Module

4

AC to AC Voltage Converters

Lesson

32

Control Circuit for Three-phase to Three-phase Cyclo-converters

Instructional Objectives

Study of the following:

- The control circuits used for the three-phase to three-phase cyclo-converters using two three-phase converters, to generate the firing pulses for the thyristors
- The functional blocks, including the circuit and waveforms

Introduction

In the last lesson − third one in the second half of this module, firstly, the circuit along with the operation of the three-phase to three-phase cyclo-converter, are described in brief. Two three-phase half-wave converters, with three thyristors as power switching devices in each converter, are needed, per phase, thus, using six such converters having a total of 18 thyristors. The mode of operation is non-circulating current one, in which only one converter is conducting at a time. Lastly, the analysis of the output waveform is presented.

In this lesson − the fourth and final one in the second half, the complete control circuit for the three-phase to three-phase cyclo-converter, is presented in detail, showing how the firing pulses are generated to trigger the thyristors. The function of the various blocks, with their respective functions, and also circuit diagrams as needed, is described.

Keywords: The control circuit for the three-phase to three-phase cyclo-converter, functional blocks.

Control Circuit for Cyclo-converters

The function of the control circuit used in this case is to deliver correctly timed, properly shaped, firing pulses to the gates of the thyristors in the power converter (rectifier/inverter) circuits, so as to generate a voltage of desired wave shape at the output terminals of a cyclo-converter. The functional block diagram of the control circuit for the three-phase to three-phase cyclo-converter, in the non-circulating current mode of operation, is shown in Fig. 32.1. The same control circuit is applicable to the cyclo-converter operating in circulating current mode, but the block designated as converter group selection will not be present in this case. There are four functional blocks in the circuit as given here.

1. Synchronising circuit
2. Reference voltage sources
3. Logic and triggering circuit
4. Converter group selection circuit

