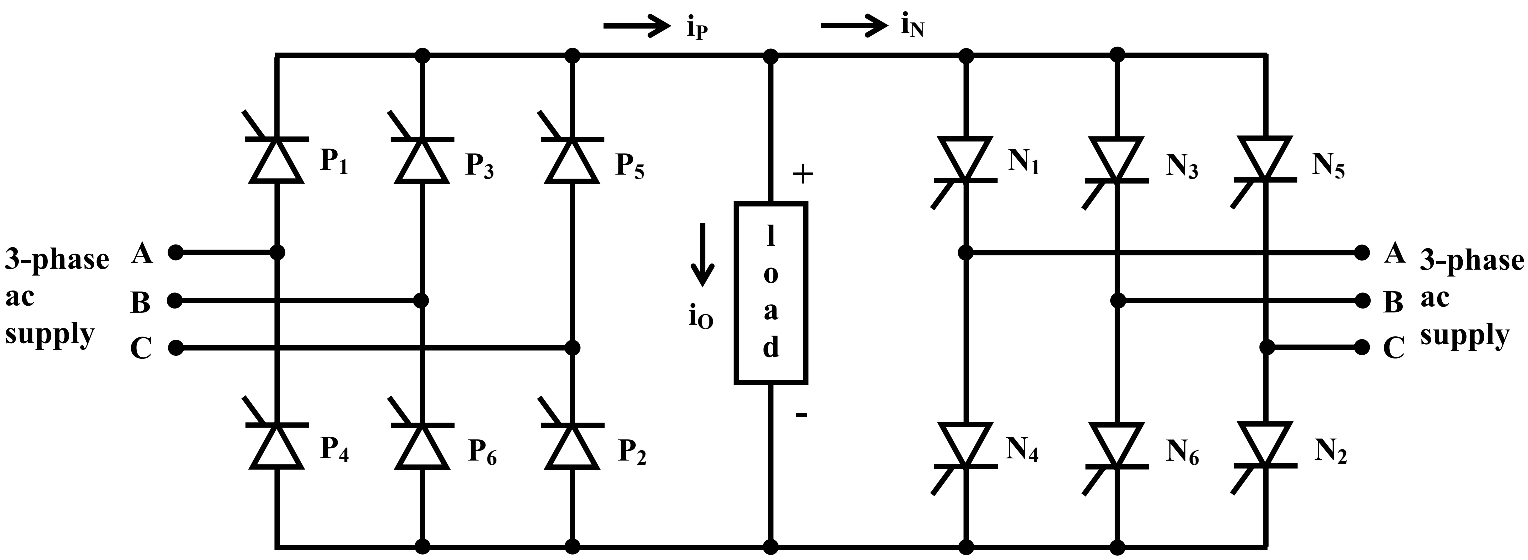

Fig. 30.1: Three-phase to single-phase cycloconverter

The procedure to be followed in the triggering of the thyristors in sequence in the two bridge converters has been briefly given earlier. The readers are requested to go through two lessons (#2.5-2.6) in module 2 (AC-DC Converters), or any standard text book. As given in the earlier lesson (#4.4), the firing angle (α) of two converters is first decreased starting from the initial value of $90°$ to the final value of $0°$, and then again increased to the final value of $90°$, as shown in Fig. 30.2. Also, for positive half cycle of the output voltage waveform, bridge 1 is used, while bridge 2 is used for negative half cycle. The two half cycles are combined to form one complete cycle of the output voltage, the frequency being decided by the number of half cycles of input voltage waveform used for each half cycle of the output. As more no. of segments of near $60°(\pi / 6)$ is used, the output voltage waveform becomes near sinusoidal, with its frequency also being reduced.

The initial value of firing angle delay is kept at $\alpha_1 \approx 90°$, such the average value (dc) of the output voltage in this interval of near $60°(\pi / 6)$ [$V_{av} \propto \cos \alpha_1 = \cos 90° = 0.0$], is zero. It may be noted that the next thyristor in sequence is triggered at $\alpha_2 < 90°$, as the firing angle is decreased for each segment, to obtain higher voltage $V_{av} \propto \cos \alpha_2 = +ve$, to form the sine wave at the output. This can be observed from the points, M, N, O, P, Q, R & S, shown in Fig. 30.2. From these segments, the first quarter cycle of the output voltage waveform from $0°$ to $90°$, is obtained. The second quarter cycle of the above waveform from $90°$ to $180°$, is obtained, using the segments starting from the points, T, U, V, W, X &Y (fig. 30.2). It may be noted that the firing angle delay at the point, Y is $\alpha = 90°$, and also the firing angle is increased from $0°$ (T) to $90°$ (Y) in this interval. When the firing angle delay is $0°$, the average value of the segment is $V_{av} \propto \cos \alpha = \cos 0° = 1.0$. The two quarter cycles form the positive half cycle of the output voltage waveform. In this region, the bridge 1 (positive) is used. To obtain the negative half cycle of the output voltage waveform ($180° - 360°$), the other bridge converter (#2) termed negative (N) is used in the same manner as given earlier, i.e. its firing angle delay (α) is first decreased starting from the initial value of $90°$ to the final value of $0°$, and then again increased to the final value of $90°$, as given earlier. The two half cycles (positive and negative) together give one complete cycle ($0° - 360°$) of the output voltage waveform.

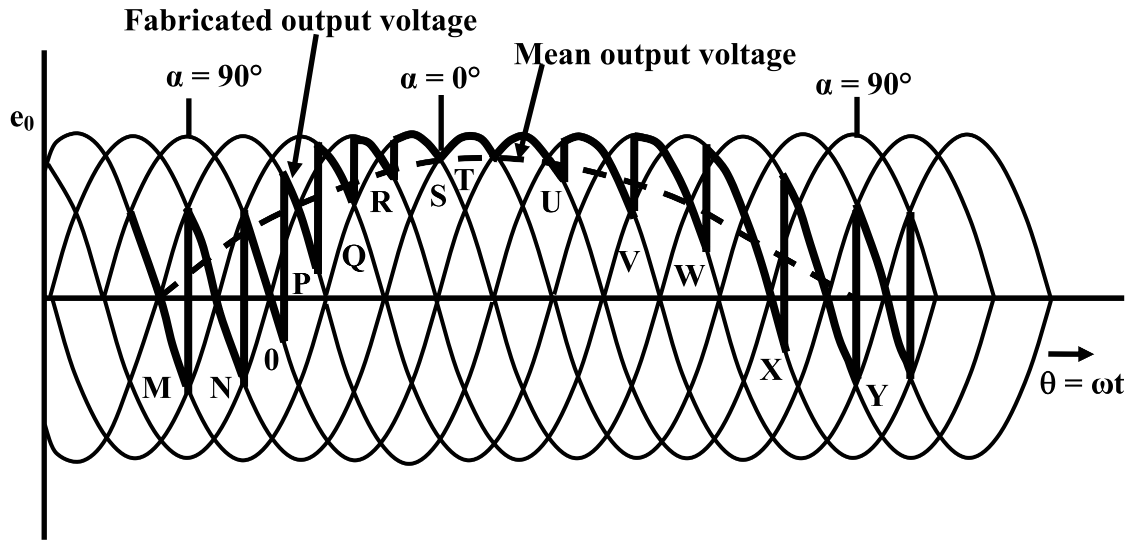

Fig. 30.2 Output voltage waveforms for a three-phase to single phase cyclo-converter.

The load on the output of the cyclo-converter is assumed to be inductive (R-L). The load can also be capacitive. For inductive load, the output current (Fig. 30.3) lags behind the voltage by its phase angle, ϕ (assumed to be positive). The load power factor is also +ve ($\cos\phi$). It may be noted that the current is unidirectional in a thyristor converter. As the current, being alternating in nature, flows in both directions in a complete cycle, two converters are connected in anti-parallel. The positive (P) converter carries current during positive half cycle of output current, while the other, i.e. negative (N) one carries current in the negative half cycle. As discussed in the previous lesson (#29), P-converter acts as a rectifier, when the output voltage is positive, and as an inverter, when the output voltage is negative (Fig. 30.3). Similarly, N-converter acts as a rectifier, when the output voltage is negative, and as an inverter, when the output voltage is positive. It can thus be inferred, in general, that one of two converters would operate as rectifier, if its output voltage and current have the same polarity, and as an inverter, if these are of opposite polarity.