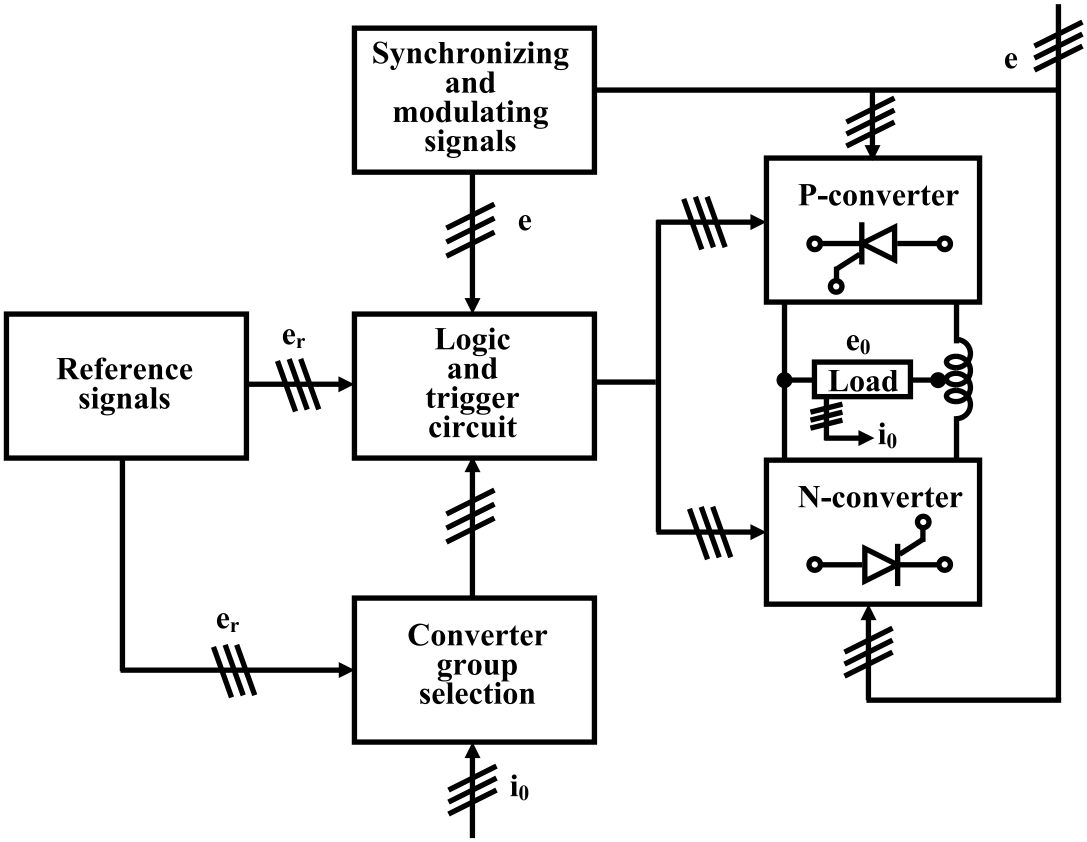


Fig. 32.1 Control circuit block diagram for a cycloconverter with non-circulating current mode

Synchronising Circuit

The main function of the synchronising circuit is to derive low voltage signals to the control circuit, which operates at low voltages. These low voltage signals must be synchronised to the voltages applied to the main power circuit. Step-down transformers may be used for this purpose with the filter circuit to avoid waveform distortion, if any. While deriving the modulating voltages at the supply frequency, the phase shifting network may also be required. To determine the instants at which the firing signals are to be produced, to be fed to the gates of the thyristors in the two converter groups, the modulating signals are compared with the reference voltages.

Reference Voltage Sources

The reference signal is designed to control the output voltage in the sense that the output voltages tend to follow the reference signal. It means that, if the amplitude and frequency of the reference signal is varied, then the amplitude and frequency of the output voltage varies automatically. In the case of three-phase to three-phase cyclo-converter, the reference signal does additional function of shifting e_{OA}, e_{OB} & e_{OC}, by phase shift of $120°$. The three-phase variable frequency, variable voltage sine wave reference voltage can be designed in various ways. As the frequency of the reference voltage signal is low, normally limited to $16\frac{2}{3}$ Hz, one-third of the line frequency of 50 Hz (may be higher (25 Hz) in some case), one of the design approach as given here, is to use a mixer, wherein two signals having frequencies, f_c & f_d are mixed to obtain frequencies ($f_c \pm f_d$). Then, a low pass filter is used to obtain a signal of required frequency, ($f_c - f_d$). The details are as follows.

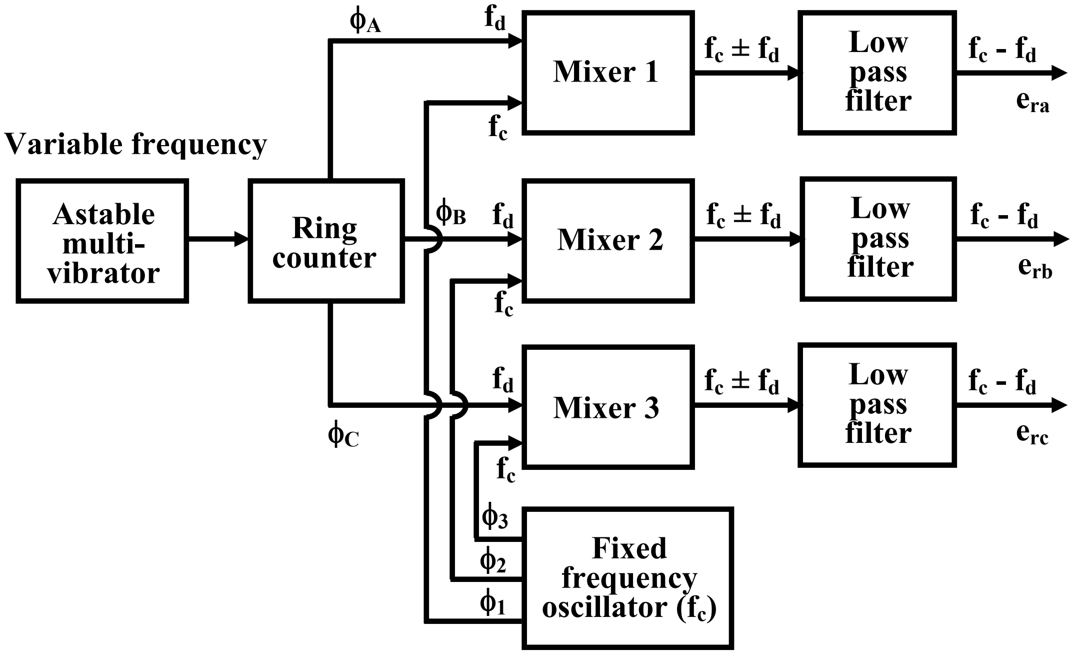


Fig. 32.2 Reference voltage generator block diagram.