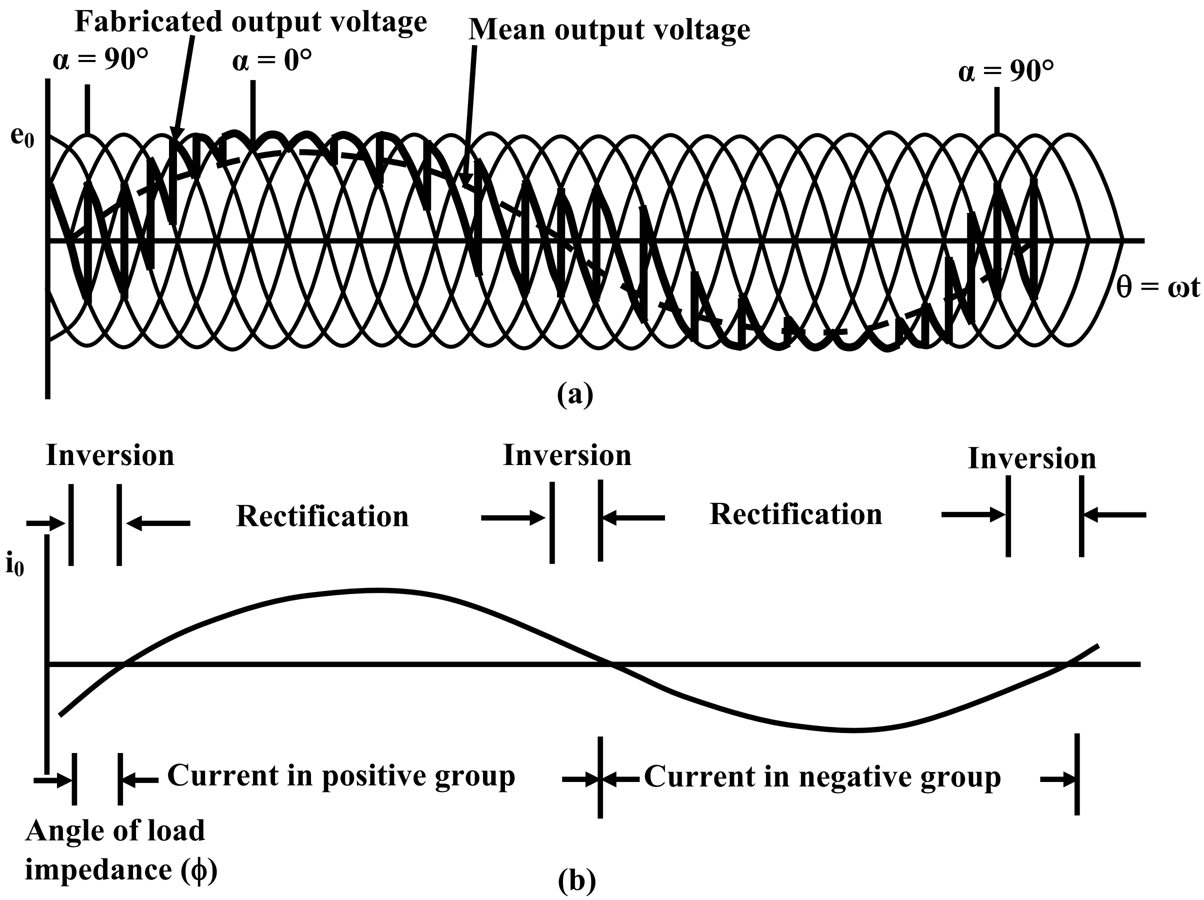

Fig. 30.3 Voltage (a) and current (b) waveforms for a three phase full-wave (six-pulse) cycloconverter.

Circulating Current Mode of Operation

In all the cases described earlier (Lesson 29 and current one (#30)), both for single-phase to single-phase and for single-phase to three-phase cyclo-converters, circulating current-free or non-circulating current mode of operation was described, wherein only one of two bridge converters conducts at a time, but not both, in which case the converters would be short-circuited. The positive (P) converter conducts, when the current is in the positive half of the cycle, whereas the negative one conducts with the current flowing in the negative half. But, in this case, i.e. circulating current mode of operation of the cyclo-converter, both the converters would conduct at a time, with an inter-group reactor (IGR) between the positive and negative groups as shown in Fig. 30.4. It may be noted that, though the output voltages of two converters in the same phase have the same average value, but their output voltage waveforms as a function of time are, however, different, and as a result, there is a net potential difference (voltage) across two converters. Due to this voltage, the reactor is inserted to limit the circulating current. As described, the main converter − positive/negative, as the case may be, acts in the rectifier mode, and the other one acts in the inverter mode, with the average value along with the sign, of the output voltage being same. Thus, the sum of their firing delay angle must be 180° (π). In other words, if α_p and α_n are the firing angles for positive and negative group of converters, respectively, then these firing angles must be controlled so as to satisfy the condition $(\alpha_p + \alpha_n) = 180° \ (\pi)$.

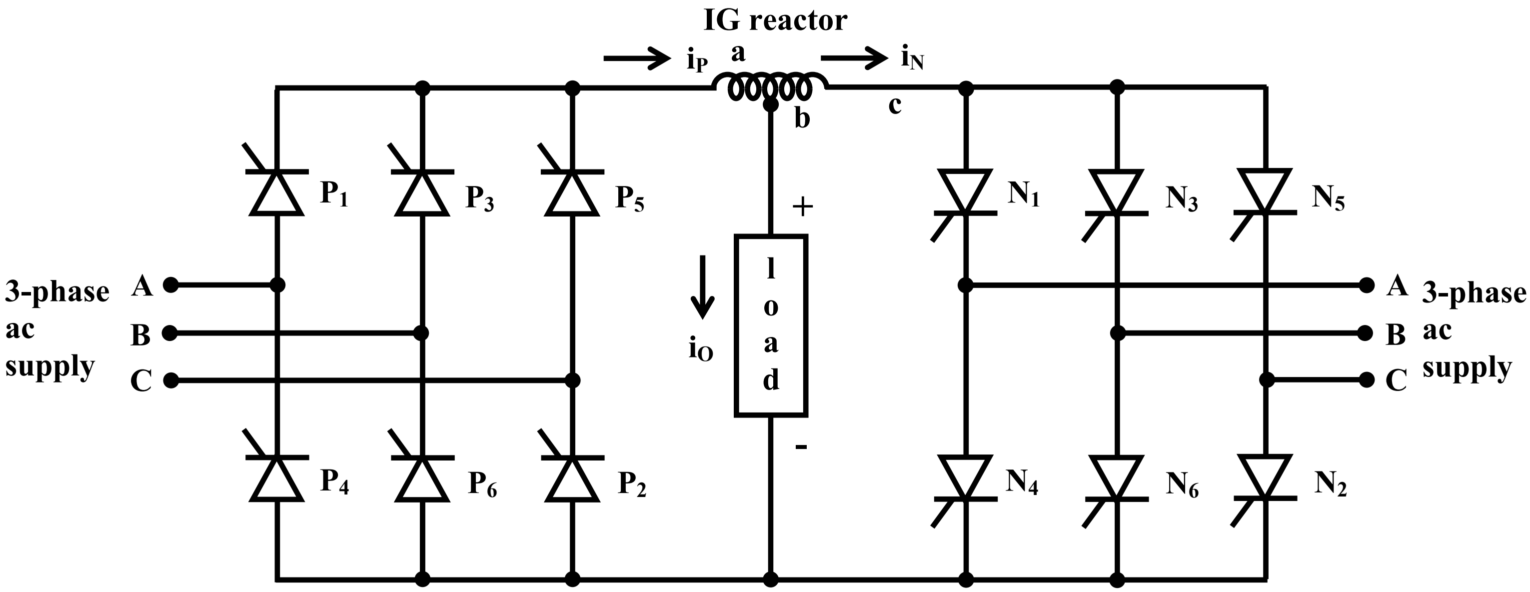

Fig. 30.4: Cycloconverter (circulating current mode) with Inter-group(IG) reactor

The continuous current of each group in the circulating current mode imposes a higher loading on each group compared to the non-circulating current mode of operation. In practice, this mode, i.e. circulating current one, would only be used, when the load current is low, so that continuous load current with a better waveform can be maintained. At the higher levels of load current, the groups would be blocked to prevent circulating current. Control circuits would be used to sense the level of the load current, allowing firing pulses to each group at low current level, but blocking firing pulses to one or the other group at the higher current levels. The reactor would be designed to saturate at higher current levels, when the cyclo-converter is operating in the non-circulating current mode, thus permitting a smaller one.