The reference voltage generator block diagram is shown in Fig. 32.2. An astable multi-vibrator is used to generate a square wave with frequency, ($3 \cdot f_d$), which is then fed to a three-stage ring counter, whose output is three numbers of three-phase, square wave (ϕ_A ,ϕ_B & ϕ_C) of frequency f_d, at a phase shift of $120°$. The fixed frequency oscillator (f_c) produces three outputs (ϕ_1 ,ϕ_2 & ϕ_3), which may be taken as three-phase. Three mixers − one for each phase, as stated earlier, are used to combine the fixed and variable frequencies. The output of each mixer stage is a square wave with half-wave symmetry, consisting of a fundamental and a series of odd harmonics. If all higher order higher harmonics are neglected, the output signal has only two frequencies, sum or difference of the fixed and variable frequencies, as given earlier. Then, a low pass filter is used to select the low frequency signal ($f_c - f_d$), and also eliminate the high frequency one ($f_c + f_d$). Finally, the three reference signals obtained are in the form,

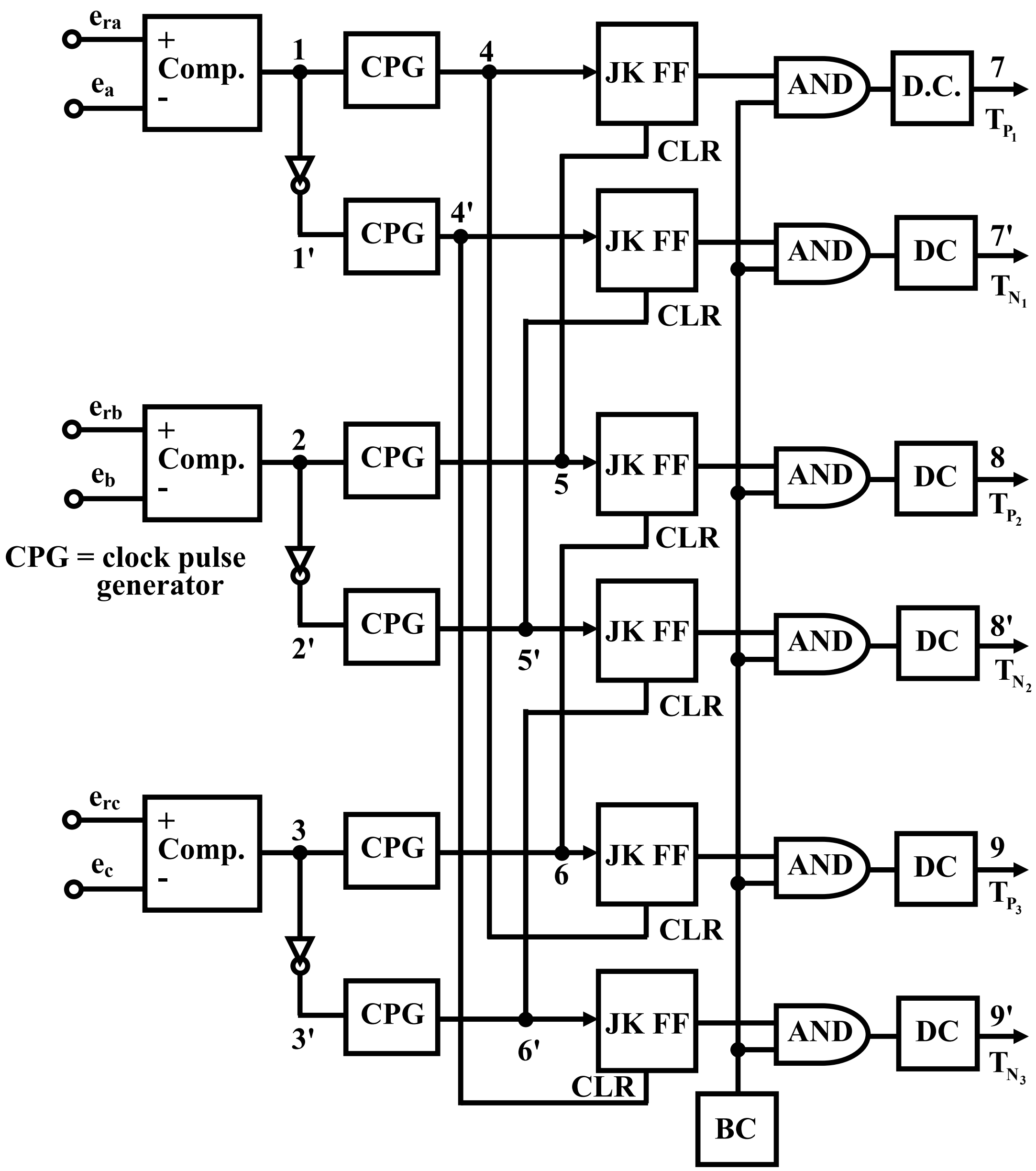
$$e_{ra} = r \cdot E_m \sin(2\pi(f_c - f_d)t),$$