Cyclo-converter, using two three-phase half-wave converters

A three-phase to single-phase cyclo-converter, using two three-phase half-wave converters, is shown in Fig. 30.5. The principle of operation is same here as described earlier. Each thyristor conducts for around 120° $(2 \cdot \pi / 3)$, with the thyristors in each converter triggered in sequence, i.e. 1, 2 & 3, whether it is P-type or N-type. It may be noted that the thyristors, 1, 2 & 3 are connected to the phases, A, B & C, respectively, in series with the load impedance, as shown in Fig. 30.5. The ripple frequency is 150 Hz, three times the input frequency of 50 Hz, as this converter is a three-pulse one. So, the inductance in the inductive (R-L) load must be high, as compared to one used in the earlier case, to make the current continuous. This inductance acts as the filter for the output (load) current. The mode of operation here is non-circulating current one. It may be noted that harmonic content, both in the output voltage and current waveforms, is higher than those present in the earlier case using two three-phase full-wave bridge converters. This is, because six pulses are used in a cycle for the earlier one, the ripple frequency being 300 Hz. Also three thyristors are used in each converter, i.e., a total of only 6 devices for two converters are needed, whereas earlier, six thyristors are used for each bridge converter, needing a total of 12 devices. This means that the cost is much lower, as also the control circuit in this case is much simpler and cheaper, as only three pulses per each converter are needed. This may be preferred, as only the harmonic content is more, which may not be a demerit in most of the applications. If it is used to drive ac motors, the high impedance at the ripple frequency is expected to make the output current near sinusoidal one, with the result that no additional filtering component is needed. Other conditions, being same, are not described here, and the waveforms also not shown, which is given in standard text book, or may be drawn from the waveforms given in .the earlier case.

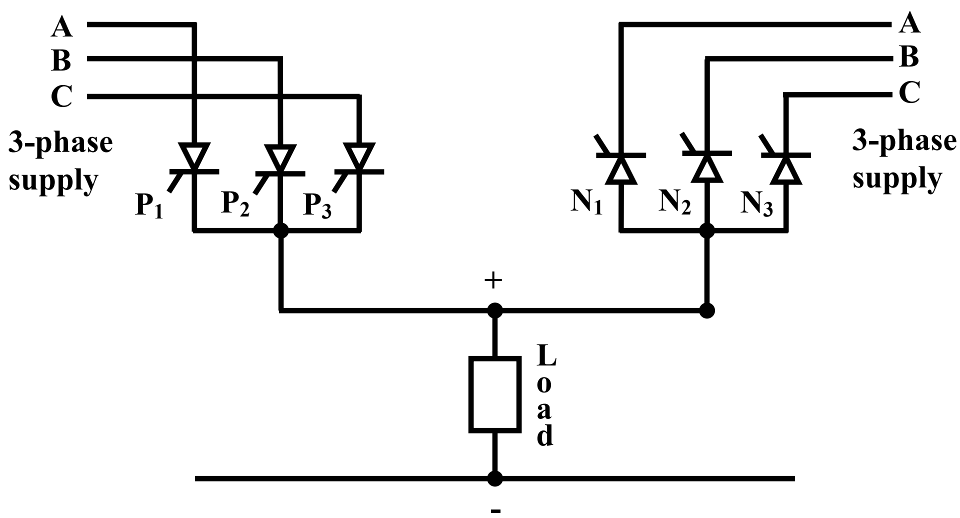

Fig. 30.5: Three-phase to single phase cycloconverter (two three-phase half-wave converter)

In this lesson, firstly, the three-phase to single-phase cyclo-converter, using two three-phase full-wave bridge converters, is described, with the circuit and various output voltage and current waveforms. The non-circulating current mode of operation is presented in detail, so as to obtain sinusoidal output voltage waveform. The circulating current mode is briefly discussed, along the change in the circuit. Lastly, the circuit for the same type of cyclo-converter, with two three-phase half-wave converters, is given, stating briefly the differences for this case. In the next lesson, the three-phase to three-phase cyclo-converter will be taken up first. Three such circuits, as described in this lesson, are needed in this case. Lastly, the analysis of the cyclo-converter output wave-forms will be presented.

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