$$e_{rb} = r \cdot E_m \sin(2\pi(f_c - f_d)t - 120°),$$

$$e_{rc} = r \cdot E_m \sin(2\pi(f_c - f_d)t + 120°),$$

where, E_m is the peak of the cosine modulating wave.

From the above equations, it can be observed that the amplitude and frequency of the reference waveforms are controlled by varying r and f_d respectively, while the phase sequence of the three-phase outputs is controlled by setting f_d, greater or lower than f_c. The amplitude is varied by changing r from 0 to 1, i.e. $1 \le r \le 0$.



e_{ra} = reference voltage for phase and output

e_a, e_b, e_c = modulating signals

Comp. = comparator

DC = driver circuit consisting of pulse isolation, amplification, and high frequency modulation.

BC = group selection and blanking circuit logic

Fig. 32.3 Block diagram of logic and trigger circuit

Logic and Triggering Circuit

The block diagram of the main logic and triggering circuit for the output of phase A, using the reference voltage, e_{ra}, is shown in Fig. 32.3. Two similar blocks − one with the reference voltage, e_{rb}, and the other with the reference voltage, e_{rc}, are used for the other two phases, B & C of the output, in the case of a three-phase to three-phase cyclo-converter circuit.

The reference voltage, e_{ra} is compared with the modulating voltages, e_a, e_b and e_c, corresponding respectively to the supply voltages, e_A, e_B and e_C. The comparators produce short pulses. These pulses drive clock-pulse generator (c_p), which is a positive edge-triggered mono-stable multi-vibrator. Therefore, six pulses are obtained ($4,\ 4'$, $5,\ 5'$, $6,\ 6'$). Now, these short pulses act as clock pulses to the flip-flops. The clearing of the pulses is done, when they are not required. This clearing is done in the sequence, $6 \rightarrow 5 \rightarrow 4$. This limits the presence of pulses only when that thyristor is supposed to conduct, otherwise pulse is blocked. The pulse output of the flip-flop is ANDed with the input coming from the blanking circuit. The output of the AND gate is given to the driver circuit, which amplifies and isolates the pulses and drives the respective thyristors. With the circulating current mode of operation, no blanking circuit is needed. Hence, this input may be set at the logic '1' permanently.

The block diagram of the logic circuit is general in the sense that the reference signals and modulating signals could be of any wave-shape. In most applications, the sinusoidal reference signals and co-sinusoidal modulating signals are commonly employed. The basic principle of the co-sinusoidal modulation is the same as that of cosine wave crossing-pulse timing control employed for firing of the thyristors in phase-controlled converters given in standard text books. The typical waveforms at different points of the logic and triggering circuit (Fig. 32.3) are shown in Fig. 32.4. The waveforms are drawn for one half cycle of the output voltage for the positive converter with load having unity power factor. The same procedure can be followed for developing the output voltage of the other half cycle of the positive converter. For the negative converter, different modulating signals have to be taken into account. This is taken care of by using an inverter at the output of each comparator (Fig. 32.3).

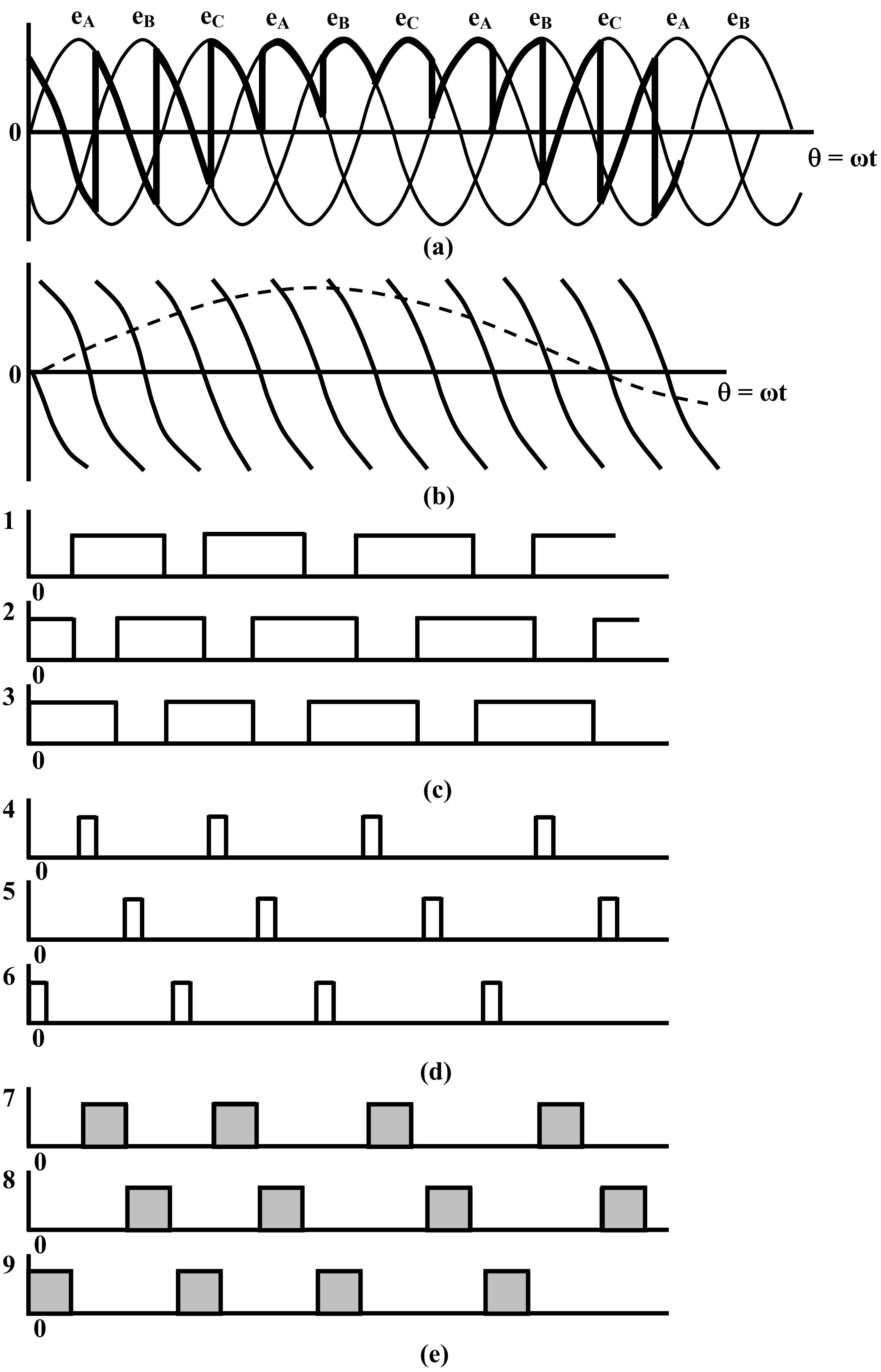


Fig. 32.4 Various waveforms of logic circuit (Fig. 32.3) for one phase only. (a) supply voltage of a three-phase half-wave (three-pulse) cycloconverter showing output voltage of one half cycle. (b) modulating signals for positive converter and reference voltage (100%). (c) outputs of comparators used in the positive group. (d) clock pulse for positive group (e) gate pulses to thyristors.

Circuit for Converter Group Selection

The block diagram of the converter bank selection is shown in Fig. 32.5. The load current is allowed to flow through the P-converter or the N-converter through suitable logic. D is the delay during which period the firing pulses to both the converters are inhibited. The delays are not introduced in some control schemes, where a small circulating current is permitted during the cross-over instants of the fundamental current only. The scheme is still recognized as the non-circulating current operation since during a major portion of the output cycle, it operates in the non-circulating current mode.

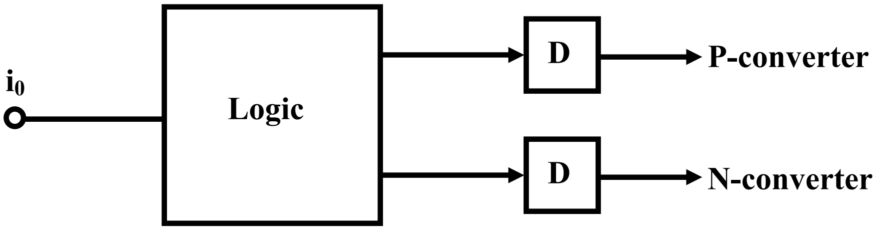


Fig. 32.5 Converter group selection in non-circulating current scheme

The circuit is an essential part of the control scheme of a cyclo-converter with the non-circulating mode of operation. The function is to ensure that only one converter operates at a time depending upon the polarity of the current. The positive converter is operated, when the load current is positive, and the negative converter is operated, when the load current is negative. The converter group selection is not straight forward primarily due to non-ideal nature of the output current waveform. Since the actual load voltage waveform itself is far from sinusoidal, the load current is also non-sinusoidal. Depending upon load circuit parameters and converter pulse number, the load current may become zero before the fundamental half-period. If the group selection and blanking circuit were to operate at each current zero instant, it may cause erratic switching of converters. The result of this is to further distort the output voltage. One possible solution to this problem is to see that the blanking circuit operates at the zero crossing of the fundamental current. The fundamental component of the load current is extracted, and the converter bank selection is made to occur at the zero crossings of this fundamental component of the current. There are, however, some operational difficulties, in the design of filter components specially, when the cyclo-converter is required to operate over a range of the output frequency, and with variable load. The filter, which operates satisfactorily over the desired range of frequency, will have to be used. Thus, the envelope distortion of the output current and the output voltage are reduced, and the possible steady state discontinuous conduction within the fundamental period does not cause any erratic switching of converters.

Because of filters, certain amount of phase shift may be introduced between the zero crossings of the fundamental output current and actual load current. In order to eliminate the waveform distortion, certain amount of circulating current may be allowed to flow during this short overlap period in some control schemes. The presence of circulating current is a must in such a design. However, if no circulating current is permitted to flow, some distortion in the output voltage is to be tolerated. This distortion arises due to the delays introduced at the zero crossings of the load current to ensure turn-off of thyristors in the outgoing group before the thyristors in the incoming group are turned on.

There may be other approaches, in one of which a closed loop control of the output voltage is used to automatically select the converter banks. This is not described here, but may be studied from the text books.

In this lesson − last one in this module, the complete control circuit used for three-phase to three-phase cyclo-converter is discussed in detail. The functional blocks, with relevant circuits and waveforms, are described, stating how the triggering signals for the thyristors are generated. In the next, i.e. last module of the course on Power Electronics, the various types of dc to ac converters, also known as inverters, with relevant points, will be presented.

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